POSTER ABSTRACT BOOK

Paper ID 112
Poster Board N°5

The "Nora and the Sea" Project: The Sunken and the Flooding City

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The ancient city of Nora (Sardinia, Italy) has always had a special connection with its surrounding sea. Time was when the sea used to be a source of cultural and economic richness, carried by the ships of Phoenician merchants or supplied by African and Roman markets. Then pirates came from the sea, marking the end of a millennial history. Nowadays, the threat to this unearthed ancient city, one of the main archaeological sites of Sardinia, comes from the sea itself, mainly due to strong seasonal storms and the global rise of the sea level. Such an urgency has been grasped by the University of Padova, which set up a project aimed at studying and preserving the coastal and submerged structures of the site, by combining archaeological research and future impact forecasts.

Topographical and functional connections between the ancient settlement and its shore have been firstly inspected, by surveying and recording all sunken or flooding structures and by building the paleo-DTM of the peninsula, that has never been affected by subsidence. A new digital terrain model has been achieved by joining past cartography with a detailed bathymetry of the seabed, performed with an echosounder and thickened along the coast with a manual survey. Geomorphologists from CNR have improved the model of the ancient seabed by performing surveys, core samplings and radiocarbon dating. That has provided the essential frame for modelling paleoenvironmental and paleosettlement reconstructions. By applying the studies upon the rise of the Mediterranean sea level during the Holocene (ANTONIOLI et alii 2007) and using values from the archaeological markers recorded all around the shore, the ancient coastline of the peninsula has been drawn along the current -1.40 meters depth. For the first time a direct perception of the real extension of the ancient city was caught, as well as the layout of the ancient shoreline, where the urban landscape was likely to have been replaced by retaining and protection walls and by the exploitation of coastal resources (such as stone quarries and boat dockings). Current investigations have focused on one of such structures, the so-called “Molo Schmiedt”, that might be explained as a breakwater, probably assembled to face an ancient progressive process of sea level rise.

On the other side, the project has also an immediate outcome in the present, thanks to the recording of the current rate of coastal erosion and of the regional sea level rise, in order to detect the ongoing situation, evaluate future forecasts and arrange protection responses. A photogrammetric analysis of aerial pictures from the last century, combined with tide gauges, as well as a decennial direct experience of coastal loss and the application of predictive modelling of sea level rise by 2100 (from IPCC 2013) have led to map out the coastline of the future peninsula. Such a high-impact tool has been transmitted to public administrations, inspiring the planning and the accomplishment of protective and coast nourishment projects.

Keywords: paleo sea level, Nora (Italy), coastal archaeology, bathymetry, paleo-environment

Paper ID 116
Poster Board N°27

Geophysical Modeling Results and Mid-Holocene Relative Sea-Level Data from Northern Java, Indonesia

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Well-constrained data on the timing and magnitude of mid- to late-Holocene relative sea-level (RSL) variations are required to improve our understanding of modern and future RSL changes on local and regional scales. However, published high-precision datasets from central Indonesia, an area that is considered particularly sensitive to future sea-level rise, are rare. In order to constrain geophysical model predictions for the mid-Holocene in the far field, we investigated a number of massive, fossil microatolls along the northern coastline of central Java, Indonesia. High-precision survey data taken with RTK GPS and reduced to mean sea level (msl) indicate that the majority of fossil corals on the reef flat are well above the height of living coral and present-day msl with elevations up to +1.2 m above msl. Samples from 14 emergent specimens have been extracted for radiocarbon dating. Results indicate a rise of relative sea level (RSL) between 6.4 – 7.1 ka BP. This record is closest to geophysical model predictions based on the ANICE-SELEN ice-sheet model coupled to an Earth model with VM1 viscosity profile. In this contribution we discuss the implications of these new findings with respect to tectonics, eustasy and isostasy, and what this could mean for the behavior of the Antarctic Ice Sheet during the Holocene.

Keywords: GIA, tectonics, fossil microatolls, southeast Asia

Paper ID 190
Poster Board N°37

Superstorms at the End of the Last Interglacial (MIS 5e, ~128-116 ka)? Modeling Paleo Waves and the Transport of Giant Boulders.

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We present the results of high-resolution field surveys and wave models along the cliffs of the northern part of the Island of Eleuthera, Bahamas. Previous studies have proposed that cliff top mega-boulders were emplaced at the end of the Last Interglacial (MIS 5e, ~128-116 ka) by giant swells caused by super-storms that find no counterpart in the Holocene (including historical times). Our results suggest that these boulders could have instead been transported from the cliff face to the top of the cliff by a storm analogous to the 1991 'Perfect Storm', if sea level during MIS 5e sea level was more than 4 meters higher than today. We remark that the data-model approach used here is essential to interpreting the geologic evidence of extreme storms during past warm periods which, in turn, is an important tool for predicting the intensity of extreme storm events in future climates. Our results indicate also that, even without an increase in storm intensity, cliffs and hard coastal barriers might be subject to significant increases wave-generated stresses under conditions of sea levels modestly higher than present.

Keywords: Last Interglacial, Sea level, MIS 5e, Superstorms

Paper ID 192
Poster Board N°35

Exploiting New Holocene Sea-Level Archives to Inform Future Sea-Level Predictions: an Example from Wales

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Current predictions of sea-level change around the UK up to the year 2100 include a land-level component that is calculated by a GIA model which, in turn, is calibrated by past relative sea-level observations. For some areas, such as most of Wales, GIA models are potentially unreliable as regional patterns of Holocene relative sea-level change are poorly constrained. The aim of this work is to establish new Holocene relative sea-level reconstructions from peat preserved in coastal freshwater back-barrier marshes at Abermawr in southwest Wales (Pembrokeshire) and Rhoscolyn in northwest Wales (Anglesey). These two sites are situated along an isostatic gradient as a result of Holocene subsidence of Pembrokeshire relative to Anglesey.

This work builds on the methods by Gehrels and Anderson (2014) who first demonstrated the suitability of peat deposits in coastal freshwater back-barrier marshes for sea-level reconstructions. Methods to establish the stratigraphy of these sites include hand-drilled coring, ground-penetrating radar, electrical resistivity tomography and seismic surveys. Sea-level index points were collected from basal Holocene peat that was dated by radiocarbon methods and is immune to sediment compaction.

Groundwater monitoring was used to show that the back-barrier water table is controlled by tide levels. Spectral analysis of the groundwater data clearly shows the relationship between the tidal and groundwater signals. We performed a Fisher-g test to calculate the significance of the tidal peaks. In all cases a peak associated with tidal constituents is shown to be highly significant. Groundwater modelling experiments were conducted to test the controls of stratigraphy, peat permeability and marsh recharge on the link between groundwater and sea level.

We present six new compaction-free sea-level index points for northwest Wales and seven for southwest Wales. The northwest Wales data are used to test the possibility of a mid-Holocene sea-level highstand in this region. The southwest Wales data provide the first Holocene sea-level reconstruction for that region. Our new Holocene relative sea-level reconstructions for Wales will be used to test and improve GIA models for the UK.

Reference:

Gehrels, W. R., Anderson, W.P., Jr. (2014). Reconstructing Holocene sea-level change from coastal freshwater peat: A combined empirical and model-based approach. Marine Geology 353: 140-152.

Keywords: Coastal Hydrogeology, Sea-level Reconstruction, Anglesey, Pembrokeshire, Coastal Wetland

Paper ID 193
Poster Board N°41

A New Glacial-isostatic Adjustment for Greenland Based on Relative Sea-Level Data and GPS Uplift Rates

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Bedrock displacement recorded with GNET-GPS stations in Greenland, reveal viscoelastic uplift rates that strongly contradict published predictions of glacial-isostatic adjustment (GIA). In particular, GPS provides evidence that GIA-induced uplift rates are considerably higher than previously assumed in the northwest and southeast of the ice sheet. These regions are characterized by the lack of relative sea-level (RSL) data to constrain the past ice sheet and bedrock displacement, and thus present-day GIA. Here, we develop a new GIA prediction by adjusting the load model of Fleming & Lambeck (2004) to the newly available GPS data. Special focus lies on south Greenland, where now more high-quality RSL data from isolation basins are available. Moreover, global seismic models suggest a lithosphere thickness and asthenosphere viscosity that is lower than the viscosity profiles inferred in Fleming & Lambeck (2004). We evaluate the impact of our new GIA model on determining ice-mass balances from GRACE. We show that commonly-used GIA predictions have underestimated the solid Earth response by 17 Gt/yr, which is about 7 % of Greenland current ice-mass loss.

References:

Fleming, K., & Lambeck, K. (2004). Constraints on the Greenland Ice Sheet since the Last Glacial Maximum from sea-level observations and glacial-rebound models. Quaternary Science Reviews, 23(9), 1053-1077.

Keywords: glacial-isostatic adjustment, Greenland, ice-mass balance, Paleo sea-level, GPS

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 205
Poster Board N°55

Examining Spatial Variability in Relative Sea-Level in the New York City/New Jersey Region during the Common Era

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Relative sea-level (RSL) reconstructions extend the 20th century instrumental record (tide gauge and satellite measurements) of spatial and temporal sea-level variability to provide a much longer context for recent trends and projected RSL rise. Common Era (last 2000 years) RSL reconstructions illustrate patterns of natural variability and include natural phases of climate and sea-level which will improve our knowledge basis for sea-level responses to climate changes.

The northeast U.S. has exhibited varying rates in RSL rise through the Common Era, primarily due to glacial isostatic adjustment. However, other factors such as ocean/atmosphere dynamics, sediment compaction, and the static equilibrium response to land ice changes, further influence the evolution of relative sea-level. The spatial variability is manifest in the tide gauge records. The tide gauge at the Battery, New York City (1856 to 2015) records a RSL rise of 2.8 mm/yr whereas the tide gauge at Sandy Hook, New Jersey (1932 to 2015), 25 km southeast, records 4.1 mm/yr.

Here we present a new reconstruction of RSL in northern New Jersey using geological and tide gauge data. A Common Era sea-level record from northern New Jersey fills in the spatial gap between records completed in southern New Jersey, New York City, and Connecticut. Our field study site is in Cheesequake State Park, where we observed sedimentary sequences dating back 2000 cal. yrs. BP. We use microfossil indicators preserved in salt-marsh sediments as a proxy to reconstruct RSL with decimeter precision. Salt-marsh foraminifera act as reliable RSL indicators because their modern distribution is strongly linked to tidal elevation. The recent application of microfossil-based transfer functions has enabled continuous records of RSL, extending centuries before the modern instrumental period, to be produced with a full consideration of uncertainty. We use a composite chronology of AMS 14C, pollen chrono-horizons, pollution histories, and a 137Cs spike (AD 1963) to achieve multi-decadal temporal precision. The RSL record for northern New Jersey shows a 2.4 m rise during the past 2000 years at a mean rate of ~1.2 mm/yr. This compares to rates from a database of Holocene relative sea-level observations for the U.S. Atlantic coast which found a rise of ~1.4 mm/yr for New Jersey and ~1.3 mm/yr for New York from 4 ka BP to AD 1900 (Engelhart and Horton, 2012).

Keywords: sea-level, climate, salt marsh, Common Era

Paper ID 224
Poster Board N°3

Modelling the Influence of Lake Agassiz on Glacial Isostatic Adjustment and the Deglaciation of the Laurentide Ice Sheet

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ANICE is a 3-D ice-sheet-shelf model, which simulates ice dynamics on the continental scale. It uses a combination of the SIA and SSA approximations and here it is forced with benthic δ18O records using an inverse routine. It is coupled to SELEN, a model, which solves the gravitationally self-consistent sea-level equation and the solid earth deformation of a spherically symmetrical rotating Maxwell visco-elastic earth, accounting for all major GIA effects. The coupled ANICE-SELEN model thus captures ice-sea-level feedbacks and can be used to accurately simulate variations in local relative sea-level over geological time scales.

In this study it is used to investigate the mass loss of the Laurentide ice-sheet during the last deglaciation, accounting in particular for the presence of the proglacial Lake Agassiz by way of its GIA effects and its effect on the ice sheet itself. We show that the mass of the water can have a significant effect on local relative sea-level through the same mechanisms as the ice-sheet – by perturbing the geoid and by deforming the solid earth. In addition we show that calving of the ice-shelf onto the lake could have had a strong influence on the behaviour of the deglaciation. In particular, when allowing lake calving, the ice-sheet retreats rapidly over the deepening bed of Hudson Bay during the deglaciation, resulting in a narrow ice dam over Hudson Strait. This dam collapses around 8.2 Kyr causing a global sea level rise of approximately 1 meter – an observation that agrees well with field data (for example, LaJeunesse and St. Onge, 2008). Without lake calving the model predicts a drainage towards the Arctic ocean in the North.

Keywords: Lake Agassiz, GIA, Deglaciation

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 227
Poster Board N°25

Numerical Modelling of the Indicative Meaning of Sea-Level Indicators in Pleistocene Sea-Level Studies

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The interpretation of sea-level indicators is essential for the study of sea-level changes during past interglacial periods. Sea-level indicators can be of different origin, for example biological, sedimentological or morphological. In order to be used in reconstructing paleo sea-level histories, it is necessary to attribute an indicative meaning to each paleo sea-level indicator. This property describes the possible vertical variation in the formation of the indicator that can be caused by different local conditions (e.g. wave exposure, tide range). For example, a beach deposit can form between the highest and lowest point of wave-sediment interaction, i.e. the ordinary berm and the breaking depth of waves. In this case, the elevation of these elements represents the limits of the indicative meaning. Especially in Holocene sea-level studies, the values for the indicative meaning are usually derived by observing a modern analog, which represents the elevational range of a certain indicator surveyed in the modern environment.

In this study, we present a set of novel methodologies to model the indicative meaning for some indicators using hydro- or morphodynamic models. We apply these methods to establish the indicative meaning of MIS 5e beach deposits on the island of Mallorca (Western Mediterranean) and of tidal notches with data from the island of Bonaire (Caribbean Netherlands). In Mallorca, we used a 1D morphodynamic model (CShore) in order to model the elevation of the beach berm and of the breaking depth of waves during typical storms between 2002 and 2013. Our results shows that beach deposits can have a large indicative meaning of up to 5.6 m. In Bonaire, we used a 3D hydrological model (Delft3D-FLOW) to calculate water levels during a complete tidal cycle (19 years). We repeated our calculations using a present-day topography and bathymetry and a MIS 5e one, derived adding to the present-day bathymetry the results of the ANICE-SELEN ice-earth coupled GIA-model. Both, field data and models, suggest that the tidal ranges did not change in Bonaire between MIS 5e and today, and that the indicative meaning of tidal notches can be constrained as a function of the tidal range.

In the investigation of paleo sea-level changes a site-based study of the indicative meaning is important. While the necessary data might not be available for known sites of MIS 5e sea-level study, the described methodologies can be used in many more places, because global datasets can be used as inputs. In an ongoing study we will use these methods in order to assign values of the indicative meaning systematically and on a local basis to the available database of MIS 5e sea-level studies.

Keywords: Hydrodynamic Modelling, Sea-Level Indicator, Beach Deposits, Tidal Notches

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 228
Poster Board N°1

A Holocene Sea-Level Database for Southeast Asia

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The study of former relative sea-level (RSL) changes is essential to disentangle changes in sea level due to vertical land motion (e.g. tectonics, Glacial Isostatic Adjustment - GIA) and eustatic (i.e, ice-equivalent sea level) causes. To study RSL changes at a regional scale, it is essential that databases of sea-level indicators are produced following standardized protocols (e.g, Hijma et al., 2015, Handbook of Sea-Level Research). Previously, this was done in several regions (e.g. the US Atlantic coast, the Caribbean, or the Mediterranean (Engelhart and Horton 2012, QSR)). A database has been compiled for Southeast Asia but it was limited in geographical extent and did not include the influence of local process such as tidal range changes and compaction. Southeast Asia is highly vulnerable to relative sea level changes, as it is characterized by low-lying, densely populated islands and subsiding deltas.

We present a database of Holocene sea-level histories in Southeast Asia and part of the Indo-Pacific from published and unpublished data, which has been evaluated using a standardized protocol. We analyzed more than 600 sea-level index points, defining their locations the height of former sea level and the age with their associated uncertainty. Radiocarbon ages were re-calibrated using Calib 7.1 (Stuiver et al., 2017) and the calibration curves Intcal13 or Marine13. In our database, we also indicated possible tectonic vertical land motion, and we present the results of GIA modelling for different areas in SE Asia. We also show regions of South East Asia and parts of the Indo-Pacific where there is an absence of data and where the collection of new RSL data is mostly needed.

Keywords: Database, Indonesia, Indo-Pacific, Holocene

Paper ID 233
Poster Board N°13

Rapid Pre-Industrial Sea-Level Rise in the Northwest Atlantic Ocean

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The Northwest Atlantic is a region where 'hot spots' of sea-level rise in the instrumental record have been linked to natural ocean-atmosphere climate variability. Here we test if these 'hot spots' are present in pre-industrial sea-level records by reconstructing relative sea-level changes from three sites (Nova Scotia, Maine, Connecticut) using foraminifera preserved in salt-marsh sediments. In all three sites we document evidence for high rates of sea-level rise in the late 18th century that were only slightly slower than rates in the 20th century. Further to the south (New Jersey, North Carolina, Florida) sea-level reconstructions do not show this pre-industrial acceleration of sea-level rise while other published paleosea-level records from the region (eastern Connecticut, New York City) have not captured it clearly, possibly due to lack of resolution. Episodes of rapid sea-level rise in the 18th and 20th centuries appear to coincide with negative phases of the North Atlantic Oscillation (NAO), a correlation that also occurs in tide-gauge records. We suggest that redistribution of water by changing wind and pressure fields are an important contributor to Northwest Atlantic sea-level variability on (multi-)decadal and centennial timescales. Rates of future sea-level rise for New York City, Boston and other population centres in New England and Atlantic Canada are possibly under-predicted because of these high rates of background natural sea-level rise during negative phases of the NAO.

Keywords: North Atlantic Oscillation, salt marsh, foraminifera, New England, Atlantic Canada

Paper ID 240
Poster Board N°21

Reconstructing Geomorphological Response of Barrier Estuary to Holocene Changes in Relative Sea Level and Sediment Supply

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Future vulnerability and resilience of coasts, and their associated communities, infrastructure and nature conservation interests, is of increasing concern due to the combined effects of climate change and sea-level rise. The Suffolk coast, UK, characterised by gravel barrier beaches and a spit feature of international geomorphological interest, has changed dramatically since the Holocene. However, existing research for the Holocene is limited. Sediments preserved within the enclosed valleys and back-barrier wetlands of Suffolk provide an opportunity to improve understanding of the complex mesoscale (years-decades-centuries) behaviour of coastlines and their geomorphological response to changes in natural forcing. This research aims to reconstruct Holocene changes in coastline behaviour to develop reconstructions of coastal evolution relating to changes in relative sea level, sediment supply and storm incidence.

Litho- and bio-stratigraphic analyses (sedimentology, particle size, and diatom analysis) have been undertaken on three marsh and wetland sites in a 5 km section between Walberswick and Dunwich. A consistent pattern of interbedded intertidal and freshwater units separated by transitional saltmarsh deposits is seen at all sites. Diatom analysis from the sites indicates increased marine and brackish conditions across the main organic-minerogenic transitions. Submitted radiocarbon analysis will provide chronological constraint for the timing of the major coastal behavioural changes identified from the analysis. Initial radiocarbon dating results suggest that the onset of peat deposition in this section of the Suffolk coast (6950-6790 cal. BP) contrasts with existing research from the Blyth estuary, 5 km north (7714-7479 cal. BP).

Combined, these results indicate that this section of the Suffolk coast has been subject to periodic barrier opening and closing during the Holocene. Though currently unresolved, longshore sediment supply, high magnitude-low frequency storm events, sea-level change, and the position of offshore banks are likely causal mechanisms for these changes. These results will improve understanding of the long-term (Holocene) natural signal of coastal change and are significant given that the regional Shoreline Management Plan has recommended managed realignment for this section of the Suffolk coast.

Keywords: Holocene, sea level, coastal change, reconstruction

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 288
Poster Board N°23

Detecting Sub-millennial Relative Sea-Level Changes from Salt-Marsh Environments in the Mediterranean: New Records from the Adriatic

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Understanding spatial and temporal patterns of historical relative sea-level (RSL) change in the Mediterranean region are hampered by a lack of long-term data, with only 7 tide gauge stations containing a record >50 years. Furthermore, the post-1993 satellite altimetry data illustrate sea levels rising at rates that exceed global averages for much of the region. Late Holocene records are sparse and heavily reliant on geomorphological, biological and archaeological indicators that are restricted in resolving sub-millennial RSL changes. In addition, these do not overlap in time with the more recent instrumental record, and their relationship with a precise former tidal level (indicative meaning) is often ambiguous. Thus the longer-term sea-level trend is poorly defined.

We combine existing late Holocene RSL data with new RSL data derived from salt-marsh deposits – a first for the Mediterranean basin. This technique utilises the quantifiable relationship between modern foraminiferal assemblages and elevation in the tidal frame to provide analogues against which fossil counterparts can be compared within dated sediment cores affording much improved vertical and temporal resolution.

Our RSL reconstruction uses local modern training sets from two micro-tidal salt-marsh sites along the central Croatian coastline yielding low vertical uncertainties. Fossil foraminifera were enumerated from chronologically constrained sediment cores using radiometric (210Pb and 14C) techniques placed within a Bayesian age-depth framework. The RSL reconstruction extends to ~1730 CE and bridges the gap between the geological and instrumental record.

We modelled the evolution of RSL change using the composite dataset and an averaged tide gauge record for the eastern Adriatic Sea. Late Holocene RSL changes show strong correlation with climate events during this period with sea-level minima recorded during the Little Ice Age. The salt-marsh reconstruction constrains 20th century RSL rise at an average rate of 1.2 mm/yr and shows good correspondence with tide gauge data. The current rate of RSL rise of ~1.4mm/yr is likely faster than anything observed in the past ~2700 years for the central Adriatic region and provides a clear signal of the anthropogenic contribution to sea-level change.

Keywords: Late-Holocene; sea-level change; salt-marsh; Mediterranean

Paper ID 290
Poster Board N°9

Trace Fossils as an Indicative of Paleo-coastlines Faunal Change during the Quaternary in Southern Brazil

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The knobby walled burrow Ophiomorpha isp. is one of the most well-known trace fossil in the world, and is an indicative of foreshore deposits. Burrow walls consist mainly of dense, regularly distributed ovoid or rounded pellets. Over 500 fragments of Ophiomorpha are found as floating material along the Rio Grande do Sul coastline in southern Brazil. These traces are generally preserved in full relief; however, only one part of the burrow is preserved. The arrangement and packing of pellets of Ophiomorpha are highly variable. In some specimens, pellets are nearly brick-like in their arrangement while, in others, pellets are less organized or patchily distributed. Those Ophiomorpha are either empty or passively filled by sand with shell fragments, whereas some have pellets filling. The differential erosion and lithification of the traces might indicate a temporal mix of the Ophiomorpha. The Rio Grande do Sul (RS) continental shelf (Amero-trading edge type margin) formed well-preserved paleo-coastlines in the center-south part, preserving and fossilizing Ophiomorpha that is deposited by oceanographic dynamics on the beach. This passive margin type coastline is significantly influenced by the geologic framework of older stratigraphic units that are deposited beneath and seaward from the foreshore. These trace fossils are a vestige of the paleo-coastlines formed in the two intermediary sea level stabilizations at 9000 yrs B.P. (between - 32 and - 45 m); and the third at 8000 yrs B.P. (between -20 and -25 m). Subsequent reworking of the paleo-coastlines, mainly by storm waves, has deposited these trace fossils on the beach. Occurrences of similar burrows in present day shorelines of RS are associated with the crustacean Sergio mirim, which reaches a maximum internal diameter of 5 cm (average 3 cm). Nonetheless, 2% of the analyzed fossil Ophiomorpha presented a larger internal diameter (up to 7 cm) and different pellets arrangement. The deepest paleo-coastline (9000 yrs B.P.) is the least reworked, eroded only by storm waves. Thus, the larger Ophiomorpha could probably be associated with the 9000 yrs B.P. paleo-coastline, indicating that a different species of crustacean inhabited the beaches of southern Brazil. Further studies are being made to determine the age and confirm this hypothesis.

Keywords: Ophiomorpha, Passive margin, crustacean

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 294
Poster Board N°11

Paleo Sea-Level Analysis Based on Vermetid-Coralline Outcrops from the Holocene of Southeastern Brazil

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Events of sea-level variation associated with sediment transportation and climatic changes are considered important factors on the lineation of the Pleistocene coastal plain in Brazil. Along the Brazilian coast many records of these variations are detected, and the sessile gastropods Vermetidae are among the most used indicators of past sea-level positions. Some well know vermetid species occupy a narrow bathymetric range within the intertidal rocky shore and are named fixed biological indicators (FBI), the altimetry precision may vary between ± 0.1 a ± 1.0 m. Petaloconchus species are usually known as fossil/subfossil bioconstructions from the Holocene of the South Atlantic. In this study, we aim to identify former positions of the sea-level and to assess the paleoenvironment of the region studied. This work was conducted at Arraial do Cabo Bay, in the central coast of the Rio de Janeiro State, southeastern Brazil. Outcrops of fossil vermetids were sampled to be analyzed for taxonomy and radiocarbon age. The altimetry of the samples was measured in field using a Pro Mark II GPS tracker by the static method, posteriorly the topographic data were processed by the GNSS (Global Navigation Satellite System) Solutions software to achieve the position of the outcrops in relation to the current sea level. The in situ fossil vermetids are represented by monospecific clusters of Petaloconchus varians; others biogenic compounds as coralline red algae, bivalves, barnacles, bryozoans, small gastropods and foraminifera were identified. Coralline red algae are represented by Lithophyllum pustulatum, Spongites fruticulosus, Spongites yendoi, Mesophyllum engelharti, and unidentified geniculate corallines. The altimetry and the calibrated radiocarbon ages of the outcrops varied respectively between + 1.184 – + 4.075 m with an error of ± 0.5 m and 1.355 – 3.737 yrs B.P. The reservoir effect (ΔR) applied was 67.0 ± 33.0. The δ18O and the δ13C of the fossil vermetids shells vary respectively between 0.403 ± 0.029 – 1.268 ± 0.023, and 1.945 ± 0.051 – 3.106 ± 0.049. These data suggest a Holocene sea-level at + 1.184 m between 1.297 – 1.395 yrs B.P., reaching a maximum level for the Rio de Janeiro coast around 4 m between 3.215 – 3.335 yrs B.P., a variation around 1.500 – 1.340 yrs B.P. were detected with FBI at +3.385 m. The concentrations of δ18O and δ13C is correlated with a warmer sea surface temperature during the late-Holocene and a high primary productivity setting.

Keywords: vermetid, coralline red algae, Rio de Janeiro, Brazil

Paper ID 298
Poster Board N°7

Holocene Climatic Reconstruction from Coastal Dunes of the Western Kachchh, India

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Coastal dunes have been documented along the margin of Kori Creek from Lakhpat to Narayan Sarovar, Western Kachchh. The present study focuses on the mechanism of dune building activity and the factors resulting into the formation of the dunes and to reconstruct the climatic history. Two generation of dunes has been documented from the site of study. At the base (Unit I) ~10m thick sand has been documented resting directly over the Tertiary Oyster Bed. Over this another thick stack of sand (Unit II) has been recorded having a thickness of ~6m. Unit II deposit consists of massive sand without any internal structure and bears the presence of rizo-concretions gives a luminescence age of ~8ka. The lower Unit I consist of poorly sorted gravelly sand at the base followed by well sorted fine sand overlain by coarse sand with finer broken shell fragments, bearing an age of ~4ka. Based on the ages it can be suggested that Unit II forms the inner core of the dune which got deposited first followed by Unit I which overlaid the Unit II. The inner core suggest less to moderate weathered conditions in comparison with the more weathered conditions that prevailed during the deposition of the outer dune deposits as revealed from the Chemical Index of Alteration (CIA). Studies all around the globe indicate that the time frame of 8000 and 4200 years was a period of cold and dry phase, and the sea fell down by around 0.5 to 4m leading to lowering of sea level and exposure of open land resulting into formation of beaches and construction of dunes. With our studies we also support the view that Kachchh Coastline got exposed leading to the formation of coastal dunes with high intensified winds.

Keywords: Kori Creek (India), Cold and Dry Phase, Coastal Dune

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 299
Poster Board N°53

Relative Sea-Level Changes from the Chesapeake Bay Over the Past 4000 Years

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A suite of proxy-based relative sea-level (RSL) reconstructions along the U.S. Atlantic coast revealed spatial and temporal variability throughout the Common Era. Glacial isostatic adjustment resulted in sea-level histories reflecting their proximity to the former Laurentide Ice sheet. In addition to local factors (e.g. sediment compaction and tidal range change), superposed are the effects of ocean dynamic processes that shows the response of sea levels to known climatic variability over the past ~2000 years.

We extend our understanding of RSL changes through a new, near-continuous 4000-year reconstruction using salt-marsh sediments and foraminifera from the Chesapeake Bay. Fossil foraminifera calibrated by local modern assemblages provided paleo marsh elevations with low vertical uncertainties (±0.06m). We corrected sample elevations for post depositional lowering processes using a compression-only geotechnical model. Changes in accumulation rate were accurately constrained using 35 radiocarbon dates coupled with event-based dating utilizing pollen chonohorizons, pollution histories and short-lived radionuclides within a Bayesian framework yielding low temporal uncertainties (40 years). We quantified changes in RSL using an Errors-In-Variables Integrated Gaussian Process model that integrated local tide-gauge measurements with the proxy record.

The reconstruction shows ~6 m RSL rise since ~2000 BCE throughout which periodic changes in the rate of RSL were identified. Rates of RSL increasing to 1.4 mm/yr between 2000 BCE and 1300 BCE precedes a significant slowdown to 0.8 mm/yr at 700 BCE concurring with widespread cooling throughout the North Atlantic. An increase in the rate of RSL rise to 2.1 mm/yr at 200 CE precedes a decrease in rate to 1.3 mm/yr at 1450 CE corresponding with the Little Ice Age. The modern rate of RSL, rising at 3.6 mm/yr, is the fastest observed in ~4000 years. The temporal length and decadal resolution of the RSL reconstruction sheds new light on the relationship of sea levels to climate variability during the late Holocene.

Keywords: Sea Level, Holocene, Climate, Atlantic

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 309
Poster Board N°43

The Improved Semi-Empirical Fennoscandian Postglacial Land Uplift Model NKG2016LU

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NKG2016LU is a semi-empirical land uplift model computed in Nordic-Baltic cooperation in the Nordic Geodetic Commission (NKG) Working Group of Geoid and Height Systems. The model gives the vertical land uplift rate in two different ways: (1) NKG2016LU_abs with the absolute land uplift in ITRF2008 (i.e. relative to the Earth's center of mass), and (2) NKG2016LU_lev with the levelled land uplift, i.e. uplift relative to the geoid.

NKG2016LU has been computed using a remove-compute-restore technique based on (1) an empirical land uplift model derived from geodetic observations and (2) a geophysical GIA model called NKG2016GIA_prel0306. The empirical model has been computed from uplift results of Global Navigation Satellite System (GNSS) time series from the Baseline Inferences for Fennoscandian Rebound Observations, Sea-level and Tectonics (BIFROST) project and levelling data. Compared to the previous model NKG2005LU, no tide gauge information was used. The geophysical model is based on a spherically symmetric (1D), compressible, Maxwell-viscoelastic earth model applying the viscoelastic normal-mode method. Ice history information is taken from Glaciological Systems Model (GSM) results, a set of 25 different 3D thermo-mechanically coupled glaciological models calibrated against ice margin information, present-day uplift, and relative sea-level records. The best-fitting geophysical Earth model to both the BIFROST uplift and Fennoscandian relative sea-level data simultaneously has a 160 km thick lithosphere, a viscosity of 7 x 1020 Pa s in the upper mantle, and of 7x1022 Pa s in the lower mantle.

No apparent uplift model (i.e. uplift relative to Mean Sea Level over a certain time period) is released for the time being. This is mainly motivated by the (accelerating) contemporary climate-related sea level rise, which implies that the apparent land uplift is different from the levelled land uplift and dependent on the chosen time interval.

Our presentation will introduce the model and its computation as well as discuss the problematic issue of handling tide gauge information. We will present climate-related sea-level changes by comparing NKG2016LU_lev with apparent uplift in tide gauges for a number of selected time periods.

Keywords: Glacial Isostatic Adjustment, Uplift model, Absolute uplift, Apparent uplift, Tide gauges

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 318
Poster Board N°59

Early Holocene Sea Level Rise in the Pearl River Estuary, China

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The Early Holocene sea-level rise was marked as the biggest recent change in the landscape of present coastal zones across the world. Several sea level curves have been proposed for the Pearl River estuary in the past three decades. However, these sea-level curves indicate a complex history of early Holocene sea level and are of low accuracy because of the lack of high-quality sea level index points during this period. Detailed early sea level history must be known as to accurately predict the future trend of sea level rise and fully understand the driving mechanisms of relative sea level which are subject to many interconnected causes, e.g. glacio-eustatic change, glacial isostatic adjustment and local tectonic movements.

This paper aims to reconstruct the early Holocene sea level history wihin the Pearl River estuary by obtaining new precise sea level index points and re-examining past sea level data and comparing the reconstructed record with simulated GIA model. The base of Holocene marine sediment (as transgressive contacts) was selected for microfossil and dating analyses for the development of high-quality sea-level index points. We selected and analyzed five sediment cores from the outer estuary, i.e. HKUV10, HKUV11, HKUV12, V37, BVC and five cores from the apex area, i.e. 16DS01, 16DS02, 16DS03, 16SP01, 16SP02, to identify the initial transgressive contacts which were validated by the lithology and the appearance of marine and brackish water diatom. Results show that the onset of marine inundation were at alt. -52.1 m dated at cal. 10580 a. BP at HKUV10, alt. -43.3 m dated at cal. 10050 a. BP at HKUV11, alt. -32.4 m dated at cal. 9750 a. BP at HKUV12, alt. ** m dated at cal. 8600 a. BP at V37, alt. ** m dated at cal. 9800 a. BP at BVC, alt. ** m dated at cal. ** a. BP at DS01, alt. ** m dated at cal. ** a. BP at DS02, alt. ** m dated at cal. ** a. BP at DS03, alt. ** m dated at cal. ** a. BP at SP01, alt ** m dated at cal. ** a. BP at SP02. Integrating the new sea-level index points and the qualified sea-level data filtered from published literature, we proposed a curve of early Holocene sea-level rise across the estuary, which draw a historic picture of marine inundation beginning from -52.1 m in the outer estuary at cal. 10580 a. BP to -20 m in the apex area 150 km away at cal. 9200 a. BP. The reconstructed record agrees well with global eustatic history but apparently lower than the newly simulated result of a lateral heterogeneous earth model (RF3L20, β=0.4) coupled with a deglacial model (ICE-5G). Assuming the predicted result of GIA is correct, the comparison may suggest minor tectonic subsidence and possible sedimentary compaction within the Pearl River deltaic basin during the Holocene, with the magnitude estimating at about * m.

Note: data shown in the abstract need further correction and calibration as we are still working on the analysis.

Keywords: relative sea level, early Holocene, the Pear River estuary, GIA, tectonic movement

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 325
Poster Board N°49

A Statistical Framework for Developing Coral-Based Reconstructions of Relative Sea Level

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Corals provide a valuable archive of past changes in relative sea level (RSL) from tropical and sub-tropical regions, particularly in locations or time periods where other high-resolution sea-level data are scarce; however, the relationship of corals to sea level is often poorly constrained, which limits their potential utility. Here, we provide a new framework for incorporating coral archives into statistical reconstructions of past RSL to accurately quantify the relationship of individual coral taxa to sea level and its uncertainty. Using the Ocean Biogeographic Information System's database (http://iobis.org/) of coral occurrences from the western Atlantic, we compiled data on the modern depth distributions of individual coral taxa and modeled the best fit probability distributions to those data. We demonstrate that most corals follow a log-normal distribution with depth and that most corals, not just A. palmata, are most likely to be in shallow water (within ~10 m of meters of sea level). We developed a hierarchical model that incorporates non-Gaussian likelihood structures of sea-level proxies and contains a 1) data, 2) process, and 3) hyperparameter level. The data level models how proxies record RSL over time. The modern depth distributions of individual coral taxa are used to infer the probability distribution of sea level, given the observed data (proxy elevation). These data are sampled, using Markov Chain Monte Carlo techniques. Temporal uncertainties are translated into equivalent errors in the dependent variable (RSL) and, along with the measurement uncertainties, are assumed to be normally distributed. At the process level, temporal correlation among the data is used to reduce uncertainty in estimates of the posterior sea-level field and to allow prediction at times when there are no data. We model the sea-level field as a Gaussian process (GP), a generalization of the multivariate normal distribution. The hyperparameter level dictates how correlations among data are modeled and these parameters are optimized to maximize the likelihood of sea level with respect to that data sample.

We applied the model to three Quaternary coral archives to evaluate its performance under various scenarios of RSL change: a Holocene record from south Florida that includes both coral and sedimentary archives and two coral archives from Barbados that represent the deglacial period and the last interglacial (MIS-5e). Using the new approach, we develop robust models of RSL variability across each of these periods. We also test the sensitivity of the model to the rates of sea-level change being modeled, the number of data points and their temporal evenness, data uncertainties, and the shape and type of the coral distribution to evaluate its performance and quantify its limitations. We suggest that the use of our statistical framework provides a valuable tool for using coral archives to develop robust reconstructions of past of RSL change with accurate estimates of uncertainties.

Keywords: Holocene, Interglacial, Deglacial, Relative Sea Level, Coral, Hierarchical Statistical Modeling

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 339
Poster Board N°39

Past Sea-Levels Reconstruction as Tool to Quantify the Post-Industrial Sea-Level Rise Acceleration Along the Mediterranean Coastlines

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Global sea-level rise is the result of an increase in the ocean volume, which evolves from changes in ocean mass due to melting of continental glaciers and ice sheets, and expansion of ocean water as it warms. Our understanding of current rates of sea-level rise from tide gauge and satellite data, requires correction for glacial isostatic adjustment (GIA) effects that are calibrated by observations of former sea levels.

The analysis of more than 1000 radiocarbon dated Relative Sea-Level (RSL) data-points resulted in an improved and quality-controlled assessment of the Holocene sea-level histories for the Mediterranean Sea coasts. We reviewed and standardized the geological RSL data-points using a new multi-proxy methodology based on: (1) modern taxa assemblages in Mediterranean lagoons and marshes; (2) beachrock characteristics; and (3) the modern distribution of Mediterranean fixed biological indicators.

These RSL data-points were coupled with the large number of archaeological RSL indicators available for the Mediterranean Sea. Such standardized methodology allowed the robust assessment of the spatial variability of RSL histories among the different regions and the comparison with latest Glacial Isostatic Adjustment (GIA) models. In west Mediterranean, RSL rose continuously for the whole Holocene with a sudden slowdown at ~7.5 ka BP and a further deceleration during the last ~4.0 ka BP, after which time observed RSL changes are mainly related to variability in isostatic adjustment. An important exception is southern Tunisia, where data show evidence of a mid-Holocene high-stand compatible with the isostatic impacts of the melting history of the remote Antarctic ice sheet.

We further compared the late-holocene rising rates with the long-term (>50 years of measurement) Mediterranean tidal gauges. Results indicate that GIA contribution accounts at least for the 25-30% of the ongoing Mediterranean sea-level rise. It implies a significative acceleration (0.3 to 1.3 mm/y) post-industrial sea-level rise, notably in the NW portion of the basin.

Keywords: Relative sea-level; Mediterranean Sea; GIA modelling; Sea-level rise; Sea-level proxies

Paper ID 342
Poster Board N°51

The Common Era Sea-Level History of Delaware Bay, U.S. mid-Atlantic coast

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Common Era geological reconstructions of relative sea level (RSL) from salt-marsh sediments capture patterns of variability during the climate transitions from the Medieval Climate Anomaly and the Little Ice Age. Recent high-resolution RSL reconstructions from the U.S. Atlantic coast (e.g., Connecticut, New Jersey, and North Carolina) present spatial and temporal variability that has been attributed to regional (e.g., glacial isostatic adjustment, static-equilibrium and ocean dynamic effects) and local (e.g., tidal-range change and compaction) mechanisms. Our techniques utilizing salt-marsh sediments have the required vertical (decimeter-scale) and temporal (decadal to centennial-scale) resolution to reveal small-scale RSL variability. Salt-marsh sediments contain accurate and precise sea-level indicators such as foraminifera, whose relationship with tidal elevation can be quantified using transfer functions. These transfer funtions are then applied to fossil foraminiferal assemblages found in the salt-marsh sedimentary record to reconstruct RSL. The temporal framework of the salt-marsh sediment is estimated using a composite chronology of radiometric analyses (e.g., 14C and 137Cs) and chronohorizons (e.g., pollution and pollen). To better understand the variability of RSL along the U.S. Atlantic coast and the driving mechanisms of Common Era sea level, we produced a new RSL reconstruction from the Great Marsh (lower Delaware Bay) using a Bayesian framework. We employed a Bayesian transfer function (B-TF) that allows foraminiferal species to have individual response functions with respect to tidal elevation to improve the reconstruction accuracy. The B-TF also employs a secondary sea-level indicator (bulk sediment stable isotope geochemistry; δ13C) to reduce the uncertainty. We used radiocarbon (n = 16), 137Cs activities, pollution chronohorizons (concentrations of zinc and lead, and ratios of stable lead isotopes (206Pb:207Pb)), and land-clearance pollen markers within a Bayesian age-depth model to develop a chronology. Finally, we estimated rates of RSL change by applying an existing errors-in-variables integrated Gaussian process (EIV-IGP) model. We observed a RSL rise of ~2.5m since 200 CE in the Delaware Bay. The rate of RSL rise increased from 1.0 mm/yr to 1.6 mm/yr between 200 CE and 500 CE, followed by a slowdown to rates of 0.3 mm/yr at 1100 CE. The modern rates of 3.2 mm/yr are the fastest observed in the Common Era. We compare these rates to other high-resolution reconstructions of RSL from along the U.S. Atlantic coast.

Keywords: foraminifera, salt marsh, sea level

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 354
Poster Board N°29

Sea-level and Storm-flood History of the Last Century Documented in a Salt Marsh Succession from the Southern North Sea

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We investigated the benthic foraminiferal assemblages in a salt marsh sediment succession from the southern North Sea coast to document the natural and anthropogenic impacts on the accretion rate during the last century. We applied two different transfer function approaches by using duration of submergence (DoS) to address the percentage of time during which the salt marsh surface is flooded, and the standardized water level index (SWLI) to further address the marsh´s surface elevation changes relative to mean high water. We further compiled historical information on 1) land use (ditching cycles, dike construction, land reclamation), 2) relative mean sea-level changes, and 3) wind force and direction, and storm floods of the last century. The foraminiferal assemblages in the sediment succession reveal temporal changes with an alternating dominance of agglutinated and calcareous taxa. Among the agglutinated species, Entzia macrescens, dominating in the lower and middle part of the profile,is indicative for a low to middle marsh environment with up to 20 % DoS and up to 30 cm below mean high water (MHW). Balticammina pseudomacrescens is dominant in the upper part of the succession, following the recent termination of ditching and documenting the establishment of a high marsh environment with around 3 % DoS and around 80 cm above MHW. Calcareous taxa are dominant before dike construction. After diking there are several short-term increases in their numbers, probably reflecting relocation from tidal flat environments during storm flood events. The overall trend of increasing grain size and abundance of agglutinated taxa indicates that the studied salt marsh region is still resilient to local relative sea-level rise.

Keywords: Salt Marsh, Duration of Submergence, Storm Flood, Foraminifers, Tides

Paper ID 362
Poster Board N°15

Balance of Subsidence and Sediment for the Sustainability of the Ganges-Meghna-Brahmaputra Delta Plain During Periods of Sea-Level Rise

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Sustainable coastal management requires a good understanding of subsidence as a natural process, as well as the manner that human interventions modify it. Subsidence is a dynamic process that may evolve with changes of sediment supply and changes of absolute sea-level. We present a reconstruction of the Holocene relative sea-level history in the Ganges-Brahmaputra-Meghna Delta (GBMD) in Bangladesh based on a broad dataset that includes more than 400 hand-drilled stratigraphic wells, 185 radiocarbon ages, and seismic reflection data (255 km of high resolution multichannel seismic images) collected during the BanglaPIRE project. The reconstruction is precise enough to distinguish between the effects of eustasy and subsidence on the relative sea-level history over the Holocene. Different morpho-tectonic units of the delta, which exhibit consistent subsidence history and rates, are defined to better constrain the regional distribution of the subsidence. While the subsidence gently increases seaward south of the continental margin hinge zone, the subsidence history is disturbed, likely by tectonic activity, in the vicinity of the Dauki Fault to the north and the IndoBurma subduction front to the east. Still, results provide evidence of moderate Holocene subsidence over the delta, ranging between 1 and 4.5 mm/a. The subsidence associated with the sediment mechanical compaction is modelled based on estimates of sediment loads and sediment properties. Results suggest that even if mechanical compaction of the sediments is relatively limited, it accounts for at least half of the subsidence. The low compaction rate may be associated with the low clay and organic matter content of the sediment. This contrasts to other deltas, such as the Mississippi or the Mekong deltas, which are muddier and thus subsiding at a faster rate. The subsidence distribution exhibits a gentle seaward increase of rate, suggesting that the seaward collapse of the delta is also limited, at least during periods of sea-level rise. This may be mainly related to the high sediment input and/or to the lack of an effective décollement surface at shallow depth, in contrast to several other large deltas (e.g., Nile, Niger). In such context, we estimate the volume of sediment needed to offset 2 to 7 m of eustatic rise that is predicted for the next century, to compensate for both eustatic rise and subsidence under natural conditions. This study may provide critical information about the possible effect of upstream sediment starvation associated with human intervention (e.g., dam construction and river diversions).

Keywords: Subsidence, Relative Sea-Level History, Delta, Subsidence Driving Forces

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 363
Poster Board N°47

Using Relative Sea-Level Data to Constrain the Lateglacial and Holocene History in McCormick Fjord, NW Greenland

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Here, we present a new relative sea level (RSL) reconstruction for McCormick Fjord, NW Greenland, based on isolation basins and bivalve shells to obtain more knowledge about the Lateglacial and Holocene glaciation history. In NW Greenland, existing RSL data is in general sparse and the RSL curves produced at nearby locations are based on very limited data. The bivalve shells were collected on raised marine terraces 15 to 52 m a.s.l. and consist of Hiatella arctica and Mya truncata. In addition, the transition from marine to lacustrine environment were identified and dated in 2 isolation lakes located 47 and 79 m a.s.l. The new dataset will allow us to construct a RSL curve for McCormick Fjord, which in turn reflects the Lateglacial and Holocene ice marginal fluctuations in NW Greenland. Furthermore, our new results increase the data density of RSL reconstructions in a region with a particularly complex ice sheet configuration, as the glacial isostatic uplift, and thus the RSL change, is affected not only by the Greenland Ice Sheet, but also by fluctuations of the North American ice complex. We furthermore intend to compare our results with existing predictions of past RSL in the area produced by the Huy2 and Huy3 ice sheet models and discuss possible improvements of the ice sheet models by incorporating our new data set.

Keywords: Relative Sea Level, Greenland Ice Sheet, Glacial Isostatic Adjustment, Isolation Lakes

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 394
Poster Board N°57

GIA in West Antarctica: Improved Constraints from Crustal Motion Measurements from the POLENET Antarctic GPS Network

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Crustal motions measured by GPS provide a unique proxy record of ice mass change, due to the elastic and viscoelastic response of the earth to removal of ice loads. The ANET/POLENET array of bedrock GPS sites spans much of the Antarctic interior, encompassing regions where glacial isostatic adjustment (GIA) models predict large crustal displacements due to ice loss since the Last Glacial Maximum (LGM), and including the sector of coastal West Antarctica where major modern ice mass loss is documented. To isolate the long-term GIA component of measured crustal motions, we computed and removed elastic displacements due to recent ice mass change. We used the annually resolved ice mass balance data from Martín-Español et al. [2016] with the Regional Elastic Rebound Calculator (REAR) [Melini et al., 2015] to compute elastic vertical and horizontal surface displacements. Uplift due to elastic rebound is substantial in West Antarctica, very minimal in East Antarctica, and variable across the Weddell Embayment.

The ANET GPS-derived and elastic-corrected crustal motion patterns ascribed to GIA are spatially complex, and differ significantly in magnitude from model predictions for many sectors of Antarctica. We present a systematic comparison of measured and predicted velocities within different sectors of Antarctica, in order to examine spatial patterns relative to modern ice mass changes, ice history model uncertainties, and lateral variations in earth properties. In the Weddell Embayment region most vertical velocities are lower than uplift predicted by GIA models. Several sites in the southernmost Transantarctic Mountains and the Whitmore Mountains have vertical uplift significantly exceeding GIA model predictions. Highest velocities occur in the Amundsen Sea Embayment sector of West Antarctica, flanked by subsiding regions. This pattern can be modeled as a viscoelastic response to ice loss on decadal-centennial time scales in a region with weak upper mantle, consistent with seismic results in the region.

Keywords: GIA, GPS, crustal motion, Antarctica

Paper ID 400
Poster Board N°19

SERCE Scientific Research Progamme: Solid Earth Response and Influence on Cryosphere Evolution

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SCAR's* Solid Earth Response and influence on Cryospheric Evolution (SERCE) scientific research programme aims to advance understanding of the interactions between the solid earth and the cryosphere to better constrain ice mass balance, ice dynamics and sea-level change in a warming world. This overarching objective is being addressed through supporting integrated analysis and the incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment (GIA) and ice sheet dynamics. The programme is designed to synthesize and integrate the extensive new geological and geophysical data sets obtained during and subsequent to the International Polar Year with modelling studies, in a timeframe to contribute to IPCC AR6. SERCE aims to provide the international collaborative framework and scientific leadership to investigate systems-scale solid earth - ice sheet interactions across Antarctica and relate these results to global earth system and geodynamic processes. Here we outline recent activities within SERCE and highlight upcoming community events.

*SCAR is the Scientific Committee for Antarctic Research

Keywords: Cryosphere - Solid Earth interactions

Paper ID 404
Poster Board N°33

Sea Level History and Paleoecology of Yellow Bar and JoCo Marshes, Jamaica Bay, New York City

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Sea level records derived from sediment cores in New York City are presented spanning the last four centuries. Yellow Bar and JoCo represent two significant marshes in Jamaica Bay that are remnant marshes serving as nurseries for fish, coastal buffers in storms, and essential habitat for birds. Using X-ray fluorescence (XRF) elemental analysis along with pollen, plant and foraminifera macrofossil analysis, AMS C-14 dating of identified macrofossils, and carbon and nitrogen stable isotopes from sediment cores we document the shifts in sea level as well as pollution history, vegetational change at the regional scale, and carbon sequestration. We compare this record to others in the New York City region, noting the significant role that both inorganic sediment supply and vegetation play in the sediment record.

Keywords: NYC sea level rise, paleoecology, carbon, foraminifera, pollen

Paper ID 409
Poster Board N°17

6000-year Records of Relative Sea-Level Change from South Florida

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Paleo-sea-level records are important for determining the contribution of local- to regional-scale drivers to projections of future relative sea-level (RSL) change. We produced ~6000-year long RSL histories from two sites where the relative contributions of drivers of RSL change are poorly known in the lower (Snipe Key) and upper (Swan Key) Florida Keys, USA using foraminifera preserved in cores of dated mangrove peat. At Snipe Key, RSL rose by ~5.1 m during the past ~5900 years compared to ~6.8 m at Swan Key during the past ~6000 years. Rates of RSL rise were highest (1-2 mm/yr) from 6000 to 4000 years ago and slowed to 0-1 mm/yr during the last four millennia. The spatial difference between sites is opposite from the pattern expected from differential GIA, which would cause Holocene RSL rise to be greater at Swan Key than at Snipe Key. We explore the influence of additional local- to regional-scale processes that may have driven differences in RSL between the two study sites as well as other regional RSL records, including non-stationary tides, sediment compaction, regional variations in hydroclimate, and the dynamic response of the Florida Current and Gulf Stream to climatic-induced changes to Atlantic Meridional Overturning Circulation (AMOC) and an associated weakening/strengthening of the Gulf Stream.

Keywords: Holocene, Florida, GIA, compaction, foraminifera

Paper ID 411
Poster Board N°45

Global Perspectives on a New Early Holocene Relative Sea-Level Record from the Mississippi Delta

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A record of early Holocene relative sea level (RSL) rise in the Mississippi Delta (7.7-10.3 ka) is derived from a sequence of basal peat deposits. The depth of the peat layers corresponds to the past elevation of intertidal marshes as they formed on stable Pleistocene basement. Peat deposits were collected from a range of depths by sediment coring and were radiocarbon dated. Applied in this region, these methods yield a unique vertically and temporally precise time series that can be compared to records from around the globe.

The early Holocene was a period of warming temperatures and retreating ice sheets. Compared to the rest of last deglacial interval, there are relatively few high-resolution RSL records from the early Holocene. Published records of early Holocene RSL changes show large variations in rates of RSL rise between near-field and far-field regions. A carefully constructed global database of sea level data spanning 8-10 ka yields new insights into spatial differences in the rates of RSL rise between our Mississippi Delta site, which was located near the Laurentide Ice Sheet, and locations around the globe. For example, the rate of early Holocene RSL rise in the Mississippi Delta shown by our record was ≥5 mm/year slower than rates of RSL rise shown in records from Southeast Asia. These observations are important for future GIA modeling work to constrain meltwater sources during the early Holocene.

Keywords: Paleo sea level data, Mississippi Delta, Peat records

POSTER SESSION
Session 1: Paleo sea level data and GIA modelling

Paper ID 457
Poster Board N°31

Antarctic-Sourced, Orbitally-Paced Global Sea-Level Changes During the Pliocene

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Geological and model reconstructions of ice volume and global sea-level changes during the mid-Pliocene warm period (MPWP, ~3.3-3Ma) are providing insights into the sensitivity of the polar ice sheets, and the potential for a threshold behavior in response to rising concentrations of atmospheric carbon dioxide. Collectively, the evidence suggests that atmospheric CO2 was around today's levels of 400ppm and marine-based sectors of the Antarctic ice sheet and large parts of the Greenland ice sheet melted raising global sea-levels by as much as 20m. Challenges still remain concerning the potentially intractable problem of constraining the absolute magnitude of peak Pliocene eustatic sea-level, and the role of orbital forcing on the frequency of ice volume/sea-level change is still widely debated.

Here, we present three new high-resolution geological archives for the MPWP: (i) ice-berg rafted debris (IBRD) mass accumulation rates from deep ocean sediment core (IODP U1361) off the Wilkes Margin of Antarctica recording fluctuations in the East Antarctic ice sheet; (ii) a continuous shallow-marine record of sea-level change from the Wanganui Basin, New Zealand; and (iii) a record sea-level-controlled terrigenous sedimentation (IODP 1124) to the deep ocean on Hikurangi margin of New Zealand. All three records are dominated by precession-paced cyclicity (~20ka) in-phase with high-latitude southern hemisphere insolation after ~3.3Ma, and provide insights into orbital-forcing of ice volume and sea-level independent of the benthic oxygen isotope records. Moreover, we have back-stripped the Wanganui record to reveal glacial-interglacial regional sea-level changes of up to ~20m amplitude. We conclude that during this interval, precession-paced Antarctic ice volume changes largely drove global glacial-interglacial sea-level fluctuations, in the absence of a significant northern hemisphere ice volume contribution.

Prior to 3.3Ma, proxy data from IODP U1361 and ANDRILL 1-A records extending back to ~5Ma, show that the Antarctic margin experienced warmer ocean temperatures, a lack of perennial sea-ice, and fluctuations in ice extent paced by obliquity. The emergence of precession at 3.3Ma coincident with the M2 glaciation in the benthic d18O record, also coincides with continent-wide cooling, ice expansion and the development of extensive seasonal sea-ice around Antarctica. We argue that a melt threshold response to orbital forcing was crossed, whereby Antarctic ice sheet melt was restricted to peak austral summer insolation (precession), rather than a longer summer melt-season controlled by mean annual insolation (obliquity). An obliquity-paced signal re-emerges in the New Zealand sea-level records after ~2.8Ma, while the EAIS IBRD record continues to be paced by precession, implying an increasingly dominant influence of continental-scale northern hemisphere ice sheets.

Keywords: Antarctic global sea-level Pliocene

POSTER SESSION
Session 2: Millennial scale ice sheet and sea level interactions

Paper ID 220
Poster Board N°61

Orbitally Driven Late Pliocene Climate Changes and their Relation to Ice Volume and Relative Sea-Level Change

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The contribution to sea-level rise of the Antarctic and Greenland ice sheets in a warming climate is uncertain. A better understanding of the physical mechanisms driving these changes is therefore needed to make more rigorous projections of the impact of regional sea-level rise. A warm interval within the Late Pliocene (3.264 to 3.025 million years before present) can be used to gain a better understanding of the response of the ice sheets to a warming climate with CO2 levels close to or higher than present. Here, we present results from transient experiments with a coupled ice-sheet sea-level model solving the gravitational self-consistent sea level across the Late Pliocene.

The full transient experiment runs from 3.5 to 3.08 Myr ago. At particular time points during the full transient simulation, namely for Marine Isotope Stage (MIS) KM5c (from 3.225 to 3.185 Myr ago) and K1 (from 3.080 to 3.040 Myr ago), the ice-sheet model is forced with multiple snapshot experiments of the HadCM3 climate model. The HadCM3 simulations used Pliocene boundary conditions with an atmospheric CO2 level set to 405 ppm. A sequence of climate model simulations covering 20 kyr on either side of MIS KM5c and K1 have been carried out with varying orbital parameters related to the specific time points. The full transient experiment starts with a global ice-volume simulation of four ice sheets regions (Antarctica, Greenland, Eurasia and North America) starting from 3.5 Myr ago to the start of the KM5c interval (3.225 Myr ago) and for the intermediate time period from 3.185 to 3.080 Myr ago between MIS KM5c and K1. For MIS KM5c and K1, the ice-sheet models for Antarctica and Greenland were run simultaneously forced by the HadCM3 climate every 2000 (KM5c) and 4000 years (K1), respectively.

Our simulations indicate that the contribution during particular warm intervals to global-mean sea level from the Antarctic and Greenland ice sheets are of similar magnitude. In cases of high eccentricity and thus large variations in climatic precession an asynchronous response in hemispheric ice volume to orbital variations is observed. Sensitivity tests are performed with different ice-sheet and Earth model parameters providing an uncertainty estimate of simulated relative sea level. We show the distinct fingerprint of the sea-level contributions of each ice sheet during this interval and perform a comparison with global relative sea level data to constrain the specific ice-volume contributions to regional sea level during warm intervals of the Late Pliocene.

Keywords: Ice sheets, Pliocene, relative sea level, GIA

Paper ID 293
Poster Board N°67

Can a Weak Solid Earth Structure Preserve the West Antarctic Ice Sheet?

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The evolution of the West Antarctic Ice Sheet (WAIS) is strongly controlled by ice-shelf basal melt and disintegration in the presence of the marine ice-sheet stability. One possible mechanism to counteract ice retreat on the millennial time scale is the solid-Earth deformation and related local sea-level fall, caused by unloading of the ice sheet. Here, we employ a coupled model for ice-sheet dynamics and solid-Earth dynamics, including a gravitationally consistent description of sea level, to investigate if viscoelastic bedrock uplift and the associated decrease in sea-level may stabilize an initiated collapse of the WAIS. For this, we start from a steady-state condition of the Antarctic Ice Sheet close to present-day observations and apply atmospheric and oceanic forcing of different strength to trigger the retreat of the WAIS. We investigate the effect of the viscoelastic bedrock deformation on the ice evolution for a range of parameters of the solid-Earth rheology (lithospheric thickness, asthenosphere viscosity). As expected, the climate forcing exerts the primary control on the occurrence of the WAIS collapse. However, for moderate climate forcing and a weak solid-Earth structure, as expected for the tectonically active West Antarctic rift system (asthenosphere viscosities of 3x1019 Pa s or less), we find that the solid Earth response limits the ice retreat to the Amundsen Sea embayment on a millennial time scale. In contrast, a stiffer Earth rheology leads to a collapse under the same climate forcing. Under a stronger atmosphere and ocean warming, weak Earth structures do not prevent the WAIS collapse; however, they produce a delay of up to 5000 years in comparison to a stiffer solid-Earth structure. We also find that in cases when the climatic forcing is too weak to force WAIS collapse by itself, an additional rise in sea level from a rapid deglaciation of the Greenland Ice Sheet may trigger the disintegration of the WAIS for asthenosphere viscosities of 3x1020 Pa s or higher. We conclude that solid Earth deformation shows important interaction with the ice sheet dynamics and it should be considered in predictions, as well as in Paleo reconstructions, of a multi-millennial time scale.

Keywords: Marine ice sheet collapse, West Antarctic rift, glacial-isostatic adjustment

POSTER SESSION
Session 2: Millennial scale ice sheet and sea level interactions

Paper ID 396
Poster Board N°63

The Grounding Line Instability in a Full Stokes Ice Sheet Model with Frictional Sliding

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Current understanding of marine ice sheet dynamics does not preclude the possibility of substantial near-future sea level rise due to unstable grounding line migration. Of particular interest is the potential contribution of the rapidly sliding Antarctic ice streams. Laboratory studies suggest that ice stream sliding occurs frictionally, that is, that the ice stream basal shear stress is proportional to the effective pressure (the normal stress minus the pore water pressure), with the constant of proportionality referred to as the coefficient of friction. Although robust experimental evidence favors a frictional description of ice stream sliding sliding, this description is both mathematically and computationally challenging. Towards this end, we present simulations of grounding line position in a new full-stokes, two-dimensional ice sheet model that incorporates frictional sliding.

Keywords: Ice sheet model, grounding line, ice stream, ice-ocean interaction

POSTER SESSION
Session 2: Millennial scale ice sheet and sea level interactions

Paper ID 437
Poster Board N°65

Antarctica's Ice Under Future Warming: Between Instability and Linear Response

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Changes in ice discharge from Antarctica constitute the largest uncertainty in future sea level projections, mainly because of the hard-to-constrain responses of its marine basins. The ice of these marine basins rests on bedrock below sea level and the bedrock often slopes down towards the center of the ice sheet. The ice on such downward sloping bed is theoretically prone to a marine ice sheet instability, but friction and buttressing through ice shelves can inhibit such instability. Further, instability may be relevant in theoretical equilibrium experiments but fast and strong forcing may dominate in future projections of the Antarctic ice sheet response.

I here present two studies that shed light on both ice-instability and forcing-dominated responses. Within East Antarctica, the Wilkes basin holds the largest volume of marine ice that is fully connected by subglacial troughs. This ice body was significantly reduced during the Pliocene and strong melting underneath adjacent ice shelves with similar bathymetry indicates the ice-sheet's sensitivity to climatic perturbations. Using recently improved topographic data in combinations with ice-dynamic simulations, I show that the removal of a specific coastal ice volume equivalent to less than 80 mm of global sea-level rise at the margin of the Wilkes basin destabilizes the regional ice flow and leads to a self-sustained discharge of the entire Wilkes basin and a global sea-level rise of 3-4 m.

For the West Antarctic Filchner-Ronne ice basin, ocean models indicate an abrupt intrusion of warm circumpolar deep-water into the cavity below the adjacent Filchner-Ronne ice shelf within the next two centuries. I present regional and continental-scale ice-sheet simulations, which are capable of resolving unstable grounding line retreat, that the sea-level response is not dominated by ice-instability and follows the strength of the forcing quasi-linearly. I find that the ice loss reduces after each pulse of projected warm-water intrusion. The long-term sea-level contribution is approximately proportional to the total shelf-ice melt. Although the local instabilities might dominate the ice loss for weak oceanic warming, we find that the upper limit of ice discharge from the region is determined by the forcing and not by the marine ice sheet instability for the Filchner-Ronne basin.

Keywords: Antarctica, ice sheet dynamics, ice instability

Paper ID 167
Poster Board N°83

Ice Sheet Contributions to Ocean Mass Change: Consistent Data Products from GRACE

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According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), about 20% of the change in global mean sea level during the last two decades originates from the Antarctic and Greenland ice sheet. During recent years an increase of the ice sheets' contribution is clearly evident in observational records. The Gravity Recovery and Climate Experiment (GRACE) mission is the only sensor directly sensitive to changes in mass. Starting from 2002, monthly GRACE gravity field solutions can be utilized to directly infer mass changes and mass redistributions in the Earth system.

Within ESA's Climate Change Initiative (CCI) projects on the Antarctic Ice Sheet (AIS) and the Greenland Ice Sheet (GIS), gravimetric mass change products based on GRACE spherical harmonic gravity field solutions are regularly generated and provided to the users. The CCI products for both ice sheets comprise mass change time series for individual drainage basins and aggregations (basin products). In addition, time series of mass change grids with a formal resolution of 50x50km2 (gridded product) are derived.

The underlying regional integration approach makes use of directly tailored sensitivity kernels, derived by a formal optimization procedure that minimizes the sum of propagated GRACE solution errors and leakage errors. In contrast to the widely used empirical rescaling of integration kernels, our approach ensures consistency between mass change estimates for individual drainage basins (or even grid cells) and the corresponding estimates for their aggregations.

We present time series from the latest version of our ice sheet basin and gridded products. Mass balance estimates and the ice sheets' contribution to global mean sea level change during the GRACE period are discussed. To assess sea level fingerprints caused by the changing ice sheets, relative sea level change patterns are modeled in a gravitationally self-consistent way based on the GRACE-derived mass balance estimates. Particular emphasis is placed on the assessment of the products' error budget. In the same framework we estimate ocean mass changes in a spatially integrated representation as well as in the grid domain. We compare them to the modeled sea level fingerprints and discuss the consistency between ice sheet and ocean mass change products.

Keywords: ice sheets, ocean mass change, GRACE

Paper ID 175
Poster Board N°85

Impact of Retreating Glacier Dynamics over the Last Quarter of a Century on Sea Level using Optical Sensors Time Series and Satellite Altimetry Data

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Globally, 10 percent of land area on Earth is covered with glacial ice, including glaciers, ice caps, and the ice sheets. Being extremely sensitive to global warming, mountain glaciers and small ice caps have retreated worldwide during the recent decades, with significant acceleration since the early 1990s causes a rise in sea level. According to IPCC AR4 report, <15% of the rate of global sea level rise was attributed to melting of ice sheets and glaciers during 1993–2003. Mapping glaciers and their changes will help us to understand the regional climate changes and hydrological cycles in those regions. Remote sensing images acquired from different platforms (satellite, aircraft) using sensors that operate in different spectral regions (visible, infrared, microwave) have been widely used to study glaciers over time. The increased availability of data from remote sensing platforms with adequate spatial and temporal resolution, near-global coverage and low financial costs allow extending the measurements of glacier parameters over larger areas and longer time spans. Remote sensing techniques have been used for spectral characterization of different snow and ice faces, a preliminary inventory of glaciers including aerial extent and position of large crevasses, and for mapping and monitoring glacial variations especially at the glacier margins and terminus location. Monitoring changes to snow and vegetation from 1993 to 2012 in Uttarakhand region of Himalayas, India using Normalized-Difference Snow Index (NDSI) and Normalized-Difference Vegetation Index (NDVI) are detected and found to be 1377 km2 and 896 km2 respectively. A study done using satellite altimetry data indicated the contribution of ocean warming to sea level rise accounts for ~30% between 1993-2012. Estimate of change in glacier properties with time-series satellite data over the large region can be made with low financial cost using semi-automated process. Total runoff from ice melting will be used as input data for modelling total runoff and correlated with the rise in sea level using satellite altimetry data. We trust this effort will help our study to assess the actual and potential impacts of a changing climate on sea level variations, regionally, in response to the glacier ice melt and ice mass loss.

Keywords: Global warming; Glacier dynamics; NDSI; NDVI, Sea level fluctuation

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 185
Poster Board N°73

Land Ice Contribution to SLR During the Satellite Era

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Within several projects aimed at constraining the mass balance of glaciers, ice caps (MGIC) and the ice sheets, we have developed consistent, rigorous estimates of land ice mass trends over the satellite era from the early 1990s to the present day. Our results combine satellite laser and radar altimetry including ERS, ENVISat, ICESat and CryoSat 2, along with GRACE data from 2003 onward. We have separate time series for Greenland, Antarctica and North Atlantic MGIC. The latter represents about half the MGIC contribution to SLR over the period of interest. For MGIC outside of this region, we utilise existing analyses of ICESat and GRACE data combined with terrestrial geodetic methods.

For the period 2003-2015, the uncertainties are smallest, due to the greatest density of complementary observations. For this period, we obtain mean rates of 84±22 Gt/yr, 269±18 Gt/yr and 135±15 Gt/yr for Antarctica, Greenland and Arctic MGIC respectively. Including the best available estimate for other MGIC contributions of 140 Gt/yr gives a total land ice contribution of 623 Gt/yr, which is a sea level equivalent of 1.73 mm/yr. This is, however, not necessarily the same as the contribution to sea level rise due to the fact that mass imbalance (depending on the method used) may include submarine ice, which has a small (density difference) impact on sea level compared to ice above floatation, which has a direct mass impact. This is particularly important for West Antarctic mass imbalance and to a lesser extent for marine terminating glaciers in Greenland. We also note that the trend in mass exchange with the ocean is not linear in time. Finally, we present the trends from the early 1990s, which have larger uncertainties and assess these estimates in relation to the sea level budget for the same time period.

Keywords: glaciers, ice sheets, satellite era

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 247
Poster Board N°95

The Greenland Ice Sheet: Linking Surface, Atmospheric and Ocean for Improved Sea Level Rise Estimates

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The Greenland ice sheet plays a crucial role globally and locally, impacting the surface energy budget and climate and weather and contributing to current and future sea level rise. The contribution to sea-level rise by mass loss from Greenland is projected to exceed 20 cm by the end of this century, with the past two decades being characterized by increased melting and total mass loss. Remarkably, the summer of 2012 set new records for surface melt extent and duration, and a record 570 ±100 Gt in total mass loss, doubling the average annual loss rate of 260 ±100 Gt for the 2003–2012 period.

Mass loss from Greenland can occur through two interconnected ways: surface loss (e.g., runoff of surface meltwater) and ice dynamics (or calving, e.g., solid ice detaching from the ice sheet, such as icebergs). Surface losses are dominated by the liquid water production, which in turn is modulated by surface properties (such as albedo) and atmospheric forcing (e.g., solar radiation, clouds, etc.). Surface meltwater also impacts ice dynamics through its percolation to the bottom of the ice through a dynamic and interconnected englacial hydrological system.

Here I present an overview of our current understanding of the surface, atmospheric and ocean processes driving mass losses from the Greenland ice sheet. In particular, I discuss how recent changes in albedo, surface melting and snow compaction have been interplaying in amplifying surface melting though positive feedback mechanisms. I also discuss how changes in the atmospheric circulation over the Arctic have been driving the spatial and temporal distribution of melting and snowfall. Lastly, I will discuss a connection between the atmospheric conditions over the Arctic and the jet stream, which can offer a potential way to connect changes in the Arctic with those occurring in the mid-latitudes. This aspect is crucial for improving our understanding of how the different Earth System components interact and for increasing our skills in estimating the contribution of future sea level rise from the Greenland ice sheet.

Keywords: Greenland, sea level rise, melting, Arctic

Paper ID 328
Poster Board N°97

Quantifying Mixing Across the Shelf Break in an Idealized Southern Ocean via Effective Diffusivity

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Accurate modeling of the heat exchange between the Southern Ocean and the Antarctic ice sheet is critical for projecting Antarctica's future contribution to sea-level rise as changes in this exchange lead to changes in sub-ice shelf melting, which in turn lead to changes in Antarctic ice flux to the oceans. This is a challenging problem due to the 1) stringent ocean modeling resolution requirements, 2) meridional heat transport across the shelf, and 3) coupled ocean-land ice interactions involving wetting and drying. The U.S. Department of Energy's Accelerated Climate Model for Energy (ACME) project aims to address this key problem. In this presentation, we employ a high-resolution idealized Antarctic Circumpolar Current (ACC) and Antarctic Slope Front (ASF) current model within an idealized Southern Ocean to better understand mixing across the shelf to address the first two challenges. Towards this end we introduce a novel online Lagrangian In-situ Global High- performance particle Tracking (LIGHT) approach within the Model for Prediction Across Scales Ocean (MPAS-O) that can be used for post-hoc scalar transport and computation of effective diffusivity. We employ this approach to quantify the diffusivity across the idealized ASF to illustrate its role as a mixing barrier in this system. These results imply a prominent role of the ASF in modulating against meridional heat transport and highlight its subsequent buffering against increased ice shelf melting.

Keywords: ocean-land ice interactions, meridional heat transport, effective diffusivity, Antarctic Slope Front

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 335
Poster Board N°91

Validation of Ocean-Ice Shelf Interactions in the Accelerated Climate Model for Energy (ACME)

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The capability for simulating sub-ice shelf circulation and submarine melting and freezing has recently been added to the U.S. Department of Energy's Accelerated Climate Model for Energy (ACME). The land ice and ocean components of ACME are the Model for Prediction Across Scales, MPAS-Land Ice and MPAS-Ocean. These models have been validated by a series of tests and intercomparisons, from idealized box domains to global domains with realistic bathymetry and ice draft. Success in these test cases is critical for gaining confidence in the scientific validity of individual model components, prior to running them in coupled model on realistic domains and with realistic climate forcing.

The first set of experiments, the Ice Shelf-Ocean Model Intercomparison Project (ISOMIP) (Hunter 2006), test the model's ability to simulate a large, cold ice shelf cavity like those under the Ross and Ronne-Filchner ice shelves. The second set of test cases, ISOMIP+ (Asay-Davis 2016), represents a smaller, more confined ice shelf supplied with warmer CDW, leading to substantially larger melt rates characteristic of the Amundsen Sea region. One purpose of these experiments is to provide a way for models to identify unusual behavior compared with other models that may warrant further investigation. We found that temperature fields, melt rates, melt patterns and flow rates in MPAS-Ocean were consistent with those from most other participating models. We also found that sub-ice-shelf boundary layers were thinner than for most other models, likely because of MPAS-Ocean's lower rates of spurious mixing (Ringler et al. 2013) and relatively high vertical resolution. Melt patterns were also considerably less noisy than for many models (notably those with stair-stepped top boundaries) because of the MPAS-Ocean's terrain-following top coordinate.

To gain confidence in the ability of MPAS-Land Ice to accurately resolve marine-ice sheet dynamics (specifically, grounding line advance and retreat), we conducted two idealized, community benchmark experiments; MISMIP3d (Pattyn et al. 2013) and MISMIP+ (Asay-Davis et al. 2016). For MISMIP3d, MPAS-Land Ice results are close to those from Stokes ice sheet models. For MISMIP+, the intercomparison is still underway, but initial results presented as guidance with the experimental design are also in approximate agreement with results from MPAS-Land Ice.

In follow-up work, we will participate in MISOMIP1 (Asay-Davis et al. 2016), a set of intercomparison experiments for coupled ice sheet–ocean models using the same setups as MISMIP+ and ISOMIP+.

Finally, we evaluate global ACME simulations with Antarctic sub-ice shelf ocean cavities. These simulations include coupled MPAS-Ocean and MPAS-Sea Ice components, forced by observed atmospheric winds and fluxes. Preliminary results show warm ocean currents running through the troughs below the Filchner-Ronne Ice Shelf. Basal melt rates are generally higher than those inferred by satellite measurements (Rignot et al. 2013), but show the expected spatial

distribution of more melting near the grounding line. A set of simulations with altered winds explore the effects of a more positive Southern Annular Mode.

Keywords: ice sheets, ocean, ice sheet-ocean interactions, ocean model validation

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 336
Poster Board N°93

Distribution of Glacial Melt Near and Off Greenland

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Greenland Ice Sheet (GrIS) basal melt is one of the major contributors to GrIS ice mass loss and thus sea level rise. So far, sufficient data that allow to trace and quantify the glacial melt water in ocean basins near Greenland are lacking. increasing melt water flow into key regions of the AMOC (e.g. Labrador Sea) are able to change local and basin wide circulation, thereby modifying dynamic topography and thus sea level. How large the impact of these freshwater intrusions on the AMOC variability are, depends strongly on the fraction of glacial melt that reaches the relevant key regions. Here, helium and neon isotope data combined with hydrography from the Labrador Sea, from the Greenland boundary current, and from the vicinity of one of the major outlet glaciers in northeastern Greenland, the 79N Glacier, will be presented, and the spatial distribution of glacial melt quantified.

Keywords: distribution Greenland melt, noble gases, boundary current

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 347
Poster Board N°69

Mass Transport Waves Derived from Geodetic Observation of Greenland Crustal Deformation During the Intense Melt Years

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The annual cycle and secular trend of Greenland mass loading are well recorded in measurements of solid Earth deformation. While bedrock Global Navigational Satellite System (GNSS) station data reveal vertical displacements in phase with loading as inferred from space observations, horizontal motions have received almost no attention. The horizontal bedrock displacements, however, can potentially track the spatio-temporal detail of ice/water mass changes with great fidelity. Our analysis of 54 GNSS coastal station data reveals that a significant excitation of horizontal amplitudes occurs during the intense melt years, such as 2010 and 2012. A suite of space geodetic observations (e.g., GRACE and CryoSat2) and climate reanalysis data (e.g., MAR Surface Mass Balance model) cannot explain these large horizontal displacements. We discover that solitary seasonal waves of substantial mass transport traveled through Rink Glacier in 2010 and 2012. (Rink Glacier ranks 6th in annual oceanward mass flux via discharge and is a western Greenland ocean terminating outlet glacier). We deduce that intense summer melting enhanced either basal lubrication or shear softening, or both, causing the glacier to thin dynamically. The associated mechanical weakening then triggered significant mass transport that extends well into the winter season. This interprepation is independently supported by glacier velocity measurements. As the GNSS-based observations of amplified seasonal mass transport waves may be unique to high melt years, we are likely to see the wave transport phenomenon become ever more present in years of future observations, as the climate continues to produce increasingly warm and earlier spring, and more intense and longer summer seasons. Increased frequency of amplified seasonal mass transport may ultimately strengthen the Greenland's dynamic ice mass loss, a component of the balance that will have important ramifications for sea level rise.

Keywords: mass transport waves, Greenland outlet glaceirs, crustal deformation, intense summer melting, ramifications for sea level rise

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 350
Poster Board N°81

The Resolution of Melt Contribution Sources in Sea-Level Fingerprint Studies

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Global sea-level change is a result of variations in the temperature and salinity of the ocean and the flux of water between land-ice reservoirs and the ocean. Each of these processes produces local variations in sea level that can vary significantly from their respective global mean values. The most iconic examples of this variability are the highly distinct and non-uniform patterns of sea-level change associated with each source of melting land ice. These "fingerprints" provide the possibility of using sea-level observations to estimate the mass flux of individual sources. Moving beyond global mean sea-level calculations to these source contributions is critical in understanding the sea-level budget over the 20th century and the last two decades of the 21st. Solving the inverse problem of source contribution is not a trivial task and robustly estimating the individual sea-level contributions is challenging, particularly given the spatial and temporal sparsity of the tide gauge network over the past century. Here we examine the fundamental limits of resolvability that will exist in any fingerprint-based analysis. We begin with a simple synthetic example that illustrates the approach before applying the method to posterior ice melt estimates obtained using the Bayesian techniques of Hay et al. (2015). We find that tide gauges, which provide an incomplete sampling of the global field, result in posterior correlations between the estimates of the individual sea-level contributions. While these correlations make it impossible to robustly separate the individual components of sea level over the past century, we demonstrate that various weighted sums of these components, as well as the total sum (i.e., global mean sea level), can be robustly resolved.

Keywords: sea level, tide gauges, Bayesian techniques

Paper ID 365
Poster Board N°75

Ice Sheet Surface Mass Balance Contributions to Global Sea Level from Contemporary Atmospheric Reanalyses

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An accurate appraisal of future eustatic change requires a detailed understanding of the various sea-level budget components. In current estimates, the Greenland and Antarctic Ice Sheets denote large areas of uncertainty. While estimates of the total contribution from ice sheets may be obtained from space-based observations of gravitational field anomalies, the partitioning of these amounts into contributions from surface, englacial, and subglacial processes remains a significant challenge. There has been recent attention focused on ice-sheet surface processes and their potentially dominant role in affecting ice-sheet sea-level contributions. The accumulation of snow on the surface of an ice sheet is generally restored to the global ocean via iceberg calving and basal melt. Large-scale atmospheric circulation variability may alter ice sheet precipitation over relatively short periods, while the glacial response may occur over much longer time scales. Additionally atmospheric conditions may induce large-scale surface melting and runoff, as has been seen over the Greenland Ice Sheet in the last decade. Atmospheric reanalyses may viewed as an important source of information on ice sheet surface processes due to their assimilation of available atmospheric observations and the global climate context that is provided. This approach has been criticized due to the relatively low spatial resolution afforded and the simplistic representation of surface processes that are typically used. This condition has changed in more contemporary reanalyses, which are available at higher spatial resolution and employ a more sophisticated representation of ice sheet surface hydrology. Here, we examine the amount and recent trends in ice sheet surface mass balance (SMB) for Antarctica and Greenland using the MERRA-2 atmospheric reanalysis for the satellite observing era, 1980-present. The study presents basin-scale estimates of SMB components including precipitation and runoff. These values are compared with estimates based on other reanalyses and regional climate models.

Keywords: Greenland, Antarctica, surface mass balance, meltwater runoff, atmospheric reanalyses

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 378
Poster Board N°77

Mass Balance and Structure of the Ross Ice Shelf, Antarctica

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Changes in ice shelf mass balance is key to the long term stability of the Antarctic ice sheet. Although the most extensive thinning occurs on the Amundsen Sea sector of West Antarctica, recent studies indicate that many other ice shelves are also experiencing widespread thinning. Here, we focus on the Ross Ice Self. An 18-year record (1994-2012) of satellite radar altimetry shows elevation change ~ 1 m/yr across the shelf. Significant variability in ice shelf height on interannual time scales makes it difficult to detect a long-term trend in the mass budget of this ice shelf. Variability of radar signal penetration into the ice-shelf surface snow and firn layers further complicates assessment of mass changes.

In this work, we investigate the Ross Ice Shelf mass balance using aerogeophyical data from the ROSETTA-ICE IcePod and NASA's Operation IceBridge. ROSSETTA-ICE is an aerogeophysical program that is planned to survey the ice shelf at a 10 km spacing over the course of three field seasons-2015-2017. This NSF/Moore Foundation supported multi-University collaborative project is designed to provide an integrated view of the ice shelf and the underlying bathymetry using the IcePod system including its ice-penetrating radars, laser altimetry, gravity meters and magnetometers.

We present results from our ongoing efforts of quantifying the mass balance of the ice shelf using ice penetrating radars and laser altimetry along with satellite data. In order to infer conditions of melt and freeze-on at the ice-water interface of the shelf, we derive a comprehensive basal reflectivity map from ice penetrating radars. Preliminary results show interesting patterns of basal reflectivity that correlate well with satellite observed and a coupled ocean model derived regions of high melt at the base of the ice shelf. We use internal layers traced from ice penetrating radars to outline the structure of the ice shelf. The structure of the internal layers and basal reflectivity from the radars are used provide an integrated view of the conditions at the surface and base of the ice shelf and the impact on the mass balance and stability of the Ross Ice Shelf.

Keywords: Mass Balance, ice sheet, Antarctica, radar

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 390
Poster Board N°87

Sources of Uncertainty in the Greenland Ice Sheet Contribution to Sea Level Rise

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The sea level rise contribution from the Greenland ice sheet appears in two forms – a dynamic contribution based on ice flow and calving rates (often also including submarine melting) and a surface mass budget (SMB) contribution from melt and run off at the surface. Ice dynamical modelling including calving processes has some well-known challenges but perhaps less well-examined are the variations caused by SMB processes. Inaccuracies in SMB pose a dual challenge when assessing the sea level rise contribution. SMB not only drives the surface melt contribution but is also the principal driver of ice sheet dynamics and can therefore also affect estimates of sea level rise from dynamical processes. In this study we focus on the Greenland ice sheet in a series of sensitivity experiments to explore the importance of key model variables to SMB estimates. We focus on albedo, retention and refreezing parameters, precipitation, model resolution and topography in the regional climate model (RCM) HIRHAM5. This is a typical RCM run at 5km resolution over Greenland, to create the best possible representations of surface mass balance of the Greenland ice sheet. It is comparable with similar RCMs that over recent years have produced a number of similar estimates of SMB but that which, on close inspection, often have substantial differences spatially and in terms of the components of SMB: precipitation, melt, runoff, retention and sublimation. Our analysis shows that the 5km resolution of HIRHAM accurately captures precipitation over the ice sheet and the retention scheme is able to reproduce both the subsurface temperature structure and the occurrence of perennial firn aquifers and perched ice layers. The modelled SMB compares very favourably with 1041 PROMICE observations giving us confidence in SMB estimates over the whole of Greenland. However, small differences in parameter choices, while important locally, are not significant over the whole ice sheet. Our experiments clearly show that surface albedo choices are more important for SMB estimates than retention parameter values. We use either an internally calculated or MODIS driven albedo in our experiments to assess bias in the model. We also examine the effect of modified ice sheet topography to estimate the importance of feedbacks between topography and SMB when modelling the dynamical evolution of the Greenland ice sheet. Finally we produce some uncertainty estimates for future projections of surface mass balance from Greenland based on HIRHAM5 forced with the EC-Earth GCM

Keywords: Greenland ice sheet, Surface mass balance

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 397
Poster Board N°79

Analysis of Surface Melt of the Greenland Ice Sheet Using a New Multi-Layer MODIS Surface Temperature-Albedo Product

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Increases in both ice discharge and surface meltwater runoff have increased the rate of mass loss of the Greenland ice sheet in recent decades. The surface temperature of the ice sheet must be known for measurement and modeling of surface mass balance (SMB) and ice sheet processes. Runoff is largely controlled by surface temperature which also affects basal melt and internal temperature of the ice sheet. Satellites can obtain accurate ice-surface temperature (IST) measurements of the Greenland ice sheet under clear-sky conditions which can be used to validate output of model-derived surface temperature. Ice sheet albedo is of also of great interest because a lowering of the albedo could indicate enhanced absorption of solar radiation possibly resulting in enhanced surface melting. The amount of absorbed radiation influences the SMB and meltwater production of the Greenland ice sheet.

A new multi-layer, daily IST-albedo Moderate Resolution Imaging Spectroradiometer (MODIS) product of Greenland that will extend from March 2000 through December 2017 has been developed to meet the needs of the ice sheet modeling community, and to facilitate studies of changes in IST, melt and albedo since 2000. The new product is produced in NetCDF format in a polar stereographic projection at a spatial resolution of 0.8 km. This product builds on an IST Environmental Data Record (EDR) of Greenland that was developed from the MOD29 standard MODIS product which extended from 2000 through 2014. In the present work, the IST record has been extended and upgraded to include additional layers of information. The MOD10 albedo and MOD05 water vapor standard products are also included as separate layers. In addition, an improved ice mask is provided. The water vapor layer will enable analysis of the accuracy of the IST retrieval. Using this new EDR, we produce a time series of IST and surface melt in different drainage basins of the ice sheet and quantify the changes in interannual melt and IST since early 2000.

Keywords: Greenland, MODIS, ice surface temperature, albedo

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 423
Poster Board N°89

Impact of 1.5°C Global Warming on the Greenland and Antarctic Ice Sheets

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For strengthening the global response to climate change, it is crucial to assess to what extent limiting global warming to low values may reduce the impacts on society. To tackle this issue, the IPCC has decided to provide a special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways.

Ice sheets are well known contributors to sea level rise and many studies have aimed to provide projections of their future contribution in response to climate change, although the focus was often on worst-case scenarios. Here we propose to review the present knowledge of how the ice sheets could be affected in the case of a limited warming of 1.5°C to 2.0°C.

We will review the various processes and feedbacks known to induce ice sheets vulnerability. They are different for Greenland, where we know that the surface mass balance plays a crucial role, and Antarctica where the major risk is marine ice sheet instability. One point of interest is to define, in terms of local forcing, the tipping points associated with these processes. We note that limiting global warming to 1.5◦C may mean substantially more warming in the polar regions. This polar amplification can be assessed from experiments following the RCP2.6 scenario that have been carried out in recent (post IPCC AR5) studies. This scenario can be considered as an upper limit for 1.5◦C. The final question concerns the long term (millennial) impact. There is a general consensus that there are tipping points both for Greenland and Antarctica, which potentially lead to irreversible mass loss. We will review the current knowledge of how long it takes to reach these tipping points and whether subsequent ice-sheet demise is, indeed, unstoppable.

Keywords: Antarctica, Greenland, Sea-level contribution, 1.5°C target

POSTER SESSION
Session 3: Contemporary contributions from ice sheets and glaciers

Paper ID 460
Poster Board N°71

Impact of Ice Sheet Surface Processes on Greenland Surface Mass Balance in the NASA GISS ModelE2 GCM

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Understanding future changes in ice sheet mass balance requires projections of climate from General Circulation Models (GCMs). Until recently, computational limitations hindered the ability of GCMs to represent ice sheet processes in detail, necessitating the use of Regional Climate Models (RCMs) and Ice Sheet Models (ISMs) to downscale GCM projections over ice sheets. Traditionally, there has been a disjoint between RCMs, which do not generally alter ice geometry, and ISMs, which feature a less detailed representation of the ice sheet surface. GCMs, such as the NASA GISS ModelE2, can capture feedbacks between ice, ocean, and atmosphere, are consistent with RCMs in maintaining the surface mass and energy balance (SMB and SEB), and are moving towards the flexible geometries of ISMs, presenting an opportunity to produce superior predictions of future ice sheet changes. Towards achieving a more accurate representation of ice sheet processes in the ModelE2 GCM, we have conducted a comparison between ModelE2 SMB and SEB for the pre-industrial and present-day Greenland ice sheet (GrIS), and simulations of SMB and SEB from the Modèle Atmosphérique Régionale (MAR) RCM. While ModelE2 captures the mean annual GrIS SMB reasonably well as compared with MAR, components of SMB and regional comparisons show larger differences. Various improvements in the representation of ice sheets in ModelE2, including a variable surface albedo scheme, a multi-layer snow model, and an elevation class scheme, in which the surface model is run over a range of different elevations, improve the agreement with MAR estimates of ice sheet runoff. Improving simulated accumulation, which is underestimated relative to MAR, is a subject of ongoing work. We also examine the potential impact of changes in ice-sheet surface albedo and surface elevation on regional atmospheric and ocean properties.

Keywords: Greenland, ice sheets, surface mass balance, GCM, surface energy balance

Paper ID 102
Poster Board N°80

A Comparison of Observed and Modelled Relative Sea-level Change over the Satellite Observational Period 1993-2013

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During the past two decades (1993-present) relative sea-level changes (RSL) have been monitored by satellite altimetry techniques. The European Space Agency (ESA) Climate Change Initiative (CCI) project on "Sea Level" has produced an improved set of sea-level products by applying a number of corrections (wet/dry atmospheric correction errors, reduction of instrumental drifts and bias) into multi-mission (TOPEX/Poseidon, Jason-1 and Jason-2, and Geosat Follow-on (GFO)) altimetry data over the period 1993-2013. We compared those data to RSL changes calculated by separation of mass (land-ice, groundwater, reservoir storage) and volume (steric) changes of water including fingerprints due to mass changes. Based on CMIP5 data and independent data sets for groundwater, reservoir storage, and glacial isostatic adjustment (GIA), local RSL changes can be calculated by summation of all the individual contributions over the satellite altimetry period at 1˚ x 1˚ resolution. On a global scale, observed and modelled GMSL are in good agreement (3.2 ± 0.5 mm/yr and 3.1 ± 0.6 mm/yr respectively). However, differences among individual models and between observations and models are larger on a regional scale (in some locations > 200%), particularly in the Eastern equatorial Pacific. For some other regions, like the Indian and South Atlantic Ocean, the agreement between models and observations is better (ranging within ±50%). The global RMS error of the ensemble of 8 CMIP5 models which contain all necessary fields to calculate RSL is 2.3 mm/yr, which is 73% of the observed global mean. The RMS error of the individual models ranges from 1.0 to 5.9 mm/yr.

Keywords: modelled regional sea-level

Paper ID 118
Poster Board N°74

Decadal Change of NAO Influence on Interannual Sea Level Variability along the US Atlantic Coast

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The northeast Atlantic coast (NEC) of the United States has recently been identified as a region which is particularly susceptible to sea level rise in a warming climate. Interannual variations in sea level are superimposed on sea level rise trends caused by atmospheric warming and Greenland Ice Sheet melt, increasing the risk of flooding due to extreme events and storm surge. Understanding the processes that modulate interannual sea level variability is crucial to improving sea level prediction and risk management in a warming climate.

The wintertime North Atlantic Oscillation (NAO), which is related to the atmospheric pressure dipole between the Azores High and Icelandic Low, modulates variability in westerly winds across the North Atlantic basin. Prior studies have found a strong negative correlation between the wintertime NAO Index and annual mean sea level anomalies in the NEC since 1970, although this relationship is highly nonstationary with no significant correlation from 1970-1986 and intensification afterwards. The relationship may be associated with the NAO influence on along-shelf wind stress in and around the Gulf of Maine.

In this study, we use a relatively new method, Bayesian Dynamic Linear Regression Modeling, which permits time-varying regression coefficients, to quantify the nonstationary impact of NAO on coastal sea level from 1950-2013. We demonstrate that a spatial pattern change of NAO-linked winds near the NEC is a significant contributor to the NAO-sea level relationship intensification from 1960-1986 to 1987-2013. Although the NAO is associated with the intensity of westerly winds across the basin, the centers of action are located in the eastern Atlantic and the NAO impact on wind stress near the NEC from 1960-1986 is weak relative to 1987-2013. We construct a new index based upon sea level pressure differences between two loci in the subtropical and subpolar North Atlantic. This index is strongly correlated with along-shelf wind stress in the western Atlantic from 1950-2013 and is a superior predictor of interannual sea level variations than NAO over this period. This suggests that monitoring local wind and sea level pressure patterns, in conjunction with the NAO index, is necessary to achieve improved sea level prediction capabilities in the NEC.

Keywords: North Atlantic Oscillation, interannual sea level variability, Bayesian Dynamic Linear Modeling, wind stress

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 124
Poster Board N°42

Global and Regional Sea Level in CMIP5 Models: piControl and Historical Scenario

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Simulations using the Earth System Models from the CMIP5 project considering the piControl and historical period will be compared amongst themselves as well as to satellite results (AVISO). The aim is to provide an assessment on how regional sea level are represented by models. The approach used in this assessment will be based on Griffies et al. 2014. These authors used a suite of global ocean-sea ice models from the Coordinated Ocean-ice Reference Experiments - Phase II (CORE-II) to explore questions about the capability of ocean-sea ice models to proper simulate the observed global mean sea level variations (zostoga) and also changes to dynamic sea level patterns (zos). Comparisons from sea level changes between the historical period and piControl run will provide considerations on sea level responses to external forcings.

Reference:

Griffies, S. M., et al., 2014: An assessment of global and regional sea level for years 1993-2007 in a suite of interannual core-II simulations. Ocean Model., 78, 35–89, doi:10.1016/j.ocemod.2014.03.004.

Keywords: cmip, climate models, sea level rise, dynamic sea level, amoc

Paper ID 127
Poster Board N°18

Sea Level Budget of the Altimetry Era Revisited

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We revisit the global mean sea level (GMSL) budget during the whole altimetry era (1993-present) and show that using a large number of data sets to estimate the different components of the sea level equation improves the budget closure. Moreover, the budget approach allows to detect bias and drifts in the observations. Six different altimetry-based sea level data sets have been considered over the period January 1993-December 2015. They include the Climate Change Initiative (CCI) sea level products from the European Space Agency (ESA). The steric data include three data sets for January 1993-December 2004 and four Argo data sets afterwards. Three glaciers time series are considered. For the ice sheets, the IMBIE data set is used until December 2003 and the CCI_ice sheet products afterwards. Both IMBIE and CCI products combine a large number of individual data sets. Changes in land water storage and atmospheric water vapour content are also accounted for. For each term of the sea level equation we use the mean of available data sets. The sum of components agree very well with the altimetry-based GMSL except at the beginning of the record (1993-1998). During the later period a single altimeter (Topex A) was operating. Moreover Topex A suffered significant instrumental drift. Previous studies attempted to estimate this drift by comparing with tide gauges and the experimental Poseidon altimeter data onboard the Topex/Poseidon mission. Here we use another approach and estimate the Topex A drift from the sum of components over January 1993-December 1998. Accounting for this correction leads to much improved agreement between observed sea level and sum of components. Using ensemble means for the GMSL and components rather than individual data sets leads to closure of the sea level budget. The trend of the residual time series is 0.0 +/- 0.2 mm/yr. The RMS is 2.4 mm/yr for the whole altimetry record. It decreases to 1.7 mm when the steric sea level is estimated with Argo (as of January 2005). We attribute the slightly larger RMS of the first decade to uncertainty of the steric component. For the whole altimetry period (January 1993-December 2015), the GMSL rate is now close to 3 mm/yr. However, significant GMSL rate difference is found between the 1st and 2nd decade of the altimetry era (2.7 mm/yr and 3.5 mm/yr respectively), suggesting sea level acceleration in the recent years.

Keywords: global mean sea leve, sea level budget

Paper ID 138
Poster Board N°76

Trends and Interannual Variability of Mass and Steric Sea Level in the Tropical Asian Seas

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For the first time the mass and steric components are separated in the Tropical Asian Seas (TAS) using Jason 1&2 satellite altimetry, GRACE satellite gravimetry and ocean reanalyses. Using observational uncertainties, statistically optimally weighted time series for both components are obtained in four regions within the TAS.

The influence of interannual ocean signals are investigated by regressing the Dipole Mode Index (DMI) and the first two principal components of the Pacific equatorial wind stress. It appears that sea level in the northernmost region, the South China Sea, is barely affected by any of the equatorial Indian and Pacific ocean dynamics. In contrast, steric sea level in the deep equatorial regions within the TAS is strongly correlated with the principal components of the Pacific wind stress. On the continental shelves, like the Java, Timor and Arafura seas, where the shallow water column is not able to expand as much as in the deep regions, we find significant correlations between equatorial wind stress and the mass component. We argue that during the La Nina phase, the large steric sea level signal in the western tropical Pacific causes a dynamic response of water mass moving into the shallow areas of the TAS. Including the indices into the regression has a significant effect on the trends in at least three of the four regions. Regressing the first principal component reduces the trends of both mass and steric sea level, while including the second principal component and the DMI increase the trends, but they do not componensate the loss caused by the first principal component. The residual mass trends are compared to trends obtained by sea level finger- prints of mass redistribution. Eventhough there are large variations within the TAS, the mass trends for the whole TAS are statistically equal.

Ultimately, the effect of omitting the TAS in global sea level budgets is estimated. The global mean sea level trend is underestimated by 0.3 mm/yr , of which 0.1 and 0.2 mm/yr are respectively contributed to the mass and steric components.

Keywords: Tropical Asian Seas, ocean mass, steric sea level, wind stress, sea level budgets

Paper ID 146
Poster Board N°34

Connection of Regional Sea Level Variations and Costal Vulnerability in the East China Sea with Large-Scale Sea-Air Interaction in the Pacific Ocean

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As the typical shelf seas in the northwest Pacific Ocean, sea level in the East China Seas (ECS) plays an important role in regional sea level variation under circumstance of global change. In this paper, ECS sea level variability is investigated with tide gauges records, satellite altimetry data, reconstructed sea surface height, and CMIP simulation fields. Sea level exhibits the interannual variability imposing on a remarkable sea level rising in the East China Seas (ECS) and its coastal region. Interannual sea level variation in the ECS is mainly modulated by the low-frequency winds over the North Pacific by local and remote processes. Local zonal wind stress exhibits effects on sea level, particularly when it leads sea level 3 months, their correlation exceeding -0.6. Meanwhile, westward propagating signals of sea level anomaly signal driven by wind stress curl variations in subtropical Pacific Ocean influence remarkably the ECS sea level variations. Besides, ocean current transports entrained by the Kuroshio show significant correlation with ECS sea level on interannual timescales. Effect of the large-scale atmospheric circulation and the Kuroshio transport are the dominant influencing factors contributing to the ECS sea level variation during El Nino events. Its interannual variations at 4-8 years period are performed noticeably in the 21st century considering the CMIP data, and sea level can reach the highest extreme level in latter half of the century. Modeled sea level including IPCC climate scenarios play a significant role on storm surge evolution, whose influence is mapped in the geographical variability. The elevation range and the maximal residual elevation increase along the northern coastline of the Jiangsu province and Liaodong Peninsula, and more vulnerable regions along the ECS coast will suffer from the increasing storm damage in the sensitive area with sea level variations.

Keywords: regional sea level, interannual variability, East China Sea, sea-air interaction, Pacific Ocean

Paper ID 154
Poster Board N°78

On the Potential to Detect Climate Change Signals in Observed Regional Sea Level Trends

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Observed regional sea level trends are a combination of natural variability and the response to anthropogenic climate change. Recent estimates of secular sea level trends from satellite altimeter observation reveal substantially different patterns than anticipated from climate projection runs. Particularly in the Pacific Ocean, previous analyses of regional trends suggest that, apart from the changes in the global mean, regional changes can largely be explained by low frequency climate modes. To increase the signal to noise ratio an alternative way to the projection of the signal on predefined Fingerprints (Hasselmann, 1993) is pursued in this study by removing the part of the signal that projects on the space of climate variability. Removing climate variability provides an independent estimate of the climate change response but relies on disjunct spaces of natural variability and climate change signal. The method is tested on an ensemble of sea level trends of the historical and scenario runs of the MPI-ESM using climate modes from a 1000 year control run. Different strategies to select optimal subspaces of climate variability are investigated. Common to all is a modest improvement in signal to noise ratio and the tendency to reduce the amplitude of the signal. Consistent with the findings for the observed sea level trends, it is found that, even in strong scenarios and for ensemble mean trends, the simulated trend projects largely on the gravest modes of climate variability. Therefore, the forced signal can not unambiguously be separated from the climate variability, which implies that the absence of a climate change signal can not be inferred from the ability to explain the signal by climate modes.

Keywords: sea level rise, detection, climate variability

Paper ID 182
Poster Board N°46

The Sea Level Budget along the Northwest Atlantic Coast: GIA, Mass Changes and Large-Scale Ocean Dynamics

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Sea level observations along the Northwestern coast of the North Atlantic Ocean show trends and accelerations well above the global average, which results in increasing flooding risks along the highly populated East Coast of the United States. In this study we look at the individual contributors to sea level changes in this region over the last 50 years (1965-2014) and compare the sum of contributors with observations from tide gauges and GPS stations. Both observations are analyzed in a self-consistent framework that takes barystatic effects, geoid changes and solid earth deformation, resulting from both Glacial Isostatic Adjustment (GIA) and present-day mass redistribution into account. The location of the region is close to the former Laurentide Ice Sheet and its accompanying forebulge, which results in a complex pattern of land subsidence and sea level rise. We use an updated data-driven GIA model to constrain this pattern. This model explains the largest part of the observed sea level and vertical land motion trends, as well as the large majoritiy of inter-station trend differences. Present-day mass redistribution caused by ice sheet and glacier melt, dam retention and groundwater depletion accounts for a smaller fraction of the observed trends and only explain a fraction of the observed acceleration. Altimetry and in-situ hydrographic observations point at a strong correlation between steric variability in the Atlantic Subpolar Gyre and sea level along the Northwestern coast. The steric signal in the Subpolar Gyre does not only accounts for the observed decadal sea level variability, but its rapid warming also explains the observed acceleration of coastal sea level. The sum of all contributors explains the observed trends in both sea level rise and vertical land motion in the region, as well as most decadal variability. The sum of contributors also explains the observed acceleration within confidence intervals. The large acceleration is predominantly caused by the ocean dynamic contribution, and linked to a rapid decrease of water density in the southern Subpolar Gyre.

Keywords: North Atlantic, Budget, Reconstructions, Tide gauges, Subpolar Gyre

Paper ID 197
Poster Board N°84

Multi-linear Regression of Sea Level in the South West Pacific as a First Step Towards Local Sea Level Projections

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Rising sea levels are a critical concern in small island nations. The problem is especially serious in the western south Pacific, where the total sea level rise over the last 60 years is up to 3 times the global average. In this study, we attempt to reconstruct sea levels at selected sites in the region (Suva, Lautoka, Noumea – Fiji and New Caledonia) as a mutiple-linear regression of atmospheric and oceanic variables. We focus on interannual-to-decadal scale variability, and lower (including the global mean sea level rise) over the 1979-2014 period. Sea levels are taken from tide gauge records and the ORAS4 reanalysis dataset, and are expressed as a sum of steric and mass changes as a preliminary step. The key development in our methodology is using leading wind stress curl as a proxy for the thermosteric component. This is based on the knowledge that wind stress curl anomalies can modulate the thermocline depth and resultant sea levels via Rossby wave propagation. The analysis is primarily based on correlation between local sea level and selected predictors, the dominant one being wind stress curl. In the first step, proxy boxes for wind stress curl are determined via regions of highest correlation. The proportion of sea level explained via linear regression is then removed, leaving a residual. This residual is then correlated with other locally acting potential predictors: halosteric sea level, the zonal and meridional wind stress components, and sea surface temperature. The statistically significant predictors are used in a multi-linear regression function to simulate the observed sea level. The method is able to reproduce between 40 to 80% of the variance in observed sea level. Based on the skill of the model, it has high potential in sea level projection and downscaling studies.

Keywords: Southwest Pacific, local sea level rise, statistical modeling, multi-linear regression

Paper ID 200
Poster Board N°24

A Reconciled Estimate of Twentieth Century Global Mean Sea-level Rise

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The rate at which global mean sea level (GMSL) rose during the twentieth century is uncertain, with little consensus between various reconstructions that indicate rates of rise ranging from 1.3 to 2 mmyr-1. Here we present a twentieth-century GMSL reconstruction computed using a novel area-weighting technique for averaging tide gauge records that (i) incorporates, for the first time, up to date estimates of vertical land motion (VLM) and corrections for local geoid changes due to ice melting and terrestrial freshwater storage (TWS), and (ii) allows for the identification of possible differences compared to earlier attempts. Our reconstructed GMSL trend of 1.1±0.3 mmyr-1 (1σ) before 1990 falls below previous estimates, while our estimate of 3.1±1.4 mmyr-1 from 1993 to 2012 is consistent with independent estimates from satellite-altimetry, leading to overall acceleration larger than previously suggested. This feature is geographically dominated by the Indian-Ocean-Southern-Pacific region marking a transition from lower than average rates before 1990 towards unprecedented high rates in recent decades. We demonstrate that VLM corrections, area-weighting, and our use of a common reference datum for tide gauges may explain the lower rates compared to earlier GMSL estimates, in approximately equal proportion. The trends and multi-decadal variability of our new GMSL curve compare well to the sum of individual contributions obtained from historical outputs of the Coupled Model Intercomparison Project Phase 5 (CMIP5). By reconciling modelled and observed GMSL change we increase confidence in process-based projections presented in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC).

Keywords: Global mean sea level, tide gauges, vertical land motion, fingerprints, climate change

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 207
Poster Board N°48

Observations of Sea Level Rise Versus the Sum of Contributors: a Comparison on Local, Basin, and Global Scales

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Most reconstructions show a rise of global mean sea level over the past 60 years that is larger than the sum of the individual contributors. To find out what causes this discrepancy, we revisit sea level on local, regional, and global scales by adding information from static fingerprints resulting from realistic sources of ice melt and changes in terrestrial water storage, as well as information of vertical land motion at tide gauge locations.
First, we compute the fraction of vertical land motion that can be explained by solid earth deformation resulting from GIA and present-day ice melt. On average, tide gauges show a subsidence of 0.2 mm/y, although after correcting for solid earth deformation from known processes, the average become negligibly small. Hence, it is unlikely that local vertical land motion will have a large impact on global tide gauge reconstructions.
Next, we compare the observed sea level trend at each station with the sum of contributors (mass, dynamics, GIA, and vertical land motion). Tide gauges in Europe and along the Pacific coast of the United States generally show agreement with the sum of contributors, while stations in the West Pacific and around Australia generally show higher trends than expected from the contributors. On average, observed trends are 0.3 mm/y higher than expected from the contributors. When the tide gauges are binned in ocean basins, this discrepancy occurs in each basin.
For each basin, we compute a sea level curve based on the 'virtual station' method. To reduce the sampling bias, we correct each individual tide gauge record using estimates of local and basin-mean effects of gravity and earth deformation. We find that the difference between reconstructed sea level and the sum of contributors is generally smaller than the value obtained by simple averaging, and for most basins, the observed sea level changes can be well-explained. For the South Atlantic and Indian Ocean, large oscillations occur, that cannot be explained from the contributors, and may be related to the sparse tide gauge coverage in these regions.

We derive a global average sea level change based on the weighted sum of the basins over 1958-2014 of about 1.5 mm/y, which compares well with the 1.3 mm/y that is expected from the sum of contributors. We also find an excellent agreement with altimetry over the overlapping period. However, on basin scale, decadal oscillations are found in reconstructed tide gauge sea level, which are absent in altimetry. These oscillations should be treated with caution, as they are probably not representative for the full basin.

Keywords: GMSL, budget, fingerprints, reconstructions, vertical land motion

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 211
Poster Board N°32

Remote Sources of Florida Current Variability on Seasonal Time-Scales: Links with Coastal Sea-Level Variability along the East Coast of United States

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The Florida Current (FC) is the western boundary current closing the subtropical gyre circulation in the North Atlantic Ocean that is often associated with climate, weather, ecosystems, and regional sea-level variability. The dynamics associated with the intense FC flow across the Florida Straits sustains a sea-level difference of over 1m between the east coast of United States (US) and the Bahamas. Changes in the FC dynamics can, therefore, drive relevant sea-level variability at both sides of the Florida Straits at various time-scales. In this presentation, recent findings are presented for a mechanism linking signals originated in the open ocean with changes in the FC dynamics and sea-level along the east coast of US.

Sustained FC observations are obtained by the Western Boundary Time-series program, and XBT Network at the NOAA Atlantic Oceanographic and Meteorological Laboratory, which provides a continuous record of the FC transport using telephone cable measurements, as well as periodic ship-based full-depth data from CTDs, LADCP, and XBTs at fixed stations across the Florida Straits at 27°N. Using these observations along with satellite altimetry sea height anomaly (SHA) data, and sea-level data from tide gauges, it is shown that the seasonal variability of the FC is largely modulated by westward propagating SHA signals that are formed in the eastern North Atlantic 4 to 7 years earlier than observed at 27°N in the Florida Straits. These westward propagating SHA signals behave approximately like long first baroclinic Rossby waves that account for a large component of the FC and sea-level variability near the western boundary of the North Atlantic Ocean. Because the FC flow is mostly in geostrophic balance, changes in the transport carried by this current are associated with changes in the sea-level gradient across the Straits. Analysis reveals that westward propagating SHA signals can lead to anomalies in the FC transport ranging between – 4 and 4 Sv (1 Sv = 106 m3/s). Through this mechanism, a decrease in the FC transport is associated with higher than normal sea-level along the east coast of US between 25°N—42°N that can reach values as large as 20 cm above mean sea-level. Results reported suggest that large sea-level variations along the east coast of US linked with seasonal FC changes may be partially predictable, given that these Rossby-wave-like signals propagate approximately at fixed rates in the open ocean. Findings of this study also emphasize the critical importance of combining different datasets that can provide key information about the dynamics and variability of ocean currents and of coastal sea-level changes.

Keywords: Ocean Currents, Florida Current transport, Satellite altimetry, Tide-gauges, coastal sea-level changes.

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 216
Poster Board N°20

Interannual-to-Decadal Variability of Sea Level in the South China Sea

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Interannual-to-decadal variability of sea level in the South China Sea (SCS) are studied using altimetric data during 1993–2012 and reconstructed sea level data over 1950–2009. The interannual variability shows a strong seasonality. Surface wind anomalies associated with ENSO explain the sea-level anomaly pattern in the interior SCS, while Rossby waves radiated from the eastern boundary dominate the sea-level variability in the eastern SCS. Decadal variability of sea level in the SCS follows that in the western tropical Pacific, with large variance found west of Luzon Island. Local atmospheric forcing makes a negative contribution to decadal variability in the central SCS, and Rossby waves radiated from the eastern boundary appear to be important. During 1993–2012, decadal sea level in the SCS is significantly correlated with the Pacific Decadal Oscillation (PDO). The decadal variability associated with the PDO accounts for most part of sea-level trends in the SCS in the last two decades.

Keywords: sea level, interannual-to-decadal variability, altimetric data, Rossby waves, PDO

Paper ID 225
Poster Board N°8

First Results from an Integrated Approach for Estimating GIA, Land Ice, Hydrology and Ocean Mass Trends within a Complete Coupled Earth System Framework

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Correctly separating the sources of sea level rise (SLR) is crucial for improving future SLR predictions. Traditionally, changes in each component of the integrated signal have been tackled separately, which has often lead to inconsistencies between the sum of these components and the integral as measured by satellite altimetry. To address these issues, the European Research Council has funded a five year project aimed at producing the first physically-based and data-driven solution for the complete coupled land-ocean-solid Earth system that is consistent with the full suite of observations, prior knowledge and fundamental geophysical constraints. This project is called "GlobalMass" based at the Bristol Glaciology Centre and Department of Maths, University of Bristol.

Observed mass movement from the Gravity Recovery And Climate Experiment (GRACE) mission and vertical land motions from a global network of permanent GPS stations are used in a data-driven approach to estimate the glacial isostatic adjustment (GIA) without introducing any assumptions about the Earth structure or ice loading history. Satellite data and in-situ observations are combined using a multivariate spatio-temporal model within a Bayesian Hierarchical Modelling (BHM) framework. Prior distributions and linear constraints are used to incorporate the physics of the coupled system, such as conservation of mass, together with the characteristic length scales of different processes in both space and time. The BHM enables dimensional reduction of the observations so that a simultaneous solution can be obtained at a global scale. It will be used to produce a consistent partitioning of the integrated SLR signal into its steric (temperature and salinity) and barystatic component for the satellite era. The latter component is caused by land hydrology and melting ice sheets and glaciers, all of which are solved for simultaneously. The BHM was developed and tested on Antarctica, where it has been used to separate surface, ice dynamic and GIA signals simultaneously. We illustrate the approach and concepts with examples from this test case and present the first results where we assess the consistency of the ICE-6G GIA model against the integral of sea surface height anomalies, ARGO-derived steric variations and GRACE-derived mass exchange.

Keywords: global sea level rise, Bayesian Hierarchical Modelling, GIA, steric variations, mass trends

Paper ID 229
Poster Board N°72

A Study on the Sea Level Rise due to the Density Change of Jeju Island

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According to a report released by the Korea Hydrographic and Oceanographic Agency in 2016, the sea level rise rate of the South Sea including Jeju Island is 3.02 mm / yr, the East Sea is 3.35 mm / yr, and the West Sea is 1.06 mm / yr. In particular, the vicinity of Jeju Island shows a sharp increasing rate (4.56 mm / yr).

An analysis of long term sea level rise rate of Jeju Island using data from tidal observatory showed that the rate of sea level rise was 5.6mm / yr (1978 ~ 2015yr) in Jeju tidal station and 3.8mm / yr (1983 ~ 2015yr) in Seogwipo tidal station. In order to analyze the rapidly increasing rate, the sea level change due to the density change was studied using temperature and salinity data of the National Fisheries Research and Development Institute. As a result of analysis, the sea level rise slowed down since 2006, and sea level change and density change are closely related. The major factors causing the density change were estimated to be the diluted water from Changjiang, Kuroshio branch and coastal current around Korea peninsula. In particular, the change in trend of seawater density affecting the sea level rise rate is analyzed to be mainly caused by the salinity in winter, and We conclude that steric effect(volume decrease) due to density change has resulted in the trend that sea level rise has slowded down since 2006.

Keywords: Sea level rise, density change, steric, Jeju Island in Korea

Paper ID 239
Poster Board N°62

Sea Level Budget Closure: Status and Prospects from an Integrative Study within ESA's Climate Change Initiative

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For many years, studies of the sea level budget have been a means of assessing and understanding how sea level is changing and what are the causes. Closure of the total sea level budget implies that the observed changes of global mean sea level equal the sum of observed (or otherwise assessed) contributions, namely changes in ocean mass and ocean thermal expansion. Closure of the ocean mass budget implies that the observed ocean mass change equals changes in mass from glaciers, ice sheets, land water storage, snow pack and atmospheric water content. Misclosure of these balances indicates errors in some of the components or contributions from missing or unassessed elements in the budget.

ESA's Climate Change Initiative (CCI) has conducted a number of projects related to sea level, namely the Sea Level CCI project, the Greenland and Antarctic Ice Sheet CCI projects, the Glaciers CCI project and the Sea Surface Temperature CCI project. Using the improved, consistent, and well-documented data products from these CCI projects, it is time to re-assess the sea level budget closure. This is the aim of the CCI Sea Level Budget Closure (SLBC_cci) project.

The project will analyze results based on CCI products in conjunction with data products from ocean profilers (e.g., Argo), GRACE-based ocean mass change assessments, and model-based data for glaciers and land hydrology. Closure of the global mean sea level budget and global ocean mass budget will be investigated in a coherent way and the quality of CCI products will be assessed. In addition, the regional variability of sea level and its steric and mass components will be investigated in a case study for the Arctic Ocean. These activities are intended to prepare the way to more comprehensive and more operational assessments of the global and regional sea level budget.

The poster will outline the envisaged developments and prospects from the project. It will give an overview on the status of datasets available and the degree of sea level budget closure at the first iteration of collected datasets.

Keywords: sea level budget, sea level change

Paper ID 243
Poster Board N°26

Temporal and Spatial Variability of the Seasonal Cycle in the Baltic Sea

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In this contribution we present an integrated analysis of the coastal and open ocean seasonal mean sea level (MSL) cycle in the Baltic Sea using tide gauge records, satellite altimetry observations, hydrographic profiles, and ocean reanalysis data. Within the project "AMSeL Baltic Sea", which is funded by the German Federal Ministry of Education and Research (BMBF) from 2015 until 2018, the tide gauge database in the Baltic Sea is significantly improved by collecting high resolution tide gauge records along the Baltic coastline with a particular focus on the southwestern part. Altogether we collected 160 tide gauge records with different temporal resolution covering a period from 1777 (only Kronstadt) until 2015 and providing 28 stations with more than 100 years of data.

Here we use this comprehensive database to assess temporal and spatial variations of the seasonal MSL cycle. Satellite altimetry observations are integrated to enhance the spatial information within the basin and to identify the relationship between open-ocean and coastal MSL variability. To assess the temporal variability of the seasonal MSL cycle we compare two different methods: first a classical 5-year running harmonic analysis (e. g. Plag and Tsimplis 1999) and second a novel state-space model in combination with Particle Gibbs with ancestor sampling PGAS (Marcos et al. 2015). Both approaches reveal a considerable interannual to decadal variability in the amplitudes and phases of the seasonal MSL cycle, whereby the state-space-model also allows an assessment of potential long-term trends. In contrast to previous studies we find, however, no evidence for any significant long-term trends in the seasonal MSL cycle, neither in its amplitudes, nor its phases. In order to better describe the obtained patterns of spatial and temporal variability, the analysis is further complemented by an assessment of individual forcing factors using ancillary datasets such as the outputs from ocean and atmospheric reanalyses, temperature and salinity profiles, and a 3D numerical ocean model.

Marcos, Marta; Calafat, Francisco M.; Berihuete, Ángel; Dangendorf, Sönke (2015): Long-term variations in global sea level extremes. In: J. Geophys. Res. Oceans, n/a. DOI: 10.1002/2015JC011173 .

Plag, H.-P; Tsimplis, Michael N. (1999): Temporal variability of the seasonal sea-level cycle in the North Sea and Baltic Sea in relation to climate variability. In: Global and Planetary Change 20 (2-3), S. 173–203. DOI: 10.1016/S0921-8181(98)00069-1 .

Keywords: Baltic Sea, MSL, Seasonal Cycle, Tide gauge data, Satellite altimetry

Paper ID 244
Poster Board N°2

Comparative Analysis of Sea Level Changes in Seven Stations on the Upper Atlantic

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Sea-level rise has been known to have direct impacts on the coastal zones which are usually major focus of human habitation and adaptation. Researches have propounded that human-induced global warming is a major cause of the global-mean sea-level rise, which has led to an increase in the global volume of the ocean. As such about 900% increase in the global volume of the ocean is expected to occur between the year 1990 and 2100. However, the impact of coastal rift and tectonic movement may also increase the sea-level in a location, while simultaneously reducing it in another location. Based on this concept, a comparative analysis of adjacent locations in the upper Atlantic Ocean region was carried out. The result showed the comparative performance of the epoch, height and uncertainty in height of stations in the coastal plains along Canada, had a low epoch and almost the same sea-level rise. On the other hand, Honolulu-United State experienced low Epoch but high height. While the coastal locations on the right of the Atlantic Ocean (Canada and United States) experienced low epoch, its adjacent coastal regions (Portugal, France and United Kingdom) experienced a high epoch. The tidal rate was observed to follow the same trend as described for the epoch. However, the tidal rate observed at Lisboa – Portugal was also low as those of coastal locations to the right of the Atlantic Ocean. The highest impact of the tidal rate was observed at St Jean-de-Luz France. The reason for this may be due to its cup-like shaped enclosure. The analysis showed that sea-level rise over the years is not linear but sinusoidal with a clear distinction from 1954. The lowest sea level occurred between 1942 and 1954, while the highest tidal height occurred between 2000 and 2006. The tidal height in Tofino-Canada differed from that of Honolulu-USA which had a distinct point of separation between 1942 and 1954. The highest tidal height in Tofino-Canada occurred between 1943 and 1945. Two reasons are suggested for this observation. First, the topography of the coastal boundary over Tofino-Canada most likely have significant influences on the tidal rate. Second, the tidal effect might constantly have been originating near Tofino.

Keywords: high and low epoch, tidal rate, sea level rise

Paper ID 265
Poster Board N°52

A Proposed Initiative to Use Existing and New Ocean Observing Platforms to Assess Attributions of Sea Level Changes in Southeast Florida

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Improvements in understanding of mean sea level changes, as well as the relationship between global and local sea level, are critical because of the direct impact of sea level changes on coastal areas, including infrastructure, ecosystems, commerce, and tourism. Proper attribution of factors affecting changes in sea level will greatly improve models that provide outlooks and forecasts. The US National Oceanic and Atmospheric Administration (NOAA) maintains several components of the global ocean observing system, with some of them making sustained observations in the Florida Current. The Florida Current flows through the Straits of Florida between the Bahamas and the southeast coast of the United States, associated with a sea level difference across the Straits of approximately 1m. Being part of the North Atlantic subtropical gyre, the Florida Current links local variations of sea level to large-scale oceanic processes.

The coast of Southeast Florida has tide gauges operated and maintained by the NOAA National Ocean Service (NOS). A suite of hydrographic observations is also currently in place, such as those from eXpendable BathyThermographs (XBT), Conductivity Temperature and Depth (CTD) sensors, Lowered Acoustic Doppler Current Profiler (LADCP), dropsonde floats, and telephone cable voltage measurements. XBT and CTD observations have already revealed that, on average, the Florida Current at 27°N has exhibited long period changes, including a warming at the surface, with respect to the mean values observed during the last 20 years. However, it is not clear whether and how these changes are contributing to local changes in sea level.

We propose to use the suite of existing instrumentation together with new systems, including underwater gliders, pressure-equipped inverted echo sounders, and atmospheric sensors, and data from satellite altimetry and gravimetry missions, to measure and monitor the different parameters that contribute to regional sea level changes off the coast of Southeast Florida, from the Florida Keys to Jacksonville. These assessments will include evaluation of changes due to variability of the intensity and jet location of the Florida Current, as well as impacts of atmospheric forcing, ocean warming, etc. The research proposed here will provide real-time data and products that can be easily communicated and used to make assessments and to feed into numerical forecast models.

Keywords: Sea Level Change, XBTs, South Florida, Ocean Observing Platforms, Altimetry

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 267
Poster Board N°50

Sea Level Variations over 1992-2015 Analyzed with the Latest ECCO Ocean State Estimate

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Sea level and its associated variations are described using the latest estimate from the "Estimating the Circulation and Climate of the Ocean" (ECCO) project. The estimate combines a state-of-the-art ocean general circulation model (MITgcm) with nearly all extant observations of the ocean from 1992 to 2015, including sea level from satellites (e.g., Jason-2), and in situ hydrographic profiles from ships (e.g., WOCE) and floats (e.g., Argo). The model is of moderate spatial resolution (40-100km) but with a domain that is truly global including the Arctic Ocean. The estimate's enhancements from earlier analyses include its longer period (4 additional years), use of new observations (e.g., GRACE ocean bottom pressure and Aquarius sea surface salinity), model improvements (e.g., geothermal heating, sea ice model), and accounting of correlated uncertainties (e.g., forcing biases).

The new analysis has improved agreements with observed global mean sea level and ocean mass changes, allowing a more accurate accounting of processes contributing to their variation. In particular, the ECCO analysis is characterized by its physical consistency in the sense of the estimate's temporal evolution being accounted for explicitly in terms of physical processes resolved by the model.

The new estimate will be presented with a focus on its sea level variations and associated changes in heat and mass. Regional and vertical distribution of the variable heat and mass fields will be explored and the nature of their evolution will be examined in relation to the ocean circulation.

Keywords: Sea Level, Ocean Circulation, Climate Change, Data Assimilation, Ocean Modeling

Paper ID 270
Poster Board N°56

Comparison of Altimetric Datasets Along the Greenland Coast

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NASA's Oceans Melting Greenland (OMG) mission is investigating how Greenland's glaciers are melting and contributing to global sea level rise in response to changing ocean temperatures. Satellite altimetry has the potential to provide information about ocean temperature changes through thermosteric expansion, but altimetry is notorious for having large errors in coastal areas. These coastal altimetry errors are mainly from land contaminated altimeter signal, uncorrected wet troposphere effects due to land contamination of the radiometer and uncorrected tide effects due to inadequately-constrained tidal solutions. Around the Greenland coast, sea ice and icebergs can also contaminate the signal. Various approaches have been used to address these coastal issues, such as retracking algorithms and correcting for atmospheric and oceanographic signals to reduce land contamination. However, these coastal altimetry datasets have not yet been evaluated against tide gauge data around Greenland nor have their solutions been compared against each other.

Tide gauges, considered "truth", from University of Hawaii's Sea Level Center are compared against altimetric datasets to evaluate differences in the various coastal datasets and to perform an assessment of their accuracy. The datasets include CLS/CNES's along-track coastal altimetry dataset (1) PISTACH and (2) PEACHI, (3) NASA MEaSUREs along-track multi-mission integrated altimeter data, (4) CryoSat-2, and (5) OSTM/Jason-2 GDR version D dataset. The accuracy of these altimetric datasets are evaluated by comparing against tide gauges found on the west, east and south coasts of Greenland. The extent to which they mutually agree or disagree in these sectors is also quantified.

Keywords: coastal altimetry, Greenland, OMG, LRM, SAR

Paper ID 279
Poster Board N°70

Rising Sea Level Trends around the Korea Peninsula with Tide Gauge Records

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Sea-level changes along the Korea coasts have been estimated based on the selected 18 tide-gauge records of the Korea Hydrographic and Oceanographic Agency (KHOA) over the last several decades. The sea level has risen 3.35mm/yr in the east, 3.02 mm/yr in the south and 1.06 mm/yr in the west, with an average rise of about 2.68 mm/yr. Especially, the highest rate of sea level rise occurs around the Jeju Island, offshore the southwestern part of the Korea peninsula.

The local tide gauge data show that rising rate of sea level in the Korea seas are higher than global rate of about 2.0 mm/ry (IPCC, 2013), further accelerating at an increasing rate in recent 30 years. These rising sea level trends with time coincide with globally rising sea level, primarily caused by global warming effect. Additionally, the rising trends of sea level are positively correlated with increased rates of carbon dioxide concentrations, air temperatures, sea surface temperatures, and precipitation observed in the Korea peninsula. This correlation plausibly supports that rising sea level is significantly linked to the ongoing global warming, triggered by human activities.

Thus, this study evidence that sea level rise is a critical signal to global warming related to human effect. The sea level changes induced by recent warming in the Korea seas and world's oceans can be considered as 'Anthropocene' sea level changes. Further study is deserved to find anthropogenic impact on sea level records.

Keywords: Sea level trends, Korea, Tide gauge records

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 291
Poster Board N°64

Climate Induced Variability of the Mean Sea Level in the German Bight

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During the last century, coastal regions have been strongly governed by a rapid growth in populations and economic assets with increasing urbanization. This led to an increased vulnerability of these regions due to natural hazards. At the same time, global mean sea levels (GMSL) have risen because of a warming climate. As such, determining the variability and potential predictability of mean sea level is of crucial importance to many societies as they struggle with different risks related to flooding and storm surges. In this study we analyze the relationship between the seasonal modes of variability of the mean sea level (MSL) in the German Bight and the large-scale atmospheric circulation and wind stress fields, through different statistical methods (e.g. Empirical Orthogonal Function Analysis and Stability Maps) of observed and reanalysis data. It is shown that the seasonal modes of MSL variability in the German Bight and their relationship with large-scale atmospheric circulation differs from one season to another and is non-stationary in time. During winter, the dominant mode of MSL variability is influence mainly by the North Atlantic Oscillation (NAO), while in spring the dominant mode of MSL variability is driven by a combination of different teleconnection patterns (e.g. NAO and Atlantic Multidecadal Oscillation (AMO)). In summer, the dominant mode of MSL variability is influence by the occurrence of atmospheric blocking situations over the British Isles and the North Sea. The dominant mode of MSL variability, in autumn, is strongly related with a wave train like pattern, with altering centers, in the geopotential height anomalies, which extends from the central North Atlantic Ocean up to eastern Russia. We show also, that at seasonal time scale, the relationship between the MSL variability and pre-defined teleconnection indices (e.g. NAO, AMO, El Niño-Southern Oscillation, and the Pacific Decadal Oscillation) is non-stationary in time. Thus, the predictability of mean sea level variability using these pre-defined teleconnection indices as predictors, is limited due to non-stationarities.

Keywords: sea level, teleconnections, climate variability, non-stationary, NAO

Paper ID 292
Poster Board N°66

Decadal Trends of Mean Sea Level Variability in the German Bight, Eastern North Sea

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During the last century, coastal regions have been strongly governed by a rapid growth in populations and economic assets with increasing urbanization, increasing the vulnerability. At the same time, global mean sea levels (GMSL) have risen as a result of a warming climate. Over the 20th century, a significant rise in GMSL has been detected by different authors using various techniques. In this study, we investigate the decadal mean sea level trends (MSL) as measured at 10 gauging stations in the German Bight (eastern North Sea) and their possible causes. The analysis is performed at seasonal scale over four different periods: 1937 – 2011, 1947 – 2011, 1957 – 2011 and 1967 – 2011, respectively. A coherent picture of the winter season (December – January - February) trends emerged, with increasing trends at all analyzed stations. The highest trends (~8 cm/decade) are observed over the period 1967 - 2011. Similar results were found for the spring season (March – April – May) and summer season (June – July – August), respectively. For the spring and summer seasons, the highest trends (~3 cm/decade in spring and ~4cm/decade in summer) are observed over the period 1967 – 2011, especially at the tide gauges situated in the northern part of the German Bight. In autumn, the picture is rather different compared to the other seasons. The highest increasing trends are observed over the period 1937 – 2011 (~2cm/decade) at the stations situated in the northern part of the German Bight , while over the period 1967 – 2011 we observed decreasing MSL trends at all the analyzed stations. It is also shown that the identified trends are potentially driven by changes in the large-scale drivers (e.g. changes in the sea level pressure patterns) as well as in the wind-related components. Hence, the identified trends and patterns could provide a valuable benchmark for a number of different studies and model simulations.

Keywords: sea level, trends, climate variability, non-stationary, NAO

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 303
Poster Board N°14

CryoSat-2 Fitness for Sea Level Studies: a Global Evaluation

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Measurements from space are key to our understanding of current and recent variations of sea level on regional and global scales. Dedicated satellite altimetry missions have provided data on sea level, amongst other parameters, for the past 40 years. Despite being focussed on assessment of the Cryosphere, the European Space Agency (ESA) CryoSat-2 mission, launched in 2010, offers a wealth of data for those interested in sea level. This presentation reports on the available products and presents results from the ongoing verification and scientific validation, with particular focus on the measurements of Global Mean Sea Level (GMSL).

Marine products from CryoSat-2, generated by a dedicated processor (CryoSat Ocean Processor or COP), have been available since April 2014. Of those, the Geophysical Ocean Products (GOP), which have consolidated orbits and are available 30 days after acquisition, are those most suited for regional and global sea level studies. The assessment, carried out within the ESA-funded CryOcean-QCV project, is performed for the sea surface height (SSH), as well as the significant wave height (SWH) and the wind speed. The mean value of the 20 Hz SSH anomaly (SSHA) noise corresponding to a SWH of 2 m is 6.3 cm for LRM (Low Resolution Mode) data and 10.2 cm for pseudo-LRM data. The standard deviation of the crossovers is 5.4 cm. These values are similar to those of other altimetric missions. The SSH is validated at the coast against the sea level measured by a set of carefully selected and quality controlled tide gauges, and compared with Jason-2 observations. Correlations between satellite SSH and tide gauge records are statistically significant at nearly all stations, with a median value of 0.78 and 0.76 for CryoSat-2 and Jason-2, respectively. In the open ocean the SSH is compared globally with the steric heights derived from temperature and salinity profiles as measured by Argo floats. The median correlation between SSH and steric heights is 0.68. However, the correlation shows a strong latitudinal dependence, with higher values at low latitudes (median > 0.8 in the 10°S–10°N band). All the results above give us confidence in computing the GMSL curve from the GOP; this matches well the same curve from other altimetry missions, suggesting that CryoSat-2 is suitable for GMSL monitoring and allows, in combination with AltiKa and the recently launched Sentinel-3, the extension of regional MSL measurement beyond the maximum latitude (66°) reached by the reference Jason satellites.

Keywords: Radar Altimetry, CryoSat-2, Altimetry products, GMSL

Paper ID 304
Poster Board N°68

Accuracy of Global Upper Ocean Heat Content E7stimation

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The simplest global mapping method and dense data coverage for the global oceans using the latest observational network ensure an estimate of global ocean heat content (OHC) within a satisfactory uncertainty for the last 60 years. The observational database conditionally presented a level high enough for practical use for the global OHC estimation, assuming that severe observational biases are not included in the data except expendable bathythermograph.

Uncertainties in global annual mean temperatures averaged vertically from the surface to 1,500 m are within 0.01 K for the period from 1955 onward as far as sampling errors are taken into account. More reduction of uncertainties in OHC is expected by conducting an objective analysis as done in sea surface temperature analyses. Compared to previous studies, the new objective analysis provides a higher estimation of the global 0--1,500 m OHC trend for a longer period from 1955 to 2015, which is an increase of 350 +/- 57 ZJ with a 95 % confidence interval.

Keywords: OHC, upper ocean, trend, objective analysis

Paper ID 305
Poster Board N°16

The Importance of 35-Day-Repeat Envisat and AltiKa Data on Estimates of the Mean Sea Level Evolution

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Global Mean Sea Level (MSL) is an essential indicator of climate change of exceptional scientific value and its rise has immediate impact on public and policymakers. Satellite altimetry provides accurate measurements of regional and global MSL and its evolution. The Topex/Poseidon and Jason-1/2/3 missions used for this measurement since 1992 are on a reference orbit, whose design was primarily dictated by oceanographic considerations, with a ~10-day repeat pattern, that only extend to ±66° latitude. These observations are complemented by observations from other missions that go closer to the poles, most notably the time series of altimetry on the ERS-1/2 and Envisat 35-day orbit repeat tracks, now continued (after and 28-month gap in 2010-2013) by the AltiKa mission.

Within the European Space Agency (ESA) Sea Level Climate Change Initiative (SL_cci) project, we have investigated the impact of the high-latitude sea level observations from Envisat and AltiKa on the derived rates of GMSL. The methodology we adopted is to fly virtual satellites along the 10-day reference mission (Jason) and 35-day Envisat/AltiKa tracks, sampling real altimetric gridded SSH anomaly field for the period between 1993 and 2013. This way we have been able to compute the GMSL for various scenarios (for instance 10-day only, or 35-day only, or both, with or without an interruption in the 35-day orbit) and computing the resulting GMSL using just the ±66° band or including all the data, i.e. also the subpolar observations from Envisat and AltiKa.

The GMSL rates computed by including the subpolar regions are not significantly different from the GMSL over ±66°. This is an important result as it justifies the continued use of the reference Jason missions to provide a meaningful sea level rise indicator. We also report on the results of a sensitivity study to estimate to what extent does the sea level trend need to increase within the polar region (where only the 35-day orbit observations are available) in order for the global trend to be statistically different at the 95 % confidence interval.

The need to have high-latitude observations obviously remains, not only because these provide a confirmation of the results from the reference 10-day mission as discussed above, but also because they may contain the fingerprints of specific processes of climate change (such as the melting of the Greenland and Antarctica ice caps). This need has so far been satisfied by the CryoSat-2 and AltiKa mission, and is now starting to be fulfilled by the Copernicus Sentinel-3 constellation of satellites, whose first satellite (Sentinel-3A) was launched in February 2016.

Keywords: Radar Altimetry, GMSL, Envisat, Sea Level CCI, Sea Level trend

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 320
Poster Board N°28

Using the Tide-Gauge Record to Detect Sea-Level Fingerprints of Accelerated Ice Loss from Greenland and Antarctica

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Tide-gauge records from the North Atlantic reveal significant acceleration in sea level starting in the late 20th century. We analyze the tide-gauge data using a model in which the accelerations are assumed to be zero prior to 1990. The estimated accelerations range from -1 to +3 m / cy2 and exhibit a systematic spatial variability. We demonstrate that model this variability in sea-level acceleration requires contributions from several distinct physical processes: accelerated mass loss from the Greenland and Antarctic Ice Sheets and acceleration associated with ocean circulation and heat uptake. Atmospheric pressure also contributes to the observed changes in sea level, at a much smaller amplitude. Because we are focusing on sea-level accelerations (i.e., sea-level rate changes), the contribution from Glacial Isostatic Adjustment (GIA) is negligible. Modeling of observed sea-level acceleration is achieved using external constraints for the important processes. The GRACE (Gravity Recovery and Climate Experiment) satellite mission provides information on monthly ice-mass change during the period 1993 to present. Using the GRACE data, we estimate the gravitationally self-consistent sea-level acceleration "fingerprints" for Greenland and Antarctica. For the North Atlantic, Greenland induces a significant spatial variation in sea-level change—which is dominated by the solid-Earth response to the mass loss there—whereas Antarctica contributes a spatially constant acceleration. Our results represent a clear detection of these significant decadal-scale ice-loss events. We will present the evidence for this detection, and discuss the implications for regional sea-level change as well as for detecting future changes.

Keywords: Regional sea-level change, Sea-level acceleration, Sea-level fingerprints, Greenland, Antarctica

Paper ID 326
Poster Board N°36

Revisiting Multi-decadal Changes to Temperature and Salinity in the Ocean Interior: A CMIP Ocean Analysis in Density Coordinates

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Assessing the forced change across an ensemble of climate models is made more difficult by the biases and differences in the surface regions of key atmosphere-ocean interactions and geographical dissimilarities in the location of watermasses. Remapping ocean properties into density coordinates provides a useful way to view property changes in a more uniform framework. The remapping facilitates directly relating ocean property changes to surface fluxes, and provides a lagrangian-like view that excludes the effect of isopycnal heave.

In this analysis, we use several different experiments in the CMIP5 suite to ascertain the forced response along with the unforced variability in interior regional and global ocean properties. We assess ocean temperature and salinity changes on multi-decadal timescales, that are not well constrained by available observations. We contrast the modelled results to those of a few observational analyses which show consistent, coherent and persistent long-term temperature and salinity changes across the observed record. The study revisits the role of isopycnal migration versus surface-forced changes in the ocean interior obtained from a previous observation-only analysis, and ascertains the consistency of these results with forced simulations over the historical period.

Keywords: ocean, temperature, salinity, density, historical

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 333
Poster Board N°38

Migration and Timing of Sea-Level Rise Hot Spots Along the U.S. Atlantic Coast

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Sea-level rise (SLR) has accelerated in a "hot spot" north of Cape Hatteras over the past several decades, including an abrupt, ephemeral rise of ~13 cm in 2009-2010. This regional acceleration in SLR has been attributed to weakening in Atlantic Meridional Overturning Circulation (AMOC), although this causal link remains debated. Here we document with tide-gauge records a shift in the pattern of SLR variability along the U.S. Atlantic coast during 2011-2015, whereby SLR decelerated north of Cape Hatteras and accelerated south of the Cape to >20 mm/yr, more than 3 times the global mean rate of SLR recorded by AVISO altimetry over the same time period. Using a similar analysis of tide gauge records from the last 95 years, we also discovered that comparable short-lived, rapid SLR accelerations (hot spots) have occurred regularly over ~1500-km stretches of the U.S. Atlantic coastline. Our analysis reveals that a cumulative index of North Atlantic Oscillation (NAO) is linked to the latitudinal position of these SLR hot spots, while a cumulative index of El Niño (ENSO) corresponds to the spatially coherent timing of sea-level rise and fall. The superposition of these two processes accounts for 87% of the variance in the spatiotemporal distribution of the rate of SLR along this coastline. The strength of the correlations between cumulative indices of NAO and ENSO imply that the pre-existing state of the gyre is important in determining the strength and the nature of the sea level response along the eastern seaboard of the U.S. rather than a simple correlation between ENSO or NAO variability and the rate of SLR.
The decline of the AMOC has previously gained the most traction as an explanation for the past acceleration of SLR north of Cape Hatteras. This interpretation is appealing because an AMOC decline is a consistent feature in ocean dynamic modeling of the evolution of regional sea-level change patterns in the context of global warming. While SLR acceleration north of Cape Hatteras may come to bear as the result of a weakening AMOC, this argument cannot explain shifts in the rates of regional SLR that we have documented south of Cape Hatteras during 2011-2015. The AMOC did not weaken over this time periodand there is no mechanism to link AMOC strength with such a strong response of sea level south of Cape Hatteras, suggesting that other processes are driving the observed regional sea level behavior.

We conclude that the formerly identified SLR acceleration in the mid-Atlantic bight primarily resulted from the cumulative effects of NAO forcing during periods when SLR was accelerating along the entire eastern seaboard of the U.S. This distinction is critical to the projection of SLR along this heavily populated coastline, and defines a new benchmark for ocean dynamic models to capture such a pattern of regional SLR variability.

Keywords: US Atlantic coast, sea level acceleration, hot spot, North Atlantic Oscillation, El Nino

Paper ID 358
Poster Board N°58

The Next-generation ECCO Global Ocean State and Parameter Estimation Infrastructure: Products and Tools in Support of Sea Level Science

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Since its inception in the late 1990s the consortium for Estimating the Circulation and Climate of the Ocean (ECCO) has developed and produced dynamically consistent global observation and model syntheses of increasing fidelity, based on formal inverse/optimal control methods, and covering the WOCE and satellite altimetric record (1992 onward). Now in its fourth generation, all aspects of the estimation system, the observational data streams and treatment, the underlying general circulation model, the adjoint-based optimization infrastructure, and the uncertainty estimates have been improved to reflect the evolving best state of knowledge. While sustaining and improving the production of global ocean (and sea ice) estimates for climate research, in its new phase ECCO is putting a special focus on requirements for sea level science. Among the goals in coming years are (1) improved treatment in ECCO of the impact of ice sheet-ocean interactions on the ocean circulation and sea level; (2) provision of software tools to conduct accurate partitioning and budget analyses of the different contributions to regional sea level change; (3) improved accessibility of the adjoint infrastructure using open-source algorithmic differentiation tools to enable more widespread use of sensitivity and uncertainty studies; (4) improved representation of mixing processes associated with tides and the internal wave field; (5) improved links between absolute (geocenter) sea level as represented by Boussinesq ocean models and relative sea level as measured at the coast; and (6) an improved ECCO web portal and interaction with NASA's Sea Level Change Team portal. Elements of these goals and how they can help understand sea level variations will be described.

Keywords: global ocean state estimation, steric sea level change, barystatic sea level change, decadal sea level dynamics and variability, sea level sensitivity

Paper ID 366
Poster Board N°22

Broad, Shallow Shelf Sea Surface Height Variabililty

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Jason-2 altimeter data collected from July 2008 through July 2016 for 23 selected coastal areas were downloaded from the PISTACH coastal products of the Basic Radar Altimetry Toolkit (Mercier, et al., 2008). The raw (20 Hz) altimeter range was corrected for effects due to the ionosphere, modelled dry troposphere, and decontaminated wet troposphere, solid earth, ocean, and pole tide, the inverted barometer effect, and high frequency impacts. A Median filter and then a Low-Pass-60-point- filter based on Birol and Delebecque (2014) were applied to the coastal Sea Surface Height (SSH) data. Nearly 300 altimeter passes for each site were analyzed.

For a variety of reasons, individual altimeter passes do not begin or stop collecting ocean data at the same distance from a coastline. In order to analyze the SSH data statistically, a nearest-point-to-land (NPTL) was determined for the SSH data for each site. The NPTL varied from 16-25 km from the coastline and included all of the data available during the time period. A "mean surface" was determined from all available profiles for an area and subtracted from each profile. All of the resulting data for each area were plotted on a common axis and an "envelope" of water levels displayed.

The envelopes reveal a noise level over the mid-shelf region, variability near the shelf edge, and higher variability closer to shore. Comparison to tide gauge water levels for one US station reveals a relationship to subtidal water level frequencies. Plots of time series of each area NPTL show intra-annual and inter-seasonal variability, with higher and lower water levels linked to seasons. For areas along the east coast of Asia, the impact of the monsoons is observed. The plots also indicate changes in water level within a season.

Because the nearest points to land are 15 to 25 km offshore, the dynamics of the inner shelf cannot be ascertained from these data. The resulting information is regional in nature and represents regional water level variability that must be considered when comparing the data to tide gauges.

Keywords: Altimeter, SSH, Shelf, Coast

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 369
Poster Board N°40

Coastal Sea Level from Delay Doppler Altimetry Along the North-Eastern Atlantic Shelf

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Satellite altimetry data of the CryoSat-2 and Sentinel-3 missions processed with Delay Doppler methodology (DDA) provide improved coastal sea level measurements up to 2-4 km from coast, thanks to an along-track resolution of about 300m and an higher signal to noise ratio.

We investigate the 10 Kilometre stripe along the North-Eastern Atlantic shelf from Lisbon to Bergen to detect the possible impacts in sea level change studies of this enhanced dataset.

We consider synthetic aperture radar (SAR) mode CryoSat-2 and Sentinel-3A DDA products from the ESA GPOD database. Moreover, we consider CryoSat-2 reduced SAR mode data (RDSAR) produced with an in-house algorithm and conventional Jason-2 and Envisat pulse-limited products from the Sea Level Climate Change Initiative (SL cci). Improved processing for coastal zone in RDSAR consists in application of enhanced retrackers. Improved processing in DDA includes modifications in both the generation of waveforms, (i.e. Hamming weighting window on the burst data prior to the azimuth FFT, zero-padding prior to the range FFT, doubling of the extension for the radar range swath) and in the SAMOSA2 retracker. Data cover the full lifetime of CryoSat-2 (6 years) and Sentinel-3A (1 year).

Once verified the increase in coastal performances with the suggested DDA processing, we will investigate the impact of the new coastal dataset for sea level change studies.

The first impact we analyse is on the trend of sea level. Here we will estimate both the absolute sea level trend, relative to the Earth ellipsoid, and the trend relative to coast (accounting for rates of vertical motion derived from GPS stations) and compare to trends of tide gauge records.

The second impact we investigate is on the coastal mean sea level surface and the corresponding mean dynamic topography. We will evaluate a mean surface from the new altimeter data that we combine to state of the art geoid models to derive the mean dynamic topography. We then compare the results to existing oceanographic and geodetic mean dynamic topography solutions, both on grid and pointwise at the tide gauge stations. The work is supported by ESA through the Sea Level CCI and the GOCE++DYCOT projects.

Keywords: Delay Doppler altimetry, coastal zone, sea level trend, mean dynamic topography, tide gauges

Paper ID 373
Poster Board N°54

Separating Decadal Global Water Cycle Variability From Sea Level Rise

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Under a warming climate, amplification of the water cycle and changes in precipitation patterns over land are expected to occur, subsequently impacting the terrestrial water balance. On global scales, such changes in terrestrial water storage (TWS) will be reflected in the water contained in the ocean and can manifest as global sea level variations. Naturally occurring climate-driven TWS variability can temporarily obscure the long-term trend in sea level rise, in addition to modulating the impacts of sea level rise through natural periodic undulation in regional and global sea level. The internal variability of the global water cycle, therefore, confounds both the detection and attribution of sea level rise.

Here, we use a suite of observations to quantify and map the contribution of TWS variability to sea level variability on decadal timescales. In particular, we find that decadal sea level variability centered in the Pacific Ocean is closely tied to low frequency variability of TWS in key areas across the globe. This internal variability is found to lead to decadal variability in GMSL that imposes a deceleration on the satellite altimeter record and can further serve to enhance or suppress the underlying long-term sea level trends depending on its phase. The results here also demonstrate that precipitation-driven variability in globally integrated quantities can be regional in nature, yet lead to decadal changes in the exchange of water between land and ocean that is measurable on global scales. The unambiguous identification and clean separation of this component of variability is an important step in uncovering the anthropogenic trend in sea level and understanding the potential for low-frequency modulation of future TWS impacts including flooding and drought.

Keywords: Decadal, Climate, Variability, TWS

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 380
Poster Board N°44

Tropical and Coastal Pacific Sea Level Variability: Adjoint Reconstruction, Mechanisms, and Uncertainties

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In this presentation we analyze mechanisms associated with fluctuations and trends in tropical and coastal Pacific Sea Level. Our primary focus is on the time-variable zonal asymmetry between Western and Eastern Tropical Pacific in relation to ENSO fluctuations and climate change. The ECCO version 4 model adjoint is employed to derive a kernel which can then easily be convolved with surface forcing anomalies to predict sea level responses. After illustrating that the method yields an accurate reconstruction of Tropical Pacific sea level variability in ECCO, it is applied to atmospheric re-analysis products to identify key regions where climate variability drives basin-scale sea level variations. Results are gauged against altimetry to assess atmospheric re-analysis errors. The convolution method is then used to analyze future climate simulations and quantify uncertainties in regional and coastal sea level projections associated with long-term wind pattern shifts and model deficiencies.

Keywords: Pacific, ENSO, climate, uncertainty, projection

Paper ID 398
Poster Board N°10

Slowdown of the Gulf Stream during 1993-2013

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The Gulf Stream (GS) properties (position, transport, and speed) derived from satellite altimeter sea surface height (SSH) measurements are analyzed in the region from 80°W to 50°W. During the study period 1992-2013, the GS experiences a strong southward shift dominated by the region east of 65°W after the GS passes the New England Seamount. This southward shift is accompanied by a weakening of the GS, associated with the SSH increase to the north of the GS. However, to the west of 70°W, the trends of the GS properties are weak, and vary between positive and negative values, consistent with the results based on in situ measurements. Therefore, our results do not support a direct link of the sea level rise acceleration along the U.S. east coast with the GS slowdown. However, it is possible that heat transport convergence by the GS system causes these observed sea level changes.

Keywords: Gulf Stream, transport, altimeter, sea surface height, North Atlantic

Paper ID 408
Poster Board N°60

Sea Level Trend and its Variability in the South China Sea

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The rates of observed sea level rise vary across the globe. Spatial variations of relative sea level rise (RSLR) together with the seasonal cycle of mean sea level in the South China Sea (SCS) were investigated in this study. Records from 27 tide gauges covering the northern and western SCS coastline and the period from 1950 to 2015 have been used to derive high quality relative mean sea level time series. Changes in mean sea level are assessed using non-linear Empirical Mode Decomposition/Hilbert-Huang Transform analysis and linear trend estimations from different time spans. Time series from individual tide gauges are analyzed to obtain local rates of sea level rise. Then the data are constructed to represent the northern and southwestern regions of the SCS. An accelerated sea level rise is detected for a period at the end of the nineteenth century. Higher rates of relative sea level rise are detected for the western part of the SCS in comparison to the northern part. The rates of sea level rise in different seasons are also investigated to estimate the effect of sea level rise on the heights of storm surges and thereby flood risk in coastal areas.

Keywords: sea level rise; regional sea level variability; seasonality; South China Sea

Paper ID 426
Poster Board N°4

Characteristics of Extreme Sea Level in the Bay of Bengal and Changes in the Recent Past – An overview

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The coast of the Bay of Bengal has witnessed the occurrence of catastrophic storm surges in the past. Studies on storm surges in the Bay of Bengal started since 1970's, which mainly focussed on developing numerical models for simulating the past storm surges. During the last two decades, we had been analysing past tide-gauge data along the coast to study the characteristics of sea level extremes and their changes in the recent past. Our studies using hourly tide-gauge data along the east coast of India and the head of Bay of Bengal indicate that surges during many storm surge events are captured in tide gauge records, even though peak surges are not often obtained. However, having a sufficiently long data set permits to describe the characteristics and study their evolution.

The head of the Bay is characterised by the presence of large semi-diurnal tides. Moreover, tropical cyclones formed in the Bay move mostly in westward and northwestward directions resulting in a landfall in the head of the Bay and at the northern part of the east coast of India. The head of the Bay lies in the Indo-Gangetic delta. This delta is undergoing subsidence, which results in a large mean sea-level rise of about 5.0 mm/yr in the region. For instance, the analysis of hourly tide-gauge data at Hiron Point, located at the head of the Bay, shows that changes in sea level extremes since 1970's are in agreement with changes in mean sea level. Moreover, inter-annual variability in sea level extremes along the east coast of India and at the head of the Bay of Bengal is found to be related to the indices of modes of climate variability such as ENSO and IOD. The head of the Bay is characterised by the presence of many rivers carrying sediment and it is highly challenging to model the sea level variations in this region. We illustrate that analysis of past tide gauge data provide information on changes in mean sea level as well as extremes.

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Keywords: Extreme sea level, storm surges, Bay of Bengal, tide-gauge data, long-term trends

Paper ID 433
Poster Board N°6

Anthropogenic Influence on Sea Level Change in the South Pacific and Associated Changes in the Subtropical Gyre Circulation in the 20th Century

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Global mean sea level has been estimated to rise about 20cm during the 20th century. However, sea level change is not uniform over the globe, but varies regionally due to several effects. Thermal expansion and ice loss due to ice sheets and glaciers are the most prominent effects for regional differences in sea level change. Salinity changes may also have significant influence on the regional sea surface height. Further, changes in ocean currents, ocean density and sea level are all tightly coupled. The subtropical gyre in the South Pacific is a large scale wind-driven ocean circulation, including the Humbuldt current, the westward southequatorial current, the East Australian current, and the eastward South Pacific current. Large scale ocean circulations play an essential role in determing the climate of the Earth over long and short term time scales. The subtropical gyre circulation is directly related to sea level change. It is characterized by a sea level high in its center. In the recent years a spin-up of this circulation has been recognized analyzing observations of sea level, temperature and salinity profiles, sea surface temperature and wind. Until now it is not clear whether this spin-up is decadal variability or whether it is a long-term trend introduced by anthropogenic forcing.

This study analyzes anthropogenic influence on the sea level change in the South Pacific ocean and associated changes in position and strength of the gyre circulations. To determine that yearly means of sea level height and related variables as ocean temperature and salinity of CMIP5 model data are analyzed. The experiments 'historical' and 'historicalNat' will be examined. The 'historical' experiment is supposed to simulate the climate of the 20th century and the 'historicalNat' experiment covers the same time period, but only includes natural forcings. Comparing the outcomes of these two experiments is supposed to give information about the anthropogenic influence.

The CMIP5 databank includes the variable 'zos', which describes steric and dynamic sea level changes. Steric sea level, that is the contribution of temperature and salinity of the water, describes the major contribution to regional sea level change with respect to the global mean. As temperature and salinity of the ocean water changes, its density changes, which leads to a contraction or expansion of the water and that also changes the sea surface height. This does not only occur at the surface, but at all layers in the ocean. Sea level change at the surface thus integrates ocean variability throughout the depth of the ocean. Sea level simulations of the different experiments are compared using long-term trends, as well as multi-year anomalies and EOF-Analysis. The changes in temperature and salinity in the deeper ocean can be used to describe the development of the gyre below the surface. These changes can be summarized in the dynamic height, which are used to analyze changes in deeper layers.

Keywords: sea level, south pacific, subtropical gyre, anthropogenic change, 20th century

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 447
Poster Board N°30

Global and Spatio-Temporal Changes in Upper-Ocean Thermal Expansion from the Perspective of an Ensemble of XBT Bias-Corrected Estimates and Contribution to Multidecadal Sea Level Rise

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Investigation of ocean heat storage and redistribution is essential for the understanding of our climate system, from natural modes of variability to the current energy imbalance caused by long-term anthropogenic warming. Thermal expansion induced by changes in ocean heat content is also a major contribution to the global mean sea level rise observed since 1970 and largely explains its regional patterns. A variety of factors, however, can introduce uncertainty into estimates of ocean heat content/thermal expansion. Mapping method was recently shown to be the largest source of uncertainty for global estimates of ocean heat content in the upper 700 m of the ocean. The impact of instrumental bias corrections for eXpendable BathyThermographs (XBTs) was only larger than mapping method for estimates from the Australian CSIRO-ACECRC-IMAS group.

Here, we present an ensemble of CSIRO-ACECRC-IMAS estimates corrected for 10 existing XBT bias schemes and also discuss the implications of this source of uncertainty for variability and change in thermosteric sea level at global, basin and regional scales. For 1970-2015, the ensemble mean trend in globally-averaged thermosteric sea level for the upper 700 m is 0.56 mm/yr. The Atlantic Ocean, the Northwest Pacific, the Tasman Sea and some areas of the South Indian Ocean exhibit trends above the global average. The Southern Hemisphere accounts for 55% of the global thermosteric sea level change in the upper 700 m, with the largest fraction coming from the upper 300 m (41% of the global). Overall, the upper 300 m explains 74% of the global thermosteric change in the upper 700 m. In terms of global mean sea level rise over the satellite era, with a rate of 2.69 mm/yr for 1993-2015, based on an adjusted estimate from Watson et al. (2015), the thermosteric sea level contribution in the upper 700 m varies from 14% to 29%, due to spread in XBT bias corrections and excluding two unrealistic estimates. Thermosteric estimates based on XBT corrections for all recommended factors lie on the upper range (29%). Although zonal spread due to XBT bias corrections is seen across all latitudes and with maxima in the tropical Pacific, the trend signal is an order of magnitude larger than the spread for all periods examined. We find that our mapping method is sensitive to time-dependent interplay between two parameters, one global ("EOF0") and one regional ("EOF1"), used to interpolate across in situ observational gaps.

Watson et al. (2015): DOI: 10.1038/NCLIMATE2635

Keywords: ocean thermal expansion, sea level budget, XBT-bias corrections, ocean heat content

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 448
Poster Board N°12

Ocean Heat Uptake and Redistribution in Contemporary Simulations of the Australian ACCESS Ocean-Sea Ice Model Forced by CORE-II and JRA-55 Atmospheric Reanalyses

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Sea level rise is one of the most evident socio-economic and environmental hazards associated with a warming climate. Since 1970, more than 90% of the excess planetary heat is found in the ocean. Ocean heat uptake along with its vertical and lateral redistribution are one of the main factors contributing to the large intermodel spread in the magnitude and regional patterns of sea level rise projections over the 21st century. We perform a heat budget analysis to quantify the physical processes involved in ocean heat uptake and redistribution in contemporary simulations from the Australian Community Climate and Earth System Simulator ocean-sea ice model (ACCESS-OM), forced with atmospheric reanalyses from the Coordinated Ocean-Ice Reference Experiments (CORE-II, 1948-2007) and the Japanese Reanalysis (JRA-55, 1958-2015). Our results show that the global vertical heat balance proposed by Munk (1966) between downward flux by diffusion and upward flux by the mean advection is only held at the tropics and has a small global impact, as in previous studies but based on global coupled-climate models (e.g. Gregory 2000; Exarchou et al 2015). Warming from vertical diffusion is balanced by cooling from mixed-layer physics in the top 500 m. Below 500 m, regardless of depth interval, warming due to mean advection and vertical diffusion counteracts cooling due to isoneutral diffusion and mesoscale eddies. Overall, the global balance is largely dominated by ocean processes in high latitude areas of the Northern and Southern oceans, however, with regional differences. The heat balance in the North Atlantic/Pacific results in a net warming at intermediate depth which is mostly explained by the advective warming from the mean circulation and subgridscale cooling from mesoscale eddies, within the 400-2000 m depth interval. The Southern Ocean reflects the global heat balance and play an important role in the net heat tendencies in the ocean interior. Stronger advective downward heat transport drives a warming signal through intermediate depths (500-1200 m) while upward heat transport from vertical diffusion drives a cooling trend in the deep ocean (below 2000 m), which is spread over the global ocean. Although the choice of surface forcing quantitatively affects the redistribution of heat by diffusive processes within the mixed layer, it has little effect in the net heat tendency in the ocean interior over the period analysed. Our simulations suggest that the model evolution away from the observed initial conditions is more influenced by the model configuration than the surface forcing product used.

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Keywords: Ocean Heat Uptake, Ocean Heat Budget, CORE-II, JRA-55, ACCESS Ocean Model

POSTER SESSION
Session 4a: Contemporary Sea Level Change

Paper ID 1
Poster Board N°82

Data-adaptive harmonic analysis of North-Atlantic sea level variability

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Abstract missing

Paper ID 115
Poster Board N°29

Drivers and Predictability of Variations in Regional Sea Level on Seasonal-to-Interannual Timescales

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Observations and eddy-permitting ocean model simulations are used to evaluate the drivers of sea level variability associated with 15 modes of climate variability covering the Atlantic, Pacific, Indian, and Southern Oceans. Sea level signals are decomposed into barotropic, steric, and inverted barometer contributions. Forcings are decomposed into surface winds, buoyancy fluxes, and Ekman pumping. Seasonal-to-interannual sea level variability in the low latitudes is governed almost entirely by the thermosteric response to wind forcing associated with tropical modes of climate variability. In the extratropics, changes to dynamic sea level associated with atmospheric modes of variability include a substantial barotropic response to wind forcing, particularly over the continental shelf seas. However, wind-driven steric changes are also important in some locations. On interannual time scales, wind-forced steric changes dominate, although heat and freshwater fluxes are important in the northwest Atlantic, where low-frequency sea level variations are associated with changes in the Atlantic meridional overturning circulation. Using the version 3 of the Met Office Decadal Prediction System (DePreSys3), the predictability of large-scale dynamic sea level anomalies on seasonal-to-interannual time scales is evaluated. For the first year of the hindcast simulations, DePreSys3 exhibits skill exceeding persistence over large regions of the Pacific, Atlantic, and Indian Oceans. Skill is particularly high in the tropical Indo-Pacific because of the accurate initialization and propagation of thermocline depth anomalies associated with baroclinic adjustments to remote wind forcing. Skill in the extratropics is hindered by the limited predictability of wind anomalies associated with modes of atmospheric variability that dominate local and/or barotropic responses.

Keywords: sea level, regional, predicability, climate variability, decadal prediction

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 131
Poster Board N°5

Using DInSAR to Assess Vertical Ground Motions at Tide Gauges

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Before the satellite altimetry era, tide gauges provide the only instrumental records available to assess global sea level rise due to climate change. However, tide gauges can be affected by vertical ground motions (subsidence or uplift), due to: (1) the global isostatic adjustment and (2) numerous anthropogenic or natural processes due e.g. to groundwater extractions or tectonic or volcanic processes. In general, the latter processes are difficult to model so that geodetic observations are needed to assess vertical ground motions at tide gauges.

In addition to permanent GPS (see for instance, www.sonel.org), levelling and Doris measurements, Satellite Aperture Radar Interferometry (InSAR) can provide deformation maps back to 1992 (ESA ERS Satellite). In this poster, we present the results in contrasted contexts with respect to the data availability and ground deformation patterns. The example of Manila (Philippines) shows that vertical ground motions exceeding 1cm/year are possible, in particular in coastal sites affected by groundwater extractions. It also illustrates that subsidence or uplifts can display a high spatial variability while being highly non-linear in time. Dakar (Sénégal) exemplifies the difficulties in appraising vertical ground motions from geological and hydrogeological information only: in spite of a most complex geological context and groundwater extraction history, the city appears mostly stable within the limits of the InSAR techniques applicable in this area (1mm/yr). Owing to a more complete archive of SAR data in Alexandria, higher precision interferometric techniques can be used (Persistent Scatterrers Interferometry, PSI), revealing a very good agreement between the different satellite and in-situ geodetic techniques (GNSS, tide gauge and altimetry), in the order of 0.5mm/yr. In Brest, a PSI analysis reveals some slow ground deformations in recent embankments, and suggests that the tide gauge and permanent GNSS station are unaffected. Overall, these examples show that reaching accuracies bellow 1mm/yr (which is the requirement for sea-level studies) is difficult without frequent revisit of the SAR satellite and long (>10 years) mission continuity. This calls for appropriate background missions for spaces agencies and companies operating satellites with SAR instruments onboard.

These studies are funded by the French Agency for Research (ANR CECILE), the University of La Rochelle and BRGM. We thank ESA for providing SAR data (ERS and Envisat).

Keywords: geodesy, tide gauge, GNSS, InSAR

Paper ID 143
Poster Board N°75

Sea Level Variability along Coast of Nova Scotia: Understanding Forcing Mechanisms and Development of an Adaptation Tool

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This presentation covers three aspects related to sea level variability along the coast of Nova Scotia, Canada. First, the linkage between tidal gauges observations and atmospheric forcing are explored through multivariate regression analysis applied to monthly time series of different seasons. The analysis suggests that inter-annual variations, including the 2009-2010 significant rise of coastal sea level, can mostly be attributed to variations of atmospheric pressure and surface wind. Secondly, through joint analysis of satellite altimeter observations and a fine-resolution global ocean reanalysis product, the relationship is explored between inter-annual variations of sea level on Scotian Shelf with a coherent sea level variation over the western North Atlantic. Thirdly, a science-based planning tool CAN-EWLAT is developed for climate change adaptation of coastal infrastructure related to future water-level extremes. CAN-EWLAT improves the IPCC AR5 projections by incorporating information on land motion measured by high-precision GPS instruments. To communicate the CAN-EWLAT tool to general public, ECoAS project is developed to educate coastal communities about SLR.

Keywords: altimeter, atmospheric pressure, wind, ocean reanalysis

Paper ID 149
Poster Board N°53

Prediction of Regional Sea Level Changes Applying Linear Inverse Models

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Prediction of sea level change is an important element in climate change risk assessment. On a regional scale, natural variations on decadal and longer scales due to internal dynamics of the climate system overlay the anthropogenic changes and can cause strong biases in long term prediction of sea level change if not taken into account properly. Linear Inverse Models (LIM) are a helpful tool to predict internally induced variations of the climate system and to understand the underlying mechanisms. A LIM describes the superposition of exponentially damped standing or travelling waves, or spatially fixed patterns in the system that are forced by short term random forcing (which might be correlated in space but not in time). We present a suite of LIMs developed to predict sea level variations for the North Atlantic for time lags from a few years up to some 20 years. To train the LIMs, provide initial conditions and evaluate the skill of the predictions, long term CMIP5 integrations from climate models are applied. In its most basic version the LIM predicts future sea level variations by only considering the regional sea level of the North Atlantic itself, while extended versions include also regional surface hydrography (both temperature and salinity), and the most sophisticated, complete, LIM includes in addition zonal mean hydrography for the entire North Atlantic and the complete salinity field of the subpolar region. Both, purely damped and oscillating modes are found in all LIMs. Periods of oscillation longer than 200 years are found. But since for the oscillating modes the damping time scales are generally much shorter than the oscillation periods, the temporal development of all modes is primarily driven by their damping time scales. While all LIMs exhibit comparable skills for predictions up to some 5 years from initialization, inclusion of hydrography improves the predictions for longer time scales. This improvement is generated by modes of longer damping time scales of up to some 80 years found for the complete LIM. Good predictability is generally found in a region between 50-60N, especially for the Subpolar Gyre, the Rockall Trough and the North Sea.

Keywords: Linear Inverse Model, North Atlantic, sea level prediction, internal variability

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 151
Poster Board N°51

Processes Responsible for Steric Sea Surface Height Anomalies in the North Atlantic

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Using output from eddy permitting/resolving ocean simulations (at 8-km and 4-km resolution), a decomposition of temperature and salinity variability into intra-annual (<1 year), inter-annual (1-7 years), decadal (7-15 years) and inter-decadal (>15 years) frequency bands is conducted in order to investigate processes leading to steric sea surface height (SSH) anomalies and respective thermosteric and halosteric components at those frequency bands. Intra-annual variability is dominated by westward-propagating eddy signals, boundary-trapped waves and inter-tropical Kelvin and Rossby waves. Inter-annual and longer timescale variations present mainly propagating Rossby waves and large-scale gyre oscillations dominated by advection. Inter-annual timescale (1-7 years) steric anomalies show, in particular, a conspicuous wave signal propagating southwestwards at mid-latitudes in the North Atlantic. Those waves, whose corresponding temperature/salinity signals have amplitudes intensified at mid-depth, play a leading role in the inter-annual variations of SSH. The nature and generation mechanism for the temperature/salinity anomalies and consequently for the SSH wave-like variations is presented and their implications discussed.

Keywords: sealevel, interannual variability, physical processes, modelling

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 152
Poster Board N°27

Sea Level Variability Changes from the Open to the Coastal Ocean Observed by Satellite Altimetry

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Since 1993, satellite altimetry indicates that sea level has been rising fast in response to global warming, with large regional variations. However, standard altimetric data do not allow studying sea level variability and rising close to the coast (<20km from the coast), where the socio-economic impacts of sea level rise occur.

Here, we study how sea level variability and trend spatially evolve from the open to the coastal ocean along altimetric tracks (from 150 km off the continental shelf to the coast) over the period 1993-2016. To do so, we analyse along-track altimetric data from Topex-Poseidon, Jason1 and Jason2 that have been reprocessed at LEGOS/CTOH using recent algorithms adapted to coastal regions to recover information in coastal zones (XTRACK dataset version 2016). In previous studies (Cipollini et al. 2017, Birol et al. 2017) we studied the western coast of Africa and showed that sea level variability is enhanced coastward (at time scales from inter-annual to multi-decadal). In the present study, we expand the methodology to deal with other regions that exhibit different dynamical regimes and continental shelf width: the southwest Tropical Pacific, the Mediterranean Sea, the coast of Peru, the coast of western Europe, and the central south Asia coast (including India). Results are compared to these obtained using the standard along-track altimetric dataset produced by the DUACS system and distributed by the Copernicus Marine Environment Monitoring Service. Different regions exhibit different evolution of the sea level variability when approaching the coast. The reasons for these differences are discussed.

Keywords: coastal, sea level, altimetry, climate change

Paper ID 155
Poster Board N°71

DFG Priority Program (SPP-1889) Regional Sea Level Change and Society ('SeaLevel')

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The Priority Program (SPP-1889) 'Regional Sea Level Change and Society (SeaLevel)', funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG), aims to perform a comprehensive, multidisciplinary analysis to advance our knowledge on regional climate-related local sea level change (SLC), while taking into account the associated human-environment interactions and socio-economic developments in the coastal zone. The SPP project consists of 20 projects from 23 German research institutions and it will provide a scientific basis for the assessment and development of adaptation policies to cope with coastal SLC by focusing in two regions: the North and Baltic Seas with potential impacts on Germany, and the South-East Asia region, which encompasses several coastal megacities, low-lying islands and delta regions. The selected regions contrast developed and developing countries, and thus differ fundamentally in their regional societal impact, cultural, political and socio-economic contexts, adaptation potential and response strategies towards SLC.

Among the main scientific objectives of SeaLevel are to: (1) improve our physical knowledge of regional climate-related SLC, and (2) projections of SLC on a regional-to-local scale, (3) investigate which socio-institutional factors enable/hinder coastal societies to cope with changing SL, (4) determine the natural and social coastal systems' responses to future SLC, and (5) assess strategies to adapt to SLC under given technical, economic, cultural, social and political constraints. To perform those integrated analyses, SLC information (local SL projections, storm surges, waves and extremes), uncertainty and risk measures need to be provided at the coastlines.

SeaLevel is organized along three work packages (WP), depending on the spatial scale, geographic foci and required natural or social sciences' participation: A) Origin of regional sea level changes at annual to multi-decadal scale, which focuses on the mechanisms of SL variability, B) Regionalization of Decadal Sea Level projections, which aims to establish reliable local projections of SL trends and estimates of future coastal SLC in the study regions, and C) Socio-economic Impacts and Risk Governance,which focuses on coastal human-environment interactions and impacts, adaptation pathways, policies and risk management strategies. A two-way, interactive approach, results from each WP will feed into the other WPs, advancing our understanding on processes influencing regional SL and creating a knowledge base for quantitative, integrated coastal zone management (CZM) studies both in the study regions but also applicable to many other endangered places around the globe.

Keywords: regional to local scale, coastal human-environment interactions, natural and social coastal systems' responses, coastal impacts and adaptation strategies, projections

Paper ID 157
Poster Board N°13

Validation of Altimetry-Derived Regional Sea Level Trends Based on Reconstruction of Baltic Sea 2D Sea Level of the Last Century

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The satellite altimetry data record is now long enough to compute regional sea level trends, but can these products really be used in regions close to the coast?

The ESA Sea Level CCI product is developed based on open ocean altimetry data, and constitutes high quality monthly sea level variability and trend analysis for the open ocean. However, it is commonly used in the coastal zone and e.g. provided by MyOcean (now Copernicus Marine Service) to the European Environmental Agency for use in their Global and European sea-level rise indicator for northern Europe (http://www.eea.europa.eu/data-and-maps/indicators/sea-level-rise-2/assessment). Here we assess the quality Sea Level CCI in the coastal zone of the Baltic Sea.

We validate the sea level variability using a 2D sea level field based on statistical modelling of monthly tide gauge observations and model reanalysis as reference. The sea level product was constructed for the EMODnet Baltic Sea Check Point. The statistical model is based on least squares regression and uses monthly mean tide gauge observations retrieved from PSMSL and model reanalysis from the Copernicus Marine Service, taking land rise information into account. The reconstruction provides monthly mean sea level of the Baltic Sea in 10 km resolution during 1900-2014, and can reconstruct the variability of the Baltic Sea with an average correlation of 96% and RMS error of 3.8 cm to 56 independent tide gauges.

The validation against this independent source of sea level information allows assessing the quality of the CCI product approaching the coast, and can therefore be used to determine how close to the coast the Sea Level CCI can be considered reliable. The CCI sea level anomalies match reconstructed sea level variability of the southern open parts of the Baltic Proper with correlation above 90% and RMS difference below 6 cm. However, the coastal zone, areas with small islands or sea ice, and areas of high natural variability needs special treatment, and the increased uncertainty of these areas is not reflected in the trend error field provided in the present version if the Sea Level CCI.

Keywords: sea level trend, satellite altimetry, tide gauge, reconstruction

Paper ID 164
Poster Board N°31

Innovations for Satellite Altimetry Processing in the Arctic Ocean: Development and Application of a New Sea Level Record (1992-2016)

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The analysis of the sea level variability in the Arctic is crucial to understand some of the most rapid changes that the Earth is currently experiencing. Measuring sea level in this region with satellite radar altimetry has always been challenging, due to the presence of sea ice, which makes the sea surface height measurements dependent on the signal reflected back from leads (open water in the fractures between the ice floes). A new initiative within the ESA Sea Level Climate Change Initiative (SL_cci) framework to improve the Arctic sea level record is on-going as a combined effort to reprocess past altimetry to create a 25-year combined sea level record for sea level research studies.

A first effort involved the reprocessing of the altimetric echoes (waveforms) with a dedicated fitting algorithm, the ALES+ retracker, which is able to retrieve the signals coming from the open ocean, from the coastal areas and from leads in the sea ice region. Signals coming from these areas are characterized by different backscattering properties: the typical open-ocean signal is shaped as a steep leading edge and a slowly decreasing trailing edge; the latter is strongly perturbed in the coastal ocean, but also near the ice edge area; in the sea ice region, the leads show up as extremely peaky echoes. The use of different retrackers to estimate the sea level from waveforms with different characteristics can cause biases and varying performances. ALES+ instead adapts the width of the fitting window in order to optimise the amount and the quality of sea level measurements using the same algorithm.

In this work, ALES+ is used to reprocess the data from two radar altimeters (ERS-2 and Envisat): this homogenous multi-mission sea level dataset is compared with empirical retrackers and tailored with editing and data from other altimeters to derive an experimental spatio-temporal enhanced sea level product (the SL_CCI DTU/TUM Arctic Ocean dataset) for high latitudes. The performances of the retracking algorithm are evaluated by means of noise statistics, performance analysis and comparison with tide gauge data in sea-ice covered regions. The first results in the ocean near Svalbard show that ALES+ is able to decrease the noise in over 70% of the domain w.r.t. the standard ocean product and to retrieve over 25% more data in the proximity of the maximum ice extent. In the sea-ice covered region, a strong coherence between the Ny-Alesund tide gauge and the altimetry processed with ALES+ (Pearson correlation coefficient R=0.83) shows improvements w.r.t the Radar Altimeter Database System (RADS, R=0.76). The data coverage in the whole domain is also significantly higher than RADS.

We will show sea level anomaly maps of the Arctic Ocean from the ALES+-retracked ERS-2 and Envisat altimeters data w.r.t. DTU15 Mean Sea Surface, and describe the similarities and differences in terms of oceanic variability. Our final objective is the expansion of the dataset to include the ERS-1 and CryoSat-2 missions, in order to perform a complete time series analysis from the full satellite era.

Keywords: Altimetry, Arctic, Sea Ice, Sea Level, Retracking

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 165
Poster Board N°33

A 20-year Coastal Altimetry Dataset in the North Sea and Mediterranean Sea

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The Adaptive Leading Edge Subwaveform (ALES) reprocessed dataset of Envisat and Jason time series, together with updated geophysical corrections, tidal and mean sea surface models, has shown that coastal altimetry is now in a mature stage in which it can be used for sea level variability studies. However, the relatively short period (2002-2015) covered by the current ALES dataset still represents a limitation to trend and long-term variability analyses.

This study is dedicated to the application of the ALES concept to the ERS-1 and -2 satellite missions, which extends the time series up to 10 years, guaranteeing more than 20 years (1991-2012 along the same Envisat ground tracks) of coastal altimetry. The reference dataset, on which the reprocessing is based, is the ESA REAPER project. The dataset is pre-processed, by means of a new fitting of the radar signal (i.e. retracking) and post-processed, by means of dedicated geophysical corrections, outlier detection, averaging and cross-calibration. The resulting along-track sea level time series are made available free of charge as the COastal Sea level Tailored ALES (COSTA) product on PANGEA data publisher (preliminary version in: https://doi.pangaea.de/10.1594/PANGAEA.871920).

The first part of the study is dedicated to the retracking strategy. The ALES algorithm selects only a portion of the altimetric signal (waveform), in order to estimate the distance between the satellite and the sea surface (range) while avoiding the noise in the tail of the signal. The algorithm is based on the relation between estimated sea state, achievable precision and width of the subwaveform and is now adapted to the ERS sampling characteristics. The sea state bias correction, which accounts for the effects of waves and the tracking errors, is recomputed for the ALES output. Preliminary results show a 15% decrease in the high-rate noise of the measurements if compared to the standard product, with larger improvements in the last 20 km from the coastline and a better precision also in the open ocean.

In the second part, joint Envisat+ERS time series are built in the North Sea and in the Mediterranean Sea to investigate seasonal variability and trends in sea level at a regional scale. Estimates of the annual cycle and trends from the altimetric time series are used in combination with tide gauge observations to characterize the magnitude and the geographic variability of these two components of sea level. The new coastal altimetry dataset enables us to explore coastal sea level changes in regions where very few tide gauge stations are available such as along the North African coast in the Mediterranean Sea. Furthermore, by providing sea level observations closer to the coast, it allows us to investigate differences between coastal and open ocean sea level along the entire coast.

Keywords: coastal altimetry, mediterranean sea, north sea, retracking

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 173
Poster Board N°69

Measuring Present-day Rates of Relative Sea-Level Change in Low-Elevation Coastal Zones: A New Approach

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Low-elevation coastal zones (LECZs) that often host large population centers are particularly vulnerable to accelerating rates of relative sea-level rise (RSLR). Traditionally, tide-gauge records are used to obtain quantitative data on rates of RSLR, given that they are perceived to capture the rise of the sea surface, as well as land subsidence which is often substantial in such settings. We argue here that tide gauges in LECZs often provide ambiguous data because they ultimately measure RSLR with respect to a benchmark that is typically anchored at depths of tens of meters. This is problematic because the prime target of interest is usually the rate of RSLR with respect to the land surface. We illustrate this problem with newly obtained rod surface elevation table – marker horizon (RSET-MH) data from coastal Louisiana (n = 274) that show that shallow subsidence in the uppermost 5-10 m accounts for 60-85% of total subsidence. Since benchmarks in this region are anchored at ~20 m depth on average, tide-gauge records by definition do not capture this important process and thus underestimate RSLR by a considerable amount. We show how RSET-MH data, combined with GPS and satellite altimetry data, enable us to bypass this problem. Rates of RSLR in coastal Louisiana over the past 6-10 years are 12 ± 8 mm/yr, considerably higher than numbers reported in recent studies based on tide-gauge analysis. It is likely that the problems with tide-gauge data are not unique to coastal Louisiana, so we suggest that our new approach to RSLR measurements may be useful in LECZs worldwide.

Keywords: sea-level change, low-elevation coastal zone, subsidence, surface-elevation table, tide gauge

Paper ID 191
Poster Board N°45

Northern North Atlantic Sea Surface Height in Climate Models - Evaluation of Mean State, Variability and Trends against Altimetric Observations

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The northern North Atlantic comprises a dynamically complex area with distinct topographic features that makes it challenging to model oceanic features with global climate models. However, these models form the basis for numerous national assessment reports of future regional sea level rise and model evaluation is therefore important in this region. We evaluate the representation of regional sea surface height in the northern North Atlantic Ocean in 18 climate models that contributed to the Coupled Model Intercomparison Project Phase 5 (CMIP5).

Modeled sea surface height is compared to observations from a 20-year altimetry record in terms of mean state, interannual variability, as well as linear trend patterns. By comparing the simulations with observations it can be assessed whether the modeled natural variability is in line with observed changes and whether a forced signal is already detectable over the past 20 years of altimetry observations. As models are expected to reproduce the location and magnitude but not the timing of internal variability, the observations are compared to the full 150 year historical simulations to assess whether the observed changes can be explained by internal variability only. The models perform well with respect to the mean dynamic topography for all considered periods. However, performance degrades when interannual variability and linear trend patterns are considered. We find that the modeled area-wide mean steric/dynamic sea level rise is larger than estimated from observations and that the marked observed increase in the subpolar gyre is not consistent with a forced response but rather a result of internal variability.

Keywords: model evaluation, internal variability, northern North Atlantic

Paper ID 209
Poster Board N°23

Direct and Indirect Estimates of Mediterranean Mass Variability

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Changes in the mass content of the Mediterranean sea are characterized using a the new JPL-Mascons gravimetric product for the period 2003-2015. The results are compared with previous estimates also based on GRACE measurements and with indirect estimates obtained from a combination of hydrographic observations, satellite altimetry and numerical modelling. Our results show that the JPL-Mascons provide a good representation of the Mediterranean mass variability (correlation with indirect estimates up to 0.85), significantly improving the previous gravimetric products (correlation lower than 0.3). Also it is shown that most of the Mediterranean mass variations at interannual scales are due to mass redistribution due to wind forcing around the Strait of Gibraltar. Sea level changes in the nearby Atlantic is a secondary source of mass variability in the Mediterranean. Also, we have estimated the role of salt changes in the variability of gravimetric derived mass estimates. Although changes in the salt content have little effect on the seasonal to interannual time scales they are non-negligible in what concerns multidecadal and long term trends.

Keywords: Mass, Mediterranean Sea, Regional Sea Level, Steric

Paper ID 215
Poster Board N°9

Low Sea Level along the Coasts of Northeast Pacific in the Winter of 2013–2014

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During the winter of 2013-2014, the unusual sea surface warming event, called "the warm blob", is developed in the northeast Pacific. The coasts of Northeast Pacific, especially north of 40°N, has experienced the lowest sea level in winter over the past 30 years. The ensemble empirical mode decomposition (EEMD) was applied to explore the variability of winter sea level along the coasts of northeast Pacific during the period 1980–2015. We found that the lowest winter coastal sea level was mainly the result of the superposition of two variability: 5-7 year quasi-periodic variation and a decreasing trend. The former is associated with the Pacific decadal oscillation (PDO) shifting from a negative to a positive phase, and the latter is related with the global warming signal.

To understand the coastal sea level change in this region, a multiple linear regressive model has been employed. The relative contributions of local longshore wind stress, remote equatorial wind stress and local wind stress curl have been computed. We found that the local longshore wind stress play the crucial role. The longshore southward wind stress anomalies in the winter associated with the positive anomalies of Aleutian Low can drive offshore flow in the Ekman layer and lead lower sea level in the coasts. More comprehensive analysis of the decreasing trend by using the analysis and numerical model data are undergoing.

Keywords: Sea level height, Northeast Pacific

Paper ID 219
Poster Board N°73

Time Variable Biases within the Satellite Era Sea Level Climate Record

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The global mean sea level (GMSL) time series derived from satellite altimetry is a seminal climate data record that describes one of the most robust manifestations of climate change. Accurate estimates of the rate of change and acceleration of GMSL are of utmost importance for evaluating model projections and for adaptation planning. In a recent contribution to the literature, Watson et al. (2015) investigated the magnitude of inter- and intra-mission biases, and in particular, the stability of these biases over time. That work suggested that time variable biases in the early part of the TOPEX record were significantly different to zero, implying a necessary reduction in the estimated trend in GMSL from +3.2 mm/yr to between +2.6 to +2.9 ± 0.4 mm/yr (1993-2014.5), depending on the choice of land motion applied at tide gauge sites used to estimate the biases. The results also suggested a change from a small deceleration over the satellite era record, to an emerging acceleration (not then statistically significant), consistent with the acceleration over the 20th Century and the acceleration noted within recent projections. Here, we revisit and update the results of Watson et al. to provide further insight into the magnitude, uncertainty and likely source of instrumental biases over the satellite period. We give emphasis to recent enhancements to the method to explore the limit of the tide gauge network when used together with observed or modelled estimates of vertical land motion to identify systematic biases in the satellite record.

Keywords: Satellite altimetry, GMSL, Vertical land motion, Bias drift

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 234
Poster Board N°3

Decomposing the Seasonal Cycle of Sea Level in the North Sea

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The main mode of variability of monthly averaged sea level in the North Sea is the seasonal cycle. Using a regional ocean model (ROMS) and tide gauges we decompose the seasonal cycle depending on the physical drivers: inverse barometer effect, steric effect and wind forcing. Since an important part of the steric effect in shallow seas is remotely forced, we present a method to separate the local and the remote steric effects. This allows us to analyze phase differences between the different forcing mechanisms and to explain the year to year variability of the magnitude of the annual cycle.

Keywords: Sea level variability, seasonal cycle, remote vs local steric effects

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 251
Poster Board N°49

Uncertainty of the 20th Century Sea-Level Rise due to Vertical Land Motion Errors

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Assessing the vertical land motion (VLM) at tide gauges (TG) is crucial to the understanding of the global and regional mean sea-level change (SLC) over the last century. Obtaining VLM corrections using the Global Positioning System with accuracy better than a few tenths of a millimeter per year is not a trivial undertaking and many factors, including the reference frame uncertainty, must be considered. In addition, since GPS stations are usually not installed at the TGs, the relative VLM between both instruments needs to be accounted for.

The GPS VLM corrections from the last solution at the University of La Rochelle have a median formal uncertainty of 0.3 mm yr−1. The relative VLM error introduced when using GPS stations away from the TGs is assessed globally at the level of 5×10^{-3} mm yr−1 km−1. Together, the uncertainty of the GPS VLM corrections propagates into the global SLC rate uncertainty by no less than 0.1 mm yr−1 (1 sigma). On top of that, the contribution of the terrestrial reference frame uncertainty to SLC rate uncertainty dominates with no less than 0.3 mm yr−1 (1 sigma). In addition, deviations of the mean pole definition of the terrestrial reference frame introduce regional SLC biases exceeding 0.1 mm yr−1.

Finally, we find that the difference in the VLM corrections from two known Glacio-Isostatic Adjustment models, using different ice history and rheologies, introduces a spurious acceleration and also a trend bias in the global SLC rate as large as 0.3 mm yr−1 which is possibly exacerbated for the regional SLC rates.

The effect of uncertain VLM at the TGs used to reconstruct the 20th Century SLC is substantial and cannot be neglected when exploring scenarios of future sea levels. Indeed, incomplete knowledge of the VLM at the TGs may be partially responsible for the range of published 20th Century sea-level rise estimates from 1.1 to 1.9 mm yr−1, together with the different TG network selection and the reconstruction approach followed.

Keywords: Vertical Land Motion; GPS; GIA; Reference frame; Tide gauges; Sea-level reconstruction

Paper ID 252
Poster Board N°39

Identifying Processes Controlling Recent Decadal Changes in Tropical Pacific Sea Level

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Over 1993-2012, the zonal tilt in tropical Pacific sea level (TPSL) increased steadily, with western TPSL rising and eastern TPSL falling. Yet, during the last five years, this zonal tilt trend has reversed, with TPSL rapidly decreasing in the west and increasing in the east. A recent statistical analysis suggests that this TPSL trend reversal will persist into the future, leading to rising seas along the American west coast in years to come. However, the basic physical processes controlling the recent TPSL trend reversal are unclear, precluding rigorous determination of whether recently observed behavior reflects a shorter period, transient interannual event or whether it is truly representative of a longer period, persistent decadal shift. To shed light on this matter, we diagnose the TPSL budget using a physically consistent, observationally constrained global ocean state estimate over 1992-2015 (ECCOv4). The ECCOv4 state estimate is an excellent fit to the TPSL observations from satellite altimetry. In the state estimate, monthly to decadal changes in TPSL are almost entirely related to heat storage; mass and salt effects are negligible. To further investigate the mechanisms of TPSL change, a conservation equation for thermosteric sea level is diagnosed. Whereas shorter period interannual TPSL changes are mostly due to advection by changes in ocean transports, longer period decadal TPSL changes are mainly owing to forcing by anomalous surface heat fluxes. The net surface heat fluxes are strongly anti-correlated with thermosteric sea level itself, hinting at an important role for sensible surface heat fluxes. Simple models of the TPSL response to surface atmospheric forcing and implications for the predicability and persistence of the ongoing shift in TPSL will be discussed.

Keywords: Tropical Pacific, decadal variability, satellite altimetry, state estimation, budget analysis

Paper ID 255
Poster Board N°7

New Insights from the Sea Level Budget

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Balancing the sea-level budget is critical to understanding recent and future climate change as well as balancing Earth's energy budget and water budget. During the last decade, advancements in the ocean observing system — satellite altimeters, hydrographic profiling floats, and space-based gravity missions — have allowed the global mean sea level budget to be assessed with unprecedented accuracy from direct, rather than inferred, estimates. In particular, several recent studies have used the sea-level budget to bound the rate of deep ocean warming [e.g. Llovel et al. 2014].

On a bi-monthly basis, the sum of the steric component estimated from Argo and the ocean mass (barystatic) component from GRACE agree total sea level from Jason within the estimated uncertainties with the residual difference having an r.m.s. less than 2 mm [Leuliette 2014]. Direct measurements of ocean warming above 2000 m depth during January 2005 and July 2016 explain about one-third of the observed annual rate of global mean sea-level rise.

Extending the understanding of the sea-level budget from global mean sea level to regional patterns of sea level change is crucial for identifying regional differences in recent sea level change. The local sea-level budget can be used to identify any systematic errors in the global ocean observing system. Using the residuals from closing the sea level budget, we demonstrate that systematic regional errors remain, in part due to Argo sampling. We present a new analysis of the steric component of the budget using the recently released Simple Ocean Data Assimilation reanalysis version 3 (SODA 3).

Keywords: sea level budget, steric sea level, ocean mass, altimetry

Paper ID 269
Poster Board N°55

NASA Applied Sciences: Coastal Applications of SWOT Mission Data

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The Surface Water and Ocean Topography (SWOT) mission is an international collaboration of two scientific communities focused on a better understanding of the world's oceans and its terrestrial surface waters. A new measurement technique using radar interferometry to obtain wide swath measurements of water elevations will allow SWOT to produce the first global survey of Earth's surface water.

SWOT data can be complementary to the operational oceanographic altimeters on the Topex/Poseidon and Jason series satellites as well, and can improve the understanding of global and regional sea level change. In the coastal zone SWOT can collect data over the tidally affected portions of rivers, and estuaries and wetlands, to help better understand the dynamics of freshwater/marine interaction dynamics.

Standard SWOT oceanic coverage of about 1 km resolution sea surface height (SSH) will provide valuable information for coastal zone studies and applications. With global sea level trends at 3.4 mm/yr (Nerem et al, 2010), greater understanding of coastal ocean dynamics and compounding conditions (tides, coastal storms), SWOT will resolve small-scale spatial variability in coastal conditions. In regions with operational coastal ocean observing systems, SWOT data may be combined with observations, as well as with dynamical models being developed to provide near real-time information for weather prediction, storm surges, and other impacts resolvable by improved surface current fields. A broad range of applications may inform coastal managers and marine operators of impacts from offshore conditions and currents relevant to their regions.

Research activities using simulated SWOT data sets are underway, which will assess quality and potential value of SWOT measurements for coastal applications. Some of these will be discussed in this presentation.

NASA's Applied Sciences Program (ASP), along with the international SWOT project teams, is supporting a program that promotes applications research and engages a broad community of potential SWOT data users. The applied science community would be a key element in a successful SWOT mission, demonstrating the high value of NASA's missions and the utility of science and data products in addressing societal issues and needs.

Keywords: SWOT, Applications, Coast, Applied Science, NASA

Paper ID 277
Poster Board N°37

Recent Sea Level Rise and Vertical Land Motion in Singapore

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As a small, low-lying, highly urbanized and densely populated island state, Singapore is particularly vulnerable to sea-level rise. In addition to the global phenomena of eustatic sea-level rise and the occurrence of regional phenomena (e.g., El Niño–Southern Oscillation), another potentially important cause of relative sea-level change along the coast of Singapore is vertical land motions (VLM) of both natural and anthropogenic origins. We have observed postseismic subsidence following the 2004 Aceh-Andaman and 2005 Nias earthquakes in the vertical position estimates from a continuous GPS (Global Positioning System) station located at the campus of Nanyang Technological University, amounting to 20 mm over the past 10 years. Additionally, Catalão et al. (2013) detected a localized subsidence rate of up to 7 mm/yr over the period of 1995 - 2000 by InSAR (Interferometric Synthetic Aperture Radar) near the shore on low flat land, associated with reclaimed areas or built areas in the past years. The aim of this work is to provide a first approximation of the combined effects of these two independent phenomena - sea-level change in response to climate change and VLM, and identify the dominant driving mechanisms responsible for regional variability in sea-level along the coasts of Singapore. We first map the spatial variation in vertical land motion by using geodetic data (InSAR and GPS), and then present a comprehensive analysis of sea level changes at seven tide gauges with relatively long-term (~25-50 years) records to investigate the regional variability in sea-level and the influencing factors.

Keywords: Sea level rise, vertical land motion, tide gauge, Singapore

Paper ID 281
Poster Board N°47

Consideration of Temporally-Correlated Noise in Multi-Variate Sea Level Trend Estimates in the Indo-Pacific Region

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Locally and regionally varying sea level trends and in particular the trend uncertainties are investigated in the context of temporally-correlated noise. We focus on the Indo-Pacific region because there has been considerable recent progress on understanding the effect of climatic variability, mass redistribution by surface wind variability and thermosteric effects by thermocline adjustment on regional sea level. Here, a maximum likelihood estimator approach is taken to determine the best fitting trend plus coloured or white noise model on the reference Jason series satellite altimetry along-track data, from 1993 to 2015. Following the approach of Zhang and Church (2012), our regression model includes climate indices and we compare the results against a single-variate model. Consistent with previous studies of tide gauge and global mean sea level data, the majority of the along-track satellite altimetry time series exhibit a coloured noise residual when fitting a linear trend. The east-west see-saw of sea level trend anomalies across the Pacific remains apparent in the 22-year record, and as expected the inclusion of climate indices in a multi-variate regression homogenises the trend across the Pacific. We find that the multi-variate regression also leads to a whitening of residual noise along waveguides but does not significantly affect the type of best fitting noise model, nor the trend error estimates. With a white noise model the largest error estimates occur where there is highest variance in the sea level time series. Here, we find error estimates are high in many other regions, notably in the equatorial Pacific and in the sub-polar gyres of the North and South Pacific, where the uncertainty estimates on the trend given by the best fitting coloured residual noise are more than twice those from an auto-regressive model of order 1 (AR1). Thus, geophysical sources of temporally correlated noise remain even when some of the decadal scale climatic variability has been taken into account. The presence of this temporally correlated noise in the sea level signal makes the emergence of acceleration in the observation record more difficult to detect and complicates efforts to separate anthropogenic and geophysical signals in sea level rise.

Keywords: Regional sea level, Trend, Uncertainty estimate, Temporally-correlated noise

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 283
Poster Board N°19

Increasing Australia's Tide Gauge Records Through Data Digitisation

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Knowledge of how sea level is changing, including regional sea-level rise and variability, is important for building confidence in future projections and informing coastal adaptation. Understanding how extreme sea level events are changing is also of particular interest since during these times coastlines are most impacted by flooding, coastal erosion and salinization. High quality tide gauge records of sufficient duration, temporal resolution and spatial coverage are required to understand the role of interannual variability and extremes at the regional scale. Australia's extensive coastline extends from the tropics to the mid-latitudes and is influenced by various meteorological drivers that cause sea level extremes as well as modes of climate variability that can influence sea levels on interannual time scales (McInnes et al, 2016). However, in Australia, fairly complete digital records of quality-controlled, hourly sea level observations are available at only two locations; the Fremantle record that commenced in the late 19th Century on Australia's west coast in Perth and the Fort Denison record that commenced in the early 20th Century on the east coast in Sydney. All other digital tide gauge records in Australia commenced in the mid-1960's or later. However, tidal records mainly in the form of charts are available at a number of locations along Australia's south coast and tropical east coast and offer the opportunity to increase the number and diversity of coastal locations where long, quality-controlled hourly sea level observations in Australia are available for research of past changes in sea level and extremes (McInnes et al, 2016).

Here we will report on progress towards digitising the first of these records, located at Williamstown in Melbourne on Australia's south coast. At this location paper tide charts are available from 1875 through to 1965 after which the digital record commences. Although a four-year gap exists in these charts from 1946-1949 inclusive, books of manual hourly tide and meteorological observations at Williamstown have been located from mid-1943 to the end of 1948. Preliminary comparisons of these two sources of data over an overlapping year (1944) indicate high consistency between the two data sources and suggest that the manual observations will be useful to infill three of the four missing years in the tide charts. Imaging of the tide records to 1926 and digitising and quality control of the 1950's is now complete. A preliminary analysis of these records and some notable extreme sea level events that have been recorded in these records will be presented and discussed.

McInnes, K.L., White, C.J., Haigh, I.D., Hemer, M.A., Hoeke, R.K., Holbrook, N.J., Kiem, A.S., Oliver, E.C.J., Ranasinghe, R., Walsh, K.J.E., Westra, S. and Cox, R.2016: Natural hazards in Australia: sea level and coastal extremes. Climatic Change. DOI: 10.1007/s10584-016-1647-8

Keywords: Tide Digitisation, Sea-level Extremes, Williamstown, Australia

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 301
Poster Board N°35

Towards Seamless Sea Level Trends from a Combination of Coastal Altimetry and TG

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Sea Level has been traditionally monitored by means of tide gauge (TG) stations installed along the coastlines and islands. The density and distribution of these TGs in addition to the vertical land movements at their locations have limited their ability for retrieval of a robust absolute global sea level change. On the other hand, satellite altimetry has been providing global maps of absolute sea surface within the last three decades with unprecedented accuracy on a frequency of 10 days or longer. However, in coastal zones around 10-50 km away from the shoreline, measurements are flagged as bad in the satellite altimetry data files which limited the recovery of useful sea signals in these strategic areas.

In recent years, there have been significant developments of specialised radar echo fitting ('retracking') algorithms in addition to the noticeable improvement of several geophysical corrections that must be applied to altimetry. These have enabled retrieval of more data closer to the shoreline and minimised the gap of the flagged-out zones between the tide gauges and the altimetric useable measurements.

One example of the aforementioned improvements is NOC's retracking algorithm, the Adaptive Leading Edge Sub-waveform (ALES). ALES is applicable to pulse-limited altimetric measurements over coastal zones and open oceans and aims at recovering coastal data better than the standard processing, maintaining the same accuracy in both open ocean and coastal areas.

In this work, we estimate global and regional sea-level trends by integrating tide gauge records with satellite altimetry data reprocessed with ALES and combined with the adoption of improved geophysical corrections for the coastal zones.

We aim to look at the evolution of sea level change from the coastal zone to open ocean in different parts of the world. The work also has the potential to assess the vertical land movements at the tide gauge locations by comparing the absolute trend from altimetry in the vicinity of the TG stations with the relative trend from the TG records. The estimated vertical movements can be then compared against the vertical velocity vectors inferred from continuous GPS time series at some TG locations.

Keywords: Radar Altimetry, Coastal Altimetry, Tide Gauge, Sea Level

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 312
Poster Board N°65

Reducing Relative RSLR Confidence Intervals Along the Texas Coast

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We present a technique to reduce the confidence intervals associated with relative sea level rise (RSLR) estimates from a high spatial density of 15 tide gauges along the Texas coast for the period from 1993-2015. Seasonally detrended monthly mean water levels between stations are highly correlated allowing to compute and remove the common steric component from the respective time series. The resulting RSLR confidence intervals are reduced from over 2.0 mm/yr to less than 1.0 mm/yr, on average 0.7 mm/yr. The resulting RSLR rates range from 0.5-6.9 mm/yr with no clear spatial correlation along the coast. The range is wider than the long-term rates of 5.3, 3.8 and 1.9 mm/yr as measured from North to South by the three National Water Level Observation Network stations covering the study area. The RSLR trends are compared with sea level rise estimates based on satellite altimetry for the overall Gulf of Mexico and for a more narrowly focused area of the Gulf of Mexico closest to the coastal stations to estimate vertical land motion. The temporal variability of the local steric component is compared to climate indexes and other potential forcings. It is hypothesized that the high RSLR spatial variability is in part the result of both the presence of growth faults and fluid extraction activities that vary in magnitude along the coast. The local significance of the RSLR differences is discussed in terms of the differences in progression of inundation frequency for nuisance flooding including comparing the time span to reach a probability of at least one nuisance flood event per year.

Keywords: relative sea level rise, vertical land motion, tide gauges, steric contribution, Gulf of Mexico

Paper ID 329
Poster Board N°1

How Well Will the Surface Water and Ocean Topography Mission (SWOT) Measure Storm Surges in Coastal Zones?

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Accurate measurements of the sea level variability and extreme events are crucial to prevent coastal zones from flooding risks and marine submersion. The global spatial coverage of these measurements is provided by satellite altimetry whose applications are less exploited for coastal areas from several problems of resolution and the sensitivity of physical processes to land contamination.The future mission of surface water and ocean topography (SWOT), a joint mission of US NASA and French CNES with contributions from Canada and UK, will be launched in 2021 over a period of 3–5 years. The satellite will be designated to address the issue of small-scale energetic processes aiming to present new perspectives of applications for coastal areas. The remaining time during the mission will be undertaken with an orbit that meets the nominal science requirement to obtain a global coverage of the earth and that has a 20.86460-day repeat. SWOT will provide high-resolution sea level measurements thanks to the pair interferometry radars with a swath of 120 km and a nadir gap of 20 km. SWOT data present a high resolution of 10-70m and a precision of 5 cm at 500 m2 pixel which increases to 2.5 cm at 1 km2 pixel.

Here, the relation between temporal and spatial distributions of SWOT coverage is investigated in order to understand its potential use for capturing the storm surges in French coast (NE Atlantic Sea and NW English Channel). First, different sceneries of cyclones have been simulated from deep water to the coast using the numerical hydrodynamic model DELFT3D with high spatial resolutions in order to calculate the multi-dimensional non-steady flow resulting from tidal and meteorological forcing. Then, the spatial changes of storm surges, calculated at many coastal positions with different topographic slopes and wave gradients, have been used to sample SWOT measurements considering the number of overpasses per repeat orbit and the instrumental errors. As preliminary results, the comparison of SSH spectra between modelled and simulated samples suggests that SWOT can reproduce surges with an average variance between 60% and 70%. In frequency domain, the potential use of SWOT for estimating the temporal variations of storm surges was investigated using a multi-resolution wavelet approach with the aim to identify the SSH frequencies responsible for the aliasing problems extracted from SWOT measurements. The variability of storm surges has been mapped for different combined energy and topography conditions in order to characterize the complex interaction between the extreme physical processes in coastal zones.

Keywords: storm surges, Satellite Altimeter SWOT, coastal zones

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 330
Poster Board N°59

A Global Vertical Land Movement Data Set from a Combination of Global Navigation Satellite System Solutions

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Coastal sea-level measurements by tide gauges provide the longest instrumental records of sea-levels with some stretching from the 19th century to present. The derived mean sea-level (MSL) records provide sea-level relative to a nearby tide gauge benchmark (TGBM), which allows for the continuation of this record in time after, for example, equipment modifications. Any changes in the benchmark levels, induced by vertical land movements (VLM), affect the MSL records and hence the computed sea-levels. In the past MSL records affected by VLM were often excluded from further analyses or the VLM were modelled using numerical models of the glacial isostatic adjustment process. Over the last two decades Global Positioning System (GPS) measurements at or close to tide gauges and the development of the associated analysis strategies have made it possible to obtain estimates of VLM in a geocentric reference system such as the International Terrestrial Reference Frame release 2008 (ITRF2008) that approach the required accuracy for sea-level studies. Furthermore, the GPS-derived VLM estimates have been shown to improve estimates of sea-level change compared to those using the aforementioned models as these models cannot predict local subsidence or uplift.

The International GNSS Service (IGS) Tide Gauge Benchmark Monitoring (TIGA) Working Group (WG) has recently reprocessed the global GNSS data set from its archive (700+ stations for 1995-2014) to provide VLM estimates tuned for the sea-level community. To achieve this, five TIGA Analysis Centers (TACs) contributed their re-processed global GPS network solutions to the WG, all employing the latest bias models and processing strategies in accordance with the second re-processing campaign (repro2) of the IGS. These individual solutions were then combined by the TIGA Combination Centre (TCC) to produce, for the first time, a TIGA combined solution (Release 1.0). This combined solution allows an evaluation of each individual TAC solution while also providing a means to gauge the quality and reliability of the combined solution, which is generally regarded as superior to the TAC solutions. Using time series analysis methods estimates of VLM can then be derived from the daily position estimates, which are sub-sequentially employed to investigate coastal sea-levels.

In this study, we show results from the evaluation of the relevant solutions, provide an evaluation of the TIGA VLM estimates and give examples of their impact on the sea-level estimates for selected tide gauges from around the world. The TAC and TIGA combined solutions, as well as the derived VLM data set are available from the IGS TIGA WG.

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Keywords: Global Navigation Satellite System, Tide Gauges, Vertical Land Movements, Solution Combination

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 331
Poster Board N°57

Uncertainty Estimates of Altimetric Global Mean Sea Level Time Series

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An analysis is being presented concerned with providing uncertainty measures for GMSL time series. For this purpose sea surface height (SSH) fields, simulated by the high resolution STORM/NCEP model for the period 1993 - 2010, were subsampled along altimeter tracks and processed similar to techniques used by five working groups to estimate GMSL. Results suggest that the spatial and temporal resolution have a substantial impact on GMSL estimates. Major impacts can especially result from the interpolation technique or the number of missing/flagged data and easily lead to artificial temporal variability in the resulting time series.

Keywords: Global Mean Sea Level, Uncertainty, Altimetry

Paper ID 351
Poster Board N°25

Understanding the Acceleration of Sea Level Rise During the Altimeter Era

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Over the last 25 years, data from TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 have been used to observe changes in global mean sea level. A rate of rise of 3.4 ± 0.4 mm/year has been observed. However, observing a possible acceleration in the rate of sea level rise is more challenging and pushes the limits of the observing system accuracy. This presentation will examine the feasibility of detecting an acceleration in the altimeter sea level record. First, the available evidence for estimating how big of an acceleration might be expected in the altimeter record will be reviewed. Next, the errors in the altimetry will be discussed in the context of tide gauge validation of the altimeter record. The role of interannual variability in GMSL in measuring the acceleration will be addressed. We will also discuss the role of decadal variability and how it might influence the determination of acceleration, including the role that the 1991 eruption of Mount Pinatubo might have had on the altimeter sea level record. Finally, we will discuss progress towards understanding the acceleration of GMSL over the 25-year record, based on consideration of all of these issues, including the importance of using the tide gauge validation to understand the errors in the acceleration estimate.

Keywords: sea level, acceleration, altimetry

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 353
Poster Board N°11

Distinguishing the Quasi-decadal and Multi-decadal Sea Level and Climate Variations in the Pacific: Implications for the ENSO-like Low-frequency Variability

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Low-frequency sea level variations with periods longer than the inter-annual timescale have been receiving much attention recently, with the aim of distinguishing the anthropogenic regional sea level change signal from the natural fluctuations. Based on the available sea level products including satellite altimeter observations, ocean model hindcast simulations, ocean reanalysis and steric sea level calculated from ocean temperature and salinity data, this study suggests that the dominant low-frequency (>7 years) sea level mode in the Pacific basin shows both quasi-decadal variations and a multi-decadal trend reversal in the early 1990s. The dominant sea level modes on these two timescales have different tropical structures: a west-east seesaw in the tropical Pacific on the multi-decadal timescale and a dipole between the western and central tropical Pacific on the quasi-decadal timescale. We found that while the sea level data over the altimeter period after 1993 sample around two quasi-decadal cycles and roughly allow a clear identification of the quasi-decadal sea level variability patterns, the other relatively longer (~60 years) sea level datasets resolve both quasi-decadal and multi-decadal sea level variations with the latter appearing as a trend in the altimeter record.

Both the quasi-decadal and multi-decadal sea level modes in the Pacific basin are closely related to the ENSO-like low-frequency climate variability on respective timescales but feature distinct surface wind forcing patterns and sub-basin climate processes. The multi-decadal sea level mode is associated with the Pacific Decadal Oscillation (PDO) and Aleutian low variations in the North Pacific and tropical Pacific sea surface temperature anomalies towards the eastern basin, while the quasi-decadal sea level mode is accompanied by tropical Pacific sea surface temperature anomalies centered in the central basin along with the North Pacific part which resembles the North Pacific Oscillation (NPO) and its oceanic expressions, i.e., the North Pacific Gyre Oscillation (NPGO) and the Victoria mode. We further conclude that the ENSO-like low-frequency variability, which has dominant influences on the Pacific sea level and climate, is comprised of at least two distinct modes on quasi-decadal and multi-decadal timescales, respectively.

Keywords: Pacific, sea level, ENSO, quasi-decadal, multi-decadal

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 361
Poster Board N°17

Sea Level Change in the 6th IPCC Assessment: A WGI Perspective

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Sea level change (SLC) has been a core topic of the Intergovernmental Panel on Climate Change (IPCC) assessments from their outset and is a key cross-cutting issue between IPCC Working Groups. Physical science aspects of SLC, including observed and projected changes, fall under the remit of Working Group I (WGI, 'The Physical Science Basis'). Risks and vulnerabilities from SLC to human and natural systems, and corresponding adaptation options, are the domain of Working Group II ('Impacts, Adaptation and Vulnerability').

Here we review, from a WGI perspective, recent developments in the preparation of the IPCC 6th Assessment pertaining to SLC. A novel challenge in this assessment cycle is how to maximize the opportunity presented by there being three Special Reports (SRs) accompanying the main Assessment Report (AR6). Further, each SR is intended to be integrative across IPCC Working Groups and released ahead of AR6. Sea level change is particularly relevant to two of these special reports, namely the SR on global warming of 1.5°C (SR1.5) and the SR on the ocean and cryosphere in a changing climate (SROCC).

Drawing upon their approved outlines, here we discuss plans for how WGI-aspects of sea level change will be assessed across these SRs, including synergies and contrasts. We also review the proposals emerging from the AR6 Scoping Meeting for the handling of SLC in the WGI contribution to the 6th Assessment Report, considering the scope of the SRs and ongoing/planned scientific research. Finally, we discuss proposed and approved approaches to the incorporation of WGI-aspects of regional SLC across these consecutive reports, together with the corresponding rationale.

Keywords: IPCC, AR6, Assessment Report, Climate change, Global warming

Paper ID 370
Poster Board N°67

The Relationship between Seasonal Average Daily Tidal Shape and its Local Winds Regime: Summer as a Case Study

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Averaging sea level on a five minute basis for every season yielded a daily average tide shape for each season in the port of Yafo in Israel. However, every season in the East Mediterranean region has a prominent synoptic season. This study tries to find whether the seasonal average daily tidal shape and the seasonal prominent synoptic system are related.

This study focuses on wind direction, which is one of the elements in the synoptic system. Frequency of the wind direction at the four tidal peaks in a seasonal average daily tidal shape might indicate a reciprocal influence of one on the other.

The case study displayed below, is of the summer. The prominent synoptic system in July and August in Israel is a Persian Trough, appearing in 87% of the days in those months in the last 19 years. This synoptic system is characterized with a diurnal wind regime. The average daily SL pattern of the summer was found to be a decreased sinus. Matching between the frequency of the wind directions in the high/low tide in the morning and in the evening of the average daily tidal shape, reveals that in the morning, when the average daily tidal shape is high, the winds have a prominent southerly component, and in the evening, when the average daily tidal shape is relatively low, the winds have a northerly component in common.

The diurnal variability of sea level and winds might be explained by a light Ekman Transport as a causal mechanism of regional sea-level variability. This process recurs twice a day in negative directions during the summer days along the Israeli coastline.

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Keywords: Sea Level, Synoptic System, Season, Summer

Paper ID 372
Poster Board N°41

A Gravitational and Loading Signal in Absolute Sea Level Near Greenland Associated with Ice Melting

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Gravitational and loading signals in absolute sea level (ASL), as measured by satellite altimeters, are expected from ongoing long term changes in land ice, but their detection has been hampered by the presence of other variability in the altimeter records. One of the largest (negative) ASL trends predicted from solving the Sea Level Equation using GRACE retrievals of mass distribution over land for the period 2005-2015 occurs near Greenland, consistent with a strong local ice melting. Using altimeter sea level and hydrography (Argo) data reveals the presence of residual ASL trends south of Greenland consistent with the gravitationally based predictions. Estimates of the circulation in the region point to relatively weak trends in (dynamic) bottom pressure as well as in deep steric height, for the period of study. We conclude that the residual ASL trends are partly related to the static equilibrium ocean response to the gravitational forcing from land ice, and that accounting for the gravitational effects, commonly neglected in oceanographic studies, is needed for detailed interpretation of the oceanic measurements.

Keywords: self-attraction and loading, land ice, altimetry, GRACE, Argo

Paper ID 377
Poster Board N°21

Diagnosis of Large-scale, Low-frequency Sea Level Variability in the NE Pacific Ocean

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Our work is aimed at understanding sea surface height variability in northeastern Pacific Ocean, which we define as east of 160E and north of 25N. Early work along these lines focused on the relative importance of propagation versus local damping of large-scale, low-frequency variations forced by Ekman pumping. Conflicting results were found even though both studies used the linearized potential vorticity equation appropriate for a 1.5 layer fluid or a first baroclinic mode. Subsequent studies pointed out the possible importance of forcing by eddies via Reynolds stresses, buoyancy forcing, and the forcing of second vertical mode variations. One thing that concerned us is that none of these models accounted for a large fraction of the height variance over the entire study area and we are therefore not comfortable with making conclusions about the relative importance of any of these effects. We have constructed a simple vertical normal model that includes linear damping, wind stress, eddy and buoyancy forcing and are carrying a series of experiments to address this question. In our model the forcing and damping terms have variable amplitudes that are fit to the observed sea surface height field from altimetry. The fitted amplitudes will be used to assess the relative importance of the different forcing terms for first and second mode variations in different parts of the study area. The model runs are in progress and results will be presented at the meeting.

Keywords: NE Pacific Ocean, Forced sea level varaibility

Paper ID 381
Poster Board N°61

Forcing of Recent Decadal Variability in the Equatorial and North Indian Ocean

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Recent decadal sea surface height (SSH) variability across the Equatorial and North Indian Ocean (ENIO, north of 5°S) is spatially coherent and related to a reversal in basin-scale, upper-ocean-temperature trends. Analysis of ocean and forcing fields from a data-assimilating ocean synthesis (ECCOv4) suggests that two equally important mechanisms of wind-driven heat redistribution within the Indian Ocean account for a majority of the decadal variability. The first is the Cross-Equatorial Cell (CEC) forced by zonal wind stress curl at the equator. The wind stress curl variability relates to the strength and position of the Mascarene High, which is influenced by the phase of the Indian Ocean Subtropical Dipole. The second mechanism is deep (700 m) upwelling related to zonal wind stress at the equator that causes deep, cross-equatorial overturning due to the unique geometry of the basin. The CEC acts to cool the upper ocean throughout most of the first decade of satellite altimetry, while the deep upwelling delays and then amplifies the effect of the CEC on SSH. During the subsequent decade, reversals in the forcing anomalies drive warming of the upper ocean and increasing SSH, with the effect of the deep upwelling leading the CEC.

Keywords: Indian Ocean, Decadal Variability, Regional Sea Level Change

Paper ID 384
Poster Board N°63

Are Long Tide Gauge Records in the Wrong Place to Measure Global Mean Sea Level Rise?

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Ocean dynamics, land motion, and changes in Earth's gravitational and rotational fields cause local sea level change to deviate from the rate of global mean sea level rise. Here we use observations and simulations of spatial structure in sea level change to estimate the likelihood that these processes cause sea level trends in the longest and highest-quality tide gauge records to be systematically biased relative to the true global mean rate. The analyzed records have an average twentieth century rate of approximately 1.6 mm/yr, but based on the locations of these gauges, we show that the simple average underestimates the twentieth century global mean rate by 0.1 ± 0.2 mm/yr. Given the distribution of potential sampling biases, we find that <1% probability that observed trends from the longest and highest-quality tide gauge records are consistent with global mean rates less than 1.4 mm/yr.

Keywords: Global sea level rise, tide gauges

POSTER SESSION
Session 4b: Contemporary Sea Level Change

Paper ID 416
Poster Board N°43

Assessment of Revised TOPEX/Jason Global and Regional Mean Sea Level Estimates Referenced to ITRF2014

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The terrestrial reference frame is the foundation for analysis and interpretation of Earth science observations, especially for data from ocean radar altimeter satellites. The accuracy of the coordinates as well as the consistency of the technique solutions within an ITRF affect the accuracy with which orbits are computed, and map into the accuracy of the estimates for global mean sea level (GMSL). The recent launch of Jason-3 offers the possibility of continuing GMSL monitoring well into the next decade. In an effort to provide a consistent TOPEX/Jason altimeter sea surface height (SSH) time series and seamless transition to Jason-3, we have generated orbits for the entire time span based on the revised ITRF2014 terrestrial reference frame. We report the efficacy of the revised terrestrial reference frame towards improving precise orbit determinations leading to the development of the NASA MEaSURE's V4.0 revised sea surface height Climate Data Record

(http://podaac.jpl.nasa.gov/dataset/MERGED_TP_J1_OSTM_OST_ALL).

We provide an assessment of recent improvements to the accuracy of the 24-year SSH time series, describe continuing calibration/validation activities, and evaluate the subsequent impact on current global and regional mean sea level estimates.

Keywords: sea level, radar altimetry, reference frame

Paper ID 444
Poster Board N°15

Effect of a Depth Dependent Gent-McWilliams Mesoscale Eddy Diffusivity on Southern Ocean Heat Uptake in a Global Ocean Sea-ice Model

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To date the Australian Community Climate and Earth System Simulator Ocean Model (ACCESS-OM; Bi et al., 2013) has employed a vertically homogeneous parameterisation of the Gent-McWilliams mesoscale eddy diffusivity parameter (kappa). A model intercomparison under the framework of the CLIVAR Ocean Model Development Panel Coordinated Ocean-ice Reference Experiments (CORE-II) showed that models utilising a depth dependent kappa display weaker changes of isopycnal slopes and associated ACC trends (i.e. a stronger eddy saturation) in response to Southern Ocean wind changes (poleward migration of the Southern Annular Mode), along with a stronger eddy compensation, with considerable decadal trends of 30–50% increase in Southern Ocean Meridional Overturning Circulation for the period 1958–2007 (Farneti et al., 2015). In this study we examine the impact of choice in mesoscale eddy diffusivity (vertically homogenous versus depth dependent) on ocean heat uptake in the Southern Ocean. Further, we apply a detailed process-based heat budget to understand the response of other processes (advection, diffusion, vertical mixing, air-sea exchanges) to the choice of kappa parameterisation.

References:

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Farneti et al., 2015: An assessment of Antarctic Circumpolar Current and Southern Ocean Meridional Overturning Circulation during 1958–2007 in a suite of interannual CORE-II simulations, Ocean Modelling, 93, 84-120, doi:10.1016/j.ocemod.2015.07.009.

Keywords: Ocean Heat Uptake, Southern Ocean, ocean heat budget, CORE, ACCESS

POSTER SESSION
Session 5: Coastal zone

Paper ID 111
Poster Board N°11

Evaluation of Coherent Sea Level Variability and Non-Linear Vertical Land Motion along the Gulf of Mexico Coastline

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We will examine the coherent part of interannual to decadal-scale sea level variability along the northern and eastern Gulf of Mexico coastline utilizing long tide gauge records extending back to 1947. The derived coherent interannual signal explains anywhere from 60% to 90% of the total interannual variability at the 7 tide gauges examined, with the lowest percentage explained occurring in the two most southeastern gauges (St. Petersburg, FL and Key West, FL.

The low-pass filtered relative sea level at the tide gauges is also examined. Relative sea level at four of the gauges is consistent with estimates of global mean sea level (GMSL), indicating little vertical land motion. At three of the gauges (Port Isabel and Galveston in Texas, and Grand Isle in Louisiana), the long-term seal level change is substantially different from both the GMSL reconstruction and long-term sea level in other parts of the Gulf of Mexico, indicating significant VLM.

The inferred VLM at these slights is clearly non-linear, and VLM rates in the past (from approximately 1960-1990) were significantly higher than present day rates, when we have GPS measurements available. This has important implications for extrapolating a decade of linear VLM measured by GPS receivers into the past and future for studies of climate induced changes in sea level.

Keywords: Costal sea level variability, vertical land motion, Gulf of Mexico, decadal variability

POSTER SESSION
Session 5: Coastal zone

Paper ID 120
Poster Board N°50

Sea Level Variability at the Coast from Extreme Events to Interdecadal Timescales: An Underestimated Contribution from Waves?

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Tide gauge records and satellite altimetry indicate that global mean sea level has risen by 16±3 cm during the 20th century. This rise is essentially due to thermal expansion of the ocean and land ice loss from glaciers and ice sheets in response to anthropogenic emissions of greenhouse gases. It is projected to continue over the 21st century and raise concerns for coastal regions. But coastal sea level variations are influenced by other processes such as tides, atmospheric surges and wave induced run-up and set-up. Here we examine the relative importance of the processes causing sea level variations at the coast over the last 23 years from observational datasets and model reanalyses focusing on coastal sites distributed along the world's coastlines for which tide gauges records are available. We show that the long term wave signal can dampen or enhance the effect of the ocean thermal expansion and land ice loss at the coast, over all time scales from subannnual to multidecadal. We estimate that the effect of waves generally explains 60%±20% of the coastal sea level variations at interannual to multidecadal time scales. In the Eastern Pacific, the wave effect dominates the total budget and counterbalances the thermal expansion of the ocean and land ice loss signals. These results highlight that the wave effect has to be taken into account in sea level predictions and projections.

Keywords: coastal sea level, interdecadal time scales, extreme events, waves, global scale

POSTER SESSION
Session 5: Coastal zone

Paper ID 130
Poster Board N°39

Monitoring the Evolution of Coastal Zones under Various Forcing Factors using Space-based Observing Systems

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About 10% of the global population is currently living along the coasts. In many regions, populations are exposed to a variety of natural hazards (e.g., extreme weather such as damaging cyclones and their associated storm surges), as well as to the effects of global climate change (e.g., sea level rise), and to the impacts of human activities (e.g., urbanization). Today, our knowledge regarding these processes still remains limited by the lack of observations. For example, the proportion of the world's shorelines currently affected by erosion still remains uncertain. This lack of information not only prevents us from addressing important scientific questions, but it has also practical implications for coastal managers in charge of managing coastal risks and adapting to climate change.

In this poster, we present the outcome of the International Space Science Institute (ISSI) Forum on "Monitoring the evolution of coastal zones under various forcing factors using space-based observing systems" (http://www.issibern.ch/forum/costzoneevo/) held at ISSI, Bern, Switzerland on 11-12 October 2016.

This poster first reviews the scientific questions with high societal significance, where improved remote sensing observations are needed: this includes (1) separating the contributions of climate-induced sea-level changes and vertical ground motions (uplift and subsidence) in relative (coastal) sea-level changes; (2) understanding the roles, for each different coastal geomorphological setting, of human interventions, extreme events, seasonal interannual and multidecadal variability and trends in driving coastal evolution. In a second step, we review the observations currently available or needed to address these questions. Overall, we show that since the publication of the latest IGOS report on coastal zone observational requirements (2006), the availability of high resolution topographic data, hydrometeorological reanalysis (e.g., wind, waves, pressures) and historical surge databases have greatly improved the ability to understand and model coastal flooding. In addition, there is a continued need for tide gauges collocated with GNSS and other geodetic data. However, research is needed in many other topics such as the retrieval of changing topographic and bathymetric features at the required accuracy and frequency, and in processing radar altimetry measurements in the coastal ocean.

Concerning ocean color, global analyses are expected to provide useful information (e.g. on suspended materials).

Besides the improvements of the current observing infrastructure, there is a need of strengthening the exchanges between different scientists and stakeholders concerned with coastal risks and climate change. Today, information on the evolution of coastal zones is managed at local to regional scales by coastal observatories. These entities link science information to operational observations (including space-based) and coastal stakeholders. We argue that establishing links between global providers of Earth Observation data (such as space agencies), and the emerging networks of coastal observatories, can be beneficial to both coastal science and the management of coastal risks.

Keywords: coastal zones, monitoring, remote sensing, satellites

Paper ID 132
Poster Board N°38

Uncertainties of Shoreline Change Projections Along the Sandy Coasts of Aquitaine (South Western France)

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Far from being stable, sandy shorelines are constantly evolving, threatening occasionally human assets such as buildings or transport infrastructures. In these environments, sea-level rise will exacerbate coastal erosion to an amount which remains poorly understood. To investigate this issue, we apply two suites of coastal evolution models applicable at decadal to centennial timescales on the dune-beach systems of the Aquitaine coast (SW France): one based on the Bruun rule, and the other based on a simplified version of a dune toe evolution model (Larson et al. 2004; Ranasinghe et al., 2011). Both modelling approaches are incorporate the natural variability of shoreline change at seasonal, interannual and multidecadal time scales. They are fed with probabilistic sea-level projections provided by Kopp et al. (2014) and complementary information on coastal subsidence, in order to design locally applicable sea-level rise projections.

The results show that even wide dune field have the potential to vanish completely after 150 to 200 years. However, the models predict important shifts toward erosion not earlier than the mid-21st century, suggesting that there remains several decades before current risk management practices become obsolete. Moreover, the results illustrate that mitigation of climate change has large benefits for these coastal systems, as it limits the risks of large sandy shoreline retreats according to the models outcome. As a limitation, probabilistic frameworks ignore the epistemic uncertainties affecting both sea-level projections and shoreline changes models. Here, extra-probabilistic uncertainties theories provide useful complementary information by exploring the fuzzy boundary between possible and impossible future shoreline changes.

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Ranasinghe, R., Callaghan, D., & Stive, M. J. (2012). Estimating coastal recession due to sea level rise: beyond the Bruun rule. Climatic Change, 110(3-4), 561-574.

Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., ... & Tebaldi, C. (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2(8), 383-406.

Keywords: Shoreline changes, sea-level rise

Paper ID 133
Poster Board N°40

Sea-Level Projections and Coastal Climate Services

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For many climate change impacts such as drought and heat waves, the global and national frameworks for climate services are increasingly structuring adaptation activities. Coastal zones are especially in need of climate services for adaptation, being threatened by future mean and extreme sea-level rise and its impacts, such as submergence, flooding, shoreline erosion, salinization and wetland change. In this poster, we examine how globally available sea-level projections can be integrated within coastal climate services for adaptation. We show that coastal climate services are emerging in a scattered way, depending on the regional context and the priorities of users. We identify some best practices in current coastal climate services development in a representative set of countries, review current barriers in their development, and finally examine which research is needed to support the development of coastal climate services. We suggest that a standard is needed to translate existing sea-level projections with their uncertainties across all disciplines relevant to coastal adaptation.

Keywords: coastal climate services, sea level

Paper ID 134
Poster Board N°78

Understanding Extreme Sea Levels for Broad-scale Coastal Impact and Adaptation Analysis

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Coastal impact and adaptation assessments require detailed knowledge on extreme sea levels (ESL), because increasing damage due to extreme events, such as storm surges caused by extra-tropical or tropical storms, is one of the major consequences of mean sea-level rise (MSLR) and climate change. In fact, the Intergovernmental Panel on Climate Change (IPCC) has highlighted in its 4th Assessment Report that "societal impacts of sea level change primarily occur via the extreme levels rather than as a direct consequence of mean sea level changes". Over the last few decades, substantial research efforts have been directed towards improved understanding of past and future MSLR; different scenarios were developed with process-based or semi-empirical models and used for coastal impact studies at various temporal and spatial scales to guide coastal management and adaptation efforts. The uncertainties in future sea-level rise are typically accounted for by analyzing the impacts associated with a range of scenarios leading to a vertical displacement of the distribution of ESL. And indeed most regional and global studies find little or no evidence for changes in storminess with climate change, although there is still low confidence in the results according the IPPC's most recent assessment report.

However, and much more importantly, there is still a limited understanding of present-day ESL which is largely ignored in most impact and adaptation analyses. The two key uncertainties stem from: (1) numerical models that are used to generate long time series of storm surge water levels. The bias of these models varies spatially and can reach values much larger than the expected MSLR; but it can be accounted for in most regions making use of in-situ measurements. (2) Statistical models used for determining present-day ESL exceedance probabilities. There is no universally accepted approach to obtain such values for flood risk assessments and while substantial research has explored inter-model uncertainties for mean sea level, we explore here, for the first time, inter-model uncertainties for ESL estimates at large spatial scales and compare them to the uncertainties in MSLR projections.

We find that ESL uncertainties exceed those from global MSLR projections and, assuming that we meet the Paris agreement, the projected MSLR itself by the end of the century. For Europe, as an example, they are also an order of magnitude larger than projected changes in the future storm surge climate. Our results highlight the necessity to further improve our understanding of uncertainties in ESL estimates through (1) continued improvement of numerical and statistical models to simulate and analyze coastal water levels and (2) exploit the rich observational database and continue data archeology to obtain longer time series and remove model bias. Finally, ESL uncertainties need to be integrated with uncertain MSLR projections. Otherwise, the important recent and ongoing improvements in providing more robust future MSLR projections for the end of this century (and beyond) are in danger of being of no benefit for broad-scale

impact and adaptation studies and for the resulting decision process due to unaccounted uncertainties in ESL estimates.

Keywords: storm surges, mean sea level, extreme value analysis, coastal impact analysis, adaptation

Paper ID 136
Poster Board N°2

Vanishing Islands and Community Relocations from a Sea-level Rise Hotspot in Solomon Islands

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Low-lying reef islands in Solomon Islands provide a window into the future impacts of global sea-level rise. Sea-level rise has been predicted to cause widespread erosion and inundation of low-lying atolls in the central Pacific. The limited research on reef islands in the western Pacific indicates the majority of shoreline changes and inundation to date result from extreme events, seawalls and inappropriate development rather than sea-level rise alone. In addition, studies examining coastal inundation risk in the Pacific region found islands can actually keep pace with sea-level rise and in some cases expand. However, these studies have been conducted in areas of the Pacific with current rates of sea level rise of 3-5 mm per year – broadly in line with the global average of 3 mm per year. Here, we present the first analysis of coastal dynamics from a sea-level rise hotspot in Solomon Islands where sea-level rise rates over the past 25 years are 7-10 mm per year. We analysed coastline dynamics of 33 islands using a multi-disciplinary approach including: Time series aerial and satellite imagery over a 65 year timeframe, from 1947 to 2014; historical insight from local knowledge; community social surveys; modelled wave analysis; and radiocarbon dating of coastal vegetation. From this we identified five vegetated reef islands that completely vanished over this time period and a further six islands experiencing severe shoreline recession. Rates of shoreline recession are substantially higher in areas exposed to high wave energy, demonstrating a synergistic interaction between sea-level rise and waves. Shoreline recession at two sites has destroyed villages that have existed since at least 1935, forcing community relocations. These communities were able to draw on customary land tenure regimes to adapt to higher sea levels through relocations, however, these varied from collective translocations of entire communities to ad-hoc fragmentation into smaller hamlets. In Nuatambu village over 75% of the community has relocated to higher ground utilising their own limited resources. In many cases, families made pro-active, well-planned relocations by planting food gardens at new village sites up to 12 months ahead of relocating to maintain their food security. Government-led relocation initiatives have been less successful due to limitations of state-based land tenure and reliance on external funding. These experiences from Solomon Islands can provide valuable lessons to guide adaptation responses in other small island developing states facing change in both land tenure regimes and sea levels.

Keywords: Pacific, reef islands, coastal erosion, relocations, waves

POSTER SESSION
Session 5: Coastal zone

Paper ID 137
Poster Board N°28

Long-Term Coastal Response to Sea-Level Change, Sediment Budgets and Human Interference

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The way in which a coastal zone responds to a change in sea level depends on more than just the change itself and the resulting change in accommodation space. Another important aspect, that is frequently overlooked, is the amount of sediment that is available for transport and sedimentation within the coastal zone. Long-term evolution of the coastal zone depends on the balance between accommodation–space creation and sediment supply that can come from different sources and through different transport paths. In addition, the increasingly large impact of human activities on coastal-zone evolution has to be taken into account when trying to predict future coastal response to sea-level change. In this presentation, three periods of coastal evolution in The Netherlands are highlighted that are illustrative of the variable influence of changes in sea level, sediment availability and human impact on coastal evolution.

The first case covers the period 9000-7000 calendar years Before Present (yr BP) when relative sea level (RSL) rose from -24 to -8 m MSL. This period is marked by a sea-level jump between 8450-8250 yr BP, resulting in very high rates, 2 m/century, of RSL-rise. The transgression of the shallow North Sea area resulted in an abundant availability of sediment, but due to the high rates of RSL-rise the coastal zone showed overall retrogradation. Sediment-budgeting studies show that the rate of retrogradation was spatially variable due to regional differences in erodibility, sediment distribution and paleo-topography.

The second case falls in the period of 6000-2000 yr BP. Despite a RSL-rise of 4 m during this period, large parts of The Netherlands showed stabilization of the shoreline that was followed by more than 5 km of progradation. This can be explained by a changing balance in favour of sediment supply over the creation of accommodation space by RSL-rise due to decelerating rates of RSL-rise. The rate of sediment supply did not increase.

The third and final case covers the last 75 years. In the first part of this period, the Dutch shoreline was eroding due to RSL-rise and sediment deficits. In 1990, it was decided to counteract the erosion by starting a nourishment programme that it is still active today. More than 10 million m3 of sand is nourished each year in several different ways: e.g. on the beach, on the shoreface or using ‘sand motors’. This latter approach makes use of longshore currents to distribute nourished sediment along the coast. The nourishment programme has been very successful in stopping overall erosion of the shoreline.

The final part of the presentation synthesizes what we can learn from these cases, not only for predicting future coastal response, but also for taking effective, sediment-based measures to counteract coastal erosion due to RSL-rise.

Keywords: sediment supply, accommodation space, human impact, coastal zone, long-term evolution

Paper ID 139
Poster Board N°16

Marine Flood Hazard and Crisis Management, New Questions Raised by Mean Sea Level Rise

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In the context of global change, the issue of increasing coastal flood risk related to predictable sea level rise becomes essential. Most of scientific studies conducted on that research topic in recent years shows a notable increase in the frequency and magnitude of submersion episodes, even for relatively low sea-level rise values and currently low-exposed areas (Hunter, 2012 ; Tebaldi et al., 2012). The value of the 'tipping point' is around a mean sea level rise of around 0.5 m on many low coasts (Sweet and Park, 2014).

As part of the CRISSIS research program (http://crissis2015.free.fr), the consequences of sea-level rise on coastal flood risk were assessed to the seaside resort of Leucate, a municipality on the French Mediterranean coast. Several scenarios of marine flooding have been simulated based on nested numerical modelling (coupling of the SWAN wave propagation model - Booij and al., 1999 - with the SWASH wave model - Zijlema and al., 2011 - and the MARS hydrodynamic model - Lazure and Dumas, 2007) and taking into account the effects of sea-level rise linked to global warming. These scenarios, rely on the estimation of a one-hundred-year floodhazard from joint probability statistical methods and include a sea level elevation rate of +0.2 m corresponding to a median scenario for 2046-2065 in reference of 1986-2005 period in global mean (source: IPCC WG1 Ch13 - Church and al 2013) and +0.6 m in reference to the mean sea level rise for the Mediterranean sea for 2100 (Slangen and al, 2014). The results clearly illustrate the concept of "tipping point" as they show an increase in water volumes on land and flooded areas of + 247% and + 384% respectively for the SLR + 0.2 m and SLR + 0.6 m scenarios. The significant extent of coastal flooding revealed by numerical simulations raises two key questions for the management of the municipality's territory in the next decades and, more widely, for these low-lying coastal areas subjected to strong anthropogenic pressure. First, the question of land management strategies to adopt: given the significance of economic stakes, should we give priority to defense and protection strategies at any cost, or consider consider managed retreat forward as a planning policy option, at least for the most exposed areas of the territory? Which outcomes would be socially and economically most acceptable? Second, how will crisis management procedures be adapted face to increasingly frequent and impacting marine submersion episodes? What means to commit? How to make local actors and populations more aware and ready to deal with this risk? The integrated and operational approach to coastal flood risk conducted in the framework of CRISSIS program, through study of vulnerability of people and goods, people's perception of risk - how people perceive, tolerate and accept risks, as well as organizing exercises of coastal flood simulation to test existing crisis management procedures in Leucate municipality.

Keywords: Marine flood, Numerical modeling, Sea level rise, Crisis Managment, tipping point

POSTER SESSION
Session 5: Coastal zone

Paper ID 156
Poster Board N°25

Lessons Learnt from Examining 100 years of Coastal Flood Events around the UK

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Coastal floods are a major global hazard leading to long-lasting and wide-ranging social, economic and environmental consequences. With sea-level rise accelerating, and possible changes in storminess, high sea levels will occur more frequently in the future. Without upgrades to flood protection this will significantly increase coastal flooding and impact growing populations and cities around the world's coasts. Continuing to improve the understanding of extreme sea level and coastal flood events is therefore of utmost importance.

The UK has a long history of severe coastal flooding, and at present 2.5 million properties and £150 billion of assets are potentially exposed to coastal flooding. However, there is no formal, national framework in the UK to record flood severity and consequences and thus benefit an understanding of coastal flooding mechanisms and consequences. To address this issue, we have compiled an innovative new database called 'SurgeWatch' (www.surgewatch.org) to systematic document and improve understanding of coastal flooding. Integrating a variety of 'hard' (e.g. sea level and wave records, meteorological data) and 'soft' (e.g. newspapers, weather reports, and social media) data sources we have identified 330 distinct coastal flooding events from 1915 to 2017 for the UK (and are in the process of adding an additional 400 events pre-1915, extending as far back as 245 AD). We have ranked of each of the 330 flood events using a multi-level categorisation based on inundation, transport disruption, costs, and fatalities: from 1 (Nuisance) to 6 (Disaster). For the most severe events ranked Category 3 and above, an accompanying event description based upon the Source-Pathway-Receptor-Consequence framework has been produced. To our knowledge SurgeWatch is the most detailed database on coastal flooding anywhere in the world and we hope that similar datasets will be compiled for other countries/regions, following the framework we have developed here.

In this presentation we will describe the key lessons we have learnt from undertaking a detailed and novel analysis of the drivers and impacts of the 330 flood events compiled over the last century. We demonstrate that the vast majority of the extreme sea level events are generated by moderate, rather than extreme skew surges, combined with spring astronomical high tides. We distinguish four broad categories of spatial footprints of events and the distinct storm tracks that generated them, which has implications for resilience planning. There have been rare events when extreme levels have occurred along two unconnected coastal regions during the same storm. The events that occur in closest succession (<4 days) typically impact different stretches of coastline, which is important from a management and emergency response perspective. The spring/neap tidal cycle prevents successive extreme sea level events from

happening within 4-8 days. We find that the frequency of extreme sea levels has increased by a factor of 10 over the last 100 years. Interesting, however, the number of incidents of coastal flooding has actually reduced slightly due to flood defence upgrades and improvements in forecasting and warning services over recent decades.

Keywords: coastal flooding, storm surge, sea level rise, storms, impact

POSTER SESSION
Session 5: Coastal zone

Paper ID 158
Poster Board N°45

Determining Storm Surge Return Periods: The Use of Evidence of Historic Events

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Storm surges are a major concern for many coastal communities, and rising levels of surges is a key concern in relation to climate change. The sea level of a statistical 100-year or 1000-year storm surge event and similar statistical measures are used for spatial planning and emergency preparedness. These statistics are very sensitive to the assessments of past events, and to future sea level change. The probability of a major storm surge from the Baltic Sea hitting the Copenhagen metropolitan area is determined by the Danish Coastal Authority based on tide gauge records. We have a long history for tide gauge measurements, with 120 years of data available for the calculations. However, the oldest of these tide gauge stations was set up after a major storm surge in 1872, and no events of similar severity have occurred since. In this study, we find that including the evidence of the historic event in 1872 dramatically changes the statistics, and discuss whether it is worth to include even older – and more uncertain – evidence of historic events. Further, we assess the very large impact of sea level rise on the storm surge statistics. As an example, according to the official statistics of southern Copenhagen, the flooding of a present day 100 year event will occur at least every 5 years with just 25 cm of sea level rise.

Keywords: storm surge, climate, regional, historic

POSTER SESSION
Session 5: Coastal zone

Paper ID 159
Poster Board N°3

Shoreline Retreat: Sea Level Rise or Sediment Deficit?

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Climate change effects such as accelerated sea level rise, wave climate alteration and disturbances on sediment-budgets are anticipated to lead to a range of adverse impacts in coastal regions around the world. A rise in sea level is expected to cause shoreline recession. A sediment deficit can have a similar effect in coastline retreat. Since large uncertainties exist in relation to sea level rise rates and sediment budgets, it is relevant to determine how sensitive the coast is to each of these disturbances. This paper provides a quantitative evaluation of each of these parameters in terms of modeled coastal recession through risk-based assessments using an aggregated coastal model, the DRanSTM (Dilating Random Shoreface Translation Model) relative to present day and projected sea level rise rates under distinct climate change conditions. Three different scenarios were simulated: i) historical sediment deficit under present day rates of sea level rise (0.03m); ii) historical sediment deficit under forecasted interval rates of sea level rise for 2100 based on RPC8.5 (IPCC, 2014) (0.52 0.75 0.98m); and iii) historical sediment deficit only (under stable sea level conditions). In each separate computer simulation, sediment budget and sea level scenarios were calibrated for historically erosional coastal stretch in southern Brazil, Rio Grande do Sul state, Hermenegildo beach. Results demonstrate sediment deficit controls coastal recession under current rates of sea level rise for the study area. That is, according to modeled results mean shoreline recession (50% risk) seems to be mostly caused by historical sediment budget deficit alone, which produces a 101m of recession, out of a total 124m. However, under forecasted sea level rise scenarios RPC8.5 for 2100 combined with historical sediment deficit, mean shoreline recession (50% risk) may reach 588m, when sea level will be responsible for most of mean coastal recession (487m). Similarly, when considering a pessimist or extreme scenario (1% risk) with the same rising sea levels rates and historical sediment deficit, sea level alone responsible for 725m of shoreline retreat, out of a total recession reaching values of 911m. These results point out that when considering the forecasted rates of sea level rise for 2100, coastal recession will be controlled by sea level rise, and sediment budget will play only a minor part in the overall coastal behavior. It is clear that at some point in the future as sea level rise rates increase there will be a change in the key drivers of coastal behavior. Yet, a question that still remains is by how much sea level needs to rise in order to equate or exceed the sediment deficit effects in this receding sector? The quantified approach applied in this study allows a more transparent representation of sea level rise and sediment budget contribution in influencing coastal response in climate change impacts forecasts, which are critical for decision making in coastal planning and adaptation in climate change conditions.

Keywords: Sea level rise, coastal recession, impacts, sediment budget, risk

POSTER SESSION
Session 5: Coastal zone

Paper ID 160
Poster Board N°26

Earliest Detection of Sea-Level Rise Accelerations to Inform Lead-Time to Upgrade/Replace Coastal Flood Defense Infrastructure

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There is strong observational evidence that global mean sea levels are rising and the rate of rise is predicted to accelerate, significantly threatening coastal infrastructure. In the UK, £150 billion of assets are potentially exposed to coastal flooding at present, and these numbers will increase, possibly dramatically, with any sea-level rise. Substantial upgrades/replacements to coastal defences will therefore be required to maintain existing flood risk management standards. However, this will involve long lead times relating to both planning (i.e. time to obtain the financial and political support) and implementation (i.e. time to source the company/materials) of schemes. For example, plans for building the Thames Barrier were started soon after the notorious 1953 North Sea flood, but the Barrier was not operational until 1982 – nearly 30 years later!

The issue of sea-level acceleration is particularly important, as rapid rates of rise will reduce the lead-time available for upgrading/replacing defence infrastructure. Moreover, detecting accelerations in the rate of sea-level rise is not straightforward, due mainly to the considerable inter-annual variability evident in sea level at regional/local scales, which 'swamps' the smaller underlying acceleration signal. There is therefore an immediate need to explore how quickly different sea-level accelerations can be detected, and to compare these with the lead times that are necessary for upgrading/replacing different defence infrastructure to identify specific thresholds when the lead times may not be adequate for appropriate adaptation.

These issues are particularly important in relation to the adaptive pathway approach for managing increasing flood risk that was pioneered in Thames Estuary 2100. Although the essence of an adaptive management plan is its ability to adapt when needed, it will only be effective if: (1) a significant acceleration in sea-level rise is detected and then a decision is made in timely manner to move to an alternative pathway; and (2) there is appropriate lead time to carry out the necessary adaptation.

We will describe the results of a study we are undertaking with the Thames Estuary 2100 team to investigate sea level accelerations and lead times for the Thames Barrier which protects London. We have compared different statistical methods for determining acceleration rates to assess whether we could detect sea level accelerations earlier, thereby extending the lead times available for action. We find that the most important approach to earliest possible detection of a significant sea level acceleration lies in improved understanding (and subsequent removal) of inter-annual to multi-decadal variability in sea level records, rather than the particular statistical method used. We will discuss a toolbox that we are developing to: (1) identify the timings (with uncertainties) at which accelerations in sea-level rise might first be recognized using the best possible combination of in situ and satellite-based data and most appropriate

statistical methods; and (2) to estimate the lead times; for a wide range of sea-level projections. We will also highlight the lead times required for different adaptive pathway approaches to protect London.

Keywords: sea level rise, accelerations, coastal defence, lead times, Thames Barrier

POSTER SESSION
Session 5: Coastal zone

Paper ID 168
Poster Board N°62

Improving the Communication of Uncertainties for Future Marine Flooding as Sea-level Rises using Advanced Statistical Methods

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Among all adverse consequences of sea-level rise (SLR), a most immediate one should be more frequent marine flooding of low lying coastal areas. However, a large number of different uncertainty sources affect the impact assessment related to SLR. Part of these originate from global sea-level rise SLR scenarios, their regional variability, and their interactions with solid earth deformation processes. Other are related to oceanographic processes underpinning extreme events and coastal geomorphic changes. In addition, local vertical ground motions may aggravate or moderate sea-level changes at the coast. This raises the following questions: what is the relative importance of each source of uncertainty in the final flooding projections? Which sources of uncertainty need to be considered? how to account for the lack of knowledge in these different sources? Hence, getting better insights in the role played by these uncertainties enables to ease their communication and to structure the message on future coastal impacts. In this view, we propose to explore the fesability of two advanced staistical methods.

The first one relies on probabilistic projections and variance-based global sensitivity (revisit of Le Cozannet et al., Environmental Modelling & Software, 2015). The method is applied on an urban low-lying coastal site located in the north-western Mediterranean, where the yearly probability of damaging flooding could grow drastically after 2050 if sea-level rise follows IPCC projections. The analysis shows that 1) coastal processes and particularly the wave set-up are dominant factors during the first part of the 21st century; 2) Sea-level rise and climate change scenarios dominate by 2080. Sea-level rise variability has its maximum contribution to the uncertainties in-between these two periods 3) The uncertainties on the upper limit of sea-level rise projections is important a few decades later.

The second method relies on new theories of uncertainty (here possibility theory) for representing our partial knowledge on projections of future SLR. These projections remain highly uncertain, especially due to large unknowns in the melting processes affecting the ice-sheets in Greenland and Antarctica. Based on climate-models outcomes and the expertise of scientists concerned with these issues, the IPCC provided constraints to the quantiles of sea-level projections. Moreover, additional physical limits to future sea-level rise have been established, although approximately. However, many probability functions can comply with this imprecise knowledge. We show how possibility theory can provide a more flexible and less ambiguous framework than classical probabilities to represent in a concise representation of uncertainties in future sea-level rise and of their intrinsically imprecise nature, including a maximum bound of the total uncertainty (Le Cozannet et al., Environmental Research Letters, 2017).

We suggest that the probabilistic and possibilistic theories are complementary frameworks to support the communication of uncertainties on future impacts of sea-level rise: while the probabilistic framework captures average evolutions, the possibilistic approach appears appropriate to explore the fuzzy high-end (or low-end) sea-level scenarios and their impacts. The issue is of particular importance to coastal managers responsible for adapting to the adverse effects of SLR.

POSTER SESSION
Session 5: Coastal zone

Keywords: Marine inundation, Sea-level projections, Epistemic Uncertainty, Variability, Sensitivity analysis, Message

POSTER SESSION
Session 5: Coastal zone

Paper ID 169
Poster Board N°80

Estimating Storm-Surge Statistics Globally from Tide Gauges and Modelling

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Storm surges are a significant contribution to coastal flooding, and we seek better tools to predict risk statistics on a global scale. We report on recent progress in modelling storm surges, using the Global Tide and Surge Model (GTSM) based on Delft-FM. GTSM now enables surge-tide interactions to be modelled at a global scale. We compare likelihood of sea-level extremes generated in this model to the Global Extreme Sea-Level Analysis (GESLA) tide-gauge dataset. Thus we consider whether the GTSM is appropriate to derive multi-decadal statistics of storm surges in regions where sufficient tide gauge data does not exist.

Tide-surge interaction is very important for modelling an individual surge, particularly in shallow water with large tidal range. However we have shown that for long-term risk statistics in the UK, tides can be treated independently from surge, so long as the skew-surge metric is used and seasonal effects are included. Extending this analysis globally, including the tropics, using the GESLA data, we ask whether it is necessary to include tide-surge interaction for statistical risk in these regions, and whether any seasonal dependence or other condition applies.

Keywords: Storm surge, skew-surge, global, gesla, tide-gauge

POSTER SESSION
Session 5: Coastal zone

Paper ID 174
Poster Board N°19

Mapping Sea Surface Height Variability at High Resolution with Radar Interferometry: the SWOT Mission

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The limit of spatial resolution of the present constellation of radar altimeters in mapping two-dimensional sea surface height (SSH) variability is approaching 100 km (in wavelength) with 3 or more simultaneous altimetric satellites in orbit. At scales shorter than 100 km, the circulation contains substantial amount of kinetic energy in currents, eddies and fronts that are responsible for the stirring and mixing of the ocean, especially important in the various coastal processes. A mission currently in development will use the technique of radar interferometry for making high-resolution measurement of the height of water over the ocean as well as on land. It is called Surface Water and Ocean Topography (SWOT), which is a joint mission of US NASA and French CNES, with contributions from Canada and UK. SWOT will carry a pair of interferometry radars and make 2-dimensional SSH measurements over a swath of 120 km with a nadir gap of 20 km in a 21-day repeat orbit. The synthetic aperture radar of SWOT will make SSH measurement at extremely high resolution of 10-70 m, although with relatively large instrument noise. Upon spatial averaging, the SWOT SSH data can achieve 10 cm precision at 250 m2 pixel and 2.5 cm at 1 km2 pixel. SWOT will also carry a nadir looking conventional altimeter and make 1-dimensional SSH measurements along the nadir gap. The temporal sampling varies from 2 repeats per 21 days at the equator to more than 4 repeats at mid latitudes and more than 6 at high latitudes. This new mission will allow a continuum of fine-scale observations from the open ocean to the coasts, estuaries and rivers, allowing us to investigate a number of scientific and technical questions in the coastal and estuarine domain to assess the coastal impacts of regional sea level change, such as the interaction of sea level with river flow, estuary inundation, storm surge, coastal wetlands, salt water intrusion, etc. As examples, we will illustrate the potential impact of SWOT to the studies of the San Francisco Bay Delta, and the Seine River estuary, etc. Preliminary results suggest that the SWOT Mission will provide fundamental data to map the spatial variability of water surface elevations under different hydrodynamic conditions and at different scales (local, regional and global) to improve our knowledge of the complex physical processes in the coastal and estuarine systems in response to global sea level changes.

Keywords: radar interferometry, sea surface height, coastal processes, estuarine processes

Paper ID 176
Poster Board N°9

Coastal and Regional Sea Level Rise, Subsidence and Collective Adaptation Processes in Semarang, Indonesia

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The hazardous potential of the combination of regional sea level rise and subsidence in highly populated coastal areas is receiving increasing awareness. Large cities on northern Java such as Semarang are located in flood-prone and subsiding coastal areas and thus are highly vulnerable to sea level rise. In this environment, coastal development, land use planning, and adaption measures require interdisciplinary natural and social science research. It is essential to understand the natural variations of the global, regional, and local sea level change as well as its near-time projection. Likewise, it is crucial to analyze and to explain collective bottom-up coping processes of local communities and their risk perceptions. Our interdisciplinary collaboration allows for analyzing a comprehensive picture of the interrelated sea level change – risk perception – social-economic adaption – scenario.

To achieve this aim, we use environmental data, e.g. GNSS-corrected tide gauge data and sea level information from radar altimetry as well as empirical findings from qualitative focus-group-discussions and quantitative household surveys conducted in 2016 and 2017.

GNSS-corrected tide gauge data from Semarang show a strong rise in the local sea level of 9cm/a even though the sea level decreases for 2 cm/a on a regional scale. The rise in the local sea level is caused by the 11cm/a observed subsidence which is due to tectonic instabilities, excessive groundwater withdrawal, and increased surface load. The latter is caused by massive urban construction and soil compaction on newly reclaimed land which is clearly visible in the city's landscape. This rate of subsidence is alarming in expectation of a future rising global sea level.

Results from social science research indicate that local people in Semarang have so far been able to cope with their environmental conditions and are not willing to vacate even the most exposed areas. While these people are aware of the risks they face due to coastal hazards, their knowledge about possible future scenarios and sea level rise generally remains marginal. The question arises how people are able to survive in these environments? Social capital plays a central role for local households and communities in coping with their high exposure to floods and subsidence. Through networks of trust, people have access to loans, information, and know-how that may become valuable resources for innovation and community resilience. The question however remains whether people will be able to keep up with environmental changes they are exposed to and how long staying in the affected areas will remain economically and socially feasible.

Keywords: coastal sea level change, subsidence, radar altimetry, vulnerability, adaptation

Paper ID 179
Poster Board N°60

Coastal Nuisance Flooding Caused by Astronomical Tides Alone: New York, Boston, and Other Case Studies

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Sea level rise necessarily triggers more occurrences of minor, or nuisance, flooding events along coastlines, a fact well documented in recent publications. At some locations nuisance flooding can be brought about merely by high spring tides, independent of storms, winds, or other atmospheric conditions. Given a scenario for future sea level rise at a particular location, all cases of anticipated nuisance floods can be predicted years in advance. This contrasts with the statistical projections that must be employed for severe flooding events.

Analysis of sea level at Boston shows that nuisance flooding from tides alone first began to occur there in 2011. At Atlantic City it first began in 2009. Tide-only flooding does not yet occur in Annapolis, where the tidal range is much smaller, but will begin there between 2022 and 2025. Other cases will be discussed. These floods will become more common in coming decades, even under very conservative scenarios for future sea level rise.

In some locations, such as those in the Gulf of Maine, including Boston, future predictions must account for a known secular change in the tidal range. At New York (Battery gauge), there has been a clear increase in the amplitude of M2 over much of the 20th century, but the changes appear somewhat sporadic, making extrapolation into the 21st century uncertain.

Following work by Zetler, Flick and others, it is of interest to compare and contrast the different patterns of extreme tide levels attained in diurnal versus semidiurnal tidal regimes. If misunderstood, these patterns might lead the unwary to proclaim a "hiatus" in flooding events, but in fact the flooding always resumes, with increased frequency and severity as sea levels rise.

Obviously, meteorological conditions, which cannot be predicted with comparable precision, can act to mitigate or worsen any predicted tidal-flooding event, in exactly the same way that meteorological conditions can always affect a tidal prediction. Nonetheless, knowing of such predicted events, and understanding how they are changing over time, is of both scientific and societal interest.

Keywords: Floods, Tides

Paper ID 181
Poster Board N°58

Impacts of Hydrodynamic Factors of Sea and Sea Level Rise on Coastal Zone of Trivandrum, India using Coastal Vulnerability Index Geospatial Model

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The degree to which society is potentially vulnerable to the impacts of climate change can be expressed through an assessment of either the biophysical (external) or social (internal) elements at risk.The research work has utilised Remote Sensing and GIS techniques for assessing the vulnerability of the Trivandrum coast, India due to predicted sea level rise. Multi-sensor satellite data has been interpreted using on-screen visual interpretation techniques to generate coastal thematic information followed by ground truth data collection and validation. Geospatial models for carrying out regional coastal vulnerability assessment of the entire Trivandrum coast. A new approach of integrating physical variable has been developed and demonstrated in GIS environment. Coastal Vulnerability Index (CVI) has been computed for entire Trivandrum coast based on integration of eight physical variables, those are: relative sea level, coastal geomorphology, regional elevation and coastal slope, rate of shoreline change, coastal accretion and erosion, significant wave height, land use land cover and suspended sediment concentration in GIS environment. The results show that 42 % of the Trivandrum coast is under high to very high-risk category and 54 % of the Trivandrum coast is under Moderate to Low-risk category due to the threat of predicted sea level rise.The area under very high-risk category are along north-western part of the Trivandrum coast and the area under high-risk category are in southern part of the coast.The integration of eight physical variables has made it possible to assess the coastal vulnerability more realistic for prioritising the coastal segments for planning remedial actions while preparing integrated coastal zone management plans. The major parameters affecting vulnerability are dynamic of sea level, slope and coastal erosion. Sea level rise is a realistic approach with the coastline geometry.Obviously, sea level change solely affects the configuration of the coastal areas other factors and also play a major role in hammering the west coastal environment of Trivandrum. Therefore, the analysis of coastal vulnerability to sea level rise has many advantageous sights. The vulnerability analysis provides a valuable information that helps to priories major issues which need to be addressed.

Keywords: CVI, Relative sea level, Climate change, Geospatial modeling, Vulnerability analysis

Paper ID 184
Poster Board N°46

Ocean-Atmosphere Coupled Model for Storm Surge Risk Assessment in Bangladesh Due to Climate Variability and Change

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Tropical cyclones are devastating hazards and have been big problem for the coastal population of Bangladesh. The most severe coastal damage tends to result from short-lived extreme flooding events, whose characteristics are likely to alter in the future as a result of both increases in mean sea level and changes in storm-surge activity. However, the effect of projected changes in tropical cyclone behavior and sea level rise on storm surge risk is a less explored issue. In this study, atmospheric model Weather Research and Forecasting Model (WRF) and ocean model Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) have been coupled for estimating storm surge risk in Bangladesh. The frequency, intensity and movement of cyclone were determined by characterizing the tropical cyclone landfalled in Bangladesh coast over the period of 1971 – 2015 in a statistical model. A population of 'synthetic' cyclones was developed from the outputs of the statistical model which provided boundary conditions to the coupled model. It is found that risk of storm surge is higher on the southwest coast. Projected tropical cyclone changes in intensity and frequency for mid to late 21st Century leads to storm tide return period curves that are steeper such that sea levels associated with return periods of 200 years or more become higher, those with return periods of 50 years and less become lower and the 1-in-100 year heights are little changed. Projected changes in sea level are found to make the largest contribution to increased extreme sea level risk.

Keywords: storm surge, tropical cyclone, ocean-atmosphere coupled model, sea level rise, Bangladesh

Paper ID 188
Poster Board N°68

Tropical Cyclone Storm Surge Risk to Mumbai

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In its modern history, the city of Mumbai has never been affected by storm surge from a strong tropical cyclone (TC). Could it happen, and how bad would the effects be if it did? We will describe an ongoing Columbia University project to investigate this question. We will present some basic results on the observed climatology of TCs in the Arabian Sea, where they are relatively rare. Synthetic tracks from downscaling methods will be used to augment the observational record to estimate the probability of a strong TC landfall. Storm surge and inundation calculations for some worst-case scenarios will be shown. Possible influences of climate change on the probability and severity of a TC landfall in Mumbai, through both projected changes in the large-scale environment in the Arabian Sea for TC genesis and intensification and (more importantly) sea level rise, will be described. We will close with some observations on the specific vulnerabilities of Mumbai, a low-lying coastal megacity with essentially no experience of tropical cyclones.

Keywords: storm surge, tropical cyclone, sea level rise, Mumbai, flood risk

POSTER SESSION
Session 5: Coastal zone

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Poster Board N°71

Processes Controlling Development of High Arctic Paraglacial Coastal Systems

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The coastal zone is a key interface where environmental changes impact directly on Arctic communities (Forbes et al., 2011). Recent rapid warming of the Arctic atmosphere has intensified the operation of the geomorphic processes that control coastal evolution (Overduin et al., 2014), causing increased degradation of permafrost (e.g. Wobus et al., 2011), enhanced sediment supply from deglaciated catchments (e.g. Strzelecki et al., 2015), and prolonged periods of open-water conditions and wave activity (e.g. Barnhart et al., 2014). Despite the potential significance of these climate-driven processes, relatively little is known of the physical processes that control past, present and future Arctic coastal geomorphology and, according to Lantuit et al., (2010), only about1% of the Arctic coastlines have been investigated in sufficient detail to allow quantitative analysis of the processes operating on them.

In this paper, we summarize the results of several coastal studies carried out along both accumulative and rocky coast of Svalbard during the last decade.

We reconstruct the post-Little Ice Age evolution of coasts in western, central and southern Spitsbergen to illustrate the highly variable coastal zone responses to both paraglacial and periglacial landscape transformation associated with deglaciation and intensification of extreme geomorphological processes.

Our results emphasise the role of climate changes in controlling sediment fluxes from deglaciated valleys to the coastal zone. Under intervals characterized by a warming climate, retreating local ice masses, a shortened sea-ice seasons and melting permafrost most of studied coastal systems rapidly responded to excess of freshly released sediments and experienced significant geomorphological changes leading to development of new coastal landforms (e.g. spits), progradation of existing forms (e.g beach-ridge plains, barriers) and transfromation of rocky cliffs and shore platforms.

Our research was based on a combination of methods including aerial photogrammetric and GIS analyses, sedimentological tests of coastal deposits, isotopic dating, rock surface tests, geophysical surveying and field-based geomorphological mapping in Billefjorden, Tempelfjorden, Bellsund and Hornsund.

We discuss our new data in the context of previously published coastal evolution studies from Svalbard. The study highlights the need for a greater understanding of the controls on High Arctic coastal systems, especially given the potential for future accelerated climate warming, decay of sea-ice, storminess, sea-level rise and rapidly growing human impact on Arctic resources and strategic locations.

This paper is a contribution to the National Science Centre in Poland projects UMO2013/11/B/ST10/00283: 'POROCO – Mechanisms controlling the evolution and

geomorphology of rock coasts in polar climates' and UMO2013/08/S/ST10/00585 'Model of the interaction of paraglacial and periglacial processes in the coastal zone and their influence on the development of Arctic littoral relief'.

Keywords: coastal evolution, paraglacial, periglacial, Arctic, Svalbard

POSTER SESSION
Session 5: Coastal zone

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RAUK - Forgotten Witness of Holocene Sea-Level Changes and Development of Baltic Rocky Coasts - Project Concept and First Results

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The Holocene history of Baltic Sea evolution is definitely one of the most interesting an intriguing stories of environmental change in Europe. To date, the key information on changes in sea-level and shifts in the environment associated with climate fluctuations were found in coastal lakes, marshes and wide stripe of barrier-lagoon systems of southern Baltic. Only limited research was conducted along rocky coasts, so characteristic features for Baltic islands from Bornholm, through Oland, Gotland, Fårö, Hiiumaa, Saarema to thousands of isles of Åland Archipelago.

Among the most thrilling natural wonders found along Baltic coasts are rauks or raukars, unique limestone stacks—often with humanlike features—that tower above rocky shore platforms in in northern Gotland and on Fårö, Gotland's sister island. Raukar coasts are one of the greatest touristic attractions in Sweden and the mythical coastal landscape of northern Gotland and Fårö had inspired many artists, including one of the greatest director in the cinema history – Ingmar Bergman. Surprisingly, what attracts tourists and art and culture people, have been neglected by geomorphologists and those fascinating landforms still wait for detailed explanation of their origin and preservation.

The RAUK project is designed to 'cross swords' with raukar's mysterious history and explain what controlled the formation of hundreds of limestone stacks along coasts of Gotland and Fårö, and to test if the morphology of those rocky landforms bear traces of numerous environmental changes that occurred in Baltic region over the Holocene.

We hypothesise that, information on Holocene relative sea-level changes and changes in weathering and karstic processes associated with fluctuations of climate (controlling salinity, storminess and ice-cover of Baltic) and post-glacial landscape transformation were recorded in raukars coast morphology.

The principle aims of the RAUK project are:

- to reconstruct the development of rocky coasts along central Baltic islands (Gotland and Fårö) during the Holocene, using the morphology of limestone stacks (raukars);
- and to test to what degree the relief of raukars recorded the environmental changes observed after the decay of Scandinavian Ice Sheet.

The following research questions arise from the key knowledge gaps identified in the literature review above and will provide the focus of the RAUK project:

- What processes dominated the development of raukars and surrounding rock coasts in various phases of Baltic Sea evolution?
- Whether changes in salinity, temperature, ice-cover/storminess and relative sea-level were recorded in morphology of Baltic raukar coasts?
- What are the dominant processes shaping the morphology of present-day limestone raukars, cliffs and shore platforms in Baltic region ?

• What are the rates of rock coast changes (erosion/downwearing) and what they are telling us about past and future development of limestone coast in Baltic region?

Rauk project utilises a rigorous, coherent and novel suite of techniques to analyse the spatially and temporally diverse range of processes and responses controlling the rock coast environments.

Here we present the first results of our investigations of Baltic rocky coast landforms.

This paper is a contribution to the NCN project 'RAUK' (award no. 2016/21/D/ST10/01976).

Keywords: rock coast, weathering, raukars, Holocene, Baltic

POSTER SESSION
Session 5: Coastal zone

Paper ID 196
Poster Board N°30

A View on Historical High Resolution Sea Level Data for Coastal Adaptation

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Sea level rise due to climate change and land subsidence is an especially important and relevant topic for coastal areas. Analyzing long term, high resolution tide-gauge data offers the opportunities for determining variations in key characteristics for sea level data and the analyses of extreme events (storm surges). These include changes in mean sea level and tidal constituents (e.g. M2, M4, Mf). Identified changes in the characteristics are an essential basis for improving adaption of coastal sediment management, control of investments in the infrastructure and coastal protection.

To generate high quality sea level data it is important to apply different quality control methods. Especially historical-tide gauge data are prone to errors due to the form of measurement and data recording. Further error can come from the additional steps take while digitizing the data. In our case statistical methods and neural networks are used to detect and remove different probable wrong data (e.g. outliers, discontinuities and flat lines). Resulting gaps are filled using different interpolation methods depending on the length of the gaps.

We are going to present analyses of different high resolution and high quality data sets form the German North Sea coast of Lower Saxony, Germany. These time series consist of historical digitalized data (earliest November 1917) and data from current water level measurements. Depending on the data set the temporal resolution changes between one, ten and sixty minutes. We analyzed different tidal constituents after splitting the data into different temporal periods. We take a look at changes in mean sea level and derivatives over the different periods. Changes of tidal constitutes in relation to sea level changes, land subsidence and local anthropogenic acting are discussed. The presented results show the importance of continues, long term and also high resolution measurements, as well as an adequate quality control and continues analysis of the sea level.

Keywords: tidal constituents, mean sea level, quality control

Paper ID 198
Poster Board N°82

Deep Uncertainty Surrounding Coastal Flood Risk Projections: A Case Study for New Orleans

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Future sea-level rise drives severe risks for many coastal communities. Strategies to manage these risks hinge on a sound characterization of the often deep uncertainties. For example, recent studies suggest that large fractions of the Antarctic Ice Sheet (AIS) may rapidly disintegrate in response to rising global temperatures, leading to potentially several meters of sea-level rise during the next few centuries [DeConto and Pollard, 2016]. Whether such an AIS disintegration will be triggered and if so, how fast this would raise local sea levels, is deeply uncertain. The potential temperature-driven increasing frequency and intensity of extreme storm surges serves as a second example of deep uncertainty [Grinsted et al., 2013]. Lastly, these projections hinge on the projected greenhouse gas emissions that cover a wide range [Meinshausen et al., 2011]. This raises the question: What are the implications of these deep uncertainties for the design of flood risk management strategies? More specifically, what are the annual flooding probabilities across a sample of these structural uncertainties?

We characterize the impacts of these deep uncertainties on projected flooding probabilities for a levee ring in New Orleans. We use 18 scenarios to sample deeply uncertain future projections of sea-level rise, radiative forcing pathways, storm surge characterization and contributions from fast Antarctic ice sheet dynamics. We find that in all scenarios, the ensemble median achieves the 100-year level of protection prescribed by the Coastal Protection and Restoration Authority of Louisiana Master Plan [CPRA, 2017]. However, even in the most optimistic scenario, the 500-year flood level of protection prescribed for critical infrastructure is not achieved. We put recent scientific advances projecting fast Antarctic dynamical contributions to sea-level rise into perspective in terms of their impacts on the local coastal flood risk management problem in New Orleans, Louisiana.

Keywords: sea-level rise, scenarios, coastal flooding, deep uncertainty, ice fracture processes

POSTER SESSION
Session 5: Coastal zone

Paper ID 202
Poster Board N°33

The Permanent Service for Mean Sea Level (PSMSL): A Global Dataset of Sea Level Change Information

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The Permanent Service for Mean Sea Level (PSMSL) is the internationally recognised global sea level data bank for long term sea level change information from tide gauges. Established in 1933, the PSMSL continues to be responsible for the collection, publication, analysis and interpretation of sea level data, and is based in Liverpool at the National Oceanography Centre. The PSMSL operates under the auspices of the International Council for Science (ICSU), is a regular member of the ICSU World Data System and is associated with the International Association for the Physical Sciences of the Oceans (IAPSO) and the International Association of Geodesy (IAG). The PSMSL continues to work closely with other members of the sea level community through the Intergovernmental Oceanographic Commission's Global Sea Level Observing System (GLOSS).

Currently, the PSMSL data bank holds over 68,500 station-years of monthly and annual mean sea level data from over 2300 tide gauge stations. Data from each site are quality controlled and, wherever possible, reduced to a common datum, whose stability is monitored through a network of geodetic benchmarks. PSMSL also distributes a data bank of measurements taken from in-situ ocean bottom pressure recorders.

Here we will present an overview of the PSMSL dataset, how it can be obtained, where it has been used, and how we recommend it should be cited. We will describe how the global tide gauge network has evolved over the past 200 years and examine its current state. We will also discuss our ongoing work with Système d'Observation du Niveau des Eaux Littorales (SONEL) to exchange information about geodetic links between tide gauges and GNSS receivers, allowing us to link relative sea level measured at tide gauges to the reference ellipsoid, and to provide an estimate of the rate of vertical land movement.

Keywords: tide gauges, sea level rise, vertical land movement, ocean circulation, geodesy

POSTER SESSION
Session 5: Coastal zone

Paper ID 214
Poster Board N°85

Infrastructure Interdependencies and Sea Level Rise in Coastal Areas

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The threat of Sea Level Rise (SLR) to infrastructures and their services especially in coastal areas is severe and continuing. Anticipated increases in sea level in coastal areas at urban and regional scales continue to be documented (USACE, NOAA, EPA, DOT, IPCC, city entities such as the NY Panel on Climate Change, and numerous academic studies). Substantial variations in estimates are recognized (IPCC 2012). Moreover, U.S. Census data has revealed that population continues to move to and build on coasts, and these activities depend on infrastructure services. Infrastructure service capacity does not always stay abreast of population and development changes. Impacts on infrastructure from SLR occur on top of existing vulnerabilities created by condition and performance problems that infrastructure services experience. Moreover, these problems are compounded by infrastructure interdependencies. Understanding infrastructure interconnections is a critical input for plans to reduce service vulnerabilities and consequences associated with SLR. Though estimates of coastal infrastructures at risk exist, they mostly focus on single infrastructures rather than interconnectedness.

Scenarios illustrating the interplay of alternative infrastructure interconnections and different SLR estimates are presented, drawing from a risk-based framework and network theory concepts. They are constructed from and applied to selected databases for different infrastructure combinations, configurations, and degrees of interconnectedness. Scenarios range from broad generic types of infrastructures to component-specific characteristics to plan for coastal area actions for SLR, with strategies ranging from protection to radical changes in the way services are provided.

First, critical infrastructure interdependencies and dependencies will be identified using data from major cities in the U.S. where connections exist under normal situations or arising from damages in extreme situations and that are spatially or functionally related to SLR areas. The focus is interconnected electric power, transportation, and water infrastructures with telecommunications treated as an intermediary. Second, the degree of concentration spatially, functionally or by virtue of heavy usage or facility co-location will be applied to the subset of connected infrastructures at generic and component specific levels. Third, the portrayal and quantification of interdependencies will draw from approaches used in modeling of interdependencies such as network theory. Fourth, the feasibility and effectiveness of applying alternative corrective actions for coastal planning will be applied to the data set in light of alternative SLR scenarios to determine the change in the level and type of risk of damage from those actions. The decision space is well known encompassing protection through elevation and barriers, removal, changes in how a service is provided, and modifying service procedures.

Outcomes will be how to identify interdependencies and their ramifications under alternative SLR conditions, ways of intervening and mitigating the risk, and the feasibility of applying such measures.

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Keywords: infrastructure interdependencies and dependencies, electric power, transportation, water, adaptation

POSTER SESSION
Session 5: Coastal zone

Paper ID 230
Poster Board N°57

Can Sediment Flux Offset Sea Level Rise and Subsidence in the Ganges-Brahmaputra-Meghna Delta?

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Deltas are the home of over half a billion of global populations who are often poor and experiencing multiple stresses from climate change, sea level rise, subsidence, changing catchment management and land use change etc. The Ganges-Brahmaputra-Meghna (GBM) Delta is the second largest delta in the world by area (1.7 million km2 lands), containing more than 100 million people and draining land from Bangladesh, Bhutan, China, India and Nepal. Tidal influence is extended up to 100km inland where most of the land is less than 3m above mean sea level.

There are significant evidences that the GBM delta is changing because of the influences of many different interacting factors including sea level rise. Many parts of the delta are facing threat of submergence by the year 2100 as consequences of sea level rise and subsidence. The combined extreme values of sea level rise and subsidence based on several international and national level analyses is about 20 mm/yr. On the other hand, the combined sediment flux delivered through major river systems is about 1 billion MT/yr (of which around 80% to 90% are fine suspended sediment) which is very important for the delta building processes. Now it is a big question whether sea level rise and subsidence can be offset by the incoming sediment flux and if YES, then how long and under what strategies!

Rough estimates of the sediment dispersion and recirculating processes within GBM system indicate that approximately 30% of the annual sediment load is being deposited in the tidal flood-plain which may counter against sea level rise and subsidence. Rest of the sediments are contributing to subaqueous delta formation and progradation (mostly visible in the eastern part of the delta) and transported to the Swatch of No Ground. Assuming this 30% incoming sediment flux contributing to the floodplain sedimentation (in average flooded area), the yearly thickness of the sedimentation would be at the order of 30 mm which is more than the combined impacts of sea level rise and subsidence. The above rough estimate indicates that incoming sediment flux in the GBM system can offset the combined effects of sea level rise and subsidence, assuming that the incoming sediment flux could be maintained at the present level through efficient management of flow-sediment regime both at basin scale and local level. However, the current sediment flux has a decreasing trend and in coming days is supposed to further decrease due to intensified basin scale and delta level anthropogenic interventions. The question is, how far the incoming sediment flux in the GBM system can offset the combined effects of sea level rise and subsidence! In the present paper, the above question will be addressed under a number of plausible scenarios (climatic and socio economic development scenarios adopted in Bangladesh Delta Plan 2100) in the coming days.

Keywords: Sediment Flux, Sea Level Rise, Subsidence, GBM Delta

POSTER SESSION
Session 5: Coastal zone

Paper ID 236
Poster Board N°31

Coastal Sea Level Variability from Satellite Altimetry - Applications in the UK and the Southern Indian Ocean

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In the past it has been difficult to retrieve useful data from satellite altimeters close to the coast, because contamination of the radar reflection by land or bright targets such as patches of very calm water. To address this problem, the National Oceanography Centre, UK (NOC) has developed the "ALES" altimeter re-tracker for coastal regions. With this re-tracker, there is now the capability to reprocess altimeter data from past missions to provide a continuous time series of satellite altimeter coastal sea level spanning over 20 years.

In this presentation we describe the application of satellite altimeter measurements of coastal sea level in 2 regions: the coastal seas around the UK; and the southern Indian Ocean around Mozambique, Madagascar and South Africa.

UK Sea Level SpaceWatch is a service designed to support the UK agencies responsible for the management and planning of national flood defences and for the preservation of coastal habitats threatened by sea level change.

Using data from the Jason-1, Jason-2 and Envisat satellite altimeters together with tide gauge data, Sea Level SpaceWatch provides, through an easy to use web-interface, the latest figures on observed sea level around the UK, supported by careful analyses of these data in terms of long-term trends, regional variability and confidence intervals showing the lower and upper limit for the present mean sea levels. The service complements and supplements the sea level change scenario information available from UK Climate Projections, offering planners the opportunity to verify the regional variability of sea level around the UK at multiple time scales and observe the presence of any significant inter-annual changes.

This multi-year (2002-2014) sea level data set has been validated against tide gauge data and then further analysis carried out to provide a characterisation of regional variability in sea level, in terms of the annual cycle, and inter-annual variability.

C-RISe is a recently started project which will develop and deliver a Coastal Risk Information service to South Africa, Mozambique and Madagascar, providing information on sea level rise, storm surges, wind speed and wave heights derived from satellite altimetry and validated with local in situ measurements. The goal is to enable local stakeholders to use this information to reduce the social and economic impact of coastal inundation and increasingly variable weather patterns.

Using the NOC coastal processor, satellite altimeter data for the Mozambique, Madagascar and South Africa coastal regions will be reprocessed, and these satellite observations delivered through a web-based data portal. Local partners will then be supported in using these data, and in running a number of case studies to evaluate the use of the C-RISe service in a number different application areas. Local users will also be trained in the validation and use of marine satellite data to quantify coastal hazards, and incorporate this information into ongoing development and disaster prevention initiatives.

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Both Sea Level Space Watch and C-RISe have been funded by the UK Space Agency, through the Space for Smarter Government Programme and the International Partnership Programme respectively.

Keywords: satellite altimeter, coastal risk, climate change

Paper ID 238
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A Mediterranean Coastal Database for Assessing the Impacts of Sea-Level Rise and Associated Hazards

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Uniform, consistent data on physical, ecological and socio-economic characteristics of the Mediterranean coastal zone are a prerequisite for comparative coastal impact assessment and for planning appropriate future interventions. Mediterranean policy makers and coastal administrations are encouraged to undertake adaptation measures that are in line with the Integrated Coastal Zone Management (ICZM) Protocol of the Barcelona Convention in the near future and therefore have an increasing demand for consistent scientific data. We have developed an open access spatial coastal database for the Mediterranean that aims to address these needs. The data structure of the developed database relies on a coastline segmentation process, where units that represent sections of the coast that would have a uniform response to sea-level rise have been created. Using information on coastal morphology, distribution of assets and administrative boundaries the Mediterranean coast has been segmented into 12.000 units with an average length of 4.5km. For this purpose, we have produced a classification of coastal morphology and human settlements using satellite imagery and location-tagged photographs from Google Earth. Following the segmentation, the database was populated with more than 100 parameters that characterize the Mediterranean coast, such as storm surge heights, rates of vertical land movement or spatial distribution of people and assets. Importantly the database contains not only information on current conditions of the coastal zone but also information on potential future change such as sea-level rise rates or socio-economic development that are essential drivers for future impacts. The quality of the developed database has been evaluated by experts from different Mediterranean countries and has been compared to the MEDSEA database. The database, which will be open-access after publication, is originally intended for use in risk and impact assessment to sea-level rise with the DIVA (Dynamic Interactive Vulnerability Assessment) modeling framework. Nevertheless, we anticipate that the database can also be used in a wide range of coastal applications.

Keywords: Coastal database, Coastal impact assessment, sea-level rise, Mediterranean

Paper ID 242
Poster Board N°29

Global Assessment of Coastal Wetland Resilience to Sea Level Rise

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Globally, coastal wetlands and their associated ecosystem services are at risk from sea level rise (SLR). A wide range of models exist that seek to quantify the potential magnitude of this loss. However, whilst local-scale models commonly find coastal wetlands to be relatively resilient to SLR due to increased sediment accretion, many regional and global scale models suggest a dramatic decrease in global wetland area by the end of the century. One possible reason for the discrepancy is the failure to account for bio-physical feedback mechanisms, which govern the sediment accretion processes and play an important role in the capacity of coastal wetlands to adapt to SLR. Existing regional and global scale models thus likely overestimate expected losses.

Here we present an integrated global model which accounts for the vertical adaptability of coastal wetlands, via bio-physical feedbacks between wetland accretion and SLR, as well as horizontal adaptability via interactions between inland wetland migration and accommodation space – defined as the available space for lateral wetland expansion given the current position of the wetland, the tidal frame and erosive forces. In doing so, we present robust projections of changes to coastal wetlands and their resilience due to SLR during the 21st century. We also quantify the extent to which resilience is constrained by vertical and horizontal resilience mechanisms.

The results of the model show that coastal wetlands in many regions of the world are highly resilient to SLR due to their ability to accumulate sediments and grow vertically with rising sea levels. Nevertheless, resilience was found to be dependent upon the availability of accommodation space, which varies in relation to factors such as the extent and degree of anthropogenic modifications via the development of coastal protection infrastructure, coastal roads and railways etc. Given an estimated 10% of the global population currently living in coastal areas below 10 meters and the current projections that this percentage will significantly increase in the future, our results suggest a large-scale reduction in accommodation space will be a major contributing factor to coastal wetland resilience and loss into the future.

Climate change and SLR necessitate adaptation strategies for coastal areas. The results presented here demonstrate a clear need for policy makers and coastal managers to appreciate and account for the importance of accommodation space when developing adaptation strategies seeking to minimise the impact of SLR upon the world's coastal towns and cities.

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Keywords: Sea-level rise, coastal wetlands, global modelling, wetland resilience, coastal adaptation

Paper ID 246
Poster Board N°49

Do Gridded Population Scenarios Provide Added Value in Coastal Impact Assessment?

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The Shared-Socioeconomic-Pathways (SSPs) span a range of population and economic scenarios to determine the different challenges of the impacts of climate change, also considering adaptation and mitigation, over the 21st century. Coastal zones typically face different challenges from inland areas, including differing rates of economic growth and higher population densities. Coastal SSPs have been developed to extend the generic SSPs to account for different population development in the low-elevation coastal zone (LECZ) compared to inland areas. The coastal SSPs provide grids of projected population under each of the five SSPs until 2100, which are consistent at national level to the population numbers in the generic SSPs. In this study, we use the Dynamic Interactive Vulnerability Assessment (DIVA) modelling framework to compare the exposure of population located in the 1 in 100-year floodplain based on the coastal SSPs and the generic SSPs. For the generic SSPs, we assume a spatially uniform growth rate of socio-economic conditions within each country that does not differentiate between coastal, inland, urban or rural areas. Results show that on global level exposure is 13% (SSP3) to 39% (SSP5) higher in the coastal SSPs. Further, the differences between the generic and coastal SSPs increase slightly with rising sea levels. The higher exposure in the coastal SSPs reflects the increasing urbanization levels, which the generic SSPs due to the homogeneous growth rates on national level do not account for. Consequently, the SSPs with the highest projected urbanization levels (SSP1 and SSP5) show the largest differences. SSP3, which assumes the lowest urbanization levels, shows the smallest differences. On regional level, the range of differences between the coastal and generic SSPs is wider than on global level. In Eastern Europe (SSP2, -37%) and Northern Africa (SSP4, -20%) the coastal SSPs show the highest reduction in population exposed to storm surges. Western Africa (SSP5, 115%) and East Asia (SSP5, 67%) show the highest increases in population exposure. This shows that the spatially explicit coastal SSPs provide a more holistic view on coastal exposure than the generic SSPs do, as they account for urbanization and coast- or landward migration on subnational level.

Keywords: Coastal, Exposure, Population, Shared-Socioeconomic-Pathways

POSTER SESSION
Session 5: Coastal zone

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Poster Board N°8

Improvements to Sea Level Measurements in the Coastal Zone through SAR Mode Altimetry: The ESA CP4O and SCOOP Projects.

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The European Space Agency (ESA) Cryosat-2 satellite, launched in 2010, is the first satellite to fly a satellite altimeter with the capability to operate in Delay Doppler, or Synthetic Aperture Radar (SAR) mode. This initial success has since been followed with the launch of the European Sentinel-3 satellite in 2016, which also operates a SAR mode altimeter, building on the heritage and experience gained in CryoSat-2.

SAR mode altimetry has important potential to provide much improved measurements in the coastal zone, due to a much higher along-track resolution (~300m), and a better signal to noise ratio, providing the capability to make accurate along-track measurements of sea-level close to the coastline.

We present results from two ESA studies: CP4O (CryoSat Plus for Oceans) and SCOOP (SAR Altimetry Coastal & Open Ocean Performance), in which the performance of SAR altimetry in the coastal zone and open ocean are assessed, improvements to the processing schemes are developed and tested.

The objective of the CryoSat Plus for Oceans (CP4O) project was to develop and evaluate new ocean products from CryoSat data and so maximize the scientific return of CryoSat over oceans. The main focus of CP4O has been on the additional measurement capabilities that are offered by the SAR mode of the SIRAL altimeter, with further work in developing improved geophysical corrections.

In this paper we focus on two aspects of CP4O. First we present results of a analysis of the performance of "SAR" altimeter data (delay-Doppler processed) in the coastal zone. This study quantified the performance, confirming the significant improvement over "conventional" pulse-limited altimetry.

In a second study, a processing scheme was developed with CryoSat SARin (SAR Interferometric) mode data to enable the retrieval of valid oceanographic measurements in coastal areas with complex topography. Thanks to further development of the algorithms, a new approach was achieved that can also be applied to SAR and conventional altimetry data (e.g., Sentinel-3, Jason series, Envisat).

Finally, we present initial results from the SCOOP (SAR Altimetry Coastal & Open Ocean Performance) project, which started in 2016. This project has the aim to characterise the expected performance of Sentinel-3 SRAL SAR mode altimeter products, in the coastal zone and open-ocean, and then to develop and evaluate enhancements to the baseline processing scheme

in terms of improvements to ocean measurements. There is also a work package to develop and evaluate an improved Wet Troposphere correction for Sentinel-3.

The work described in this presentation was supported by ESA through the STSE and SEOM programmes. We also acknowledge the support of CNES who provided the CNES-CCP CryoSat Products used in these studies. CNES-CPP products were developed by CNES and CLS in the frame of the "Sentinel-3 SRAL SAR mode performance assessment" study.

Keywords: Satellite altimeter, SAR mode, coastal zone, sea level

Paper ID 257
Poster Board N°69

Measurements of Subsidence and Sedimentation in the Coastal Zone of Bangladesh

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In the face of rising sea levels, the balance of land subsidence, sea level rise and sedimentation is critical for low-lying deltaic regions. Deltas commonly experience subsidence due to compaction of their thick sediment accumulations and other processes. Many are susceptible to growth faulting and seaward collapse of the sediment pile on detachment layers (salt and/or overpressured shales) augmenting subsidence rates. We present evidence for moderate subsidence rates and continuing active sedimentation at the Ganges-Brahmaputra-Meghna Delta (GBMD) in Bangladesh. Current subsidence rates are based on continuous GPS established since 2003, including three new coastal stations established in 2012, hourly tide gauge data for 1977–2012 at 16 sites, and two historical sites with ages of 300 years (salt-making kilns) and 400 years (Hindu temple). Two sets of vertical optical strainmeters record sediment compaction and inform its variation with depth. Results so far suggest that rates near the sandy Brahmaputra (Lower Meghna) river mouth are subsiding at 3–4 mm/y. Historic sites with timescales of 300-400 y also show rates of 3-4 mm/y. Tide gauges show significant variability in rates through time that raise questions about their reliability. Higher rates in some GPS data appear to be associated with muddier settings and may reflect shallow near-surface consolidation and organic matter oxidation. Optical strainmeters confirm that most compaction is in the near-surface, similar to other deltas worldwide. Sedimentation estimates based on sedimentation plots, marker horizons, and surface elevation tables (SETs) suggest that accumulation rates in natural areas near the coast currently compensate for relative subsidence and sea level rise, whereas human-modified areas that have been embanked farther inland receive insufficient sediment and are at risk of salinization and land loss. We hypothesize that the moderate subsidence rate of the delta is due to its relatively coarse sediment and buttressing of the margin by the continental rise that prevents growth faulting. The GBMD is dominantly sand and silt with less compactable muds than many deltas. The continental slope-continental rise break is shallow at 1 km water depth due to the high sediment supply feeding the Bengal Fan. Thus the thick wedge of continental rise sediments is at a higher elevation than the top of the weak overpressured sediments within the delta that could act as a décollement surface. This prevents the seaward collapse of the delta and the associated higher rates of subsidence seen at other deltas. Continued stability of the delta is threatened, however, by proposed modifications of the river systems (dams, river diversions) upstream that threaten the sediment supply that balances the subsidence and sea level rise.

POSTER SESSION
Session 5: Coastal zone

Keywords: coastal subsidence, deltas, Bangladesh, sedimentation, relative sea level rise

Paper ID 258
Poster Board N°15

Sea Level Rise Impacts on the Nearshore Wave Climate

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Sea level rise is traditionally considered to be the main climate change driver that will affect coastal safety. However, for coastal safety assessments the impacts of a changing wave climate also needs to be taken into account. The deep-water wave climate (height, direction and period) can change because of changes in the atmospheric forcing. The coastal (nearshore) wave climate could additionally change as a result of SLR-induced larger water depths, implying reduced wave dissipation. Recent studies in shallow seas suggest a strong increase due to sea level rise of nearshore waves with a short wave length.

Here, we show results of the effect of a changing sea level on the nearshore extreme wave climate. For this analysis we use the process based XBeach model, to calculate the nearshore wave climate. Short waves and infragravity waves are generated within the model domain. For the external forcing at the boundaries we use a wide range of SLR projections including high-end projections related to rapid mass loss of the Antarctic ice sheet. To analyse the impact of different slopes of both the offshore as the nearshore bathymetry several representative cross-shore profiles are chosen for several locations across the globe.

For the Dutch coast we additionally analyse, the interaction of nearshore hydrodynamics with dune morphology. At this location, short waves are projected to increase under a higher sea level due to less wave dissipation in the nearshore zone. However, infragravity wave are projected to remain unaltered, since they depend primarily on (unchanged) offshore wave conditions. Even under a SLR of 2.5 m, the infragravity wave-height remains approximately the same in the nearshore zone. Subsequently, we found changes in dune erosion volume to be linear dependent with sea level changes, which essentially reflects that the same infragravity-wave energy (which forces dune erosion) impacts the dune at an SLR-steered higher location on the dune front.

Sea level studies can benefit from these results, because it is often assumed that local impact studies are needed to translate global or regional wave projections to site specific local nearshore hydrodynamics. Our work suggests that regional projections of change in the offshore wave climate might be a good proxy for changes in the driving force behind dune erosion. Whether this can be generalized remains to be proven.

Keywords: dune erosion, wave climate, nearshore, sea level rise, XBeach

Paper ID 261
Poster Board N°36

Using Machine Learning to Correct SRTM and Improve Global Assessments of Coastal Vulnerability to Sea Level Rise

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Worst-case projections suggest that the world could experience over 2 meters of mean sea level rise by 2100, permanently inundating wide areas and making damaging coastal flooding more common. Exposure analysis using NASA's 3-arcsecond, satellite-derived SRTM global elevation model suggests that land currently home to nearly 130 million people could be at risk of either permanent inundation or frequent exposure to msinor floods after 2 meters of rise. Employing the more recent, 1-arcsecond version of SRTM increases this estimate to 140 million people. However, other research suggests that all versions of SRTM suffer from positive elevation bias, especially in regions of urban development and dense vegetation. This been shown to lead to severe error and underestimation of coastal flooding exposure. Here, we present a new method using neural networks to correct SRTM in the low elevation coastal zone, training against much more accurate lidar measurements in countries where such data are available. We find that, after this correction, average elevation bias becomes virtually zero and RMSE is cut nearly in half. Furthermore, this method nearly eliminates the positive correlation seen between population density and elevation error. Exposure analyses using these corrections project significantly higher potential threats from sea level rise and coastal flooding than has previously been reported.

Keywords: machine learning, neural network, exposure, srtm, elevation

POSTER SESSION
Session 5: Coastal zone

Paper ID 262
Poster Board N°73

Adaptation to a Changing Climate in the Coastal Zone – A Case Study of Prime Hook National Wildlife Refuge

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Prime Hook National Wildlife Refuge and its adjacent water bodies are important natural features along western Delaware Bay, USA. Historically salt and brackish marsh habitats, portions of the Refuge were diked and managed as freshwater impoundments starting in the early 1980s. Over the past decade, some of these impoundments have reverted to saline conditions, largely due to several storm events (including Hurricane Sandy in 2012) that have caused flooding, erosion, and opened several breaches between the Refuge and Delaware Bay. Because of these significant morphologic changes, the United States Fish and Wildlife Service (USFWS) completed a series of surveys and coastal engineering analysis to aid in developing restoration alternatives for managing the Refuge. As part of this effort, seasonal shoreline surveys were conducted in the fall of 2011 through the spring of 2017 to provide a temporal span of data for evaluating the rapid retreat. The analysis followed the program developed by the U.S. Geological Survey (Thieler, et al., 2009) and the guidance of the shoreline analysis protocol produced for the National Park Service (Psuty, et al., 2010). This information coupled with historic survey positions demonstrated an acceleration in shoreline retreat of approximately 1.3 m/year to 3.1 m/year. Herein will present findings from an analysis that evaluated the relationship between sea level rise and shoreline retreat using the Bruun Rule (Bruun, 1954, 1962). Scientists and engineers have widely used the Bruun Rule to examine the relationship between sea level rise and shoreline retreat for over 50 years. The Bruun Rule calculates the amount of shoreline retreat as a function of sea level change based on the closed sediment balance between the beach/nearshore and offshore bottom profile. Moreover, this work will compare results between the Bruun Rule and Modified Bruun Rule Eq. (1) that includes the landward transport of sediment due to overwashing, aeolian transport, etc. (Rosati, J.D., 2013). $R \approx S(W^*+VD/S \div h^*+Bo)$ (1) The findings will demonstrate the difference between the two methods and correlate the results to sea level rise observations (Delaware Geologic Survey, 2016) to shoreline retreat. Also, this work will review the results of the strategic planning used in conjunction with the analysis to recommend a preferred alternative for managing the Refuge under the new environmental regime aimed at resiliency. A variety of marsh and beach configurations were developed and tested for their effects on water levels and salinity within the Refuge. The preferred design included dredging of 50 kilometers of conveyance channels and "thin layer" disposal of 460,000 cubic meters of sediment within the marsh and placement of 1.0 million cubic meters of sand along the shoreline to reconstruct the dune and back-barrier system.

Keywords: sea level rise, resiliency, shoreline

Paper ID 264
Poster Board N°1

Effects of Climate Change and Variability on Agriculture in the Coastal Zone in Nigeria

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Climate variability and change is posing serious challenges to the humanity due to its negative impacts. This study aims at reviewing the effects of climate change and variability in the coastal zone in relation to agriculture and estimation of the determinants of adaptation to climate change. Tackling climate change is one of the biggest challenges this region faces. African countries, Nigeria inclusive are particularly vulnerable to climate change because of their dependence on rain fed agriculture, high levels of poverty, low levels of human and physical capital, inequitable soil distribution and poor infrastructure. The developing nations are expected to feel the impacts heavily due to lack of adequate capacity to adapt to the effects of this change. Nigeria is a developing nation with little capacity to cope with the impacts of this variability on agriculture. This study also attempts at reviewing the changes in the patterns of both precipitation and temperature in the coastal zone from long-term data presented by various studies to identify possible impacts these variability could have on agriculture and possible roles of soil and water management in mitigating the impacts in Nigeria. The study reveals both spatial and temporal increasing temperature and decreasing rainfall amount and duration in Nigeria. The annual rainfall was found decreasing at a rate of 0.19% per year and the number of rain days dropped by 53% in the north-eastern Nigeria and 14% in the Niger-Delta Coastal areas. The August break is now being frequently experienced in July. Temperature increase of 1.10C was observed in Nigeria for the 105 years on the temporal scale which would result into scarcity of water. These would result into salt intrusion along the coast, erosion and flooding in the south, drought and desertification in the marginal arid zones of the country which would have negative impacts on crop yields. Efficient and effective irrigation systems would be required to mitigate the negative impacts on food production. Appropriate drainage systems would also be needed to prevent the impacts of sea incursion and high flooding of the agricultural fields to ensure adequate food security in the country.

Keywords: Climate, Agriculture, Nigeria, Coastal Zone

POSTER SESSION
Session 5: Coastal zone

Paper ID 272
Poster Board N°23

The Effect of Dramatic Sea Level Rise on Tree Ring Anatomy of Deceased Atlantic White Cedars

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The state of Delaware is projected to lose between 8 % and 11% of its landmass to the sea by 2100, resulting in a 1.5-billion-dollar loss in assessed tax value. Of Delaware's 11,000 acres of freshwater tidal wetlands 84% to 98% may potentially become inundated. Ones that are not directly inundated will experience the impact of salt water intrusion and rising water tables. They provide shoreline erosion control, flood protection, and natural products such as timber. Unfortunately, due to hydrological alterations and other anthropogenic activities, they are disappearing. Due to the economic and ecological benefits of freshwater tidal wetlands, the State of Delaware lists their inundation and loss as one of the top five concerns relating to sea level rise and The Nature Conservancy deemed them globally endangered. Once prominent up the entire eastern seaboard, cedar swamps (found in freshwater tidal wetlands) consisting of mostly Atlantic white cedars (Chamaecyparis thyoides) are now vanishing due to sea level rise and anthropogenic changes to waterways. The St. Jones River in Dover, DE was straightened through dredging in the early 1930's, resulting in a dramatic salinity increase, which stressed the thriving Atlantic white cedar population surrounding the river, leading to a dramatic die off. Many of these dead specimens remain standing providing us with the opportunity to examine the impact of increased salinity on the growth of tree rings for this important fresh water wetland species. Atlantic white cedars are incredibly durable, lightweight, and decay and weather-resistant. Because of these features their wood is used for outdoor furniture, house siding, boats, decks, and light poles. Not only do these trees have a high ecological value, they also have a high economic value. We collected two cross sections from eleven Atlantic white cedar snags from swamps alongside the St. Jones River. The cross sections were air dried, planed, and sanded with 80, 150, 320, and 400 grit sandpaper. The rings were examined under a microscope and dot dated. We then generated skeleton plots based on ring widths allowing us to become familiar with the wood. The ring widths were then measured with a linear encoder and processed through COFECHA for quality control. The resulting chronology was then run through ARSTAN to detrend the data, removing the impact of growth patterns related to age and climate. The detrended tree ring chronology was then assessed for patterns in growth rings related to increased salinity. We were particularly interested in the time to death after exposure. Preliminary analysis indicates that a narrowing of the rings occurred for about 15 years, which was followed by the death of the tree. The results of this natural experiment are important because they indicate how coastal forests will react to future sea level rise. Information obtained from this study will help better prepare for future water level rises in forested communities and assist in predicting future impacts of human activities. Better understanding of this issue can help prevention practices and, in turn, save millions of dollars.

Keywords: Sea Level Rise, Coastal Forests, Freshwater Tidal Wetlands, Tree Rings, Atlantic White Cedar

Paper ID 280
Poster Board N°34

Coastal Vulnerability Assessment due to Sea Level Rises in Korea

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Recently, the coastal environment has been threatened by impacts of storm surges and higher waves during typhoon in Korea. In addition, the vulnerability of coastal zone has been steadily increased by long-term sea level rises (SLR) due to global warming effects. However, the scientific indices to assess the coastal vulnerability and an integrated database system of coastal disaster are still under development.

The purpose of this study is to develop the coastal vulnerability assessment system (CVAS) related to SLR with the basic framework of IPCC. Three coastal vulnerability indices, the CEI (Coastal Exposure Index, SLR), the CSI (Coastal Sensitivity Index, human, physical and geographical sensitivity) and the CAI (Coastal Adaptation Index, socio-economic and governmental adaptation), were developed to evaluate the CII (Coastal Impact Index) and the CVI (Coastal Vulnerability Index).

Assessment of coastal vulnerability was applied to coastal zone in South Korea. The proposed CII and CVI are classified into 5 grades from the lower at Grade 1 to the higher at Grade 5 in vulnerability. The validity of CII and CVI was compared with the field survey and then its applicability was confirmed. The CII with consideration of exposures and damages was able to clearly assess the sensibility of coastal zone. The CII and CVI can be easily used to determine the vulnerable areas.

Indicator database was constructed by numerical modeling along with national statistics information. Indicator D/B was generated with spatial data in coastal areas by GIS analysis, and then classified into five grades by probability distribution. The results of coastal vulnerability assessment show three types of risk areas. ① high exposure areas (Jeju, Pohang), ② high sensitivity areas (Incheon, Changwon and Busan), ③ low adaptation areas (Haenam, Jindo). These results will be able to support the decision making for improving more safety and comfortable coastal zone.

Keywords: Coastal Vulnerability Assessment, Sea Level Rise, Korea

Paper ID 282
Poster Board N°75

Communicating Sea Level Science Through an Interactive App

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Coastal management and planning incorporates a range of physical science and social science from climate science, oceanography, geology as well as engineering, planning, and communication. Developing a common language so that the process can be inclusive and communicated to the broader public is critical. Conveying the complex science that is behind changes in sea level and the intrinsic spatial variability can be a challenge. Blending this science with economic projections and probabilities for planners who are focused on identifying vulnerable populations and potential pathways of impact adds an additional obstacle. Map based data visualizations have been found to be an effective cross platform communication tool.

We have developed an innovative map based climate change communication tool, the free Polar Explorer: Sea Level app. This interactive app is a compendium of data visualizations organized into book-like chapters, offering a guided tour through the multiple layers of science that impact sea level rise. Framed around a series of major questions, the app moves the user through data layers at whatever level of complexity they chose. Each map begins with a few sentence introduction, on how the given map links to sea level, before launching into the interactive map. For a more in depth look the user can listen to a short recording on the data displayed in the map, or for those who want a more in depth understanding a one page background piece on the topic with links to further visualizations, videos and data is clickable. Regardless of the level of complexity selected each map is composed of clickable data allowing the user to fully explore the science.

The map layers cover a wide range of topics, from sea level basics like "What is sea level?" including maps about shifting shorelines, past sea levels and elevations beneath the sea, to more complex selections like an introduction to the geoid and gravitational impacts on sea level. Questions like "Why does sea level change?" includes categories like the role of ocean temperature, and how that differs from ocean heat content, in addition to what are the roles played by a warming atmosphere, melting glaciers and ice sheets in sea level change? Additionally a series of maps looks isostatic rebound and the effect on some of our coastlines. Other sections focus on "Where is sea level changing now?" examining world tide gauge data for local sea level, as well as satellite altimetry data for ocean sea level.

Planners and coastal managers will find the section on "Future predictions" looking at our coastal regions and what effect a foot to six feet of sea level rise will have, extremely useful. This section and the 'Who is Vulnerable?' that highlights areas most often impacted by weather and extreme events, will assist managers in how to best plan for extreme events. Whatever the challenges future sea level change brings, the challenge of communicating in an interactive, visual and accessible way must be addressed. The Polar Explorer: Sea Level app can be the tool for that. (http://www.polarexplorer.org)

Keywords: Communication, Planners, Maps, Data Visualizations, App

Paper ID 284
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1966-2016: 50 years of Relative Sea Level Rise in Venice, Italy

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On November 4, 1966, an exceptional high tide of +194 cm above mean sea level (amsl) affected the city of Venice, with almost the entire historical center flooded by up to 1 m of sea water. In the years that followed, this height has never been surpassed. However, the frequency of high tides, i.e. tides above +110 cm amsl flooding more than 12% of the city center, has continuously increased. Land subsidence (LS) of both natural and anthropogenic origin and rise of the Adriatic mean sea level (SLR) have been the main causes of such an increase. During the last 100 years, the two contributions have been quantified in 14 cm and 12 cm, respectively, with a cumulative relative sea level rise (RSLR) of 26 cm. However, this LS value refers to an average estimate, which is only partially representative of the actual displacements experienced by the city. In this contribution, a detailed quantification of the RSLR of Venice over the last 50 years is proposed. An accurate assessment of LS is performed by processing and superposing the outcome of levelling surveys carried out in 1961, 1973, 1993, and 2000, together with the results of Interferometric processing of Synthetic Aperture Radar images acquired from 1992 to 2002 by ERS-1/2 satellites, between 2003 and 2010 by ENVISAT, from 2008 to 2013 by TerraSAR, and between 2013 to 2015 by COSMO-SkyMED. The record from the tide gauge in Trieste, which is a city on the Adriatic Sea close to the Alps and known to be stable, provides the SLR amount over the targeted time interval.

Keywords: Coastal subsidence, relative sea level rise, Venice

POSTER SESSION
Session 5: Coastal zone

Paper ID 289
Poster Board N°32

On the Effects of Uniform and Non-Uniform Sea-Level Rise on European Shelf Tides

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In theory, sea-level rise has not only a direct linear effect on the total instantaneous water level, but also an indirect effect on tide, surge, waves and induced sediment transport. Focusing on the SLR effect on the water level, the total water level x can be written:

$$x=xT,0+xS,0+SLR+I$$

With xT,0 and xS,0 being respectively the tide and the surge water level contributions for SLR=0. SLR is the sea-level rise contribution and I the term of interaction between xT,0, xS,0 and SLR. Several studies have investigated the effects of SLR on the tides of the western European continental shelf (mainly the M2 component). We further investigate this issue using a modelling-based approach, considering uniform SLR scenarios from -0.25 m to +10 m above present-day sea level.

Assuming that coastal defenses are constructed along present-day shorelines, the patterns of change in high tide levels (annual maximum water level) are spatially similar, regardless of the magnitude of sea-level rise (i.e., the sign of the change remains the same, regardless of the SLR scenario) over most of the area (70%). Notable increases in high tide levels occur especially in the northern Irish Sea, the southern part of the North Sea and the German Bight, and decreases occur mainly in the western English Channel. These changes are generally proportional to SLR, as long as SLR remains smaller than 2 m. Depending on the location, they can account for +/- 15% of regional SLR. High tide levels and the M2 component exhibit slightly different patterns. Analysis of the 12 largest tidal components highlights the need to take into account at least the M2, S2, N2, M4, MS4 and MN4 components when investigating the effects of SLR on tides. Changes in high tide levels are much less proportional to SLR when flooding is allowed, in particular in the German Bight. However, some areas (e.g., the English Channel) are not very sensitive to this option, meaning that the effects of SLR would be predictable in these areas, even if future coastal defense strategies are ignored. Additional numerical computations show that SLR-induced tidal changes result from the competition between reductions in bed friction damping, changes in resonance properties and increased reflection at the coast, i.e., local and non-local processes.

The above results are based on the assumption that sea level will rise uniformly. However, future sea-level rise will display regional variability. We therefore analyze to what extent tidal changes induced by a uniform or a non-uniform SLR would be significantly different by considering a synthetic idealized non-uniform SLR field, based on Slangen et al. (2014). This SLR scenario corresponds to the current state of knowledge of the regional variability of future sea-level rise on the European continental shelf, given a global mean sea-level rise of 0.5 m by 2100 and the RCP4.5 climate change scenario. The preliminary estimate of tidal changes by 2100 under a plausible non-uniform SLR scenario shows that even if changes display similar patterns, high water levels appear to be sensitive to the non-uniformity of SLR.

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Keywords: tide, sea-level rise, tidal component, European shelf, resonance

POSTER SESSION
Session 5: Coastal zone

Paper ID 296
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Environment Risk Assessment Due to Climate Change Impacts on Informal Settlements on the Coastal Regions of Mumbai

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Global climate changes are expected to affect coastal communities around the world, many of which are already considered vulnerable to ongoing climate vulnerability. (IPCC 2001; MONIRUL AND MIRZA 2003). Changes in climate, and related impacts on natural and human systems, have recently been observed on all continents (IPCC 2014) and while not an isolated cause, the majority of disasters worldwide are now climate-related (CRED 2015, UNISDR 2015).
Climate change-related risk to urban areas, and more so to informal settlements in the Indian context, is augmented by the rapid pace of urbanization and the failure of basic service provision to keep up with an ever increasing population.
In Mumbai and other cities of developing nations, the risk to the informal settlements is greatly compounded by their location on flood prone areas and coastal zones. The lucrative opportunities that the city as a financial capital has to offer, play an important part in luring rural migrants who are content to have a place to stay, irrespective of the dangers they have to deal with. This inherent vulnerability is aggravated by the densities and lack of infrastructure to safeguard them from storm events.
This paper investigates the impact of sea-level rise and coastal surges on the informal settlements located along the coast of the Mumbai Metropolitan Region, through the example of one such settlement- Guzder Bandh. This settlement lies on the western suburban coast of Mumbai within a presence of two older fishing communities. These communities often lie on land that has been reclaimed from the sea and are hence more susceptible to climate change risks.
Purely technical frameworks can offer only an incomplete understanding of the risk faced by such communities as they cannot account for issues of livelihood and other social issues that are dependent on the community's relationship with the sea.
The paper explores the strategies that the inhabitant's develop to the effects of climate change. The very nature of the location of these settlements implies that they will bear the larger burden of increased storm activity and sea-level rise. Their financial position coupled with the insecurity of the tenure does not do much to afford adequate adaptive measures such as improved and safe building materials. The possibility of relocation can hardly be considered due to political constraints as well as dearth of availability of less stressed land pockets. Livelihood means also play a decisive role in not looking for an alternative location.

The marginalised communities form the focus of the city's adaptive capacity and research investigations in that direction are imperative. The paper attempts to address the gap between assessing future vulnerability and long-term policy on climate change at a city level, and optimizing the existing adaptive capacity at a community level.

Keywords: Environment, risk reduction, adaptation, sea level, storm surge

Paper ID 297
Poster Board N°27

Assessing the Impact of Sea Level Rise on Coastal Infrastructure in England and Wales Using Advanced Multivariate Extreme Value Methods

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The Cabinet Office National Risk Register ranks coastal flooding as one of the highest current risks facing the UK. Recent coastal flooding events in England and Wales have further highlighted the potential impacts of these events. The flooding over the Winter of 2013/2014 was notable both for its long duration, lasting over 2 months, and its spatial extent, affecting many different areas of England and Wales. Hundreds of people were evacuated with many properties inundated. Mainline railway infrastructure suffered dramatic failure with extended extend periods of disruption and substantial economic costs arising as a result. This risk is set to increase with sea level rise.

Whilst sea level is an important aspect of coastal flooding, it has long been recognised that extreme coastal flooding in England and Wales can arise from the joint occurrence of extreme waves, winds and sea levels. This paper therefore describes the development and application of a state-of-the-art multivariate extreme value statistical model to offshore winds, waves and sea levels to assess coastal flooding. The methodology overcomes the limitations of traditional methods. It has been extensively applied to assess the present day risks of coastal flooding and it has now evolved to facilitate analysis of future flood risk as a result of sea level rise.

The output of the new statistical modelling procedures is a Monte-Carlo (MC) simulation comprising many thousands of offshore extreme events and it is necessary to translate all of these events into overtopping rates for use as input to flood risk assessments. It is computationally impractical to transform all of these MC events from the offshore to the nearshore. Computationally efficient statistical emulators of the SWAN wave transformation model have therefore been constructed. The emulators translate the thousands of MC events offshore. Estimates of sea level rise 100 years into the future have been incorporated within the statistical analysis to enable coastal flood risk impact assessment.

The methodology has been applied to assess future risks associated with the railway infrastructure at Dawlish, on the south coast of England site of the recent failure, on the south coast of England. Moreover, the methodology has also been used to assess impacts on properties along the North Coast of Wales. The results of the application highlight the significant impacts of sea level rise and these results are used to aid the exploration of appropriate mitigation measures.

Keywords: extremes, flooding, risk, Monte Carlo, emulators

Paper ID 307
Poster Board N°48

A Multivariate Statistical Retrospective of Several High-impact Coastal Events from the Last Decade

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Predicting coastal impacts from extreme combinations of storm waves, storm surge, tide and sea level is often difficult because 1) the time periods of available historical quantitative (e.g. wave buoy and tide gauge) observations are often relatively short, 2) discontinuities in those observations are often present and, 3) in some cases, the required (local) data are lacking all together. These factors typically lead to high statistical uncertainties and difficulties in accurately evaluating the significance of particular events and their proximal factors.

In this study we explore multivariate extreme value analysis methods applied to meteorological/oceanographic numerical hindcasts as a way of improving statistical certainty and potentially the interpretation and prediction of coastal extremes events. In this study, we combine a 37-year numerical wind-wave hindcast with tide gauge data, a global tidal model and satellite altimetry data to provide information on hydrodynamic parameters that influence high impact coastal extremes. Wave height, wave period, wave direction, tides, non-tidal water levels and total water level duration parameters from hindcast and tide gauge sources are combined in univariate and multivariate probabilistic models. These models are then evaluated for their ability to predict the severity of a number of historical severe erosion and/or inundation events that have occurred in Australia and Pacific island nations.

Keywords: Sediment Transport, Storms, Coastal Structures

POSTER SESSION
Session 5: Coastal zone

Paper ID 310
Poster Board N°35

Coastal Hazards and Integration of Impacts on Local Adaptation Planning

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Data on sea and groundwater levels, sea level, precipitation, land subsidence, geology, and geotechnical soil properties are combined with information on flood and erosion protection measures to analyze water-related impacts from climate change at an exposed coastal location. Future sea extremes will have a large impact but several coupled effects in the hydrological system need to be considered as well to provide for optimal protection and mitigation efforts. For instance, the investment and maintenance costs of securing functional water and wastewater pipes are significantly reduced by incorporating knowledge about climate change. The translation of regional sea level rise evidence and projections to concrete impact measures should take into account the potentially affected stakeholders who must collaborate on common and shared adaptation solutions. Here, knowledge integration across levels of governance and between research, private and public institutions, and the local communities provides: understanding of the immediate and potential future challenges; appreciation of different stakeholder motives, business agendas, legislative constraints etc., and a common focus on how to cost-efficiently adapt to and manage impacts of climate change. By construction of a common working platform that is updated with additional data and knowledge, e.g. from future regional models or extreme events, advances in sea level research can more readily be translated into concrete and local impact measures in a way that handles uncertainties in the future climate and urban development as well as suiting the varying stakeholder needs.

Keywords: coastal adaptation, sea level, integrated approach

POSTER SESSION
Session 5: Coastal zone

Paper ID 311
Poster Board N°64

Quantifying Washout's Influence in Coastal Response to Sea-level Rise Scenarios in Southern Brazil

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Over the last few years, concerns about the current global climate change increased in an alarming way. One of the most direct consequences of these changes is the accelerated rising sea-levels putting coastal zones all over the world at risk. However, large uncertainties in the magnitude of coastal impacts still exist as a result of local geomorphological characteristics. Hence, an identical increase in water base level may affect differently each coastal sector. In this context, a low lying coast with a high degree of exposure to ocean dynamics, such as the study area in focus (Cassino beach, RS, southern Brazil), is expected to be highly vulnerable to sea-level rise impacts. The region´s susceptibility is amplified by the presence of numerous small-scale creeks (washouts) which drain the coastal plain disrupting foredune continuity. In order to analyze coastal response under sea-level rise scenarios, model simulations focused in quantifying the influence of morphological and sediment budget variability in the presence of washouts or dunes. In order to generate the initial substrate for computer simulations, topographic surveys at one washout channel and adjacent dune and beach were obtained using a GPS RTK (Real Time Kinematics) in July 2016. Two independent sets of simulations considering two IPCC sea-level rise scenarios (RCP 2.6 and RCP 8.5) were designed to evaluate coastal response under rising sea-levels for the year 2030. One focused in quantifying the effects of changes in sediment budget and another in quantifying the influence of topographic (substrate) differences. The simulations were executed using the software RanSTM (Random Shoreface Translation Model), an aggregated coastal model in a stochastic version, which makes it possible to establish the differences in coastal response caused by varying effects such as sediment budget, substrate resistance and geometry. All simulations involving washout substrate profile showed a total mean recession distance (50% risk level) numerically higher than those with dune substrate profile, even though differences between the two in each scenario were not statistically significant (RCP 2.6: Dune -48 m; Washout -54 m and RCP 8.5: Dune -105 m; Washout -112 m). In order to identify separately which factor has greater influence in overall coastal retreat, further data analysis indicated that changes in sediment budget, due to the washout presence, controlled 83% of coastal recession in simulations for RCP 2.6 scenario and 67% for the RCP 8.5 scenario. Whereas, topographic differences in substrate profiles only influenced 17% of coastal recession for the RCP 2.6 scenario and 33% for the RCP 8.5 scenario. These values highlight the relevance of sediment budget in controlling coastal behavior comparatively to substrate morphology influence in the study area, especially, when sea-level rise rates are relatively slow, such as those projected for year 2030 in RCP 2.6 scenario. In conclusion, these results can provide a more transparent basis in forecasts of coastal response to sea-level rise by identifying its controlling factors assisting the development of appropriate management policies for the region, bearing in mind its specificities.

Keywords: Coastal modelling, Sea-level rise, Coastal retreat

POSTER SESSION
Session 5: Coastal zone

Paper ID 316
Poster Board N°10

Amplification of Flood Frequencies with Local Sea Level Rise and Emerging Flood Regimes

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The amplification of flood frequencies by sea level rise (SLR) is one of the most economically damaging impacts of climate change on coastal areas. Understanding the magnitude and pattern by which the frequency of current flood levels increase is important for developing more resilient coastal settlements, particularly since flood risk management (e.g., infrastructure, insurance, communications) is often tied to estimates of flood return periods. The Intergovernmental Panel on Climate Changes Fifth Assessment Report characterized the amplification factor (AF) by which the frequency of flooding of a given height increases. However, this characterization neither rigorously considered uncertainty in SLR nor distinguished between the amplification of different flooding levels (such as the 10% versus 0.2% annual chance floods); therefore, it may be seriously misleading. Because both historical flood frequency and projected SLR are uncertain, we combine joint probability distributions of the two to calculate AFs and their uncertainties over time. Under probabilistic relative sea level (RSL) projections, while maintaining storm frequency fixed, we estimate a median 40-fold increase (ranging from 1 to 1314-fold) in the expected annual number of local 100-year floods for tide-gauge locations along the contiguous U.S. coastline by 2050. While some places can expect disproportionate amplification of higher frequency events and thus primarily a greater number of historically precedented floods, others face amplification of lower frequency events and thus a particularly fast growing risk of historically unprecedented flooding. For example, with 50 cm of SLR, the 10%, 1%, and 0.2% annual chance floods are expected respectively to recur 108, 335, and 814 times as often in Seattle, but 148, 16, and 4 times as often in Charleston, SC.

Keywords: probabilistic sea level rise, coastal flooding, risk management, deep uncertainty, extreme value theory

Paper ID 321
Poster Board N°20

Future Flood Risk of Guangzhou City, China

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Global warming-sea level rise has become a major environmental problem around the world. All coastal locations are at risk to the impacts of accelerated sea-level rise. Especially for coastal megacities, such as Shanghai and Guangzhou in China, climate change plus rapid urbanization and subsidence are putting them at increasing risk of flooding. And they both had been evaluated being the top risk city to flood among the largest coastal cities in the world, based on growing population and asset, changing climate and subsidence, as well as existing coastal defenses and their level of protection.

Authors of this article have contributed much effort to the research of sea-level rise and its threat to coastal cities in South China, especially for Pearl River delta, so we would also like to put forward some discussion about the future flood risk of Guangzhou based on its geographical characteristic, subsidence and flood defense level. (1) Geographical location and terrain features. Guangzhou is located at the edge of the Pearl River Delta and is about one hundred kilometers away from the sea, the effect of storm surge is always significantly reduced when arrival. And topographically, Guangzhou city features hills and low mountains, which are not vulnerable to flooding. That is, the natural condition of Guangzhou is better than many coastal cities, such as Miami (near the sea, about 35% of its area are lakes), New Orleans (pot shaped geomorphology) and Mumbai (island city). (2) Subsidence. The subsidence rate of Pearl River delta is 0.2~1.7mm/a during the last 10 000 years, and it is 0.5~1.8mm/a over the last several decades in Guangzhou city. The thickness of Quaternary alluvium in Pearl River Delta is 20~30m in general, therefor, land subsidence induced by compaction of alluvium is limited. In addition, the exploitation of groundwater in this area is rare. By estimate with all above elements taking into account, subsidence of this area would be around 10cm by 2050, far below the value of 40cm that Stephane et al. adopted in their research report published in Nature Climate Change in 2013, as well as the values of some other coastal cities. (3) Flood defenses level. The general defense level of Guangzhou city is 200-year flood standard, but not 20-years standard that some assessment works adopted. And as a measure against the possible serious flood in future, the regular maintenance and upgrading have been implementing since decades years ago.

Therefore, the estimate to the flood risk, which is based on questionable data, may have some deviation and in turn, has negative effect on accuracy of forecasting flood disaster to coastal cities. Furthermore, the implications of climate change for each coastal megacity vary significantly, so each city requires independent assessment. Guangzhou is located in low-lying areas and along waterways. It is also facing increasingly prone to flooding due to an uncertain future. There is a pressing need to start planning how to manage flood risk now.

Keywords: flood risk, Guangzhou, city plan, sea level rise

POSTER SESSION
Session 5: Coastal zone

Paper ID 327
Poster Board N°21

New York City's Future Flood Risk from Tropical Cyclones and Sea-level Rise

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In a changing climate, the risk of future flooding along the United States' Atlantic coast depends on both storm surges and rising sea levels. We combine probabilistic sea-level rise projections and large sets of synthetic tropical cyclones downscaled from RCP 8.5 runs of three CMIP5 models to assess the impact of changing tropical storm characteristics and sea-level rise on future coastal inundation in New York City in 2100 and 2300 CE. Modeling results indicate that there will be minimal change in modeled storm surge heights from 2010 to 2100 or 2300, because the predicted strengthening of the strongest storms will be compensated by storm tracks moving offshore at the latitude of New York City. However, projected sea-level rise causes overall flood heights associated with tropical cyclones in New York City in coming centuries to increase greatly compared to historical or present flood heights. Our projected sea-level rise includes an ensemble of Antarctic projections generated for RCP 8.5 climate scenarios. We find that the 1 in 500-year flood event increases from ~3.4 m above mean tidal level during 1970-2005 to ~3.9 – 4.8 m above mean tidal level by 2080-2100, and to as much as ~13.1 m above mean tidal level by 2280-2300. Results from this study provide a framework for future risk assessments of coastal flooding in New York City and surrounding communities.

Keywords: Tropical Cyclones, Coastal Hazards, Storm Surge, Sea-level Rise, Flood Heights

Paper ID 340
Poster Board N°52

Towards a Regional Assessment of Coastal Flood Risk – A Review of Methods Applied in Norway, Sweden, Finland, Denmark, and Germany

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The coasts of Norway, Sweden, Finland, Denmark, and Germany face hazards from storm surges governed by eastward propagating atmospheric lows. Surge and tide levels, as well as their corresponding impacts, vary between storms and location. The exposure and physical vulnerability of the coastline in these countries are also unevenly distributed, and demands location specific flood-risk analysis. National methodologies for assessing extreme sea-level events generally differ in some way, e.g., the statistical methods applied in extreme value analysis, projections of future changes in extremes, and/or approaches for dealing with coastal flood risks. This includes local to regional climate change projections for the future mean sea level change and extremes, and, for instance, variations due to location, morphodynamic change, and glacio-isostatic adjustment. Next, the transformation of this knowledge to concrete coastal impact and design measures and its use in national and local governance adaptation schemes in the five countries is discussed. Here, national approaches to deal with risk, risk acceptance and uncertainty vary, among other factors, as a result of the different assessments of extreme events. In hazard and vulnerability assessments, where results are highly dependent on the availability and quality of the underlying observational data and statistical methods in use, it is necessary to gain a deeper understanding of the physical processes (i.e., the atmospheric and oceanographic genesis of storms and other contributing factors) in order to make robust strategies for adaptation and risk reduction. Inasmuch as the countries bordering the northeast Atlantic Ocean, the North Sea, and the Baltic Sea deal with similar coastal hazards and climate change challenges, the development of enhanced scientific transnational collaboration to share the existing knowledge and perspectives regarding future impact of extreme sea levels is suggested. This will provide more comprehensive and robust measures of mitigation and adaptation and it will secure a wider dissemination of results across the scientific community and levels of governance, between the northern European countries.

Keywords: Storm surges, sea level rise, extreme value analysis, flood risk, method comparison

Paper ID 343
Poster Board N°18

USGS Coastal Storm Modeling System: Envisioning California's Coastal Future

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Climate change over the course of the 21st century and beyond will significantly impact coastal systems worldwide, in particular low-lying coastal margins, due to sea level-rise (SLR) and changing storm patterns. SLR occurs gradually over a number of years, but episodic events associated with storms and climate cycles will continue to be a major cause of costly and hazardous flood events. It is therefore imperative to study both the inundation potential due to SLR as well as flooding from extreme water levels super-imposed on expected future sea levels.
The USGS Coastal Storm Modeling System (CoSMoS) is a numerical modeling system that projects coastal flooding and coastal change due to both sea level rise and storms driven by climate change. CoSMoS provides 40 different flood projections designed to meet federal and state SLR planning guidance as well as a broad range of risk tolerances. End-users are able to choose a combination of SLR scenarios ranging from 0 – 2 meters (m, at 0.25 m increments), plus a 5 m scenario, in combination with 4 storm scenarios: daily conditions during a spring tide; annual winter storm; 20-year return interval storm; and 100-year return interval storm. CoSMoS 3.0, which focuses on the 480 km stretch of shoreline extending from the U.S. / Mexico border to Point Conception, CA, also provides projections of shoreline change for both sandy beaches and cliffs.
Concurrent development of innovative communication tools that easily and effectively disseminate model projections to stakeholders has been an integral component of the project. CoSMoS projections are delivered to coastal practitioners, managers and the general public through the Our Coast, Our future flood mapper developed in partnership with Point Blue Conservation Science. Flooding projections are also used in combination with socioeconomic information to provide coastal managers with a first-order assessment of potential impacts to coastal infrastructure, homes, businesses, and ecosystems. And we have developed virtual reality SLR visualizations that help bring the information to a local and visceral level, making the information feel more real to viewers. Moreover, we have an extensive outreach program in which we partner with local boundary organizations and local stakeholders to ensure that the information we develop is utilized by as many relevant stakeholders as possible. This has resulted in the CoSMoS information being utilized by more than 600 coastal practitioners - from city to county to state partners - throughout California.
During this presentation, we will provide a brief overview of the modeling methodology, demonstrate our communication tools and provide highlights of how the information has been used by coastal professionals in both short- and long-term coastal and hazard mitigation planning, as well as climate vulnerability assessments and adaptation projects.

Keywords: sea level rise, coastal storms, virtual reality, climate change, shoreline change

POSTER SESSION
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Paper ID 345
Poster Board N°4

Coastal Flood Protection Management Under Uncertainty – the Danish Case

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In Denmark, the responsibility of coastal climate adaptation and flood protection lies with the municipalities and private house owners, while the national state agency, Danish Coastal Authority (DCA), must obtain a national overview of the flood risk in the coastal zone to guide the communities in their planning of flood risk management and flood protection measures. However, the flood challenge is never as simple as expected as flooding may occur from several sources and with different probabilities. In the community process of planning for coastal flood protection, DCA must ensure that measures do not create new challenges with flooding from other sources. For this, DCA must maintain a detailed knowledge of the numerous factors affecting the flood hazard, separately or jointly, so the potential future flood hazard can be assessed along the entire and diverse Danish coastline. As the flood hazards are governed by uncertainties, focal points to the DCA are to communicate these uncertainties in a form that supports community planning.

Looking exclusively at current coastal flooding hazards, uncertainties arise e.g. from the evaluation of tide gauge measurements and historical events in extreme value analysis, from alongshore variation in waves and water levels, and from river, groundwater and ocean water level interactions. Additional uncertainties arise from climate change models and scenarios, and natural system changes where regional or local projections of mean sea level, storminess, precipitation, storm surges and future return water levels etc. are needed. In order to optimize flood protection and risk management it is thus important to understand the causes of uncertainty and to act on a classification of 'uncertainty distributions' rather than from the median of projected changes alone.

The paper presents flood hazard mapping from a number of Danish locations based on revised extreme sea level statistics and the RCP8.5 scenario (Grinsted et al, 2015) that include multiple additional factors and their corresponding uncertainties affecting current and future flood hazards. From this the paper discusses challenges and national opportunities in providing for a diverse planning and optimal coastal flood management in time and space based on an intensified dialogue across levels of governance.

Grinsted, Jevrejeva, Riva, Dahl-Jensen (2015). Sea level rise projections for Northern Europe under RCP8.5, Clim. Res., vol. 64 doi:10.3354/cr01309

Keywords: Flood hazard, Uncertainty, Coastal planning, Climate change, Flood risk management

Paper ID 346
Poster Board N°76

Adaptation to Sea-Level Rise in the Mediterranean – Should We Stay or Should We Go?

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The high concentration of population and economic activities along the Mediterranean coasts constitutes a significant challenge for adaptation to sea-level rise. Despite the existence of the Integrated Coastal Zone Management Protocol (ICZM) of the Barcelona Convention, which calls for a common approach to coastal management in the region; and a large number of regional and national programmes addressing the challenge of climate change in the region, no comprehensive and comparative assessment of coastal impacts of sea-level rise and associated adaptation needs has been so far carried out for the entire basin. To address this gap we employ the Dynamic Interactive Vulnerability Assessment (DIVA) modelling framework to assess the long-term (until 2100) impacts of sea-level rise and to explore the potential benefits of a range of coastal adaptation measures for the Mediterranean basin. We focus on coastal flood risk and erosion and evaluate the implementation of adaptation options. For adaptation to coastal flooding we consider hard protection (in the form of dikes); setback zones, which are explicitly described in the ICZM protocol; and accommodation, in the form of household-level adaptation measures. For adaptation to coastal erosion we consider beach nourishment. In order to effectively map the solution space we assess potential impacts under a range of physical (RCP 8.5 and 4.5) and socio-economic (SSP2, SSP3 and SSP5) scenarios. Further, we use the downscaled version of the DIVA global database, which contains the latest information on coastal physical and socio-economic parameters for the Mediterranean nations.

Our results suggest that adaptation in the form of hard protection or the combination of hard protection with setback zones reduces by several orders of magnitude both the number of people affected by floods and the damages to assets. Nevertheless, substantial initial investments are required for building dikes while hard protection may be undesirable in touristic areas. Further, the implementation of setback zones involves numerous institutional and governance challenges. Accommodation, in the form of implementing measures to reduce flood damage at household-level, can effectively reduce damage costs and is relatively easy to implement. Beach nourishment for countering coastal erosion is highly cost-effective under all scenarios. However, challenges arise with respect to future sand availability but also to the large number of small pocket beaches, particularly in the eastern part of the basin. Importantly, costs of protection are unevenly distributed between countries and amount to a significant proportion of the GDP for some Mediterranean nations. We conclude that a mix of protection by dikes and setback zones in unprotected areas, as well as beach nourishment, seem to be the most efficient strategies for reducing future impacts. However, specific protection options for most vulnerable and densely populated regions, as well as for important places such as large ports and world heritage sites, will need to be considered and implemented.

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Keywords: coastal impacts, Mediterranean, adaptation

POSTER SESSION
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Paper ID 355
Poster Board N°77

Sea Level Budgets for Decision Makers: A Tale of Two Cities

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As coastal cities prepare for a future altered by climate change, understanding the processes that are causing oceans to rise now and producing accurate projections of future sea level change becomes a high priority. Despite continuing efforts, accurately projecting sea level change remains a challenge. In addition, it is unclear how we can best make use of uncertain projections of sea level rise in practice to achieve urban sustainability and resilience. Given the multiple processes that influence sea level, little thought has been given as to how individual communities can develop customized plans that benefit from our improving understanding of the individual processes that influence contemporary sea level change. One approach may involve the framework we propose here of making process-driven predictions of sea level rise. The framework could serve as a guide for decision makers to navigate the large volume of scientific news and to focus on the most relevant information from the literature for the region for which they are responsible.

For illustration purposes we focus in this presentation on two coastal populated urban areas, Boston and Miami, where in the last 25 years the sea level experienced accelerations of 3 ± 1 meters per century per century (m/cy2) and 1 ± 1 m/cy2, respectively. To interpret present-day accelerations at both cities, we model the observed sea level variability using the admittance approach based on several processes: an ongoing mass loss of Greenland and Antarctica as measured by GRACE, changes in dynamic and steric sea level as provided by the state-of-the-art ocean state estimation GECCO, and changes in the atmospheric pressure from reanalysis products. Modeled budgets for post-1990 sea-level acceleration are constrained by the tide-gauge record, to which we have achieved an excellent fit within data errors . The example is illustrative as the sea level in Boston and Miami is higher by 75–100 mm compared to the early 1990s, but the underlying processes that cause the observed acceleration differ significantly between the two locations. Ocean dynamics has dominated sea-level acceleration in Boston, whereas melting glaciers have played a secondary role. In contrast, Miami is less sensitive to the ocean-dynamic-induced acceleration and instead receives the full impact of accelerated mass loss from the Greenland and Antarctic Ice Sheets, which account for most (>80%) of the accelerated sea level rise there. The takeaway message from this analysis for response planners is the importance of monitoring the individual processes in the sea level budget. Officials in Miami will particularly benefit from following climate news related to melting Greenland, whereas officials Boston would be advised to pay particular attention to changes in ocean circulation. To put the potential effects of the individual processes into perspective, we also discuss possible future scenarios of sea level rise and what those higher oceans imply for extreme climate events, such as storm surges and flooding.

Keywords: Sea level acceleration, Sea level budget for urban planners, Sea level projection for coastal stakeholders

Paper ID 367
Poster Board N°56

Science-based Tools for Coastal Adaptation to Rising Sea Level

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Pressures on the coastal zone are increasing in response to both human- and climate-induced Pressures on the coastal zone are increasing in response to both human- and climate-induced phenomena, in particular storms and sea-level rise. To ensure critical coastal infrastructure is resilient in the future, adaptive management and timely interventions are required. Here we focus on the coastal energy sector, where critical infrastructure needs to be resilient over a 500-year timeframe when considering new nuclear power stations. Management strategies at sites of critical coastal energy infrastructure must therefore consider vulnerability to changing flood and erosion hazards as a consequence of storms and sea-level rise. To make informed decisions about the future, plausible model outputs and monitoring data are required to explore system sensitivities to storm conditions and human intervention. These data may be input to Decision Support Tools (DSTs) or Decision Support Systems (DSSs) that enable users to explore the efficacy, lifetimes and economic costs of alternative management options. Here we present model applications and scenarios considered for a DST developed for the UK energy sector as part of the Adaptation Resilience Coastal Energy Sector (ARCoES) project. A series of numerical models, forced and validated by data from coastal monitoring systems, have been used to generate a matrix of inundation scenarios at selected sites of national importance. LISFLOOD-FP has been applied as a coastal inundation model to map depth, extent and velocity of flood waters from extreme coastal and riverine events under rising sea levels. Future sea-level projections have been chosen to represent the high-end emission scenarios up to 2500AD. Incremental increases in mean sea level have been combined with joint-probability storm tide and wave conditions for a range of event severities. Wave overwashing or overtopping volumes have been calculated for various defences, hard engineered, sand dune or gravel barrier using XBeach-G and XBeach. The use of XBeach and XBeach-G has enabled the role of storm-driven beach morphology to also be considered within the impact assessment. All modelled data are visualized within a web-based geospatial DST. This web-based tool enables the user to identify infrastructure and emergency access routes that could potentially be ‘at risk’ to future marine flooding. The simulated conditions currently apply present-day management and defence options, allowing the user to identify ‘tipping points’ in the resilience of the current management practices. When combined with information on potential interventions to mitigate this future flood risk, users are thus able to make informed decisions in a timely manner to resource and plan new coastal management priorities.

Keywords: Sea Level Rise, Adaptation, Decision Support Tools, Modelling, Energy Infrastructure

POSTER SESSION
Session 5: Coastal zone

Paper ID 374
Poster Board N°53

Contrasting Sea Level Rise and Geomorphic Influences on Storm Tides for Dredged Harbors

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In recent centuries, human activities have greatly modified the geomorphology of coastal regions, yet studies of historical and future relative sea level (RSL) rise impacts on coastal flood extremes typically ignore the influence of geomorphic change. Here, we evaluate the influence of 20th Century manmade changes such as dredging and wetland landfill on present-day storm tides for the New York City metropolitan area. The analysis includes the port of New York/New Jersey and nearby Jamaica Bay, a heavily dredged and landfilled urban harbor/estuary. Our work creates and validates hydrodynamic models for the 19th century, based on detailed maps of bathymetry, seabed characteristics, and tide observations, for use alongside existing 21st century models.

Changes to storm tides are evaluated here in the context of a complete flood hazard assessment, including hundreds of tropical and extratropical cyclones. Separate assessments were performed holding geomorphology constant and RSL constant, to isolate the differing geomorphic and RSL rise influences on storm tides. Preliminary results show that RSL rise has had a relatively static influence on storm tide increases at these locations, with 37 cm rise since 1878 leading to approximately the same rise in flood levels. The influence of geomorphic change is an increase to the 10-year storm tide for some areas of 15-30 cm (e.g. Newark Bay, Jamaica Bay), of a similar magnitude to global sea level rise from 1870s to present. Geomorphic changes to more extreme events are larger – at Jamaica Bay, for example, we find an increase of 45-50 cm in the 100-year storm tide. These results demonstrate that geomorphic change in harbors should not be ignored for studies of past or future RSL rise impacts.

Keywords: geomorphology, sea level rise, dredging, storm surge, probabilistic assessment

POSTER SESSION
Session 5: Coastal zone

Paper ID 376
Poster Board N°41

Forecasting Sea Level Rise impacts on Coastal Landscapes

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Coastal changes, driven by sea-level rise (SLR), vary along the coast due to differences in SLR rates, physical processes such as tides, waves, and storm frequency and intensity, ecological setting, and societal actions to manage or adapt the landscape. Broad-scale forecasts of the coastal response to SLR often simplify the impacts problem to one of flooding, wherein the projected water level is raised upon the current elevation to determine whether an area is likely to become submerged. Although this inundation or "bathtub" approach is straightforward and simple to apply, in many settings it does not reflect the widely recognized dynamics of response to SLR that drives coastal evolution. Many environments will adapt to keep pace with SLR by moving and changing, while others may fail catastrophically as they become incrementally submerged. Uncertainties in our knowledge of how the cumulative result of coastal processes, and subsequent management approaches will change as sea level scenarios increase, have made forecasting specific changes at a particular location and point in time challenging. Furthermore, limitations in the ability to forecast outcomes quantitatively at local, regional, and national scales affect whether, when, and how some decisions are made. Coastal managers require improved understanding to anticipate the magnitude and likelihood of future sea-level rise impacts on natural resources, habitat, and infrastructure, as well as to evaluate the consequences of different actions (or inaction).

Using a probabilistic (Bayesian network, BN) approach, we have developed a capability to examine and forecast the spatial and temporal variability of potential SLR impacts, and their corresponding uncertainties at a variety of spatial and temporal scales. At the regional scale, we developed coastal response model to evaluate the likelihood of inundation or dynamic landform response to SLR for the Northeastern-mid Atlantic U.S. from Maine to Virginia. Relative SLR scenarios derived from multiple sources of information, including Coupled Model Intercomparison Project Phase 5 (CMIP5) models, are presented probabilistically over timescales that complement management and planning horizons. Scenarios are used in combination with elevation and land cover information to forecast the likelihood of dynamic response for different land cover types.

We have also developed BNs to evaluate the SLR-driven evolution of barrier islands and associated habitat changes for piping plovers (Charadrius melodus), a federally-listed species that relies on beach and barrier island habitats for much of its lifecycle including breeding. This approach provides forecasts of morphology and habitat suitability under different SLR rates. To implement this approach, we use BNs to forecast the most likely (1) shoreline change rate, (2) barrier island morphology, and (3) plover habitat suitability. This framework also allows us to evaluate scenarios related to coastal management plans and/or future scenarios where shoreline change rates may differ from historical observations. Using a probabilistic framework makes it possible to portray results using standardized uncertainty terminology in a manner that can be applied to inform decision-making as well as highlight knowledge gaps and research avenues. The application to shorebirds is also generalizable to a variety of forecasting problems for natural and human-influenced coastal systems.

POSTER SESSION
Session 5: Coastal zone

Keywords: coastal response, probabilistic, morphologic change, sea level rise impacts, decision support

POSTER SESSION
Session 5: Coastal zone

Paper ID 393
Poster Board N°70

Economic Damages from Superstorm Sandy Attributable to Sea Level Rise Caused by Anthropogenic Climate Change

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In 2012, Superstorm Sandy hit the East Coast of the United States, creating widespread major storm surges and causing more than $50 billion in economic damage. The potential influence of climate change on the power and track of the storm have been debated, but sea level rise driven by anthropogenic climate change more clearly contributed to damages. Here, we attempt to quantify this effect. Between 1900 and Sandy, roughly 10-20 cm of global mean sea level rise appears attributable to human-caused warming. The global range can be conservatively applied to the Mid Atlantic coast, which has arguably experienced greater than average climate-linked rise within the same period. To quantify the potential ramifications with respect to Sandy, we simulate storm surge and damage in New York, New Jersey and Connecticut, both as they occurred, and as they would have occurred across a range of lower sea levels corresponding to different estimates of attributable sea level rise. For hydrodynamic modeling, we employ the U.S. Army Corps of Engineers' Coastal Storm Modeling System (CSTORM-MS), including ADCIRC for storm surge and separate wave modeling components. In our control surge simulation effort, we reproduce the flood depth field as observed at 456 USGS water level sensors in the target region with a bias of -0.012 m and root mean square error of 0.355 m. After employing Moving Least Squares (MLS) to remove a clear spatial correlation in error, we achieve overall bias of -0.001 m and RMSE of 0.223 m. We then simulate surge and generate flood depth fields based on 9 counterfactual sea levels from 4 to 24 cm lower than the control, using CSTORM-MS and an identical MLS adjustment. Damages for each simulation are estimated using a HAZUS model applied to mean water depth for each Census block. For intermediate counterfactual sea levels, damage is interpolated, so as to develop estimates across a continuous distribution of attributable sea level rise. We find that anthropogenic climate-linked rise is most likely responsible for more than 10% of the damages caused by Sandy. In other words, climate change likely caused multibillion dollar damages during this event. The same general approach demonstrated here may be applied to other past and future coastal storms in order to estimate sea-level-linked anthropogenic climate damages from these events and improve estimates of climate-linked damages more broadly.

Keywords: attribution, Superstorm Sandy, coastal impacts, storm surge, economic damages

Paper ID 399
Poster Board N°61

Quantifying the Role of Wetlands in Coastal Resilience and Potential Flood Impact Due to Sea Level Rise and Marsh Migration

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The recurrent flood risks due to storm surge on coastal areas in the United States are expected to increase with changing climate and growing population. Studies show that global financial losses from hurricanes will be doubled by 2100 due to the combined effect of sea level rise (SLR), more frequent and intensified storm. The increasing rate of SLR will also alter coastal wetland dynamics - causing submergence and landward movement of wetlands across the coastal landscape. While wetlands can attenuate the impact of storm surge by reducing wave energy, erosion and currents velocity, the ecosystem services provided by wetlands are likely to become more valuable and yet at the same time more threatened. Before decision makers can develop effective climate adaptation plans, they need reliable scientific information about the value of wetlands in terms of flood protection and an estimate of future inundation extent and damage caused by storm surge, SLR and marsh migration. In this study, we aim to develop and implement an integrated framework to quantify the protective value of natural and nature-based features such as coastal wetlands in the Chesapeake Bay regions. This also includes computing the precise extent to which the lands will be inundated and an estimate of potential damage caused by future SLR projections. We used a two-dimensional, shallow water hydrodynamic model coupled to a phase averaging wave model (ADCIRC+SWAN) to simulate the flooding for a set of low to high intensity historical storms. For each hurricane, two simulations are prepared: a baseline with the land cover in place at the time of the hurricane and a counterfactual simulation in which all wetland land cover is replaced with bare land. The difference in flooded area and flood depths shows the attenuation function of wetlands in the region. To estimate the dollar value of that service, we combine parcel-level residential property values with flood depth-damage functions; the difference in damages between the two simulations is our estimate of the value of the protective service provided by wetlands. Furthermore, local SLR projections are combined with respective marsh migration scenarios in the modeling approach to quantify the changes in future flood inundation and damages. Primary analysis shows that with 1.83m rise in sea level the total estuarine wetland in Virginia and Maryland will reduce up to 86% and 88% respectively. A comparison of the flooding extent for current and future scenarios suggests that for strong hurricanes total flooded area can increase up to 116 % and 78% in the coastal counties of these states. Furthermore, preliminary damage estimation indicates the property damage in Maryland alone can rise up to 1150 million USD under the projected SLR and marsh migration. In terms of valuing the current protective services, we found wetlands in the Chesapeake Bay region provided protective services in all five of the hurricanes we analyzed, ranging in value from $55 to $454 million. The value is highest for the worst hurricanes meaning that wetlands may become increasingly valuable with climate change and SLR.

Keywords: "Registration Fee" "Per Diem for 2 nights"

POSTER SESSION
Session 5: Coastal zone

Paper ID 401
Poster Board N°22

Shoreline Retreat at Country Club Beach, Durban, South Africa: Is this a Manifestation of Sea Level Rise or Restored Equilibrium?

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Durban is a tourist city with the beach being its number one attraction. CountryClubBeach is located within Durban's northern coastline. This is an urban beach located within the Durban Bight, a log-spiral bay on the southeast African coast. The Durban coastline has been transformed by the siting of a harbour mouth to the south which interrupted the south-north littoral drift, necessitating a beach nourishment scheme (831 008 cumecs supplied in 2016). The northern beaches were revamped in 2012: a concrete promenade was constructed, fronted by stabilised and vegetated dunes, which moved the high water mark (HWM) 20-30m seawards. There is limited space available as the northern beaches are squeezed between a highway and the Indian Ocean.

Storm waves are predominantly from the east to south-east during summer and autumn, usually associated with tropical disturbances in the south-west Indian Ocean and low pressure troughs, and from the south to south-east during winter to spring, associated with cold fronts and cut-off low (COL) pressure systems. However, the COL pressure systems can occur at any time of year. Research by the authors has shown that the south-east swells cause most beach erosion. A number of high-swell events have impacted the KZN coastline in recent years, most notably the second largest recorded event (Hs 8.5m, Hmax 14m) during 19-21 March 2007 coincident with the highest tide of the year, followed by high-swell events in July-August 2011, 24 August - 18 November 2014 and 3 - 7 October 2016. Storms often occur in clusters, resulting in progressive erosion, as was experienced during austral spring 2014. The beaches recovered within two years of the 2007 event, and within six months of the 2011 storm clusters. However, since 2014 full recovery did not occur. Country Club beach experienced significant erosion following a high-swell event in October 2016 (Hs 4.7m, Hmax 10.1m) culminating in the loss of 20-30m of beachfront by mid-November 2016. This erosion placed the HWM where it was before the 2012 dune stabilisation and beachfront revamp.

Sea level rise (SLR) at Durban is 2.7mm p.a. (Mather et al 2009). Is the Country Club Beach shoreline retreat due to SLR, increasing storm frequency or decreased sediment supply? Or is it simply the restoration of a HWM equilibrium? South Africa has experienced a drought since 2015 (associated with El Nino) which has reduced sediment supply to the coast. Durban's beaches are artificially sand nourished, but this only re-supplies the southern beaches where the sand is currently pumped, with progressively less supply reaching the central beaches and more limited sediment capable of reaching the northern beaches. The present northern beaches coastal retreat is probably a combination of all these factors. El Nino drought conditions may play a major role as the beaches are not being resupplied with sufficient sediment. While beaches may ultimately recover to a degree between storm events, going forward the local municipality will need to decide whether to accept defeat and retreat or pay the escalating cost of defending against SLR.

Keywords: Shoreline retreat, coastal erosion, high swell events, sea level rise

Paper ID 405
Poster Board N°37

A Web Platform for Understanding Global and Regional Sea Level Projections

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Future sea level change will expose coastal communities around the globe to significant socioeconomic risk. Accurate regional sea level projections are therefore necessary for assessing future flood and inundation hazards so that mitigation resources can be properly allocated. Projecting sea level is an inherently interdisciplinary problem though, requiring expert input from a number of often-disparate scientific communities. Furthermore, when new studies are published, they can be inaccessible to the very stakeholders they intend to benefit. We have sought to address both of these challenges by developing a web platform to assemble the current body of sea level projection research. Our platform allows non-scientific stakeholders to explore the most up-to-date peer-reviewed sea level projections. Advanced functionality allows scientific users to break projections into their constituent components, allowing the user to add, subtract, or change various projections of each sea level component. Our approach allows new research or model runs in one discipline to instantly be incorporated into the larger context of total regional sea level change. The tool gives a way to view the range of future sea level scenarios for an area of interest in a manner that is intuitive and representative of the current state of knowledge of the scientific community. Additionally, the user is given an interactive projection map and has the ability to select any ocean location to view a time series of sea level change to 2100.

Keywords: Sea, Level, Projection, Web, Framework

Paper ID 413
Poster Board N°5

Modeling Future Sea Level Impacts to Guide Planning and Policy in the Hawaiian Islands, United States of America

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Understanding the impacts of future sea-level rise (SLR) on coastal process is critical for future planning. Hawaii's future, like that of other South Pacific islands, depends on maintaining healthy coastal resources. Yet, a recent study finds that over the past 80 years, roughly 70% of three of the most-populous Hawaiian Islands show long-term historical shoreline retreat.
In response to concerns, the Hawaii State government proactively passed Act 83, which requires a SLR vulnerability and adaptation report be completed by a consortium of government agency heads. Researchers at the University of Hawaii modeled: (1) static and groundwater inundation to establish a baseline of potential flood impacts; (2) coastal erosion of sandy shorelines including possible impacts of SLR; and (3) annual wave inundation (runup and overtopping) to show the impact from dynamic wave events. Tetra Tech, a private consultant, modeled the 100-year flood and performed an SLR vulnerability and adaptation assessment. The report relies on this research, to be used by legislators, planners, and other State decision-makers for use in formulating policies to protect against the impacts of SLR.

From our experience engaging with planners, legislators, and coastal managers, successful communication of sea-level science to inform policy-makers must bridge the gap between what science is capable of achieving (taking into account the complexity of physical processes and compounding uncertainty in applying models to limited data) with what policy-makers inevitably want: a clear-cut map of impacts devoid of uncertainty.

Keywords: coastal hazards, policy, reefs, erosion, inundation

POSTER SESSION
Session 5: Coastal zone

Paper ID 420
Poster Board N°47

On-line Decision Support Tools to Quantify and Visualize Local Sea Level Rise Scenarios

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Decision support tool users gain a powerful teaching, planning, and design aid when they can quantify and visualize potential impacts from sea level rise and coastal nuisance flooding. Projections of future sea levels are often represented by scenarios due to the combination of uncertainty about the extent and timing and the potential high consequences. Despite the uncertainties inherent in a scenario approach, U.S planners and engineers have become familiar with planning for change sea levels using these scenarios. The capability of coastal communities and practitioners to plan under deep uncertainty has been supported for a number of years by the U.S. Army Corps of Engineers (USACE) Sea Level Change Calculator and National Oceanic Atmospheric Administration's (NOAA) Sea Level Rise Viewer. The calculator provides elevation information for various scenarios of sea level rise and supports comparisons between scenarios produced by different groups. This information is used in elevation-based screening-level vulnerability assessments and climate preparedness and resilience planning and engineering design for USACE coastal projects. The viewer maps the potential impacts of various sea level rise and coastal nuisance flooding scenarios and provides access to the supporting geospatial data that can inform climate-related planning activities. Both tools now deliver the latest actionable science on local sea level rise scenarios by incorporating data from the 3rd and 4th U.S. National Climate Assessments. Technical and non-technical users value both tools for their ability to communicate thresholds and potential impacts of various sea level rise and coastal nuisance flooding scenarios. The tools complement each other by providing actionable and site-specific detail on projected flood elevations for 5-year intervals from 2010 to 2100 and elevation and inundation depth information. Their combined output can be used by floodplain managers, community resilience staff, professional engineers, and surveyors, in conjunction with other local information, to plan and design for future sea levels. This presentation will describe the methods used to develop each tool as well as demonstrate their functionality.

Keywords: Decision Support Tool, local scenarios, visualizations, vulnerability assessment, nuisance flooding

Paper ID 425
Poster Board N°17

Assessment of Damage and Adaptation Costs of Coastal Flooding Under Sea Level Rise in Coastal China

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In China, more than 40% of the population live in coastal areas, which contribute nearly 60% of the national gross domestic product. These areas are experiencing frequent storm surges and coastal flooding which has caused US$ 76.74 billion direct economic losses and 7138 fatalities from 1989 to 2014. As consequences of global climate change and land subsidence, plus the growth of population and assets exposure in coastal China, the flood risk has increased, and will continue to increase if no further adaptation measures are taken. Given China's rapid urbanisation, it is crucial to identify what the future impacts of coastal flooding in China will be, and how these trends may alter under changing climatic conditions (e.g. sea level rise) and anthropogenic drivers (e.g. enhanced subsidence), and what adaptation can be undertaken to reduce possible risks. Presently, there is no combined national and regional assessment of future flooding, damage and adaptation costs due to sea-level rise in China.

This research quantitatively assesses damage and adaptation costs of coastal flooding in China using the Dynamic Interactive Vulnerability Assessment (DIVA) modelling framework. To achieve this, impacts under a range of RCPs (Representative Concentration Pathways, RCPs) climate scenarios representing future sea-level rise, SSPs (Shared Socio-economic reference Pathways, SSPs) representing socio-economic change have been analysed. These are combined with new data on coastal characteristics, subsidence and current protection standards. To assess future impacts under human intervention, subsidence control plans and protection plans from the Chinese government reports have been included.

Preliminary results show that 25-123 cm of relative sea-level rise in China is projected in 2100. Including subsidence, the results suggest that 28.2 million people are expected to be flooded annually under a 100-year flood event in 2100. The related floodplain area has an extent of 81,000 km2 and US$ 7.19 billion assets are at risk. If human-induced subsidence is not considered, these numbers decrease: 76,000 km2, 25.6 million people and US$ 6.34 billion assets are then exposed to the 100-year flood event. Furthermore, flood risk is most serious in coastal mega-cites, e.g. Shanghai and Tianjin, because of local human-induced subsidence.

For protection, the number of population affected by flood is up to 4.3 million per year if the protection level keeps constant under worse case, while the number drops to 0.5 million population per year with enhanced protection. This study emphasises that future control of subsidence and enhanced adaptation lessen flood impacts effectively by at least one order of magnitude.

Keywords: Impact assessment, scenario analysis, subsidence, protection

Paper ID 429
Poster Board N°7

Impact of Sea-Level Rise on Biophysical and Socioeconomic Characteristics in the Volta Delta, Ghana

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Delta regions are dynamic and rich coastal environments with diverse economic activities that provide some of the most densely populated areas on the earth. Delta history over the last few thousand years is strongly controlled by sea-level rise. Today and in the future, deltas are being shaped by multiple factors such as climate-induced eustatic sea level rise; natural and human-induced subsidence; changes in sediment delivery to the coastal zone due to catchment changes, especially construction of dams on major rivers, intensified agriculture and/or aquaculture, and mining and urbanisation. These environmental challenges have significant implications for the livelihoods of delta residents. Thus, the integrated assessment of deltas as coupled biophysical and socio-economic systems and how they respond to environmental stress, including sea level rise, is now attracting the attention of the scientific research community. This attention has mainly been focused on the major deltas to the detriment of smaller but regionally significant ones, such as the Volta delta, Ghana. For this delta previous scientific studies are limited, with most focus on the upstream Volta River basin. Many contemporary problems as a result of the impact of sea level rise are recognised in the Volta delta, especially erosion and flooding of the open coast fringe, such as at the towns of Keta and Fuvemeh. This has resulted in economic hardship, increased migration out of the delta and environmental degradation. It is projected that subsidence as a result of increased hydrocarbon exploration activities along the Volta delta coast and irrigated farming practices will further increase the impact of sea level rise in the future. Between 2013 and 2016, the shoreline in Fuvemeh eroded at a rate of about 3 m/yr. Within this period, flooding from energetic wave activities, and possibly aided by sea level rise, destroyed about 50 houses and displaced over 250 inhabitants. In Keta, coastal erosion has destroyed about 5000 houses since 1960s and endangered over 500,000 people. Although groynes and revetments approaches have been adopted to manage erosion and flooding in Keta, how these defence structures and the entire Volta delta systems will respond to the impacts of sea level rise in the future is not fully understood. This paper reviews various factors, including non-climate components that are driving sea level rise in the Volta delta and how the biophysical characteristics and socioeconomic factors will readjust to the change in the future.

Keywords: Sea level rise, Volta delta, socio-economic, biophysical, climate change

POSTER SESSION
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Paper ID 430
Poster Board N°51

The Effectiveness of Nature-based Solutions for Risk Reduction in the Coastal Zone: What We Know and Don't Know

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As exposure to hazards in the coastal zone increases globally there is growing interest in nature-based solutions for risk reduction. This paper provides an overview of the state-of-art in field and laboratory evidence of the effectiveness (or not) of nature-based solutions for risk reduction in the coastal zone. This overview is based on recently published studies analyzing datasets of field measurements in coastal habitats and numerical models of the role of wetlands in hurricane damage reduction. Syntheses of global datasets of wave measurements and restoration projects in multiple coastal habitats quantify and help understand when and where these solutions may be physically and economically effective. Coral reefs are the most effective in reducing wave heights but also the costliest to restore. Mangroves and salt-marshes tend to be a lot cheaper to restore though they generally favour less energetic coastlines. Under the right conditions, mangrove restoration can be 2-4 times more cost-effective than equivalent submerged breakwaters. In comparison with data on wave reduction, less is known about the role of coastal ecosystems during storm surges and particularly, their economic value for risk reduction during extreme events. In addition to the global review, this paper briefly examines the role and value of coastal wetlands during extreme events. Recent estimates have shown that coastal wetlands avoided more than US$ 625 million in flood damages across 12 states. However, the magnitude of this reduction – and hence the effectiveness of these wetlands – varies widely from county to county. Together, these studies demonstrate the necessity for continued, rigorous evaluations of coastal ecosystems to understand their impacts on coastal flood risk. Measuring these impacts is crucial, both for providing accurate risk assessments as well as appropriately advancing conservation and restoration activities for risk reduction in the coastal zone.

Keywords: Natural Defenses; Coastal Risk; Flooding

POSTER SESSION
Session 5: Coastal zone

Paper ID 431
Poster Board N°12

Application of Information and Communication Technologies for Coastal Governance and Sustaining Fishery Sector in Indo-Pacific and Beyond

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The Indo-Pacific is the largest marine bio-geographic area on the globe, spanning an area from South Africa to Mexico, and providing habitat for many thousands of species. Marine and inland fishery are the fastest developing sector in the world and there is an increasing need for appropriate governance through information and communication technologies (ICTs) for its sustainable development in Indo-Pacific region . Lack of information and communication facilities in fishing communities inhibits the social, political and economic empowerment of the majority of the population. ICTs played an significant role in all aquaculture community across the world since the dawn of civilization to examine long-term sea-level variations and their implications for past climate change in Indo- Pacific region . The world is experiencing an Information Communication Technology revolution, a revolution that has enormous socio-economic implications in the global and regional sea-level change aiding fishery sector in developed and developing countries of Asia-Pacific and European region . Several research and training institutes has undertaken different initiatives in ICTs which are also facilitating in expanding and developing the time scale for extreme sea levels and waives and its impacts on the aquatic resources . However, coastal communities continue to be unable to access to adequate technical and managerial information on global and local sea level change which is required to improve their practices to enhance aquatic production and continues to be crucial for development of coastal resources under the challenges of climate vulnerability as well as sea-level variability on timescales of months to centuries, at the local, regional and global levels.

Therefore, ICTs are essential for ocean governance and also to aid the efforts towards sea level rise so as to achieve the sustainability of the fishery resources to mitigate impacts and adaptation assessments and wider management of coastal zone .

This presentation deals with issue involved in conclave of fisheries management ,coastal and estuarine resources planning ,coastal risk and vulnerability , social-ecological vulnerability and resilience in coastal region , Human Pressures on Coastal Environments, land water-seawater interactions, economic issues and challenges related to Indo-Pacific aquatic resources due to seal level change.

This presentation deal with the role of ICTs in governance of fishery sector to examine long-term sea-level variations and their implications for past climate change in Indo- Pacific region . It aims at discussing the new ICTs which are being used across the globe in coastal zone management for resource assessment, capture or culture to processing and commercialization as to achieve the sustainability of the fishery resources to collect the information and data required to mitigate impacts and adaptation assessments and wider management of coastal zone .

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Keywords: Coastal Zone, Extreme Sea Levels, Global And Regional Sea-Level Change, Data Analyses For Sea Level Changes, ICTs For Ocean Governance

POSTER SESSION
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Paper ID 432
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Impacts of Climate Change on Sea – level and Coastal Resilience Plans

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"This Research paper discusses two most important aspects which are instigating rise in sea levels due to climate change. These two mechanisms are glacier melting and increase in ocean temperatures. Due to rise of sea levels, the communities have threats of high tides, storms and salt water intrusions. The effects of climate change are expected to further deteriorate situation around coastal areas. Current challenges that disturb man-made infrastructure and shoreline ecologies, such as coastline corrosion, sea flooding, and water contamination, is already an alarm in several regions. Facing the added strain of climate change may necessitate innovative methodologies for land, water, waste, and ecosystems management. Increasing populaces and development along the seashores intensify the susceptibility of sea environments to sea level rise. The paper further elaborates the coastal resilience plans that are prepared after learning lessons from the best resilience strategies adopted by different coastal areas around the world. The main focus is on increasing resilience of coastlines by protecting natural barriers, hardening artificial barriers and educating people about these threats".

Keywords: Key Words: Climate, Change, Sea-level, Resilience, Plans

Paper ID 435
Poster Board N°44

Study of Land Use Changes in Coastal Zone and the Response to Climate Changes in Taiwan

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More than 70% of large cities are located along the coast due to abundant natural resources and facilitated sea transportation. The number of CCAs (Coastal Cities and Agglomerations) has dramatically increased 4.5 times during the past 60–70 years. The demographic trends show over 75% of the global population will live in coastal communities before the end of this century. Research found economic development in the coastal region will speed the growth of real estate markets and change the land use and land cover. The coastal zone is a dynamic environment located on the interface between marine and territorial habitats and freshwater and salt water systems. The coastal land use and cover changes not only alter the coastal environment but affect the interaction between the marine and territorial systems. Moreover, the impacts from climate change increases the complexity of the coastal environment. Taiwan is an island country with 36,000 km2 of territorial area. Because two-thirds of the land is hillsides not suitable for development and the population has increased to 23 million from 21 million since 1998, the percentage of coastal land use is increasing rapidly, and conflicts among different land-use types along the coast have risen dramatically. Along the 1,140 km shoreline in Taiwan, approximately 55.5% of the shoreline was composed of artificial shorelines in 2011. Due to the critical need for comprehensive coastal planning, Taiwan just passed the Coastal Management Law this year (2014). In the law, the concept of climate change adaptation is clearly illustrated in “shore land area” and “offshore area.” The sea level rise will attack the high-density coastal cities, and the land use types will affect the risk levels. This proposed research will focus on the relationship between sea level and land use changes along the shore and the related impacts to the offshore environment. Coastal cities in Taiwan will be studies, and a localized adaptation model will be generated through the land use change analysis and adaptation indicator examination.

Keywords: Coastal Zone, Climate Adaptation, Comprehensive Coastal Planning

Paper ID 438
Poster Board N°79

Population Distribution Modelling and Its Spatial Pattern in the Yangtze River Delta Region, China

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We used a multiple regression model method in a GIS environment to combine a variety of data sets, including the census, administrative division, land use, DEM, road, river, school and hospital data to generate a 200m by 200m gridded population of the Yangtze River Delta region, and analyzed the population spatial distribution pattern in both the delta region and its low elevation coastal zone (LECZ). Our findings show that the population distribution is uneven, which forms hot and cold spots of population distribution. Laoximen community in Shanghai has the highest population density up to 101700 /km2, comparing with the average population density of 675 /km2 in the whole region. The LECZ, distributed within a distance of 190 km from the coastline, accounts for 33.5% of the total land of the delta region. 37.7 % of the LEZC is distributed below 4 m, 61% of the LECZ is within 60 km distance from the coastline. The LECZ covers about half of the total population of the Yangtze River Delta. 90% of the population in the LECZ distributes at an altitude below 7 m. The higher population density concentrated in the altitude of 0～4 m, with density larger than 10 000 people/km2, and the maximum density up to 32 000 people/km2 is at 3 m a.s.l. Population is highly concentrated in a small area in the LECZ. 8.94% of the population with density larger than 30 000 people/km2 is concentrated in only 0.16% area of the LECZ. The area with population density larger than 3 000 people/km2 only accounts for 4.58% of the total LECZ region, but it covers 49.06% of the total population.

Keywords: Population, spatial pattern, low elevation coastal zone, Yangtze River Delta, China

Paper ID 442
Poster Board N°13

The Need for a Shift in Climate Change Adaptation Language

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The language of climate change adaptation in the IPCC documents and elsewhere centers around protection, accommodation, and retreat with a general consensus that, moving forward, all three will be necessary. However, such nomenclature has the potential to be maladaptive in the long-term. Specifically, use of the word protection to describe hard engineered structures is inconsistent with the general principles of adaptation, including the concept of co-benefits, robustness to a range of possible futures, and an emphasis on long-term outcomes. Focusing on coastal vulnerability to sea level rise and flooding, we argue that use of the word protection in climate adaptation plans is inappropriate for the following reasons: (1) physical barriers may reduce hazard in the short-term but are not adaptable to changing conditions, (2) seawalls can increase damage by inhibiting drainage of flooded areas and disrupting natural systems, (3) so-called protective structures can create a false sense of security, thus encouraging development in hazard prone areas, and (4) barriers do not enhance resilience, and thus when they fail, populations may be highly vulnerable to disasters. We propose that hard engineered structures should be classified as "near-term hazard reducing measures" with the understanding that they may increase residual risk, and that true adaptation builds resilience through accommodation and planned retreat. The efficacy of an adaptation plan depends not only on hazard and exposure, but also on community understanding of, and response to, various strategies. Thus the language used to communicate climate preparedness should accurately reflect the short- and long-term risk of climate related disasters and avoid mislabeling near-term hazard reduction as protection.

Keywords: adaptation, sea level rise, risk perception, resilience, communication

Paper ID 443
Poster Board N°63

Characteristics of the Relative Sea Level in Abu-Qir Bay, Alexandria, Egypt

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Relative sea level variability in Abu-Qir Bay, Alexandria, Egypt was investigated for a period of 21 years from January 1990 to December 2010.The recorded hourly water level ranged from0.01 m to1.0 m above the zero level of the tide gauge. The monthly mean sea level varied between 0.22 m in January 1990 and 0.68 m in November 2009. The annual mean sea level ranged between 0.35 m in 1990 and 0.55 m in 2004, with a general trend of increase over the study period with a rate of 6 mm/year.

The World Tides package was used for the sea level analysis; in order to get the astronomical tides and surge elevations over the study period. Both the amplitudes and the phases of the five main tidal constituents namely: O1, K1, N2, M2 and S2 were constructed. Over the study period, the Mean Sea Level (MSL) in Abu Qir Bay was 0.47 m, and the semidiurnal type of tides in the Bay was confidently determined. The surge level varied between -0.49 m and +0.51 m over the period of investigation.

The statistical characteristics of sea level, astronomical tides and surges were examined over the study period. The frequency of occurrence was calculated for both: the sea level and surges. While the 0.5 m water level had the highest frequency of occurrence (16.6%), the one meter level had the lowest one (0.003%). For the surge elevations, the frequency varied between 0.001% and 16.3% for the surge levels of 0.55 m and 0.005 m, respectively. The empirical relationships between years and heights for both water and surge levels were constructed in the present work. Results of the present study revealed that no extreme year had been observed during the study period. The calculated regional factor of flooding risk for Abu-Qir Bay according to the present data set is 0.97.

Keywords: Relative sea level, Abu-Qir Bay, Astronomical tides, Surges, Return periods, Risk probability, Flooding factor

Paper ID 445
Poster Board N°84

Numerical Study of Coastal Flooding on Combined Impacts from Tide, River and Storm Surges in the Coastal Areas of Shanghai, China

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Shanghai, the biggest economic entity in China, is inherently vulnerable to coastal flooding because of its low-lying topography (3-4 m elevation), long coastal line (172km) and flat peninsular shaped landform surrounded by Yangtze Estuary and Hangzhou Bay. With a massive freshwater discharge from Changjiang River and the highly possible coincidence of Tropical storm impact from western Pacific during summer, the coastal flooding in Shanghai can be extremely severe (threat to the city's safety). The interaction of astronomical tides, storm surges, and bay convergence amplification may lead to more complex, variable, and abrupt disasters. In order to better understand the flood risk at the local city level of Shanghai, coastal flooding process is reproduced. Use is made of numerical simulation of MIKE11, MIKE 21 and Typhoon cyclone coupled model to simulate the worst possible scenario of coastal flooding when the time of storm surge coincides with astronomical high tides and Changjiang River spate. These combined effects of disaster chain are applied to a digital elevation model (DEM) to illustrate the extent, duration and intensity to which coastal areas are susceptible of overtopping and associated onshore inundation using calibrated hydrodynamic parameters. The results indicated that the horizontal extent and intensity of coastal flooding depends on factors such as typhoon intensity, seawalls criterion and onshore and offshore topography. Spring tidal amplitude (~2m) superposition with storm surge (~1.5m by 2002 Typhoon Rammasun) along with complex coastal geometry comprising of bay, islands and several river drainage systems cause differential flooding along the coastal regions. The risk level is quite high at South Coast of Shanghai as tide and storm surge is amplified when propagation into Hangzhou Bay, and the convergence effect additionally increased the water level up to ~0.4m at inner part of the bay. The risk level is even more severe at North Coast of Shanghai although fetch and the resultant wind-waves is reduced due to sheltering of islands at mouth bar, however the back water effect due to massive discharge from Changjiang River (80,000m3/s) could additionally increase water level up to ~0.5m around Huangpu River outlet. The computed possible maximum tide level along the coast was around 4 m, which caused seawall failure and can penetrate the river system and inundate low-lying areas along riverbanks. The inundation occurred along 115 km coastal stretch (67% of the seawalls), with inland penetration distance reaching a maximum of about 10-15km at certain low-lying areas in Jinshan District and south bank of Huangpu River. The estimated total inland inundation was about 700km2 along the coastal belts and major riverbanks, with average inundation depth 0.3~0.4m. The long duration of inundation retreating (>10day) due to trough effect indicates the significance of pumping and drainage system design in coastal flood disaster management in such a low gradient landscape of Shanghai, while conservative dike systems reinforcement is still the priority.

Keywords: storm surge, coastal flooding, Shanghai

POSTER SESSION
Session 5: Coastal zone

Paper ID 449
Poster Board N°55

Recent Efforts for an Increased Coordination of Sea Level Monitoring in Europe : EuroGOOS Tide Gauge Task Team

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EuroGOOS (http://www.eurogoos.eu/) is an International Non-Profit Organisation committed to European-scale operational oceanography within the context of the Global Ocean Observing System of the Intergovernmental Oceanographic Commission of UNESCO (GOOS, IOC). For a more efficient coordination EuroGOOS has established a number of Task Teams, each focusing on one marine observation technology (HF-Radars, Tide Gauges, Gliders, ARGO floats, Marine Mammals, Fixed Platforms and FerryBox), that promote scientific synergy and technological collaboration among European observing infrastructures. Task Team members exchange open source tools, collaborate in areas of common interest, and jointly make European data available to the EuroGOOS ROOS regional data portals, which in turn are feeding data to the European Marine Observation and Data Network (EMODnet) and Copernicus Marine Environmental Monitoring System (CMEMS). Task Teams are set up within the framework of the European Ocean Observing System (EOOS), setting out a vision for an integrated end-to-end ocean observing in Europe.

The importance of sea level hazards and the increasing need of tide gauge data, based on recent coastal disasters (tsunamis, storm surges), and the projections of sea level change in the future, has yielded the establishment of the EuroGOOS Tide Gauge Task Team (EuroGOOS TGTT: http://www.eurogoos.eu/tide-gauge-task-team/), that has the role of bringing together the European and adjacent seas tide gauge community by: compiling information on existing sea level networks, providing expertise on tide gauge observations to operators and scientists and supporting national and regional sea level initiatives to maintain a permanent and sustainable system.

The EuroGOOS TGTT launched a questionnaire in 2016 to evaluate the problems of the existing national tide gauge networks: maintenance, spare parts, personnel, etc. One of the main conclusions was that more than half of the institutions and near 30% of the tide gauge stations in Europe and adjacent coasts would be facing problems of funding in some way. There is an urgent need therefore of ensuring the sustainability of tide gauge stations in the region. The questionnaire has also provided information on the current status, characteristics and main applications of existing stations.

With the aim of recovering a platform for the communication and exchange of experiences between operational and scientific/user sea level communities in our region, a first workshop was held on La Rochelle in November 2016, with presentations about status of existing national networks in Europe and nearby countries, sea level measurements technologies, new requirements on quality control and data processing, etc. Back-to-back a side meeting was held at the OST/ST International Congress on Satellite Altimetry: Altimetry and tide gauges for sea

level, from which a list of recommendations from the altimetry community to the EuroGOOS TGTT was prepared.

This initiative is not trying to replicate previous and existing efforts but rather fostering collaboration, scientific and technological development and by this enhancing the European and adjacent countries capacity, under the new umbrella of international programs of data exchange such as CMEMS, as well as the existing ones such as the Global Sea Level Observing System (GLOSS) or the Permanent Service for Mean Sea Level (PSMSL).

Keywords: tide gauges, international coordination, coastal sea level monitoring, sustainable multi-purpose networks

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Session 5: Coastal zone

Paper ID 451
Poster Board N°24

Assessing Climate Change Impacts at the Coastal Land Margin with Transdisciplinary Research Outcomes

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Our extensive transdisciplinary efforts since 2010 in the northern Gulf of Mexico (Mississippi, Alabama, and the Florida panhandle) have resulted in an advanced capability to model and assess hydrodynamic and ecological impacts of climate change at the coastal land margin (visit http://agupubs.onlinelibrary.wiley.com/hub/issue/10.1002/(ISSN)2328-4277.GULFSEARISE1/). The concerted efforts of natural and social scientists as well as engineers have contributed to a paradigm shift that goes well beyond "bathtub" approaches. Potential deleterious effects to barrier islands, shorelines, dunes, marshes, etc., are now better understood. This is because the methodology enables assessment of not just eustatic sea level rise (SLR), but gets to the basis of projections of climate change and the associated impacts, i.e., carbon emission scenarios. The paradigm shift, input from coastal resource managers, and future expected conditions now provides a rationale to evaluate and quantify the ability of natural and nature-based feature (NNBF) approaches to mitigate the present and future effects of surge and nuisance flooding.

Over the majority of the 20th century, the largely linear rate of eustatic SLR was realized by thermal expansion of seawater as a function of a gradual increase in the average annual global temperature. Global satellite altimetry indicates that the rate of global mean SLR has accelerated from approximately 1.6 to 3.4 mm/year. While the year-by-year acceleration of the rate of rise cannot be measured adequately, it is reasonable to assume that it was relatively stable throughout the 20th century. For the 21st century, general circulation models project that posed atmospheric carbon emission scenarios will result in higher global average temperatures. A warmer global system will introduce new mechanisms (e.g., land ice loss, isotatic adjustments, and changes in land water storage) that will contribute to relatively abrupt changes in sea state levels. The additions to thermal expansion will drive higher sea levels and the increases in sea level will be attained by further accelerations in the rate of the rise. Because of the nature of the new mechanisms that will govern sea levels, it is unlikely that future accelerations in the rate of rise will be smooth.

To further address the complications associated with relatively abrupt changes in SLR and related impacts of climate change at the coastal land margin we intend to: (1) refine, enhance, and extend the coupled dynamic, bio-geo-physical models of coastal morphology, tide, marsh, and surge; (2) advance the paradigm shift for climate change assessments by linking economic impact analysis and ecosystem services valuation directly to these coastal dynamics; (3) pursue transdisciplinary outcomes by engaging a management transition advisory group throughout the entire project process; and (4) deliver our results via a flexible, multi-platform mechanism that allows for region-wide or place-based assessment of NNBFs. This presentation will share examples of our recent efforts and discuss progress to-date.

POSTER SESSION
Session 5: Coastal zone

Keywords: Natural and nature-based features, surge/nuisance flooding

Paper ID 463
Poster Board N°43

Characteristics of Residual Water Level Variation along China Coast and its Relation to Sea Level Change

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Using 25 stations' tide data, this paper preliminarily investigate the characteristics of residual water level variation along China coast, and its relation to sea level change during 1980-2012. The Residual water level along China coast shows significant seasonal variation. The residual water level variation presents obviously regional characteristics, and the amplitude of variation is big in the south coast, small in the north part. For temporal variation, annual mean residual water level basically shows no clear tendency change during 1980-2012, but it has a 2-5a periodic signal. Residual water level time variation and spatial distribution characteristic along China coast all show different characteristics with mean sea level, however, the Residual water level has an impact on short-term sea level change.

Keywords: China coast, residual water

POSTER SESSION
Session 5: Coastal zone

Paper ID 466
Poster Board N°42

Robust Coastal Protection under 21st Century Sea-Level Rise

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Coastal flood risk is increasing throughout the world due to rising sea-levels and growing exposure of population and assets. A number of studies have explored the global implications of increasing coastal flood risks, few studies have explored adapting through coastal protection, but no study has addressed the questions if and where protection is economically robust across a full range of sea-level rise (SLR), socio-economic development (SED) and discount rate uncertainty over the 21 st century. This study provides such an analysis using the DIVA framework and a global database of 12.148 coastal segments.

We find that for 12% of the global coastline it is economically robust to invest in protection (i.e. protecting is cheaper than not protecting under every scenario considered). These 12% of coastline account for 84% of global coastal floodplain population and for 91% of assets in the global coastal floodplain.

Keywords: costal protection, DIVA framework

POSTER SESSION
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Paper ID 468
Poster Board N°14

European Sea-Level Science, Research and Innovation Policy

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The European Commission remains strongly committed to spearheading investment in research and innovation that will assist us all to better adapt to climate change. Sea-level rise remains one of the most important coastal hazards associated with anthropogenic climate change, particularly when we think about longer-term coastal adaptation and management. We will continue to work towards implementing the Paris Agreement and its goals on adaptation, of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring adequate adaptation responses. The European Commission will highlight the need to strengthening scientific knowledge on climate, including sea level research, systematic observation and early warning systems, in a manner that informs climate services and supports decision-making.

Keywords: European Sea-Level Science, European Commission, Paris Agreement

POSTER SESSION
Session 5: Coastal zone

Paper ID 469
Poster Board N°6

Characterization and Prediction of Harbour Oscillations

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Harbor oscillations (also called seiches) may have dramatic coastal impacts. Such strong events occur in many harbours around the world. These vertical water level oscillations, which can can generate significant surging, are associated with strong horizontal currents which seriously affect operations and cause severe and expensive damages on harbour facilities and moored ships. The aim of our work is to provide to harbour authorities a model capable to predict such events to prevent damages and secure harbour procedures.

Harbours are semi-enclosed basin with natural resonant periods given by geometry and bathymetry of the basin. Hence, the first effort of this work consists in the characterisation of the eigen periods for each harbours along the French metropolitan coast. This characterisation is done using both the analysis of in-situ tide-gauge data and mild-slope equation model (Berkhoff, 1972) results. Consistent results are found between the two methods and show a large range of resonant-periods from a few tens of seconds to several hours.

Seiches occur when the bassin is excited at its open boundaries by waves matching the eigen frequencies of the basin. The large range of harbours resonant-periods imply that many mechanisms must be investigated as potential forcing factors. For instance, the large resonant-periods may be forced by meteorological waves, whereas shorter resonant-periods are generally linked to infragravity waves. In our work, meteorological waves are estimated using the HYCOM hydrodynamic model forced by meteorological fields with high resolution in time and space, whereas infragravity waves are estimated from the spectral wave model WaveWatchIII. Here, we focus on links between short-periods seiches with typical periods of 30s to 600s, and the infragravity waves at the open boarder of the harbours.

Previous studies highlighted the link between the incoming gravity waves integral parameters and the observed seiches. In these studies, the integral parameters of the gravity waves are used as a proxi of the underlying infragravity waves. In our work, we consider the directional wave spectrum, including both gravity and infragravity bands, provided by WaveWatchIII hindcasts. We thus include the directionality and the free infragravity waves in our study to correlate short-period seiche events to the background long waves at the open boundary of the harbours.

Keywords: harbour oscillation

Paper ID 470
Poster Board N°59

Atmospheric Drivers of Sea-Level Fluctuations and Nuisance Floods along the Mid-Atlantic Coast of the USA

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As sea levels have risen and continue to rise, the risk of coastal flooding has increased in turn. While many studies have examined specific extreme flooding events, far fewer have explored the systematic associations between weather events and smaller, nuisance flood events. In this research, we take a synoptic climatological approach to assess this connection. We utilize self-organizing maps (SOMs) to separately cluster two atmospheric fields, sea-level pressure and 700-hPa geopotential height. We then utilize the output from these classifications to assess the impact of atmospheric conditions on the short-term fluctuations of sea level for the period 1979–2012, as well as the likelihood of nuisance flood occurrence, at five tidal gauges from Cape May, NJ, to Charleston, SC, along the mid-Atlantic coast of the USA. Results show the impacts of both the inverted barometer effect as well as surface wind forcing. Beyond this, the SOM nodes show a clear spatial continuum of associations between circulation and anomalous sea level, including some significant sea-level anomalies associatedwith relatively ambiguous pressure patterns. Moreover, the transitions from 1 day to the next are also analyzed, with results showing that rapidly deepening cyclones, or persistent onshore flow, can be associated with the greatest likelihood of nuisance floods. Results are generally weaker with 700-hPa height than sea-level pressure; however, in some cases, it is clear that the mid-tropospheric circulation can modulate the connection between sea-level anomalies and surface circulation.

Keywords: Atmospheric Drivers, Sea-Level Fluctuations, Nuisance Floods

POSTER SESSION
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Paper ID 471
Poster Board N°65

Small Islands Adapting to Sea Level Change and Extreme Events

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Maldives is group of coral atoll islands where the average elevation is approximately 1.5m above the mean sea level. The small size of the islands, forces the communities to live by the coast. Historical tide gauge records of the country shows an alarming rate of 3.75 mm/year rise of mean sea level (extreme sea level). Therefore, undoubtedly sea level rise is of grave concern to these islands. This sea level rise supplemented by intensified extreme events such as storm surges exacerbates the vulnerability of the communities on the islands. Frequent erosion and inundation has always been a challenge to the communities which would worsen with further sea-level rise. The government of Maldives has been taking measures to address or dull the potential impacts associated with sea level rise. The past experience and the emerging scientific findings on sea level rise has led to revisit the policies and strategies. Land reclamation, island zonal planning, coastal protection and modification projects are better informed. Guidance manual for climate risk resilient coastal protection was formulated based on the practiced solutions to assists planners, decision-makers and technical specialists to incorporate climate change risks and to build better and more resilient coastal defenses. The environmental impact assessment regulations has been modified to impose a setback of minimum 20m from the vegetation line for infrastructure development. The recent land reclamation has set an elevation level of at least 0.2 to 0.3m higher than the existing land. Building codes are revised to construct public infrastructures such as mosques and power houses to be raised above the ground. Here it presents two cases where the information on sea level rise and extreme events could be used in future reclamations and another case where how these information has been put in planning the flood mitigation in one of the islands.

Keywords: Small Islands Adapting to Sea Level Change, Extreme Events

Paper ID 177
Poster Board N°66

Critical Storm Surge Submerged Lagos Coast of Nigeria: Evaluation of its Characteristics and Consequences

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Critical storm surge hits the coast of Lagos, south western part of Nigeria, in 2012. More than 2000 people lost their lives with majority displaced when about 20,000 m2 reclaimed land was flushed off. In this study, Meteorological field; Mean Sea Level Pressure (MSLP), Ocean temperature, wave height and Wind speed alongside predicted astronomical tides associated with the surge event were examined to evaluate the ocean-atmospheric exchanges in terms of its characteristics (Pre-, During and Post-surge event). Inundation Map of Lagos coast was developed using different senario (0.2,0.5,1.0 and 2.0m) of sea level rise. Results show that mean sea level pressures (MSLP) over North and South Atlantic Ocean, wind direction and speed, wave height and Sea Surface Temperature Anomalies (SSTA) play crucial roles during the pre-, during and post-storm surges. The characteristics of ocean-atmospheric exchanges reveal the sensitivity of storm surges, over Lagos coast, to anomalous atmospheric warming. There exist see-saw relationships between the MSLP over both hemispheric parts of the Atlantic Ocean. Further investigations show that wave height, ranging from moderate to rough-sea (about 2–4m), coupled with relatively strong wind (>> 10knots) must have been generated 2 to 3 days before the event over the fetch area. The study further discusses the destructive characteristics of storms surge event and also demonstrates the need for precautionary measures not only for limiting the possible damages but also for managing the possible failure of coastal defense measures under a changing climate for vulnerability and adaptation strategy probable.

Keywords: Astronomical tide, sea-level-rise, Inudation Map, SSTA, coastal vulnerability

POSTER SESSION
Session 5: Coastal zone

Paper ID 2
Poster Board N°67

Disappearing beaches of Morocco in the face of climate change

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Abstract missing

Paper ID 113
Poster Board N°26

initMIP-Antarctica: An Ice Sheet Model Initialization Experiment of ISMIP6

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ISMIP6 (Ice Sheet Model Intercomparision Project for CMIP6) is the primary activity within the Coupled Model Intercomparison Project – phase 6 (CMIP6) focusing on the Greenland and Antarctic Ice Sheets. Ice sheet model simulations are strongly influenced by their initial conditions, but the impact of these conditions on simulations of ice sheet evolution over the next couple centuries remains poorly understood. To better understand this impact and the associated error, an initial intercomparison exercise (initMIP) has been designed to compare, evaluate and improve initialization procedures and estimate their impact on century scale simulations. Following the initMIP-Greenland, a new initMIP-Antarctica has been designed to explore uncertainty associated with model initialization and spin-up and to evaluate initialization procedures. It consists of a set of three forward experiments of the Antarctic Ice Sheet that are each run for one hundred years: i) a control run (ctrl), ii) a surface mass balance anomaly run (asmb) and iii) a basal melt anomaly applied under the floating ice 30 (abmb) of the Antarctic Ice Sheet. All other model parameters are the same as those used for the initialization procedure. In this study, we present the first results of initMIP-Antarctica performed by different modeling groups and highlight the similarities and differences observed in the different simulations.

Keywords: Ice sheets, modeling, projections, sea level, Antarctica

Paper ID 119
Poster Board N°32

Response of the North Atlantic Dynamic Sea Level and Circulation to Greenland Meltwater and Climate Change in an Eddy-permitting Ocean Model

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The response of the North Atlantic dynamic sea surface height (SSH) and ocean circulation to Greenland Ice Sheet (GrIS) meltwater fluxes is investigated using a high-resolution model. The model is forced with either present-day-like or projected warmer climate conditions. In general, the impact of meltwater on the North Atlantic SSH and ocean circulation depends on the surface climate. In the two major regions of deep water formation, the Labrador Sea and the Nordic Seas, the basin-mean SSH increases with the increase of the GrIS meltwater flux. This SSH increase correlates with the decline of the Atlantic meridional overturning circulation (AMOC). However, while in the Labrador Sea the warming forcing and GrIS meltwater input lead to sea level rise, in the Nordic Seas these two forcings have an opposite influence on the convective mixing and basin-mean SSH (relative to the global mean). The warming leads to less sea-ice cover in the Nordic Seas, which favours stronger surface heat loss and deep mixing, lowering the SSH and generally increasing the transport of the East Greenland Current. In the Labrador Sea, the increased SSH and weaker deep convection are reflected in the decreased transport of the Labrador Current (LC), which closes the subpolar gyre in the west. Among the two major components of the LC transport, the thermohaline and bottom transports, the former is less sensitive to the GrIS meltwater fluxes under the warmer climate. The SSH difference across the LC, which is a component of the bottom velocity, correlates with the long-term mean AMOC rate.

Keywords: Sea level, AMOC, subpolar gyre, convection, Greenland Ice Sheet

Paper ID 123
Poster Board N°30

Projected Storminess Contribution to 21st Century Changes in Sea Level Extremes around the UK Coastline

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The impacts of sea-level rise will be experienced first and most acutely during extreme events: high tides, storm surges and energetic surface waves. Although long-term mean sea-level change is recognised as one of the most robust aspects of climate change, changes in the extreme events might also arise as a result of changes in atmospheric storminess.

Here we investigate changes in storm surge events for the UK by driving a barotropic tide and storm surge model of the UK coastal waters with atmospheric surface pressure and winds from climate model projections of the 21st century.

In an effort to apply realistic surface winds, and to capture changes at the mesoscale, we exploit the EuroCordex suite of regional climate model simulations. We use simulations driven by an ensemble of CMIP5 models under the RCP8.5 pathway.

Preliminary results appear to confirm previous work suggesting that storminess will be a relatively small component of the total change when compared to the mean-sea-level contribution.

We investigate the viablity of omitting the regional model downscaling step.

Keywords: Storm, Surge, Extremes, CMIP5, UK

POSTER SESSION
Session 6: Projections

Paper ID 145
Poster Board N°24

Sea Level Rise under the Shared Socioeconomic Pathways

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Future sea level rise is assessed by modeling the response to scenarios that formalize different socio-economic futures and different levels of climate change mitigation. For the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, the Representative Concentration Pathways formed the cornerstone of climate and sea level projections. For the next IPCC assessment, the scenario space will be extended with five Shared Socioeconomic Pathways (SSP) that represent different societal storylines and at least five year-2100 radiative Forcing Targets (FTs). Here, we present Sea Level Rise (SLR) projections for this SSP-FT scenario space based on probabilistic output from a new comprehensive sea level emulator within the MAGICC climate model. In 2100, SLR likely ranges relative to 1986-2005 are 40.5-63.6 cm for FT 2.6 Wm-2, 44.7-70.29 cm for FT 3.4 Wm-2, 48.3-75.8 cm for FT 4.5 Wm-2, 53.2-83.2 cm for FT 6.0 Wm-2, and 57.3-87.9 cm for the Baseline scenarios that assume no dedicated climate change mitigation. Median 2081-2100 annual rates of sea level rise are 4.3 mm/yr and 9.7 mm/yr for the FT 2.6 Wm-2 and the Baseline scenarios, respectively. We link specific scenario indicators to projected SLR and find that, by 2050, SSP scenarios accumulating less than 1000 GtC of emissions since 1850 are estimated to stay below 70 cm of SLR in 2100. Under all SSP-FT 2.6 Wm-2 scenarios, sizeable cumulative negative emissions ranging from around 3 GtC to 128 GtC are realized in 2100, keeping median SLR below 55 cm. Our results also suggest that a 2050 carbon price of around 117 US$2005/tCO2, representing the overall SSP average, would correspond to a median 2100 SLR of around 60cm. 21st century decarbonisation plays a key role for limiting long-term SLR, while global sea levels will continue to rise after 2100 under all SSPs. The probabilistic design of our study also allows for an investigation of the less likely, upper end of the SSP SLR trajectories, informing the sea level rise impact research commmunity. 95th percentile estimates for the SSP Baseline scenarios yield up to 127 cm in 2100 relative to 1986-2005. Upcoming analyses based on the more complex coupled climate models of the Climate Model Intercomparison Project phase 6 (CMIP6) will help to validate and update the findings presented here.

Keywords: sea level rise projections, SSP scenarios, probabilistic analysis

Paper ID 150
Poster Board N°36

Regional Projection of North Atlantic Sea Level Trends and Statistics from High Resolution Ocean Modeling

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Regionalization of climate projections are a means to investigate the impact of unresolved processes on sea level change estimates. We present results from a high resolution set-up of the Massachusetts Institute of Technology General Circulation model (MITgcm) covering the North Atlantic starting from 30°S and including the Arctic Mediterranean. The boundary and initial conditions are provided by results from CMIP5 integrations of the earth system model of Max Planck Institute for Meteorology in medium resolution (MPI-ESM-MR). To correct for biases in the mean state of the climate model, boundary and initial conditions as well as relaxation fields from the climate model run are defined relative to the climatological state 1960-1990 of the North Atlantic model forced with NCEP reanalysis data. The North Atlantic model is integrated from 1850-2100. Up to 2005 the forcing is provided by the CMIP5 historical run of the climate model. From 2006 onwards two integrations are performed, forced by the RCP 4.5 and 8.5 projections, respectively. Results are presented focussing mainly on three aspects: 1) agreement between the two models regarding trends and interannual to decadal statistics of sea level on scales resolved by the climate model, 2) quantification of the change in variability on different time scales from pre-industrial to future times, and 3) processes determining deviations in trends and statistics between in the North Atlantic model and the climate model. The discussion is separated into near-coastal and open-ocean regional aspects.

Keywords: Sea level projection, North Atlantic, regionalisation of climate projection, decadal variability, interannual variability

POSTER SESSION
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Paper ID 153
Poster Board N°28

Analysis of Sea Level Sensitivity in MPI-ESM model

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We present a sea level sensitivity analysis based on simulations with the Max Planck Institute Earth System Model (MPI-ESM). As part of the CMIP6-FAFMIP experiment, the model is driven by surface forcing anomalies targeted to identify the response of sea level to specific forcing functions. In the FAFMIP experiments, a prescribed set of surface flux perturbations is applied to the ocean. The experiments were carried out with the MPI-ESM1.2-LR and MPI-ESM1.2-HR, using the same version that is applied for "historical" and "scenario" experiments in the upcoming CMIP6. MPI-ESM-1.2LR features a resolution of ca. 200 km in the atmosphere (ECHAM6.3 T63L47) and variable resolution (25-200 km) in the ocean (MPIOM1.6 GR1.5/L40). MPI-ESM-1.2HR features a resolution of ca. 100 km in the atmosphere (ECHAM6.3 T127L95) and quasi-uniform 40 km in the ocean (MPIOM1.6 TP04/L40). We analyze forcing mechanisms and their regional response under well-defined conditions and identify their sensitivity to model resolution. The model experiments are designed to identify the response of sea level change due to the thermal expansion and changes in the ocean density and circulation pattern. In different sensitivity experiments the model is perturbed with momentum, heat and freshwater fluxes, derived from ensemble-mean changes simulated at the time of doubled CO2 under the 1pctCO2 scenario, respectively. The comparison of this experiments shows that the trend in global sea level is simulated well in the heat flux perturbation compared to the other experiments. The sea level trend in the North Atlantic Ocean and the Southern Ocean is captured reasonably well in the heat flux perturbation experiment. The steric effect on the sea level trend is also analyzed and further decomposed to the thermo and halosteric components. The impact of flux perturbations in regional sea level trend differs substantially in both pattern and magnitude of changes. Although the heat flux perturbation has the major effect in most of the global ocean but the momentum and water flux perturbation is also important in regional sea level trends.

Keywords: sea level projections, FAFMIP, CMIP6

POSTER SESSION
Session 6: Projections

Paper ID 183
Poster Board N°10

Scenarios of Twenty-First Century Mean Sea Level Rise for Canada

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Existing scientific literature and high profile assessments (such as by the Intergovernmental Panel on Climate Change) provide a wide range of estimates for global mean sea level rise in the twenty-first century. At the local scales, the ranges or uncertainties are even larger. There is a pressing need to compile plausible local mean sea level rise (SLR) scenarios to aid coastal communities for adaptation. Here we develop three local mean SLR scenarios for Canada for the twenty-first century, Low, Intermediate, and High, based on four accepted global mean SLR scenarios. The global scenarios are adjusted to account for three factors that affect local mean sea levels. The first factor is the net effect of the glacial isostatic adjustment from a model, with its component of vertical land motion further replaced by satellite Global Positioning System (GPS) data. The second is the effect of steric and dynamic ocean adjustment from the ensemble of global climate models. The third is the model-based effect of land-ice melt including glaciers and ice sheets. For each scenario, larger SLR will be along the southeastern Atlantic coast, the Pacific coast and the Beaufort Sea coast in the twenty-first century. Under the Intermediate Scenario and the High Scenario, the RSL may rise up to 0.6 and 2.0 m over 2010-2100, respectively. The proposed multiple plausible scenarios allow coastal engineers and managers to consider multiple future conditions and develop multiple response options, as well as choose the most suitable option according to the risk tolerance of infrastructure.

Keywords: sea level rise scenarios, sea level projections, local sea level, Canada

Paper ID 189
Poster Board N°44

Projected Sea Level Rise, Gyre Circulation and Water Mass Formation in the Western North Pacific: CMIP5 Inter-Model Analysis

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Future changes in the dynamic sea level (DSL), which is defined as sea-level deviation from the global mean sea level, is investigated over the North Pacific, analyzing data from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The analysis provides more comprehensive descriptions of DSL responses to the global warming in this region than available from previous studies, by using surface and subsurface data until the year 2300 under middle and high greenhouse-gas emission scenarios.

The DSL changes in the North Pacific until 2100 are characterized by a DSL rise in the western North Pacific around the Kuroshio Extension (KE), as also reported by previous studies in both the scenarios. From 2100 to 2300, DSL rises most of the North Pacific with the large positive DSL change located on the KE front only in RCP8.5. DSL changes little after 2100 in RCP4.5 related to the faster stabilization of the radiative forcing than that of RCP8.5. Subsurface density analysis indicates that DSL rise around the KE is associated with decrease in density of subtropical mode water (STMW) and with northward KE migration, while the density decrease of STMW (northward KE migration) is relatively strong between 2000 and 2100 for both RCP4.5 and RCP8.5 (2100 and 2300 for RCP8.5). The STMW density decrease is related to large heat uptake to the south and southeast of Japan, while the northward KE migration is associated with the poleward shift of the wind stress field. These features are commonly found in multi-model ensemble means and the relations among representative quantities produced by different climate models.

Keywords: CMIP5 Climate Models, Western North Pacific, Kuroshio Extension, Subtropical Mode Water

POSTER SESSION
Session 6: Projections

Paper ID 201
Poster Board N°14

Coastal Sea Level Rise with Warming Above 2 Degree

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Holding the increase in the global average temperature to below 2 ºC above pre-industrial levels, and pursuing efforts to limit the temperature increase to 1.5 ºC, has been agreed by the representatives of the 196 parties of United Nations, as an appropriate threshold beyond which climate change risks become unacceptably high. Sea level rise is one of the most damaging aspects of warming climate for the more than 600 million people living in low-elevation coastal areas less than 10 meters above sea level. Fragile coastal ecosystems and increasing concentrations of population and economic activity in coastal areas, are reasons why future sea level rise is one of the most damaging aspects of the warming climate. Furthermore, sea level is set to continue to rise for centuries after greenhouse gas emissions concentrations are stabilised due to system inertia and feedback time scales. Impact, risk, adaptation policies and long-term decision making in coastal areas depend on regional and local sea level rise projections and local projections can differ substantially from the global one.

Here we provide probabilistic sea level rise projections for the global coastline with warming above the 2 degree goal. A warming of 2°C makes global ocean rise on average by 20 cm, but more than 90% of coastal areas will experience greater rises, 40 cm along the Atlantic coast of North America and Norway, due to ocean dynamics. If warming continues above 2°C, then by 2100 sea level will rise with speeds unprecedented throughout human civilization, reaching 0.9 m (median), and 80% of the global coastline will exceed the global ocean sea level rise upper 95% confidence limit of 1.8 m. Coastal communities of rapidly expanding cities in the developing world, small island states, and vulnerable tropical coastal ecosystems will have a very limited time after mid-century to adapt to sea level rises.

Keywords: coastal sea level rise, probabilistic sea level projections, warming of 2 degree

POSTER SESSION
Session 6: Projections

Paper ID 212
Poster Board N°22

Projections of Sea-Level Change Along the Atlantic and Gulf Coasts of North America: Quantifying the Contribution From Glacial Isostatic Adjustment

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Regional sea-level projections require that the contributions from different processes are quantified and summed. In some regions, the on-going response of the solid Earth to past changes in ice sheets – referred to as glacial isostatic adjustment (GIA) – is an important or even dominant contributing process. In this study, we quantify the contribution of GIA to future relative sea level change along the North American coastline between Newfoundland and Texas. This is the first analysis to estimate uncertainty ranges on the GIA contribution to future sea-level changes. Contributions from ocean steric and dynamic changes as well as those from future changes in land ice are also estimated to provide context for the GIA projections.

We infer GIA model parameters using recently compiled and quality-assessed databases of past sea-level changes, including new databases for the United States Gulf Coast and Atlantic Canada. At 13 cities along this coastline, we estimate the GIA contribution to range from a few centimeters (e.g., 3 [−1 to 9] cm, Miami) to a few decimeters (e.g., 18 [12–22] cm, Halifax) for the period 2085–2100 relative to 2006–2015 (1–

Keywords: Projections, Glacial Isostatic Adjustment, Uncertainty, Spatial Variability

Paper ID 226
Poster Board N°42

Difference of Regional Sea Level Changes between Extended RCP2.6 and RCP4.5 Scenarios in MIROC5.0

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The COP21 invited the IPCC to provide the special report on the impacts of global warming of 1.5degree C above preindustrial levels. Climate model MIROC5.0 shows about 1.5 and 2.0degree C global warming based on RCP2.6 and RCP4.5, respectively. We have extended RCP2.6 and RCP4.5 to 2300 in order to estimate the difference of sea level changes between two scenarios. The extended RCP2.6 is also available for the Inter-Sectoral Impact Model Inter-comparison Project (ISIMIP). The difference of the global averaged thermosteric sea level rises between the scenarios is about 32cm at the end of the 23rd century. However, the difference of local sea level change is suppressed in the tropical Pacific by the changes in the dynamical wind field. The significant difference is not seen until the end of the 21st century due to the large interannual variability.

Keywords: thermo-steric, tropical Pacific, regional sea level, climate model, inter-annual variability

Paper ID 232
Poster Board N°16

A High-end Sea Level Rise Probabilistic Projection Including Rapid Antarctic Ice Sheet Mass Loss

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The potential for break-up of Antarctic ice shelves by hydrofracturing and following ice cliff instability might be important for future ice dynamics. One study suggests that the Antarctic ice sheet could lose a lot more mass during the 21st century than previously thought. To investigate the impact of this new information on a high-end total global sea level rise projection we have developed a probabilistic process-based method. It is shown that uncertainties in the projections increase when including the temperature dependence of Antarctic mass loss and the uncertainty in the Coupled Model Intercomparison Project Phase 5 (CMIP5) model ensemble. Including these new uncertainties we provide probability density functions of global mean sea level in 2100 conditional on emission and high-end Antarctic mass loss scenarios. These projections suggest that under the RCP8.5 emission scenario previous extreme sea level scenarios developed for adaptation purposes could be significantly exceeded.

Keywords: sea level rise, process-based method, high-end projections, antarctica, probability density function

Paper ID 235
Poster Board N°20

The Paris Agreement's Imprint on 2300 Sea Level Rise

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Sea level rise is one of the major impacts of climate change and will continue for long after greenhouse gas emissions have ceased. The 2015 Paris Agreement aims at reducing climate-related risks by limiting greenhouse gas emissions and global mean temperature increase. Here we quantify the effect of emission constraints of the Paris Agreement on climate-driven sea level rise until 2300 using a contribution-based methodology that is consistent with the IPCC AR5 sea level estimates. We study median sea level rise for scenarios stabilizing global mean temperatures between 1.5° C and 2° C above pre-industrial levels and for net-zero greenhouse gas emission scenarios that lead to declining temperatures. We find that once global mean temperatures pass 1.5 °C, sea level rise below one meter until 2300 is out of reach for temperature stabilization scenarios. Further, net-zero emissions reduce sea-level rise caused by temperature overshoot only within limits in our model. We show that delayed near-term mitigation action leads to increased sea level rise far beyond 2100, underlining the importance of early action for limiting long-term sea level rise.

Keywords: Projections, Long-term Sea Level Rise, Paris Agreement, Climate Policy

POSTER SESSION
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Paper ID 248
Poster Board N°34

Simulation of the Greenland Ice Sheet Evolution using a Hybrid Initialization Procedure

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Recent observations show an accelerated ice loss of the Greenland ice sheet during the past few decadesmaking it a major contributor to sea-level rise. The SeaRISE experiments revealed the sensitivity of current ice sheet models to external forcing. Although the models are resulting in general in a similar trend of mass loss, the model responses are not always homogeneous. This may an effect of different employed e.g. numerics, approximation to the Stokes flow, spatial resolution, and largely to ice sheet initialization.

In our study we use a hybrid initialization approach that combines assimilation and a temperature spin-up over longer periods. The temperature spin-up is performed with two different climatic forcings: (1) present-day climatic and (2) palaeoclimatic conditions and two different maps of the geothermal flux. As we employ the higer-order approximation to the Stokes flow grid refinements are made during the whole initialization procedure. The presented procedure is performed with the thermomechanical coupled Ice Sheet System Model (ISSM) and is part of the initMIP-Greenland intercomparison exercise (Model: AWI-ISSM).

In order to examine the difference of ice sheet evolution for both different initializations, we re-run the SeaRISE experiments.

Keywords: Greenland, numerical modeling, mass loss, ISSM, initialization

POSTER SESSION
Session 6: Projections

Paper ID 260
Poster Board N°38

Linear Predictability: A Sea Surface Height Case Study

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A benchmark of linear predictive skill of global sea surface height (SSH) is presented, complementing more complicated studies of SSH predictive skill. Twenty years of the ECCOv4 state estimate (1992-2011) are used, fitting ARMA(n,m) models where the order is chosen by the Akaike Information Criteria (AIC). The prediction on the basis of monthly detrended data shows skill generally of the order of a few months, with isolated regions of twelve months or more. With the trend included in the analysis, the predictive skill increases, particularly in the South Pacific. Annually averaged data are also used, although the time-series are too short to assess the variability.

Keywords: sea level, linear models (ARMA), predictive benchmark, ECCOv4 state estimate, linear trend

POSTER SESSION
Session 6: Projections

Paper ID 263
Poster Board N°8

Evaluating Potential Tipping Points of Antarctic Outlet Glaciers

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Antarctica is currently loosing mass and its forthcoming contribution to sea-level rise could substantially increase during the coming centuries. This is essentially due to geometrical constraints, i.e., in regions where grounded ice lies on a bedrock below sea-level sloping down towards the interior of the ice sheet (retrograde slope). For a such configuration the ice sheet is considered potentially unstable, as suggested by theory. However, recent observations on accelerated grounding-line retreat and new insights in modeling Pine Island and Thwaites glaciers give evidence that such self-entertained retreat, called marine ice sheet instability (MISI), has already been on its way. Although West Antarctica appears to be the most vulnerable region for MISI occurrence, similar topographic configurations are also observed in East Antarctica, in the Wilkes Basin in particular. Therefore, evaluating the MISI potential at a pan-Antarctic scale is becoming a priority. Here, using the f.ETISh ice sheet model, an ensemble of simulations of the entire contemporain Antarctic ice sheet has been carried out. In particular, we investigate the debuttressing of ice shelves required to initiate MISI for each coastal region around Antarctica by forcing the model with sub-shelf melt pulses of varying duration and amplitude. We further identify the currently grounded areas where the outlet glaciers could hardly stabilize and the related rates of contribution to sea level rise.

Keywords: Antarctica dynamics MISI modeling

Paper ID 295
Poster Board N°12

Can You Spot the Difference? Distinguishing between End-of-Century Sea-Level Projections for 1.5°C and 2.0°C Worlds

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Changes in ocean volume (global thermal expansion and ocean dynamics) can be linearly related to global temperature change. Additional sea-level components, such as mass changes in ice sheets, glaciers and land-water storage have unique spatial patterns that contribute to sea-level change and will be indirectly affected by global temperature change. The relationship to global temperature allows us to estimate the difference in local sea-level change for different global temperature pathways. The mitigation scenario RCP 2.6 shows an end-of-century global temperature range of 0.9 to 2.3°C (median 1.6°C) relative to the pre-industrial period. We project local sea-level change for RCP 2.6 using sub-sets of models in the CMIP5 archive that follow global temperature pathways whose 2100 averages are 1.5°C and 2.0°C. The method used to calculate local sea-level change is probabilistic and combines the normalised spatial patterns of sea-level components with global average projections of individual sea-level components. We consider where and why these projections are similar and dissimilar in spatial pattern and magnitude.

Keywords: probability, projections, pathways, patterns

Paper ID 313
Poster Board N°6

How Robust are Dynamic Sea Level Changes in Future Model Projections?

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The robustness in modeled projections of future, regional sea level changes is explored by examining the uncertainty due to internal model variability, and the differences between models. The focus of the regional sea level signal here is only on dynamic sea surface height changes, and not those from land ice melt or other changes with a regional imprint on sea level. Climate model projections of regional sea level changes usually focus on the total sea level change projected for each region, which includes the global mean change due to thermosteric increase of volume. This thermosteric increase is the largest signal of sea level change from coupled models, which normally do not include other large effects directly, such as land ice melt. But when looking at only regional, dynamic sea level changes in the RCP8.5 scenario, without the global mean, a large portion of the low to midlatitude ocean does not have statistically significant dynamic sea level changes at the 90% confidence level for the 21-member ensemble presented in the IPCC AR5 report. Further investigations into the sources of uncertainty are made to partition the uncertainty between internal model variability and intermodel differences by testing how much of a dynamic sea level signal remains after averaging large ensembles together for individual models, and comparing the results between models.

Keywords: sea level change, climate change, interdecadal variability, regional sea level

POSTER SESSION
Session 6: Projections

Paper ID 314
Poster Board N°4

Modelling Sea-Level Fingerprints of Glaciated Regions with Low Mantle Viscosity

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Sea-level fingerprints, the unique spatial patterns of ice-melt-driven sea-level change, play an important role in understanding past and projecting future changes in relative sea-level (RSL). Over century timescales, viscous flow within the Earth is a small component of the total deformation in most regions, and so fingerprints computed using elastic Earth models are accurate. However, in regions where the viscosity is relatively low, the viscous component of deformation can be significant, in which case it is important to consider models of visco-elastic deformation (Hay et al., Journal of Climate, 2017).

There is evidence that the glaciated regions of Alaska, Patagonia, and Iceland are situated on top of mantle regions in which the local viscosity is several orders of magnitude lower than typical global mean values (Sato et al. Tectonophysics, 2011; Lange et al., Geophysical Research Letters, 2014; Compton et al., Geophysical Research Letters, 2015). The goal of this work is to determine the importance of viscous flow in computing RSL fingerprints associated with future ice mass loss from these regions. We use version 5.0 of the Randolph Glacier Inventory to estimate the ice load distribution required for calculating sea-level fingerprints. For the glaciated regions that have lower than average viscosity, we calculated fingerprints using an elastic Earth model and a visco-elastic model to quantify the influence of viscous flow on the sea-level output. Using glacier mass loss values provided by Huss and Hock (Frontiers in Earth Sciences, 2015) for Representative Concentration Pathway 4.5, we computed the global sea-level response at 2100 CE relative to 2010 CE due to melting from all glacier regions represented in the Randolph Glacier Inventory. On comparing the results of the two models we found that ice-load-induced viscous flow contributes significantly to the RSL fingerprints, particularly in near-field regions. For example, at Anchorage, Vancouver and New York, the elastic calculation gave relative sea-level changes of -18 cm, 1 cm and 9 cm, respectively, which can be compared to values based on the visco-elastic calculation of 3 cm, 3 cm and 8 cm.

Keywords: sea-level fingerprints, glacier melt, visco-elastic deformation, sea-level projections

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CMIP5 Projections of Polar Ocean Warming, and Implications for Forcing Ice-Sheet Models

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Changes in ice sheet discharge arising from ocean-induced perturbations at marine termini constitute the largest, and most uncertain, component of 21st century global mean sea level rise (SLR) projections. To account for this future SLR contribution, the climate research community is developing Earth System models that include an explicitly coupled ice sheet. However, such models will not be available for the next round of the coupled model intercomparison project (CMIP6, expected this year) and may not provide satisfactory quantification of interactions in the fully coupled climate system for many years. Projections of the ice sheet contribution to sea level rise will thus continue to require the use of "off-line" oceanic fields that must be translated to a basal mass loss and/or iceberg calving parameterization.

Previous analyses have employed several strategies to sample subsurface temperature change projections from off-line climate models and/or model ensembles, often without substantial discussion of underlying assumptions. Here, I highlight some general features of centennial-timescale CMIP5 near-ice sheet ocean warming projections, including the spatial, temporal, and inter-model variability across this model ensemble. These results are used to illuminate key choices involved in developing climate forcing strategies, and their implications for SLR projections based on CMIP6 simulations.

Keywords: Climate model, Antarctic, Greenland, ocean, temperature

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Antarctica's Role in Future Sea Level Change and Analogies in the Last Interglacial.

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The accuracy of predictions as well as reconstructions of Antarctic sea level contributions is hampered by limited knowledge about boundary conditions (topographic as well as climatic) and flow dynamics. At the same time nonlinear processes governing the marine basins of the Antarctic Ice Sheet (AIS) can lead to dramatic ice surges in a relatively short time. These two factors contribute to a wide range of potential contributions of the AIS to future sea level change. Here, we present our 3D ice sheet modeling efforts reconstructing AIS dynamics in the Last Interglacial (LIG) as well as in the coming centuries identifying key vulnerabilities with respect to a warming of the Southern Ocean and the atmosphere. We present transient simulations of AIS evolution throughout the LIG and the coming centuries to millennia driven by a GCM-derived and proxy-constrained climate forcing. We compare the dynamics in a coarse (40 km) resolution shallow-ice/shallow-shelf model (RIMBAY) equipped with a simple 3D ocean forcing to the dynamics in higher resolution simulations (10-20 km) with PISM. Further we discuss the effects of different boundary conditions (topographic, climatic) on ice flow as well as the effects of different choices of model spin-ups. Depending on the model assumptions and for reasonable LIG temperature anomalies we reconstruct a wide span of AIS responses during the LIG, ranging from a moderate reduction in ice volume to a complete collapse of the marine West Antarctic ice sheets. This behavior is mirrored in prognostic simulations spanning the next centuries, in which the ice dynamics are very sensitive to the applied climate forcing. Therefore, improved boundary conditions, such as the present day ice shelf mass balance and sub shelf ocean circulation patterns are in dire need to further constrain potential climate thresholds triggering nonlinear ice sheet responses in the coming decades and centuries.

Keywords: Antarctica, ocean forcing, ice-ocean interaction, future, paleo

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A New NOAA Seasonal Sea Level Prediction Research Initiative

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A crucial part of NOAA's service mission is to make U.S. communities more resilient to rises in coastal sea level, which on a seasonal timescale may increase the threat for nuisance ("sunny day") flooding, as well as enhance the severity of storm surge events. Over a season, variability in climate or ocean dynamics, in combination with longer-term trends, can influence coastal sea level in a way that is potentially predictable. To leverage these emerging scientific findings, the Climate Program Office's Modeling, Analysis, Predictions, and Projections Program, in partnership with the National Marine Fisheries Service, has solicited proposals for exploratory three-year projects starting in FY 2017 to help develop NOAA's capability to produce skillful seasonal (i.e, 2-9 month) predictions of coastal high water levels as well as changing living marine resources. This presentation will describe the goals, scope and intended activities of this research initiative and its coordination via a new MAPP Ocean Prediction Task Force.

Keywords: seasonal prediction, seasonal variability

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Time-dependent Expansion Efficiency of Heat in Climate Models

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Under global warming, the ocean absorbs more than 90% of heat uptake in the Earth system. A direct consequence of ocean warming is thermal expansion of seawater, an important contributor to both historical and future sea level rise. The expansion efficiency of heat, ε (unit: m/J), is defined as the increase of global thermosteric sea level for a given amount of heat uptake. Given that the thermal expansion coefficient α strongly depends on local temperature and pressure, ε is closely related to the mean state of ocean and the regional warming patterns. As all of these factors are time dependent, ε should vary temporally. However, the literature indicates that the temporal variation of ε is negligible (<5%) in models from the Coupled Model Intercomparison Project Phase 5 (CMIP5). A possible explanation is that a shift of the regional warming patterns offsets the increase of ε due to a warming mean state. To test this hypothesis, we diagnose the impact of 1) the mean state change and 2) the warming pattern change on the temporal evolution of ε under the Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.5 scenarios over 2006-2100. For the mean state change, we find that it results in a positive trend in ε. Its impact is greater in the scenarios of higher radiation forcing, featuring 2-8% increase of ε. On the other hand, the warming pattern change leads to a 12-14% decrease in ε, with the strongest reduction occurs in the RCP2.6. Moreover, we identify a slowdown of the warming rate in the surface at low- and mid-latitudes under all the scenarios. There is also an acceleration of warming in the Arctic captured by some models under the RCP8.5. Those two phenomena contribute to the reduction of ε found here. The counteracting effects of the mean state change and the warming pattern change result in small temporal variations in ε. Our results may help explain and potentially reduce the spread in projected global sea level rise.

Keywords: expansion efficiency, climate models

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Verification of Wave Forecasts in the Context of Changing Sea Levels

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Abstract missing