COMPARISON OF STERIC SEA LEVEL FROM AN ENSEMBLE OF OCEAN REANALYSES AND OBJECTIVE ANALYSES: PRELIMINARY RESULTS

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METHODS AND DATA

1. Introduction

Steric Sea Level (SSL) accounts for 30 to 60 % of the Global Sea Level rise and it is the main responsible for regional sea level change. With the aim of quantifying the Global and regional SSL change from ocean syntheses, its uncertainty and the consistency among different reanalyses and the relative contribution of different depth ranges, a comparison is being carried out in the framework of the joint GSOP-CLIVAR and GODAE initiatives. We present here some initial and preliminary results.

Participating products – Data provided as monthly means

Product	*ARMOR*	*CFSR*	*CGLORS*	*ECCO*	*ECDA*	*EN3*	*GECCO2*	*GEOS5*
Institute	CLS	NCEP	CMCC	JPL	GFDL	UKMO	U. HAMB.	GMAO
Type#	OA	REA	REA	REA	REA	OA	REA	REA
Period*	1993-2010	1980-2011	1989-2010	1993-2011	1993-2011	1993-2011	1948-2011	1993-2010
Product	*GLORYS*	*GLOSEA*	*GODAS*	*IK09*	*K7OC*	*MOVEC*	*MOVEG2*	*NODC***
Institute	MERCATOR	UKMO	NCEP	JAMSTEC	JAMSTEC	JMA	JMA	NOAA
Type#	REA	REA	REA	OA	REA	REA	REA	OA
Period*	1993-2009	1993-2010	1980-2011	1993-2010	1975-2011	1993-2011	1993-2011	2005-2011
Product	*ORAS4*	*PEODAS*	*UR025.4*					
Institute	ECMWF	BOM	U. READ.					
Type#	REA	REA	REA					
Period*	1958-2009	1993-2009	1993-2010					

TOTAL: 19 Products, of which 15 Ocean Syntheses and 4 Observation-only products

*# OA: Observation Only (Objective Analysis); REA: Ocean Synthesis (Reanalysis) * Period refers to the files uploaded ** Seasonal values time-splined to monthly and no provision of depth ranges*

2. Intercomparison Strategy

Validation Period (2005-2009)

Goal: Compare the products with independent SSL estimates, derived from difference between satellite altimetry and satellite gravimetry.

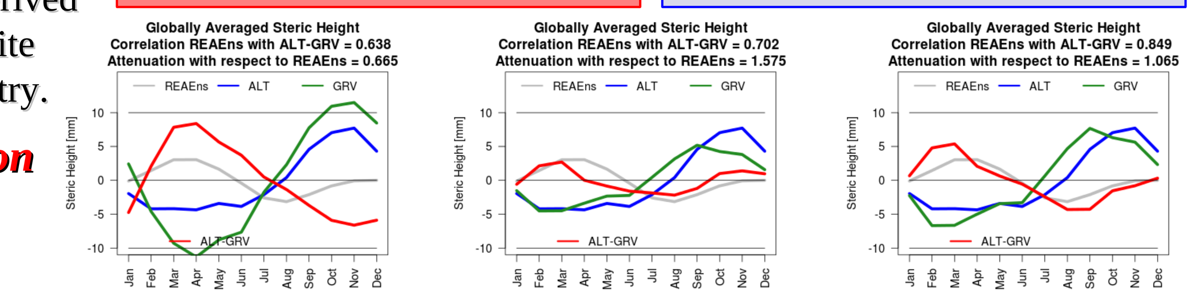
Extended Intercomparison Period (1993-2009)

Goal: Depict consistencies among products and assessing comparison results during the altimetry era.

Verifying Steric Sea Level Observations:
SSL = TOTAL SL – EUSTATIC = ALTIMETRY – GRAVIMETRY

AVISO MONTHLY MAPS (1/3x1/3) OF MULTI-SATELLITE SLA REFERENCED TO 2005-2009 PERIOD

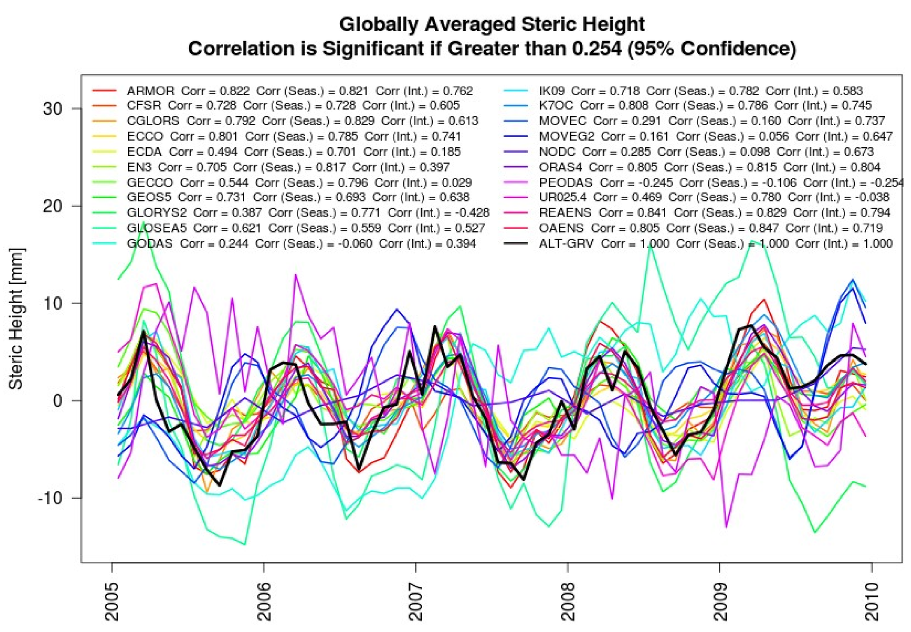
GRACE OCEAN EQUIVALENT WATER THICKNESS (Ensemble of JPL, CSR, GFZ 500 Km SOLUTION, Release RL05) REFERENCED TO 2005-2009 PERIOD



2005-2009 Annual cycle of the global mean sea-level and its components (ALT: total sea-level from altimetry; GRV: eustatic sea level from gravimetry; ALT-GRV: derived steric; REAEns: steric sea level from the ensemble of ocean reanalyses) for three different GRACE data. GRACE solutions at 300 Km, release R04 (let); GRACE solutions at 500 km, release R05 (middle); GRACE solutions at 500 km with attenuation factor for recovering from filtering attenuation, release R05 (right). Also shown the correlation between ALT-GRV and the reanalyses ensemble mean SSL. GRACE Data from the rightmost comparison will be considered later on.

VALIDATION PERIOD (2005-2009)

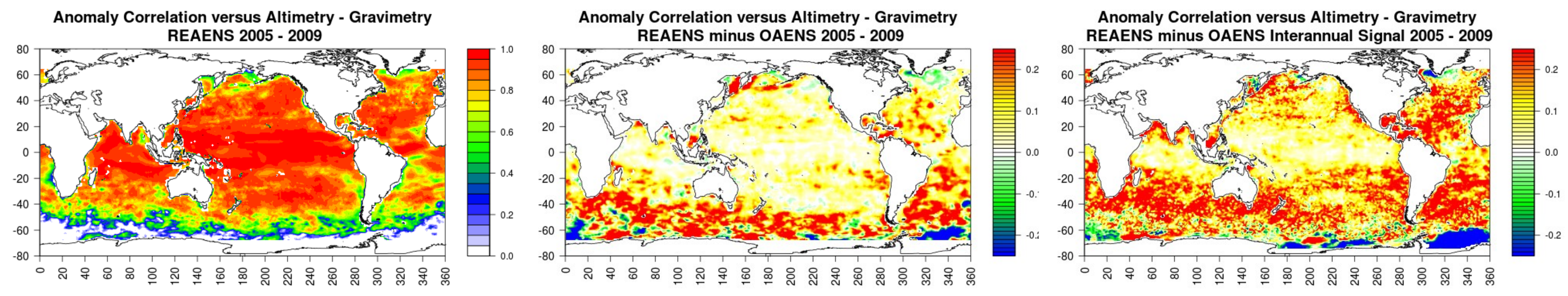
3. Global Mean SSL



2005-2009 Global Mean Steric Sea Level for all the products and the satellite based estimates (ALT-GRV). Also indicated the correlation of the full, the seasonal and the interannual signals with the corresponding signal from ALT-GRV.
Note how the Reanalysis ensemble (REAENS) outperforms all the individual products and the ensemble of objective analyses (OAENS) in terms of correlation.

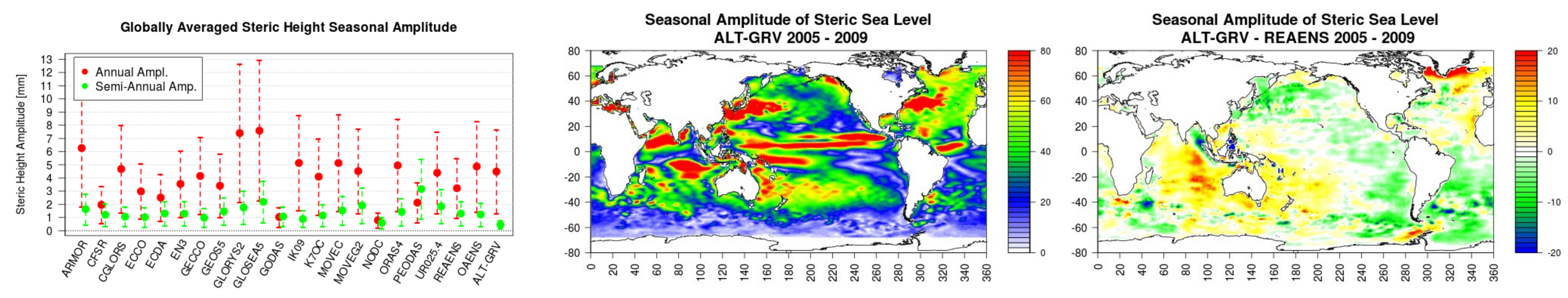
5. Regional SSL

Area-averaged point-by-point correlation with ALT-GRV: REAENS = 0.83 OAENS = 0.74



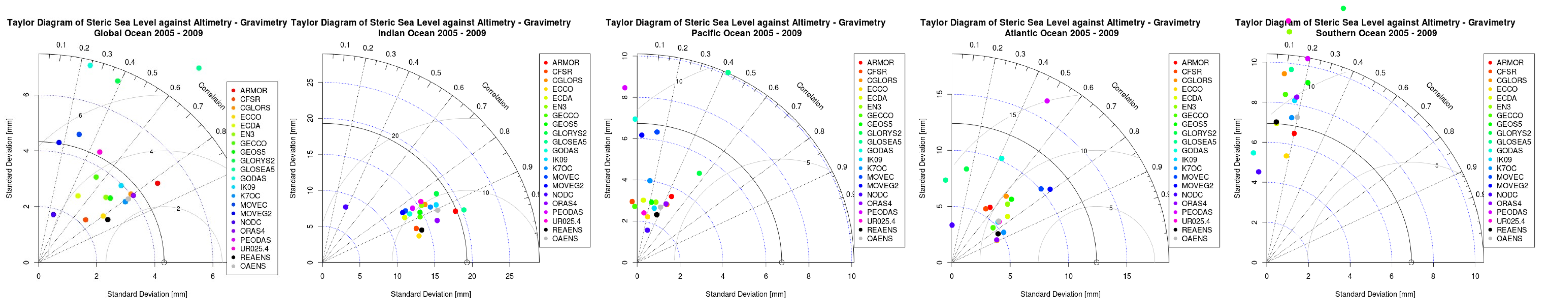
2005-2009 Anomaly Correlation Maps vs ALT-GRV: REAENS (left), REAENS minus OAENS (middle), REAENS minus OAENS for the interannual signal only (right). The plots show, respectively, the very good skill score of the reanalysis ensemble except in the Antarctic region, its superiority w.r.t. objective analysis ensemble especially in the Southern and Atlantic Oceans, which is even larger for the interannual (seasonality removed) signal.

6. Seasonality of SSL



2005-2009 Seasonal Amplitude of steric sea level: Global SSL Annual (6-month period) and Semi-Annual (3-month) Amplitudes for all the products (left); ALT-GRV Annual Amplitude Map (middle) and Annual Amplitude Map difference between ALT-GRV and REAENS (right). Note how the annual amplitudes are generally well-captured. REAENS underestimates the seasonality of the SSL especially in the Indonesian region and in correspondence of the ice-sheet costal areas.

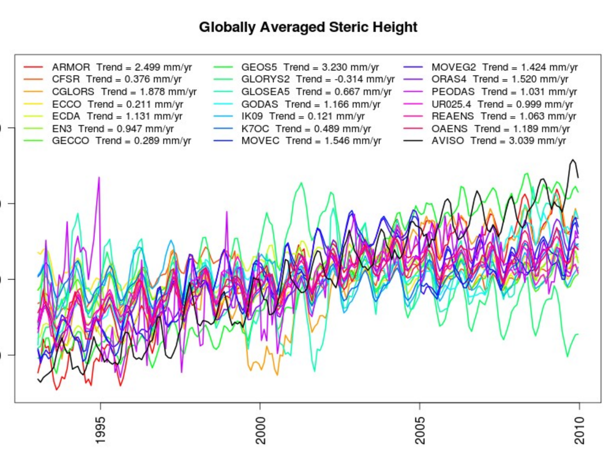
4. Basin-scale comparison



2005-2009 Taylor diagrams vs ALT-GRV for the SSL averaged within the Global, the Indian, the Pacific, the Atlantic and the Southern Oceans, respectively from left to right.
The empty circle on the x-axis represents the reference observational point (ALT-GRV) in the Taylor Diagram. The comparison indicates the good performance of he ensemble of reanalyses (REAENS) in almost all the Oceans except the Southern. The products generally present a variability smaller than that of ALT-GRV (concentric lines centred at the axis origin). The Indian Ocean is the one that exhibits the greater agreement between the products. RMSEs (concentric lines centred at the observation point) are generally below 10 mm.

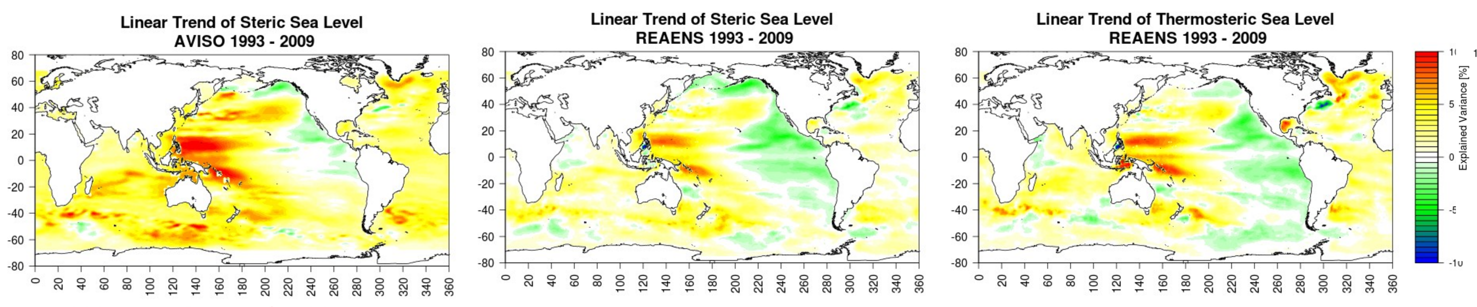
EXTENDED INTERCOMPARISON PERIOD (1993-2009)

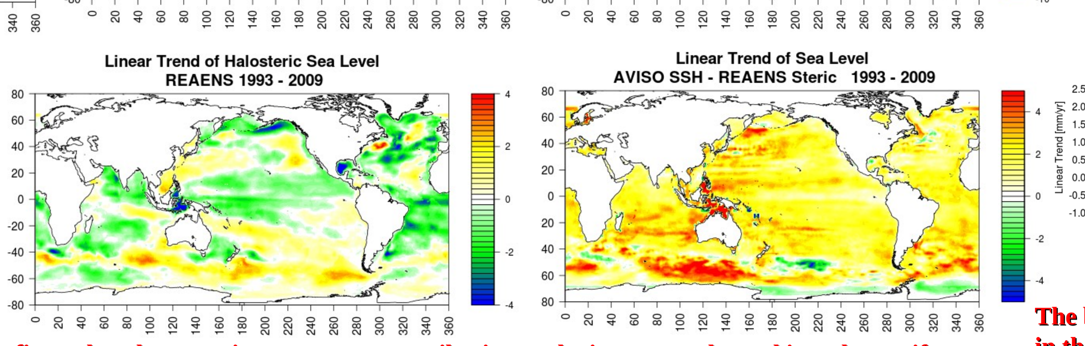
8. Global Ocean comparison



Global Ocean SSL for all the products for the period 1993-2009, along with global SSH from altimetry (AVISO). Also shown the linear trends. For the latter, the ensemble of reanalyses and that of objective analyses consistently indicate 1.1 and 1.2 mm/yr, respectively.

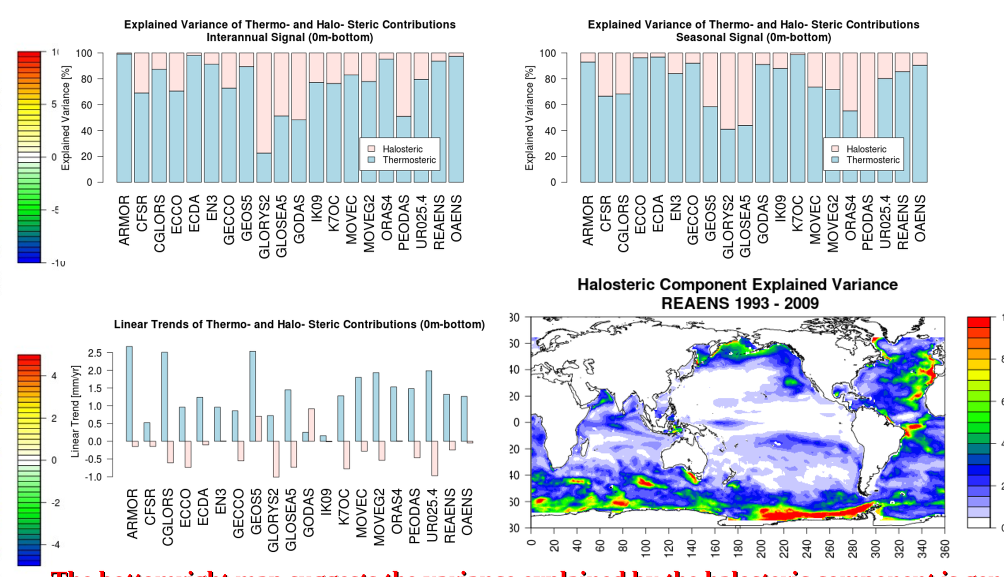
9. Ensemble Regional Trends





1993-2009 Trend Maps for SSH from AVISO altimetry data (topleft), the Total Steric, Thermosteric and Halosteric SSL from REAENS, and the Trends Difference between AVISO and REAENS. Note the different colorbar for the Halosteric SSL. Most of the trends are driven by the Thermosteric component.
The map of SSH - REAENS trends confirms that the eustatic component contribution to the interannual trend is rather uniform over the Global Ocean, except in the polar areas.

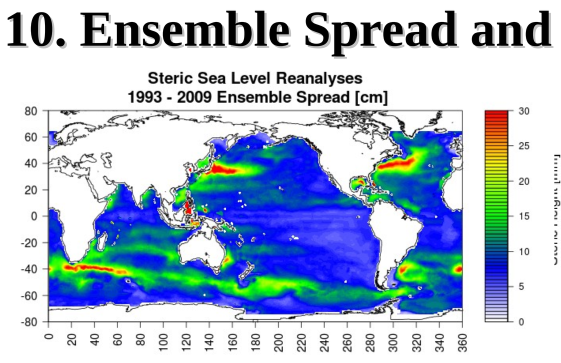
11. Thermal and Haline contributions

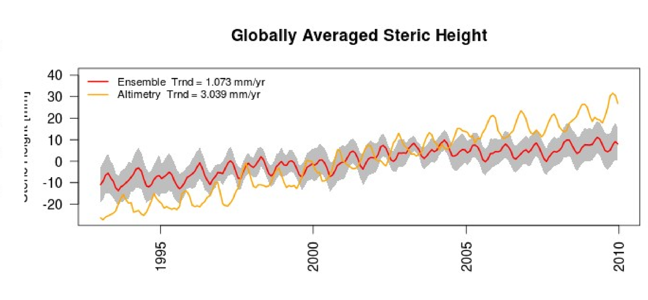


Explained Variance of Thermo- and Halo- Steric Components of GSSL (top panels), their contribution to the total steric trend (bottomleft) and map of point-by-point explained variance of the Halosteric Component (bottomright). The Global SSL variability is dominated by the thermosteric component, although products do not show coherent on that, ranging from 22% to 98%. The products agree on the fact that the halosteric component impacts the SSL variability more on seasonal scale than on interannual scale. The contributions of the halosteric component on the GSSL Trend is found generally smaller and of negative sign (-0.2 mm/yr for REAENS).

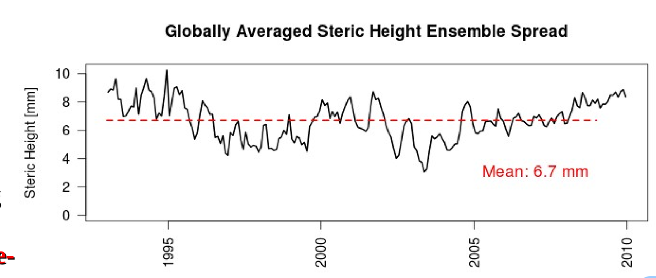
The bottomright map suggests the variance explained by the halosteric component is generally small, except in Arctic areas, in the Tropical Atlantic, in some coastal areas and in correspondence of the Mediterranean Sea outflow on the Atlantic.

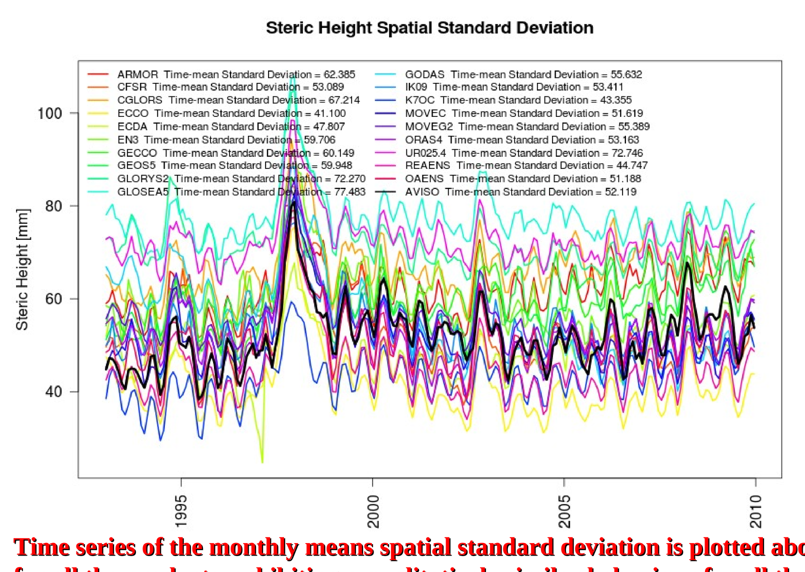
10. Ensemble Spread and spatial variability





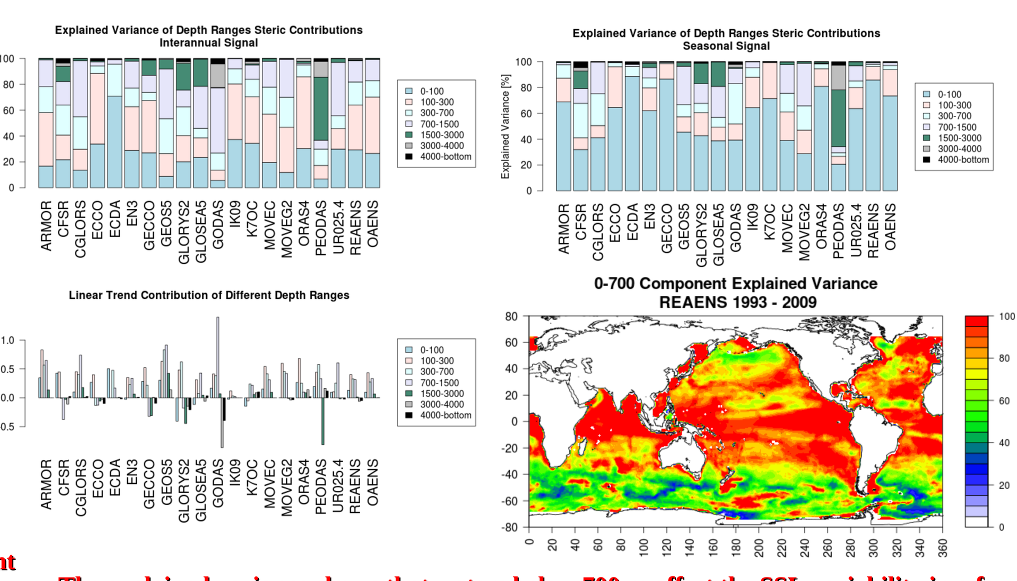
The point-by-point SSL spread (above) presents value between 5 and 10 mm except in areas of strong mesoscale activity, reaching values of about 5 cm, in the Indonesian region and in some other coastal areas (Gulf of Mexico, Labrador Sea, Red Sea outflow, etc.). The GSSL Ensemble Spread timeseries among the SSL products exhibits a non-stationary behaviour in time with different peaks. Its time-mean value is equal to 6.7 mm.





Time series of the monthly means spatial standard deviation is plotted above for all the products, exhibiting a qualitatively similar behaviour for all the products - with a clear peak in correspondence of the 1997-1998 El Nino event -, with values likely related to the product resolution (greater time-mean values for eddy-permitting reanalyses).

12. Vertical regions contributions



Explained Variance of different vertical regions of GSSL (top panels), their contribution to the total steric trend (bottomleft) and map of point-by-point explained variance of the 0-700 m region (bottomright). The first 300 m (to be assumed as well-observed region for 1993-2009 period) explain ~95 % of the seasonal variability but only 65% of the interannual variability (REAENS), the remainder located between 300 and 1500 m. Although there is no much consensus on the trend contribution results, it appears that 100-700 m contributes mostly on the interannual trend, the bottom waters generally showing a falling SSL behaviour.

The explained variance shows that waters below 700 m affect the SSL variability in a few areas including the Southern Ocean, the northern North Pacific and a in some areas of the North Atlantic (e.g. off Greenland ice-sheet coasts).

Summary and Future Work

A comparison between different reanalyses and objective analyses is being carried out, with a total of 19 participating products. Preliminary results suggest that, although many differences between the products are appreciable, the ensemble of the reanalyses outperforms all other products and the ensemble of objective analyses for both the Global and Regional SSL, thus proving to be an appealing tool for further analyses. Future works will focus on a deeper interpretation of the results and understanding the main deficiencies of the ensemble.

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