Observational Requirements for Coupled Syntheses

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Why (Ocean) Synthesis?

- A complete picture of the ocean for the purpose of climate research and applications will only come from a synergy between observations, modeling and data assimilation.

- Goal of ocean synthesis (reanalysis) is therefore to obtain best possible description of the ocean by combining all available data with the dynamics of an ocean circulation model.
Call for Data Synthesis

• **Improve understanding** of climate variability and climate sensitivities.

• **Improve climate forecasts** by merging coupled models with the **climate data base** (certainly relevant for SSH predictions).

• Assimilation of climate observations is needed to **improve model skill**:
  – Improve initial conditions
  – Improve model parameters
  – Improve forcing functions/bc.
CLIVAR Imperatives

- Anthropogenic Climate Change
- Decadal Variability, Predictability and Prediction
- Intraseasonal and Seasonal Predictability and Prediction
- Improved Atmosphere and Ocean Components of ESMs
  - Ocean model development
  - Analysis and Evaluation
  - Process studies/“Climate Process Teams”

Data Synthesis and Analysis
- Ocean
- Coupled Data Assimilation Systems (with WOAP)

Ocean Observing System
- Development and System Design
- (Build LINKS WITH IGBP for Carbon, Biogeochemistry, Ecosystems)

Capacity Building
Ocean State Estimation

- State estimation or “data assimilation” is least-squares fitting of models to data. (Nudging, 4DVAR, 3DVAR, adjoint, OI, OM, Kalman filter, RTS smoother, ensemble KF, AD, Pontryagin principle, relaxation, line-searches, breeding vectors, SVD, optimals, Hessians, quelling, dual,....)

- The apparently different methods are variant algorithms used to find the minimum of an objective (or cost) function, the extent to which an approximation to that minimum is acceptable, and whether one seriously seeks an estimate of the error of the result.
Finding a minimum, subject to the model, is a numerical, not a conceptual or mainly scientific problem.

But the nature of the minimum, in addition to the model structure, depends directly on the weight matrices in $J'$. If $P, Q, R$ are incorrect, so is the solution.
Consistency of Assimilation

The temporal evolution of data-assimilated estimates is physically inconsistent (e.g., budgets do not close) unless the assimilation’s data increments are explicitly ascribed to physical processes (i.e., inverted).

Climate Syntheses need to preserve first principles (Bengtsson et al., 2007)
Several global ocean data assimilation products are available today.

Underlying assimilation schemes range from simple and computationally efficient (e.g., optimal interpolation) to sophisticated and computationally intensive (e.g., adjoint and Kalman filter-smoother).

Intrinsically those efforts can be summarized as having three different goals, namely

- climate-quality hindcasts,
- high-resolution nowcasts, and
- the best initialization of forecast models.
Trend in Sea Level 1992-2001 (cm/yr)
Trend in Sea Level 1962-2001 (cm/yr)
GECCO: most of the changes are due to changes in heat content. Those changes are primarily redistribution in the ocean due caused by changing winds, but partly also due to heat fluxes over the northern hemisphere.
1994-2001 time-mean Atlantic MOC for contributing groups this time
MOC strength at 900 m (near the depth of MAX MOC strength) 25N
Köhl et al., 2010
Ocean synthesis/reanalysis

N. Atlantic Temp
(0-300 m)
Annual ocean heat content 0-700m relative to 1961-90 average

Heat Content Change ($10^{22}$ J)

Year

Levitus WOA

Ishii et al 2006

Willis et al 2004
World Ocean Yearly HC, 0-700m
1957-1990 reference period
[1969-2003 trend, $10^{22}$ J/yr]

- Present paper (average of 4 seasons) [0.32]
- Ishii and Kimoto (2009) [0.24]
- Domingues et al. (2008) [0.41]

Levitus et al 2009

0.8 W m$^{-2}$
0.3 W m$^{-2}$
Global Heat Content Anomaly ($10^{22}$ J)
Adjoint Sensitivity Study: Mechanisms of MOC variability at 25 N (Köhl, 2005)

1) Local Ekman transport
2) Coastal down-welling at east coast
3) Kelvin wave propagation along the west coast
4) Baroclinically unstable long Rossby waves
Influence of temperature and salinity at 310 m depth (level of largest sensitivity)

- Wave-like signal in the Canary basin
- Neg. T/pos. S anomalies in the Labrador/Irminger Sea
- Gradient south east of Iceland enhances NAC inflow into GIN sea -> more outflow though Denmark Strait
Data Issues for Synthesis

We need to do all required efforts to maintain the existing observing capabilities and use existing data as much as possible! We also need to do efforts to improve the observing system!
Data Challenges

Data Coverage in space and time.
Data inhomogeneity.
Data Quality; examples include:
  - XBT bias
  - ARGO biases
  - SST offsets
  - Altimetry drifts

• Requires Data Reanalysis and expansion of proxys
• Requires exploitation of new measurements.
• There is no limitations in measurements that can be used.
• We need error information for all input fields.
Ocean Temperature Observations 1950-2005

- Salinity obs. much worse.
- Long-term halosteric contribution unknown.
Challenge: Data Continuity

Global number of temperature observations per month as a function of depth

1980-2006

MBT and XBT Data Sets

Figure 3: Statistic of global MBT and XBT observation versus time
Input Data Sets and Controls

Global 1° WOCE Synthesis 1952 through 2002

Köhl and Stammer (2008a, b)
OceanObs’09

• Finish initial observing system by 2015 (presently only at 60% level).
• Sustain it and expand in terms of sensors, parameters (integrate biogeochemistry and biology).
• Expand according to readiness.
• Improve data and service infrastructure.
Observational Requirements

- Altimetry+ (calibration with tide gauges)
- ARGO+ → deep sampling (deep hydrography for calibration)
- Under Ice hydrography
- Scatterometer
- Mass/GRACE
- SST/SSS
- Sea Ice parameters
Observational Requirements

- Time series stations, partly as independent data for testing.
- Quality surface underway data, partly for calibration purposes
- Surface fluxes, including run off
- Transports in key areas, incl. boundary currents, overflow regions.
- ....
New Obs. that need attention

• SSS
• GRACE
• Sea ice thickness
• CFC’s
• .....
Surface Salinity

Simulated SSS for Atlantic
Estimating Run off and E-P

NCEP + const.
NCEP + seasonal
Opt.
Dai and Trenberth

Romanova et al. (2010)
Required: Design Studies

• To evaluate impact of individual observing parameters on state estimation.
• To optimize sampling strategies.
Perfect Model Simulation

Zhang and Rosati et al., Balamaseda et al., OO09
Fig. 5. Impact of modern global ocean observing capabilities on the global meridional overturning circulation. The panels show RMS variability differences between ocean state estimates, based on bi-weekly averaged fields over the year 2006. Top left: impact of jointly adding SST, SSH and in situ (TS) data to a baseline estimate consisting only of hydrographic climatology. Top right, bottom left, bottom right: impact of adding SST, SSH, and in situ (TS) data individually. Units are in Sv.

Heimbach et al., OO09
Fig. 4. Impact of Argo on the average salinity in upper 300 meters ($S_{300}$). (a) Effect of Argo T and S, (b) effect of Argo T only. Units are psu.

Balmaseda et al., Heimbach et al., OO09
Climate Forecasts

• An ultimate goal of ocean data assimilation is to improve SI and decadal climate forecasts.

• (Best) State Estimate
  – Data Assimilation in the Separate Component Models
  – Leads to initialization shocks.
Reducing Coupling Shock

- Initialization schemes all suffer from the inconsistencies between the interaction of the model and initial conditions (e.g., the model winds along the equator do not support the assimilation thermocline slope).
- To mitigate coupling shock, coupled model initialization schemes have been developed using only anomalies.
- Further improvements required.
- Might need other data than best state estimates.
A decade of progress on ENSO prediction

- Steady progress: ~1 month/decade skill gain
- How much is due to the initialization, how much to model development?

Relative Reduction in SST Forecast Error
ECMWF Seasonal Forecasting Systems

Half of the gain on forecast skill is due to improved ocean initialization

OceanObs 09, Venice 21-25 September 2009

Balmaseda et al., OO09
“We need data assimilation for coupled models as a prediction and evaluation tool for weather and climate”

(B. Hoskin, Climate Modeling Summit, ECMWF)

• Requires
  – Initialization
  – Parameter Estimation
Thank You!