Overview of data assimilation in oceanography or how best to initialize the ocean?

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AWI

Outline

- Ocean observing system

- Ocean models

- Data assimilation techniques

- Reanalysis products

- Coupled atmospheric ocean data assimilation

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Ocean observing system

- Increase in near real data availability since end of nineties

- Primarily source of information are satellite data

- SST (AVHRR), Salinity (SMOS), Dynamical ocean topography, sea-ice data (ENVISAT, CRYOSAT, …)

- Satellite products are used for assimilation.
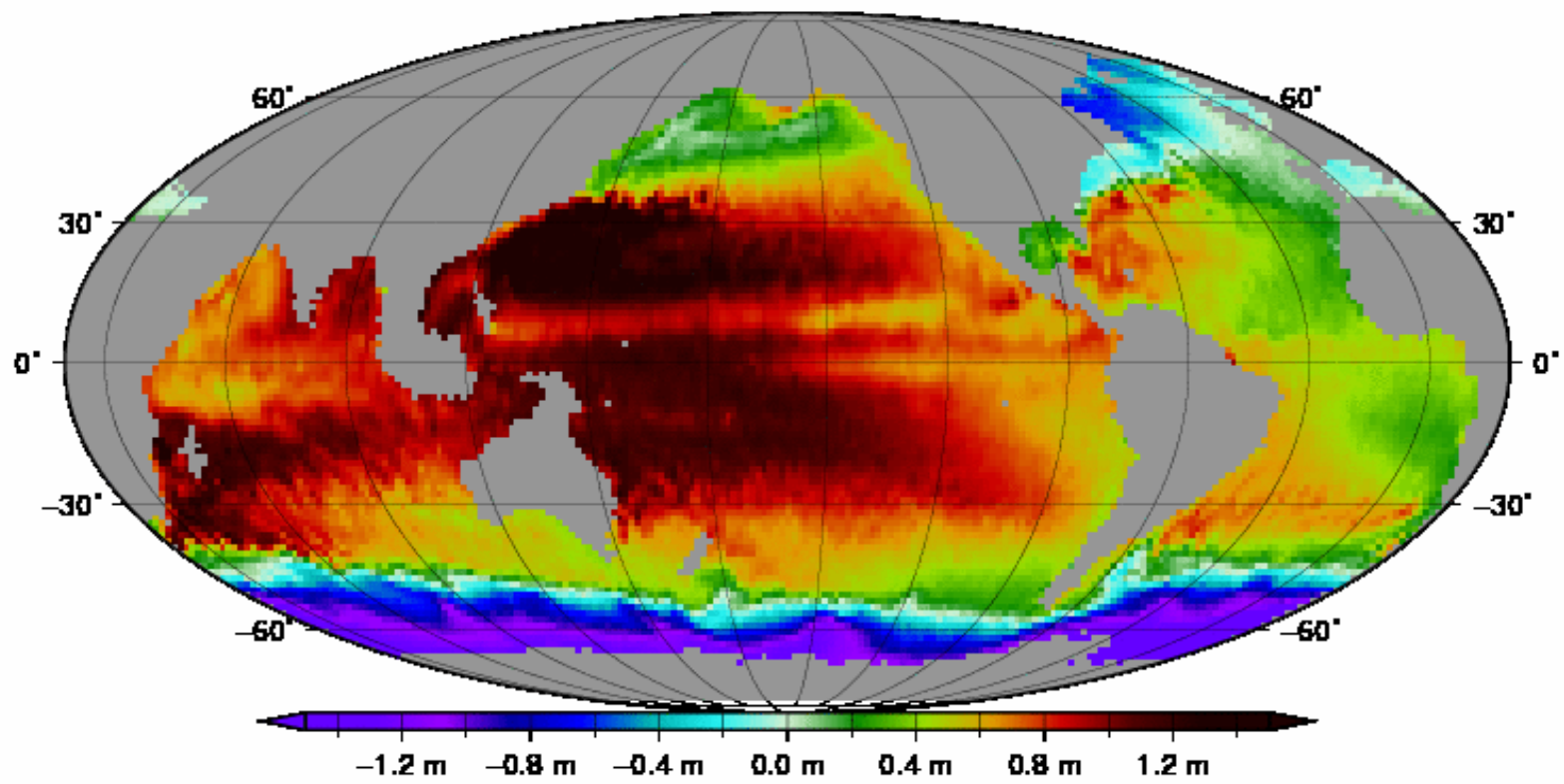
August 2010 SMOS Level 3 Data @ 1°x1°   [PSU]
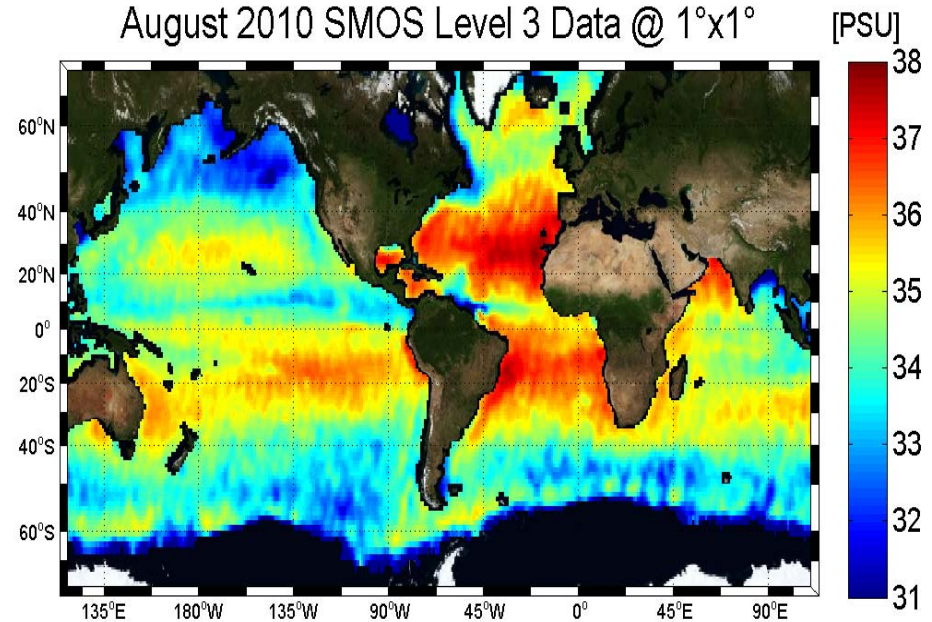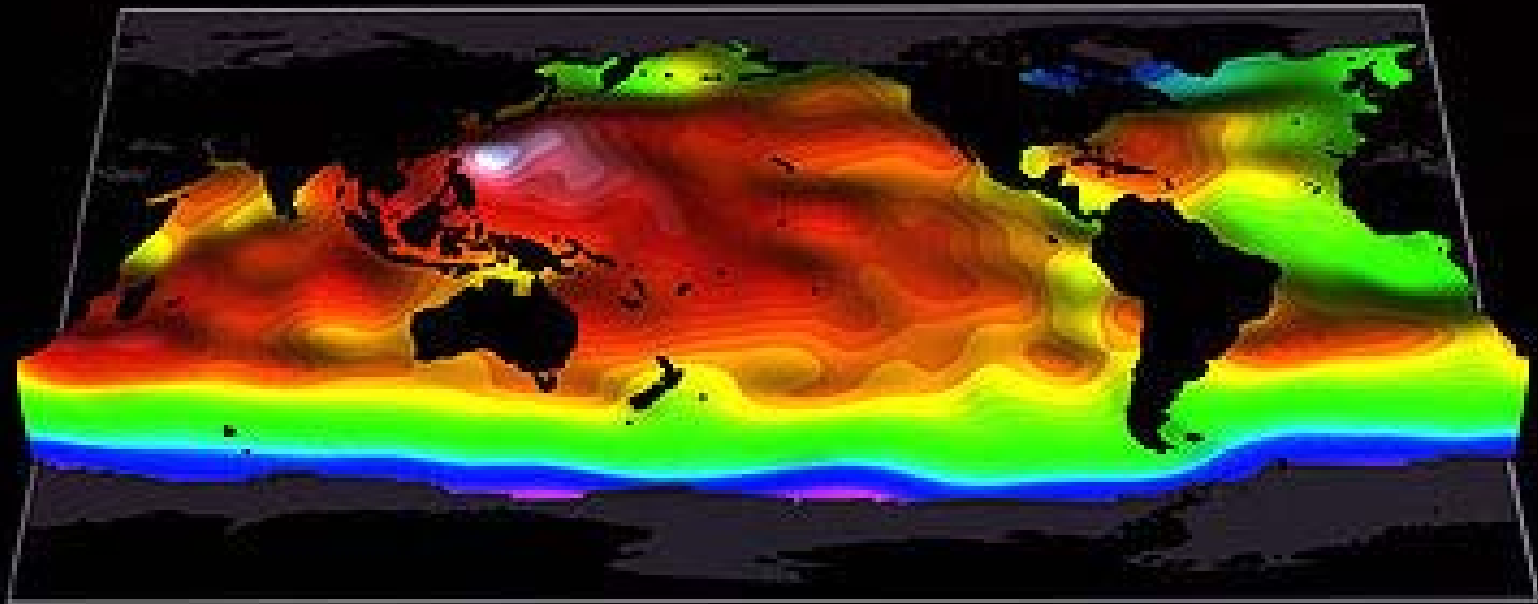
IFREMER / CERSAT

Mission	Cycles	repeat period (day)	data source
Jason1	70-113	10	GDR-C CNES/NASA
T/P	413-456	10	MGDR-B / NASA
ENVISAT	23-34	35	GDR / CERSAT
GFO	120-145	17	GDR / NOAA

GOCE

Launched March 17, 2009

2004−01−06

−1.2 m   −0.8 m   −0.4 m   0.0 m   0.4 m   0.8 m   1.2 m

Ocean Dynamic Topography (cm)   Oct 3-12, 1992

-120   -80   -40   0   40   80

☐ No Valid Data

Ocean observing system

Other data used for assimilation are:

• Surface drifters measuring velocity, temperature, salinity

• Hydrographic sections data

• Besides surface data only substantial data set that measures temperature and salinity up to 2000m are ARGO floats

• Some regions are observed more for example tropical oceans

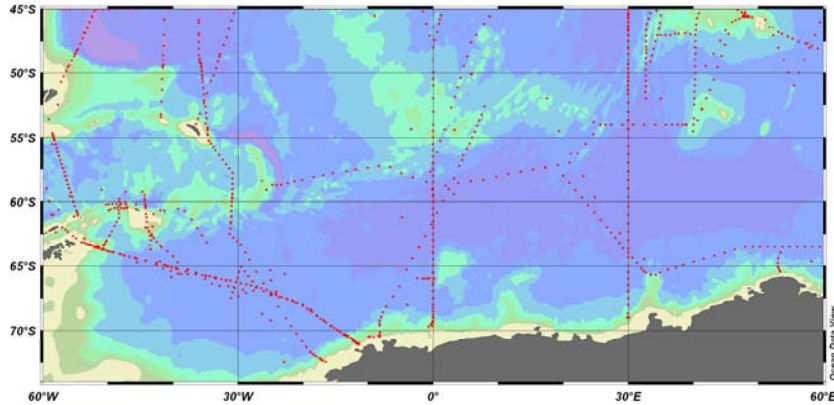• Generally polar regions are not well observed

3159 Argo Floats   April 2008

ARGENTINA (11) CHILE (8) EUROPEAN UNION (28) IRELAND (4) MEXICO (0) RUSSIAN FEDERATION (1)
AUSTRALIA (163) CHINA (11) FRANCE (152) JAPAN (381) NETHERLANDS (16) SPAIN (2)
BRAZIL (7) COSTA RICA (0) GERMANY (153) SOUTH KOREA (99) NEW ZEALAND (10) UNITED KINGDOM (101)
CANADA (97) ECUADOR (3) INDIA (88) MAURITIUS (4) NORWAY (7) UNITED STATES (1813)
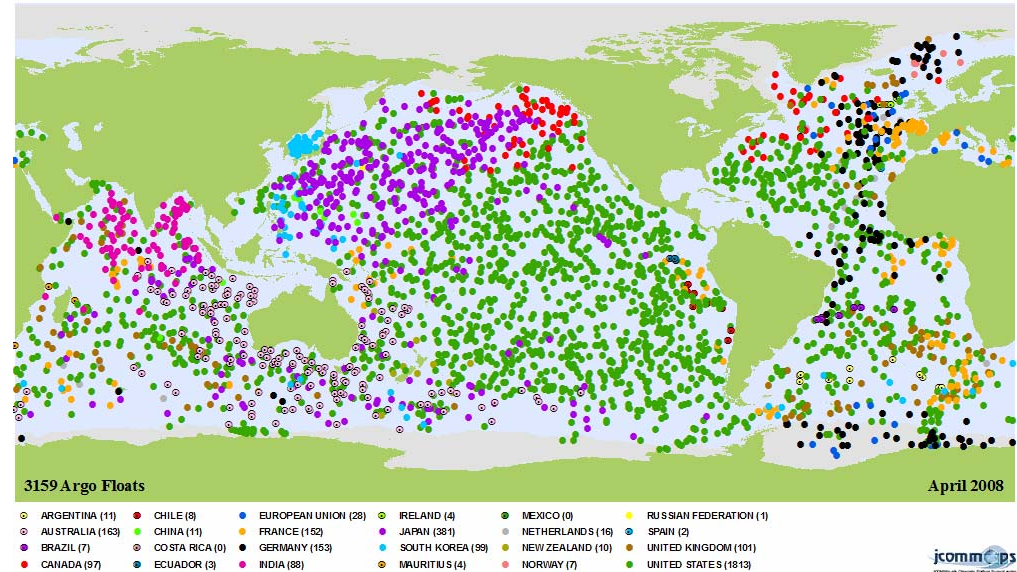
ARGO float distribution April 2008

Ocean still underobserved especially subsurface ocean variables!
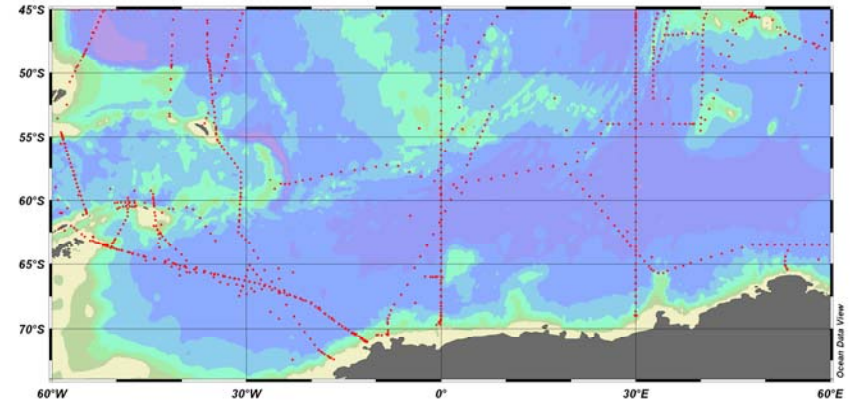
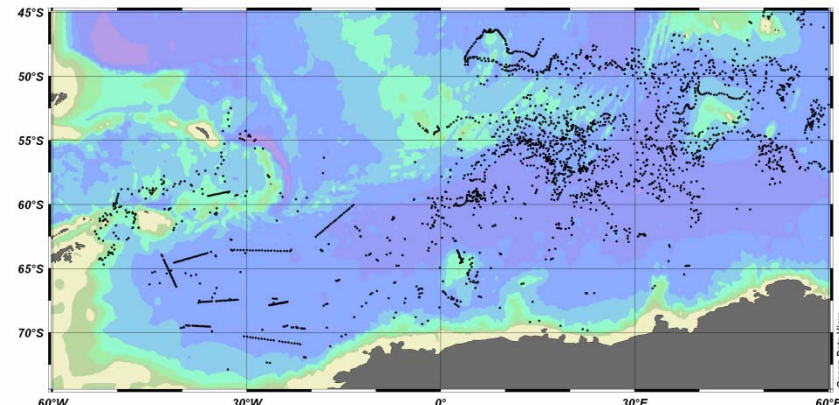# Weddell Sea

WOCE: CTD-stations
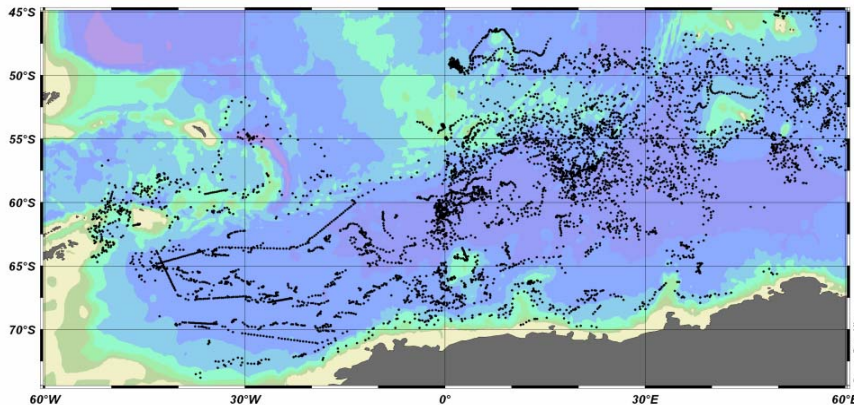
1100 CTD casts

WOCE: CTD-stations winter

< 300 CTD casts

AWI floats

7000 float profiles

AWI floats winter


>3000 float profiles

Floats are free drifting underwater buoys. Their compressibility is less than or equal to seawater and, hence, they gain positive buoyancy as they sink. For this reason, float pressure cases are often made of aluminum or glass. At a certain depth, the buoyancy force acting on the pressure case equilibrates with the weight of the float and it stops sinking. This physical concept, called neutral buoyancy, is the basis of floats.

Ocean models

• Solve the standard set of hydrostatic ocean dynamics primitive equations

• For forcing daily atmospheric ECMWF or NCEP data are used

• Sources of uncertainty: representation of topography, forcing, resolution and parametrizations

• Low resolution models can not represent well location of the Gulf Stream for example. To improve this density in some models is corrected with density from climatology.
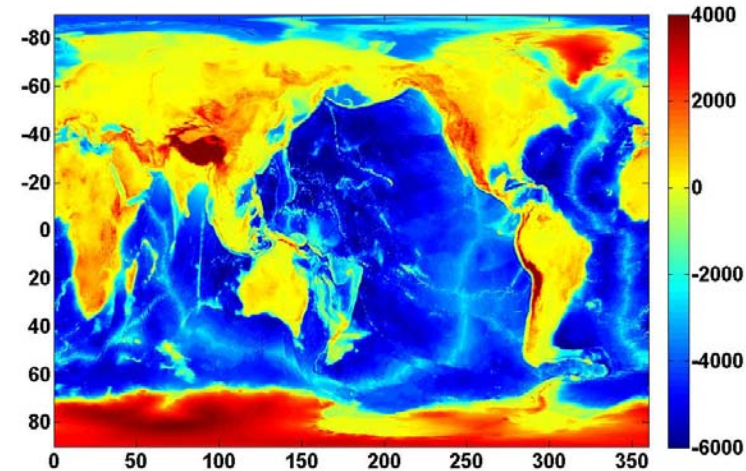
Representation of topography is one of uncertainty in ocean modeling

Data assimilation one way of controlling model bias!

Sequential data assimilation algorithms

$$\mathbf{w}_k^a = \mathbf{w}_k^f + \mathbf{K}_k(\mathbf{w}_k^o - \mathbf{H}_k\mathbf{w}_k^f),$$

$\mathbf{w}_k^f$, $\mathbf{w}_k^a$ denote forecast and analysis of ocean state vector consisting of temperature, salinity, SSH and velocity fields at time t_k at all grid points;

$$\mathbf{K}_k = \mathbf{P}_k^f\mathbf{H}_k^T(\mathbf{H}_k\mathbf{P}_k^f\mathbf{H}_k^T + \mathbf{R}_k)^{-1}$$

$\mathbf{w}_k^o$ observation available at t_k

$\mathbf{P}_k^{\tilde{f}}$ forecast error covariance matrix is time evolving error covariance matrix derived from ensemble of model states, multivariate, nonstationary, nonisotropic.

$\mathbf{R}_k^{\tilde{}}$ observational error covariance matrix

Possible approximations to $\mathbf{P}_k^{\tilde{f}}$ are instead of ensemble derived, also a stationary in time covariance (full or reduced rank).

Data assimilation

- Alternative technique 4D-Var (for example ECCO)

- This technique also requires specification of the errors in terms of covariance.

- Initially temperature and salinity are usually corrected and forcing through time (Note the fluxes obtained are the best fluxes for the ocean model corrections. Not necessarily the best fluxes for use in atmosphere.)

- Computationally more expensive then Kalman filter methods
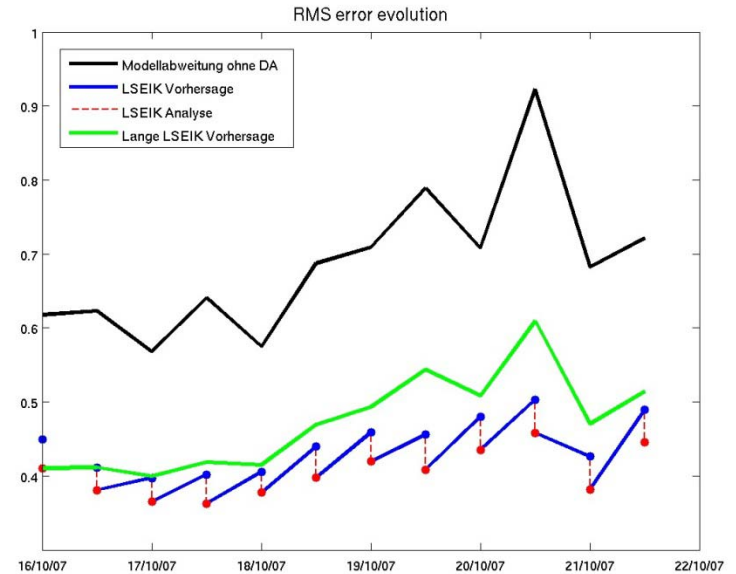
Example of ability to improve the forecast by applying ensemble based Kalman filter algorithm for assimilation of sea surface temperature into regional ocean model for North and Baltic Sea. (Loza et al.)

Monthly RMS error compared to ARGO
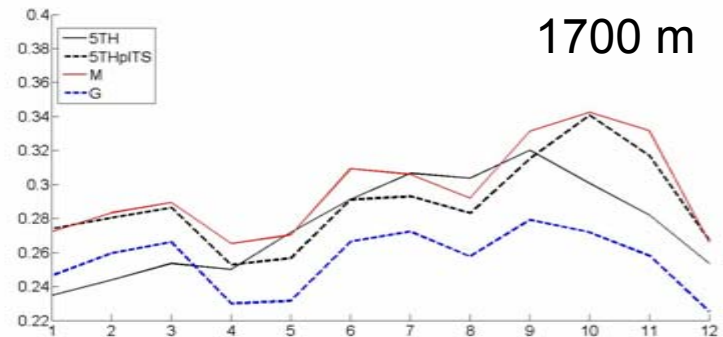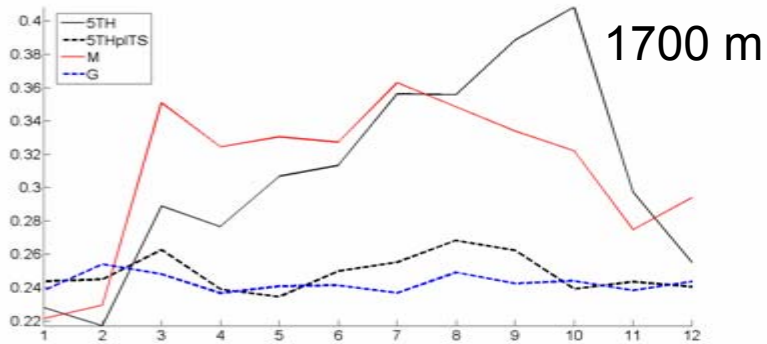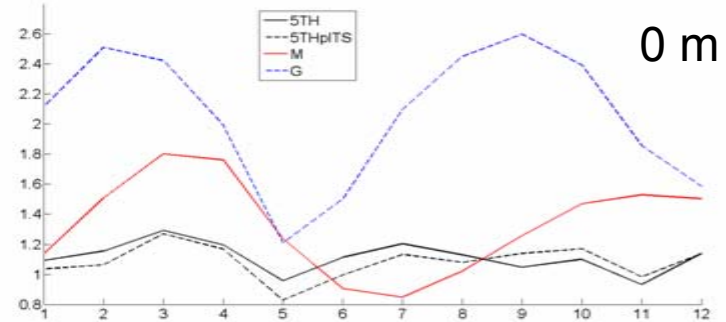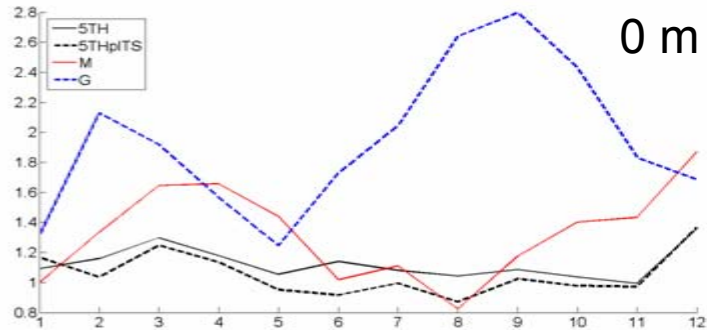
RMS errors for every month of 2004 for South Atlantic (left) and for South Indian Ocean (right), at level 0 (upper panels) and at level 1700 (lower panels). The results of experiments 5TH (black line), 5THplTS (dashed black line), for model run without data assimilation (red line) and climatology (dashed blue line) are shown. Note the different scale in upper and lower panels.

Ocean reanalysis

Ocean reanalysis are also available. For example SODA and GECCO efforts are compared here.

SODA

- 1958-2001
- Daily surface winds from ERA 40
- POP 0.25^o 0.4^o
- 40 levels
- Sequential OI

GECCO

- 1952-2001
- NCEP/NCAR reanalysis
- MIT 1° global model
- 23 levels
- Variational data assimilation method

SODA in contrast to GECCO does not use any altimetry measurements.

Besides in-situ measurements nighttime SST from AVHRR is assimilated in both products.

RMS sea level variability showing the mean position of the Gulf Stream as well as details such as Gulf of Mexico Ring formation.

SODA-POP RMS sea level (20yr)
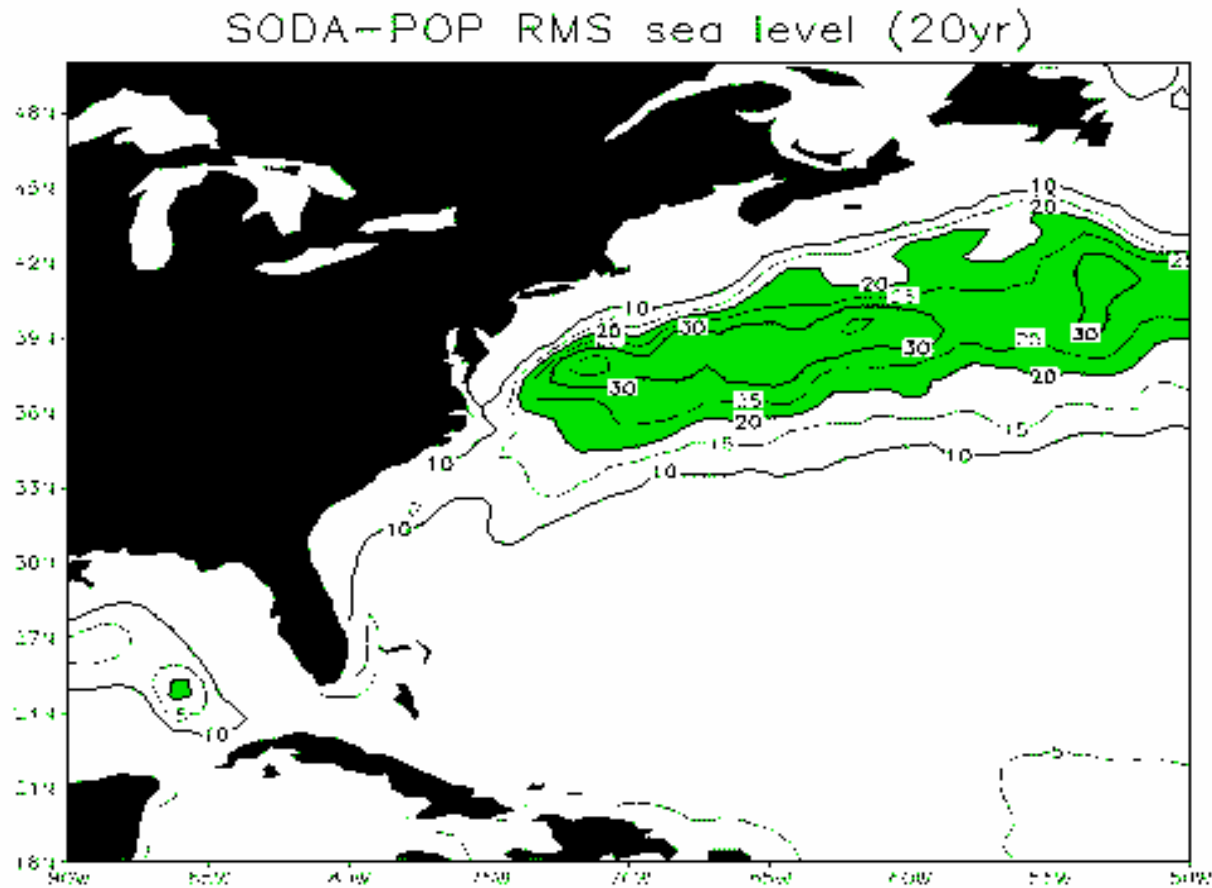
Coupled ocean atmosphere data assimilation

- Techniques for coupled ocean atmosphere data assimilation are currently under development

- It is expected that assimilation of both atmosphere and ocean simutaniosly would produce the best results

- However, first assimilation is done separately for ocean and for atmosphere Only in forecasting step these are coupled.

Conclusion

- Better understanding of oceans plays a critical role in setting the rate and nature of global climate variability, e.g. heat budget, freshwater budget, carbon budget
- Compared to atmospheric data assimilation where data are in abundance, ocean data assimilation is characterized with sparse observations
- Ocean observations cover surface but very poorly deeper ocean.
- In addition primarily satellite derived products are assimilated
- Bias in ocean models is still a major problem

Conclusion

- By data assimilation we can try to reduce the negative impact of biases in model representations of atmospheric and oceanic processes

- Develop tools to facilitate model-observations comparisons. This is complicated in oceanography since there is still no operational oceanography

- Develop fully-coupled data assimilation schemes

- Develop proper estimates of model and data uncertainties