Predicting Mesoscale Variability of the North Atlantic Using a Simple, Physically-Motivated Assimilation Scheme

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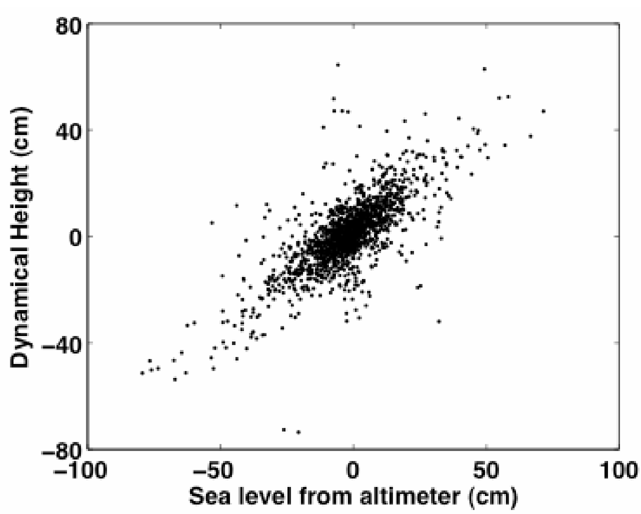
Background

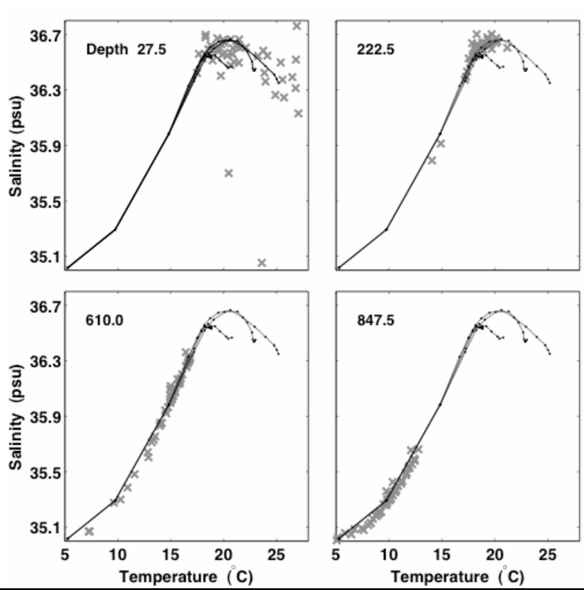
- Require computationally efficient scheme to assimilate Argo and altimeter data into regional ocean and global coupled models.
- Scales of interest are 1-30d, 10-10,000km.
- Must deal with bias in our ocean models, and rudimentary knowledge of background errors.

Observed Sea Level and Dynamic Height From Argo



- NW Atlantic
- Anomalies
- Colocated data
- RL at 1160m
- Correlation is 0.75, slope close to 1
- Simple physical balance

Argo Temperature and Salinity



- *Scatterplots of T and S at different depths*
- *~55.2W, 38.4N*
- *Complex, depth dependent structure*
- *Lines show Yashayaev climatology*
- *Shows importance of vertical advection in at depth*

Modelling Uncertainty in the Background State

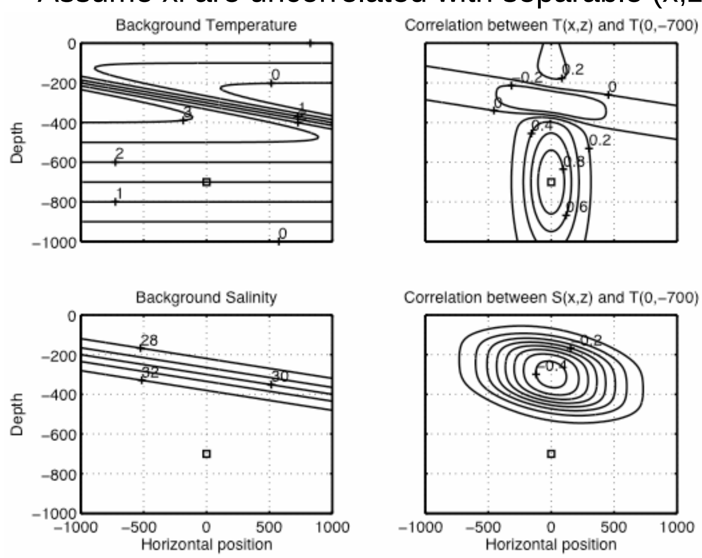
Motivated by these physical balances, assume

$$T = T_b - \partial T_b / \partial z \xi_D + \xi_T$$
$$S = S_b - \partial S_b / \partial z \xi_D + \xi_S$$
$$\eta = \eta_b + \Delta_\rho \xi_D + \int (\alpha_T \xi_T + \alpha_S \xi_S) dz$$

Builds on: ***Cooper and Haines (1996), Troccoli and Haines (1999), Haines et al. (2006), Ricci et al. (2005), Weaver et al. (2006)***

Implications for the B Matrix

Assume xi are uncorrelated with separable (x,z) covariance:



- **Complex T, S covariance**
- **Depends on background**

State and Parameter Estimation

Let *x* and *y* be true ocean state and observation vectors, and theta a vector of uncertain parameters of covariance of xi. Posterior pdf of state and parameters given observations is

$$p(x,\theta \mid y) \propto p(y \mid x)p(x \mid \theta)p(\theta)$$

Under Gaussian error assumption, maximizing posterior pdf is the same as minimizing

$$L(x,\theta) \propto \log | B_{\xi\xi}(\theta) | + J(x,\theta) - 2\log p(\theta)$$

$$J \equiv (y - Hx)^T R^{-1}(y - Hx) + (x - x_b)^T B^{-1}(x - x_b)$$

$$B \equiv MB_{\xi\xi}(\theta)M^T$$

Online estimation of theta similar in principle to Dee (1995).

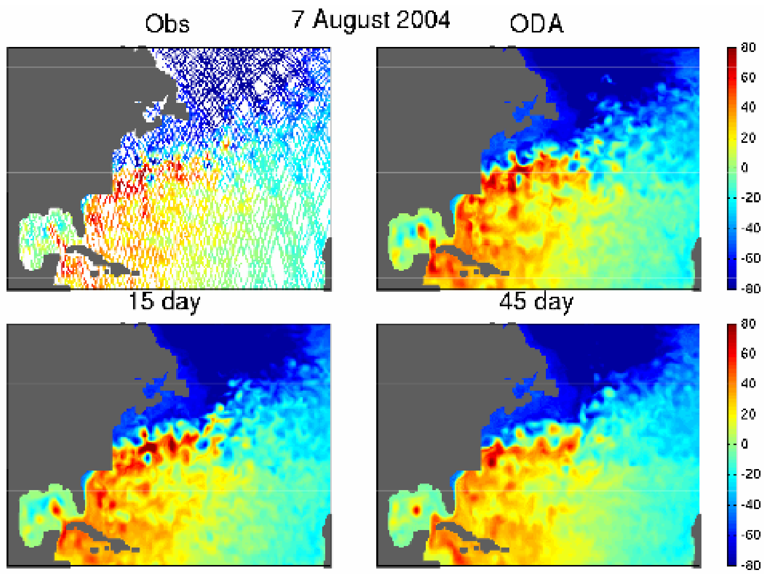
Some Details of the Scheme

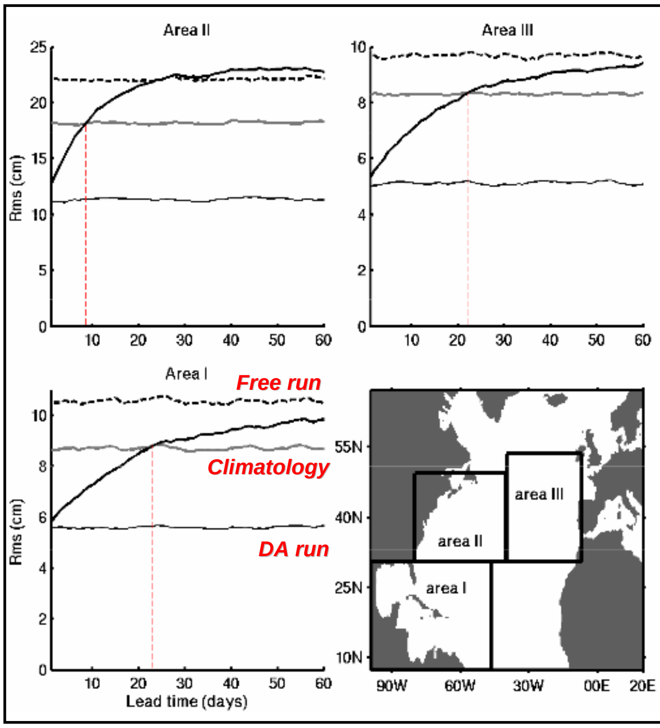
- Spectral nudging is used to suppress bias in T and S. Online, cheap and necessary. Ensures model and observed climatology match (e.g. western boundary currents separate as observed, mean PE correct) and statistics of variability are reasonable.
- Lagrangian interpolation of Argo data to analysis time.
- Estimate ocean state daily, and covariance parameters every 2 days. B changes with time (via theta) and background state (via the transformation).

North Atlantic Example

- POP ocean model, 1/3 degree, 23 levels.
- Spectrally nudged to Yashayaev monthly climatology.
- Daily atmospheric forcing from NCEP reanalysis.
- Assimilate Argo and altimeter data, 2003-5.
- Vertical gradient of background is linear combination of climatology and forecast.
- Uncertain covariance parameters (theta) are horizontal length scales and variance of the xi variables.

Typical Snapshot of Sea Level

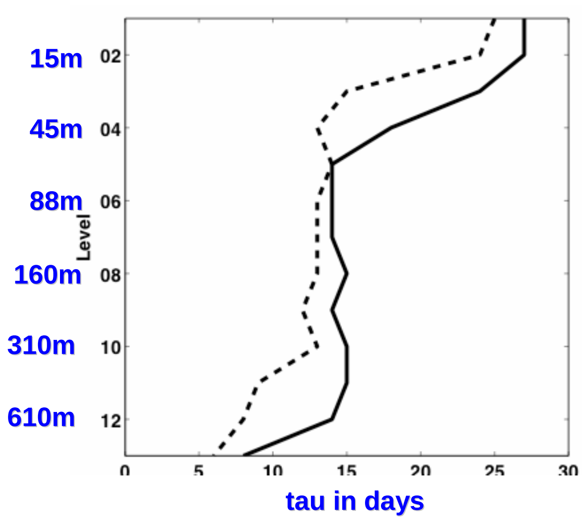




Forecast Skill For Sea Level

- •Rms of obs-pred vs lead time
- •Based on 24 monthly forecast runs (each 60d)

Forecast Skill for T and S



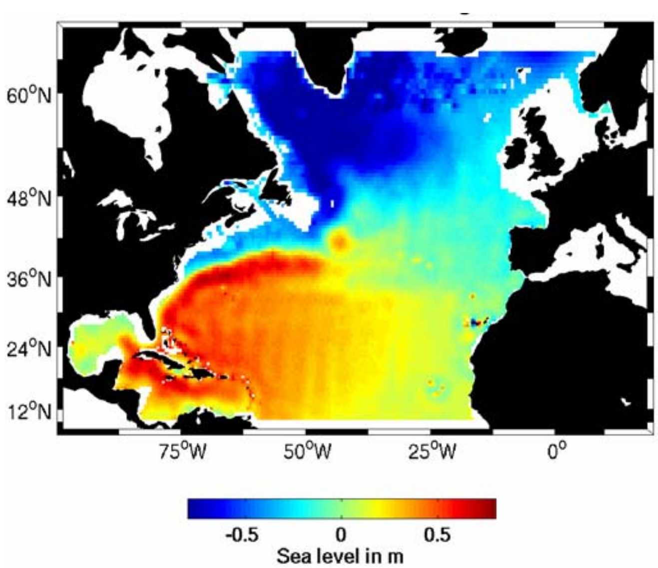
Summary

- ✓ New scheme is computationally efficient (adds 30% to run time and memory) and has useful skill.
- ✓ Plan to compare pre-operational version (with XBT) to existing operational forecast systems (e.g. SEEK).

- ➢ Works because simple physical balances built into B (which changes with time and background).
- ➢ Online bias correction is critical for forecasting North Atlantic mesoscale.
- ➢ Online estimation of B parameters gives scheme robustness and flexibility. Possible because joint posterior pdf maximized rather than marginal.

Mean Surface Topography From Space

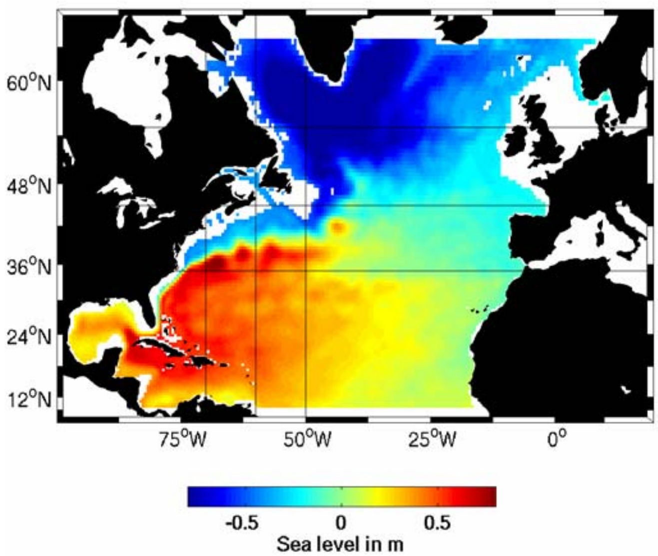
(Jianliang Huang, NRCAN)



MSSH
- GSFC00
- Altimeter data 1993-9
- Multiple satellites
- Accuracy O(10cm) in GS

Geoid
- GGM02C
- Regionally enhanced by blending with terrestrial gravity data

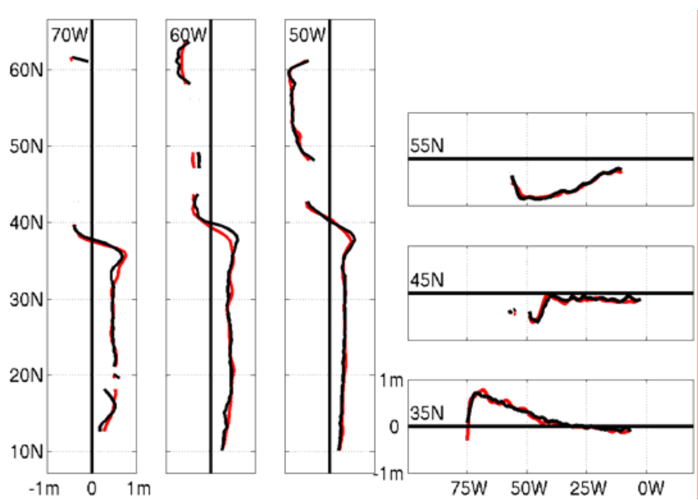
MSST of the Spectrally Nudged Model



- POP
- Realistic surface fluxes
- 1991-1999
- Spectral nudged
- Yashayaev climatology

Similar to classical diagnostic calculation based of decades of hydrographic data.

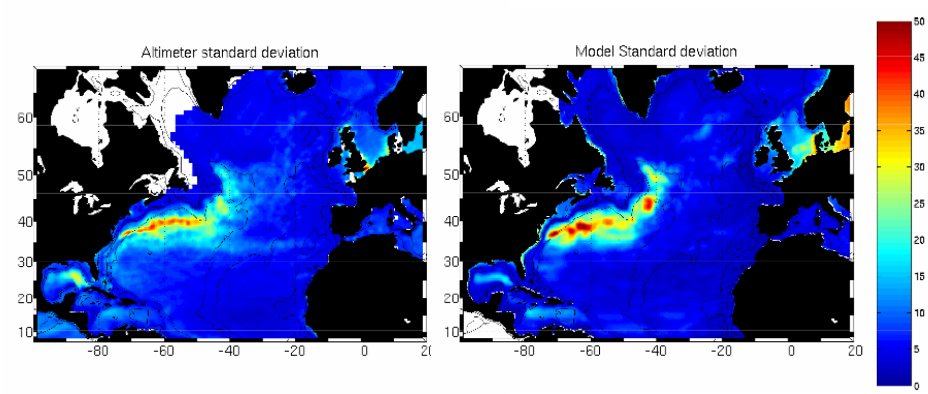
Comparing GRACE and Model-Based MSST



GRACE: Black
Ocean model: Red

Over whole NA, rms(error)=7.6cm!

Spectral Nudging Gives Realistic Sea Level Variability



Standard Deviation of Altimeter Data 1993-2001

Standard Deviation of Model's Sea Level 1991-9