POPDART: An Ensemble Data Assimilation System for the Ocean Component of CESM

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Acknowledgements

The CESM project is supported by the National Science Foundation and the Office of Science (BER) of the U.S. Department of Energy. NCAR is sponsored by the National Science Foundation.

This work was partially supported by a NOAA Cooperative Agreement (grant NA06OAR4310119) with the Geophysical Fluid Dynamics Laboratory (GFDL) and by the NOAA Climate Program Office under the Climate Variability and Predictability Program grant NA09OAR4310163. Computing resources were provided by the Climate Simulation Laboratory at NCAR's Computational and Information Systems Laboratory (CISL), sponsored by the NSF and other agencies. Support with accessing data from the WOD09 was provided by CISL's Data Support Section.

At the National Center for Atmospheric Research, a 48-member ensemble adjustment Kalman filter (EaKF) has been used to assimilate daily subsurface temperature and salinity data into the POP2 1°x1° global ocean model from 1998-2005. The new ocean assimilation system dovetails with an existing EaKF system for the CAM4 2°x2° atmospheric model, using unique members of the CAM posterior ensemble to force each POP2 ensemble member. Ocean analysis can potentially be used for dynamical studies of the world ocean, as well as intialization of seasonal, interannual and decadal timescale coupled ocean-atmosphere forecasts

The ocean assimilation system

- 48 member ensemble adjustment Kalman filter implemented using the Data Assimilation Research Testbed (DART)
- Each member of the ocean ensemble forced by a unique member of a CAM4/EaKF atmospheric analysis .
- Assimilation state consists of the prognostic ocean-model state of (T,S,U,V,SLH on the POP2 1°x1°, 60 vertical level grid)
- Horizontal localization of approximately 11° . No localization in the vertical, allowing the observations at any depth to impact the entire water column.
- No covariance inflation. Spread in the ensemble maintained primarily through the use of an ensemble of atmospheric forcing states.
- Daily assimilation of temperature and salinity data from the 2009 World Ocean Database from 1998-2005. No satellite SST or altimetry assimilated.

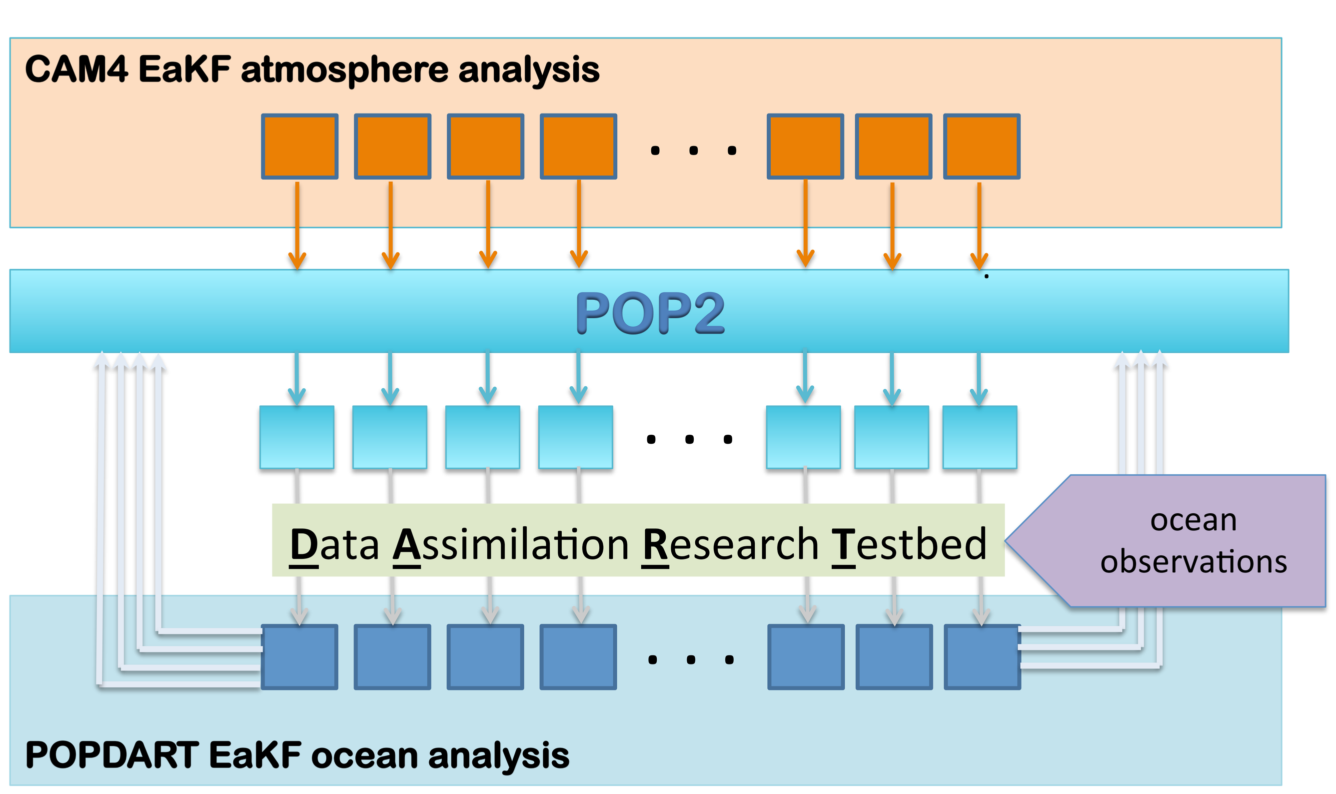
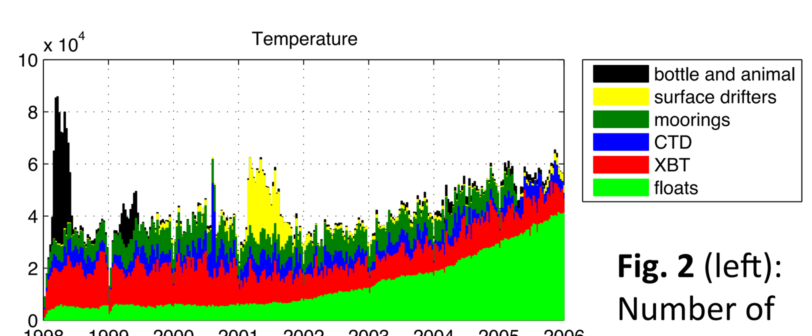


Fig 1: Schematic of POPDART system.

Assimilated observations

We assimilated subsurface temperature and salinity from the WOD09. The Argo network of "floats" has dramatically increased the observational coverage of the world ocean in the upper 2000m. The change is especially dramatic for salinity (Fig. 2) Coverage below 2000m is sparse and intermittent and generally hovers around 200-300 observations taken every 10 days.



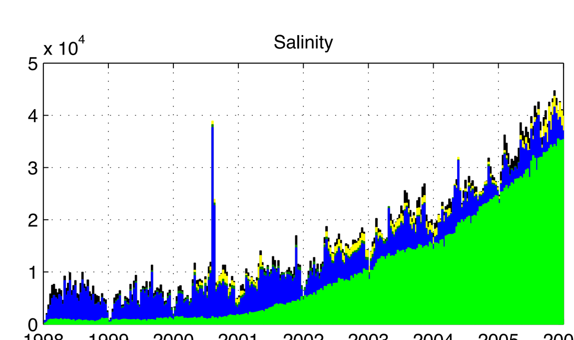


Fig. 2 (left): Number of assimilated observations in 10-day intervals from the 2009 World Ocean Database.

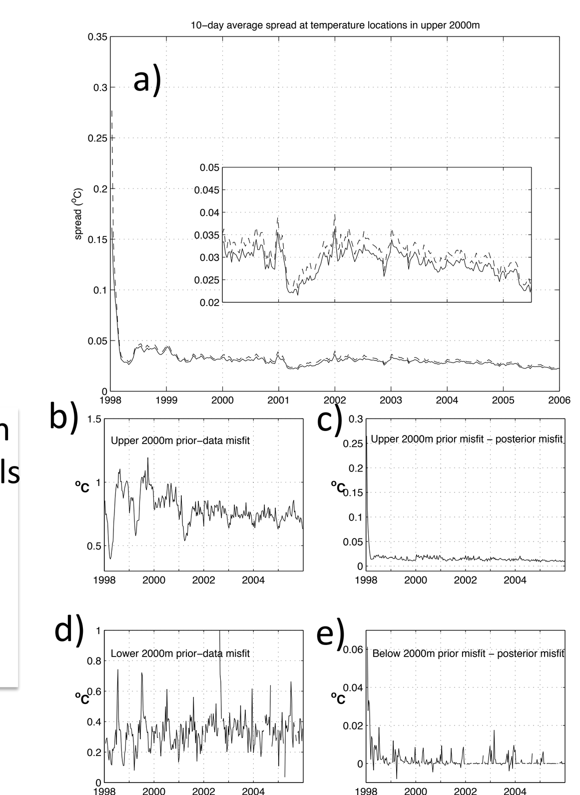


Fig. 3 (far right): a) Prior (dashed) and posterior (solid) spread at the location/time of observations averaged over 10-day intervals in the upper 2000m. b,d) Prior-observation absolute error in upper 2000m and below 2000m. c,e) Prior misfit – posterior misfit in upper 2000m and below 2000m.

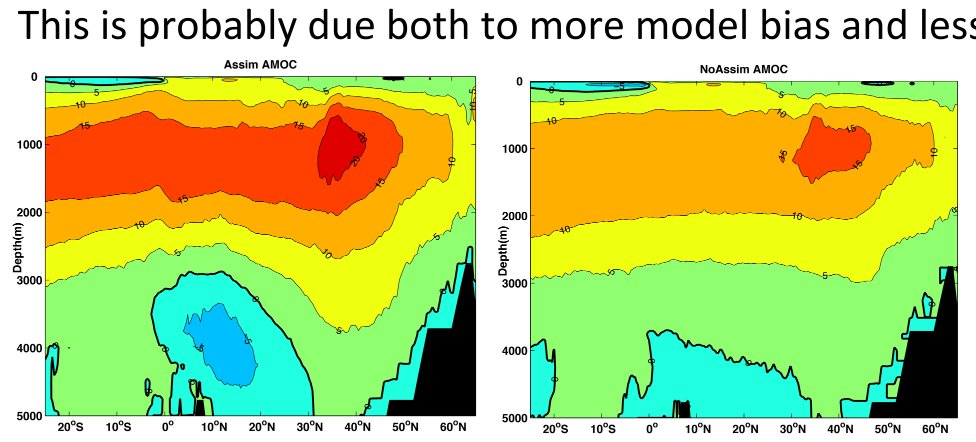
Comparison to identically forced ocean without assimilation

To understand the role that data plays in constraining the ocean, we compare the time/ensemble mean analysis with assimilation (hereafter "Assim") to the time/ensemble mean of an identically atmospheric-forced collection of 48 ocean simulations ("NoAssim").

Generally, the assimilation of data brings the mean state from 2000-2005 into better agreement with independent observations. The maximum of the Atlantic meridional overturning circulation (AMOC) is stronger by ~4 Sv. At 26°N, comparison with the RAPID array estimates show that this is a more realistic estimate (Fig. 4-5). Assimilation also leads to a stronger deep western boundary current (DWBC) below 2500 m equatorward of the Grand Banks (Fig. 6). The 8.2 Sv (vs. ~3.5 Sv in NoAssim) of flow at the continental shelf near 37°N compares more favorably to estimates of ~16 Sv reported by Joyce et al (2005) when data are assimilated. Assim also has a more realistic pathway of the Gulf Stream (and Kuroshio, not shown), which helps ameliorate (but not eliminate) major biases in upper ocean temperature, salinity and sea level on the northern edge of the subtropical gyre.

Diagnostics of the assimilation system

Ensemble variance for both temperature and salinity evaluated at the location of observations is always lower in the posterior than in the prior (as predicted by Kalman Filter theory). (Temperature: Fig. 3a; Salinity: not shown)). Major changes in the observing network (i.e. the drifter campaign of 2001 and the more gradual deployment of Argo floats from 2000-2006) are reflected in the variance reduction through time. In the upper 2000m, model-data misfits evaluated before assimilation tend to stabilize and slowly decline through the lifetime of the assimilation (Fig. 3b). Not so in the sparsely observed deep ocean, where there is no clear reduction in error over time (Fig. 3d). For individual observations, theory states that the prior misfit will always be greater than the posterior misfit. When the posterior is evaluated after the collection of all observations at a given time have been assimilated, this need not be the case if the model is biased. We observe that prior misfits are always larger than posterior misfits in the upper 2000m (Fig. 3c). In the deep ocean, however, assimilation leads to a degraded posterior on a number of occasions (Fig. 3e) . These diagnostics highlight that the state of the upper ocean is much more effectively estimated than the deep ocean. This is probably due both to more model bias and less data in the deep ocean.



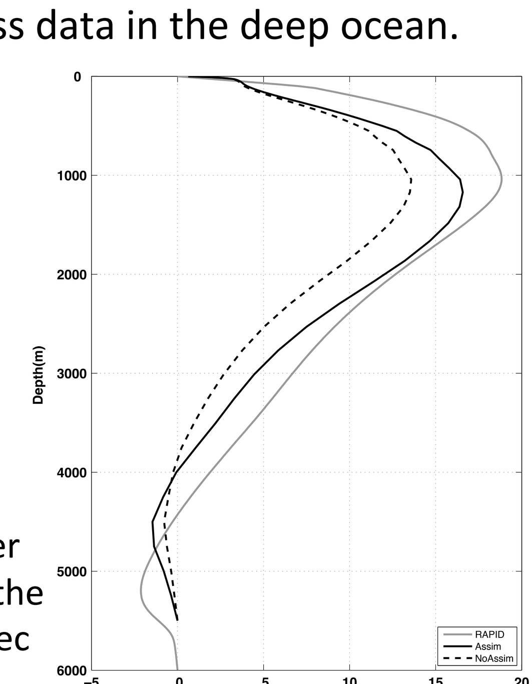


Fig. 4 (above): AMOC (in Sverdrups) with assimilation (left panel) and without assimilation (right panel). Averages over 2000-2005 **Fig. 5** (right): AMOC profiles at the location of the RAPID array estimates at 26°N. Average from April 2004-Dec 2005.

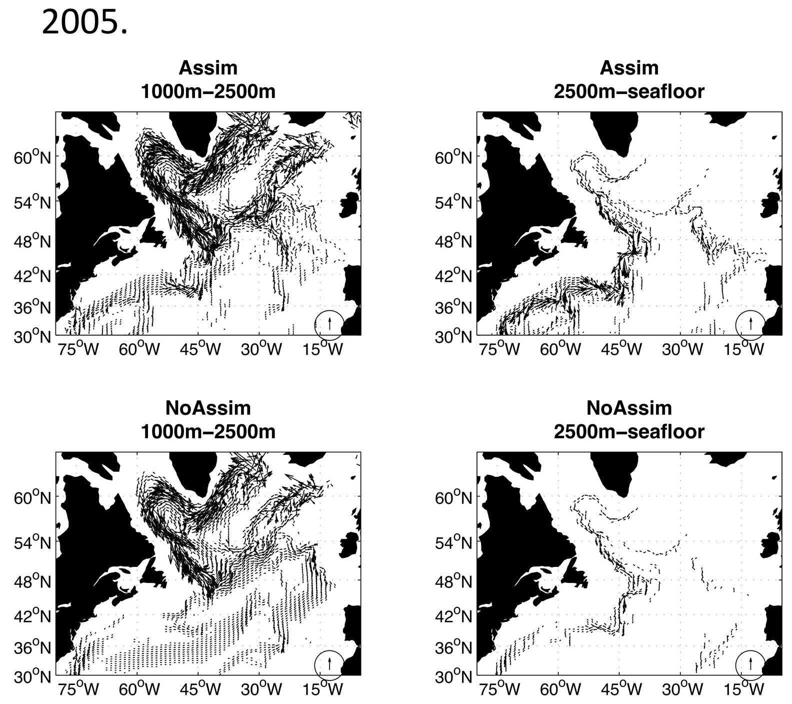


Fig. 6: Transport in the deep western boundary current (DWBC) with assimilation (upper panels) and without assimilation (lower panels) . Left panels are the combined transport from 1000m-2500m. Right panels are the combined transport below 2500m. Circled arrow in right corner represents 5 Sv. Averages from 2000-2005.

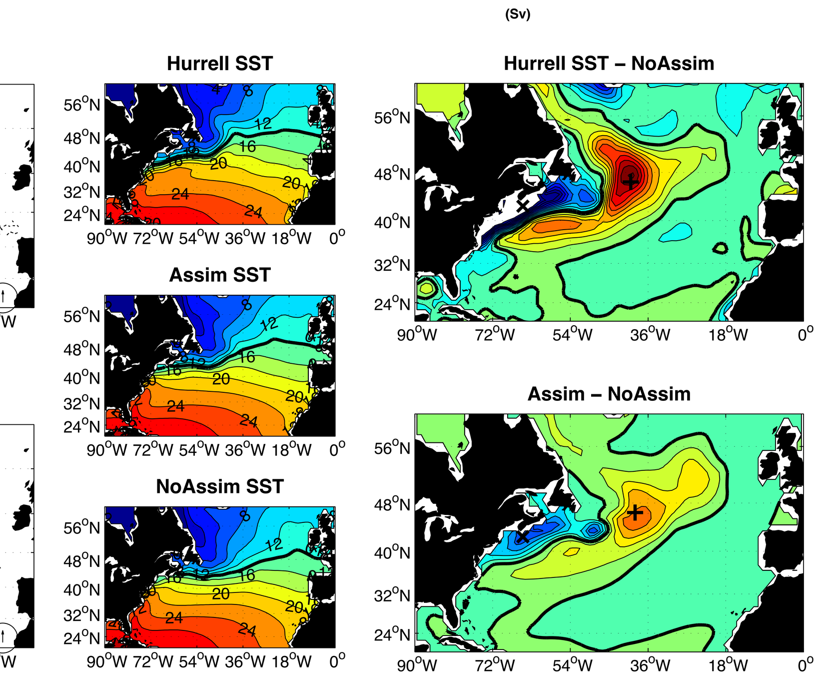


Fig. 7: SST from the Hurrell satellite-based dataset (top left), Assim (middle left) and NoAssim (bottom left). Differences between Hurrell SST and NoAssim (top right) and Assim and NoAssim (bottom right). Units are °C. Averages over 2000-2005.