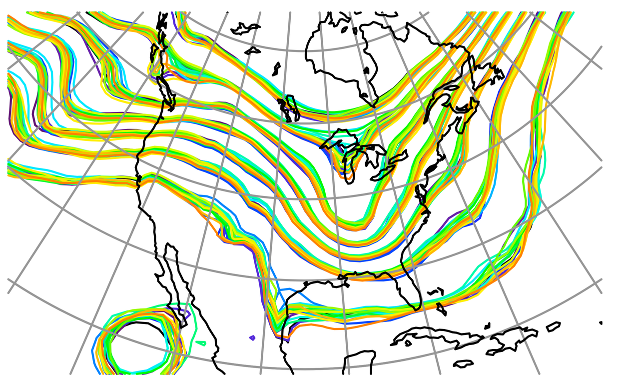

Weakly Coupled Atmosphere-Ocean Data Assimilation: CAM-DART-POP

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1. Abstract and Preliminaries

The Data Assimilation Research Testbed (DART) ensemble Kalman filter has been combined with the Community Atmosphere Model (CAM) and the Parallel Ocean Program (POP) to create weakly coupled ensemble analyses of the ocean that maintain a more desirable ensemble spread than if POP is forced with a single atmosphere. The impact on the ocean of using an ensemble of atmospheric forcings is assessed by comparing the fit to the observations and the ensemble spread. The spread can be thought of as a measure of the uncertainty in the estimate of the system. Ensemble methods typically produce too little ensemble spread and analyses that give too little weight to observations.

DART/CAM is used to create an 80-member atmospheric reanalysis assimilating all observations used in the NCEP/NCAR reanalysis. Each member of the CAM assimilation is forced from below by a single ocean analysis. A 48-member reanalysis with DART/POP is created using all temperature and salinity observations available in the World Ocean Database. The atmospheric forcings required for POP are obtained from the first 48 ensemble members from the CAM reanalysis, such that each POP instance uses a different sample estimate of the atmospheric forcing. The baseline case uses a single atmosphere for all the POP ensemble members.

1.1 Atmospheric Assimilations

- CAM Version 4: will be used for the next IPCC
- 80 ensemble members
- (1.9° x 2.5°) 96 latitudes, 144 longitudes, 26 levels
- Variables influenced by the assimilation: surface pressure, temperature, horizontal winds, specific humidity, cloud liquid, and cloud ice
- Assimilation performed every 6 hours starting 1 Dec 1997
- All observations used in the NCEP/NCAR reanalysis. Globally, about 100,000 observations every 6 hours
- Adaptive Inflation used to maintain ensemble spread

1.2 Oceanic Assimilations

1.2.1 DARTPOP23

- 1 degree grid with displaced pole, 60 levels (POP gx1v6)
- active sea ice (CICE) model
- use all World Ocean Database obs in a +/- 12 hour window
- assimilate every midnight
- ran from January 1998 through December 1999
- 23 ensemble members initially drawn from a model climatology
- each member has identical observed atmospheric forcing

1.2.2 DARTPOP48 differed in that:

- 48 ensemble members initially drawn from a model climatology
- atmospheric forcing for each POP member comes from a unique CAM ensemble member analysis

2. The Result: Better Estimates of the Oceanic State

The larger ensemble and diverse atmospheric forcing lead to improvements in some aspects of the ensemble mean ocean analysis. The remainder of the poster is dedicated to exploring the effectiveness of the assimilation when compared to observations.

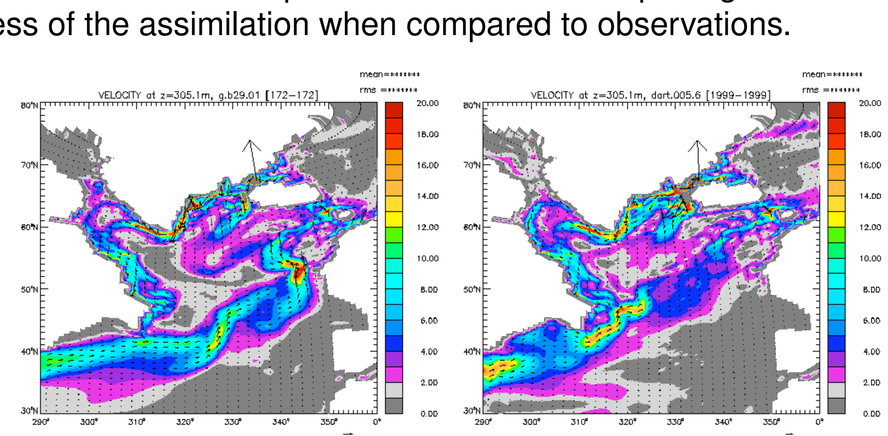


Figure 1: *Two-year estimate of the POP velocity at approx 300m shows a significantly improved North Atlantic Current path in the assimilation (right) compared to a POP free run (left). The current is much tighter and follows the coast much more closely, traditionally a problem with free runs. These results were from the DARTPOP23 experiment.*

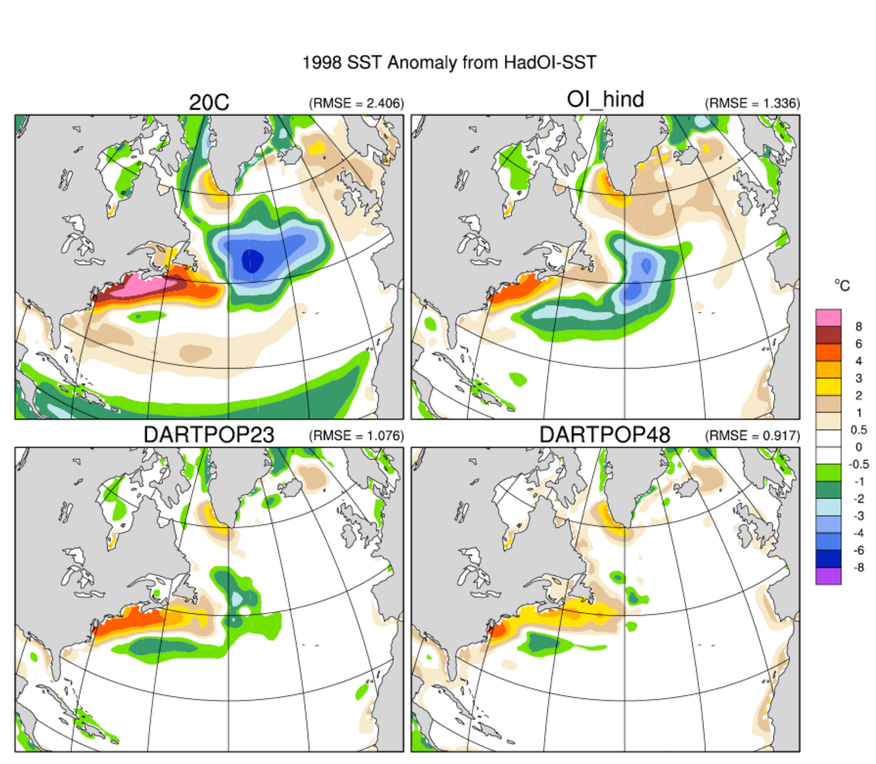


Figure 2: *The difference between the Hadley OI SST and various POP experiments. The top-left panel is a fully coupled 20th century run. The top-right panel is an ocean-ice hindcast simulation. The top two panels do not use DART, the bottom two do. The panel labelled 'DARTPOP23' shows a much smaller difference than either of the experiments that do not use DART. The bottom-right panel ('DARTPOP48') shows a dramatically improved fit to the Hadley product.*

3. Atmospheric Observations routinely used with DART

DART supports a wide variety of observations; from the standard radiosonde to GPS radio occultations. The design paradigm for DART means that once an observation type is supported, all models that work with DART can assimilate those same observations.

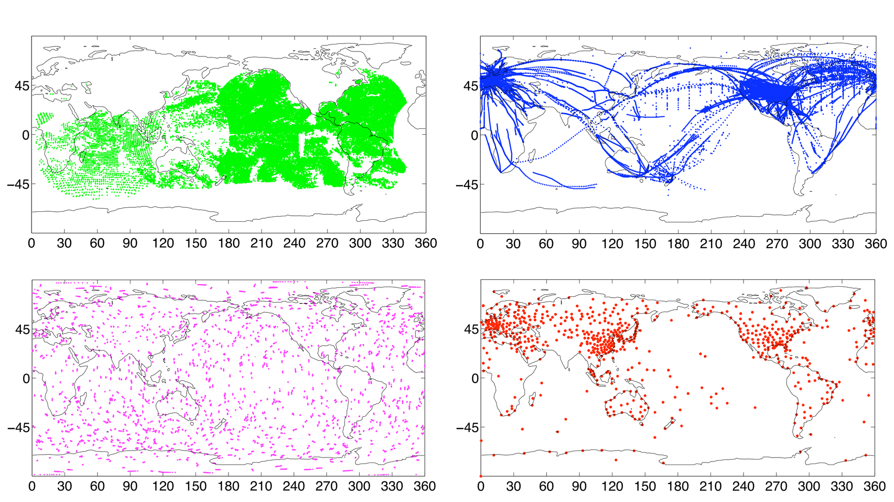


Figure 3: *Typical atmospheric observation density routinely assimilated by DART. Observation locations for 1 Dec 2006.*

4. World Ocean Database (2005) Observation Counts for 1998 and 1999

FLOAT_SALINITY	68200
FLOAT_TEMPERATURE	395032
DRIFTER_TEMPERATURE	33963
MOORING_SALINITY	27476
MOORING_TEMPERATURE	623967
BOTTLE_SALINITY	79855
BOTTLE_TEMPERATURE	81488
CTD_SALINITY	328812
CTD_TEMPERATURE	368715
STD_SALINITY	674
STD_TEMPERATURE	677
XCTD_SALINITY	3328
XCTD_TEMPERATURE	5790
MBT_TEMPERATURE	58206
XBT_TEMPERATURE	1093330
APB_TEMPERATURE	580111
Total	**3749624**

5. Diagnostics: error with respect to the observations

The DART system applies a forward operator to each ensemble member model state to determine the expected observation value (see Figure 8). DART has diagnostic capabilities based on comparing the expected observations to the actual observations. The following diagnostics are calculated immediately **prior** to assimilating the observations - at this point, the ocean state has evolved for 24 hours since the last assimilation. It is possible to achieve a low RMSE by rejecting all the observations that do not agree with the ensemble, so the number of observations rejected must be considered. Not all observations *should* be used, however!

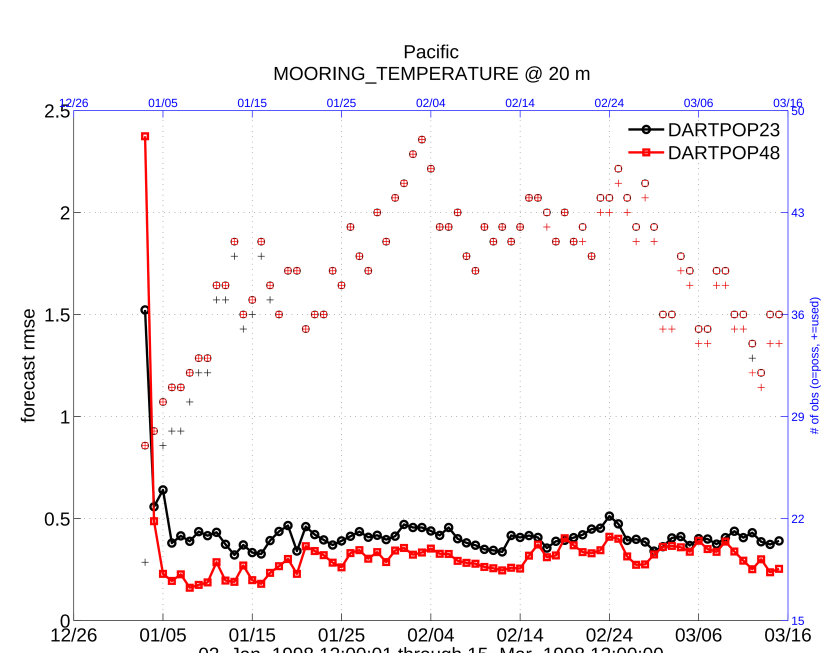


Figure 4: *The solid lines depict the RMSE and should be interpreted using the scale on the left. The lighter symbols depict the number of observations possible and the number used and should be interpreted using the scale on the right. The difference is the number rejected by the assimilation system. The DARTPOP48 moored temperatures in the Pacific exhibit a systematic decrease in error as defined by the observations.*

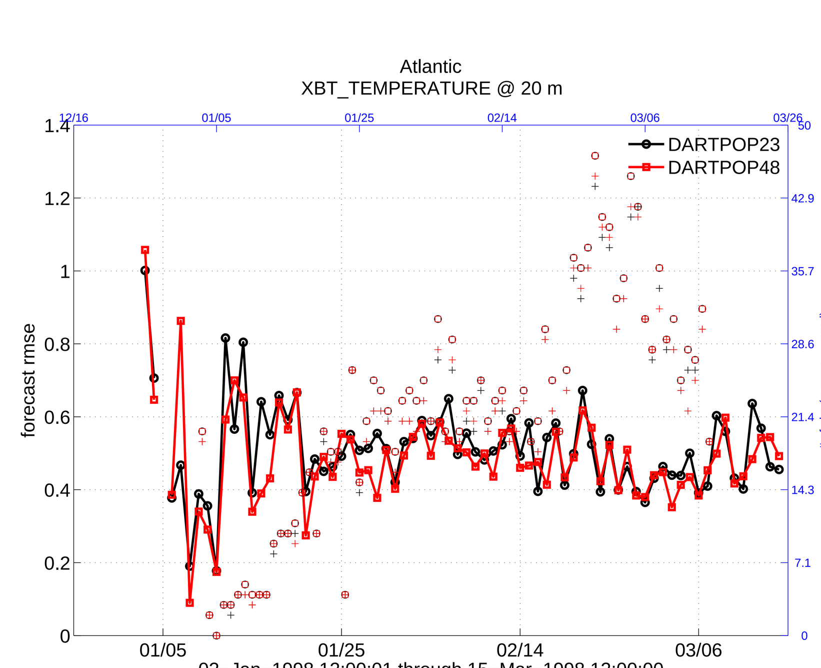


Figure 5: *The error in the XBT temperatures in the Atlantic are about the same, even though (in general) fewer observations were rejected by the assimilation system for the DARTPOP48 experiment.*

6. Diagnostics: ensemble spread

A healthy ensemble data assimilation system will maintain the ensemble spread (the standard deviation of the ensemble), fundamentally trying to ensure that the true state is contained within the ensemble manifold. Too little spread and the system can become more confident in the ensemble than the observations, too much and the system is not informative. The latter is not the problem here. These figures show the assimilation system performance at the beginning of the experiments. They start off with the spread of the climatologically-based initial ensemble and show the constriction of the ensemble as it becomes more consistent with the observations.

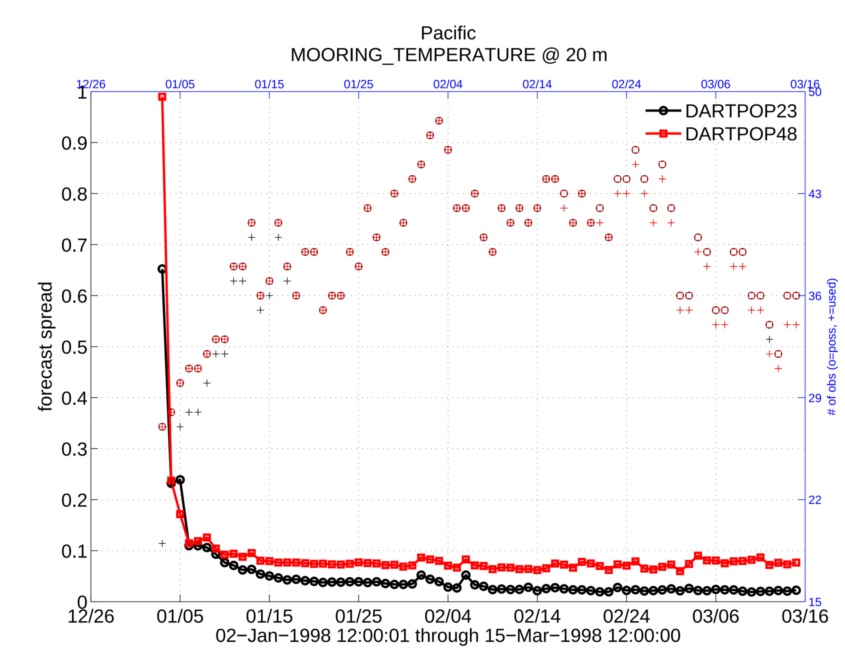


Figure 6: *The spread of the ensemble as calculated by the estimated temperatures at the moorings in the Pacific. The DARTPOP48 case has more than twice the ensemble spread of the DARTPOP23 case.*

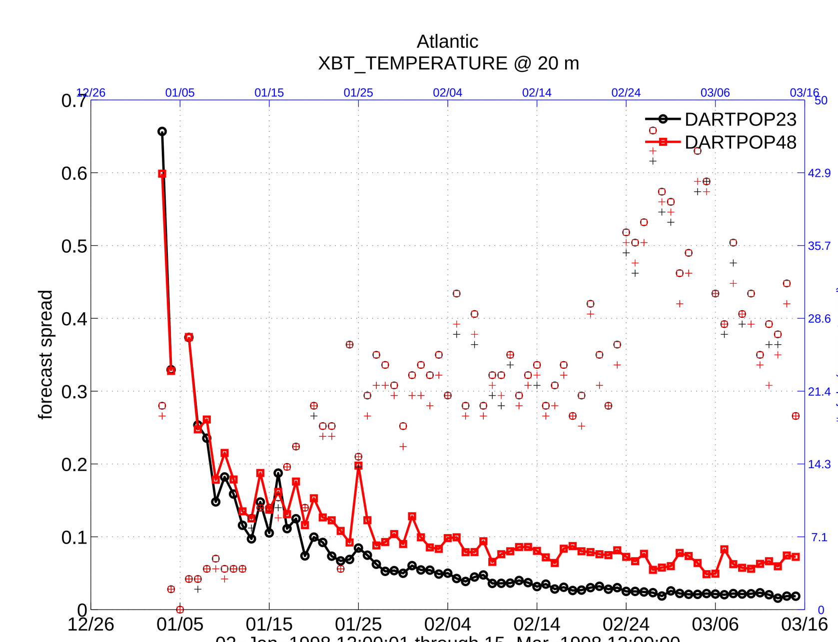


Figure 7: *The DARTPOP48 case levels off with a larger ensemble spread, which is what was hoped for by using multiple atmospheric forcing fields.*

7. DART: understanding the diagnostics

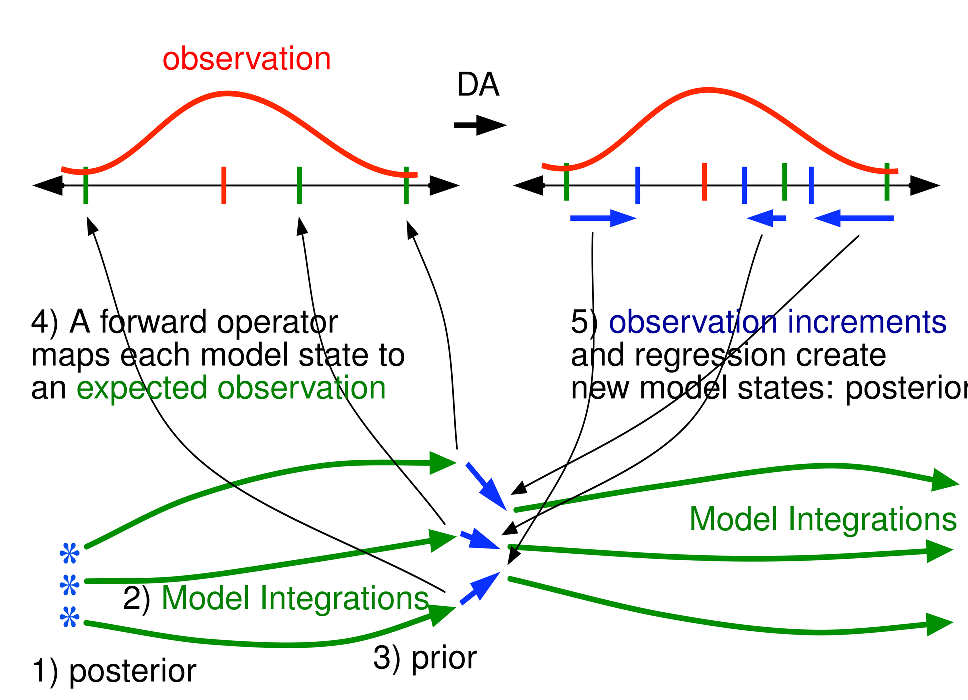
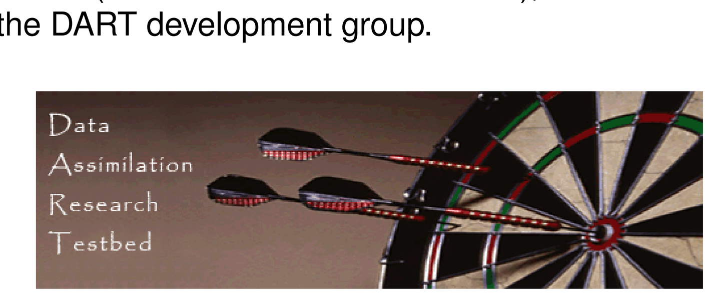


Figure 8: *The diagnostics are calculated at step 4.*

8. For further information

Our DART web site is: **http://www.image.ucar.edu/DAReS/DART** There you will find information about how to download the latest revision of DART from our subversion server, information on a full DART tutorial (included with the distribution), and contact information for the DART development group.



References

[DART 09] J. Anderson, T. Hoar, K. Raeder, H. Liu, N. Collins, et al., 2009: The Data Assimilation Research Testbed: A Community Data Assimilation Facility. *BAMS* **90** No. 9 pp. 1283–1296

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