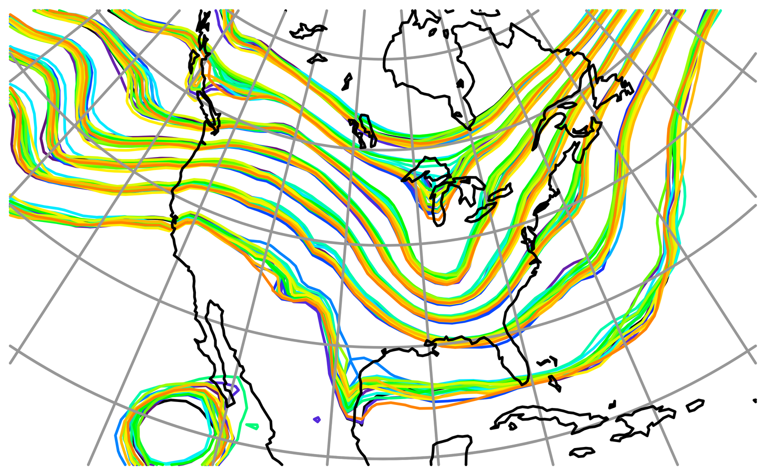

Loosely Coupled Atmosphere-Ocean Data Assimilation: CAM-DART-POP

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1. Overview

The Data Assimilation Research Testbed has been combined with the Community Atmosphere Model (CAM) version 4 and the Parallel Ocean Program (POP) to create loosely coupled ensemble analyses of the ocean that are consistent with the analyses of the atmosphere. The performance of the assimilation is assessed by comparing the short-term forecast state to the observations about to be assimilated; a metric that is not dependent on a third party analysis. DART has a wide range of observation-space diagnostic tools to evaluate the performance of the assimilation.

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
- all members are forced by the same ocean analyses
- adaptive Inflation used to maintain ensemble spread

1.2 Oceanic Assimilations

1.2.1 DARTPOP48

- 1 degree grid with displaced pole, 60 levels (POP gx1v6)
- 48 members initially drawn from a model climatology
- active sea ice (CICE) model
- assimilate every midnight starting 3 January 1998
- use all temperature and salinity obs in the World Ocean Database in a +/- 12 hour window
- atmospheric forcing for each POP member comes from a unique CAM ensemble member analysis

1.2.2 DARTPOP23 differed in that:

- 23 members initially drawn from a model climatology
- each member has identical observed atmospheric forcing

2. DART: Assimilation Schematic

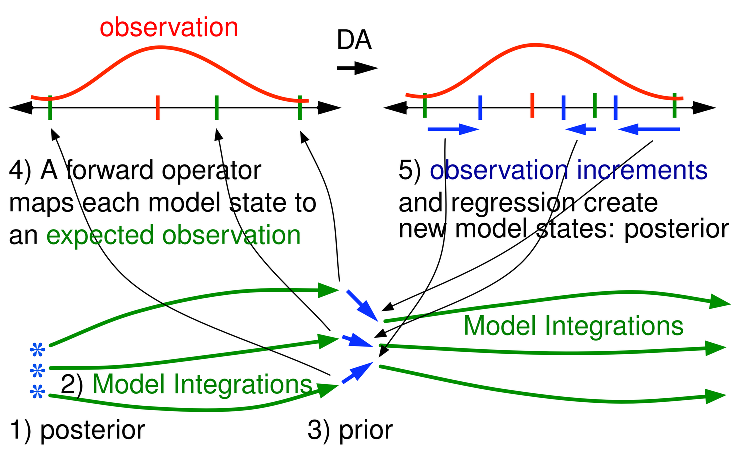


Figure 1: *Illustration for a toy ensemble size of 3.*

The DART system allows direct comparison of the forecast model state to the observations as part of the assimilation algorithm at virtually no additional expense. All performance metrics are relative to the observations, *i.e.* at step 4 of Figure 1. Observations that are too far away from the prior ensemble mean are not used in the assimilation or the performance metrics. 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!

3. Atmosphere

The atmospheric assimilation started with 1998 and will continue to the present. The 80 member ensemble is capable of quantifying uncertainty and model performance over a period when the atmosphere is very well observed; providing an excellent means of estimating variability in the presence of uncertainty.

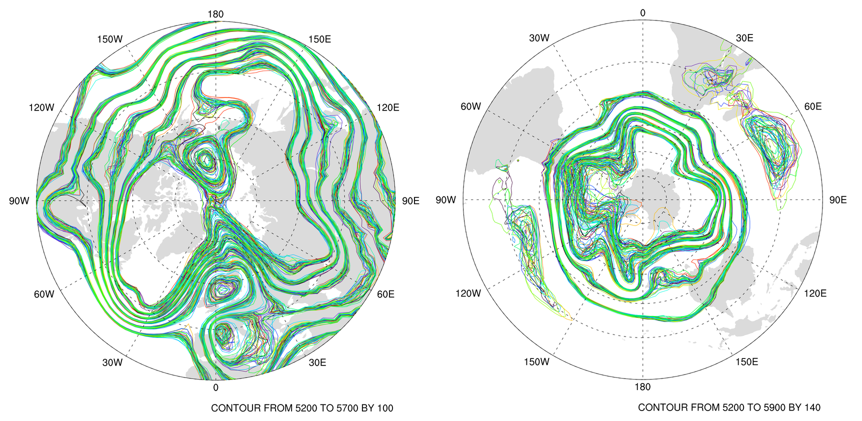


Figure 2: *Contours of the 500hPa geopotential height in 40 of the 80 CAM members for 6 hour forecasts valid 12:00 UTC 17 February 2003 (left) and 06:00 UTC 1 July 2001 (right). All of the model states are consistent with the observations, the ensemble captures the uncertainty in the system.*

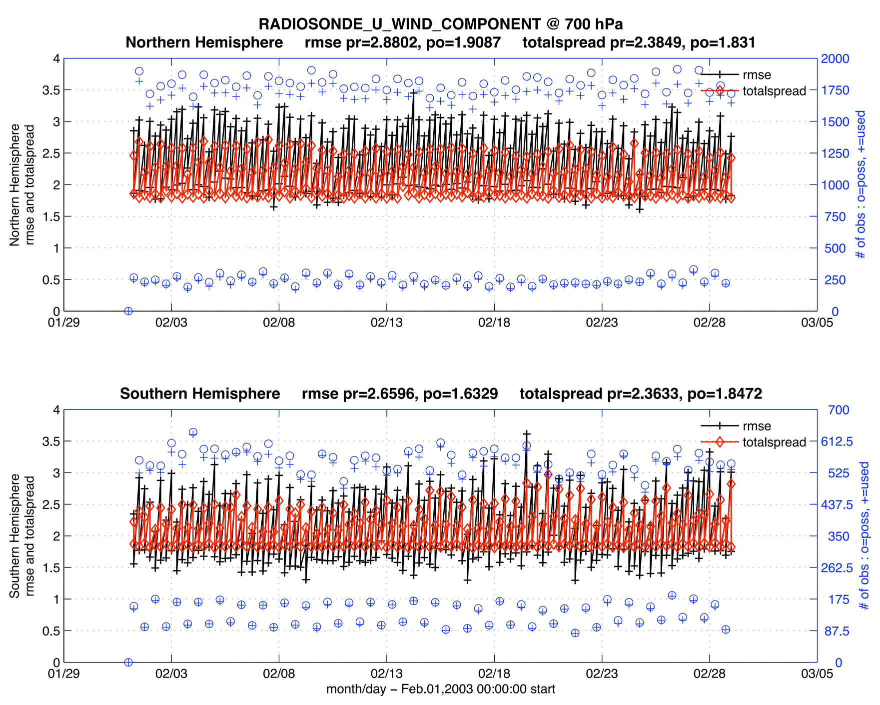
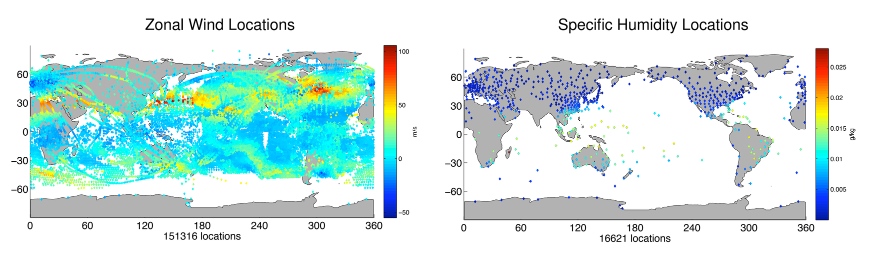
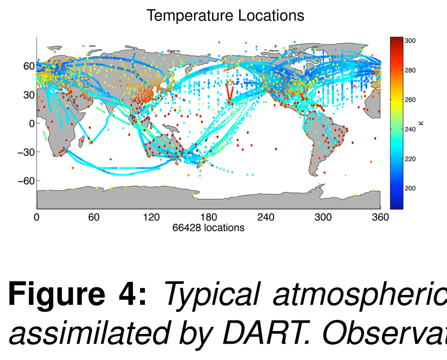


Figure 3: *The RMSE and spread of the 6 hour forecasts of the U winds compared to radiosonde observations for the month of February, 2003 ≈ 5 years into the assimilation. The totalspread (the square root of the pooled ensemble variance and the observation error variance) remains fairly steady in both hemispheres. Similar plots for vertical profiles are also standard with DART.*

4. Atmospheric Observations used with DART

DART supports a wide variety of observations. The design paradigm for DART means that once an observation type is supported, all relevant models that work with DART can assimilate those same observations. The following table simply lists those used for this experiment. There are many more supported by DART; GPS Radio Occultations, for example.





RADIOSONDE_U_WIND_COMPONENT	54706
RADIOSONDE_V_WIND_COMPONENT	54706
RADIOSONDE_TEMPERATURE	43436
RADIOSONDE_SPECIFIC_HUMIDITY	21800
AIRCRAFT_U_WIND_COMPONENT	13822
AIRCRAFT_V_WIND_COMPONENT	13822
AIRCRAFT_TEMPERATURE	13689
ACARS_U_WIND_COMPONENT	30838
ACARS_V_WIND_COMPONENT	30838
ACARS_TEMPERATURE	30716
SAT_U_WIND_COMPONENT	90494
SAT_V_WIND_COMPONENT	90494
Total	**489361**

Figure 4: *Typical atmospheric observation density routinely assimilated by DART. Observation locations for 17 Feb 2003.*

5. Ocean

The large ensemble and diverse atmospheric forcing lead to improvements in some aspects of the ensemble mean ocean analysis; our focus is the 24hour forecast of the ensemble when compared to observations.

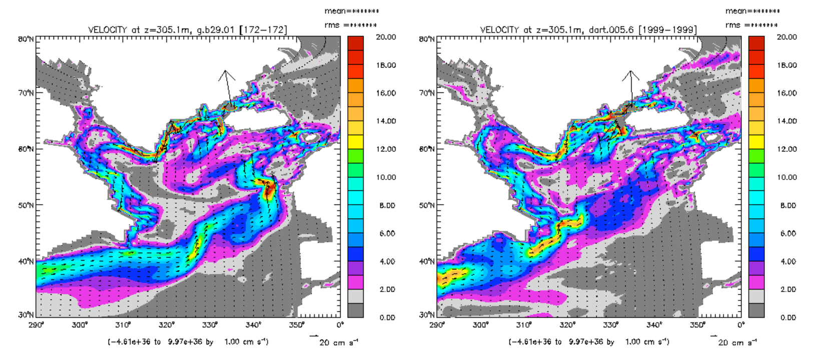


Figure 5: *Two-year estimate of the velocity at approx 300m shows a significantly improved North Atlantic Current path in the assimilation (right) compared to a POP free run (left). The current is much tighter and follows the coast much more closely, something free runs fail to do. These results were from the DARTPOP23 experiment.*

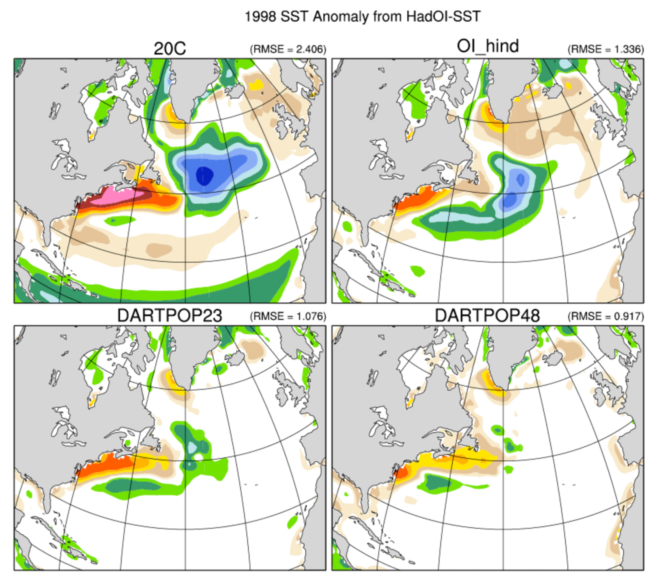


Figure 6: *The difference between the Hadley OI SST and various POP experiments. The top-left panel is a fully coupled 20th century run. The top-right panel is an ocean-ice hindcast simulation. The top two panels do not use DART. Both DART results (bottom panels) show a dramatically improved fit to the Hadley product.*

The following figures have multiple axes. The solid lines depict the RMSE or spread and use the left axis. The unconnected symbols depict the number of observations used and the number possible using the scale on the right; their difference is the number rejected by the assimilation.

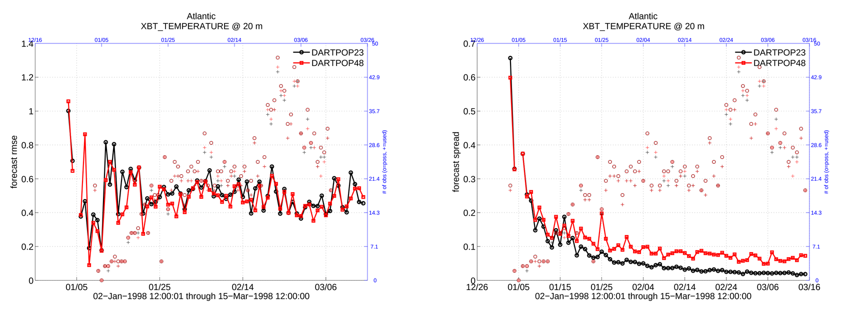


Figure 7: *The error in the XBT temperatures in the Atlantic (left) are about the same, even though (in general) fewer observations were rejected by the assimilation system for the DARTPOP48 experiment. The ensemble spread (right) shows improvement as a result of using the ensemble of CAM atmospheric forcing fields.*

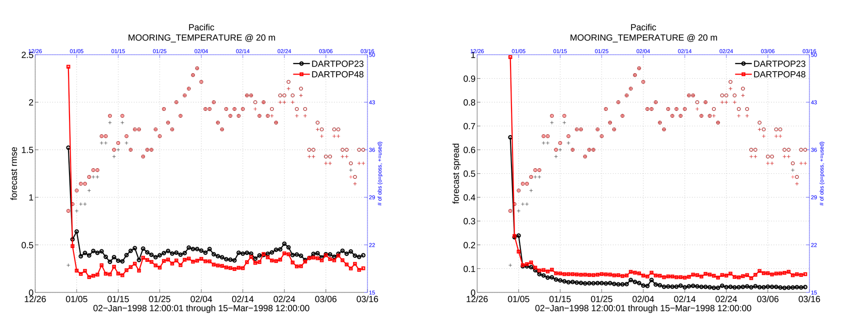
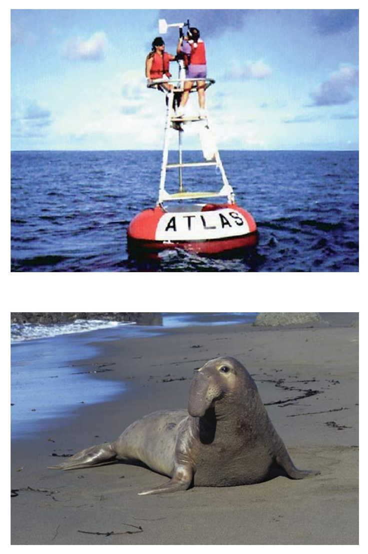


Figure 8: *The DARTPOP48 moored temperatures in the Pacific exhibit a systematic decrease in error (left) while maintaining a larger ensemble spread (right).*

6. 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**

7. More Observation-Space Diagnostics

DART has many more diagnostics than those shown here; rank histograms, 3D plots of the observation locations color-coded to the observation value/QC value/rmse/bias/spread/rejected observations, mapping tools, ...

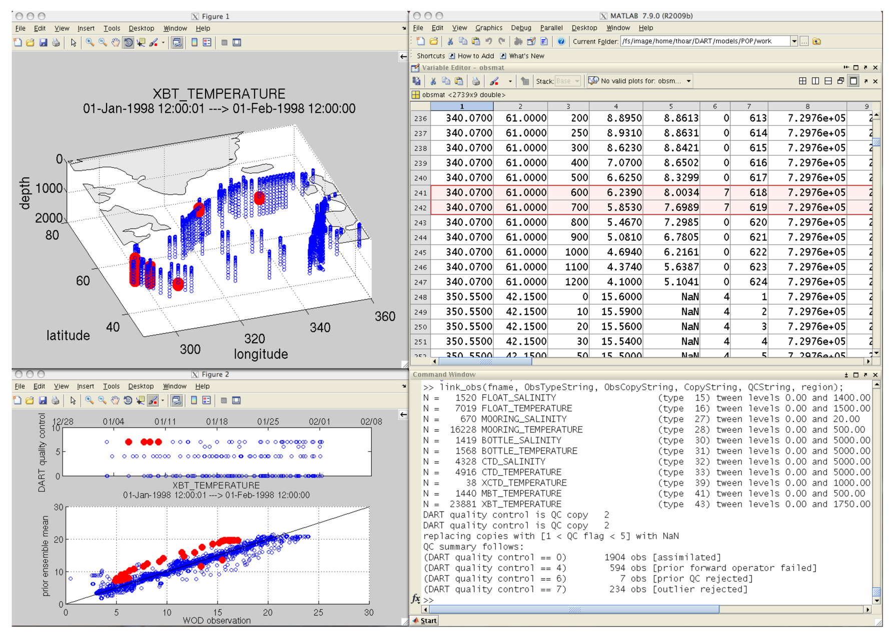
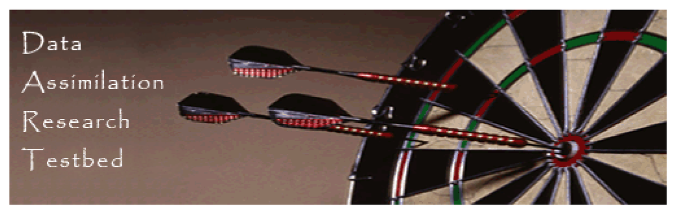


Figure 10: *DART's diagnostic tools make it easy to explore what observations are being rejected, and why. This is an example of some XBT observations in the North Atlantic. The information in the plots is linked, selecting observations in one view highlights them in all the views.*

8. For further information

Our DART 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, R. Torn, and A. Arellano, 2009: The Data Assimilation Research Testbed: A Community Data Assimilation Facility. *BAMS* **90** No. 9 pp. 1283–1296

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