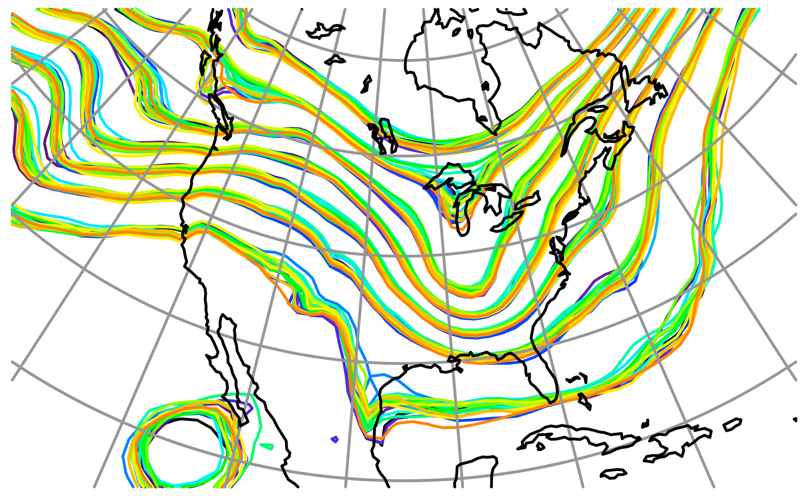

New Diagnostics of CAM from DART

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1. Ensemble Data Assimilation

Data Assimilation (DA) combines observations of a physical system with predictions from a numerical forecast model. DA can be used for many purposes, including:

- constructing initial conditions for forecasts,
- evaluating errors in the model and observations,
- finding appropriate values for model parameters,
- designing better observational systems.

The Data Assimilation Research Testbed (DART) is a community software facility that can be used for all the above purposes. DART provides a variety of ensemble filtering (EF) algorithms. The distributed code (**http://www.image.ucar.edu/DAReS/DART**) includes a variety of low-order models for educational purposes and geophysical model interfaces (CAM, AM2, WRF, ...) which can be used for model intercomparison in the context of identical observations and assimilation algorithm. EF uses an ensemble of (CAM) model states, influenced by observations, to estimate the probability distribution of the atmospheric state.

2. DART-CAM description

The examples shown below result from assimilations using an 80 member ensemble of CAM 3.6.32 and a set of advanced algorithms for creating the best representation of the atmosphere which CAM can manage, while accounting for the uncertainties in the observations. Observations $(O(10^5 - 10^6))$ are assimilated every 6 hours, with model advances in between. Observations available include:

1. upper air: radiosondes, ACARS, satellite drift winds, (The examples shown below used only 1.)
2. surface: winds(10m), T and Q(2m), P_{surf},
3. scatterometer winds (QuickSCAT),
4. Doppler radial velocity and reflectivity,
5. GPS radio occultation, refractivity,
6. ground-based GPS,
7. and AIRS (Atmospheric Infrared Sounder).

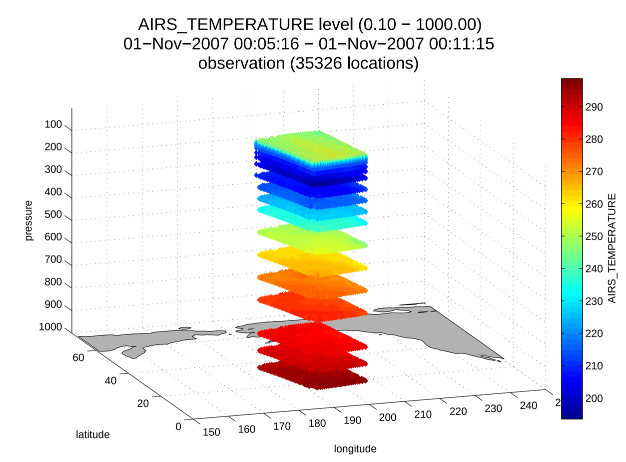

Figure 1: *Five minutes' worth of AIRS temperature retrievals.*

3. What does DART produce?

Output is in portable netCDF files and one custom-format observation file. Matlab©scripts are provided to investigate:

1. Rank histograms,
2. Bias, error, and spread as a function of height or time,
3. Ensemble trajectories,
4. Innovations,
5. 3D plots of observation densities and rejection attributes.

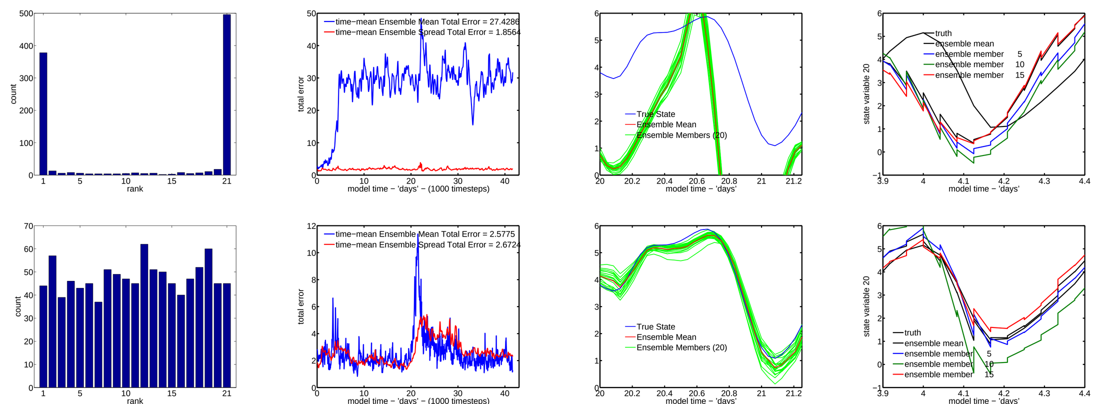

Figure 2: *Examples of some diagnostic plots which can be generated for any DART experiment, any model. These are 'perfect model' experiment results with the Lorenz 96 model. The top row of plots is from an experiment that exhibited filter divergence. The bottom row of plots used covariance inflation.*

6. Tendency Errors The standard output can be used to derive time-averaged tendency errors of the state variables over periods which are short compared to climate runs. These tendency errors have shown significant correlation with model bias as measured from long climate runs. [4]

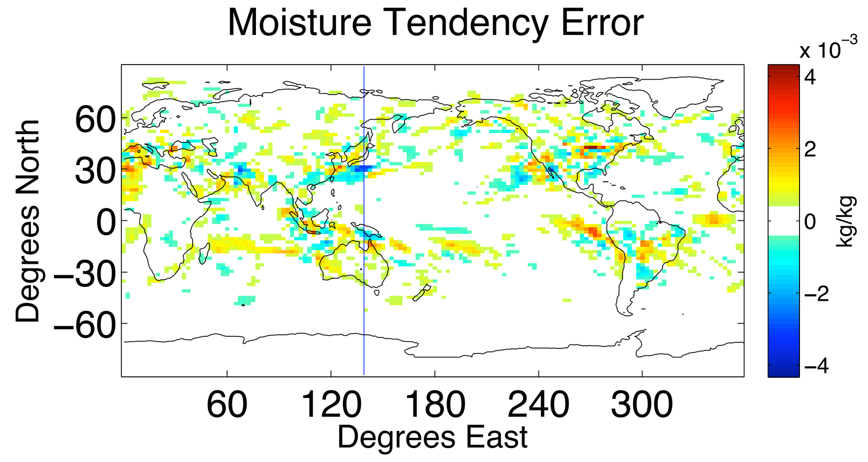

Figure 3: *The average time tendency error of CAM's moisture field "Q" at approximately 760hPa. This is the 6-hr forecast minus the analysis averaged over July 1-6, 2003, converted to daily tendency.*

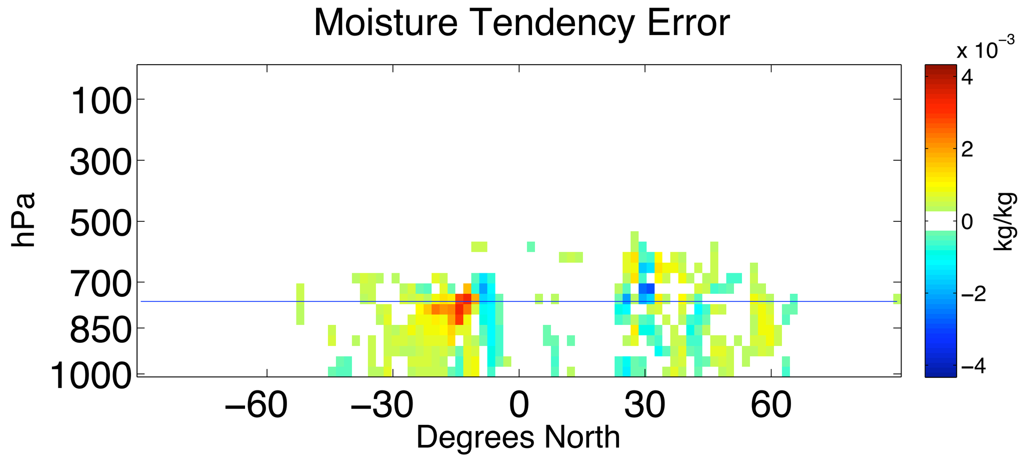

Figure 4: *The average 6-hour time tendency of CAM's moisture field "Q" at taken at a vertical slice through $\approx 140°$ E. longitude*

7. 3D plots of model bias at the observation locations. This can be used to pinpoint areas where the analysis disagrees with the observations (accounting for the observation error), and where there are enough good observations to justify investigating the source of the bias there.

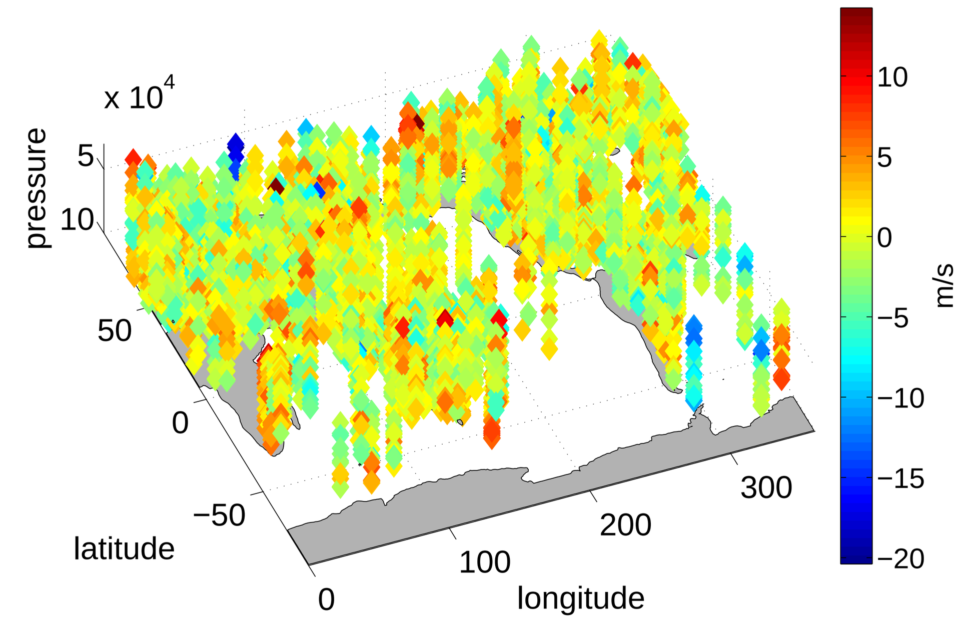

Figure 5: *The misfit between the ensemble mean estimate and the Radiosonde U wind observations between 300hPa and 1000 hPa. prior ensemble mean - NCEP BUFR observation (9542 locations) 01-Jul-2003 06:00:01 - 06-Jul-2003 00:00:00*

8. An experimental application of DART-CAM output is the calculation of "sensitivities" of one model variable to all the others. These are correlations between the ensemble of values of the variable of interest and the ensembles of each of the other model variables: either the state variables found in the standard output, or non-state variables written to history files. These are statistical sensitivities, and capture the nonlinear behavior, as opposed to mechanistic sensitivities derived from a (linearized) adjoint model.

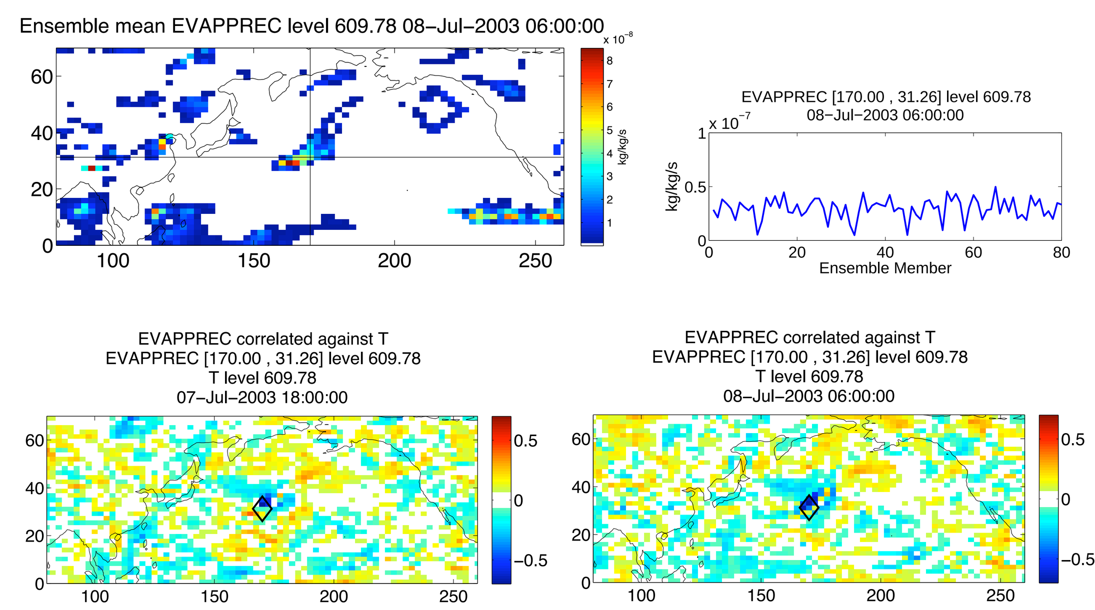

Figure 6: *Ens. EVAPPREC field mean (upper left) and ensemble (upper right). Correlation of EVAPPREC with the Temperature field from 12 hours earlier (lower left) and at the same time (lower right).*

4. Analyses Available

DART-CAM produces (re-)analyses on the native CAM grid, which are not contaminated by foreign model error. It also automatically provides an analysis error estimate (the ensemble spread), which varies with time, location, and state variable. Standard "state" variables are PS, T, U, V, Q, CLDLIQ and CLDICE, but others can be added without code modification. The analyses are available as standard NetCDF output from DART, or packaged as a set of initial files for immediate use by CAM. These are currently being used as initial conditions for forecasting studies of Arctic sea ice (Kay), North Pacific cyclogenesis (Chang), and CAPT boundary layer studies of the Central Pacific (Hannay & Williamson).

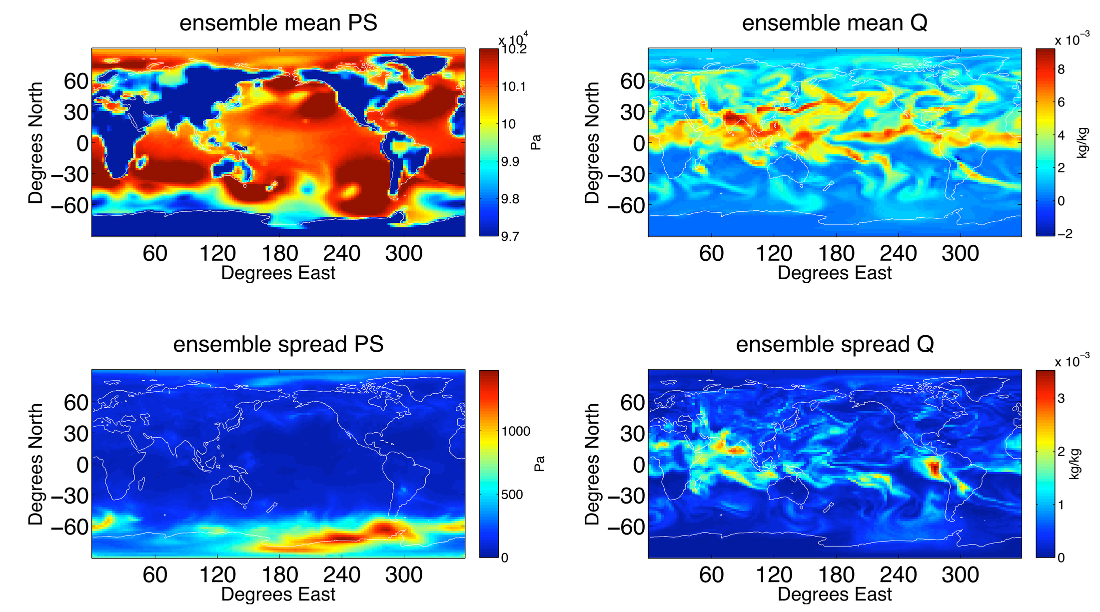

Figure 7: *July 2007 80 mems 'standard obs' Cam 3.6.32*

References

[1] Anderson, J., 2008 *Spatially and temporally varying adaptive covariance inflation for ensemble filters. Tellus A*,, doi:10.1111/j.1600-0870.2008.00361.x

[2] Anderson, J., Collins, N., 2007, *Scalable Implementations of Ensemble Filter Algorithms for Data Assimilation. Journal of Atmospheric and Oceanic Technology*, **24** 1452-1463, doi: 10.1175/JTECH2049.1

[3] Anderson, J., 2003 *A local least squares framework for ensemble filtering. Monthly Weather Review*, **131**, 634-642, doi:10.1175/1520-0493(2003)131<0634:ALLSFF>2.0.CO;2

[4] Yang, X.-Q. and J. Anderson, 1996, *Correction of Systematic Errors in Coupled GCM Forecasts. J. Climate*, **13**, 2072-2085.

CCSM, June 2009, Breckenridge CO