DART: A Facility for Ensemble Data Assimilation

J. Anderson, T. Hoar, K. Raeder, N. Collins, H. Liu, G. Romine, A. Arellano, G. Lawson, R. Torn

National Center for Atmospheric Research
Institute for Mathematics Applied to Geosciences
Boulder, Colorado, USA
dart@ucar.edu

DART: The Data Assimilation Research Testbed

The Data Assimilation Research Testbed (DART) is a mature community software facility providing researchers access to state-of-the-art ensemble data assimilation tools. The freely-available DART distribution includes fully functional low-order and high-order models, support for commonly available observations, hooks to easily add both new models and observation types, diagnostic programs to interpret the results, and a full tutorial suitable for self-study or teaching data assimilation concepts, including exercises using the models distributed with DART.

DART is used regularly with a number of geophysical models including NCAR's WRF and CAM atmospheric models. During 2009, the POP (Parallel Ocean Program) model and the newest version of the Planet WRF model were integrated with DART. Novel observation types also continue to be added to DART, for example, radiance observations from the MOPITT instrument on earth and from TES on Mars.

http://www.image.ucar.edu/DAReS/DART has information about how to download DART, a full DART tutorial (included with the distribution), and contact information for the DART development group. For more details, see:

J. Anderson, T. Hoar, K. Raeder, H. Liu, N. Collins, et al., 2009: The Data Assimilation Research Testbed: A Community Facility. *BAMS* **90**, 1283–1296.

New Diagnostic Tools for Observations

A set of new observation diagnostic tools is now available with DART. Observations used by DART have many attributes including location, time, value, quality control flags and a unique integer identifier. By using data "brushing", highlighting an observation in a plot of one attribute automatically highlights this observation in plots of all other attributes allowing users to explore the behavior of assimilation experiments.

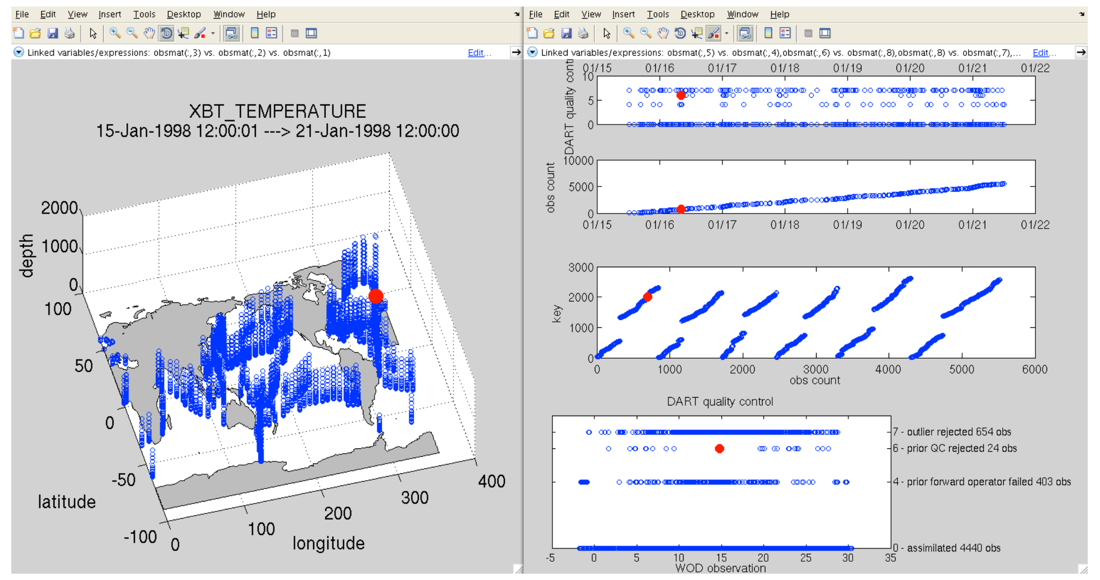

Figure 1: *Linked observation diagnostics for an assimilation with DART and the POP ocean model. An observation rejected by DART quality control has been highlighted in the lower right plot. Other attributes of this observation including its location (left panel) and time (right third panel from top) are automatically highlighted.*

POP: Initial Conditions for Decadal Prediction

A DART interface to the Parallel Ocean Program is now available thanks to a collaboration with Los Alamos National Lab and NCAR's Climate and Global Dynamics Division. An assimilation of in situ observations of temperature and salinity for 1998 and 1999 has produced ensemble initial conditions that can be used for coupled model decadal predictions for the IPCC AR5. Less than two months were required from the start of the project to the assimilation of real observations, thanks to DART's clean interfaces and mature software tools.

The two-year assimilation used:

- 1 degree grid with displaced pole, 60 levels (POP gx1v6);
- Active sea ice (CICE) model;
- 23 ensemble members;
- Each has identical observed atmospheric forcing;
- Ensemble of atmospheric forcings from DART/CAM to be tested soon.

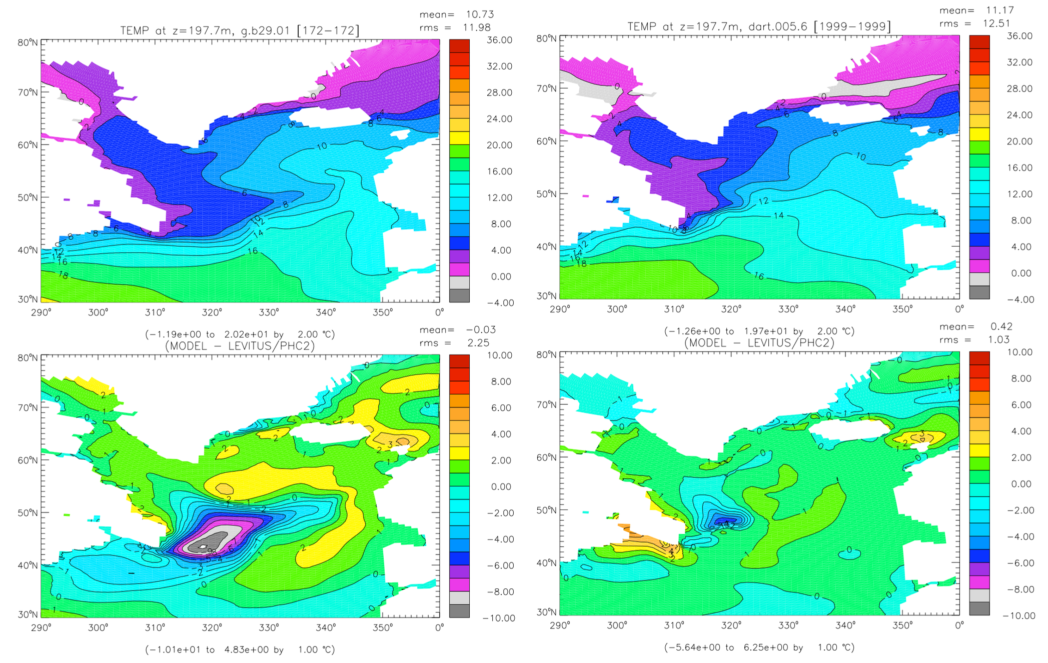

Figure 2: *Two-year average North Atlantic temperature (top) at ≈ 200m depth and differences from Levitus climatology (bottom) for POP free run forced by observed atmosphere (left), and the assimilation (right). The assimilation significantly reduces POP systematic errors.*

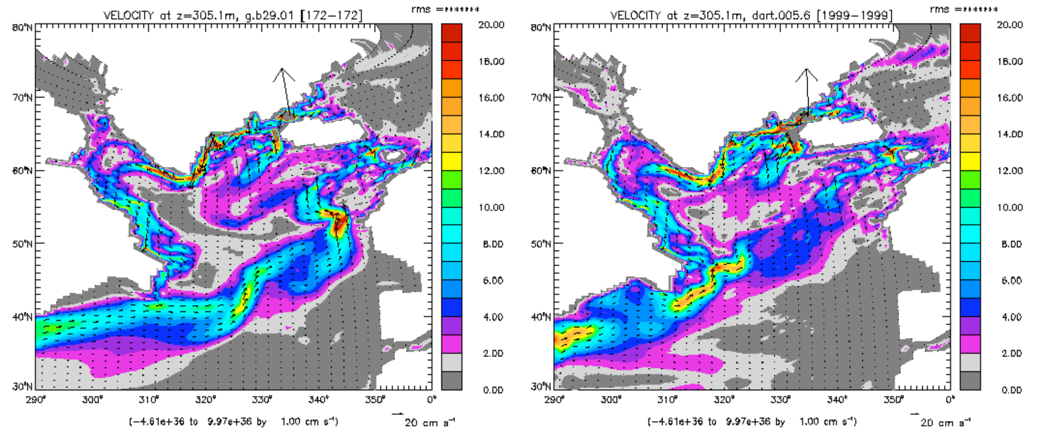

Figure 3: *Two-year average POP velocity at approx 300m shows a significantly improved North Atlantic Current path in the assimilation (right) compared to a POP free run (left).*

WRF: Analysis of Atlantic Tropical Storms (Ryan Torn)

The DART/WRF (Weather Research and Forecasting Model) system has been used to produce ensemble analyses for Atlantic tropical storms from the 2008 (retrospectively) and 2009 (in real-time) seasons.

These simulations use a standard set of WRF parameterizations and settings:

- WRF 5-class microphysics;
- 36 km grid spacing ARW core, 36 vertical levels up to 20 hPa;
- domain is as shown in the right-hand side of Figure 4;
- assimilate conventional obs (surface pressure, rawinsondes, aircraft, satellite winds, tropical cyclone (TC) position and minimum SLP) each six hours;
- uses spatially-adaptive inflation;
- 96 ensemble members;
- initial ensemble generated by random draws from NCEP covariances;
- lateral boundaries are generated the same way as the initial ensemble.

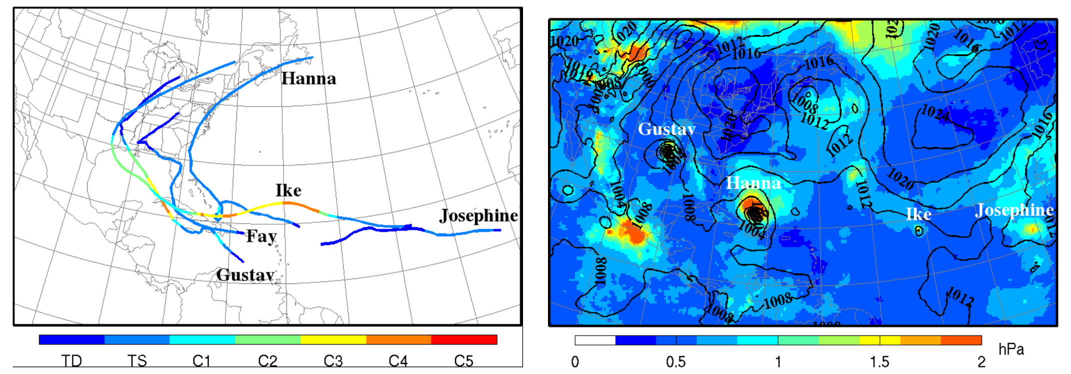

Figure 4: *Left: Best track data for 5 2008 Atlantic storms from the National Hurricane Center. Right: Ensemble-mean (solid) SLP analysis valid 00 UTC 2 September 2008 when four tropical cyclones exist in the Atlantic. The shading is the ensemble spread.*

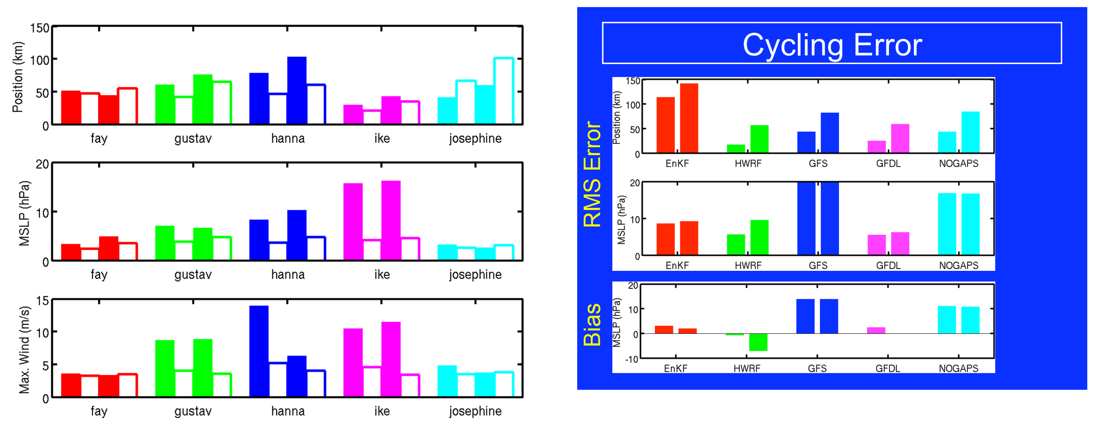

Figure 5: *Left: RMS error and spread in position, minimum SLP and maximum wind for the posterior (left of TC name) and prior (right of TC name) for five 2008 storms. Right: RMS error and bias in the posterior (left bar) and prior (right bar) position and minimum SLP averaged over all storms during the 2009 Atlantic hurricane season for WRF/DART (EnKF), and four other prediction systems.*

In addition to the storms presented here, there are track and intensity forecasts for ten more storms at: **http://www.atmos.albany.edu/facstaff/torn/hfip/results.html**. Those figures depict the ensemble members, the Official NHC forecast (human), the GFS forecast, the WRF forecast initialized from the GFS analysis, and the verification. There are also summary statistics over 69 different forecast initialization times.

PlanetWRF: TES Observations on Mars (Greg Lawson)

- A DART interface to an updated version of the PlanetWRF general circulation model has been completed by scientists at CalTech and NCAR. PlanetWRF is configured and used for Mars, Titan and Venus.
- Work is underway to assimilate observations from the Thermal Emission Spectrometer (TES) on the Mars Global Surveyor. TES was in a sun-synchronous nearly polar orbit (inclination of 93°) making about 12.5 orbits per Mars day. Data are available from 1997-2006.
- A set of observing system simulation experiments has been completed using a fixed dust distribution and simulated TES 15 μm radiances and observational errors. Ten sols of simulated assimilation produced good estimates of the true temperature and winds.

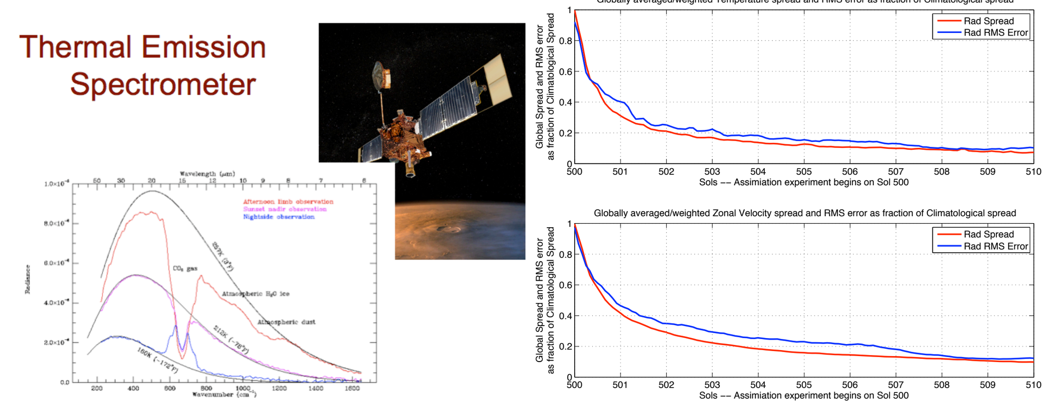

Figure 6: *Left: An artist's rendition of the Mars Global Surveyor carrying TES and mean TES radiances as a function of wavenumber. Right: Results from a 10 sol OSSE assimilating simulated TES radiances. Global mean temperature RMS and spread (top) and wind RMS and spread (bottom) are significantly reduced below the model's climatological spread.*

Initial assimilations of real data have had some success. When the DART quality control algorithm discards observations that are more than 3 standard deviations removed from the prior ensemble mean, nearly half the radiances are discarded. However, assimilation of the remaining observations does produce analyses with considerably smaller ensemble mean RMS error than prior estimates. This suggests that model bias remains large.

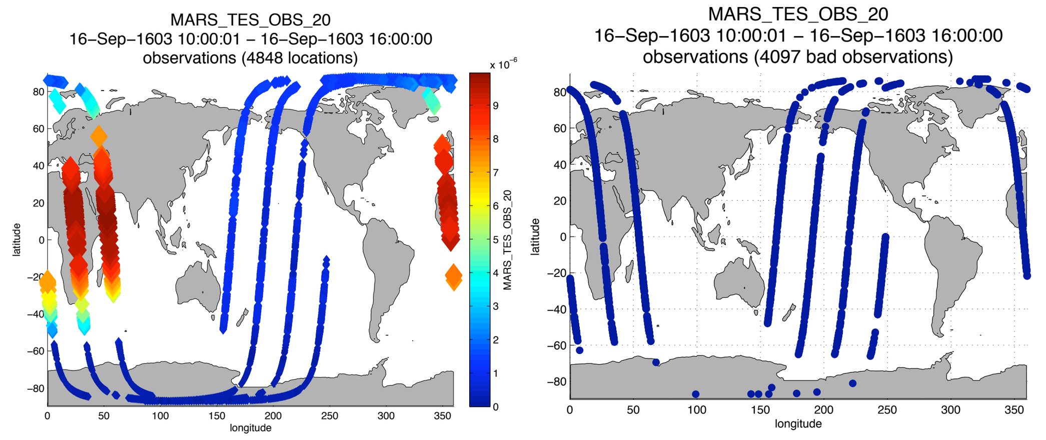

Figure 7: *Observations assimilated and their value (left), and position of rejected observations (right) for four orbits of TES assimilation. The Earth landmasses are shown for visualization purposes only.*

CAM: Impact of COSMIC on Reanalyses

Global atmospheric reanalyses for September 2006 through August 2007 have been generated using a recent version of NCAR's Community Atmospheric (climate) Model. Reanalyses using radiosondes, aircraft, and satellite cloud drift motion vectors can be compared to ones that also use GPS radio occultation soundings from the COSMIC satellites (Fig. 8). COSMIC observations yield improved estimates of temperature and moisture with global coverage, from the lower troposphere through the stratosphere, regardless of cloud cover, and independent of the radiosonde network (Fig. 9). They are especially valuable over oceans where conventional observations are sparse and many remote sensing observations can suffer from contamination by clouds. The assimilations use:

- Finite Volume dynamical core, 2°× 26 levels, CAM (3.5);
- 80 ensemble members with adaptive inflation.

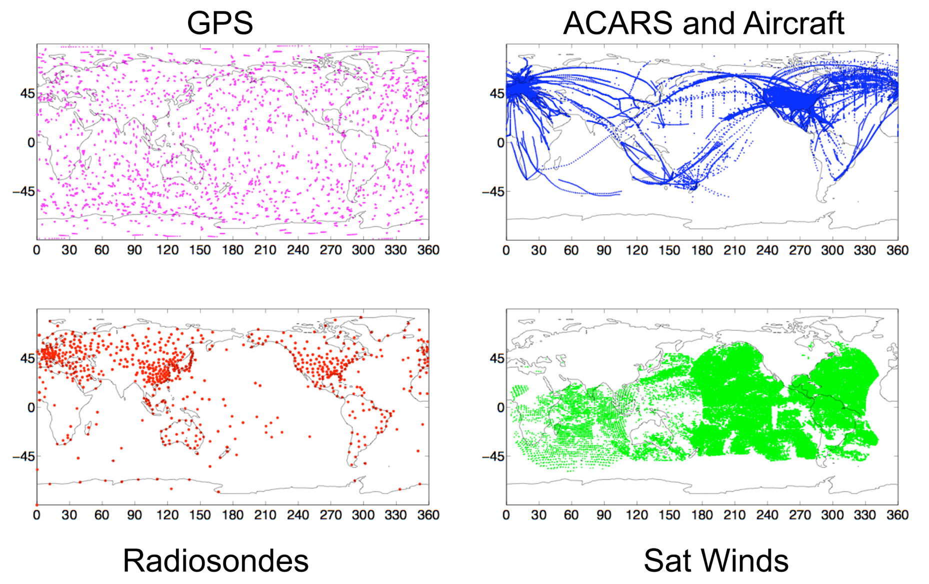

Figure 8: *The observation locations for various observation types for 1 Dec 2006.*

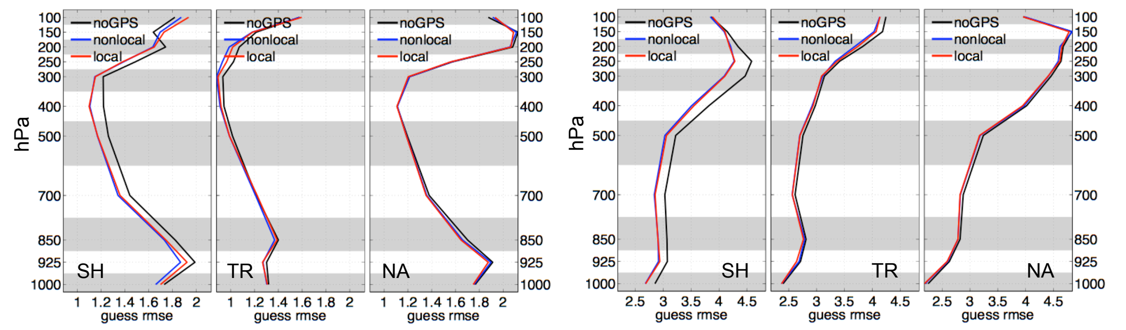

Figure 9: *DART analyses compared directly to observations. Each profile shows the RMSE of a month of 6 hour forecasts for Dec 2006 relative to the radiosonde temperature/wind observations. The left 3 frames show T for the Southern Hemisphere, Tropics, and North America. The 3 on the right show U. The 3 colors are for; no GPS assimilated, and 2 distinct forward operators for the GPS.*

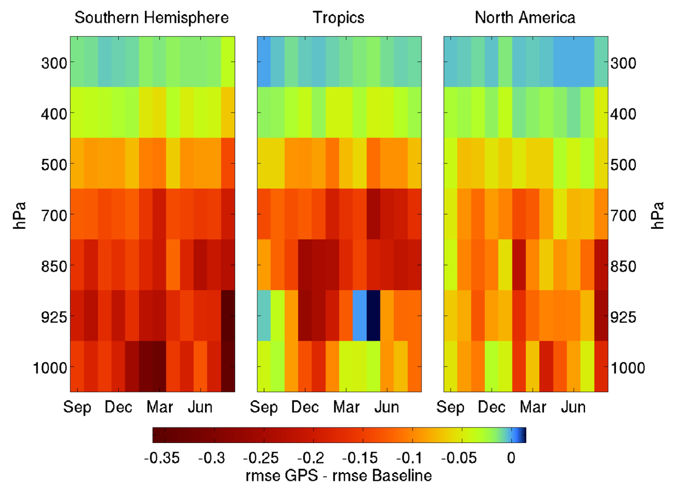

Figure 10: *Monthly versus height pattern of the improvement in RMSE of specific humidity due to the inclusion of GPS observations in the assimilation for the same regions as in Fig. 9. Warm colors correspond to GPS improving the forecast fits to radiosonde observations.*