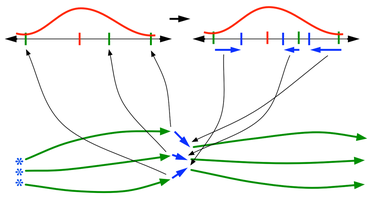

DART Data Assimilation with CESM Models

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1. DART is ...

The Data Assimilation Research Testbed (DART) is an open source community software facility for ensemble data assimilation developed at the National Center for Atmospheric Research (NCAR). DART provides both state-of-the-art ensemble data assimilation capabilities and an interactive educational platform for researchers and students. DART works with dozens of geophysical models, ranging from the Lorenz 3-variable model to coupled climate models, and assimilates dozens of observation types from a variety of sources, including:

- temperature, winds aloft, surface winds, moisture from NCEP, MADIS, and SSEC,
- total precipitable water, radar observations, radio occultation observations from GPS satellites,
- ocean temperature and salinity from the World Ocean Database,
- land observations such as snow cover fraction, ground water depth, tower fluxes, cosmic ray neutron intensity, and microwave brightness temperature observations.
- virtually any observation can be used, if the model can generate an estimation of its value.

2. Multi-Component Assimilation – CAM-FV + POP + CLM

Separate re-analyses for different model components (atmosphere, ocean, land) are useful but may be inconsistent. A DART interface to the fully-coupled CESM is now available and has been used for 'multi-component coupled data assimilation' where observations of each component model directly impact only that model (e.g. atmospheric observations update only the atmospheric state) but the fully-coupled model is used for the ensemble forecasts.

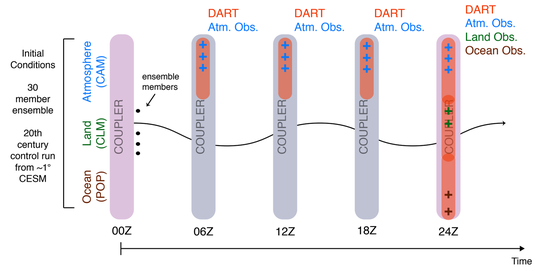


Figure 1: *Schematic of the multi-component coupled data assimilation with CESM and DART. Assimilation of observations in the atmosphere component happens every 6 hours, while assimilation in the land and the ocean components occur every 24 hours.*

Such a coupled system not only makes better use of near-surface observational data (see Figure 2) but also improves representation of processes that are linked by strong air-sea interaction (see Figure 3).

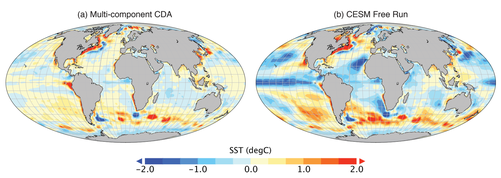


Figure 2: *Comparison with independent data [merged Hadley-OI sea surface temperature] show that the multi-component CDA reduces the SST bias more than the CESM free run.*

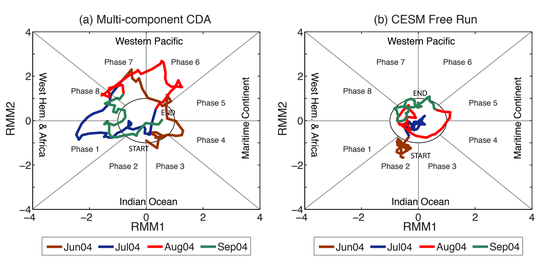
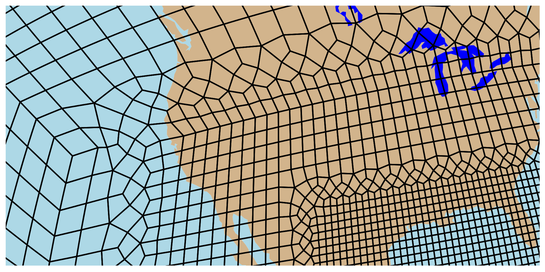


Figure 3: *The 2004 boreal summer state of the Madden Julian Oscillation is shown as a point in the phase space of Real-time Multivariate MJO Series 1 (RMM1) and Series 2 (RMM2) for two experiments – compared to observations, the multi-component CDA signal is more realistic.*

2.1 Cross-Component Assimilation

In addition to using fully coupled forecasts, DART will also enable 'cross-component coupled data assimilation', where observations of any component can impact the state variables of all component models during the assimilation step.

3. Forecasting Hurricane Katrina with a Variable Mesh, Spectral Element CAM



The spectral element (SE) dynamical core is becoming the default for NCAR's Community Atmosphere Model (CAM). It is implemented on a cubed sphere grid, which is irregular in latitude and longitude, but enables grid refinement. Assimilation requires interpolating the model state to the locations of the observations **many** times: efficient interpolation algorithms are essential.

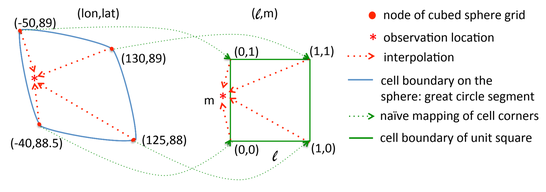


Figure 5: *Naïve mapping of the cubed sphere cell onto the unit square can result in a poor interpolation. DART uses an efficient, accurate interpolation algorithm.*

Our DART assimilation produces an ensemble of 80 equally-likely sets of CAM-SE restart and initial files every 6 hours. We randomly chose member 10 for the following illustrations of Hurricane Katrina at 00Z 27 Aug 2008.

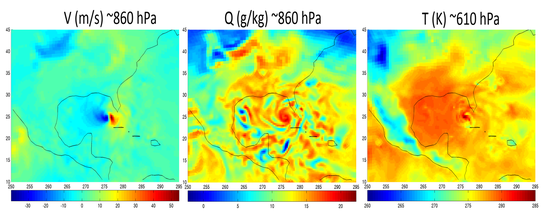


Figure 6: *These samples show: hurricane force winds (left), banded structure (center), and the warm core (right).*

Before DART/CAM-SE, initial conditions were generated from the Climate Forecast System Reanalysis (CFSR). DART produces a stronger, more compact cyclone, closer to the observed cyclone.

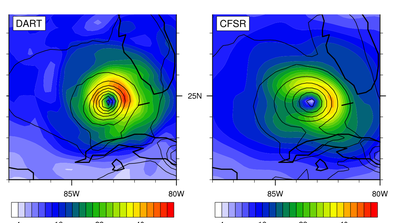


Figure 7: *DART ensemble member 10 (left) and CSFR (right). 850 hPa winds are in color shading, surface pressure is contoured (4 hPa interval). The National Hurricane Center's best-track archive records Hurricane Katrina as having 850 hPa winds of approximately 54 m/s at this time.*

4. Chemical DA – CAM-CHEM

In this study, a 30-member ensemble assimilation of meteorology plus chemistry has been performed. A spin-up of a deterministic CAM-Chem run for 1.5 years precedes a meteorological spin-up of two months (April-May 2008). Assimilation of standard meteorological observations and the carbon monoxide (CO) measured by IASI (Infrared Atmospheric Sounding Interferometer) and MOPITT (Measurement Of Pollution In The Troposphere) is performed during June and July 2008. The ensemble spread is generated via inflation and perturbed emissions factors at the surface.
IASI and MOPITT sounders are nadir sounders that measure tropospheric CO. IASI has global coverage daily, MOPITT takes 4 days to cover the globe. Figure 8 shows the difference between a control run (meteorological data assimilation only) and various CO assimilation runs. Figure 9 shows comparisons with the independent Tropospheric Emission Spectrometer (TES).

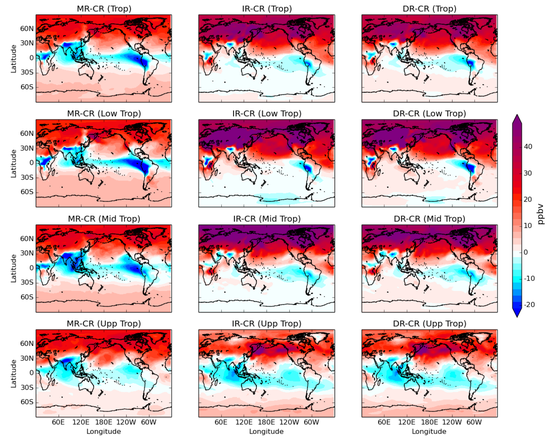


Figure 8: *Data Assimilation Impacts on model CO, July 2008. Tropospheric CO data assimilation generally increases concentrations over the Northern hemisphere. A low model bias is corrected, more efficiently by IASI due to superior coverage. CR: Control Run, MR: MOPITT assimilation run, IR: IASI assimilation run, DR: MOPITT + IASI assimilation run.*

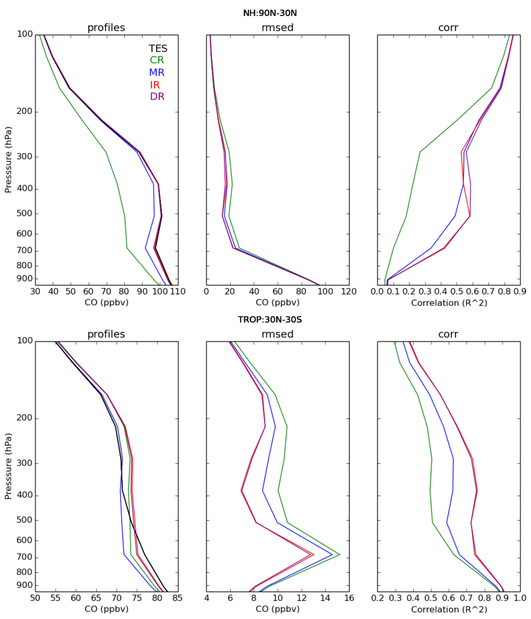


Figure 9: *Regional CO measurements during July 2008. Comparisons with TES, which is also a nadir sounder that measures CO, show great improvement of the CO fields. Bias and also variability are improved (unbiased root mean square error and correlation).*

5. Model Prediction Across Scales – MPAS

Assimilation with DART+MPAS (CESM physics) can be set up through DART's MPAS interface. Contact Soyoung Ha (syha@ucar.edu) for details.

6. Whole Atmosphere Community Climate Model – WACCM

WACCM (Whole Atmosphere Community Climate Model) is identical to CAM, but with the model top extended to 5×10^{-6} hPa ($\approx$ 145 km) and with additional chemical, dynamical, and physical processes to model the upper stratosphere, mesosphere, and lower thermosphere. The DART/WACCM interface facilitates studying of dynamical and chemical processes of specific events above the top of conventional atmospheric models and reanalysis products.
To illustrate the capabilities of WACCM+DART, a 40 member ensemble simulation was performed for January and February 2009 when a strong sudden stratosphere warming (SSW) occurred. Radiosonde and aircraft temperatures and winds, satellite drift winds, and COSMIC radio occultation observations are assimilated in the lower atmosphere. Middle and upper atmosphere temperature retrievals from TIMED/SABER and Aura MLS are also assimilated [Pedatella et al. 2013].

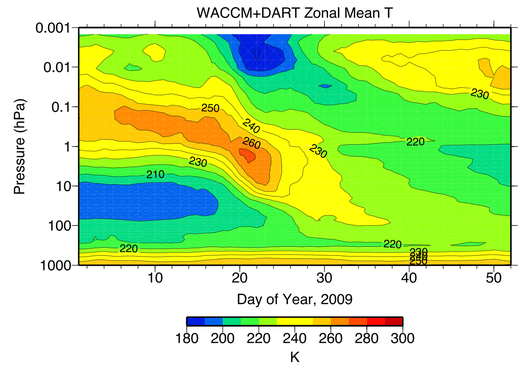


Figure 10: *WACCM+DART analyzed ensemble mean temperature during the 2009 SSW, averaged over longitude and from 70-80N. Around day 15 the stratopause (near 0.1 hPa) begins to descend, followed by a significant increase in stratospheric temperatures. This is accompanied by an approximately 40-50 K cooling of the mesosphere near 1×10^{-3} hPa ($\approx$ 95 km). Around day 35 the stratopause reforms at high altitudes.*

N. Pedatella et al., 2013: *Application of data assimilation in the Whole Atmosphere Community Climate Model to the study of day-to-day variability in the middle and upper atmosphere. GRL* **40** pp. 4469–4474

7. Education

DART contains a variety of instructional materials to appeal to different types of learning:

- a tutorial directory with 23 self-paced modules,
- an interactive MATLAB tutorial with point-and-click GUI examples,
- a user Application Program Interface (API),
- a web site dedicated to explaining how to use DART, and
- real live people to answer questions!

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

7.1 Further Information

http://www.image.ucar.edu/DAReS/DART has information about downloading DART from our subversion server, a full DART tutorial (included with the distribution), and how to contact us.

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