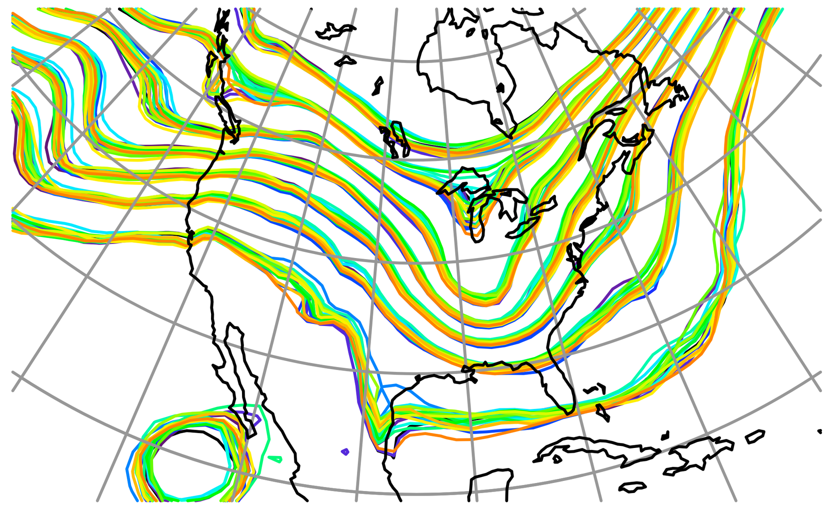

DART: Tools and Support for Ensemble Data Assimilation Research, Operations, and Education.

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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 works with a wide variety of climate and weather models and observations. Building an interface between DART and a new model does not require an adjoint and generally requires no modifications to the model code. DART works with dozens of models, including:

- weather models, e.g. WRF, COAMPS, NOAH, MPAS Ocean and MPAS Atmosphere,
- components of climate models, e.g. CAM, POP, CLM, WACCM, MITgcm-Ocean,
- ionosphere/thermosphere models, e.g. TIEGCM, GITM,
- low-order and simple models such as the Lorenz models for assimilation research and educational use.

DART 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.

DART provides both state-of-the-art ensemble data assimilation capabilities and an interactive educational platform to researchers and students.

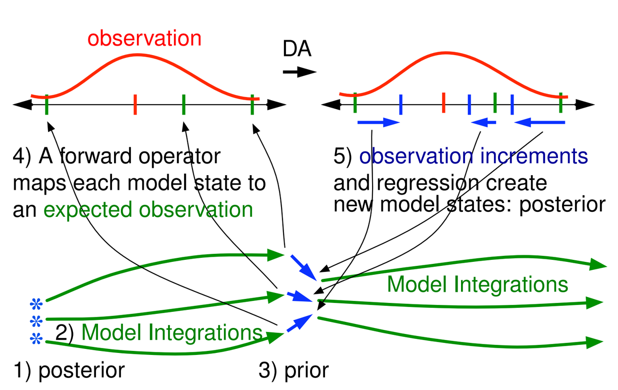


Figure 1: *Schematic for a toy ensemble size of 3.*

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

1.1 Education

DART contains a variety of instructional material 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!

1.2 Further Information

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

2. Model for Prediction Across Scales – MPAS

MPAS is based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement. It is jointly developed, primarily by NCAR and LANL/DOE. **http://mpas-dev.github.io**
The MPAS-Atmosphere model development team is led by Bill Skamarock in NCAR/MMM while the Ocean/Ice core is developed by the LANL/DOE team led by Todd Ringler. The DART specialists are Soyoung Ha and Chris Snyder in NCAR/MMM.

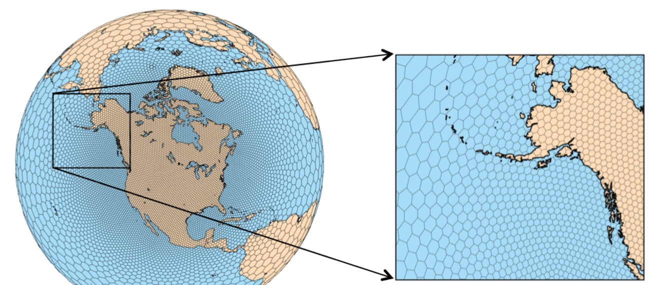


Figure 2: *An example of the variable-resolution MPAS grid.*

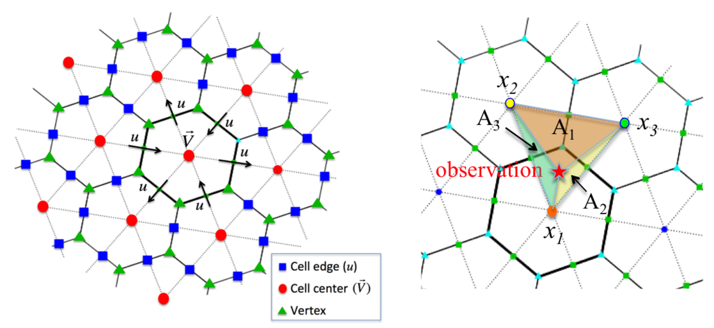


Figure 3: *Schematic of the interpolation scheme implicit in the MPAS/DART observation operators. A Barycentric interpolation in the triangle is used for scalar variables. Because the prognostic wind variable is a normal velocity on the edge, there are other options to assimilate winds.*

2.1 Assimilation Results

These are results to demonstrate the DART/MPAS capabilities. The effect of the grid resolution is explored two ways: (1° vs. 2°) and (uniform vs. variable) mesh. The assimilation was performed with an 80-member ensemble cycling every 6 hours using NCEP PrepBUFR and GPS RO observations.

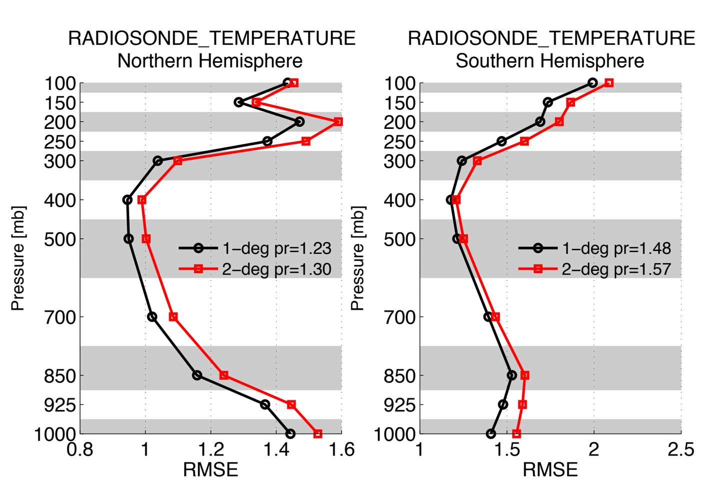
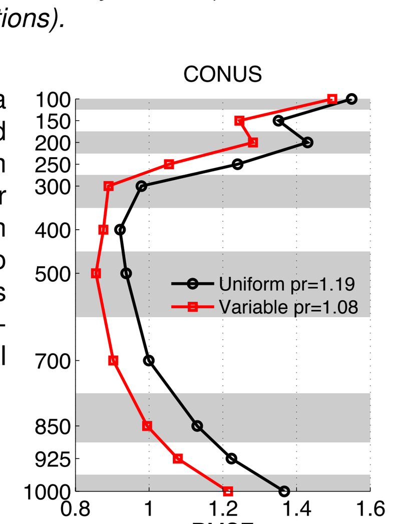
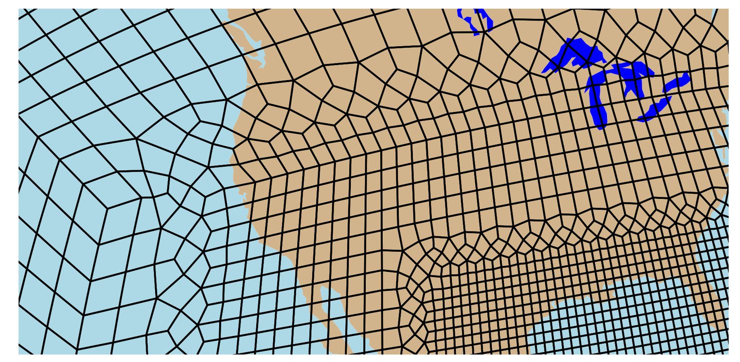


Figure 4: *In quasi-uniform meshes, double the resolution increased the 6-h forecast skill by ≈ 5% (in a verification against common observations).*

A variable mesh with a 1:4 ratio reduces the grid resolution from 240-km worldwide to 60-km over CONUS. The fine-mesh area shows a better fit to the observations and has much smaller memory requirements than a global 60-km grid.



3. Community Atmosphere Model - Spectral Element



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 arbitrary locations of the observations **many** times. Efficient interpolation algorithms are essential.

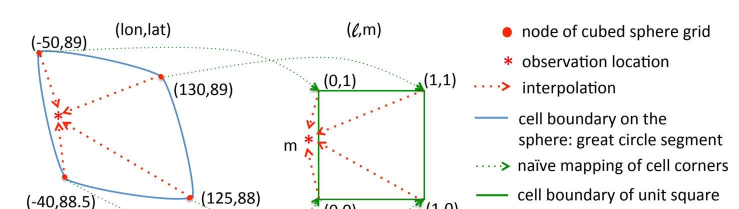


Figure 5: *Naïve mapping of the cubed sphere cell onto the unit square can result in a poor interpolation. DART uses an efficient, accurate interpolation algorithm.*

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.

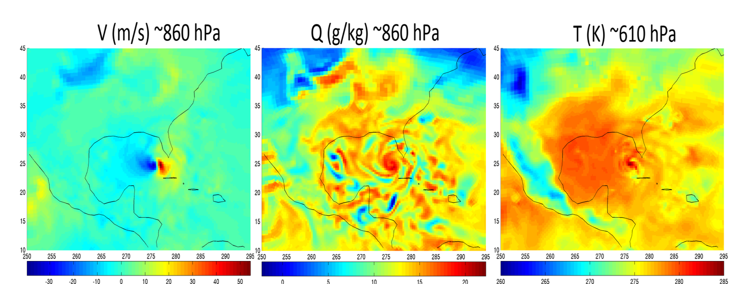


Figure 6: *These samples show: hurricane force winds (left), banded structure (center), and the warm core (right).*

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

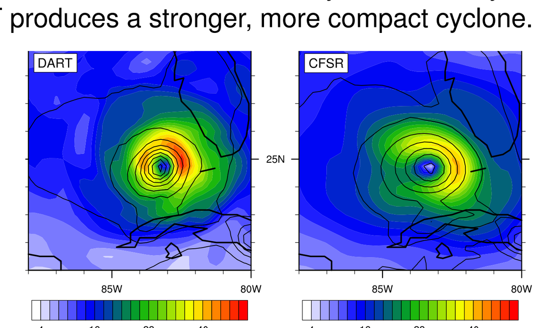


Figure 7: *DART ensemble member 10 (left) and CSFR (right). 850 hPa winds are in color shading, surface pressure is contoured (4 hPa interval). The National Hurricane Center's best-track archive records Hurricane Katrina as having 850 hPa winds of approximately 54 m/s at this time.*

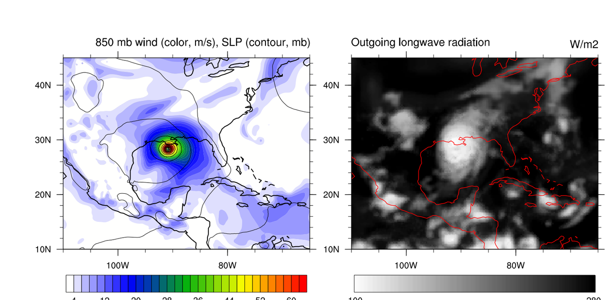


Figure 8: *60 hour CAM5 forecast initialized at 00Z August 27th, 2014 using one of the DART ensemble members. 850 hPa wind speed (color shading) and sea level pressure (8 hPa contours) are shown on the left, simulated outgoing longwave radiation is shown on the right.*

4. Chemical DA – CAM-CHEM

This research is covered more fully in a poster: "*Assessment of IASI CO and MOPITT CO data assimilation in 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 every day, MOPITT takes 4 days to cover the globe. Figure 9 shows the difference between a control run (meteorological data assimilation only) and various CO assimilation runs. Figure 10 shows comparisons with the Tropospheric Emission Spectrometer (TES).

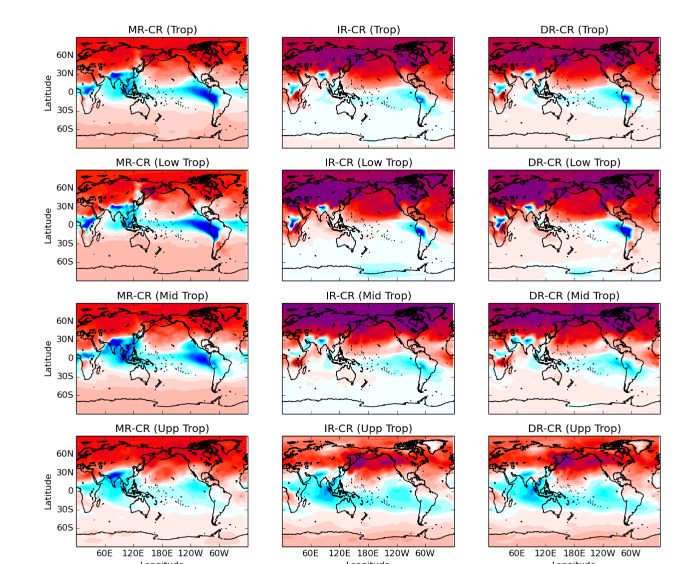


Figure 9: *Data Assimilation Impacts, July 2008. Tropospheric CO data assimilation generally increases concentrations over the Northern hemisphere. A low model bias is corrected, with more efficiency with IASI due to superior coverage. CR: Control Run, MR: MOPITT assimilation run, IR: IASI assimilation run, DR: MOPITT + IASI assimilation run.*

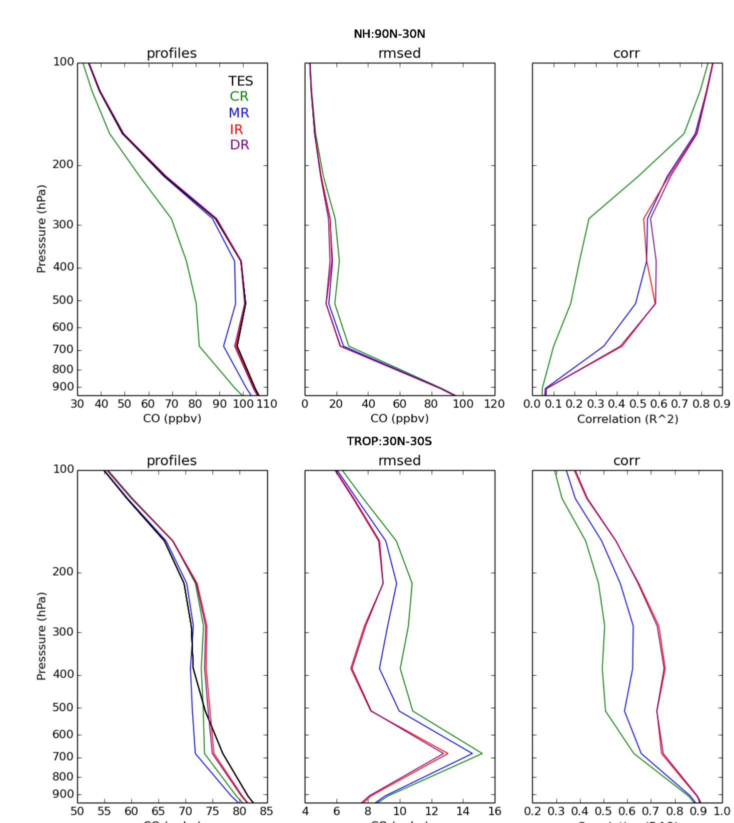
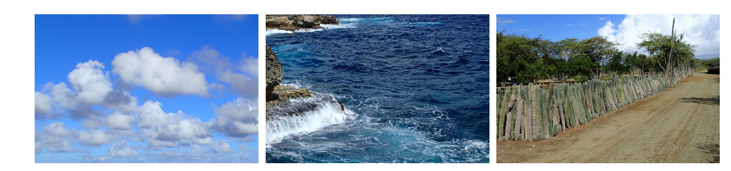


Figure 10: *Regional CO measurements during July 2008. Comparisons with TES, which is also a nadir sounder that measure CO, show great improvement of the CO fields. Bias and also variability are improved (unbiased root mean square error and correlation).*

5. Multi-Component, Coupled Model Assimilation



Separate reanalyses for different model components (i.e. the atmosphere or ocean) are essential but such reanalyses may occasionally be inconsistent as they are produced independently. Coupling the model components enables a more self-consistent reanalysis, whereby the atmosphere and the ocean states are better balanced with each other. DART and CESM may be used to perform a 'multi-component coupled data assimilation' system in which observations are assimilated into each of the respective atmosphere/ocean/land model components during the assimilation step but all the components are coupled dynamically during the forecast. Such a coupled system not only makes better use of near-surface observational data (see Figure 12) but also improves representation of processes that are linked by strong air-sea interaction (see Figure 13).

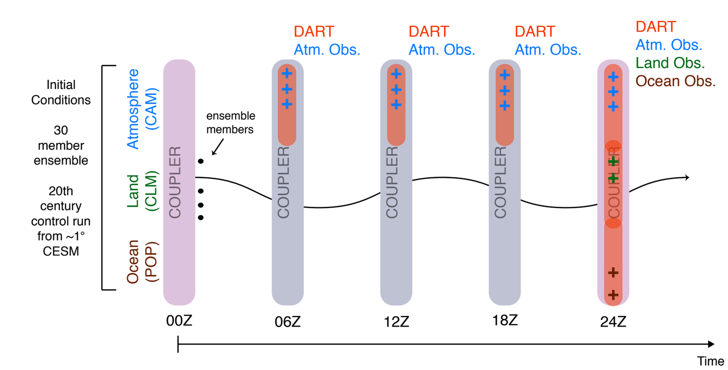


Figure 11: *Schematic of the multi-component coupled data assimilation with CESM and DART. For example, assimilation of observations in the atmosphere component happens every 6 hours, while assimilation in the land and the ocean component occurs every 24 hours.*

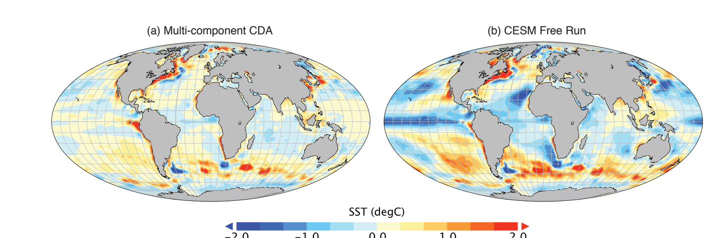


Figure 12: *Comparison with independent data [merged Hadley-OI SST] show that the multi-component CDA reduces the SST bias more than the CESM free run.*

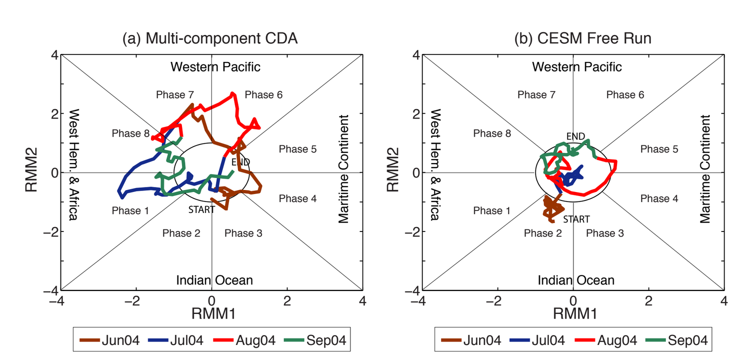
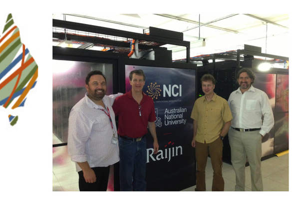


Figure 13: *The 2004 boreal summer state of the MJO is shown as a point in the phase space of Real-time Multivariate MJO Series 1 (RMM1) and Series 2 (RMM2) for two experiments – compared to observations, the multi-component CDA signal is more realistic.*

In the future, DART will also enable 'cross-component coupled data assimilation' in CESM. All model components will be updated simultaneously at each assimilation step, i.e., observations of the atmosphere will immediately update the ocean state as part of the assimilation and vice versa.

6. Land Surface Data Assimilation – CABLE

Brad Evans, *TERN/eMAST* **Luigi Renzullo**, *CSIRO*



Researchers from CSIRO, Macquarie University and the National Computing Infrastructure (NCI) teamed up with US collaborators to install and run DART on NCI's supercomputer (Raijin) and coupled it to Australia's Community Atmosphere Biosphere Land Exchange (CABLE) land surface model. The endeavour marks significant progress toward the vision of the Ecosystem Modelling and Scaling Infrastructure (eMAST) facility under the Terrestrial Ecosystem Research Network (TERN) to develop Australia's first modelling and data integration system for ecosystem science and monitoring at unparalleled scales in space and time. The system brings together a range of disparate ecological observations from ground- and space-based sensing networks into CABLE's modelling framework.

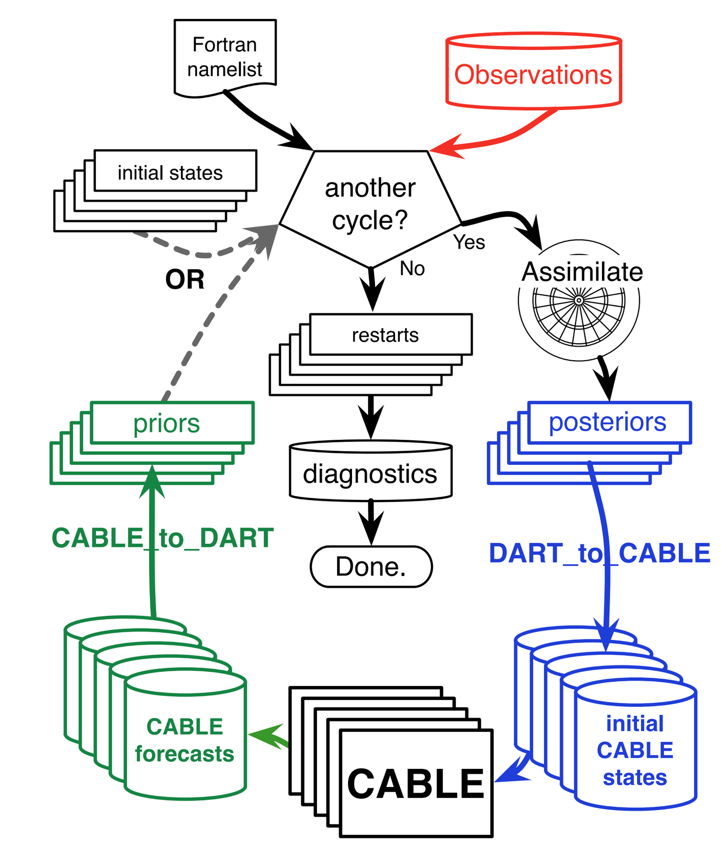


Figure 14: *A schematic of the assimilation system with DART and CABLE. Starting at the top: DART reads in an initial ensemble, the observations, the run-time control information and performs an assimilation to create posterior estimates of the CABLE variables.* DART_TO_CABLE *conveys the posteriors to a set of CABLE restart files which are advanced by CABLE to the time of the next observation.* CABLE_TO_DART *then extracts the prognostic state variables of interest and converts them to a DART-compliant format.*

Some of the instruments providing the observations that can be assimilated in the CABLE/DART system. Left-to-right: Eddy Covariance (Cape Tribulation), OzFlux (Scott Farm), CosmOz (Tullochgorum).

NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

The Terrestrial Ecosystem Research Network Ecosystem Modelling and Scaling Infrastructure is supported by the Australian Government through the National Collaborative Research Infrastructure Strategy (NCRIS).

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