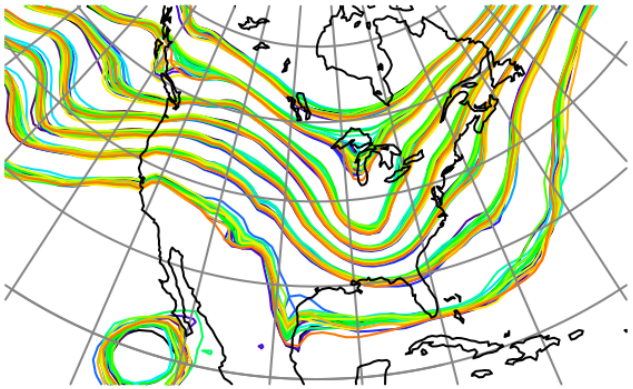

Using DART Tools for CAM Development

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DART: Jeff Anderson, Tim Hoar, Nancy Collins, Johnny Hendricks
CSEG: Alice Bertini, Mariana Vertenstein, Steve Goldhaber, Jim Edwards
And: Nick Pedatella (HAO), Raffaele Montuoro (CIRES, TAMU).

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Outline

1) Context
2) Motivation and Examples of Tools
3) Making Tools Available
4) Summary

1) Goal

Make Data Assimilation Research Testbed (DART) tools immediately usable in leading edge CAM development.

DART = Ensemble Kalman Filter
= 6 hour, CAM, ensemble forecasts
+ Bayesian statistical correction by observations

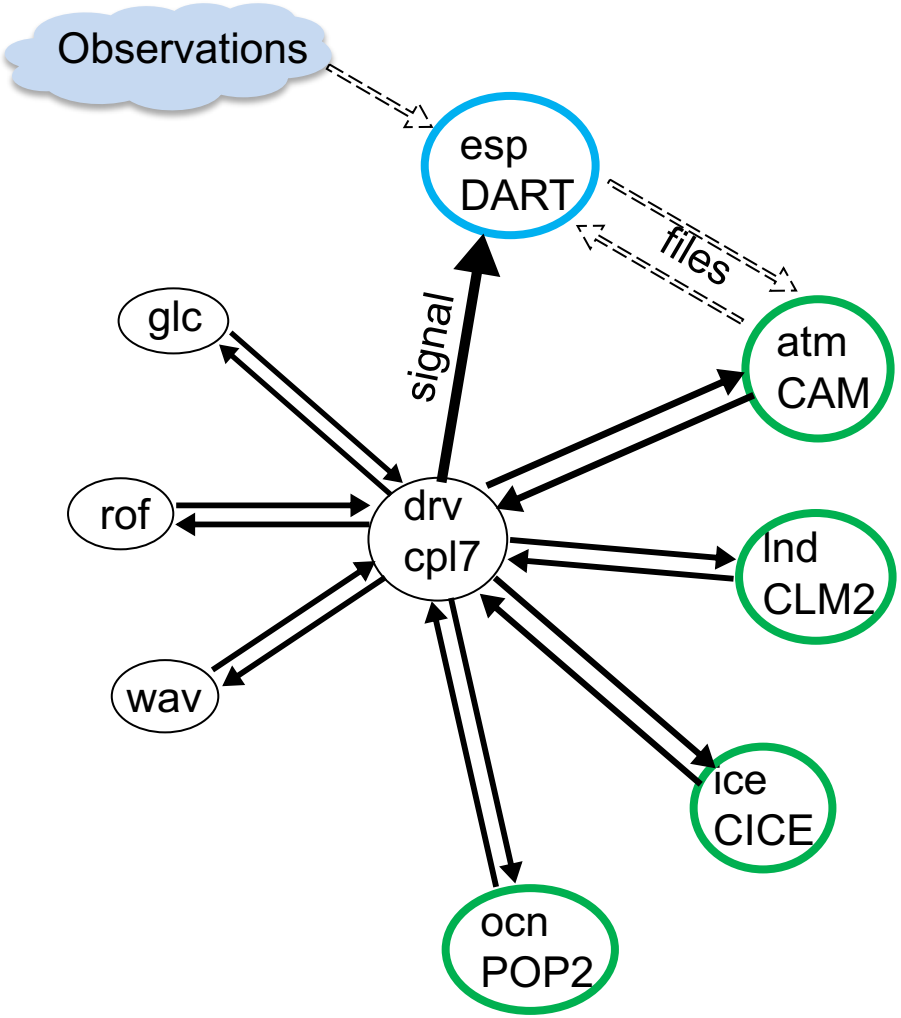
Strategy

Develop pre-tag testing of β versions of CESM2-CAM-FV+DART.

Who: Data Assimilation Research Section (CISL) + Software Engineering Working Group

Result: Eliminate the post-tag step of verifying and usually fixing the interface between CESM and DART

DART⇔ CESM



DART uses
CESM infrastructure and
the new ESP component
to interface to
model components.

These models
have DART interfaces

CAM assimilations have
active lnd and ice
(not ocn) components

DART Uses New and Old CESM capabilities

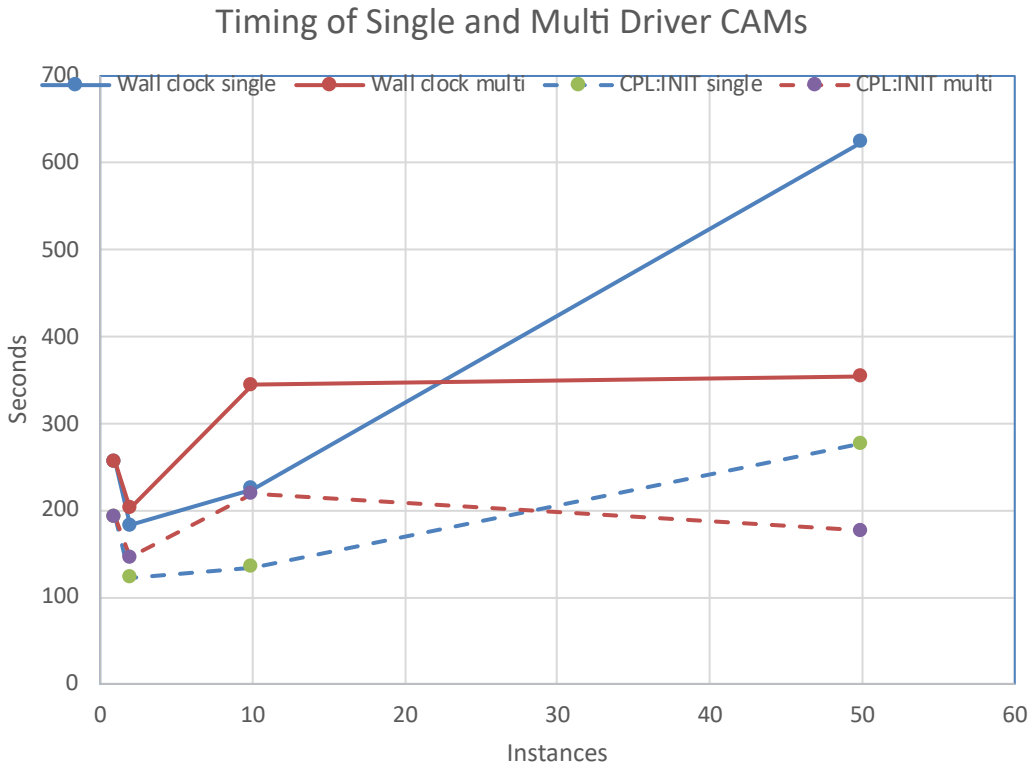
- Multi instance (ensemble forecasts)
- Multi driver (Montuoro)
- Multi component
- Pause-resume (first version)
- st_archive and naming convention accommodates DART

Multi-instance CAM wallclock

drv = 1

drv = # instances

nodes/instance = constant



All Flavors of CAM-FV Can Be Evaluated

- ✓ CAM-Chem
- ✓ WACCM(-X)
- ✓ Virtually any version such as CAM4, 5, yours, ...
- ❑ CAM-SE; interface probably needs updating.
- ❑ MPAS-A; can be developed from existing pieces (easily? Zarzycki, Ha).

Even More Options

+ Any CAM model state (from CAPT, a climate run, ...) can be compared directly to observations.
+ More focused and detailed than anomaly correlations.
  “T is biased relative to radiosonde observations north of 50N, but the winds are not”.
+ The model state can be compared to any observations assimilated by NCEP (even radiances), and more, by calculating the model estimates of the observations during the forecast.

2) Examples of Model Evaluation Tools

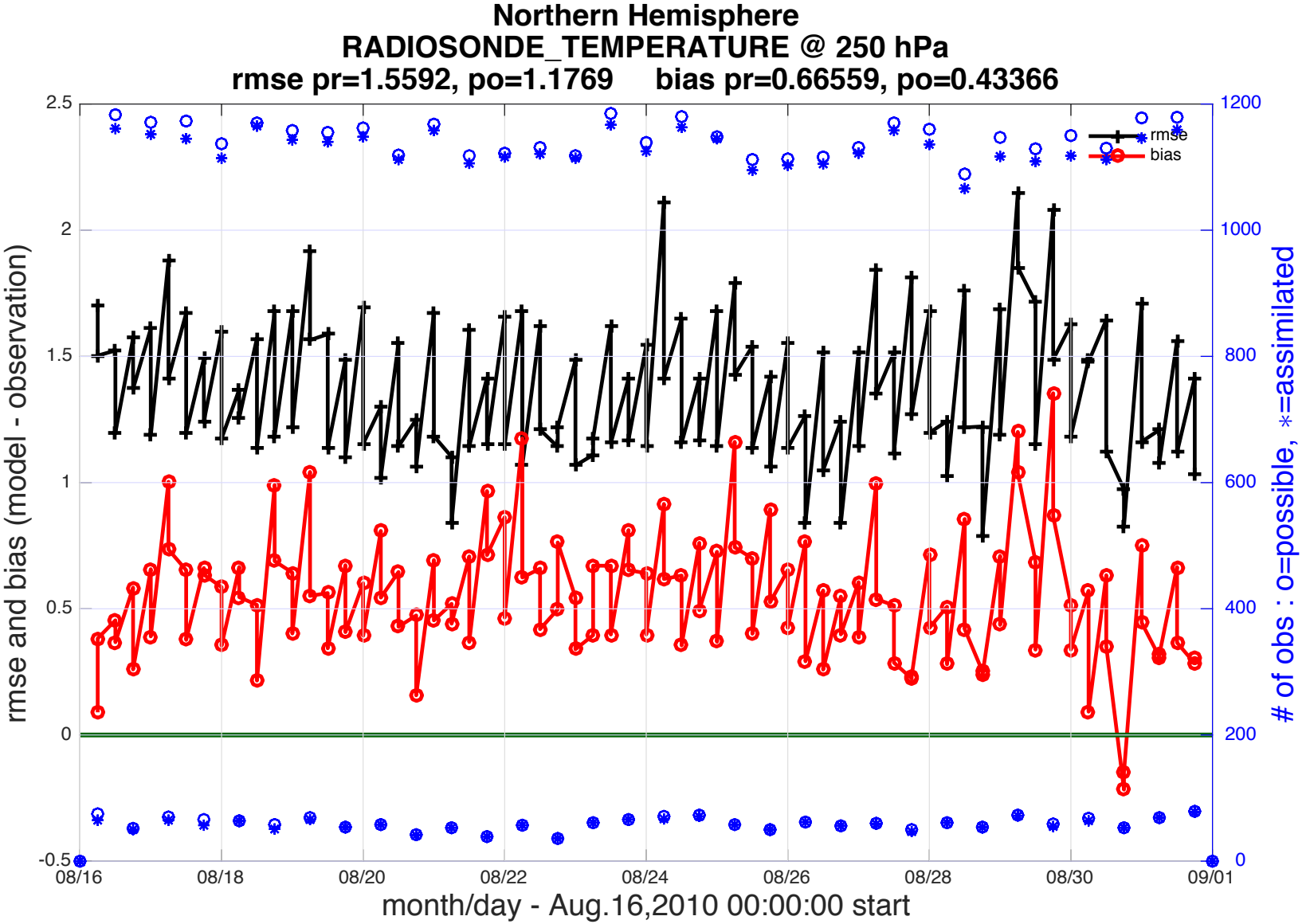
Oldies but goodies:
Looking forward to generating new examples with CESM2 and collaborators.
Shallow overview.

Evaluate CAM State in “Observation Space”

Use CAM state to generate an estimate of an observation.
E.g. interpolate the T field to the location of a thermometer.
Or 10^6 thermometers . . .

T measurement may, or may not,
have been used in the assimilation.

“Obs Space” Time Series



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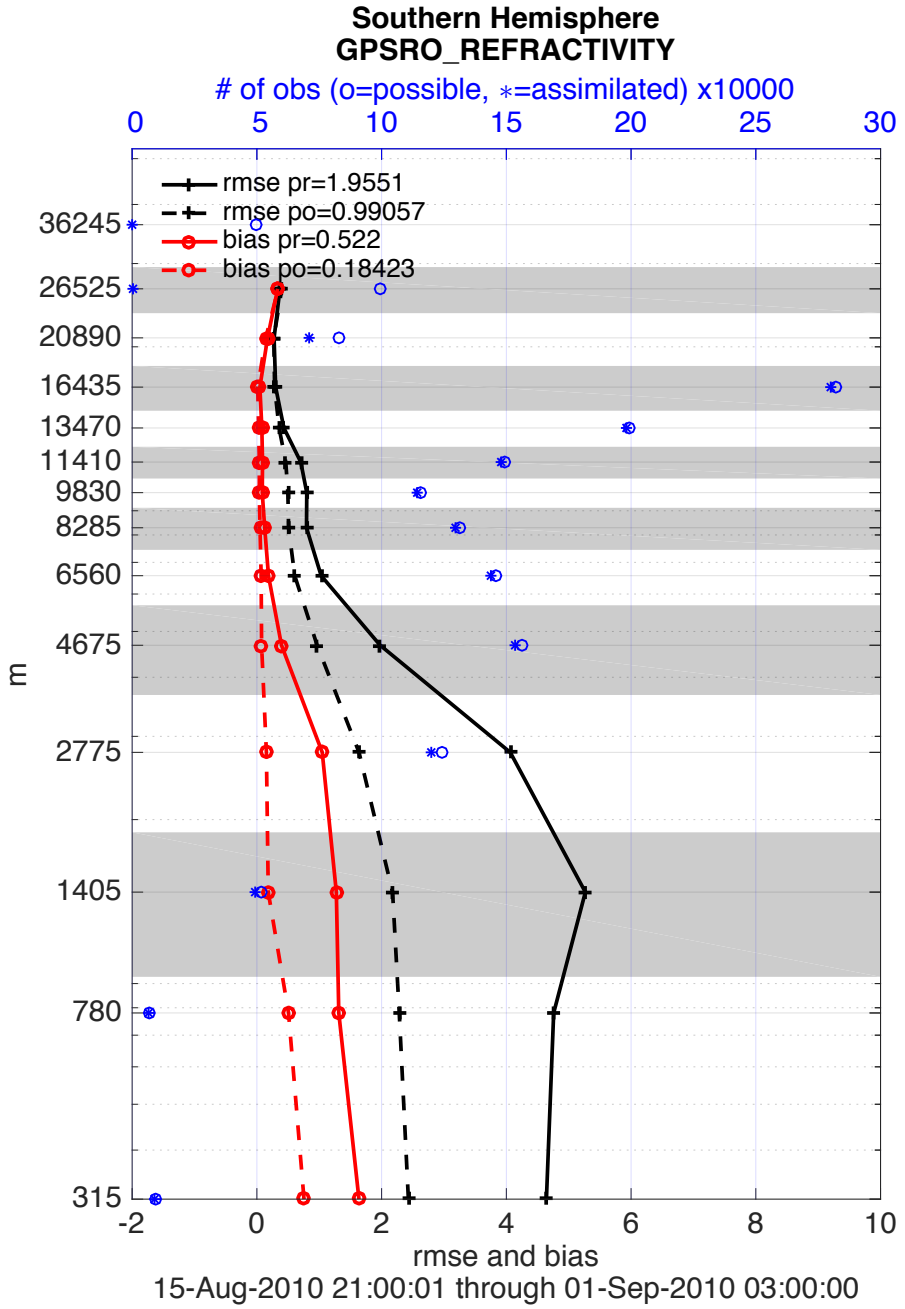
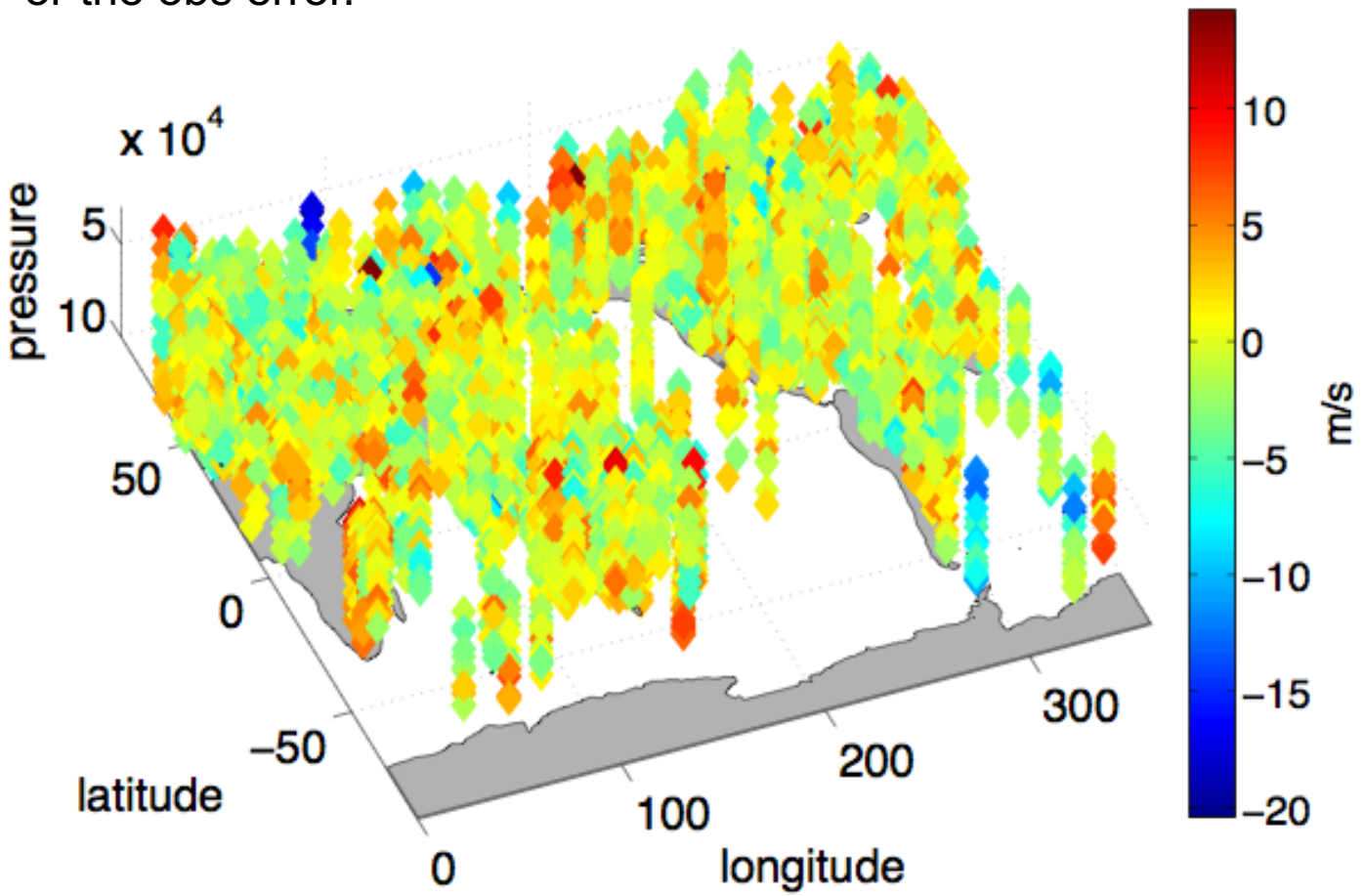
“Obs Space” Profile

Calculate index of refractivity from CAM’s T, Q, ... and compare against COSMIC GPS measurements.



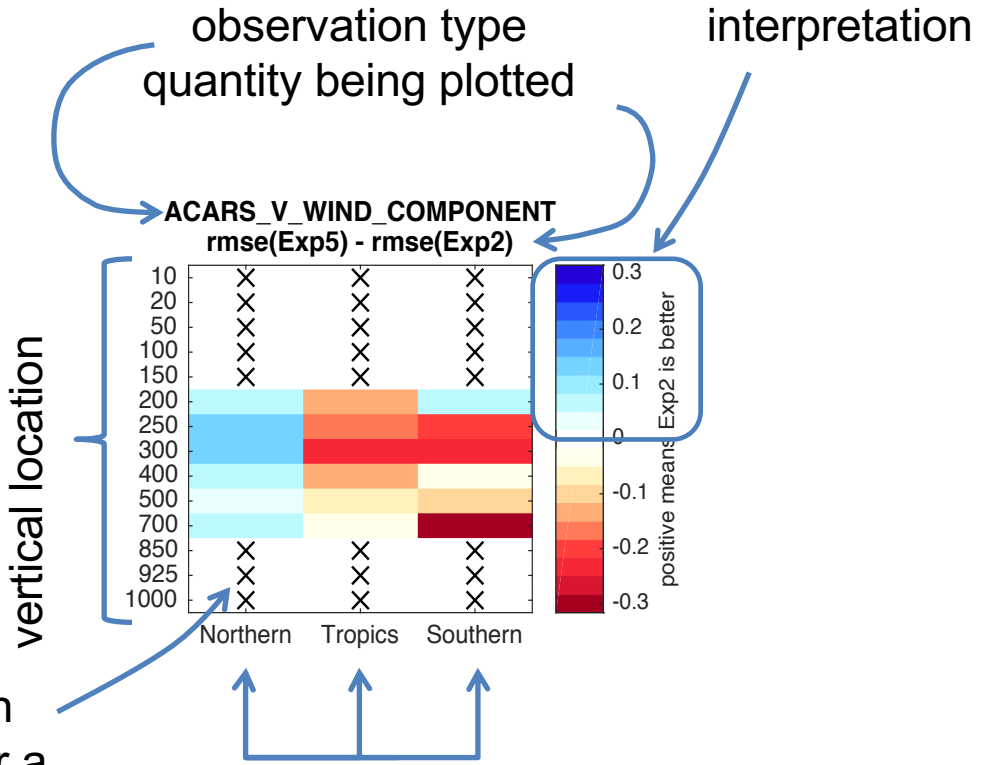
Model Biases at Observation Locations

- Matlab script generates the model bias at each obs location, here U from radiosondes.
- Bias can be absolute units, or normalized by the obs value, or the obs error.



“Obs Space” Comparison of 2 CAMs

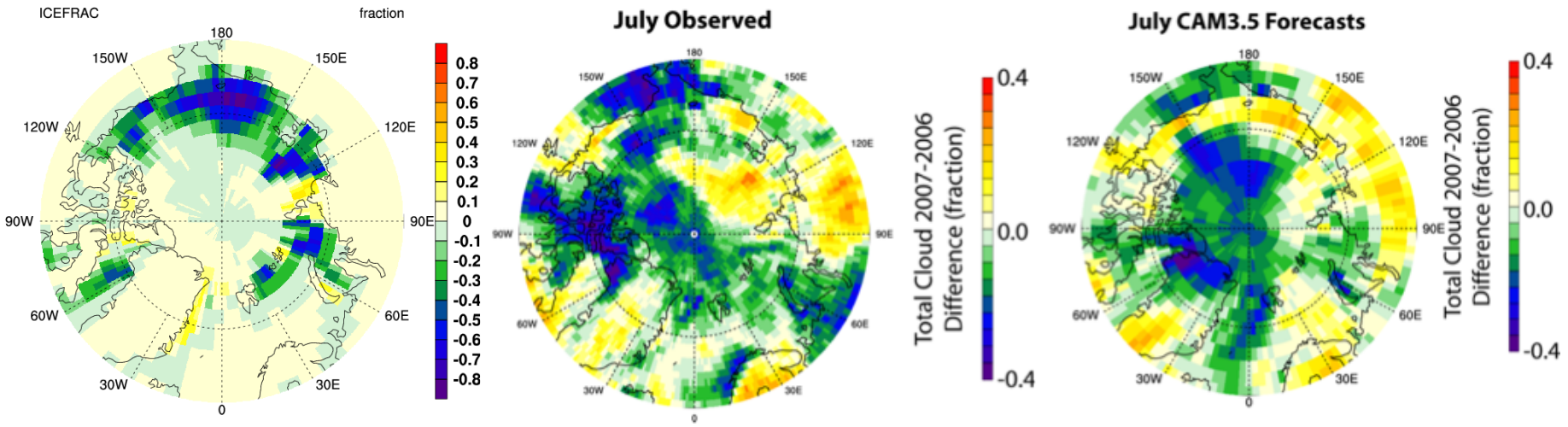
Performance of 2 CAMs compared against the observations successfully assimilated by both models.



Northern: 20-90N
Tropics: 20S-20N
Southern: 90S-20S

Initial Conditions for Process Studies

Kay, et al. 2009; Cloud response to the 2007 Arctic sea ice loss in CAM3.5 and CAM4

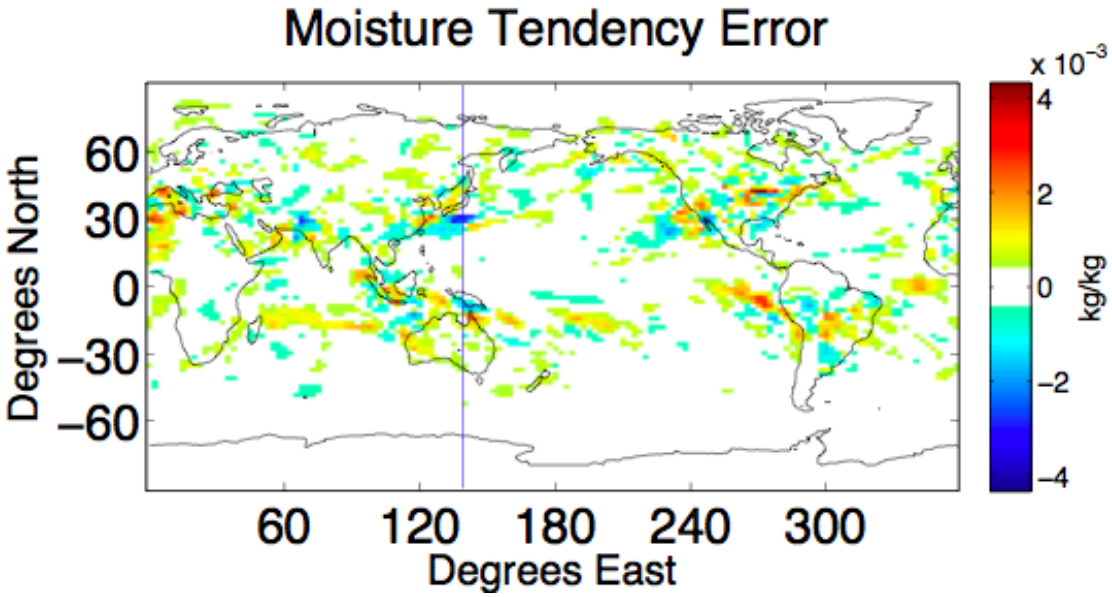


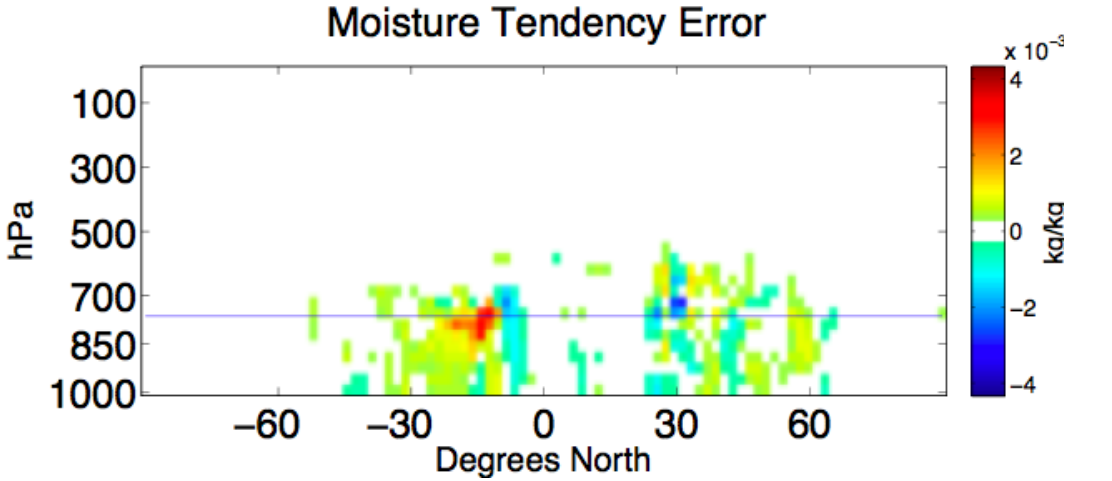
CAM3.5 has an unrealistic feedback between stratus clouds and sea ice because stratus clouds are only diagnosed over open water.

+ On CAM's native grid -> no interpolation or foreign model error to wonder about.
+ Analysis error estimate comes for free from ensemble spread; varies with location, time, and field.
+ Analyses can be generated with study-focused observation sets.

Tendency Errors

DART-CAM can provide time-averaged tendency errors of the state variables over short periods. These have significant correlation with model bias as measured from long climate runs. Shown is a 6-day average of 6-hour Q tendency errors from July 2003. This highlights areas where CAM wants to stray from reality.





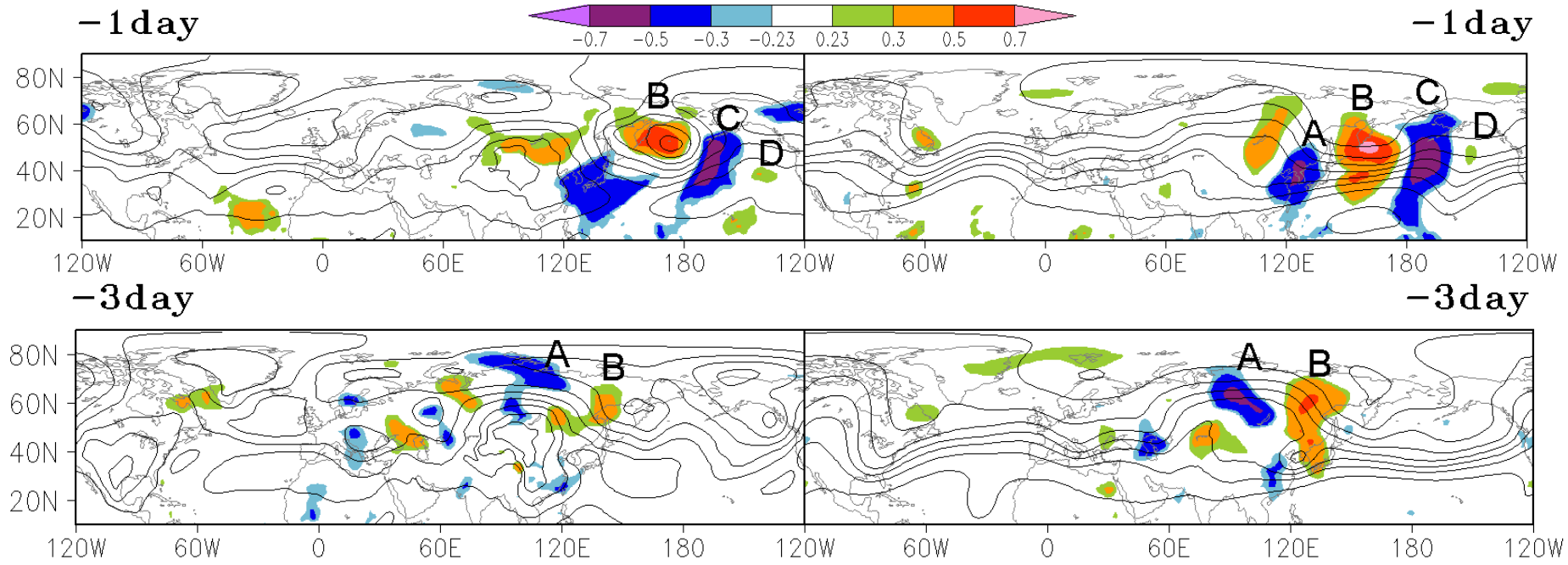
Ensemble-based Sensitivity Studies

Chang, et al. 2012, Medium Range Ensemble Sensitivity Analysis of Two Extreme Pacific Extratropical Cyclones

$$\text{"}sensitivity\text{"} = \frac{\mathrm{cov}(\mathbf{J_M}, \mathbf{x_{iM}})}{\sqrt{\mathrm{var}(\mathbf{x_{iM}})}\sqrt{\mathrm{var}(\mathbf{J_M})}} \quad = \text{correlation}$$

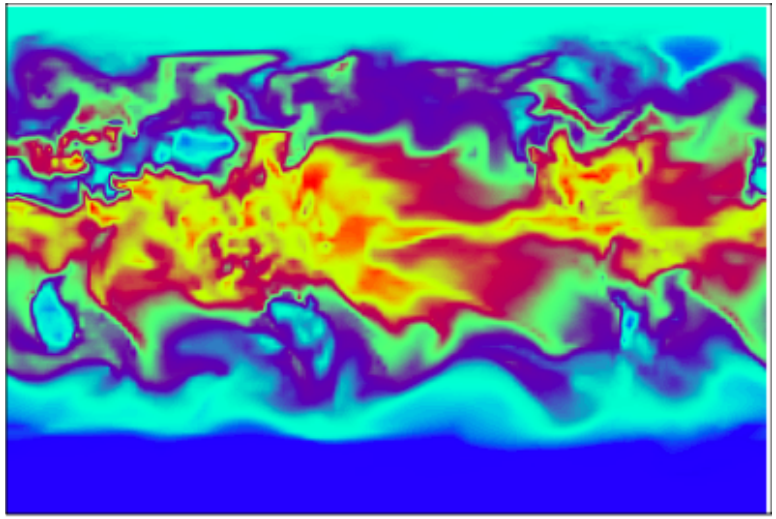
$\mathbf{J_M}$=cyclone minimum pressure at a chosen time

$\mathbf{x_{iM}}$= Sea Level Pressure $\mathbf{x_{iM}}$= 300 hPa Z



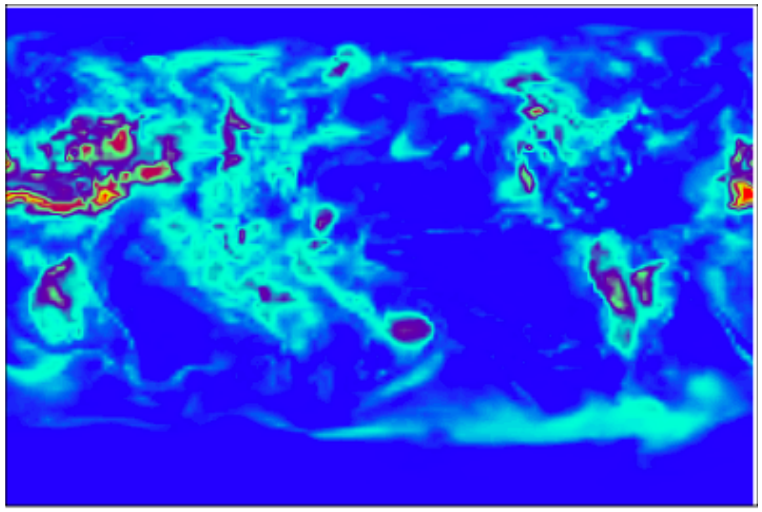
Ensemble Mean (analysis) and Spread (confidence)

Q level=30 Mean



posterior ensemble state
Range of Specific humidity: 6.61214e-06 to 0.0217079 kg/kg

Q level=30 spread

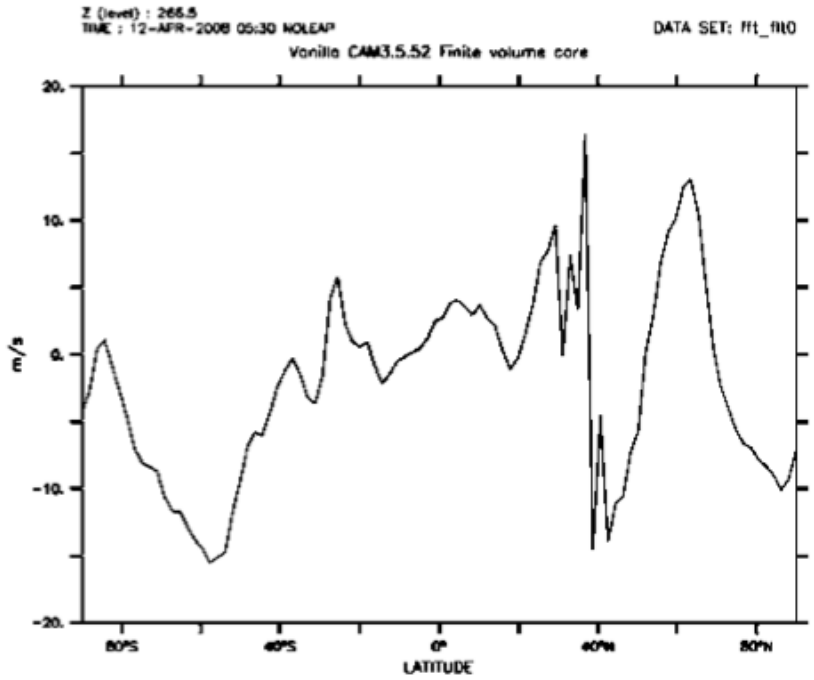


posterior ensemble state
Range of Specific humidity: 2.05892e-05 to 0.00680974 kg/kg

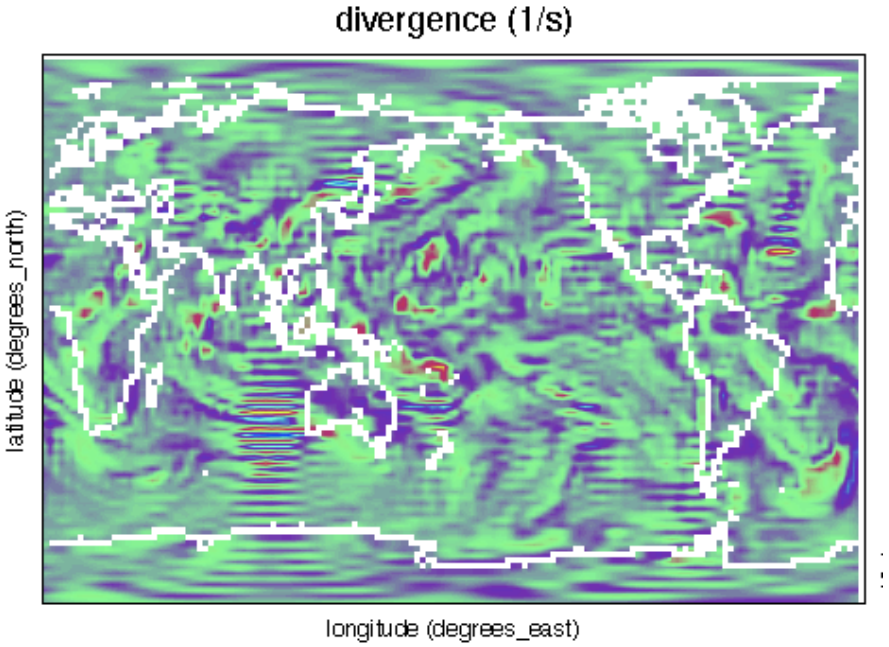
Change in spread during a forecast is a diagnostic of model error growth.

FV dy-core noise (circa 2008)

- First noticed in DART-CAM assimilations.
- Seen in free-running FV CAM, even on the cubed-sphere grid (Lauritzen).



Meridional wind (V) for free running CAM. Sporadic intermittent noise is especially visible at upper level v winds.



Divergence field in free running CAM at model level 10 (around 200 hPa). Noise visible throughout the run.

3) Making These Tools Available

- Tools exist.
- Bottleneck; making DART work with chosen CESM+CIME.
- The Fix; Develop pre-β tag testing of CESM2-CAM-FV in the context of DART.
- CAM will be first implementation.
- Other components will use it as a template.
- They will need forcing files from CAM+DART → new reanalysis.

Proposed Testing Procedure

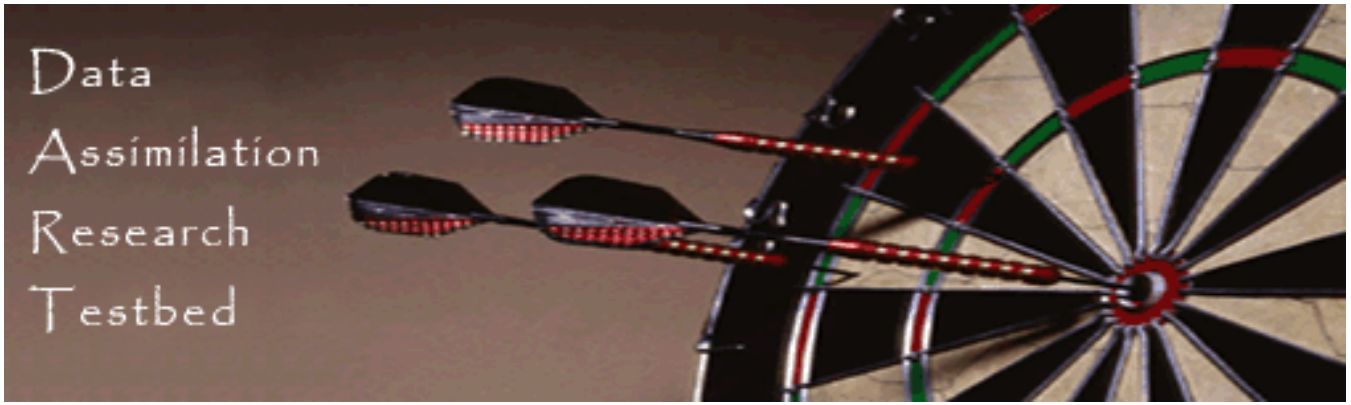
1. Run a DART+CESM setup script to
   A. build a small ensemble, low resolution, sparse observation case
   B. stage input files
   C. set namelist values (both DART and CESM)
2. First forecast + assimilation cycle.
   A. 1-24 hours, depending on the component
   B. DART can start from a single model state;
      perturbs it to make an ensemble (or tell CESM to).
3. 2 more assim cycles in 1 job to test the
   A. multi-cycle capability
   B. interim restart file management
   C. st_archive for history and restart files
4. Set up and run a large ensemble (~100), 1-degree case for
   A. 1 cycle = 1-24 hours, depending on the component.
   B. Still small observation set.
5. Repeat some steps for CAM variants

4) Wrap-up

CAM+DART:

- ✓ will be incorporated into β-tag testing to make it usable at release,
- ✓ provides state-of-the-art data assimilation tools to assist with CAM model development efforts,
- ✓ helps identify model deficiencies,
- ✓ efficiently focuses almost any model version(s) on an actual synoptic situation.
- ✓ eliminates uncertainty from foreign model bias, interpolation error.

Learn more about DART at:



www.image.ucar.edu/DAReS/DART

Anderson, J., Hoar, T., Raeder, K., Liu, H., Collins, N., Torn, R., Arellano, A., 2009: *The Data Assimilation Research Testbed: A community facility.* BAMS, **90**, 1283—1296, doi: 10.1175/2009BAMS2618.1