The Use of the Data Assimilation Research Testbed with CAMs, WACCM, and CESM

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NCAR

Outline

Recent DART-CAM activities

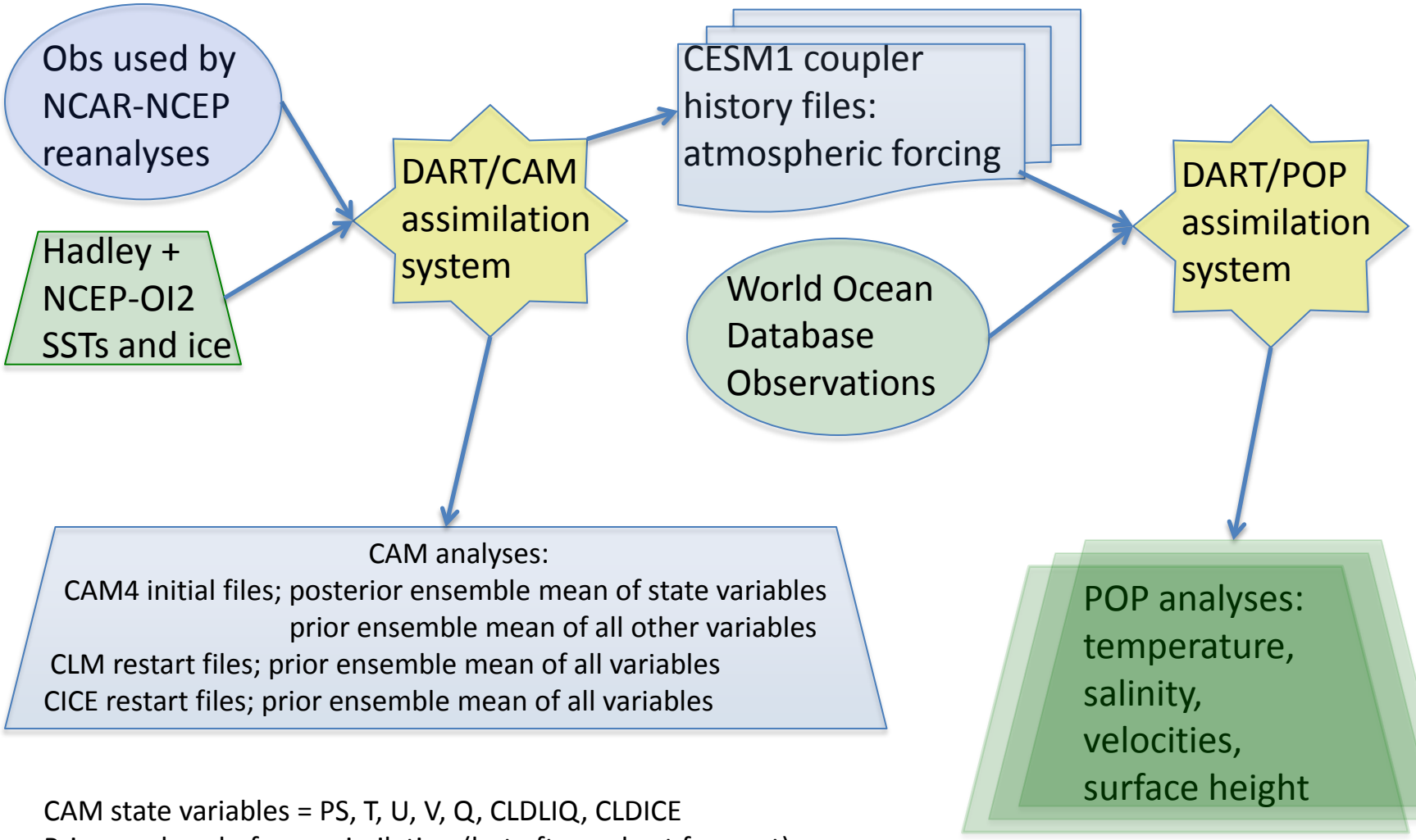
- A decade of 2-degree analyses for forcing DART/POP assimilations (Karspeck, Yeager), etc.
- Assimilation with CAM+SKEBS (Berner) to evaluate Stochastic Kinetic Energy Backscatter
- New ensemble forecast study (Kay) of recent record Arctic warmth
- Continuing numerical noise reduction work (Lauritzen)

DART-WACCM

- Motivations
- Development steps
- Projects and questions

A Loosely Coupled, Ocean-Atmosphere, Data Assimilation System

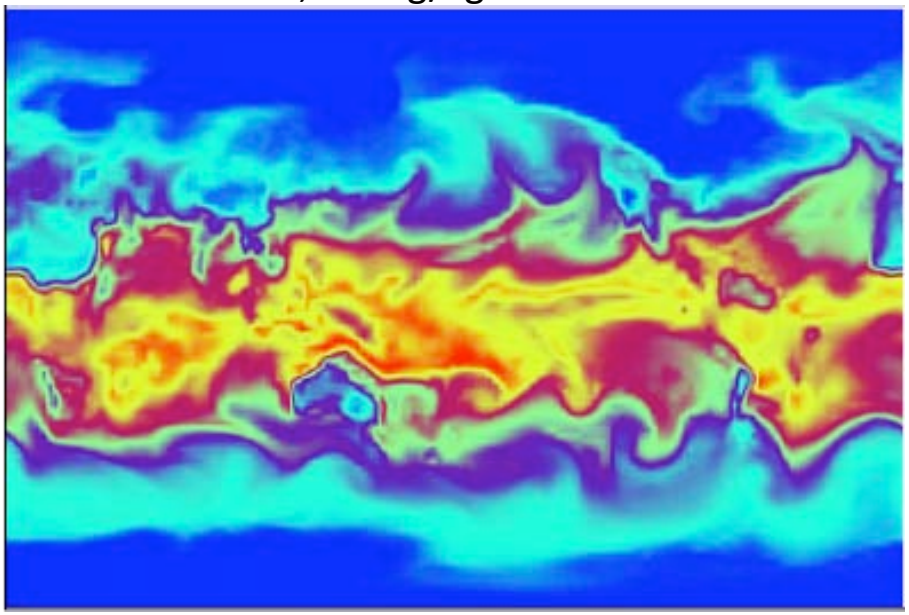
POP work by Yeager, Karspeck, Vertenstein



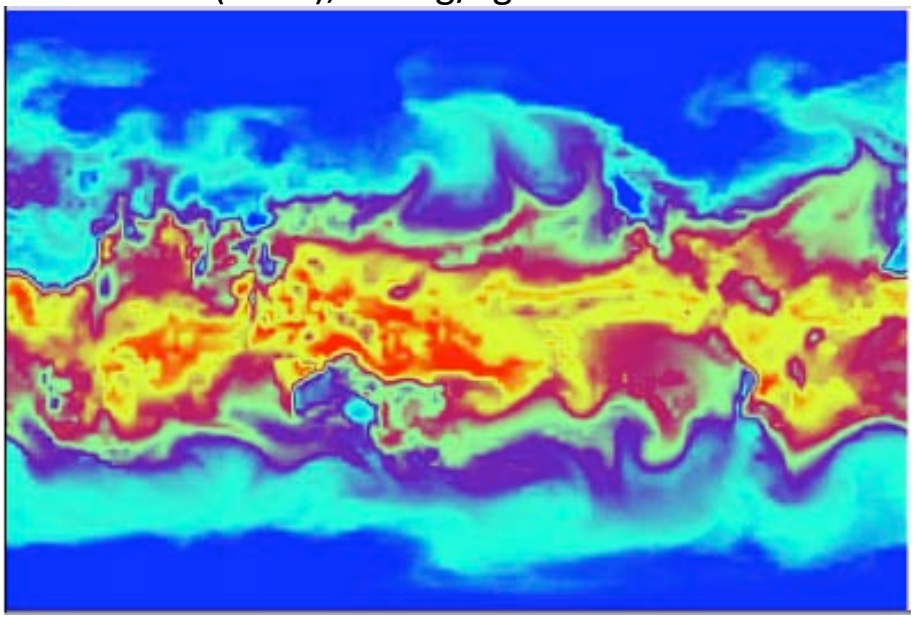
CAM state variables = PS, T, U, V, Q, CLDLIQ, CLDICE
Prior = values before assimilation (but after a short forecast)
Posterior = values after the assimilation of observations at that time

DART-CAM Specific Humidity Analyses (and more) @ 992 hPa

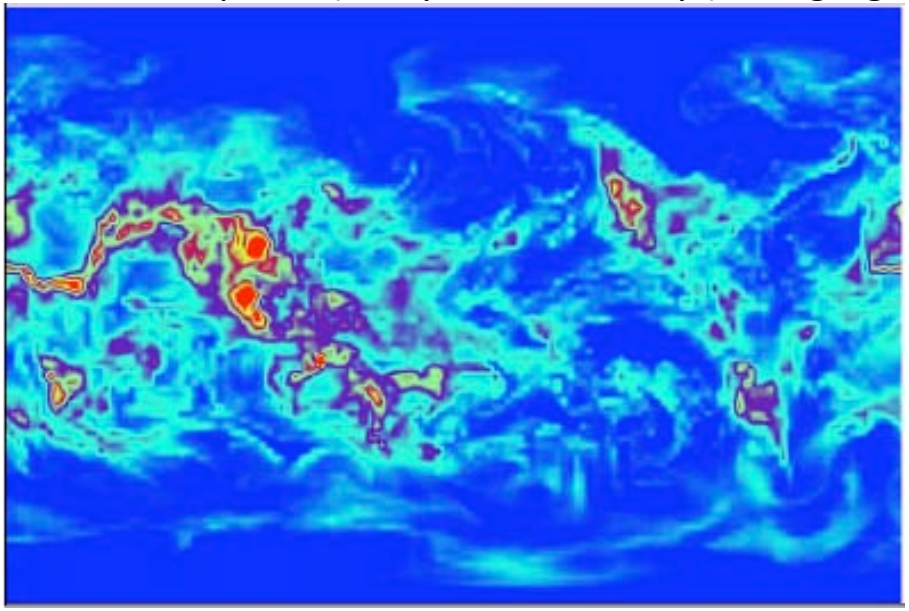
Ensemble Mean, 0-21 g/kg



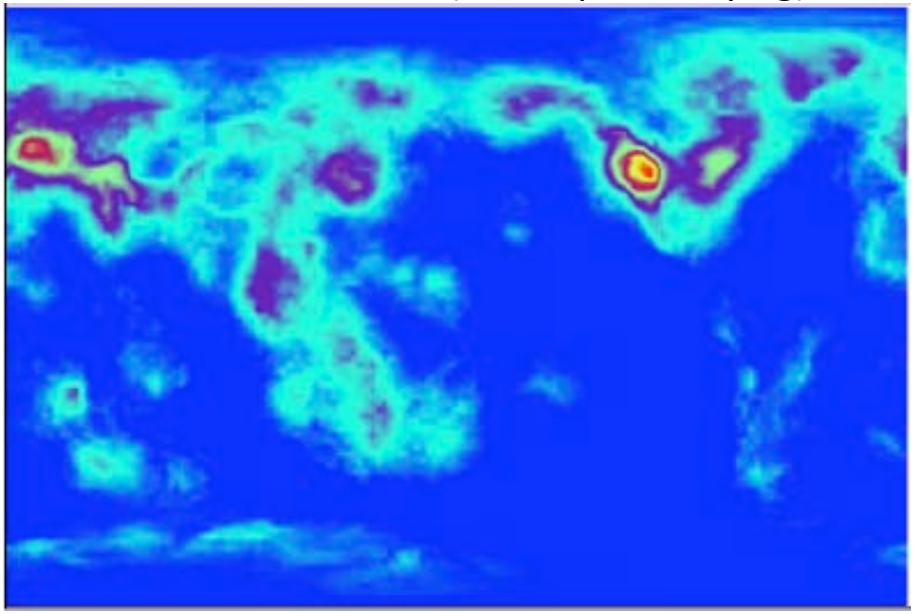
Member 1 (of 80), 0-21 g/kg



Ensemble Spread (Analysis Uncertainty!), 0-4 g/kg



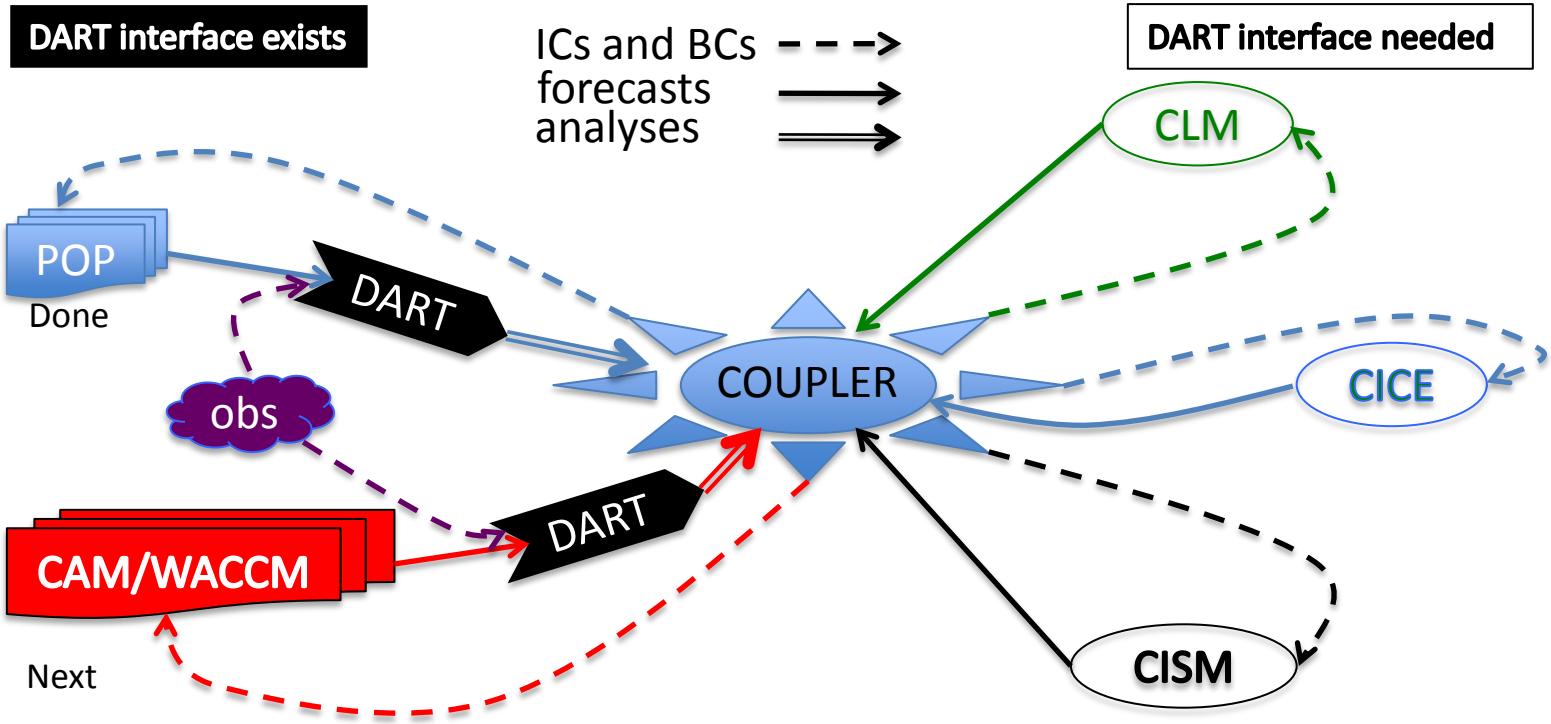
Prior Ensemble Inflation (time+space varying), 0-7



Future Fully Coupled Assimilation in CESM

with help from Vertenstein, et al.

- Implement the interactive ensemble manager in CESM for each component which will assimilate observations.

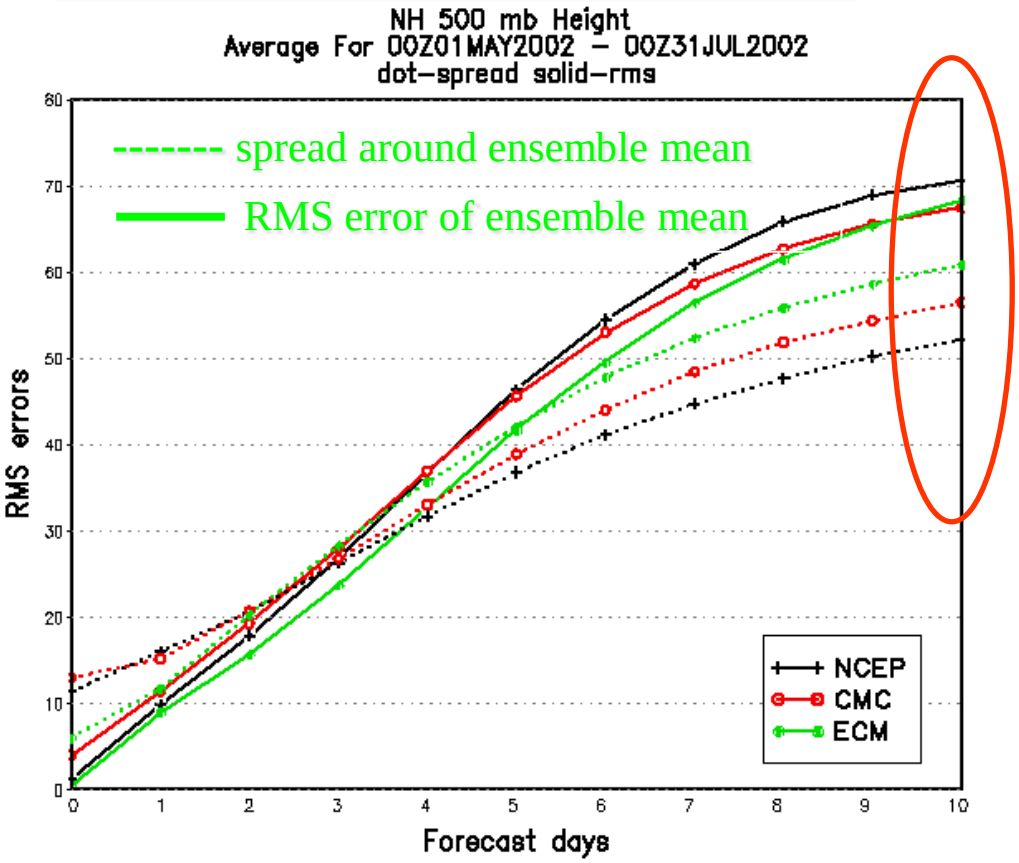


- Enable assimilations on thousands of processors, which DART can do, but CAM within DART hasn't been able to do *efficiently*.
- This may require using CAM (etc.) restart files, instead of initial files, to communicate with DART. Or interactive ensemble manager will fix it.

CAM+SKEBS (Berner)
Underdispersiveness of ensemble systems

As Buizza (2004) showed, the RMS error grows faster than the spread

- Ensemble is
- Ensemble forecast is **overconfident**

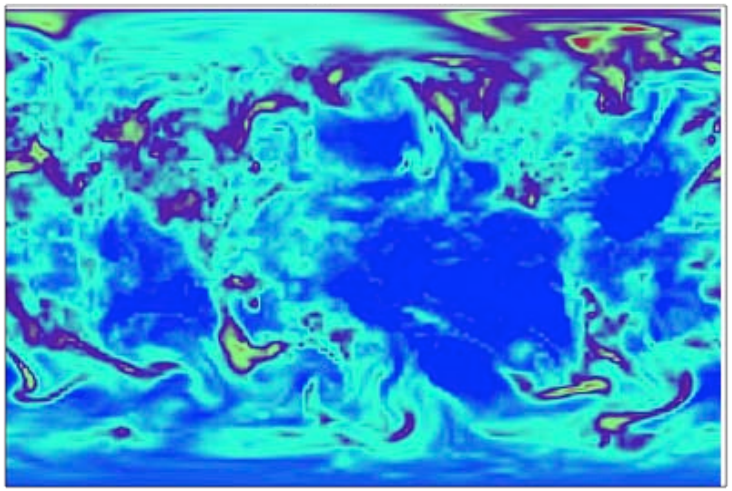


Attempt to fix with Stochastic Kinetic-Energy Backscatter Scheme:

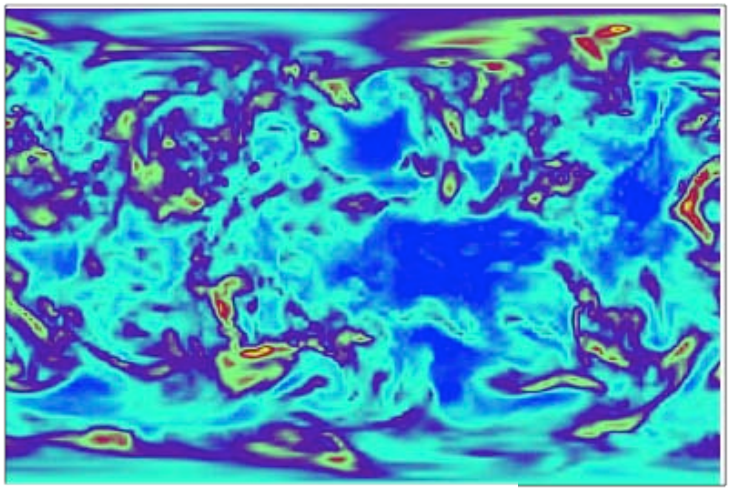
A fraction of the dissipated energy is scattered upscale and acts as streamfunction forcing for the resolved-scale flow.

DART/CAM+SKEBS: Impacts

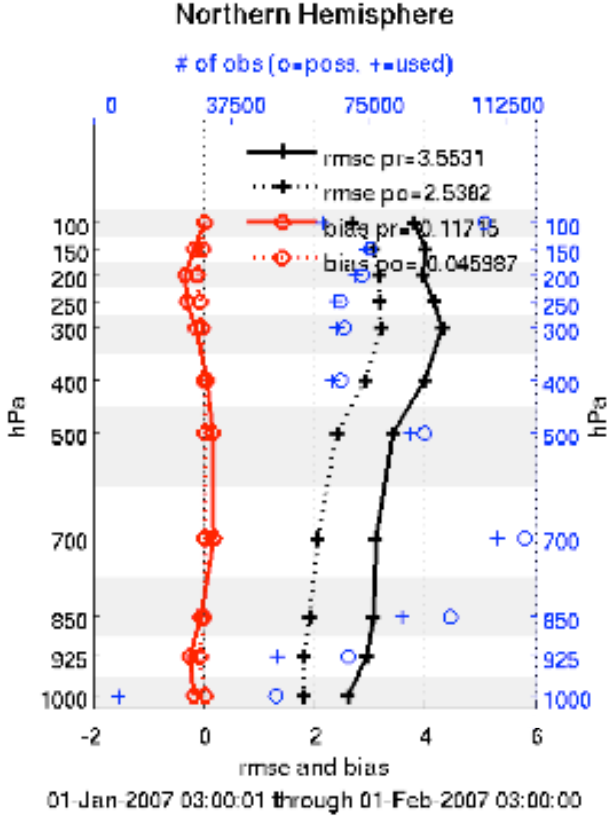
Ensemble Spread Temperature (K)



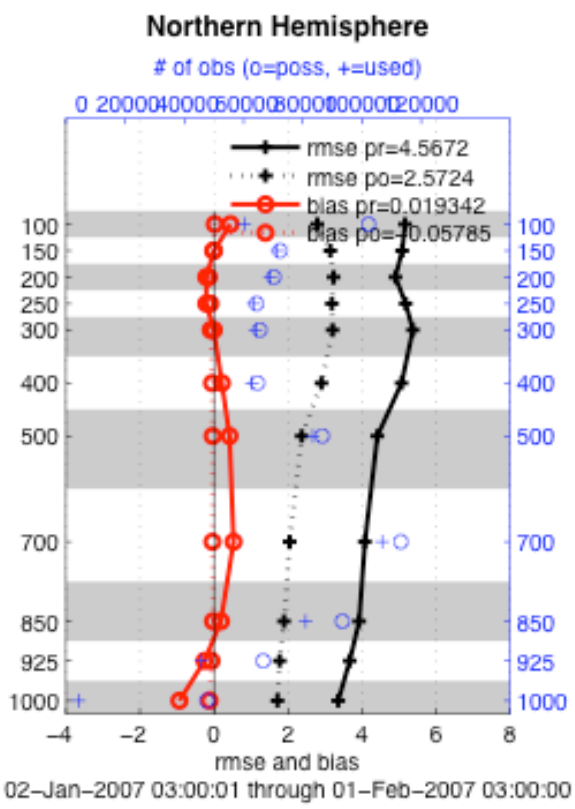
Ensemble Spread Temperature (K)



CAM4



CAM4+SKEBS

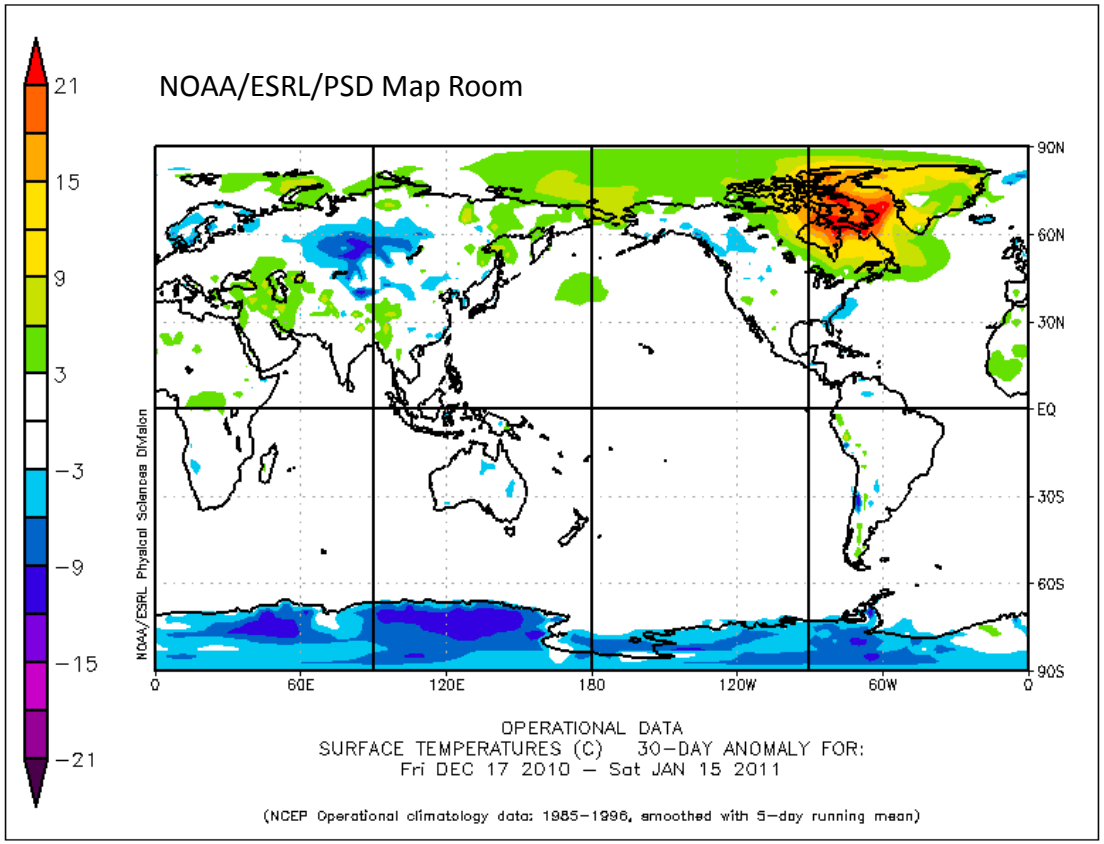


DART/CAM+SKEBS

- Berner has implemented a *simple* form in CAM (FV).
- Development proceeding with input from assimilation with DART/CAM.
- Assimilation enables:

  rapid comparison of model formulations
  for a variety of actual synoptic conditions
  selected by the developer
  and direct comparison against observations.

Ensemble Forecast of Recent Record Arctic Warmth



Kay will use DART/CAM analyses as the initial conditions and for verification.

Compare Dec 2007 (“normal”) with Dec 2010 (and …?), the influence of:

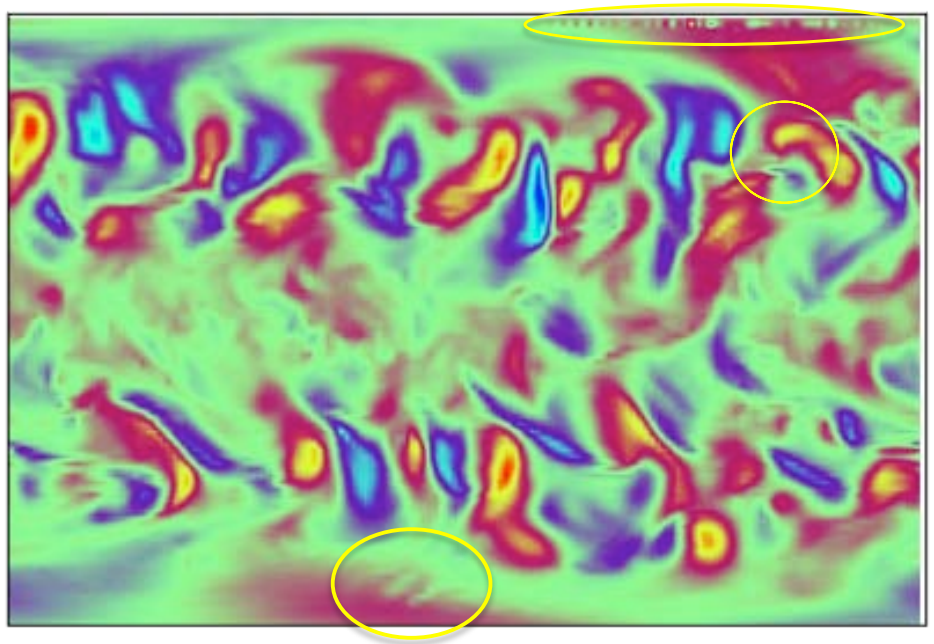
- the Arctic Oscillation (strong negative phase during the warm period and previous winter)
- sea ice coverage (interactions with the atmosphere)
- whatever else looks interesting.

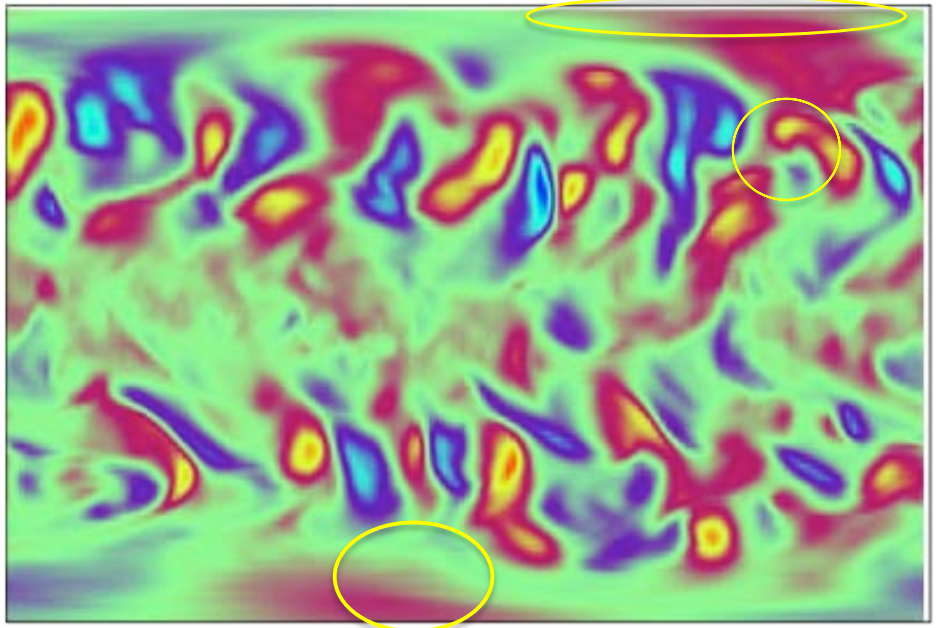
More Noise Found in CCSM4 (CAM4 FV mode)

Instantaneous meridional velocity (VS).
6-hour forecasts from analysis ICs.
Default damping;
- 2 dy and 2 dx noise O(several m/s).
- = spurious mixing of tracers and energy transport

∇^4 damping (Peter Lauritzen);
- Improved; not perfect.

Fixes can be evaluated for identical synoptics using short forecasts.





Examination of climate model output in a data assimilation framework helps identify model deficiencies.

DART-WACCM

Motivation

- Interest from university community and ACD
- to extend data assimilation through the UTLS and into the stratosphere (and beyond?)
- with more comprehensive assimilation of chemical tracers: extends work by Ave Arellano (ACD->U. AZ) assimilating MOPITT CO into CAM-Chem.
- The WACCM interface to DART is essentially done.

Development

- Yudin (ACD) outlining the development.
- 4x5x66, GHG demonstration (no chem tracers) (available next week)
- 2 degree x88, offline chemistry (6 species) (within a month)
- 2 degree x88, online chemistry (125 species) (Wyoming? 40-60x cost of 2-deg CAM)
- Large, ensemble memory footprint will be handled by building WACCM with purely OpenMP parallelism (until DART-CESM has atmospheric interactive ensemble manager).

DART-WACCM Projects and Pitfalls

- Yudin (ACD); assimilate O_3, O, CO, HNO_3, Q, T, winds, airglow… from HIRDLS, MLS, OMI, SABER, MOPITT, TES, GUVI, TIDI, …?
- Neef (Potsdam); length of day observations. Very experimental.
- Other ideas/collaborators?

? Does WACCM have sufficiently comprehensive and realistic chemistry (and everything else), and enough variability, to conform to the real observations?

? What observation sets are trusted and comprehensive enough to constrain the WACCM model state?

? The true chemical state of the atmosphere has significant unknowns(?); how will we judge success vs. "needs improvement" vs. "can't say yet".

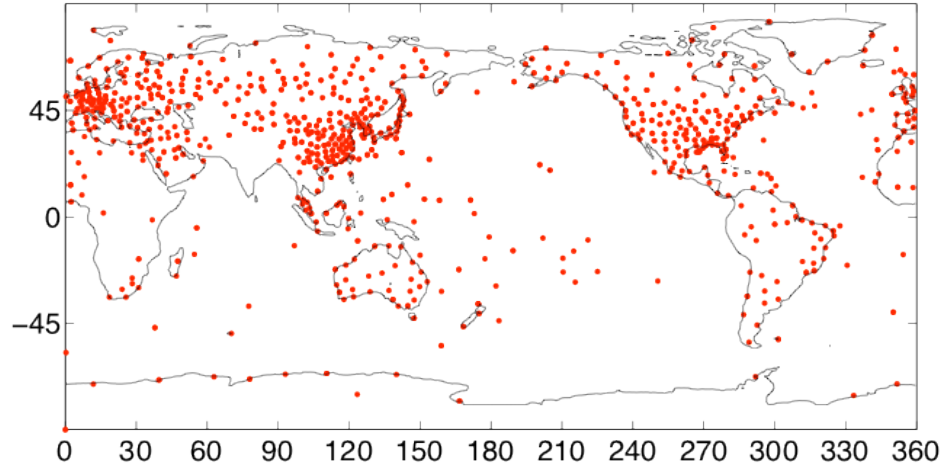
? Can we show enough success with simplified treatments to earn the computer resources to do the (more) complete problems?

? …?

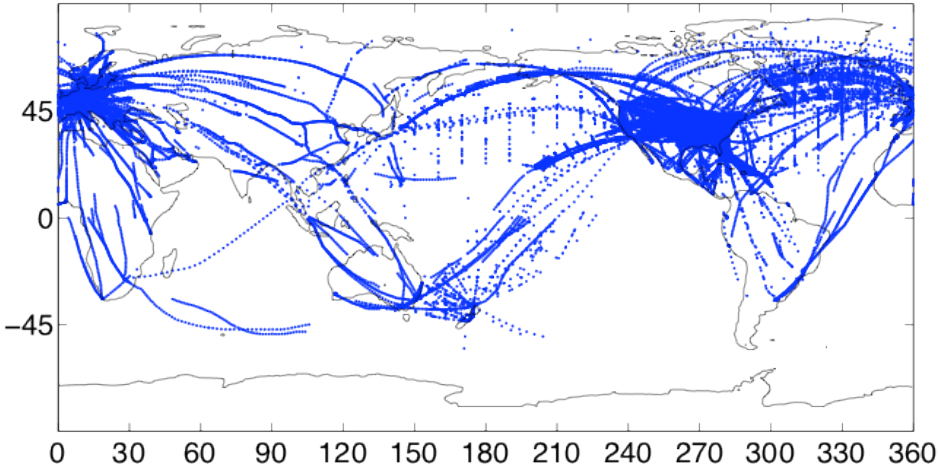
Ensemble data assimilation can facilitate answering these questions and improving WACCM.

Typical daily atmospheric observation set coverages (e.g.)12/6/2006)

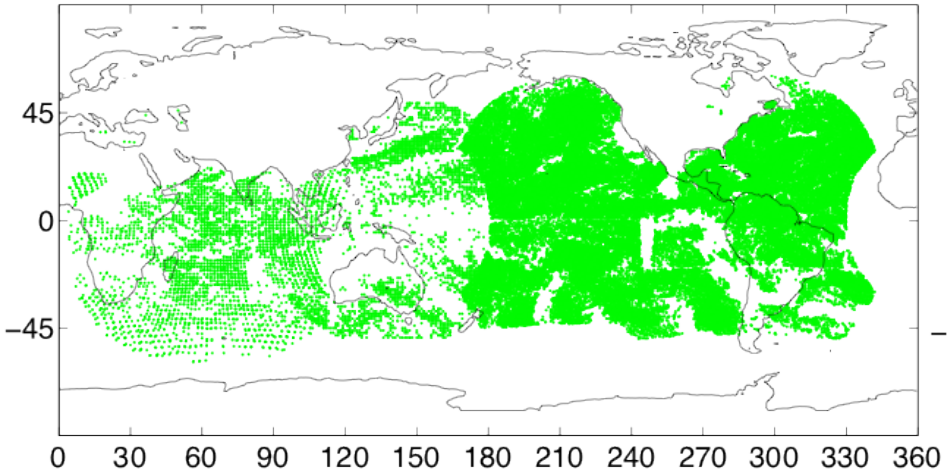
- Radiosonde



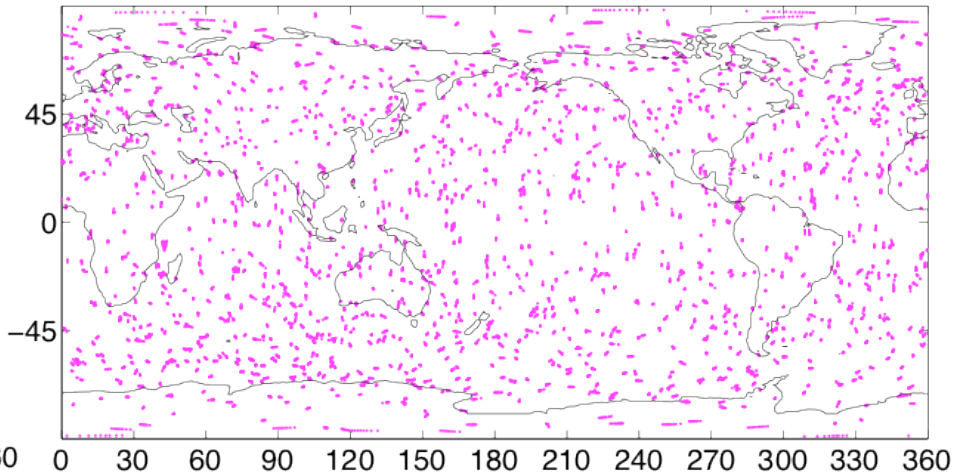
- ACARS/Aircraft



- Satellite drift winds



- GPS radio occultation



Observations of moisture and pressure are also available.

Bias corrected radiance observations will be available by late 2011.

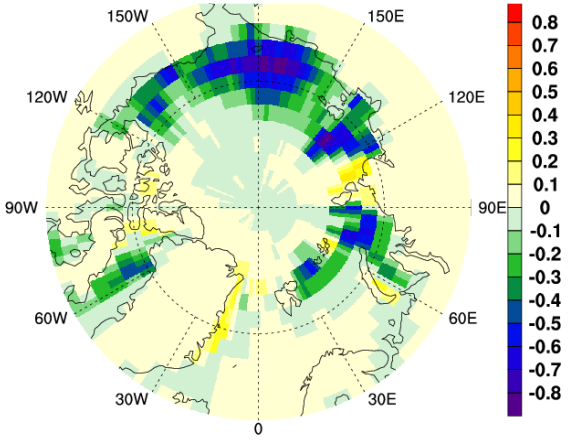
CAM4's cloud response to sea ice loss; July 2006 to 2007

Forecasts started from DART-CAM analyses identified erroneous cloud response to disappearing sea ice.

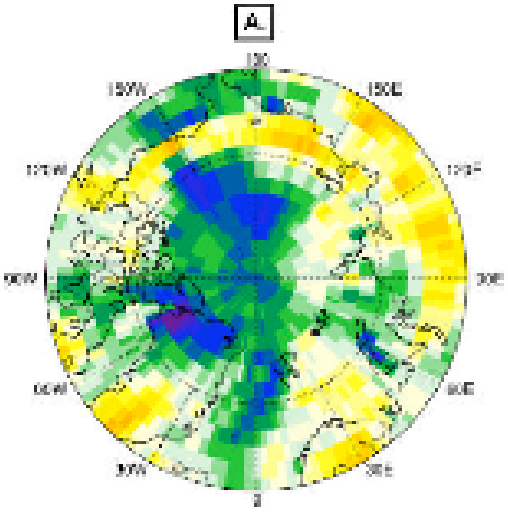
Jen Kay found that low clouds were only diagnosed over open water, not ice, and the low cloud scheme should have required a well mixed boundary layer.

Short forecasts with a climate model from analyses, compared against observations, point to model improvements.

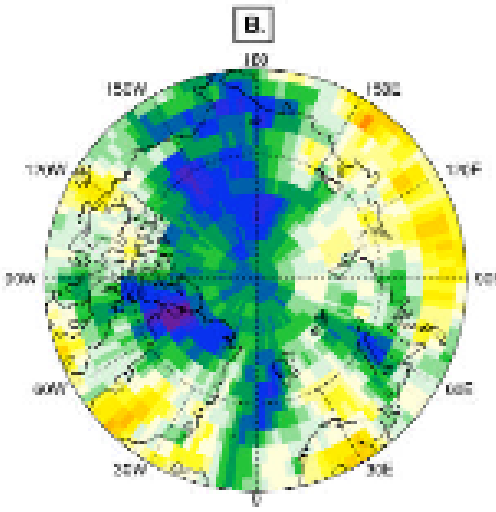
Observed ice fraction loss



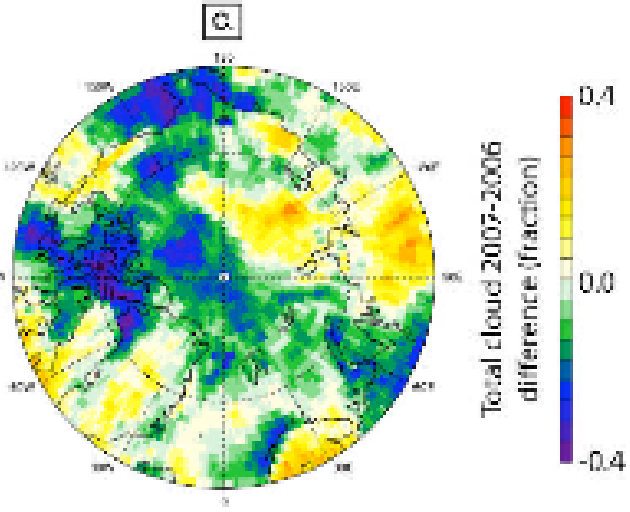
July CAM4 Forecasts



July CAM4 Forecasts with CLDST_MIXBL



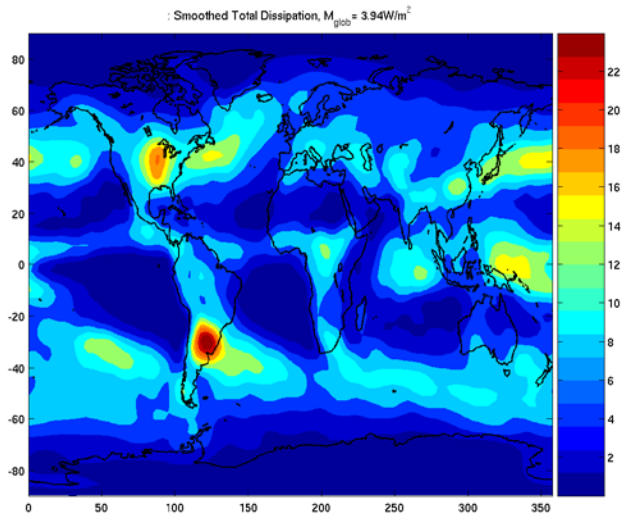
July Observed



Stochastic kinetic-energy backscatter scheme

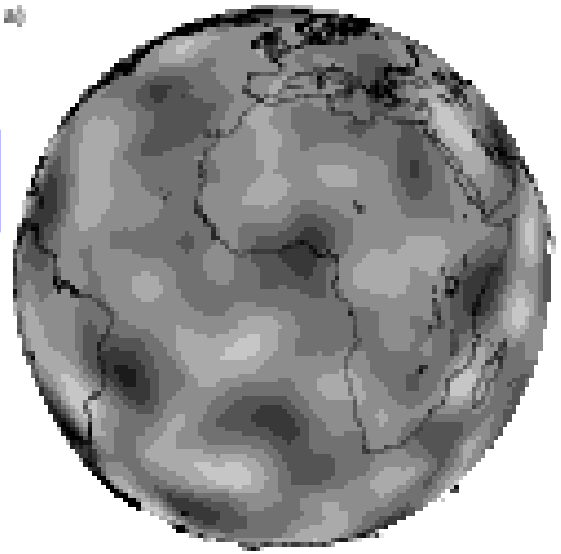
Rationale: A fraction of the dissipated energy is scattered upscale and acts as streamfunction forcing for the resolved-scale flow

$$\Delta\psi^* \propto \sqrt{D}\psi'$$



Total Dissipation rate from numerical dissipation, convection, gravity/mountain wave drag.

ψ'



Spectral Markov chain: temporal and spatial correlations prescribed

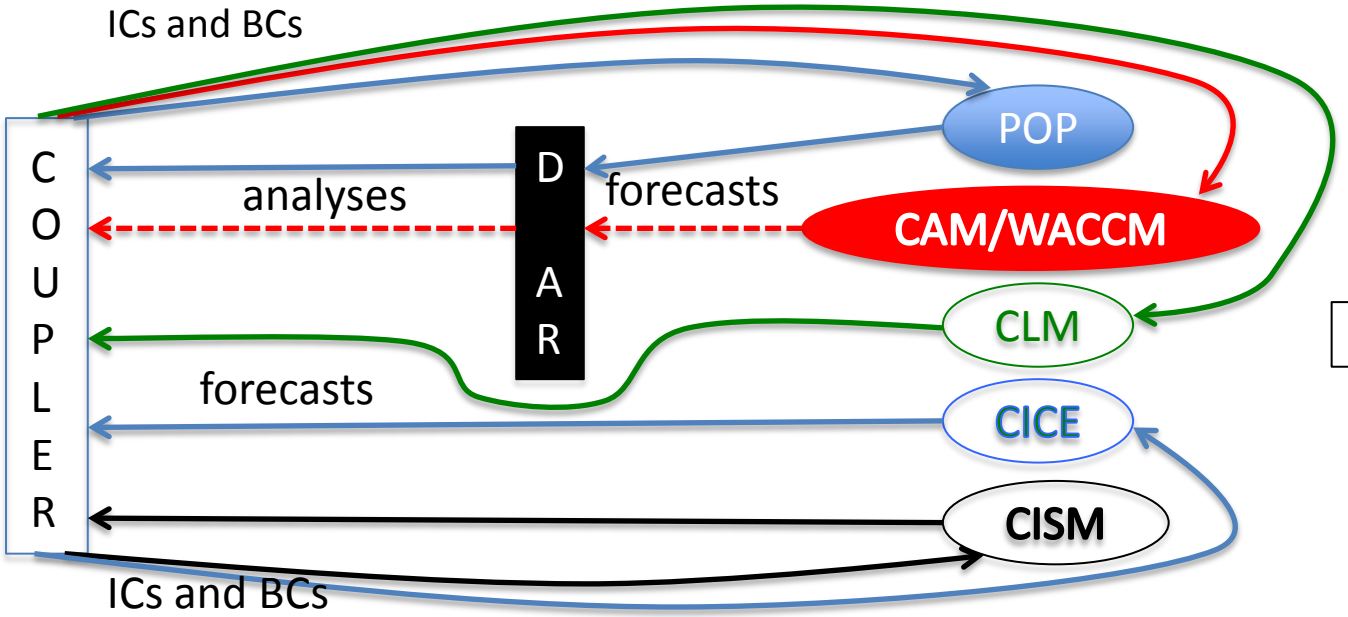
Steps Toward Fully Coupled Assimilation

- ☑ CESM can advance ensemble of ocean states.
- ☑ CESM (POP + data atmosphere) can assimilate ocean observations (minor script changes call a DART script).
- ☐ CESM augmented to enable ensemble forecasts for all components.
- ☐ DART←→component interfaces are needed for CLM4 (talk has started), CICE4, CISM.
- ☐ Investigate using CAM (etc.) restart files, instead of initial files, to communicate with DART.
- ☐ Enable assimilations on thousands of processors, which DART can do, but CAM within DART hasn't been able to *efficiently*.

Fully Coupled Assimilation in CESM

Vertenstein (and Craig?)

- Implement the interactive ensemble manager in CESM for each component which will assimilate observations.



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