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

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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

Hadley + NCEP-OI2 SSTs and ice

Obs used by NCAR-NCEP reanalyses

DART/CAM assimilation system

CESM1 coupler history files: atmospheric forcing

World Ocean Database Observations

DART/POP assimilation system

CAM analyses:
CAM4 initial files; posterior ensemble mean of state variables
prior ensemble mean of all other variables
CLM restart files; prior ensemble mean of all variables
CICE restart files; prior ensemble mean of all variables

POP analyses: temperature, salinity, velocities, surface height

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

POP work by Yeager, Karspeck, Vertenstein
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.
As Buizza (2004) showed, the RMS error grows faster than the spread.

- Ensemble is overconfident.

Attempt to fix with the 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)

CAM4 CAM4+SKEBS Ensemble Spread Temperature (K)

Northern Hemisphere

CAM4

# of obs (o=poss, +=used)

CAM4+SKEBS

Northern Hemisphere

# of obs (o=poss, +=used)

rmse pr=3.5531
rmse po=2.5382
bias pr=0.1175
bias po=0.045987

rmse pr=4.5672
rmse po=2.5724
bias pr=0.019342
bias po=0.05785

01 Jan 2007 03:00:01 through 01 Feb 2007 03:00:00

rmse and bias

02 Jan 2007 03:00:01 through 01 Feb 2007 03:00:00

rmse and bias
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.
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. \( \nabla^4 \) 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.
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. 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?)

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