Results from an Ensemble Reanalysis with the Community Earth System Model 2.0

Kevin Raeder, Jeff Anderson, Tim Hoar, Nancy Collins, Moha El Gharamti
NCAR/CISL Data Assimilation Research Section
1. Evaluate weather prediction capabilities of CAM.
   • Confront climate model with observations.
   • Identify systematic short-term forecast errors.
   • Compare to earlier CAM reanalysis.

2. Provide forcing for CESM component model simulations and reanalyses.
   • POP ocean model.
   • CLM land surface.
   • CICE sea ice model.
   • Offline chemistry transport models.
Model:
• CESM 2.1 release, also used for CMIP 6.
• Atmosphere: CAM6 0.9 degree latitude by 1.2 degree longitude, 32 levels.
• Land: CLM 5.0 BGC-CROP version, same grid as CAM.
• SST and Sea Ice: Specified daily 0.25 degree from AVHRR.
• Aerosols, greenhouse gases, volcanic forcing: from CESM when available.
Reanalysis Quick Facts: Assimilation

Assimilation:
• DART Manhattan.
• 80 members.
• 6-hour window.
• Updated adaptive inflation.
• Tuned parameters for localization, inflation.
Observations assimilated:
• Temperatures and winds from radiosondes, ACARS and aircraft.
• Cloud motion vector winds.
• GPS radio occultation refractivity.
• AIRS temperature retrievals.

Observations evaluated:
• Radiosonde specific humidity.
• AIRS specific humidity retrievals.
• Radiosonde, land and marine altimeter.
Reanalysis Quick Facts: Observations

Sample of observations used in 1 day.
Color contours from DART (20 of 80 ensemble members). Show Uncertainty.

Black from operational NCEP FNL analysis.
An Ensemble Reanalysis with CAM in CESM: Results

Color contours from DART (20 of 80 ensemble members). Show Uncertainty.

Black from operational NCEP FNL analysis.

Agrees with NCEP where well-observed.
An Ensemble Reanalysis with CAM in CESM: Results

Color contours from DART (20 of 80 ensemble members). Show Uncertainty.

Black from operational NCEP FNL analysis.

Yes, tropical heights are really that uncertain!!!
Remote sensing reduces SH uncertainty.

Color contours from DART (20 of 80 ensemble members). Show Uncertainty.

Black from operational NCEP FNL analysis.
An Ensemble Reanalysis with CAM in CESM: Results

Color contours from DART (20 of 80 ensemble members). Show Uncertainty.

Black from operational NCEP FNL analysis.

AGU Dec. 2019
DART/CAM 6 Reanalysis Timeline

CAM4 2 Deg

Completed 2012

01-Jan-1999 01-Jul-2010 01-Jan-2020
DART/CAM 6 Reanalysis Timeline

CAM4 2 Deg
Completed 2012

CAM6 1 Deg
Complete Spring 2020

01-Jan-1999 01-Jul-2010 01-Jan-2020

CAM 6 Phase 1 Supported by NCAR Strategic Capability (NSC)

AGU Dec. 2019
DART/CAM 6 Reanalysis Timeline

CAM4 2 Deg: Completed 2012

CAM6 1 Deg: Complete Spring 2020

CAM6 1 Deg: Expected Spring 2021

CAM 6 Phase 2 Contingent on Additional NCAR Computational Resources
Products You Can Use

Four output products available as they are completed:

1. 80-Member ensemble of CAM6 initial conditions.
2. 80-Member ensemble of forcing files for other CESM components.
3. Comparison of CAM6 6-hour forecasts to observations.
4. Ensemble mean and spread.
1. 80-Member ensemble of CAM6 initial conditions.

Available once per week.

High-quality, 1 degree initial conditions. Members sample initial condition uncertainty (not ad hoc perturbations). Consistent with CAM dynamics, minimize forecast spin-up. Only biases present are from CAM, not another model. Can be down/up-scaled for different resolutions.
2. 80-Member ensemble of forcing files for other CESM components.

Available hourly to daily as appropriate for each variable.

Provide forcing for ensemble simulations or data assimilation.

Can be used directly with CESM coupler to force:
- POP (MOM)
- CLM/CTSM
- CICE

Physically-consistent, realistic, balanced for CESM use.
Realistic ensemble uncertainty consistent with observing network
2. 80-Member ensemble of forcing files for other CESM components.

**Downward longwave heat flux**

20 of 80 members for 00Z 13 Sep 2010

Black is ensemble mean.
2. 80-Member ensemble of forcing files for other CESM components.

Black is ensemble mean.
3. Comparison of CAM6 6-hour forecasts to observations.

Available every 6 hours.

Reveal CAM6 model systematic differences from observations. Short-term systematic errors often related to longer-term. Can focus on specific regions and quantities. Helpful as baseline for new model development.
3. Comparison of CAM6 6-hour forecasts to observations. Example: SH Temperature profiles, September 2010.
3. Comparison of CAM6 6-hour forecasts to observations. Example: SH Temperature profiles, September 2010.
3. Comparison of CAM6 6-hour forecasts to observations. Example: SH Temperature profiles, September 2010.

Northen Hemisphere
AIRS_SPECIFIC_HUMIDITY @ 3.125000e+02 hPa

data file: /Users/raeder/DAI/ATM_forcXX/CAM6_setup/Rean_spinup_2010/Diags_NTrS_2010-09/obs_diag_output.nc

![Graph showing Southern Hemisphere GPSRO_REFRACTIVITY at 8285 m with rmse and totalspread data.

Data file: /Users/raeder/DAI/ATM_forcXX/CAM6_setup/Rean_spinup_2010/Diags_NTrS_2010-09/obs_diag_output.nc]
Atmospheric ensemble reanalysis essential for CLM, CICE, POP DA

Want to do ensemble DA for other CESM components:

• Land, ice and ocean are strongly forced by atmosphere.

• Single deterministic forcing leads to loss of variability.

• Loss of variability is key challenge to ensemble DA.

• Example for CLM ensemble makes this clear.
Initializing carbon cycle predictions from CLM by assimilating biomass and LAI observations

Andrew Fox$^{1,2}$, Tim Hoar$^2$, William Kolby-Smith$^1$, Jeffrey Anderson$^2$ & David Moore$^1$

1. University of Arizona
2. National Center for Atmospheric Research
Single forcing leads to ensemble collapse.
Who’s doing the work?

Kevin Raeder: Overall project lead, keeps everything running (really hard). This has been essentially 24/7 for 6 months so far.

Nancy Collins: Observations, software engineering.

Tim Hoar: Diagnostics, support for forcing other components.

Moha El Gharamti: Improved DART inflation, DART tuning.

Jeff Anderson: Organizational support.

A National Lab with dedicated support staff is really required to do this.
This is a Demanding Computational Task

Phase 1 of CAM6 requires the following resources:

Computation:
• 240 nodes on NCAR’s Cheyenne supercomputer.
• Approximately 18 million core hours.

Storage:
• Forcing files: 18.2 Tb
• Weekly ensemble restarts: 80 Tb
This is a Demanding Computational Task

CAM Reanalysis Completion: Updated 3 Dec. 2019

- Actual Rate
- Required Rate
- Baseline Test
- Baseline Rate

Renalysis Months Completed

Calendar Date

06/01/19 07/01/19 08/01/19 09/01/19 10/01/19 11/01/19 12/01/19

Cheyenne Down for Upgrades

Start of Dedicated Queue

AGU Dec. 2019
What other output would people like?

Periods with more frequent ensemble state output.
• Forcing for off-line chemistry simulations/DA,
• Forcing for simulations/DA of models above troposphere,
• Boundary forcing for regional simulations/DA (WRF, MPAS...),
• Baseline for DA experiments with deeper atmosphere models.

Other diagnostic output???

Contact us at dart@ucar.edu
The wheels are turning, don’t delay.
We would like to acknowledge high-performance computing support from Cheyenne (doi:10.5065/D6RX99HX) provided by NCAR's Computational and Information Systems Laboratory, sponsored by the National Science Foundation.
An Ensemble Reanalysis with CAM in CESM: Results

That’s hurricane Earl (2010).
Even at 1 degree, CAM6 provides good position.
A bit weak but still a hurricane.
DART/CESM Assimilation

DART Multiple Component Data Assimilation

Important! There are *multiple* instances of each model component.

DART assimilates observations into components separately

Coupler moves the components to the next time step

Started with CCSM4 20th Century 30-member ensemble for all model components