Results from an Ensemble Reanalysis with the Community Earth System Model 2.1
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Motivation for an Ensemble Reanalysis with CAM

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.
Reanalysis Quick Facts: Model

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 Coverage: Specified daily 0.25 degree from AVHRR.
- Sea Ice Thickness from CICE model.
- Aerosols, greenhouse gases, volcanic forcing: from CESM when available.
Assimilation:
• DART Manhattan.
• 80 members.
• 6-hour window.
• Updated adaptive inflation.
• Tuned parameters for localization, inflation.
Reanalysis Quick Facts: Observations

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.
Sample of observations used in 1 day; more than 450,000 for this date.
Color contours from DART: Ensemble members (20 of 80) show Uncertainty. Black from operational NCEP FNL analysis.
An Ensemble Reanalysis with CAM in CESM: Results

Color contours from DART: Ensemble members (20 of 80) show Uncertainty. Black from operational NCEP FNL analysis.

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

Yes, tropical heights are really that uncertain!!!

Color contours from DART: Ensemble members (20 of 80) show Uncertainty. Black from operational NCEP FNL analysis.
Remote sensing reduces SH uncertainty.

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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 Apr.

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

CAM 6 Phase 1 Supported by NCAR Strategic Capability (NSC)
DART/CAM 6 Reanalysis Timeline

- CAM4 2 Deg: Completed 2012
- CAM6 1 Deg: Complete Apr.
- 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.

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

Direct visible incident solar radiation

20 of 80 members for 00Z 13 Sep 2010

W m$^{-2}$

CONTOUR FROM 150 TO 150 BY 0

Black is ensemble mean.

AMS Jan. 2020
2. 80-Member ensemble of forcing files for other CESM components.
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.
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Example: SH Temperature profiles, September 2010.

![Graph showing comparison of CAM6 forecasts to observations with rmse and bias values.]
3. Comparison of CAM6 6-hour forecasts to observations. Example: SH Temperature profiles, September 2010.

Northern Hemisphere
AIRS_SPECIFIC_HUMIDITY @ 3.125000e+02 hPa

- rmse $pr = 0.11745$
- totalspread $pr = 0.13827$

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

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1. University of Arizona
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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.

All: Product evaluation and quality monitoring.

A National Lab with dedicated support staff is really required to do this.
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
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.
For more information:

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