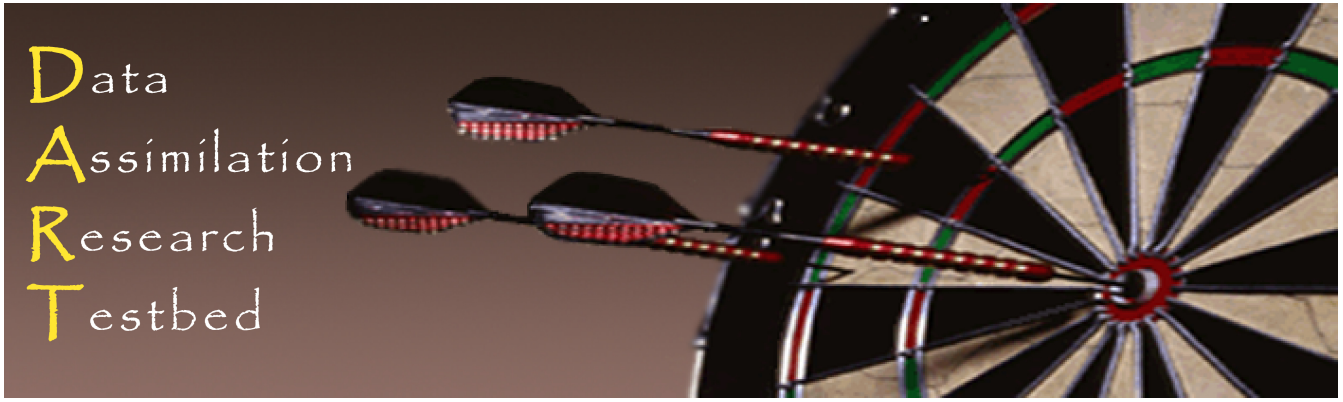
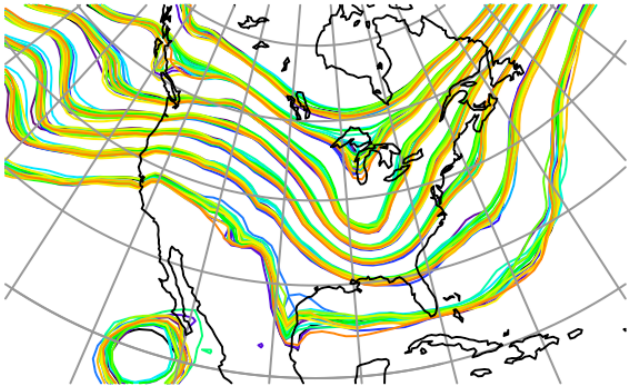


Results from an Ensemble Reanalysis with the Community Earth System Model 2.1

Kevin Raeder, Jeff Anderson, Tim Hoar, Nancy Collins, Moha El Gharamti
NCAR/CISL Data Assimilation Research Section



The National Center for Atmospheric Research is sponsored by the National Science Foundation. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

NCAR | National Center for
UCAR | Atmospheric Research

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.

Reanalysis Quick Facts: Assimilation

Assimilation:

- DART Manhattan.
- 80 members.
- 6-hour window.
- Updated adaptive inflation.
- Tuned parameters for localization, inflation.

Reanalysis Quick Facts: Observations

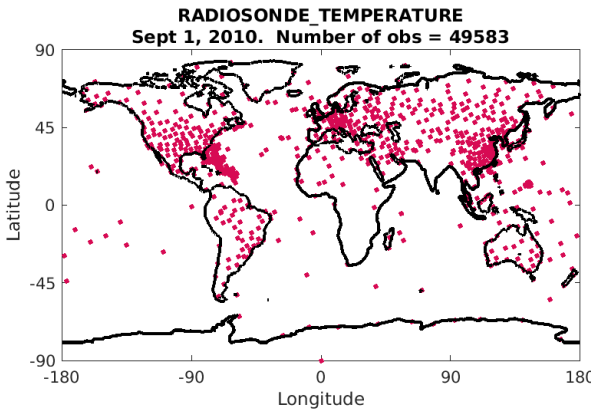
Observations assimilated:

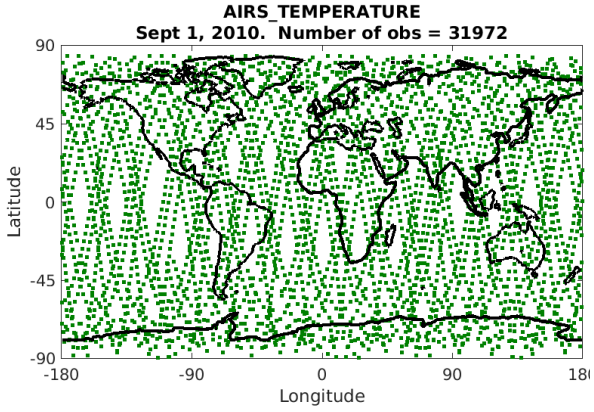
- Temperatures and winds from radiosondes, ACARS and aircraft.
- Cloud motion vector winds.
- GPS radio occultation refractivity.
- AIRS temperature retrievals.

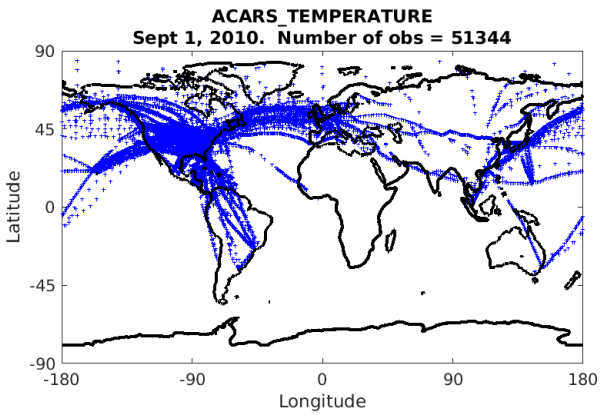
Observations evaluated:

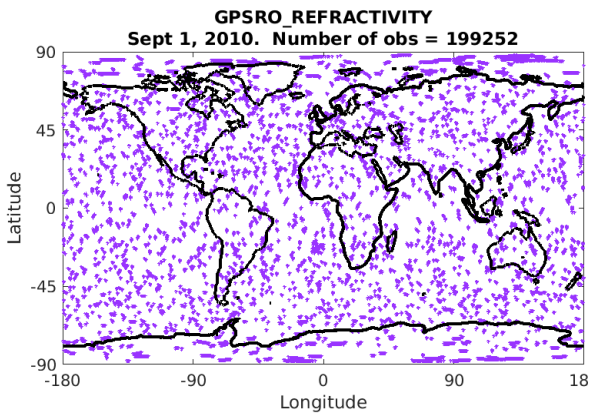
- Radiosonde specific humidity.
- AIRS specific humidity retrievals.
- Radiosonde, land and marine altimeter.

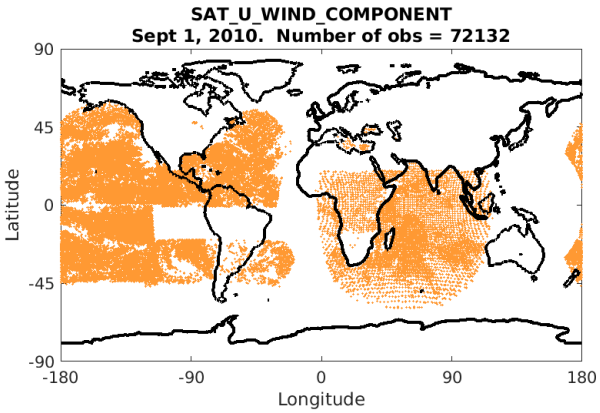
Reanalysis Quick Facts: Observations

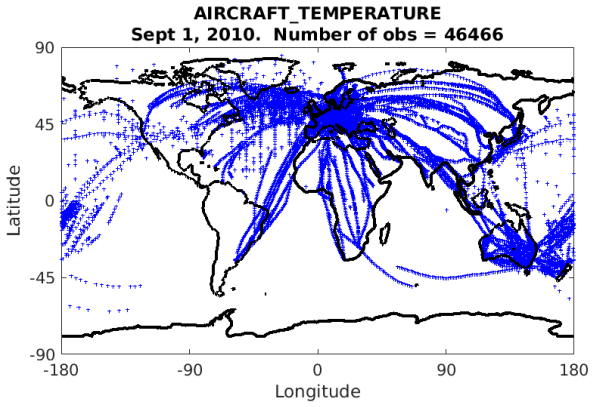






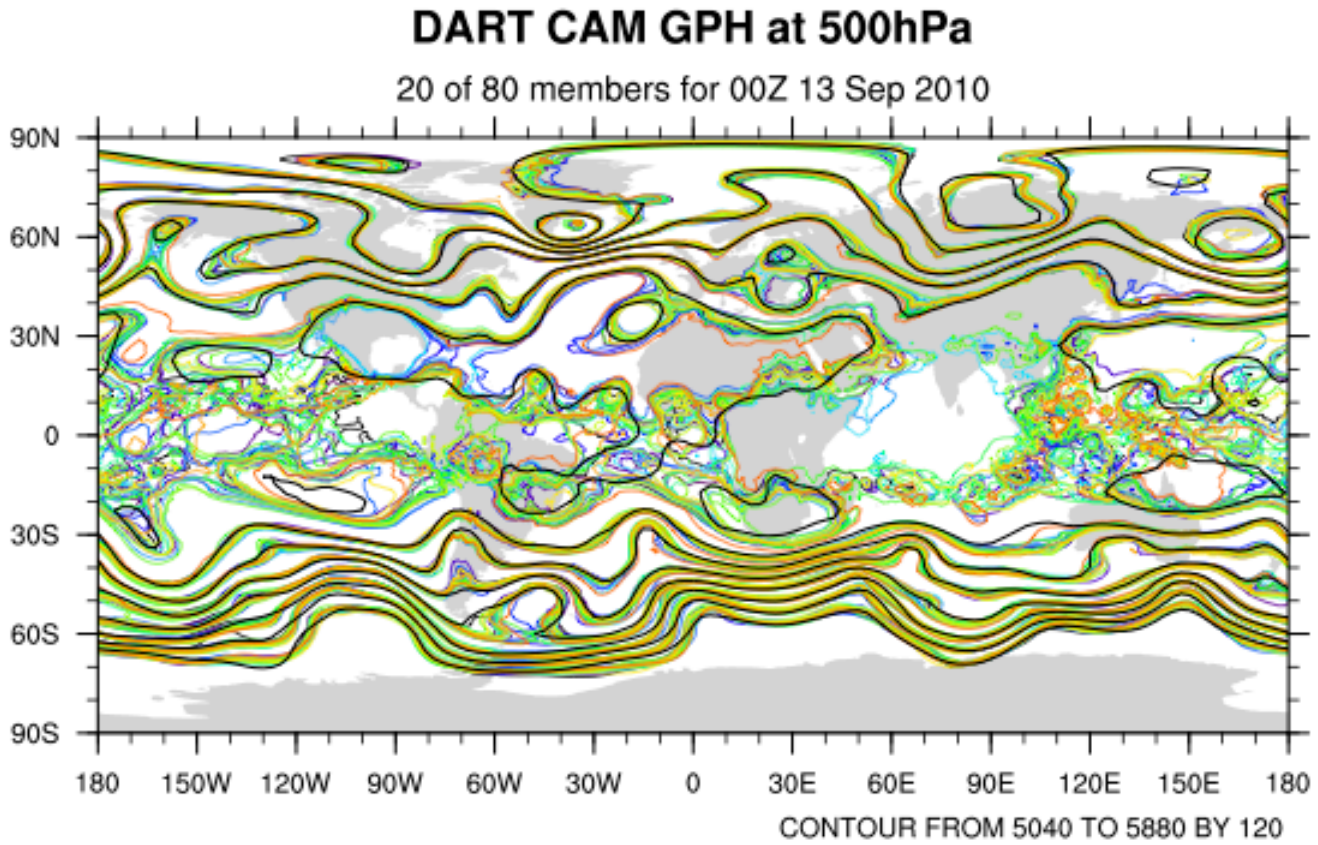






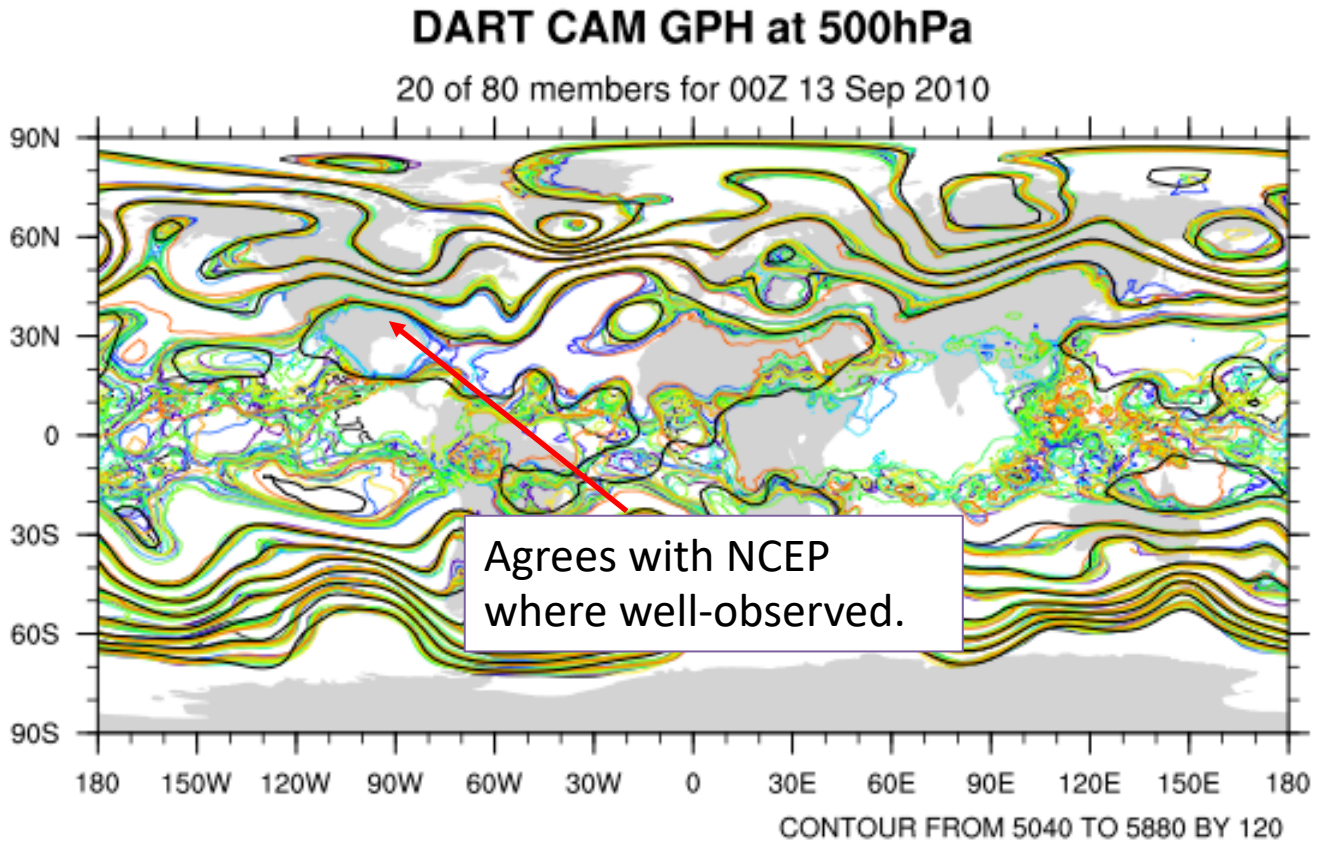
Sample of observations used in 1 day; more than 450,000 for this date.

An Ensemble Reanalysis with CAM in CESM: Results



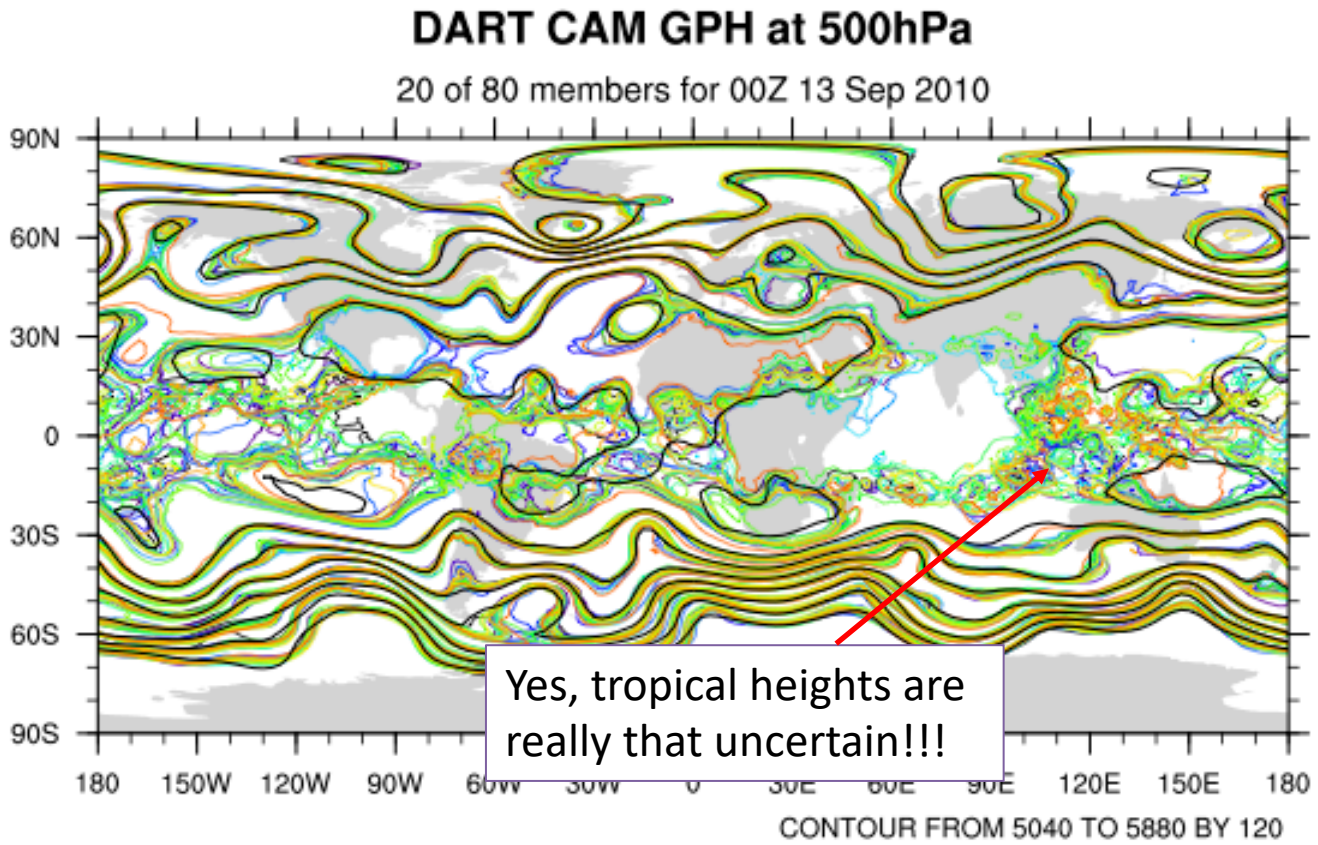
Color contours from DART: Ensemble members (20 of 80) show Uncertainty. Black from operational NCEP FNL analysis.

An Ensemble Reanalysis with CAM in CESM: Results



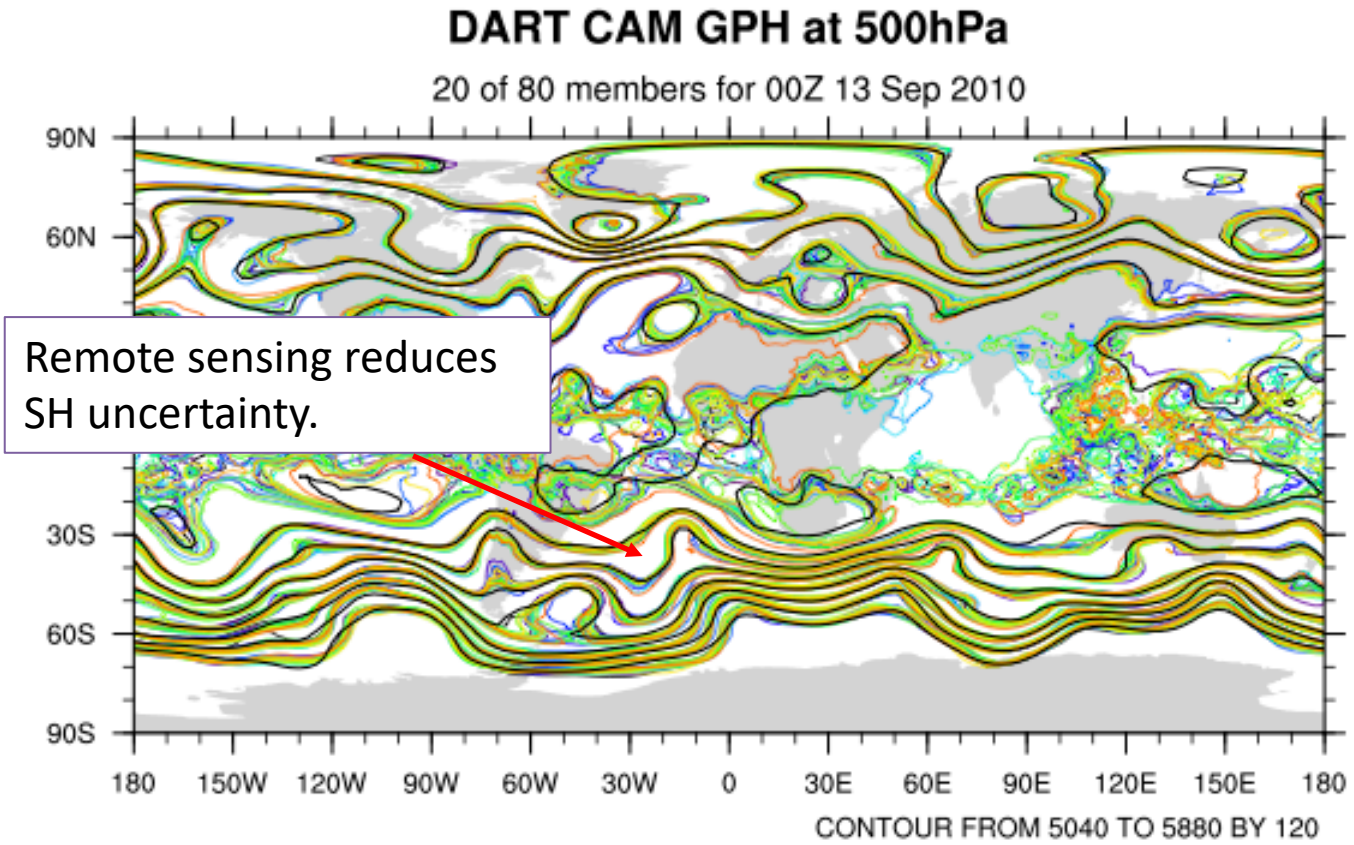
Color contours from DART: Ensemble members (20 of 80) show Uncertainty.
Black from operational NCEP FNL analysis.

An Ensemble Reanalysis with CAM in CESM: Results



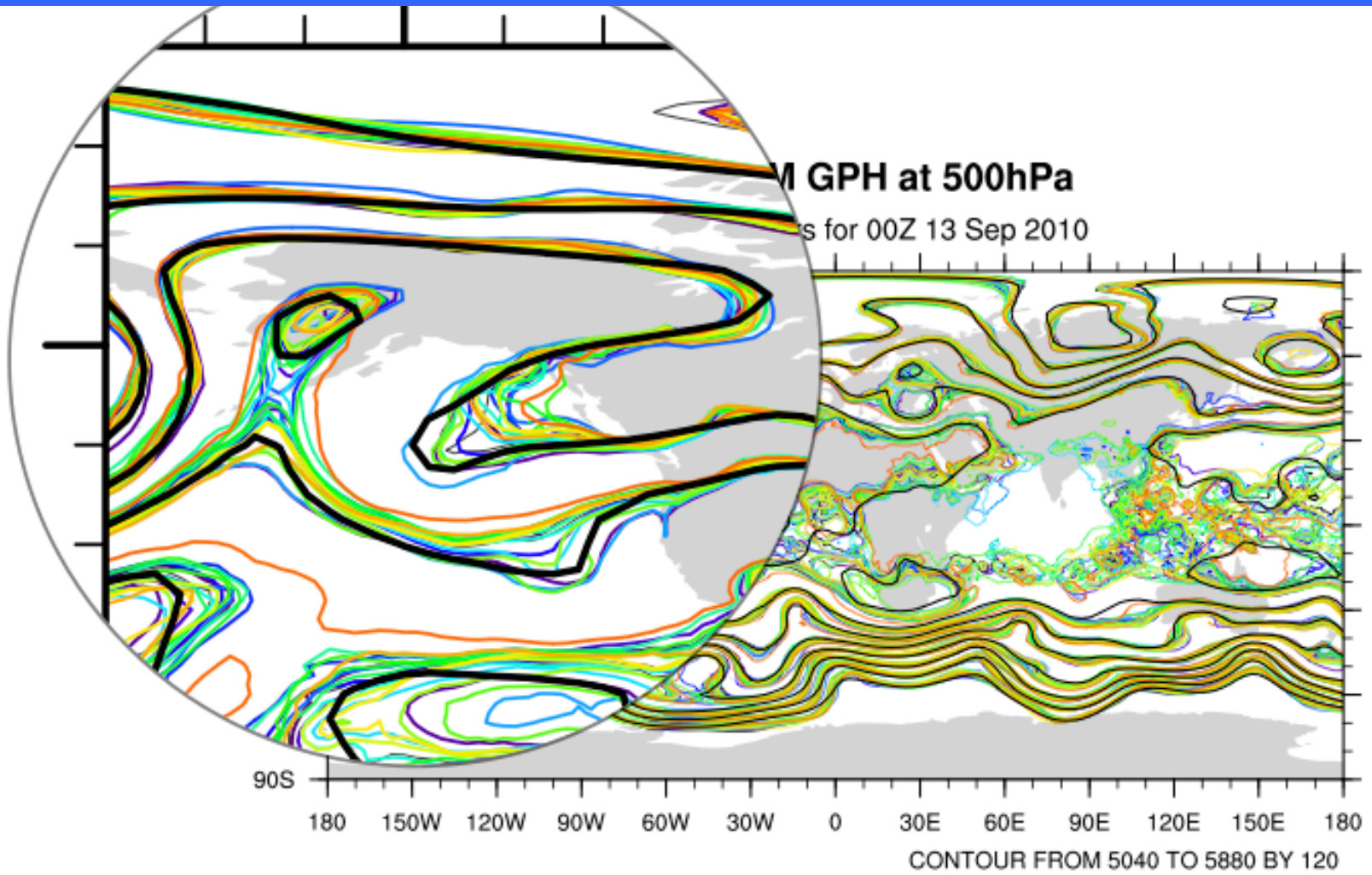
Color contours from DART: Ensemble members (20 of 80) show Uncertainty. Black from operational NCEP FNL analysis.

An Ensemble Reanalysis with CAM in CESM: Results



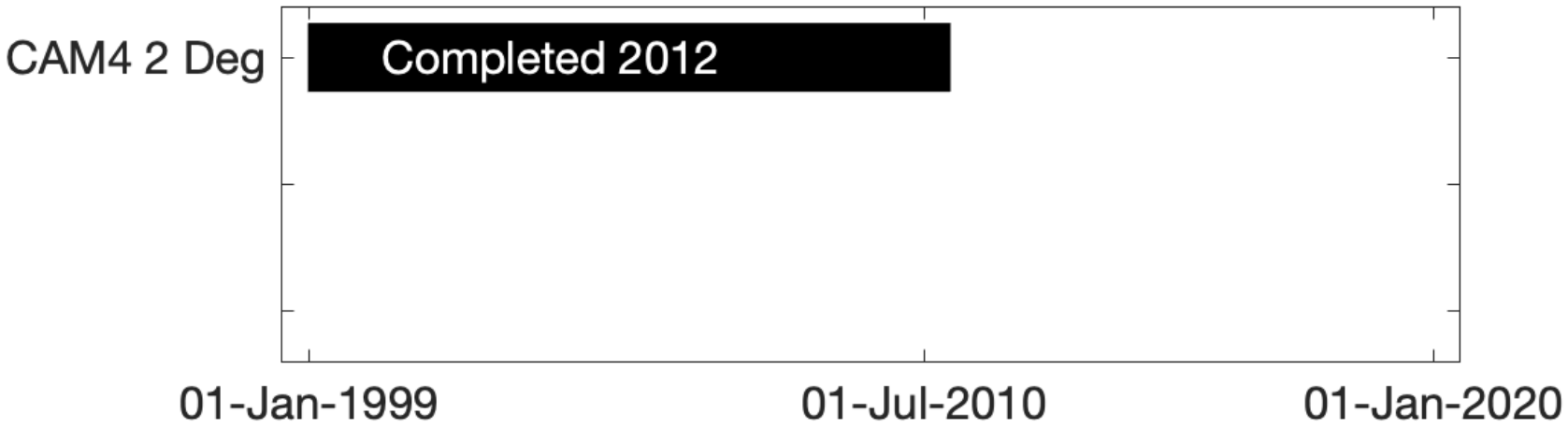
Color contours from DART: Ensemble members (20 of 80) show Uncertainty. Black from operational NCEP FNL analysis.

An Ensemble Reanalysis with CAM in CESM: Results

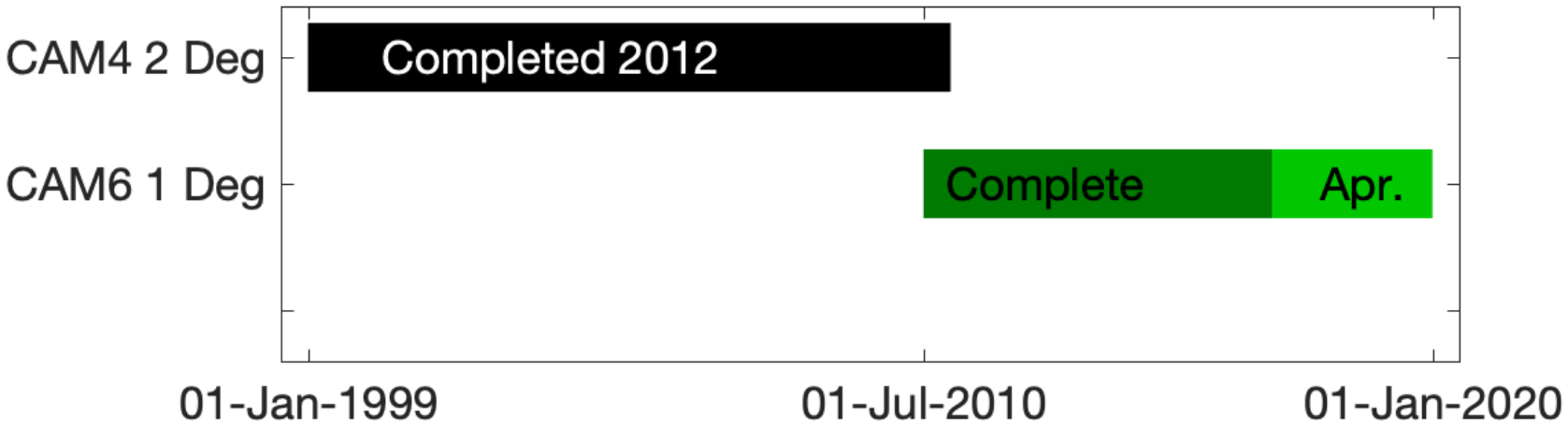


Color contours from DART: Ensemble members (20 of 80) show Uncertainty.
Black from operational NCEP FNL analysis.

DART/CAM 6 Reanalysis Timeline

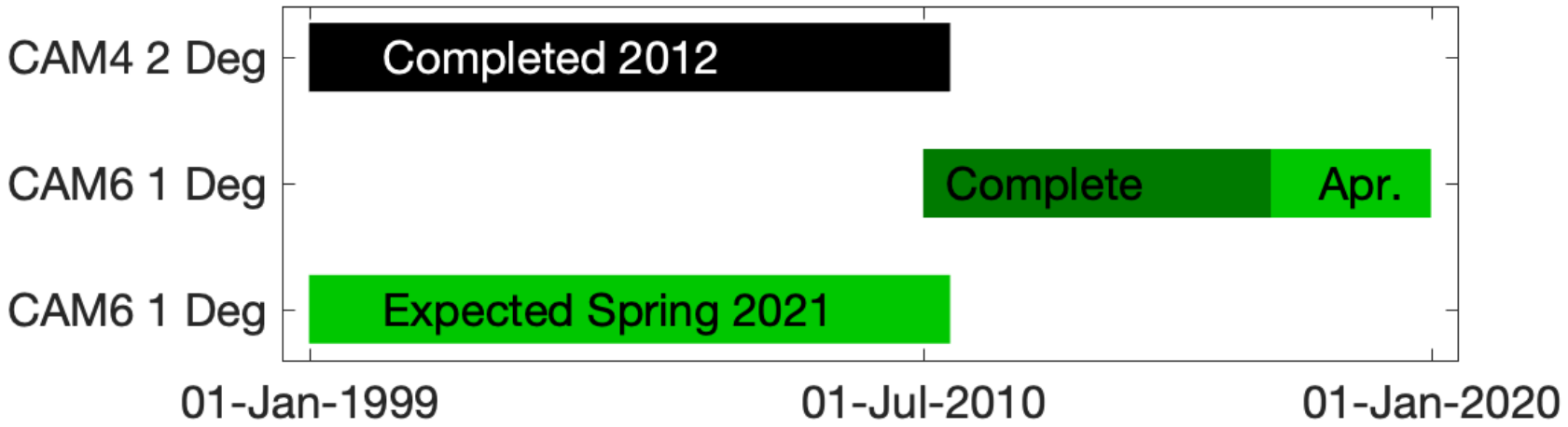


DART/CAM 6 Reanalysis Timeline



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

DART/CAM 6 Reanalysis Timeline

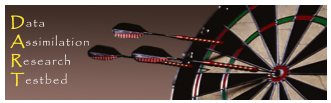


CAM 6 Phase 2 Contingent on Additional NCAR Computational Resources

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.

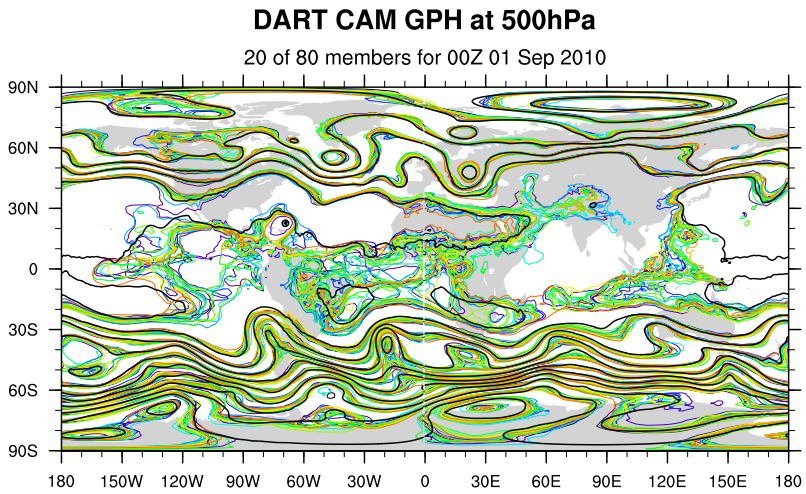


Products You Can Use

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.



Products You Can Use

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.

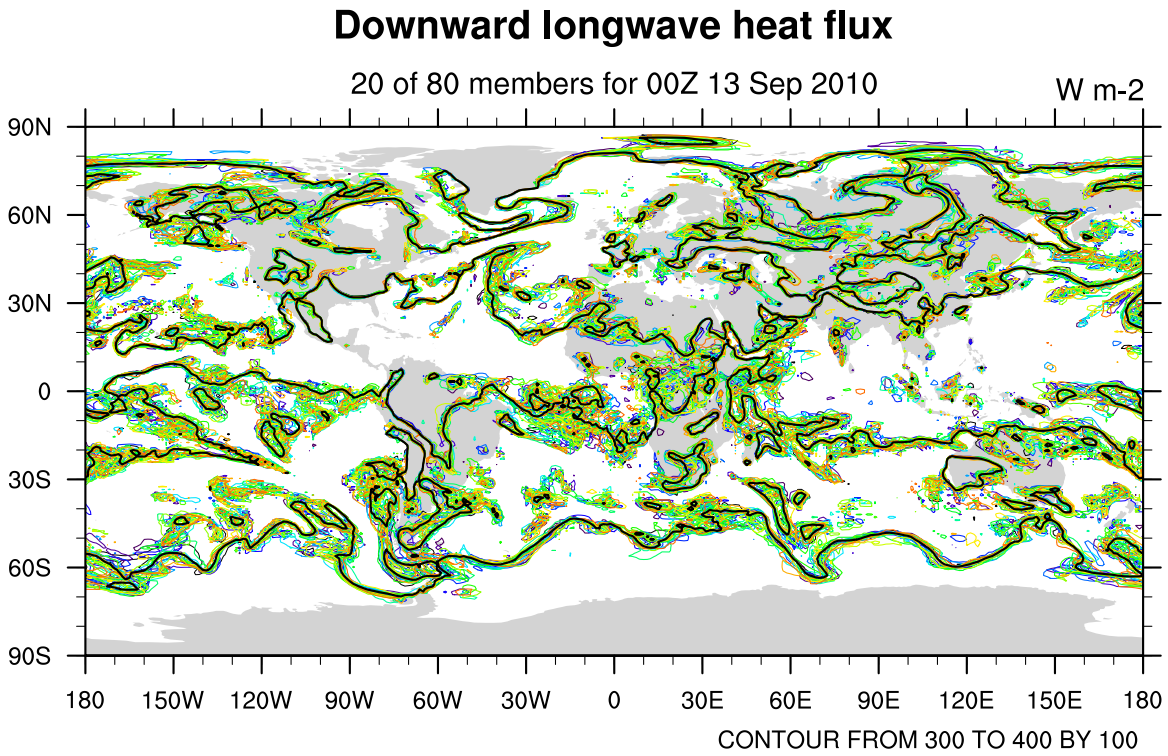
Can be used directly with CESM coupler to force:

- POP (MOM)
- CLM/CTSM
- CICE

Physically-consistent, realistic, balanced for CESM use.
Realistic ensemble uncertainty consistent with observing network.

Products You Can Use

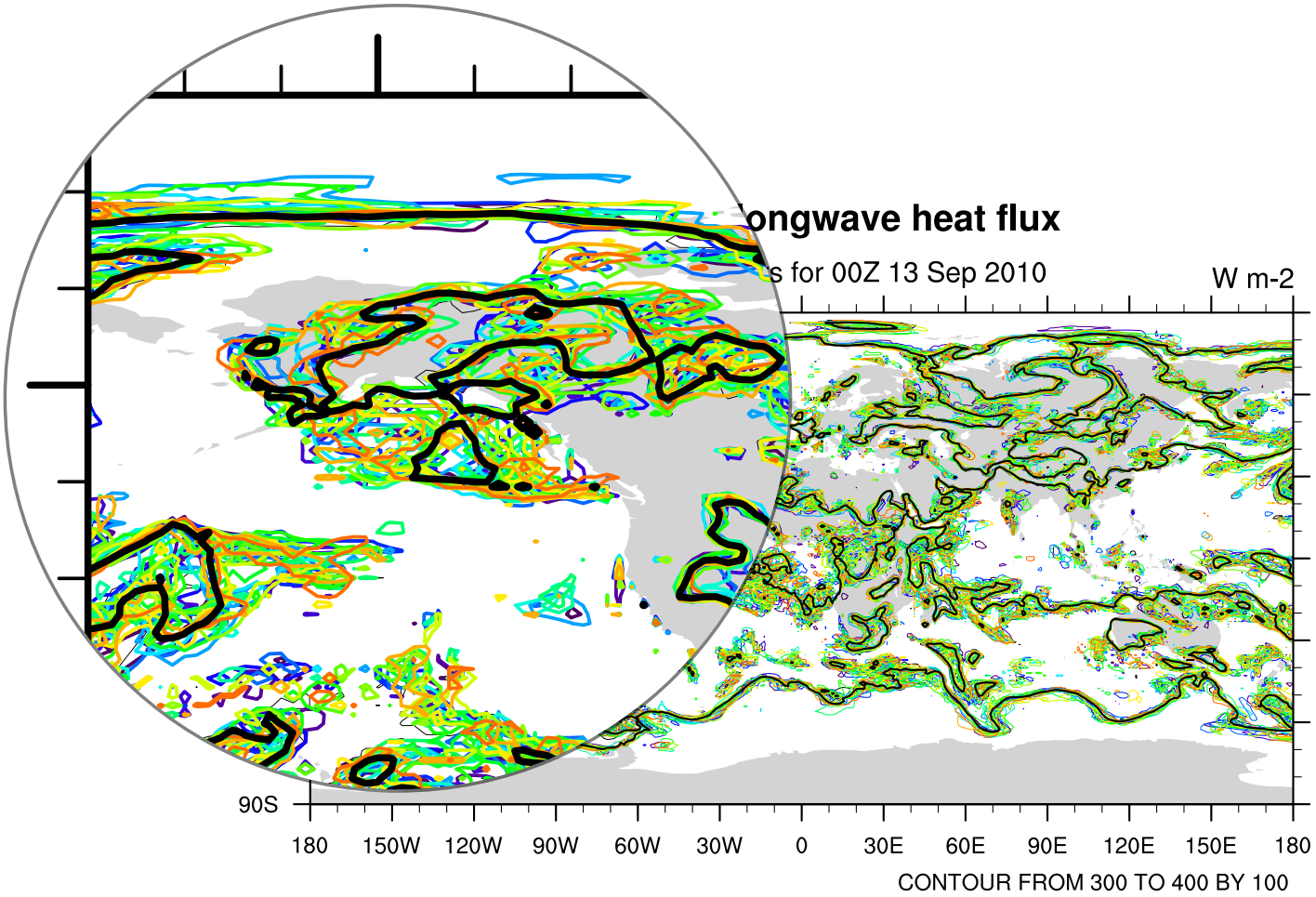
2. 80-Member ensemble of forcing files for other CESM components.



Black is ensemble mean.

Products You Can Use

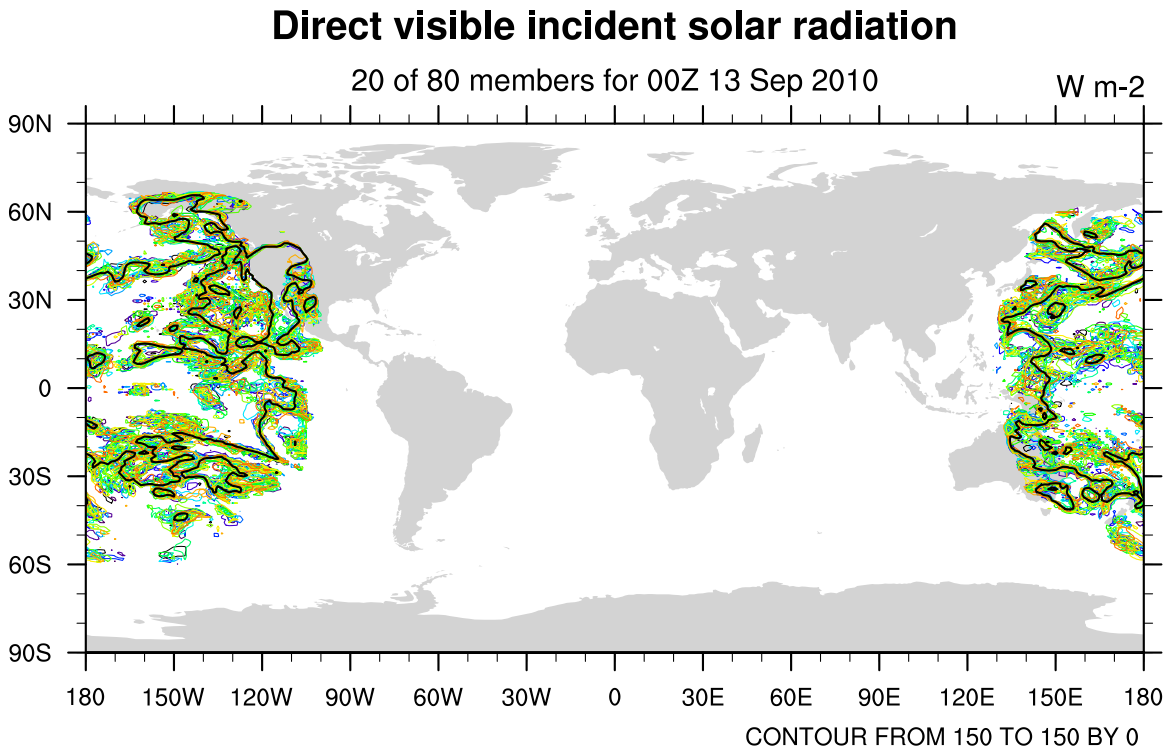
2. 80-Member ensemble of forcing files for other CESM components.



Black is ensemble mean.

Products You Can Use

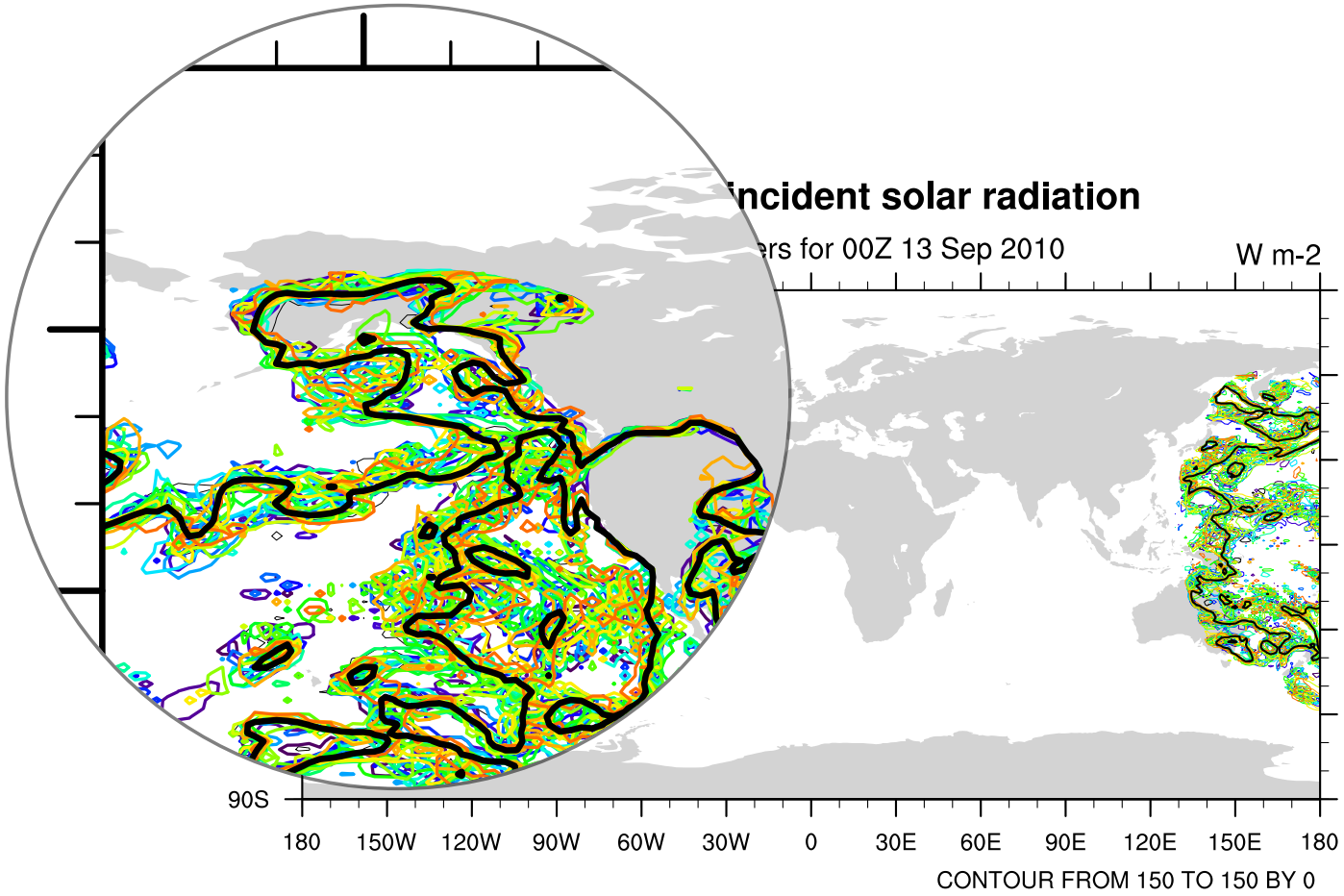
2. 80-Member ensemble of forcing files for other CESM components.



Black is ensemble mean.

Products You Can Use

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



Black is ensemble mean.

Products You Can Use

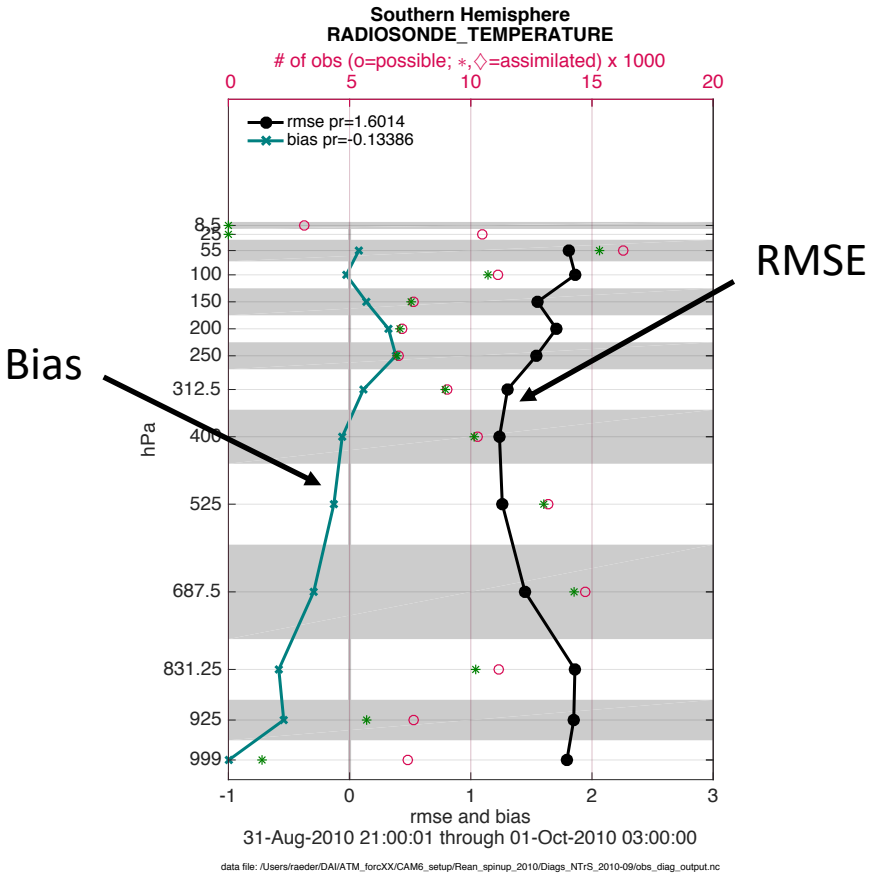
3. Comparison of CAM6 6-hour forecasts to observations.

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.

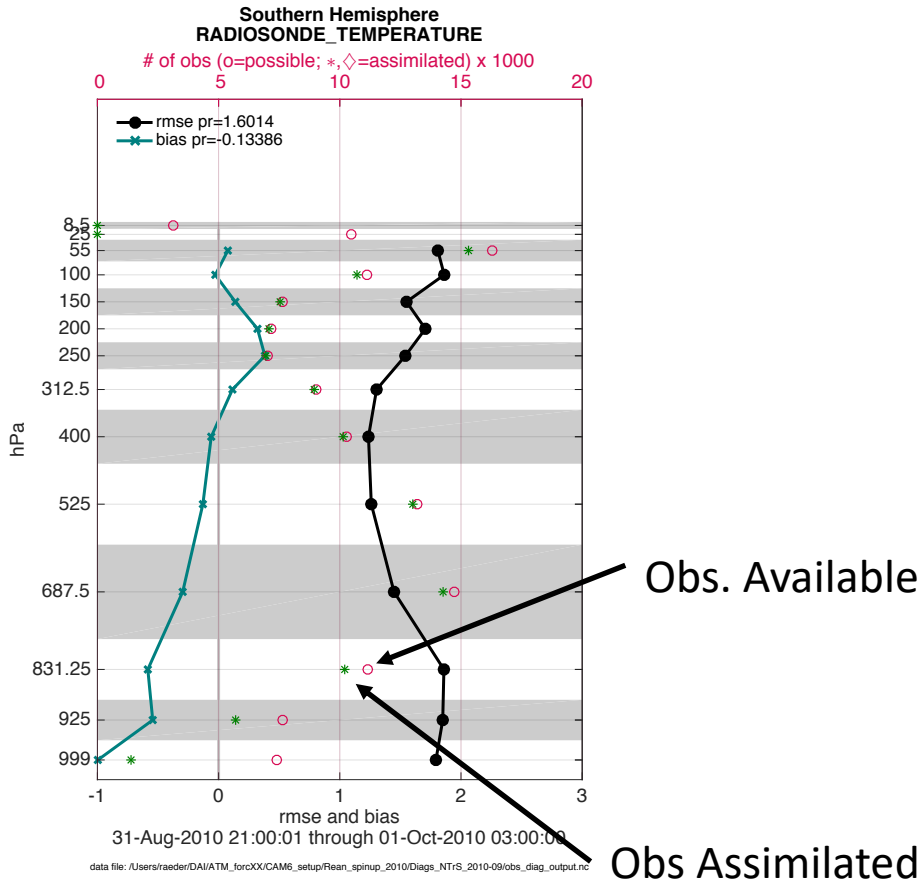
Products You Can Use

3. Comparison of CAM6 6-hour forecasts to observations.
   Example: SH Temperature profiles, September 2010.



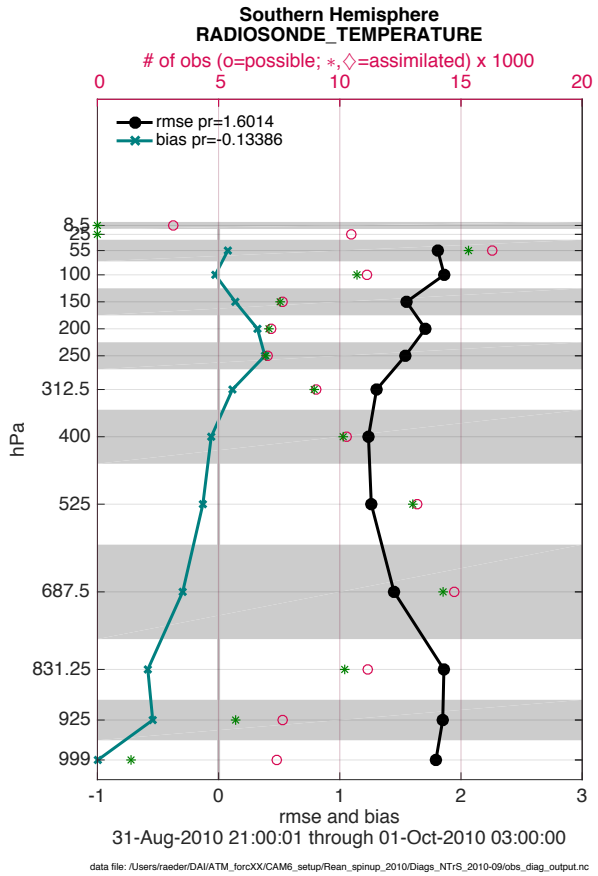
Products You Can Use

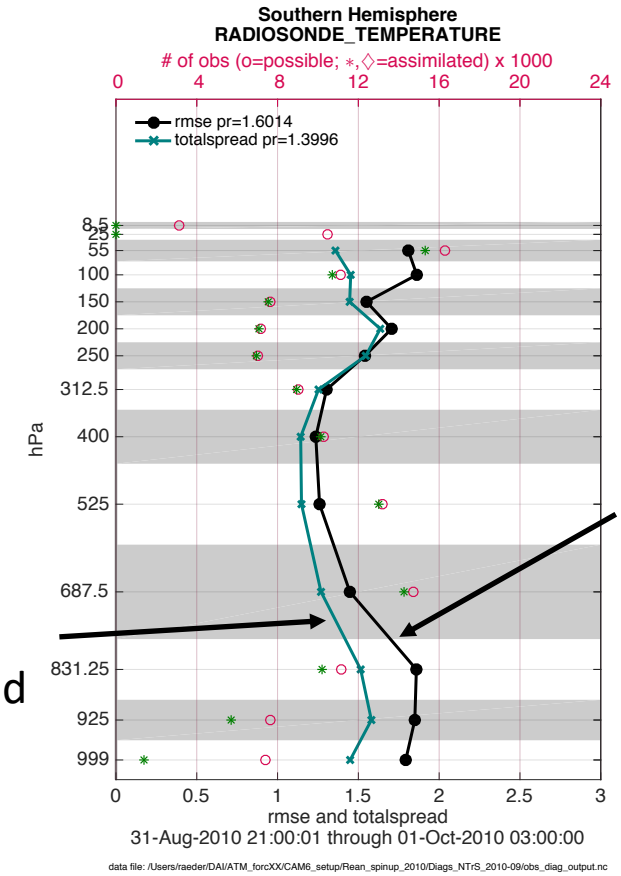
3. Comparison of CAM6 6-hour forecasts to observations.
   Example: SH Temperature profiles, September 2010.



Products You Can Use

3. Comparison of CAM6 6-hour forecasts to observations.
   Example: SH Temperature profiles, September 2010.



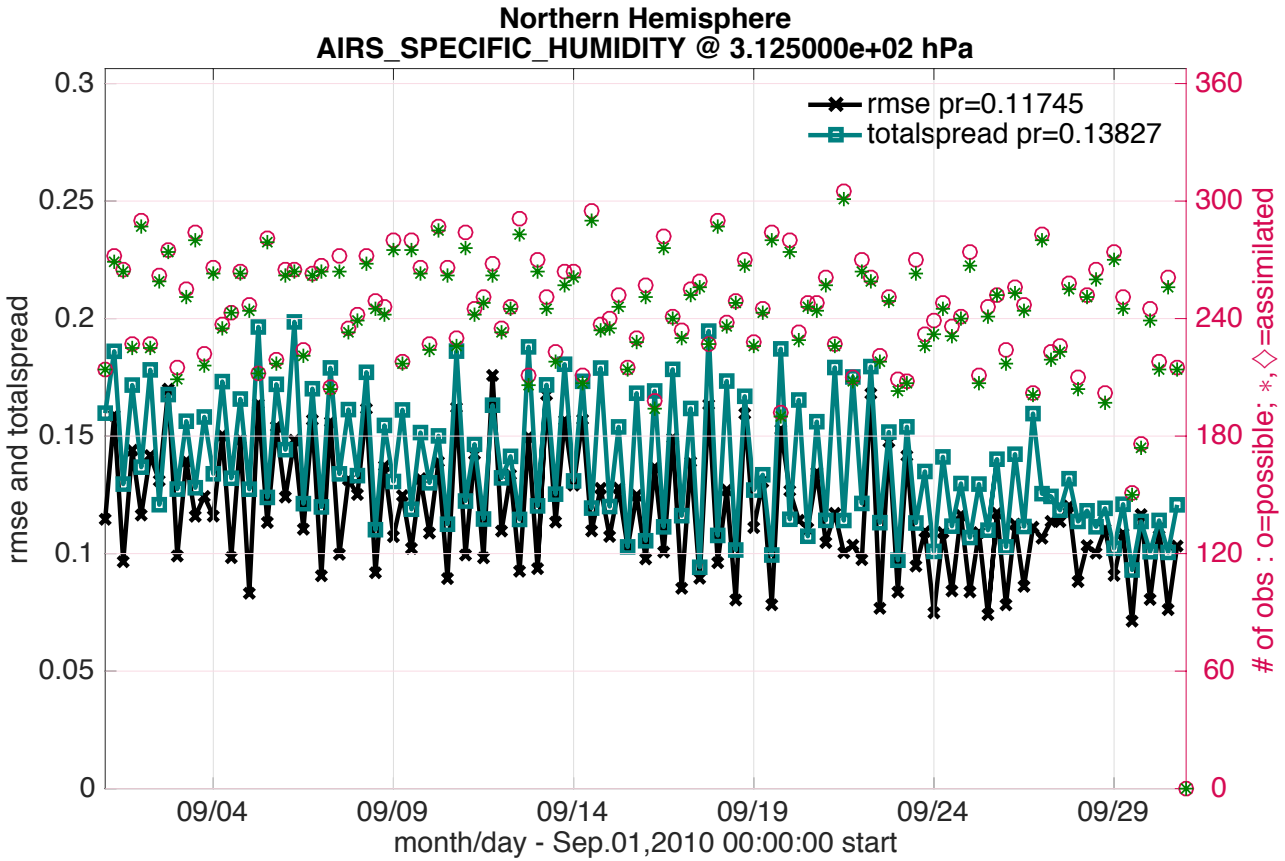


Total Spread

RMSE

Products You Can Use

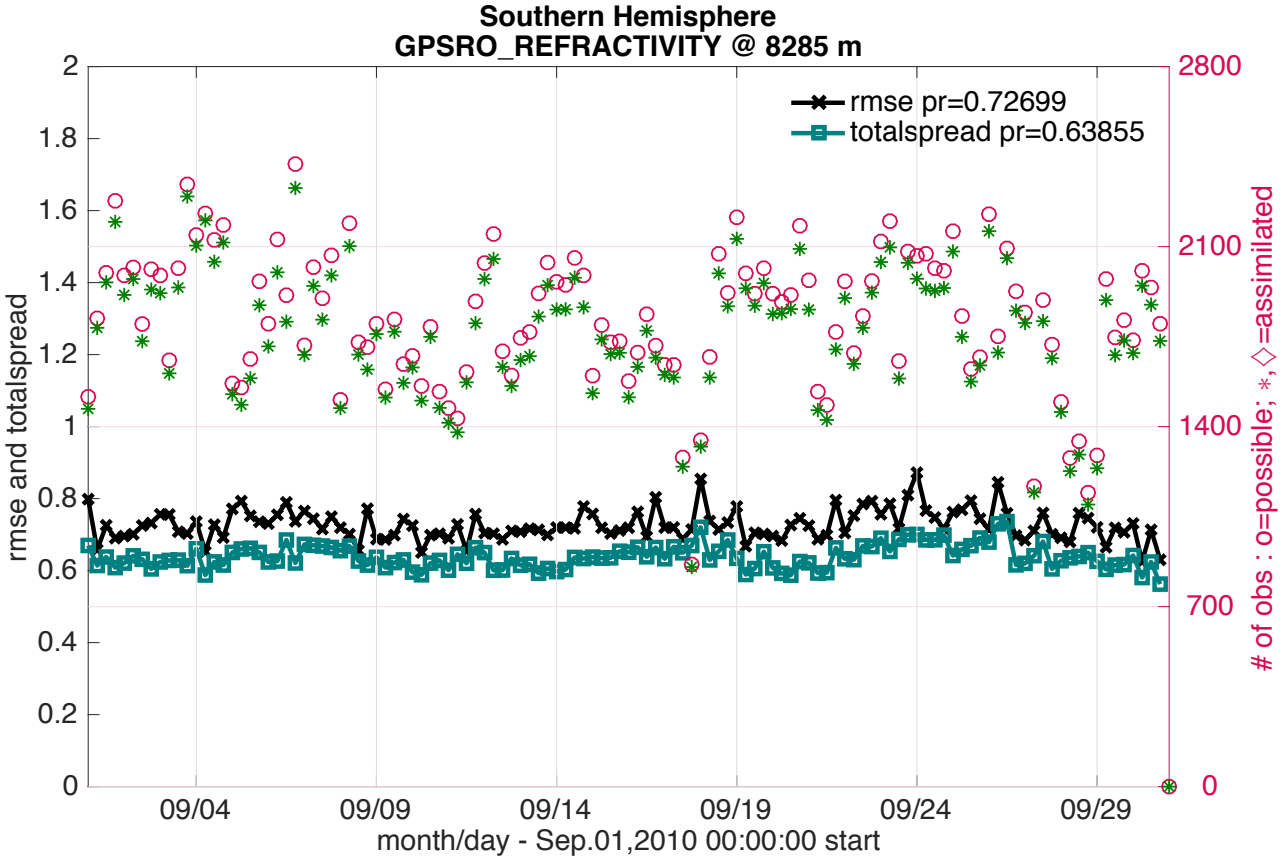
3. Comparison of CAM6 6-hour forecasts to observations.
   Example: NH AIRS Spec. Humidity, upper troposphere, Sept. 2010.



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

Products You Can Use

3. Comparison of CAM6 6-hour forecasts to observations.
   Example: SH GPS RO, upper troposphere, Sept. 2010.



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]

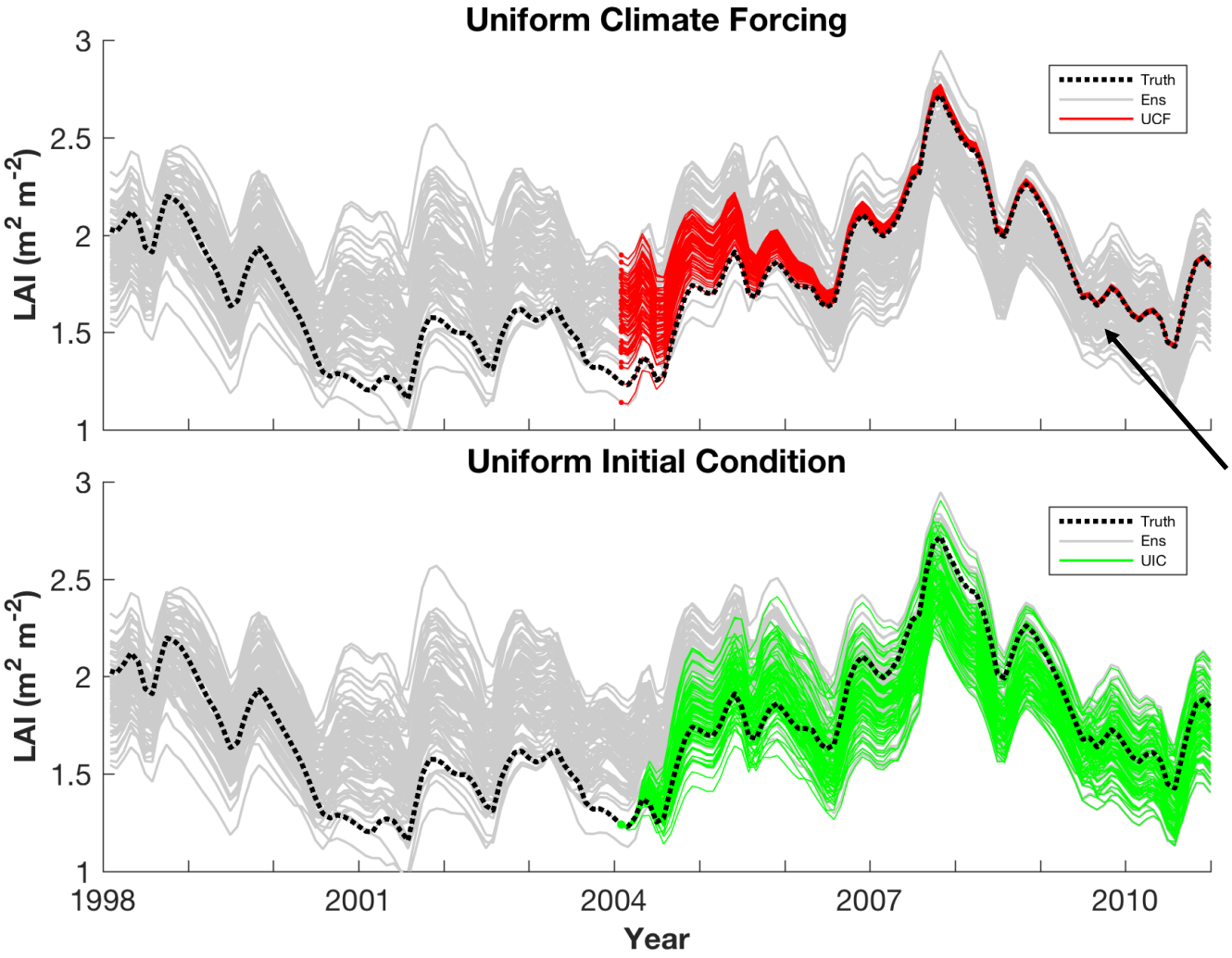
1. University of Arizona
2. National Center for Atmospheric Research

U.S. DEPARTMENT OF ENERGY | Office of Science

This work is funded by DOE **Regional and Global Climate Modeling DE-SC0016011**

Uniform Climate Forcing v. Initial Conditions

Ensemble Integrations of CLM 4.5.



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.

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

TIME CRITICAL REQUEST

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.

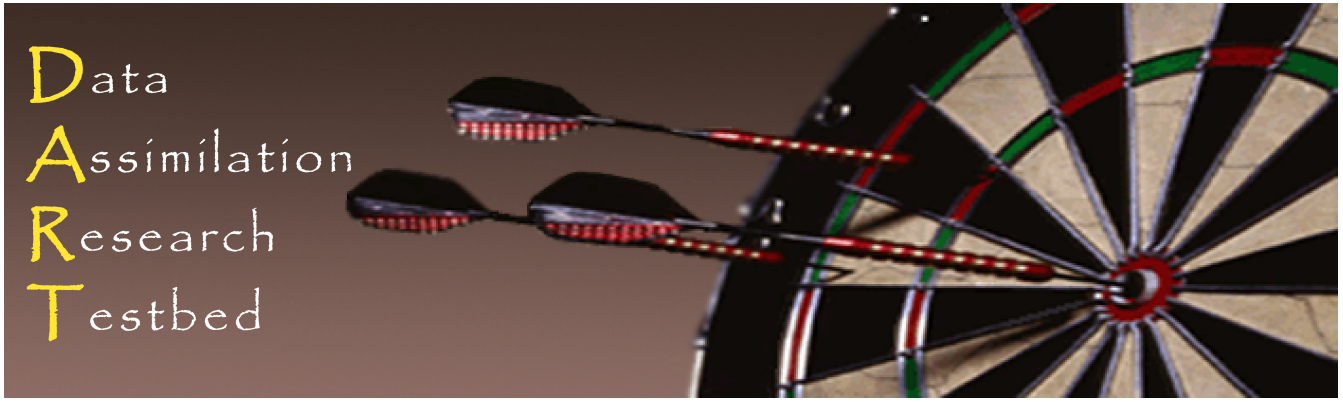
Other diagnostic output???

Contact us at dart@ucar.edu

The wheels are turning, don't delay.

For more information:

CAM GCOM CAM-Chem PBL_1d ROMS NOAH-MP
GITM WRF-Hydro CICE WACCM
CLM
AM2
SQG
POP
BGRID
COAMPS
WRF
MITgcm_ocean
MPAS_ATM
WACCM-X
NCOMMAS
MPAS_OCN
TIEGCM
COAMPS_nest
WRF-Chem
NAAPS
PE2LYR
CABLE
CM1



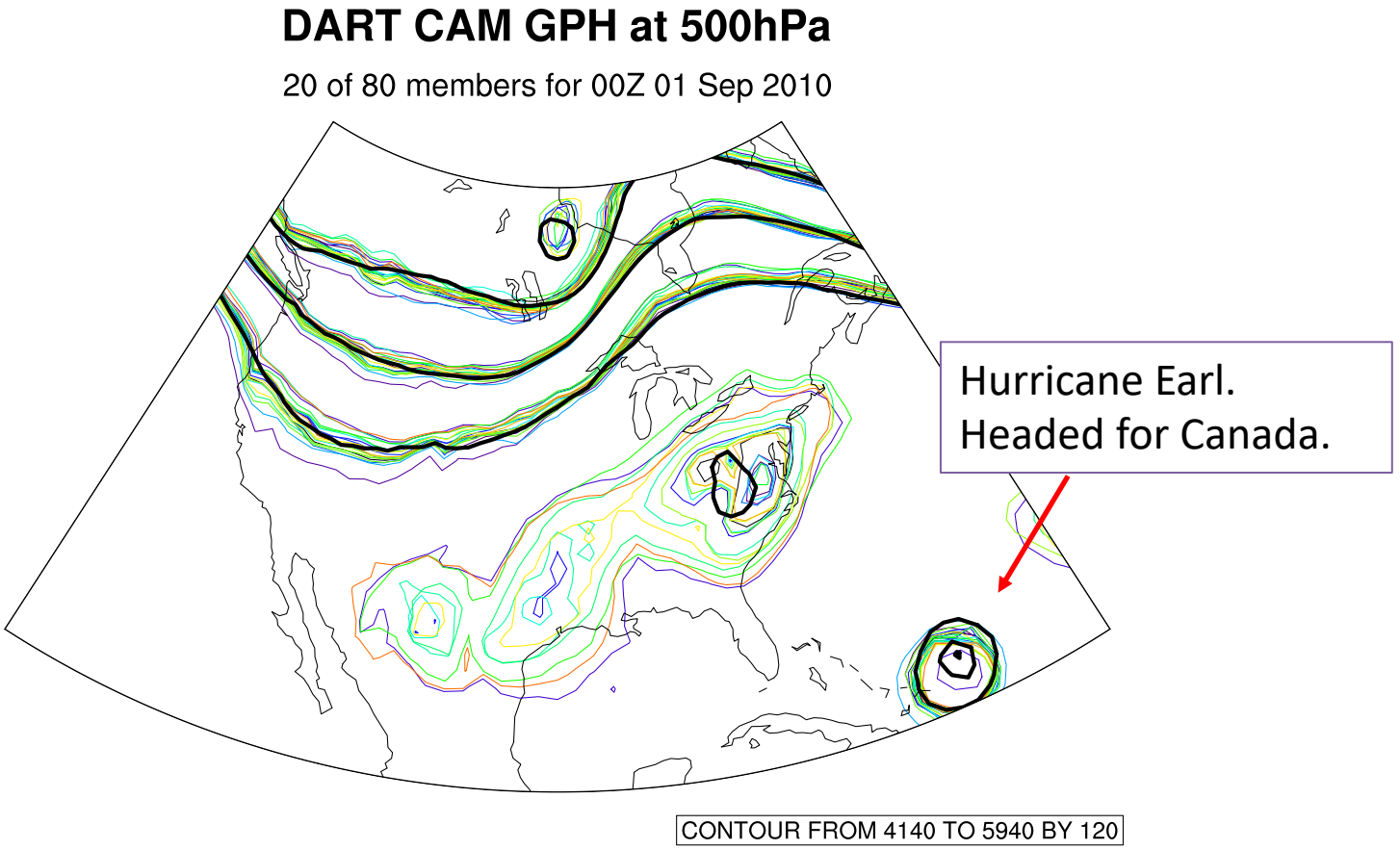
https://dart.ucar.edu

dart@ucar.edu

CISL Computational & Information Systems Lab

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

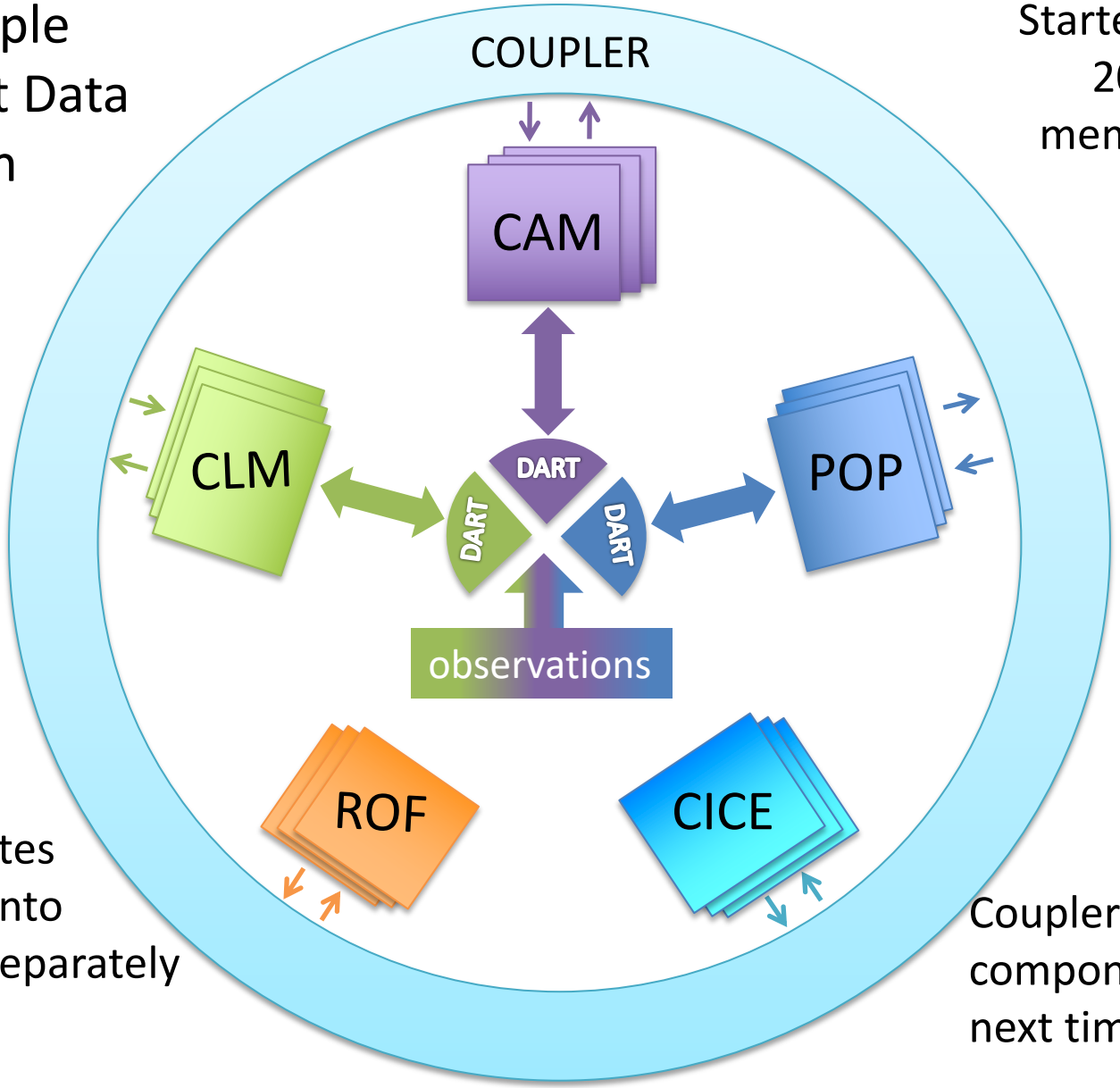


That's hurricane Earl (2010).
Even at 1 degree, CAM6 provides good position.
A bit weak but still a hurricane.

DART/CESM Assimilation

DART Multiple Component Data Assimilation

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



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

DART assimilates observations into components separately

Coupler moves the components to the next time step