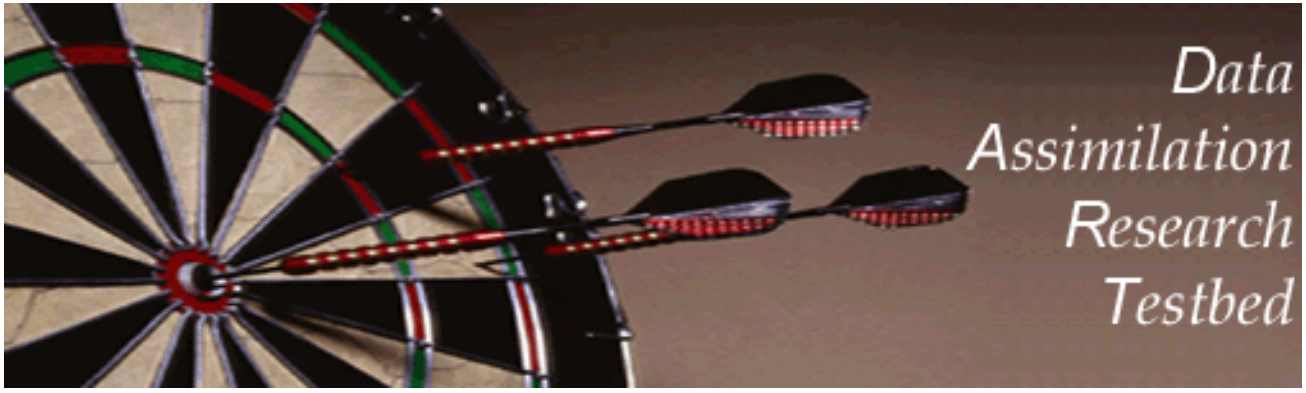
Using the DART-CAM Ensemble Data Assimilation System for Climate Model Development

Jeffrey Anderson, Kevin Raeder, Tim Hoar, Nancy Collins, Hui Liu
NCAR Data Assimilation Research Section (DAReS)



DART/CAM

A mature ensemble data assimilation facility for CAM.

Runs on variety of parallel architectures and compilers.

Easy to use with CAM3.x spectral and FV.

YOU can run CAM as an ensemble NWP model.

Competitive with operational NWP assimilation capabilities.

Converges within a few days in N.H. and tropics, a week in S.H.

Results from CAM Assimilation: January, 2003

Model:

CAM 3.1 T85L26

U,V, T, Q and PS state variables impacted by observations.

Land model (CLM 2.0) not impacted by observations.

Climatological SSTs.

Assimilation / Prediction Experiments:

80 member ensemble divided into 4 equal groups.

Adaptive error correction algorithm.

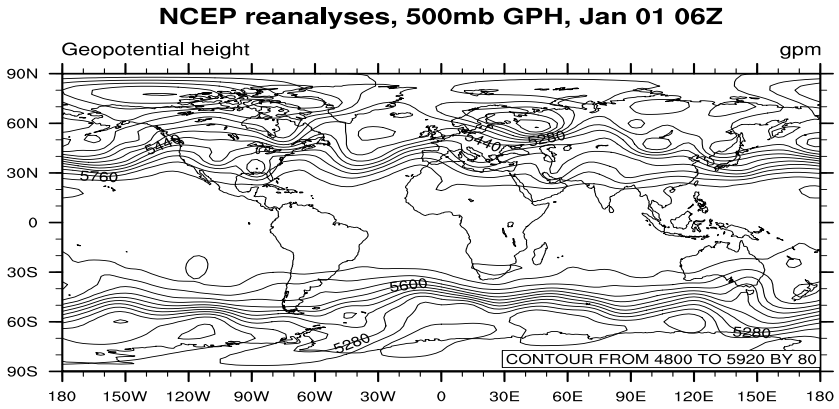
Initialized from a climatological distribution (huge spread).

Uses most observations used in reanalysis
(Radiosondes, ACARS, Sat. Winds..., no surface obs. or retrievals).

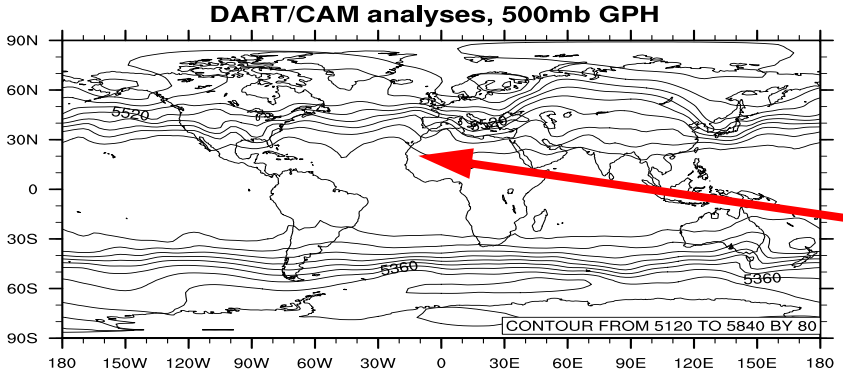
Assimilated every 6 hours; +/- 1.5 hour window for obs.

After 6 hours.

NCEP

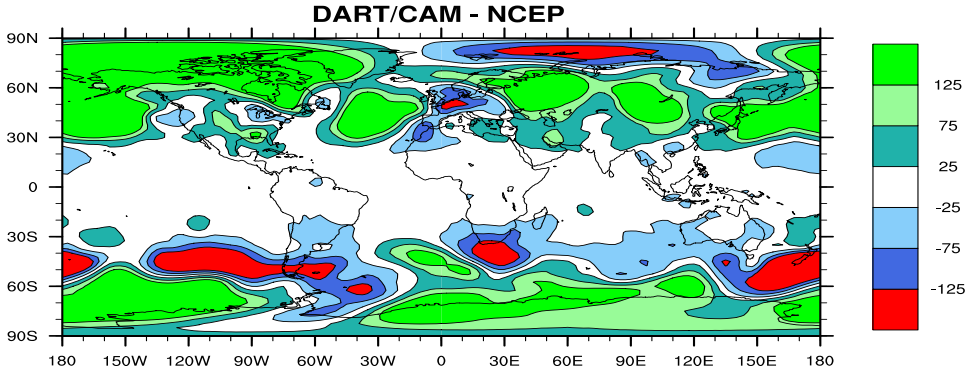


DART/CAM



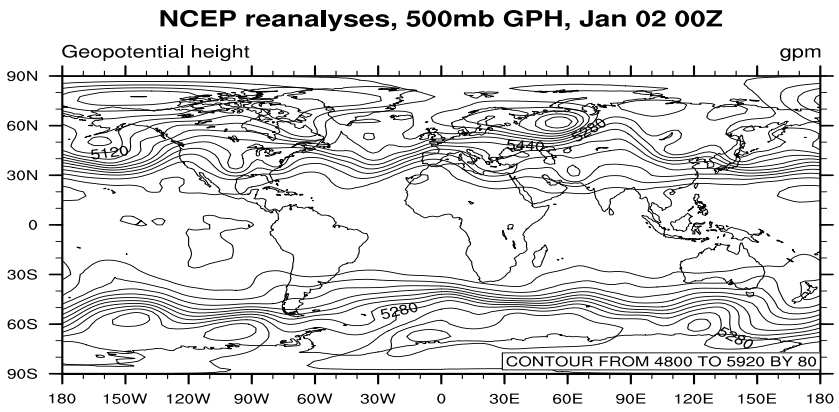
CAM
starts with
climatology!
Nearly zonal.

Difference.

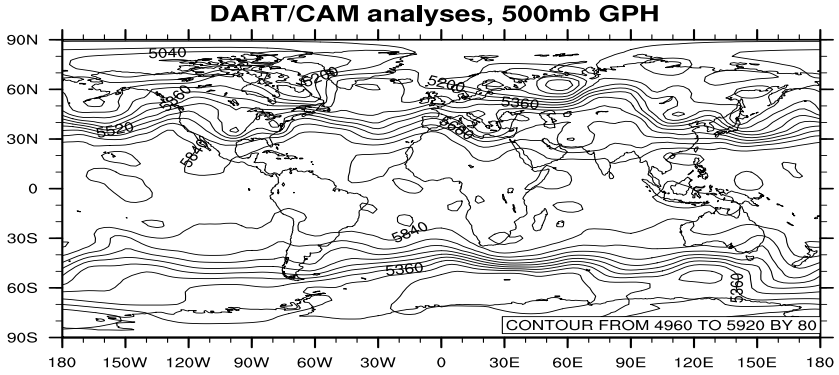


After 1 day.

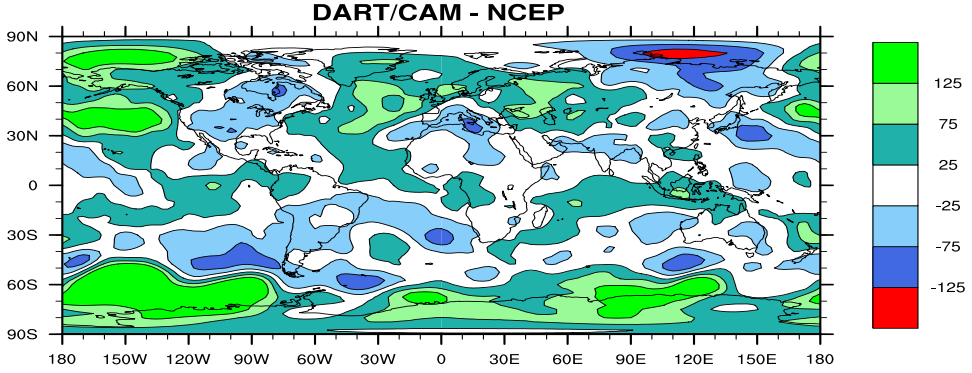
NCEP



DART/CAM

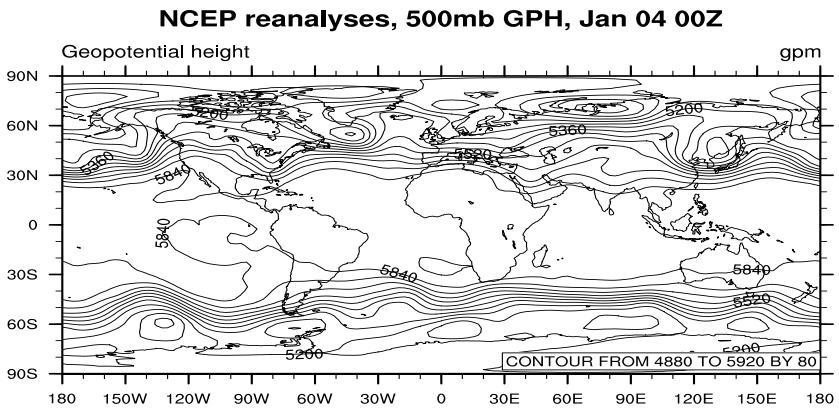


Difference.

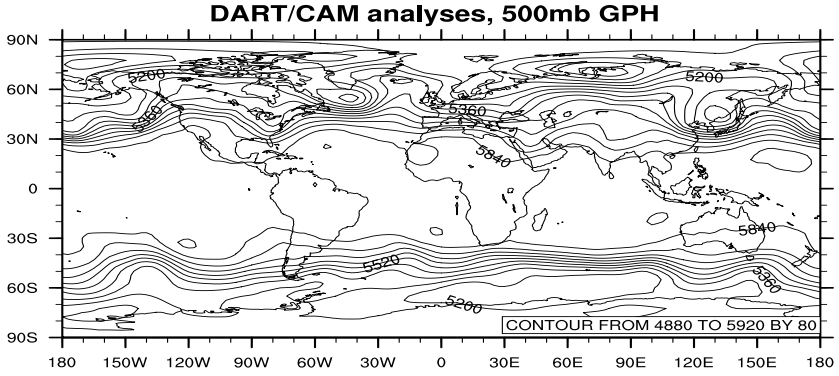


After 3 days.

NCEP

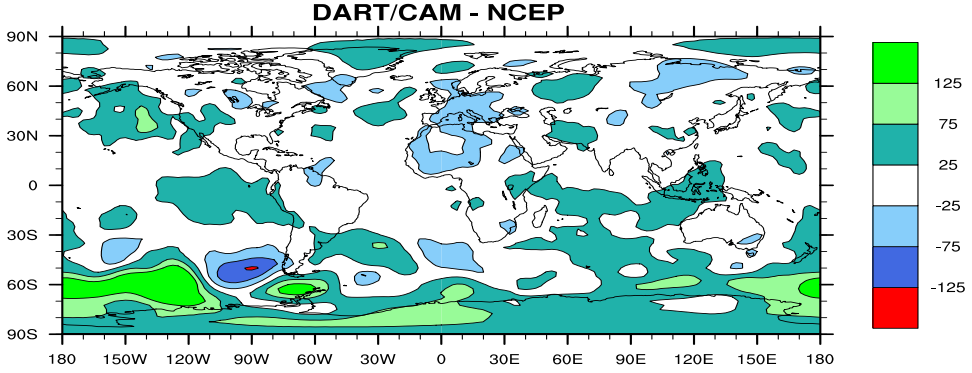


DART/CAM



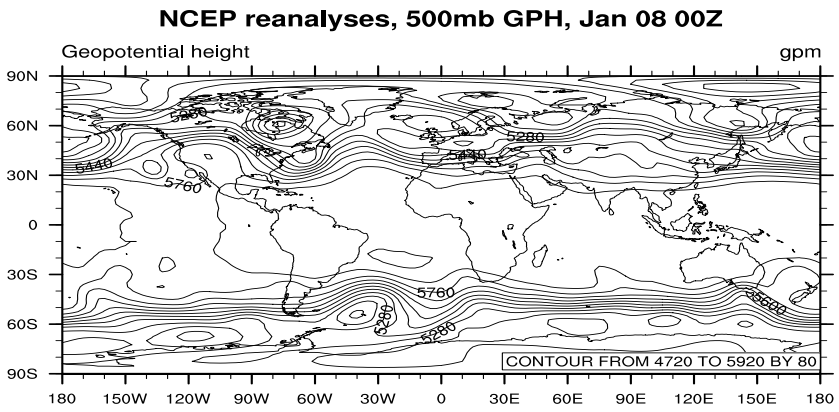
CAM gains zonal structure.

Difference.

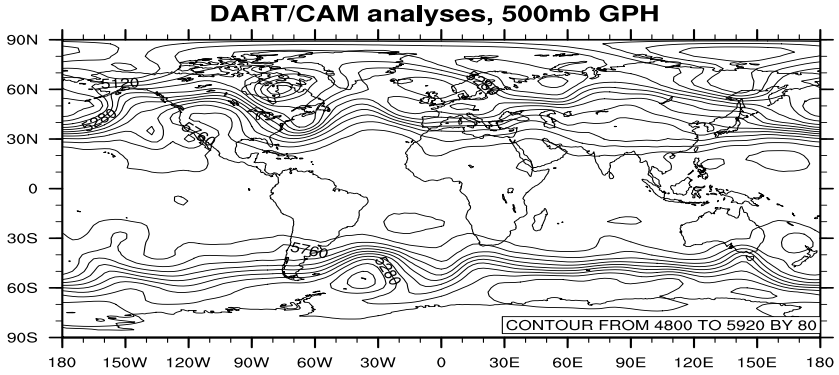


After 7 days.

NCEP

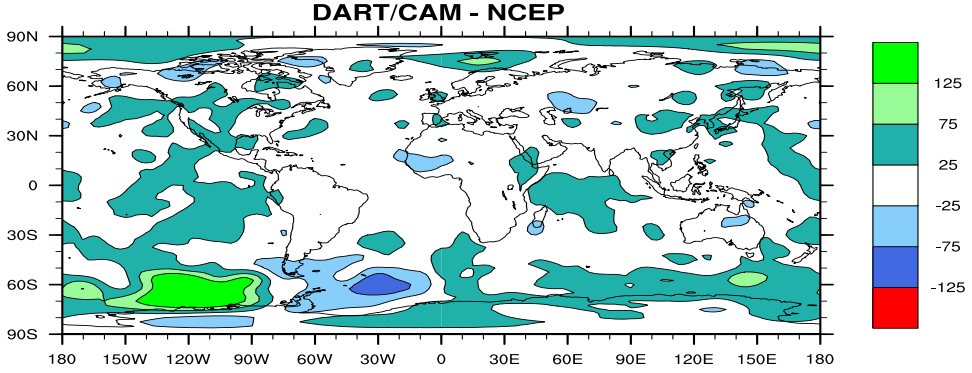


DART/CAM

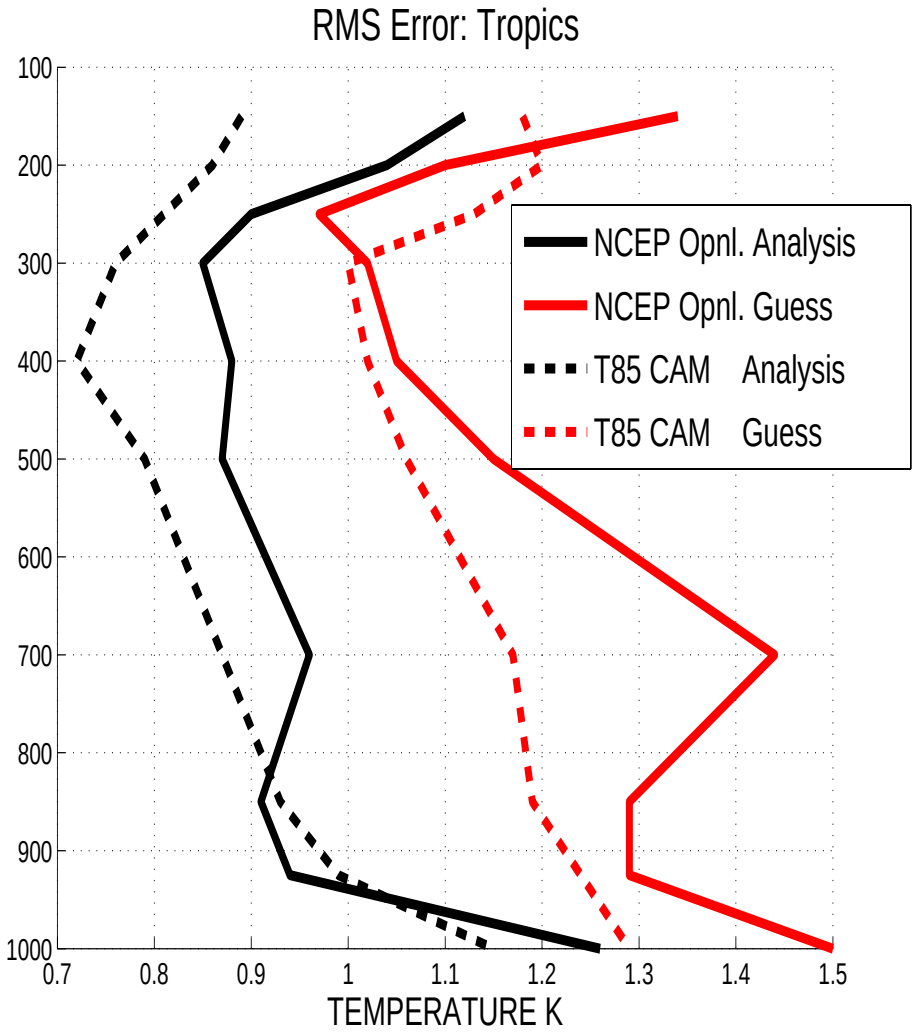


NH converged. SH poorly observed.

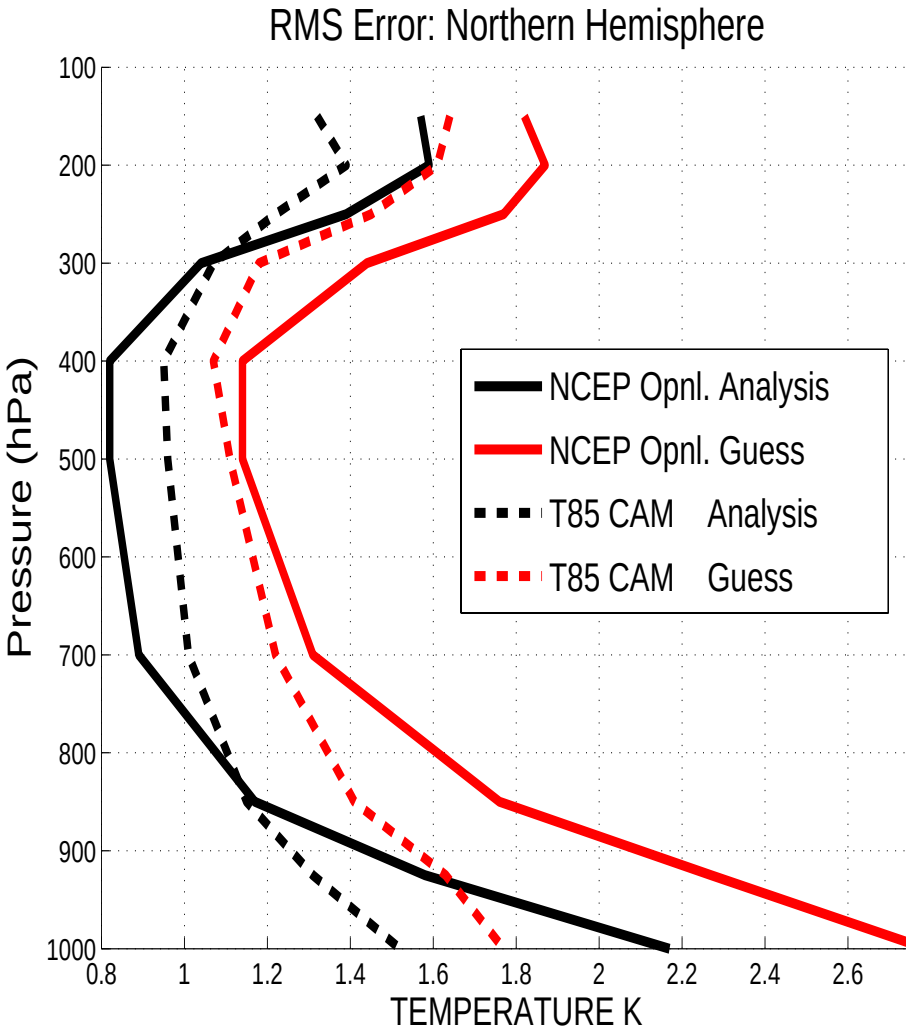
Difference.



6-Hour Forecast and Analysis Observation Space Temperature RMS

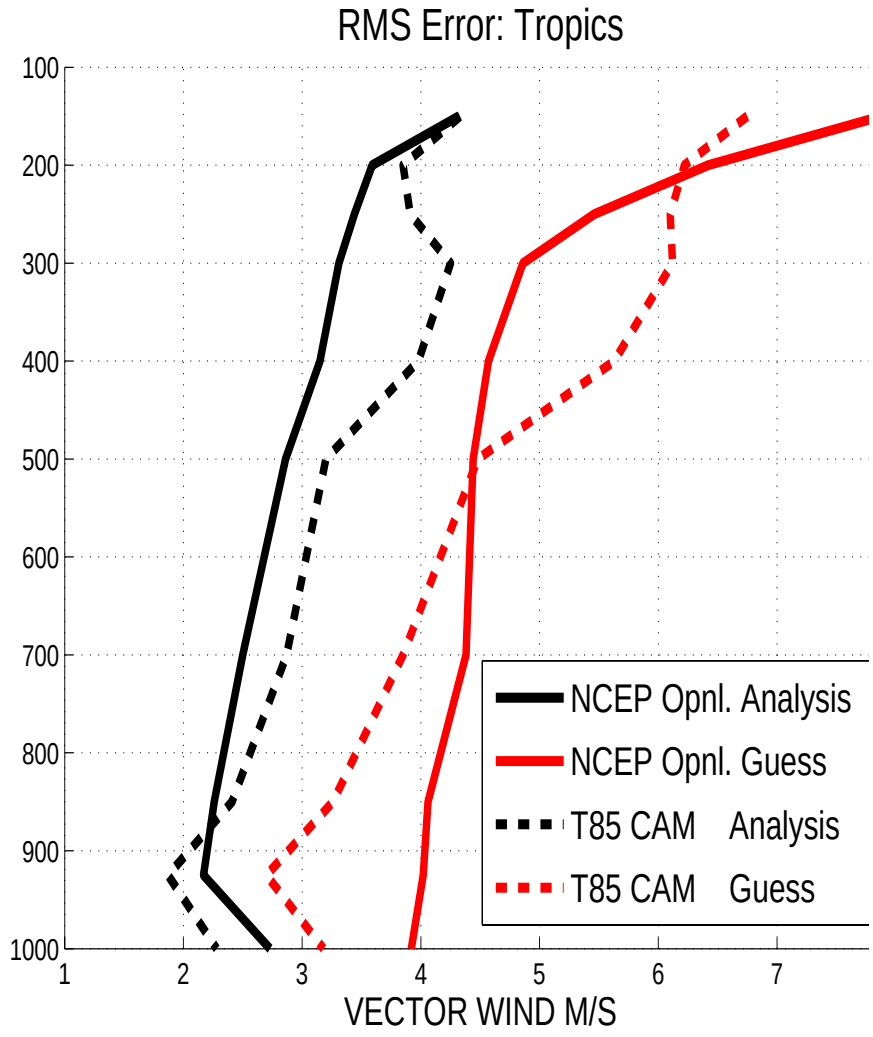


Tropics

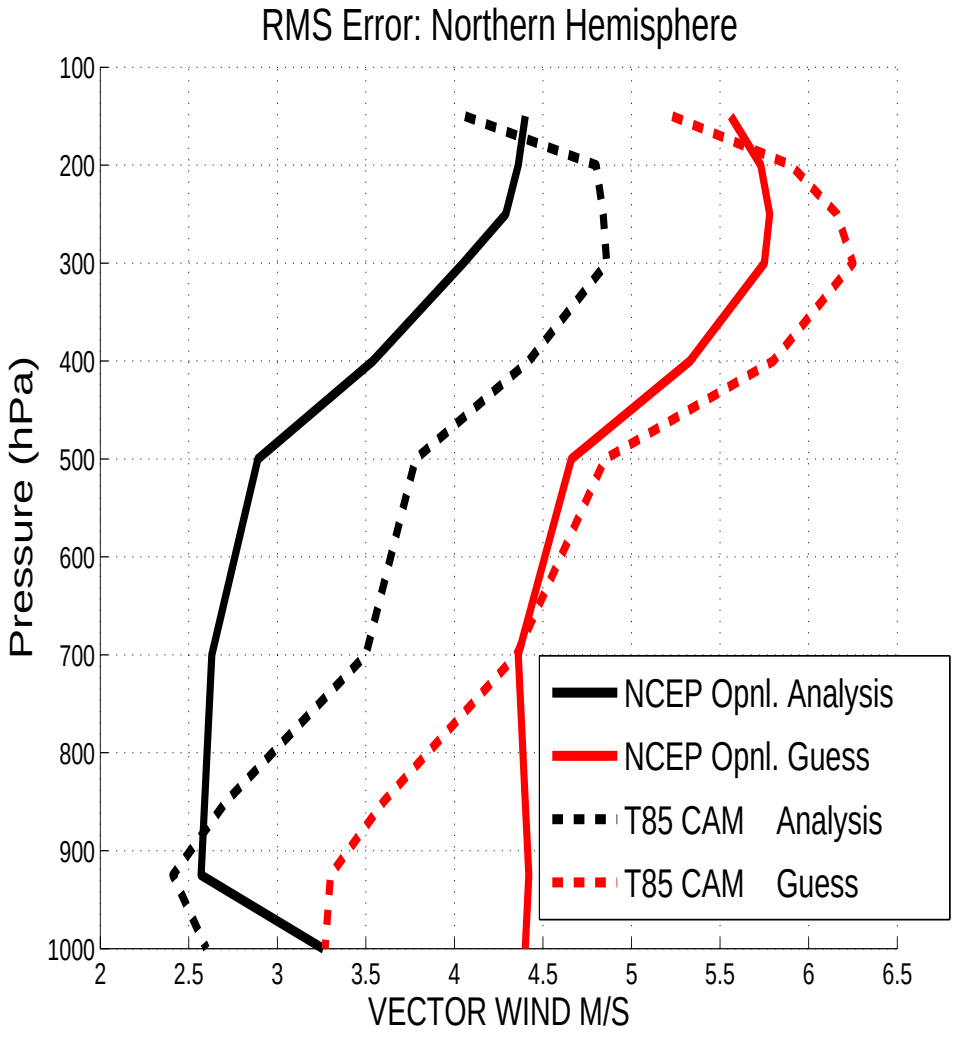


Northern Hemisphere

:6-Hour Forecast and Analysis Observation Space Wind RMS



Tropics



Northern Hemisphere

DART/CAM for assessing model errors.

Can compare CAM analyses and forecasts to observations.

No contamination/confusion from another forecast model.

Initial conditions for forecasts come from CAM only.

Comparisons can be made directly to observations.
(Can also compare to other analyses of course).

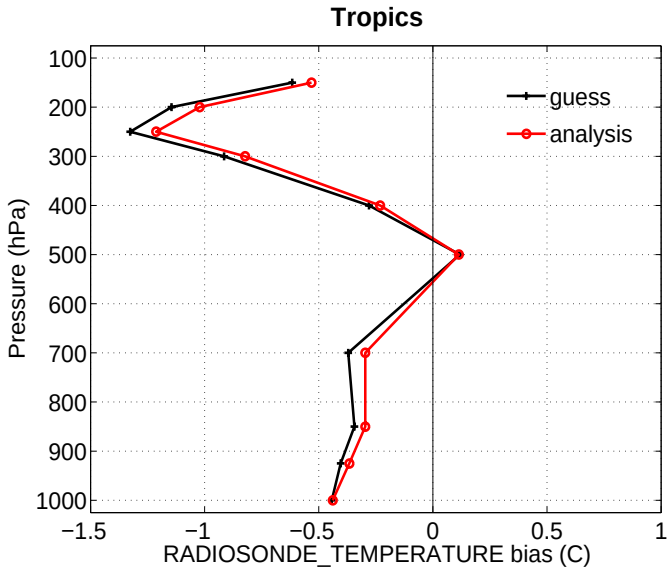
All capabilities shown in Monday's talks, PLUS ensembles.

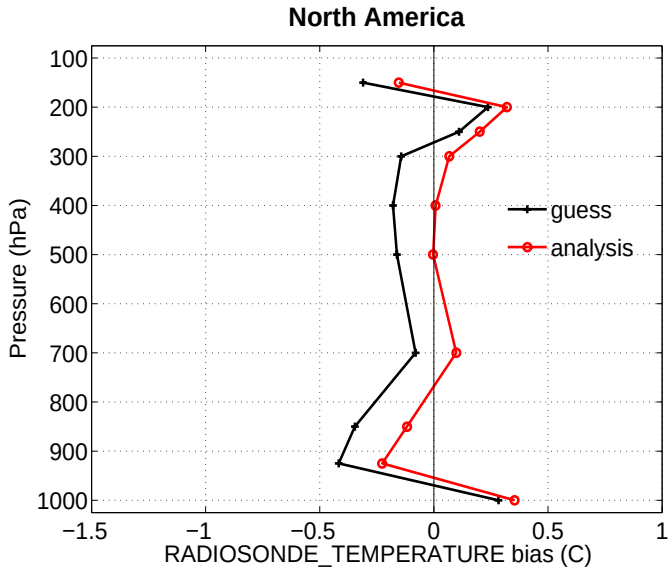
Ensembles give error bars, other estimates of significance.

Example of low-resolution assimilation comparisons.

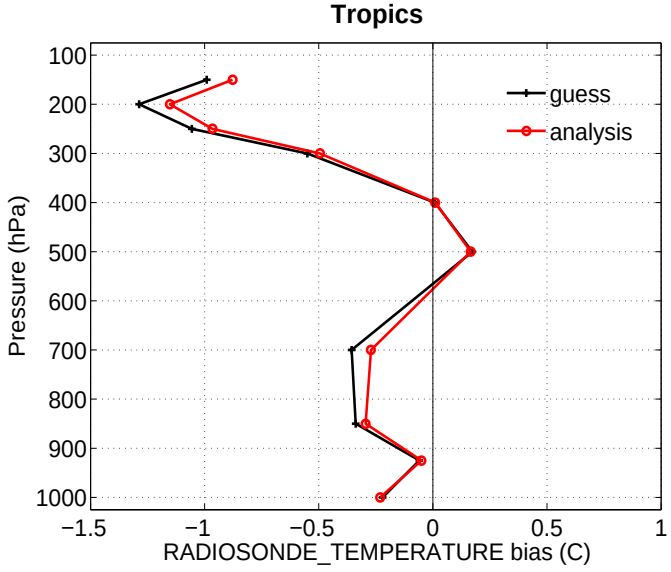
CAM spectral vs. FV for January, 2003: Temperature Bias

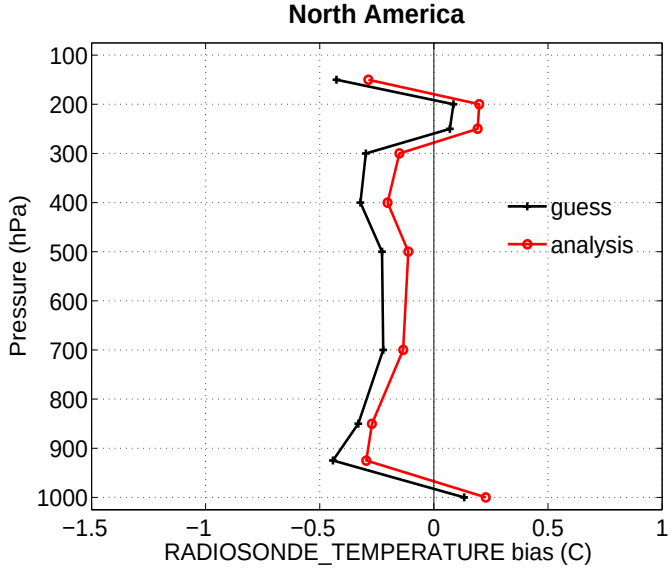
Spectral T21





Finite Volume 2x2.5

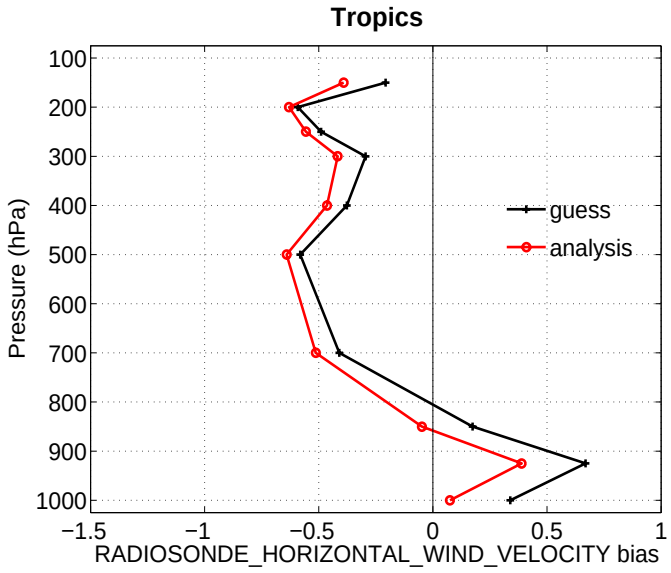


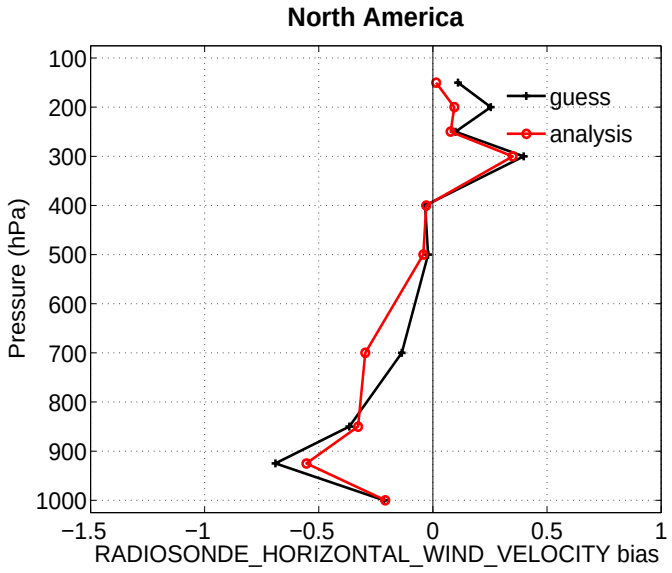


Example of low-resolution assimilation comparisons.

CAM spectral vs. FV for January, 2003: Wind Velocity Bias

Spectral T21





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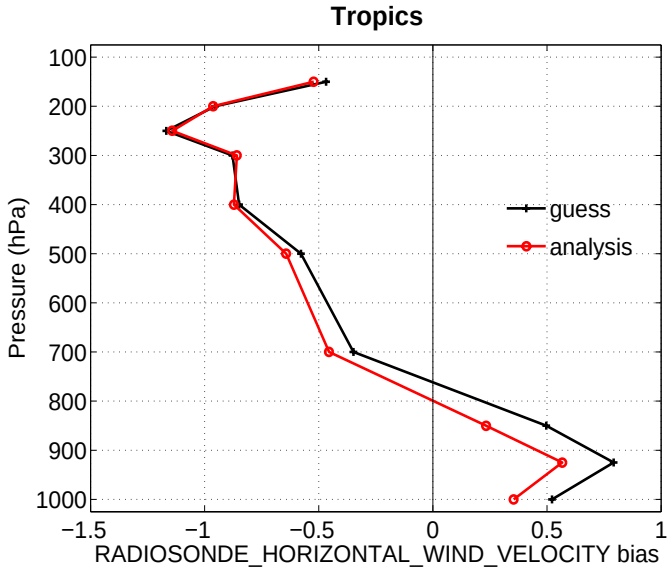
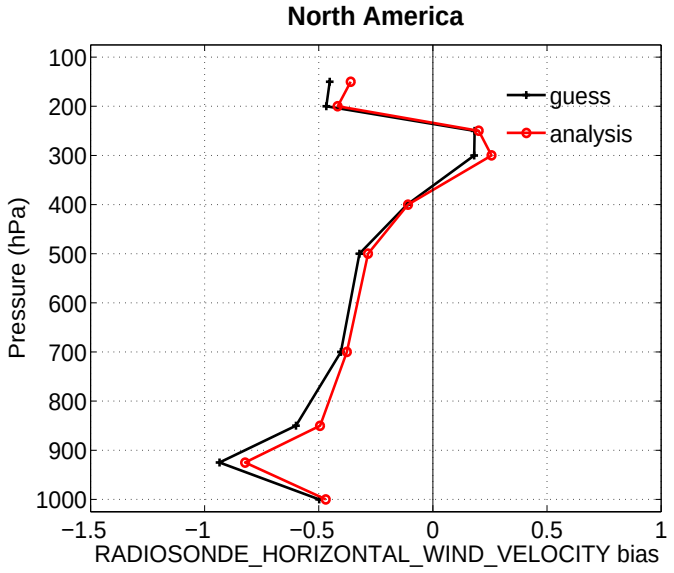
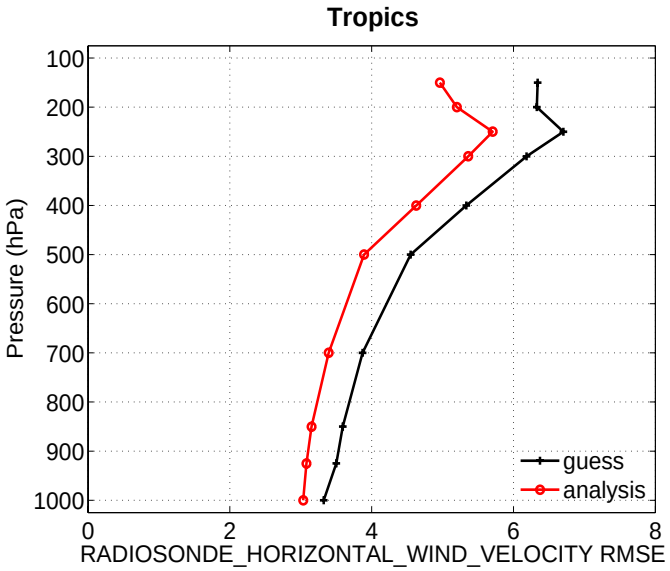


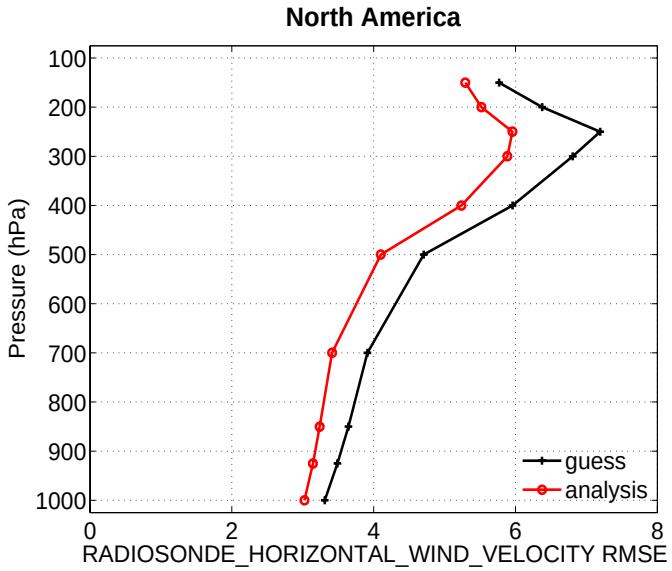


Example of low-resolution assimilation comparisons.

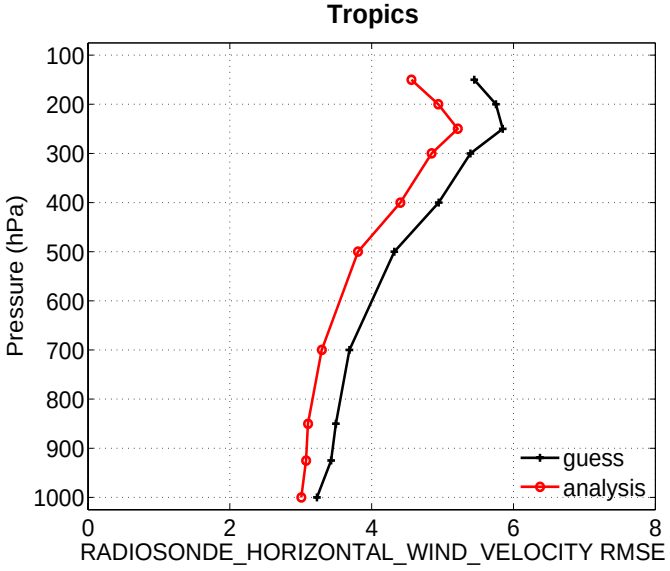
CAM spectral vs. FV for January, 2003: Wind RMS

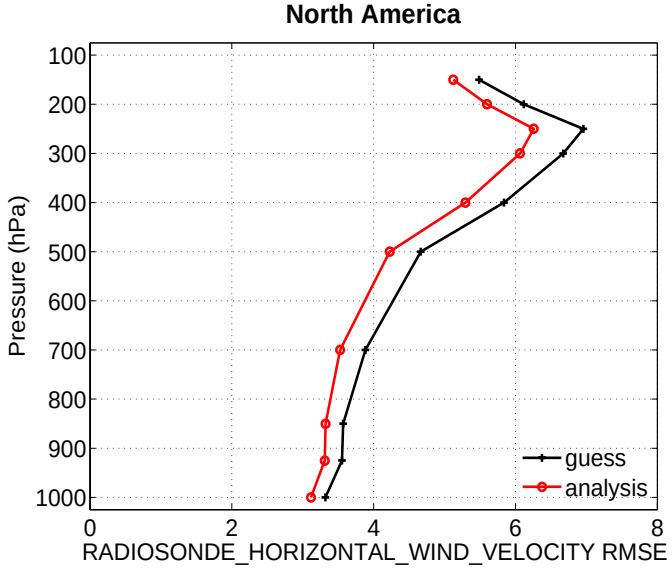
Spectral T21





Finite Volume 2x2.5





Ensemble Sensitivity Analysis

Can compute correlation (covariance) between ANY forecast or analysis quantity and ALL other forecast and analysis quantities or functions thereof at any time lag.

Can get same information as unlimited number of adjoint and linear tangent integrations over arbitrary periods.

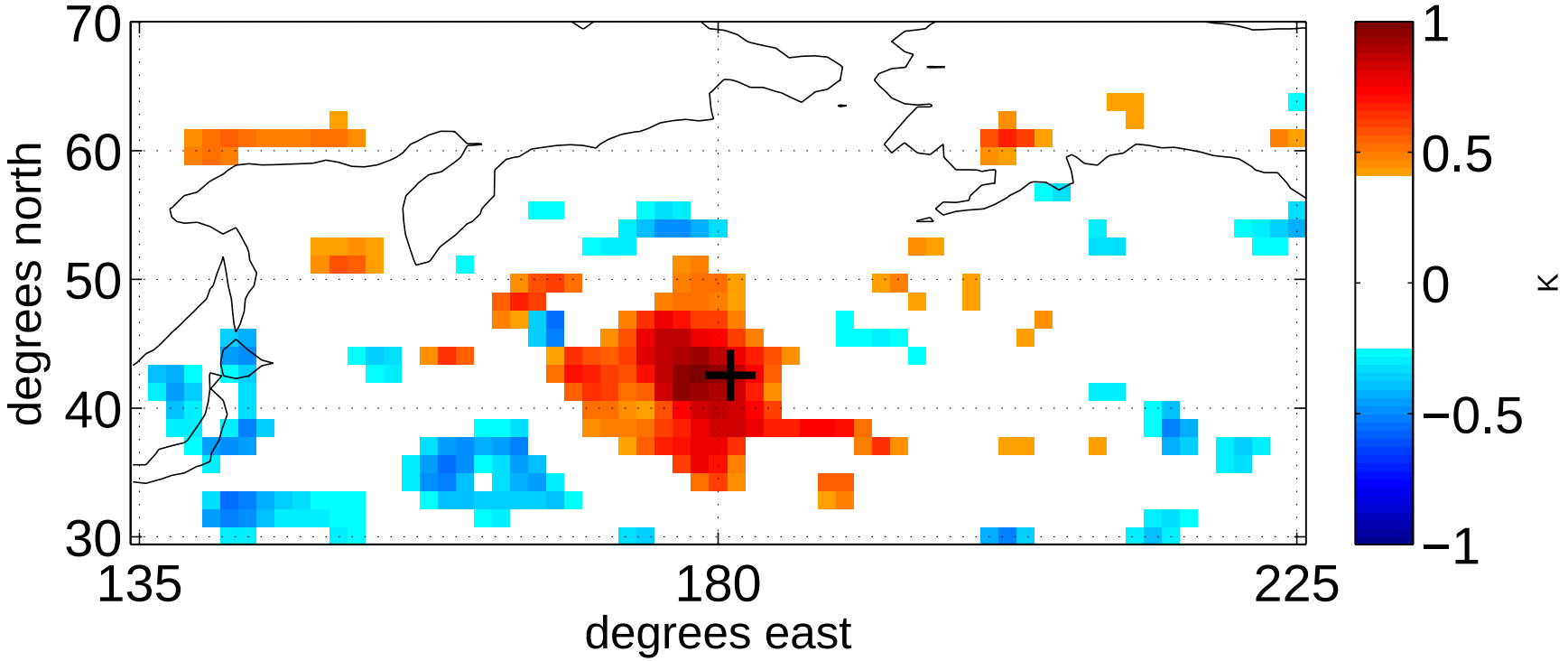
Explore relations between variables, observations, or functions thereof.

Example 1: Base point is 500 hPa mid-latitude temperature.
Look at impact on evolution of 500hPa temperatures.

Similar to linear tangent integration.
Significant correlations from 20 member T85 ensemble.

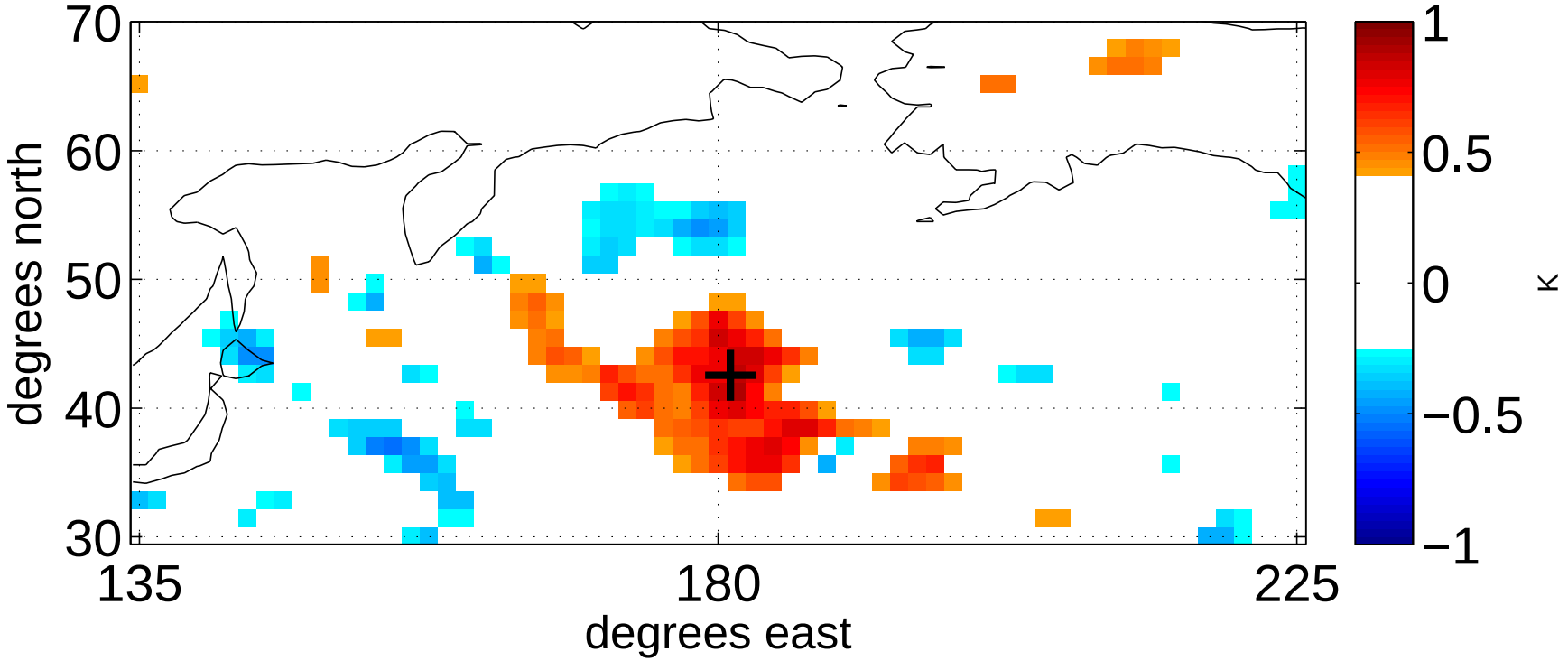
Forward in Time Sensitivity (Linear Tangent equivalent)

Time lag 00 hours: 500 hPa Temperature to 500 hPa Temperature



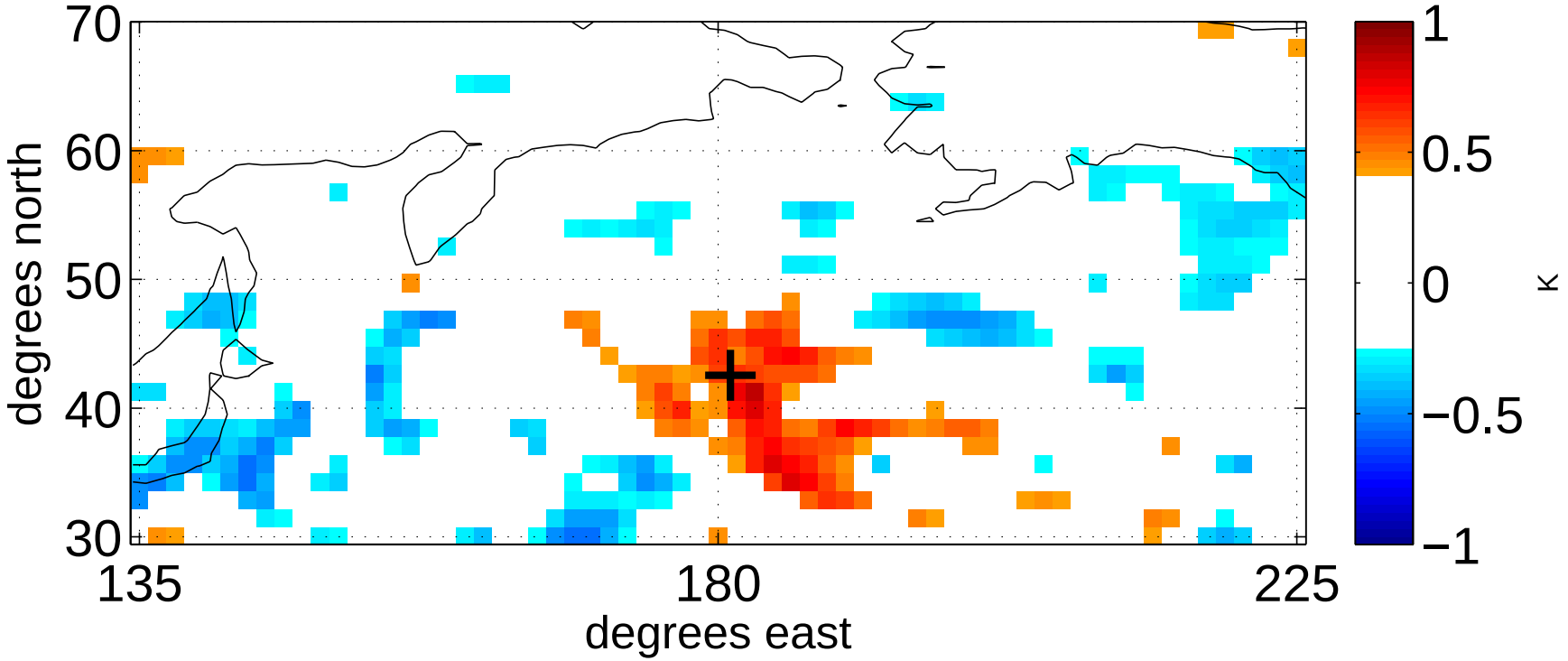
Forward in Time Sensitivity (Linear Tangent equivalent)

Time lag 06 hours: 500 hPa Temperature to 500 hPa Temperature



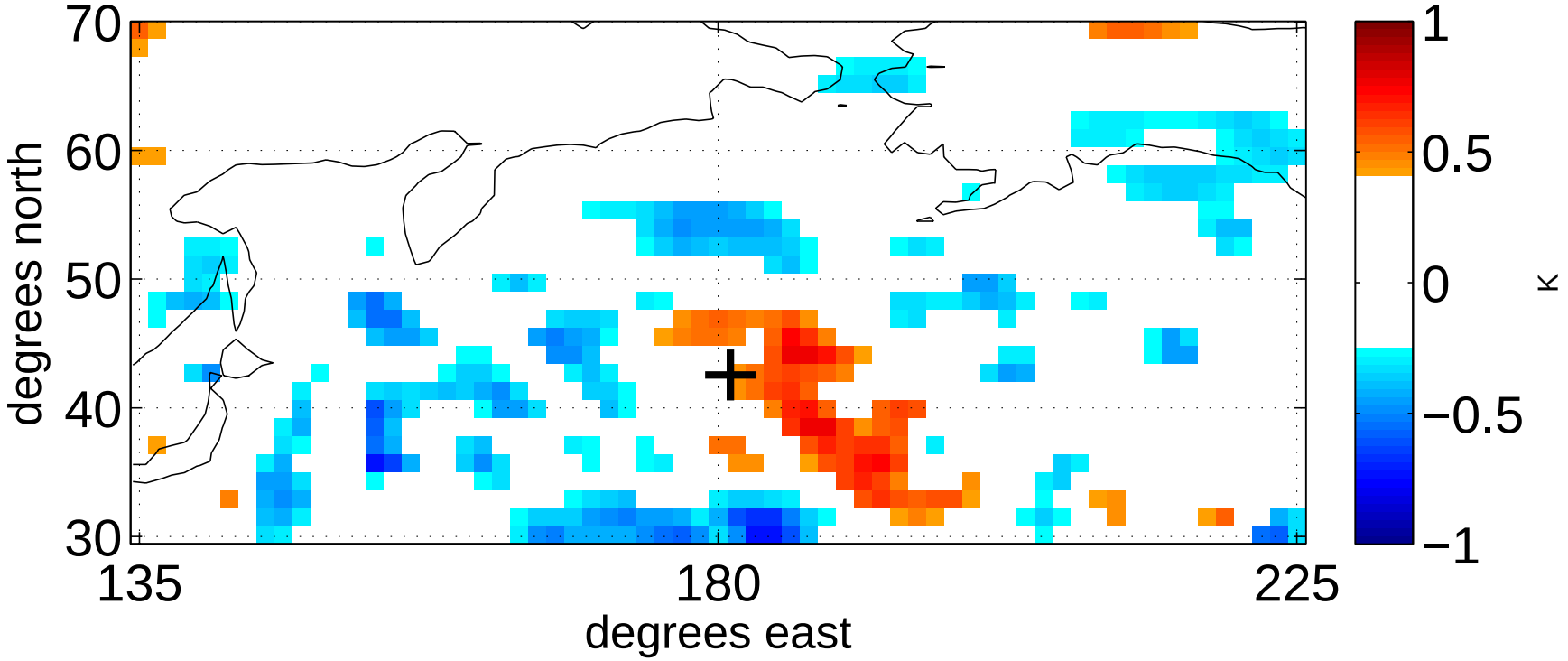
Forward in Time Sensitivity (Linear Tangent equivalent)

Time lag 12 hours: 500 hPa Temperature to 500 hPa Temperature



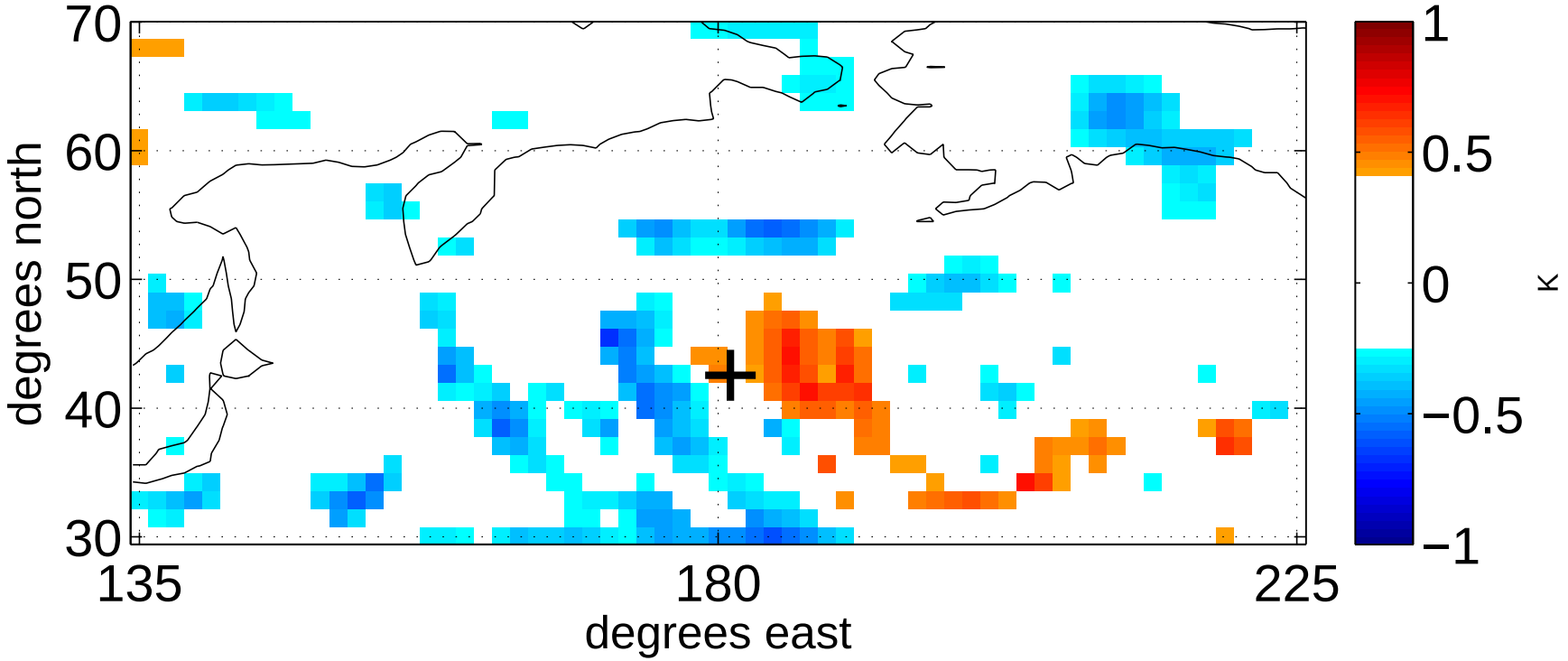
Forward in Time Sensitivity (Linear Tangent equivalent)

Time lag 18 hours: 500 hPa Temperature to 500 hPa Temperature



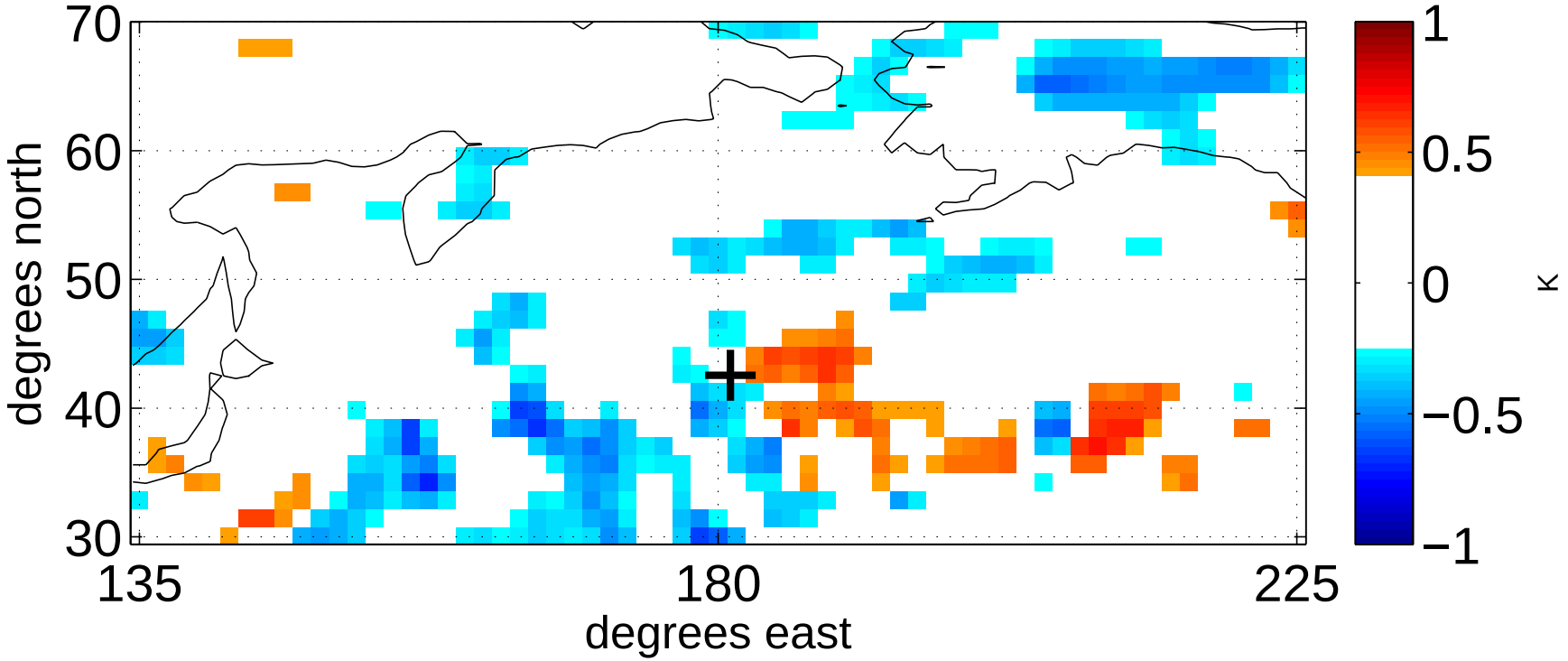
Forward in Time Sensitivity (Linear Tangent equivalent)

Time lag 24 hours: 500 hPa Temperature to 500 hPa Temperature



Forward in Time Sensitivity (Linear Tangent equivalent)

Time lag 30 hours: 500 hPa Temperature to 500 hPa Temperature



Ensemble Sensitivity Analysis

Can compute correlation (covariance) between ANY forecast or analysis quantity and ALL other forecast and analysis quantities or functions thereof.

Can get same information as unlimited number of adjoint and linear tangent integrations over arbitrary periods.

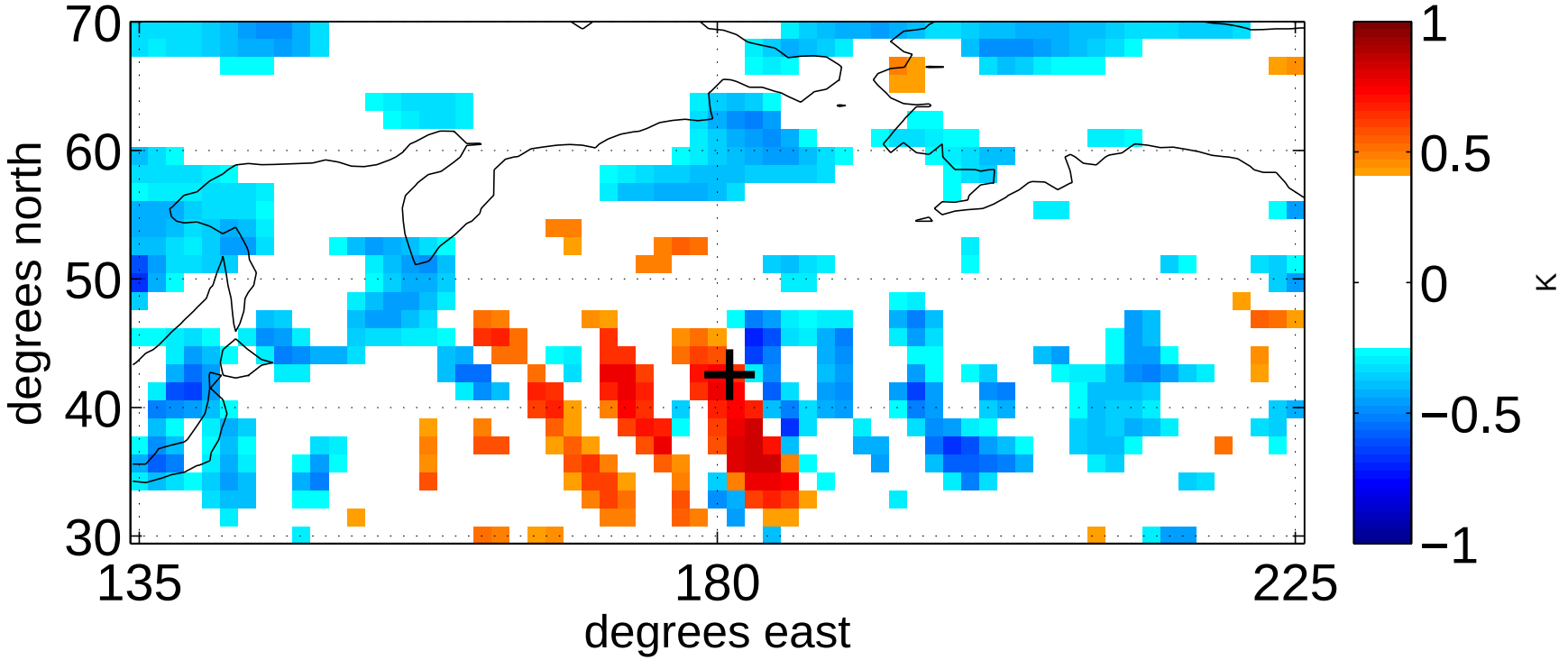
Explore relations between variables, observations, or functions thereof.

Example 2: Base point is 500 hPa mid-latitude zonal velocity.
Look at impact of previous 500 hPa temperature.

Compare to an adjoint integration.

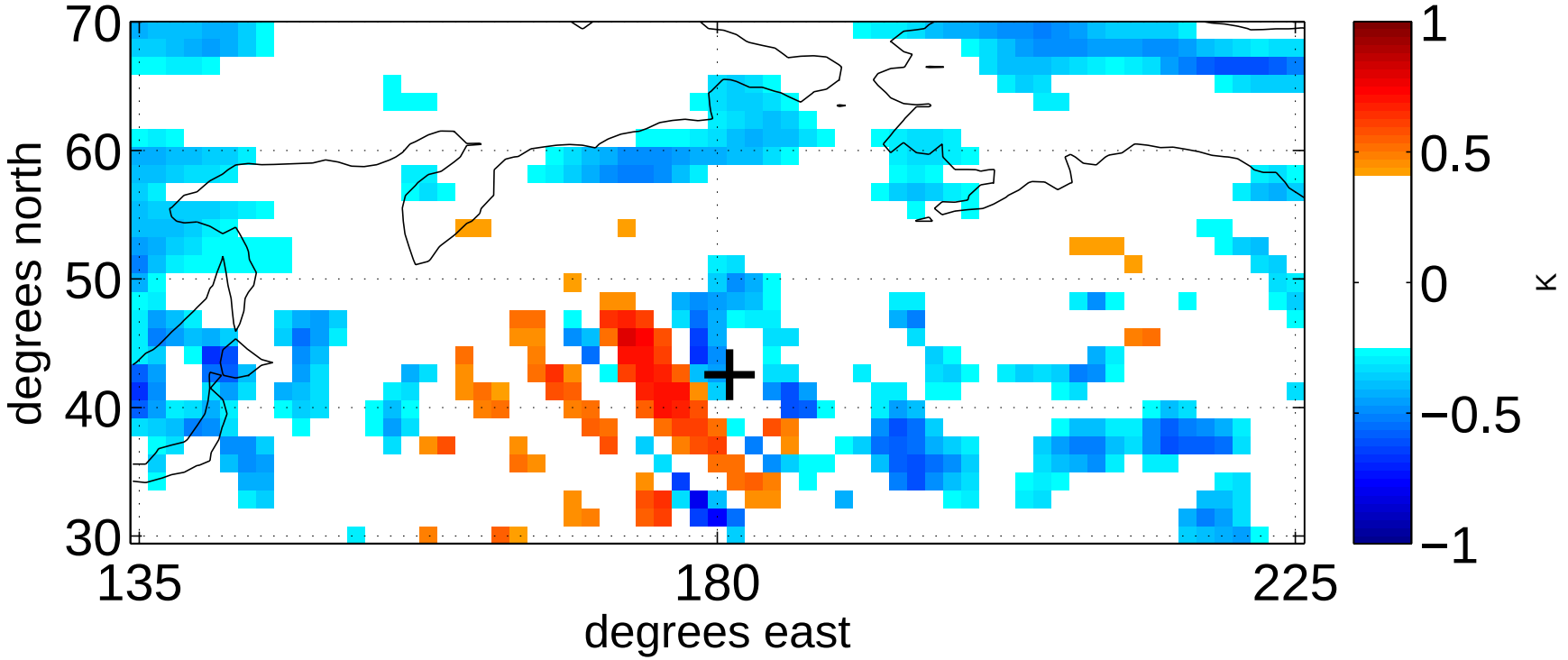
Backward in Time Sensitivity (Adjoint equivalent)

Time lag -00 hours: 500 hPa Zonal Velocity to 500 hPa Temperature



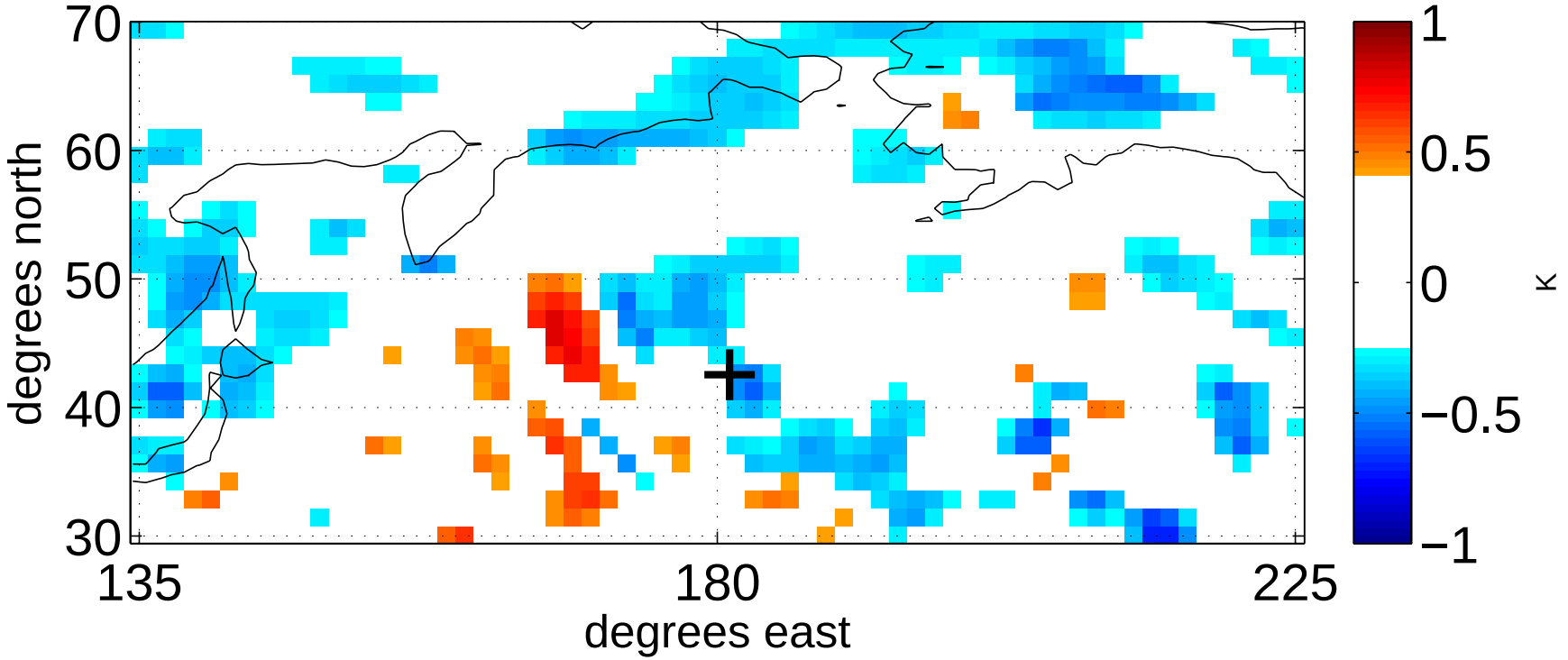
Backward in Time Sensitivity (Adjoint equivalent)

Time lag -06 hours: 500 hPa Zonal Velocity to 500 hPa Temperature



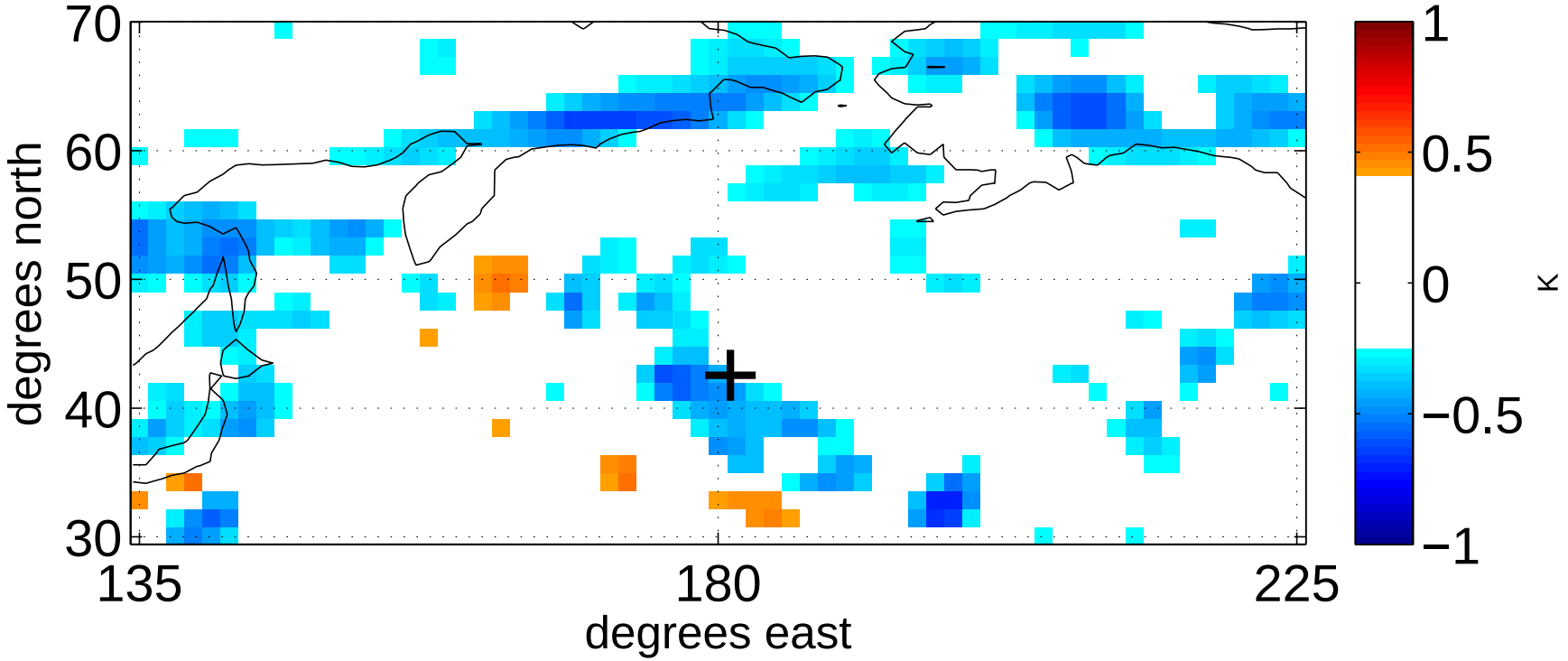
Backward in Time Sensitivity (Adjoint equivalent)

Time lag -12 hours: 500 hPa Zonal Velocity to 500 hPa Temperature



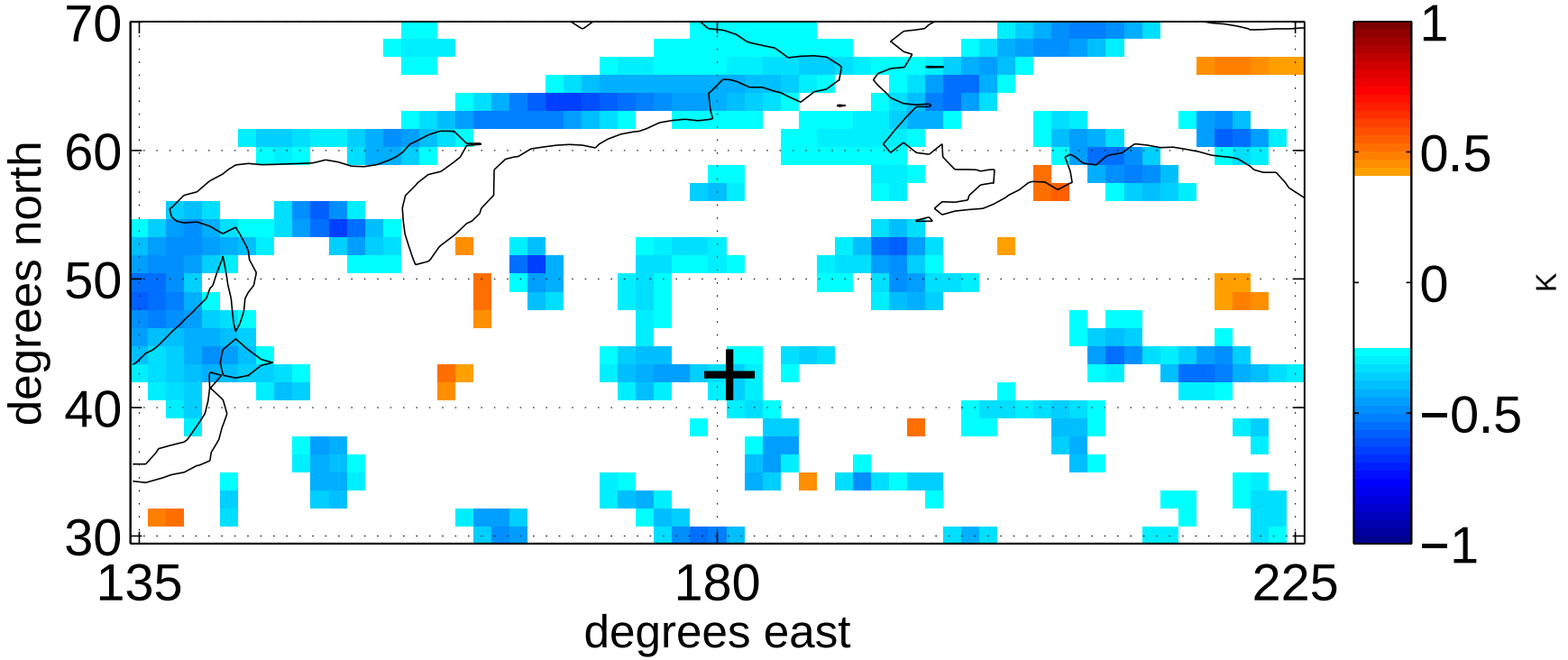
Backward in Time Sensitivity (Adjoint equivalent)

Time lag -18 hours: 500 hPa Zonal Velocity to 500 hPa Temperature



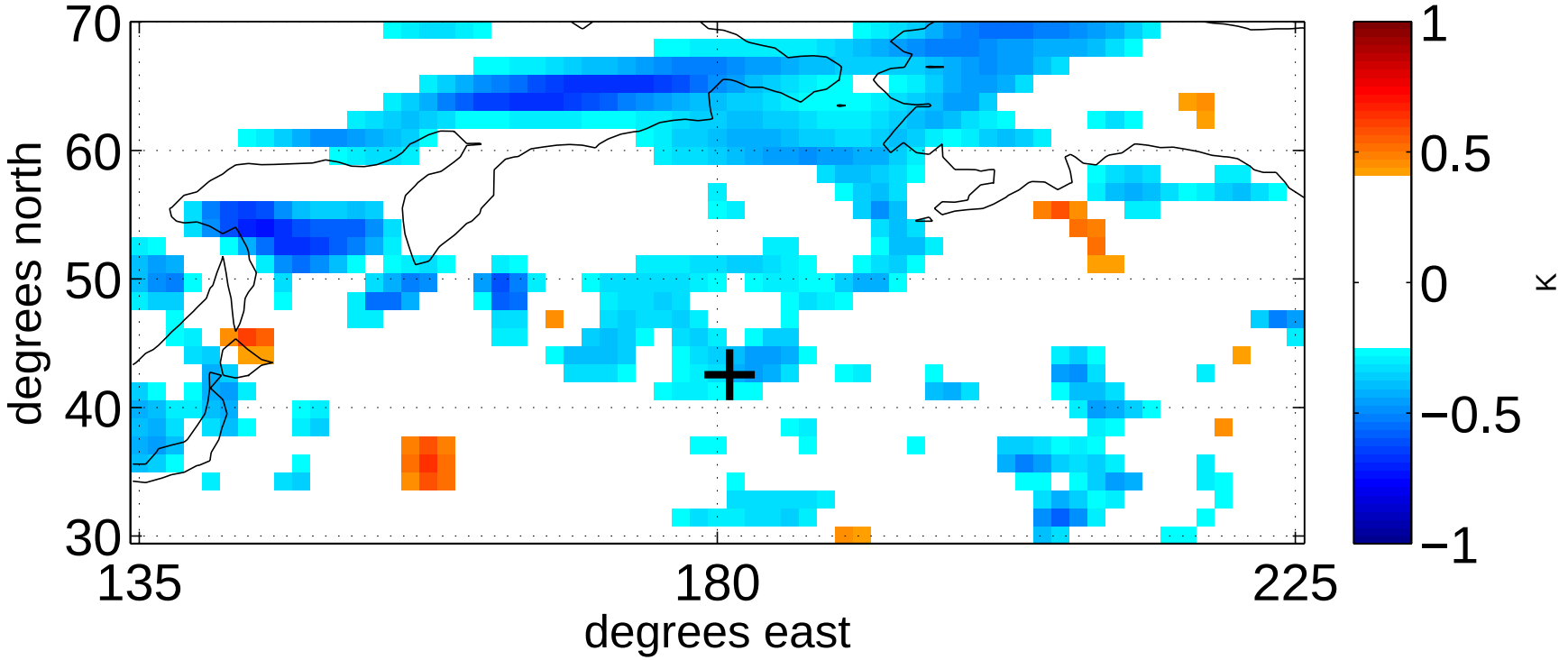
Backward in Time Sensitivity (Adjoint equivalent)

Time lag -24 hours: 500 hPa Zonal Velocity to 500 hPa Temperature



Backward in Time Sensitivity (Adjoint equivalent)

Time lag -30 hours: 500 hPa Zonal Velocity to 500 hPa Temperature



Adding new model variants, new observations is simple.

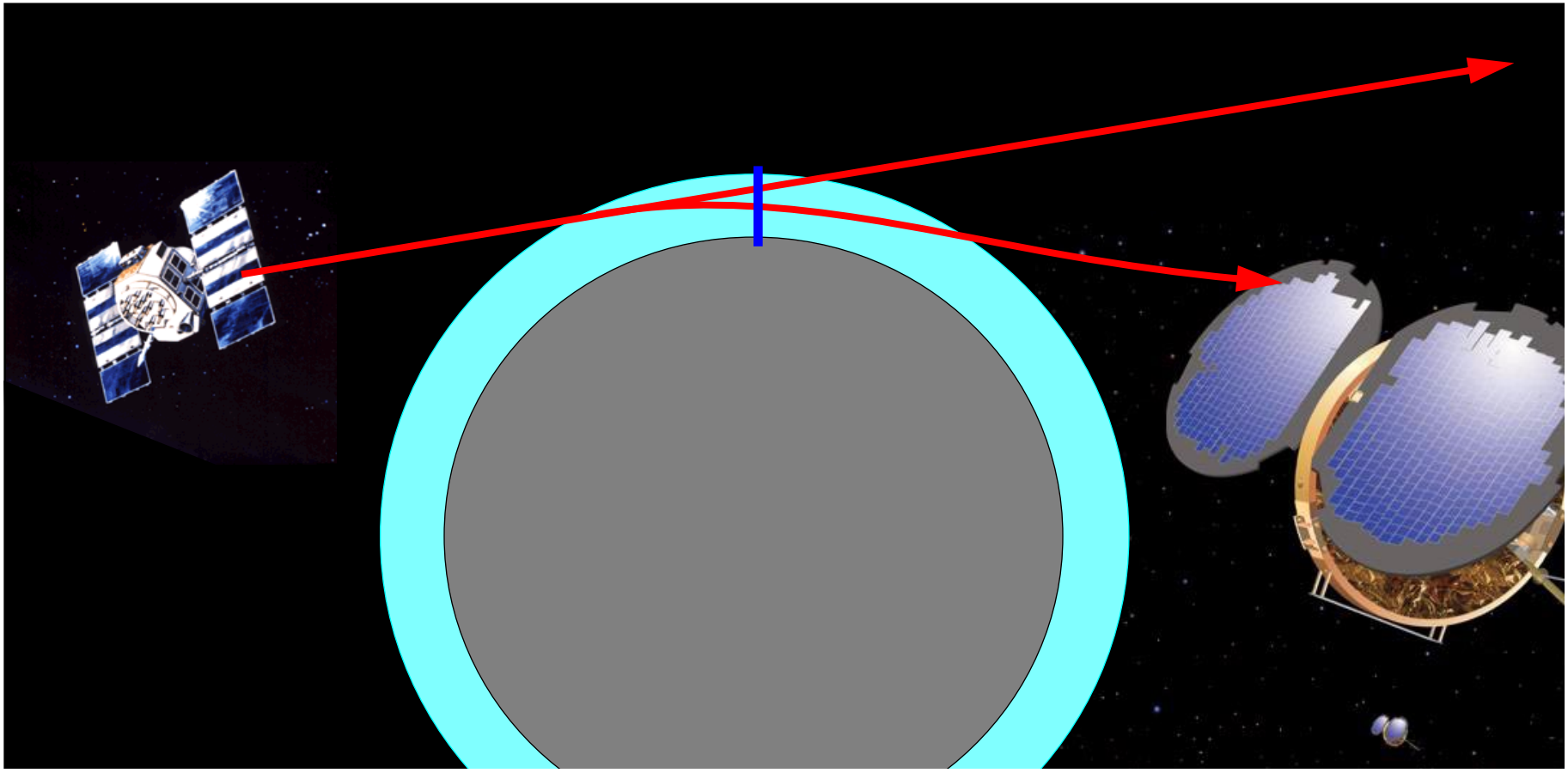
1. Incorporating existing model requires handful of interfaces.
   A. No need for linear tangents or adjoints.
   B. Finite Volume CAM added in 1-month by ACD's Ave Arellano.

2. Adding observations also straightforward.
   A. Only need forward operator (map state to expected observation).
   B. No linear tangents or adjoints.
   C. Several different GPS operators added in weeks.

Assimilating GPS Radio Occultation Observation

Assimilated as refractivity along beam path.

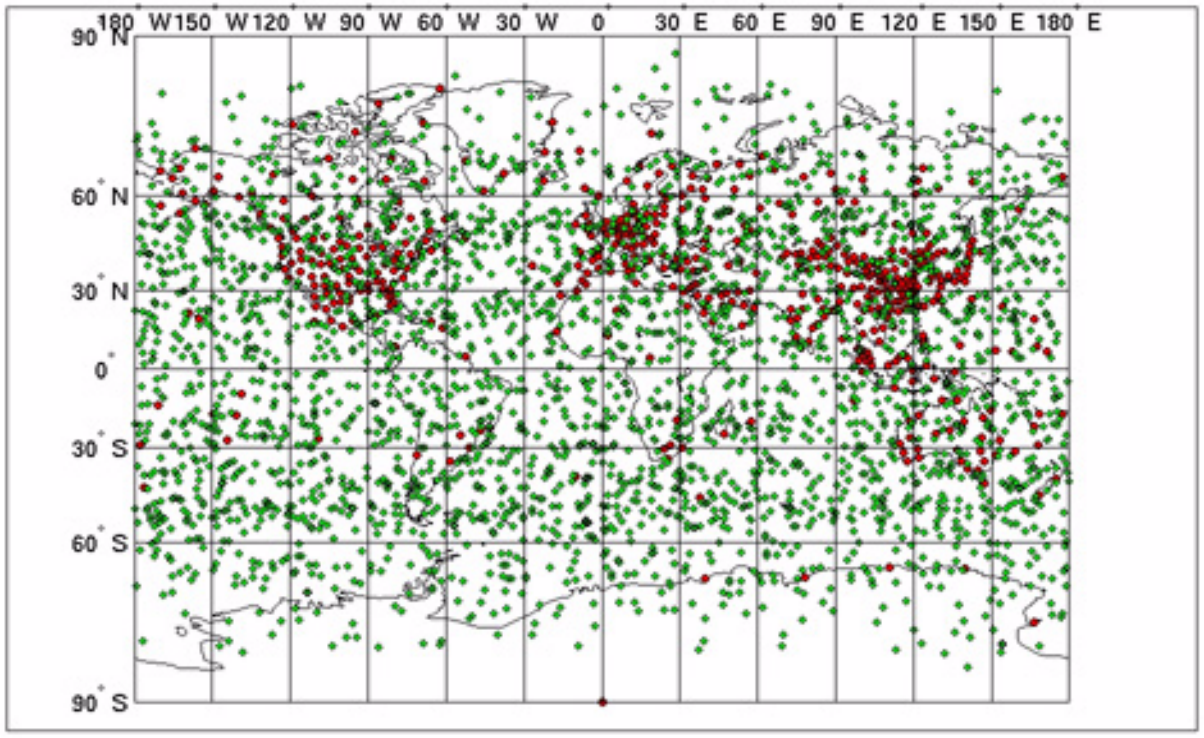
Complicated function of T, Q, P and ionospheric electric field.



Get a sounding as GPS satellite sets relative to low earth satellite.

GPS and other novel observations may help detect climate model bias.

DART/CAM can assimilate COSMIC occultations and
ground-based observations.
GPS provides soundings of temperature and water vapor world-wide.
Not impacted by clouds.
Sees down into boundary layer in tropics.



Daily COSMIC Soundings; Daily Radiosondes.

Adding additional tracers or model variables is straightforward.

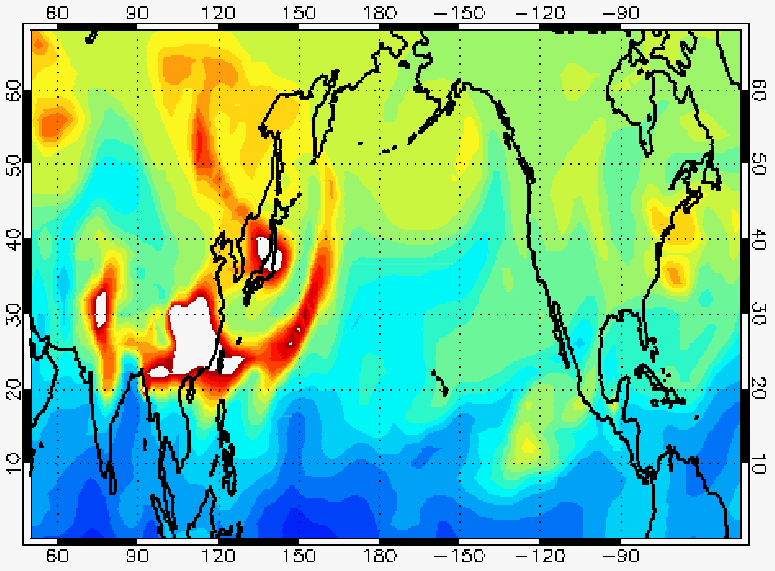
DART/CAM in use in ACD for CO Assimilation.

Assimilate standard observations plus MOPITT CO observations.

Work by Ave Arellano and Peter Hess supported by Kevin Raeder.

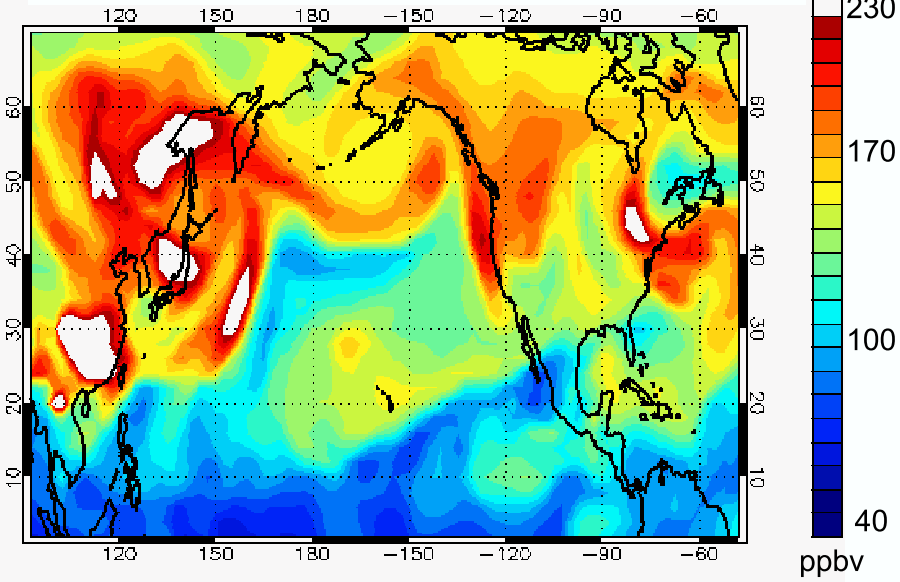
Impact of Assimilation in Modeled CO

No Assimilation @700 hPa 041706 18Z



Assimilating MOPITT CO provides important constraints to regional CO distribution in the troposphere.

Assimilation @700 hPa 041706 18Z



Suggests the utility of assimilation in providing better initial/boundary conditions to regional CO forecasts.

Looking for source of model systematic error.

Eric DeWeaver and collaborators, U. Wisconsin.

Assimilate all observations except over poles.

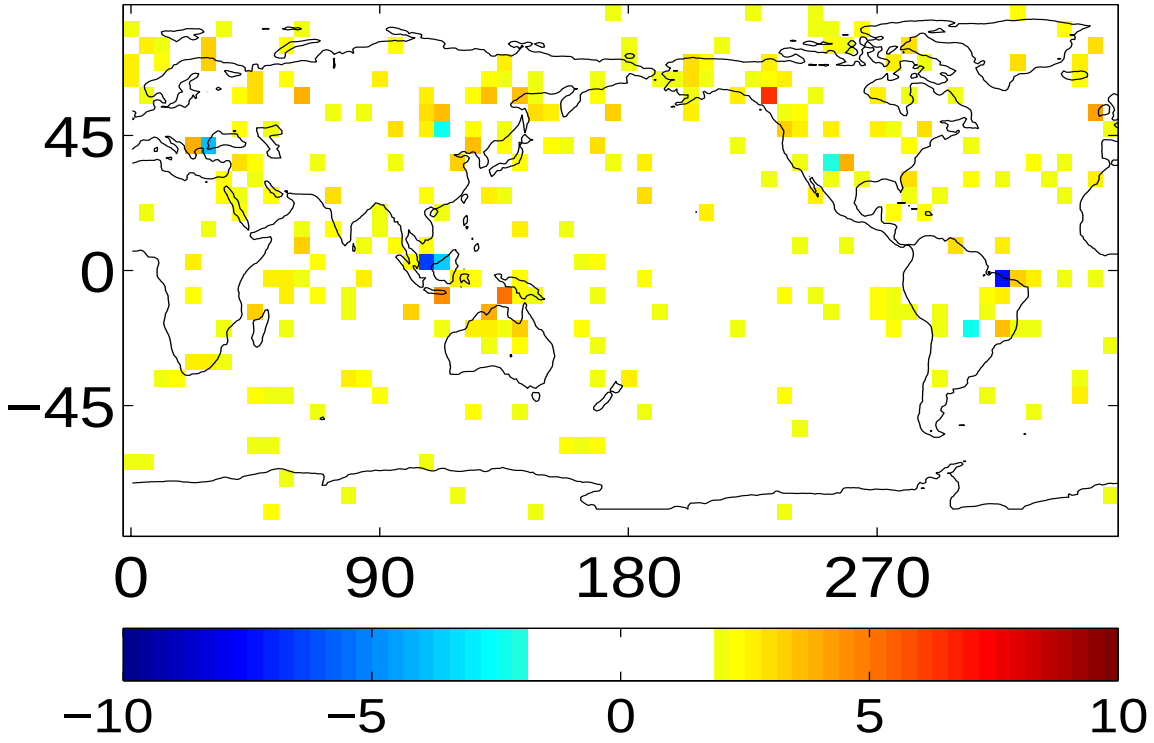
Does this reduce systematic errors over pole?

Assimilate ONLY over poles.

What happens to systematic errors elsewhere?

Using COSMIC and other novel observations in polar regions

Climate Model Parameter Estimation via Ensemble Data Assimilation.



T21 CAM assimilation of gravity wave drag efficiency parameter.

Oceanic values are noise (should be 0).

0< efficiency< ~4 suggested by modelers.

Positive values over NH land expected.

Problem: large negative values over tropical land near convection.

May reduce wind bias in tropical troposphere, but for 'Wrong Reason'.

Assimilation tries to use free parameter to fix ALL model problems

Direct parameter estimation.

May be difficult to implement directly, BUT...

Can still use an ensemble of parameter values.

This allows sensitivity analysis for parameter values.

What would change in analyses/forecasts if parameter were changed?

Can look at any variable or function of variables or observations.

Potentially very powerful analysis tool.

Comes with error bounds as always; can filter out noise.

Summary:

1. DART/CAM allows ensemble NWP capability with CAM.
2. Can produce ensemble analyses and forecasts.
3. Assimilate traditional obs., special obs., novel obs.
4. Ensembles facilitate error bars on diagnostics.
5. General sensitivity capability:
   Any adjoint or linear tangent question.
   PLUS statistical significance. When does linear break down?
6. Parameter estimation and sensitivity.
7. System is easy to run.
8. Runs in parallel on variety of platforms and compilers.
9. DART also runs with other models of interest like WRF.

We are seeking collaborators to do CAM science with DART/CAM.