MODIS Data Assimilation at GMAO

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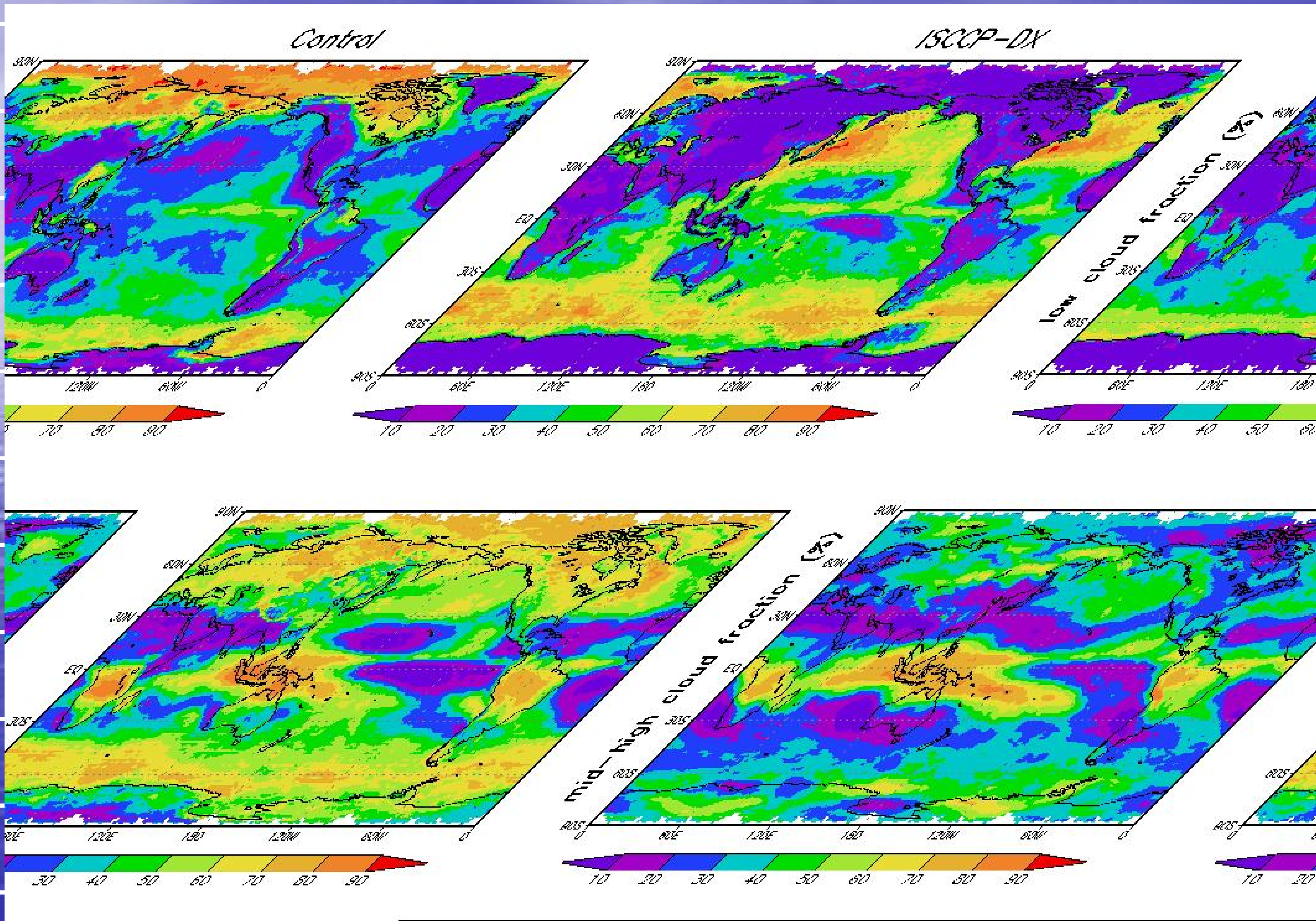
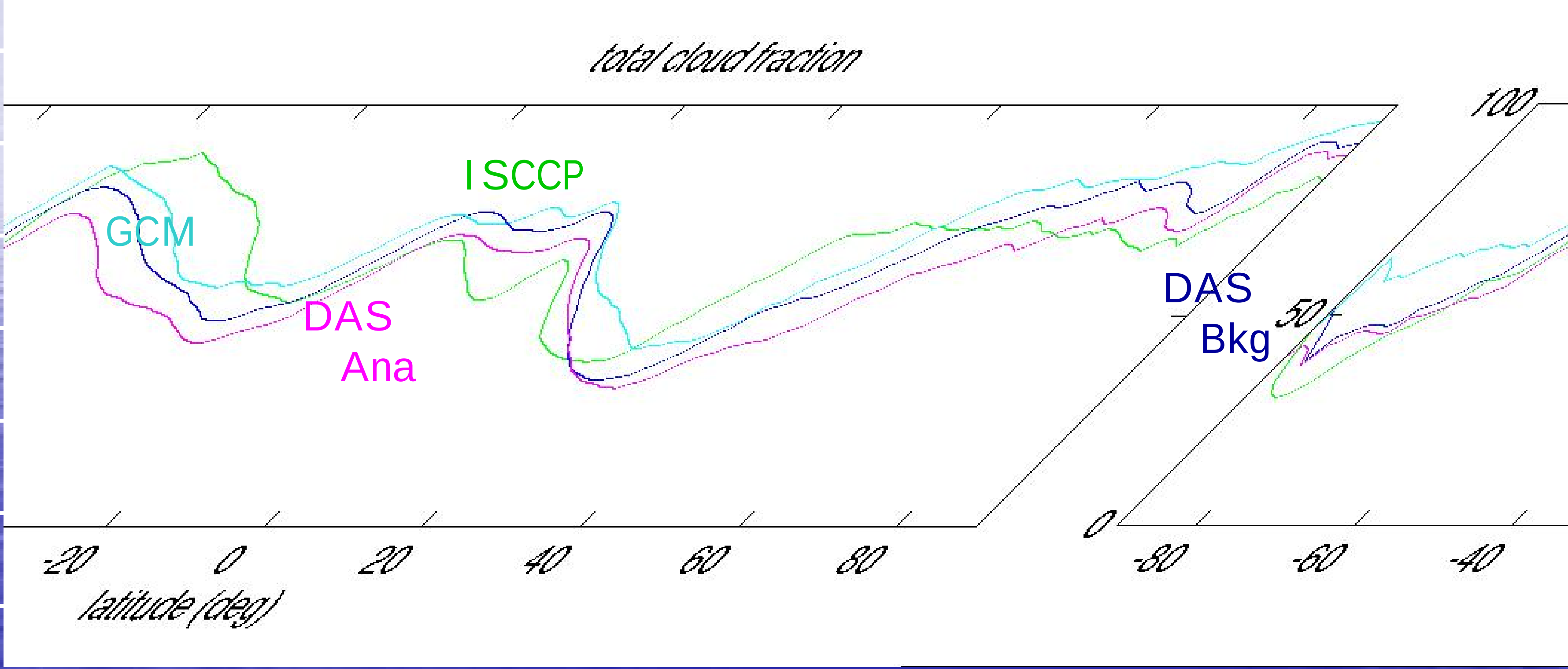
Outline

- Assimilation of cloud observations:
  - ISCCP
  - MODIS
- Assimilation of MODIS wind data
- Aerosol data assimilation

Clouds in the control DAS



From GCM to DAS



Reasons to Assimilate Cloud Data

- Improve cloud analysis/climatology
- Improve cloud/precipitation forecasting (impacting diurnal temperature range, visibility, aviation, agriculture, etc.)
- Improve cloud background for interpretation of satellite radiances
- Improve cloud-radiation parameterizations via constraints by various cloud data types, leading to improved understanding of clouds and climate predictions

Approaches to Cloud Data Assimilation

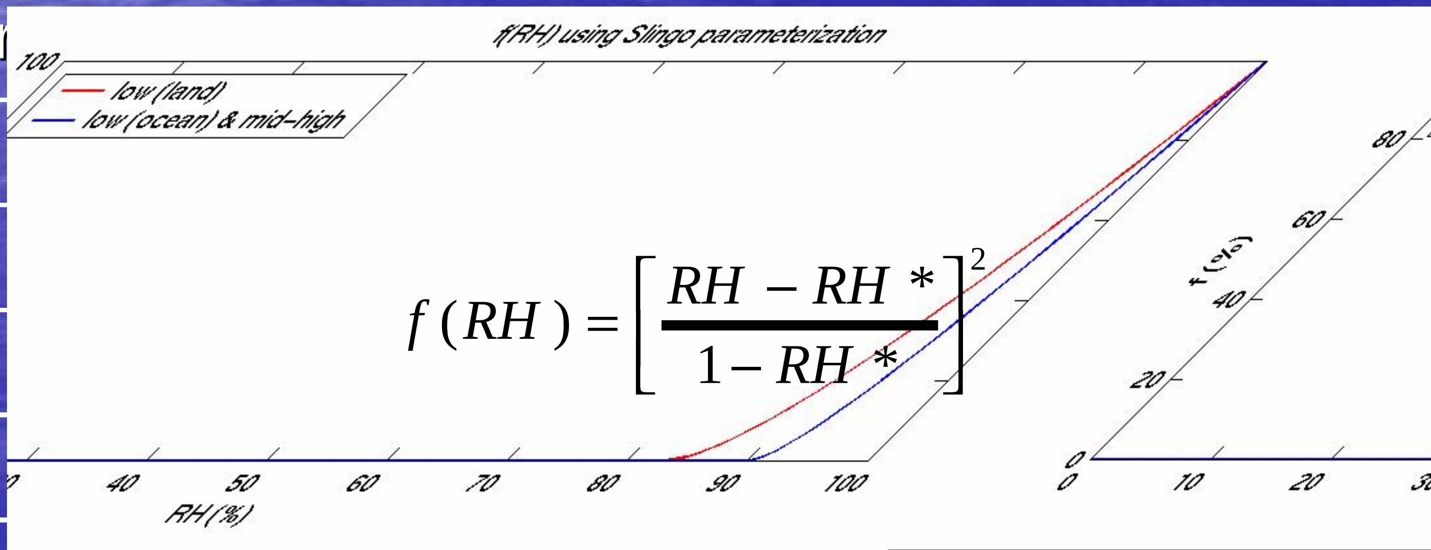
- Assimilation of cloudy radiances:
  - e.g., Janisková et al., 2002
  - Radiative transfer model explicitly accounts for clouds
  - Cloud liquid water and cloud ice included as control variables
- Pseudo-RH/RH correction:
  - e.g., Macpherson et al., 1996
  - Cloud observations used to generate pseudo-RH data consistent with model's diagnostic parameterization, or
  - Cloud observations used to correct co-located RH observations, consistent with model's diagnostic parameterization
  - Cloud fraction parameterization is never modified
- Parameter Estimation:
  - e.g., Wu and Smith, 1992; GMAO
  - Cloud observations used to modify model's diagnostic cloud parameterization
  - RH analysis not directly affected by cloud observations

Parameter Estimation Approach

- Recognize empirical elements of cloud parameterizations that treat unresolved sub-grid-scale moisture variability, uncertain microphysical details, and cloud overlap assumptions.
- Address the resultant biases by slowly varying associated cloud parameters to drive model towards cloud observations.

Cloud Fraction Parameterization

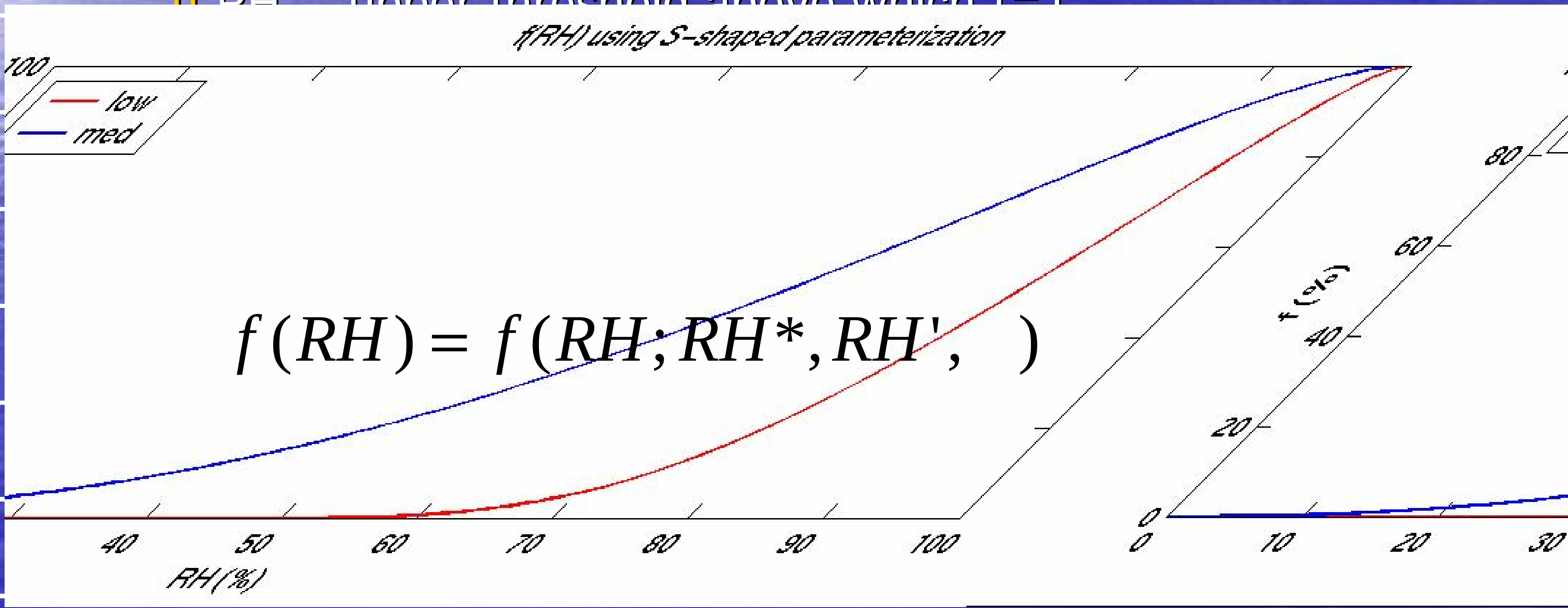
- CCM3 diagnostic cloud fraction parameterization:
  - Convective: function of convective mass flux; adjusts environmental RH
  - Non-convective: based largely on RH, with corrections for vertical velocity, stability, land/ocean, low level str



$$f(RH) = \left[\frac{RH - RH^*}{1 - RH^*} \right]^2$$

Cloud Parameter Estimation

- Revised diagnostic parameterization:
  - Quadratic f(RH) is generalized to a smoothly asymptoting S-shaped polynomial, depending on 3 parameters:
    - ü RH* – critical RH below which f=0
    - ü RH' – upper threshold above which f=1



$$f(RH) = f(RH; RH^*, RH', \quad)$$

Adaptive Parameter Estimation

- Sequential algorithm:

$$\alpha^f(t_{n+1}) = \alpha^a(t_n)$$ persistence

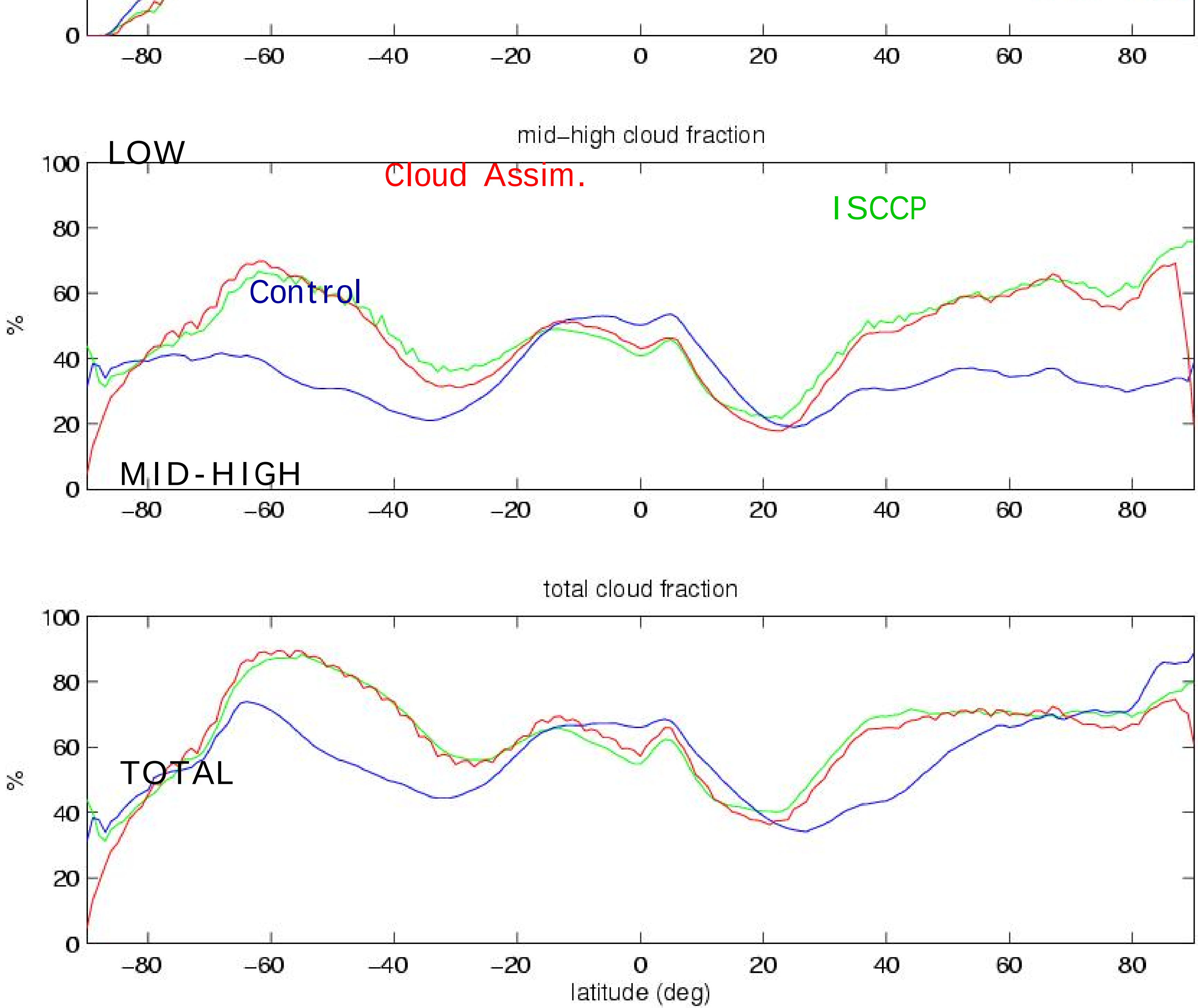
$$\alpha^a(t_{n+1}) = \alpha^f(t_{n+1}) + \delta\alpha$$ parameter analysis

- Increment $\delta\alpha$ determined by minimizing the cost function:

$$J(\delta\alpha) = (\delta\alpha)^T B^{-1}(\delta\alpha) + \left(C^{obs} - f(RH;\delta\alpha)\right)^T R^{-1}\left(C^{obs} - f(RH;\delta\alpha)\right)$$

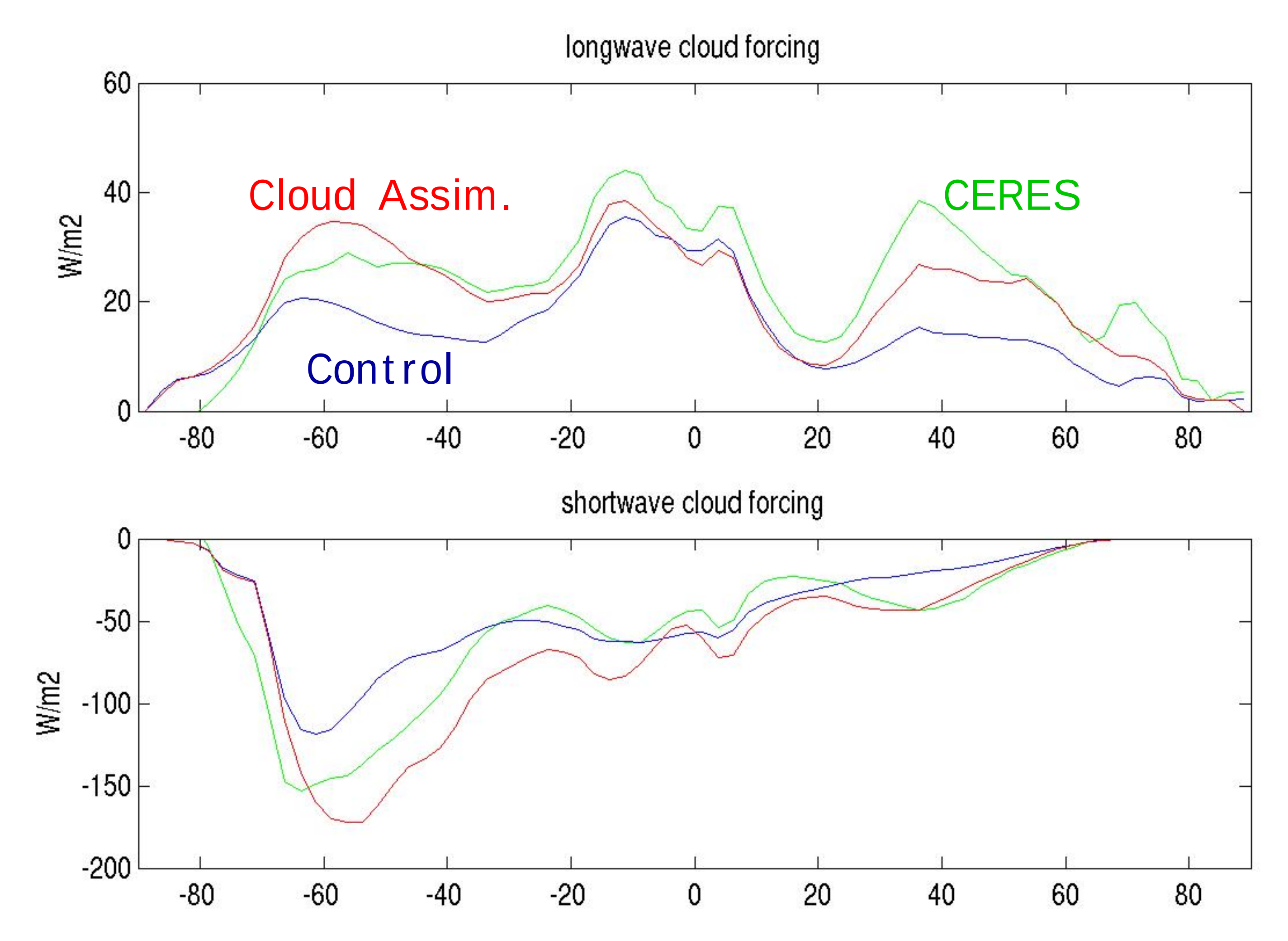
Parameter Estimation Details

- Three stage estimation procedure:
  - Cloud Fraction (ISCCP or MODIS)
  - Liquid water Path (SSM/I)
  - Cloud optical depth (ISCCP or MODIS)
- Cloud fraction estimation occurs in two pressure bands: low and mid-high. Estimated from ISCCP-DX data to approximately correct for low cloud obscuration.

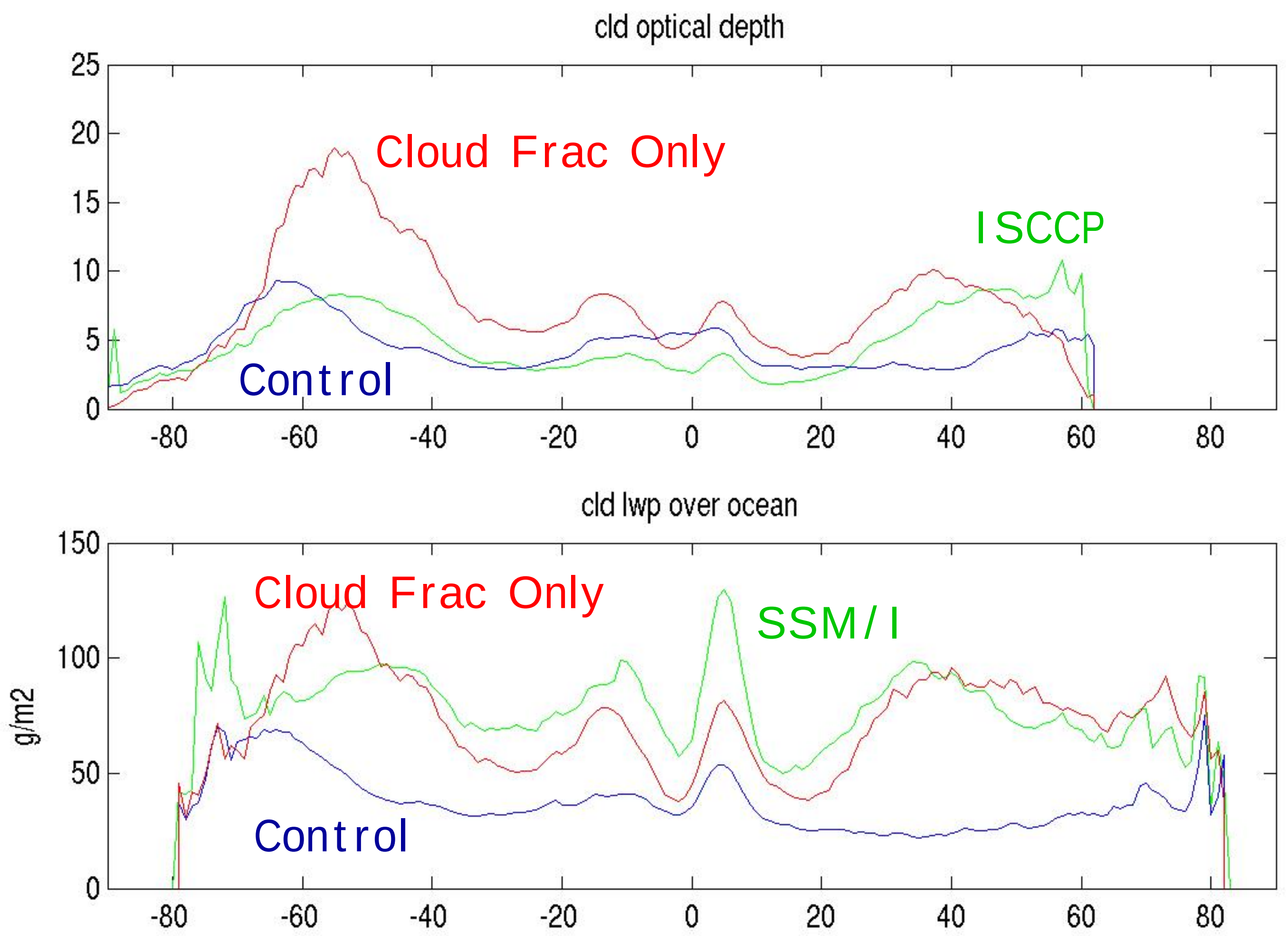


0
-80
-60
-40
-20
0
20
40
60
80
mid-high cloud fraction
LOW
Cloud Assim.
ISCCP
Control
MID-HIGH
%
100
80
60
40
20
0
total cloud fraction
TOTAL
latitude (deg)

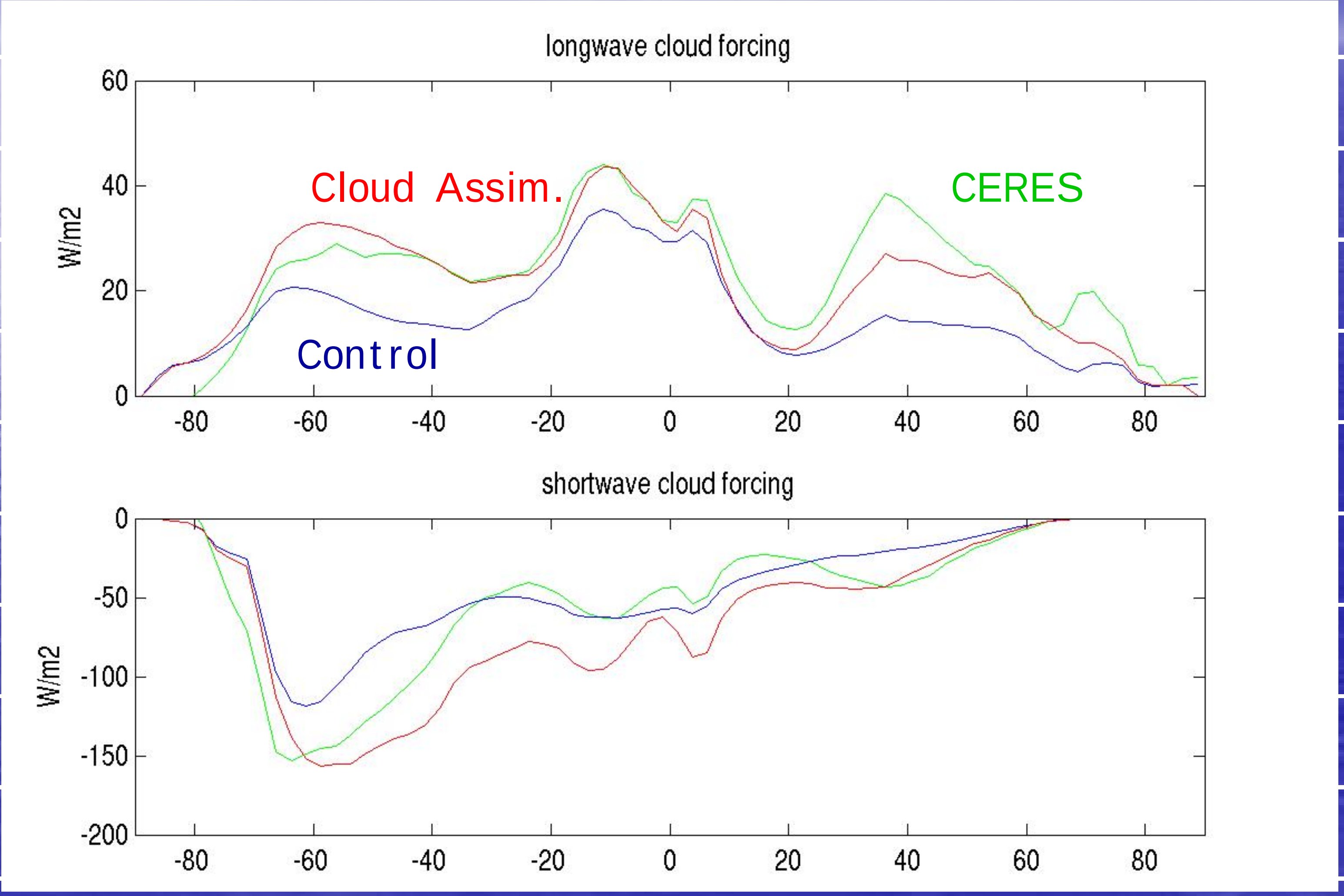
CERES TOA: Cloud Fraction Only



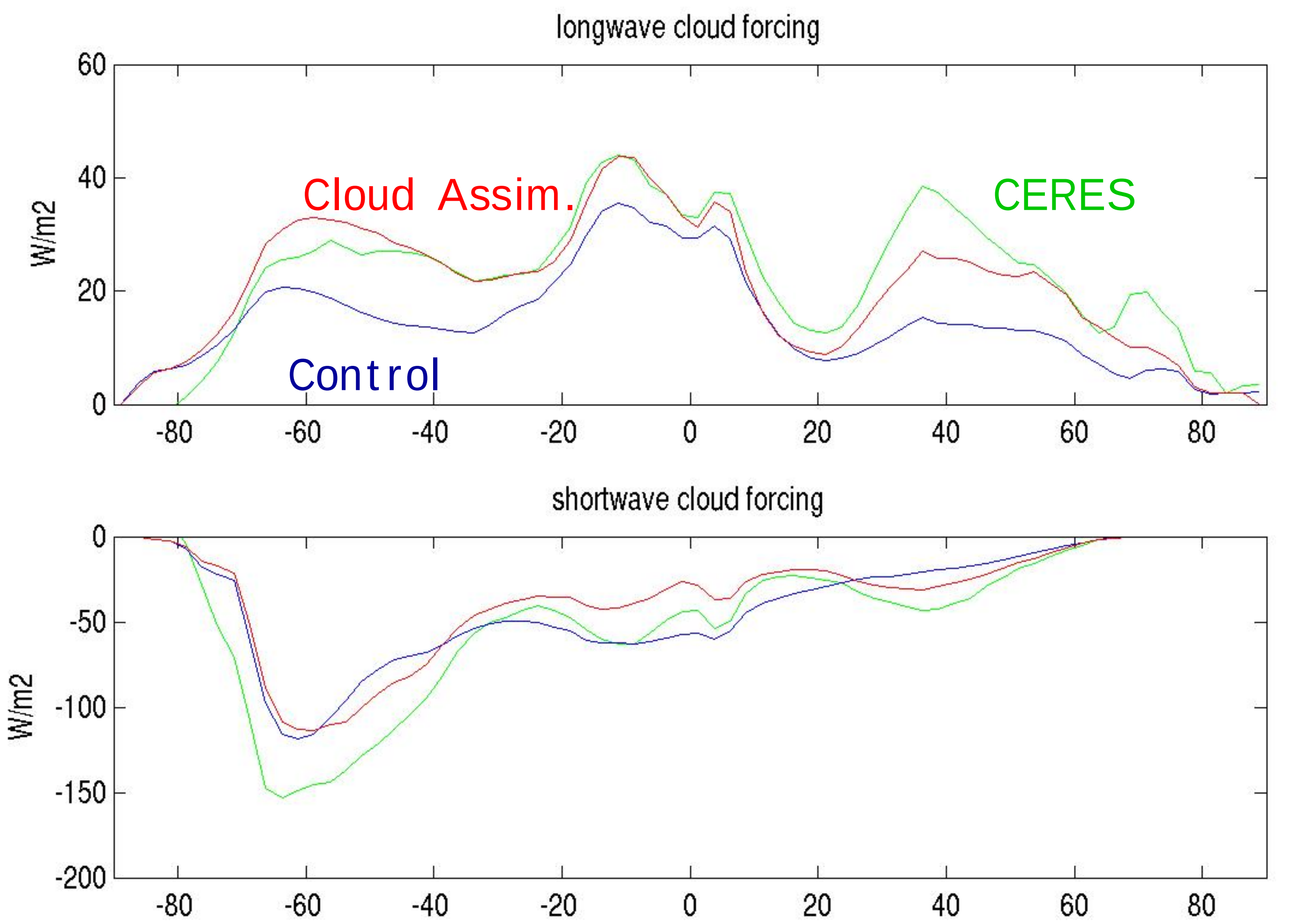
Cloud Optical Depth/Liquid Water Path



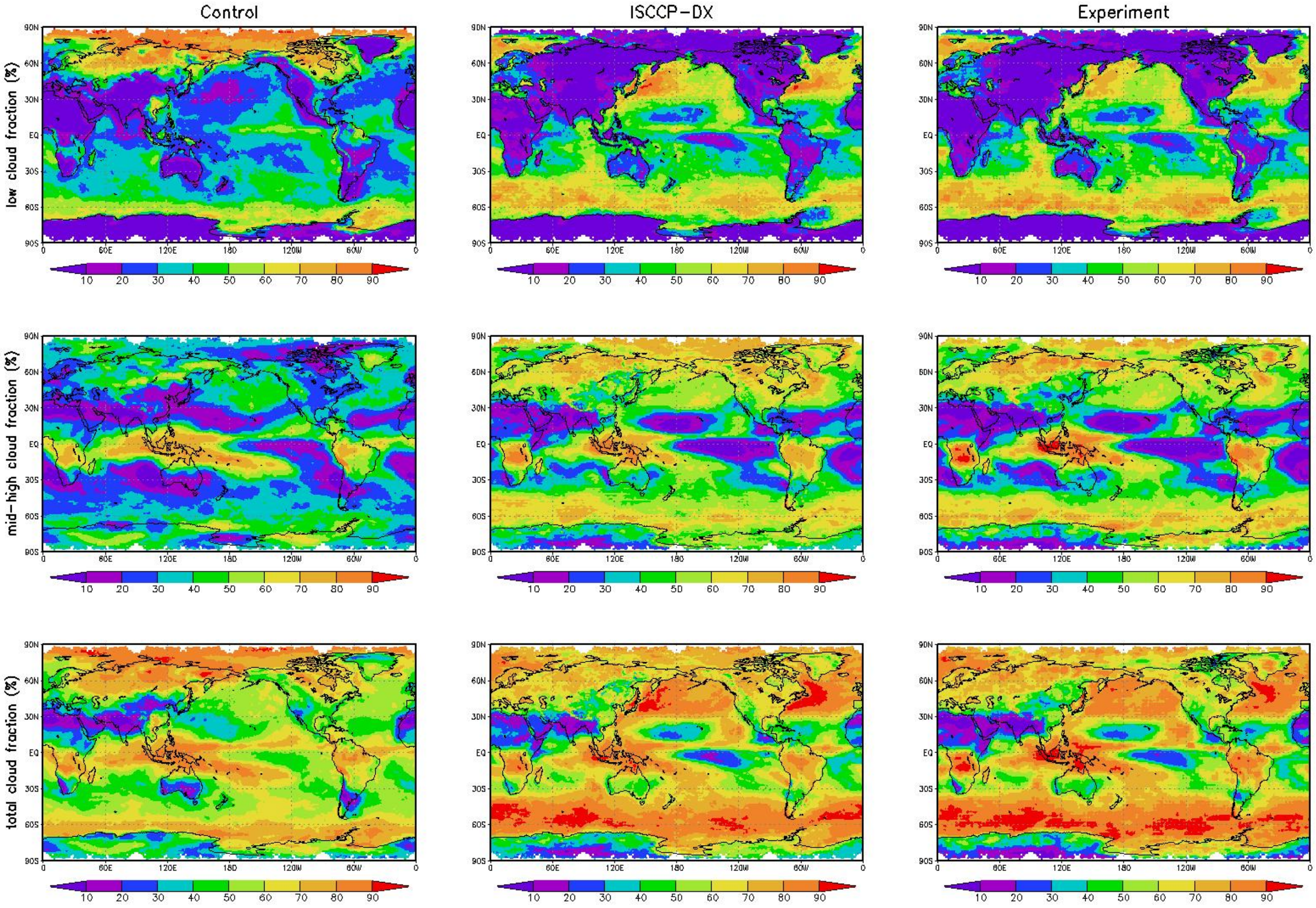
CERES TOA: CF+CLW Data



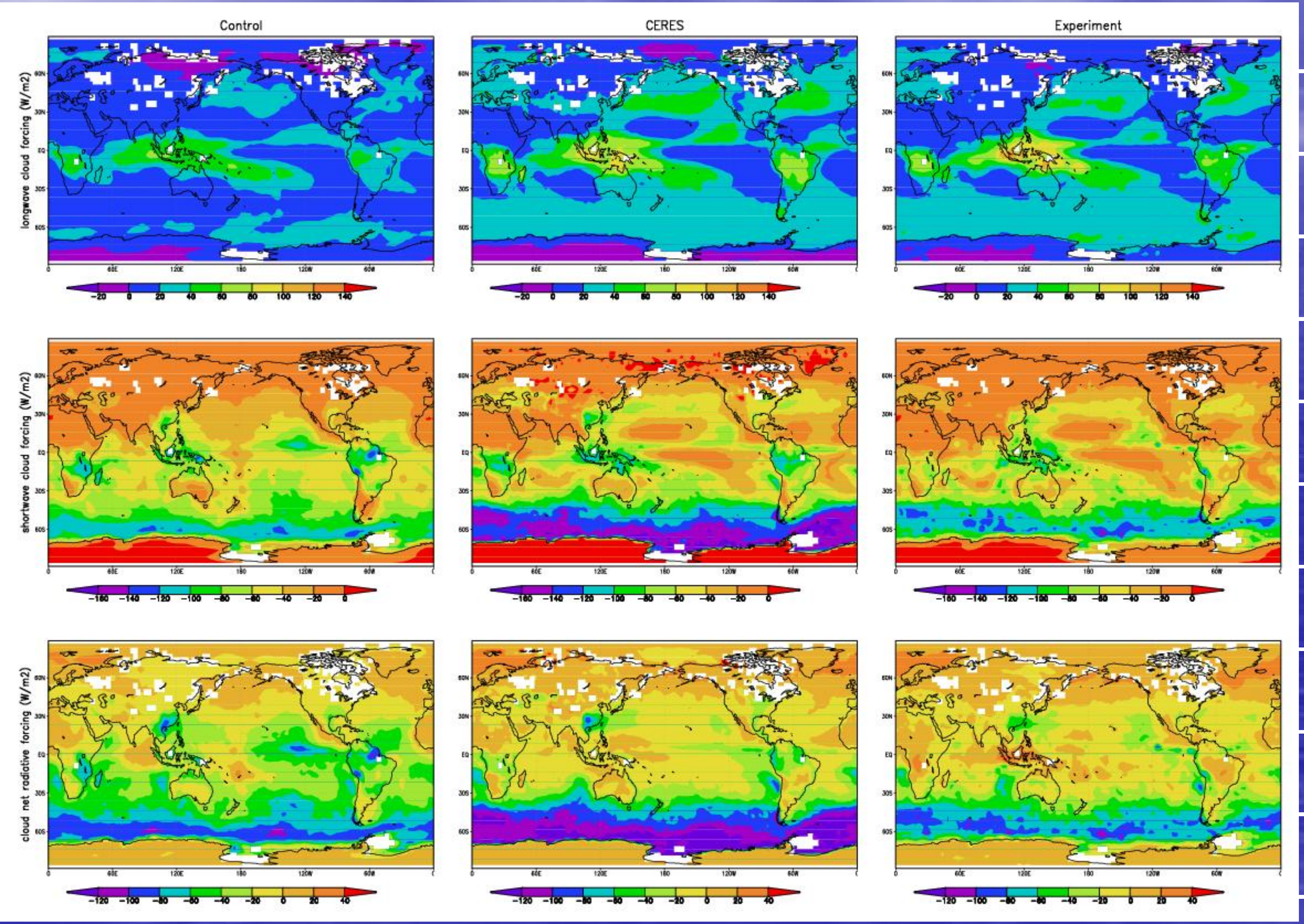
CERES TOA: Cloud+CLW+COD



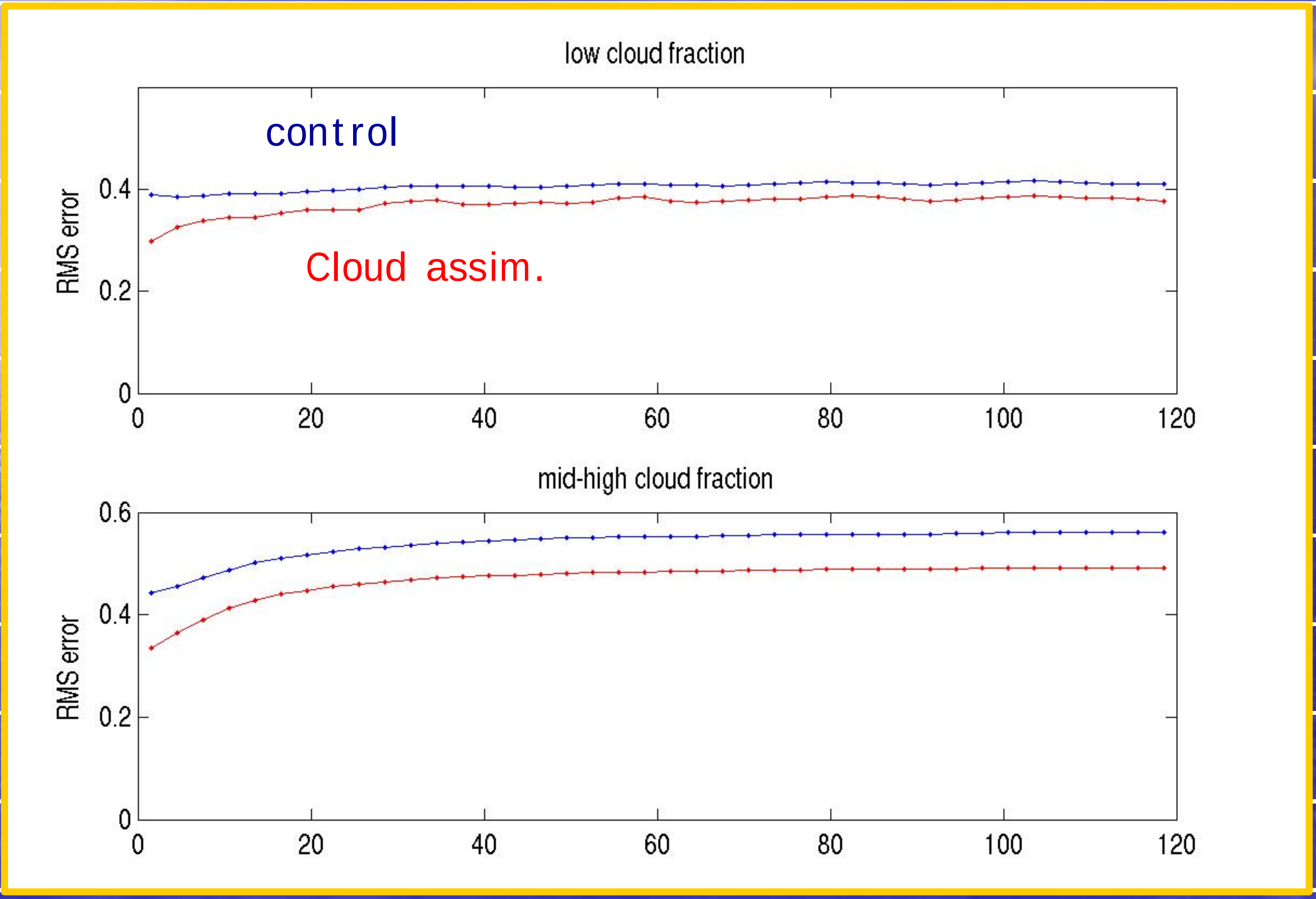
Cloud Fraction



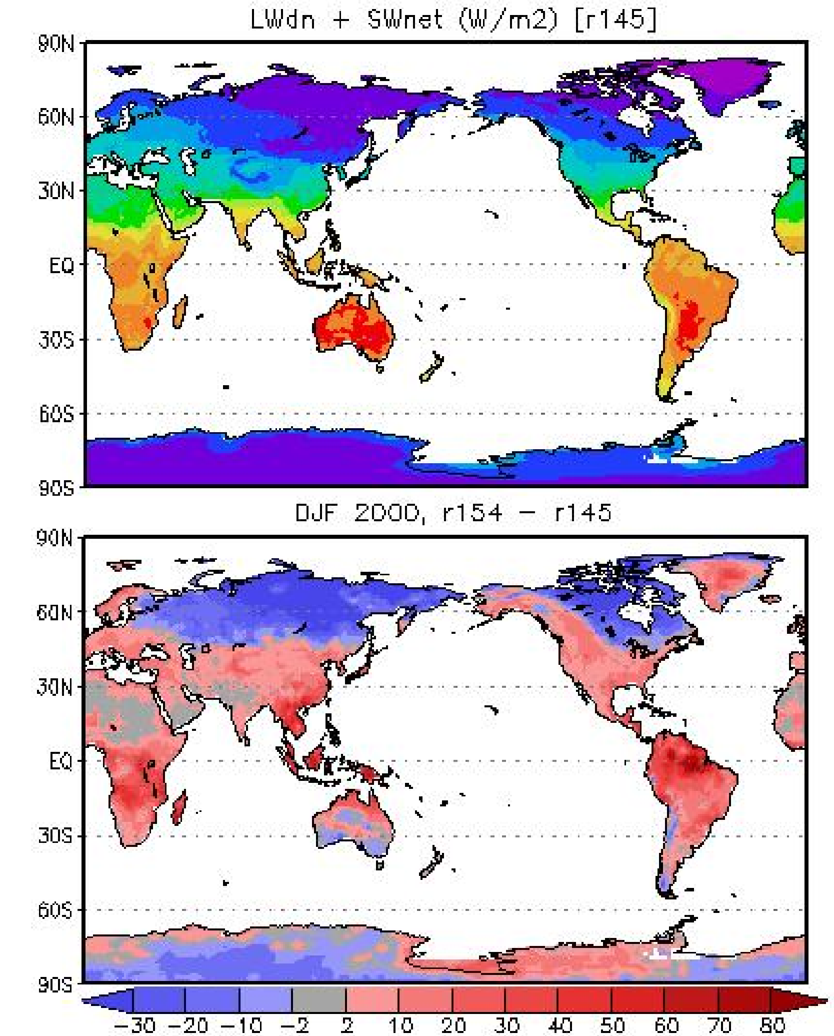
Cloud Forcing: CERES

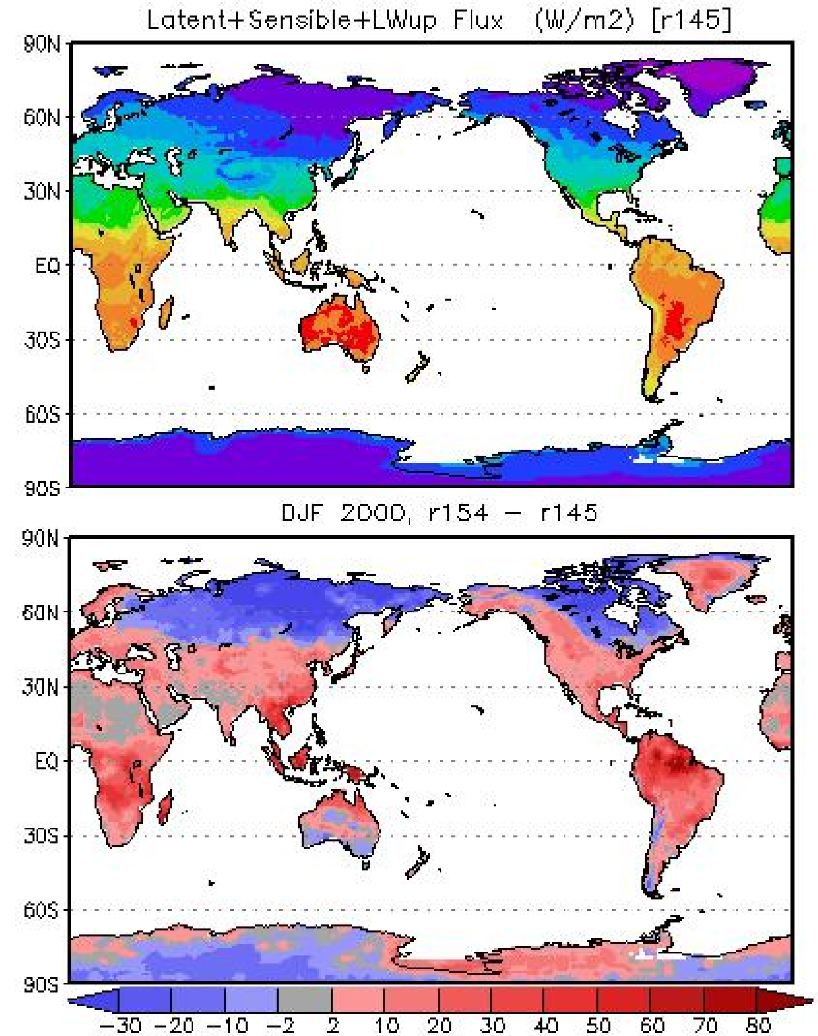


Cloud Fraction: Forecast Skill



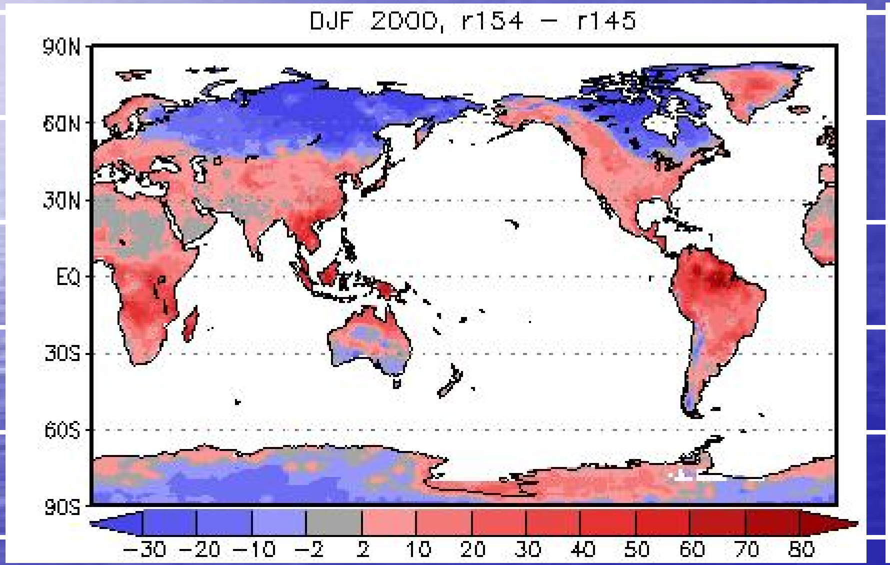
Land Surface Radiation Budget



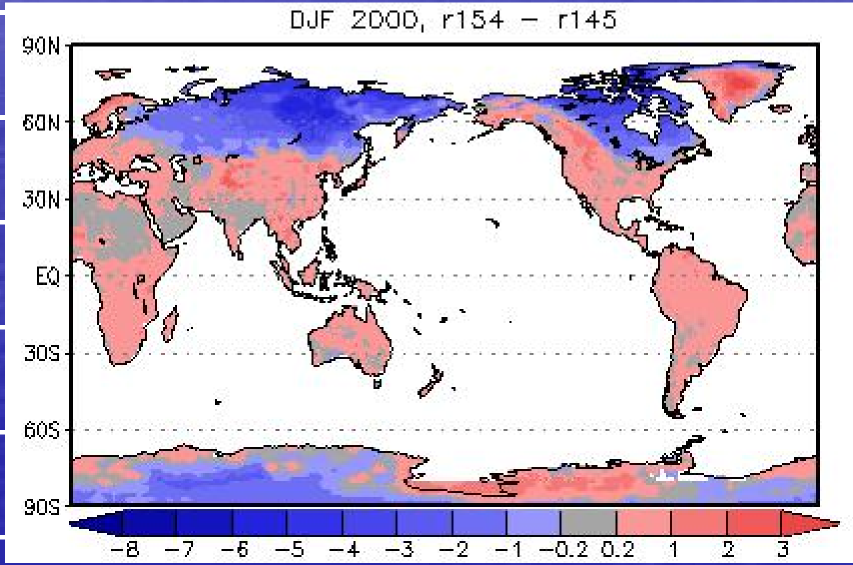


Skin Temperature Response

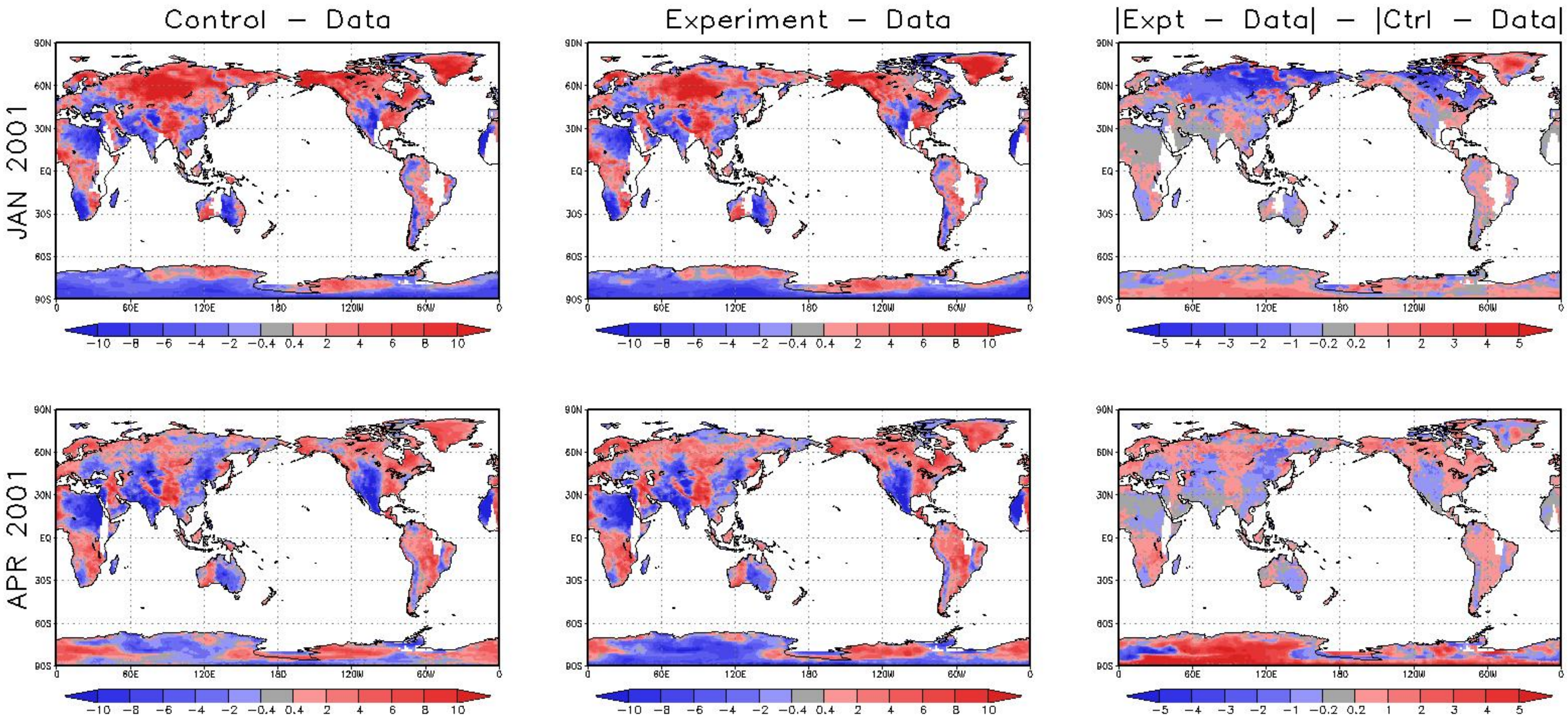
Latent+Sensible+LW up Delta



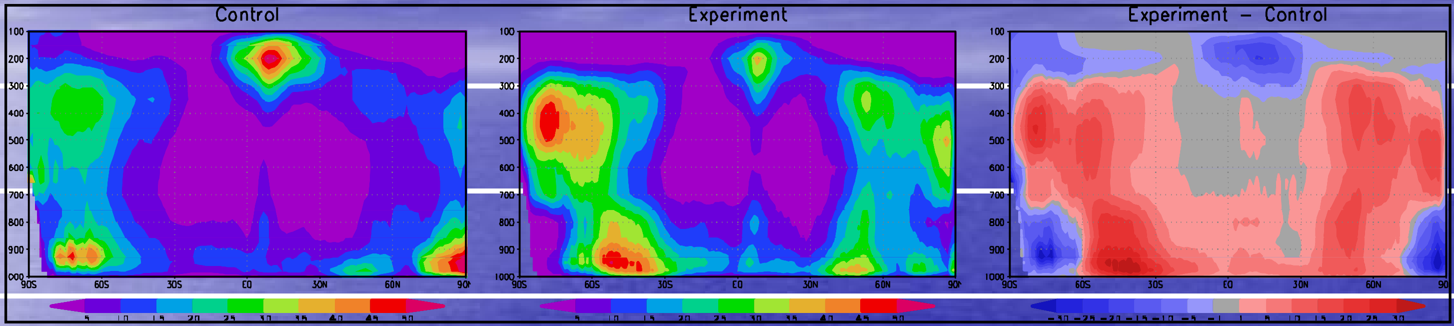
Skin Temperature Delta



CERES: Skin Temperature



Vertical Cloud Distribution



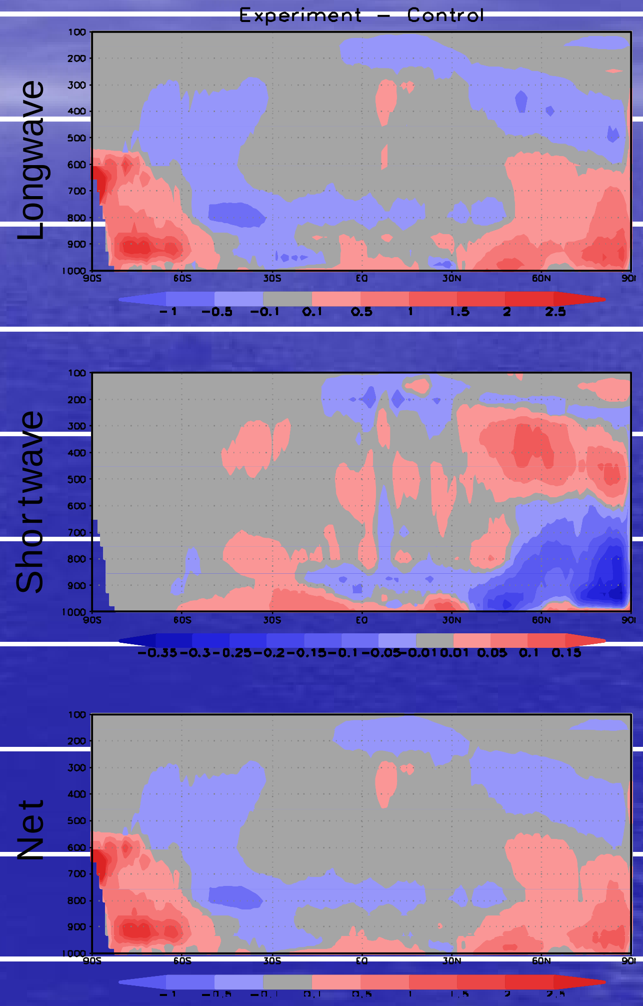
Zonal-height plots for July 2000 of fvDAS cloud fraction (%) for the control run (left) and a run assimilating ISCCP-DX derived cloud fraction and optical depth and SSM/I liquid water path (center). The right panel shows the difference.

The following changes are most evident:

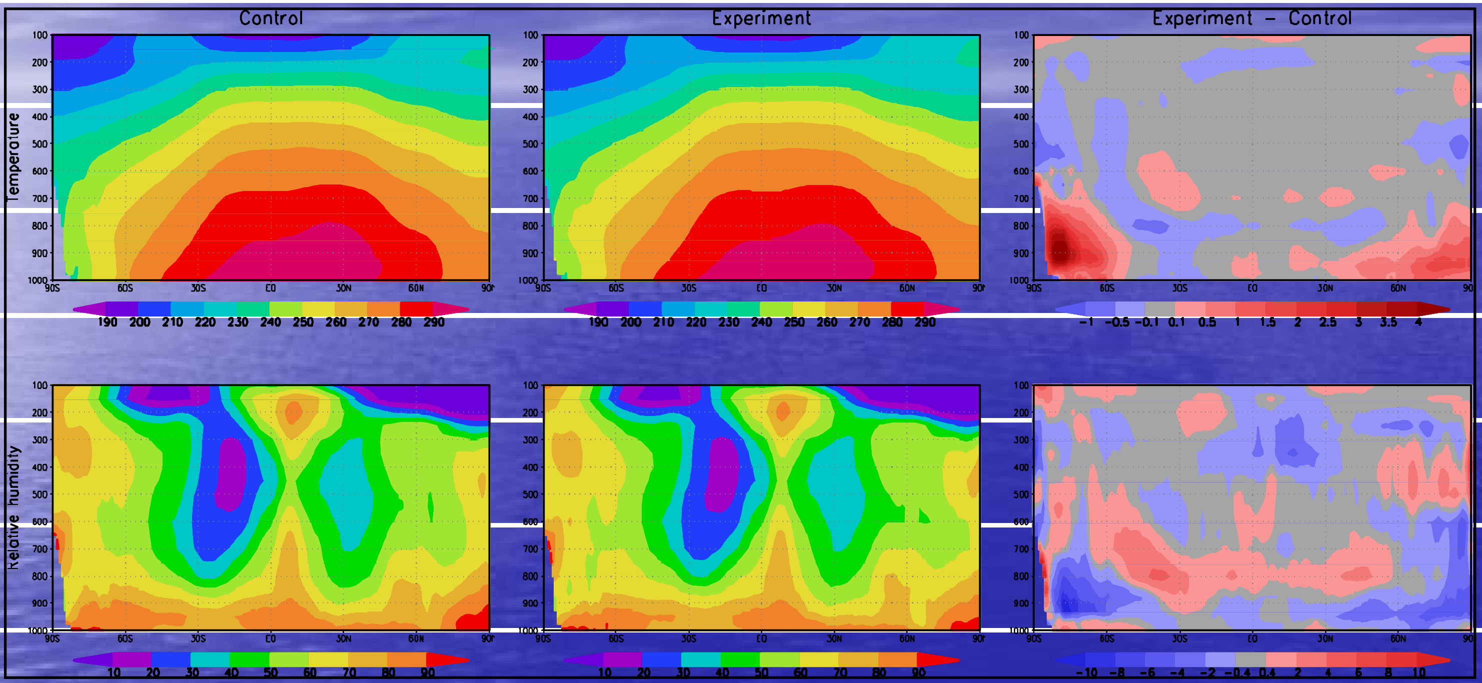
1. a decrease in tropical cirrus;
2. a general increase in low-level cloud, except at high latitudes where there is a decrease. The increase is strongest in mid-latitudes and especially in the southern hemisphere;
3. an increase in mid-level cloudiness in mid- and high-latitudes.

Heating Rate Changes

Zonal-height plots for July 2000 of radiative heating rate (K/day) differences between a cloud assimilating run and the control run. The heating rates are generally consistent with longwave cooling/heating at cloud top/base and heating by shortwave absorption within clouds.

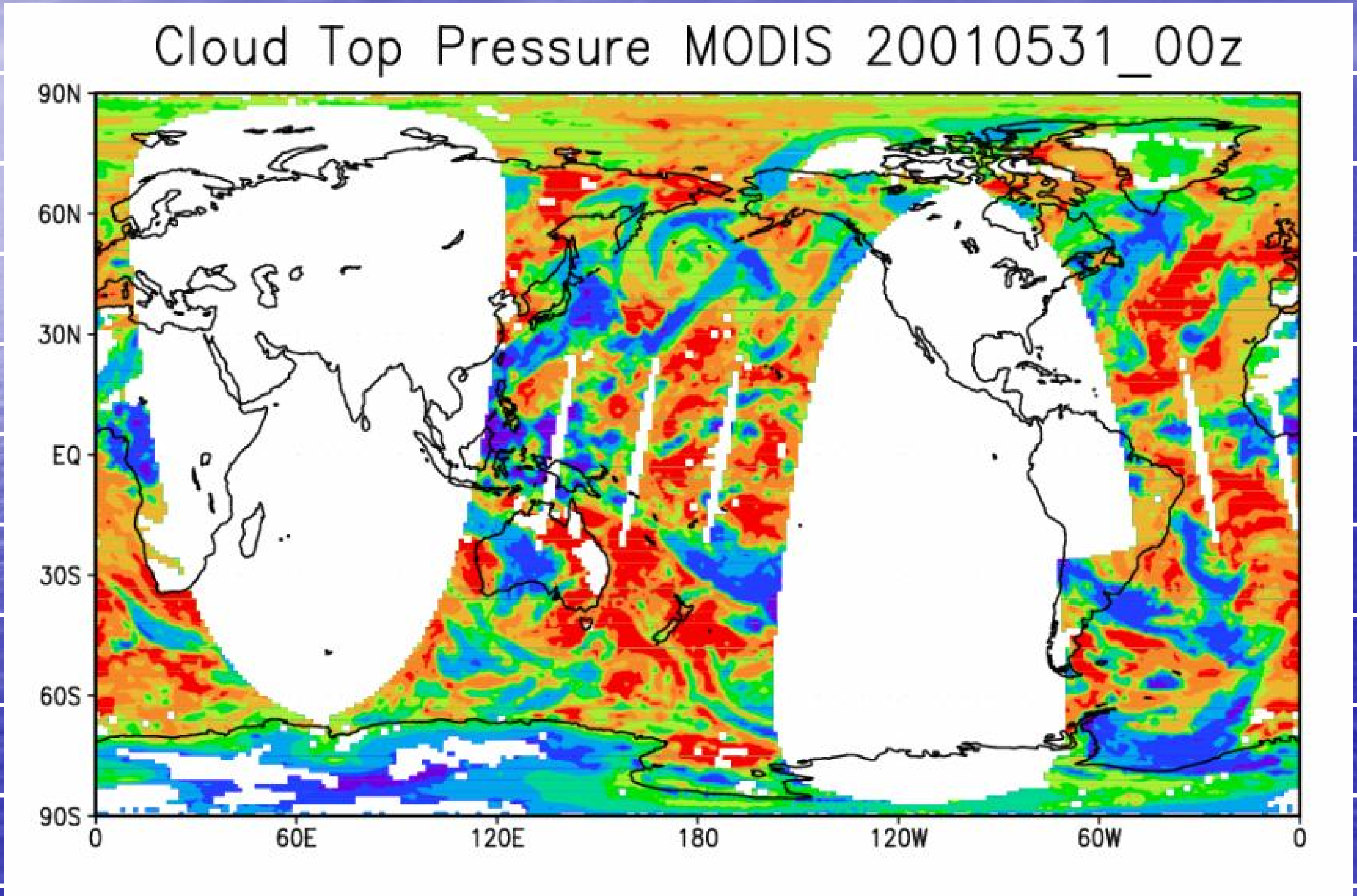


Temperature and RH changes

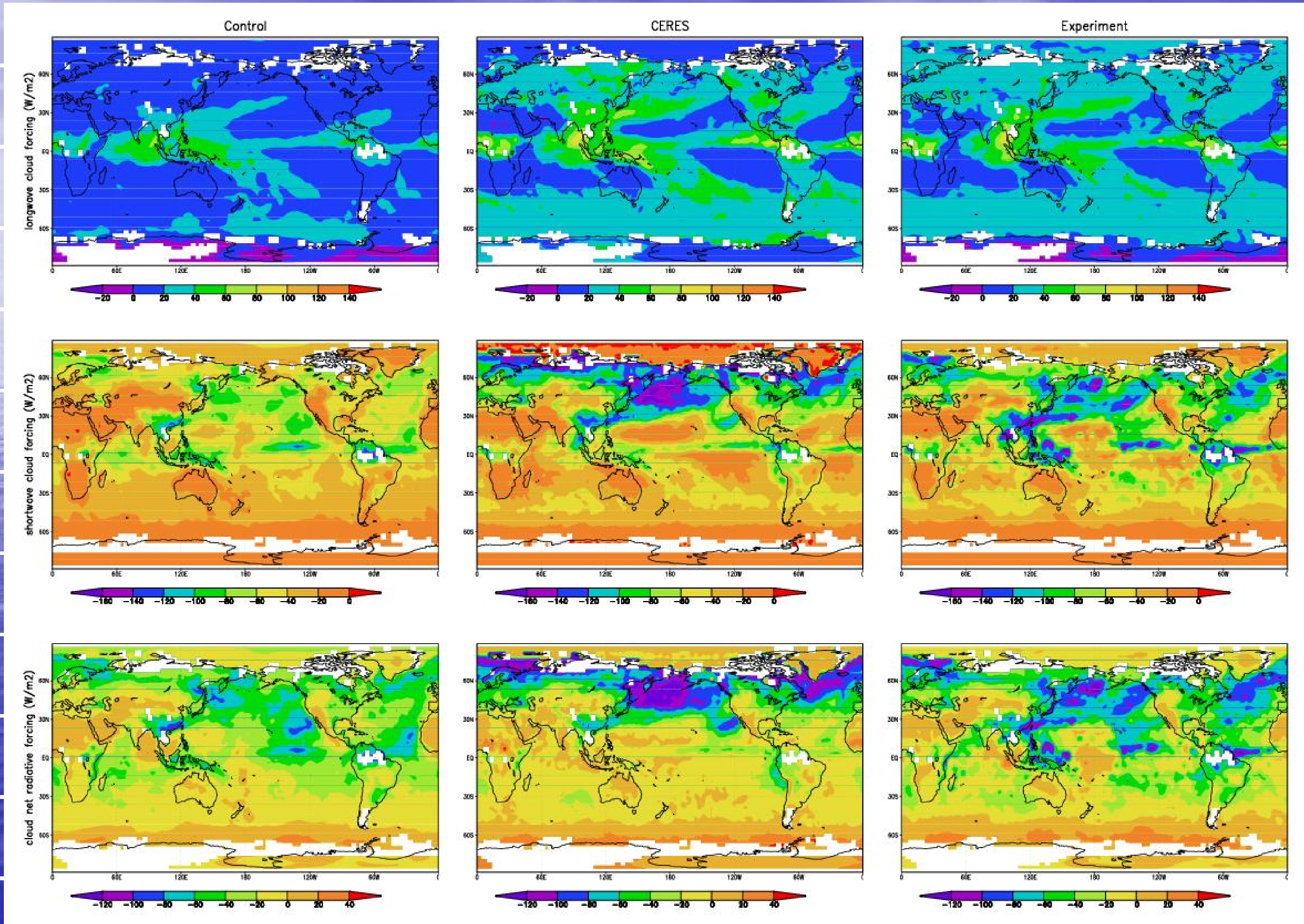


Zonal-height plots for July 2000 of temperature (K) and relative humidity (%) for the control run (left) and a run assimilating ISCCP-DX derived cloud fraction and optical depth and SSM/I liquid water path (center). The right panel shows the difference. The temperature change is reasonably consistent with the change in net radiative heating rate. Changes in relative humidity (bottom panel) seem to correlate with changes in cloudiness for high-latitudes and tropical cirrus, and with a deepening in the boundary layer for mid- to low-latitude low-level clouds.

MODIS (Terra) Coverage



Cloud Forcing: MODIS vs CERES



Future Plans

- Extend algorithm to new statistical-prognostic cloud parameterization in GEOS-5
- Explore other MODIS observables (Water path, Effective radius)
- Use AMSR-E LWP retrievals
- Convective clouds: merge with precipitation assimilation (Arthur Hou and Sara Zhang)
- Assumed-PDF cloud parameterizations

MODIS winds assimilation

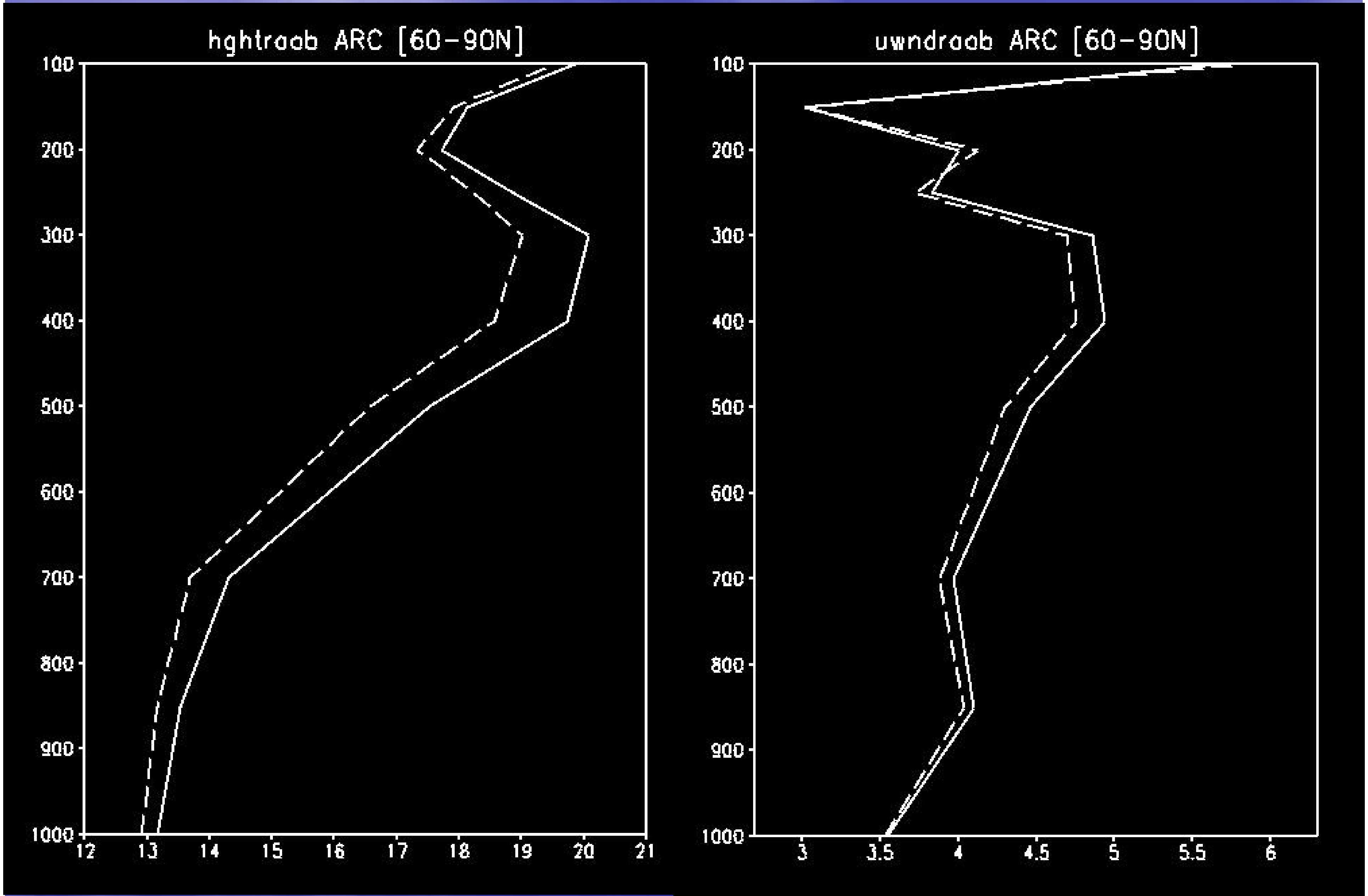
Lars Peter Riishojgaard and Yan-Qiu Zhu
GMAO

GMAO MODIS winds experiments

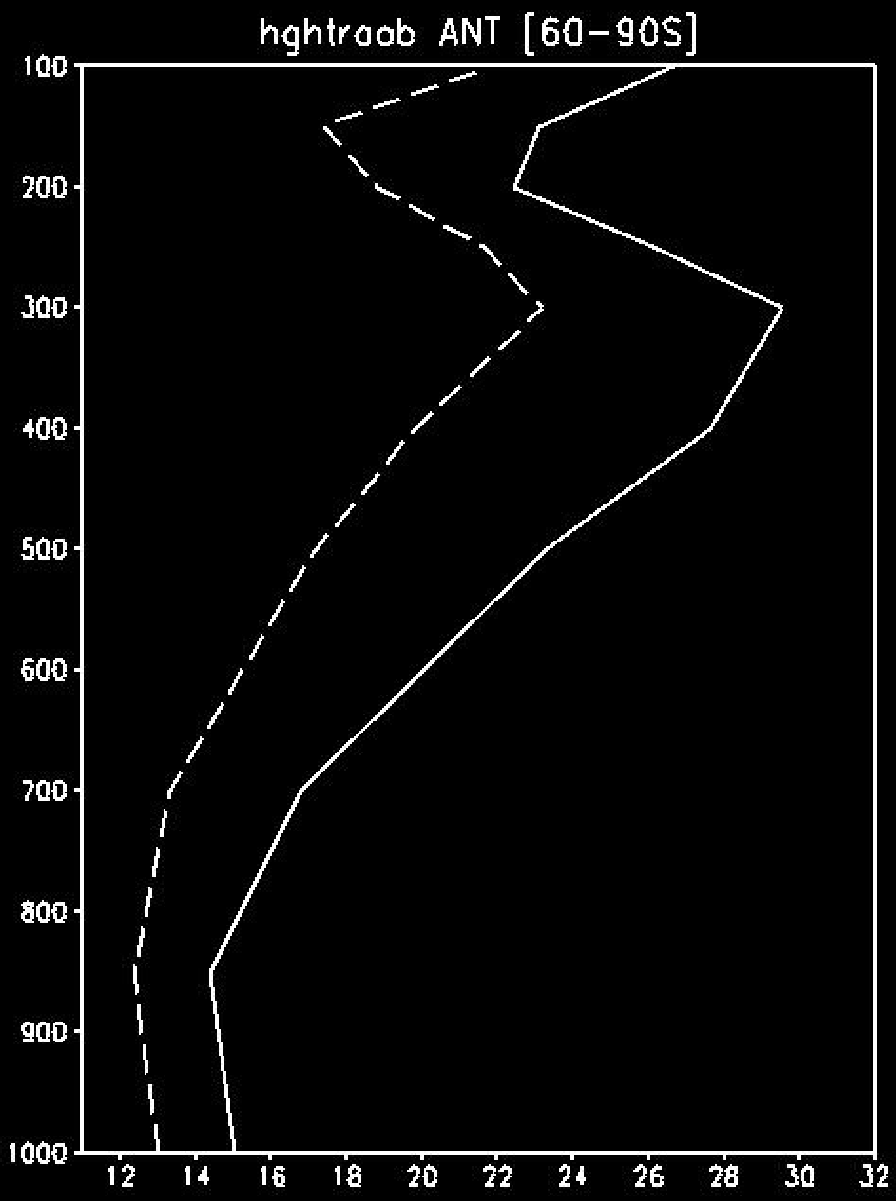
- MOWSAP (MODIS Winds Special Acquisition Period): November 8, 2003-January 31, 2004
  - Winds generated by CIMSS and by NESDIS (pre-operational mode)
    - Same algorithm, different code bases
    - Different backgrounds for QC and height assignment
  - Winds generated from MODIS Aqua and MODIS Terra imagery
  - Assimilation experiments by GMAO, ECMWF, Met Office, CMC
  - Experimental setup: 5-day forecast every other day; 42 members in the ensemble

Diagnostics

- External verification: Observation minus forecast residuals (OmF) versus RAOBs
- Average forecast skills (anomaly correlation coefficients) verified against self, NCEP
- Time series of day-5 anomaly correlations



hghtraob ARC [60-90N]
uwndraob ARC [60-90N]
100
200
300
400
500
600
700
800
900
1000
12
13
14
15
16
17
18
19
20
21
3
3.5
4
4.5
5
5.5
6


hghtraob ANT [60-90S]
100
200
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500
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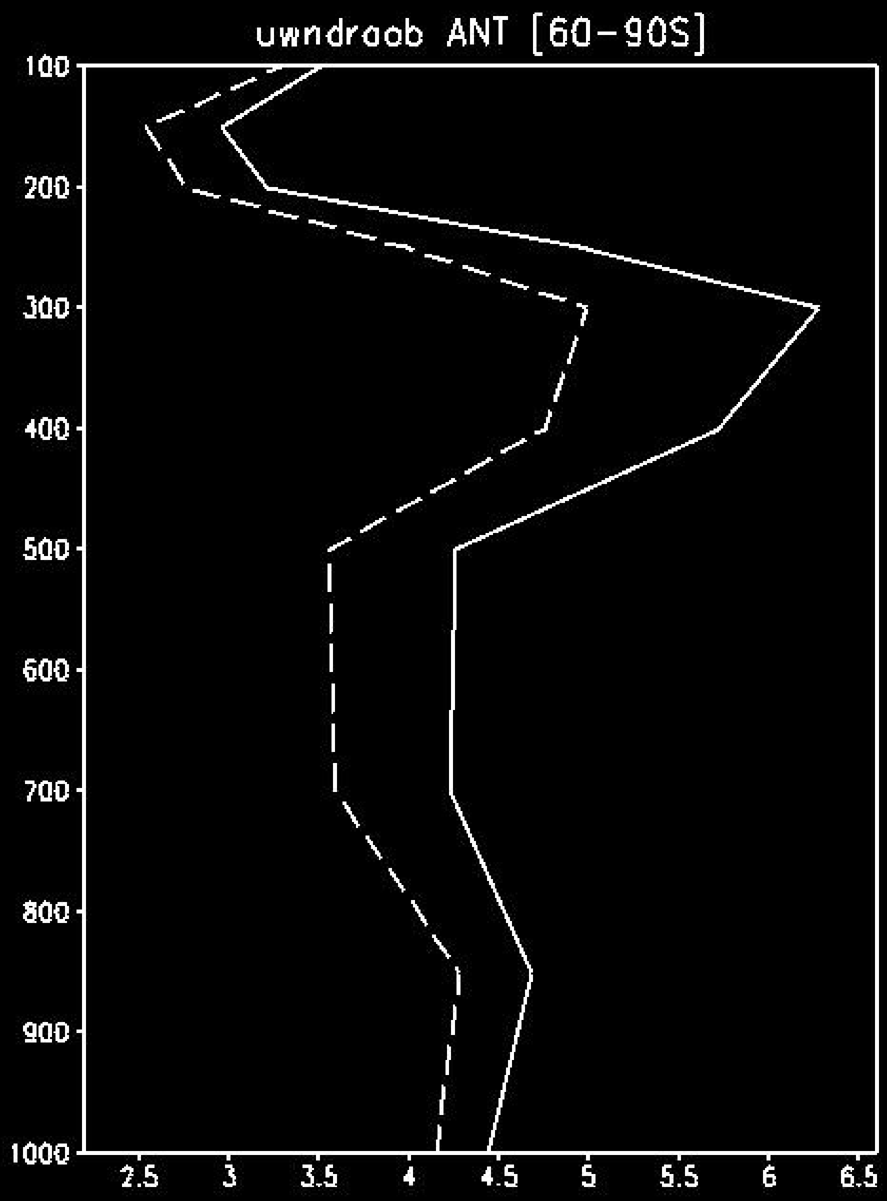
700
800
900
1000
12 14 16 18 20 22 24 26 28 30 32


uwndraob ANT [60-90S]
100
200
300
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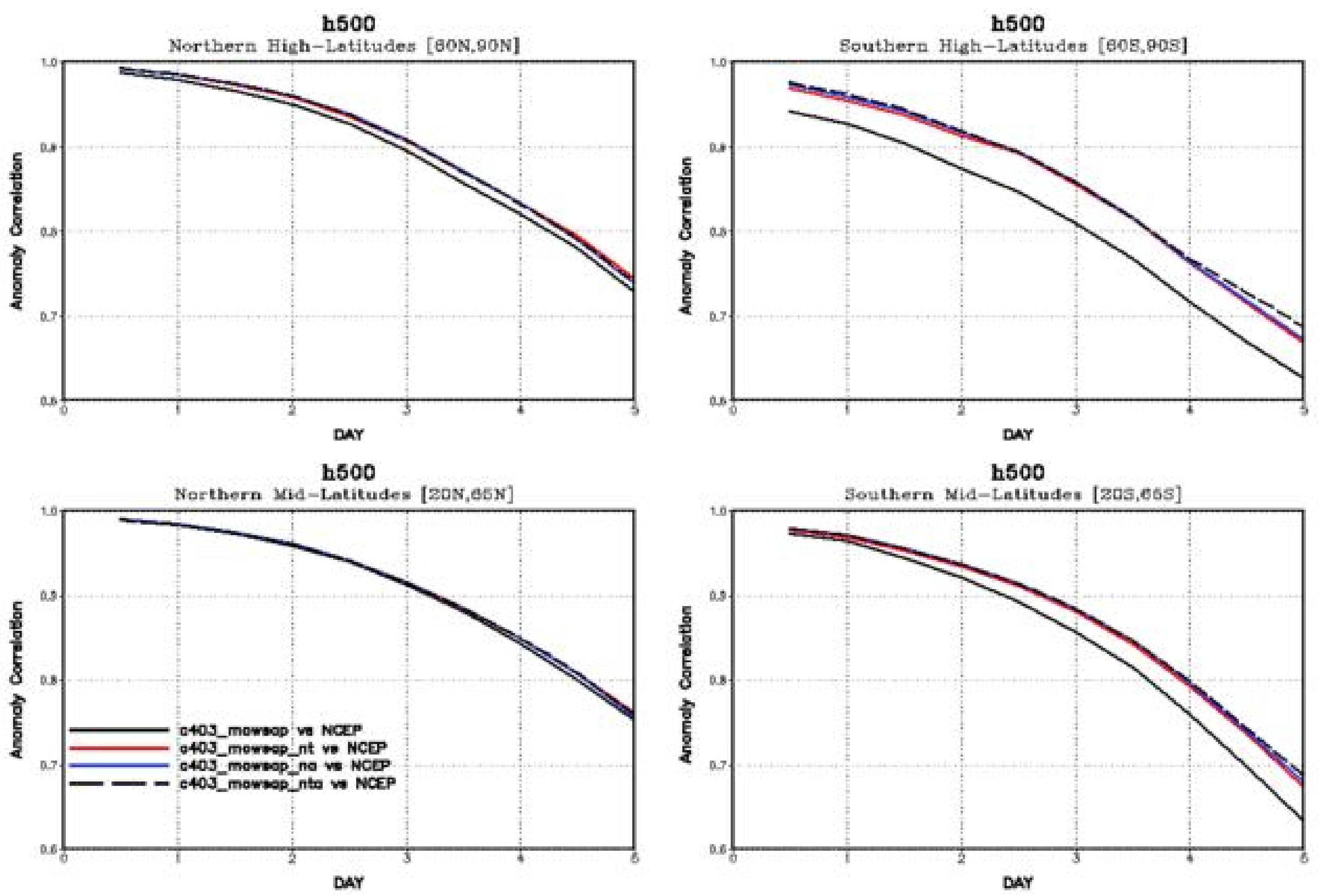
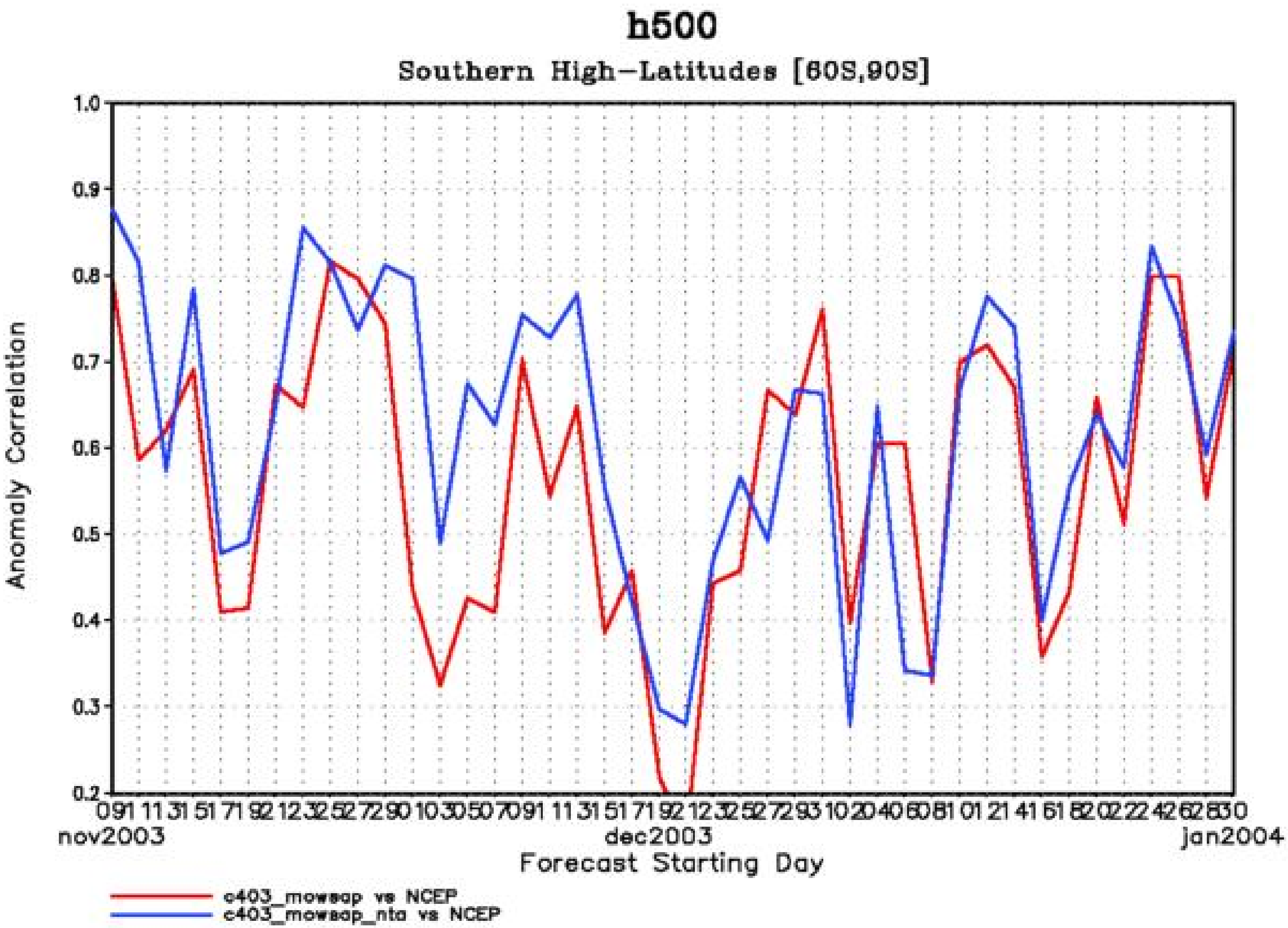
500
600
700
800
900
1000
2.5 3 3.5 4 4.5 5 5.5 6 6.5



h500
Northern High-Latitudes [60N,90N]
h500
Southern High-Latitudes [60S,90S]
h500
Northern Mid-Latitudes [20N,65N]
h500
Southern Mid-Latitudes [20S,65S]
Anomaly Correlation
DAY
c403_mowsap vs NCEP
c403_mowsap_nt vs NCEP
c403_mowsap_no vs NCEP
c403_mowsap_nto vs NCEP


h500
Southern High–Latitudes [60S,90S]
Anomaly Correlation
Forecast Starting Day
nov2003
dec2003
jan2004
c403_mowsap vs NCEP
c403_mowsap_nta vs NCEP

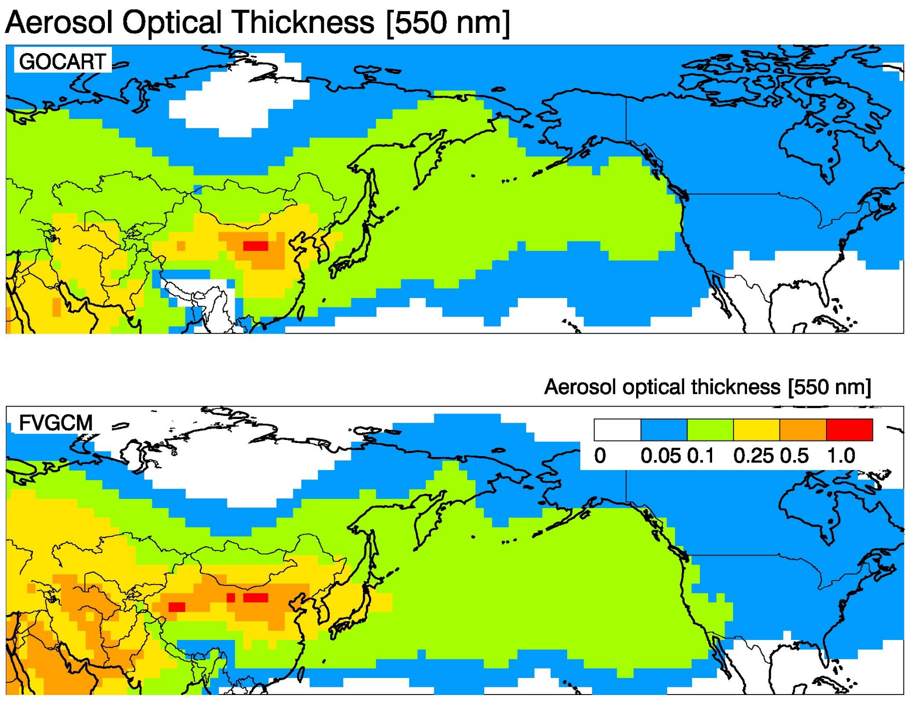
Summary

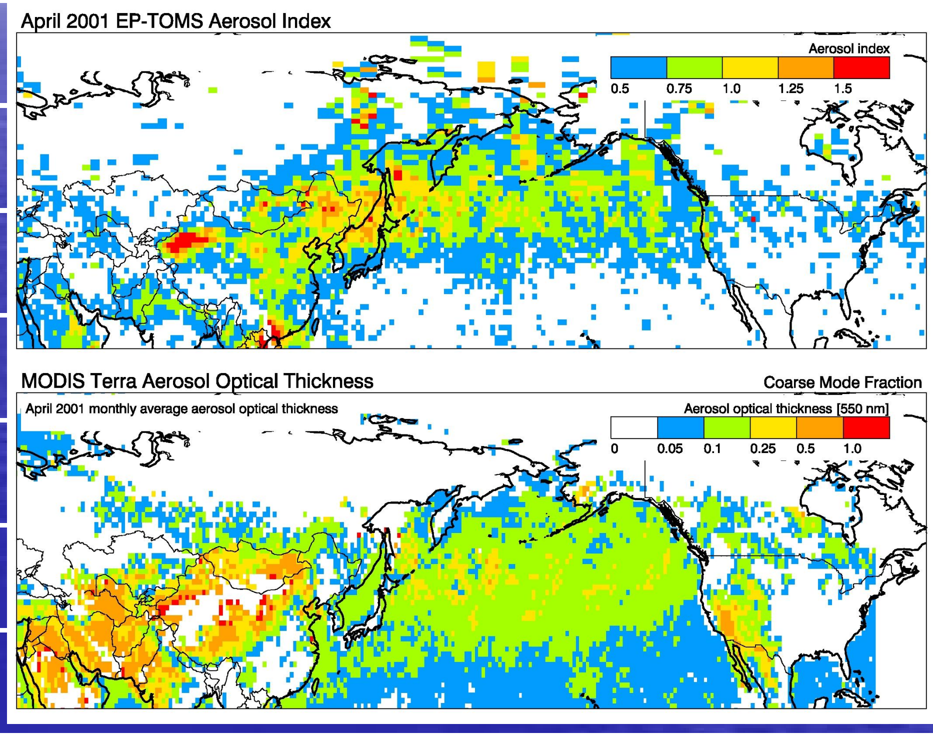
- MODIS winds complement other observations in the high latitudes; more so in the SH than in the NH due to the current data sparsity
- Based on independent verification statistics the, quality of the information is acceptable
- Positive overall contribution to forecast skill
  - Substantial impact in the SH
  - Impact extends to entire hemisphere
  - Improvements in average forecast skill results primarily from improving the skill of the worst forecasts
- Timeliness remains an important issue; current delay is 4-6 hours; some improvement possible via use of Direct Broadcast capability

Aerosol Data Assimilation at GMAO

- Emphasis on estimation of
  - Global, 3D aerosol concentrations
  - Aerosol sources and model parameters
  - Observing System Simulation Experiments (OSSE)
- Aerosol Transport model
  - Aerosols transported on-line within GMAO's Finite-volume Data Assimilation System (fvDAS)
  - Aerosol modules from GOCART:
    - Absorbing aerosols: Dust and black carbon
    - Non-absorbing aerosols: sulfates, organic carbon, sea-salt

Monthly AOT: ACE Asia (April 2001)

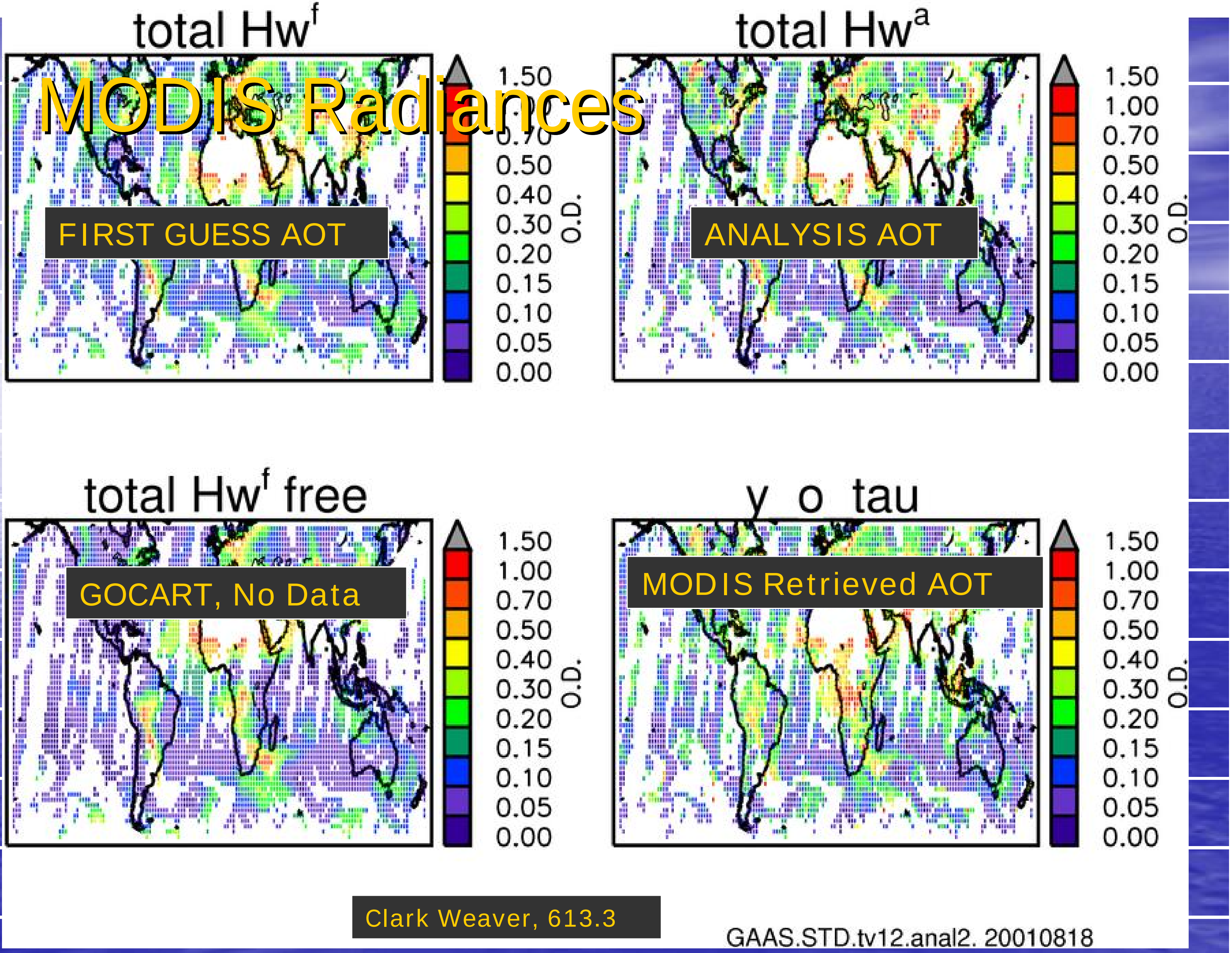




Aerosol DAS, cont.

- Aerosol Observing Systems:
  - TOMS: Aerosol index and 380 nm radiances
  - MODIS: Optical Depth retrievals or radiances
  - AERONET: Optical Depth and Index of Refraction
- Assimilation Methodology
  - Physical-space Statistical Analysis System (PSAS)
  - Anisotropic/flow dependent error statistics
  - Bias estimation (indirect information on sources)
  - Joint estimation source defects
- Current status:
  - off-line assimilation of MODIS data in GOCART (Weaver)

MODIS Radiances



Clark Weaver, 613.3

Summary

- Cloud observations have a very positive impact on the fvDAS cloud radiative forcing and land surface
- MODIS winds complement other observations in the high latitudes
- On-line aeorosol data asismilation enables:
  – Production of long term analyzed datasets
  – Aerosol forecasting in support of field campaigns
  – Simulation of future aerosol instruments