Stratospheric Processes And their Role in Climate (SPARC) Data Assimilation Workshop

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Investigations of Polar Stratopause Temperatures using a High-Altitude Version of GEOS-5

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Recent studies have shown that the altitude of the polar stratopause can change dramatically in response to sudden stratospheric warmings (SSWs) and that these changes can be difficult to reproduce in a data assimilation system (DAS). A high-altitude version of the GEOS-5 (Goddard Earth Observing System) DAS is used to investigate the dependence of the stratopause temperatures on the model top and higher altitude observations during the major SSWs of January 2006 and January 2009. The newly developed high-altitude version of GEOS-5 extends from the surface to ~95 km, thus covering the stratosphere and mesosphere

Stratopause Temperature Problem

Stratospheric Sudden Warmings (SSWs) from 2006 and 2009 show large changes in the polar stratopause (Manney et al., 2008; Manney et al., 2009).

GEOS-5 (and GEOS-4) analyses have trouble representing these dynamic polar stratopause changes (Manney et al., 2008; Manney et al., 2009).

<u>**Question:**</u> Can a higher altitude DAS more realistically track these changes?

Outline

GEOS-5 Data Assimilation System

GEOS-5 DAS High-Altitude Extension
- Non-LTE IR (Fomichev)
- Model Error Fields

Results from January 2007 experiments
- Winds and Temperature
- O-F Statistics

Future Plans

GEOS-5 System

Current operational NASA global atmospheric modeling and assimilation system (Rienecker et al., 2008).

Earth System Modeling Framework (ESMF)

Dynamical Core: FVGCM (Finite Volume GCM; Lin, 2004)

Radiative Transfer: NASA CLIRAD (Chou and Suarez, 2002)

Gravity Wave Drag: WACCM based

Data Assimilation System: GSI (Grid-point Statistical Interpolation: NCEP)

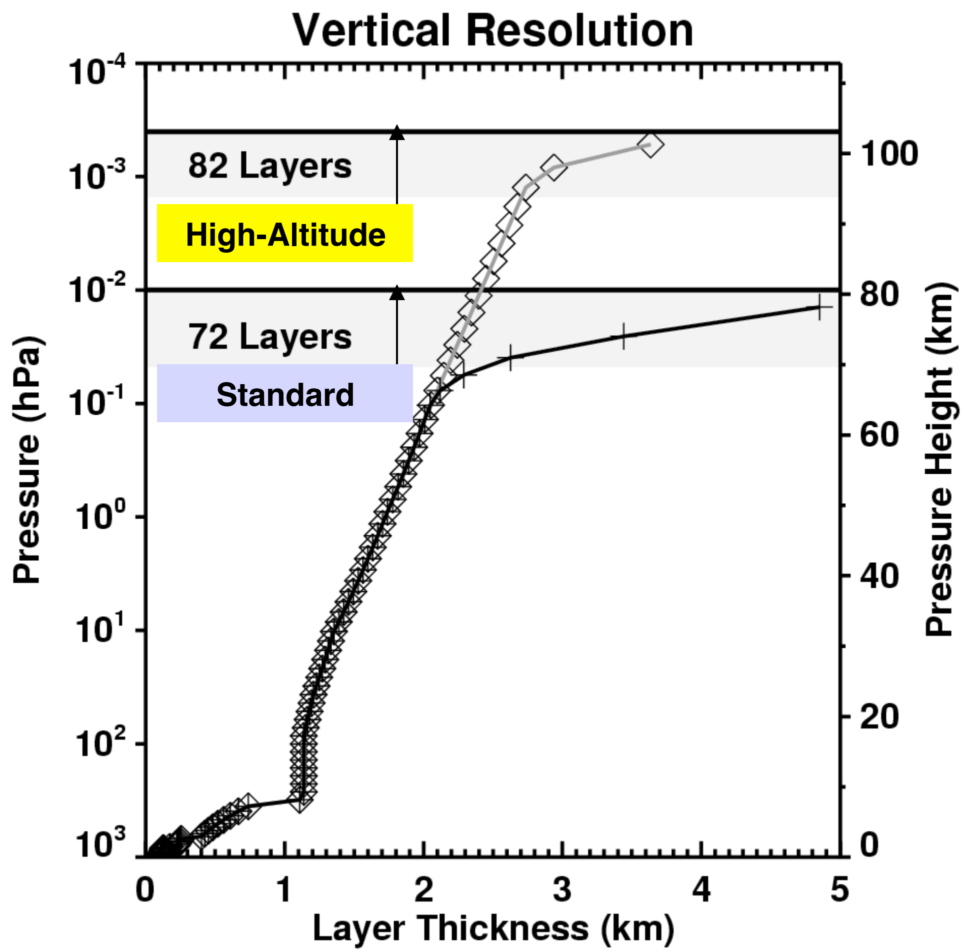
GEOS-5 High-Altitude DAS

The GEOS-5 (Goddard Earth Observing System: Version 5) high-altitude DAS is currently under development.

Plan:

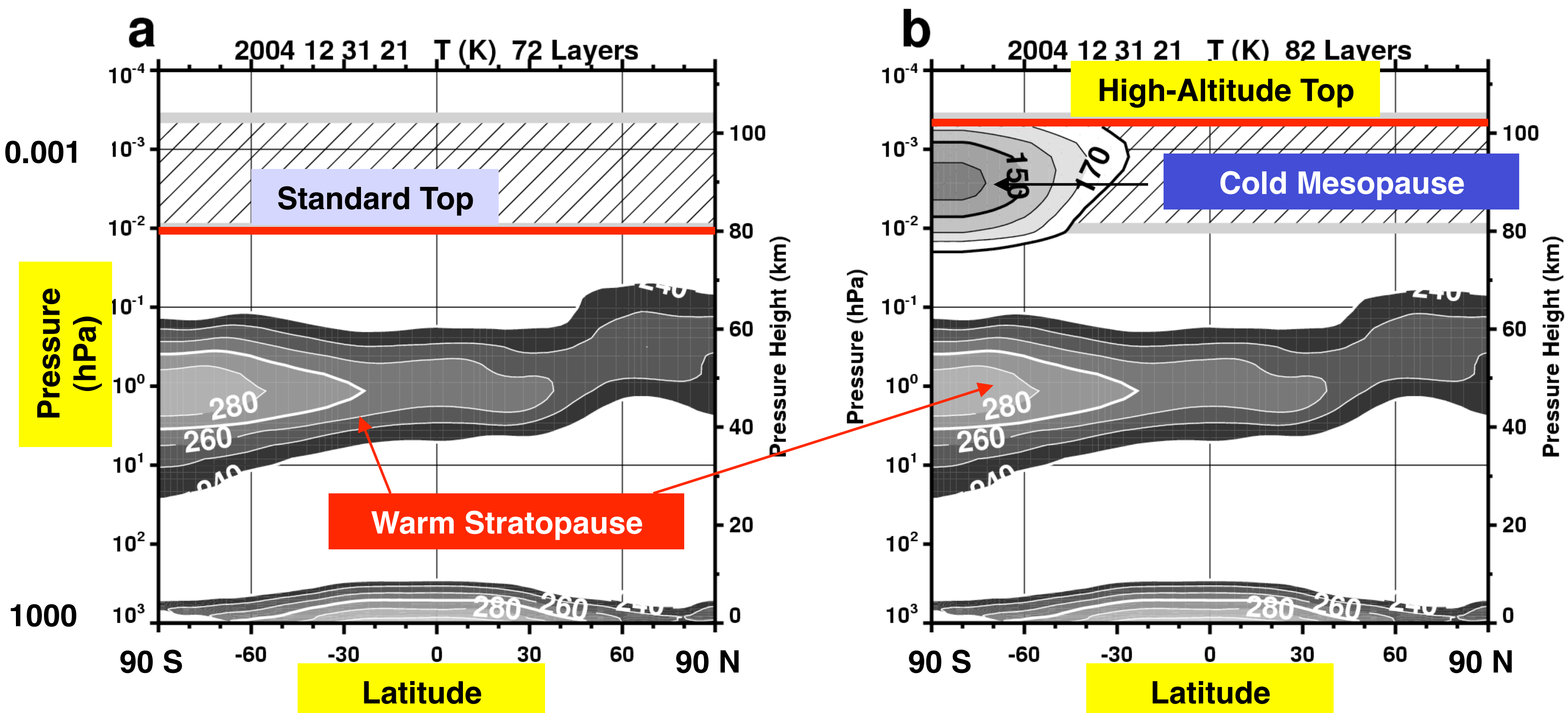
Build on successful Navy NOGAPS-ALPHA high-altitude DAS (Hoppel et al., 2008).

First assimilate Aura MLS temperatures followed by TIMED SABER temperatures.



GEOS-5 High-Altitude DAS

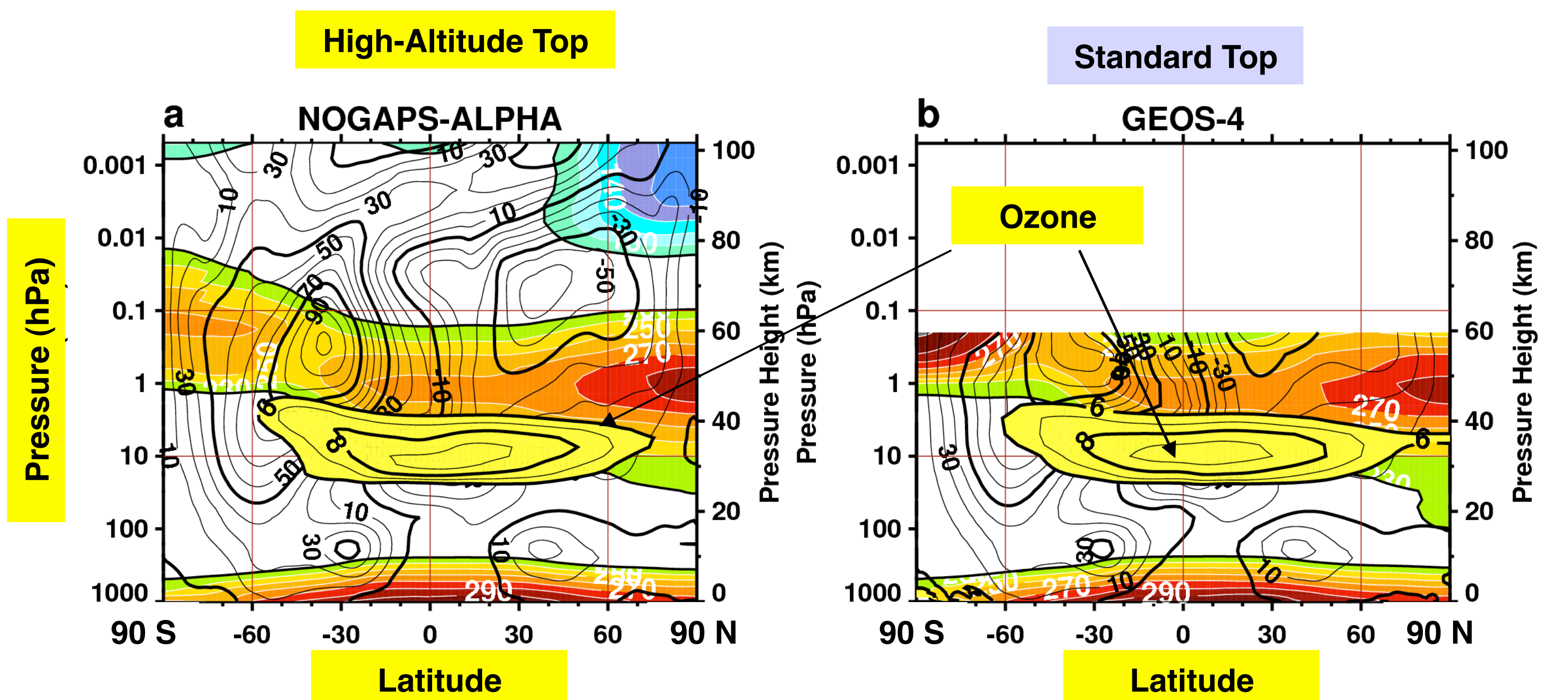
Short GCM forecast from climate initial conditions



High-altitude allows for model and data assimilation in the entire middle atmosphere (Jets are not cut-off just above the stratopause) with a full mean meridional circulation

NOGAPS High-Altitude DAS

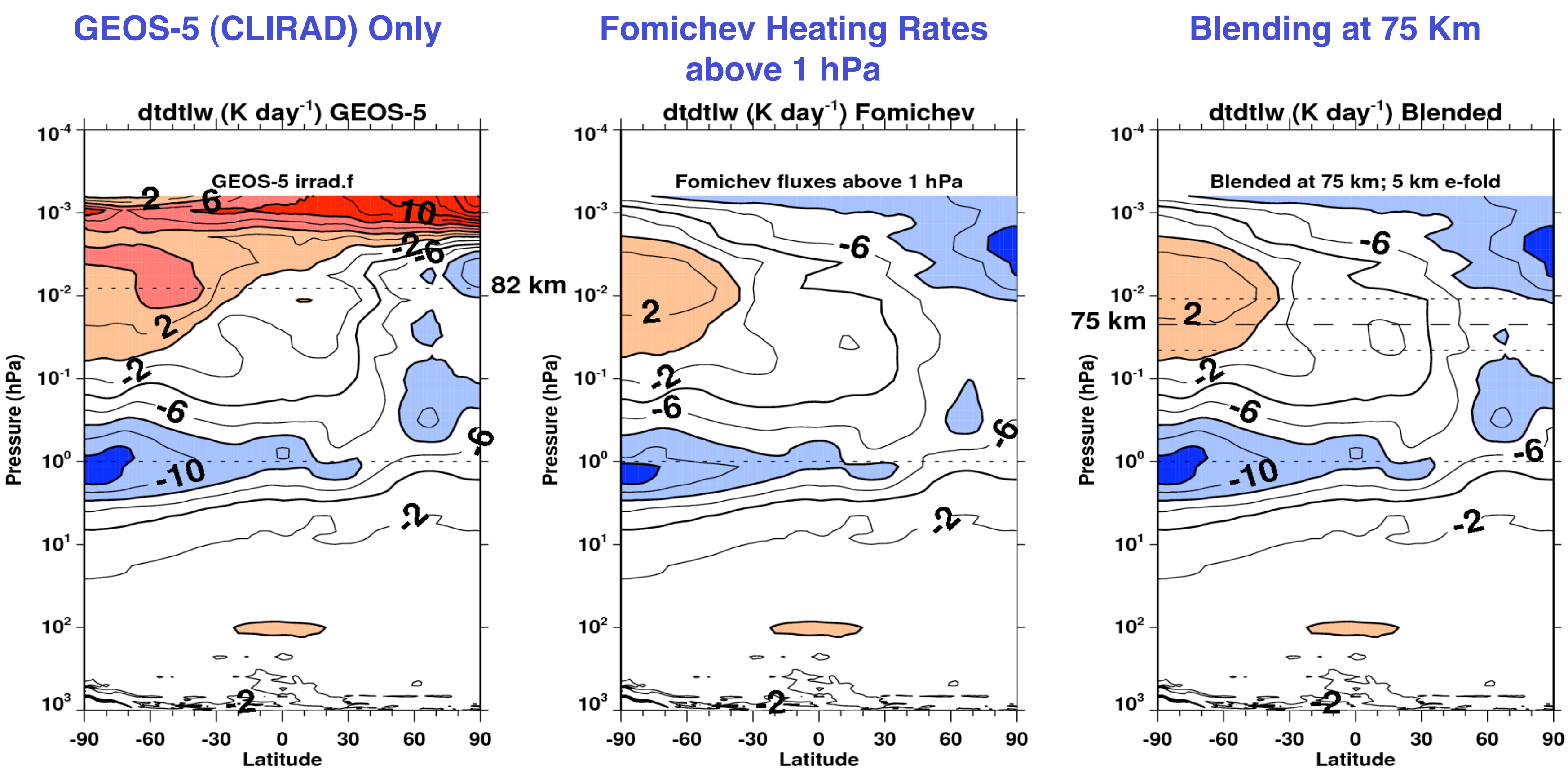
Monthly Average for June 2007



NOGAPS-ALPHA (Navy Operational Global Atmospheric Prediction System – Advanced Level Physics High Altitude) DAS (Hoppel et al., 2008) uses the same radiative transfer code as GEOS-5 and a similar GWD formulation allowing GEOS-5 high-altitude to benefit from NOGAPS-ALPHA development.

GEOS-5 High Altitude IR Non-LTE Extension

Following NOGAPS-ALPHA, NASA CLIRAD radiative fluxes are blended with independently calculated IR fluxes (Fomichev, 1998) at high altitudes.



1-Day Forecast (1 Jan2005)

Model Error Extensions

The NCEP DAS allows for latitude and altitude variations of model error standard deviations, horizontal length scale, and vertical length scale for streamfunction, velocity potential, temperature, ozone, etc.

These quantities have to be extended for higher altitudes. They are usually calculated from a series of 24 and 48 hr forecasts. These require some bootstrapping. In the meantime we can..

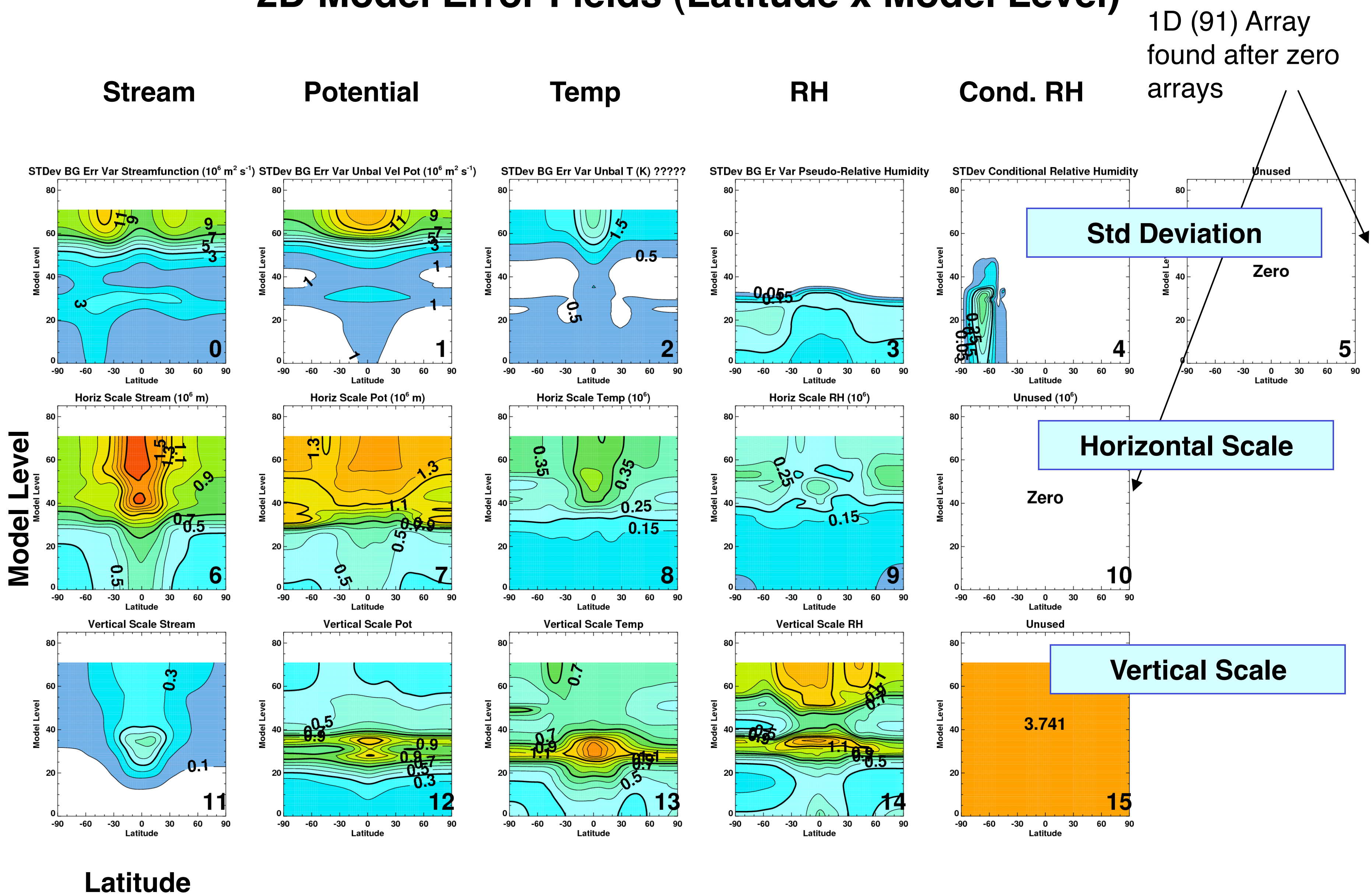
Simply extend the top values as most of the model error fields are nearly independent of altitude at upper levels.

GMAO GEOS-5 Code → Assimilation Component

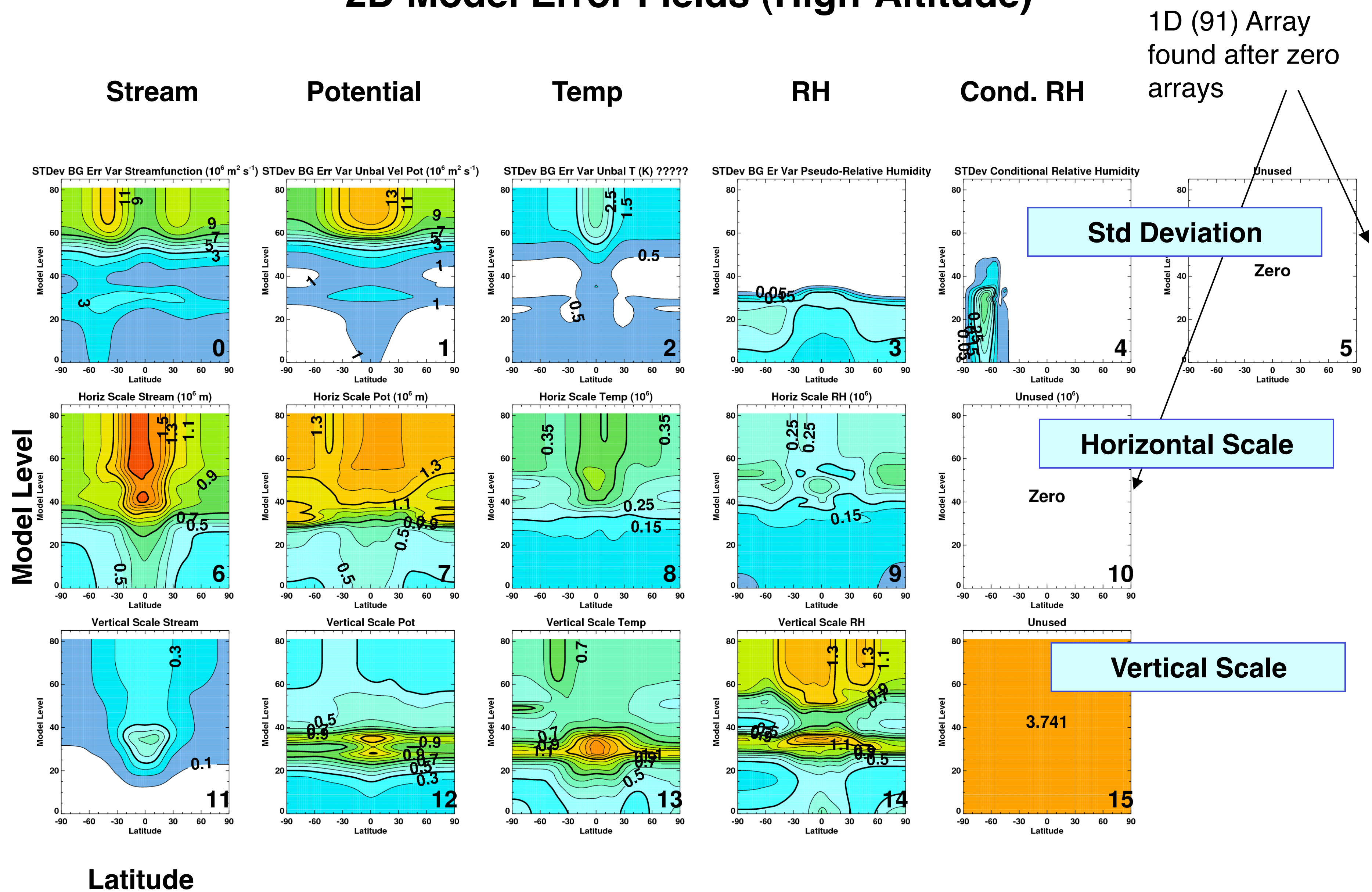
The same system as NCEP

Wu, W.-S., R. J. Purser, and D. F. Parish, Three-dimensional variational analysis with spatially inhomogeneous covariances, *Mon. Wea. Rev.*, 130, 2905—2916, 2002.

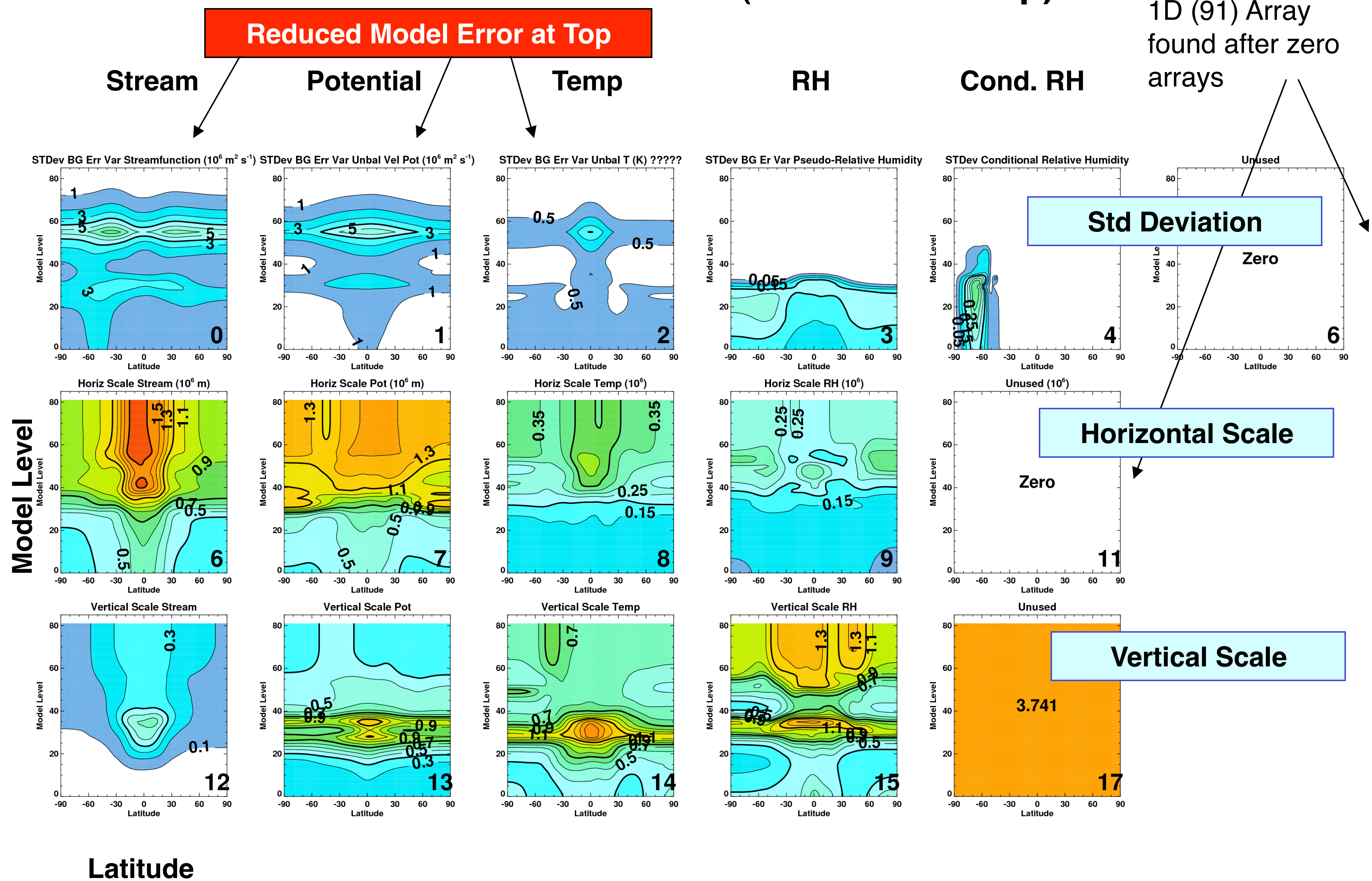
2D Model Error Fields (Latitude x Model Level)



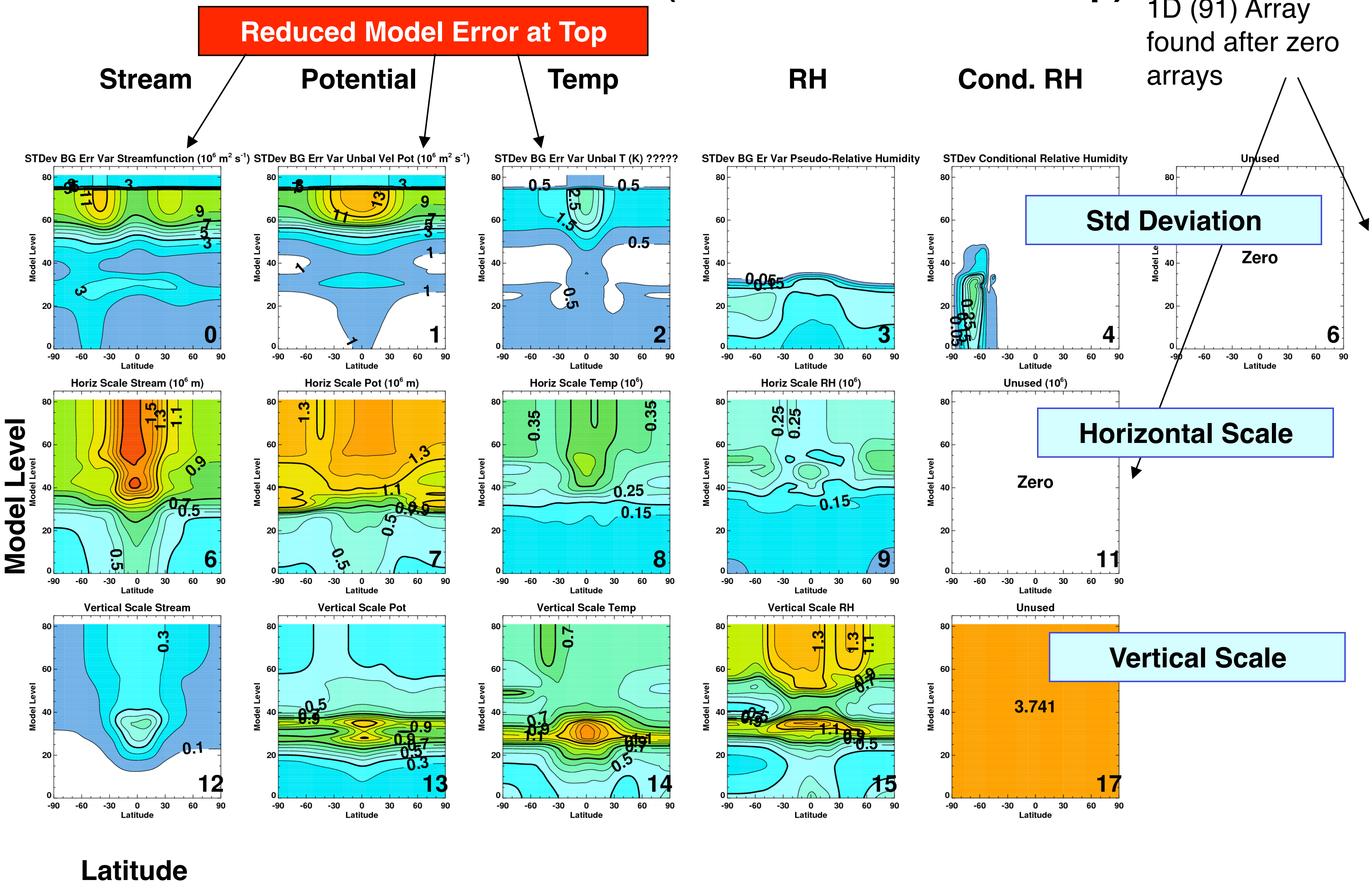
2D Model Error Fields (High-Altitude)



2D Model Error Fields (Reduced at Top)



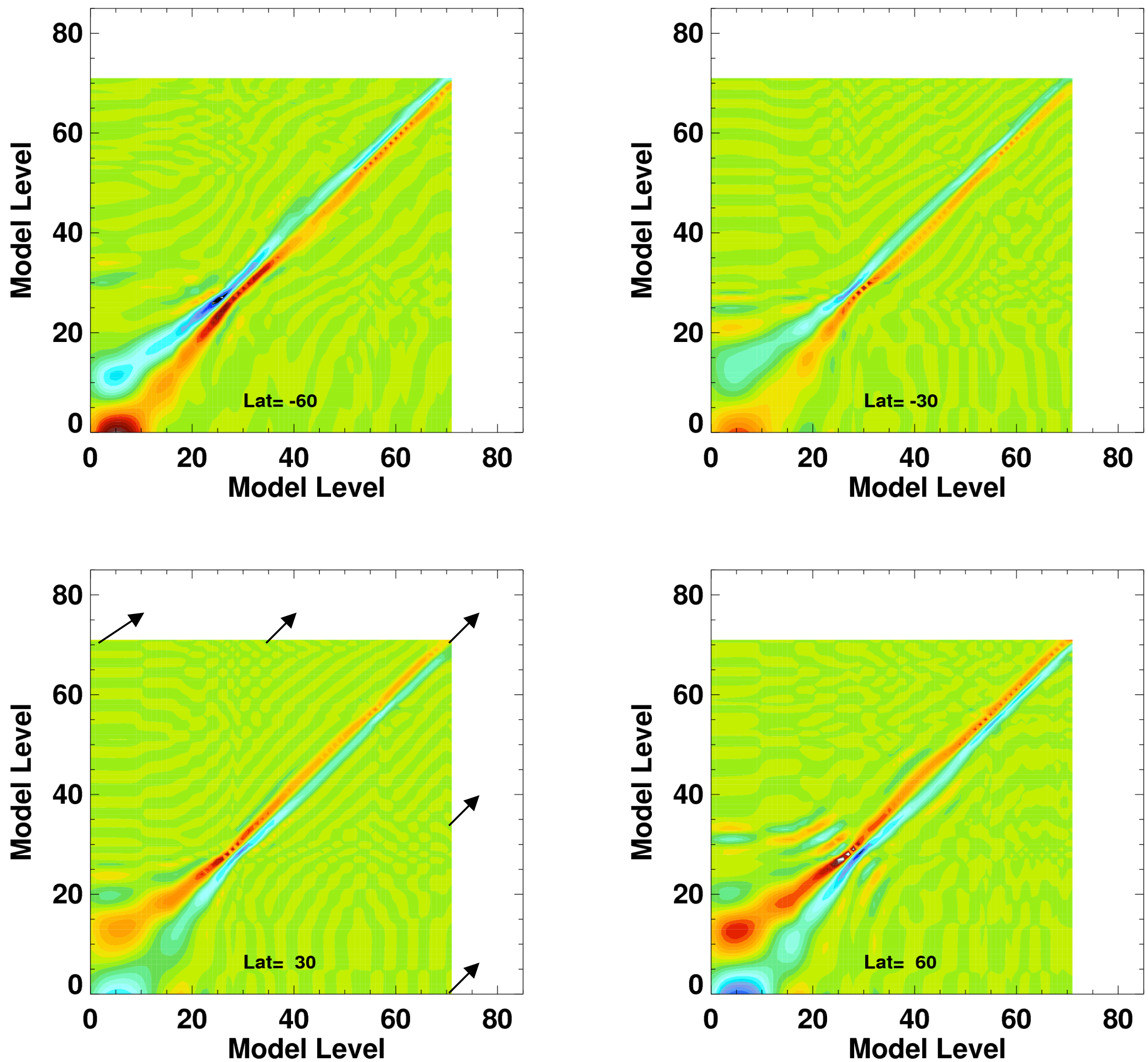
2D Model Error Fields (Some Reduction at Top)



Stream Function Temperature Correlation

All vertical levels at –60, -30, 30, 60 degrees latitude

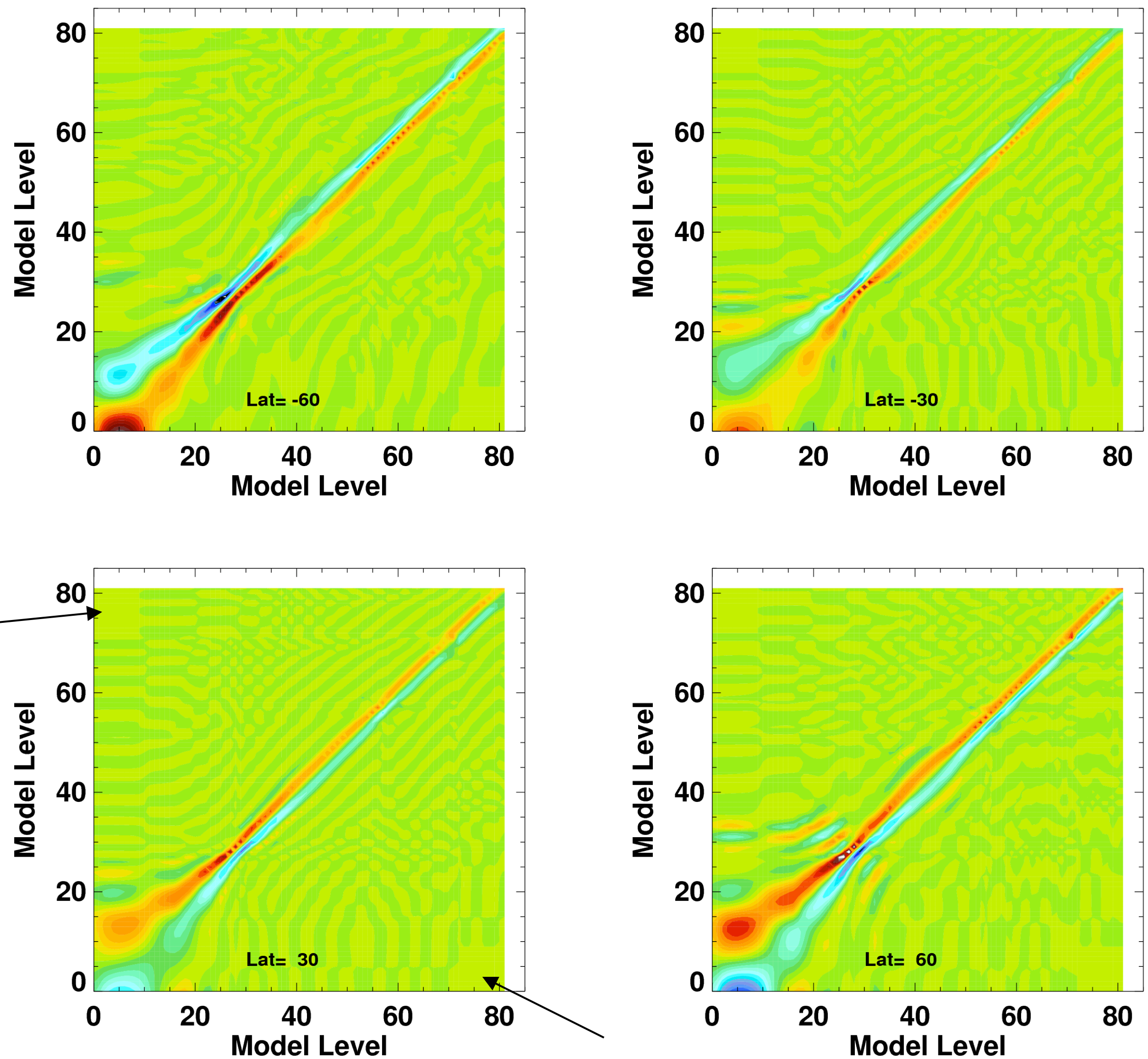
Extrapolate by shifting arrays diagonally at each latitude.



Stream Function Temperature Correlation (Extended)

All vertical levels at 60N

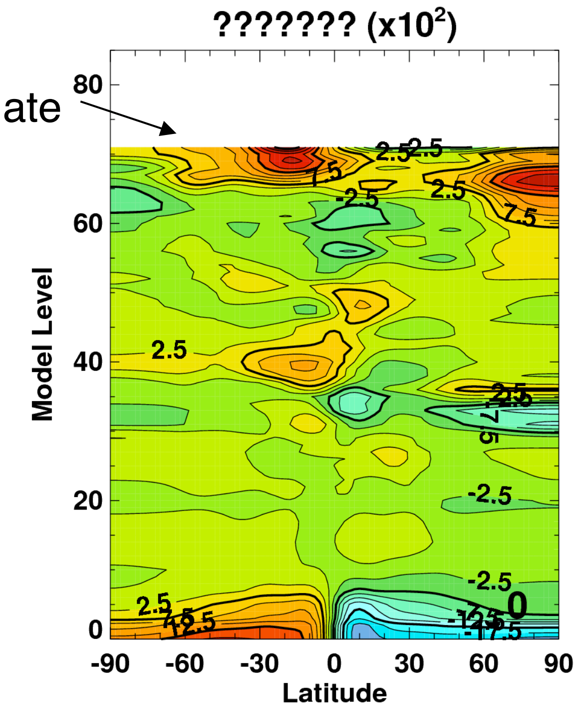
Fill Corners with Zeros

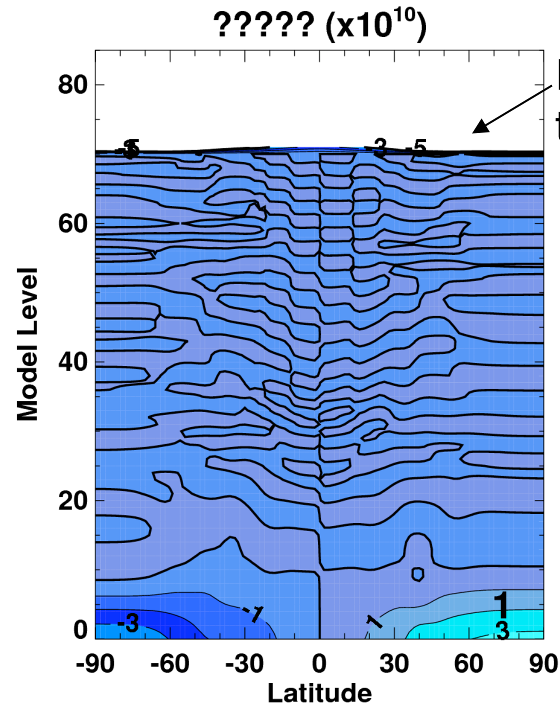


Stream Function Velocity Potential Correlation

Balanced Projection for Velocity Potential

Balanced Projection for Surface Pressure

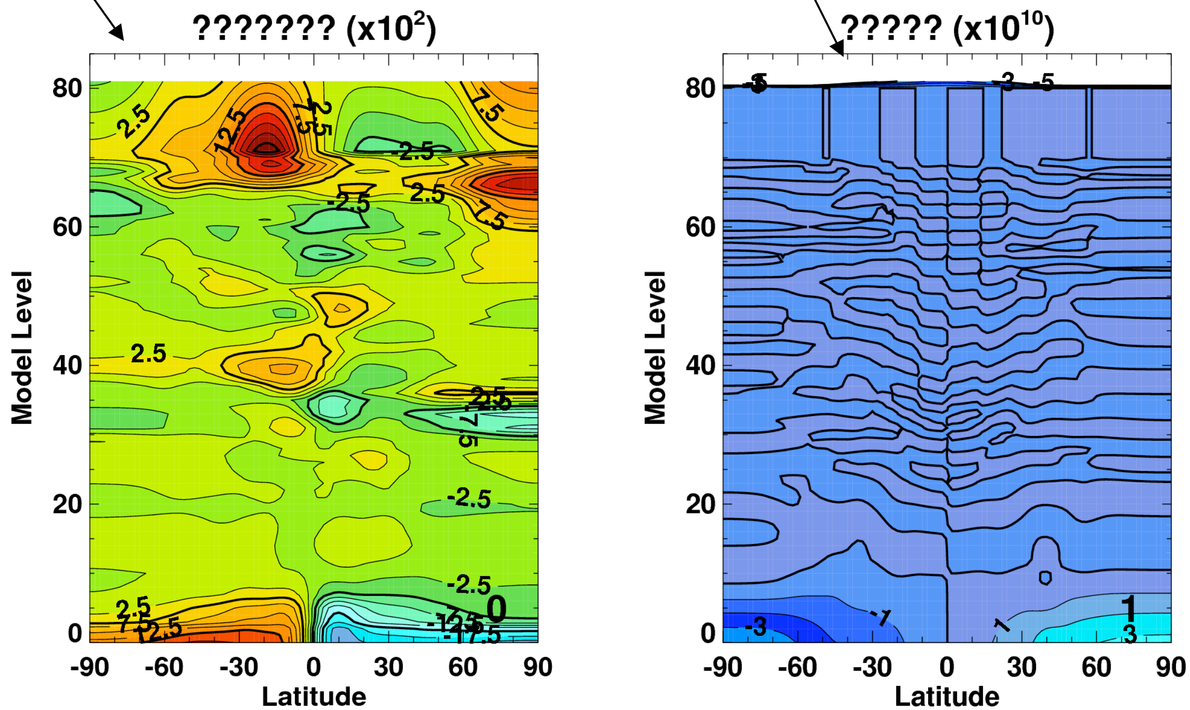




Stream Function Velocity Potential Correlation

For now, linearly interpolate from 72 top value to average of 62-72 values.

For now, set to zero



Experiments

Initial Time: 19 December 2006 00 UTC

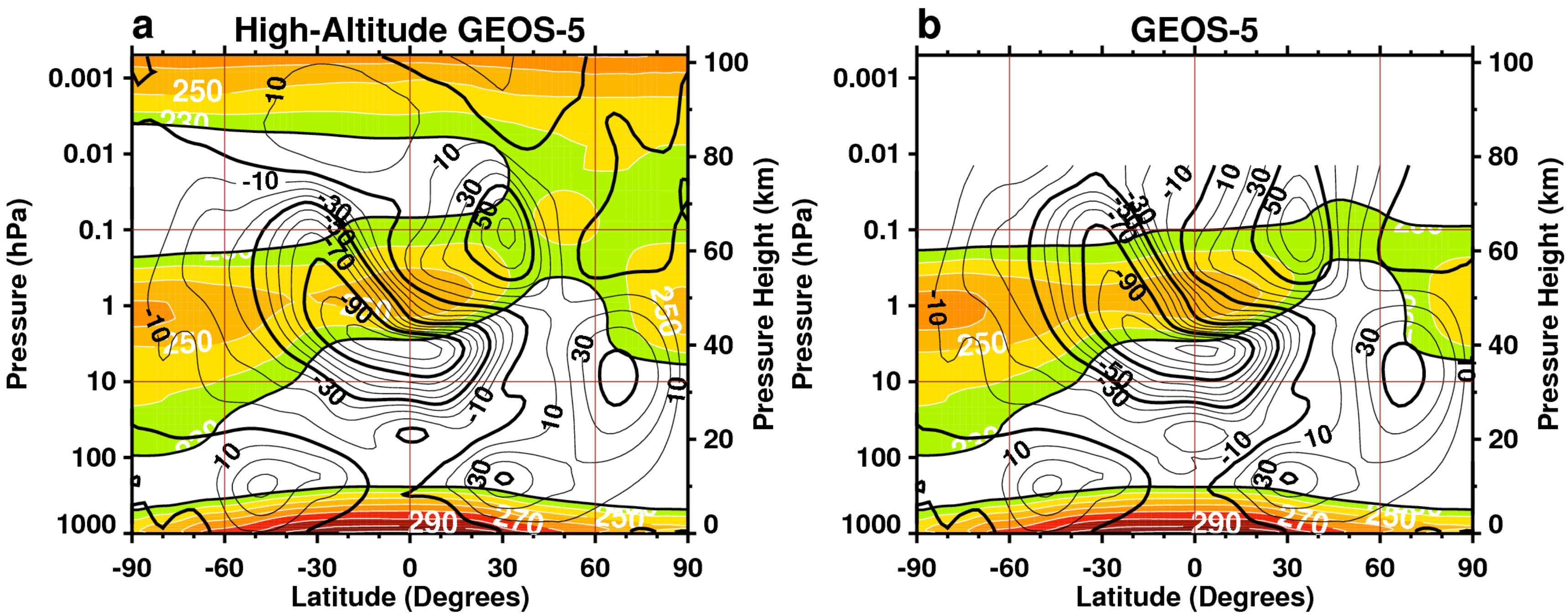
Initial Fields: Operational GEOS-5 at lower levels, climate and extrapolated fields at upper levels

End Time: 31 January 2007 18 UTC

Observations: Conventional only; Conventional and MLS temperature profiles

January 2007 Average

Temperature (Colored Contours)
Zonal Wind (Black Contours)



No High-Altitude MLS Data
No Fomichev IR Cooling

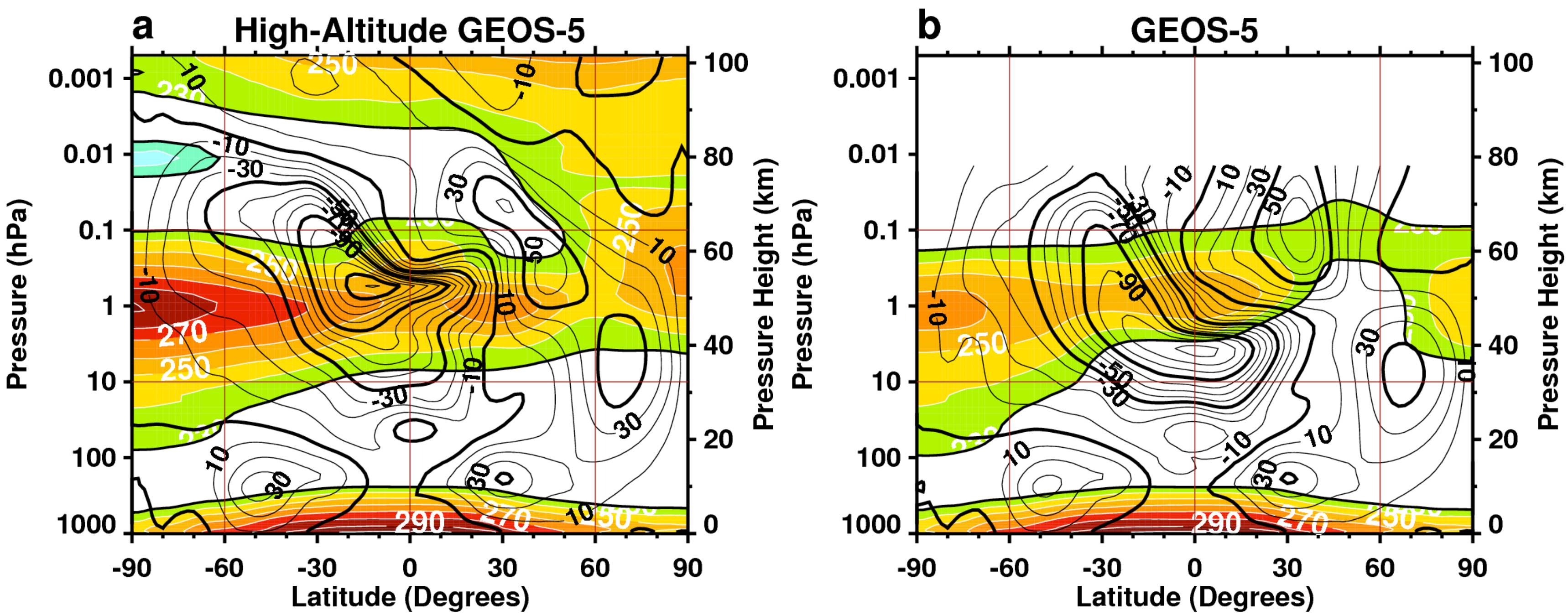
coy033

Conventional Obs Only

coy032

January 2007 Average

Temperature (Colored Contours)
Zonal Wind (Black Contours)



With High-Altitude MLS Data
Reduced Model Error at Top

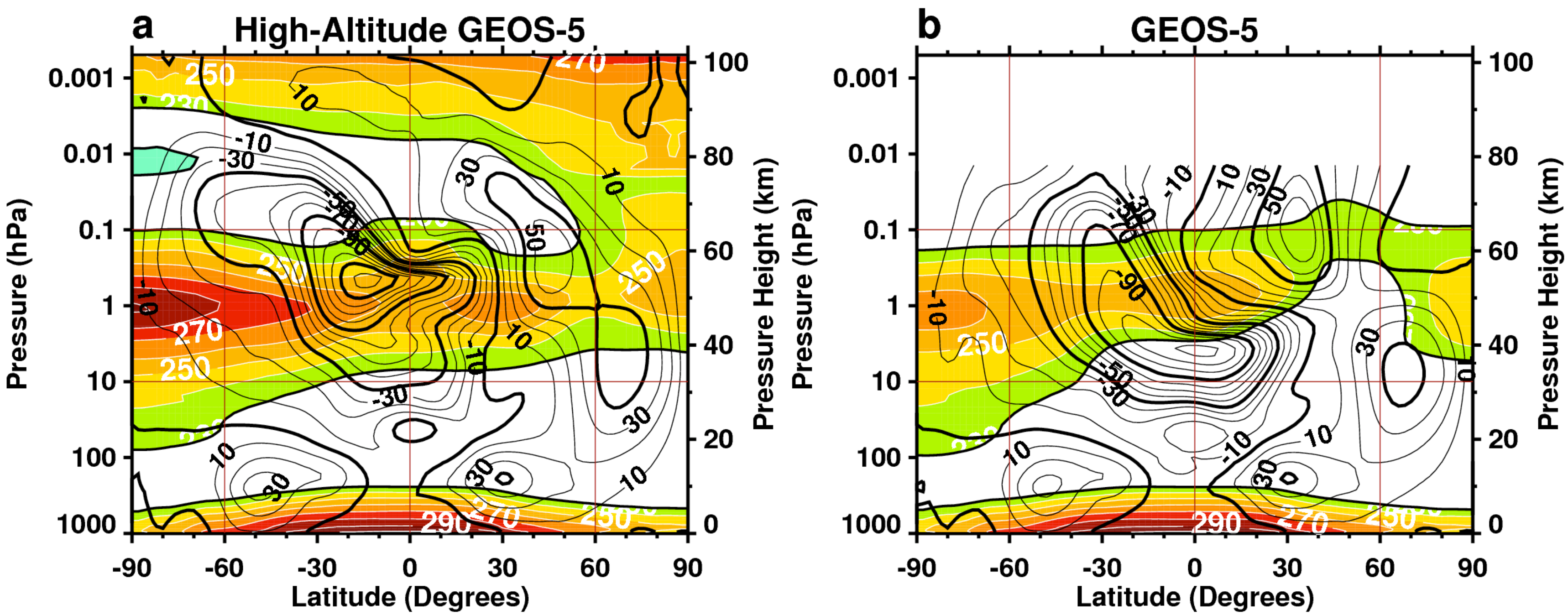
Conventional Obs Only

coy035

coy032

January 2007 Average

Temperature (Colored Contours)
Zonal Wind (Black Contours)



With High-Altitude MLS Data
Reduced GWD efficiency
0.125 – 0.0625

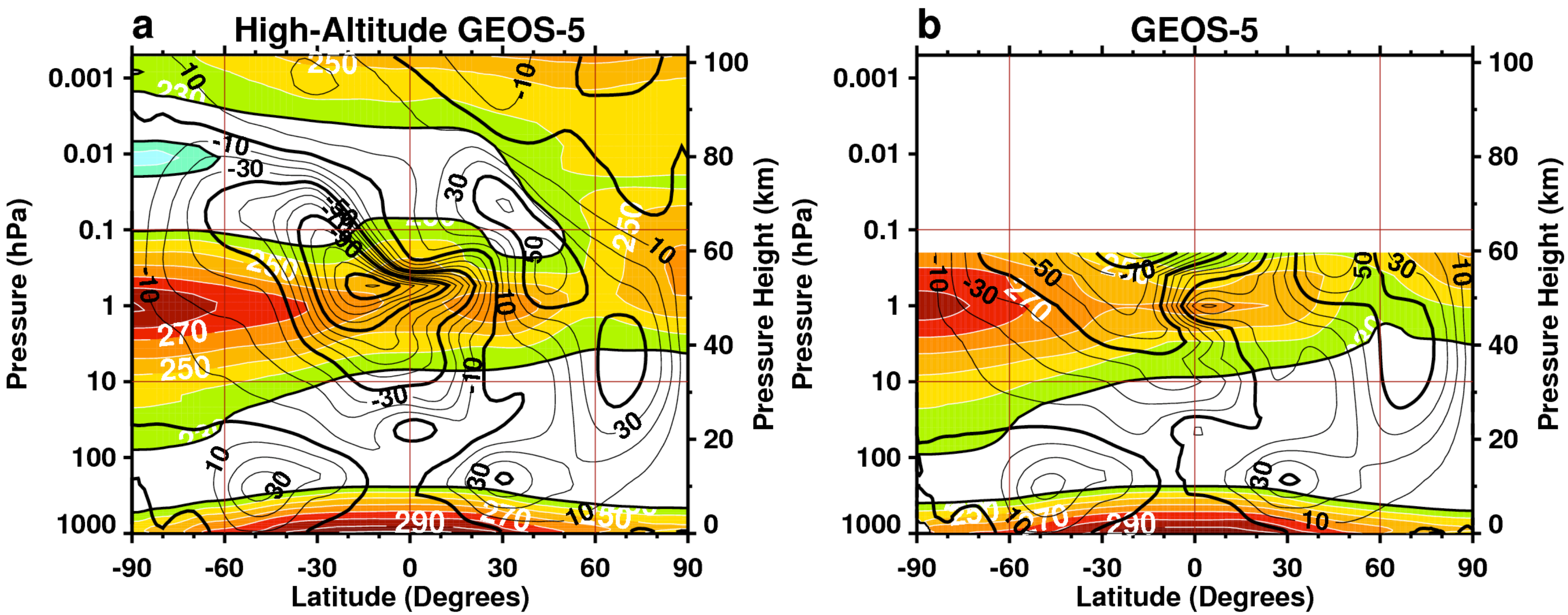
coy039

Conventional Obs Only

coy032

January 2007 Average

Temperature (Colored Contours)
Zonal Wind (Black Contours)



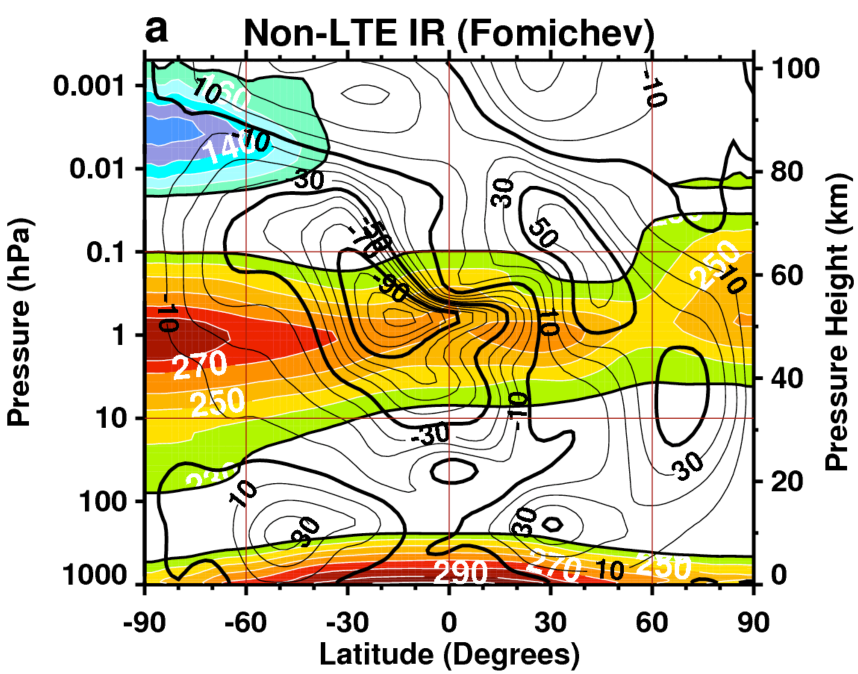
With High-Altitude MLS Data
Reduced Model Error at Top

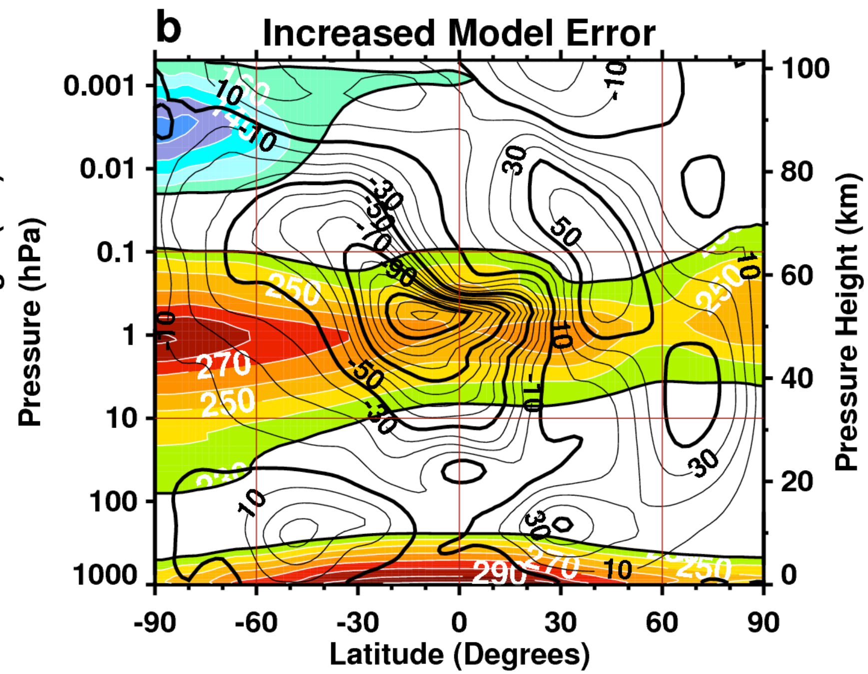
Full GEOS-5 Assimilation

coy035

January 2007 Average

Temperature (Colored Contours)
Zonal Wind (Black Contours)





With High-Altitude MLS Data
Reduced Model Error at Top
Fomichev IR
Solar Bug Fix

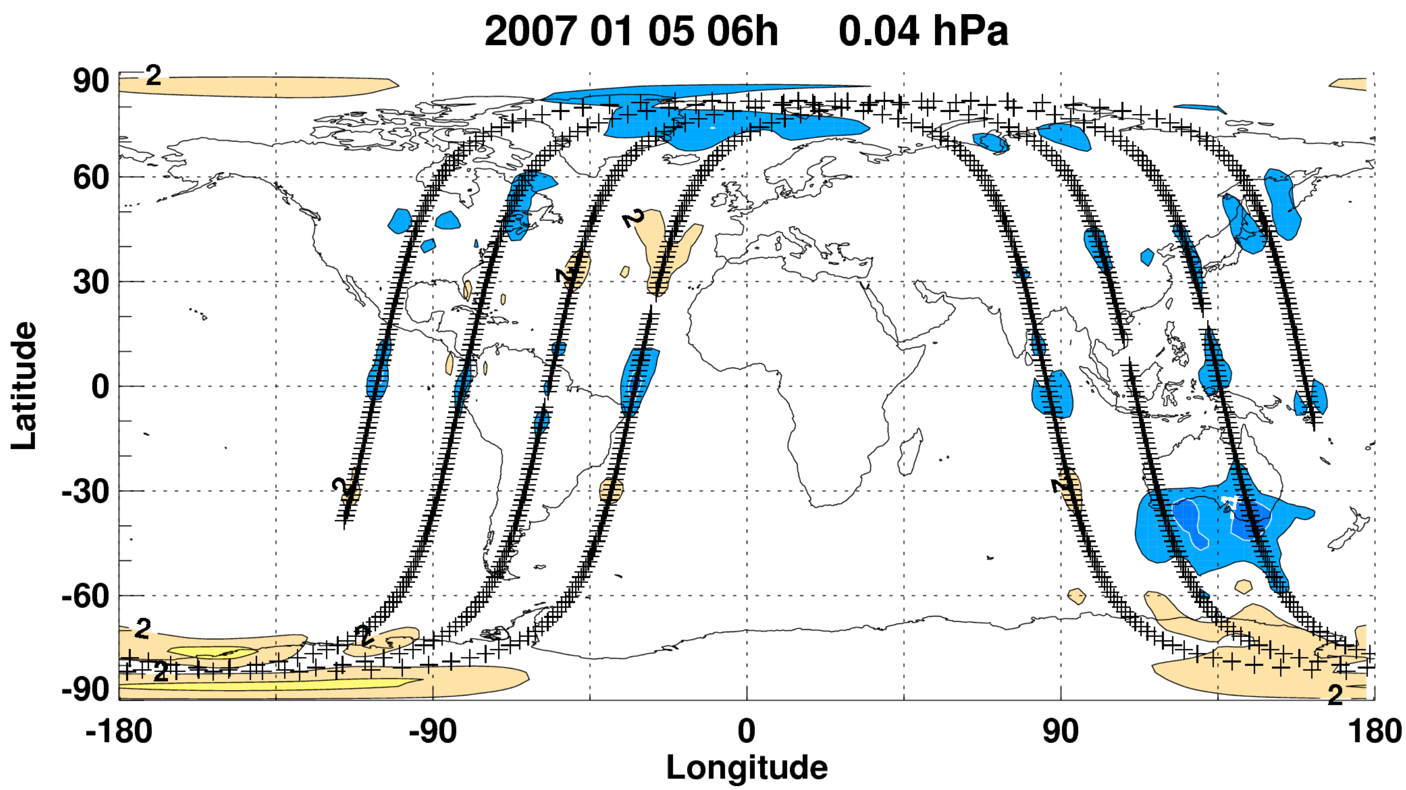
coy040

As on the left
Plus: Increased Model Error near top

coy041

A – F at 0.04 hPa

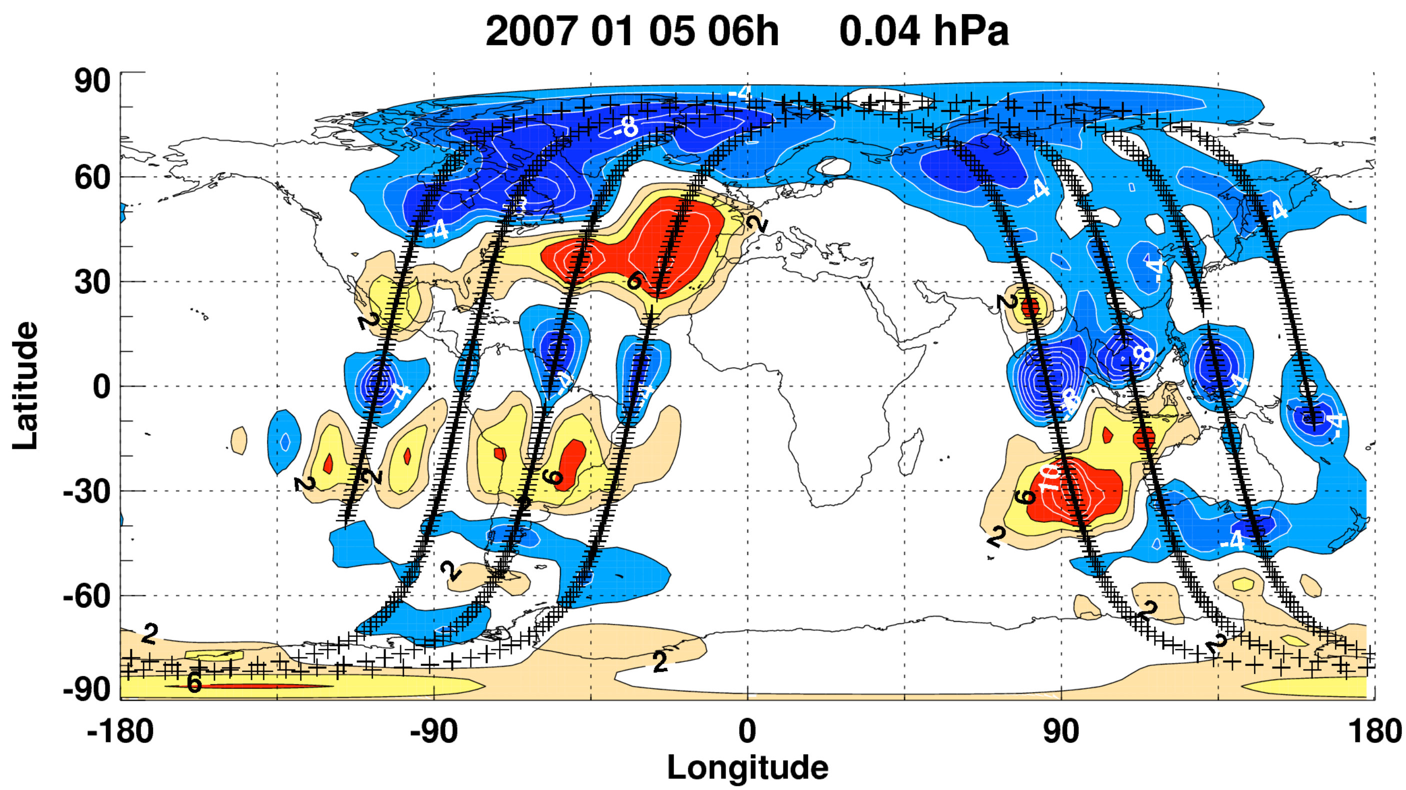
Model Error Decreased



A – F for MLS Temperature

EXP coy040

A – F at 0.04 hPa

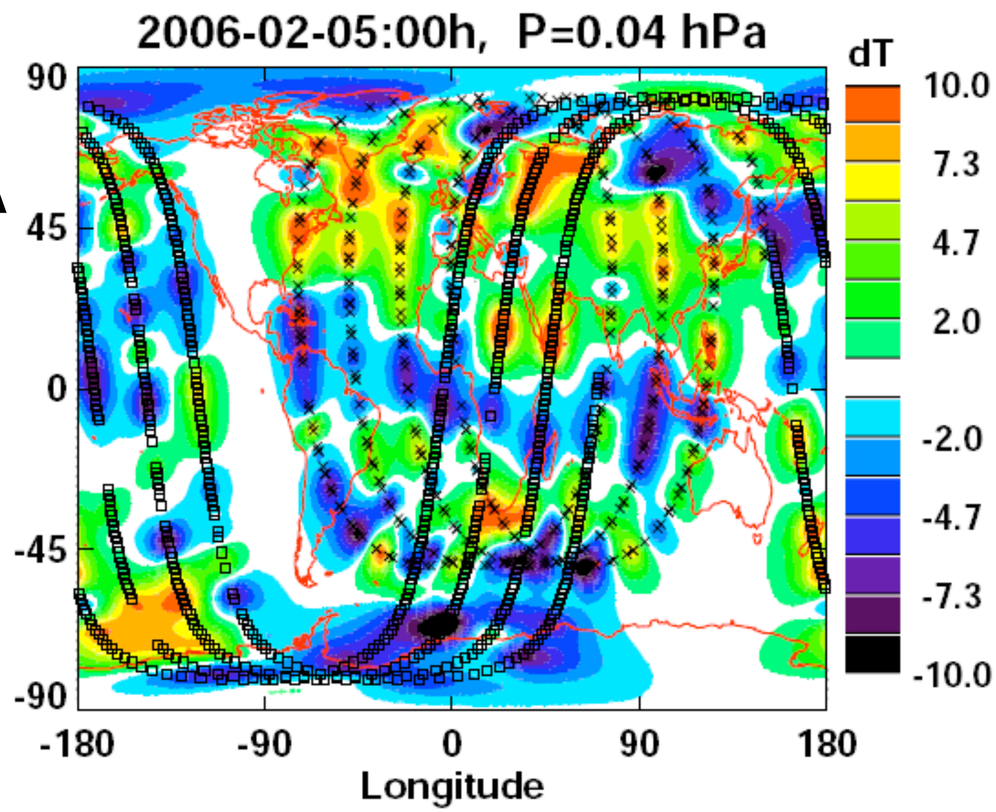


A – F for MLS Temperature

EXP coy041

A – F at 0.04 hPa (From Hoppel et al., 2008)

NOGAPS-ALPHA
NAVDAS

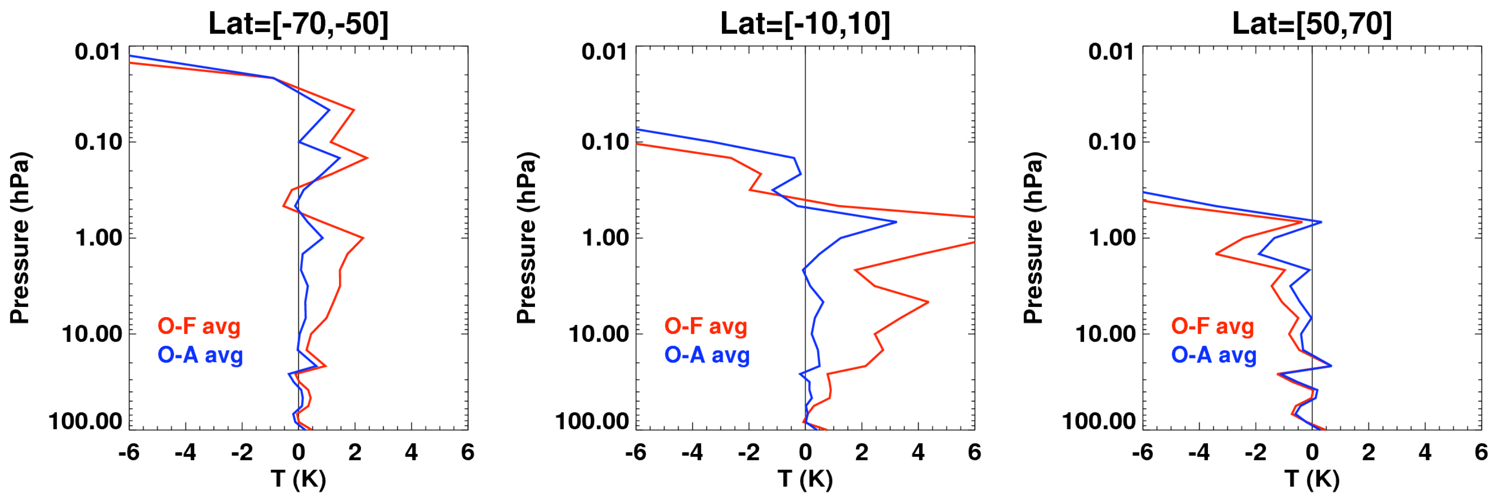


A – F for MLS and SABER Temperature

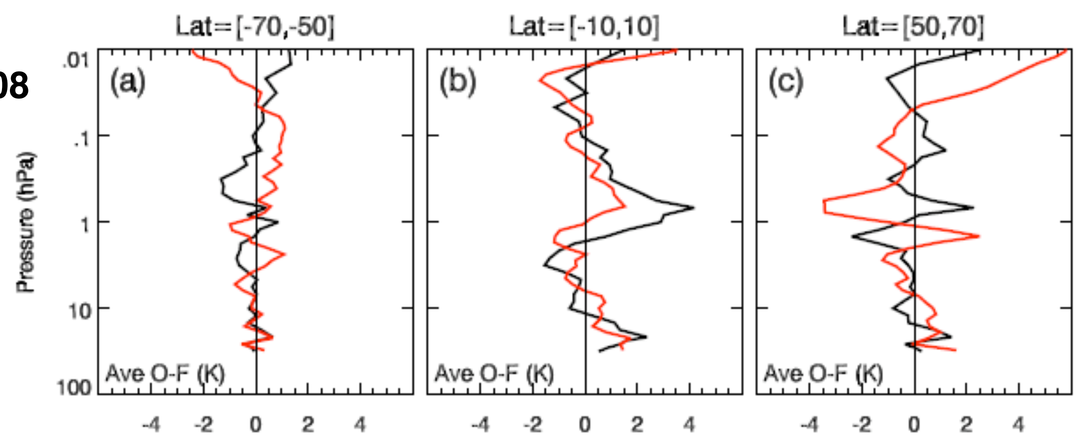
EXP coy041

MLS O-F Average (January 2007)

Strongly Reduced Model Error

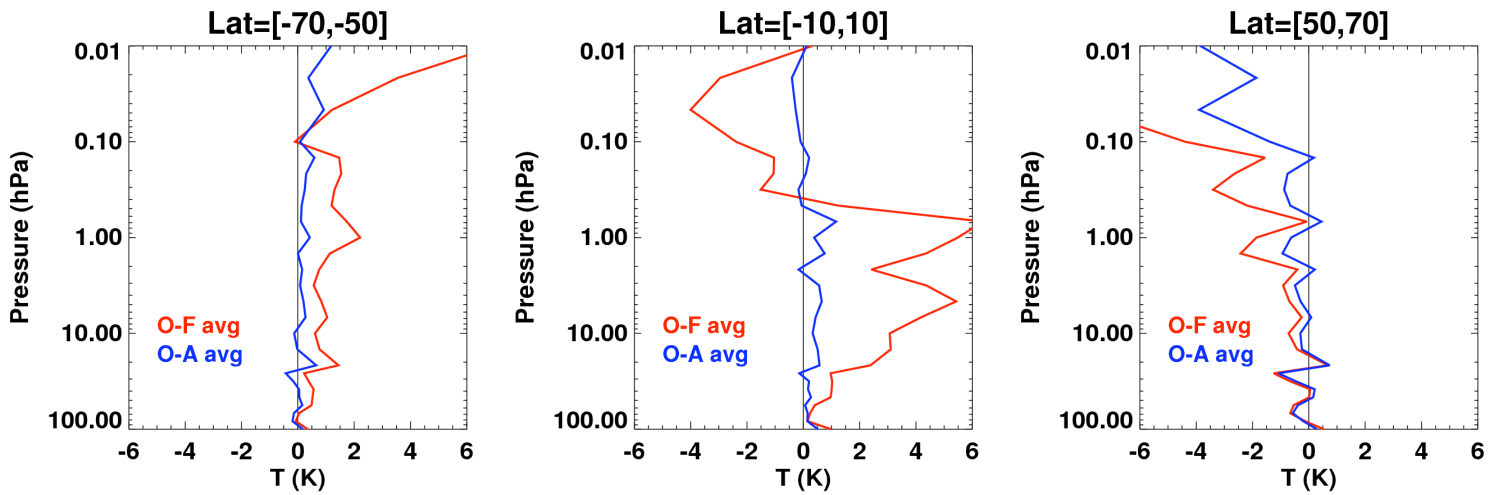


From Hoppel et al., 2008
Jan-Feb 2006 Average
Black → MLS
Red → SABER

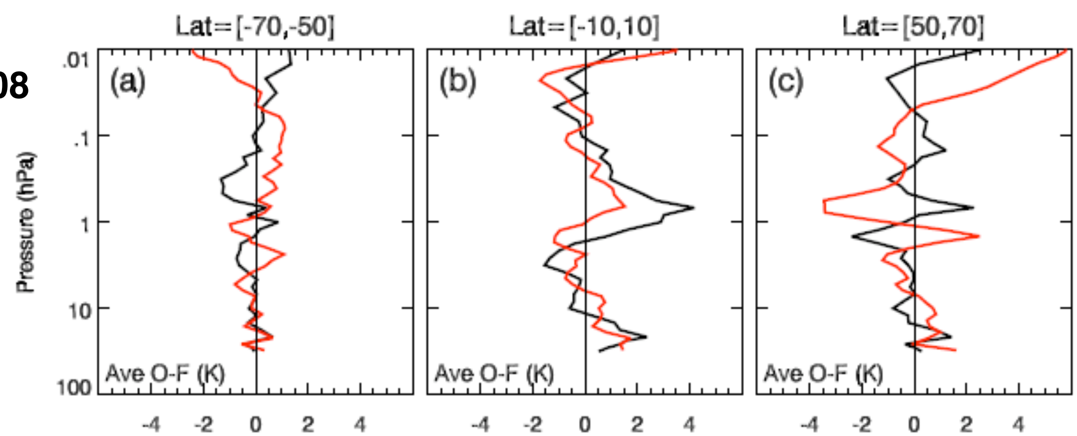


MLS O-F Average (January 2007)

Somewhat Reduced Model Error

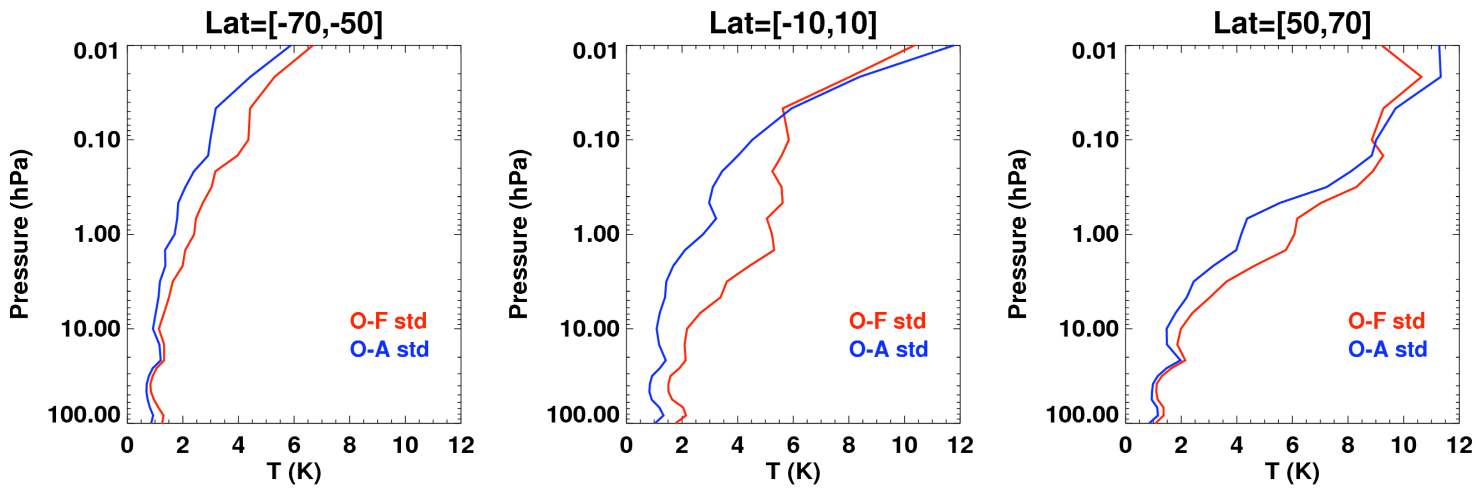


From Hoppel et al., 2008
Jan-Feb 2006 Average
Black → MLS
Red → SABER

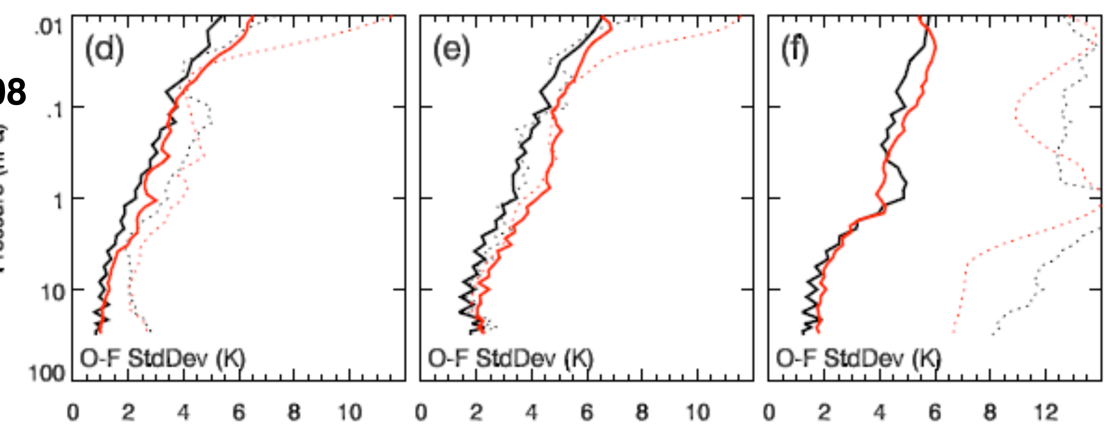


MLS O-F STD (January 2007)

Strongly Reduced Model Error

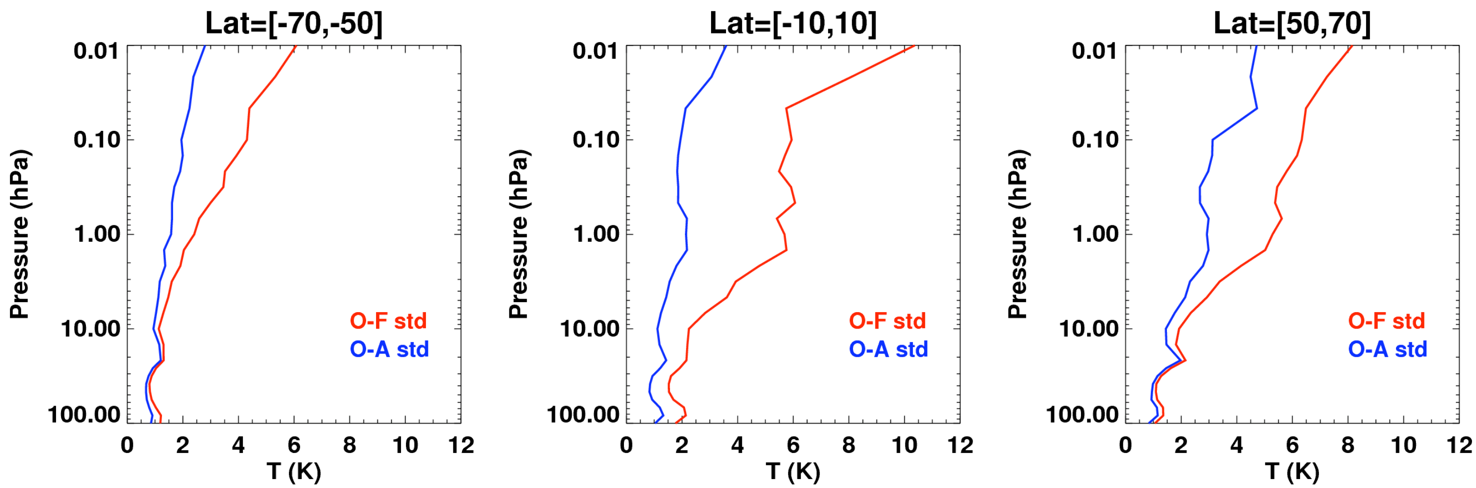


From Hoppel et al., 2008
Jan-Feb 2006 Average
Black → MLS
Red → SABER

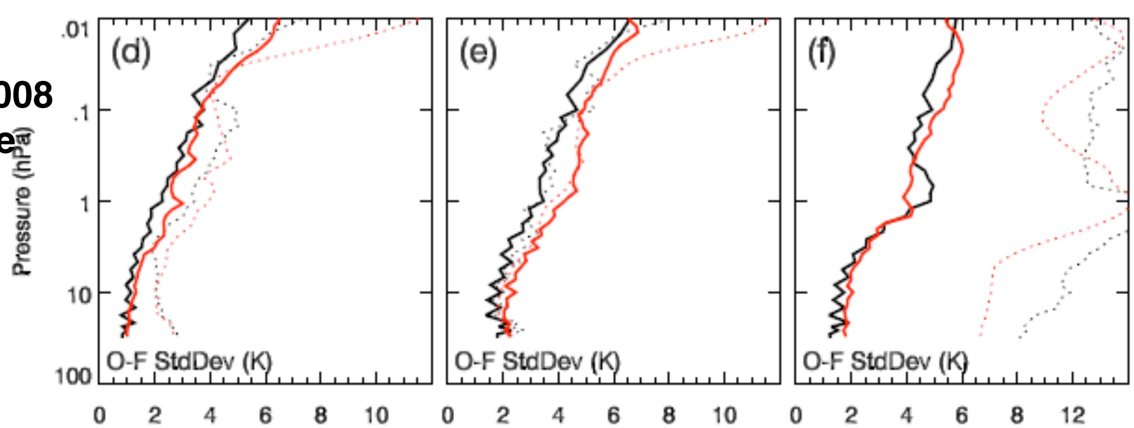


MLS O-F STD (January 2007)

Somewhat Reduced Model Error

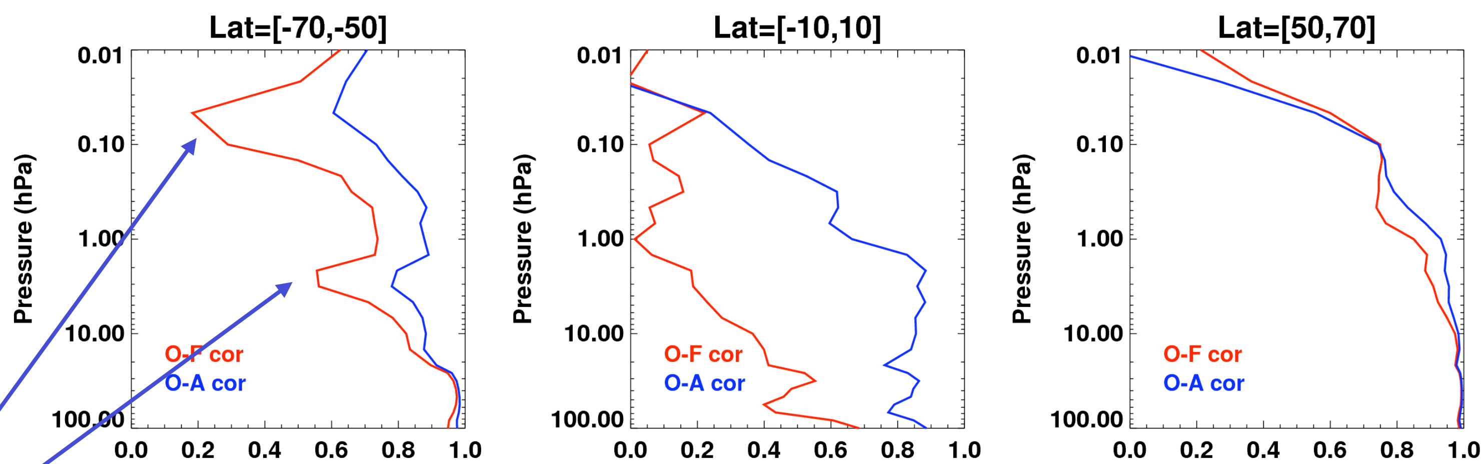


From Hoppel et al., 2008
Jan-Feb 2006 Average
Black → MLS
Red → SABER

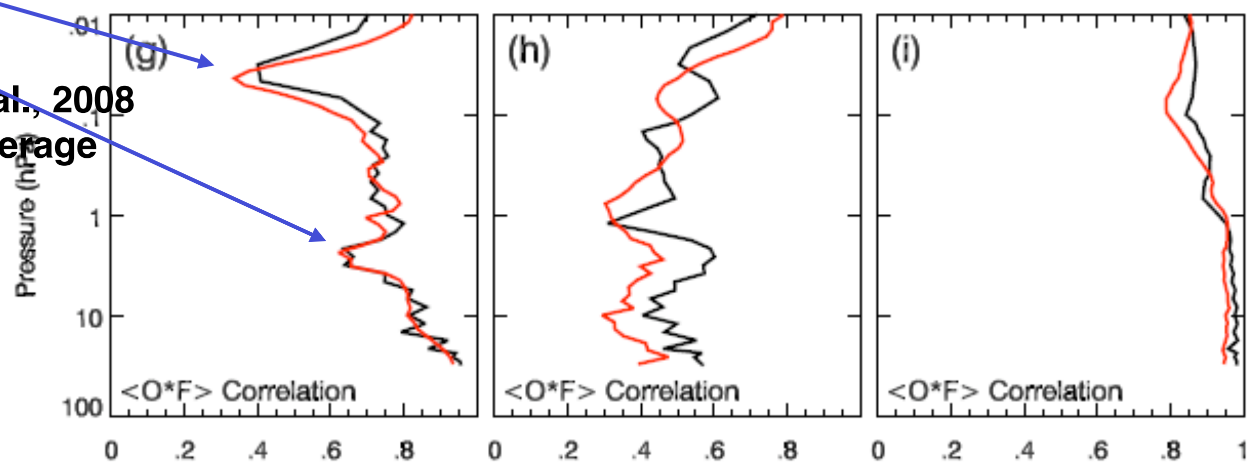


MLS O-F Correlation (January 2007)

Strongly Reduced Model Error



Odd Structure



From Hoppel et al., 2008
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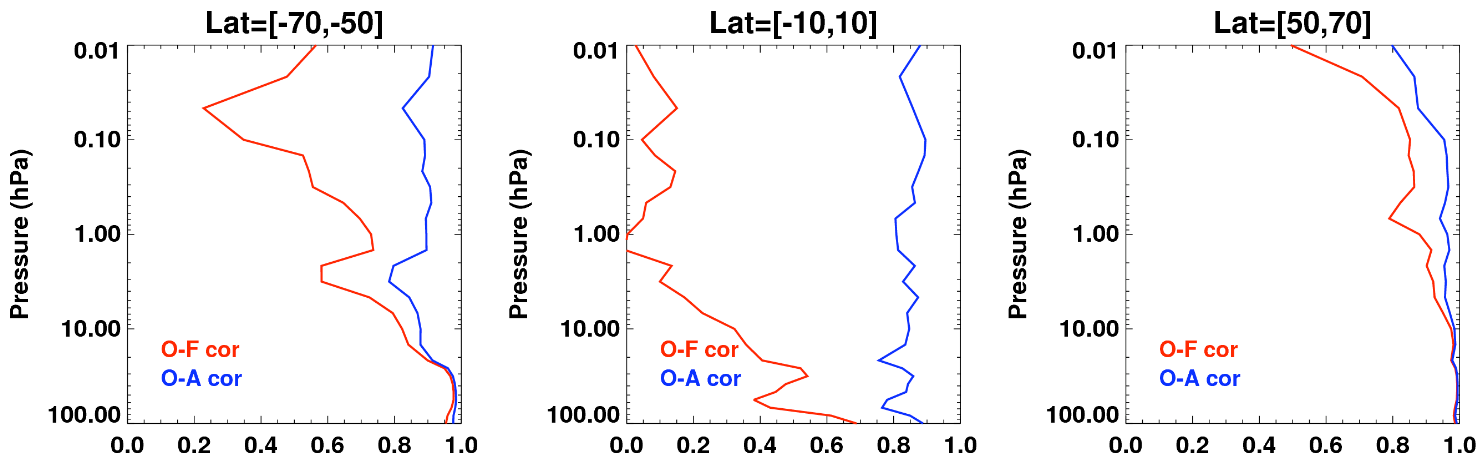
MLS O-F Correlation (January 2007)

Somewhat Reduced Model Error



From Hoppel et al., 2008
Jan-Feb 2006 Average
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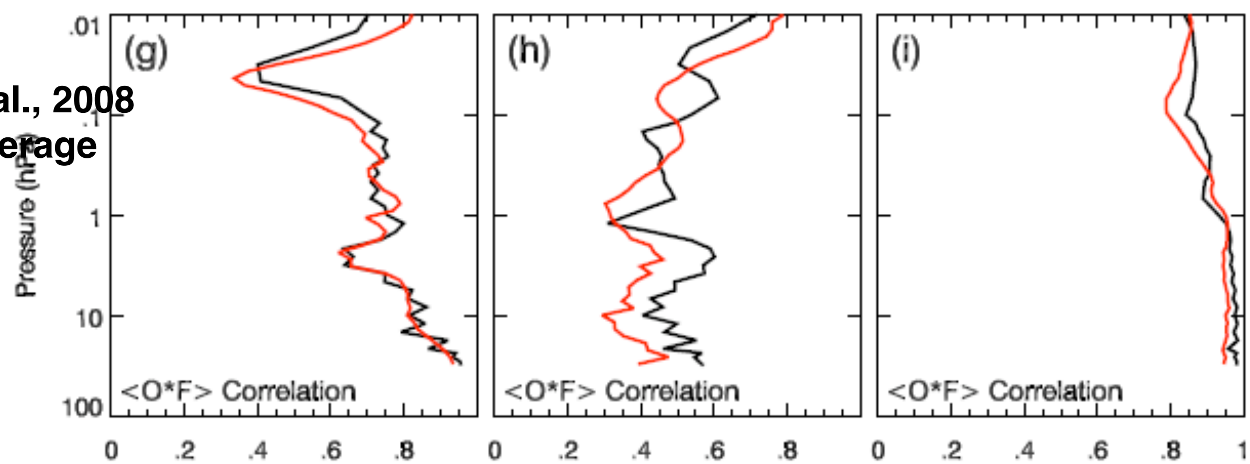
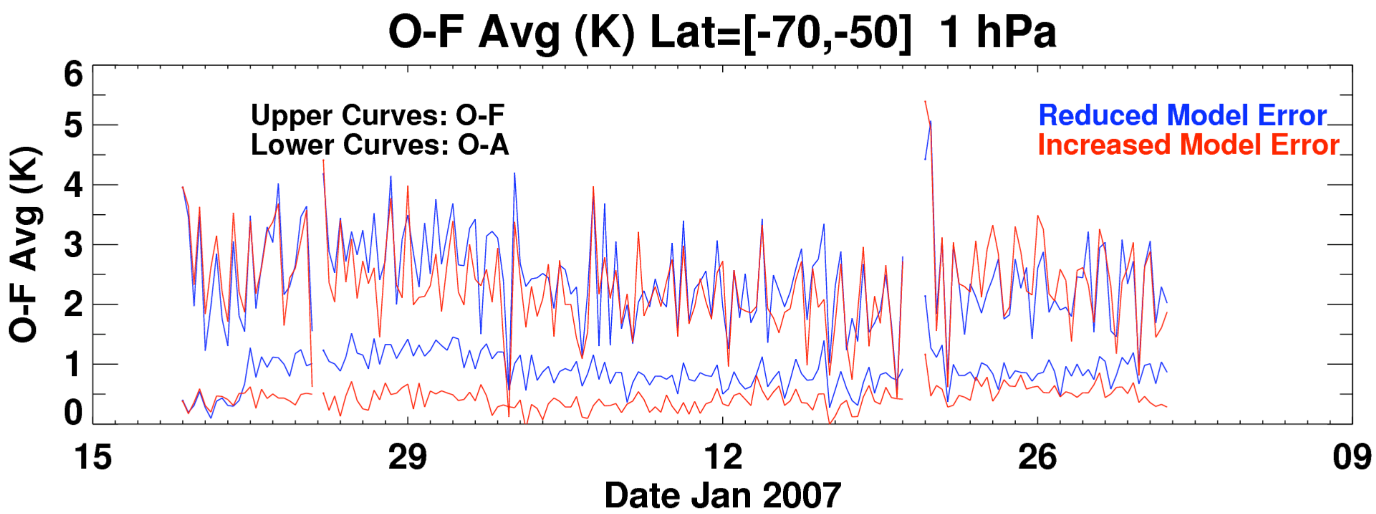
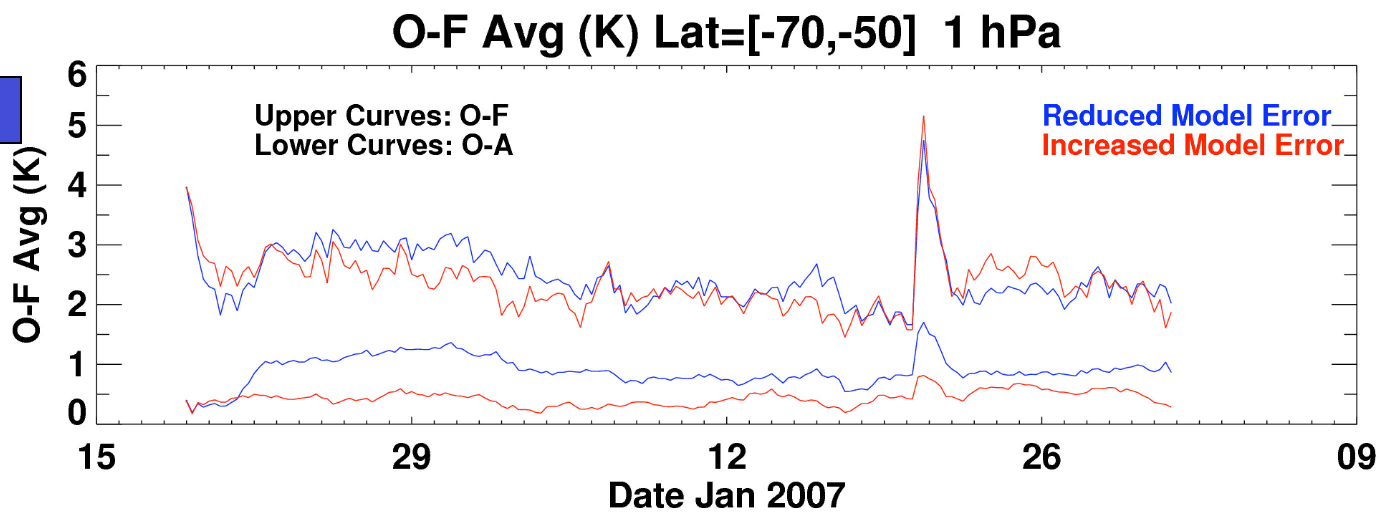


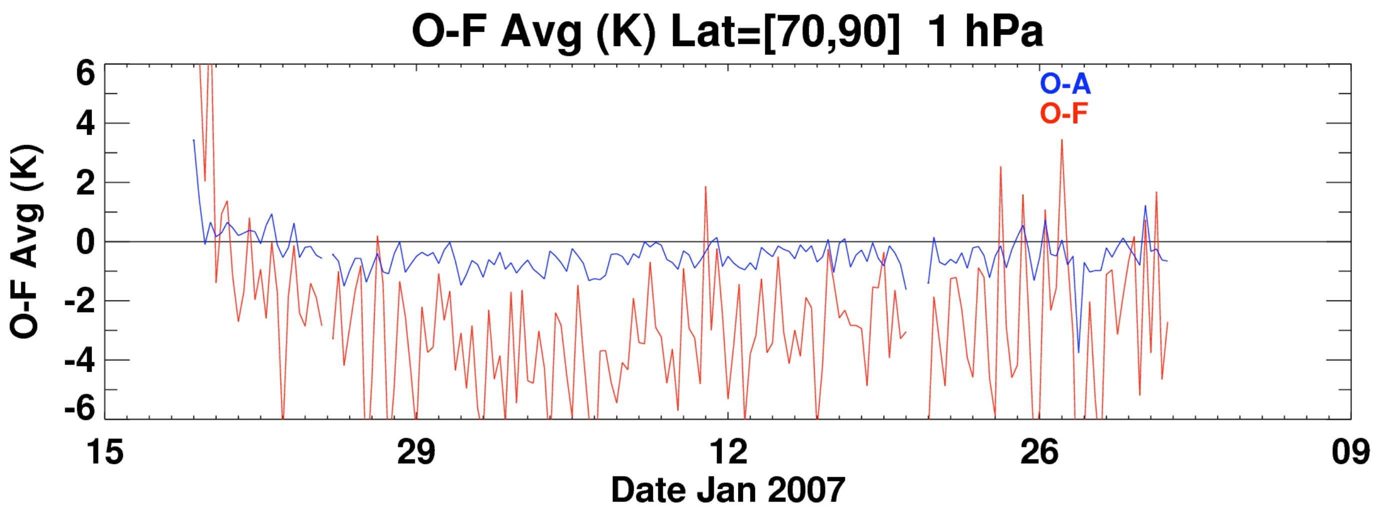
O-F Avg (Stratopause)



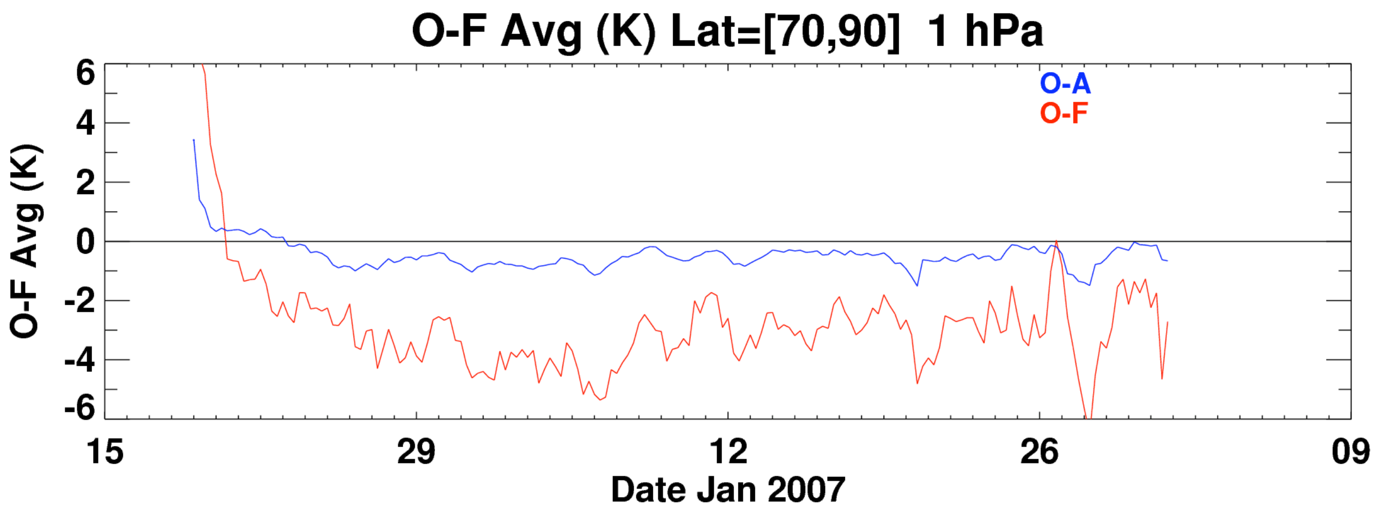
Smoothed



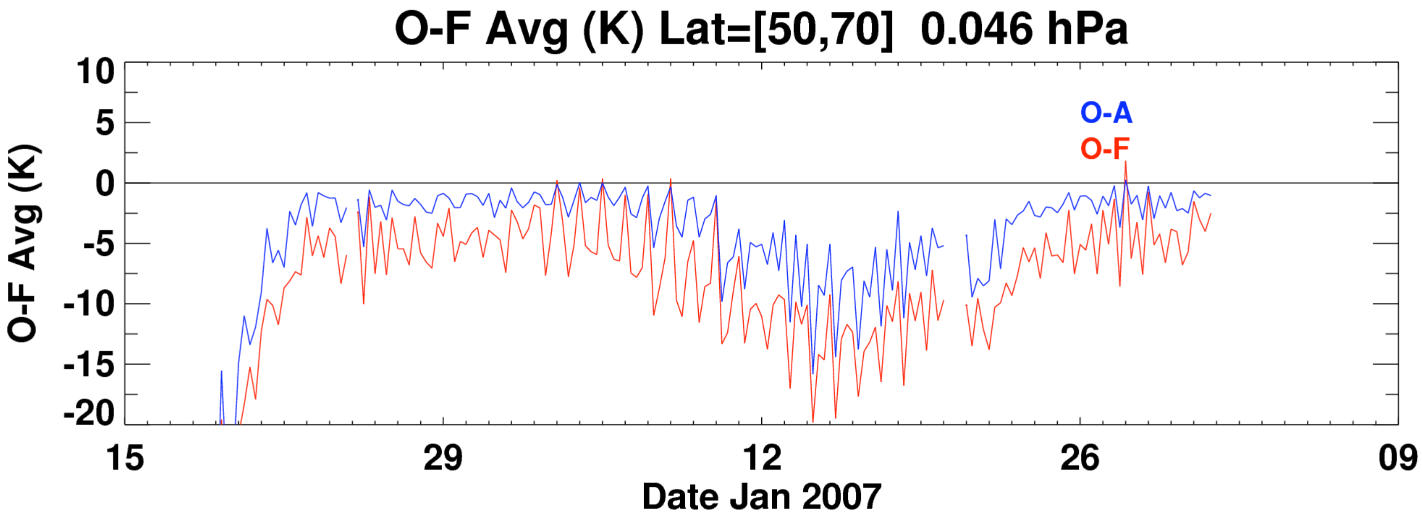
O-F Avg (Stratopause)



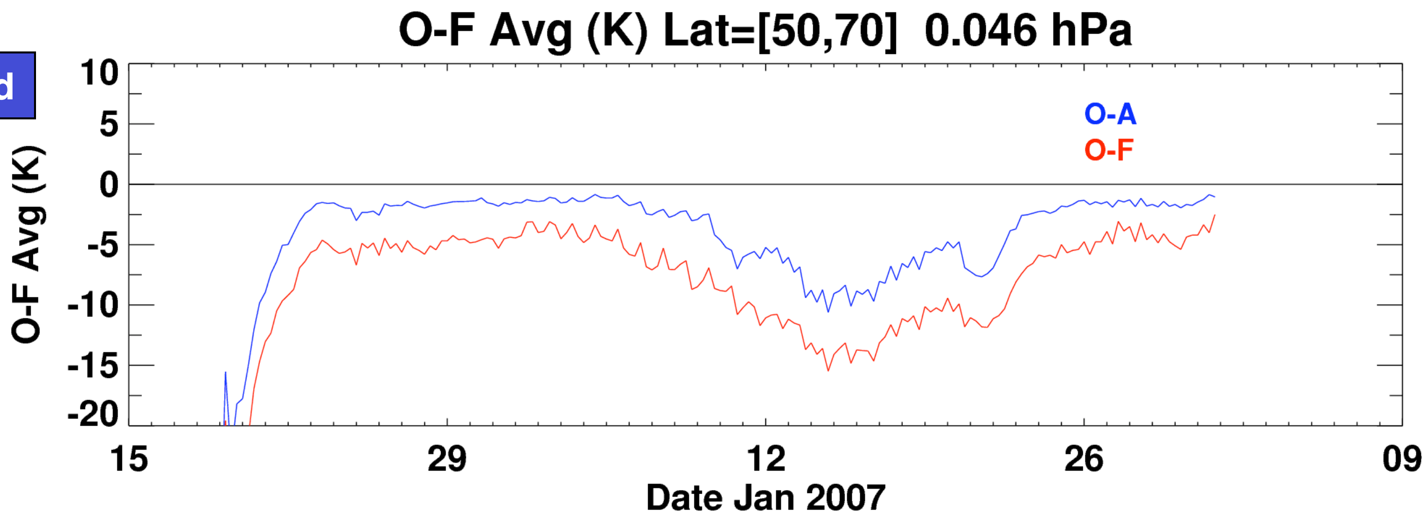
Smoothed



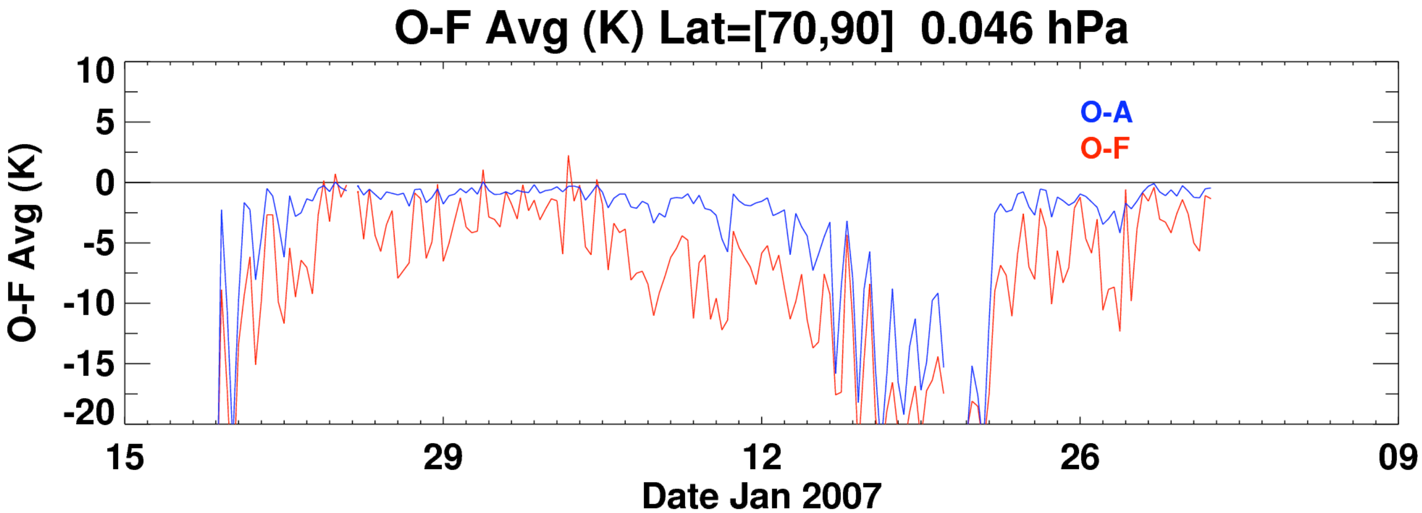
O-F Avg (Mesosphere)



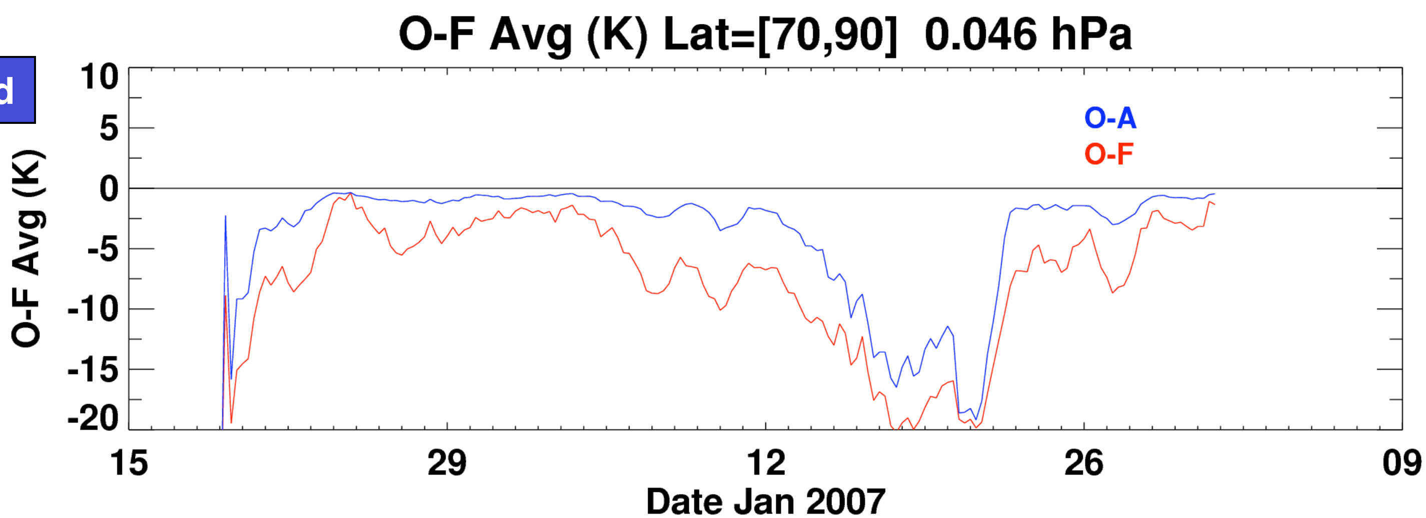
Smoothed



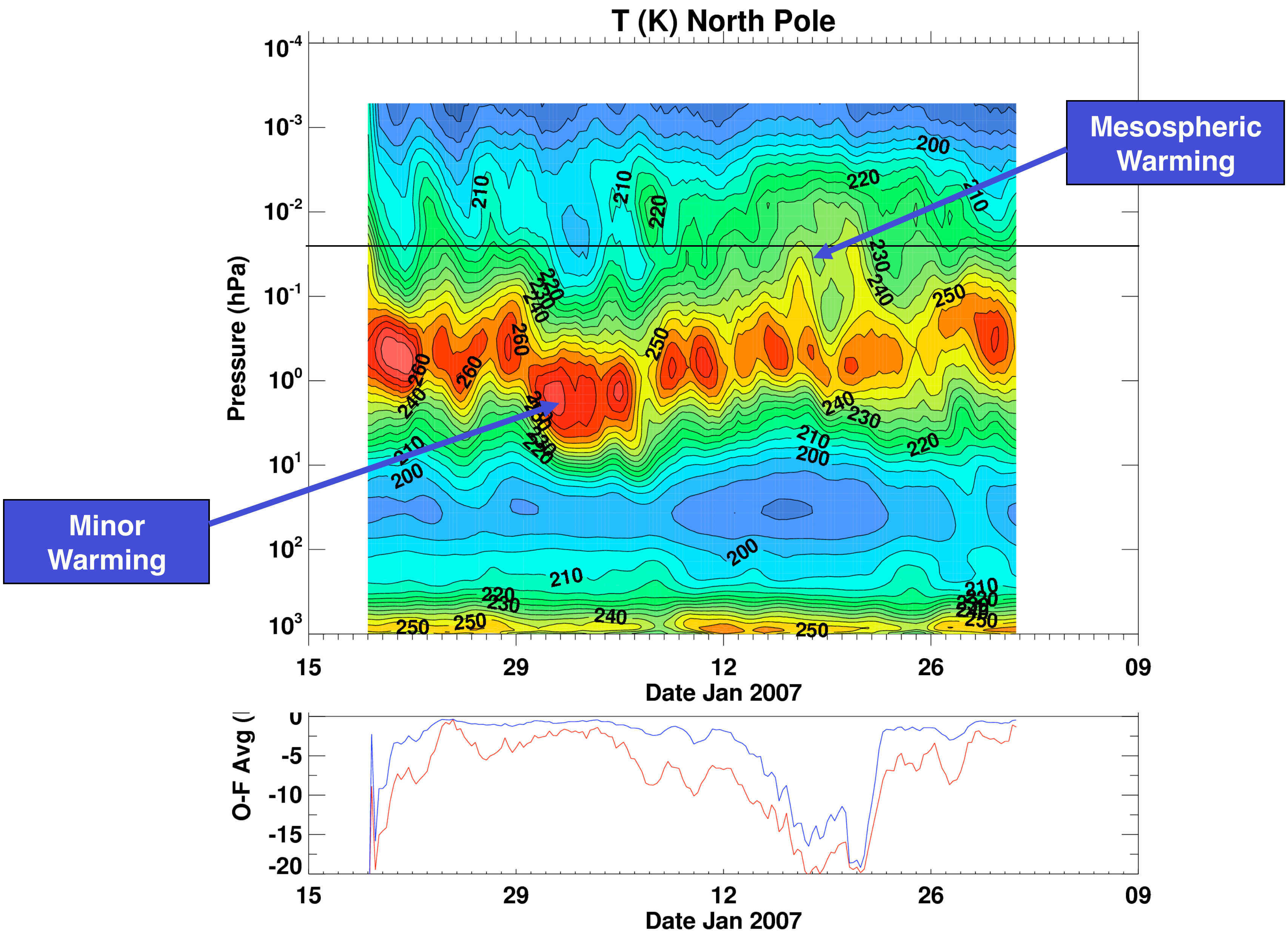
O-F Avg (Mesosphere)



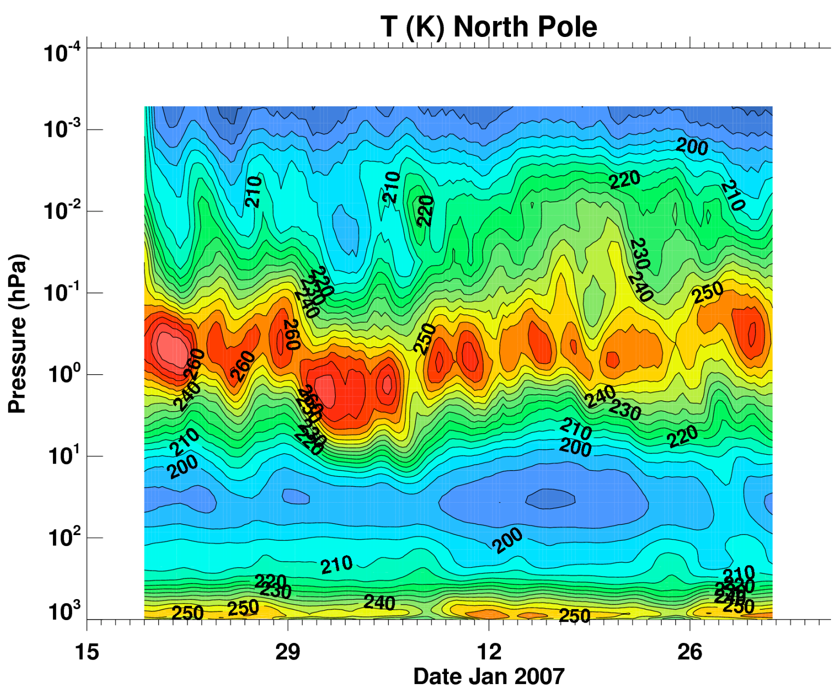
Smoothed



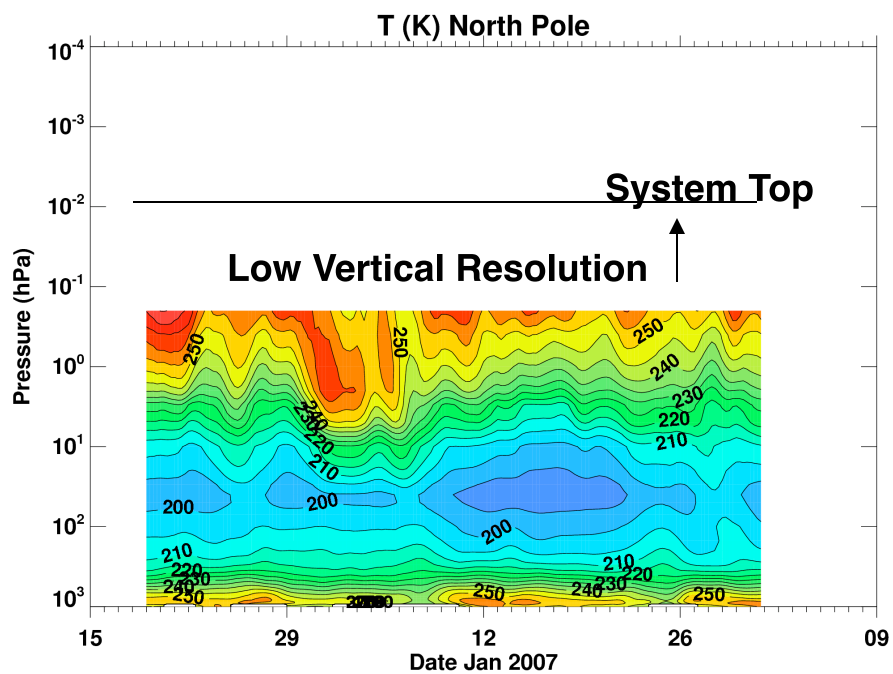
T(K) North Pole



Temperature Comparisons (North Pole)



GEOS-5 High-Altitude



GEOS-5 Operational

The GEOS-5 High-Altitude System fully resolves the stratospause and will lead to improved stratospause dynamics

Summary and Future Work

The GEOS-5 system has been extended to the mesospause and is ready for studies of the dynamically changing stratopause

Summary:

1. O-Fs decrease during mesospheric warming of Jan 2007
2. O-F biases are large in the tropics and upper mesosphere
3. Southern Hemisphere O F correlations show low "peaks" in the upper stratosphere and lower mesosphere, consistent with NOGAPS-ALPHA

Future:

Addition of SABER temperature profiles

Addition of standard radiance observations to the high-altitude system

Improvements in model bias and tropical forecasts

GWD tuning

Residual Circulation Diagnostics

Assimilation during more active winters: 2006 and 2009

Assimilation of constituents (mesospheric CO from MLS)