Progress in Strato./Meso. Assimilation with NAVDAS & NOGAPS-ALPHA

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Outline

- Description of the NAVDAS assimilation.
- Tuning the NOGAPS-ALPHA with gravity wave parameterizations.
- Examine MLS & SABER temperature assimilation.
- Examine upper-atmosphere forecast skill for Jan-Feb 2006.

NAVDAS
(NRL Atmospheric Variational Data Assimilation System)

- 3DVAR system; operational October 1, 2003
- NAVDAS was designed by Roger Daley,
  - along with Ed Barker, Keith Sashegyi, Pat Pauley, Jim Goerss, Nancy Baker, Tom Rosmond, Tim Hogan, Bill Campbell, Clay Blankenship, Liang Xu, Randy Pauley, Peter Steinle, Tom Lougheed

$$(1) \quad \mathbf{z} = \left[\mathbf{H}\mathbf{P_b}\mathbf{H^T} + \mathbf{R}\right]^{-1}\left[\mathbf{y} - H(\mathbf{x_b})\right] \quad \text{"Solver"}$$

$$(2) \quad \mathbf{x_a} - \mathbf{x_b} = \mathbf{P}_b\mathbf{H}^T \mathbf{z} \quad \text{"Post-multiplier"}$$

y - observation vector
$\mathbf{x}_b$ - the background vector
H - forward or observation operator
$\mathbf{P}_b$ – background error covariance
$\mathbf{X}_a$ – analysis vector
R – observation error covariance
H – linearized observation operator

- Formulates the Solution in Observation Space (not Model Space)

Assimilation Setup and Observation Summary

- **Assimilation Setup**
- 6-Hour update cycles
- Time window for MLS & SABER data is 4 hours
- Model resolution: T79L60 (top=.005 hPa) or T79L68 (top=.0005 hPa)
- Dates: Jan – Feb 2006

- **Standard Observations**
- Geostationary winds
- AMSU-A radiances channels 4-10
- MODIS AQUA & TERRA winds
- QuickSCAT
- Surface: land, ship, buoy, rawinsonde, profiler, pibal
- Aircraft: MDCARS, AMDAR, etc.

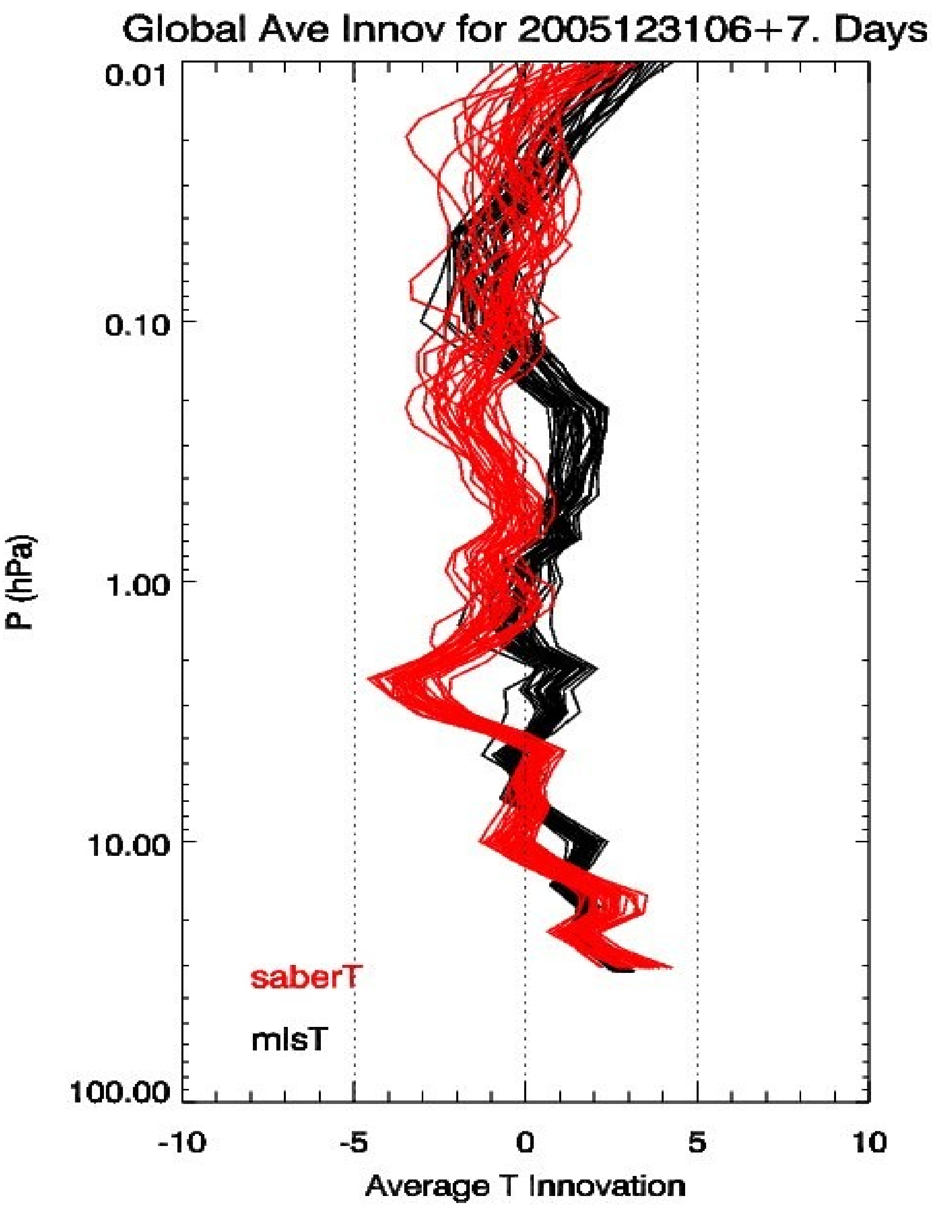
- **New Observations**
- MLS v1.5 Temperature: 32 - 0.01 hPa
- SABER v1.06 Temperature: 32 - 0.01 hPa
- MLS v1.5 Ozone & H2O: 300 - 0.01 hPa
- AIRS H2O retrievals: 1000- 100. hPa (experimental)

Removal of SABER-MLS Biases

* MLS and SABER Global Average O-F for 29 update cycles.

* Each line is the average O-F for a single 6-hour update cycle.

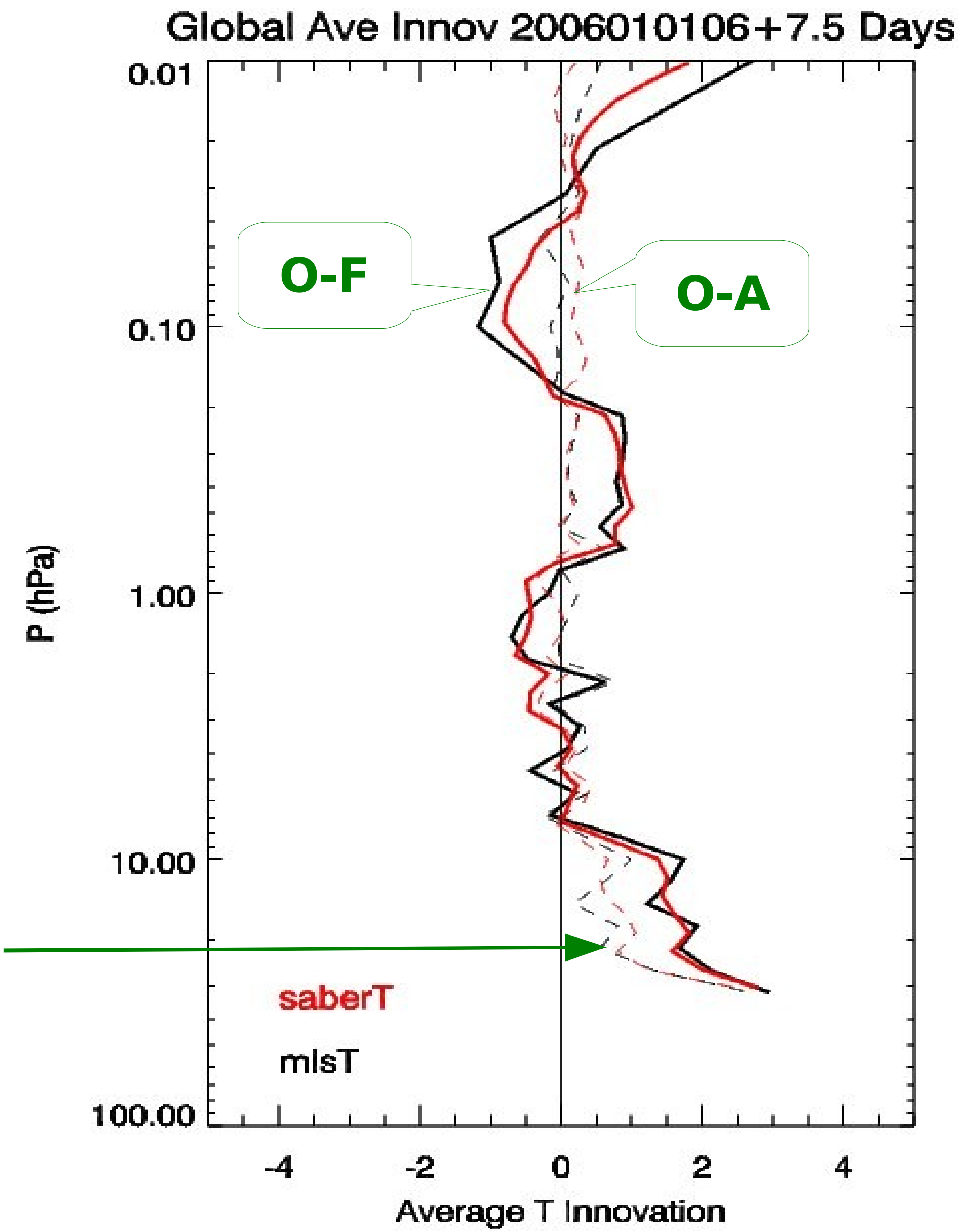
* Average difference between the SABER and MLS O-F is used as a “bias” correction to the SABER data.



Global Average O-F with SABER-MLS bias correction.

* **Innovations (O-F) averaged over all the update cycles**

* **Dashed lines = residuals (O-A)**



AMSU-A channel 10 (peaks at ~50 hPa) overlaps the bottom of the MLS & SABER data. Relative bias may cause the non-zero residual

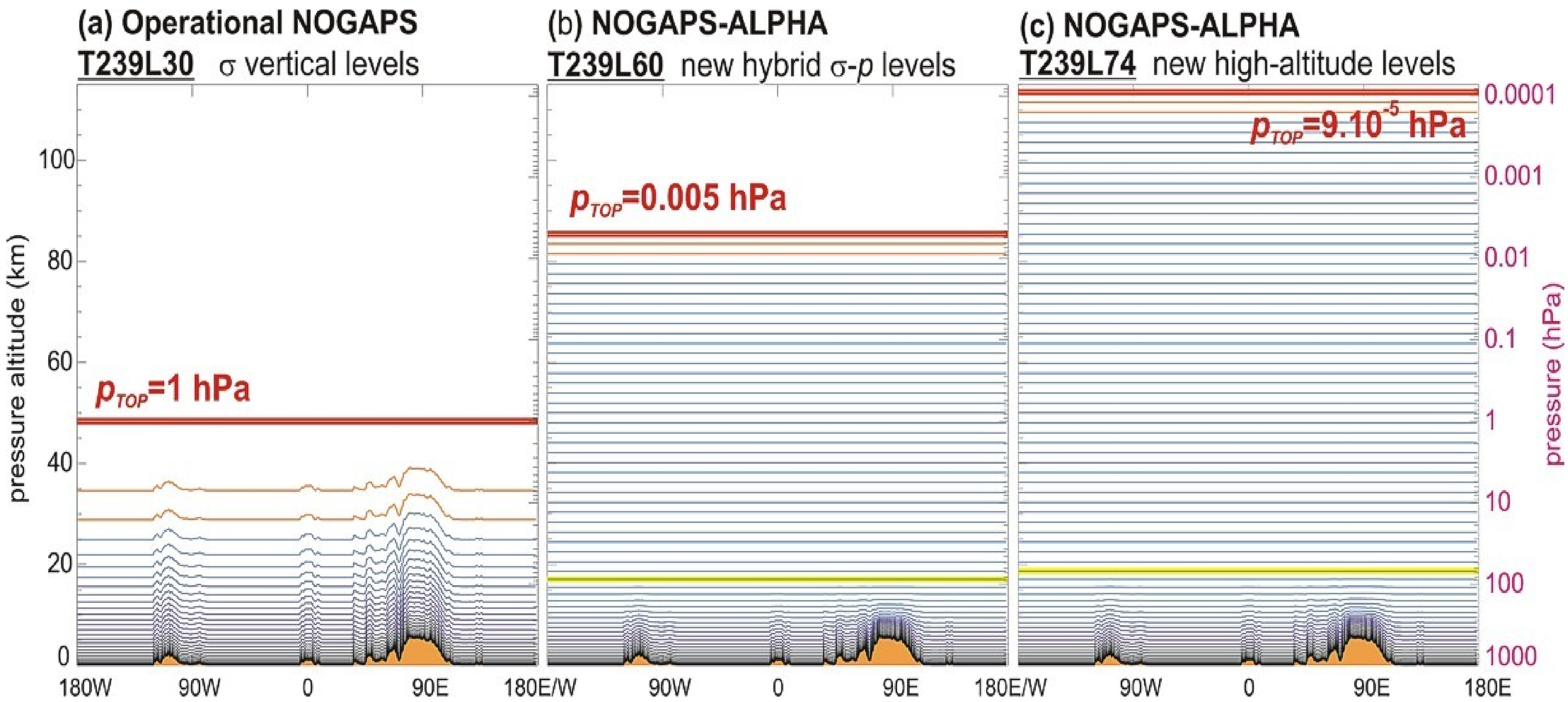
Topic Change: **Tuning the NOGAPS-ALPHA model in the stratosphere and mesosphere**

"...the details of the assimilation method *[..]* and the improvement of the representation of error covariance are secondary to addressing the problems of bias and physics" -- Ricky Rood, *SPARC Newsletter, 2005*

Notation: Dates are expressed as YYYYMMDDHH, i.e. 2006012000 = 20 Jan 2006, 00 UT

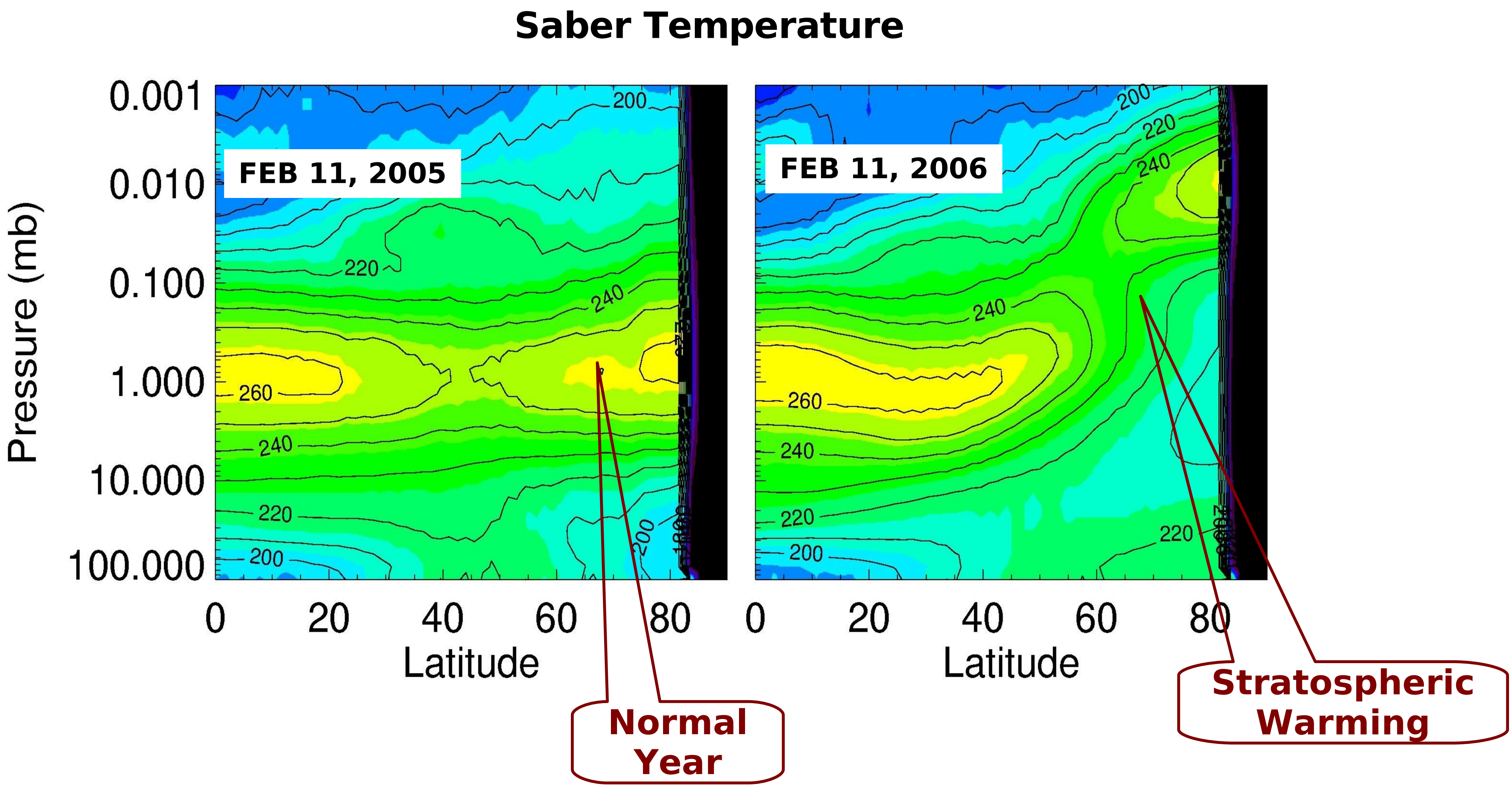
NOGAPS-ALPHA Overview

(Advanced Level Physics High Altitude)



- **new hybrid *σ-p* vertical coordinate** (to maintain smooth vertical layer thickness profiles over all topography; increased vertical domain), **increased vertical resolution**
- **new physics packages (NASA CLIRAD SW/LW heating, prognostic ozone, ...)**
- **non-LTE cooling (Fomichev) extends model to 110-115 km (74 levels)**
- **latest upgrade: WACCM non-orographic GW scheme [Garcia et al., 2007 JGR]**

SABER data for 2 years

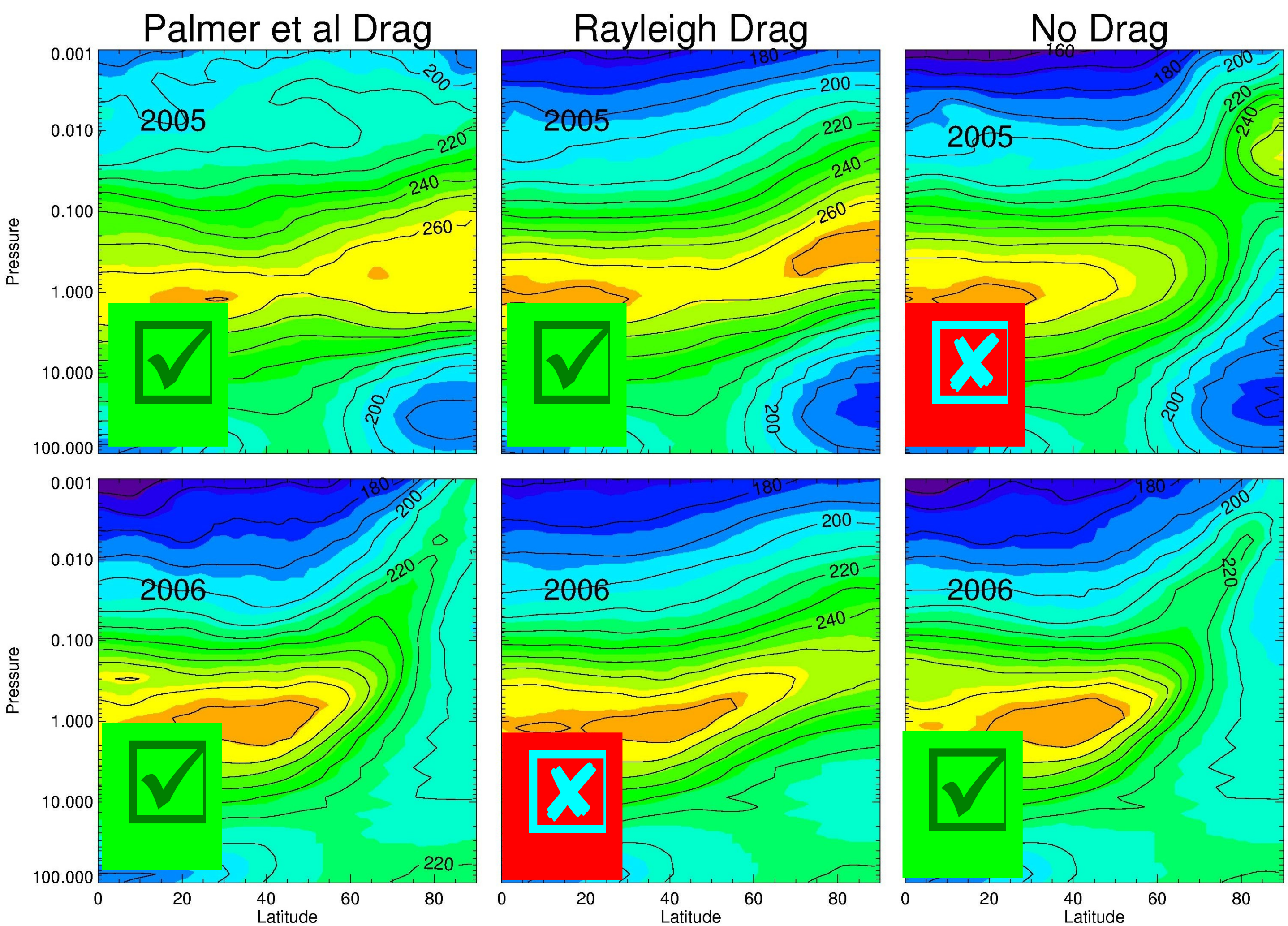


[Siskind et al., 2007 GRL]

Results from first 6 simulations

(2 yrs x 3 parameterizations)

Realistic GWD | Invariant GWD | No GWD



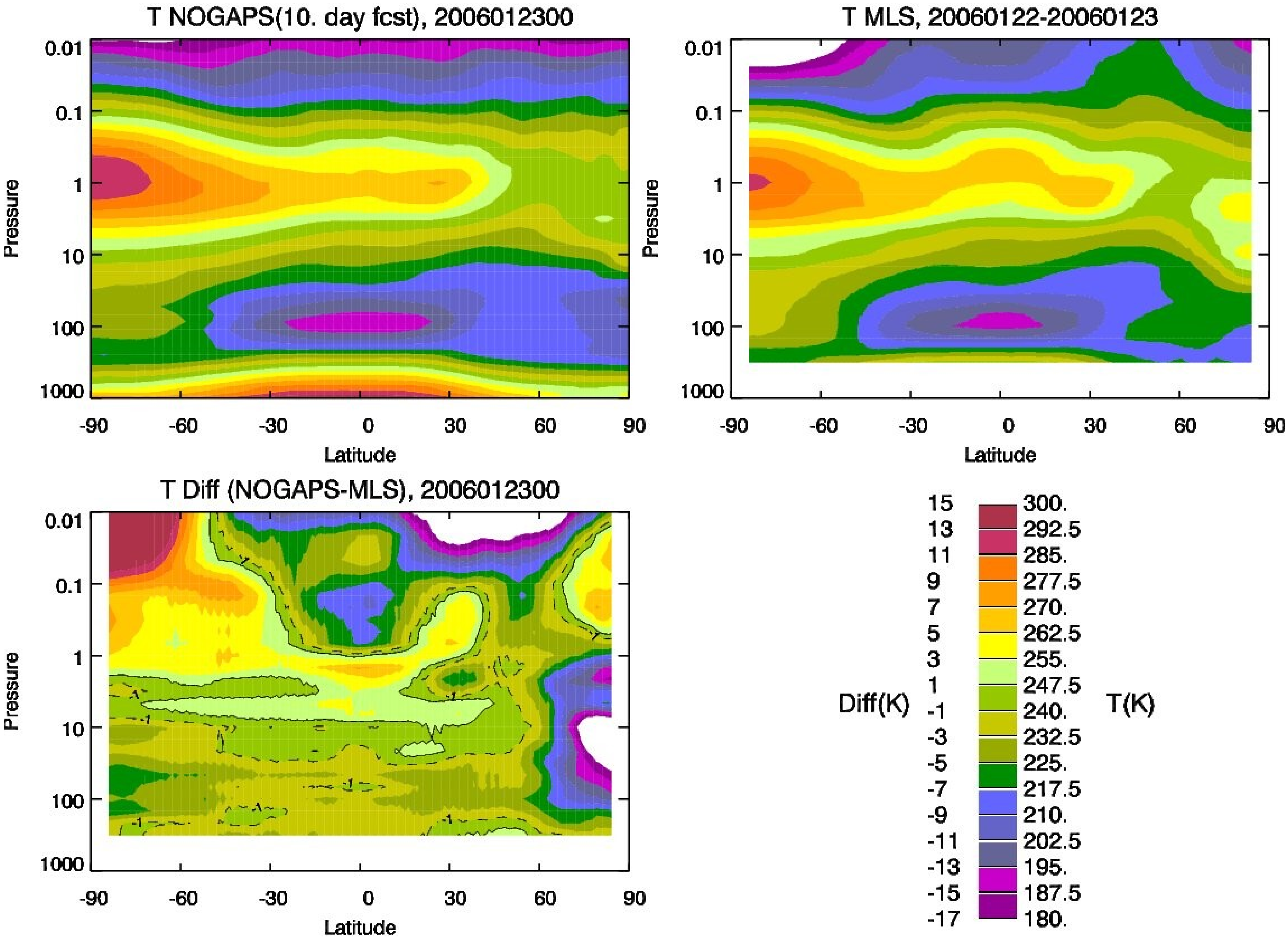
← 2005 "normal"

← 2006 "anomalous"

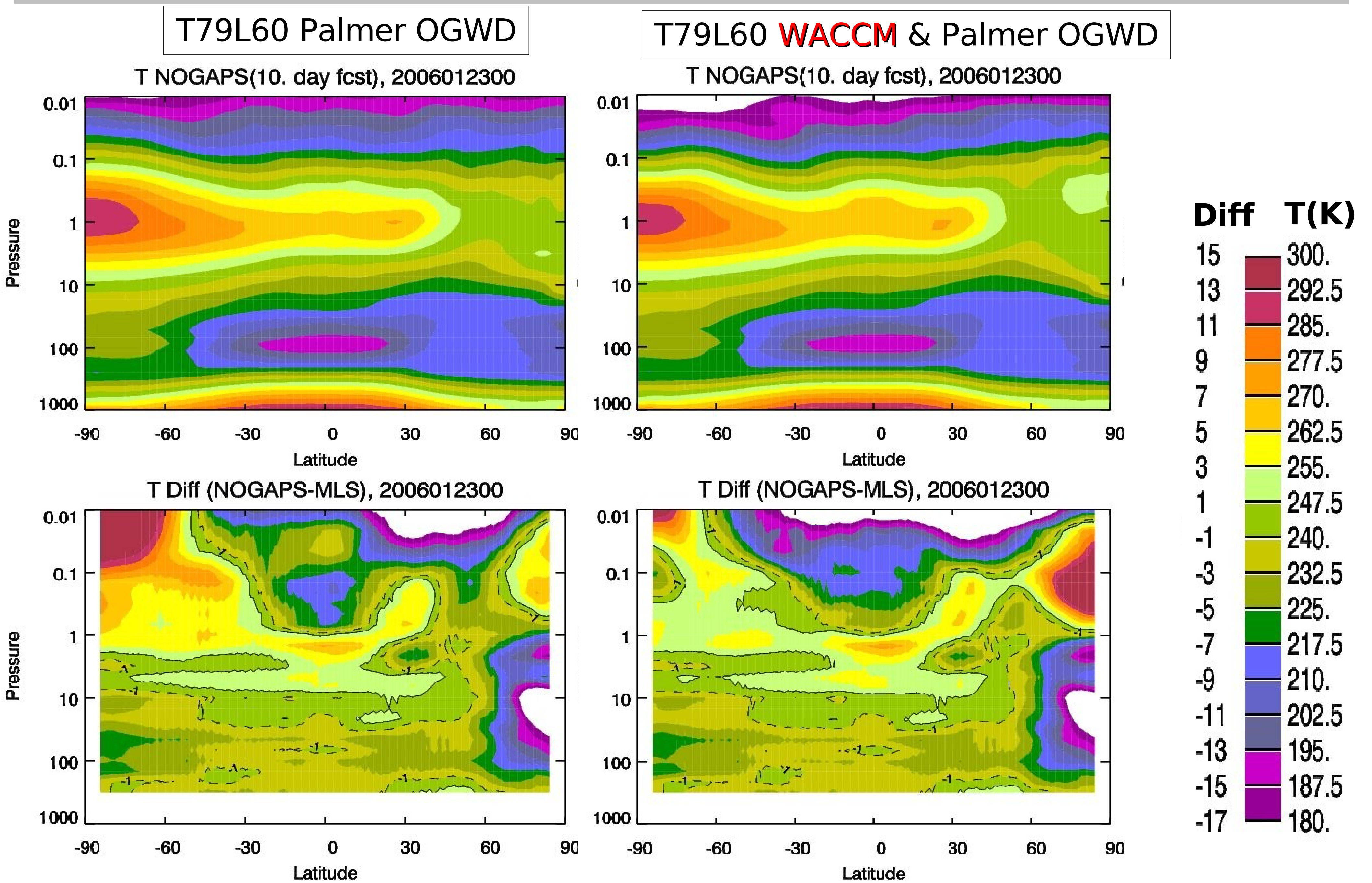
Suggests "anomalous" 2006 due to heavily suppressed mesospheric OGWD

[Siskind et al., 2007 GRL]

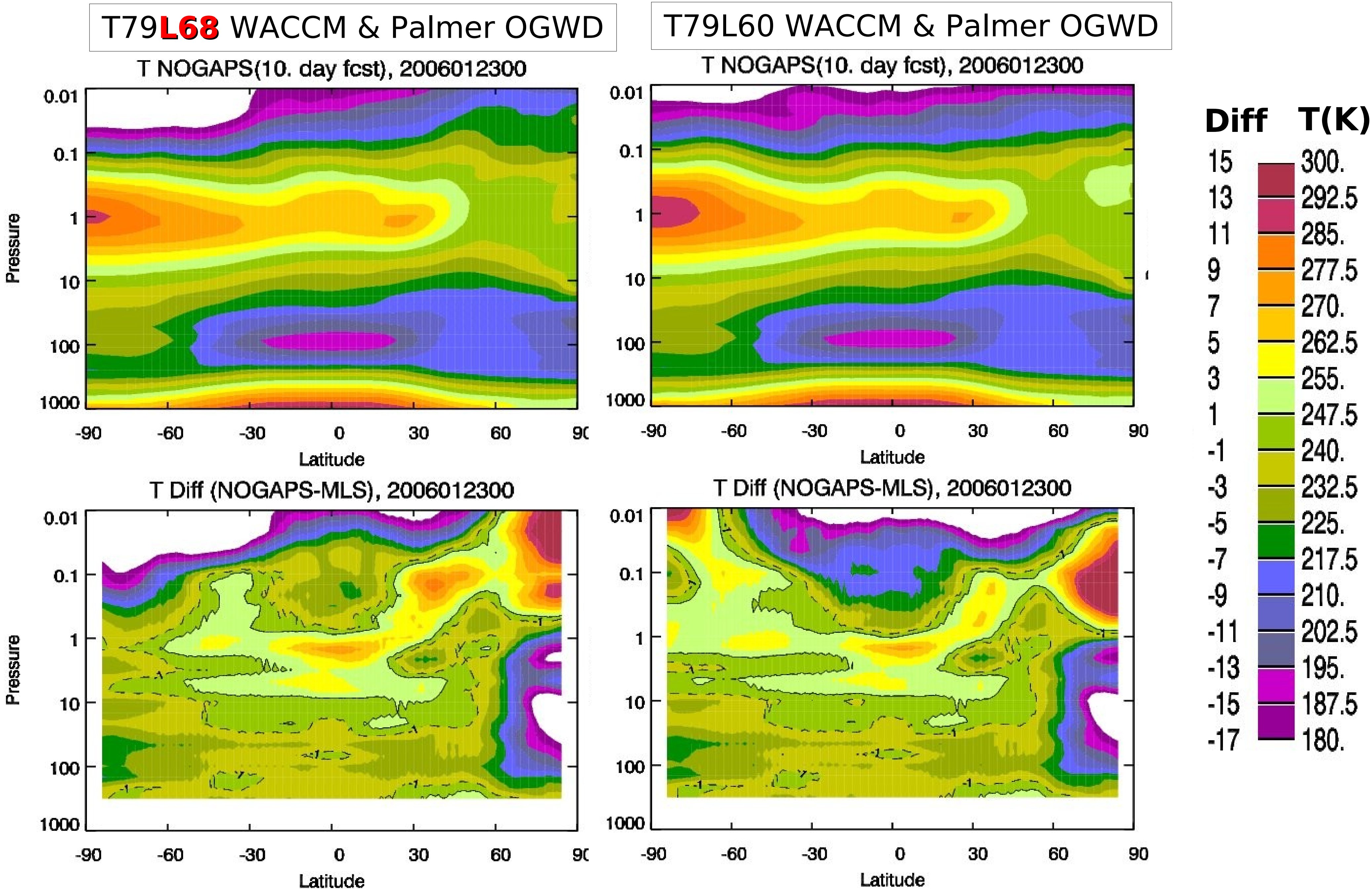
10-day NOGAPS-ALPHA forecast compared with MLS
(T79L60 Palmer OGWD)



10-day NOGAPS-ALPHA forecast compared with MLS (Impact of adding WACCM gravity waves to L60)



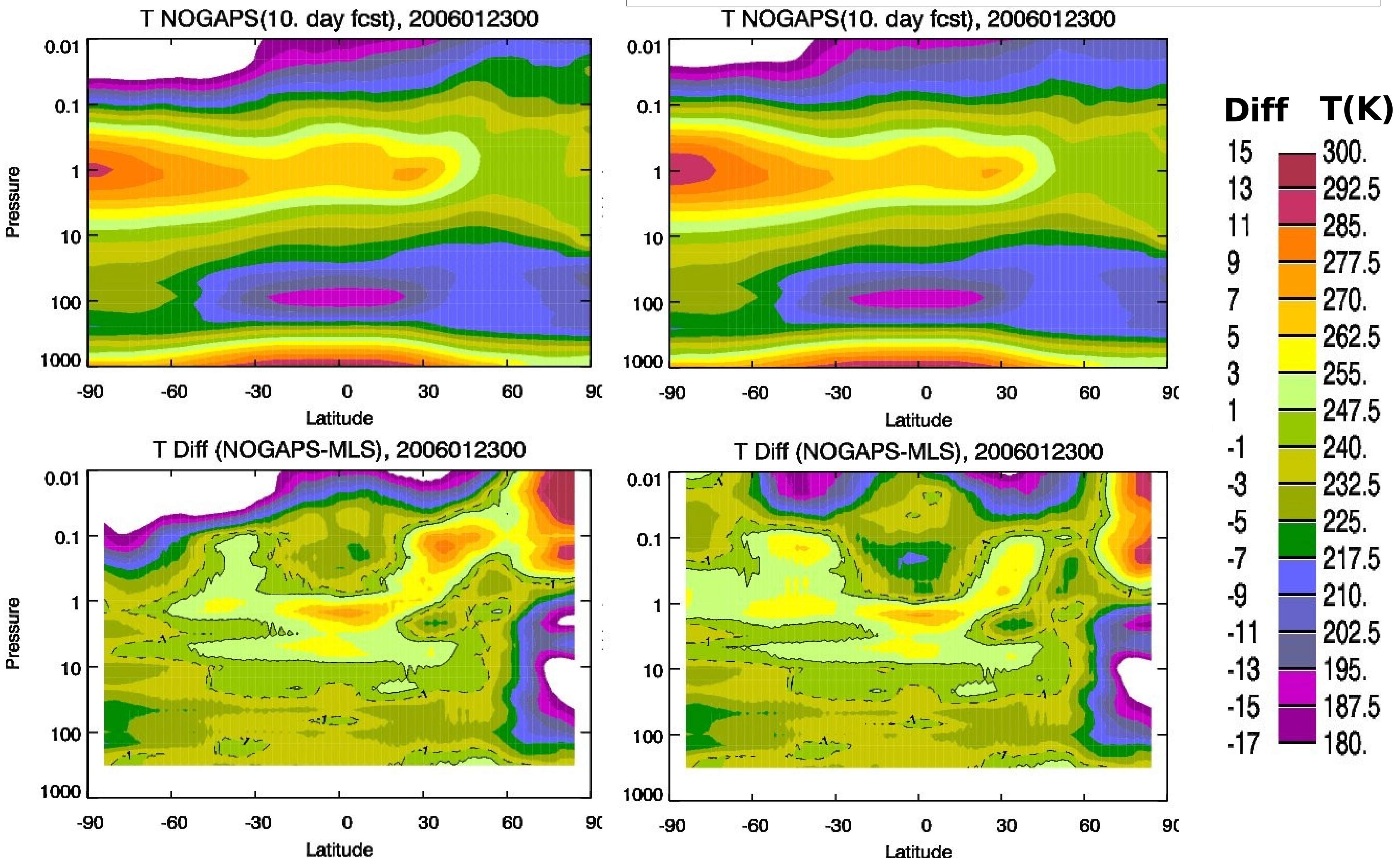
10-day NOGAPS-ALPHA forecast compared with MLS
(Impact of raising model top from ~83km to ~96km)



10-day NOGAPS-ALPHA forecast compared with MLS (Impact of 60% reduction in WACCM gravity wave efficiency)

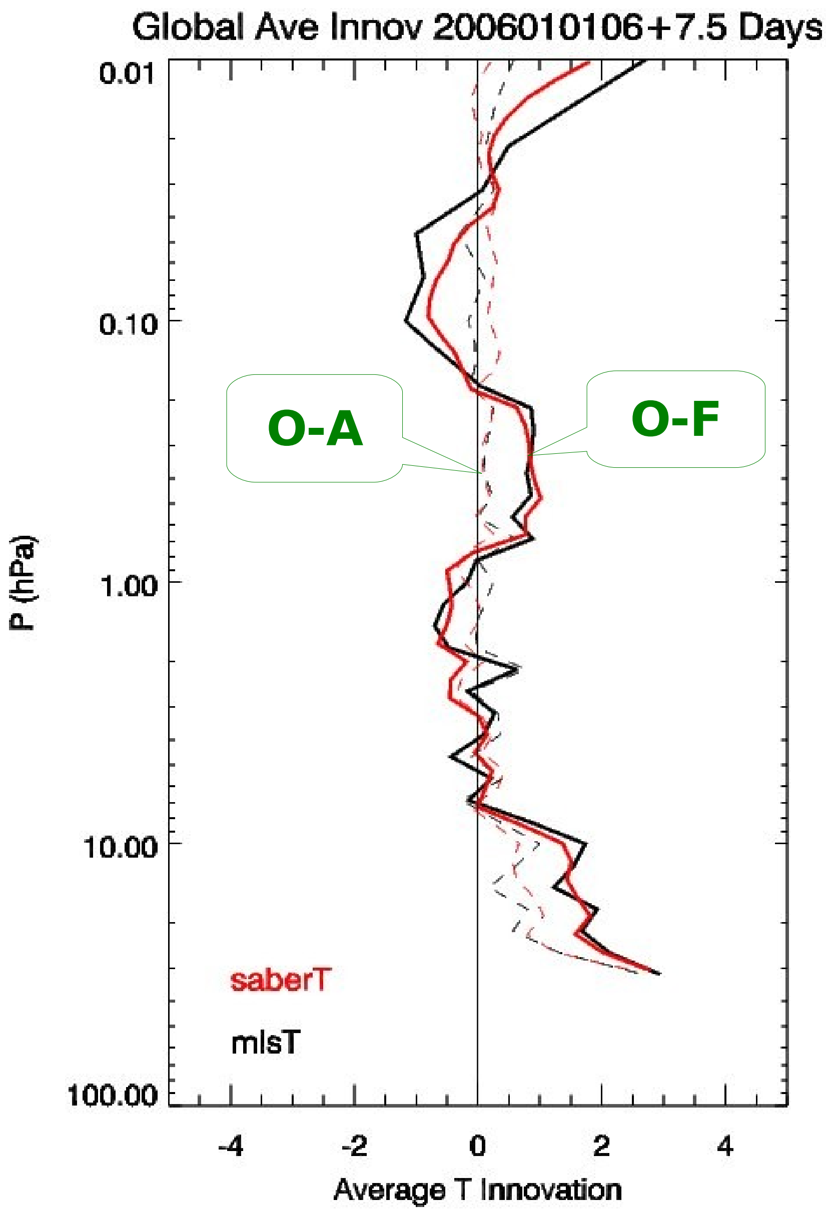
T79L68 WACCM & Palmer OGWD

T79L68 WACCM* (***effgw_spec=.05***) & Palmer

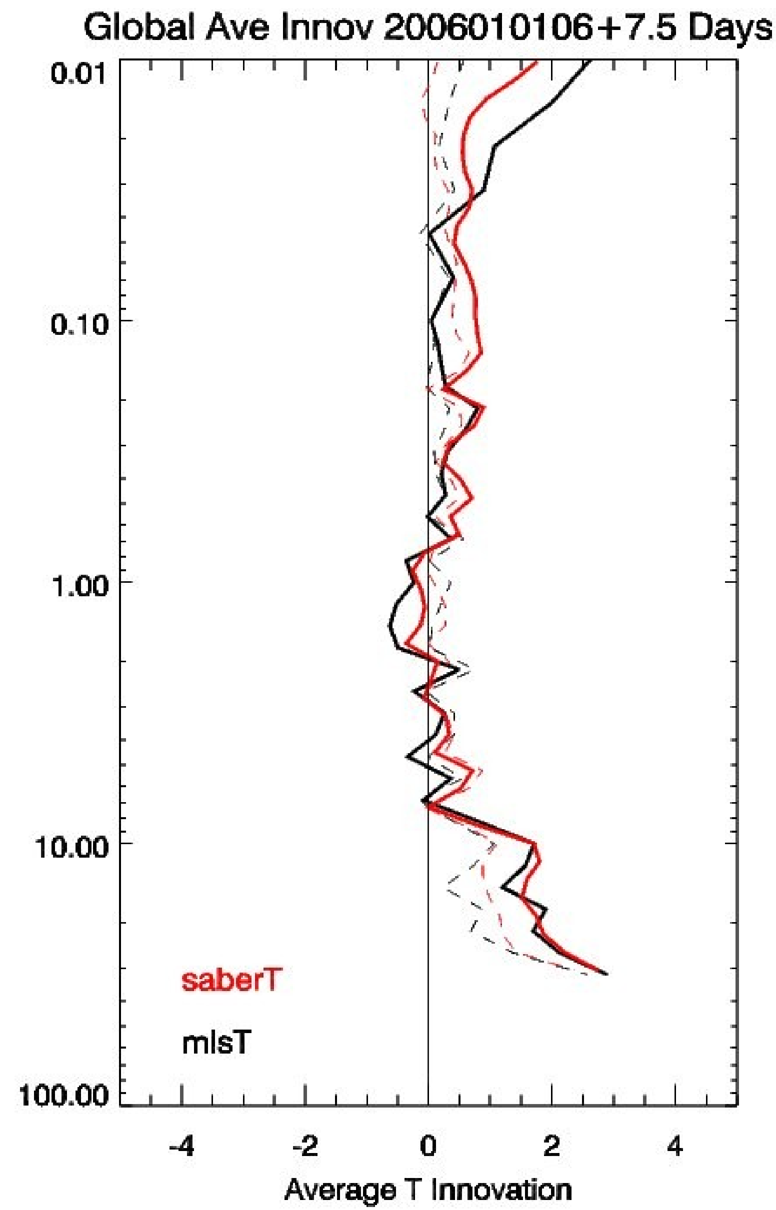


Does a better model lead to smaller innovations? ... yes

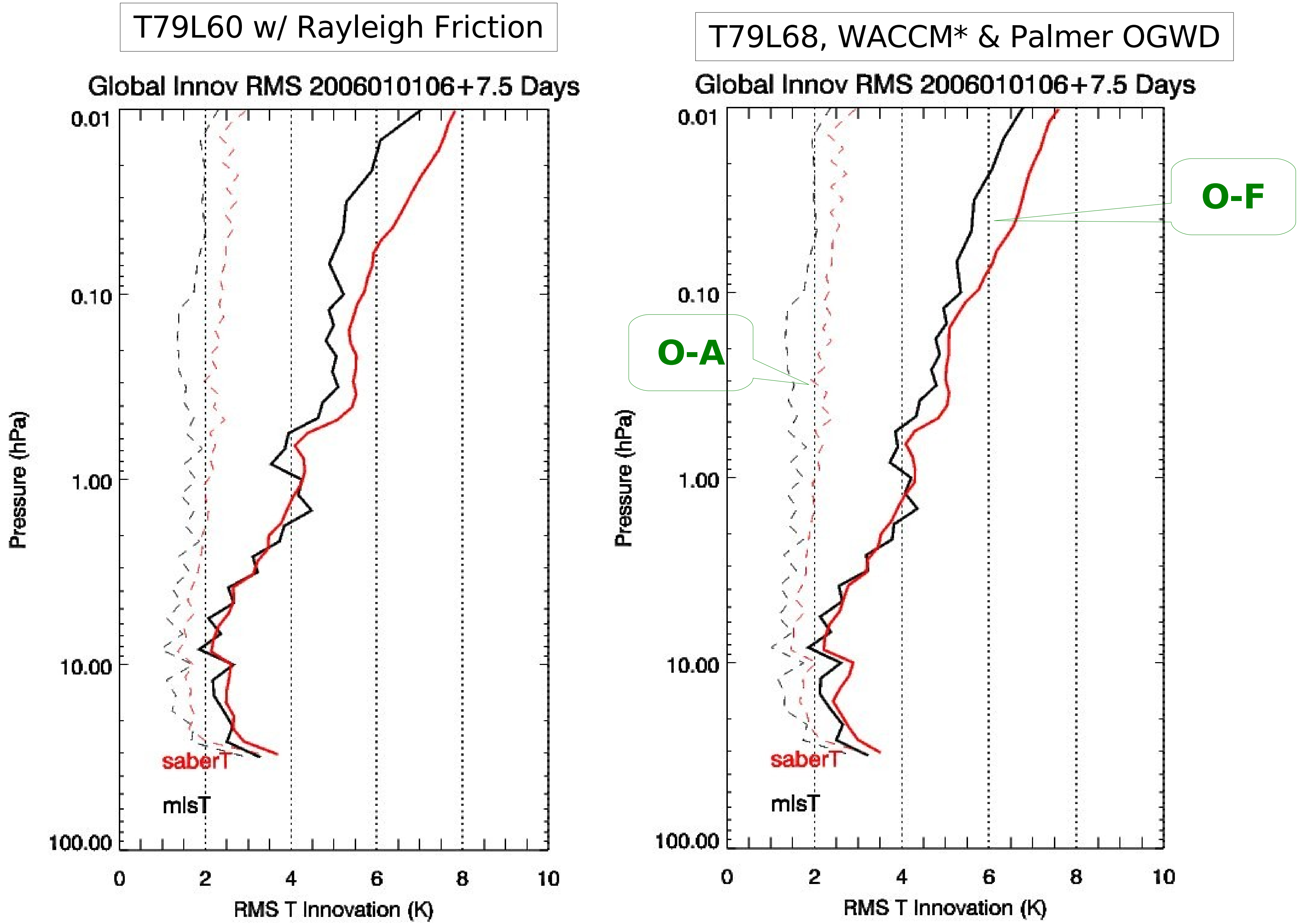
T79L60 w/ Rayleigh Friction



T79L68, WACCM* & Palmer OGWD



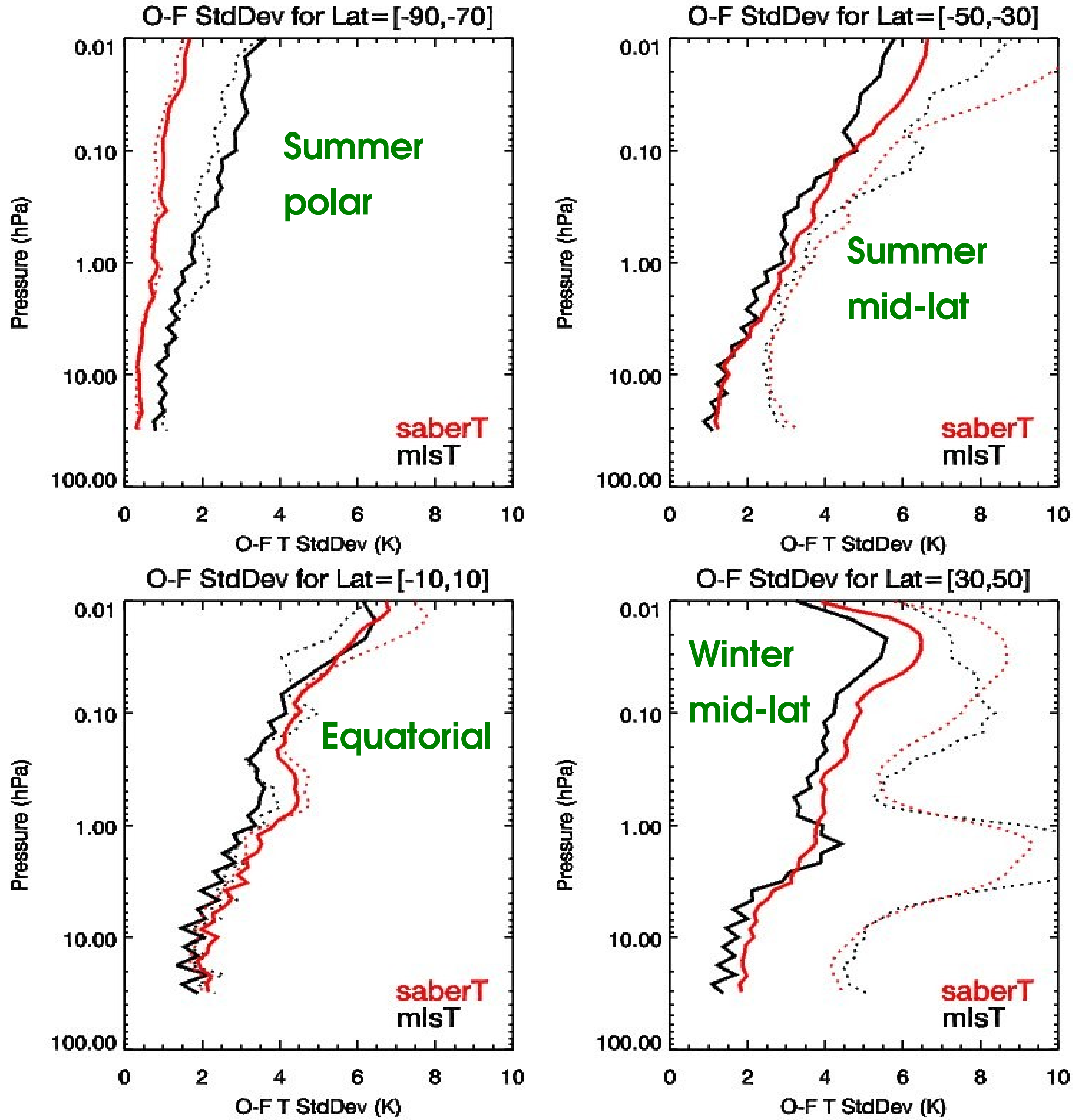
Does a better model reduce the innovation RMS? … not yet



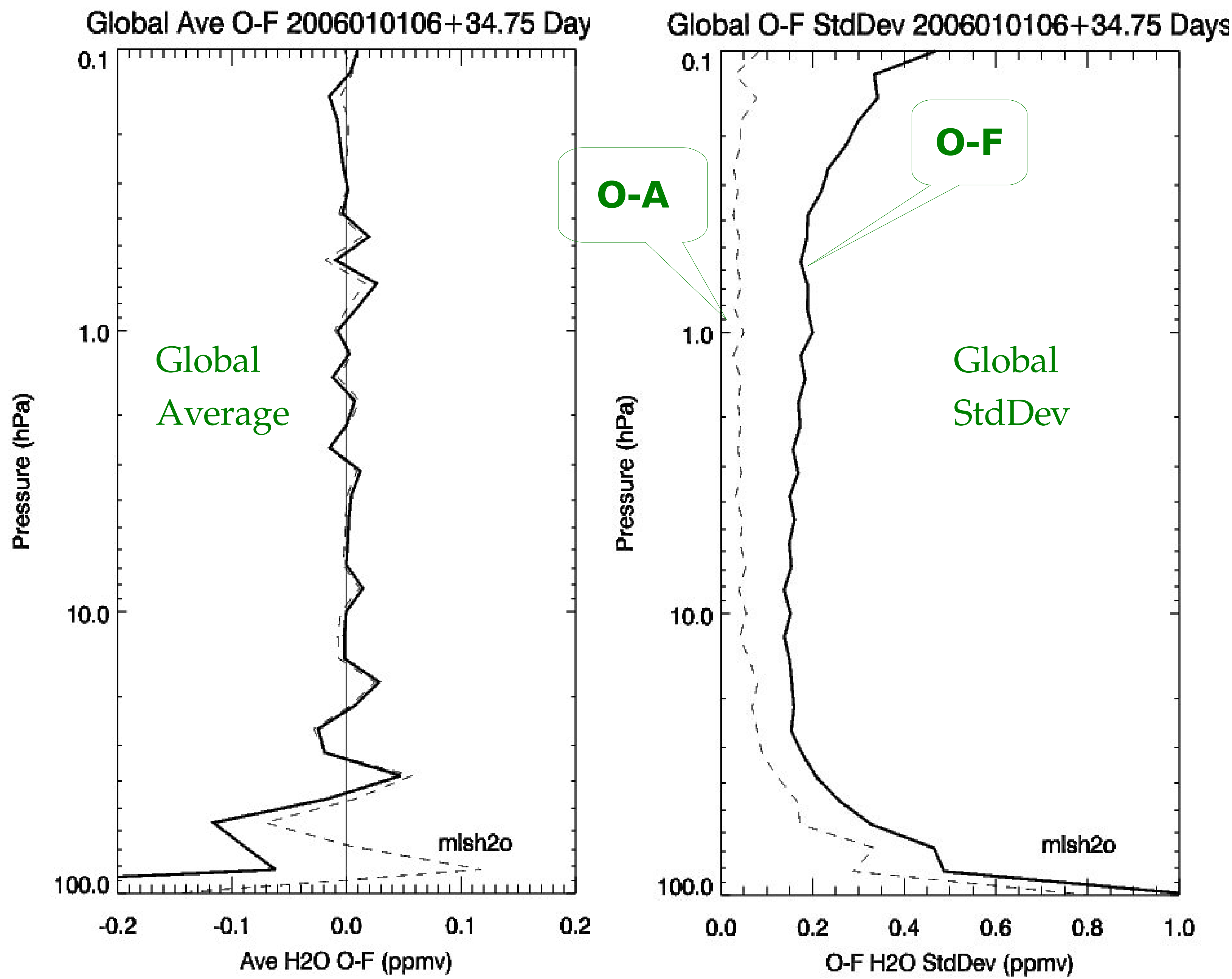
O-F StdDev averaged for 36 days (Jan 1 – Feb 6, 2006)

O-F StdDev
Obs StdDev

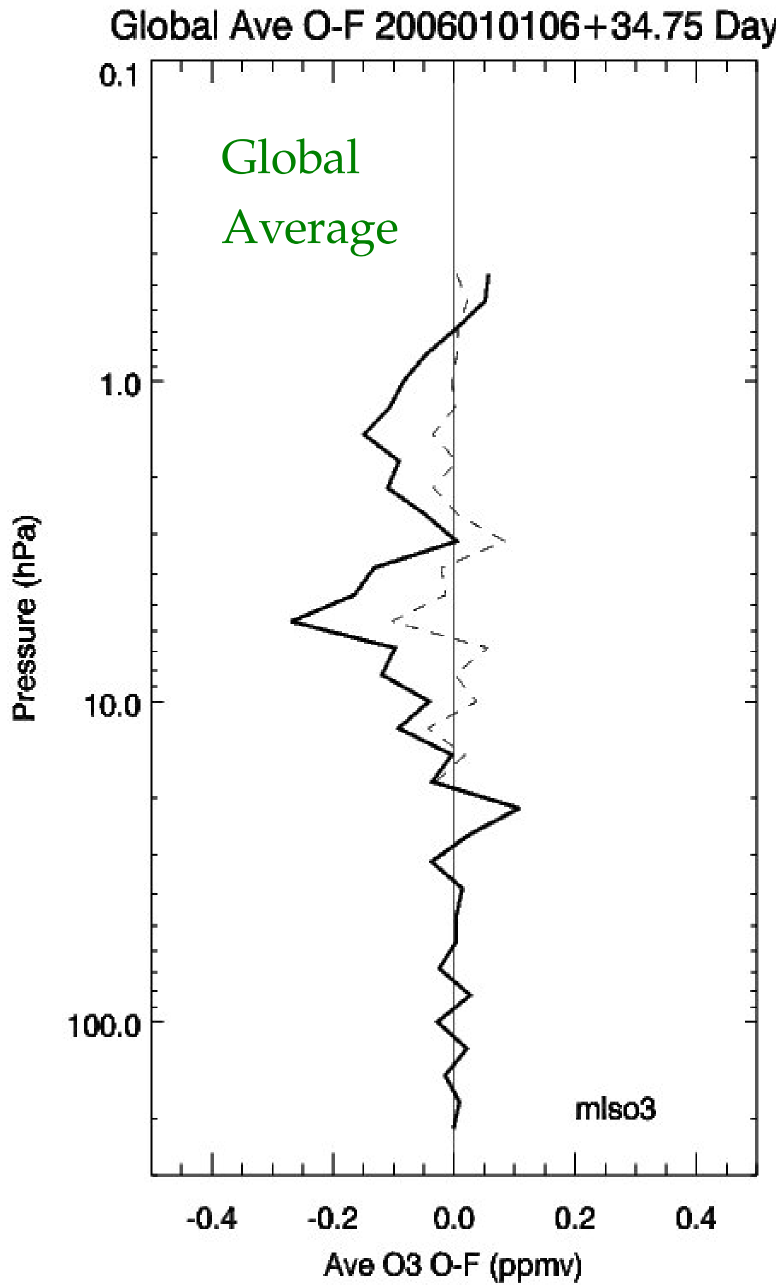
*** In the polar-summer and equatorial regions;**
O-F StdDev ≈ Obs StdDev

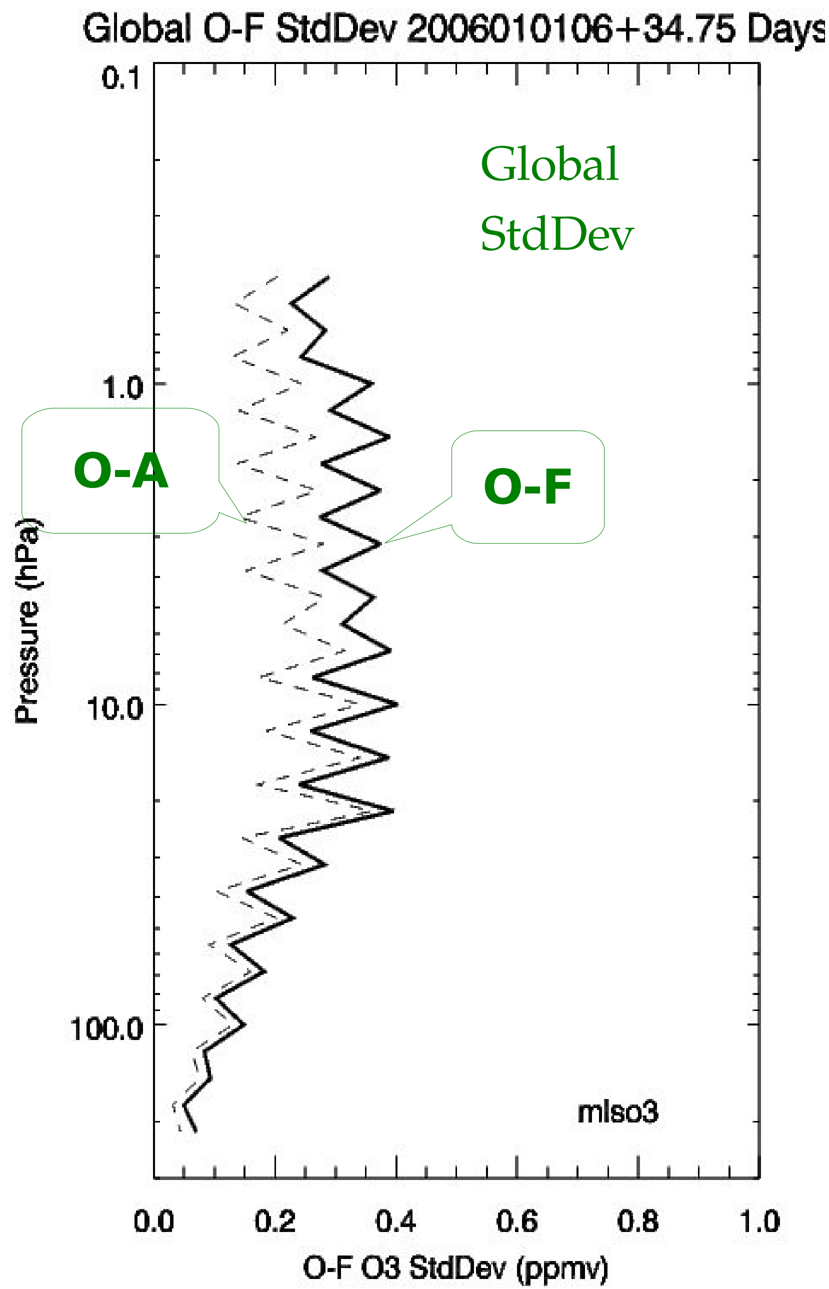


MLS Water Vapor Assimilation, O-F Statistics



MLS Ozone Assimilation, O-F Statistics



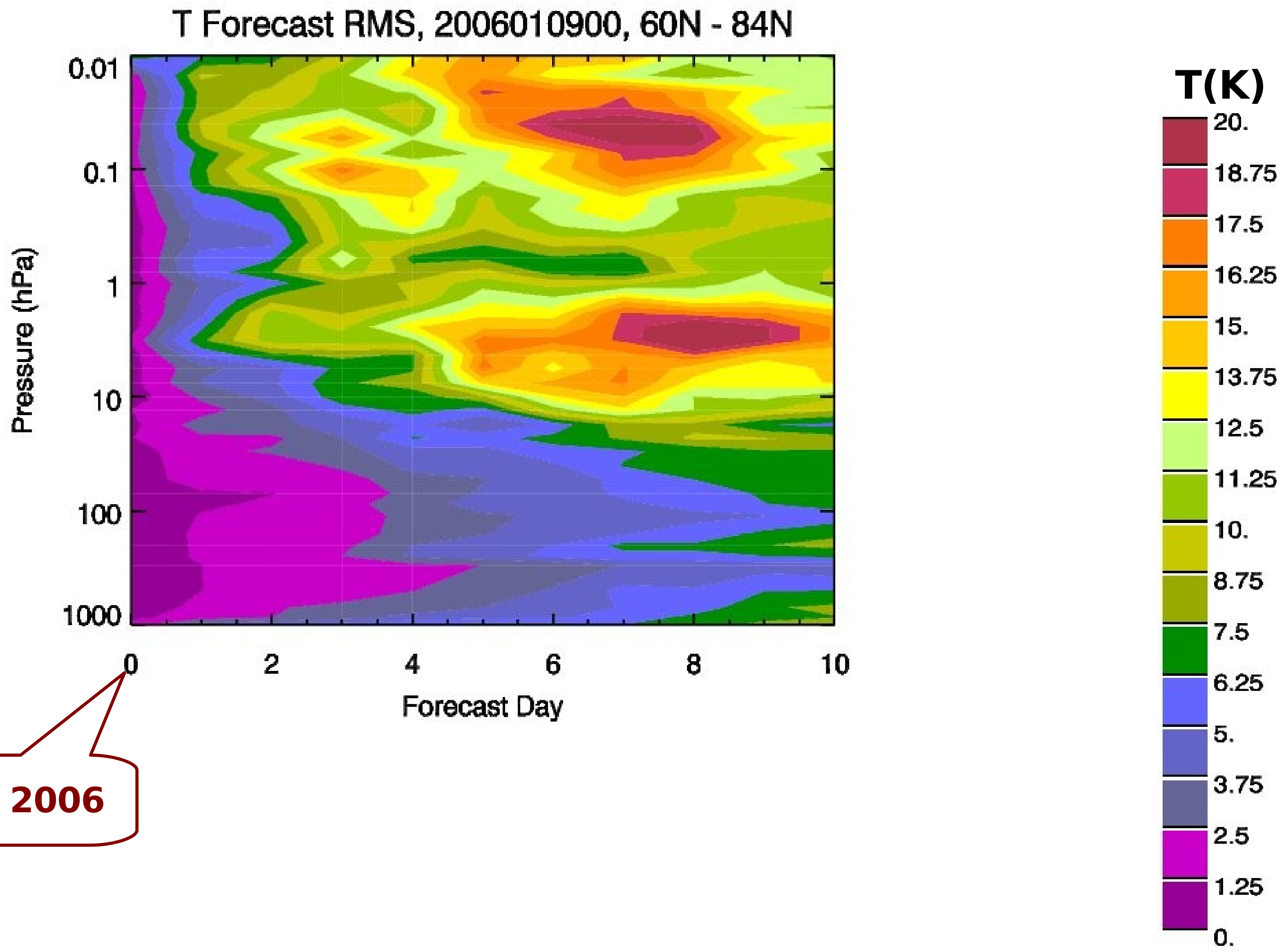


Topic Change: **Predictability of the strat. and meso. and SSW with the T79L60 model**

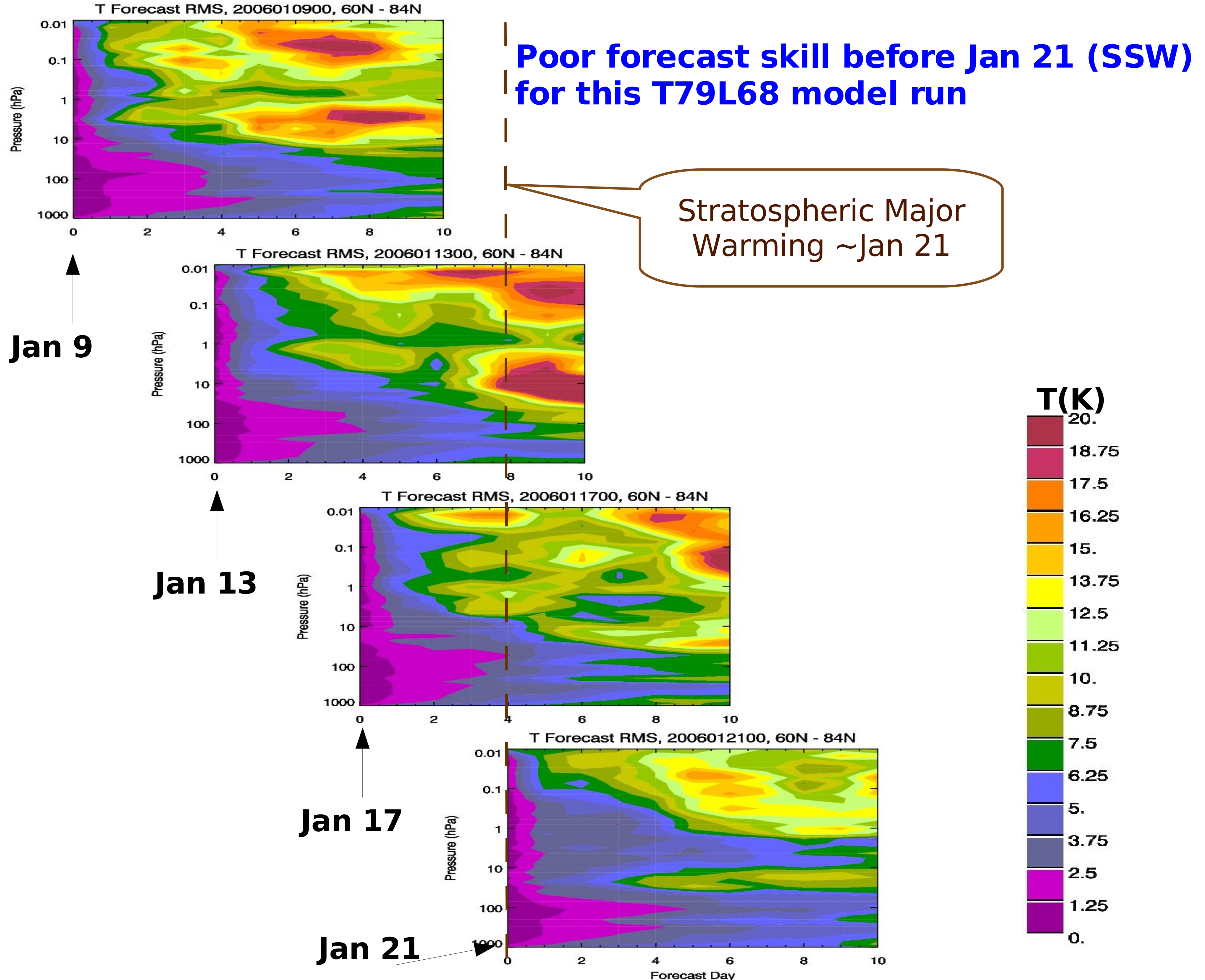
"given the high degree of variability in the mesosphere due to the presence of a strong gravity-wave fields – leading to much shorter correlation lengths in both time and space – mesospheric assimilation is likely to be a challenging proposition." -- Ted Shepherd, JAS 2000.

Evolution of forecast error with forecast length

Arctic: 60°N-84°N , T79L68 WACCM* & Palmer

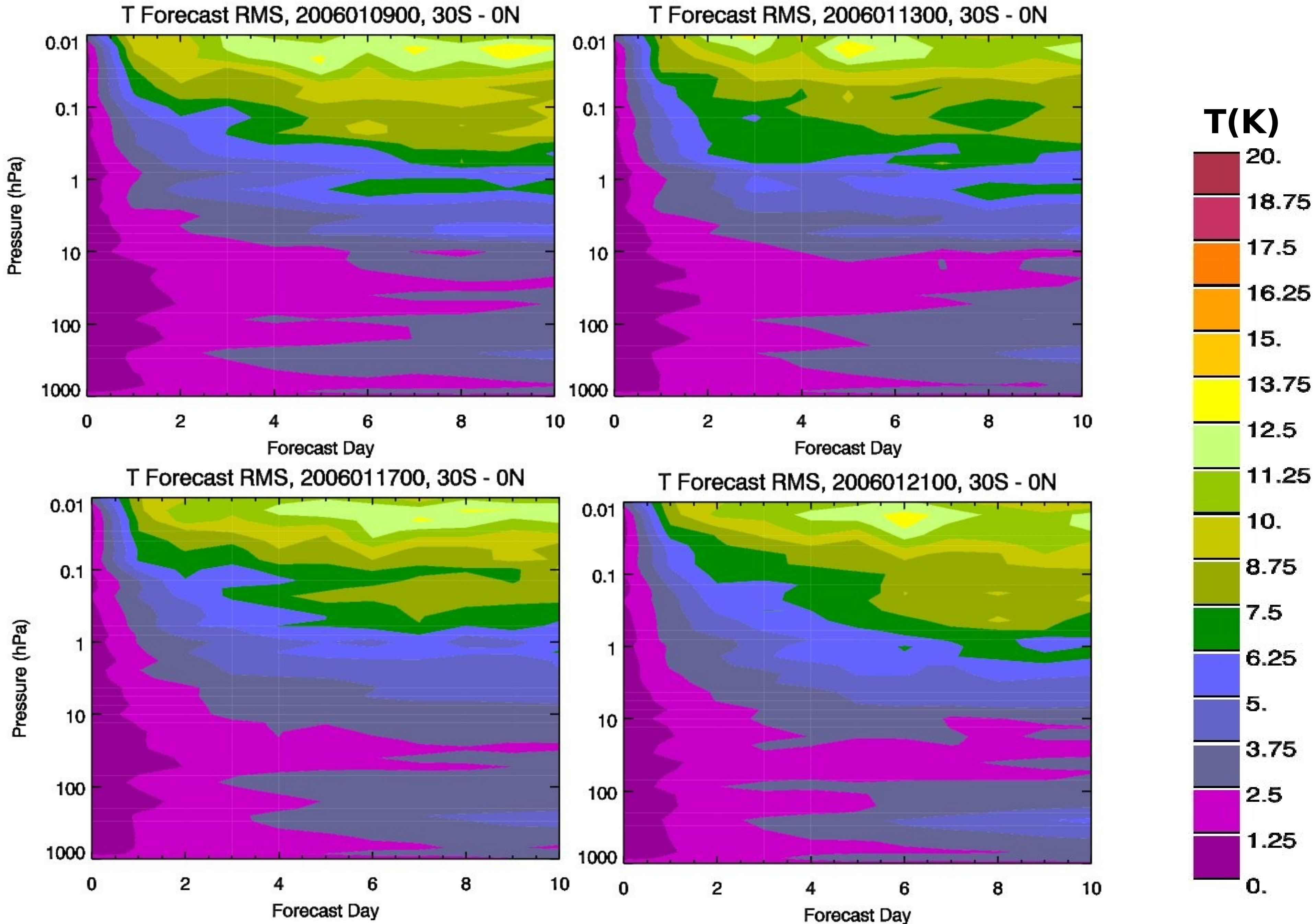


Jan 9, 2006


Poor forecast skill before Jan 21 (SSW)
for this T79L68 model run
Stratospheric Major
Warming ~Jan 21
T Forecast RMS, 2006010900, 60N - 84N
T Forecast RMS, 2006011300, 60N - 84N
T Forecast RMS, 2006011700, 60N - 84N
T Forecast RMS, 2006012100, 60N - 84N
Pressure (hPa)
0.01
0.1
1
10
100
1000
0
2
4
6
8
10
Forecast Day
Jan 9
Jan 13
Jan 17
Jan 21
T(K)
20.
18.75
17.5
16.25
15.
13.75
12.5
11.25
10.
8.75
7.5
6.25
5.
3.75
2.5
1.25
0.

Evolution of forecast error with forecast length

SH Summer: 30°S-0°S , T79L68 WACCM* & Palmer

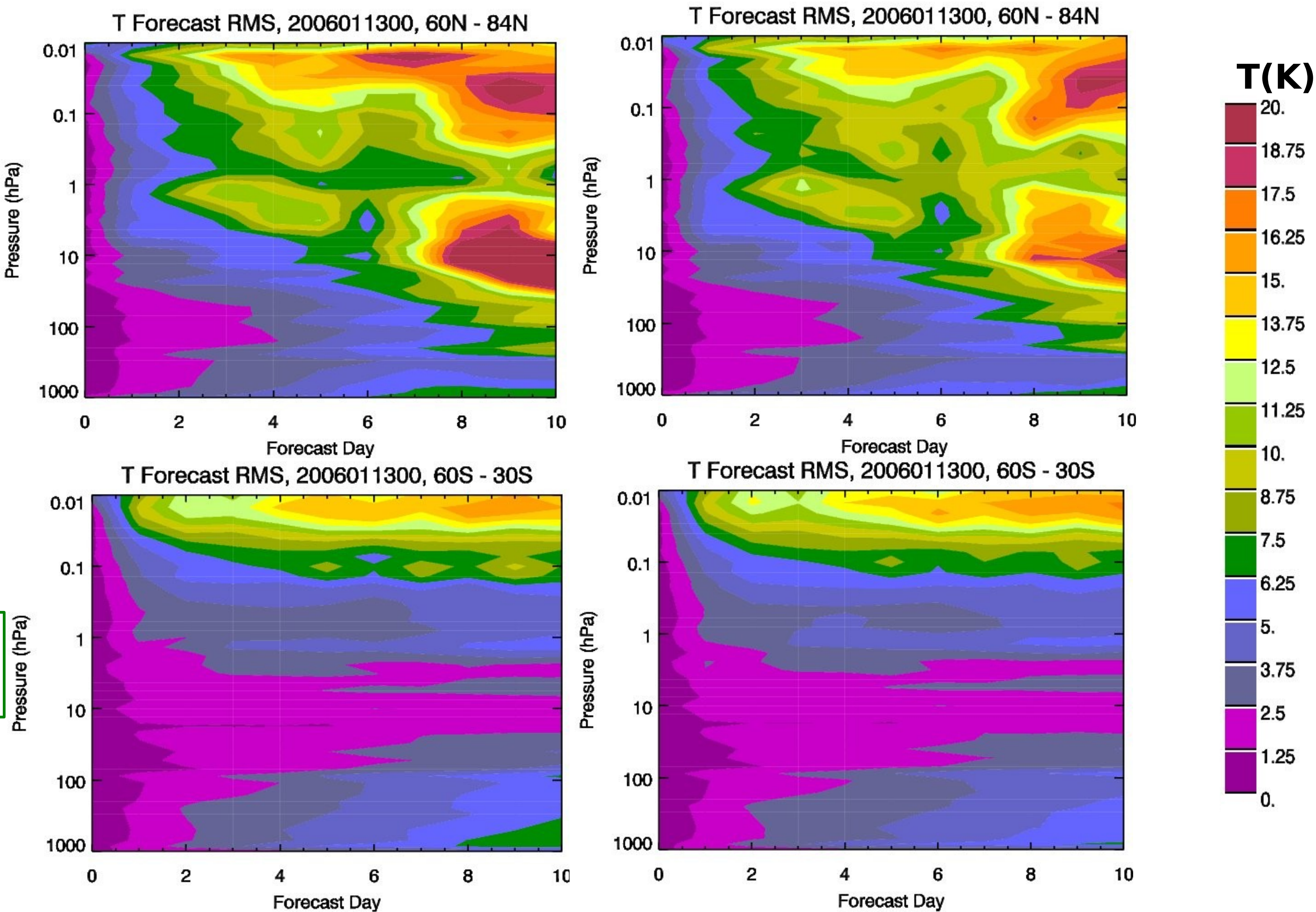


Impact of increased horizontal resolution (1.5° to 0.5°)

T79L68 WACCM* & Palmer	T239L68 WACCM* & Palmer

Winter-polar

Summer mid-lat



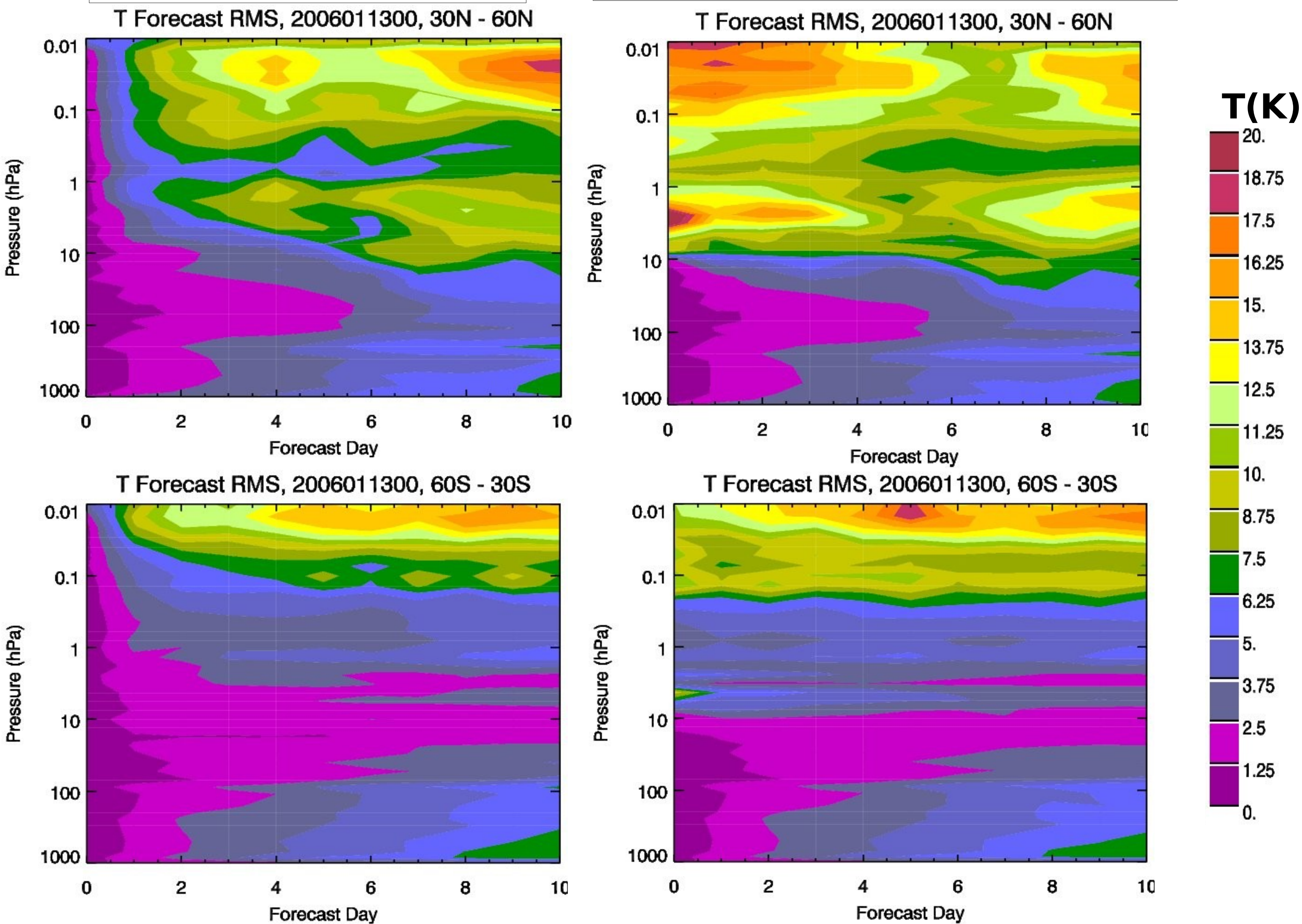
Comparison with forecast initialized from zonal-mean climatology in strat/meso (P < 10 hPa)

Initialized from analysis

Initialized by climo. at P<10 hPa

Winter mid-lat

Summer mid-lat



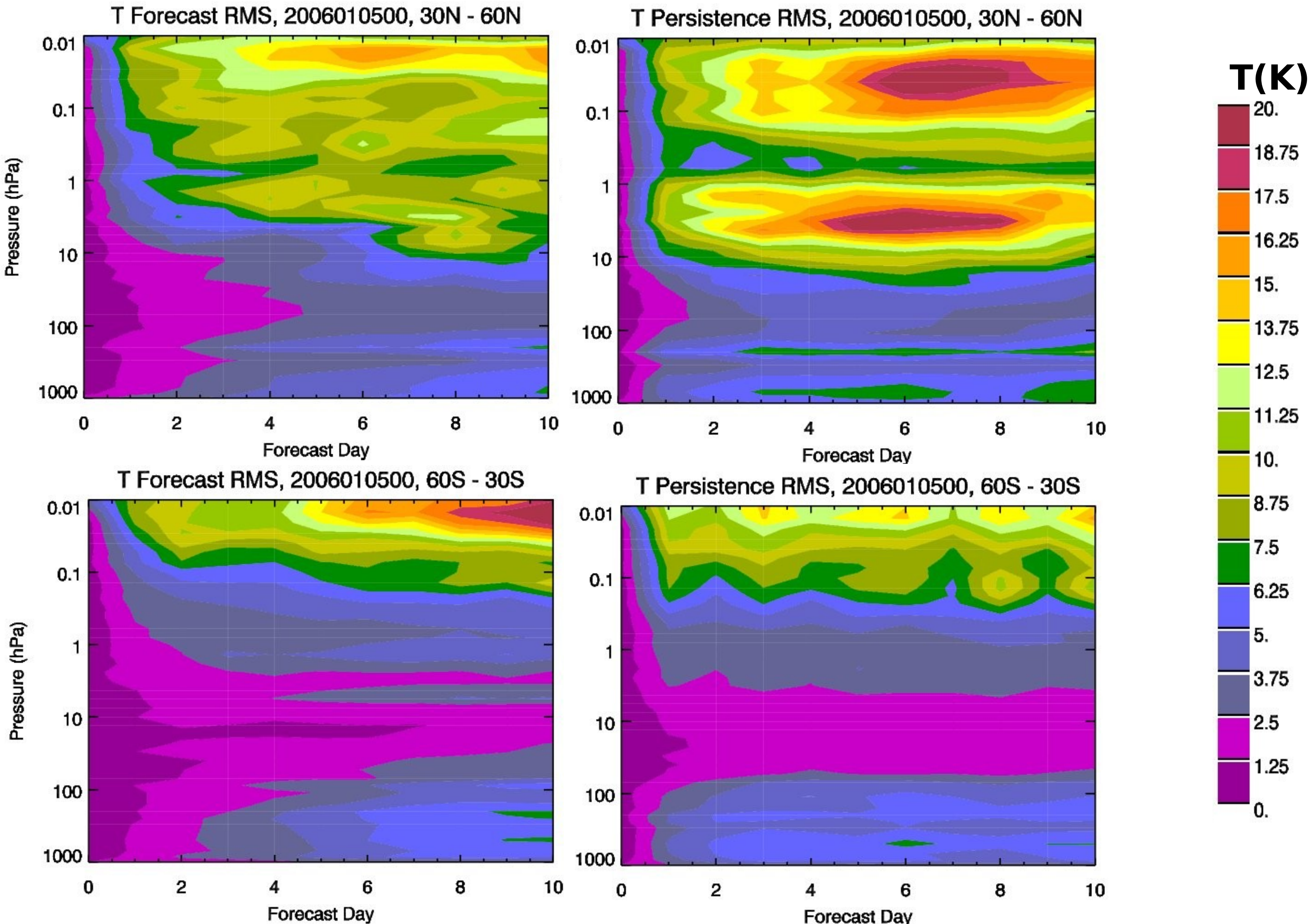
Is persistence better than forecast in the strat/meso?

T79L68 WACCM* & Palmer

Persistence (no change)

Winter mid-lat

Summer mid-lat



Conclusions

- MLS & SABER temperature assimilation has proved useful for providing initial conditions and verification fields for NOGAPS-ALPHA forecasts.
- Model errors/deficiencies currently limit the quality of the stratospheric/mesospheric temperature assimilation.
- Much more work needs to be done.

EXTRA SLIDES

END OF PRESENTATION – EXTRA SLIDES FOLLOW

3DVAR Data Assimilation Review

In an operational NWP model, **data assimilation** is used to incorporate real-world observations. The goal of data assimilation is to give the best estimate (**analysis**) of atmospheric state for the NWP initial conditions by combining forecast model fields (**background**) and **observations**.

We minimize a penalty function:

forward operator | analysis variables | background

$$J(x) = \left(y - \mathrm{H}(x)\right)^T R^{-1} \left(y - \mathrm{H}(x)\right) + \left(x - x_b\right)^T P_b^{-1} \left(x - x_b\right)$$

observation
s | observation error covariance | background error covariance

This is an optimal estimation problem constrained by the error covariance matrices of the background and the observations. The solution is:

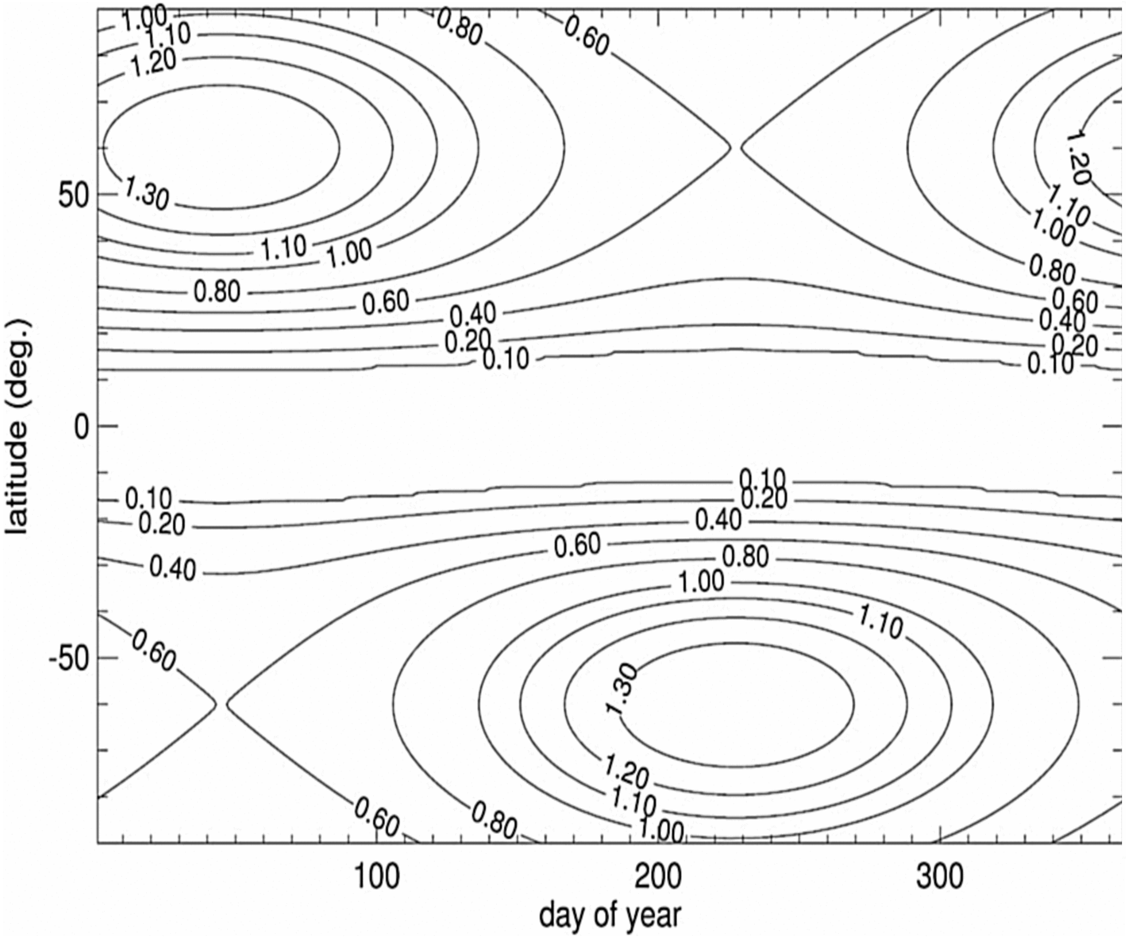
Jacobian | innovation

$$\vec{x}_a - \vec{x}_b = \mathbf{P_b H}^T \left(\mathbf{H P_b H}^T + \mathbf{R}\right)^{-1} \left(y - \mathrm{H}(x)\right)$$

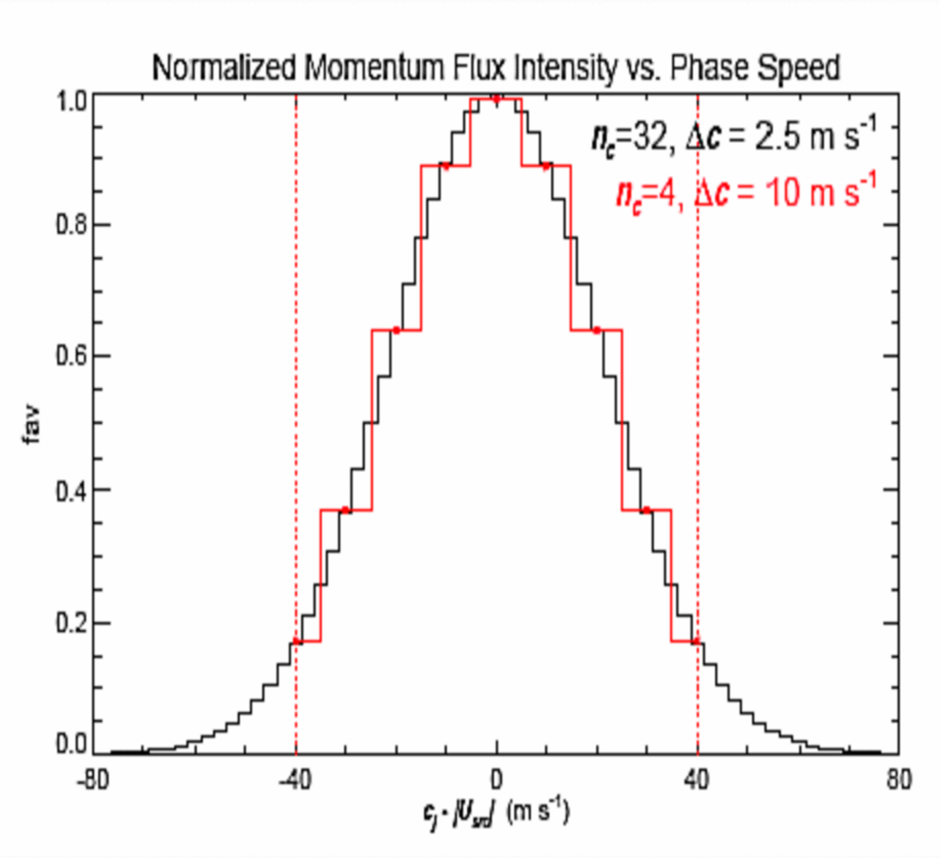
correction

Use of WACCM GWD parameterization (non-orographic waves)

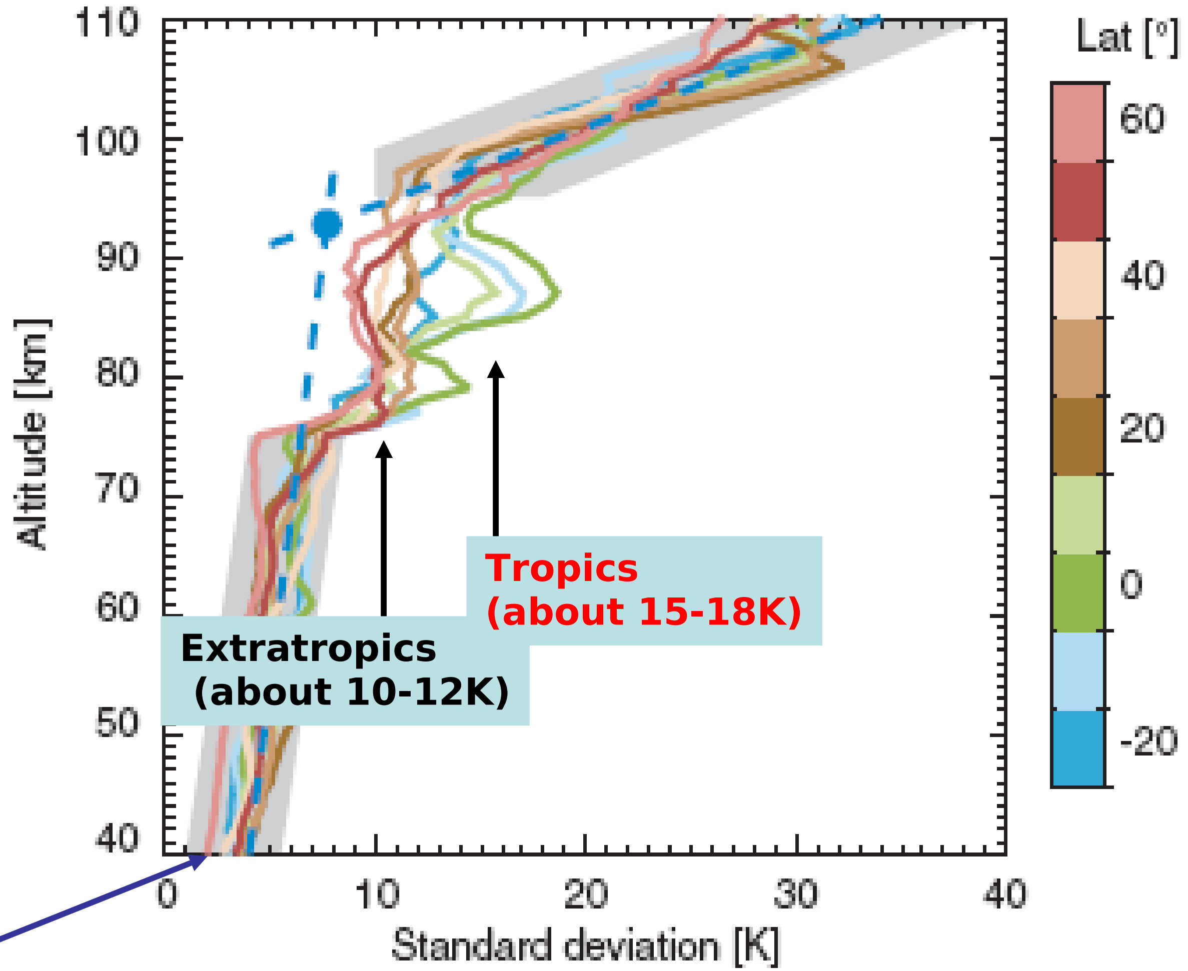
Seasonally varying source from the Troposphere (launch at 500 mb)



Can vary spectral shape: either narrow or wide



Altitude profiles-CRISTA 2 (Aug 97)



Tropics (about 15-18K)

Extratropics (about 10-12K)

About 2-4K at 40 km (3 mb)

Fig. 9. Vertical profiles of temperature standard deviations for CRISTA-2. Data are for 60°−20°S in 10° latitude bins. Dashed lines indicate two regimes of almost linear increases (see text).

Background Temperature Error (RMS)

.... latitude ....

Pressure	90	70	50	30	10	-10	-30	-50	-70	-90
0.01	9.9	8.6	5.8	3.8	3.8	3.8	3.8	5.8	8.6	9.9
0.12	8.5	7.3	5.0	3.3	3.3	3.3	3.3	5.0	7.3	8.5
1.33	6.2	5.4	3.6	2.4	2.4	2.4	2.4	3.6	5.4	6.2
10.0	4.0	3.5	2.4	1.6	1.6	1.6	1.6	2.4	3.5	4.0
50.0	2.3	2.0	1.4	0.9	1.0	1.0	0.9	1.4	2.0	2.3
90.4	2.1	1.8	1.3	0.9	0.9	0.9	0.9	1.3	1.8	2.1
107	2.1	1.9	1.3	1.0	1.1	1.1	1.0	1.3	1.9	2.1
217	2.3	2.0	1.4	0.9	1.0	1.0	0.9	1.4	2.0	2.3
513	2.6	2.3	1.5	1.0	1.0	1.0	1.0	1.5	2.3	2.6
719	2.6	2.3	1.5	1.0	1.0	1.0	1.0	1.5	2.3	2.6
886	2.3	2.0	1.3	0.9	0.9	0.9	0.9	1.3	2.0	2.3
906	2.2	1.9	1.3	0.9	0.9	0.9	0.9	1.3	1.9	2.2
1023	1.9	1.7	1.1	0.7	0.7	0.7	0.7	1.1	1.7	1.9

Background Covariance model for Ozone and H2O Univariant Assimilations

	Ozone	H2O
Background RMS	0.3 ppmv	1.0 ln(q)
Horizontal Correlation length	385 km	385 km
Vertical correlation length	0.3 log(P)	0.3 logP (~2 km)

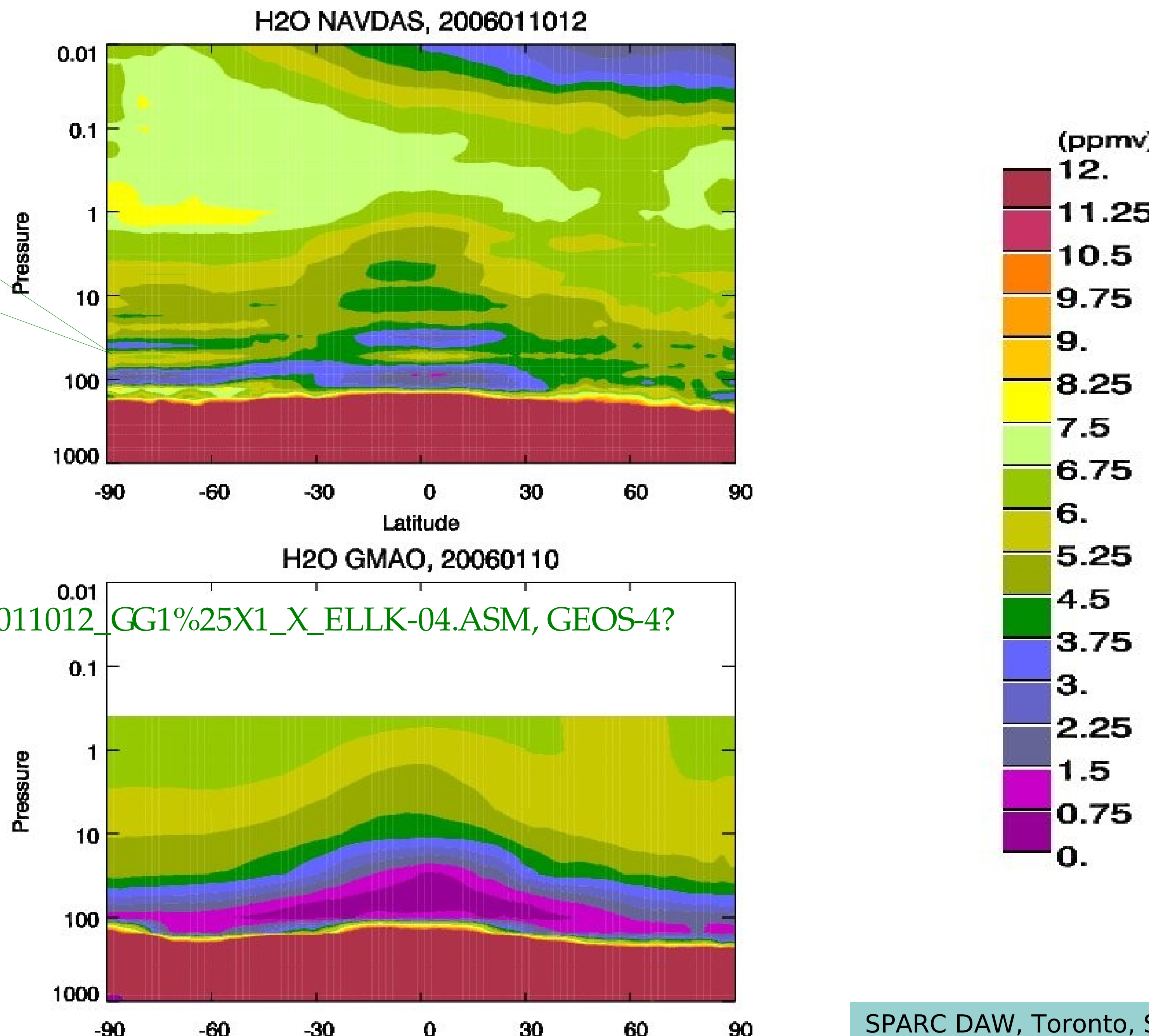
* Vertical and horizontal correlation models use the SOAR function:
  $f = (1+s)*\exp(-s)$, where s is the normalized distance.

* MLS & SABER temperature errors are assigned from retrieval data with additional constraints: error ≥ 2° & error ≥ 0.3 * (O-F)

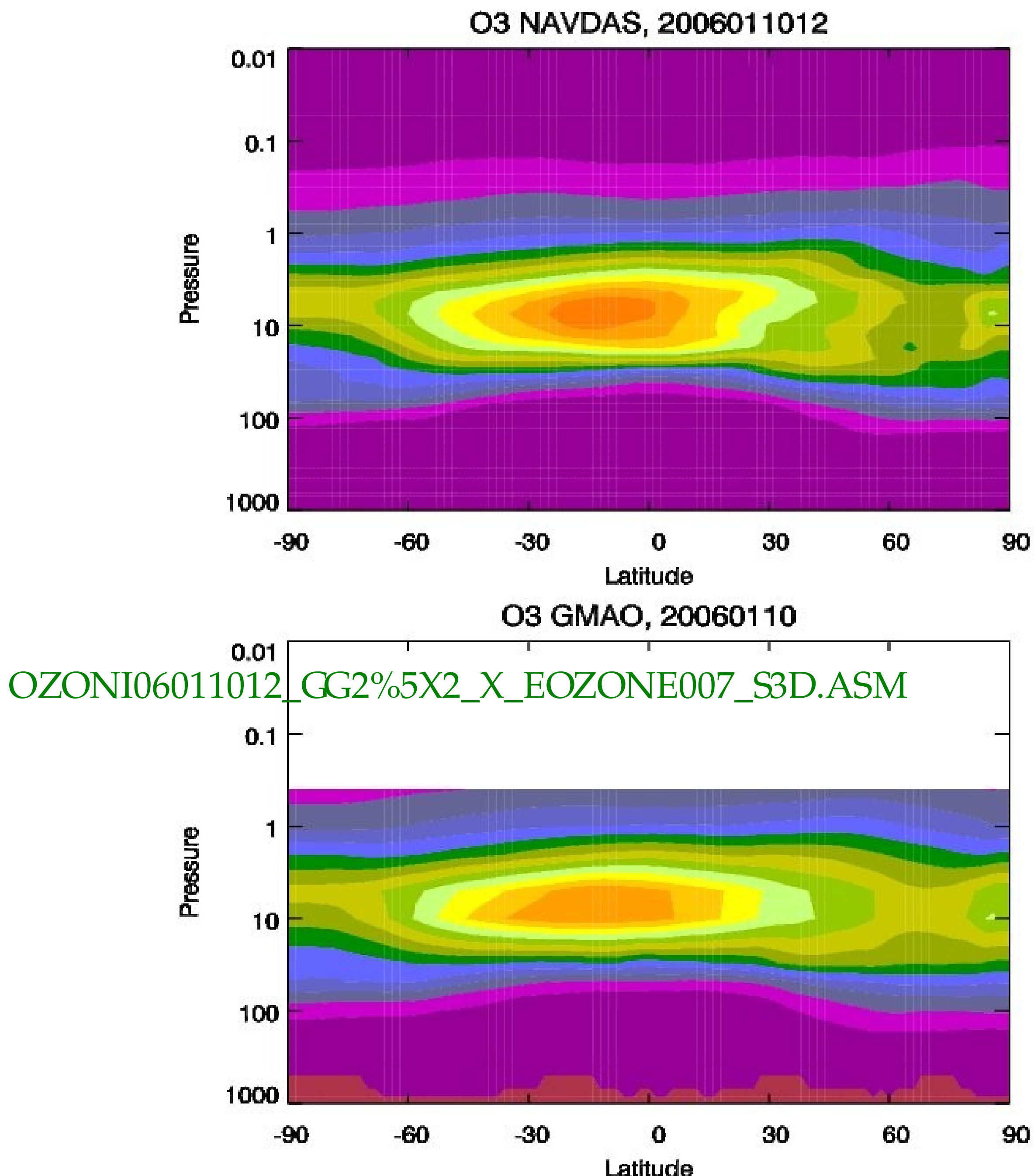
* MLS H2O error is assigned from retrieval data with additional constraints:
  q error ≥ 20% & ln(q) error ≥ 0.3 * (O-F)

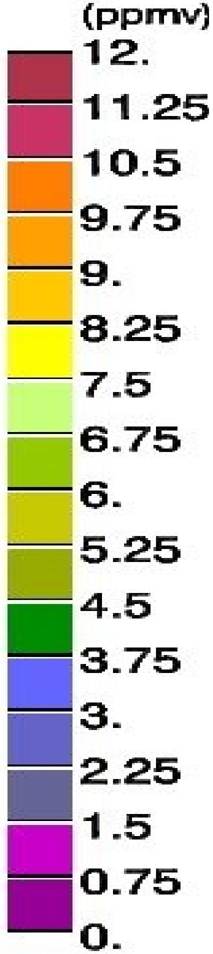
MLS version-2 H2O Assimilation Example

Vertical oscillations in MLS data?



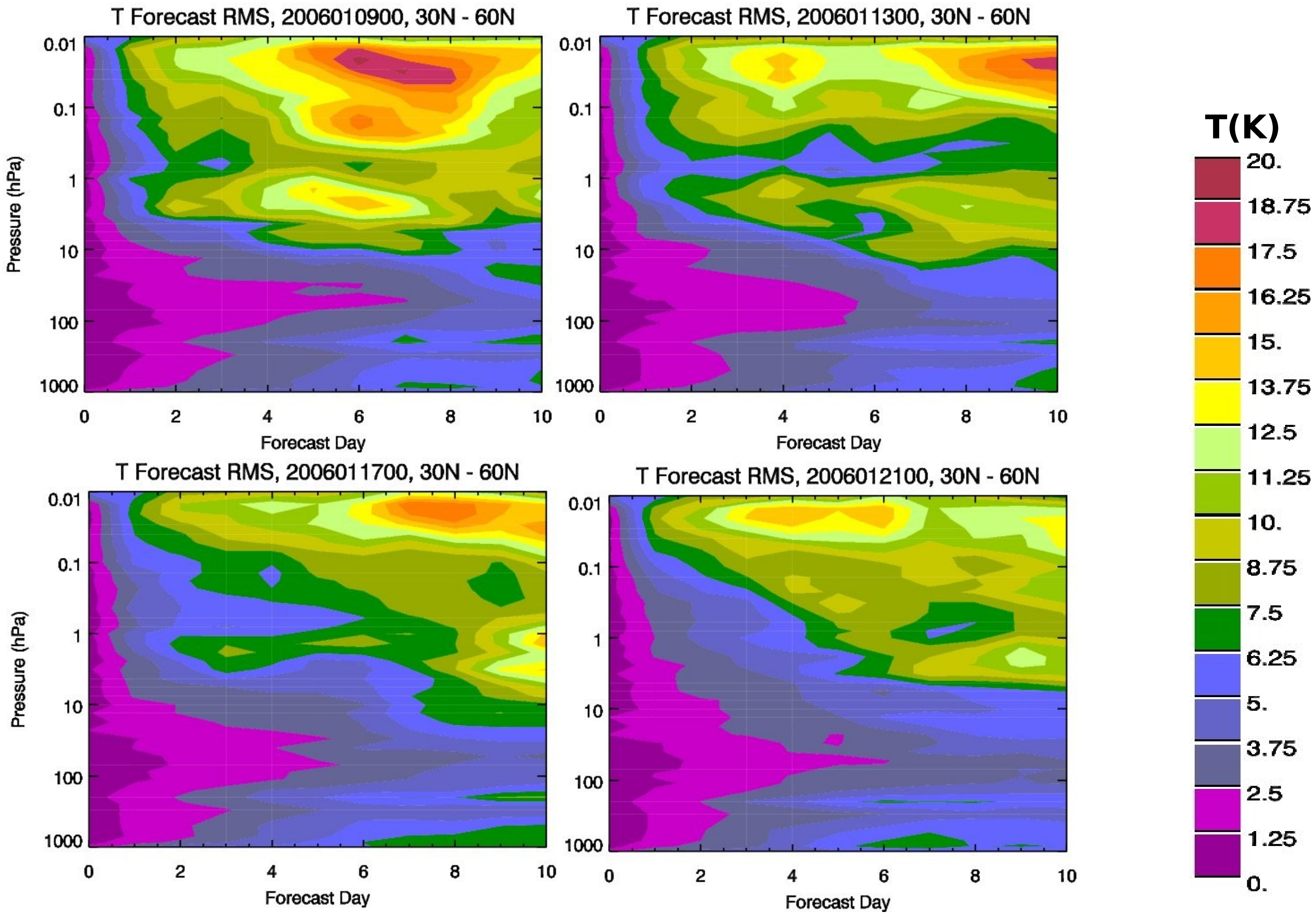
MLS version-2 Ozone Assimilation Example





Evolution of forecast error with forecast length

30°N-60°N , T79L68 WACCM* & Palmer



Example of combined MLS and SABER T increment (4-hour time window)