The effect of temporal correlation on the predictability of the MLT region in a stochastic non-orographic gravity wave drag parameterization

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Motivation

- Modeling studies have shown that predictability in the mesosphere is limited both in space and time.
- *Nezlin et al.* (2009) show that improved assimilation of tropospheric and stratospheric data reduces the error in the mesosphere, but smaller spatial scales ($k \geq 10$) remain unpredictable.
- *Liu et al.* (2009) studied the error propagation for perturbations initialized at different elevations: they show that the error progresses downward from the upper atmosphere, highlighting the role of gravity waves.
- *Shepherd et al.* (2000) investigate horizontal transport and found that correlation scales (temporally and spatially) are much shorter in the mesosphere compared to the stratosphere. They attribute these differences to the prominence of gravity waves in the mesosphere.

- Gravity waves are prominent in the mesosphere where they explain the momentum and thermal budgets to first order. Thus, GWD can impact substantially the predictability in the mesosphere.

- Mesoscale gravity wave drag is typically parameterized with a *deterministic source* function specified at a lower boundary (e.g., *Garcia et al.,* 2007).

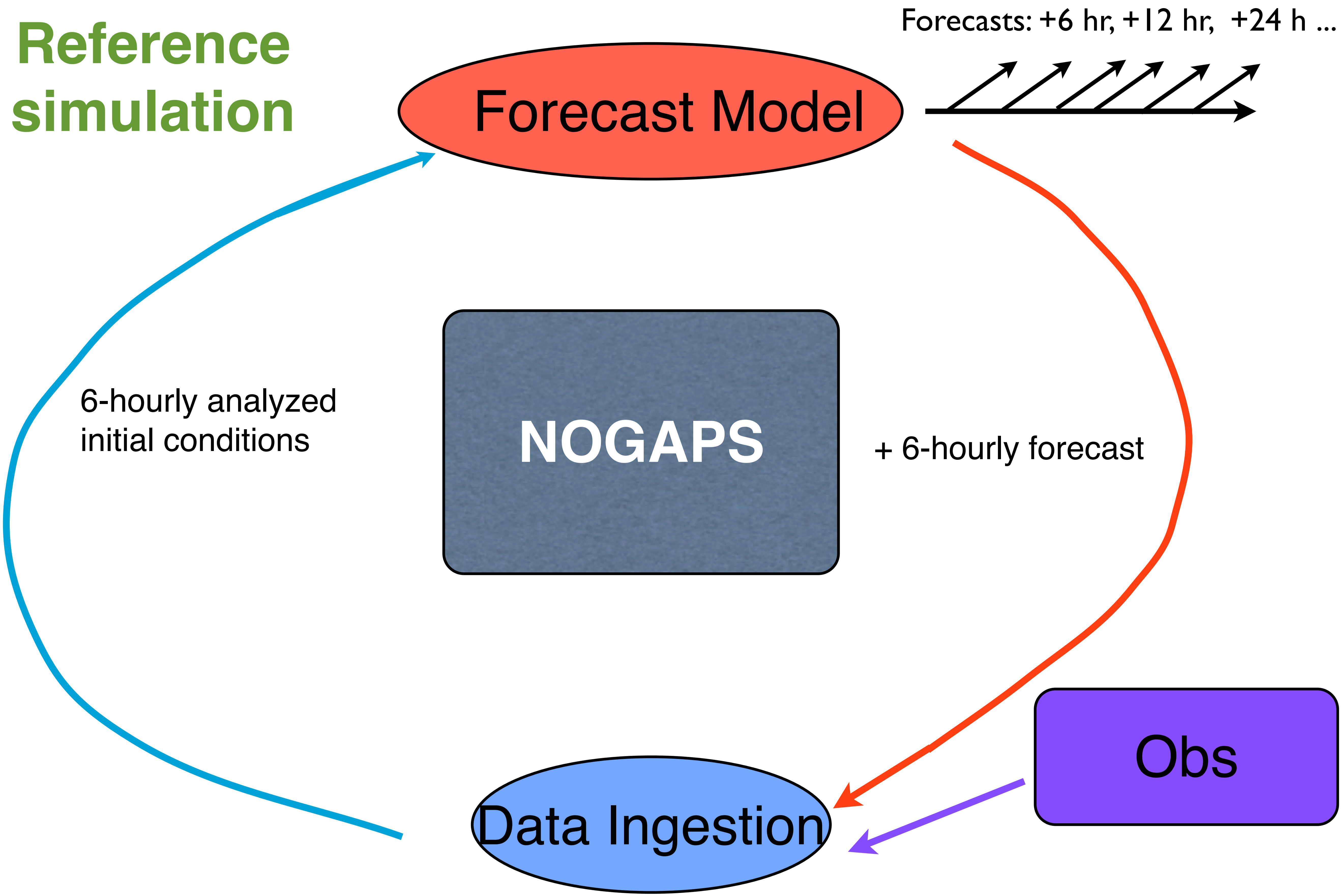
- Recent advances have shown that a *stochastic* representation of the source function is computationally efficient and is capable of reproducing the same mean climate obtained from the deterministic source (*Eckermann*, 2011).

- The question is now <u>how relevant the stochastic method is for predictability</u>.

Design of the numerical experiments

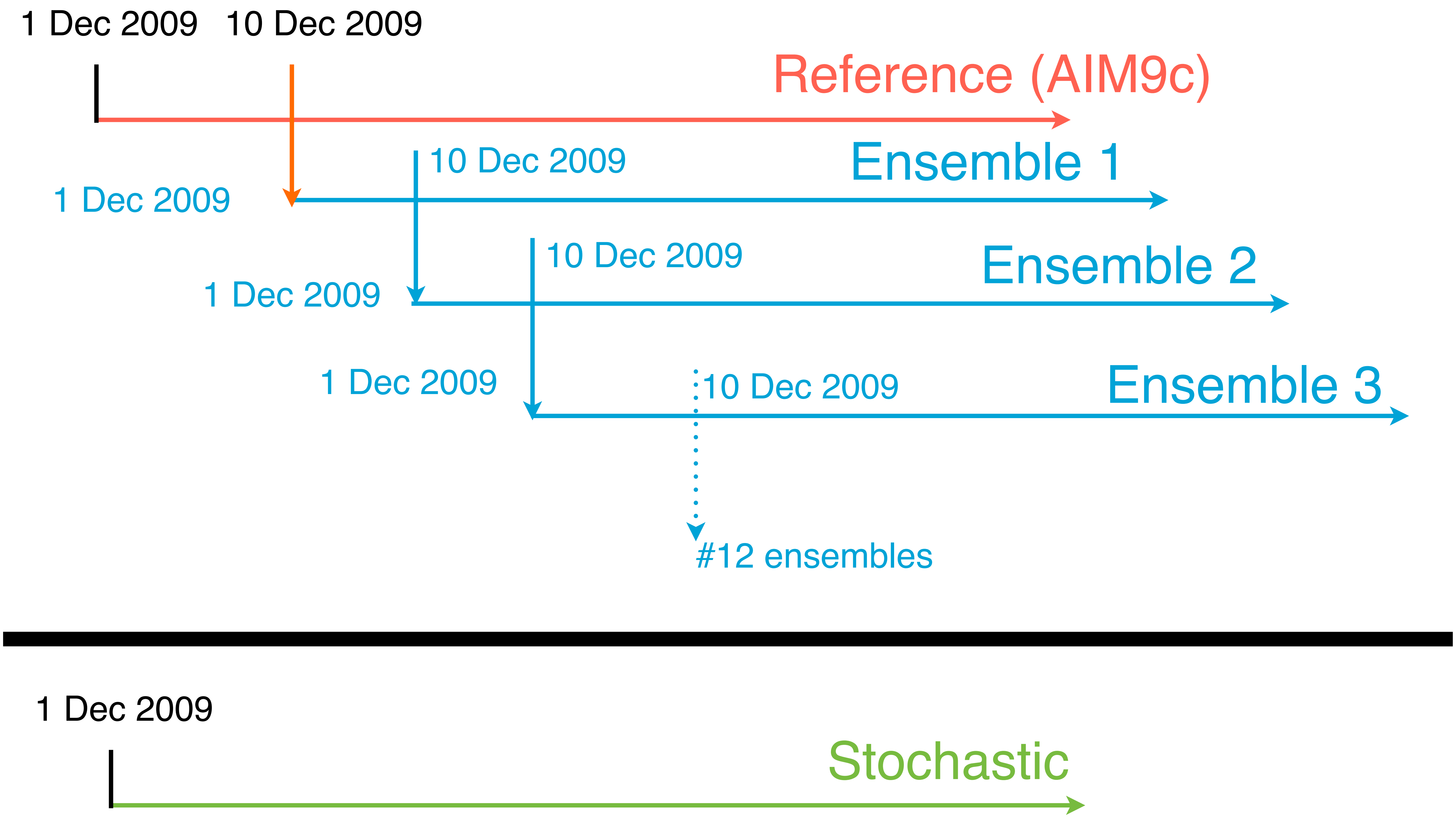
- We use ensemble simulations obtained from the Navy's Operational Global Atmospheric Prediction System (NOGAPS) - Advanced Level Physics High Altitude (ALPHA) which uses the Naval Research Laboratory Atmospheric Variational Data Assimilation System (NAVDAS) as the data ingestion component.
- Ensemble simulations are produced for December 2009.

Reference simulation



NOGAPS with the standard multi-wave GWD
vs
NOGAPS with stochastic scheme

In its standard configuration, NOGAPS-ALPHA uses a modified WACCM GWD scheme (*Garcia et al.*, 2007) with 65 waves between ±80 m s^{-1}. A new stochastic scheme (*Eckermann*, 2011) has been developed that consists of a single wave sampling randomly the interval between +80 and -80 m s^{-1}. The two schemes represent two limiting end points in which the temporal evolution of the source spectrum is either deterministic or totally uncorrelated.



One realization only for the stochastic scheme

Evaluation of the errors

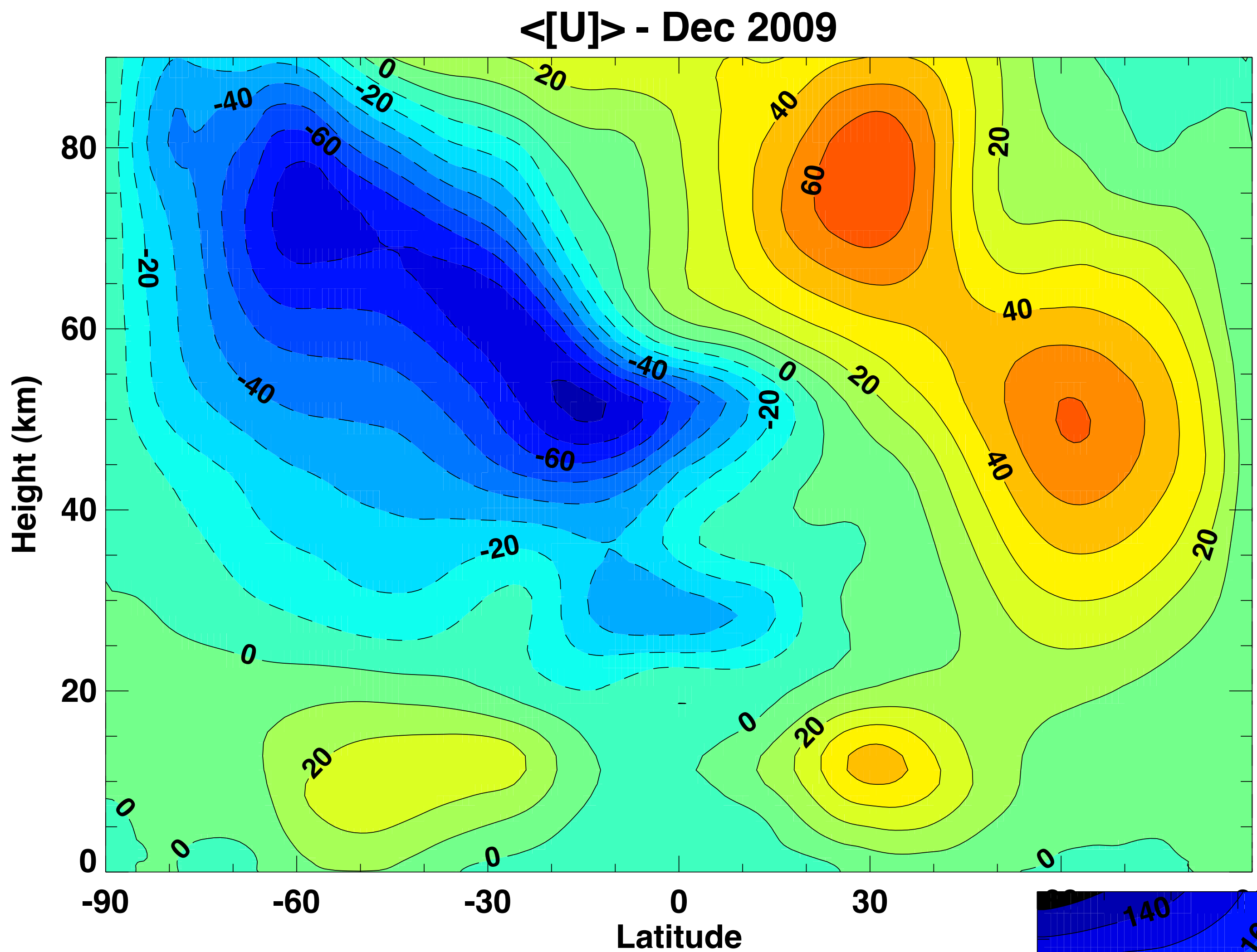
x_i are the ensemble members of the deterministic scheme
x_{ref} is the first analysis product with the deterministic scheme
x_{stoch} is the stochastic single realization

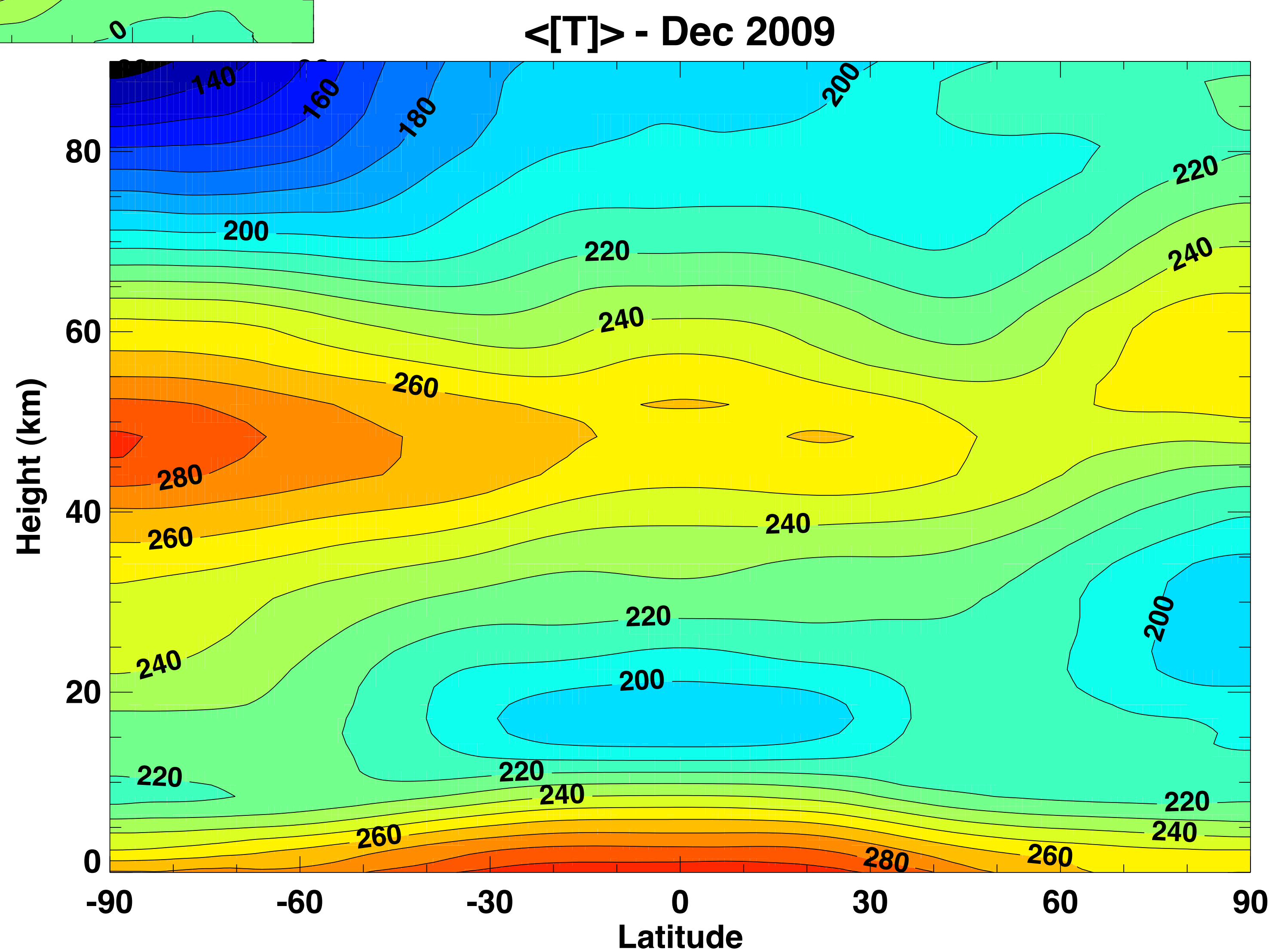
$$(\Delta X)_{\text{determistic}} = \frac{1}{N}\sum_i \left(x_{ref} - x_i\right)$$

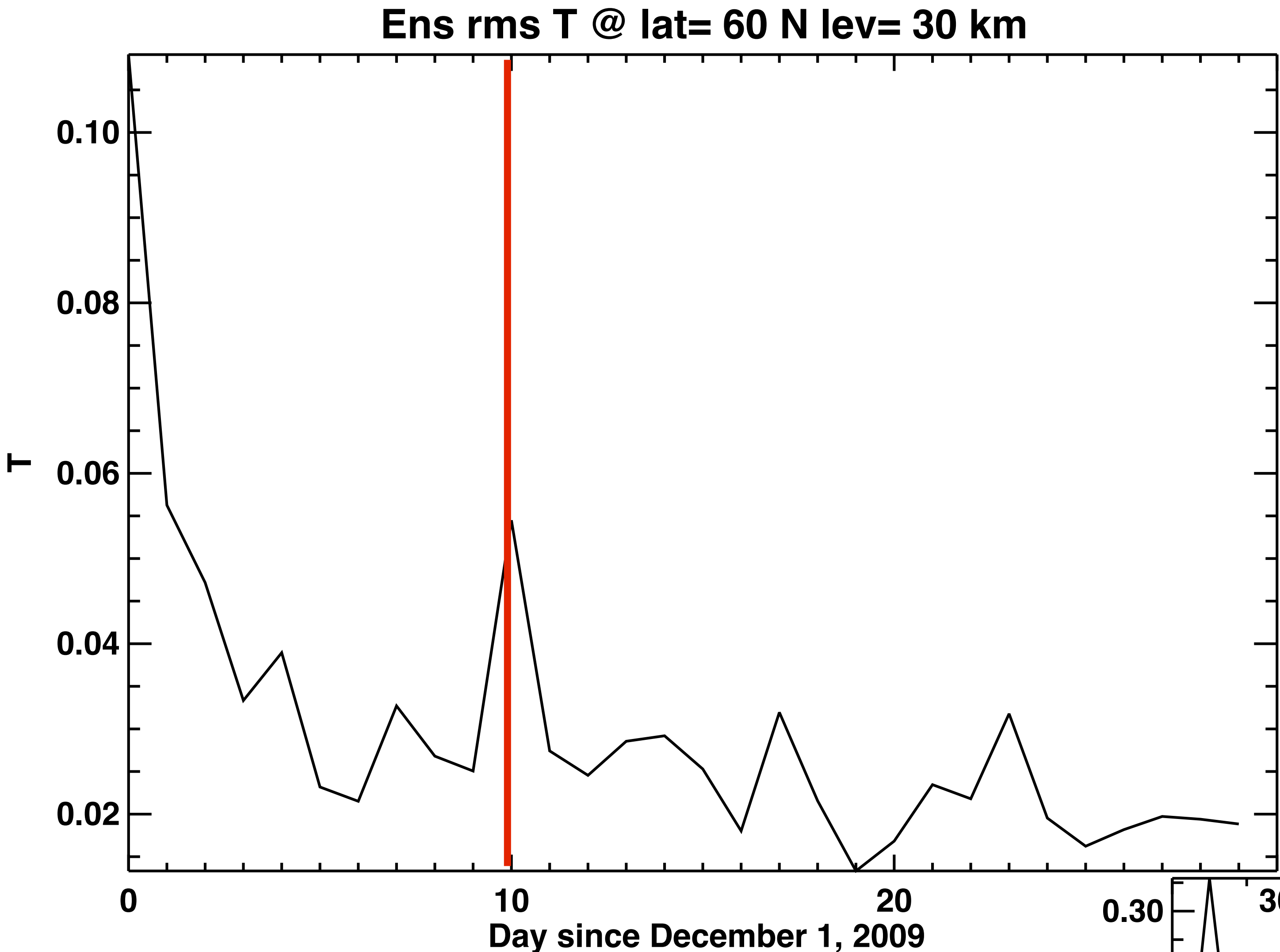
$$(\Delta X)_{\text{stochastic}} = \frac{1}{N}\sum_i \left(x_{stoch} - x_i\right)$$

Atmospheric Background Behavior

Ensemble mean, time averaged fields

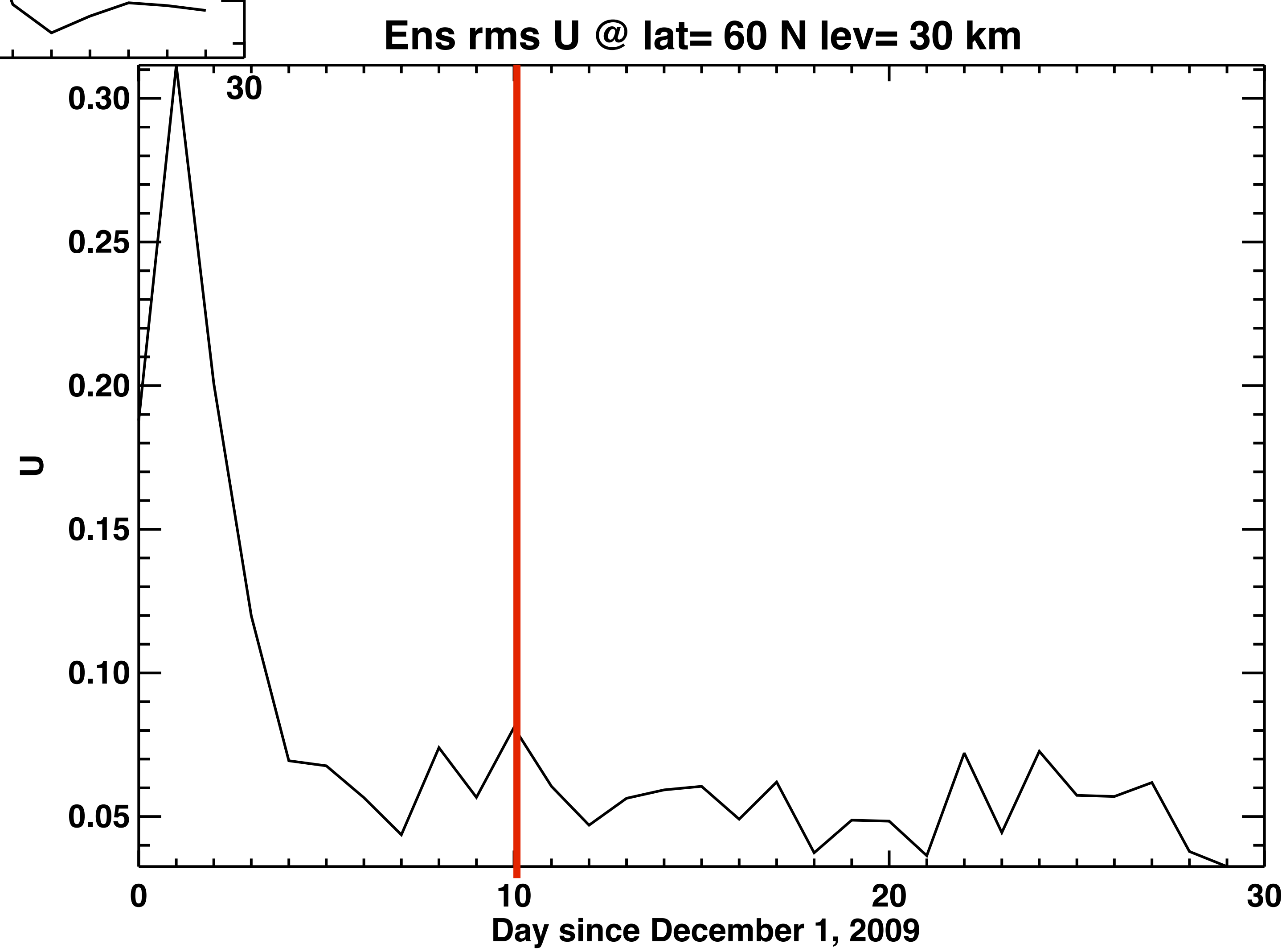






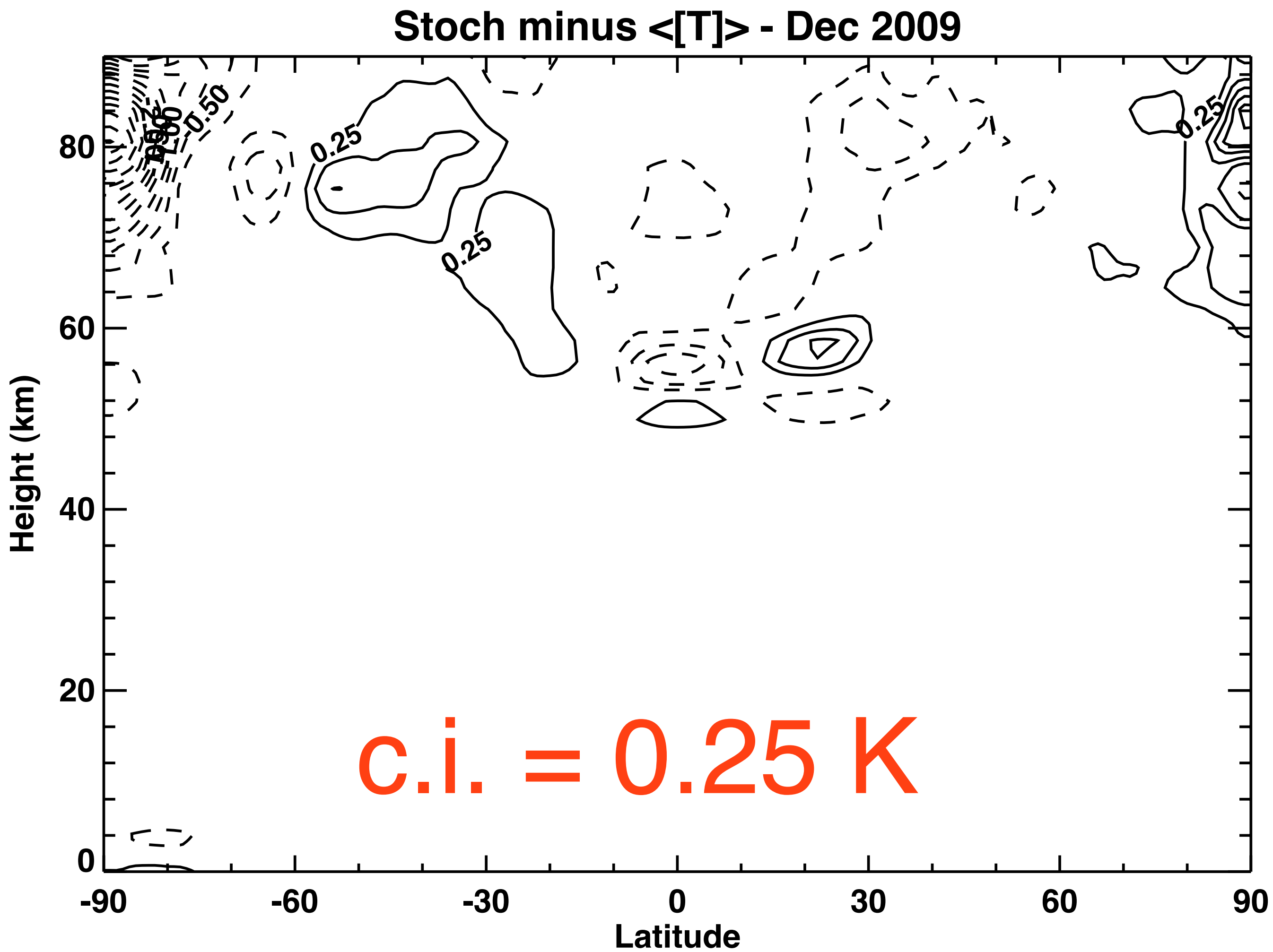
Temperature

Zonal Wind



Ensemble rms reach an asymptotic value after about 10 days from initialization

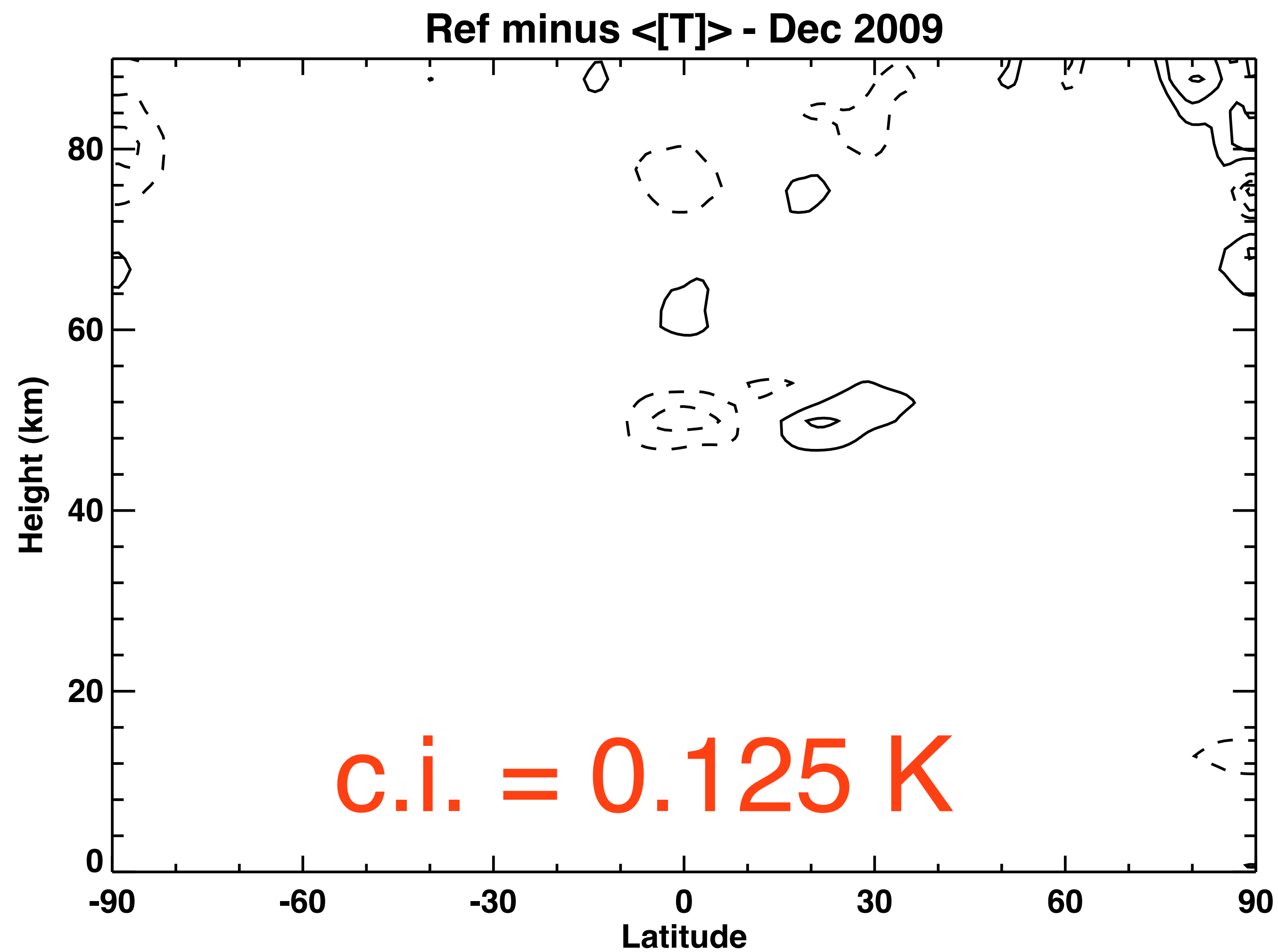
Temperature
Time mean biases



Stochastic scheme

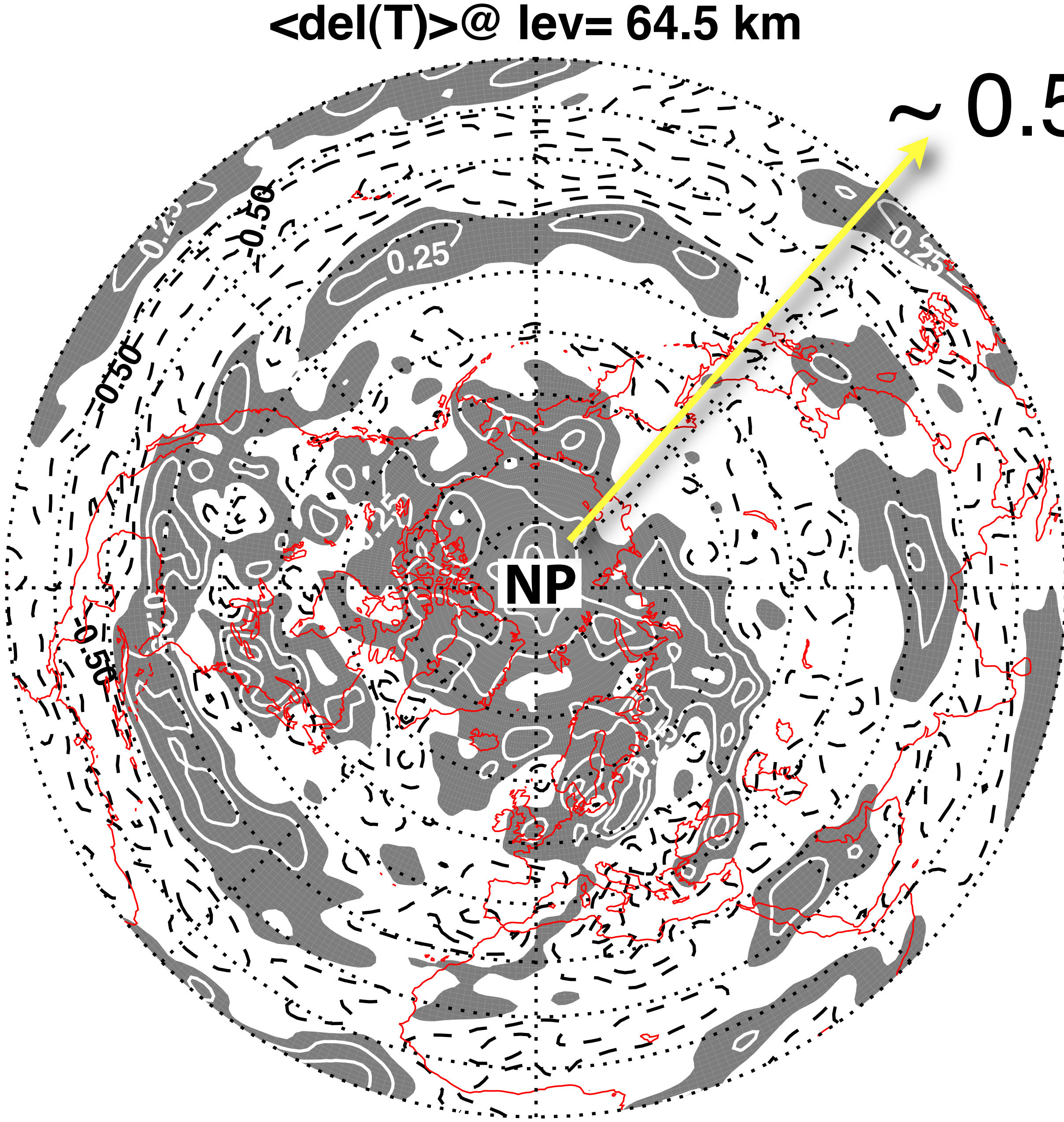
Deterministic scheme

Only days after 10 December 2009 to reduce the effect of initial transience



Spatial Structure of Temperature Errors

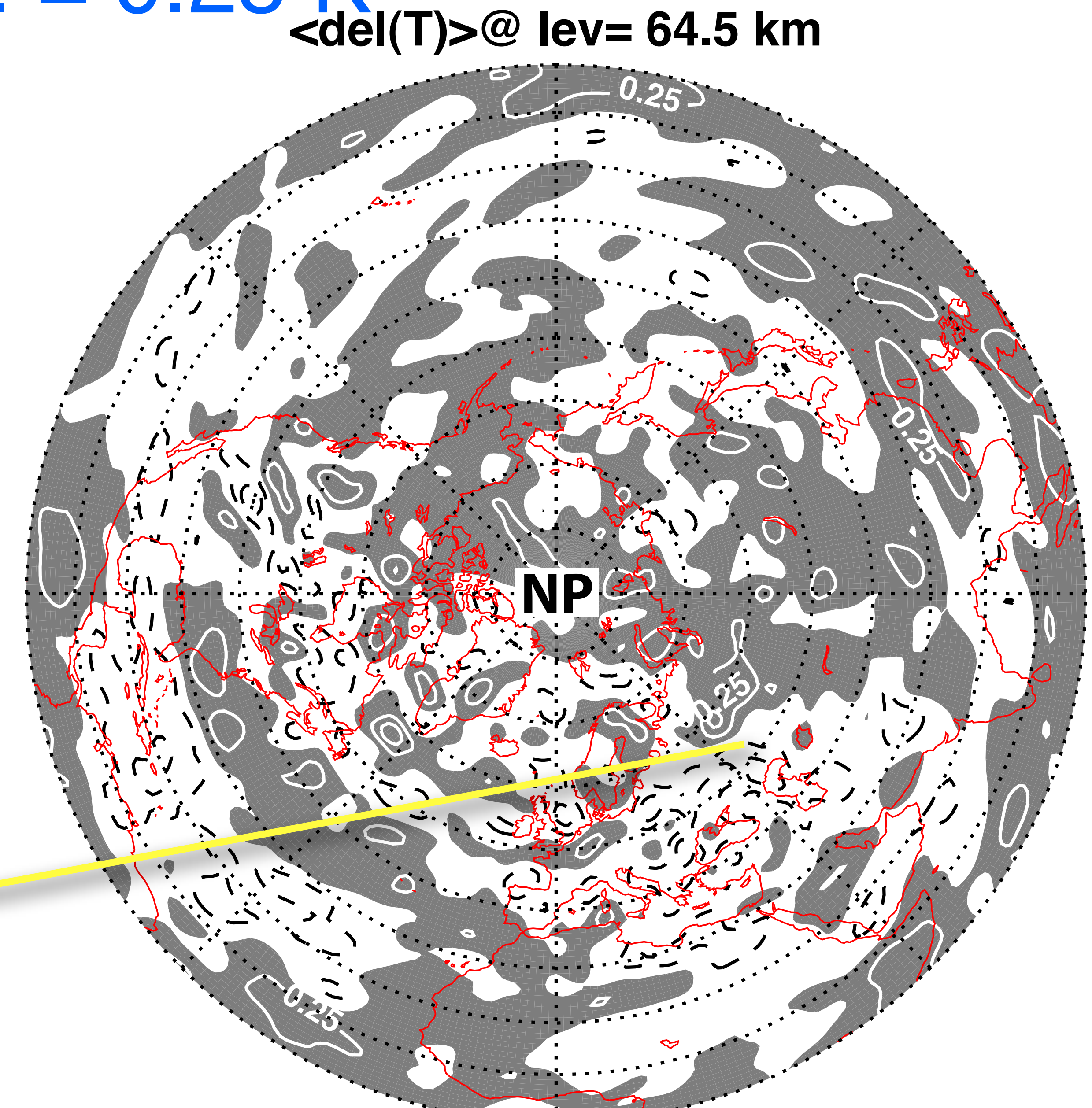
Lower Mesosphere



~ 0.5 K

Stochastic

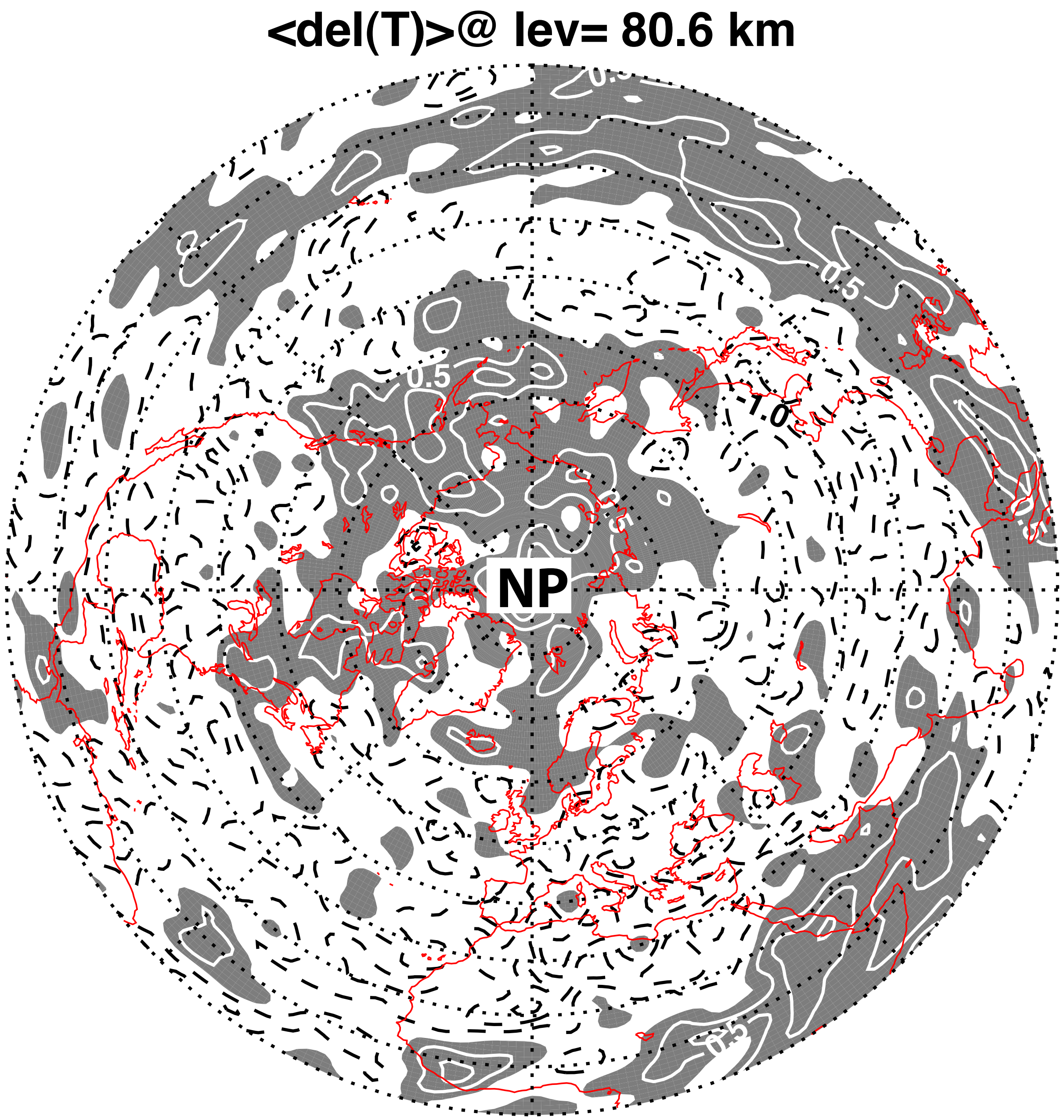
c.i. = 0.25 K



Deterministic

~ 0.5 K

Shading: del(T) ≥ 0

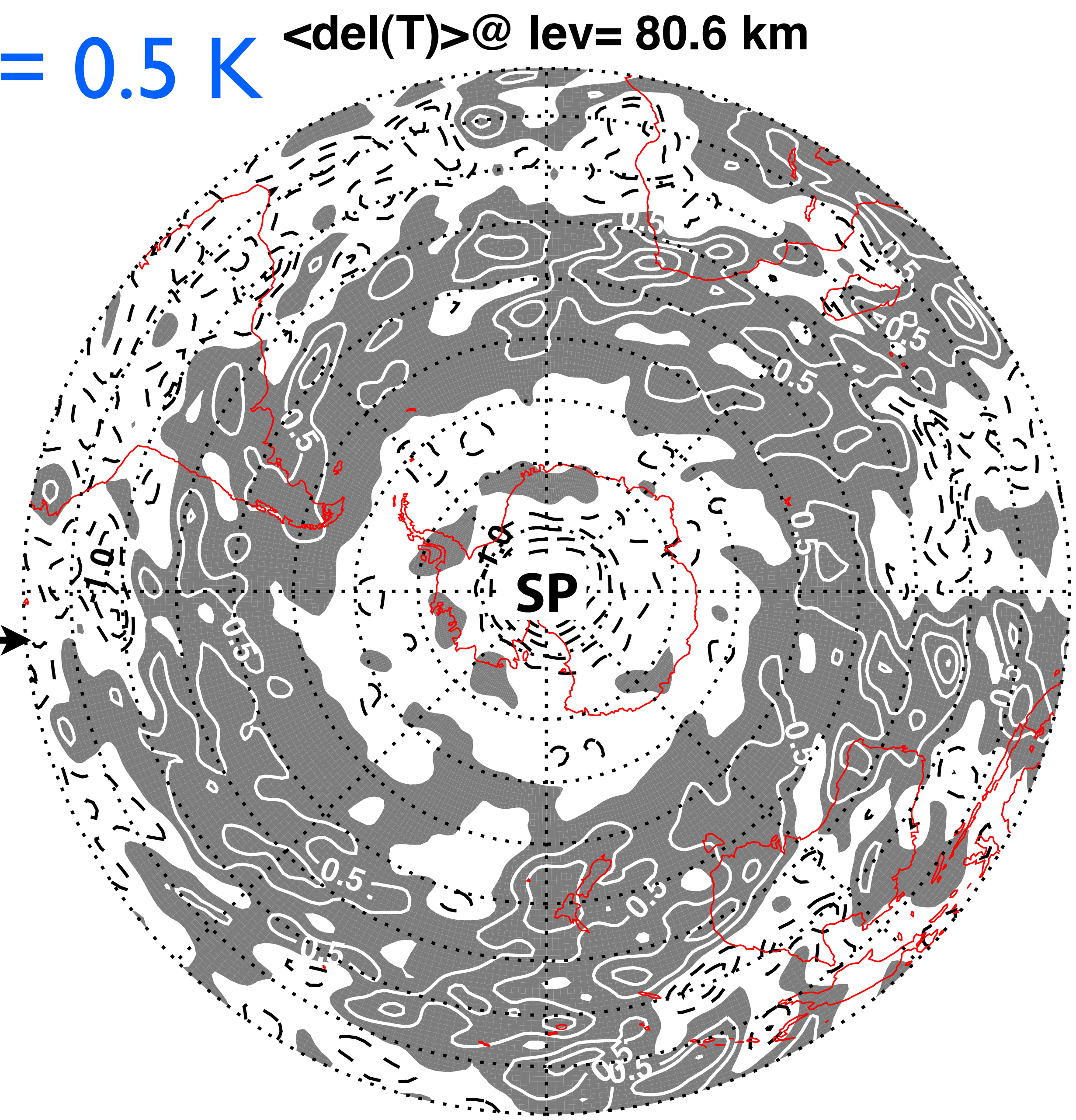


Upper Mesosphere

NH

c.i. = 0.5 K

SH



- The stochastic scheme produces mean errors that are comparable to the errors produced by the deterministic scheme.

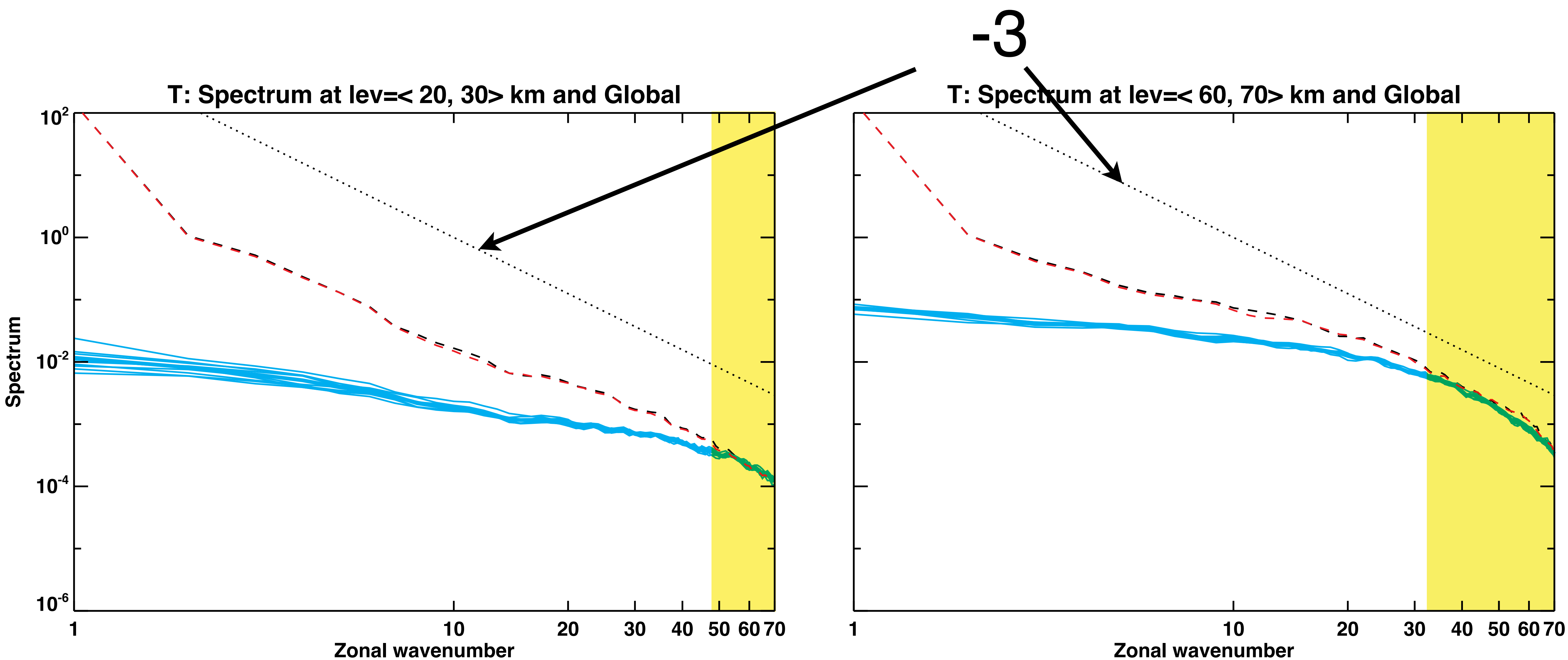
- The mean errors are largely spatially incoherent up to the lower mesosphere.

- Notable exceptions are: (1) the high latitude mesopause where the stochastic scheme produces zonally coherent up-/down-welling in the summer/winter hemisphere, and (2) the tropical lower mesosphere where quadrupole cells of warm/cold air are associated with the SAO.

Spectral Behavior: Spatial Scales

Lower Stratosphere

Lower Mesosphere



Deterministic Scheme

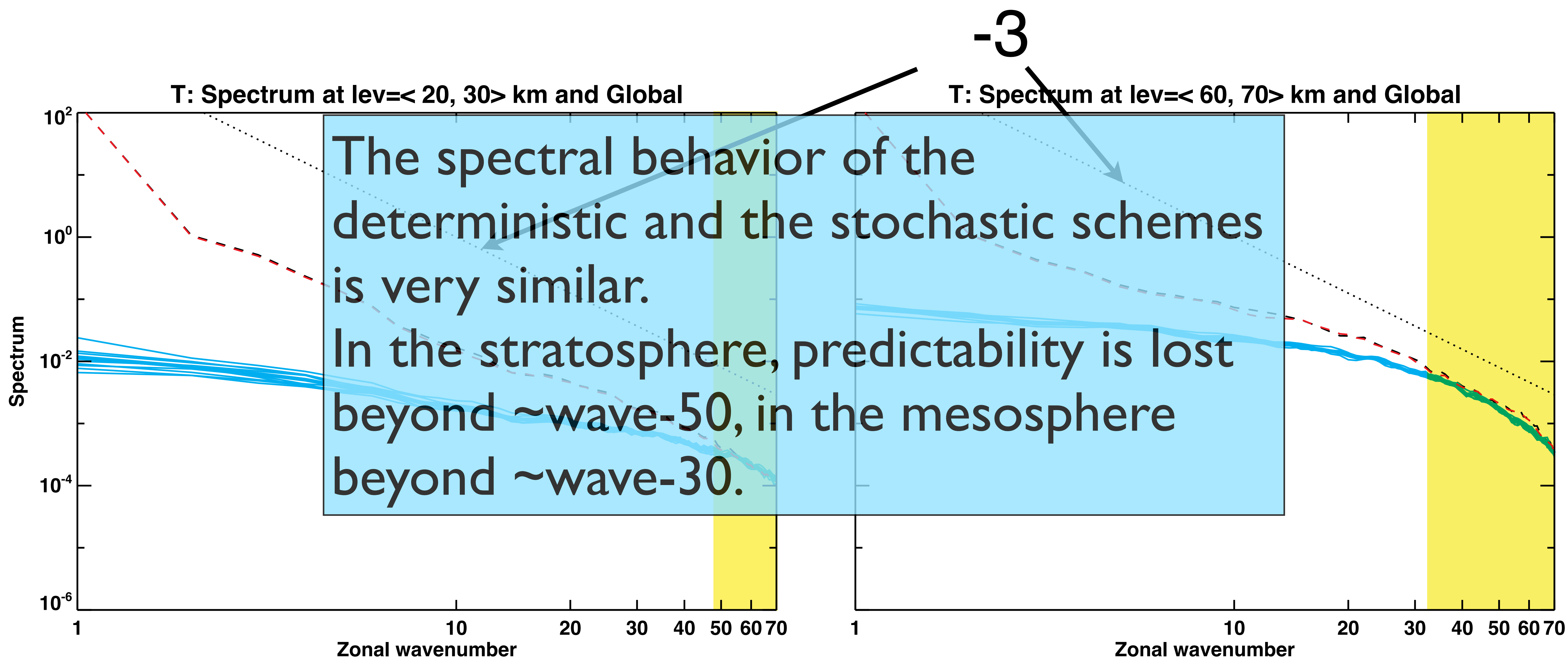
Stochastic Scheme

Ensemble Errors

Unpredictable Scales

Lower Stratosphere

Lower Mesosphere



The spectral behavior of the deterministic and the stochastic schemes is very similar.
In the stratosphere, predictability is lost beyond ~wave-50, in the mesosphere beyond ~wave-30.

Deterministic Scheme

Stochastic Scheme

Ensemble Errors

Unpredictable Scales

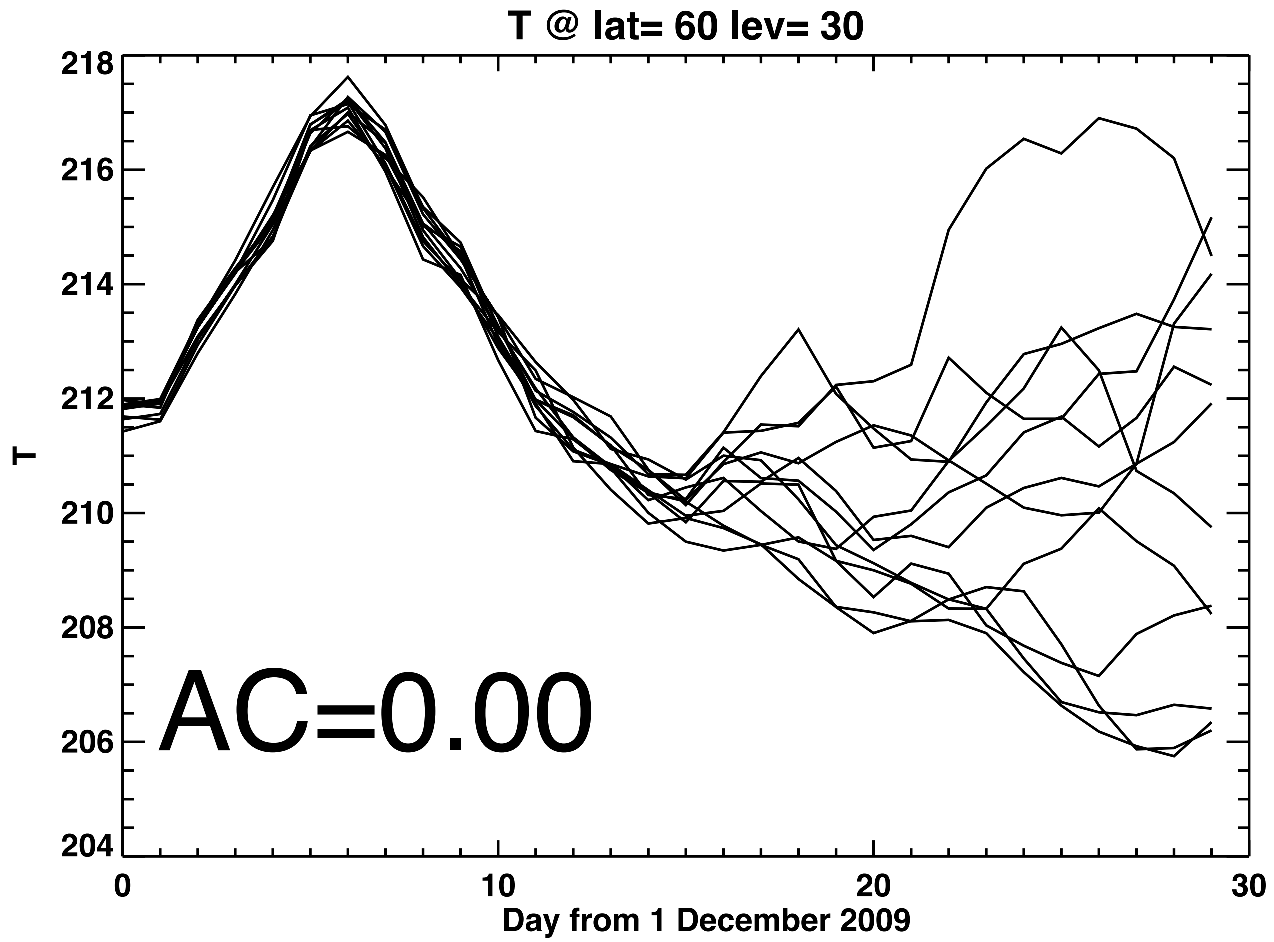
GCM Simulation with different values of the AC

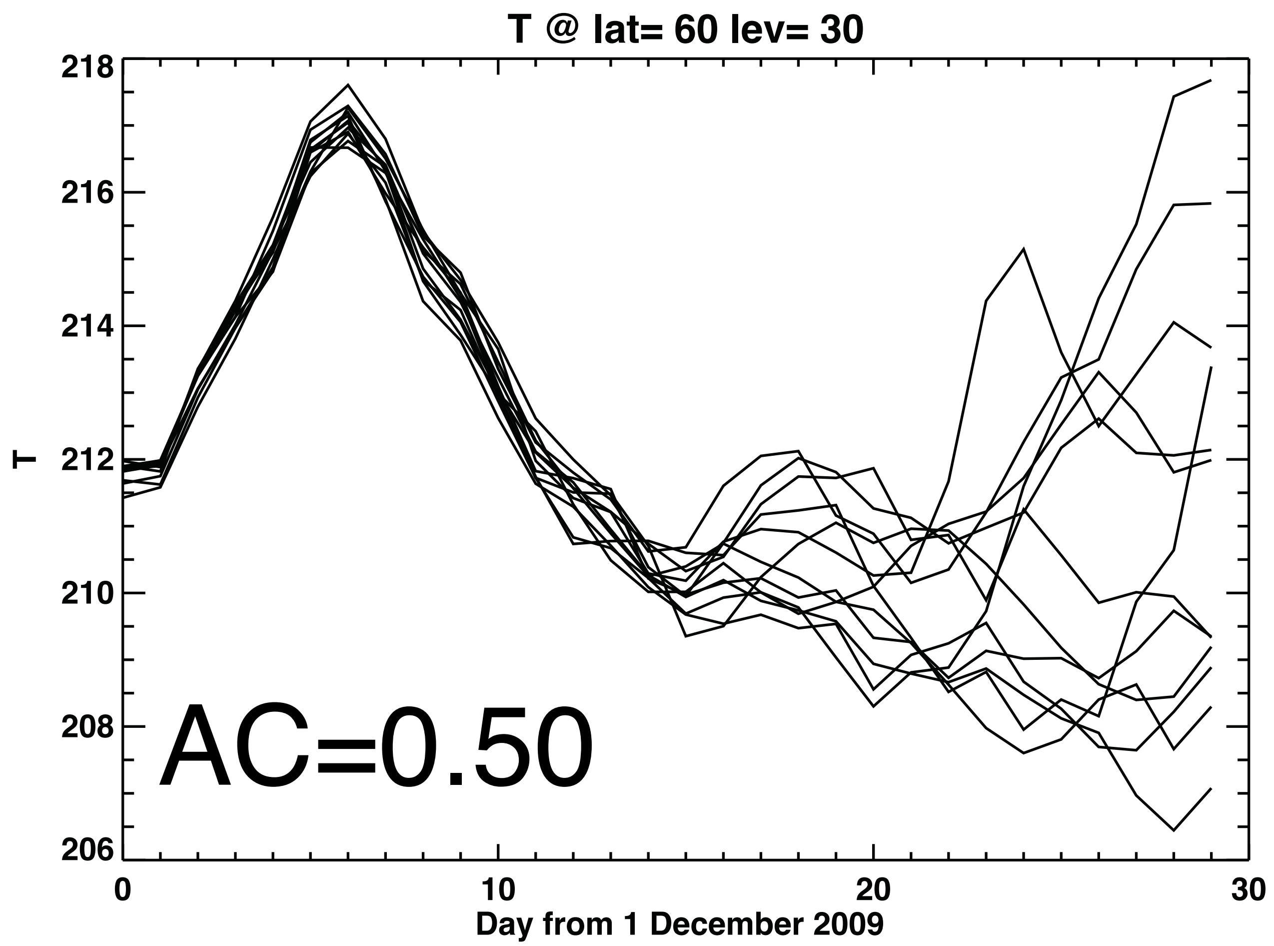
- See Eckermann's talk: the GWD parameterization has been modified to include the ability of choosing different values of lag-1 auto-correlation (AC), effectively implementing an auto-regressive (AR) process of the first order in the GWD.
- What is the effect on the mean state and characteristics of the errors?

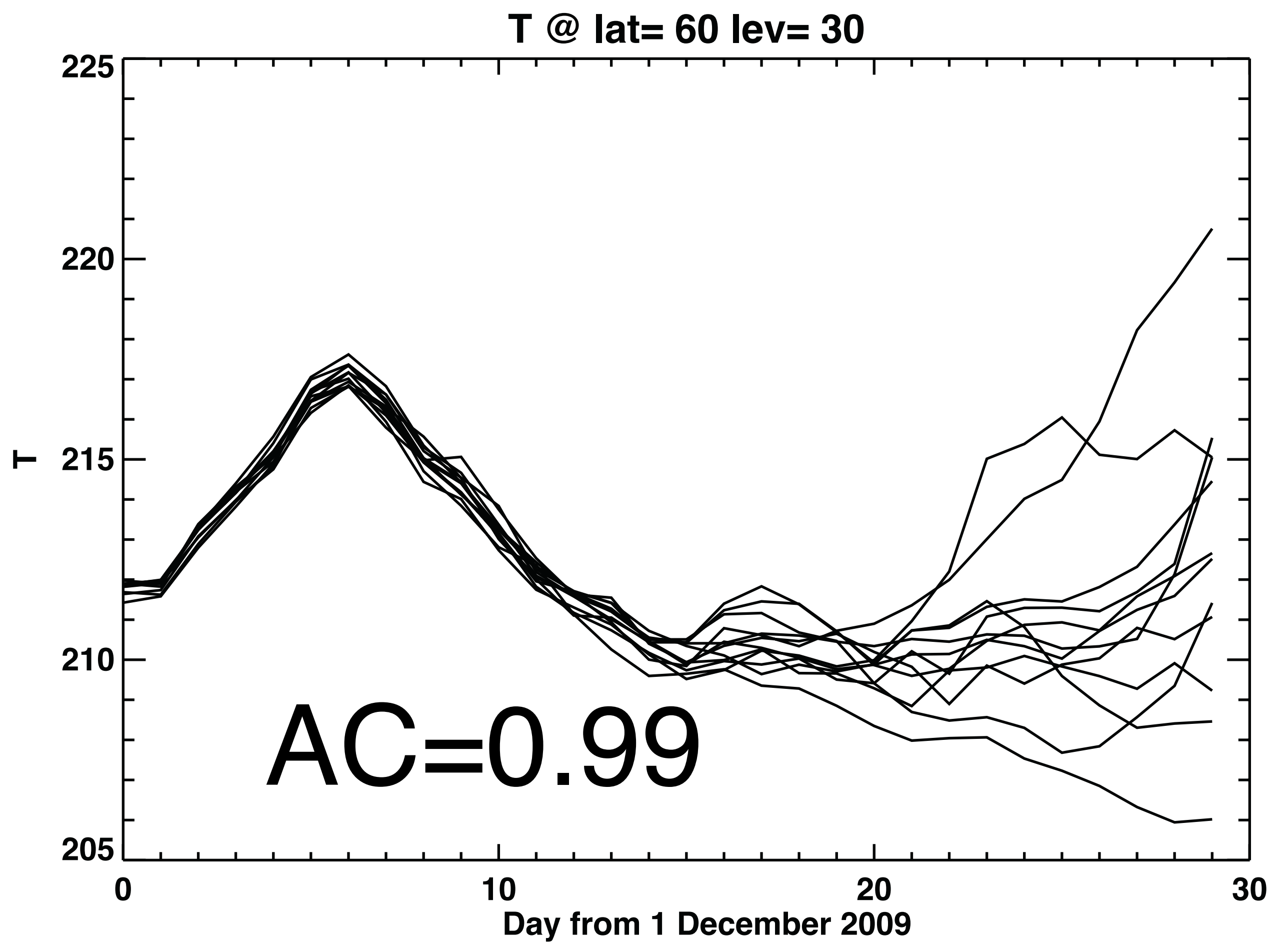
GCM Simulations

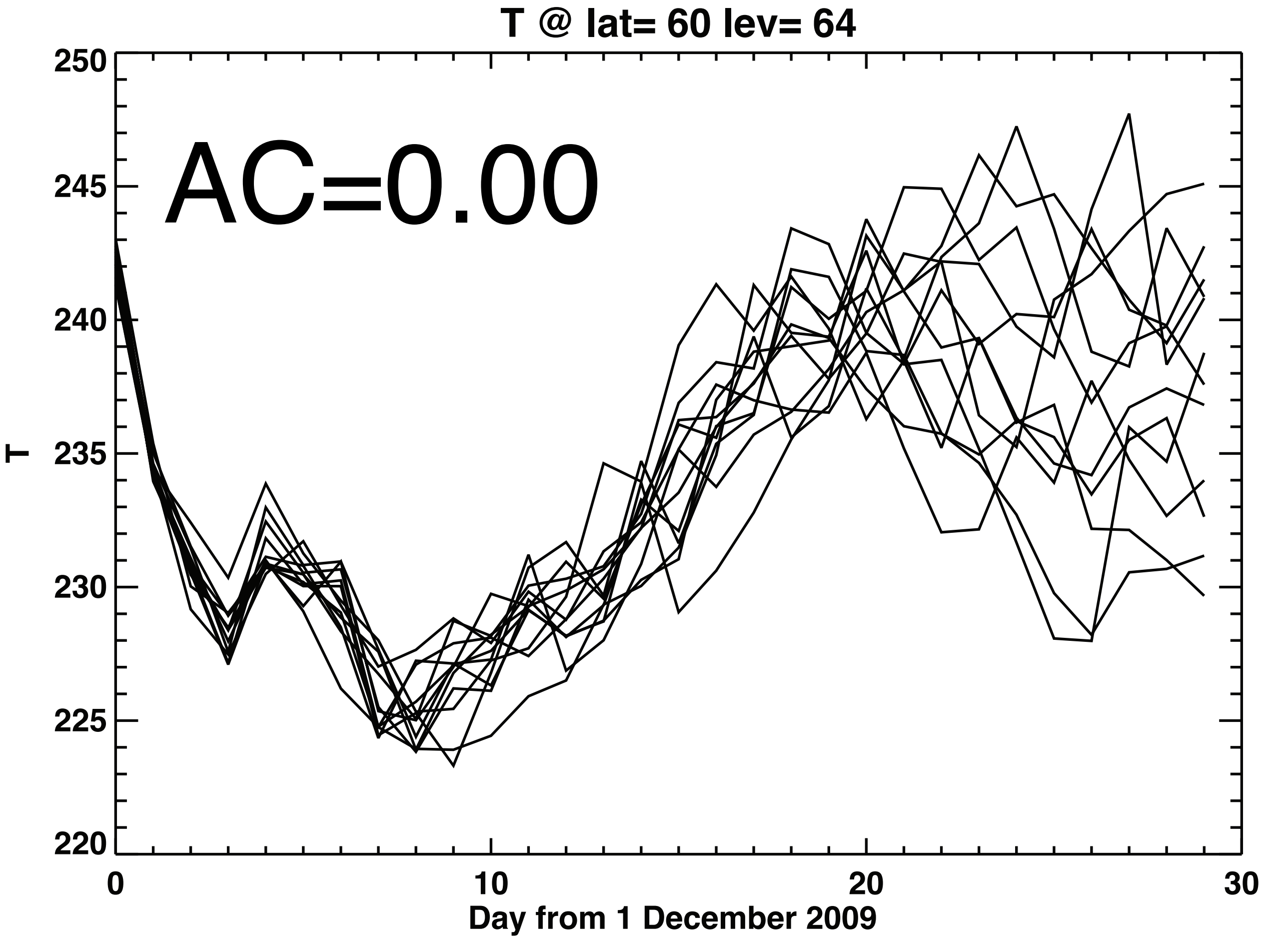
- 12 ensembles/30 days simulations initialized from 1 December 2009 analysis.
- Three values of the AC: 0.00, 0.50, and 0.99.

Mid-latitude / Mid-Stratosphere



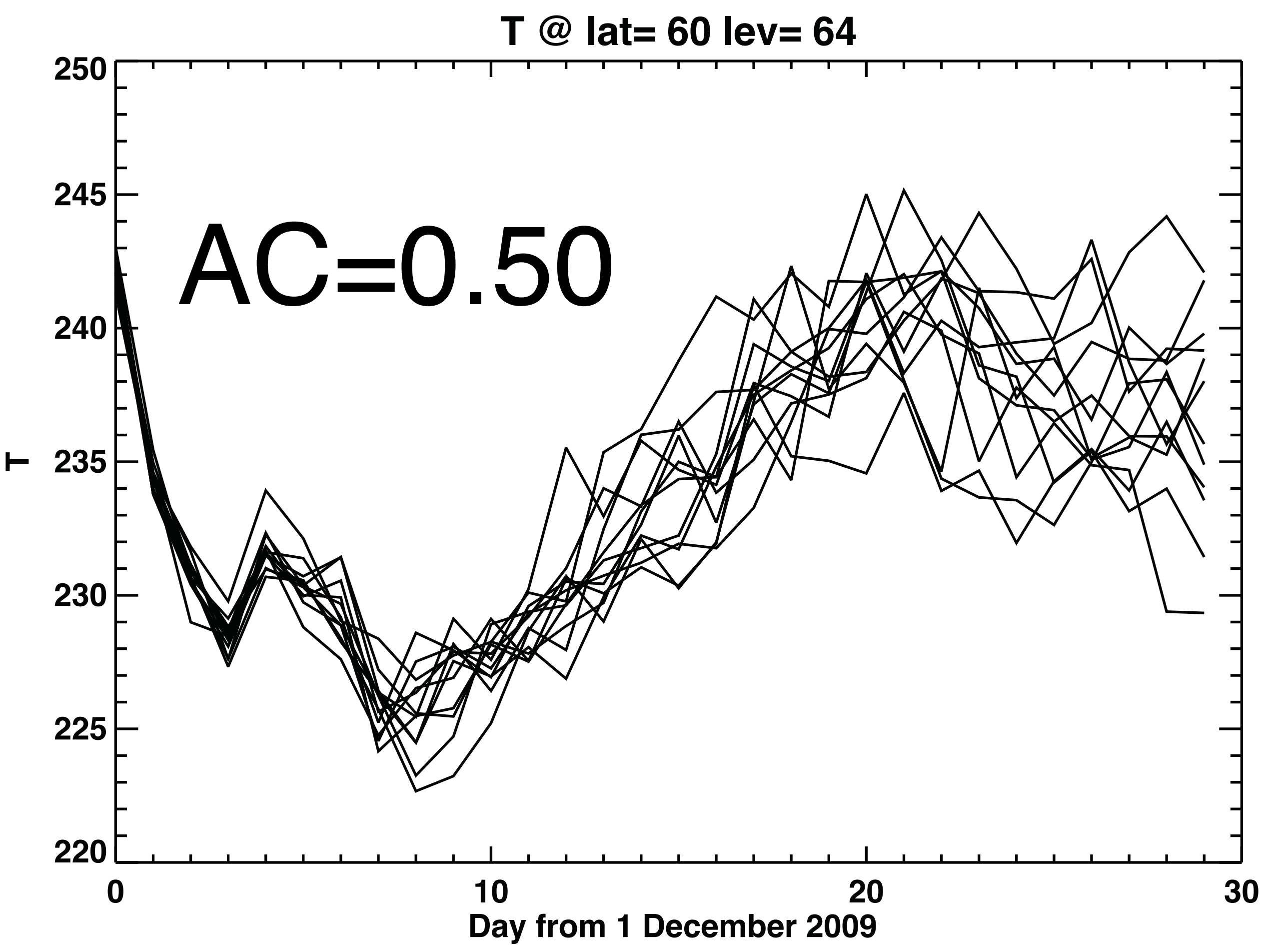


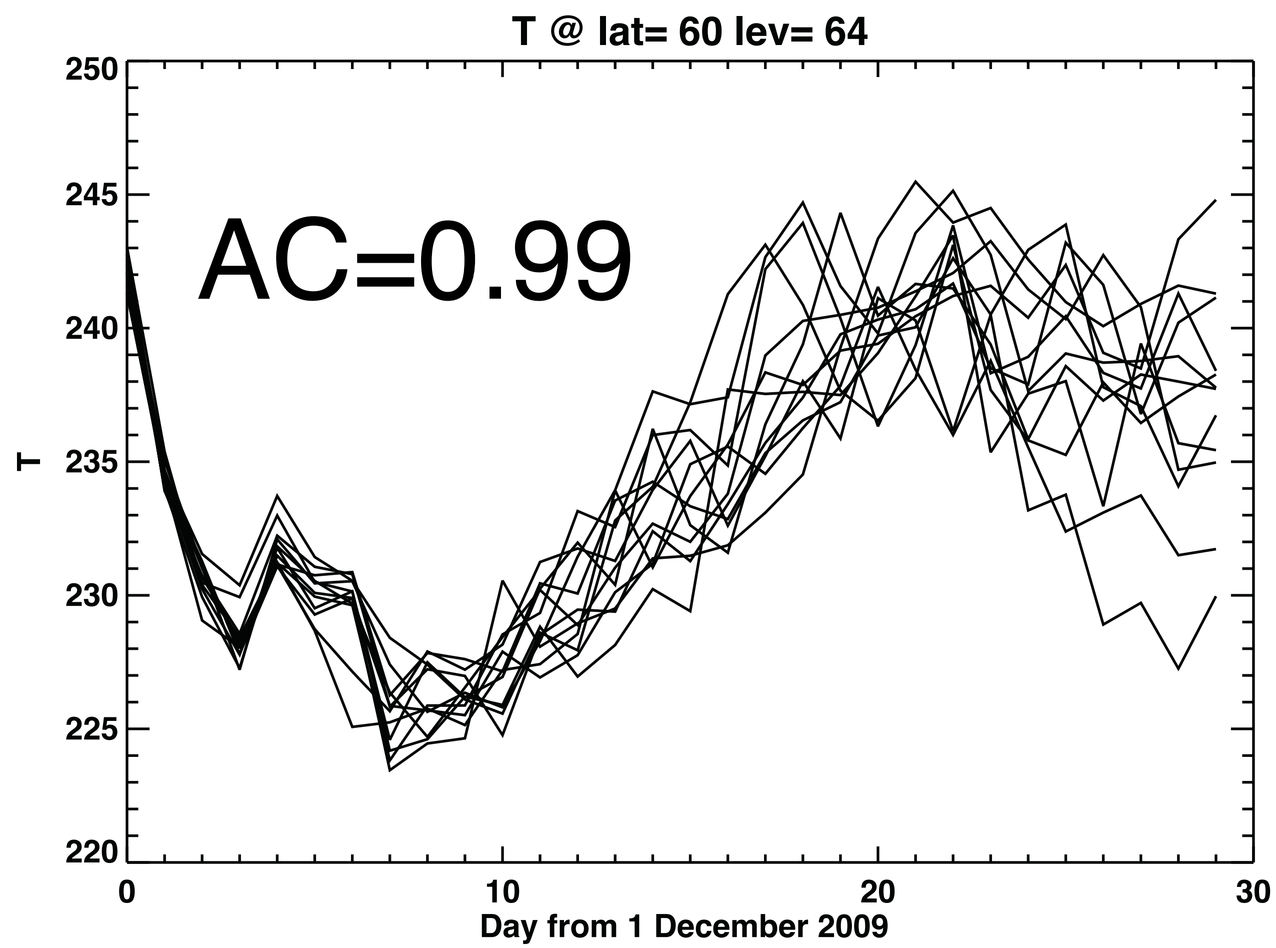




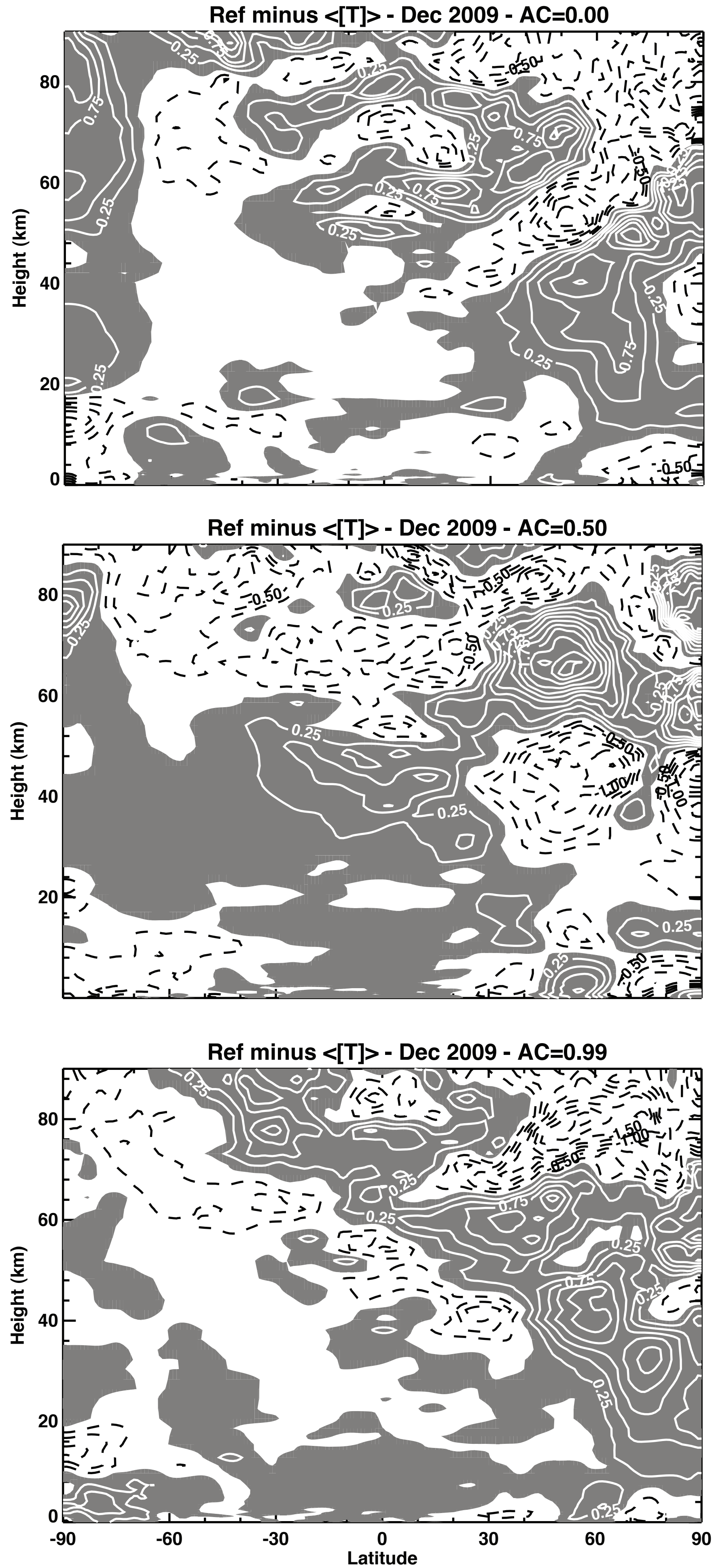
Mid-latitude / Lower Mesosphere

The spread of the ensemble members and the temporal behavior are similar in the three cases, both in the middle stratosphere and the lower mesosphere.





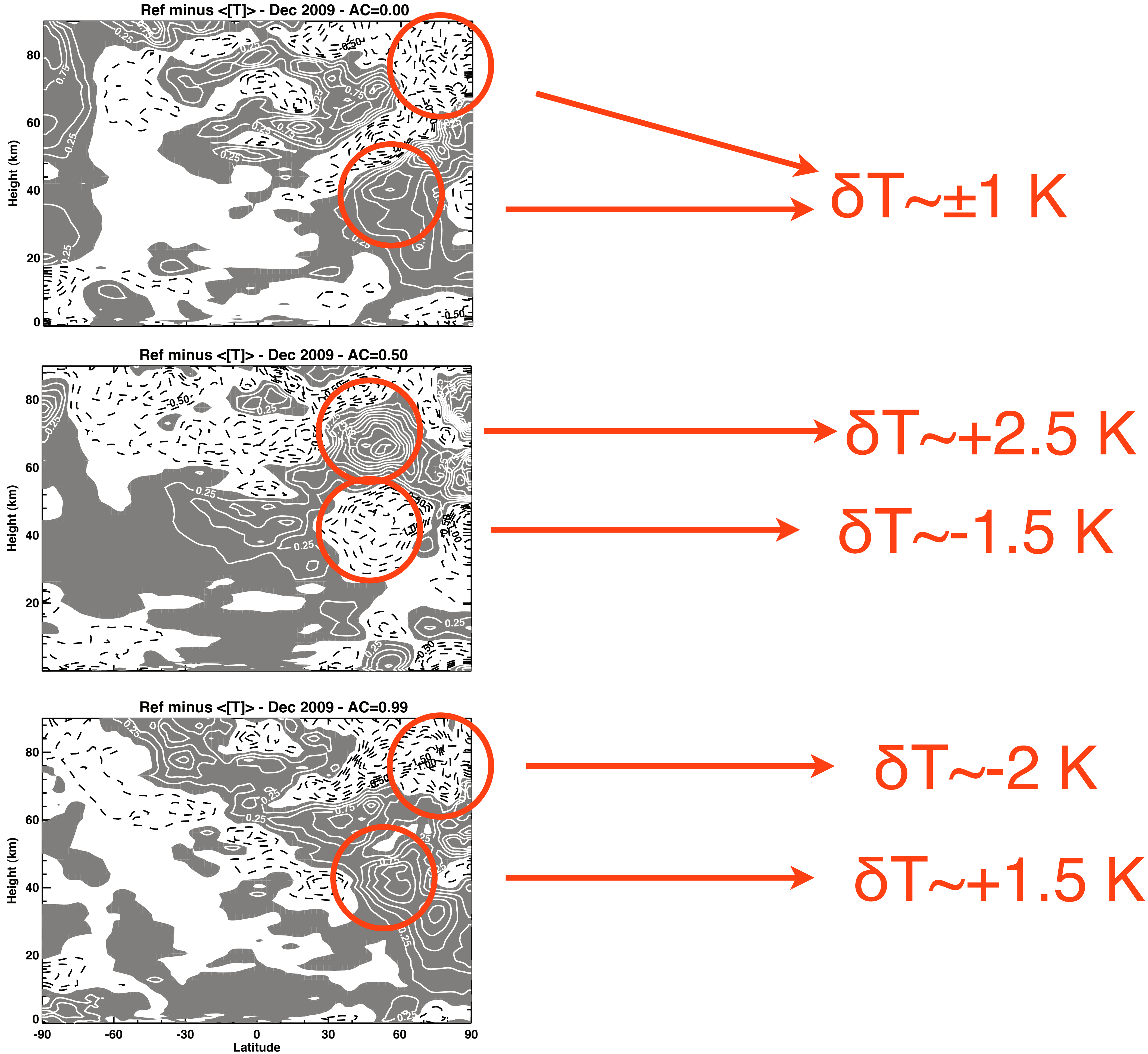
Zonal Mean Errors



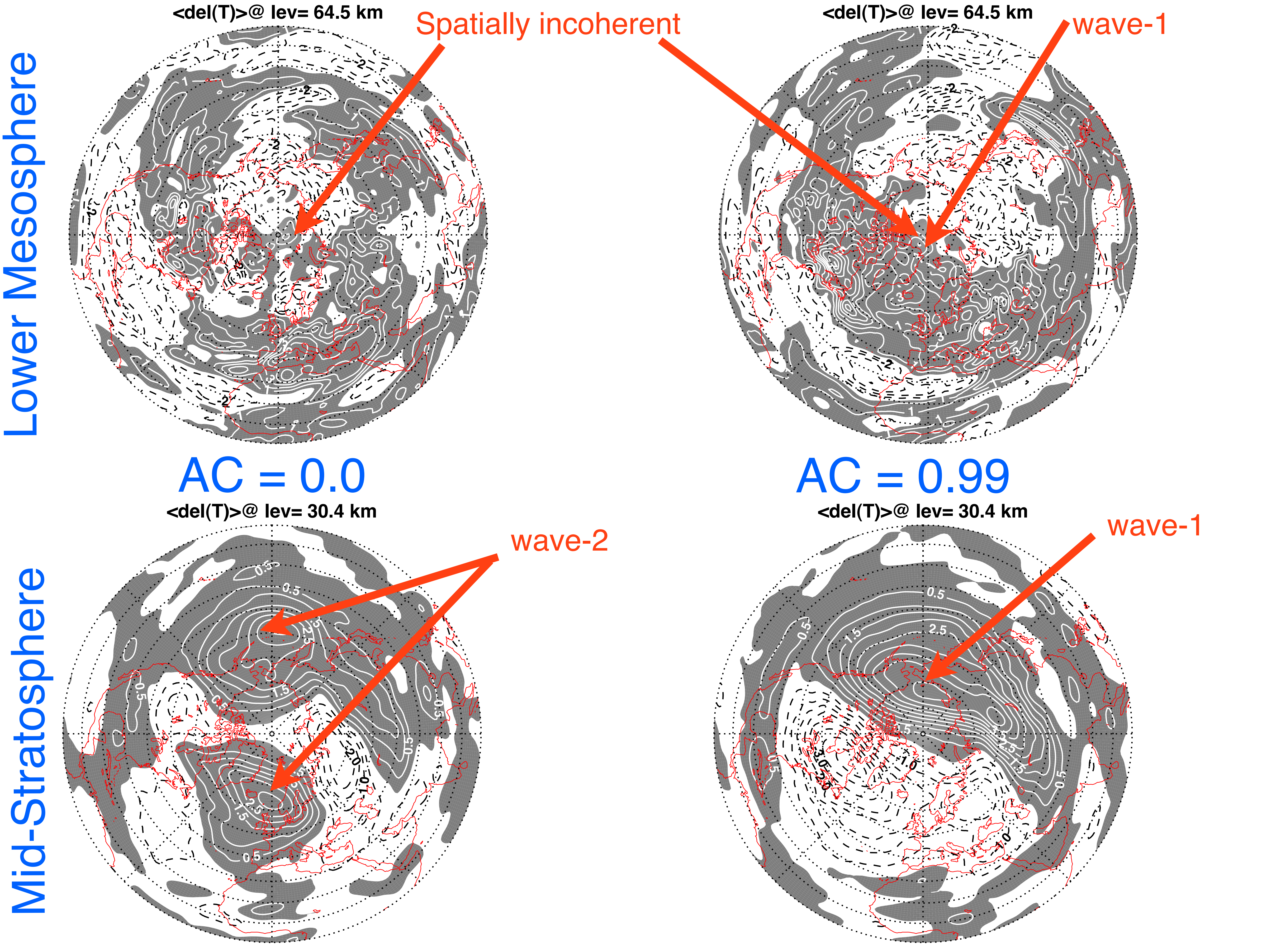
AC = 0.0

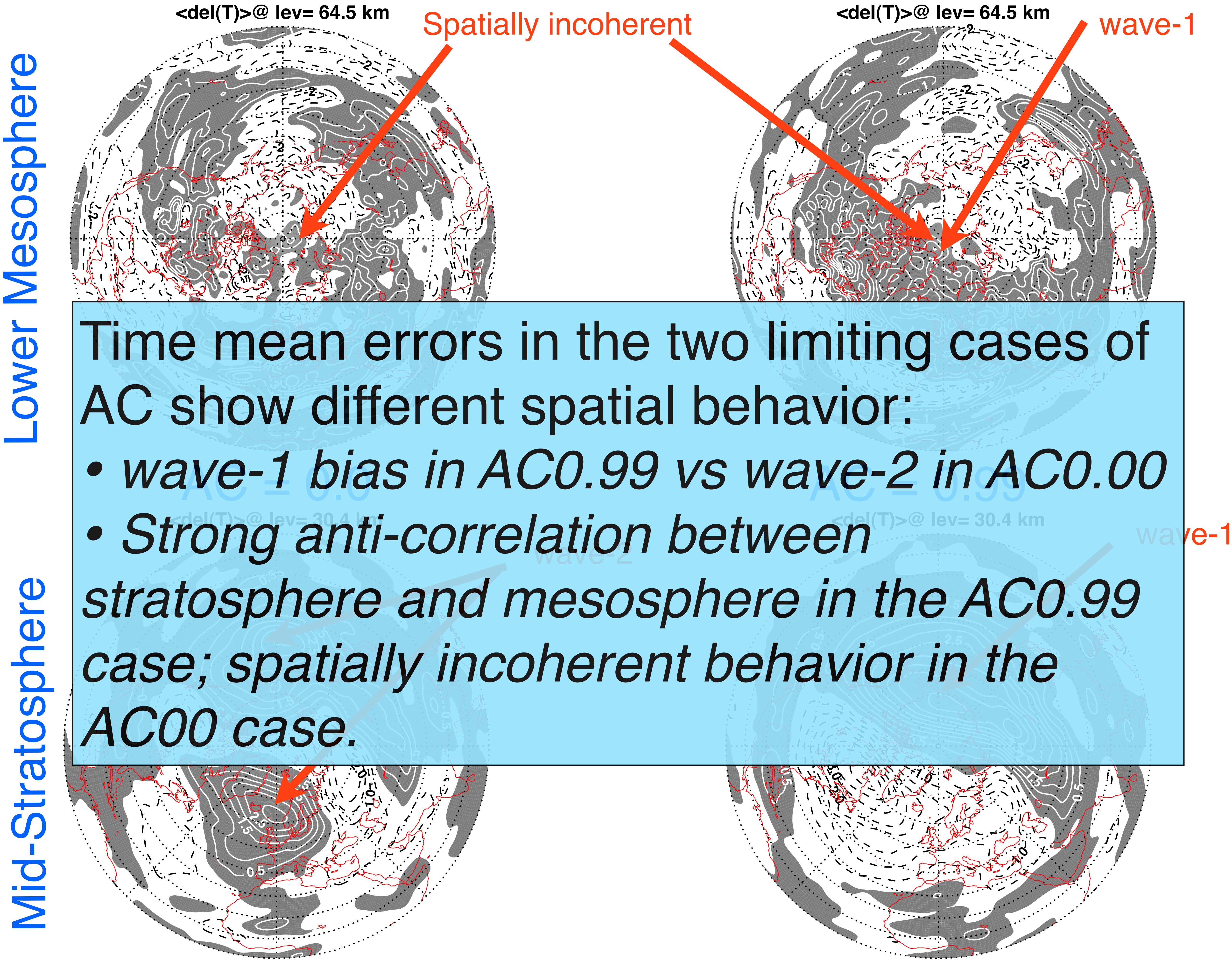
AC = 0.5

AC = 0.99



Ref minus <[T]> - Dec 2009 - AC=0.00
Ref minus <[T]> - Dec 2009 - AC=0.50
Ref minus <[T]> - Dec 2009 - AC=0.99
Height (km)
Latitude
δT~±1 K
δT~+2.5 K
δT~-1.5 K
δT~-2 K
δT~+1.5 K


Lower Mesosphere
Mid-Stratosphere
<del(T)>@ lev= 64.5 km
<del(T)>@ lev= 64.5 km
Spatially incoherent
wave-1
AC = 0.0
AC = 0.99
<del(T)>@ lev= 30.4 km
<del(T)>@ lev= 30.4 km
wave-2
wave-1



Time mean errors in the two limiting cases of AC show different spatial behavior:

- *wave-1 bias in AC0.99 vs wave-2 in AC0.00*
- *Strong anti-correlation between stratosphere and mesosphere in the AC0.99 case; spatially incoherent behavior in the AC00 case.*

Concluding Remarks

- **<u>DAS / Time mean error biases</u>:** Error biases are comparable between the deterministic and the stochastic scheme below 60 km and outside the tropics. Above 60 km at high latitudes and in the tropical lower mesosphere, <u>significant biases</u> indicate that unbalanced circulation anomalies can result from the stochastic scheme even in the context of a DAS.
- **DAS / <u>Spatial scales and predictability</u>:** The stochastic and deterministic multi-wave GWD are similar, but scales predictability extends to <u>shorter scales</u> in the mesosphere ($k \leq 30$) compared to *Nezlin et al.* ($k \sim 10$).
- **<u>GCM / Simulations with different values of the AC</u>**. There is little evidence that the magnitude of the zonal mean errors changes with the value of AC. There is clear evidence that the errors aggregate around different spatial scales depending on the value of AC.