Errors in the mesosphere in specified dynamics WACCM

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Are the upper mesosphere and lower thermosphere "slave" to the lower atmosphere?

Questions:

- Does the unpredictability of atmospheric dynamics originate in the lower atmosphere?
- How are the errors propagated?
- To what altitude is meteorological data needed in order to predict the dynamical variability above?

Question that will not be addressed:

- Is a global model with moderate resolution a sufficient tool to address the above?

Tool used: WACCM4

WACCM runs

- free-running (FR)
  - 45-day base run, beginning January 1; meteorological (“met”) data saved every hour
  - two additional realizations with slight differences in initial tropospheric zonal wind
- nudged (SD=specified dynamics)
  - nudge with meteorological fields from base run
    - temperature, horizontal winds, several surface variables
  - use initial conditions that are slightly different from “base”
  - several runs to test aspects of nudging
    - altitude range of meteorological data
    - frequency of meteorological data

- entire process repeated with three different gravity wave formulations:
  - WACCM4 (Lindzen-type GW parameterization with interactive sources depending on convection and fronts)
  - WACCM3 (same GW parameterization except with specified GW sources)
  - no GW parameterization (“Rayleigh friction” damping)

NOTE: All SD runs here use output from another WACCM run; not actual reanalysis data.

WACCM runs

Advantages of this setup

- “true” atmosphere is known (=BASE case)
- model physics agrees perfectly with meteorological data
- external forcing (due to e.g. solar or composition changes) is identical in all simulations
- meteorology fields for nudging are perfect; no interpolation onto a different horizontal grid is needed
- allows control over data frequency and vertical range for nudging

- FOCUS: efficacy of nudging process in reducing simulation errors

nudging process

$$T_{predicted} = T_{n-1} + \Delta T_{advection} + \Delta T_{diabatic} + \Delta T_{adiabatic} + \Delta T_{diffusion}$$

free running: $T_n = T_{predicted}$

nudged: $T_n = (1-\alpha)T_{predicted} + \alpha T_{met}$

applied every timestep over certain vertical range

Linear interpolation in time is used to get T_{met} at every timestep

VARIATIONS IN NUDGING

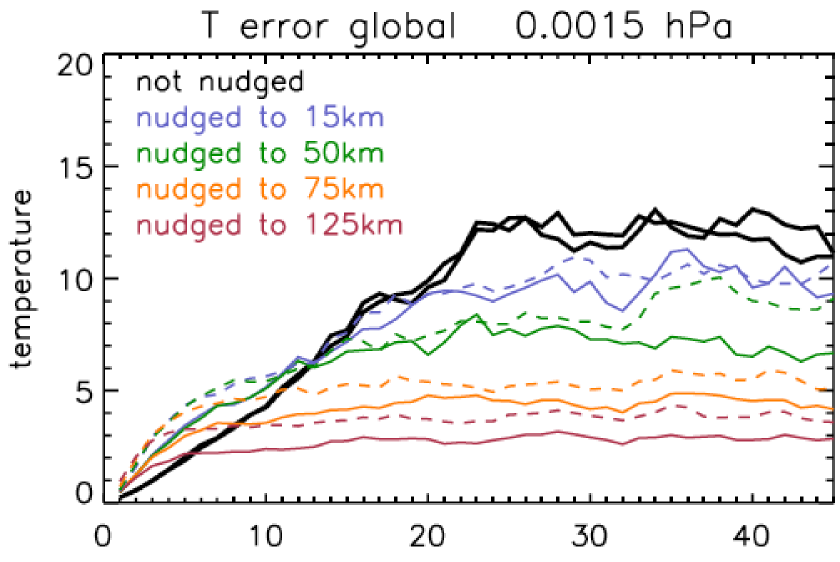
- altitude range where nudging is applied
- frequency that T_{met} is available
- strength of α

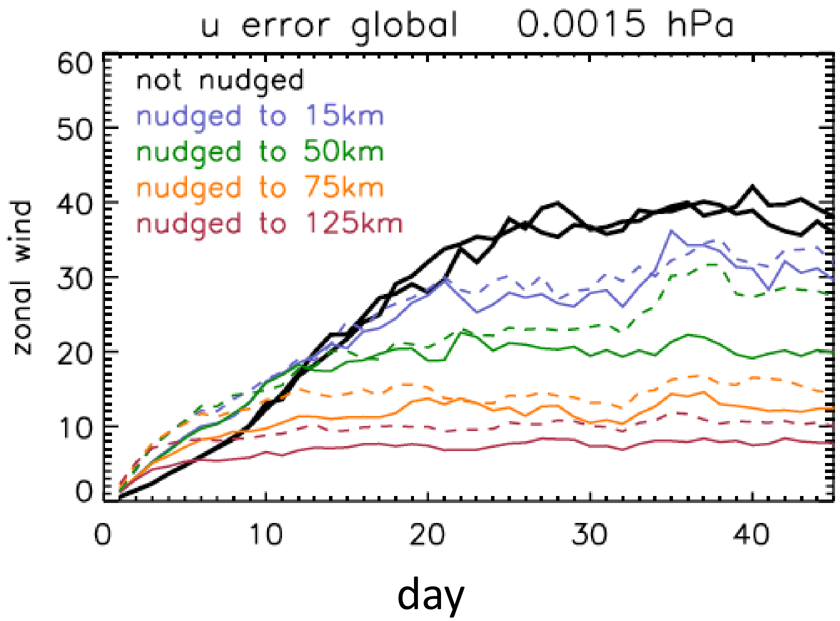
WACCM4 free running (FR) and nudging (SD) runs

name	type	nudge region*	frequency of met data	relaxation time	comments
BASE	FR				used to generate all “met” fields
DIFF1	FR				perturbed initial u
DIFF2	FR				perturbed initial u
15km 1 hr	SD	nudge <15 km	1 hr	50 hrs	
15km 6 hr	SD	nudge <15 km	6 hr	50 hrs	
50km 1 hr	SD	nudge <50 km	1 hr	50 hrs	
50km 6 hr	SD	nudge <50 km	6 hr	50 hrs	standard for SD-WACCM
75km 1 hr	SD	nudge <75 km	1 hr	50 hrs	
75km 6 hr	SD	nudge <75 km	6 hr	50 hrs	
125km 1 hr	SD	nudge <125 km	1 hr	50 hrs	
125km 6 hr	SD	nudge <125 km	6 hr	50 hrs	

* nudging tapers off over 10 km region above this level

RMS error growth in the MLT





~90 km

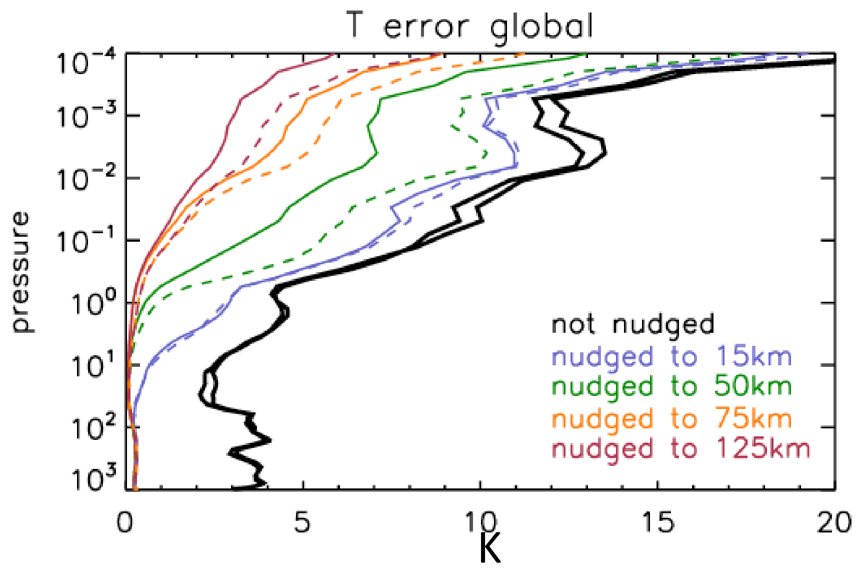
RMS using data at every longitude & hour

solid: met data updated every hour
dashed: met data updated every 6 hours

initial error growth is faster for nudged runs

RMS error plateaus after 10-25 days

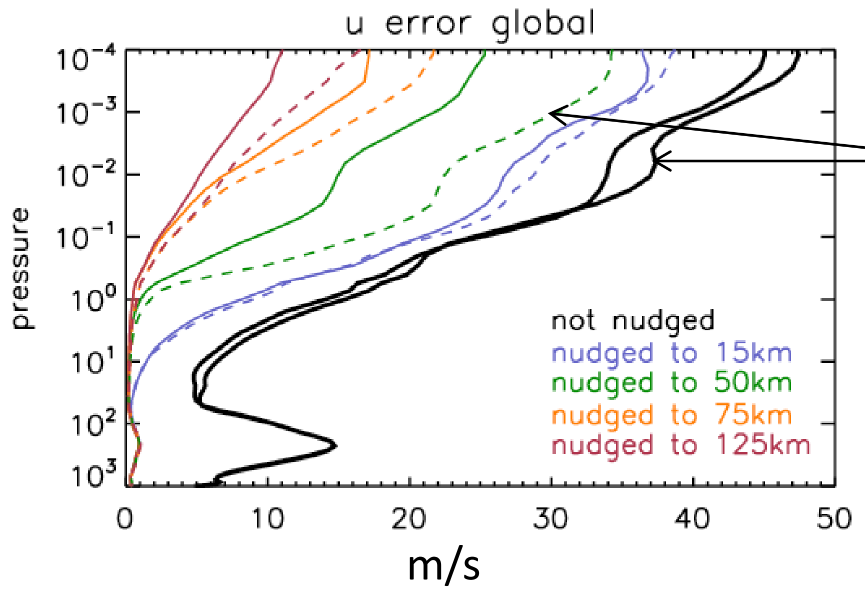
RMS error growth versus pressure



solid: met data available every hour
dashed: met data available every 6 hours

error from last 10 days of each run

error grows above ~1hPa even when the temperature and horizontal winds are nudged there



for RMS error, improvement of standard WACCM (green dashed line; nudged to 50 km with 6 hr met data) over free-running is less than a factor of 2

Why is there RMS error for constraint to "perfect" data?

free running: $T_n = T_{predicted}$

nudged: $T_n = (1-\alpha)T_{predicted} + \alpha T_{met}$

for α=0: $T_n = T_{predicted}$

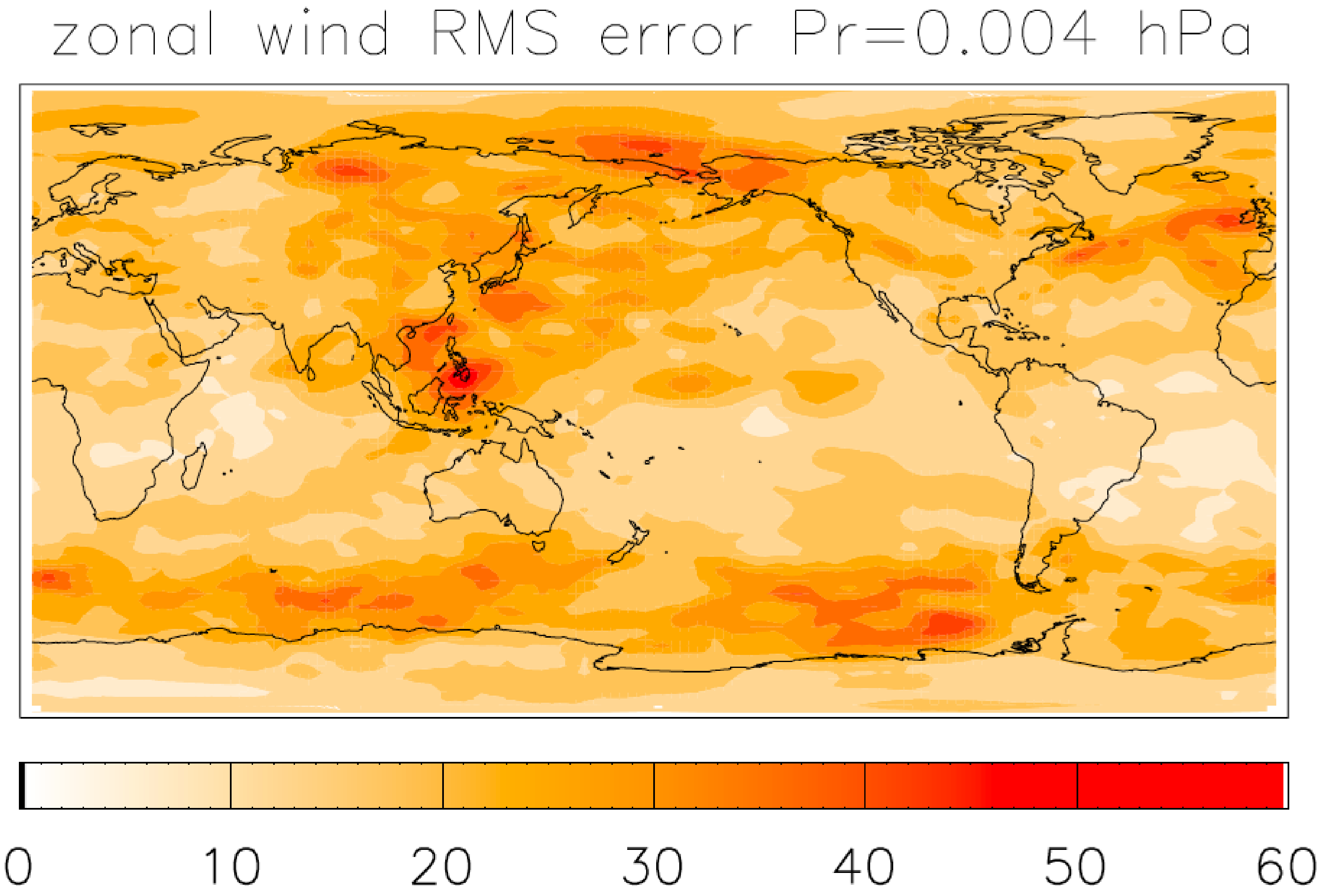
for α=1: $T_n = T_{met}$

$0 < \alpha < 1$: $T_n = (1-\alpha)T_{n-1} + \alpha\ T_{met} + (1-\alpha)[\Delta T_{advection} + \Delta T_{diabatic} + \Delta T_{adiabatic} + \Delta T_{diffusion}]$

note different timestep

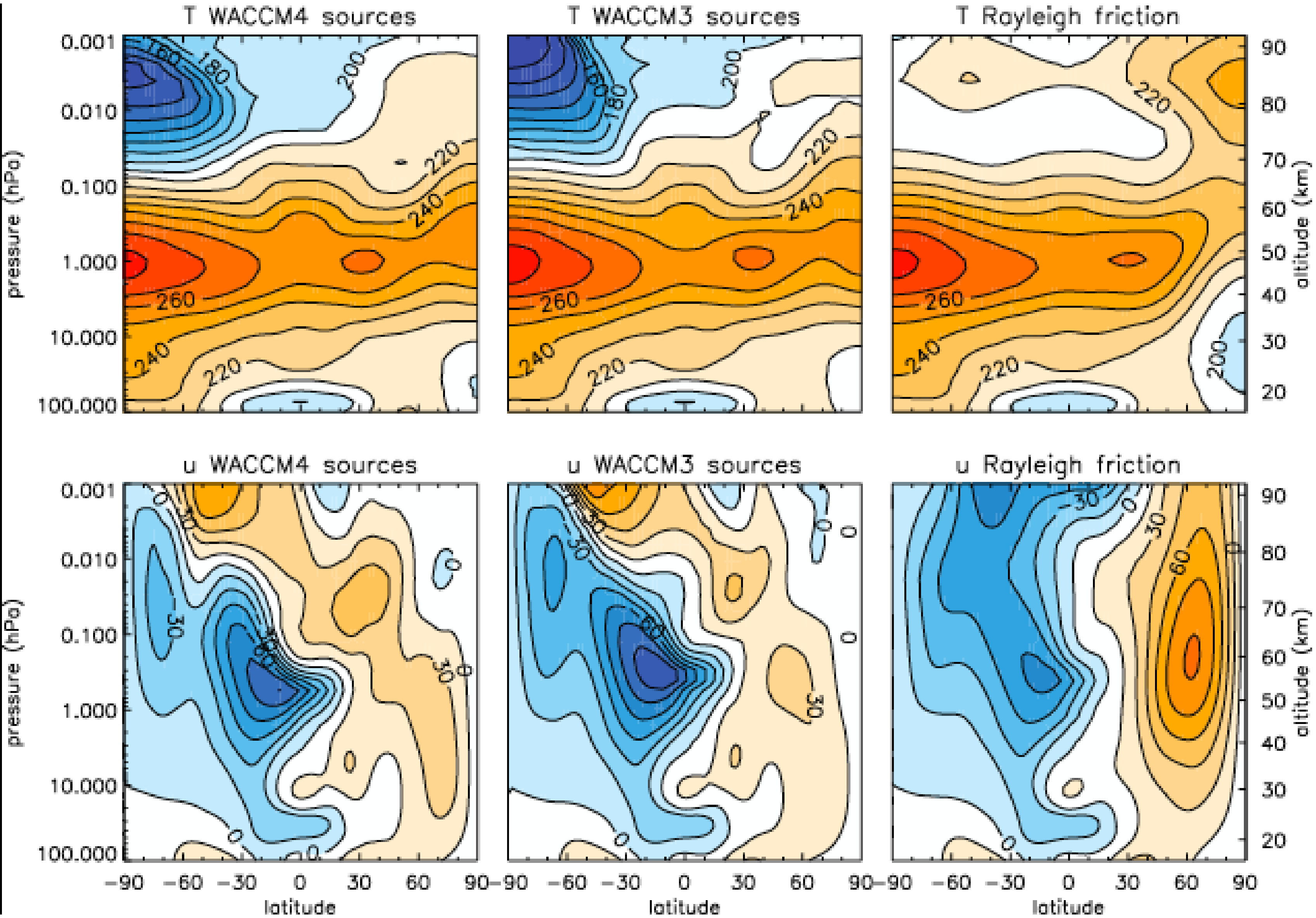
- inherent lag in nudging process
- formulation of dynamical equations is different

Where are the errors?



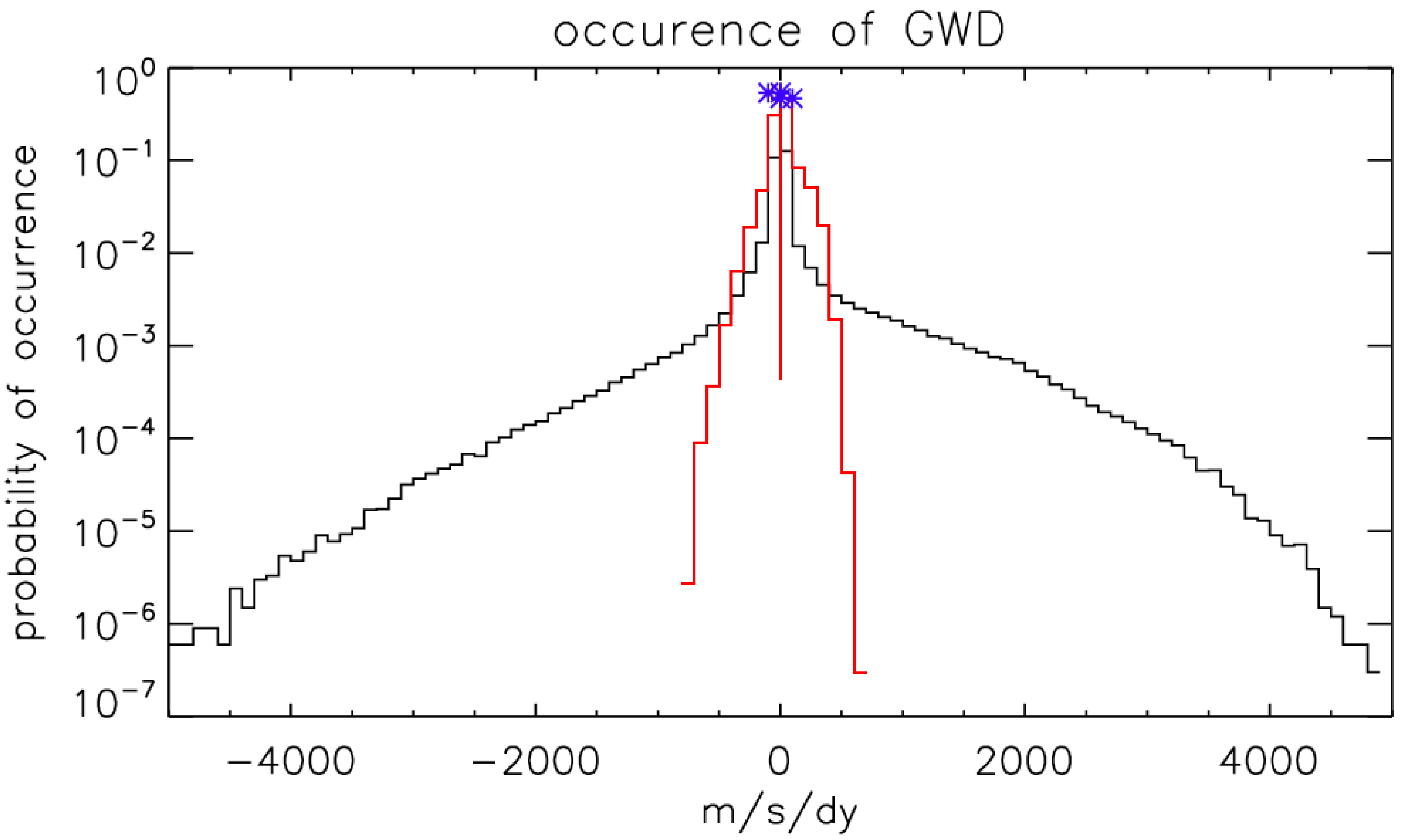
- errors averaged over 10 days
- pattern of error includes large-scale features and localized “hot spots”

Use different representations of impact of GW on the mesosphere



- WACCM4:
  - interactive non-orographic GW sources in troposphere
  - propagation depends on winds
- WACCM3
  - specified GW sources
  - propagation depends on winds
- Rayleigh friction
  - linear damping on u & v

Net GW drag value at individual gridpoint & timestep

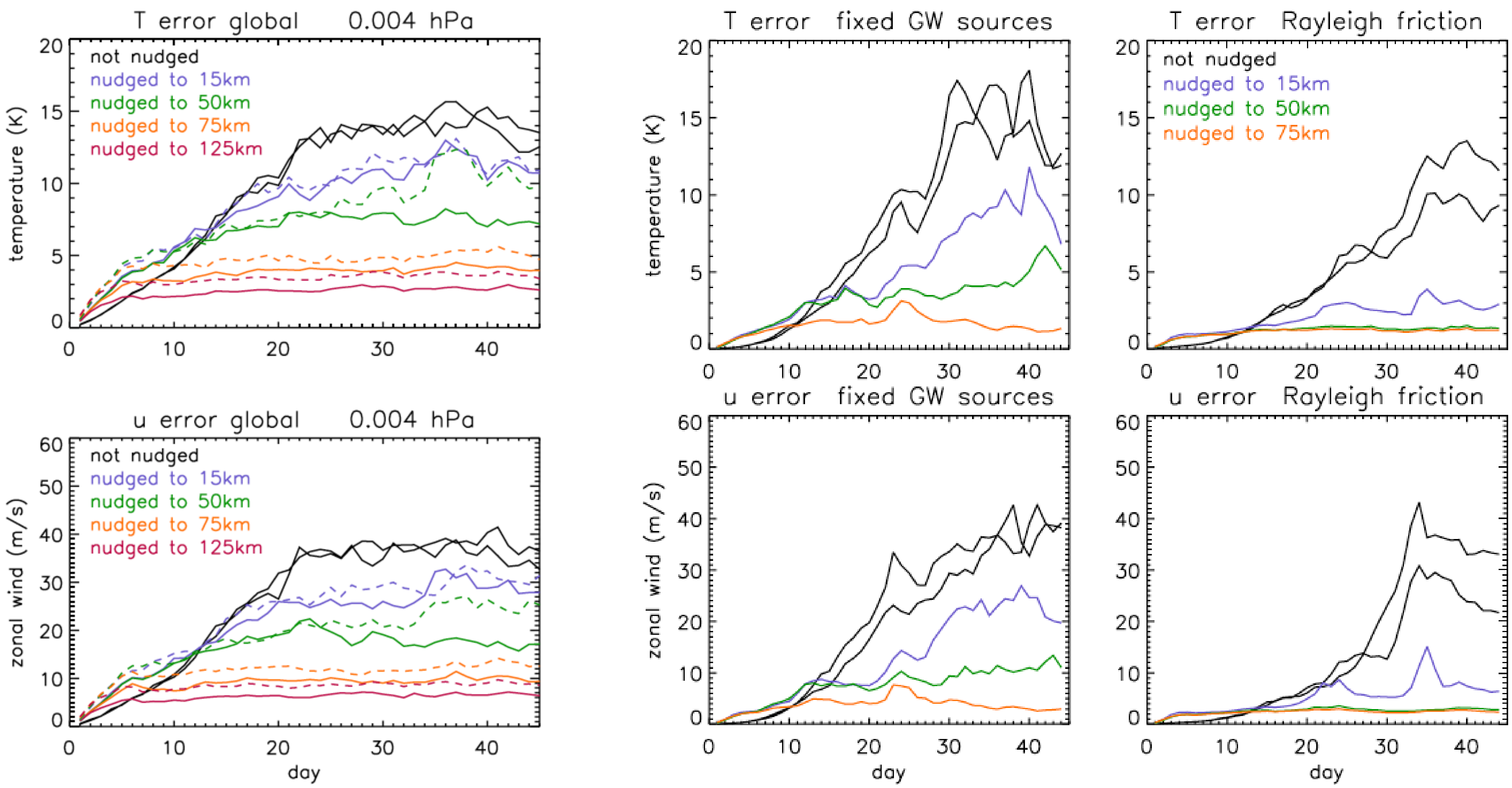


- black: WACCM4 GW parameterization
- red : WACCM3 GW parameterization
- blue: Rayleigh friction

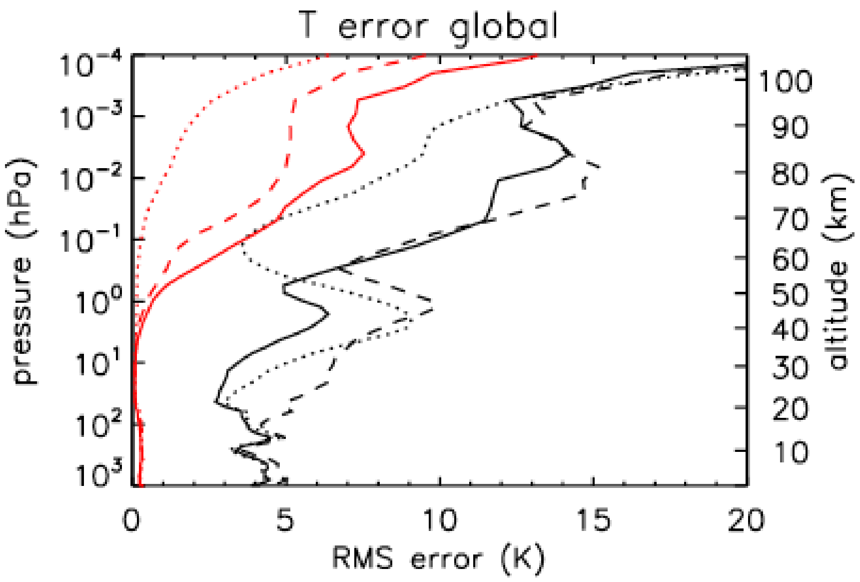
With WACCM4, very large momentum forcing occurs very rarely.

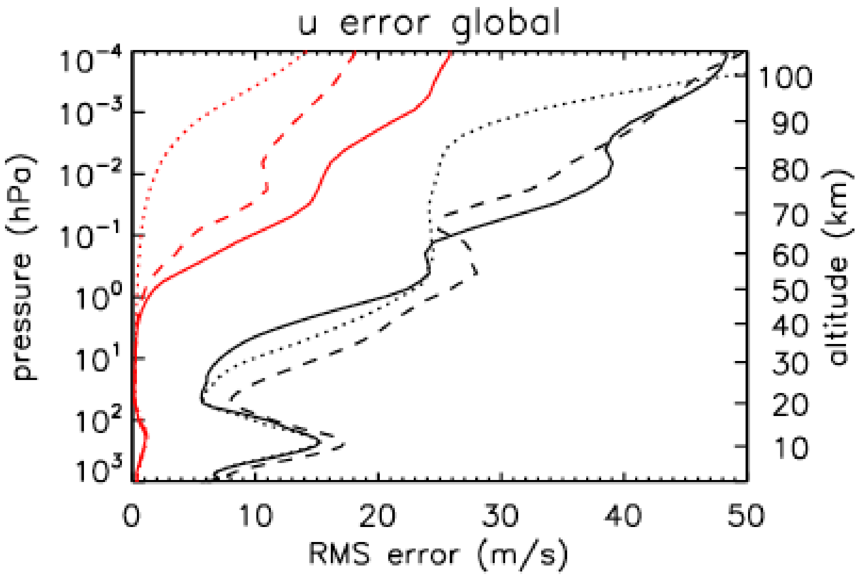
With WACCM3, momentum forcing range is much smaller.

Compare error growth with different GW drag



Compare error growth with different GW drag





- black: free-running
- red: nudged to 50 km with hourly met data

- solid: interactive GW sources
- dashed: specified GW sources
- dotted: no GW parameterization

Conclusions: nudging simulations to assess lower or middle atmosphere control of the dynamical variability of the MLT

- With “perfect” meteorological data, SD-WACCM simulations are closer to the base (“true”) atmosphere than free-running simulations.
- Tests with nudged WACCM indicate that the mesosphere is not strongly deterministic.
- The largest source of error is gravity wave drag from the parameterization.
- Model using parameterization without interactive GW sources is more predictable; i.e., with nudging using perfect data, simulation in MLT is close to “true” atmosphere.
- Some initial error growth comes from the formulation used for nudging.

WACCM without interactive GW sources has slower error growth and lower overall error but *this does not mean that this model is more realistic*. GW transport some of the uncertainty (noise) in the troposphere into the mesosphere.

Accurately characterizing error growth is important for data assimilation.