How well does SD-WACCM constrain dynamical variability in the mesosphere?

Anne Smith, Dan Marsh, Nick Pedatella
NCAR*

Tomoko Matsuo
CIRES/NOAA

- NCAR is sponsored by the National Science Foundation
- Model runs performed at the NCAR-Wyoming Supercomputing Center

nudging process

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

free running: $T = T_{predicted}$

nudged: $T = (1-\alpha)T_{predicted} + \alpha T_{met}$ applied every timestep over certain vertical range

Linear interpolation in time is used to get T_{met} at every timestep
normally nudged (3-D): u, v, T → overconstrained

VARIATIONS IN NUDGING

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

WACCM runs

- free-running (FR)
  - 45-day base run, beginning January 1
  - 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
    - relaxation timescale of nudging

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

WACCM runs

Advantages of this setup

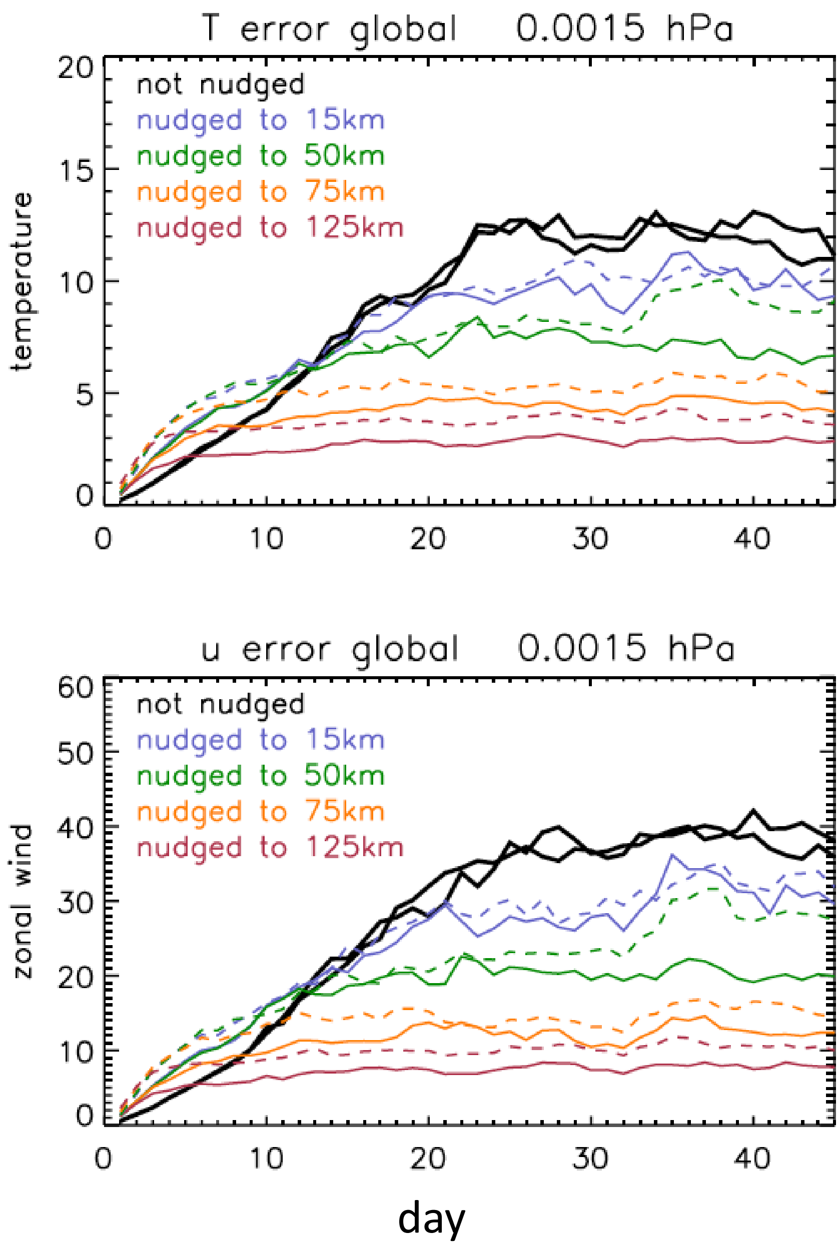
- "true" atmosphere is known (=BASE case)
- model physics agrees perfectly with meteorological data
- external forcing (due to e.g. solar or composition changes) is identical in all cases
- meteorology fields for nudging are perfect; no interpolation onto a different horizontal grid is needed
- allows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

free running (FR) and nudging (SD) runs

name	type	nudge region*	frequency of met data	relaxation time	comments
BASE	FR				used for 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	
25 hr relax	SD	nudge <125 km	1 hr	25 hrs	
6 hr relax	SD	nudge <125 km	1 hr	6 hrs	
1 hr relax	SD	nudge <125 km	1 hr	1 hrs	

* nudging tapers off over 10 km region above this level

RMS error growth in the MLT



~90 km

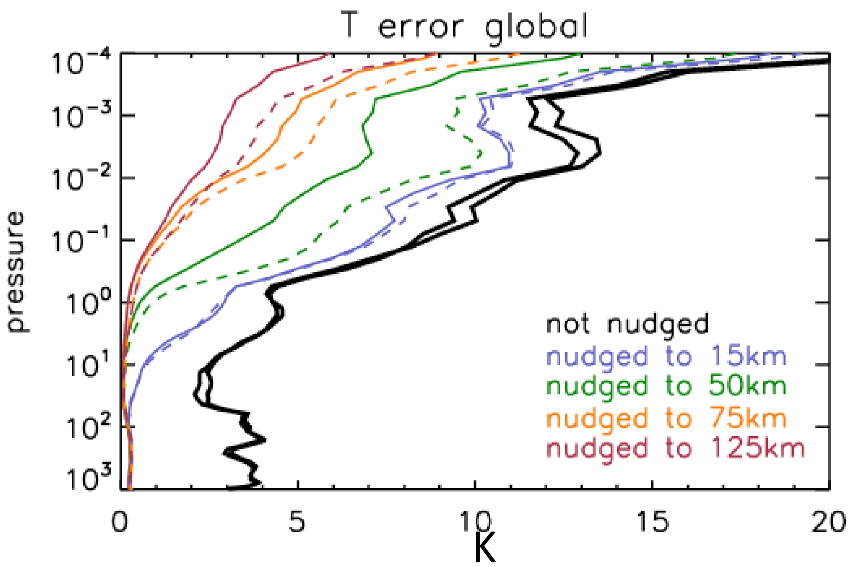
RMS using data at every longitude & hour

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

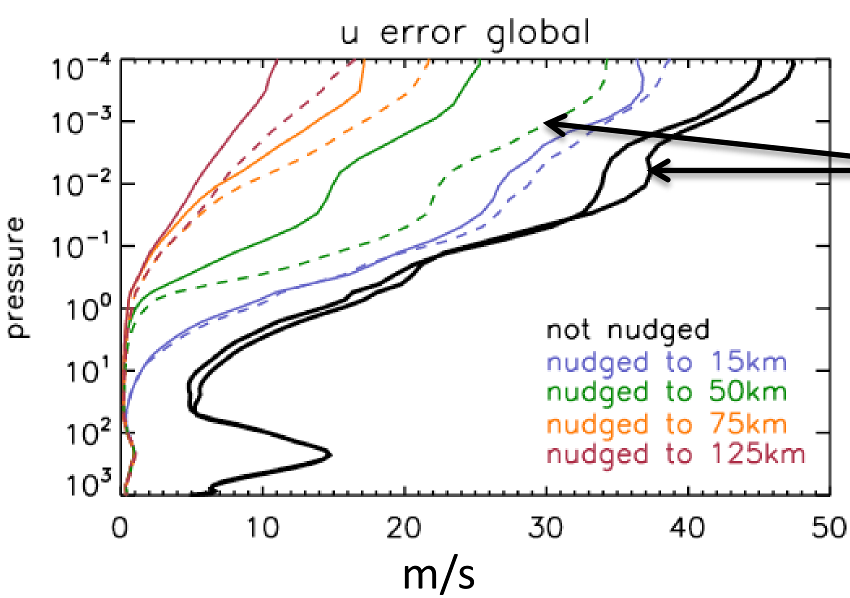
RMS error growth versus pressure



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

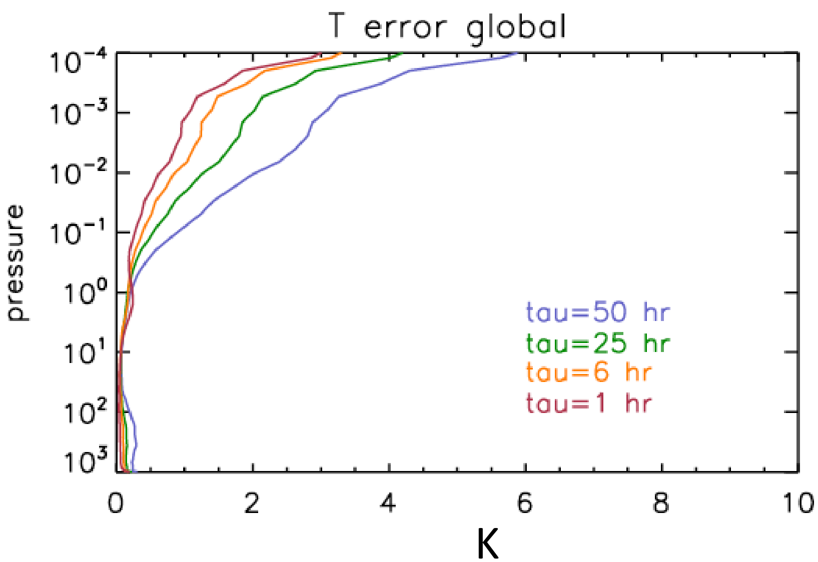
error from last 10 days of each run

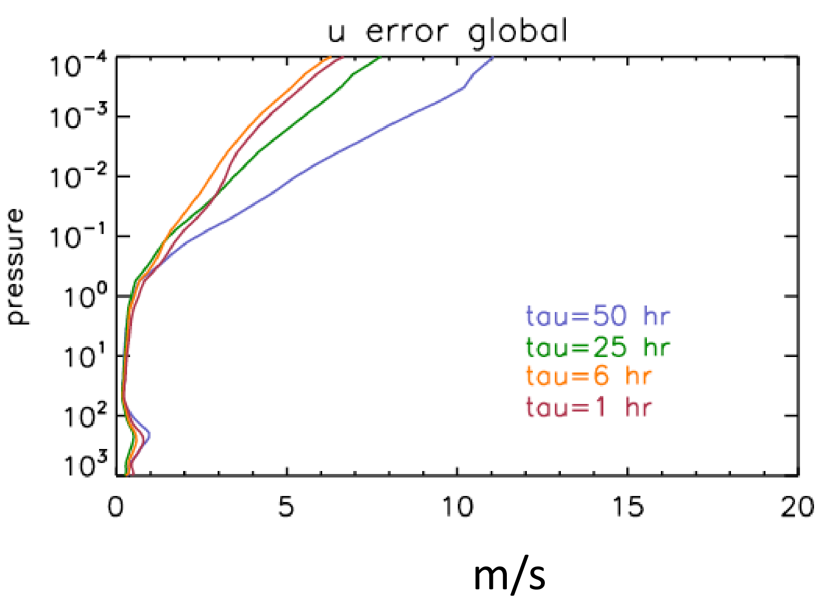
error grows above ~1hPa even when the temperature and horizontal winds are nudged there



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

RMS error growth for different τ





τ is the relaxation time (inverse of strength of nudging; proportional to $1/\alpha$)

all cases shown have met data available every hour

all cases nudged to 125 km

RMS error declines slowly as nudging becomes tighter

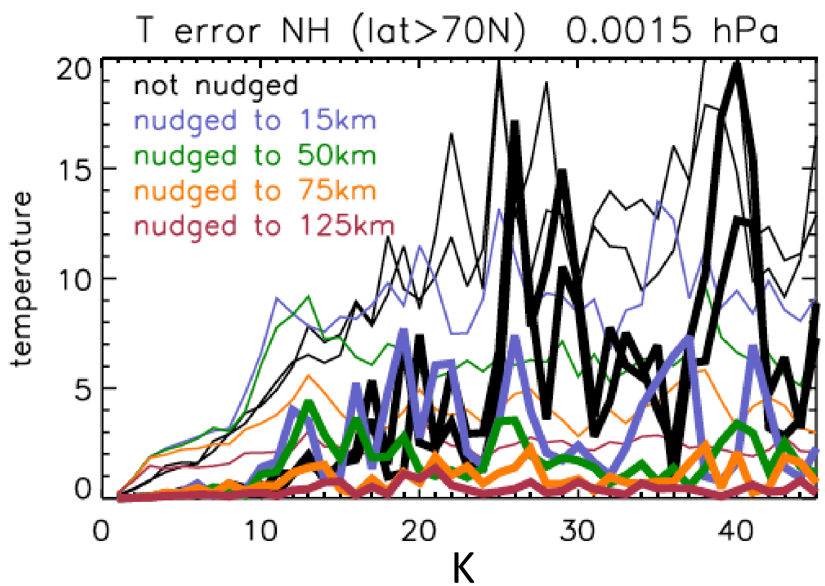
Why does RMS error persist for tight constraint to "perfect" data?

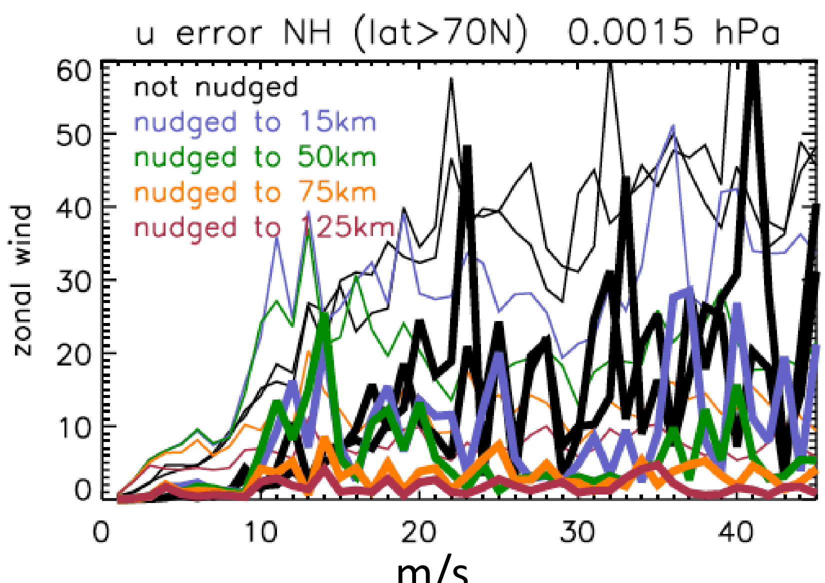
free running: $T = T_{predicted}$

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

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

Error for zonal daily mean - NH winter





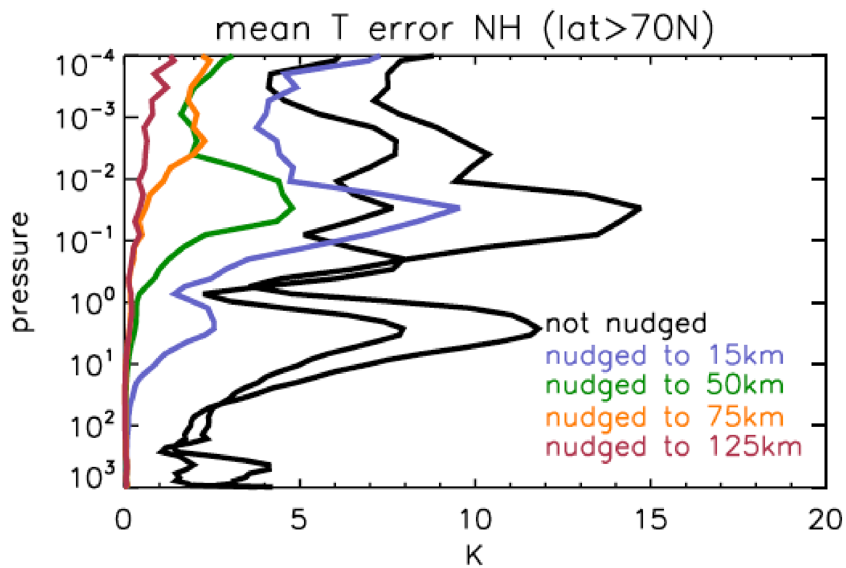
Thin lines: RMS error at ~90 km, 70°-90°N

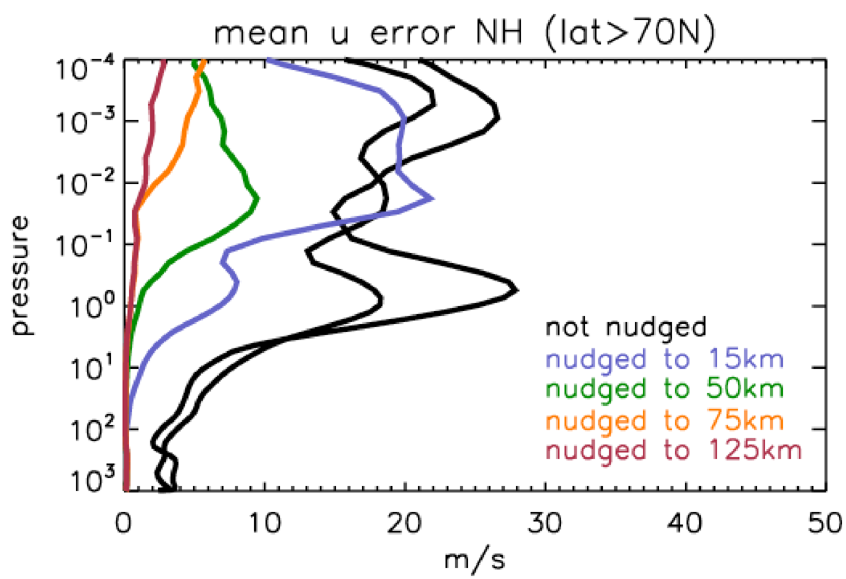
Thick lines: RMS error for daily zonal averages

(all cases use 1-hr met data)

Nudging is somewhat successful in keeping mean state close to basic atmosphere during variable NH winter conditions.

Pressure variation of daily mean error - NH winter



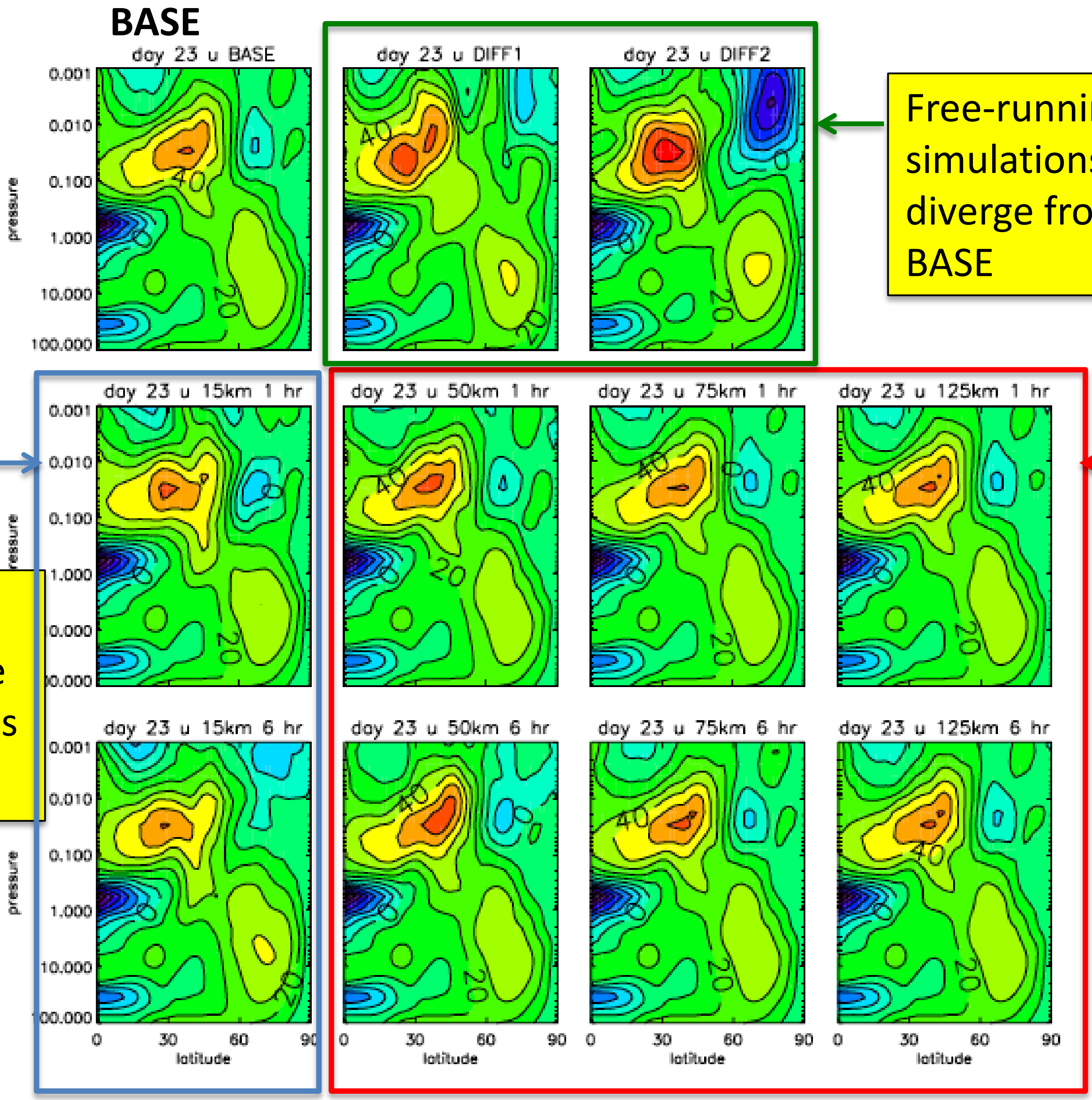


RMS error for daily zonal averages

All cases use 6-hr met data (green lines have the standard settings for WACCM)

Nudging the troposphere only has similar mean errors to the free-running (no nudging) simulations.

Zonal daily mean wind for a typical individual day

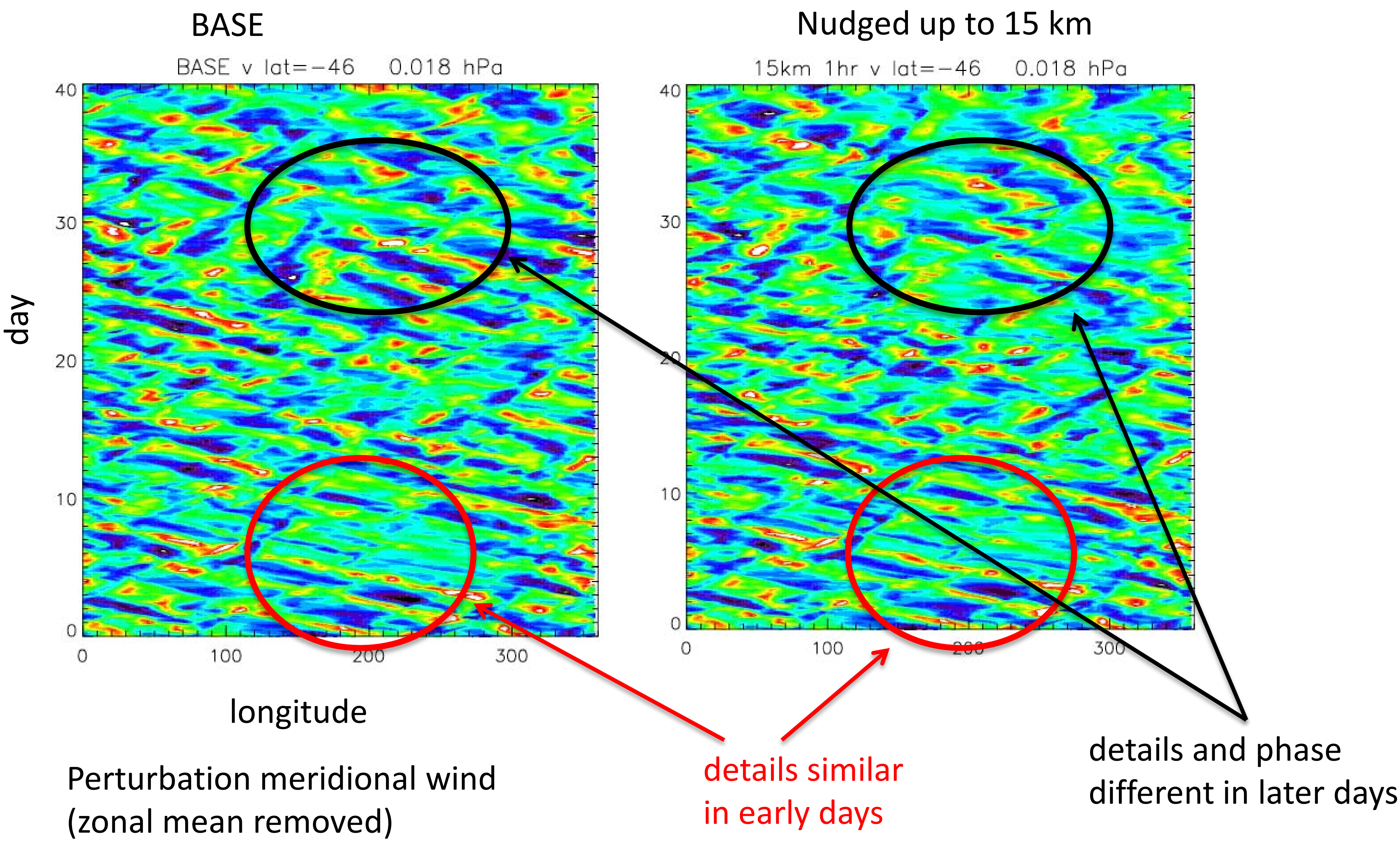


Free-running simulations diverge from BASE

Nudging at least to the stratopause gives reasonable agreement.

Nudging of troposphere only is not as good.

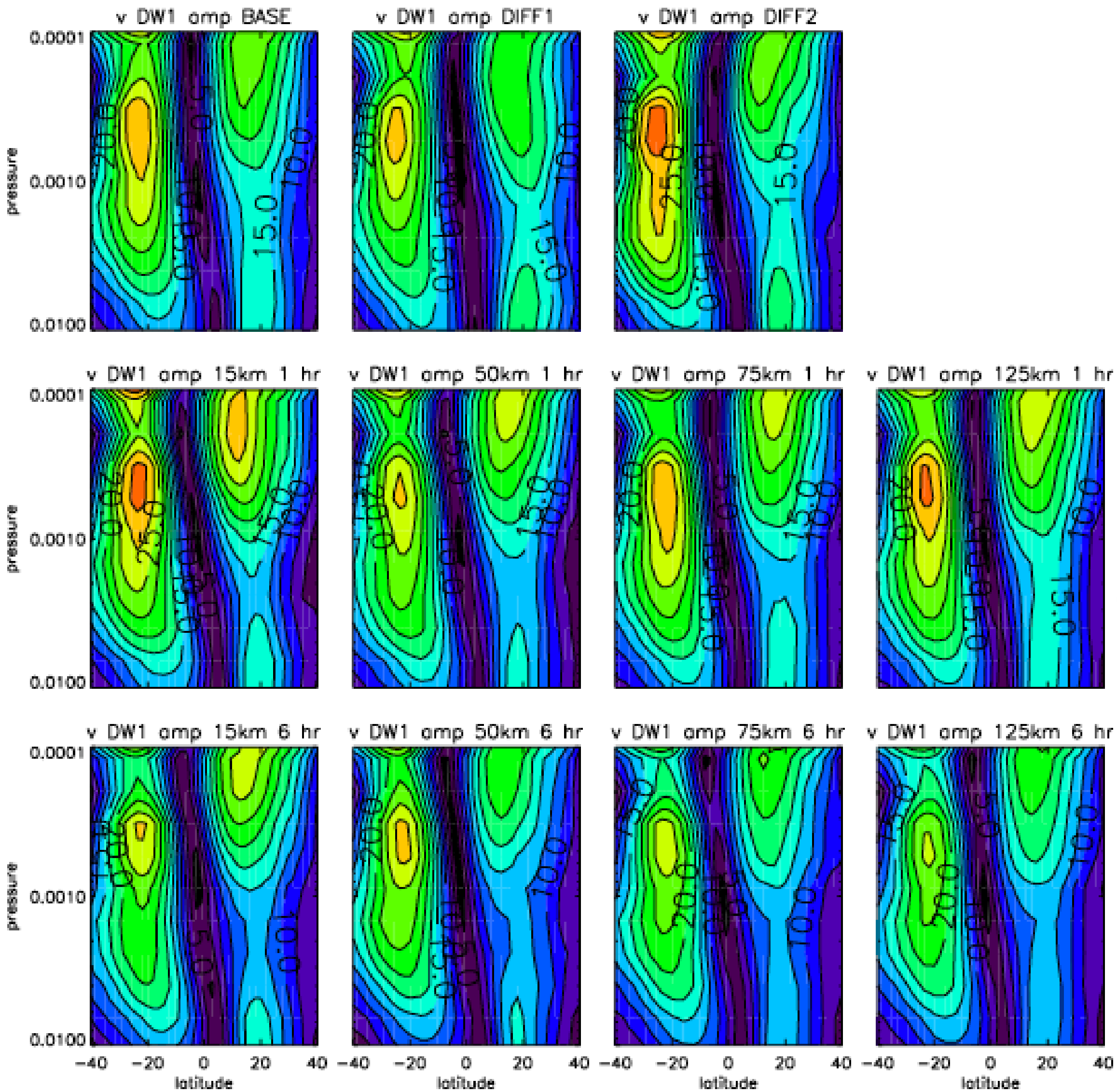
Q2D wave in simulation nudged to 15km



Perturbation meridional wind
(zonal mean removed)
at 46°S, 0.18 hPa (~75 km)

migrating diurnal (24 hr) tide

BASE



TIDE IN MERIDIONAL WIND

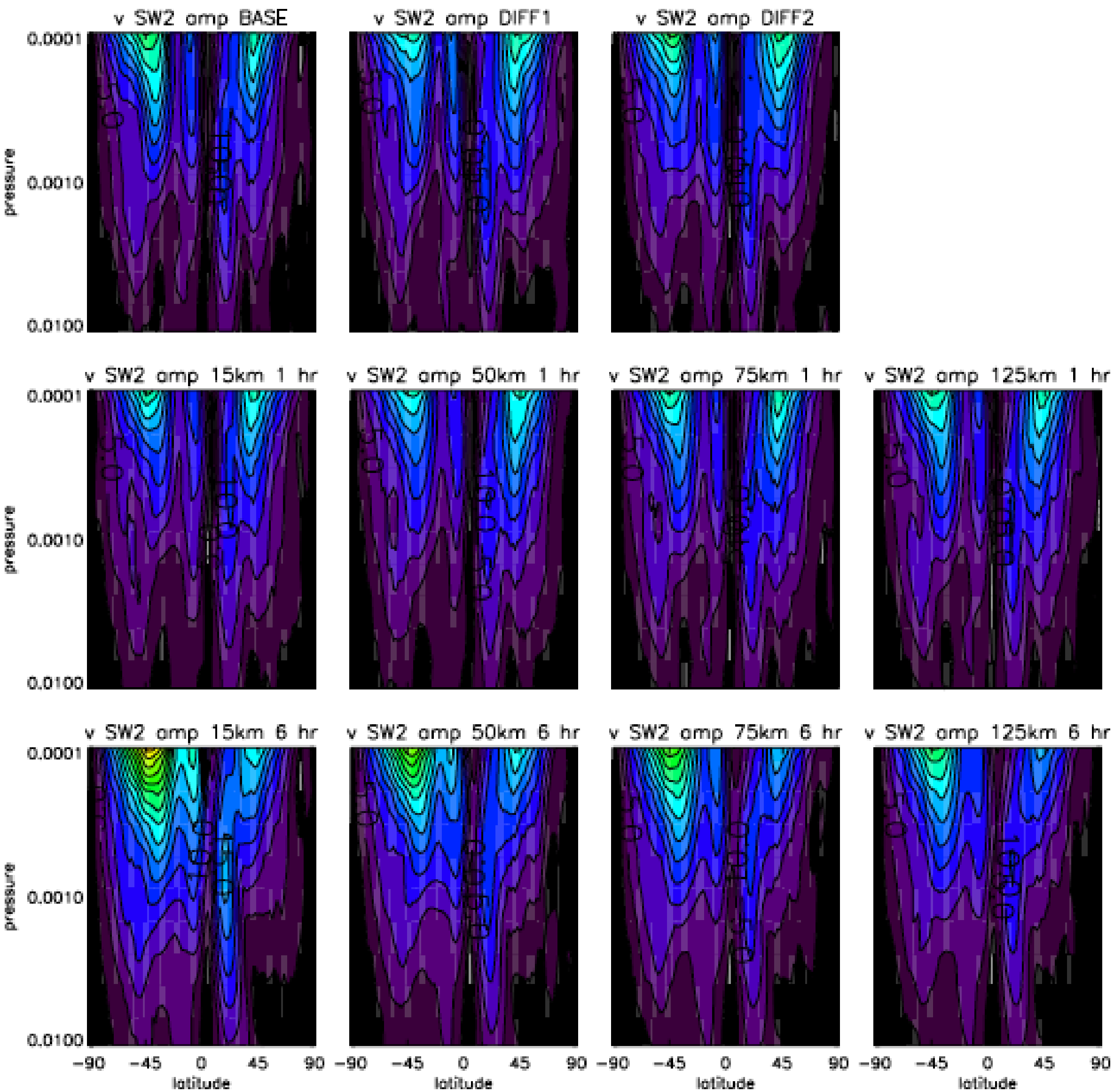
Tide structure is similar in all cases (FR as well as nudged).

← amplitudes ~similar to base with 1 hr met data

← lower amplitude with 6 hr met data

migrating semidiurnal (12 hr) tide

BASE



Tide in meridional wind:

← amplitude ~ similar to base with 1 hr met data

← ***higher*** amplitude with 6 hr met data

Conclusions: lower or middle atmosphere control of the dynamical variability of the MLT

- Models constrained to meteorological analyses can simulate observations better than unconstrained models.
- Tests with nudged WACCM indicate that the system is not completely deterministic.
- Potential sources of error (even if lower atmosphere is perfectly known):
  - waves generated by instability (quasi-2 day wave; 5 day wave, etc)
  - gravity waves, including parameterized
  - stratosphere
- RMS errors grow with height before or as soon as the constraint is removed. Expanding altitude range of constraint improves the prediction of MLT dynamics.
- There is a modest reduction of error for more frequent meteorological data.
- Continued MLT observations are needed.