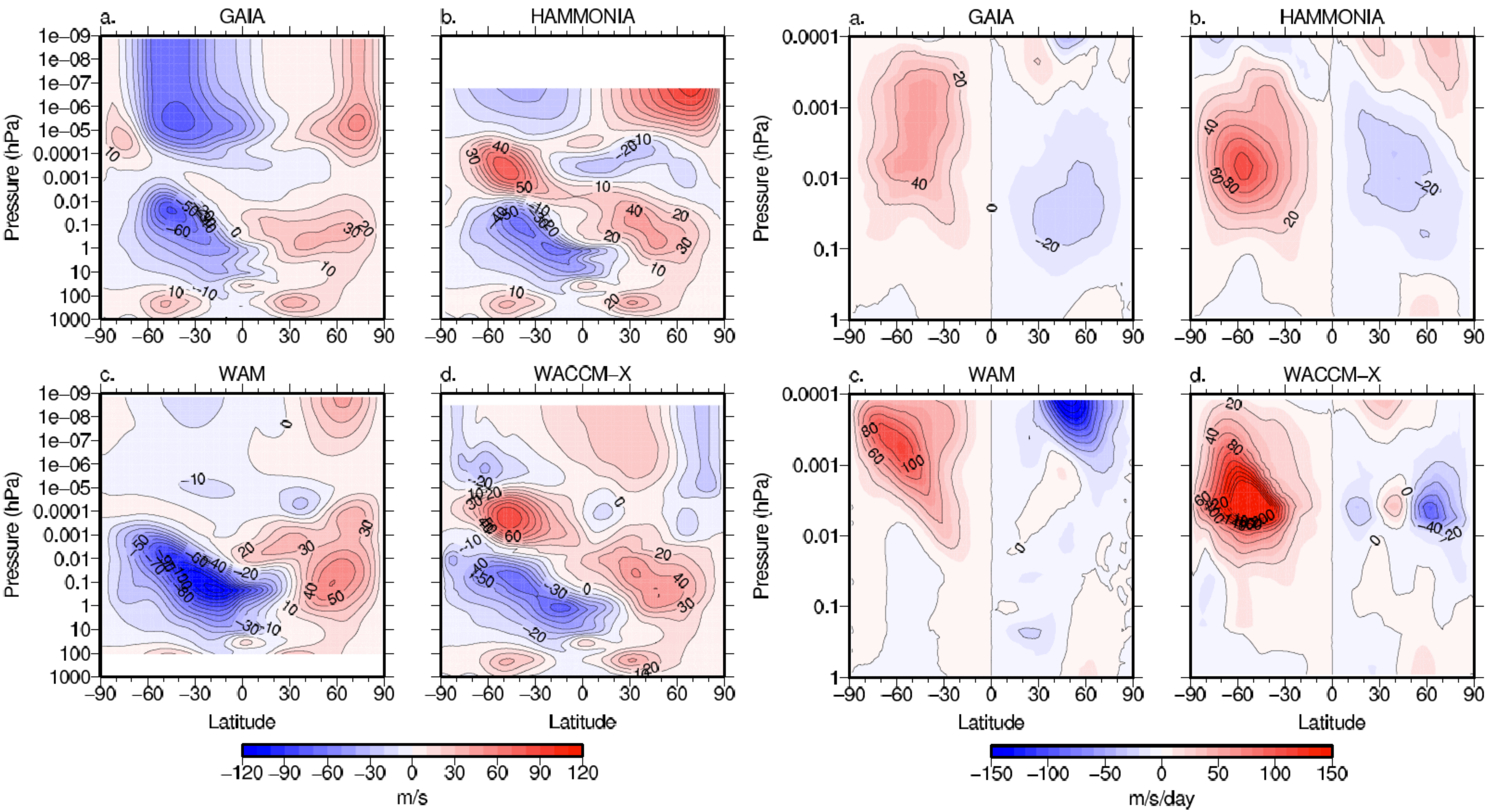
Preliminary Evaluation of Gravity Wave Forcing in WACCM-SE NE120

Han-Li Liu[1], Joe McInerney[1], Sean Santos[2]
Peter Lauritzen[2], Mark Taylor[3], Nick Pedatella[4]
1. NCAR/HAO, 2. NCAR/CGD, 3. DOE/SNL, 4. UCAR/COSMIC

Motivation

- Gravity wave forcing plays a dominant role in driving MLT circulation, as well as stratosphere QBO.
  - Represented currently by GW parameterization.
  - Source of uncertainties/biases.
- Gravity wave perturbations may directly impact ionospheric variability, including ionospheric irregularities.

GWF: (1) A major driver of MLT dynamics; (2) A major source of uncertainty in MLT.



Pedatella et al. (2014)

WACCM-SE Model Setup

- WACCM-SE with specified chemistry.
- NE120 (~0.25deg) horizontal resolution.
- 0.1 scale height 40-5.9×10^{-6}hPa, 0.06-0.016 scale height below: 209 Levels.
- Sponge layer (top 3 scale heights):
  - Horizontal diffusion (second order): effective for smaller scale waves.
  - Rayleigh friction: effective for larger scale waves.
- Transition from RRTMG to WACCM RT set to 0.04hPa (default at 0.0001hPa, though known limit of RRTMG is 0.009hPa)

WACCM-SE Model Simulation

- Aggressive damping needs to be applied for spin-up to keep model stable (e.g.: divergence damping, sponge layer thickness).
- Scale back damping once "wave surge" passes out of computing domain.
- With 900s model time step, remapping subcycling (se_nsplit) set to 60 or larger.
  - Larger than recommended value for WACCM (20).
  - Probably because large vertical motion and/or large vertical phase speed of GWs, and high vertical resolution.

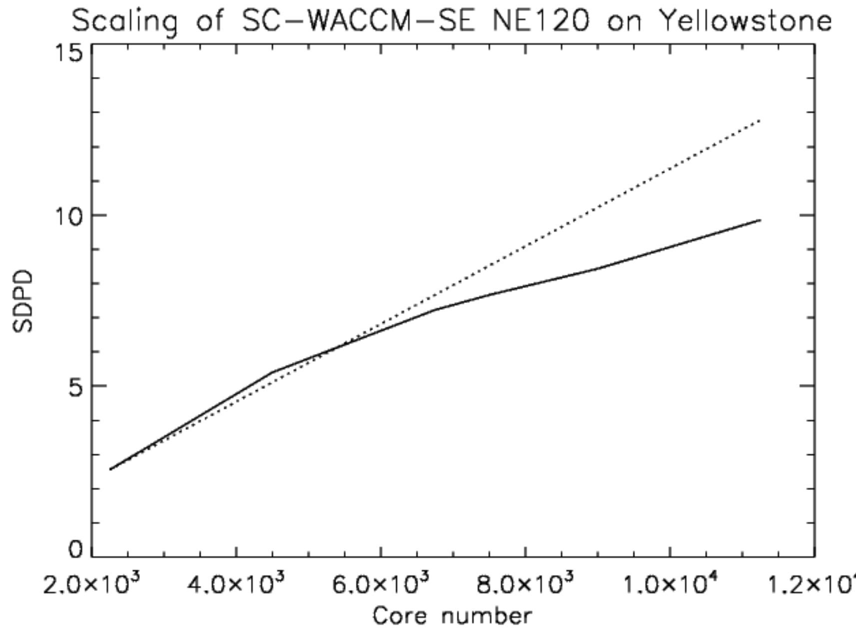
Table 2: Recommended namelist settings for the floating Lagrangian vertical coordinate version of CAM-SE based on *tstep_type* = 5 (RK5), *qsplit* = 1, *hypervis_subcycle* = 4 (maybe 3 is stable at ne30 - 8% change in computational cost; it is not stable for ne120) (*hypervis_subcycle* = 1), and *ftype* = 0 for CAM (red) and WACCM (blue).

resolution	dtime	se_nsplit	rsplit	*hypervis_subcycle*	Δt_{remap}[s]	Δt_{tracer}[s] $= \Delta t_{dyn}$[s]	$\Delta t_{hypervis}$[s]	ν [m^4/s]
ne11np4[a]	1800 (1800)	1 (5)	2 (2)	3 (1)	1800 (360)	900 (180)	300 (180)	2.0×10^{16} (2.0×10^{16})
ne16np4[b]	1800 (1800)	1 (5)	3 (3)	3 (1)	1800 (360)	600 (120)	200 (120)	7.0×10^{15} (7.0×10^{15})
ne30np4	1800 (1800)	2 (10)	3 (3)	3 (1)	900 (180)	300 (60)	100 (60)	1.0×10^{15} (1.0×10^{15})
ne60np4	1800 (1800)	4 (20)	3 (3)	4 (1)	450 (90)	150 (30)	37.5 (30)	1.0×10^{14} (1.0×10^{14})
ne120np4[c]	900 (900)	4 (20)	3 (3)	4 (1)	225 (45)	75 (15)	18.75 (15)	1.0×10^{13} (1.0×10^{13})
ne240np4	600[d] (600)	5 (25)	3 (3)	4 (1)	120 (24)	40 (8)	10 (8)	1.1×10^{12} (1.1×10^{12})

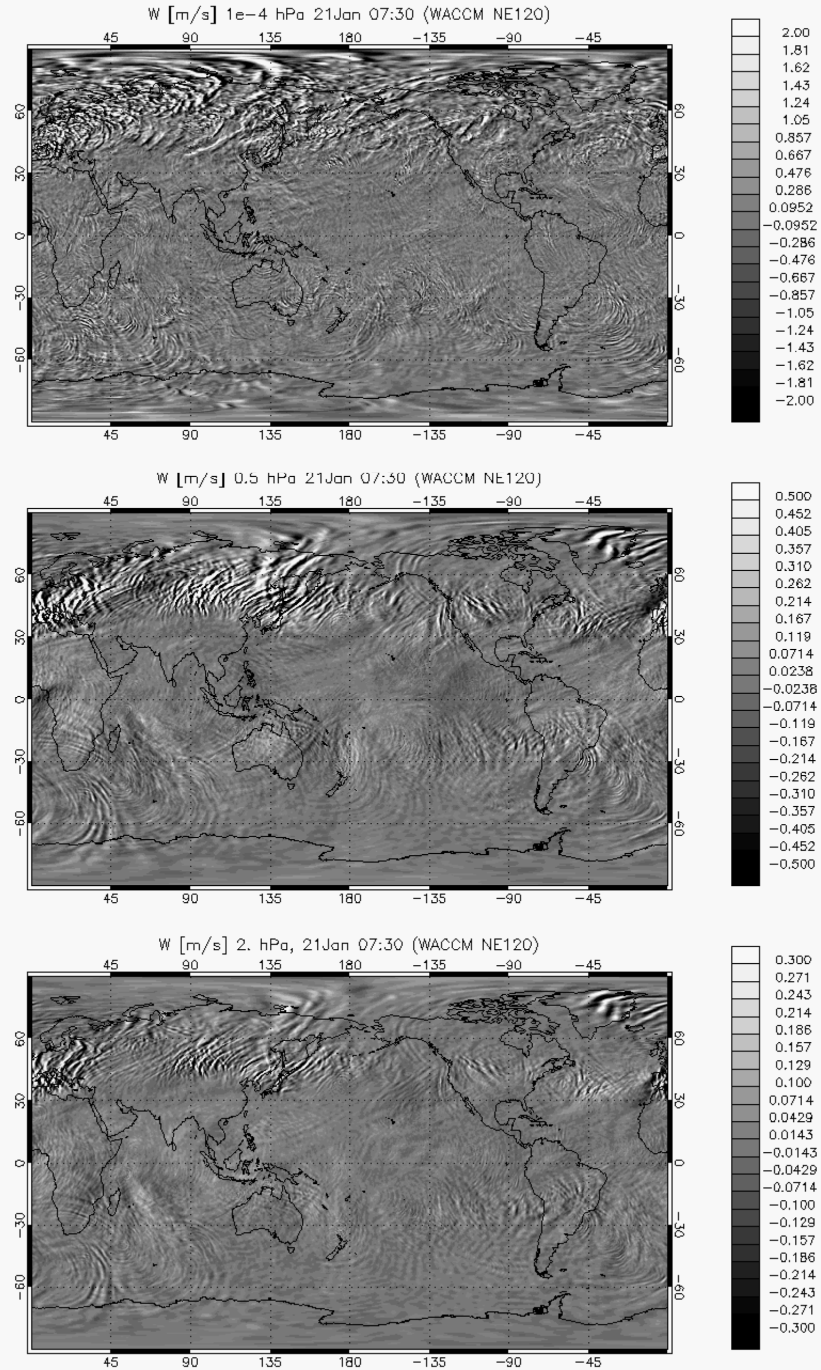
[a] untested
[b] untested
[c] if winds are maximum 600 m/s; for CAM it is 120 m/s
[d] 900 works, however, gravity wave noise!

Model Performance

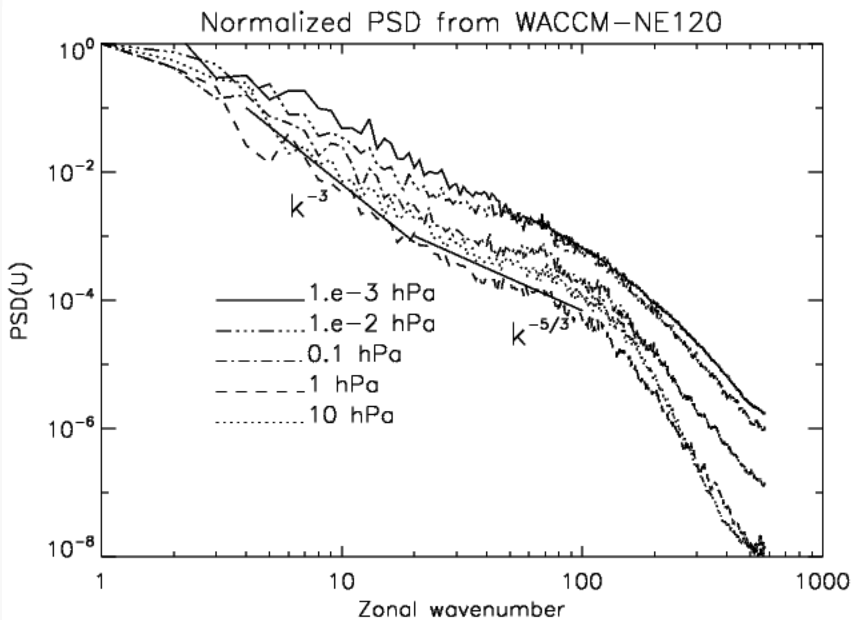
- Scaling with number of processors on Yellowstone:



- 20k Core hours for each model day, or 7.3M core hours for each model year (at 4500 cores).
- Were able to run a total of 1.5 month (including spin-up) with our allocation.

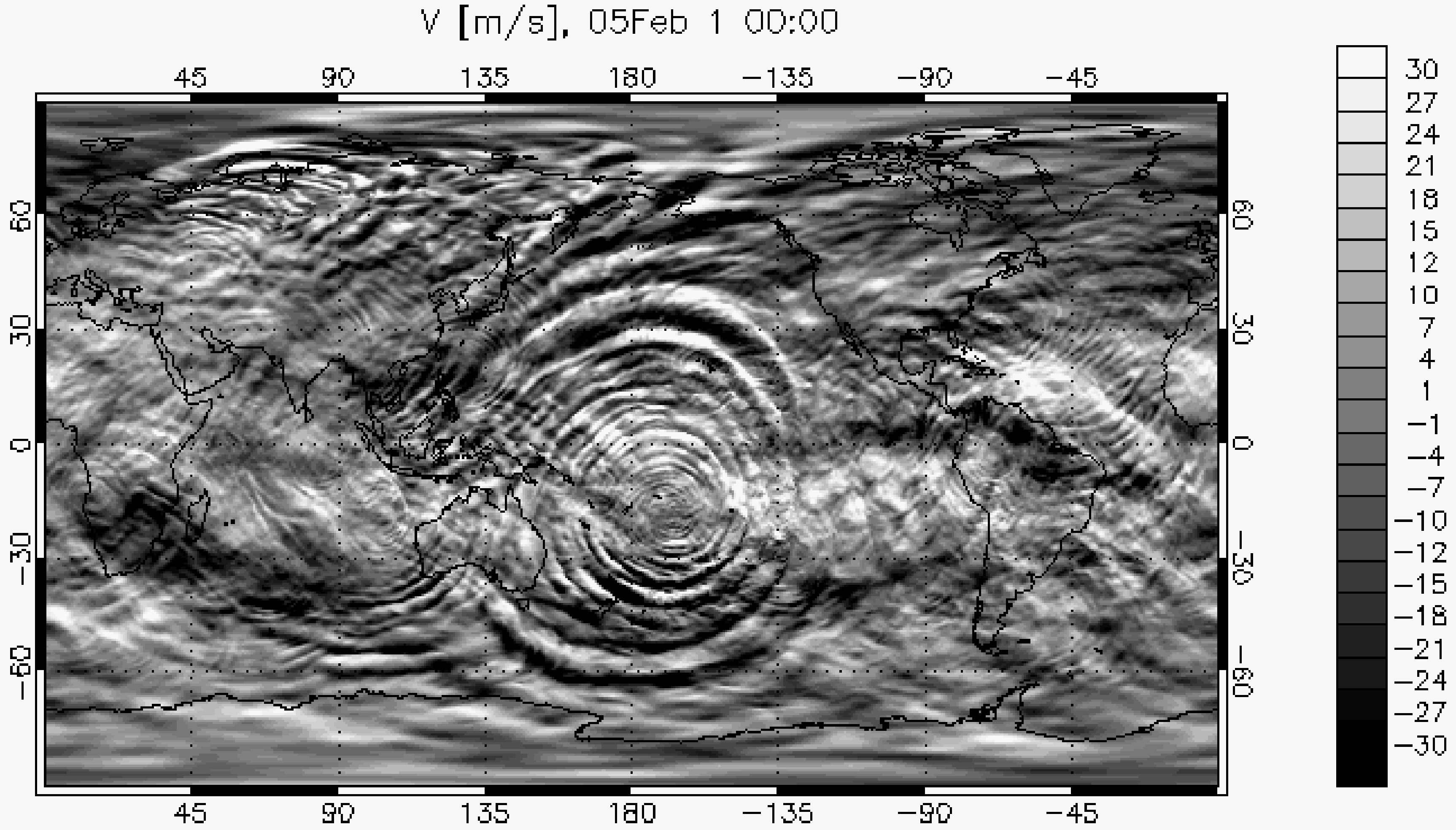


W [m/s] 1e-4 hPa 21Jan 07:30 (WACCM NE120)
W [m/s] 0.5 hPa 21Jan 07:30 (WACCM NE120)
W [m/s] 2. hPa, 21Jan 07:30 (WACCM NE120)

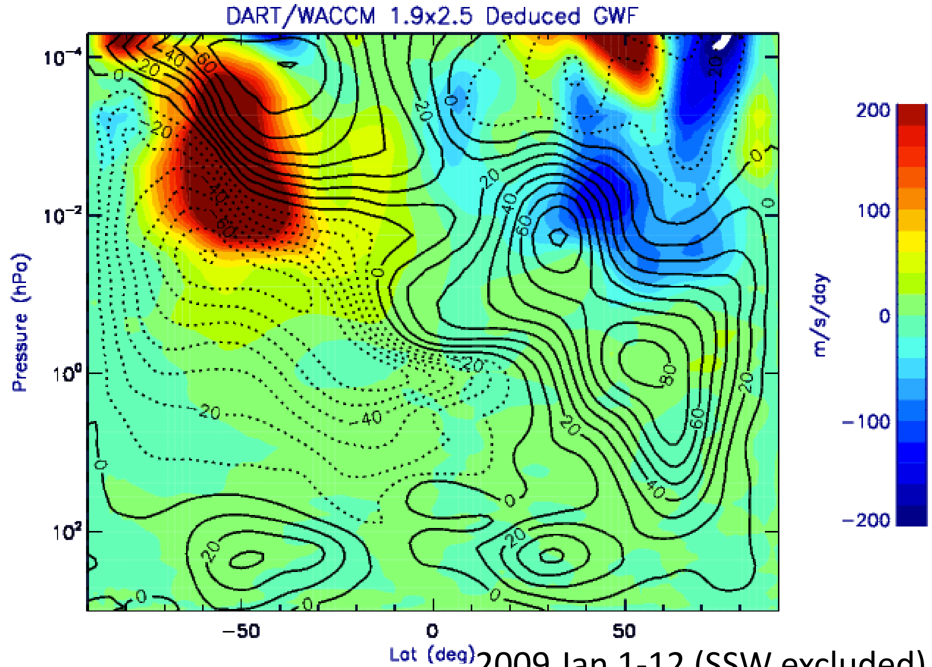


Normalized PSD from WACCM−NE120
PSD(U)
Zonal wavenumber
k−3
k−5/3
1.e−3 hPa
1.e−2 hPa
0.1 hPa
1 hPa
10 hPa

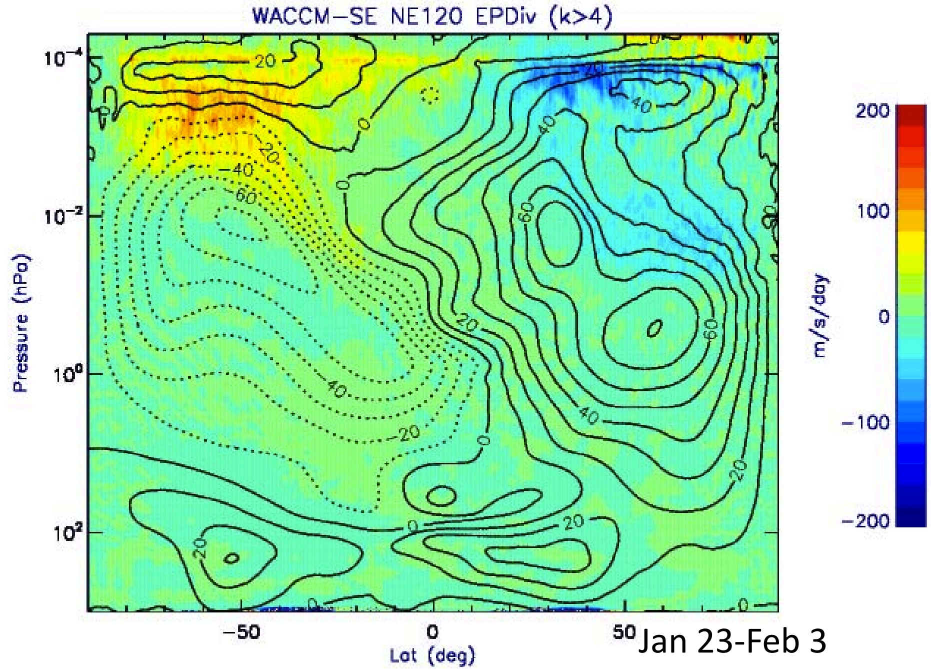
Dynamically Active MLT



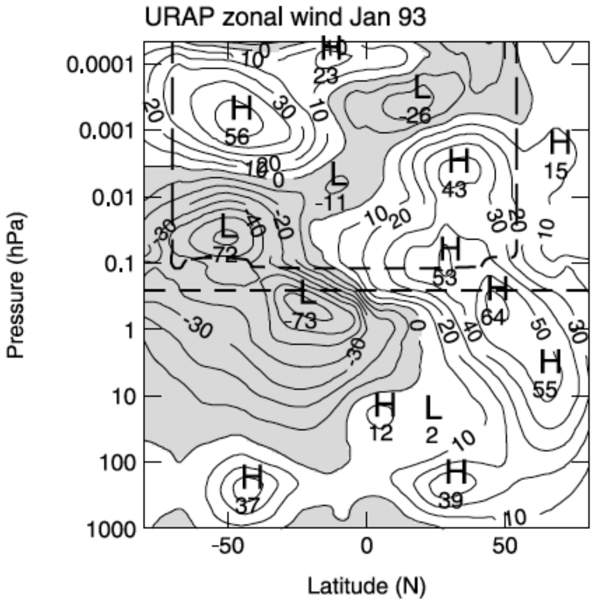
Zonal Wind and GW Forcing



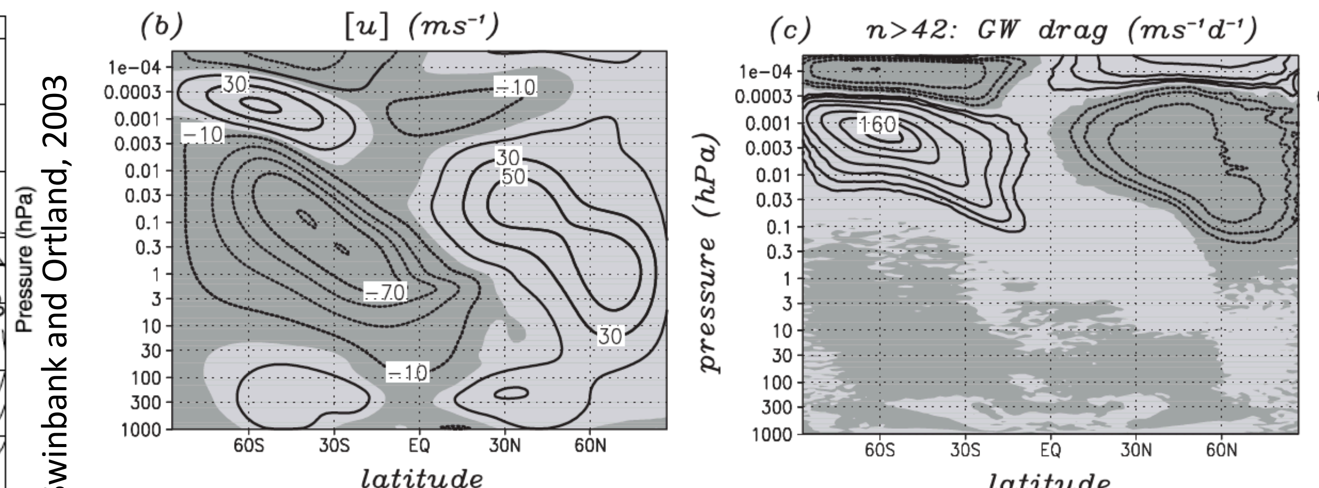
2009 Jan 1-12 (SSW excluded)



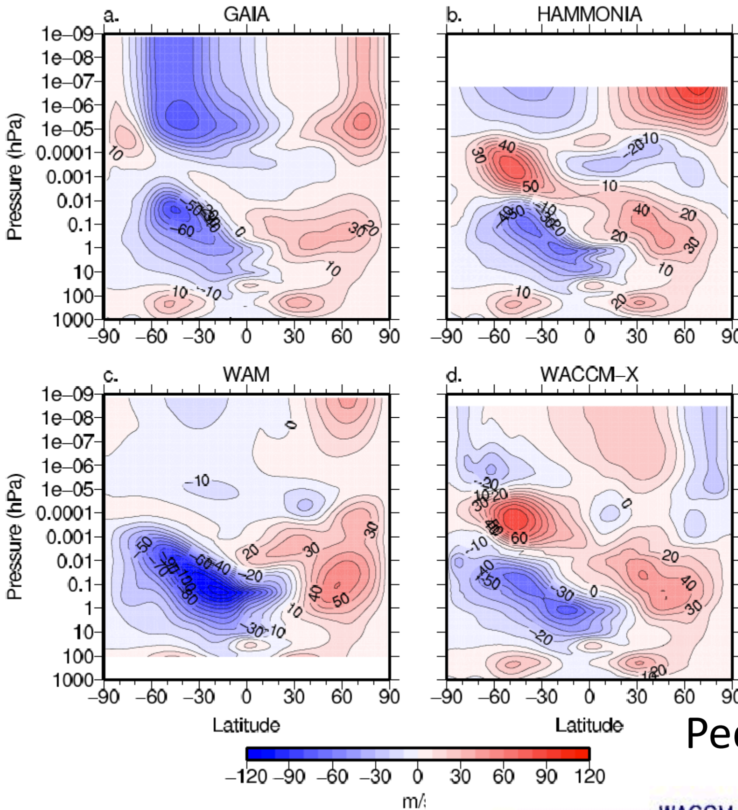
Jan 23-Feb 3

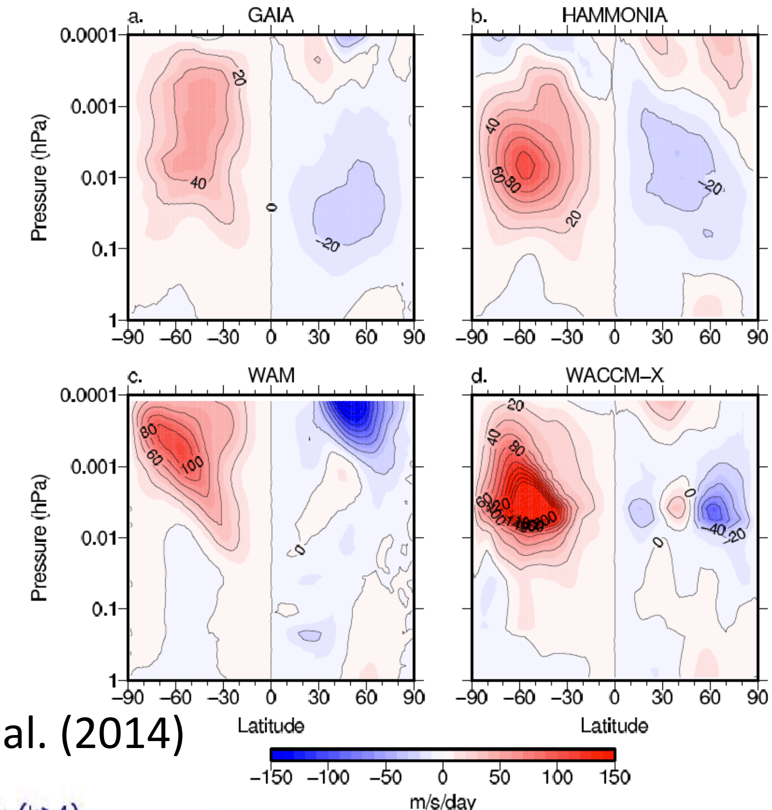


Swinbank and Ortland, 2003

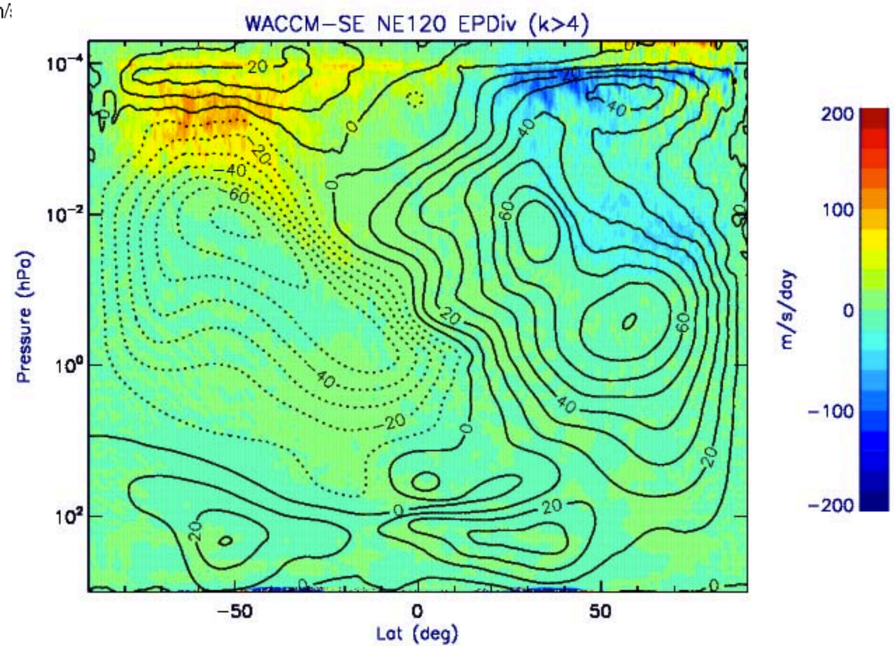


Becker, 2009

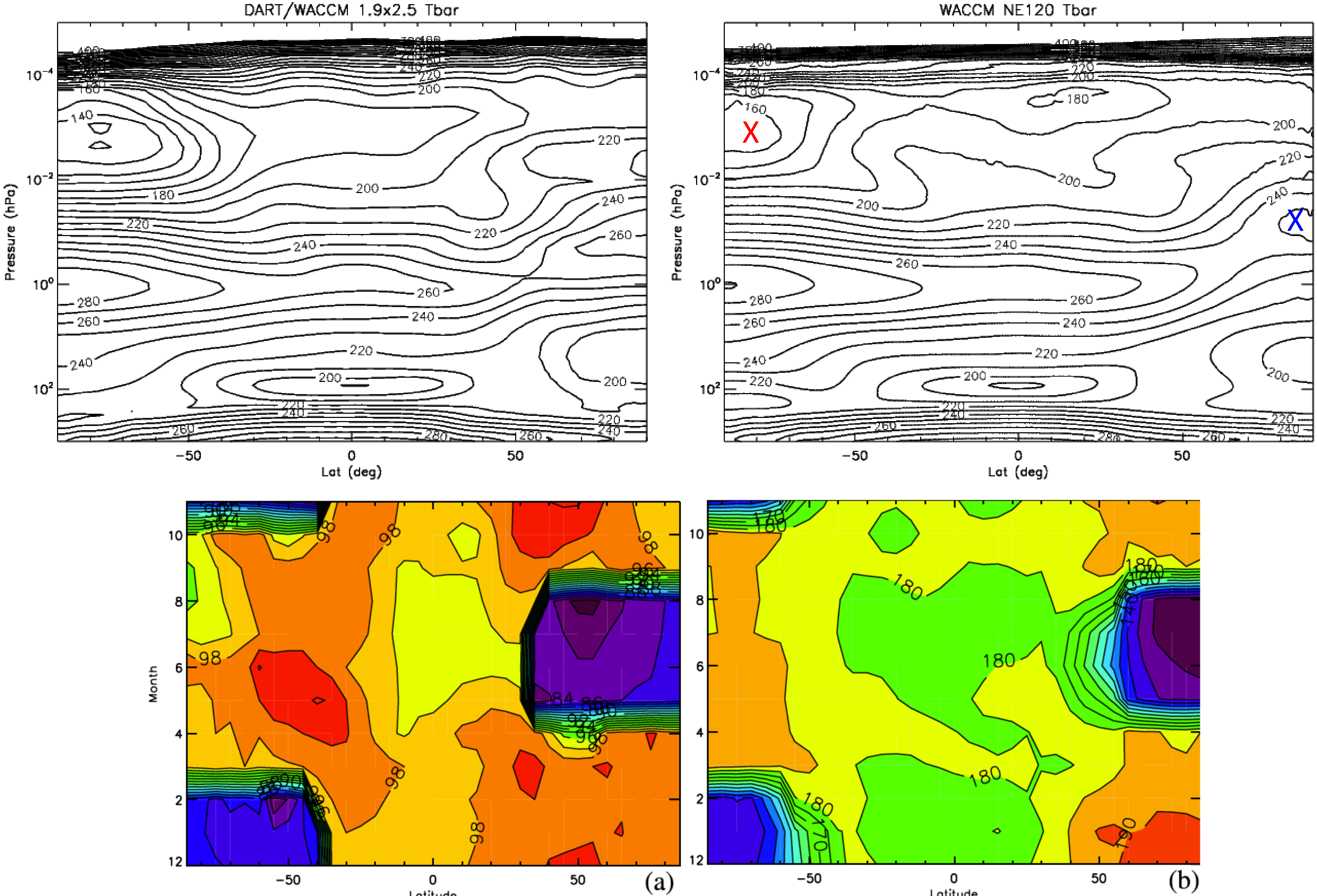




Pedatella et al. (2014)

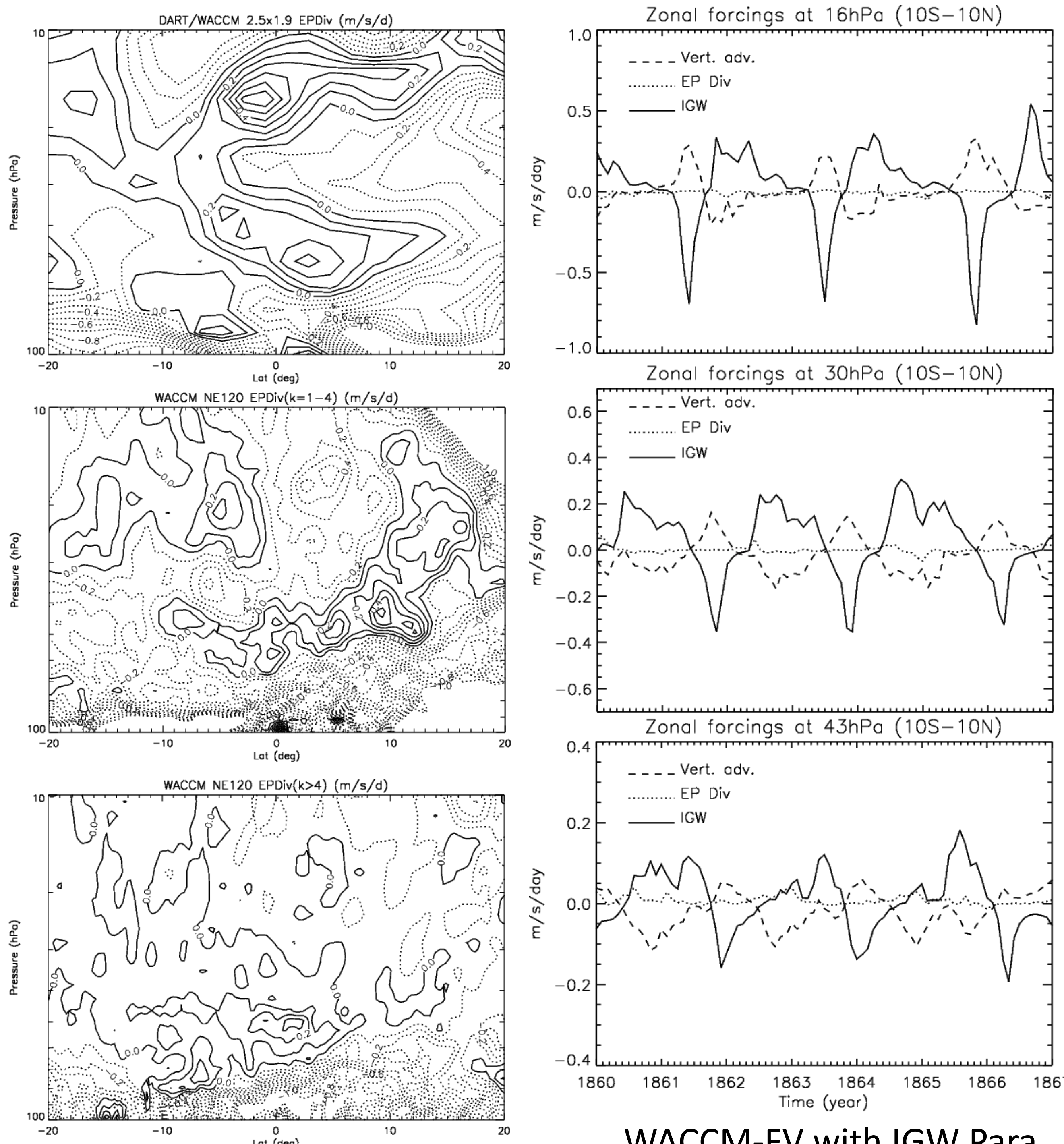


Mean Temperature



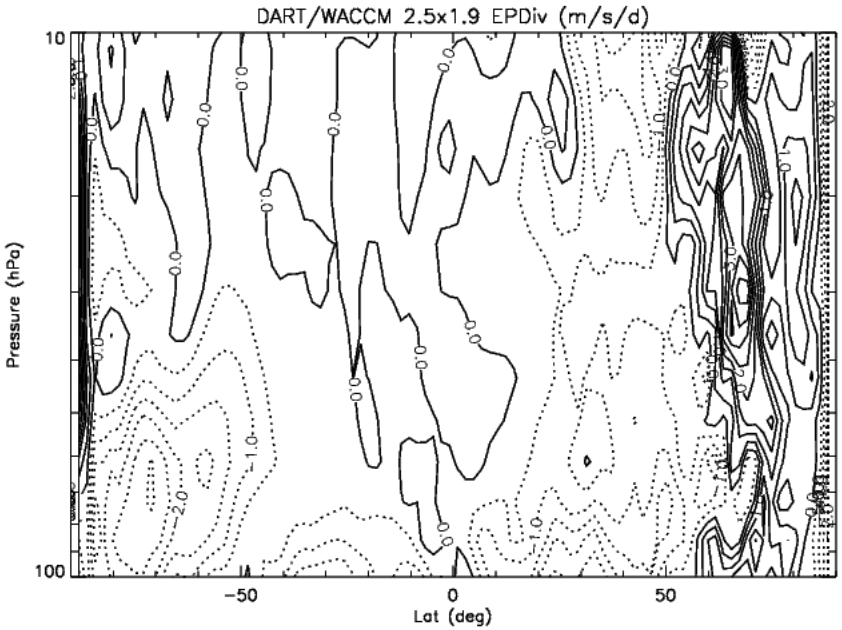
Xu et al., 2007

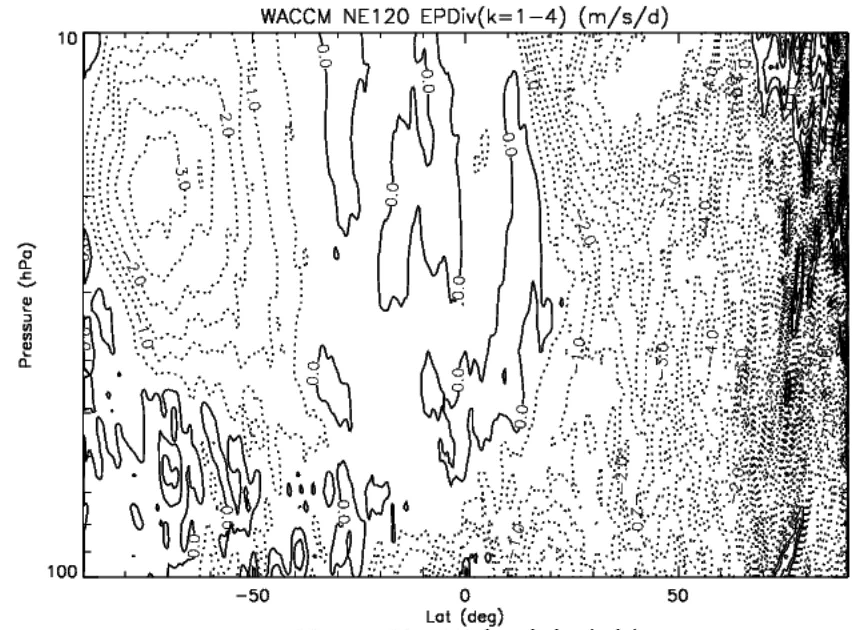
Wave Forcing in Equatorial Stratosphere

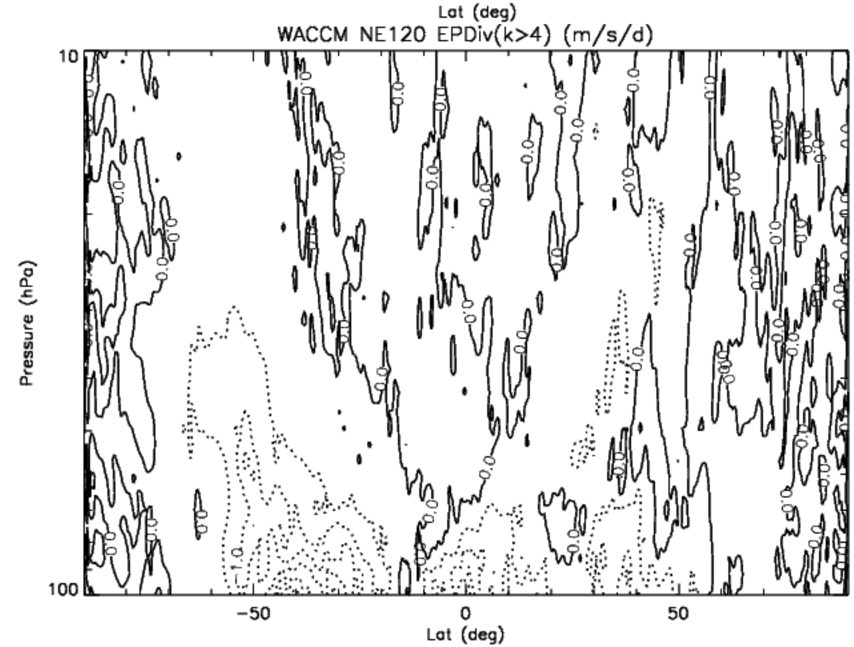


WACCM-FV with IGW Para.

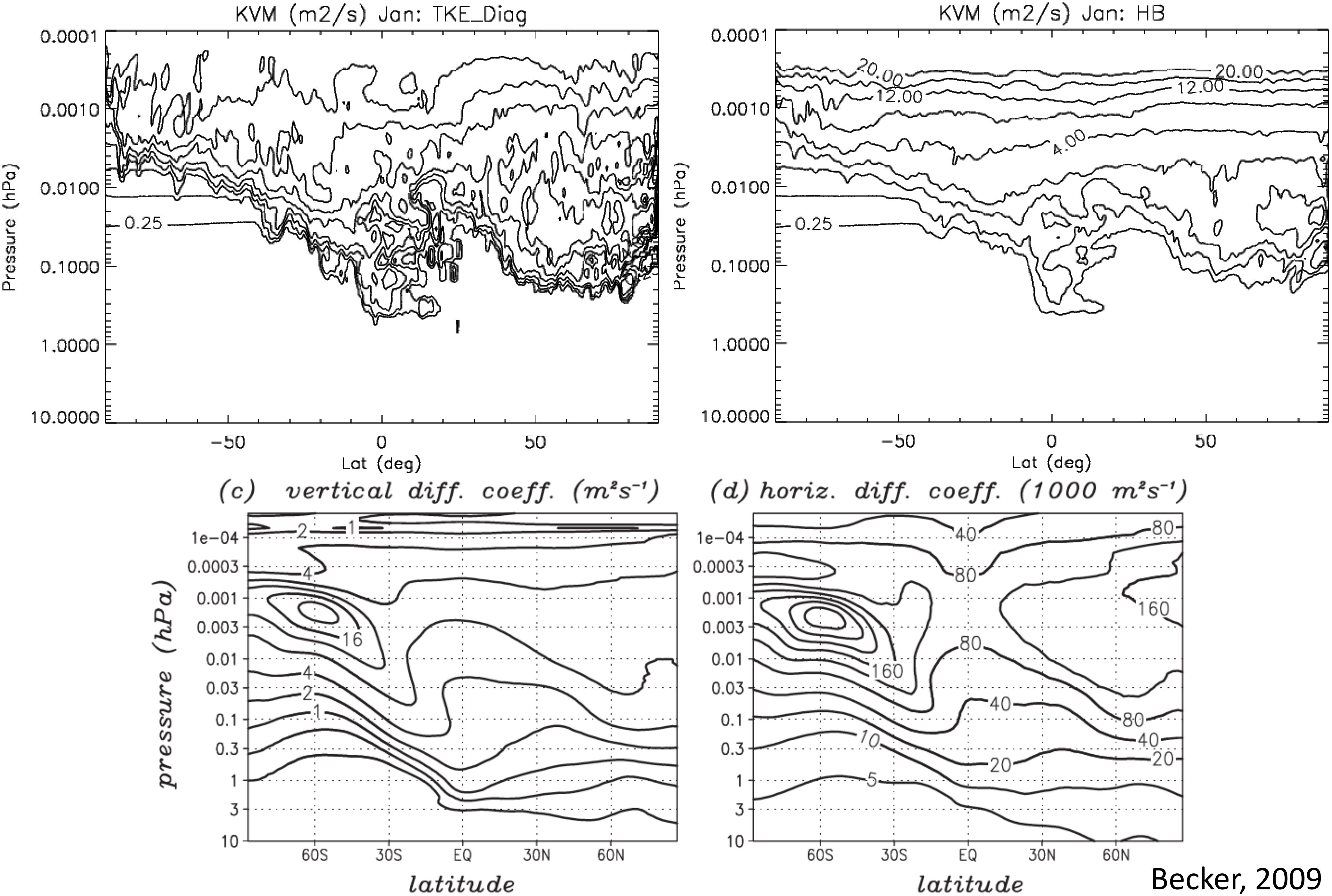
Wave forcing in Stratosphere: Mid to High Latitude





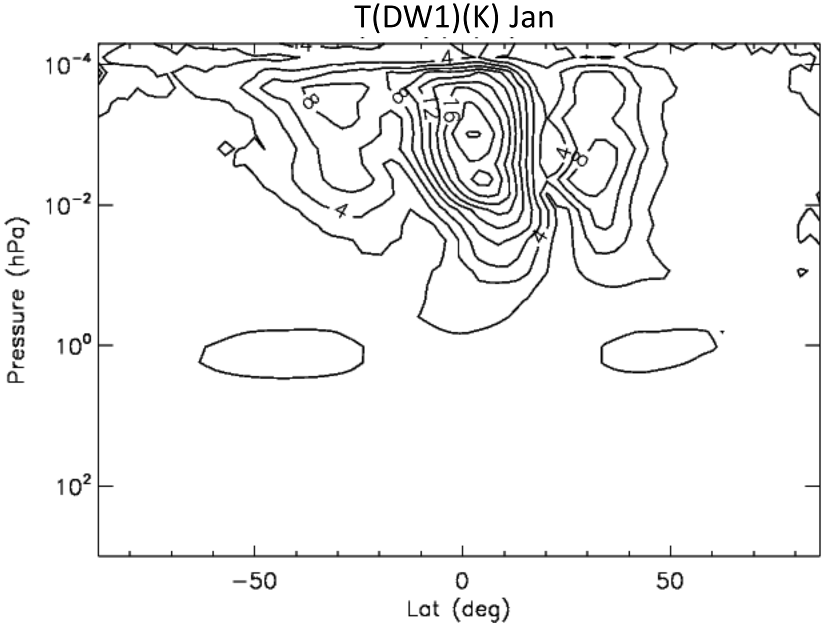


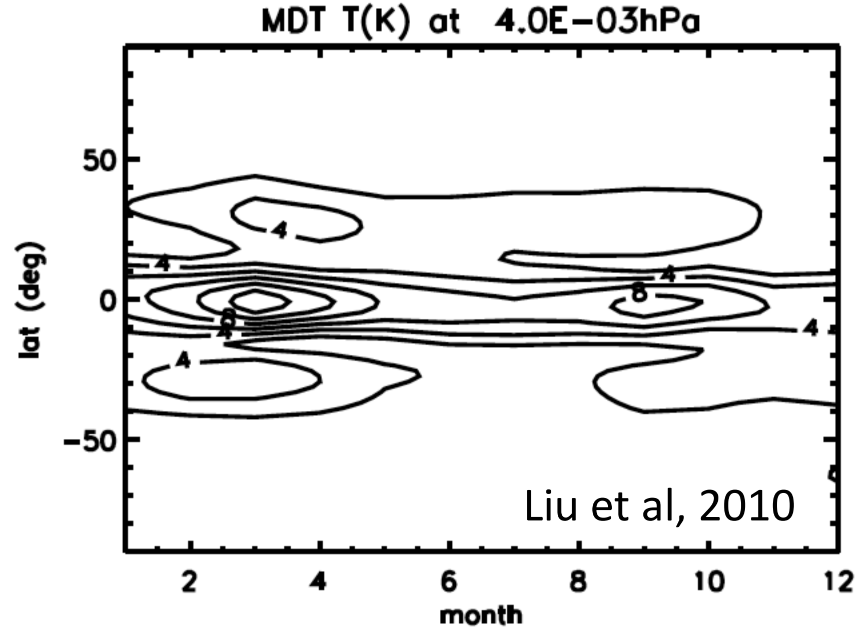
Eddy Viscosity

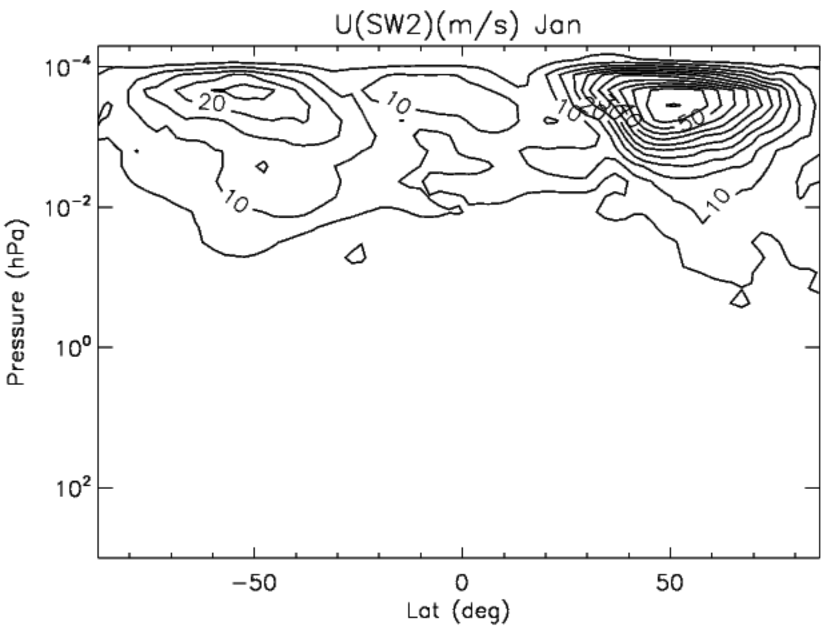


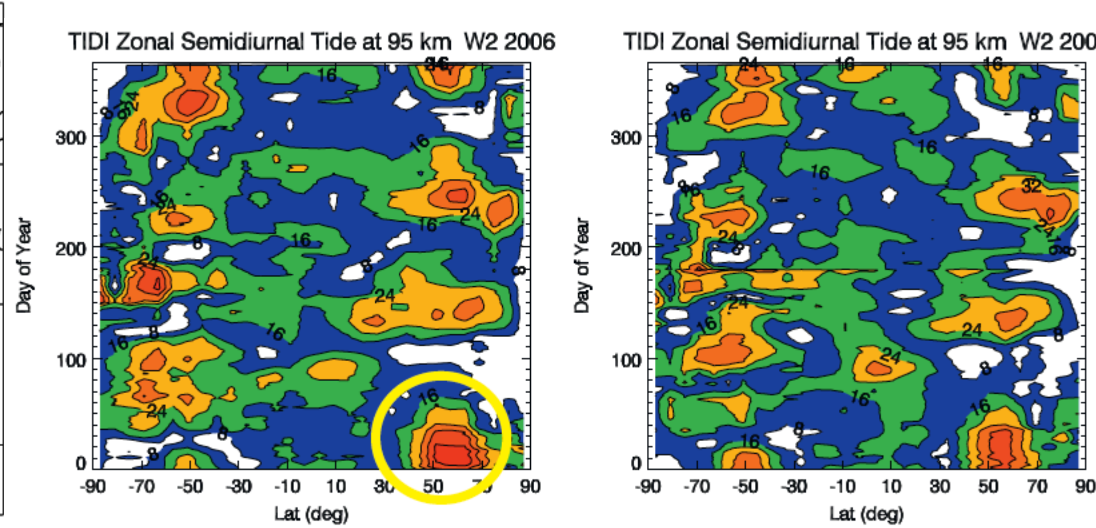
Becker, 2009

Migrating Tides









Wu et al., 2011

Summary and Future Works

- WACCM-SE NE120 feasible.
- Resolved GW forcing is not large enough to reverse the winter stratospheric/mesospheric jet.
- Resolved GW forcing can reverse summer stratospheric/mesospheric jet, but still weak. The reversed jet strength and summer mesopause temperature is ~20K too warm.
- Mesopause temperature at mid-latitudes and winter high latitudes agree better with observations.
- Migrating tides stronger and show the correct hemispheric structure in MLT.
- Need to evaluate the “missing waves” and/or “missing forcing” for better parameterization.
- Implementing horizontal eddy/molecular diffusion.
- Make longer runs—NSC proposal to get more time.

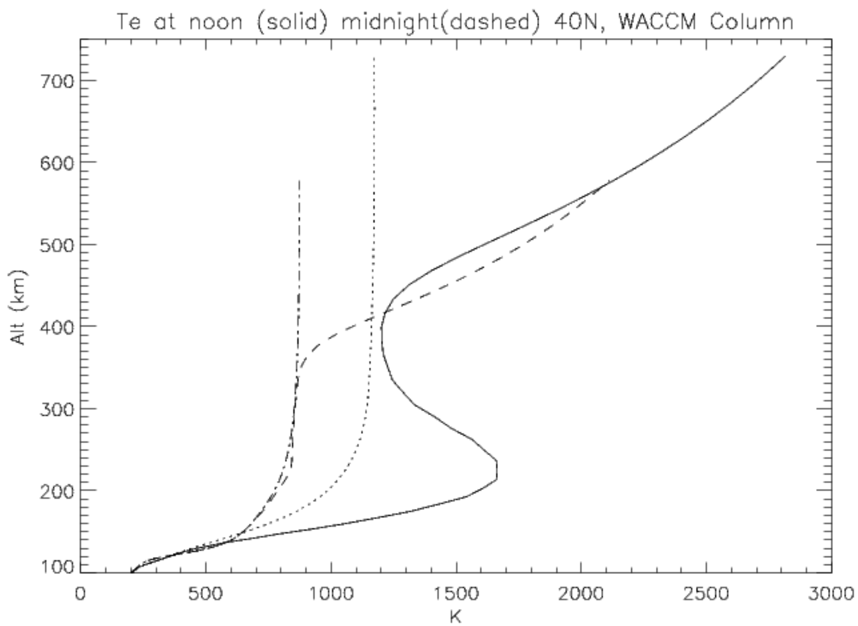
WACCM/WACCM-X Development

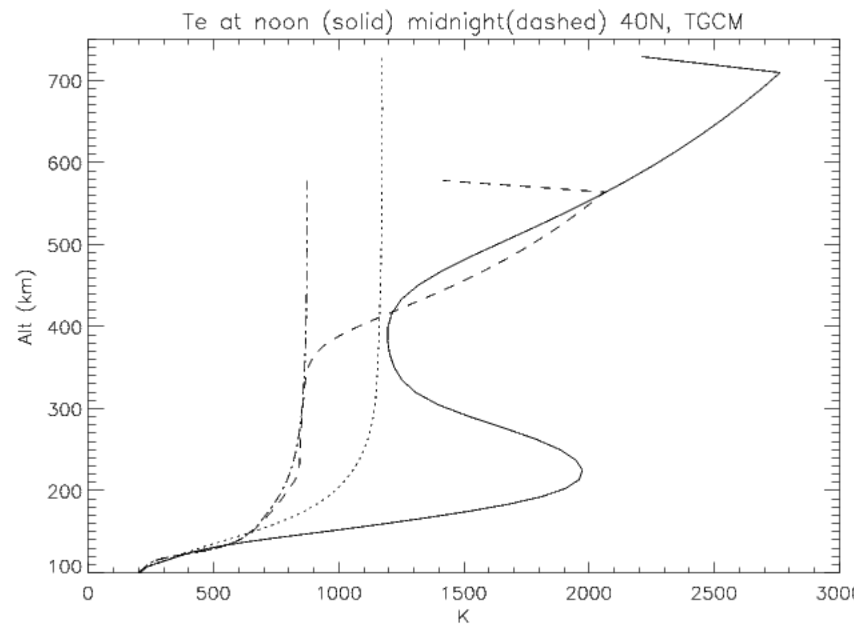
WACCM/WACCM-X Developments

- WACCM-X Ionosphere modules:
  - Vertical plasma transport, including ambipolar diffusion.
  - Time-dependent electron/ion temperatures.
- WACCM-X/Ionosphere-Plasmasphere/Electric Dynamo coupling.
- Data Assimilation using WACCM-DART.

WACCM-X Ionosphere Modules: Column Model Test

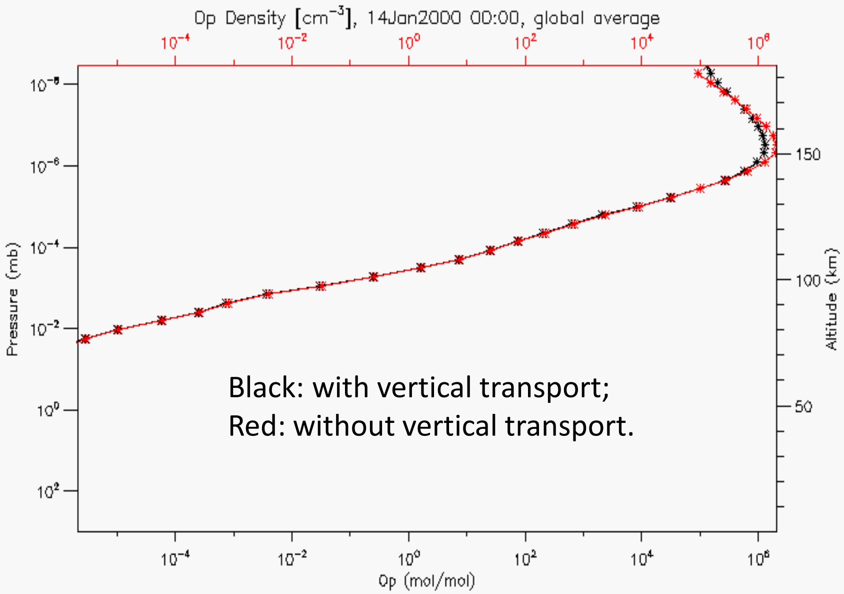
- Ambipolar diffusion: Similar to TIME-GCM, but currently only in vertical direction.
- Time-dependent Te/Ti solver.
- Horizontal components of O+ transport.

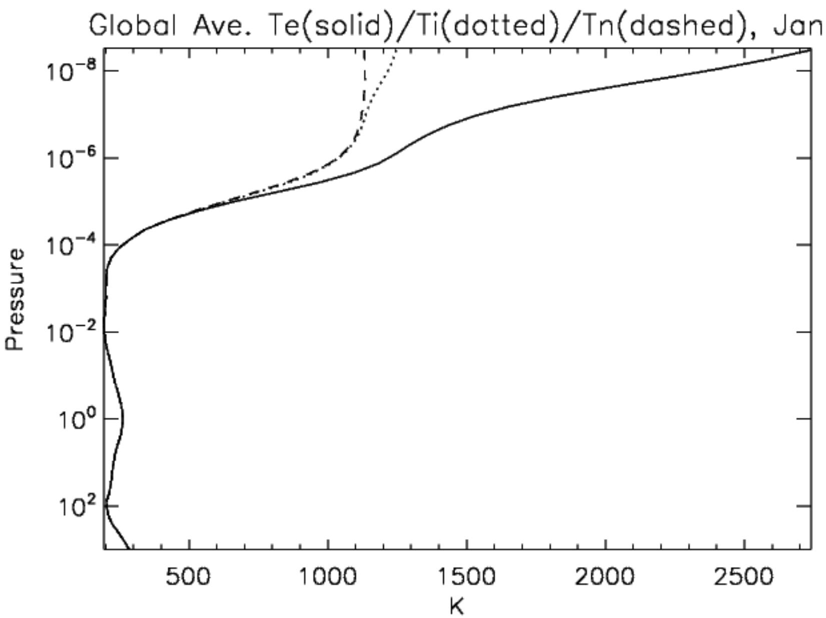


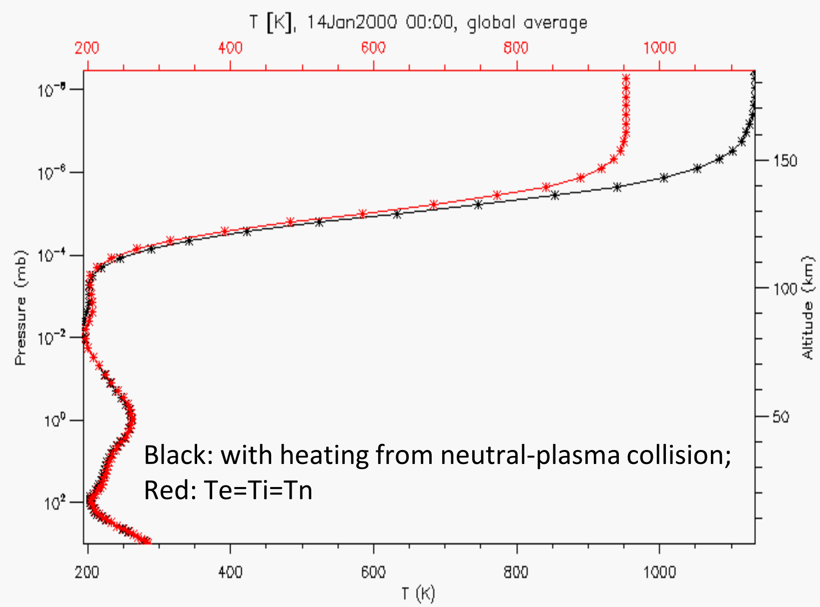


Column Model: Use TGCM Background, including Ne, but WACCM-X ionization rates, and new time-dependent solver for Te.

WACCM-X Ionosphere Modules : Full Model Test





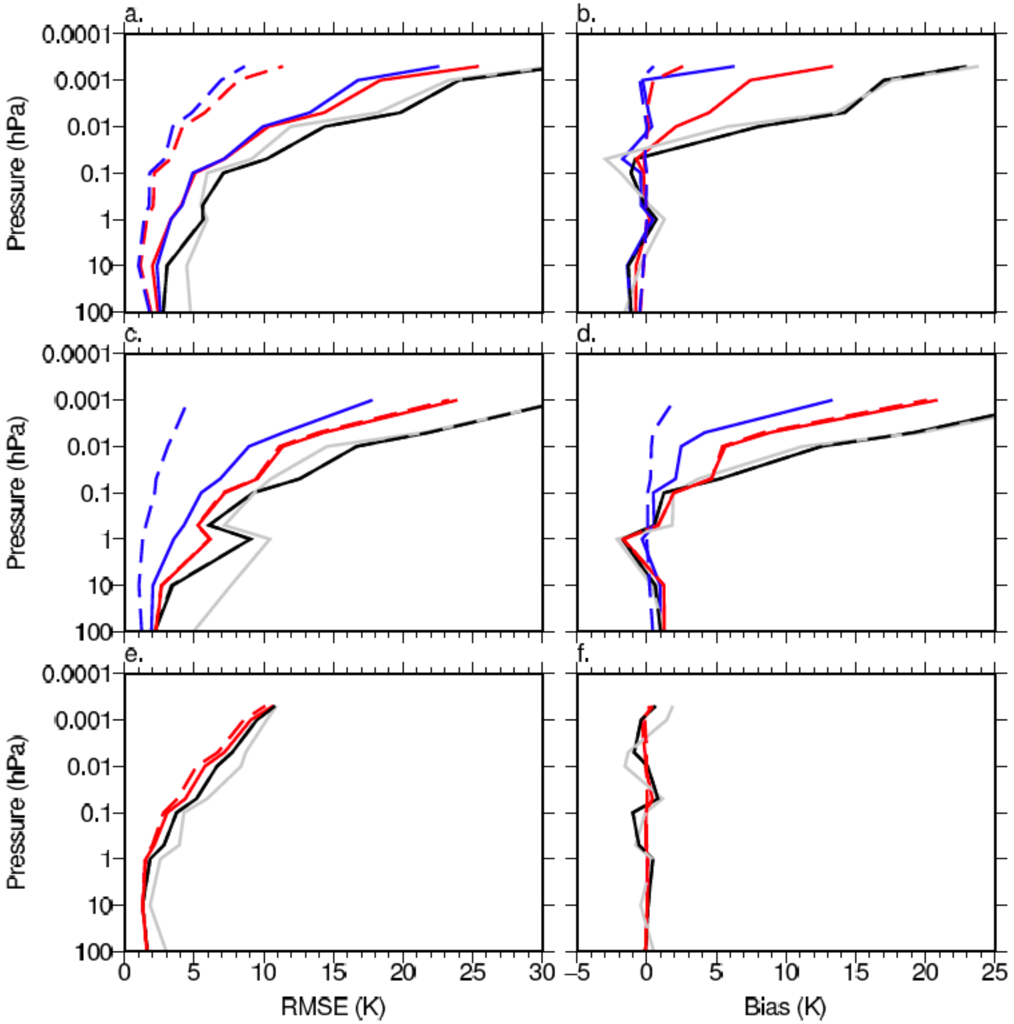


WACCM-X/Ionosphere-Plasmasphere/Electric Dynamo Coupling

- Two-way coupling of an Ionosphere-Plasmasphere model (TIME3D) and Edynamo, with neutral wind read in from WACCM-X output.
- TIME3D/Edynamo recently converted into a module.
- Building WACCM-X interface with this new module.

Data Assimilation using WACCM-DART

- Effort led by Nick Pedatella, in collaboration with Kevin Raeder and Jeff Anderson.
- Assimilates both lower atmosphere data and upper atmosphere observations (SABER and MLS Temperature).



Pedatella et al, submitted