Comparison of Gravity Waves from High Resolution WACCM Simulations with Observations

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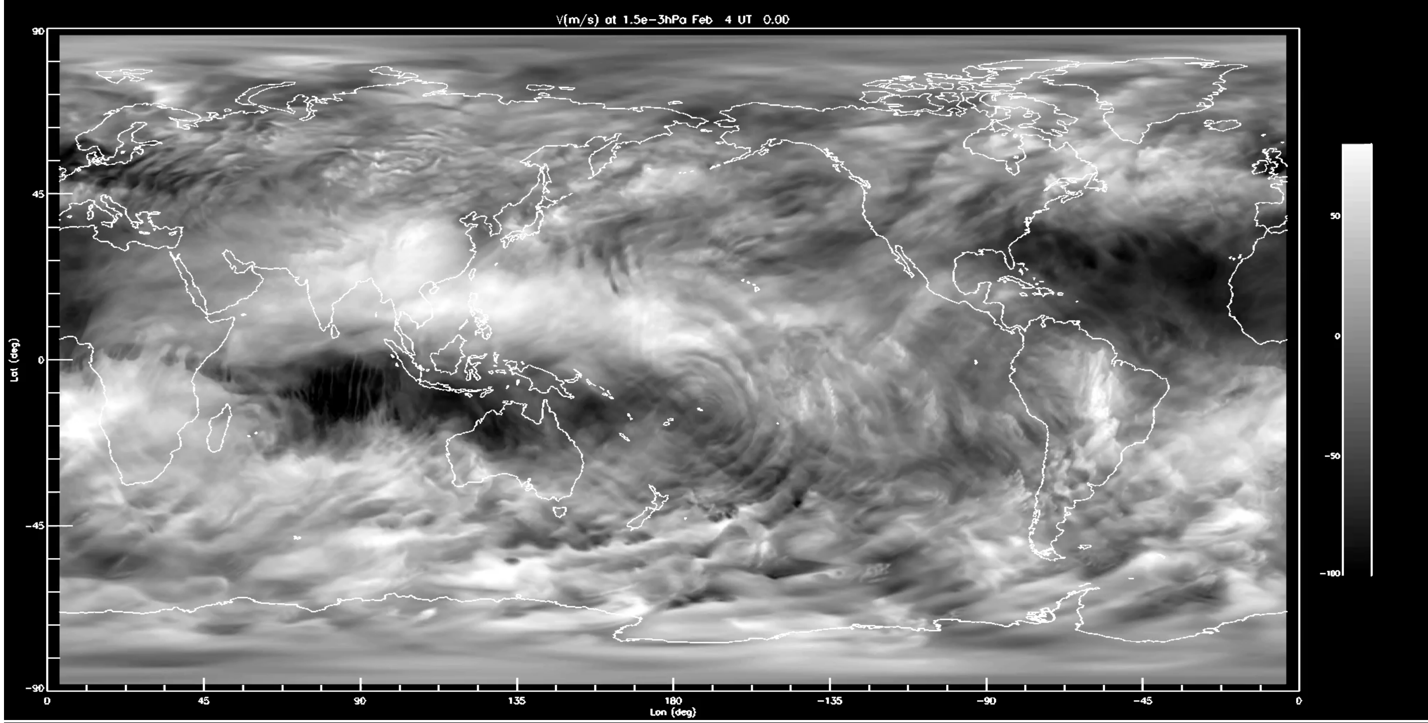
Motivation and Objective

- Gravity waves are important for middle and upper atmosphere circulation and transport.
- Gravity wave perturbations strongly affect ionosphere E and F region electrodynamics.
- Examine gravity wave energy density, **momentum fluxes**, and wave characteristics as resolved by WACCM-SE NE120-NP4/L209 and compare with observations:
  - Seasonal variation
  - Altitude, latitude, and longitude dependence
  - Spectral dependence
  - Intermittency

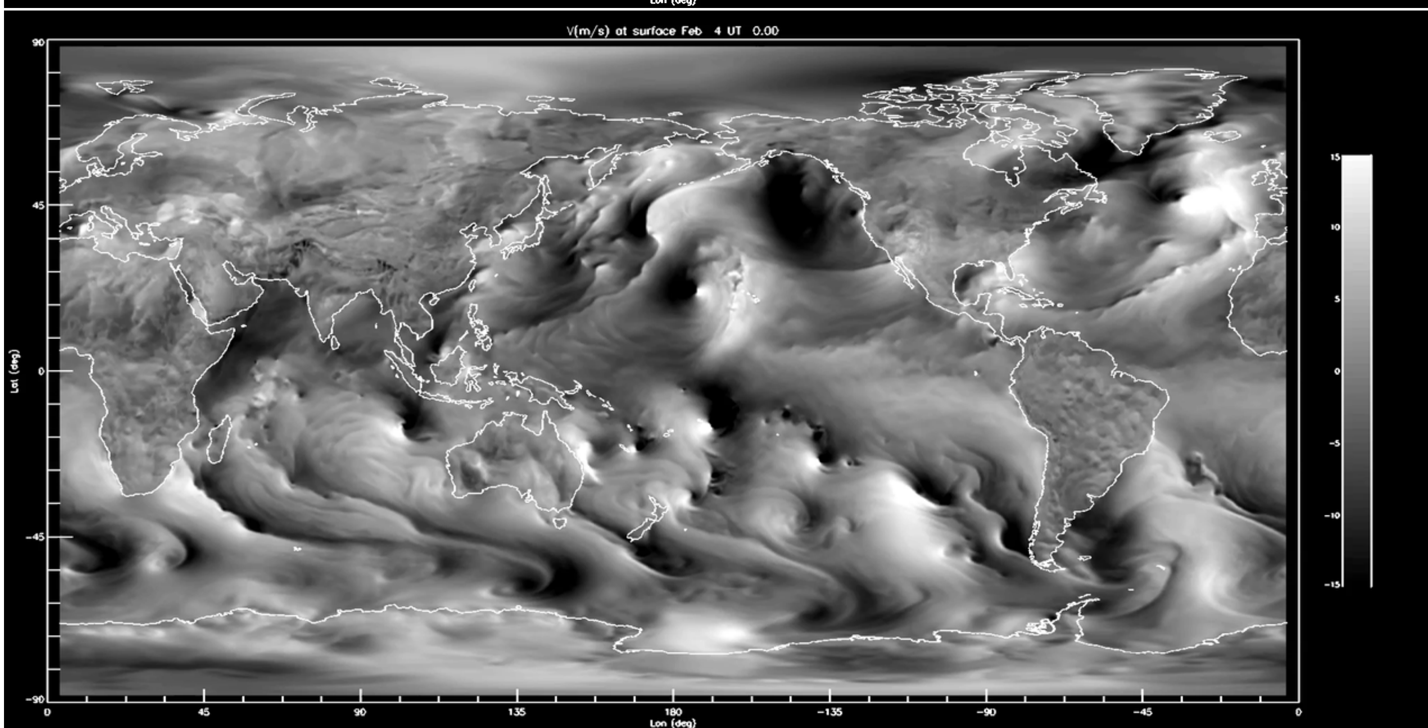
WACCM With Spectral Element Core

- NCAR Whole Atmosphere Community Climate Model (WACCM, 0-145km) with continuous Galerkin spectral finite element dynamical core (solved on cubed-sphere—so no polar singularity).
- Resolution: quasi-uniform grid ~25km horizontal; 0.1 scale height (500-700m) vertical.
- Scalable up to 10000+ cores on NSF NWSC/ Yellowstone.
- GW parameterization turned off.

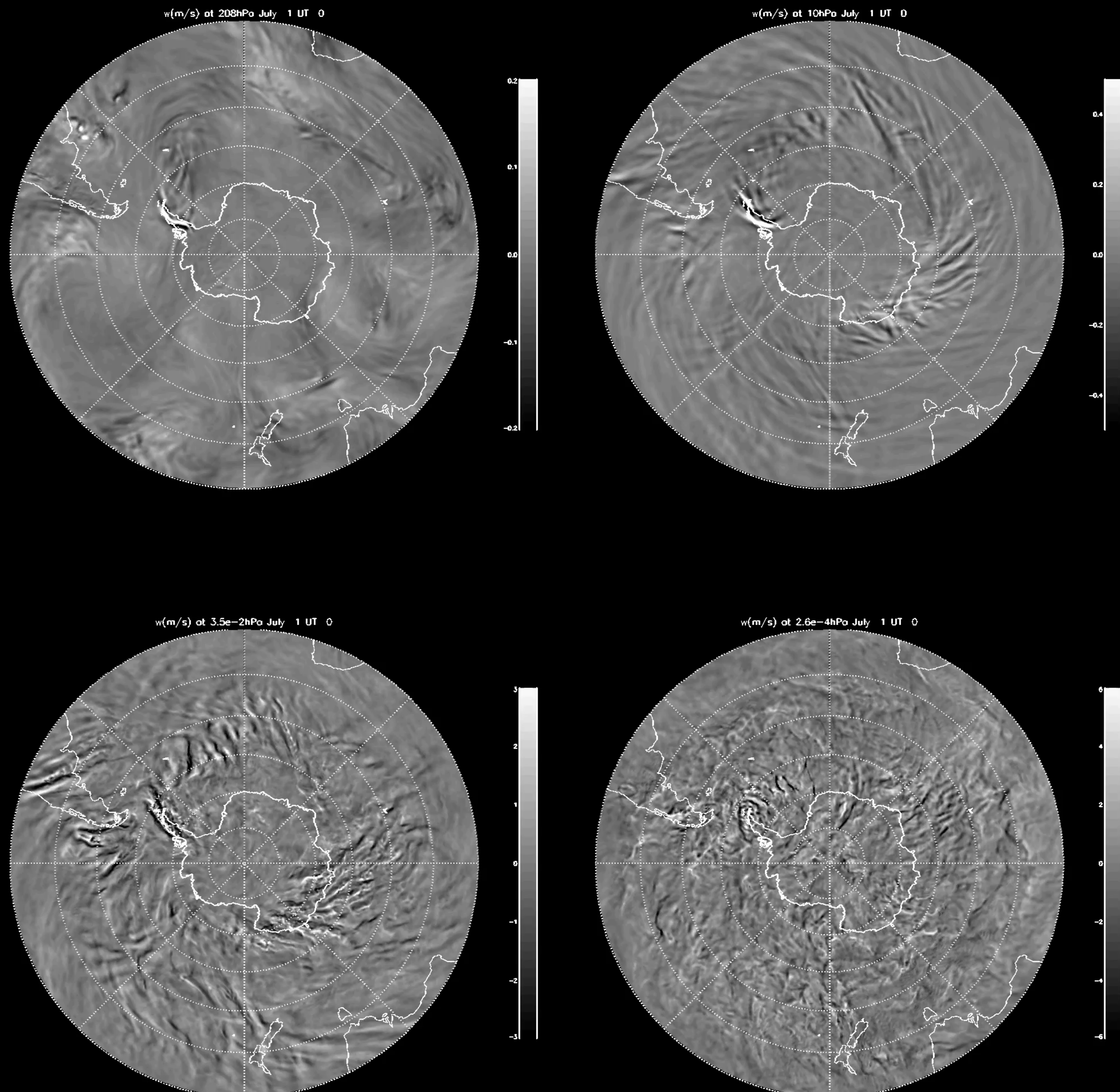
Lower Thermosphere



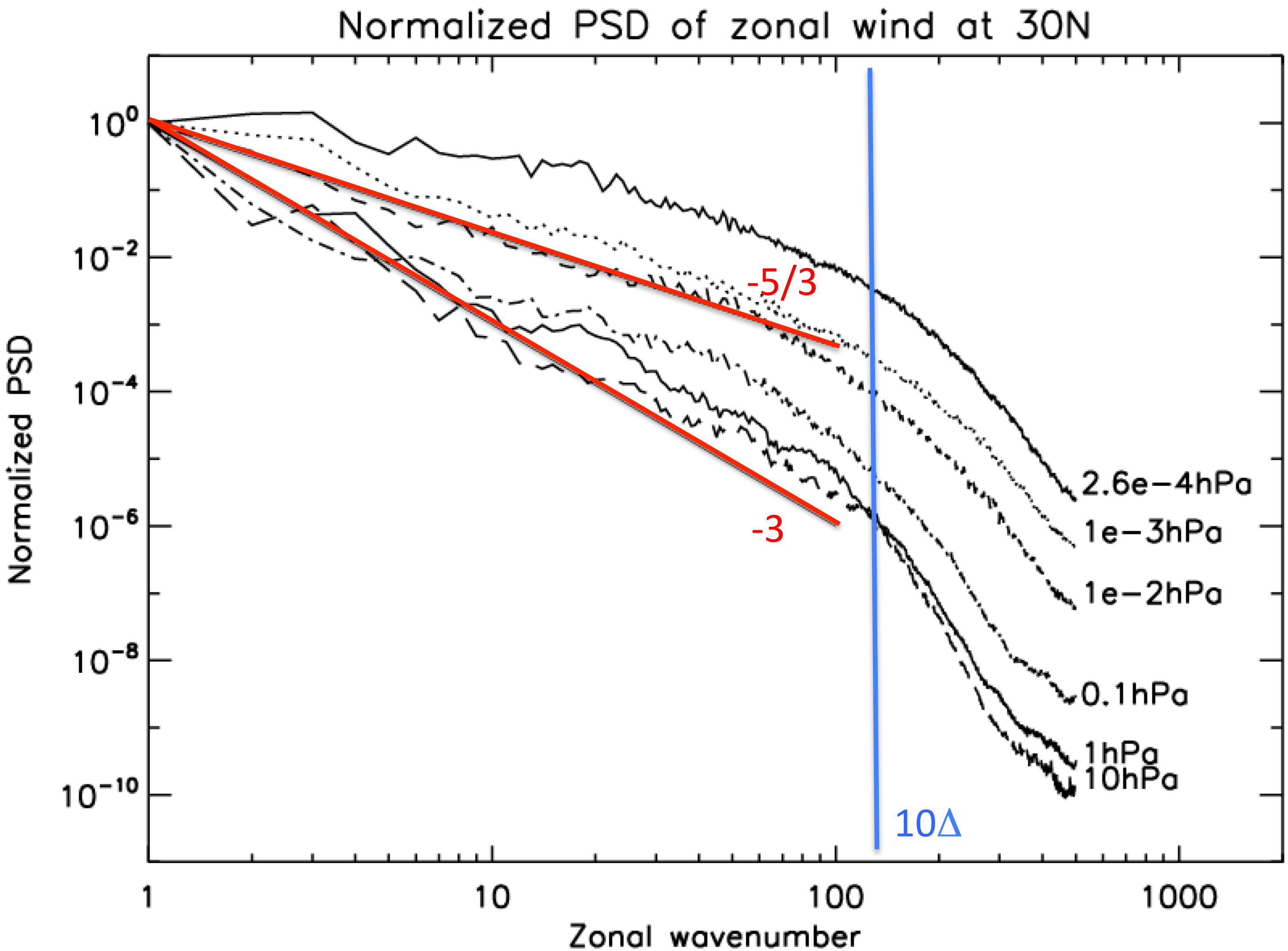
Surface

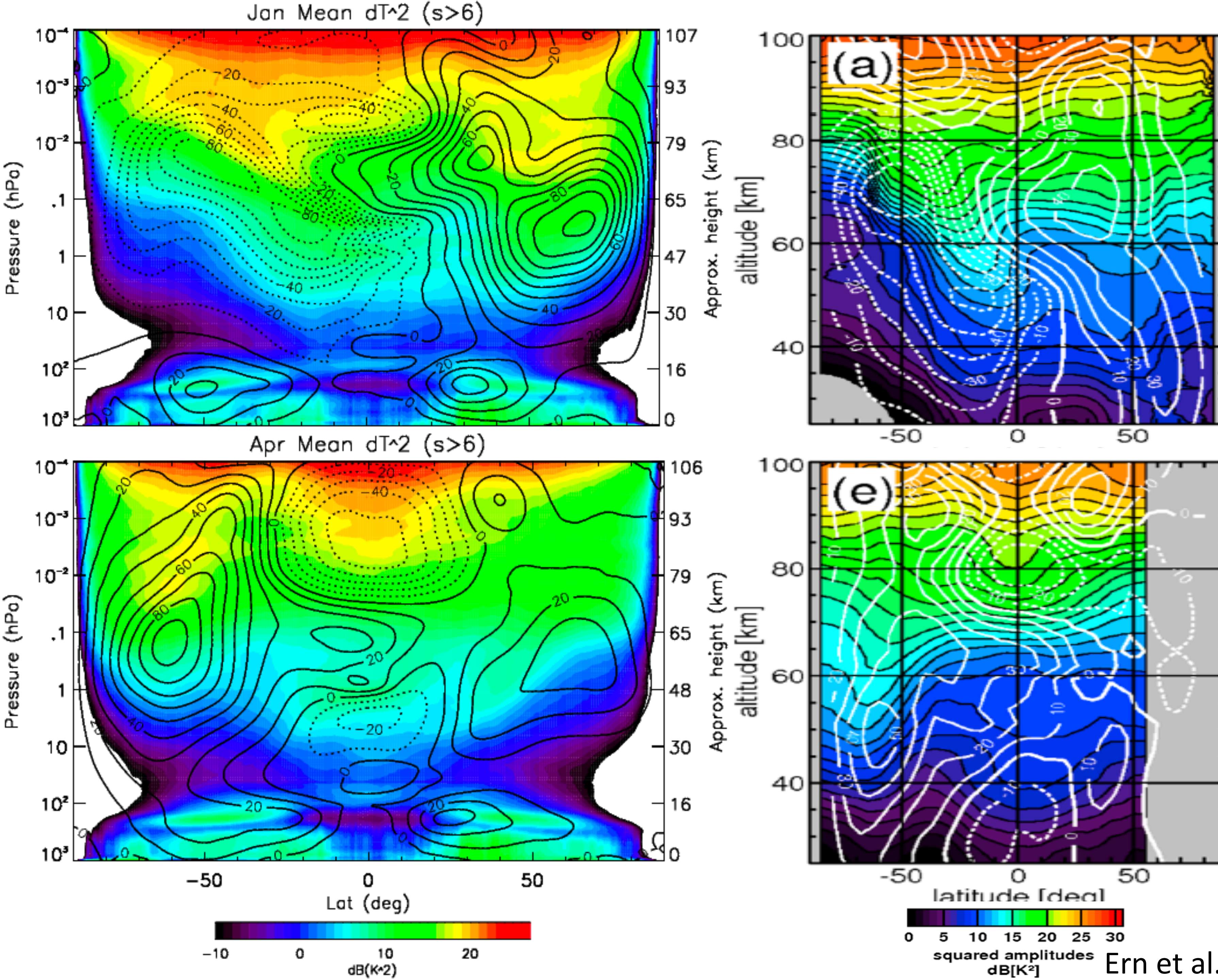


Liu et al., 2014

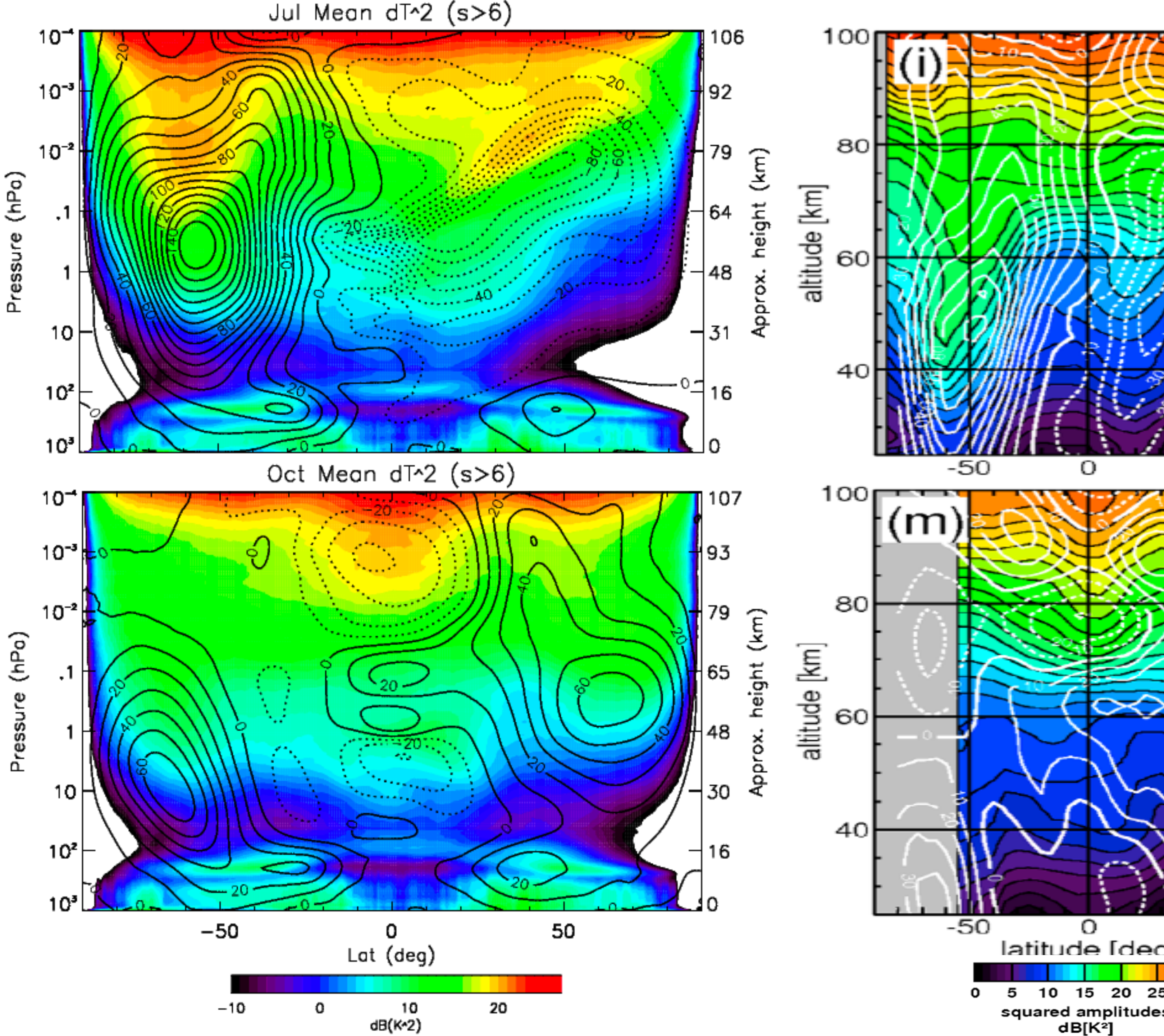

w(m/s) at 208hPa July 1 UT 0
0.2
0.1
0.0
-0.1
-0.2
w(m/s) at 10hPa July 1 UT 0
0.4
0.2
0.0
-0.2
-0.4
w(m/s) at 3.5e-2hPa July 1 UT 0
3
2
1
0
-1
-2
-3
w(m/s) at 2.6e-4hPa July 1 UT 0
6
4
2
0
-2
-4
-6

Power Spectrum Density: Altitude Dependence





Ern et al., 2011

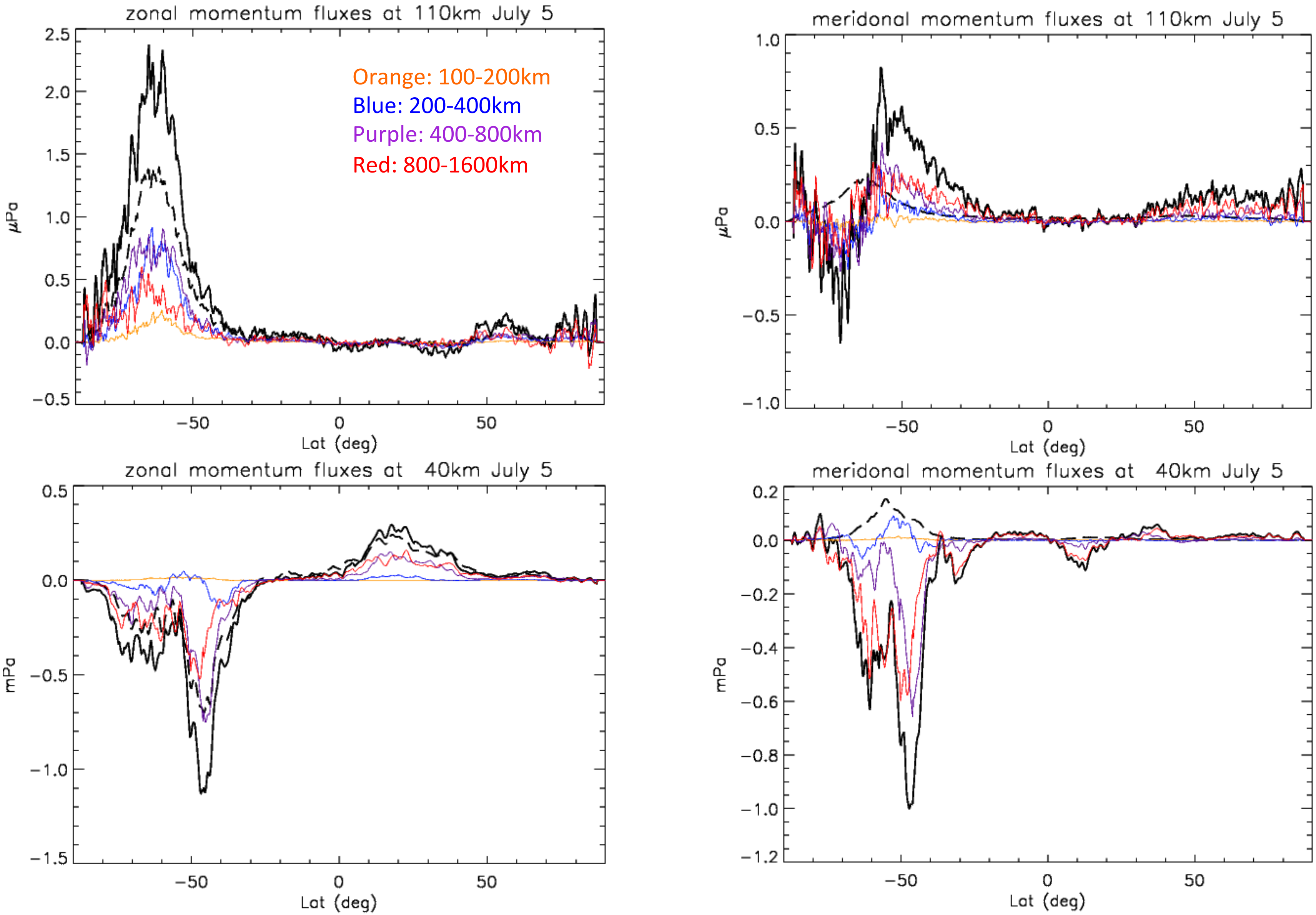


Ern et al., 2011

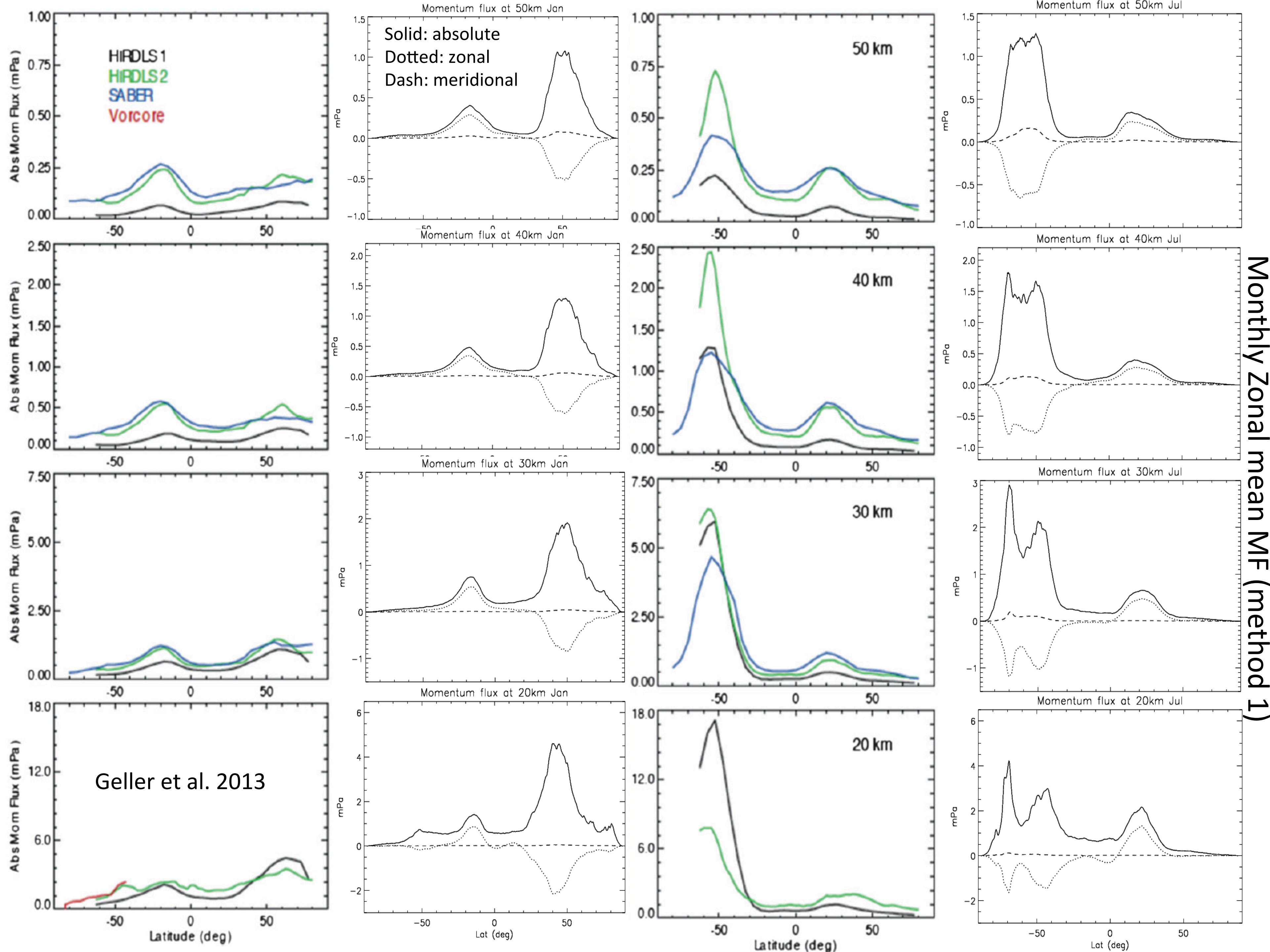
Analysis Methods

- Gravity wave momentum flux-method 1:
  - Perturbations with s between 7 and 150
  - Compute fluxes (hourly) and obtain daily average.
  - Construct monthly average based on daily averages.
  - Pros: straightforward, without the need to identify wave events. Useful for surveying general morphology of wave activities.
  - Cons: Underestimation, especially for higher frequency waves. Problematic for stationary (mountain) waves.
- Gravity wave momentum flux-method 2:
  - By using wavelet filter, reconstruct all field variables in 5 scale ranges in zonal direction: 0-100km, 100-200km, 200-400km, 400-800km, 800-1600km.
  - Compute fluxes over the respective scale ranges. Can study scale dependence.
  - More expensive and current used for case studies, and to check method 1. Problematic for waves propagating predominantly meridional.
- Both absolute and directional fluxes are calculated.

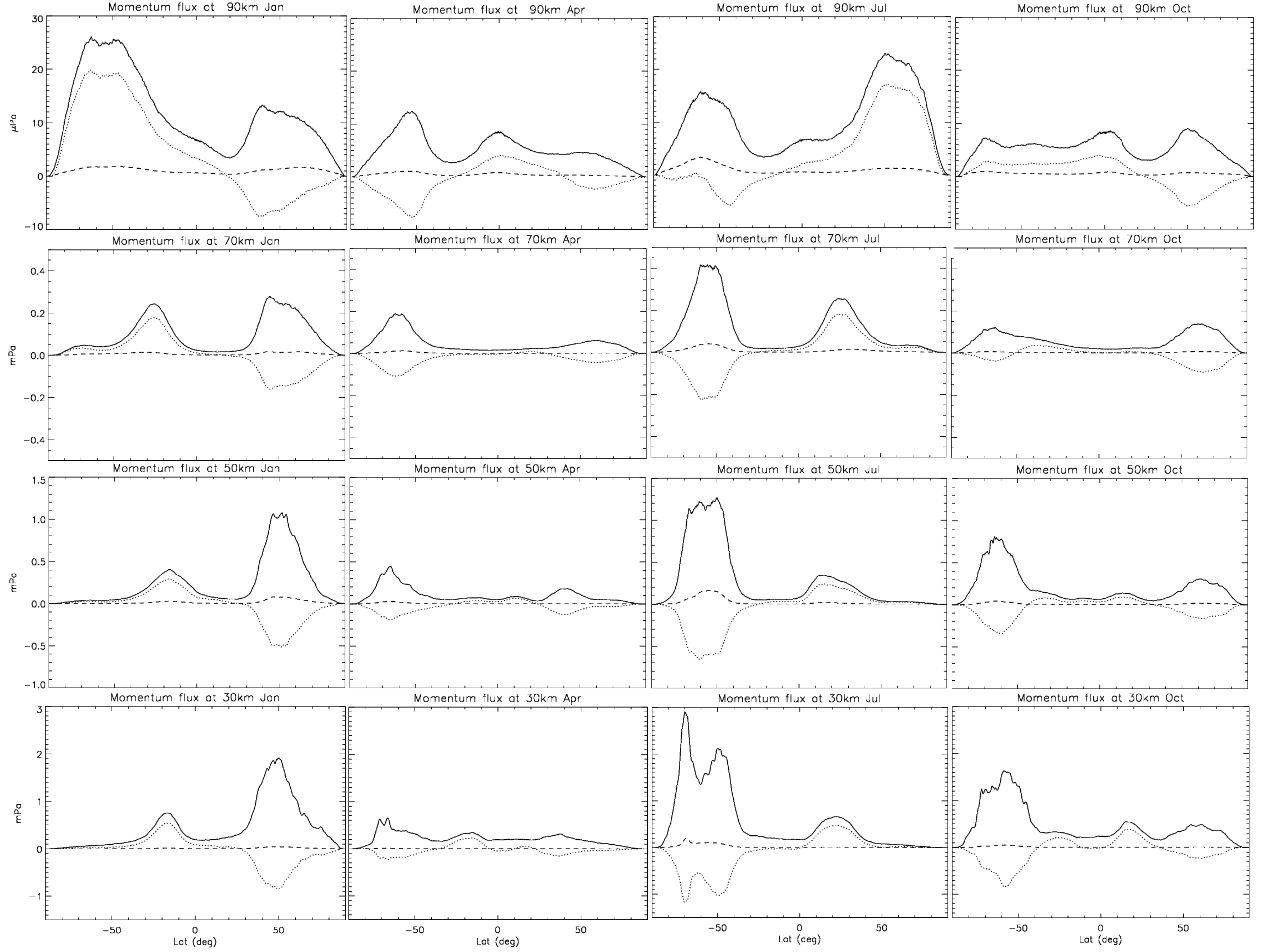
Zonally/daily averaged MFs from two methods



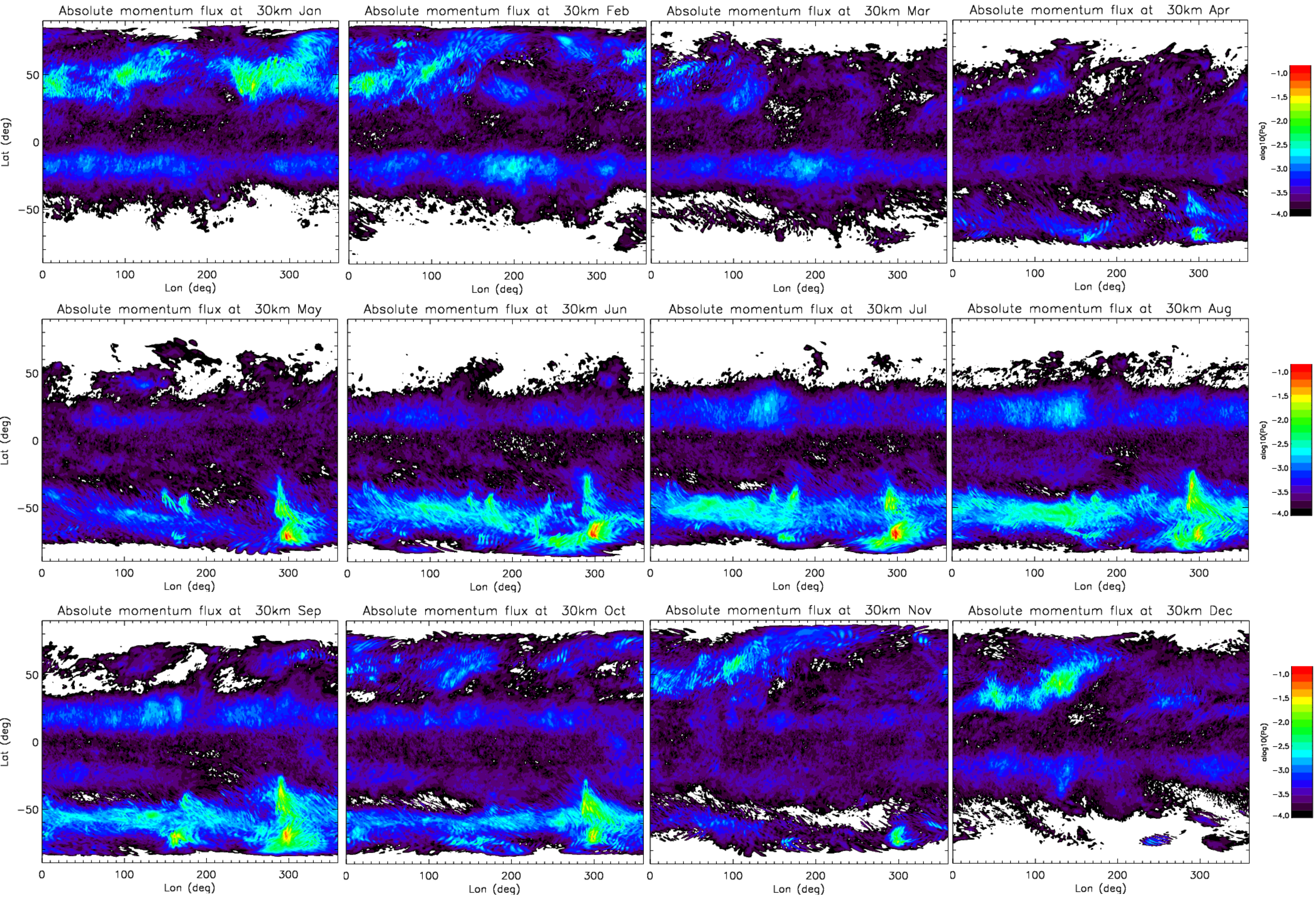
Solid lines: Method 2; Dash lines: Method 1.



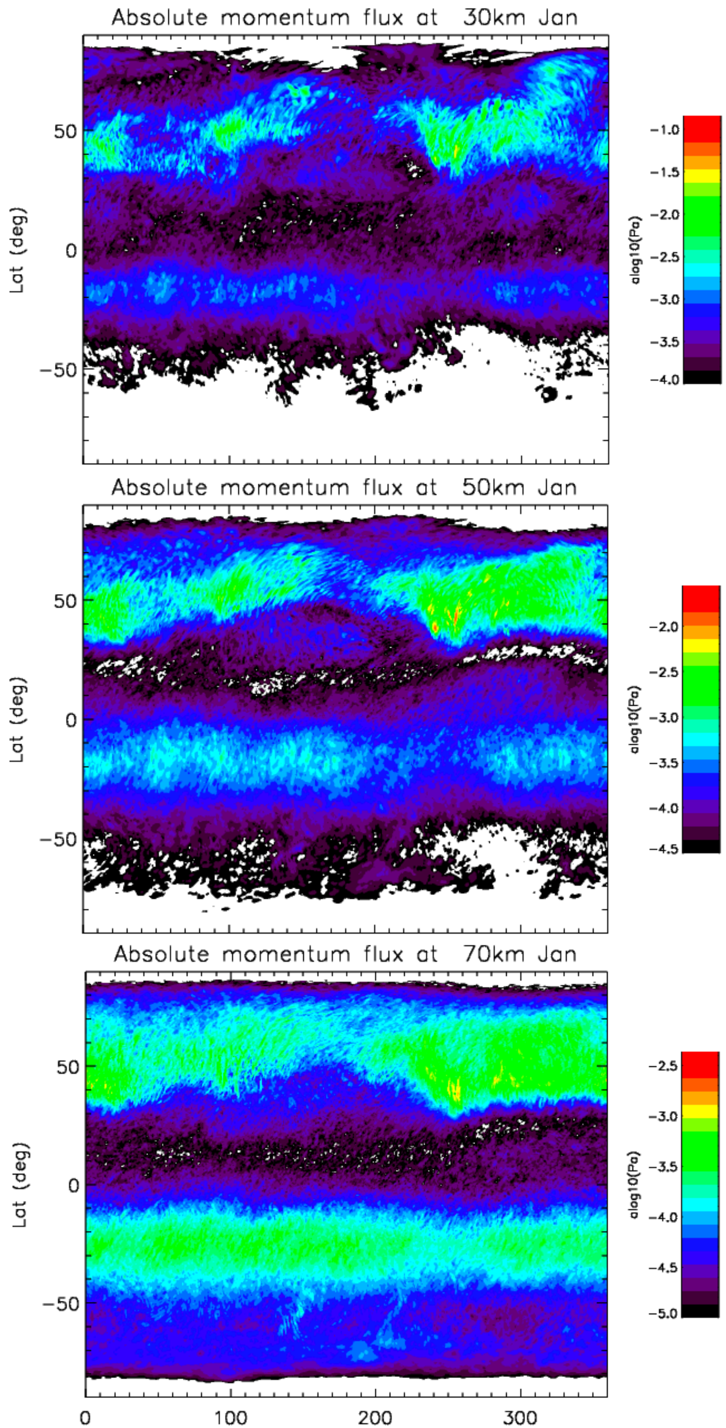
HIRDLS 1
HIRDLS 2
SABER
Vorcore
Solid: absolute
Dotted: zonal
Dash: meridional
Momentum flux at 50km Jan
Momentum flux at 40km Jan
Momentum flux at 30km Jan
Momentum flux at 20km Jan
Momentum flux at 50km Jul
Momentum flux at 40km Jul
Momentum flux at 30km Jul
Momentum flux at 20km Jul
50 km
40 km
30 km
20 km
AbsMom Flux (mPa)
mPa
Latitude (deg)
Lat (deg)
Geller et al. 2013
Monthly Zonal mean MF (method 1)



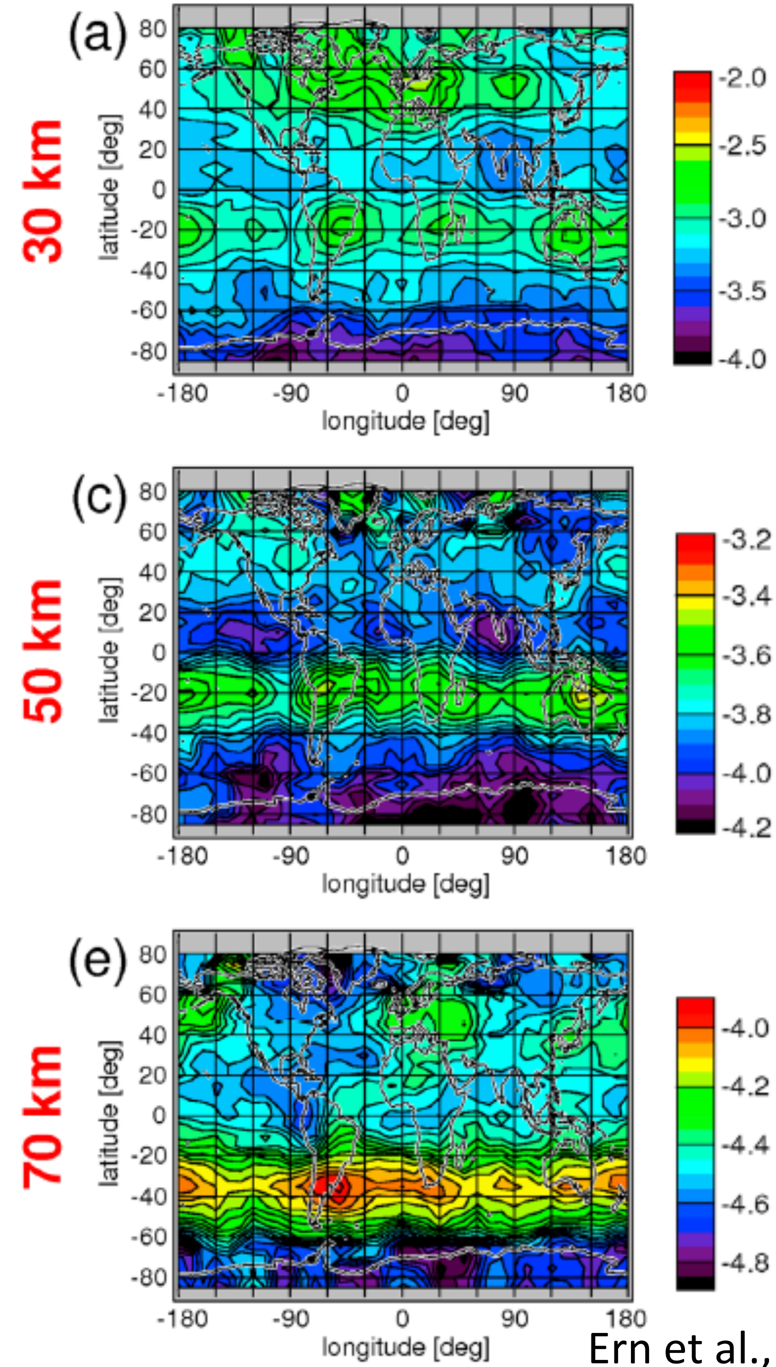
Momentum flux at 90km Jan
Momentum flux at 90km Apr
Momentum flux at 90km Jul
Momentum flux at 90km Oct
Momentum flux at 70km Jan
Momentum flux at 70km Apr
Momentum flux at 70km Jul
Momentum flux at 70km Oct
Momentum flux at 50km Jan
Momentum flux at 50km Apr
Momentum flux at 50km Jul
Momentum flux at 50km Oct
Momentum flux at 30km Jan
Momentum flux at 30km Apr
Momentum flux at 30km Jul
Momentum flux at 30km Oct
μPa
mPa
Lat (deg)



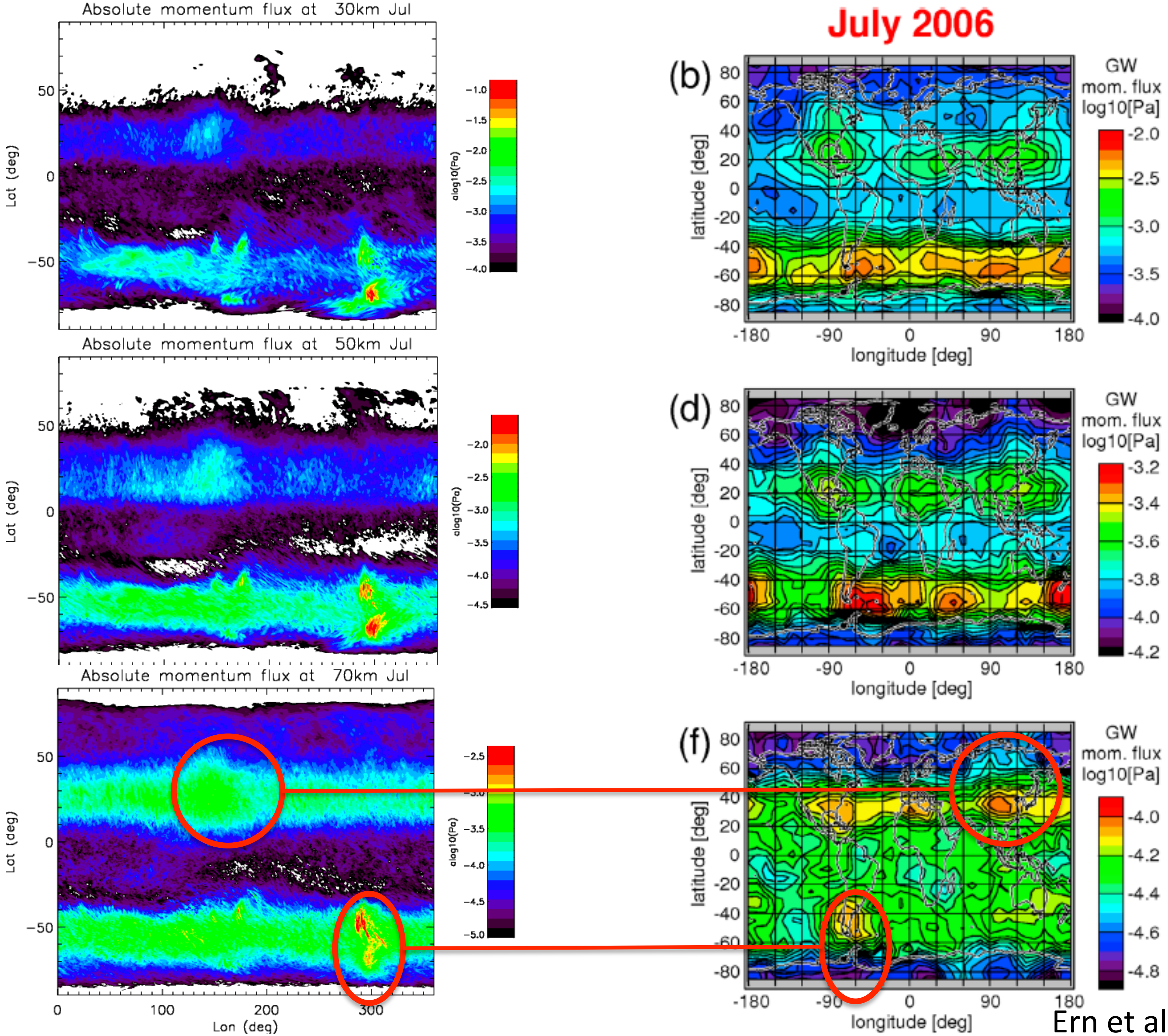
Monthly mean Absolute MF



January 2006

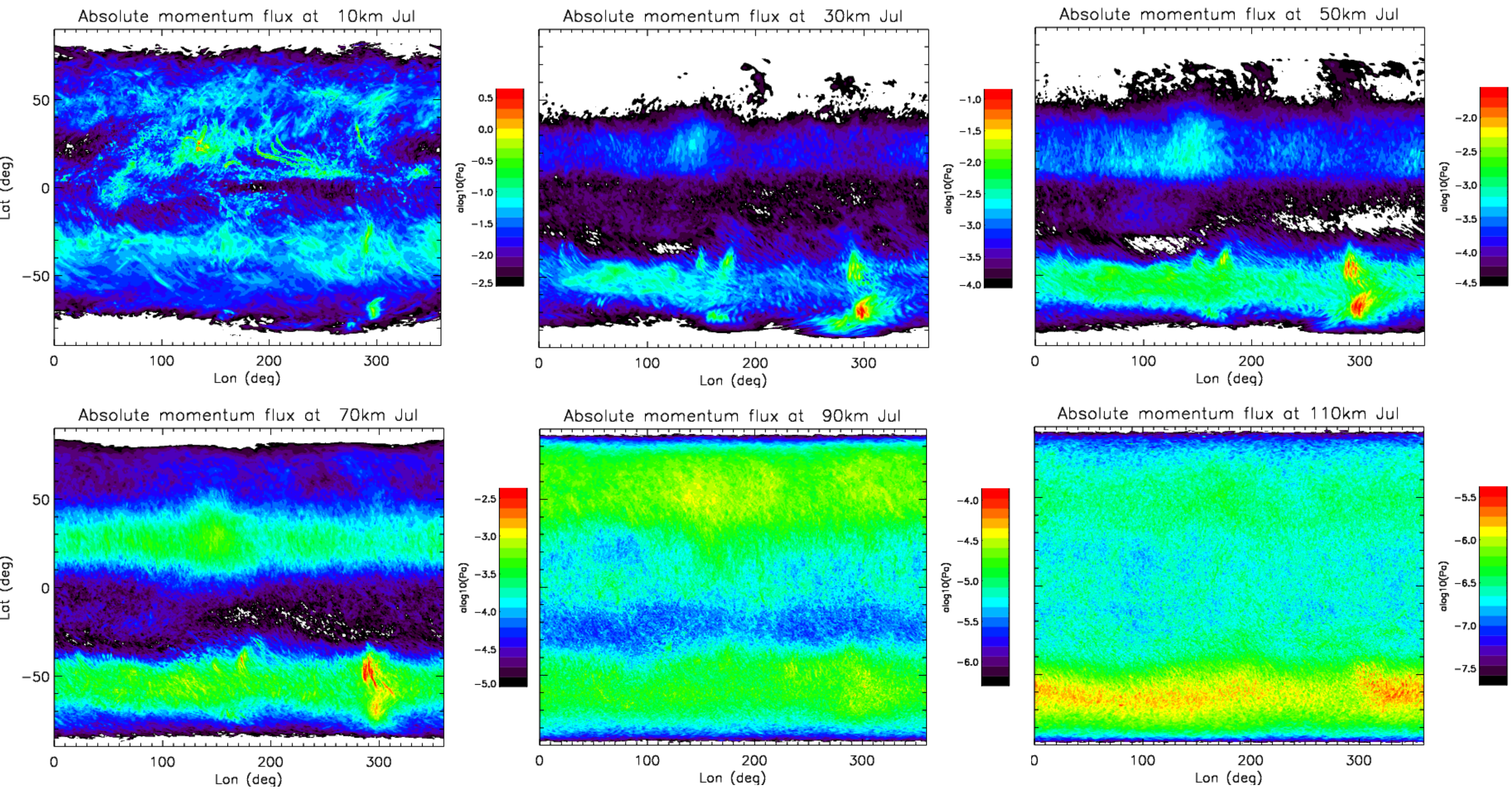


Ern et al., 2011

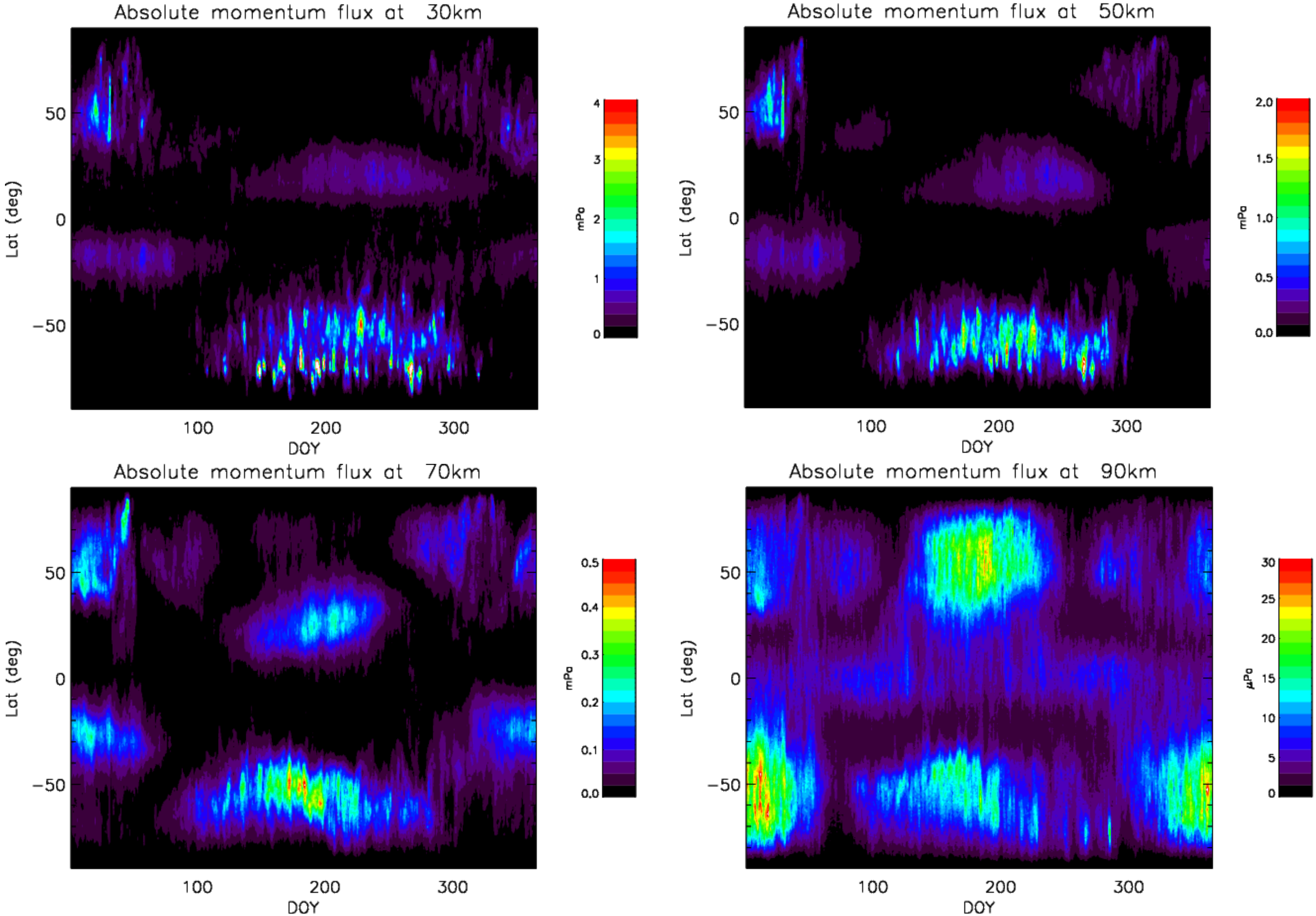


Ern et al., 2011

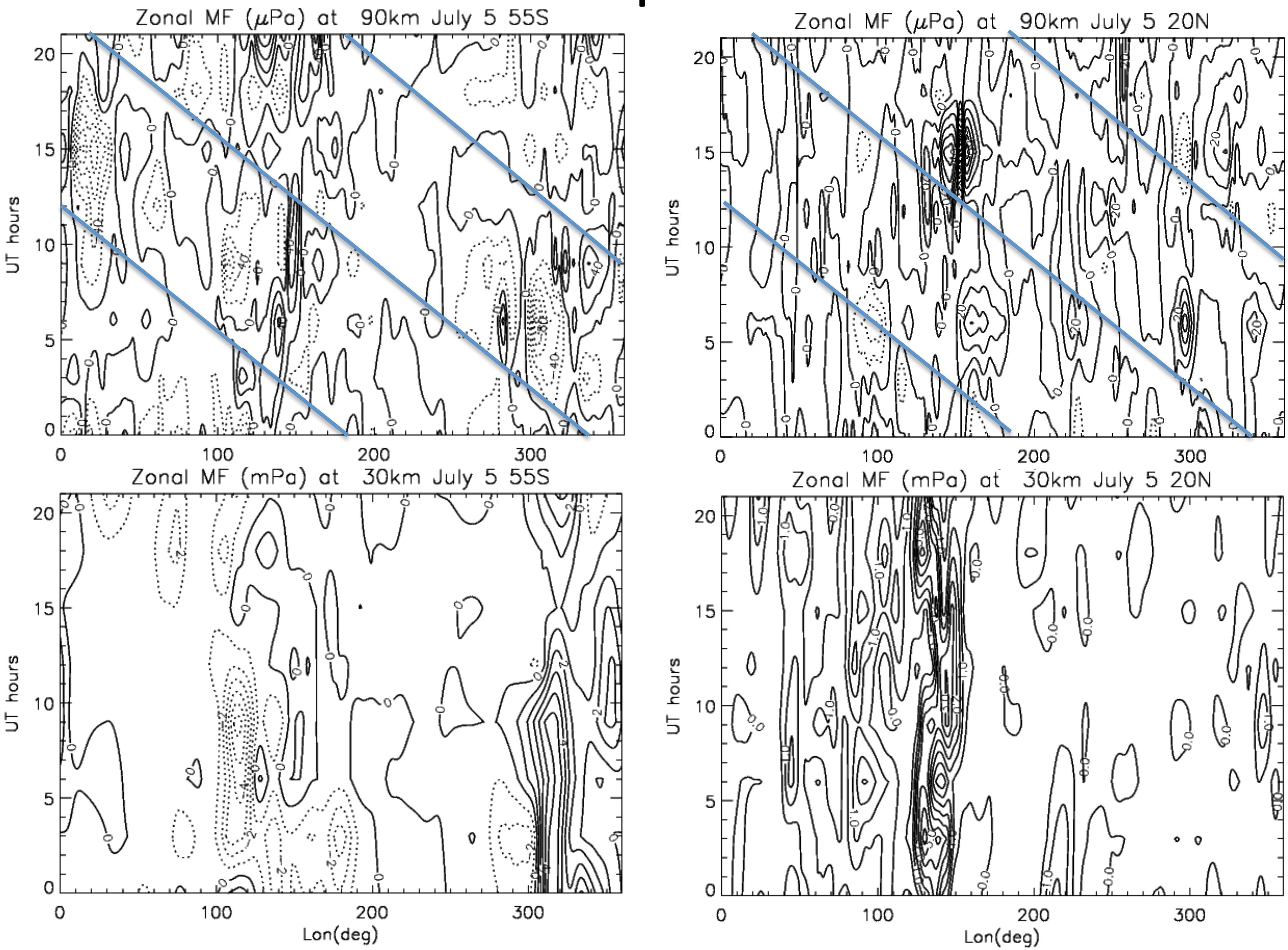
MF Vertical Variation in July: Tropopause to Lower Thermosphere



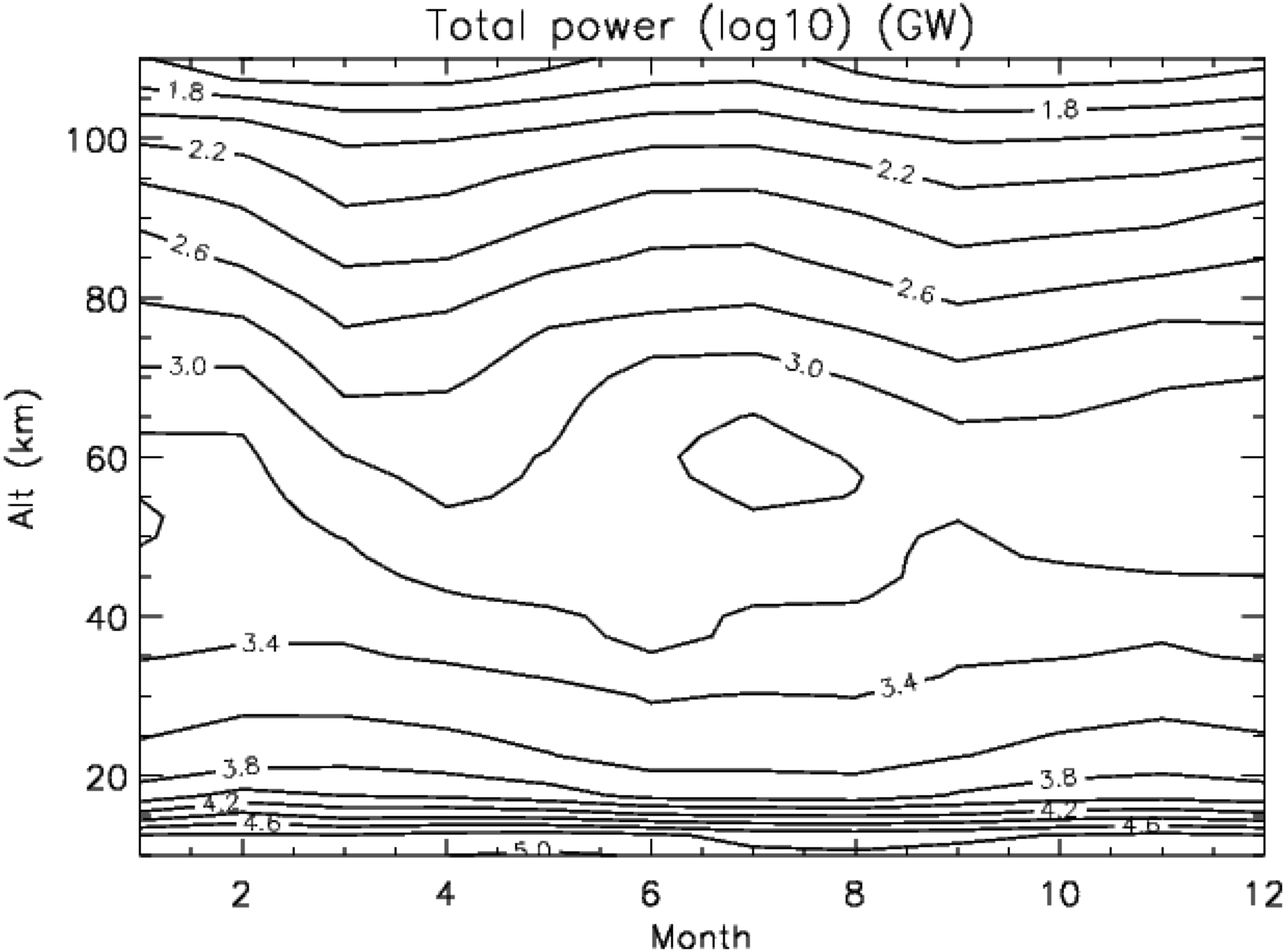
Variabilities: Daily to Seasonal



Zonal and Temporal Variations

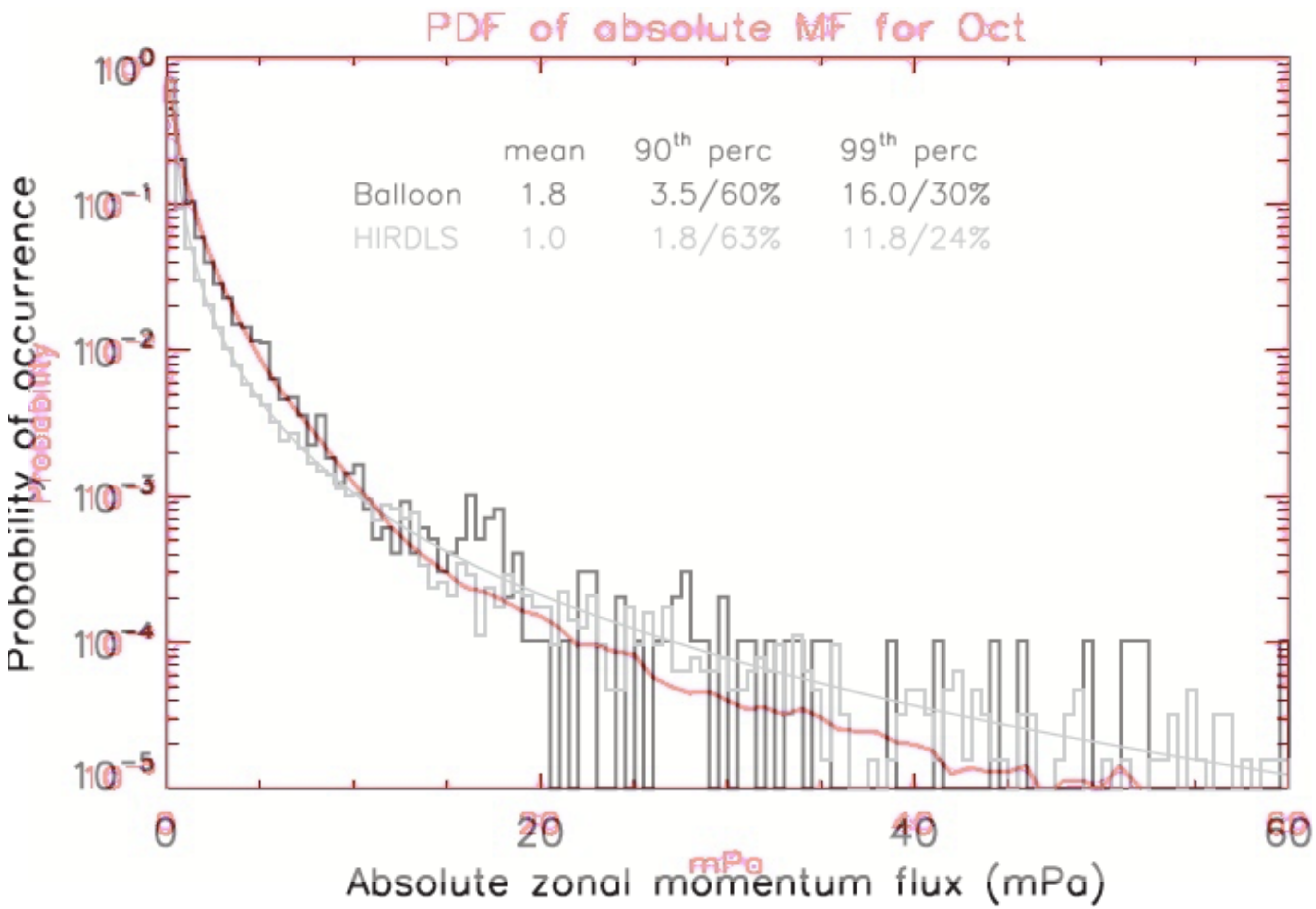


Total Vertical Energy Flux

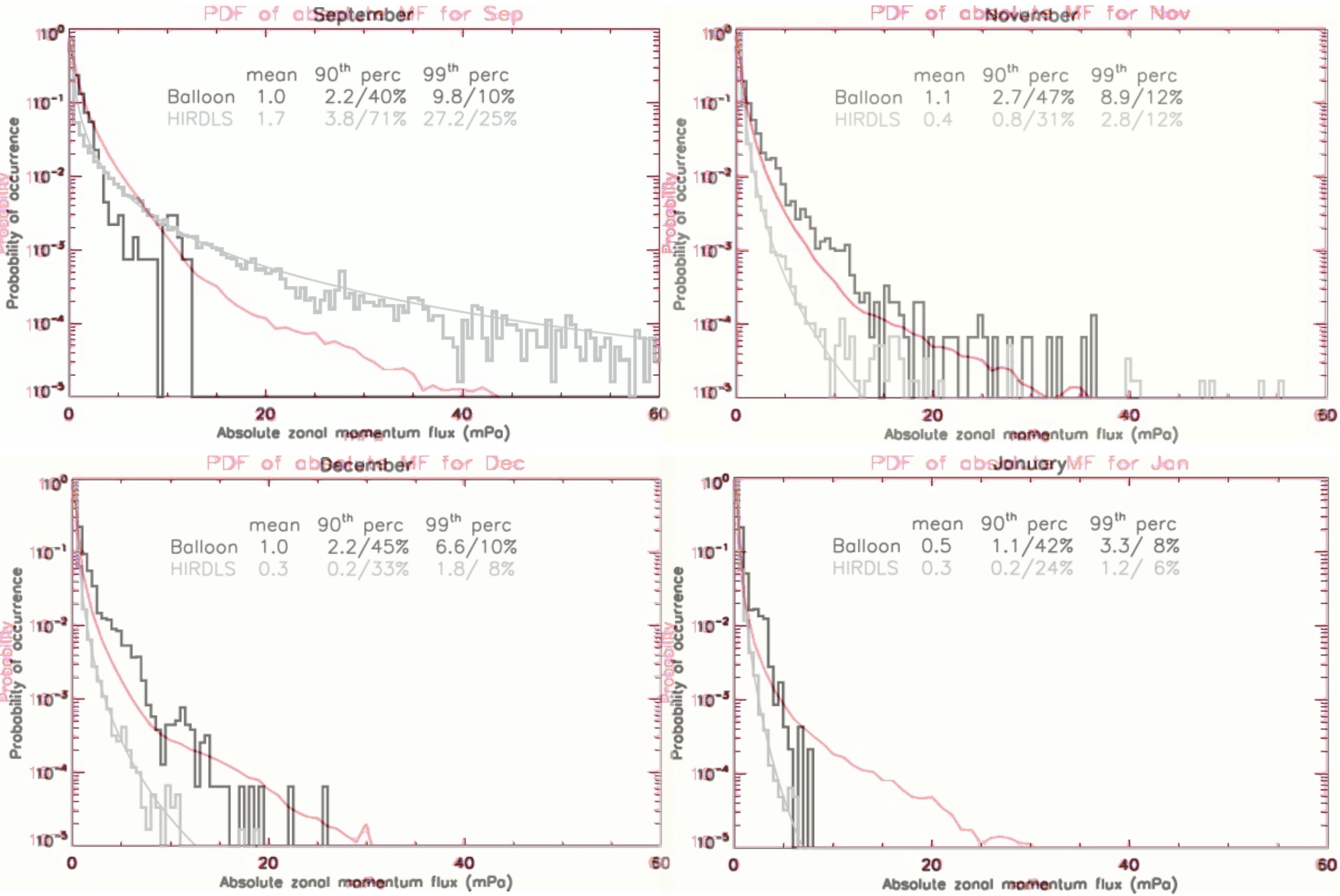


~100GW at lower thermosphere, comparable to Joule heating budget of the thermosphere.

Probability Density Function

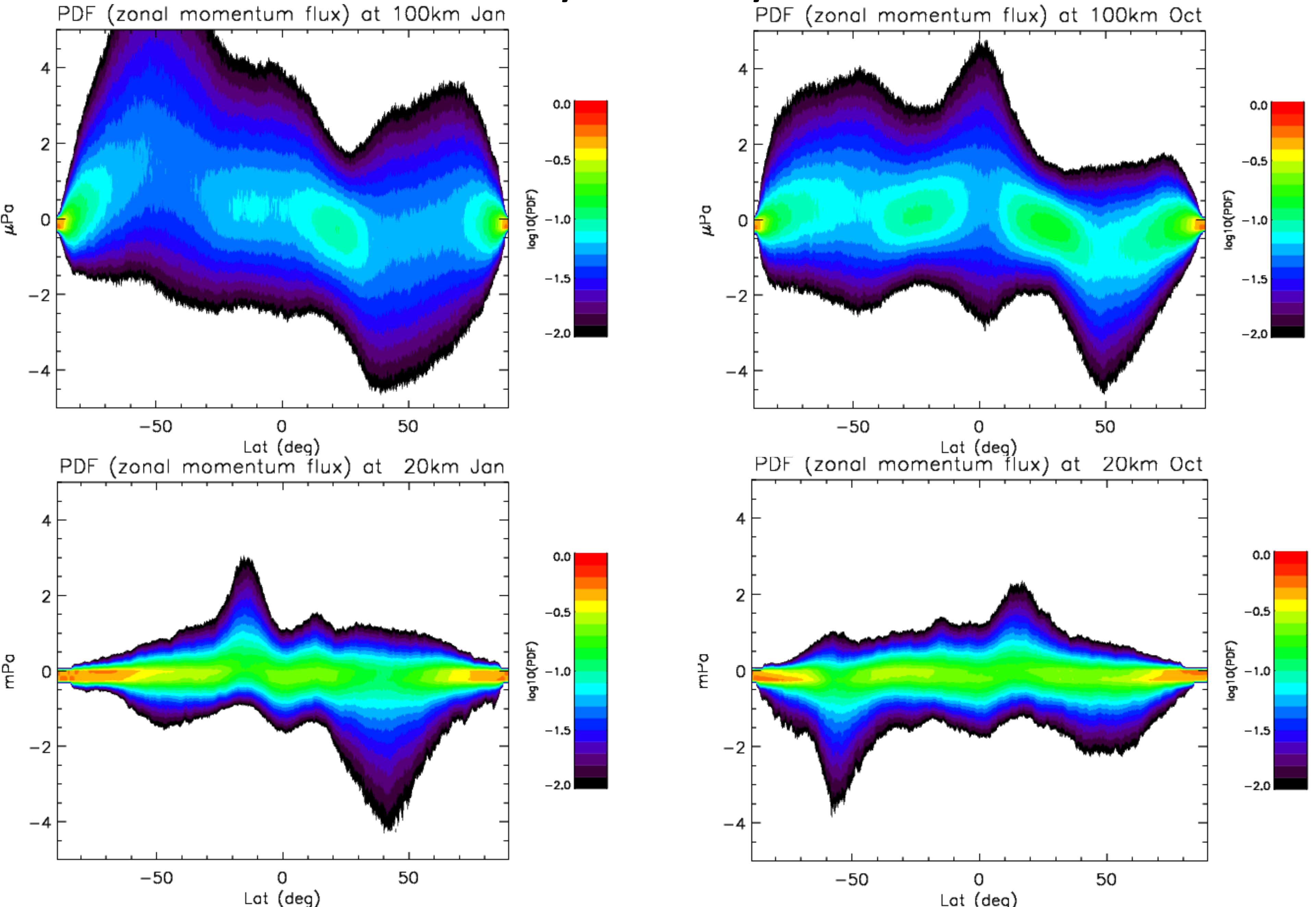


Hertzog et al., 2012

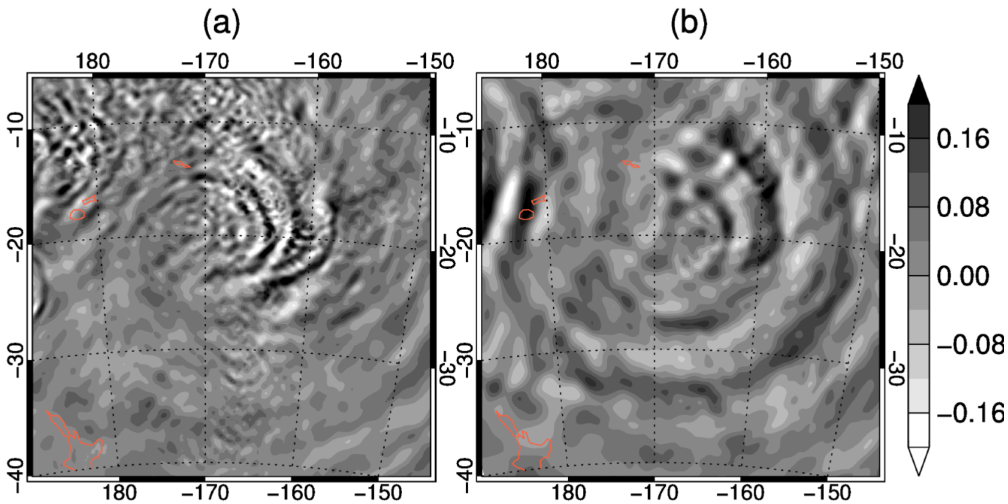


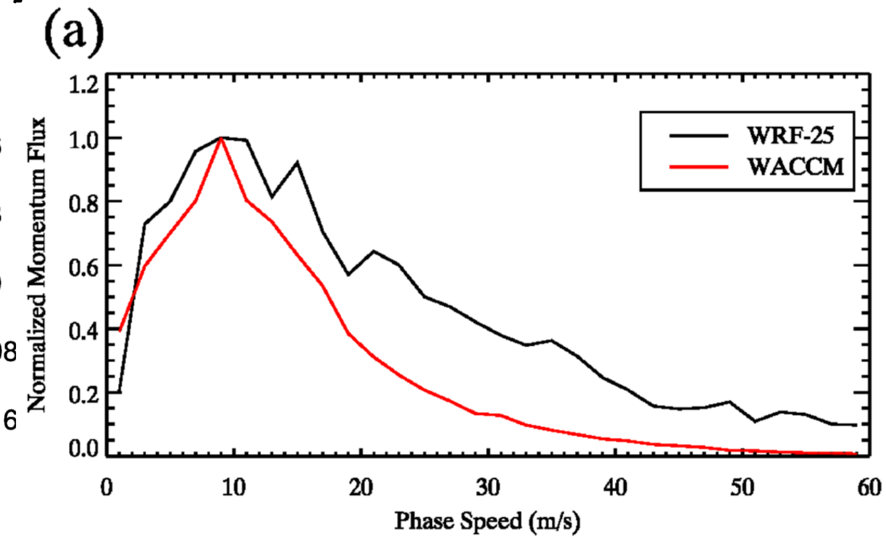
Hertzog et al., 2012

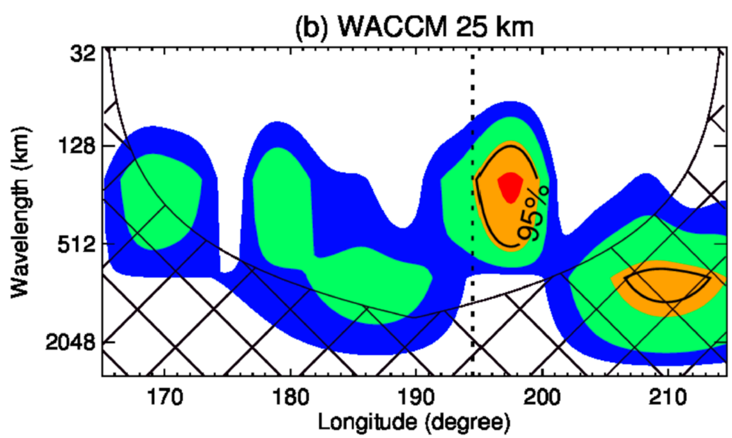
Probability Density Function

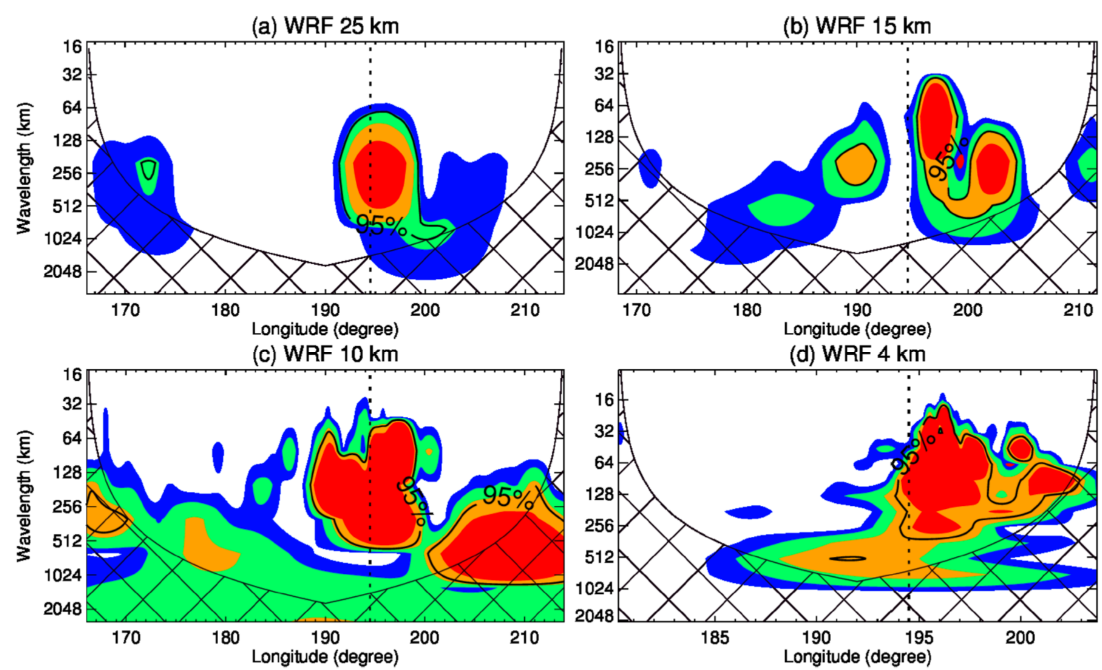


WRF Driven by WACCM









Wu et al., In preparation

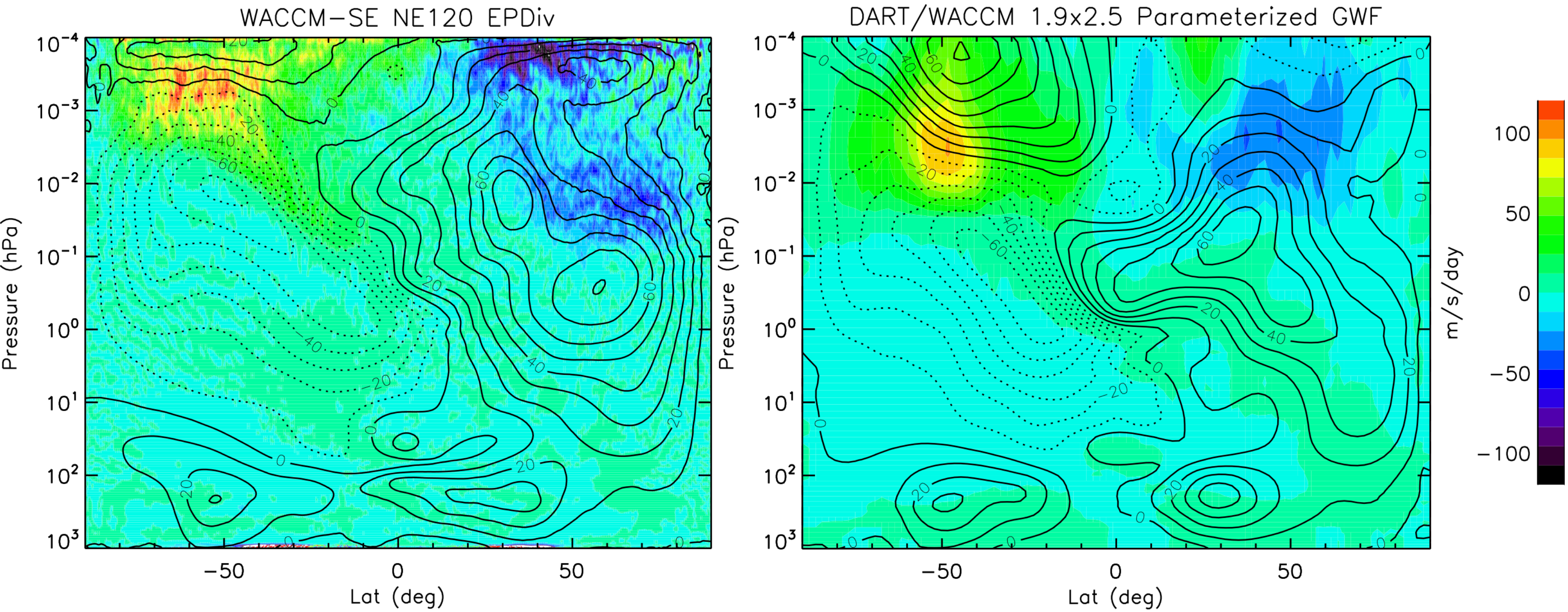
Summary (1)

- WACCM-SE NE120/L209 can resolve gravity waves with horizontal scales of ~250km without severe numerical damping.
- Scale dependence
  - Contribution to zonal momentum flux comes mostly from waves with zonal scales larger than 400km.
  - Increasingly more contribution from smaller scales at increasing altitude. Consistent with the increasingly shallower slope of PSD.
  - Stratospheric/mesospheric wind too strong and reversal altitude too high, probably due to lack of wave activities for scales below ~250km.
- Intermittency and seasonal dependence: In general agreement with observations.

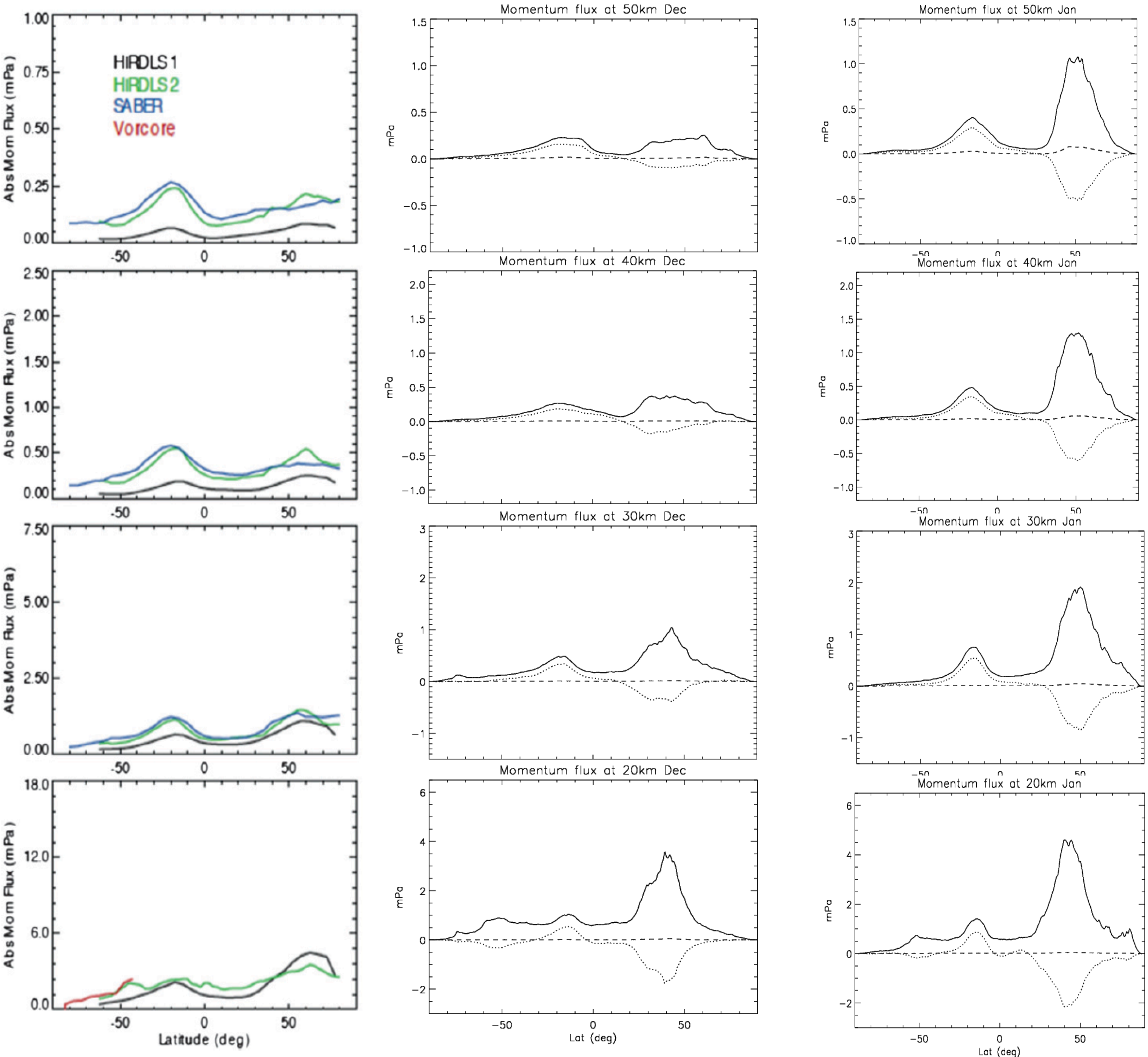
Summary (2)

- Temporal and spatial variation: General features in good agreement with observations:
  - Stratosphere and lower mesosphere: Strong wave activities at winter middle and high latitudes; secondary peak over summer subtropical region; southern winter strongest, from orography and fronts and/or jets.
  - Summer peak shifts to higher latitudes with altitudes, and becomes stronger relative to the winter peak.
  - Wave activity has a strong annual cycle at lower altitudes and a strong semi-annual cycle at higher altitudes.
  - Momentum flux strength and direction affected by wind. Longitude variation modulated by planetary waves and tides.
  - Wave activities over summer Atlantic notably weaker in model than in observations.
- Gravity wave energy input to the thermosphere is comparable to Joule heating (~100GW).

Zonal Wind and GW Forcing

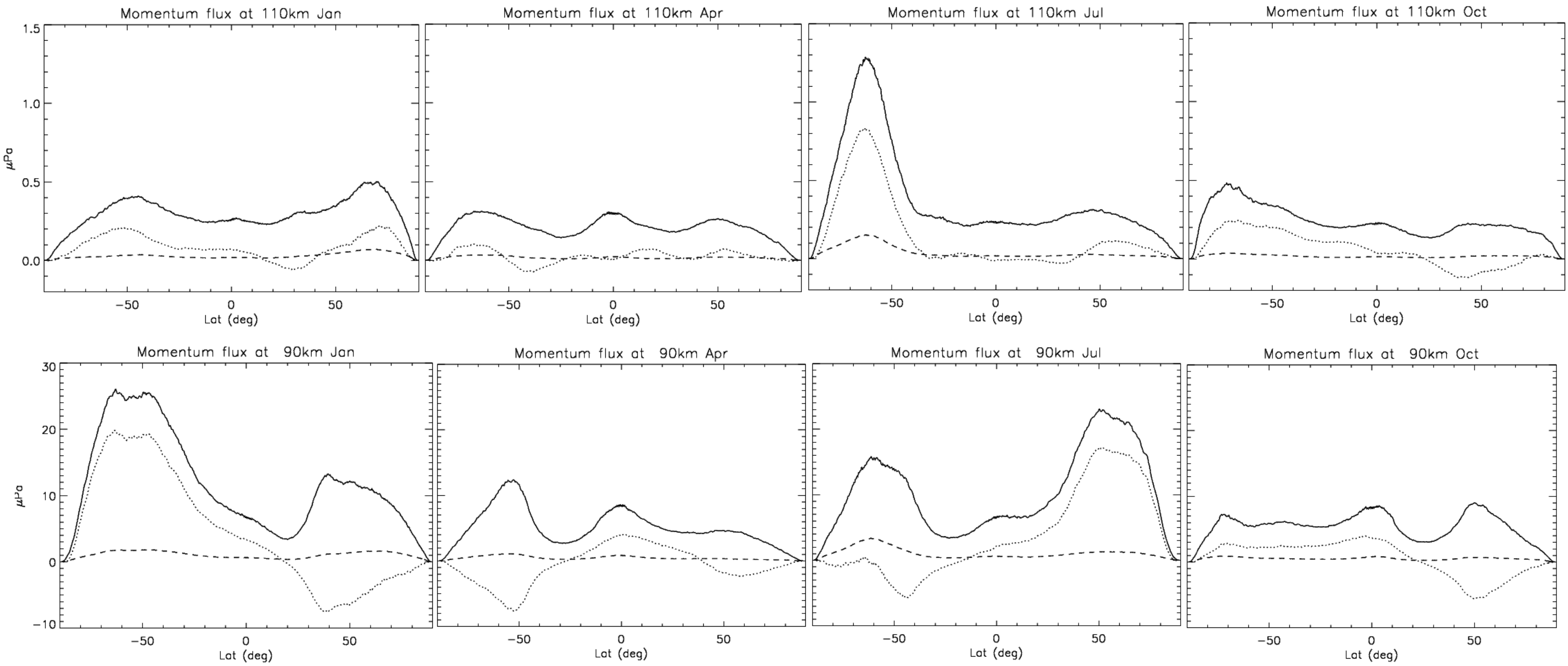


Liu et al., 2014

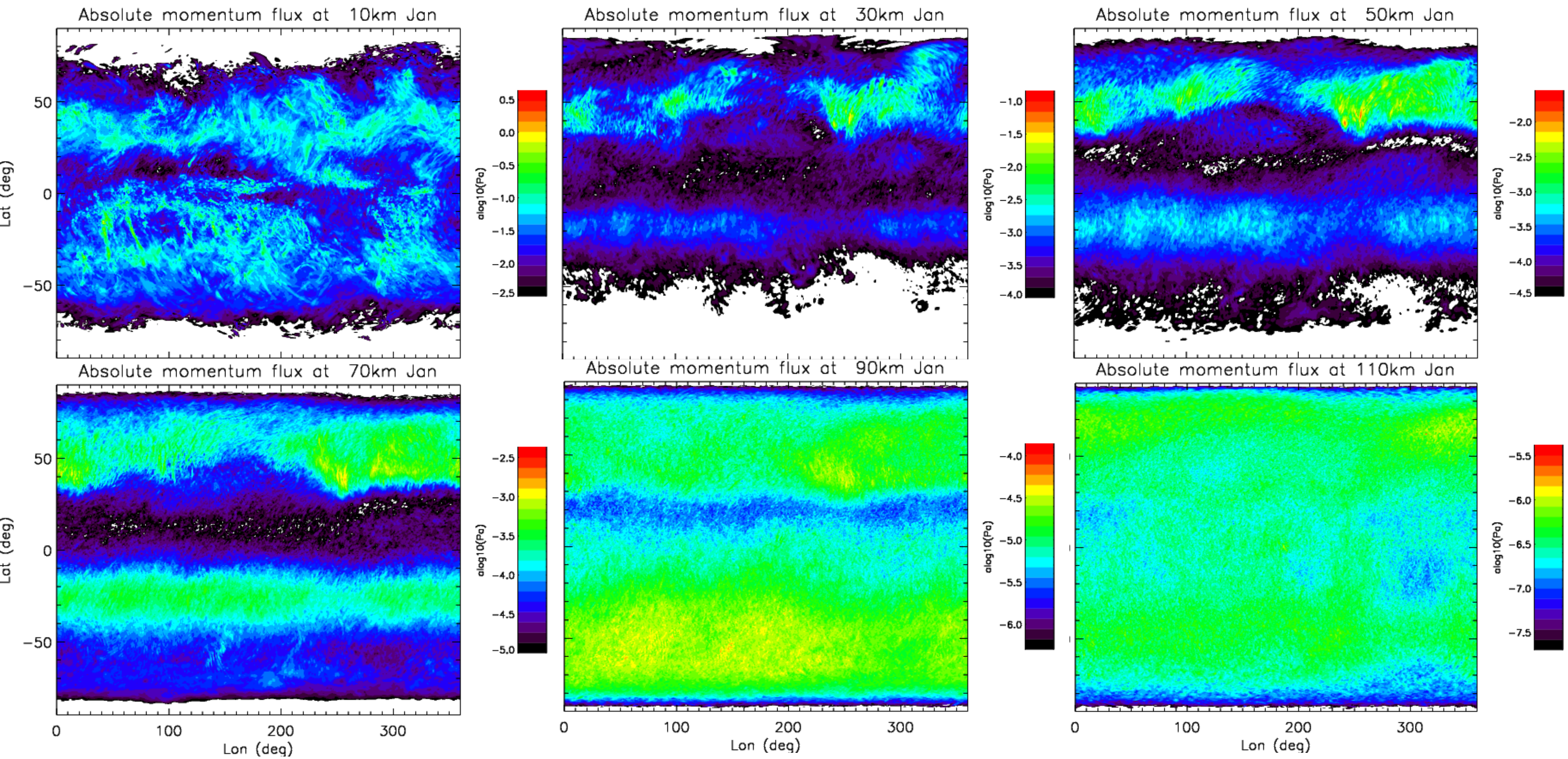


Variation of the northern winter peak

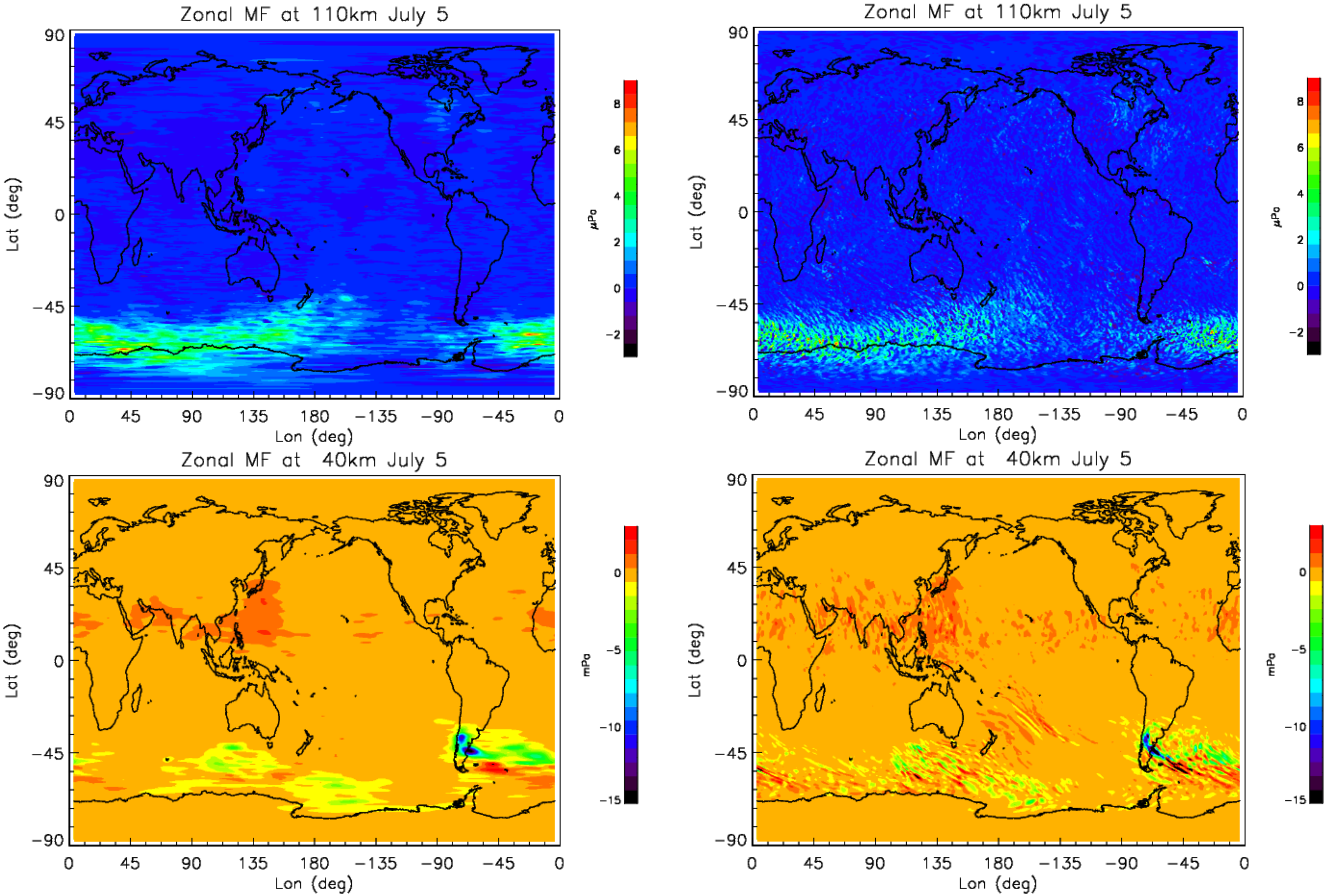
MF in the Lower Thermosphere



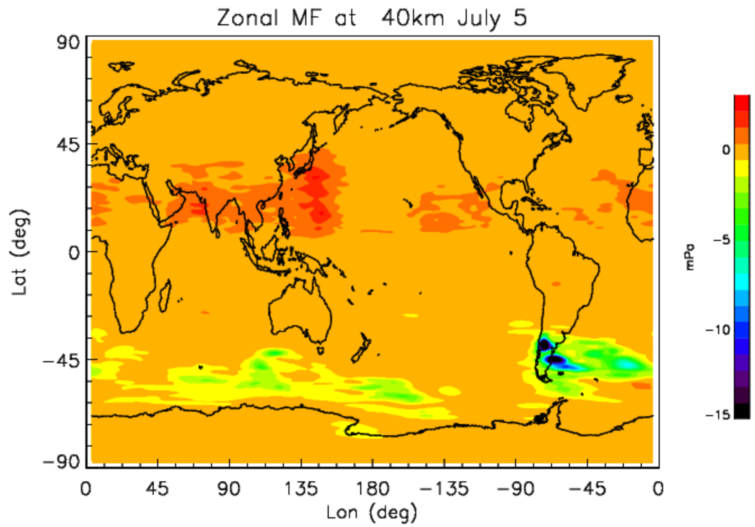
MF Vertical Variation in January: Tropopause to Lower Thermosphere

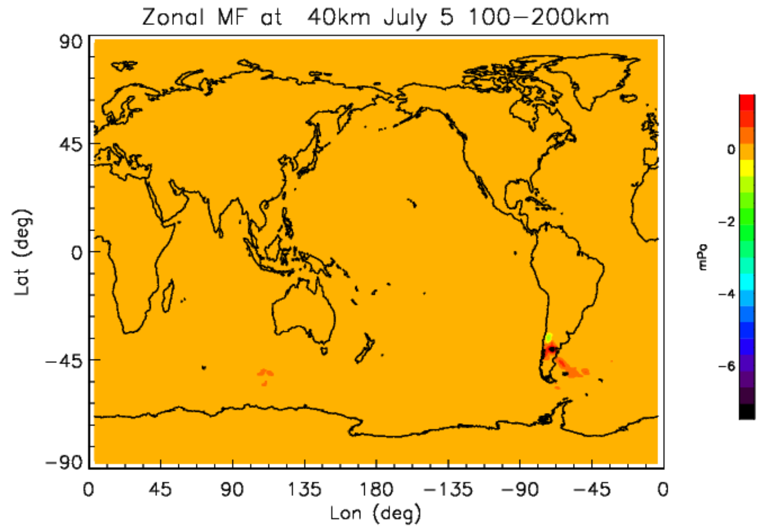


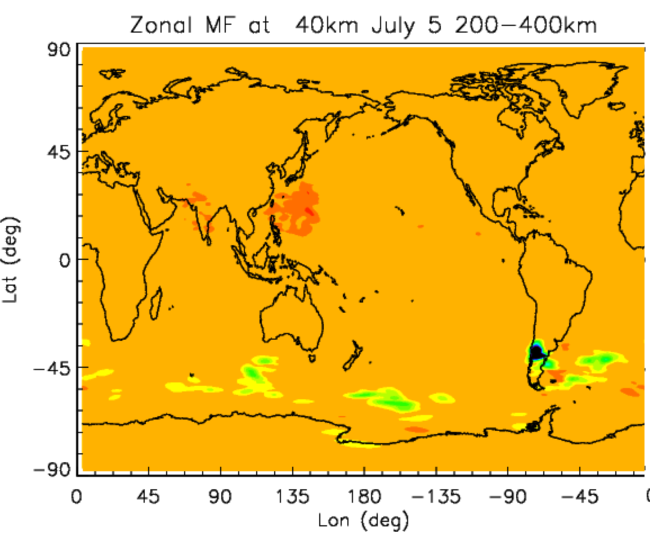
Zonal Momentum Fluxes using Two Methods

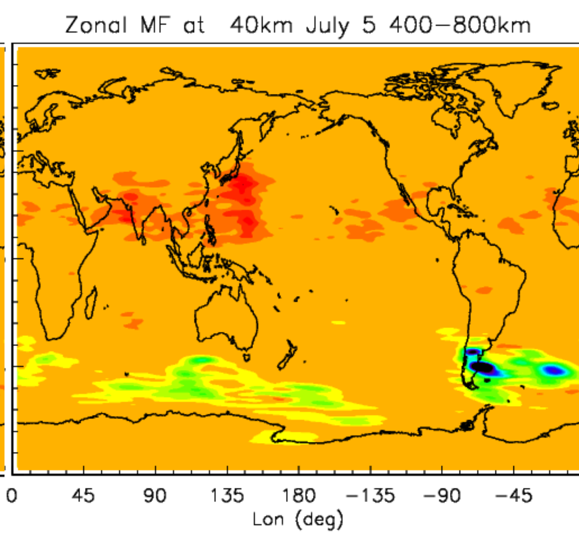


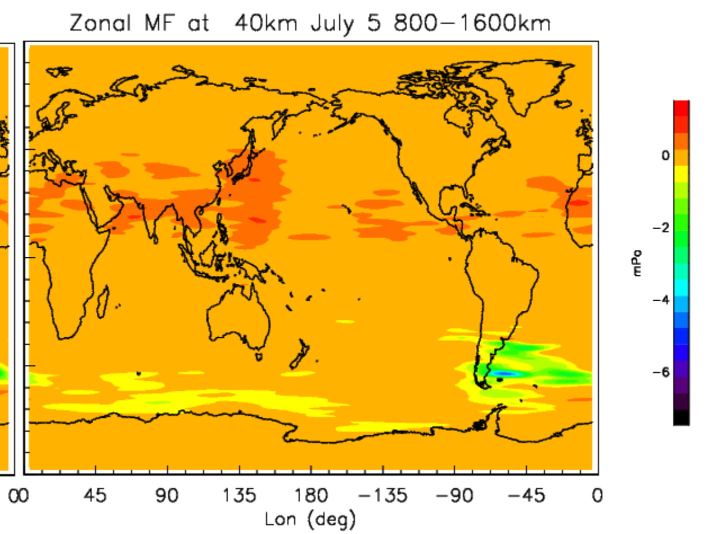
Scale Dependence of MF (zonal)

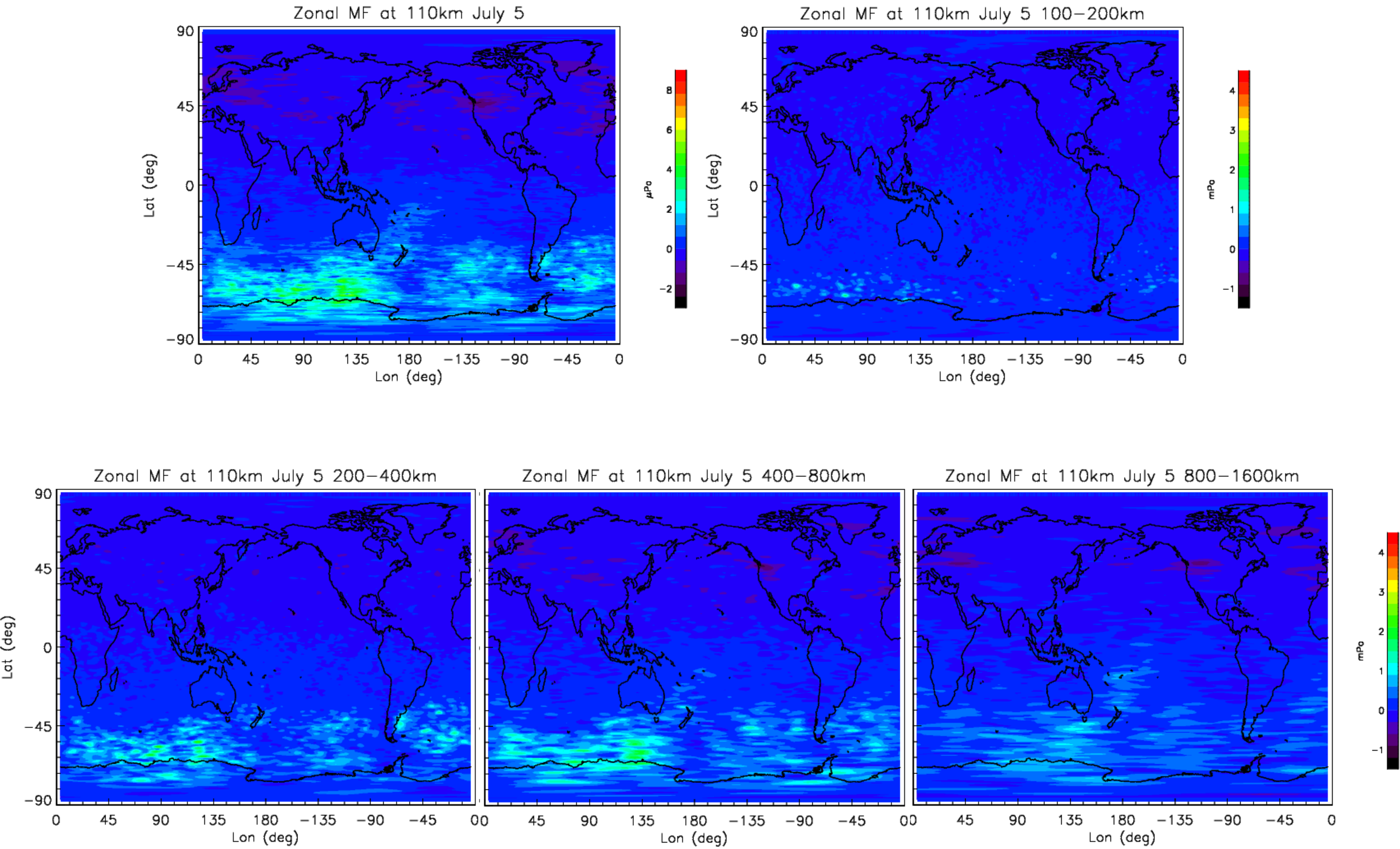











Zonal MF at 110km July 5
Zonal MF at 110km July 5 100–200km
Zonal MF at 110km July 5 200–400km
Zonal MF at 110km July 5 400–800km
Zonal MF at 110km July 5 800–1600km
Lat (deg)
Lon (deg)
90
45
0
−45
−90
0
45
90
135
180
−135
−90
−45
0
μPa
mPa