Thermospheric and Ionospheric Composition and Gravity Wave Parameterization

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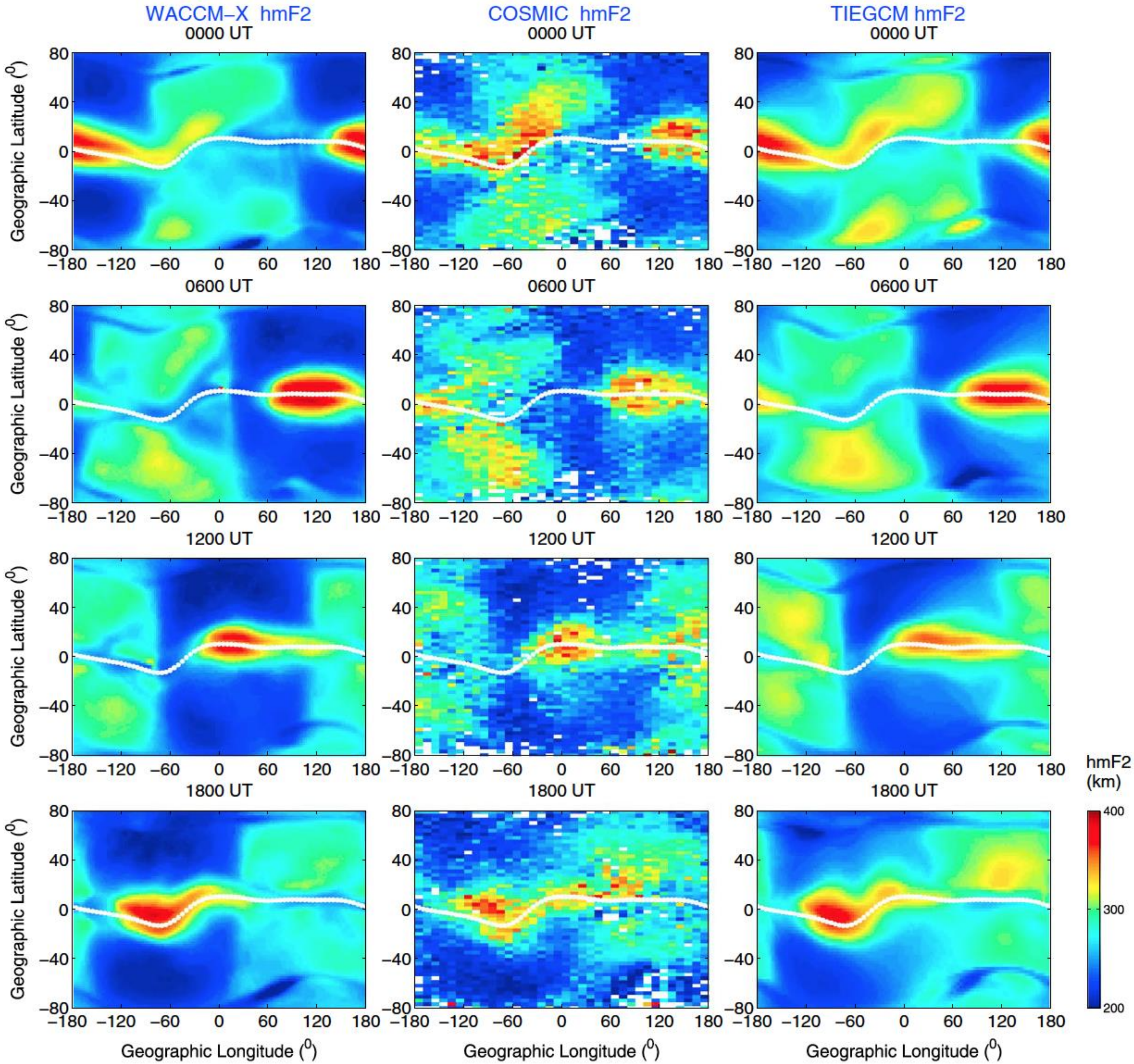
Whole Atmosphere Community Climate Model with thermosphere/ionosphere eXtension

- Interactive Ionosphere Modules
  - Interactive electric wind dynamo.
  - F region O+ transport.
  - Te solver (option of time-dependent and time-independent solver)
- High-latitude ionosphere (Heelis, Weimer, or AMIE).
- Thermosphere physics, including species dependent mean mass and specific heat in model dynamical core.
- Model domain extended to 4×10^{-10} hPa, with ¼ scale height resolution (126 levels).
- WACCM-X v2.0 released as part of CESM2.0
- WACCM-X v2.1 will soon be released as part of CESM2.1.

Two Issues with WACCM-X v2.0

- Low ionospheric density
- Absence of semi-annual variation of thermospheric density

Solar Min hmF2: March



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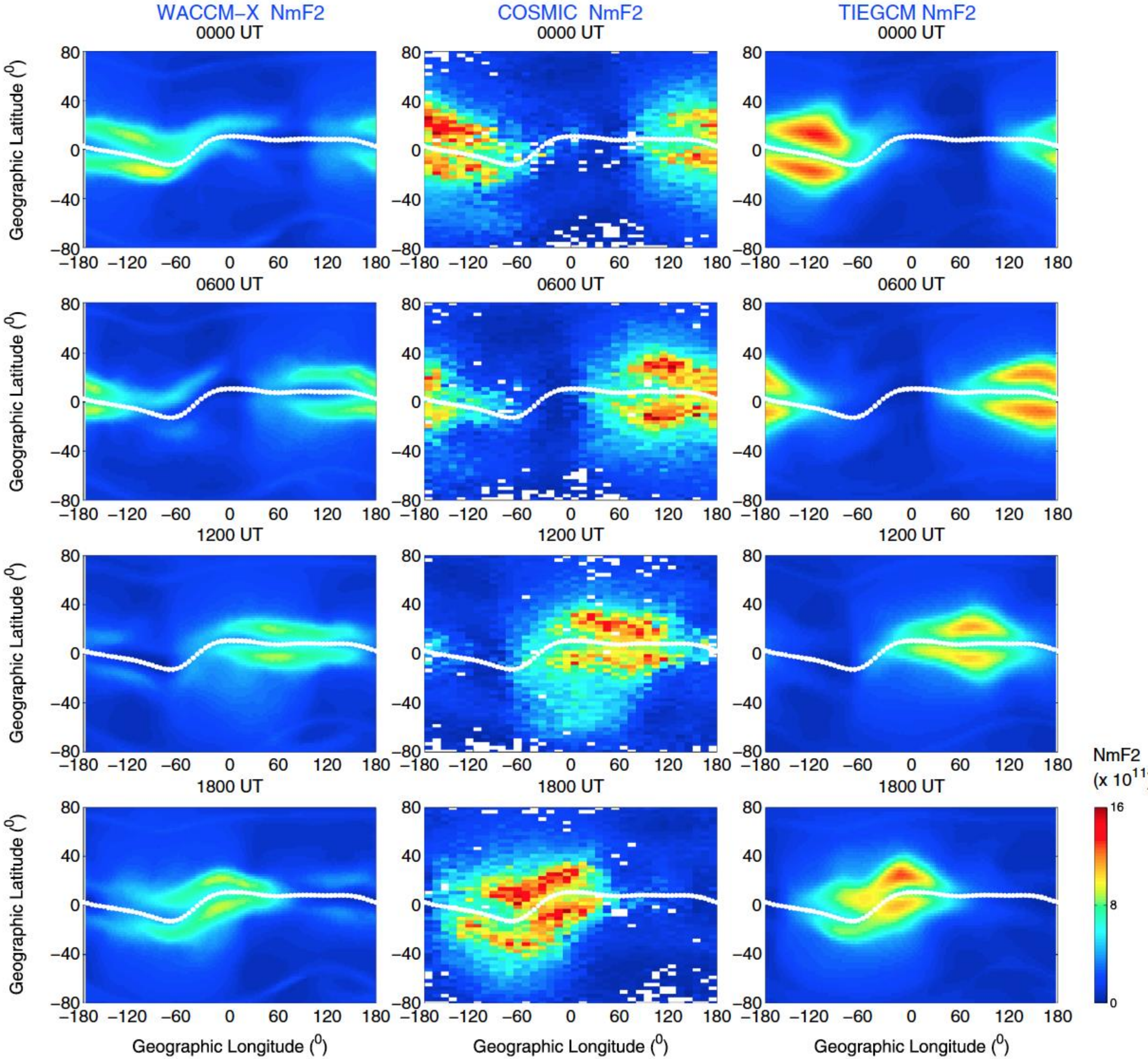
Solar Min NmF2: March



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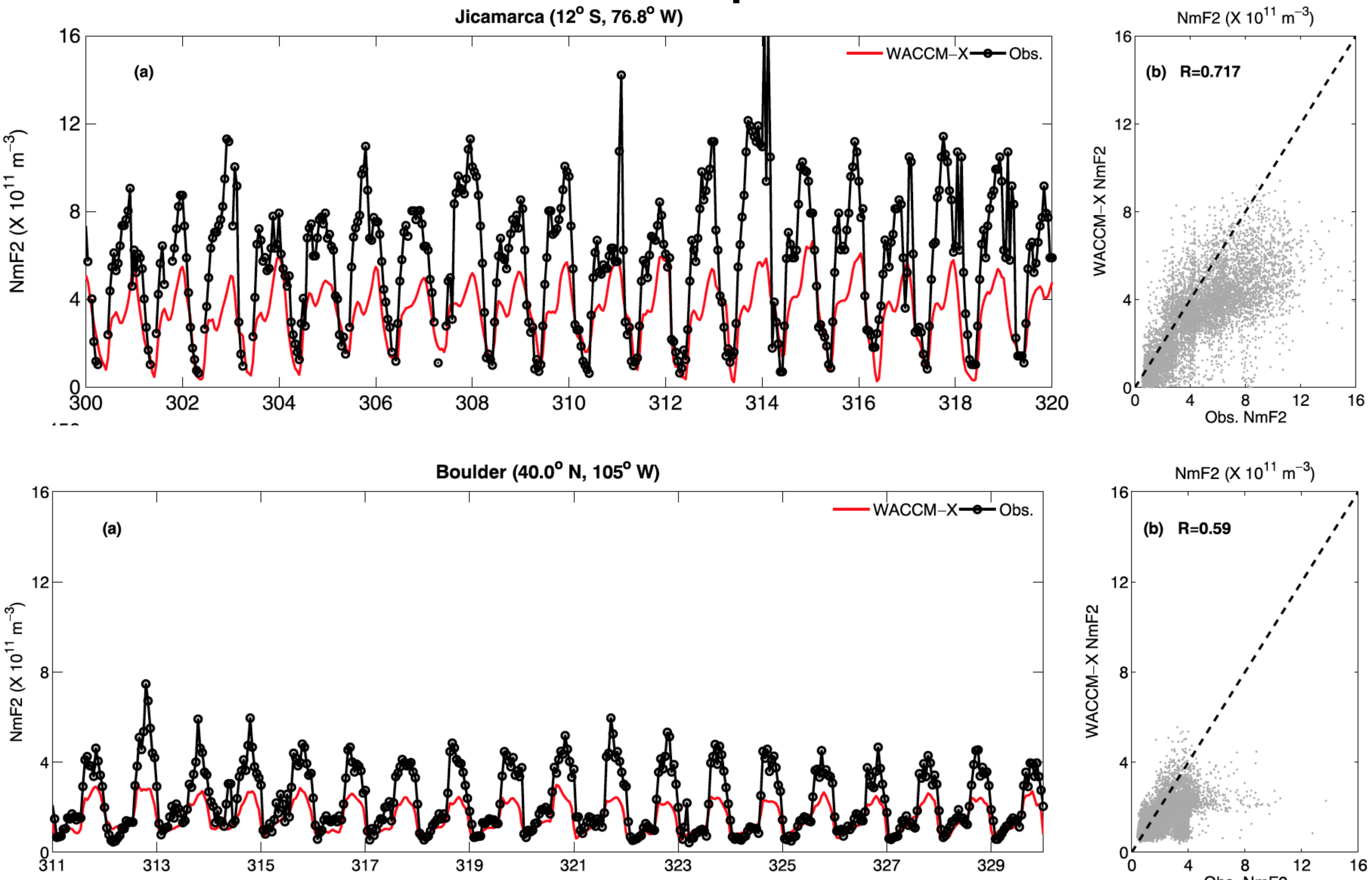
NmF2 Comparisons



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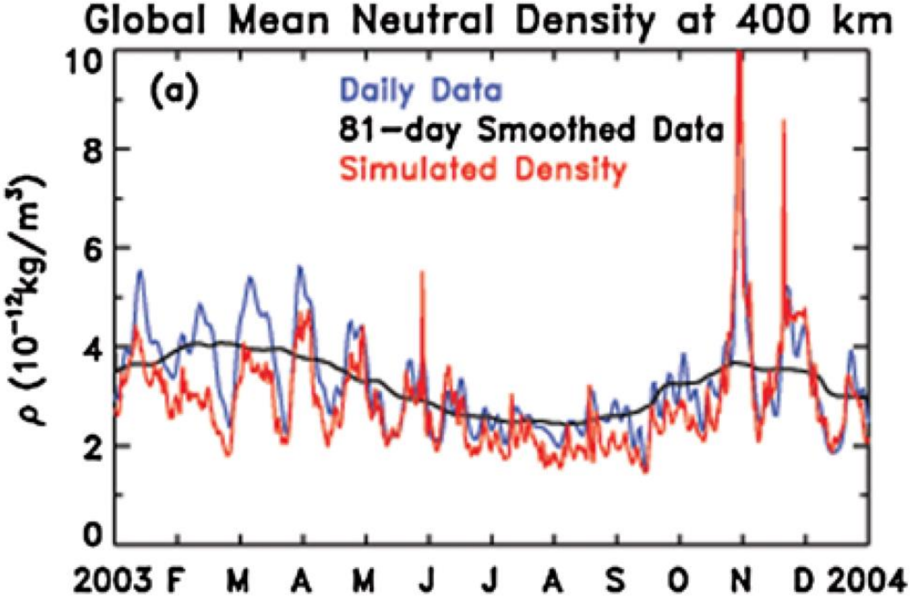
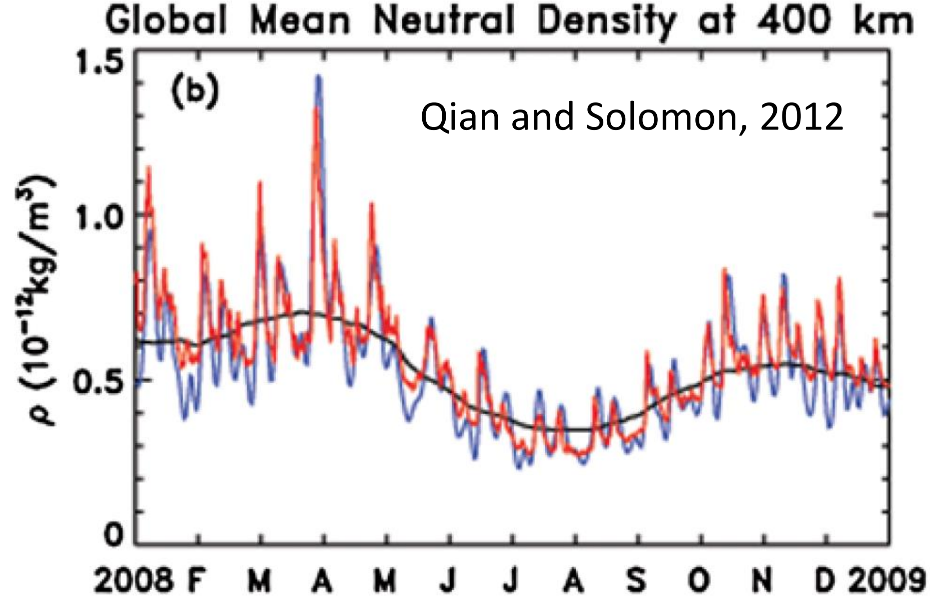
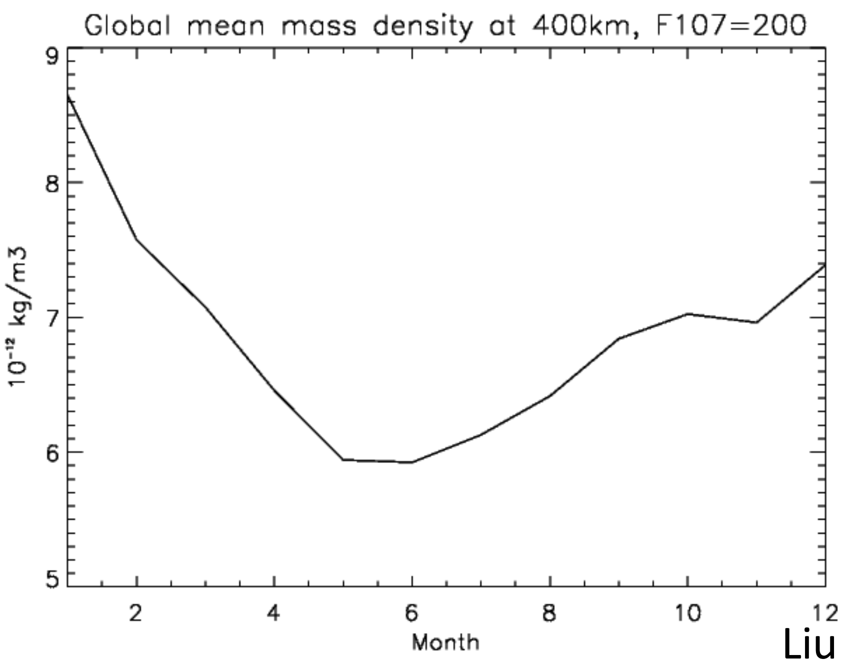
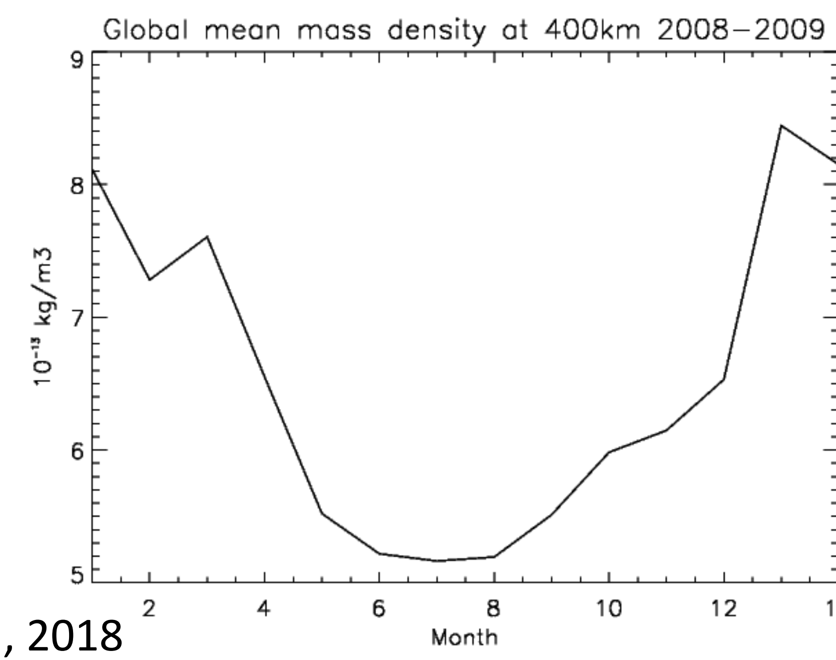
Annual Variation of Neutral Density



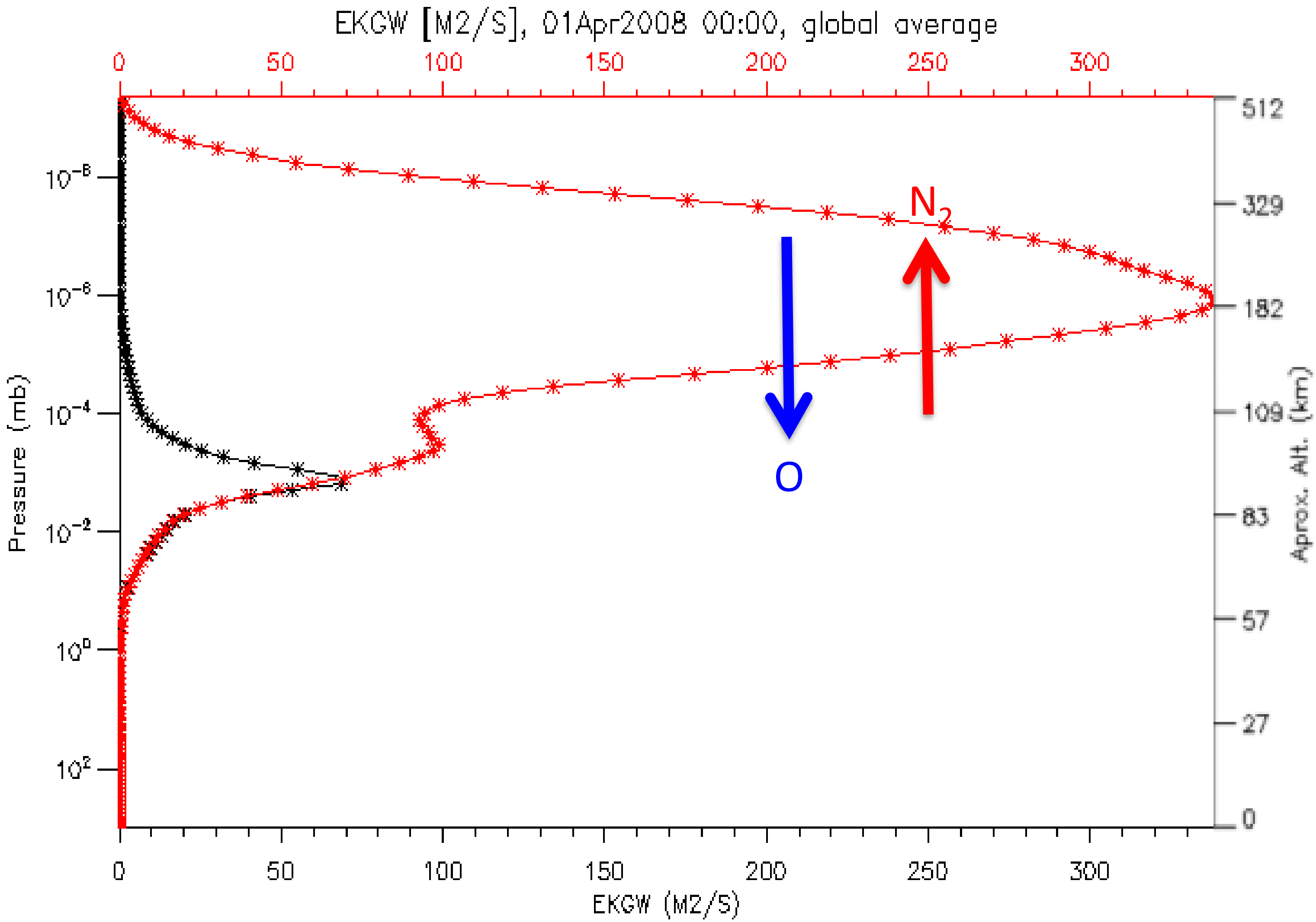






Liu et al., 2018

Effective Eddy Diffusion



Red line: from default GW parameterization

WACCM-X v2.0 Treatment (Garcia et al. 2007)

$$\tau(Z) = \tau(Z_0)\exp\left(-\frac{2}{H}\int_{Z_0}^{Z}\lambda_i dz'\right), \qquad \text{(A9)}$$

✔

$$\lambda_i = \frac{N}{2k(U-c)^2}\left[\alpha + \frac{N^2}{(U-c)^2}K_m\right]. \qquad \text{(A10)}$$

✔

$$\left(\frac{\partial}{\partial t} + U\frac{\partial}{\partial x}\right)\theta' + w'\frac{\partial\overline{\theta}}{\partial z} = -\delta\theta', \qquad \text{(A11)}$$

✔

$$\delta = \frac{c_{gz}}{2H} = k\,\frac{(U-c)^2}{2HN}. \qquad \text{(A12)}$$

Only for breaking GWs

$$\overline{w'\theta'} = -\left[\frac{\delta\,\overline{w'w'}}{k^2(U-c)^2+\delta^2}\right]\frac{\partial\overline{\theta}}{\partial z}. \qquad \text{(A13)}$$

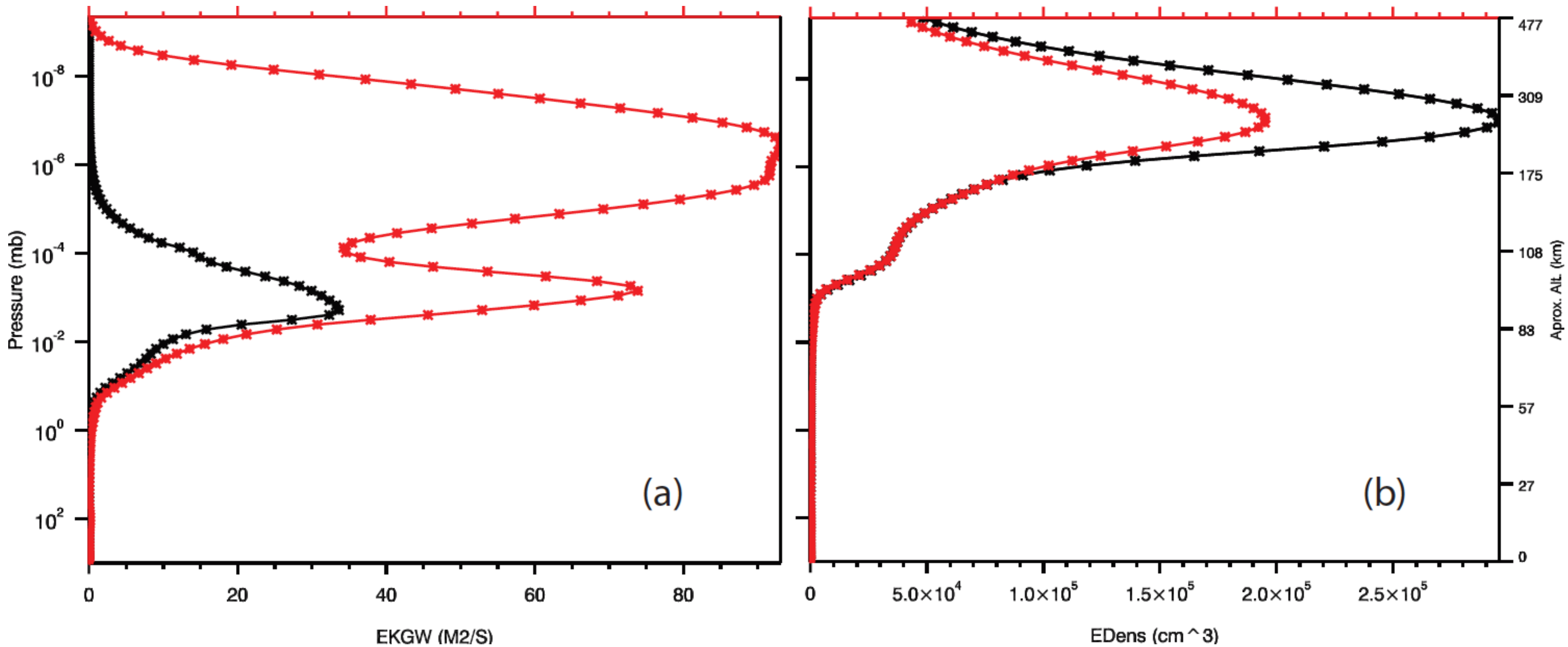
✔

$$\frac{\partial E'}{\partial t} = (U-c)\,\frac{\partial\tau^*}{\partial Z} = -e\rho\,\frac{k\,(U-c)^4}{2NH}. \qquad \text{(A16)}$$

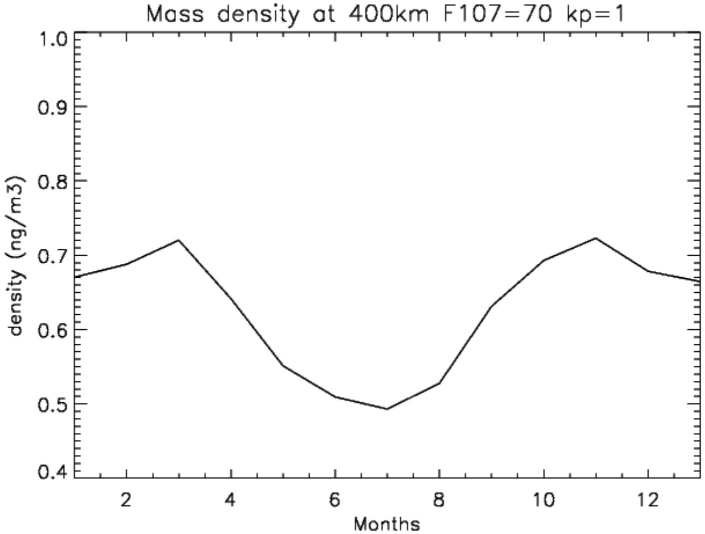
Only for breaking GWs

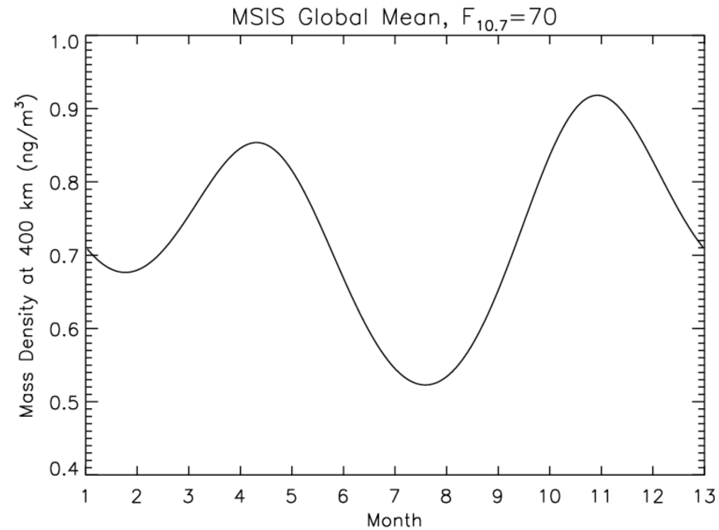
Fix in WACCM-X v2.1

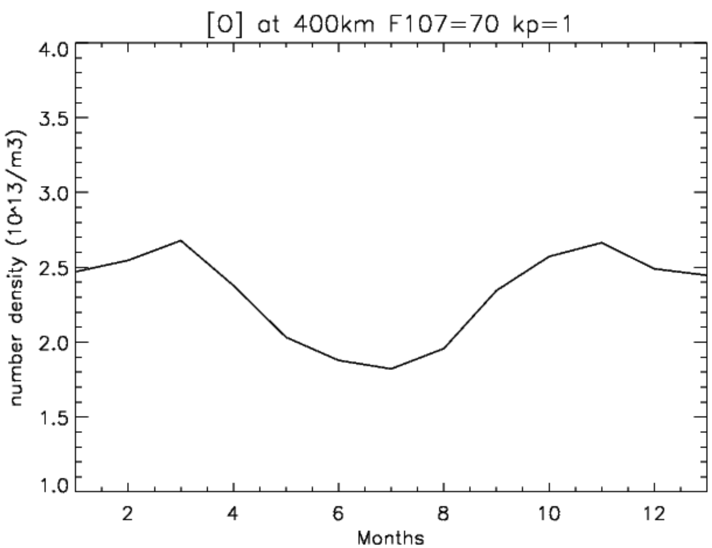
- Reduce eddy diffusion and dissipative heating from gravity wave parameterization above the turbopause.
- Reduce the phase speed spectral width: from +/- 80 m/s to +/- 45 m/s.

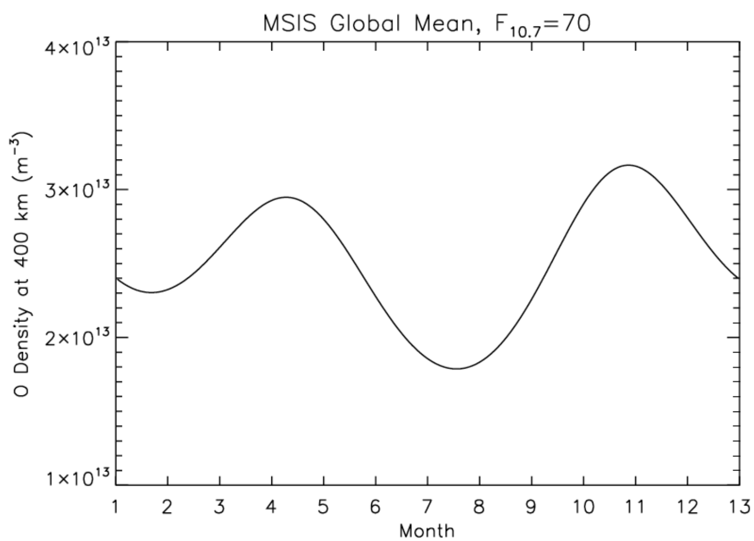


WACCM-X and MSIS: Mass Density and [O]

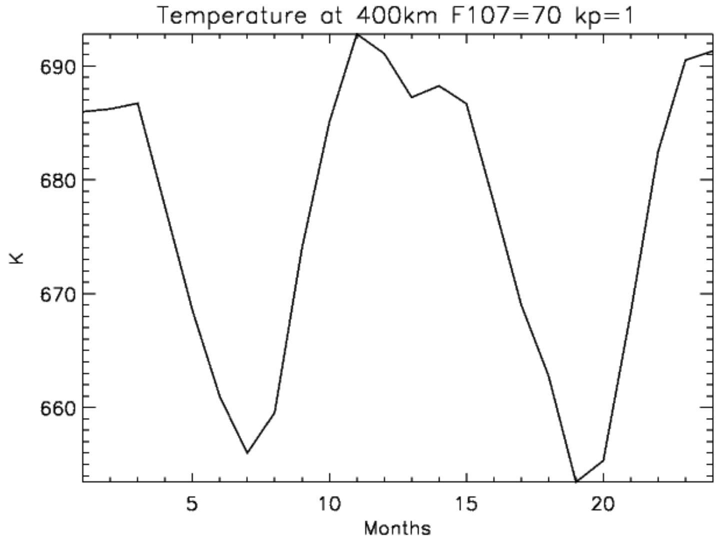


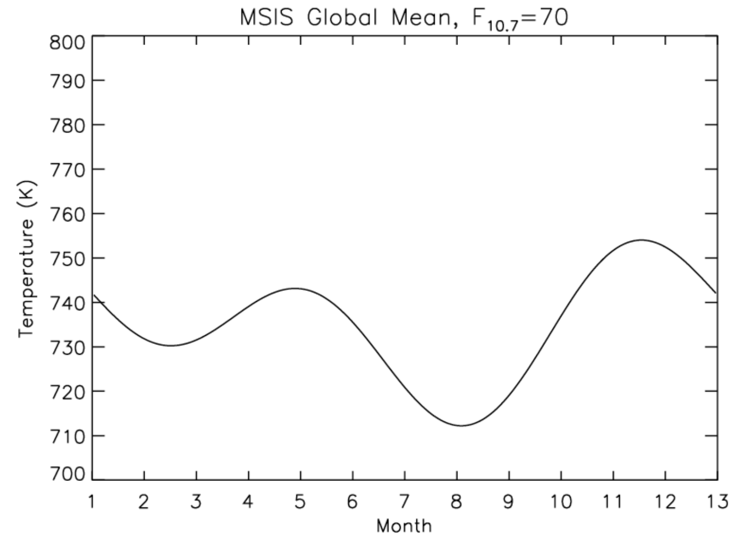


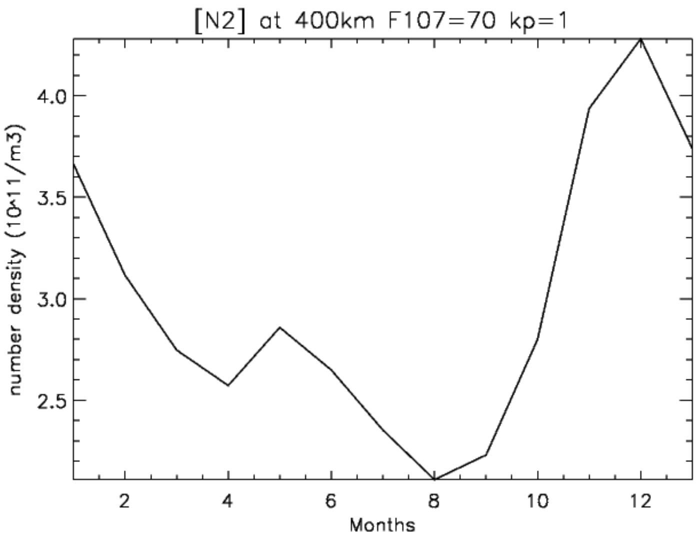


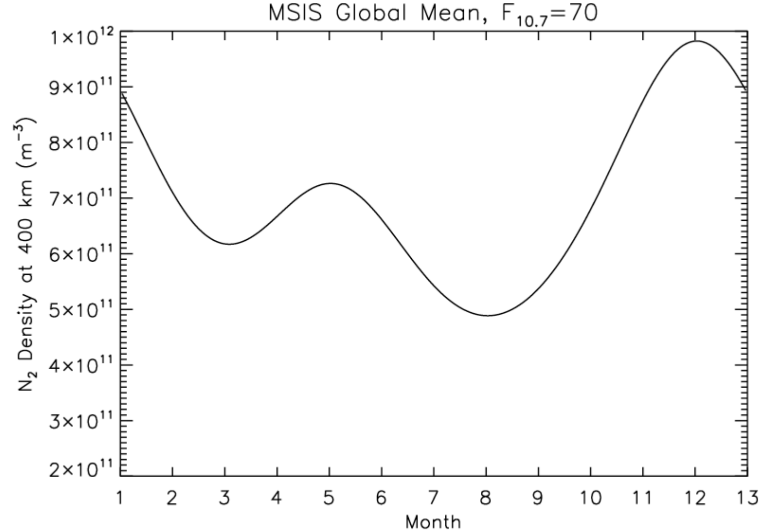


Temperature and $[N_2]$





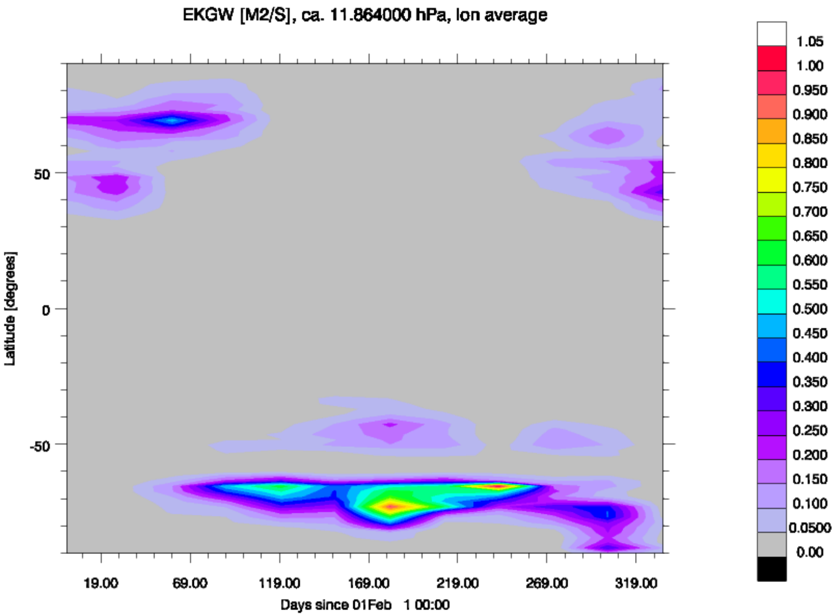


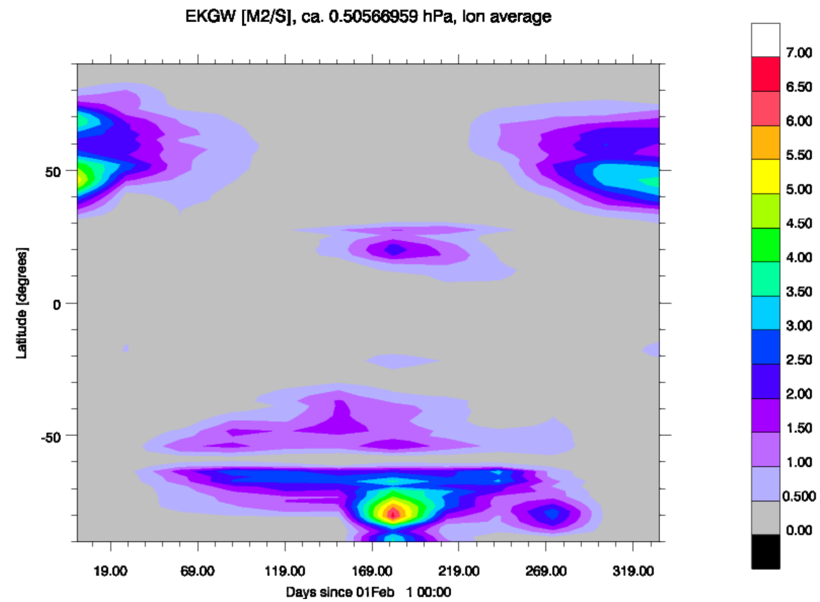


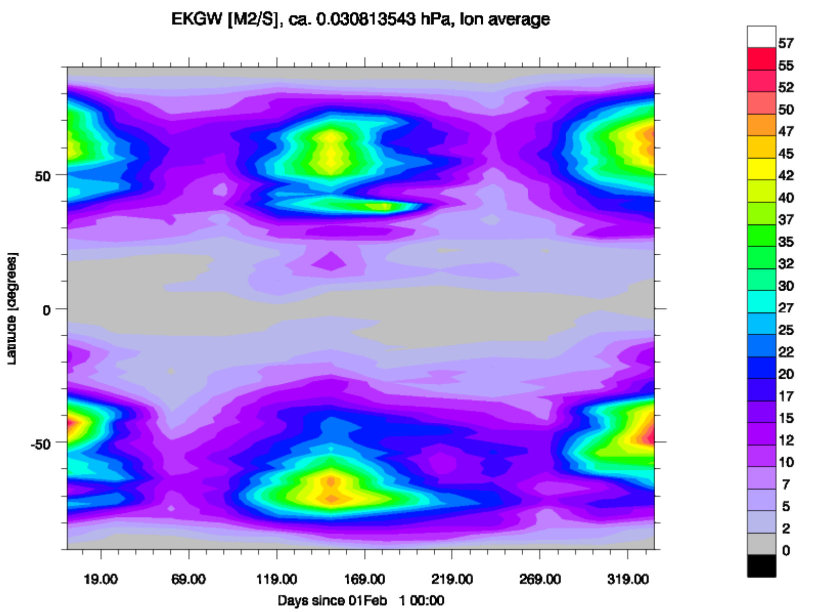
Semi-Annual Variation of Thermospheric Density

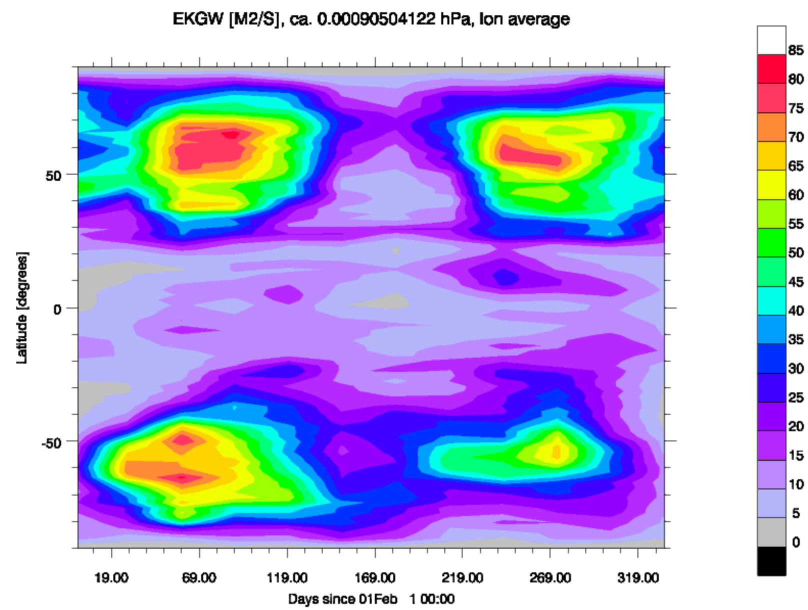
- Large-scale circulation (“spoon effects”):
  - Vertical/meridional circulation more rigorous during solstitial periods.
  - This results in stronger thermosphere mixing, thus smaller O/N_2 in the upper thermosphere, during solstitial periods.
- Seasonal variation of eddy diffusion:
  - Parameterization: Weaker wave filtering at equinox, thus stronger wave breaking/mixing at MLT.
  - Different in high-resolution results.

Kzz in WACCM-X

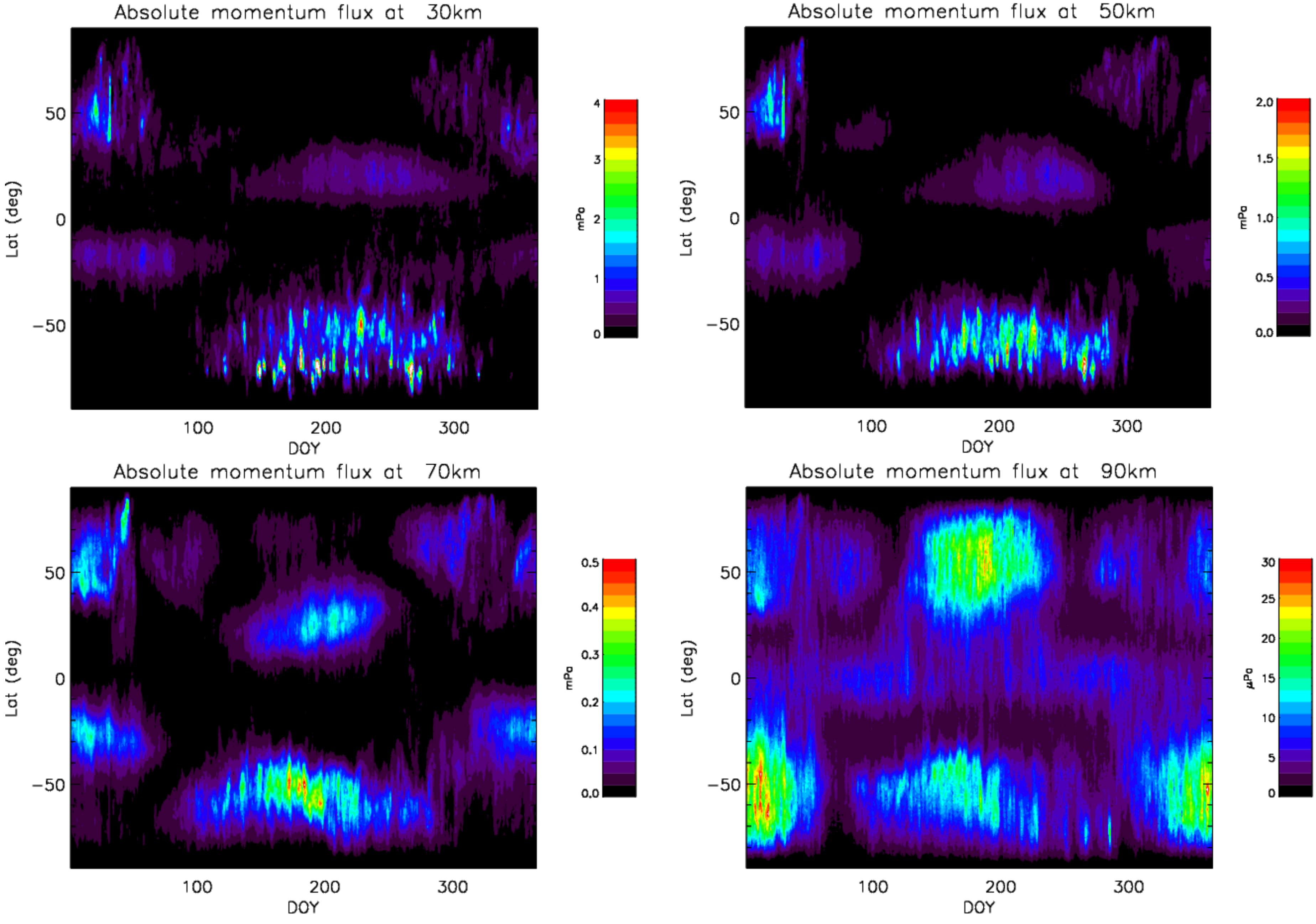








MF Variability from High Res WACCM



Some Remaining Issues/Uncertainties

- Composition/thermal structures.
- Semi-annual variation still small compared with MSIS.
- Gravity wave seasonal variation.
- Gravity wave spectral width.
- Effective eddy diffusion and dissipative heating of gravity wave in a viscous environment.