Thermospheric and Ionospheric Composition and Gravity Wave Parameterization

Hanli Liu\textsuperscript{1}, Rolando Garcia\textsuperscript{2}, Stan Solomon\textsuperscript{1}

\textsuperscript{1}: NCAR/HAO
\textsuperscript{2}: NCAR/ACOM
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 $4 \times 10^{-10}$ hPa, with $\frac{1}{4}$ 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 NmF2: March

J. Liu et al. 2018
NmF2 Comparisons

Jicamarca (12° S, 76.8° W)

(a) WACCM-X - Obs.

(b) $R = 0.717$

Boulder (40.0° N, 105° W)

(a) WACCM-X - Obs.

(b) $R = 0.59$

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Annual Variation of Neutral Density

Global Mean Neutral Density at 400 km

(a) Daily Data
81-day Smoothed Data
Simulated Density

(b) Qian and Solomon, 2012

Global mean mass density at 400km, F107=200

Liu et al., 2018
Effective Eddy Diffusion
WACCM-X v2.0 Treatment (Garcia et al. 2007)

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

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

\[ \left( \frac{\partial}{\partial t} + U \frac{\partial}{\partial x} \right) \theta' + w' \frac{\partial \bar{\theta}}{\partial z} = -\delta \theta', \quad \text{(A11)} \]

\[ \delta = \frac{c_{gz}}{2H} = k \frac{(U - c)^2}{2HN}. \quad \text{(A12)} \]

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

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

EKGW [M2/S], ca. 11.864000 hPa, lon average

EKGW [M2/S], ca. 0.50566959 hPa, lon average

EKGW [M2/S], ca. 0.030613543 hPa, lon average

EKGW [M2/S], ca. 0.0009050412 hPa, lon average
MF Variability from High Res WACCM

Absolute momentum flux at 30km

Absolute momentum flux at 50km

Absolute momentum flux at 70km

Absolute momentum flux at 90km
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.