Release Notes for the Whole Atmosphere Community Climate Model - eXtended, v. 2.1

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Revisions of the Whole Atmosphere Community Climate Model with Thermosphere and Ionosphere Extension (WACCM-X), designated v. 2.1, were released as an element of CESM 2.1 in January, 2019. WACCM-X 2.1 is currently based on the dynamical core and column physics of WACCM 4, and runs at 1.9° x 2.5° resolution. WACCM-X 2.0 is described in the paper by H.-L. Liu et al. (2018), and has been recently used to study diverse upper-atmosphere and ionosphere phenomena ranging from climate change (e.g., Solomon et al., 2018) to solar eclipse effects (e.g., McInerney et al., 2018). These notes summarize changes, improvements, and options added in the transition from v. 2.0 to v. 2.1.

Revision of eddy diffusion parameterization

The most significant issue with WACCM-X 2.0 was that atomic-to-molecular composition ratios in the thermosphere, particularly in the F-region above ~200 km, were systematically lower than observations, empirical models (e.g., Picone et al. 2002) or predecessor numerical models (e.g., Roble and Ridley, 1994; Qian et al., 2014; Maute, 2017). Low atomic/molecular composition results in depressed ionospheric electron densities in the F-region as well (e.g., Wu et al., 2017; J. Liu et al. 2018). This is because O^+, which is the primary F-region ion, reacts with molecules (chiefly N_2 and O_2) to produce molecular ions, which recombine with electrons to convert ions to neutrals at a much higher rate than O^+ does.

The cause of this problem was identified as excessively high eddy diffusion coefficients above the turbopause, ~100 km altitude. The eddy diffusion formulation is based on the Lindzen gravity wave parameterization scheme, which does not account for molecular diffusion, and implicitly assumes that wave dissipation mainly arises from wave breaking, which is not always true, especially in the thermosphere. High eddy diffusion mixes heavier molecules higher into the thermosphere, and lighter atoms downward into the mesosphere, thereby lowering the atomic-to-molecular composition ratio in the upper thermosphere. Therefore, we implemented a simple ramp-down of the eddy diffusion coefficient with increasing altitude, similar to the approach used in earlier models such as the TIME-GCM. This restored atomic/molecular composition to expected values, and raised ion and electron densities.

D-region ion chemistry

Another improvement to the WACCM-X ionosphere is the optional addition of full D-region ion chemistry, as described in the WACCM documentation and in the paper by Gettleman et al. (submitted, 2019). This enables more realistic treatment of lower ionosphere contributions to TEC during, e.g., flares, high energy particle events, and better accounts for the contribution to electron column density for comparison to measurements.

Electron temperature solver

An issue with WACCM-X 2.0 was that the time-dependent electron temperature solver can exhibit grid-scale oscillations at very low electron density, manifesting as randomly-distributed spikes at some grid points. These are not energetically important, since it only occurs when electron density is very low, and hence the electron gas does not carry much energy. As a short-term measure while the solver is being improved, we added the heritage steady-state electron temperature solver from the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) as an option, but the default remains the time-dependent solver.

Magnetospheric inputs

The default specification of polar-region electric potential is provided by the Heelis (1982) empirical model, which is driven by the Kp geomagnetic index. In WACCM 2.1, the Weimer (2005) empirical model, driven by upstream solar wind and interplanetary field measurements at 5-minute cadence, is now provided as an option. The implementation method and merging with the low-latitude electrodynamo is the same as in the TIE-GCM, as described in Solomon et al. (2012). Another option for high-latitude magnetospheric forcing is provided by the Assimilative Model of Ionospheric Electrodynamics (AMIE) using file-based inputs, see Richmond & Kamide (1988), Lu et al. (2017)

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