The Extended Unified Model – a new non-hydrostatic model for the thermosphere

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1. Overview

'Space Weather Atmosphere Model and Indices' (SWAMI) is a Horizon 2020 project which aims to enhance the understanding of space weather processes and their impact on atmospheric density, chiefly by developing a unique new whole atmosphere model, which will be a blend of the physics-based Unified Model (UM), and the Drag Temperature Model. The UM currently spans the 0-85 km altitude range, but its dynamical setup makes it potentially very well suited to the thermosphere, and we describe work to extend the UM up to an altitude of ~170 km. We discuss the development of new radiation and chemistry schemes appropriate for the higher altitudes, and associated work on UM robustness, as well as initial work focused on developing the UM for use in the entire thermosphere.

2. Setting up a stable Extended UM

The Extended UM with a upper boundary around 170 km requires additions to the **radiation** scheme (for more accurate heating rates and photolysis rates for the photochemical reactions), new **chemistry** (for the large rise in temperature in the lower thermosphere) and appropriate model **dynamics** (robust enough to run in the less dense thermosphere, where wave amplitudes are large, appropriate representation of gravity waves).

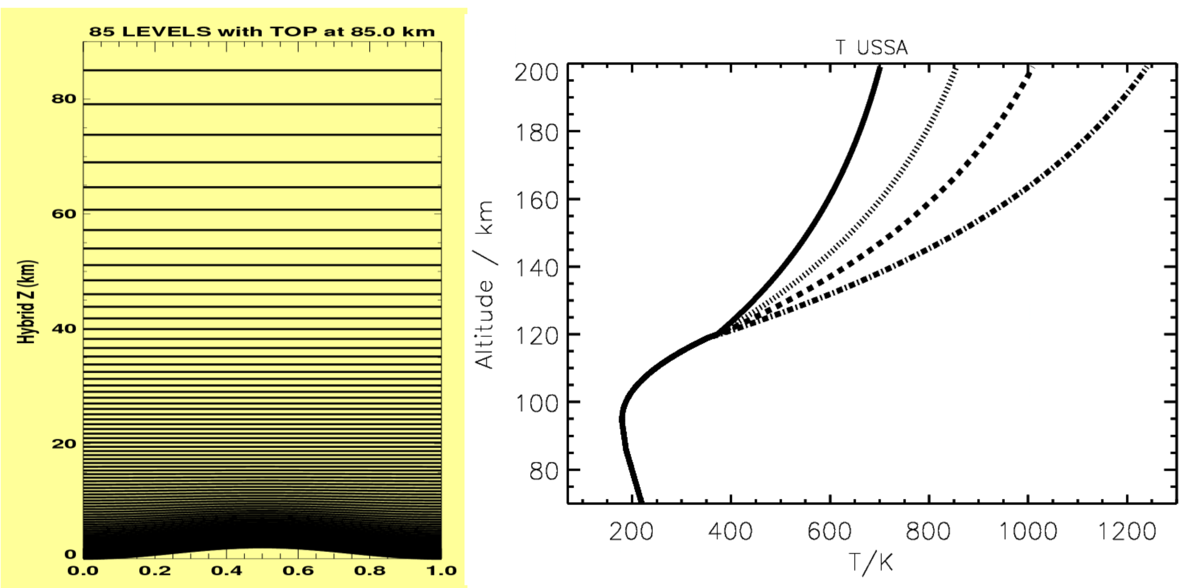

Figure 1 *Left: UM levels for the 85 km version (widely used for Met Office weather and climate applications). Right: temperature climatology with exobase temperatures of 800, 100, 1200 and 1500 K*

Figure 1 shows the existing UM levels. It is more tractable to incrementally raise the UM lid from 85 km to 170 km rather than going to 170 km in one go. Accordingly we start with a lid at 100 km. Using unaltered physics and chemistry, the model ran for a few months before crashing, and we diagnosed that this was due to issues with the radiation scheme (see also Box 3). By replacing radiative heating rates above 70 km with relaxation to the climatological temperature shown in Figure 1, the UM version is now stable, with a reasonably accurate climatology, and can be used as a test bed for further development.

3. Radiation and Chemistry

Figure 2 (top) shows the overestimation of infrared radiative cooling rates above around 65 km altitude and of solar radiative heating rates above around 85 km altitude if a non local thermodynamic equilibrium (LTE) formulation is not used. Figure 2 (bottom) shows a similar result (for the 15 µm CO_2 band) using LTE heating rates from the current UM scheme and non-LTE rates from the Fomichev scheme. The UM has been modified to adopt the Fomichev heating rates above 70 km.

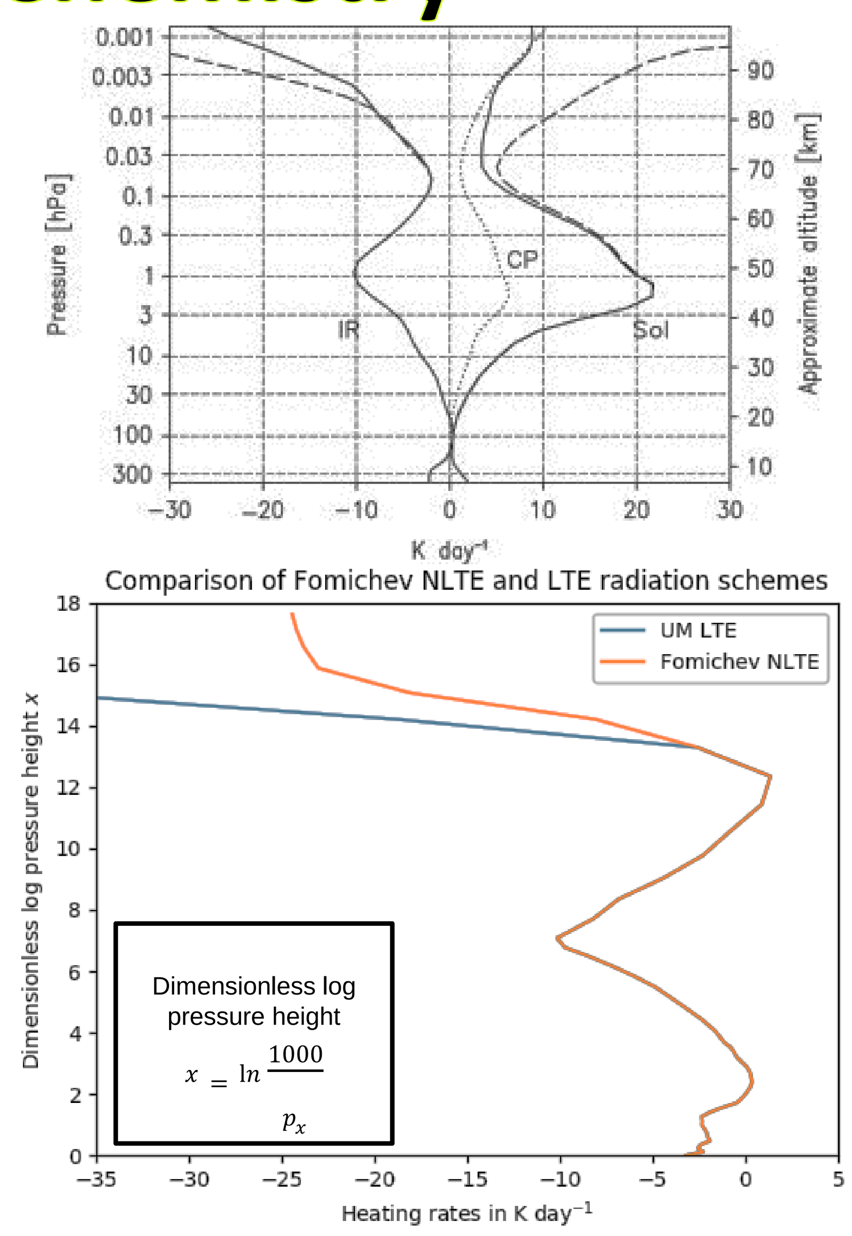

Figure 2 *Top: Radiative heating rates from non-LTE (solid) and LTE (dashed) formulations (after Fomichev, 2009) Bottom: Comparison of 15 µm CO_2 cooling in UM (blue) and Fomichev scheme (orange).*

Figure 3 shows that the stratospheric O3 layer produced by the 100 km UM-UKCA well replicates that produced by WACCM, indicating basic model reliability. In the mesosphere - lower thermosphere, the UM-UKCA produces ~5% of the O, and ~20% of the O3 produced by WACCM, which highlights the requirement for a photolysis scheme extended to shorter wavelengths, in order to generate realistic O and hence O3 concentrations above the mesopause. This is being worked on through changes to the radiation and UKCA chemistry schemes.

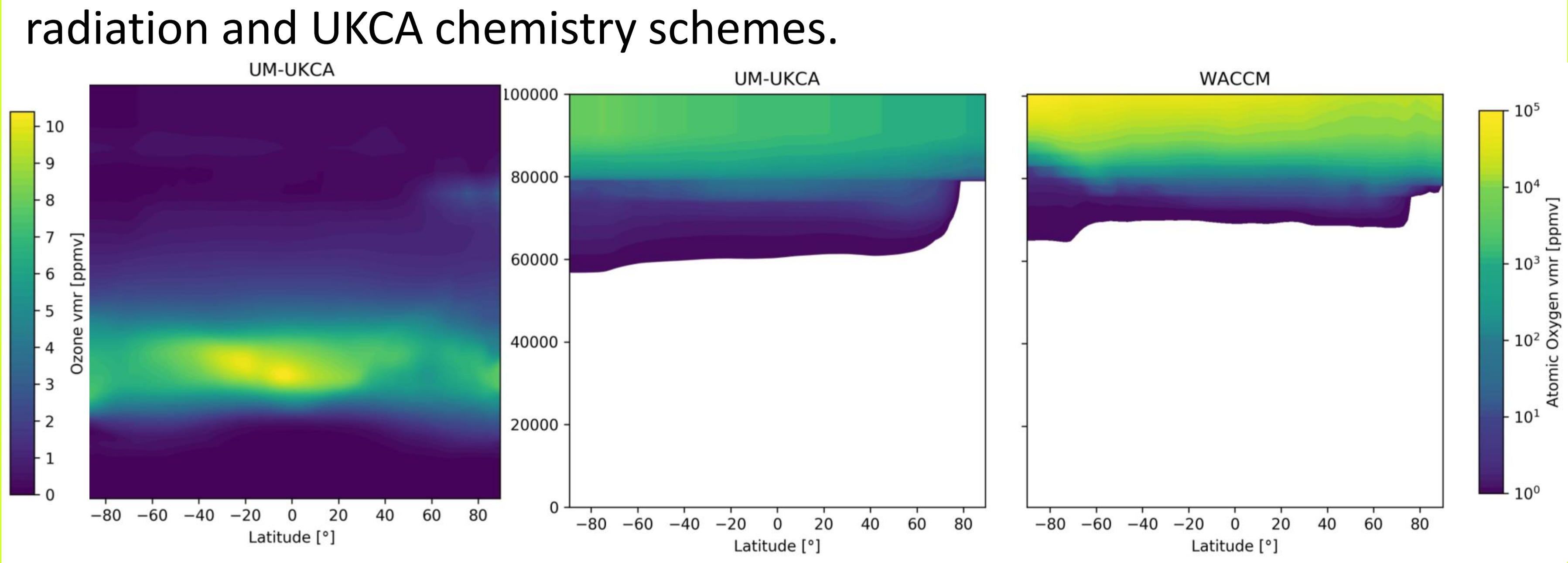

Figure 3 *UM-UKCA and WACCM output for November nighttime, for O3 (l) and O (mid and r)*

4. Dynamics

A next step is to extend the UM lid to 120 km and experiment with a) different vertical resolutions; b) the gravity wave (GW) parametrization scheme. Figure 4 shows that zonal wind acceleration due to this scheme is non-zero and additional diffusion may be required to ensure a realistic profile of GW-induced acceleration in the lower thermosphere and associate accurate mean flow and tidal amplitudes.

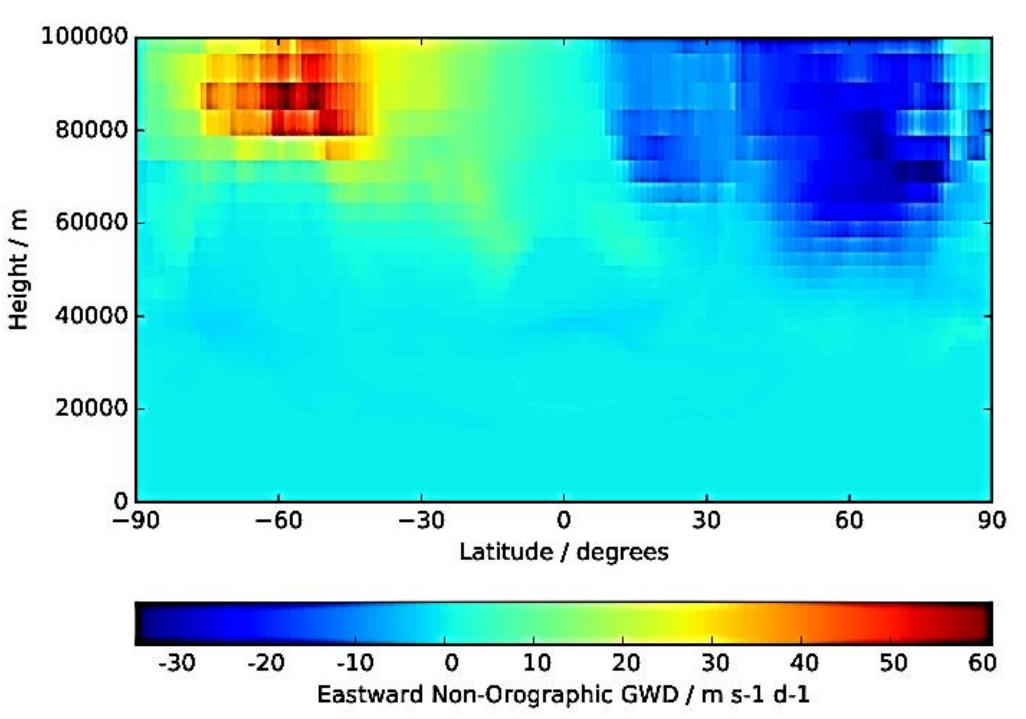

Figure 4 *du/dt (m s⁻¹ day⁻¹) due to GW parametrization in January in 100 km lid UM.*

Our ultimate goal is to produce a Whole Atmosphere version of the UM. Dynamics-only UM tests with lids of up to 600 km show instability due to growing acoustic waves and GWs. Molecular viscosity and diffusion has been added which damps these waves in a physically realistically way above ~130 km (Figure 5). This addition will also be an important part of the 170 km model.

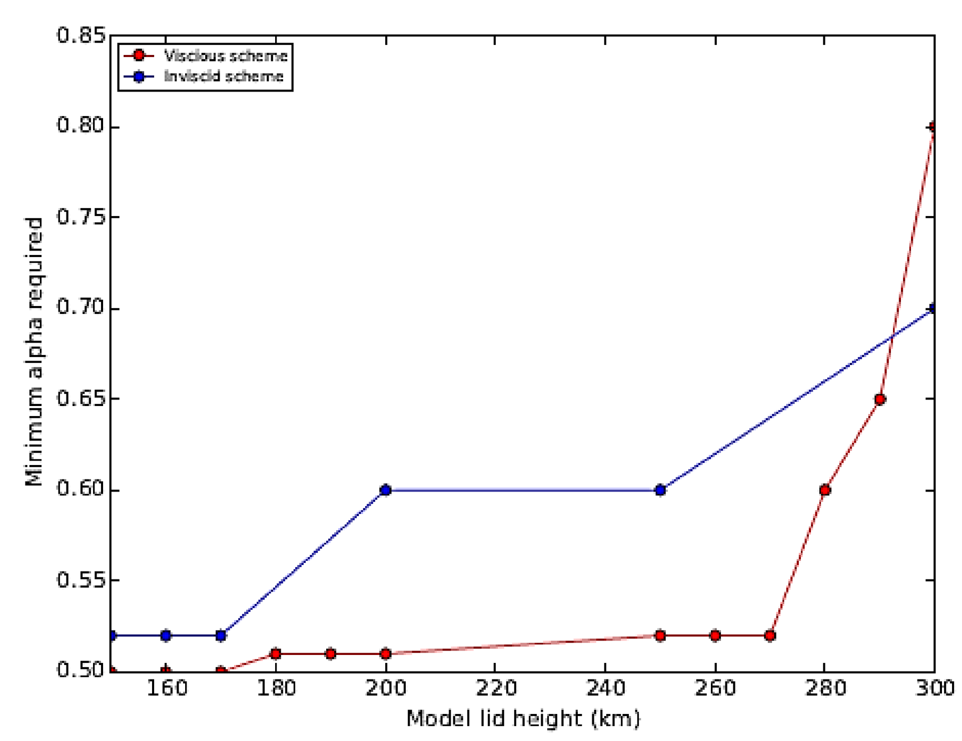

Figure 5 *Height of stable UM simulations with inviscid (blue) and viscous (red) formulations, plotted against off-centring parameter α*

References

Fomichev, V.I., 2009, *J. Atmos. Terr. Phys.*, 71: 1577-1585

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