



Interaction between Stratospheric and Tropospheric Chemistry in a Coupled Chemistry Climate Model

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ABSTRACT

We have coupled two detailed stratospheric and tropospheric chemistry schemes within the UK Met Office Unified Model (UM). Both schemes have been successfully used independently in previous UM studies. The stratospheric scheme is the same as that used in the SLIMCAT/TOMCAT 3D off-line CTM. It contains a description of O_x , NO_y , HO_x , Cl_y , Br_y , source gases and methane oxidation gas-phase chemistry as well as heterogeneous chemistry on sulphate aerosols and polar stratospheric clouds. The tropospheric scheme is that used in the well-established STOCHEM model. This includes detailed non-methane hydrocarbon chemistry, and many of the natural sources (e.g., lightning NO_x , isoprene from vegetation) are derived interactively from underlying climate model. The schemes operate independently but the common fields in the two schemes (e.g. O_3) are merged in the overlap region in the UTLS.

UM+SLIMCAT Results

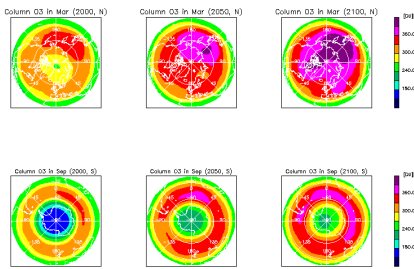


Fig. 1. Total column ozone in Arctic in March (top) and in the Antarctic in September (bottom) for the years 2000, 2050, and 2100. The results are based on 10-year timeslice runs with stratospheric chemistry being coupled to UM. GHG values are taken from IPCC A2 scenario and the SSTs are the same and fixed in these three runs. (For more details about coupled model see Tian and Chipperfield, QJRM, in press, 2004).

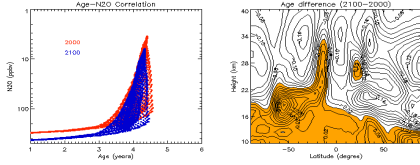


Fig. 2. (left) Mean age and N_2O correlation for 2000 and 2100 and (right) the difference in the age of stratospheric air between 2000 and 2100. Positive contours are shaded.

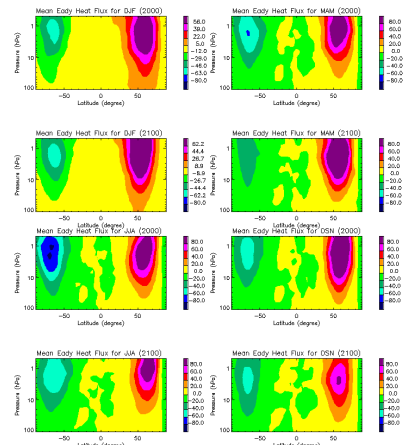


Fig. 3. The ensemble, seasonal mean horizontal eddy heat flux from run 2000 and 2100.

Conclusions: The persistent ozone recovery is evident from 2000 to 2100 in the polar stratosphere. The age of air in 2100 is younger than that in 2000 in the middle and upper stratosphere. Significant differences in eddy heat flux can also be noted between 2000 and 2100.

References: Chipperfield, M. P., Multiannual simulations with a three-dimensional chemical transport model. *JGR*, 104, 1781-1805, 1999.

The Coupled Model

GCM (UM)

- UM horizontal resolution: 2.5° latitude x 3.75° longitude; 64 levels surface to 0.01hPa (~80 km).
- Atmosphere-only model, driven by prescribed SSTs.

Stratospheric Chemistry (SLIM/TOMCAT)

- Full stratospheric chemistry scheme from SLIMCAT/TOMCAT CTM [Chipperfield, 1999] which includes O_x , HO_x , Cl_y , Br_y , and NO_y families, CH_4 oxidation; source gases; heterogeneous chemistry on liquid aerosols and solid PSCs.
- 28 Eulerian chemical tracers with ~42 chemical species.
- O_3 , H_2O , CH_4 , and N_2O fields are coupled to UM radiation scheme.
- Lowest level for chemistry calculation 142 hPa.

Tropospheric Chemistry (STOCHEM)

- Lagrangian transport scheme, maps to an Eulerian grid of resolution 5° x 5° x 10 vertical levels, up to 50 hPa.
- Air parcels carry mixing ratios of 70 chemical species, 160 chemical reactions, including 11 NMHCs.
- Emissions are prescribed, some natural emissions (lightning NO_x and C_2H_6 from vegetation are interactively linked to UM variables).
- Dry and wet removal from the boundary layer and within/below clouds.

- Two chemistry schemes overlap between 50-142 hPa; fields can be exchanged between sub-models every 3 hours

Motivation and Aims: Future changes in climate are expected to cause important changes in the distribution of key chemical species in both the stratosphere and troposphere. Stratospheric cooling may enhance polar O_3 loss in the near future but ultimately lead to larger levels of O_3 than in the past. In the troposphere there are many competing processes (e.g., increases in water vapour, and hence OH) which may lead to increases or decreases in regional pollution. Due to limitations in computer resources, and the general immaturity of coupled chemistry-climate models (CCMs), those stratospheric or tropospheric processes have so far only been studied in isolation and then often with simplified models. However, these stratospheric and tropospheric changes will interact and should be studied together in a fully coupled model.

UM+SLIMCAT+STOCHEM First Results

The chemistry modules have been coupled by exchanging relevant fields in the overlapping UTLS region (50-150 hPa). As a first test of the model, we have passed SLIMCAT O_3 fields to STOCHEM every 3 hours, and used them in both the photolysis scheme and for stratosphere-troposphere exchange (STE). Preliminary results for O_3 , OH and O_3 net chemical production are presented in Fig. 5. Relatively small differences ($\pm 2\%$) (compared to using the stratospheric O_3 climatology) are found when just photolysis is coupled, but larger changes ($\pm 20\%$) occur when STE is also included. The next steps will be to extend the range of species exchanged in the tropopause region (e.g., CH_4 , N_2O , CH_3Br). The full model is found to run reasonably efficiently in coupled mode, allowing multiannual simulations. Some efficiency measures can probably be included to improve performance.

UM+STOCHEM Results

A version of STOCHEM coupled to the 19-level UM has been used to simulate the period 1990-2030 using a new "business as usual" (BAU) emissions scenario from IIASA. In this run, the UM was driven with monthly SSTs from an earlier IS92a-forced simulation of HadCM3, with a coupled ocean. Surface temperatures show an increase of ~1K between the 1990s and the 2020s. The simulated O_3 responds to both changes in emissions and changes in the physical climate.

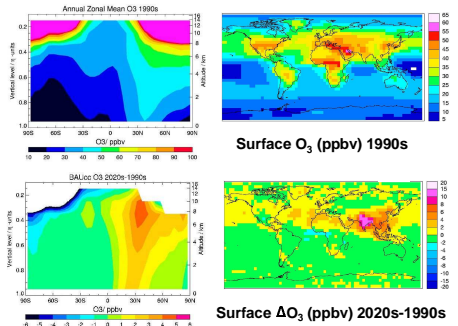


Fig. 4. Decadal mean zonal mean O_3 and surface O_3 for the 1990s, and their changes up to the 2020s. This simulation used a fixed O_3 climatology above 100 hPa. Results in the lower stratosphere are masked, as we have low confidence in both the model dynamics and chemistry in this region. Tropospheric changes are driven by increases in emissions (mainly S.E. Asia and from ships), and are strongest in the upper troposphere at ~30-40°N. Rises in temperature and water vapour increase both O_3 production and O_3 destruction chemistry, but net O_3 production falls, when compared to a run with fixed climate.

But what are the likely effects of including stratospheric change as well? Changes in stratospheric ozone will affect tropospheric photolysis rates and the influx of ozone to the troposphere.

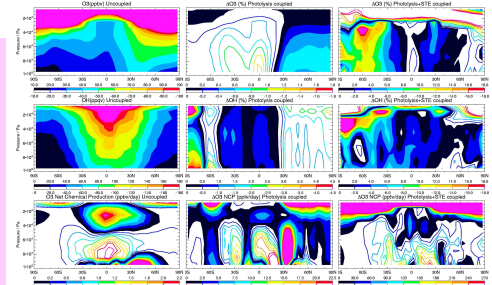


Fig. 5. Preliminary results from the coupled model. Middle /right columns shows changes when tropospheric photolysis rates/both photolysis rates and strat-trop exchange are coupled to SLIMCAT stratospheric ozone values.

Acknowledgements: This research was supported by the U.K. Natural Environment Research Council (NERC) UTLS-O3 programme and UGAMP. DS is supported by an Environment Agency/NERC fellowship.