Sensitivity of a coupled chemistry-climate model to climate model biases

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Interactions between atmospheric chemistry, aerosols, and the biosphere are important components of an Earth System Model. To understand the uncertainties of the coupled system, we need to investigate the role of biases in the coupling between model components. For example, the performance of an atmospheric chemistry model may differ when run using prescribed meteorology from that run in a coupled chemistry-climate model. Here, we examine the response of a coupled chemistry-climate model to known biases in some of the climate model fields which drive the chemistry component of the model.

We make use of a new community model called the UK Chemistry and Aerosols model, UKCA, developed jointly in the UK and coupled to the Hadley Centre's climate model, HadGEM1. We will present the known climate model biases and explore the impact of these on a tropospheric chemistry scheme running within UKCA.

A. Temperature and Specific Humidity Biases

A 10-year integration of the Hadley Centre's climate model, HadGEM1, has been used to construct a present-day climatology of temperature and specific humidity, which is shown in Figure 1 for the Dec-Jan-Feb (DJF) time period.

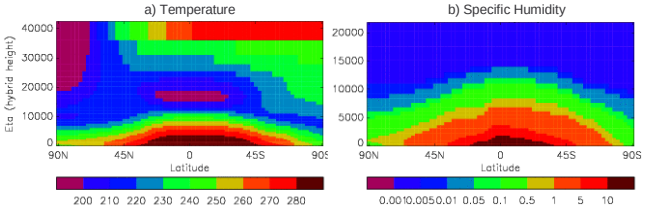

Figure 1: Climatology of a) temperature in Kelvin and b) specific humidity in g/kg for the DJF time period from a 10-year integration of HadGEM1.

Figure 2 shows the HadGEM1-ECMWF differences in temperature and specific humidity, with the grey shaded areas showing where the biases in HadGEM1 relative to ECMWF are statistically significant at the 90% confidence interval. It indicates that HadGEM1 is too cold in the upper troposphere in the tropics and extra-tropics in DJF. In the tropical stratosphere, there are both cold and warm biases of the order of 3K. For specific humidity, the troposphere is too dry in the tropics and too moist in the extra-tropics.

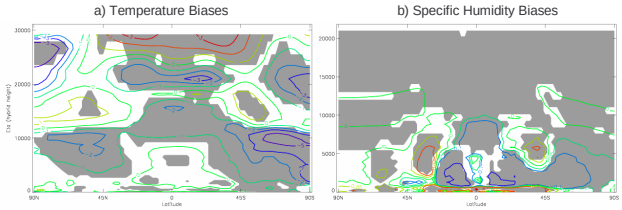

Figure 2: HadGEM1-ECMWF differences in a) temperature in Kelvin and b) specific humidity in g/kg for DJF. Differences are statistically significant at the 90% confidence interval where shaded.

The objective of this work is to assess the impact of these model biases on the performance of a tropospheric chemistry scheme.

B. Model Experiments

Four experiments were carried out with a tropospheric chemistry scheme running in the UKCA model and coupled to HadGEM1 as follows:

Run 1) Control – temperature and humidity biases not removed
Run 2) Temperature bias removed
Run 3) Specific humidity bias removed
Run 4) Temperature and specific humidity biases removed

In all experiments, the underlying dynamics of the climate model were unchanged; the corrections to temperature and specific humidity were only applied to the fields provided to the chemistry. This was carried out at every time step using multi-annual monthly mean HadGEM1-ECMWF temperature and/or humidity differences.

C. Impact of Temperature Bias

The DJF O_3 and OH distributions from Run 1 can be seen in Figure 3. When the cold temperature bias is removed, there is a decrease in NO_x concentrations. This results in a decrease in O_3 (Fig. 4a), which is statistically significant at the 90% confidence interval, albeit small and limited in spatial extent. A larger and more spatially distributed decrease in OH (Fig. 4b) also occurs, resulting in a significant increase from 9.97±0.03 to 10.19±0.03 years in the global tropospheric lifetime of CH_4 against OH loss.

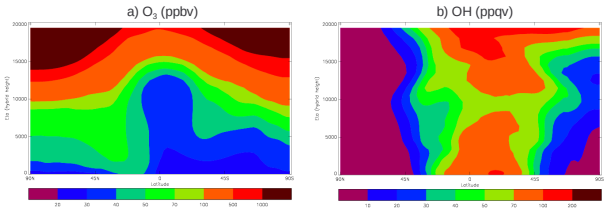

Figure 3: DJF zonal mean distributions from Run 1 of a) O_3 in ppbv and b) OH in ppqv.

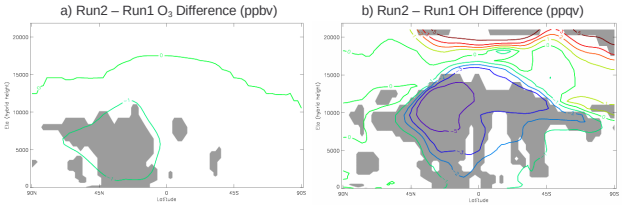

Figure 4: DJF distributions of a) Run2 – Run1 O_3 difference in ppbv and b) Run2 – Run1 OH difference in ppqv. Shading shows where differences are statistically significant at the 90% confidence interval.

D. Impact of Specific Humidity Bias

The differences in O_3 and OH resulting from the removal of the specific humidity bias in HadGEM1 can be seen in Figure 5. It indicates that when the extensive dry bias in the coupled model is removed, there is a small but significant decrease in O_3. A substantial increase in OH in the tropical and southern hemisphere extra-tropical troposphere is evident as a consequence of an increase in water vapour. As a result, the methane lifetime is reduced from 9.97±0.03 to 9.61±0.03 years

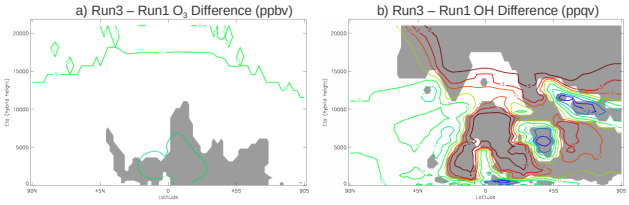

Figure 5: DJF distributions of a) Run3 – Run1 O_3 difference in ppbv and b) Run3 – Run1 OH difference in ppqv. Shading shows where differences are statistically significant at the 90% confidence interval.

E. Impact of Combined Temperature and Specific Humidity Biases

When both the cold and dry biases are removed simultaneously, it results in a significant decrease in O_3 and an overall increase in OH. The methane lifetime is thus reduced from 9.97±0.03 to 9.58±0.02 years.

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For further information on UKCA, see http:www.ukca.ac.uk

Conclusions: Significant biases in the climatologies of temperature and specific humidity from the climate model, HadGEM1, relative to ECMWF re-analyses are evident. The aim of this work was to investigate the response of a coupled chemistry-climate model to these known biases.

When the temperature and humidity bias were removed separately, there was a small and spatially limited decrease in O_3 in DJF. However, the decrease was statistically significant at the 90% confidence interval in both cases. The impact on OH differed in the two cases: when the temperature bias was removed, it resulted in a decrease in OH whereas when the humidity bias was removed, an increase in OH occurred. This has implications for the global tropospheric lifetime of CH_4 against OH loss. The combined effect appears to show some non-linearity in the methane lifetime.

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