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

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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 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.

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 OH against OH loss.

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 when both the cold and dry biases are removed simultaneously.

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.

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.