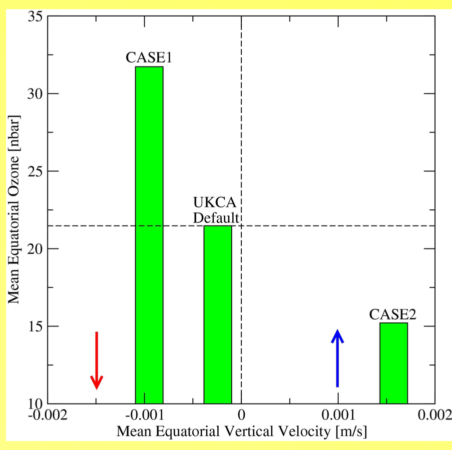
The Role of Tropical Vertical Velocities in Determining Tracer Gradients in the Upper Troposphere and Lower Stratosphere



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Abstract:

Many chemistry-climate models (CCMs) have a tendency to overestimate ozone in the tropical upper troposphere and lower stratosphere (UT/LS). There are many possible reasons for this overestimation, including models' representation of the transition from the upward branch of the Hadley cell to the rising branch of the Brewer-Dobson circulation. We analyse tropical vertical velocity profiles in the UT/LS region in idealised model sensitivity studies. We use the non-hydrostatic UK Chemistry and Aerosol community model (UKCA) and apply spatial "filtering" and a targeted addition of "ascent velocities" (resulting in an offset in the departure point of the semi-Lagrangian trajectories) to the vertical velocities "seen" by the tracer transport scheme. Tropical tracer gradients of ozone and vertical velocity profiles will be analysed and their changes described. Results confirm that part of the overestimation of UT/LS ozone can be explained by the characteristics of the modelled vertical winds in this transition region. We quantify the effect of changing tropical up- and downwelling on ozone in our model.

Model:

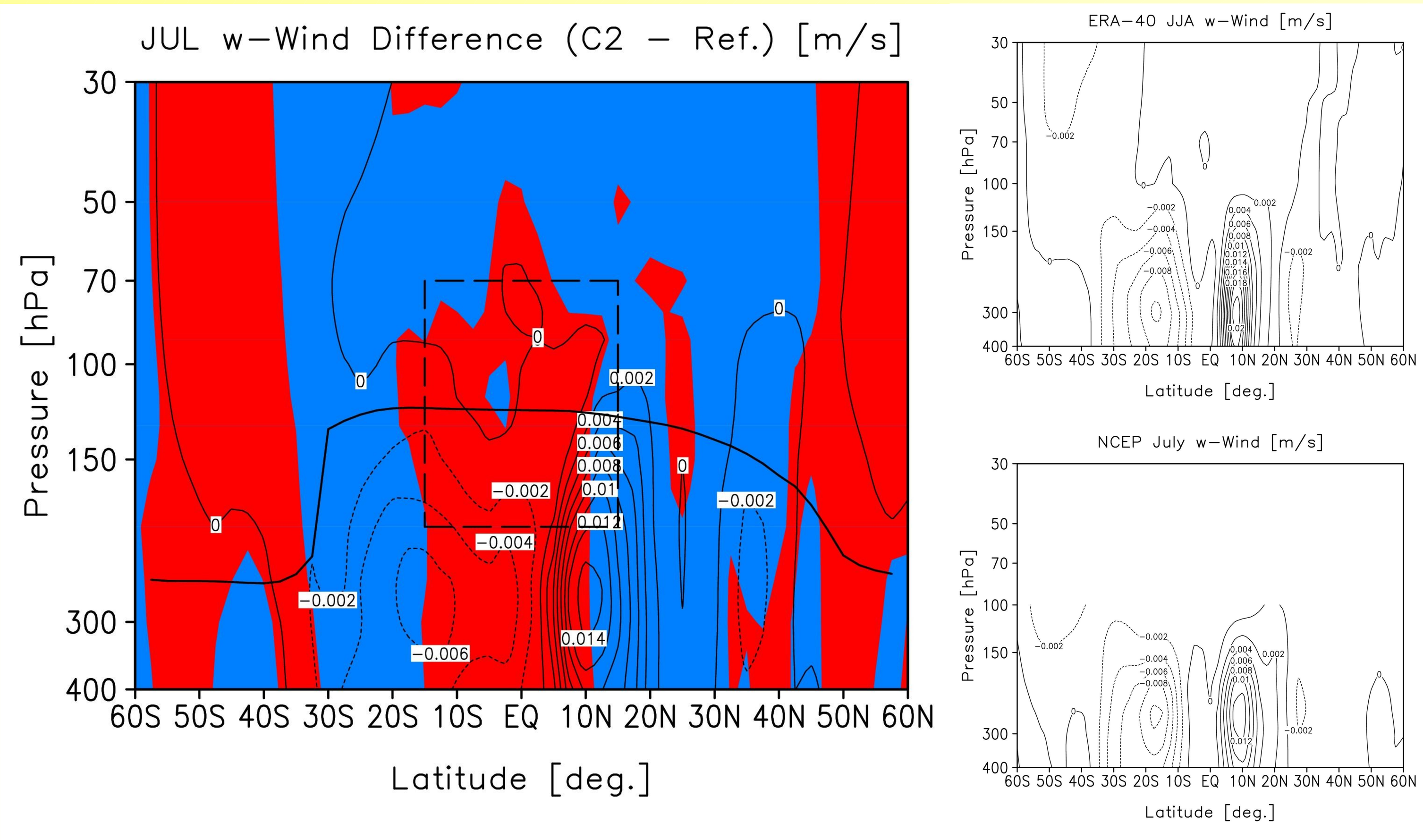
This study uses the UKCA model, the UK Chemistry and Aerosol Community Chemistry-Climate GCM. The GCM is the Met Office's Unified Model (UM) with 60 levels (L60) extending from the surface to around 83km with N48 horizontal resolution (3.75°x2.5° in longitude and latitude). The sensitivity runs are started 1st September after spinning up the model for ten years with the analysis focusing on the July.

Experiment:

We specify a small "displacement" in the vertical departure point of tracer trajectories. For numerical stability a small horizontal diffusion of vertical velocities in the form of a "moving" five-gridpoint average is applied before a vertical velocity offset is added in the region indicated by dashed lines (the dynamical model core is not directly affected, apart from possible feedbacks due to changing tracer concentrations).

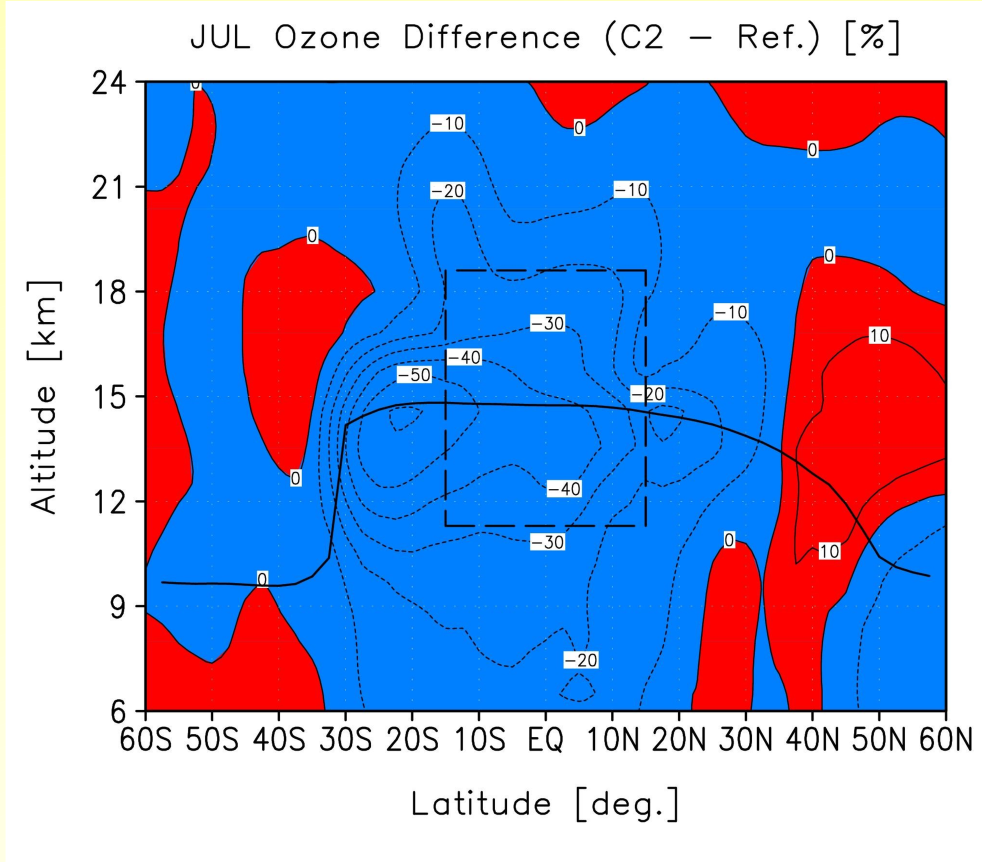
Case 1: the homogeneous offset results in additional downwelling in the model.

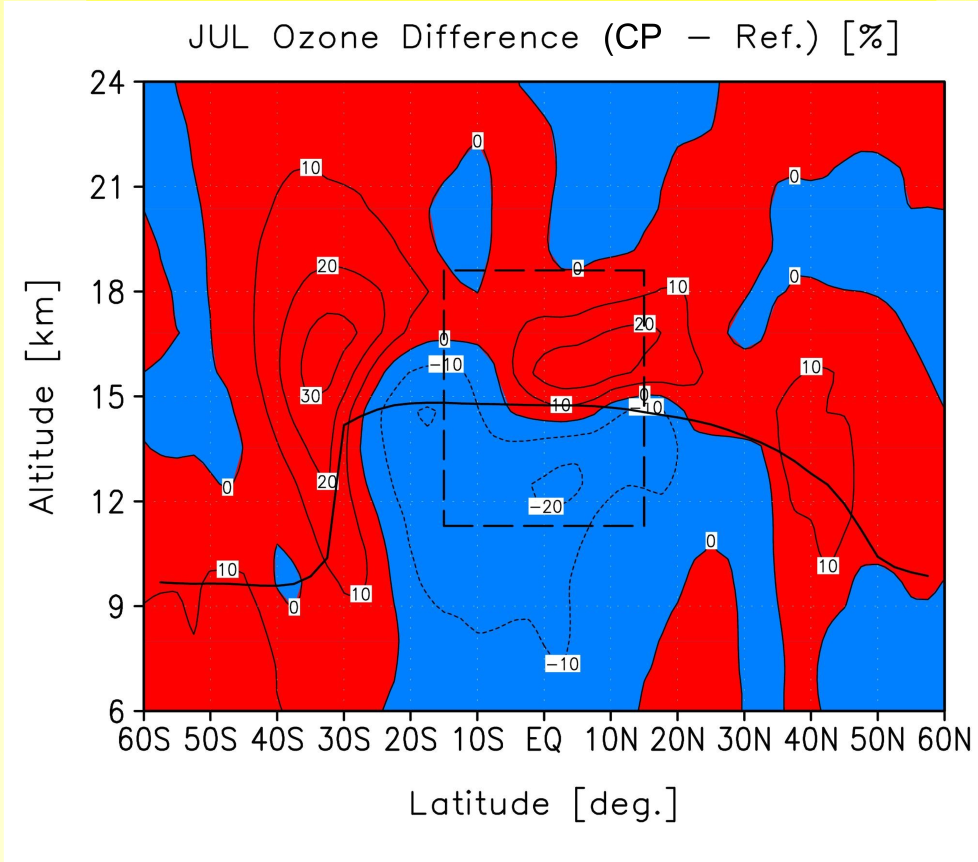
Case 2: the homogeneous offset results in additional upwelling in the model.

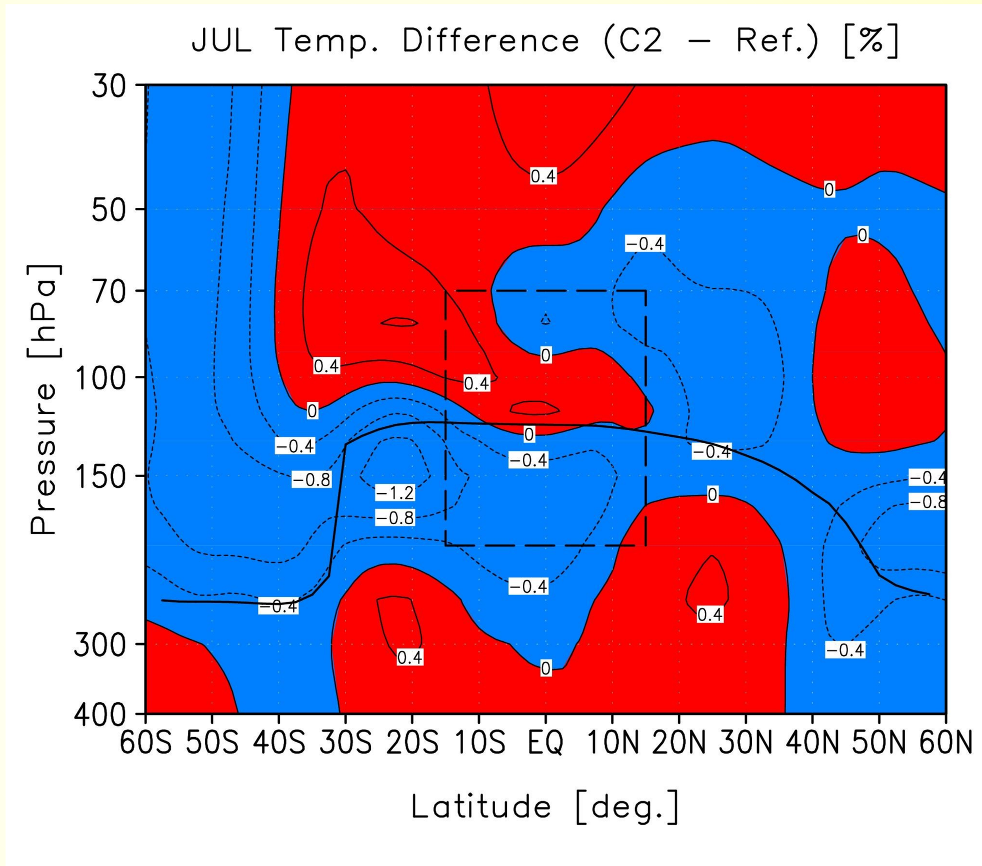


Above:

July monthly and zonal mean vertical velocities from a **default UKCA** integration (isolines). The difference between the **Case 2** and the default UKCA integration for July are indicated by shadings (red: positive, weaker downwelling or stronger upwelling; blue: negative, stronger downwelling or weaker upwelling). To **the side:** Mean vertical velocities from ERA-40 and NCEP. Note latitude variations in the position of the maximum and in the extent of the tropical "zero wind line" ("ITCZ characteristics").







Above left:

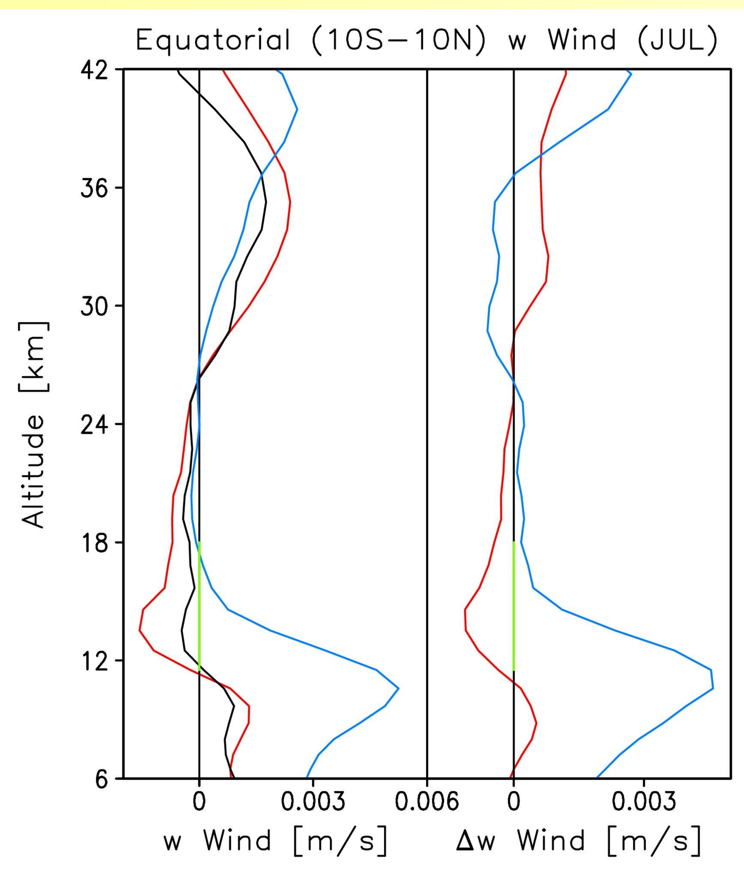
Difference in monthly and zonal mean ozone between **Case 2** and the **default UKCA** (isolines) for July. Shadings indicate the sign of the difference. The thick solid line indicates the position of the tropopause in July for the **default UKCA** integration. Note the large percentage decrease in ozone around the tropopause.

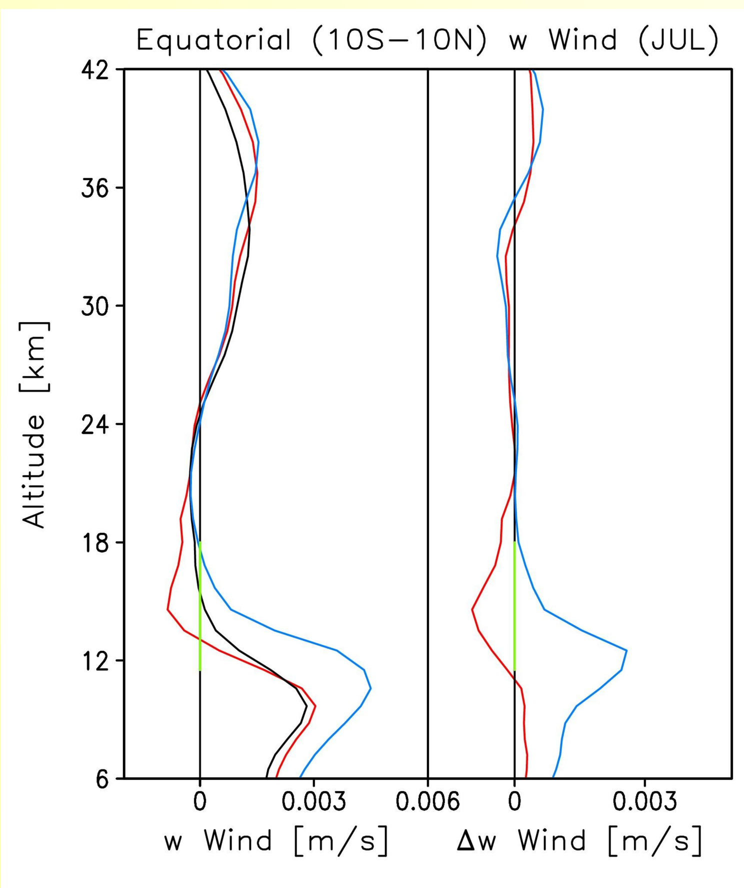
Left:

As above, but for the corresponding change in temperature (changes in percent).

Above right:

Sensitivity check: In the default UKCA model convection is called every second time-step. Calling convection every time-step shows some similarities in the calculated ozone differences to our idealised change (above left). This statement is true for July, but not for all other months!





Far left:

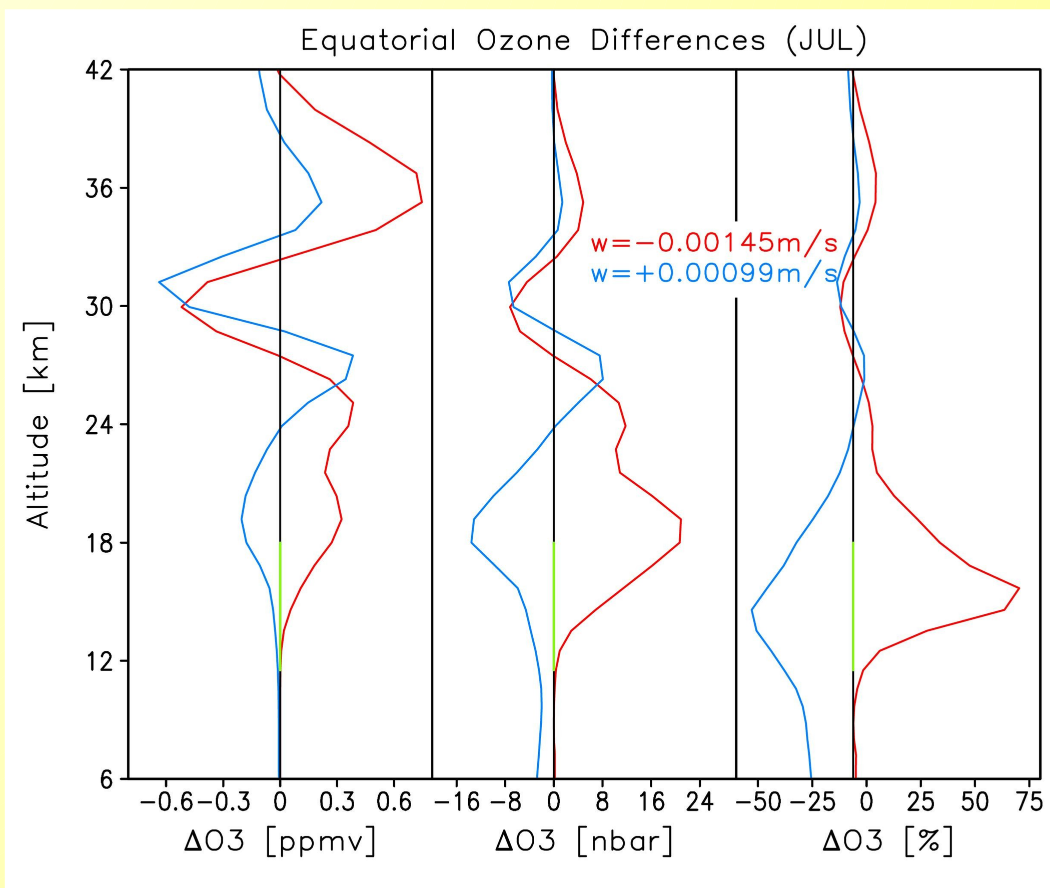
July monthly and zonal mean vertical wind profiles averaged over the equatorial belt for the **default UKCA (black)**, **Case 1 (red)** and **Case 2 (blue)** integrations.

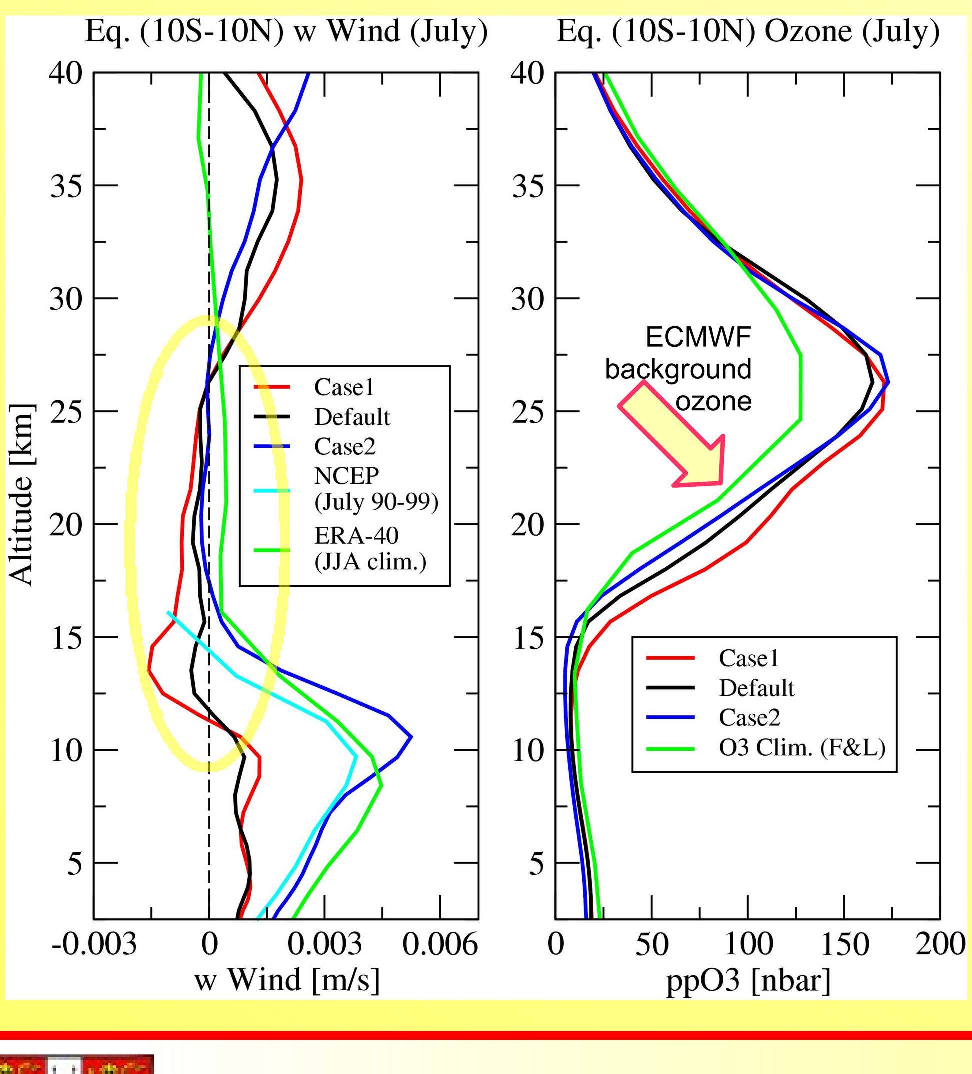
Left:

Annual and zonal mean vertical wind profiles averaged over the equatorial belt for the **default UKCA (black)**, **Case 1 (red)** and **Case 2 (blue)** integrations.

Right:

July monthly and zonal mean ozone profile differences for **Case 1 (red)** and **Case 2 (blue)** integrations relative to the UKCA default integration. From left to right: in volume mixing ratio, partial pressure and in percent.





Summary and Preliminary Conclusions:

This is a model dependent sensitivity study, to highlight the crucial role of vertical velocities in a tropical transition region from the Hadley to the Brewer-Dobson Circulation in determining the vertical ozone gradient.

1) Even though **Case 1** and **Case 2** differ in sign only (and not in magnitude) the response is non-linear! The modelled response differs in spatial distribution and amplitude **(far left and above)**.

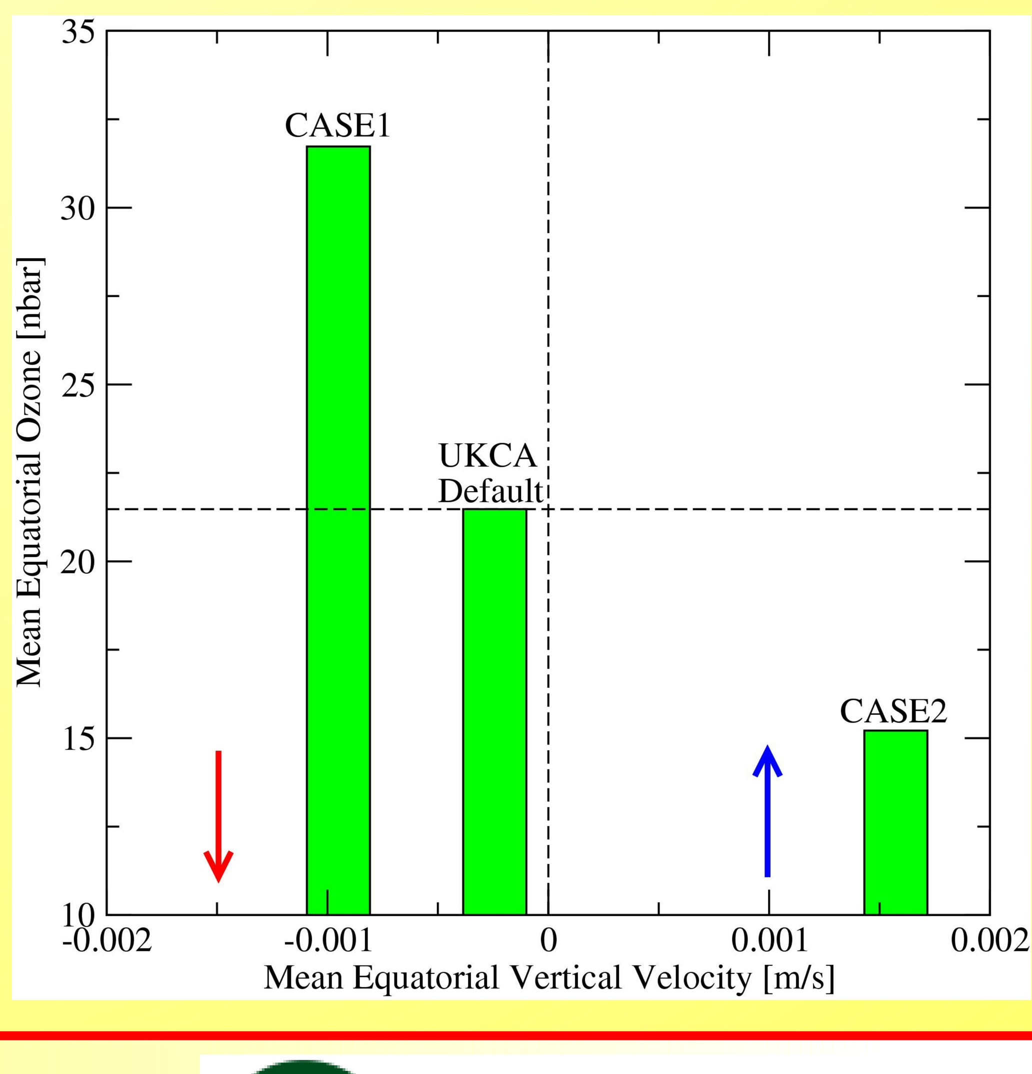
2) The modelled ozone changes are significant with ozone being reduced by up to 50% around the tropopause in **Case 2** **(left and above)**.

3) In some months the idealised experiment shows a similar response to changing the calling frequency of the convection scheme **(top right)**.

As illustrated **above left**, the "mean" depends on the strength of single "high w events" (how much latent heat is released in a single event) and their "occurrence frequency" (how often are events initiated; this might depend on the calling frequency of the convection scheme). The default model is likely to underestimate both for July.

Far left: The above vertical w profiles compared to NCEP and ERA-40.

Far right: Summary of resulting changes in the upper tropical troposphere.



UKCA Paper:

Morgenstern, Olaf, Peter Braesicke, Margaret M. Hurwitz, Fiona M. O'Connor, Andrew C. Bushell, Colin E. Johnson, and John A. Pyle, The World Avoided by the Montreal Protocol, accepted for GRL, 2008.

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