Ozone Flux across the Dynamical Tropopause: Does the PV value matter?

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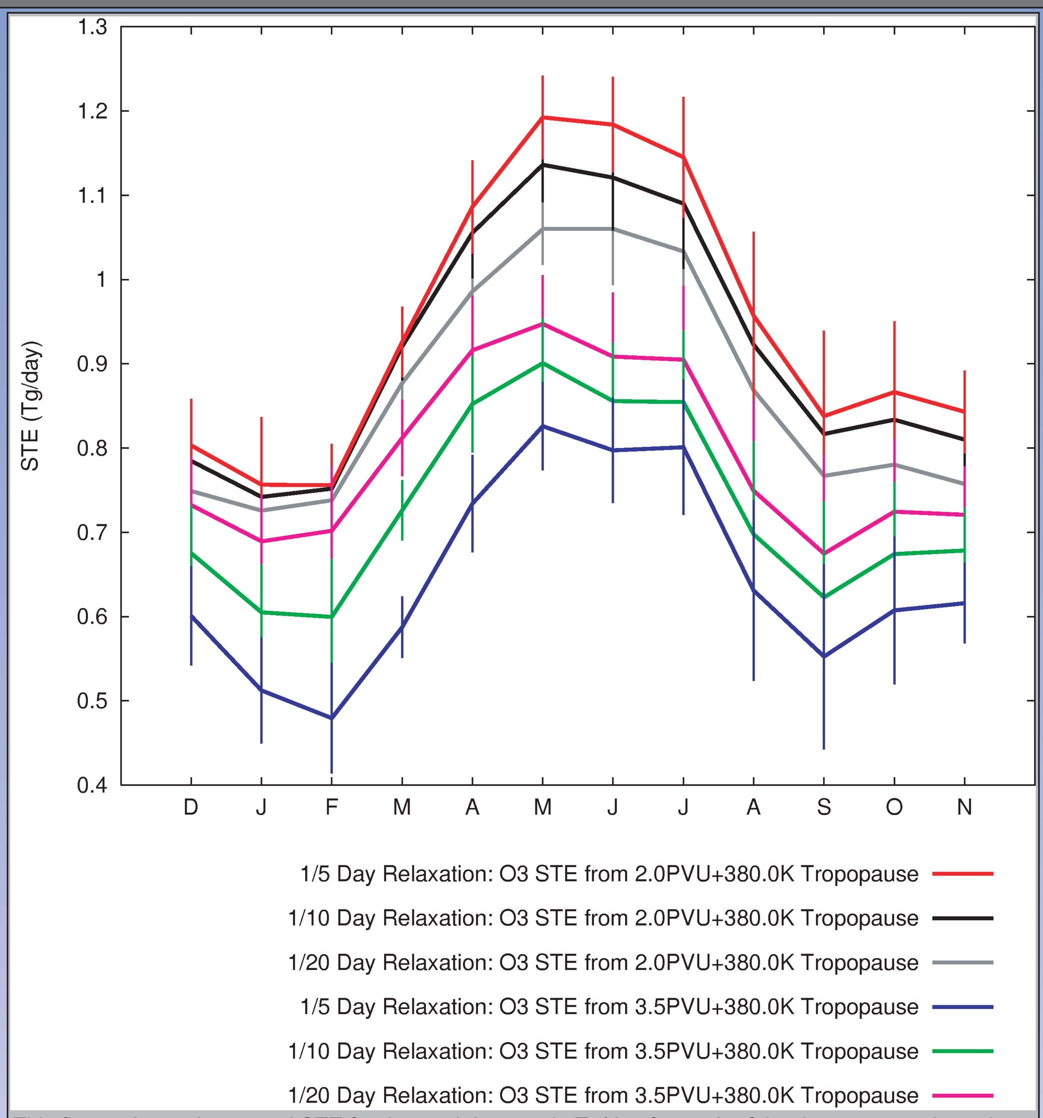
1. Model Description and STE

This study uses the UK Met Office's Unified Model (UM) HadGAM2 at N48L60 resolution (2.5°x3.75° with 60 vertical levels up to 84km), to which three "ozone-like" tracers have been added to simulate simple chemistry. Each of these tracers is relaxed to the SPARC ozone climatology at each timestep with different relaxation times of 1/5-days, 1/10-days and 1/20-days. An age-of-air tracer was also included in the study, and the results of this are discussed in Box 3. In total the model was run for 13 years, not including a 16-month spin-up period.



This figure shows the annual STE for the model set-up in Tg/day for each of the three tracers through both dynamical tropopause definitions. The error-bars are one standard-deviation.

Stratosphere-Troposphere Exchange

Along with these three tracers, there are also two different tropopause definitions. One tropopause is defined at 2.0PVU+380.0K, and the other at 3.5PVU+380.0K (see Box 2). These two definitions are used to create a tropospheric mask so that all gridcells within the troposphere can be determined at each dynamical timestep. The changes to the ozone tracers due to the dynamics are determined each timestep, and then only the component of that tracer which is contained within the troposphere is recorded. It is the monthly-mean change due to dynamics of that tracer within the defined troposphere which is outputted as a 3D field.

This 3D field is then integrated to give a total over the whole globe. Any motion within the troposphere is integrated out, leaving only the transport through the tropopause giving any non-zero contribution which is the Stratosphere-Troposphere Exchange (STE).

These monthly values have then been averaged to give the plot above. The total STE for the year is 340Tg/year (0.95Tg/day) for 1/5-Day relaxation with the 2.0PVU+380.0K tropopause down to 232Tg/year (0.65Tg/day) for the 1/5-Day relaxation with the 3.5PVU+380.0K tropopause.

There is an interesting trend seen in the results above. For the 2.0PVU+380.0K tropopause the STE is lowered as the relaxation time is increased, whereas for the 3.5PVU+380.0K tropopause this trend is reversed, meaning that as the relaxation times are increased the STE values for both tropopauses seem to be converging.

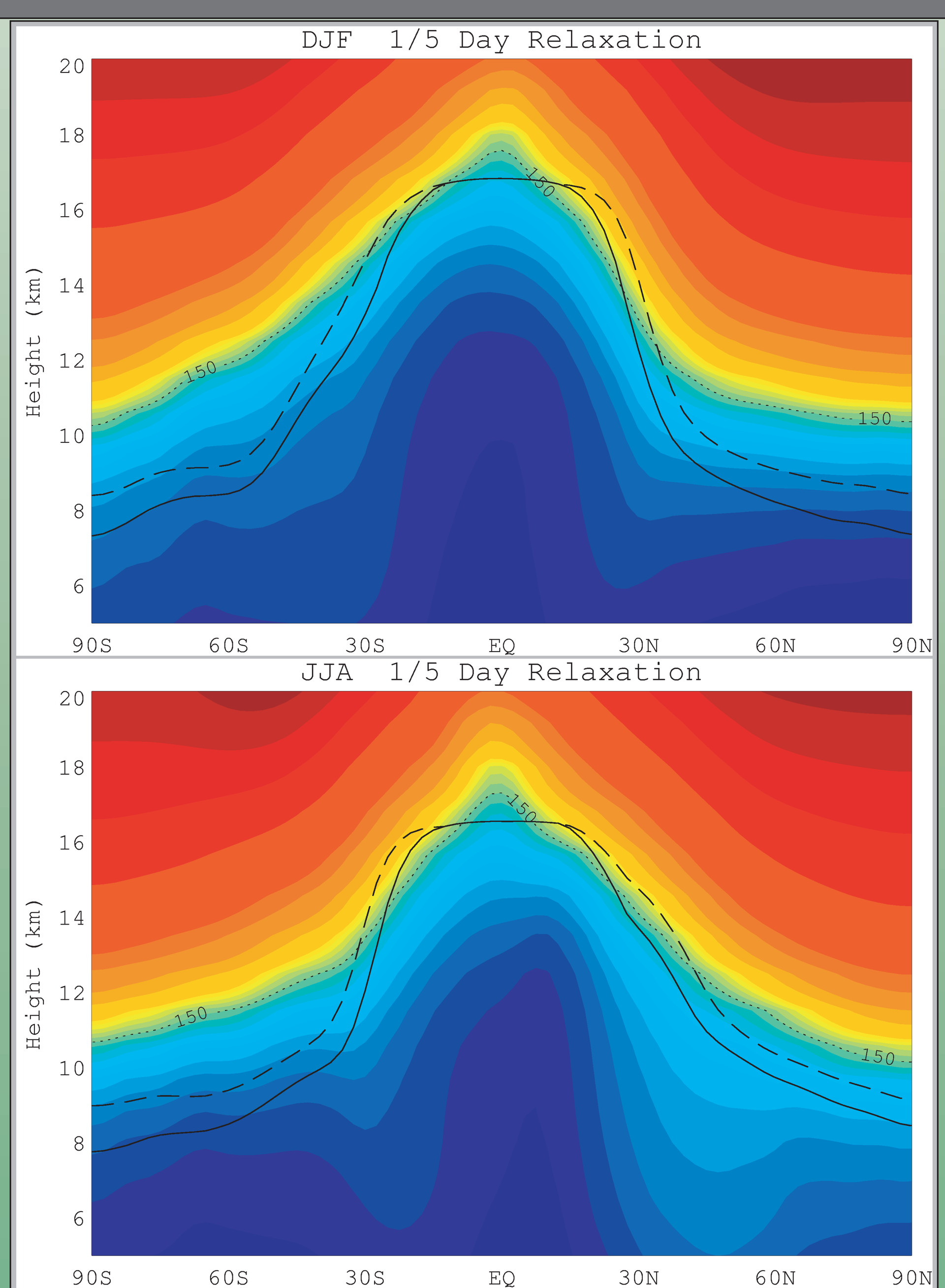
It is clear from the above graph that the largest disparity can be seen in the 1/5-Day relaxation case, so we shall focus on results from that tracer here. Results will be given by season, mainly focusing on December-January-February (DJF) and June-July-August (JJA).

2. Tropopause Position

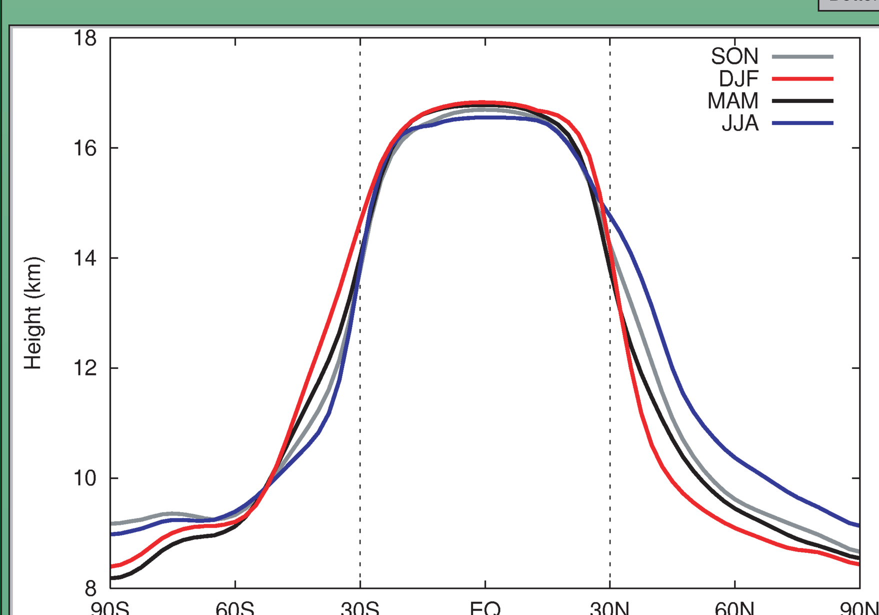
The plots to the right show seasonal zonal mean ozone cross-sections for DJF and JJA averaged over the whole 13-year simulation. The differences between the two tropopause definitions can be clearly seen in the extratropical regions, before they merge in the tropics.

The seasonality and symmetry of the tropopause can also be seen in these plots, along with the seasonality in ozone. The difference between these dynamical tropopauses and the chemical 'ozonopause' at 150ppbv is also quite evident. Since the 3.5PVU+380.0K Tropopause cuts the ozone field at higher concentrations any effects will be seen more clearly with this definition. From now on only results using this tropopause definition will be shown. The full seasonality of the tropopause can be seen in the plot below-left.

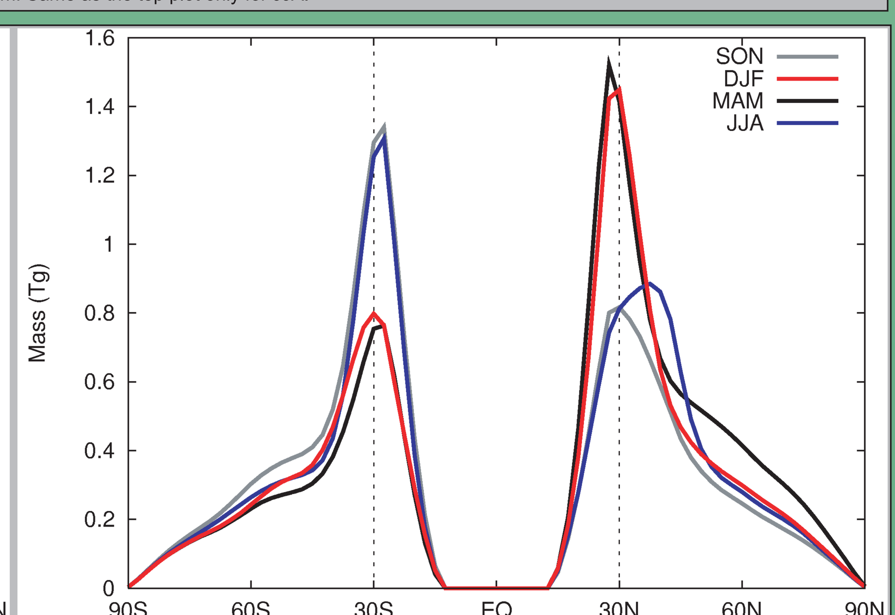
The plot below-right shows the total ozone mass that is contained between our two tropopause definitions. The variability between the seasons can be clearly seen. There is a pronounced wide maximum at around 40°N during JJA which is not present in other months. A possible explanation for this feature is the Indian Monsoon, which will be discussed more completely in Box 4 to the right.



Top: Zonal Mean ozone field for DJF with both the 2.0PVU+380.0K (solid line) and 3.5PVU+380.0K (dashed line) Tropopause shown. The 150ppbv ozone gradient is also shown (dotted line).
Bottom: Same as the top plot only for JJA.



Left: 3.5PVU+380.0K Tropopause by season, averaged over the whole 13-year simulation.



Right: The ozone mass in Tg contained between the two dynamical tropopause definitions, averaged by season over the whole 13-year simulation.

3. Age-of-Air

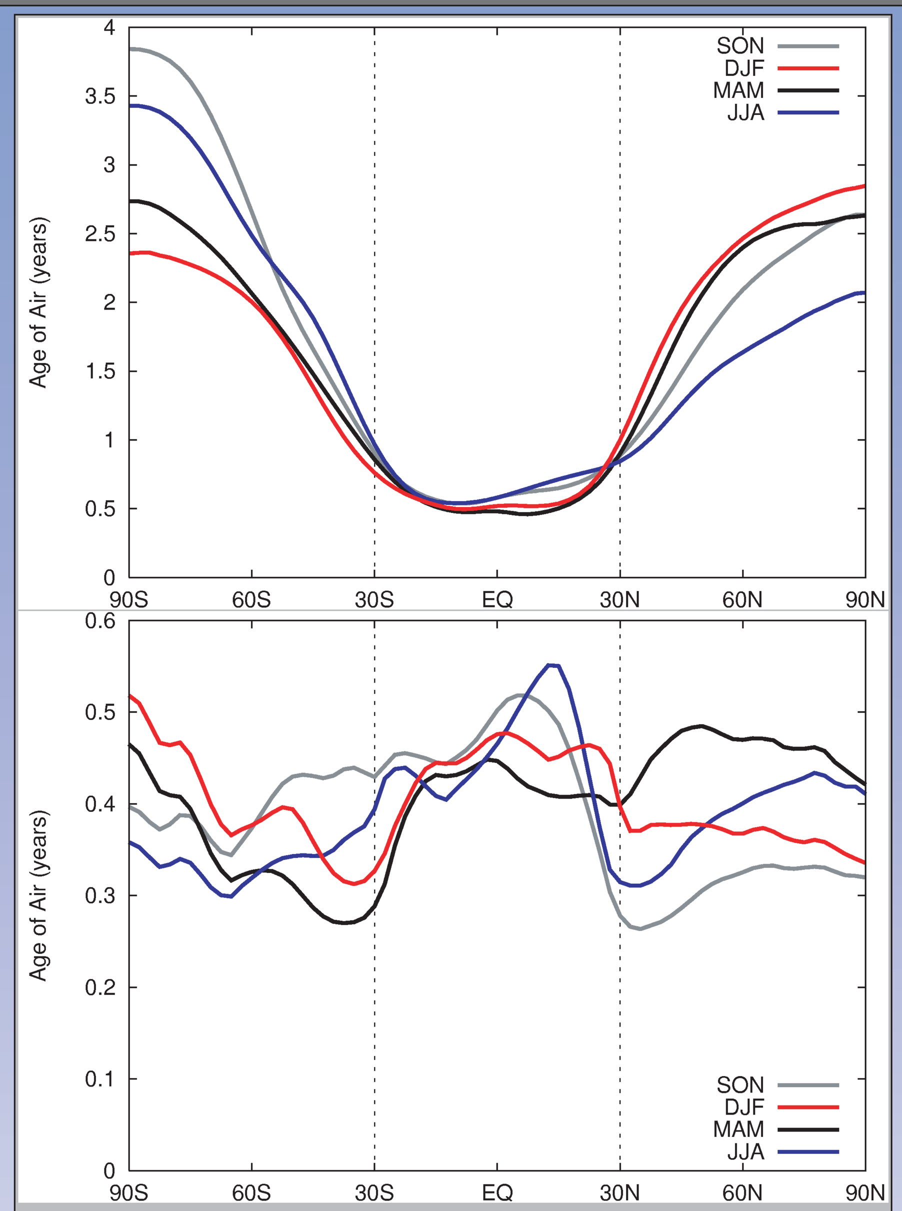
As well as the three 'ozone-like' tracers, an age-of-air tracer was also included in the model. The final 3 years out of the 13-year simulation have been used to produce the two plots to the right.

The top plot shows the age-of-air by season at 17km, which cuts through the top of both tropopause definitions at the equator. There is a clear seasonal cycle in this plot, as was also seen in the tropopause- and mass-plots shown in Box 2.

The bottom plot shows the age-of-air along the 3.5PVU+380.0K Tropopause. As expected variability along the tropopause is much smaller compared to that at 17km. A certain amount of seasonality can still be seen.

The age-of-air at 17km north of 30°N is youngest in JJA, whereas in the southern hemisphere (SH) the youngest air is modelled in DJF.

The age-of-air at the dynamical tropopause shows the strongest gradient in the northern subtropics during JJA. In the SH it is less clear cut, but stronger subtropical gradients are modelled for DJF and MAM. It should be noted that DJF and MAM are very similar in their mass differences.



Top: Age-of-air at 17km. The colours show the average age for the each season averaged over the last three years of the 13 year simulation.
Bottom: Age-of-air along the 3.5PVU+380.0K Tropopause for the same period at the top plot.

There is a clear transitional region around 30°N and 30°S in the age-of-air plots. The large peaks seen in the mass-plot in Box 2 also occur around these latitudes.

The tropopause plot in Box 2 shows that there is a large difference in diagnosed tropopause heights north of 30°N, with highest elevations in JJA. There is also a transition region at this latitude.

Seasonality of STE

On a global scale STE is continuously increasing during MAM, and STE itself peaks during May-July and then decreases during JJA. To a large extent this seasonality is determined by northern hemisphere (NH) dynamics and relates to the decrease in age-of-air modelled between MAM and JJA.

4. Ozone along the Tropopause

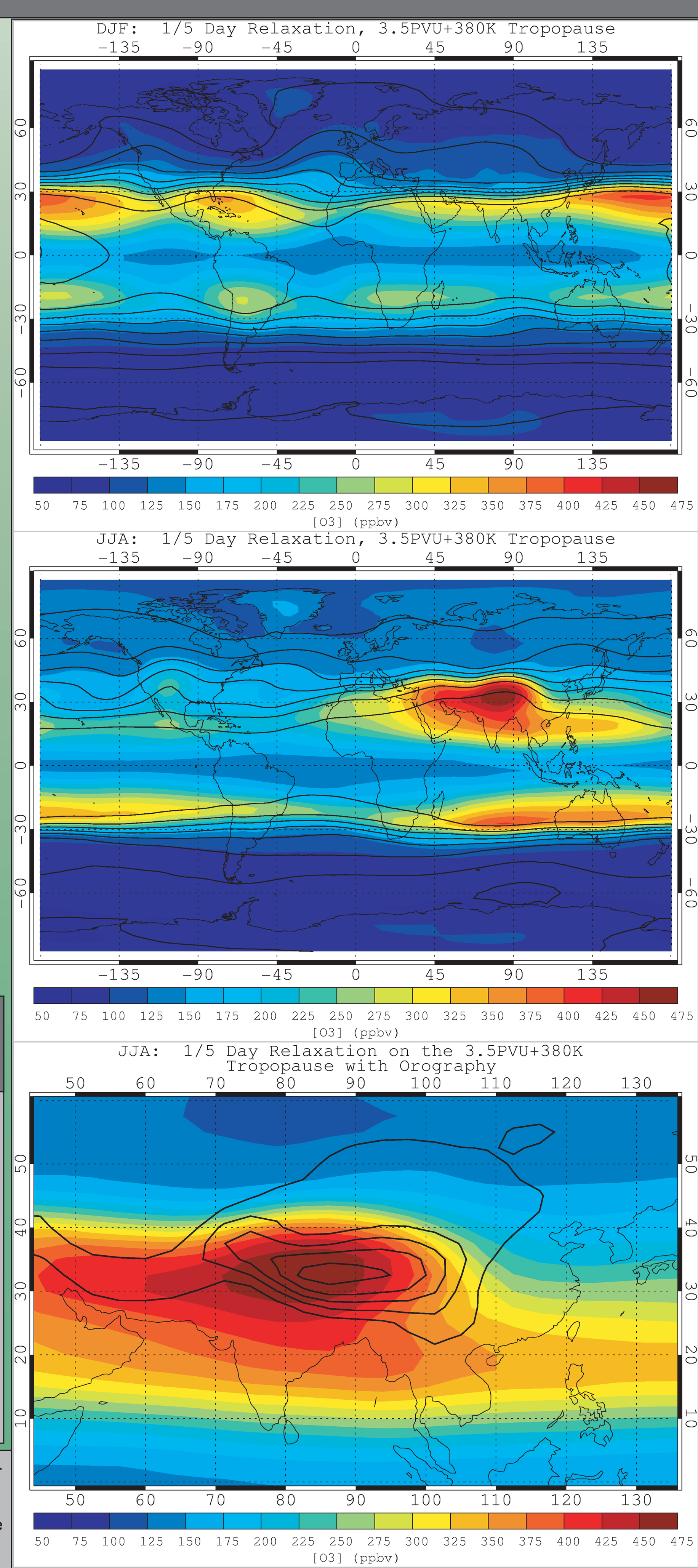
The shading on the plots to the right show ozone concentrations along the dynamical 3.5PVU+380K Tropopause and variation in the tropopause height is shown as isolines with a 1km spacing.

In DJF (top-plot) ozone is increased in both subtropical regions. More than one maxima can be seen in this season.

This is contrasted in JJA (middle-plot) where there is a large distinct maximum at 30°N,80°E. The shape of the tropopause is also altered at this location.

Comparing this feature to the model orography there is a clear relationship, with the modelled ozone maximum being to the south-west of the Himalayas. Both temporal variability and spatial distribution suggest that these high ozone values are linked to the Indian Monsoon circulation.

This feature is also visible on the 2.0PVU+380.0K Tropopause, but with a smaller amplitude since this tropopause cuts the ozone gradient at lower values.



Top: The ozone concentration in ppbv along the 3.5PVU+380.0K tropopause for DJF. The tropopause is shown as contours at 1km spacing.
Middle: Same as the top plot, but for JJA.
Bottom: This shows the Indian subcontinent for JJA, with the colours being the ozone concentration and the contours being the model orography at 1km spacing.

Conclusions

With up to 1% of the total Ozone mass contained between the tropopause definitions and the 45% variation seen in the STE due to the choice of relaxation time and tropopause definition, the PV value chosen *does* matter.

There is clear evidence of an Indian Monsoon signal that affects the tropopause and modulates the ozone concentration on it. The age-of-air studies show a matching seasonality.