Conclusions

1. Vertical velocities control tracer concentrations at the tropopause and above for tracers with lifetimes $\geq 30$ days.
2. Details of convective injection at the cold point are not important species with lifetimes $\geq 30$ days. Convection does impact shorter lived species.
3. Tracers peak above convection with convergence of vertical velocity. Sharp peaks result from the convergence of vertical velocity in isolated regions.
4. There are many caveats to using a simple 1D model. Further verification and comparison will be conducted with observations and with global models.

Model Description

The model is constructed as a one-dimensional transport model, with a basic tendency equation for each tracer:

$$\frac{d[X_i]}{dt} = \frac{d[X_i]}{dt}_{adv} + \frac{d[X_i]}{dt}_{mix} + \frac{d[X_i]}{dt}_{loss}$$

where $[X_i]$ is the mixing ratio of tracer $i$, and the tendencies correspond to advection ($adv$), a convective source ($conv$), parameterized chemical loss ($loss$), mixing ($mix$) and diffusion ($diff$). Diffusion is currently off.

Advection ($adv$): A one-dimensional flux form semi- Lagrangian transport algorithm. It is explicitly mass conserving and positive definite. Constant vertical velocities are used to drive the model, and are derived from the ECMWF analysis (Figure 2). The seasonality (maximum in DJF) is expected from the seasonality of the Brewer-Dobson circulation.

Mixing/Diffusion: Because the transport is explicitly mass conserving and strong convergence of vertical velocity exists in the TTL, we add mixing and diffusion to represent the other two dimensions of motions in the TTL. Mixing is parameterized as a relaxation to background conditions with some diffusion to represent the other two dimensions of motions in the TTL. This formulation can be shown to be identical to an entraining and detraining source (parameterized using a mixing operator in the vertical, but is not used here).

Convection/Loss: Loss is represented as a simple e-folding chemical lifetime ($\tau_i$), noted in Table 1 below. Convection is parameterized assuming a fractional source ($f$) and a source mixing ratio $[X_i]_{conv}$ (Table 1) so that:

$$\frac{d[X_i]_{conv}}{dt} = f[X_i] + (1-f)[X_i]$$

Table 1: Tracer properties

<table>
<thead>
<tr>
<th>Tracer Name</th>
<th>Symbol</th>
<th>$[X_i]_{conv}$</th>
<th>Lifetime (days) ($\tau_i$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>CO</td>
<td>100ppbv</td>
<td>60</td>
</tr>
<tr>
<td>Ethane</td>
<td>$C_2H_6$</td>
<td>600pptv</td>
<td>45</td>
</tr>
<tr>
<td>Acetylene</td>
<td>$C_2H_4$</td>
<td>50ppbv</td>
<td>15</td>
</tr>
<tr>
<td>Radon</td>
<td>$^{222}Ra$</td>
<td>1pptv</td>
<td>4</td>
</tr>
</tbody>
</table>

Results

Observations & Base Simulation

Figure 3: ACE tropical average mixing ratios by season for (A) CO, (B) $C_2H_6$ and (C) $C_2H_2$.

Figure 4: 1-D model simulated normalized mixing ratios for DJF (thick lines). Convective source (thin line)

Figure 3 shows observed profiles from ACE observations by season.

Figure 4 indicates that the model can reproduce some of the main features of profiles: note the peak in $C_2H_6$ in UT, and tail off of all tracers with height: shorter lived species first.

Figure 5 illustrates Ethane tendencies from the base simulation. Convection dominates below 10km. Above 10km advection mostly balances diffusion and loss.

Vertical Velocity ($w$)

Figure 6 shows that TTL tracer concentrations are strongly dependent on $w$. With strong $w$, as with weak diffusion/mixing (not shown), tracers can ‘peak’ due to convergence in $w$. The peak is not due to convective outflow.

This confirms that the annual cycle in CO in the LS is due to the annual cycle of vertical velocity.

Figure 7 illustrates the effect of reducing the convective cloud top. For longer lived species ($\tau_i > 15$ days), convective injection above 12km is not important for TTL and LS tracer profiles. Figure 8 illustrates that the magnitude of convection affects tropospheric concentrations, but it is the vertical velocity (through the seasonal cycle in Fig 8) which impacts concentrations at the top of the TTL.