Processes Regulating Short Lived Species in the TTL

A. Gettelman, M. Park., W. J. Randel and D. E. Kinnison, National Center for Atmospheric Research (andrew@ucar.edu)

Conclusions

1. Vertical velocities control tracer concentrations at the tropopause and above for tracers with lifetimes >~30 days.

2. Details of convective injection at the cold point are not important species with lifetimes >~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.

Motivation

Processes in the Tropical Tropopause Layer (TTL) are important for setting the chemical boundary conditions of the stratosphere, especially for short lived species (lifetimes < 3-6months). Short lived species containing Bromine, in particular, are critical for understanding stratospheric chemistry. We explore hydrocarbons with similar lifetimes. Global models do a 'decent' job of simulating some of these short lived species, shown in Fig 1 for Ethane (C_2H_6) with a lifetime of 45 days fromWACCM, compared to ACE satellite observations.

WACCM and ACE have similar patterns, but there are significant diferences in the TTL. This study explores these transport processes.

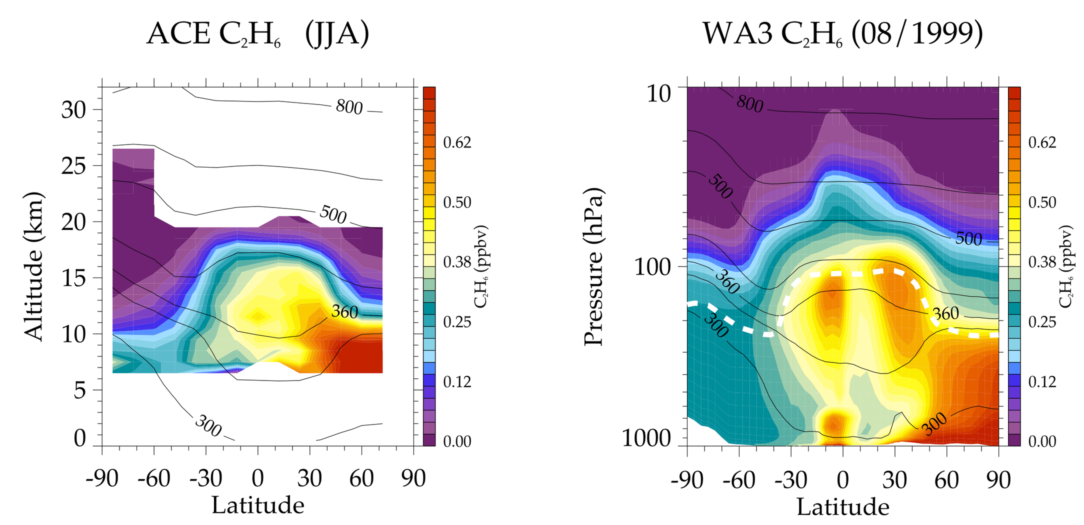

Figure 1: Zonal mean JJA C_2H_6 (Ethane) for ACE (left) and WACCM (right)

Model Description

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

$$d[Xi]/dt = d[Xi]_{adv}/dt + d[Xi]_{conv}/dt + d[Xi]_{loss}/dt + d[Xi]_{dif}/dt + d[Xi]_{mix}/dt$$

[Xi] 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 (*dif*). Diffusion is currently off.

Advection (adv): A one-dimensional flux form semi langrangian transport algorithm. It is explicitly mass conserving and positive definite. Constant vertical velocitites 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.

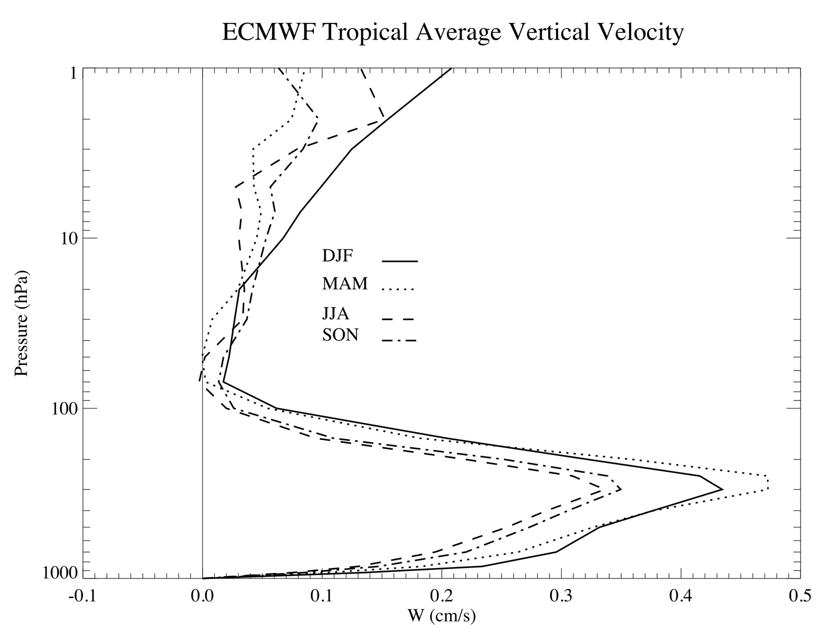

Figure 2: Tropical averaged ECMWF vertical velocities for four seasons.

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 characteristic time, set to 30 days in the standard runs. Diffusion is parameterized using a δ^2 operator in the vertical, but is not used here.

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

$$d[Xi]_{conv}/dt = (f[Xi]_{src} + (1-f)[Xi])/dt$$

This formulation can be shown to be identical to an entraining and detraining mass flux convective scheme, if we neglect downdrafts and entrainment. The fractional source ***f*** is estimated using cloud fraction derived from the CloudSat cloud radar (scaled by a turnover time, here set to 2 hours). CloudSat is a cloud radar that provides radar returns from thick clouds, hence it is a good proxy for convection.

Table 1: Tracer properties

Tracer Name	Symbol	$[Xi]_{src}$	Lifetime (days) (τ_l)
Carbon Monoxide	CO	100ppbv	60
Ethane	C_2H_6	600pptv	45
Acetylene	C_2H_2	50ppbv	15
Radon	^{222}Rn	1pptv	4

Results

Observations & Base Simulation

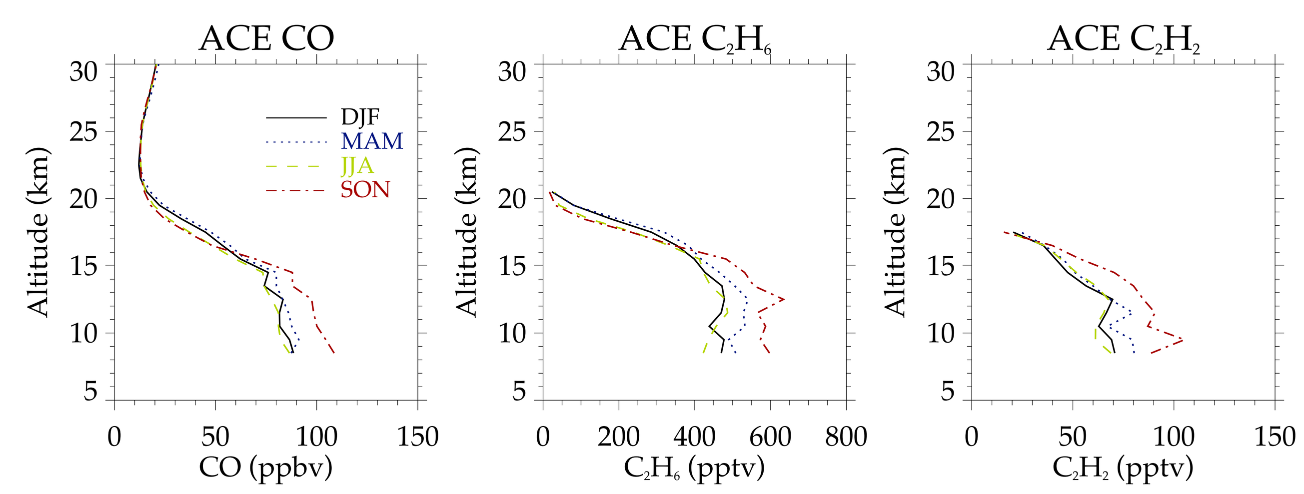

Figure 3: ACE tropical average mixing ratios by season for (A) CO, (B) C_2H_6 and (C) C_2H_2.

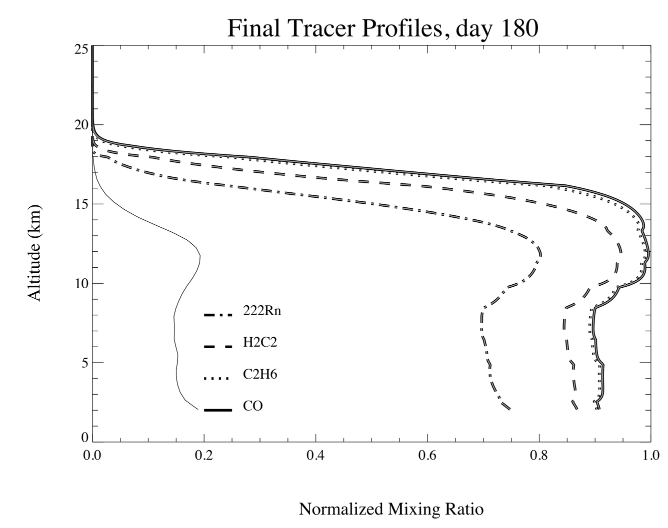

Figure 4: 1-D model simulated normalized mixing ratios for DJF (thick lines). Convective source (thin line)

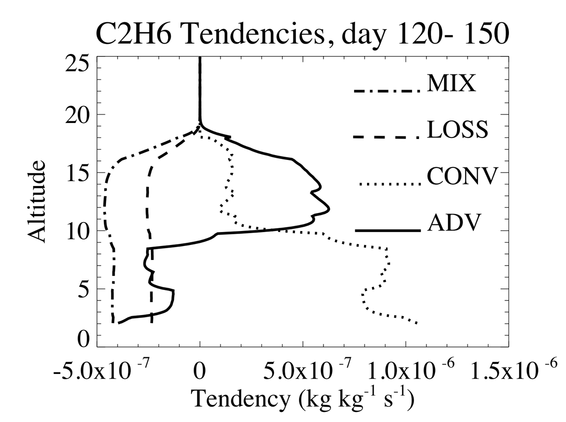

Figure 5: Steady C_2H_6 tendencies

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.

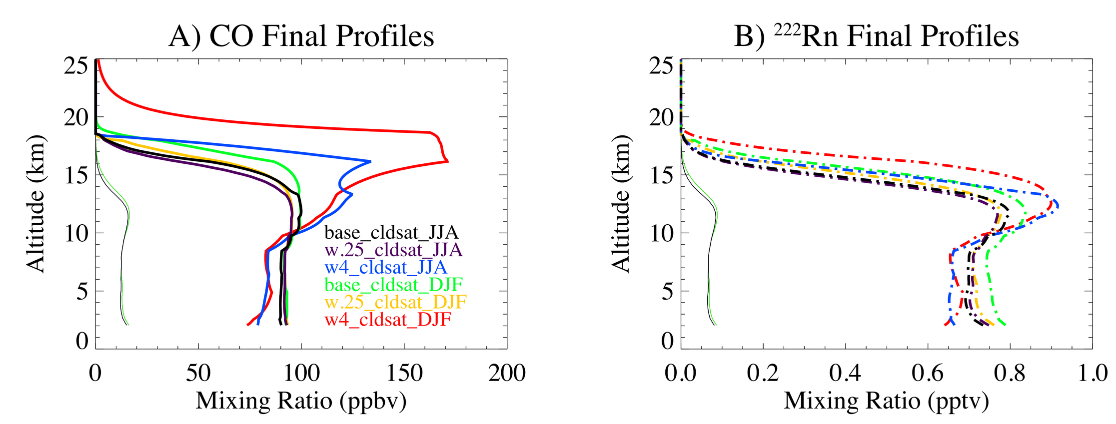

Figure 6: Final mixing ratio profiles of (A) CO & (B) Radon for different seasons and vertical velocities.

Effects of Convection

Figure 7 illustrates the effect of reducing the convective cloud top. For longer lived species (τ_l> 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.

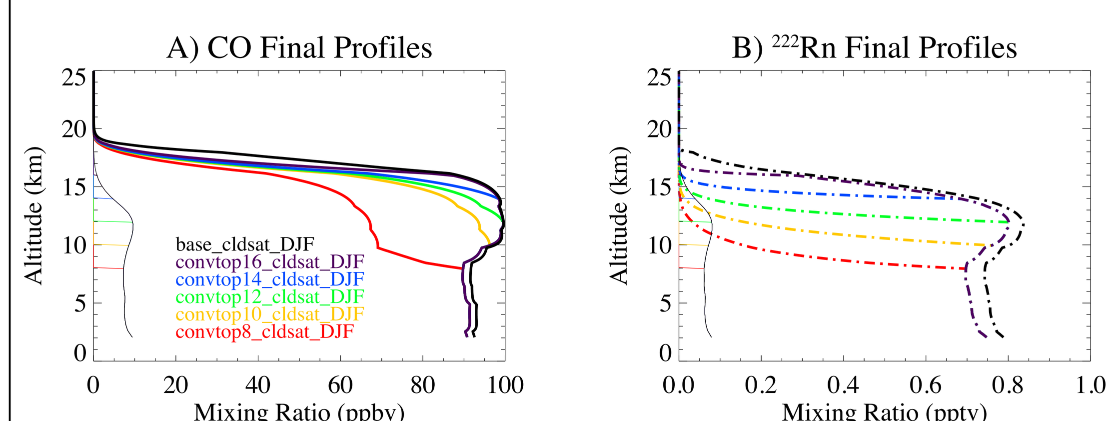

Figure 7: Final mixing ratio profiles of (A) CO & (B) Radon for convective tops at at different altitudes.

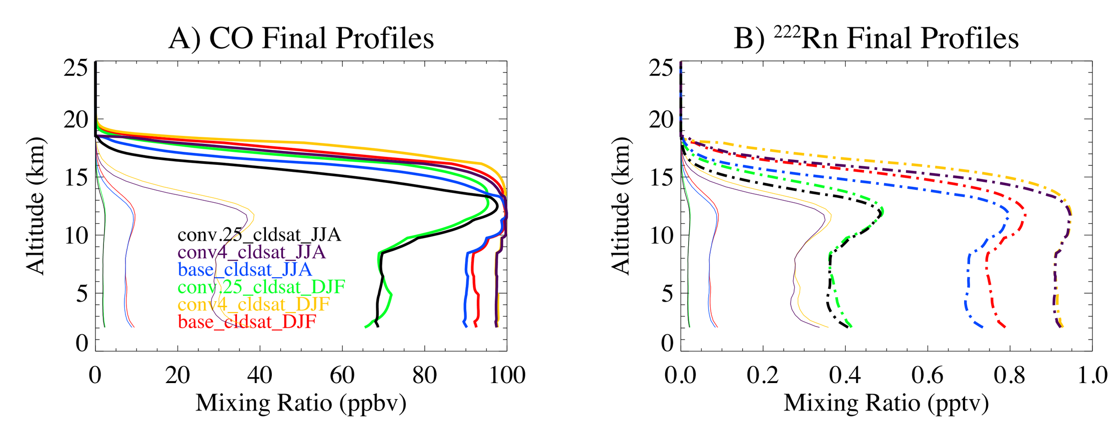

Figure 8: Final mixing ratio profiles of (A) CO & (B) Radon for convection with different magnitudes.