Ozone Temperature Correlations in the Upper Stratosphere as a Measure of Chlorine Content

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A little history:

1975 Barnett et al first suggest that chemical time constant can be determined from ozone-temperature correlations

1985-6 Douglass, Rood show that ozone temperature correlations are also affected by dynamical perturbations that affect both ozone and temperature. They also pointed out that time delays of the ozone response can impact correlations. They looked for meteorologically stable conditions as optimum for detecting chemical sensitivities and suggested that changing chlorine would impact the sensitivity.

The chemical sensitivity of ozone to temperature change is a strong function of altitude, as well as chemical composition

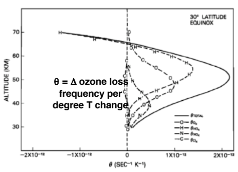

Figure 1. Linearized chemical response of ozone to small temperature perturbations from Stolarski and Douglass, 1985. Note that sensitivity maximizes near 50 km (1 hPa) and that chlorine sensitivity is near zero. Thus, adding chlorine will decrease net sensitivity.

We will express the temperature sensitivity in exponential format: $O_3 = O_{3o} \exp(\text{slope}/T)$

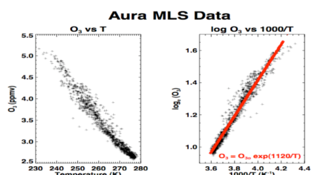

Figure 2: Ozone vs temperature at 1 hPa using data from the MLS experiment on Aura. Ozone shows a small curvature as a function of temperature that is removed by plotting the log of ozone vs 1000/T. The slope of this straight line is the temperature coefficient.

Even at 1 hPa, ozone is not completely in photochemical steady state with temperature fluctuations

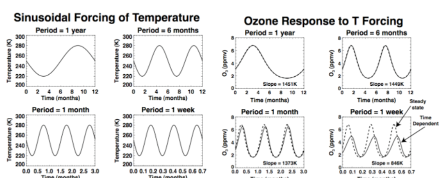

Figure 3: Results from a simple Chapman chemistry box model of the the response of ozone to sinusoidal temperature variations. For a one-year period (seasonal cycle), the time-dependent result matches the steady-state response and the exponential temperature coefficient is the same for both (1451K). For a 6-month period, the results are nearly the same, but for a one-month period the time lag results in a decreased temperature coefficient (1373K). For a one-week period the temperature coefficient is 846K. In the atmosphere, temporal and spatial variations will consist of a mixture of time scales that will confuse the deduction of photochemical temperature sensitivities.

MLS data on Aura illustrate the seasonal cycle of ozone and temperature at 1 hPa for mid latitudes

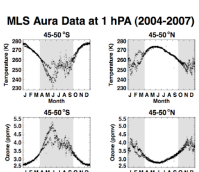

Figure 4: MLS data for ozone and temperature for northern and southern mid latitudes illustrate a seasonal cycle that follows the solar zenith angle over much of the year with ozone anti-correlated to temperature. In the winter, planetary wave disturbances add noise to this picture and increase the mean temperatures above the continuation of the summer cycle.

GEOS CCM
(Goddard Earth Observing System Chemistry Climate Model)
GEOS 4 Atmospheric GCM combined with Goddard Stratospheric CTM
Coupled radiatively through ozone, carbon dioxide, methane, nitrous oxide, and CFCs
Run at 2x2.5 latitude-longitude resolution with 55 vertical levels
Pawson et al., J. Geophys. Res., 113, D12103, doi:10.1029/2007JD009511, 2008

Time evolution of the ozone temperature relationship in our GEOS CCM

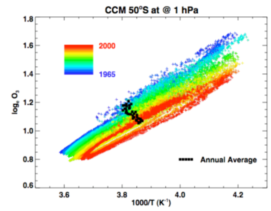

Figure 5: Daily zonal mean log of ozone plotted vs 1000/T from our GEOS CCM simulations of the past stratosphere. Note the following points:

1. The slope decreases from 1965 shown in blue to 2000 shown in red
2. By 2000 the relationship shows a small hysteresis
3. Annual average shows opposite slope because change is driven by chlorine affecting ozone with temperature responding

Loss terms have long-term variations and seasonal variations that complicate chemical interpretation

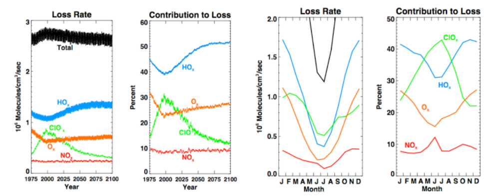

Figure 6: Loss rates at 1 hPa 50°S from GEOS CCM simulations. Note that as chlorine contribution increases, HO_x and O_x contributions decrease. Right panels show the mean seasonal variation for each catalytic loss cycle. Again, chlorine varies in the opposite sense from HO_x and O_x with the phase slightly different.

Temperature coefficient exhibits strong altitude and latitude dependence as shown in CCM and data

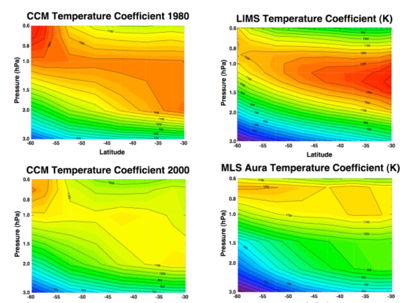

Figure 7: Cross sections of the temperature coefficient vs latitude and pressure altitude for 1980 and 2000 (averaged over 5 years) from GEOS CCM simulations in left panels. Right panels show temperature coefficient derived from LIMS data for 1978-79 (7 months) and MLS Aura data for 2004-2007. At lower altitudes, the coefficient is strongly affected by dynamical influences and there are differences with the model.

Conclusions

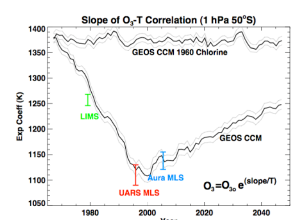

Figure8: Summary plot of temperature coefficient vs time for two GEOS CCM simulations, one using the UNEP scenario Ab, the other holding chlorine fixed at 1960 values. Deductions from data are shown for 3 satellite instruments.

Ozone temperature correlations can be used to see the impact of chlorine on upper stratospheric ozone

The method has many difficulties:

- Sensitivity is a function of altitude, latitude, and season
- Deduced sensitivity depends on time scale of variations
- Transport affects both ozone and temperature

It is critical to use measurements of ozone an temperature that are contemporaneous and have good vertical resolution