VSRT MEMO #067

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To: VSRT Group
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Subject: One-dimensional vertical model of wind and temperature over the summer pole

In memo #66 it is suggested that the constant solar heating at the summer pole might assist the gravity wave driven pole to pole circulation of water vapor via the mesosphere. The motivation is from the seasonal variation of ozone in the mesosphere seen by the spectrometer observing the line at 11 GHz. Recent data, shown in Figure 1, are following the same semi-annual trend in 2009 as seen in 2008. [The data along with analysis tools and plots is available on line at www.haystack.mit.edu/ozone/]. The most likely cause of the maxima at the equinoxes and minima at the solstices is the destruction of ozone by atomic hydrogen produced by the dissociation of water into hydrogen and the hydroxyl radical, OH, and carried by the meridional circulation. [A simplified picture of the chemistry of ozone in the mesosphere is given in an article on the 11 GHz line in the American Meterological Society Journal of Atmospheric and Oceanic Technology, Rogers, A.E.E., Lekberg, M., and Pratap, P., Seasonal and Diurnal Variations of Ozone near the Mesopause from Observations of the 11.072 GHz line, **26**, pp. 2192-2199, October 2009]

The simple one-dimensional model of a vertical column of air above the summer pole has been refined to include the variation of solar heating with altitude from Fomichev (2009). The model has also been extended to cover a column of air from the ground all the way to the thermosphere. Over a million equal mass parcels of unit cross-section are needed to adequately cover the six orders of magnitude range in pressure. Using equal mass parcels greatly simplifies the algorithm as the conservation of mass is simply maintained by replacing a parcel leaving the vertical column in the mesosphere replaced by one entering at the bottom of the column.

The heating is approximated by

$$\frac{dT}{dt} = \left(1 + s - \left(T(h)/T'(h)\right)^4\right) R(h)$$

where $s = 1$ for 24^{hr} daytime Sun

$s = 0$ for 24^{hr} night

T(h) = temperature vs height

$T'(h)$ = equilibrium temperature without motion and solar heat

R(h) = heating rate K/day

This assumes that the parcel will radiate approximately as a black body so that the radiated power rises with fourth power at temperature to reach a new equilibrium. The heated air expands and in expanding a given parcel moves up in height given by the sum of all the expanded parcels below.

As a parcel moves it is assumed to change temperature with the adiabatic lapse rate. Since most of the "action" is in the stratosphere and mesosphere the departure from the adiabatic lapse rate due to moisture is ignored as it is only significant in the lower troposphere. Hydrostatic equilibrium is assumed so that the pressure on the given parcel is given by the number of parcels above it times the weight of each parcel.

Numerical Simulation

The numerical simulation shown in figure 2 is started and continues in loops of increasing time. Without solar heat the equilibrium is established to the temperature profile shown in black. When the solar heat with the heating profile, shown in green, is turned on the temperature profile starts to change and vertical motion starts. When a parcel initially at 80 km moves above 80 km it is released and a new parcel is added to the bottom of the column. After an equivalent of about 30 days a new equilibrium temperature is reached shown in blue and the flow rate of parcel leaving the column at 80 km levels out at about 8 m/s.

If half the exiting parcels are placed into another column without solar heat and the bottom parcel removed from this column the parcels move down and reach an equilibrium temperature profile shown in red. It was found necessary to reduce the fraction of parcels transferred to prevent the temperature at 50 km going over 300 K. This might be reasonable if some of the meridional circulation descends before reaching the winter pole.

The temperature profiles can be seen to follow the general trends of the summer, equinox and winter profiles measured at the South Pole by Pan and Gardner (2003). It should be emphasized that this model considers only vertical paths and ignores the effects of the Earth's rotation. Without eddy friction or momentum transfer from gravity waves the pole to pole flow would move in an inertial frame and hence the flow would appear to spiral when viewed in the Earth's rotating frame. For the summer flow from the North Pole the flow would appear to move towards the southwest. As stated in memo #66 a thermally driven vertical flow might assist the gravity wave driven flow is only presented as a possible means of increasing the meriodional flow and full 3-D analysis, including the Earth's rotation is needed to determine if the thermal pump is significant.

Pan, W., and C.S. Gardner, "Seasonal Variations of the Atmospheric Temperature Structure at South Pole," *JGR*, **108**, D18, 4564, doi 10, 1029/2002JD003217, 2003.

Fomichev, V.I., "The Radiative Energy Budget of the Middle Atmosphere and Parameterization in General Circulation Models," *Journal of Atmosphere and Solar-Terrestrial Physics*, **71**, 1577-1585, 2009.

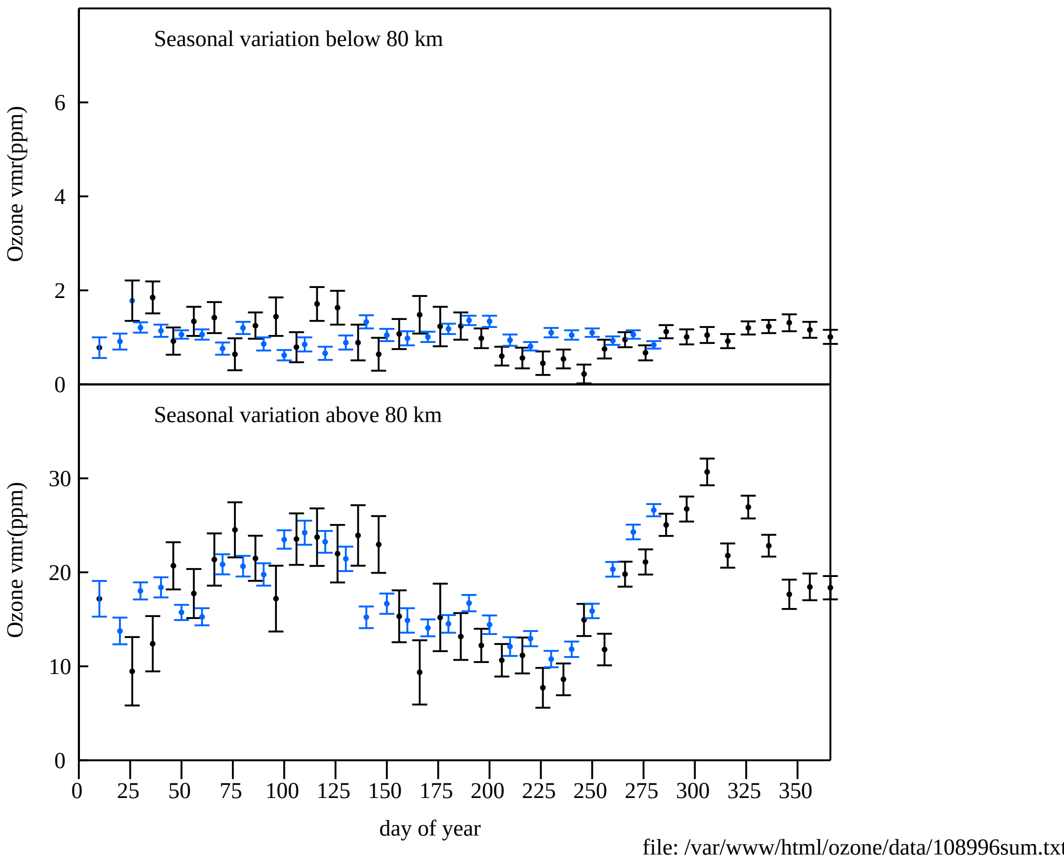

Fig. 1. Seasonal variation of ozone. Black points are 2008 data and blue points are for 2009.

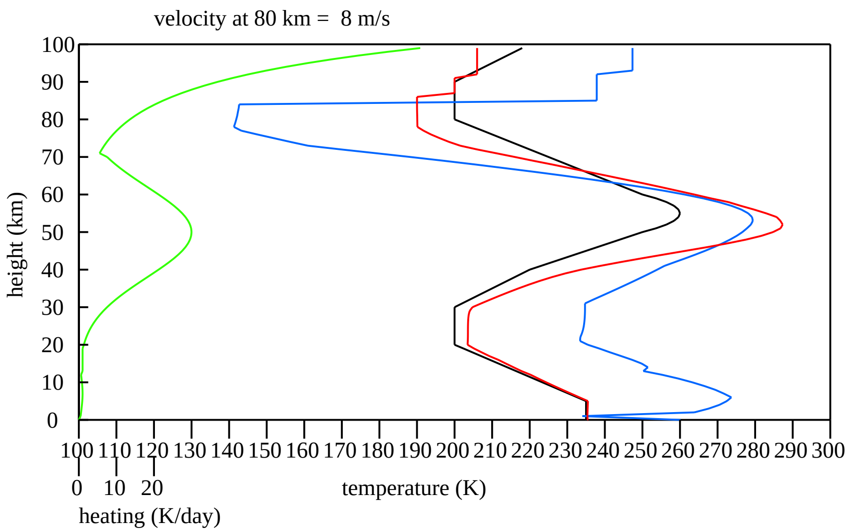

Fig. 2. 1-D vertical model of summer and winter poles. The green curve is the solar heating which is turned on at the summer pole. The black curve is the assumed equinox temperature profile. The blue and red curves are the model profiles for the summer and winter poles respectively.