Study of Mass Transport between the Troposphere and Stratosphere

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1. Background

Predicting climate change due to an increase in atmospheric carbon dioxide was first studied using simplified one-dimensional models such as radiative-convective models. These models, however, could not represent the horizontal transport of heat, water vapor, ozone and other substances. Therefore, the general circulation model(GCM) developed at the Meteorological Research Institute(MRI) is used in this study to assess the influence of the global warming on the transport of ozone.

2. Objective

Prior to the evaluation of ozone transport, preliminary calculation was made for the upward mass flow from the troposphere to stratosphere in low-latitudes. Dissipation of eddies, propagating upward from the troposphere, in the middle atmosphere drives the mean meridional or diabatic circulation, resulting in cross-tropopause mass flux: upward flux in the tropics and downward flux in the extratropics. The detail of this cross-tropopause flux, however, is not necessarily well understood. To examine how tropospheric particles are transported from the troposphere to stratosphere in the tropics, the trajectory calculation of tracer particles, equivalent to the calculation of Lagrangian motion, is made with the use of GCM simulated winds.

3. Experiment

The GCM used is a spectral transform model rhomboidally truncated at wave number 24 with 92 layers (R24L92), and its resolution is approximately 2.9°(lat.) by 4.5°(lon.) in the horizontal and 700 m in the vertical. The physical processes are nearly the same as in R13L23(Shibata and Chiba, 1990). The model is integrated for about 2 years and 2 months, and winds data are sampled every 2 hours from 00Z 15 June of 3rd year for the last 2 months. Ten thousand particles are used as tracers and their trajectories are calculated with time step of one hour. Initially, one thousand particles are isotropically distributed in a box region of 1° by 1°, extended from 200 to 150 hPa, and ten boxes are located equally-spaced, *i.e.* 36° apart from adjacent boxes, on the equator.

4. Results

Monthly mean fields in this period, as seen in Fig.1, show that the model well reproduces major features of the real atmosphere, ensuring the framework of this experiment.

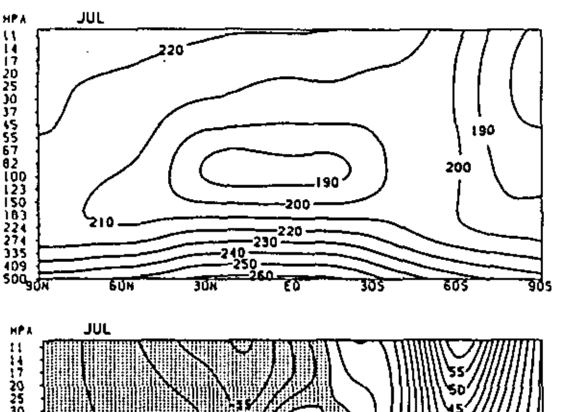

Figure 1. Zonal mean temperature(upper panel, interval 10 K) and zonal wind(lower panel, interval 5 ms^{-1}) from 500 to 10 hPa for July.

The trajectories of the particles, which are situated higher than 300 hPa on July 31, are shown in Fig.1. In the troposphere the vertical motion due to convection can be seen in the tropics, and the slanting motion due to baroclinic wave activity in the extratropics. In the stratosphere, on the other hand, horizontal motion circulating high-cells, though their interhemispheric difference is large, is dominant. It is worth while to note that there is a bulge around

15°S and 70 hPa in the winter hemisphere, while no corresponding trajectories can be seen in the summer hemisphere. This bulge indicates that a dominant Lagrangian mass flux from the troposphere to stratosphere occurs in not the summer hemisphere but the winter hemisphere. This result qualitatively agrees with the satellite observation of CH_4 and N_2O (Jones and Pyle, 1984)

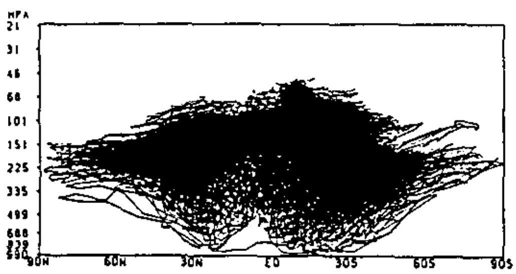

Figure 2. Trajectories projected on the meridional section for the the particles situated higher than 300 hPa *on July 31*.

To investigate this bulge in more detail, trajectories are drawn for the particles situated higher than 70 hPa on July 31. Fig.3a and 3b are the vertical and horizontal maps, respectively. In addition to the interhemispheric difference mentioned above, there are other prominent features in these figures.

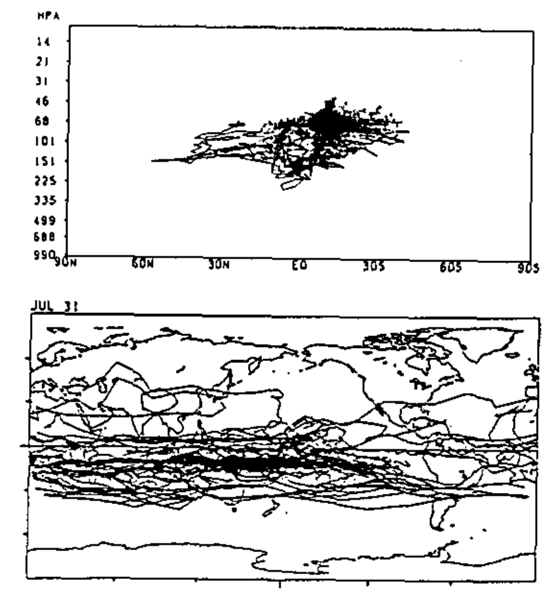

Figure 3. Trajectories projected on the (a) meridional plane and (b) geographical plane for the the particles situated higher than 70 hPa on July 31.

Tracers crossing the tropopause from below pass very limited area, *i.e., fountain area*, (120-180°W, 10-15°S), in the winter hemisphere. This can be more clearly seen for the particles situated higher than 50 hPa(not shown). In particular, the meridional extent in the very vicinity of the tropopause is very small, being in contrast with that above 90 hPa(Fig.3a).

Diabatic heating, on the other hand, shows no such bulge in the corresponding area, as shown in the zonal mean field of Fig.4, and it is rather symmetric about the equator in the lower stratosphere and just below the tropopause in the tropics. Then, other factors as well as diabatic heating seem to be responsible for yielding the locality in the tracer upward transport.

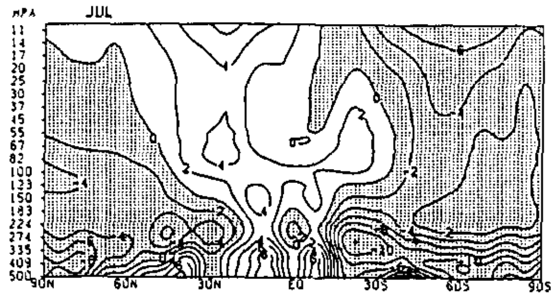

Figure 4. Zonal mean diabatic heating for July. Unit is 0.1 $K\ day^{-1}$ and contour interval is 0.2 $K\ day^{-1}$.

Figure 5 shows winds and pressure(upper panel), and diabatic heating(lower panel) on 360 K isentrope, which coincides with the thermal tropopause in the tropics. Comparison with Fig.3 indicates that both conditions of very weak wind and large diabatic heating are satisfied only in the latitudinal band region of 10-15°S, except for 130-70°W, in the winter hemisphere. This result is of natural because the fulfillment of the conditions gives the field favourable for persistent and large diabatic upward motion.

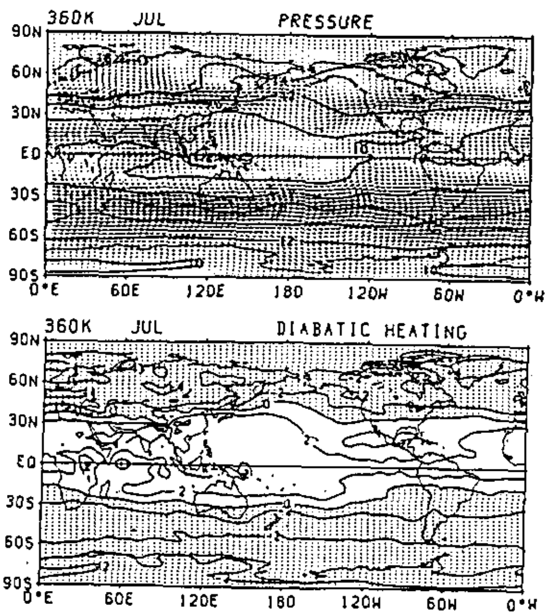

Figure 5. Geographical maps of (upper panel) winds and pressure(unit 10 hPa, contour interval 20 hPa) and (lower panel) diabatic heating(unit

$10^{-1}\ K\ day^{-1}$, contour interval 0.2 $10^{-1}\ K\ day^{-1}$) on the isentrope of 360 K.

On 380 K(Fig.6) and 400 K(Fig.7) nearly the same fulfilment can be seen as in 360 K. Above all, in the fountain area the degree of the fulfillment is exclusively large. Hence, once entered in this area, the particles cannot go outside and continue to rise due to large diabatic heating. That is, the net diabatic heating (vertical velocity in isentropic coordinates) along the trajectory is the largest in the fountain area.

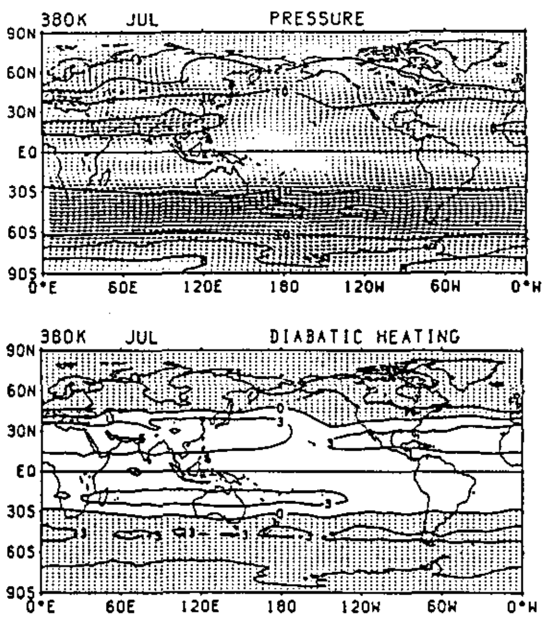

Figure 6. The same as in Fig.6 but for 380 K.

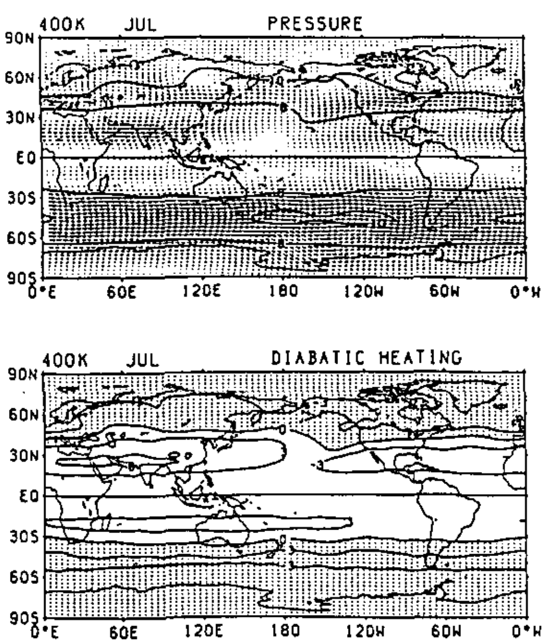

Figure 7. The same as in Fig.6 but for 400 K.

4. Summary

- Tracer transport across the tropical tropopause are investigat ed by using GCM(R24L92) simulated winds for June and July.
- Tracer particles are substantially transported from the troposphere into the stratosphere not in the summer hemisphere but in the winter hemisphere.
- The transport into the stratosphere occurs in a narrow limited area, *i.e.*, fountain area, where wind is very weak and diabatic heating is relatively large.

References

1. K. Shibata and M. Chiba, J. Meteorol. Soc. Japan, **68**, 687(1990)
2. R. L. Jones and J. A. Pyle, J. Geophys. Res., **89**, 5263(1984)