A new diagnostic for evaluating transport between the tropical upper troposphere and mid-latitudes lower stratosphere in chemistry-transport models

Lee H.[1], Youn D.[1,2], Wuebbles D.[1], and Patten K.[1]

University of Illinois at Urbana-Champaign, Urbana, USA[1]

Seoul National University, Seoul, Korea[2]

Introduction

Horizontal transport from the equator to mid-latitude summer is one of the major routes of stratosphere-troposphere exchange. We classified data by the tropopause height and found observational evidence of the tropical air intrusion at mid-latitudes. As effective methods for diagnosing this transport process in chemistry-transport models, we examined probability density functions in chemical tracer profiles and tracer-tracer correlations in the upper troposphere and lower stratosphere region and compared the results with AIRS and MLS satellite observations. We developed a simple index possibly indicating horizontal exchange between the tropical troposphere and mid-latitude stratosphere and examined its interannual variation.

Model and Data

- MOZART-3.1 driven by fvGCM 1998
- Calculation of the thermal tropopause height from fvGCM 1998 temperature data (Reichler et al., 2003)
- Satellites: AIRS and MLS

	AIRS v. 5 (2003~2007, 5 years)	MLS v. 2.2 (2004~2008, 5years)
O3	28 levels (1100 ~ 0.1 hPa)	12 levels (215.4 ~ 3.16 hPa)
CO		12 levels (215.4 ~ 3.16 hPa)
H2O	14 levels (1049 ~ 60 hPa)	18 levels (215.4 ~ 3.16 hPa)
Tropopause	WMO (1992) criteria	WMO definition, inferred from MLS and GEOS-5 temperatures

- WOUDC ozonesonde (January 1994 to March 2006)

Thermal-tropopause relative height

- Clear separation in vertical profiles according to the tropopause heights

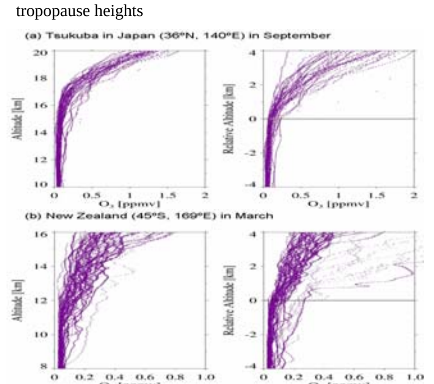

Figure 1. O3 profiles from WOUDC ozone sondes observed (a) near Tsukuba in Japan (36°N, 140°E) in every September between 1994 and 2005, and (b) in New Zealand (45°S, 169°E) in every March. Profiles are shown in altitude coordinates (left) and in thermal-tropopause relative altitude coordinates (right).

- Finer vertical resolution

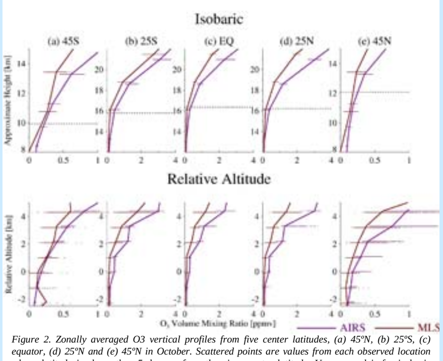

Figure 2. Zonally averaged O3 vertical profiles from five center latitudes, (a) 45°N, (b) 25°S, (c) equator, (d) 25°N and (e) 45°N in October. Scattered points are values from each observed location whose latitude is closer than 5 degrees from the given center latitude. Upper panel is for isobaric vertical coordinate and lower panel is for relative altitude coordinate. Dotted lines represent zonally averaged tropopause height at each center latitude. Scale height of 7km is used to estimate the approximate height from the pressure.

Separation of probability density functions

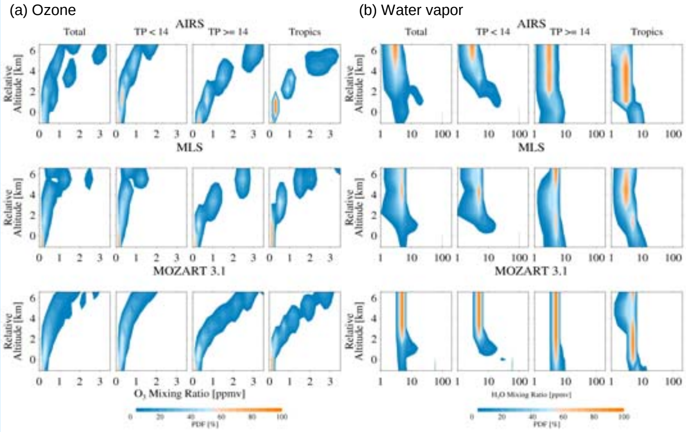

Figure 3. Vertical profiles of (a) O3 and (b) H2O probability density functions (PDFs) in the northern hemisphere mid-latitude region (40°N~ 50°N) and the tropics (5°S~ 5°N) from AIRS, MLS and MOZART-3.1 result driven by fvGCM meteorological field in JAS (July, August and September). Relative height to the thermal tropopause is used as a vertical coordinate. Mid-latitude PDFs are sorted by tropopause level 14km. From left to right, total mid-latitude PDF, PDF when the tropopause height (tp hgt) is lower than 14km, PDF when tp hgt is higher than 14km and total PDF in the tropics.

O3 and H2O PDFs during July, August and September are calculated and displayed in Figure 3. Vertical transition near the tropopause are clearly shown near the tropopause level. Due to the discordance between the real atmosphere and model meteorological fields, the total PDFs from MOZART-3.1 can be different from satellite observations. More importantly, when comparing the total PDFs, both of satellites and MOZART-3.1 clearly shows broader distribution with multiple peaks above 3 km level for O3 and below 2 km level for H2O. The bifurcation of PDFs are related with various tropopause heights. For O3 and H2O, PDFs from the higher tropopause case show similar features to the tropical PDFs. Also the PDFs for the higher tropopause cases have a less distinctive annual cycle than the total PDFs.

Tracer-tracer correlations

The tracer-tracer correlation can be used to identify the transition region between tropospheric and stratospheric air masses (Hoor et al., 2002; Pan et al., 2004, 2007) and it varies based on its origin. Figure 4 shows MLS and MOZART O3-CO and O3-H2O relationships in the NH mid-latitude and tropics during July to September. The transition characteristics of both species form the shape of correlation map. Mid-latitude O3-CO correlation for high tropopause cases are similar to those in the tropics. This means that higher tropopause occurrences at mid-latitudes are related to air transport from the tropics.

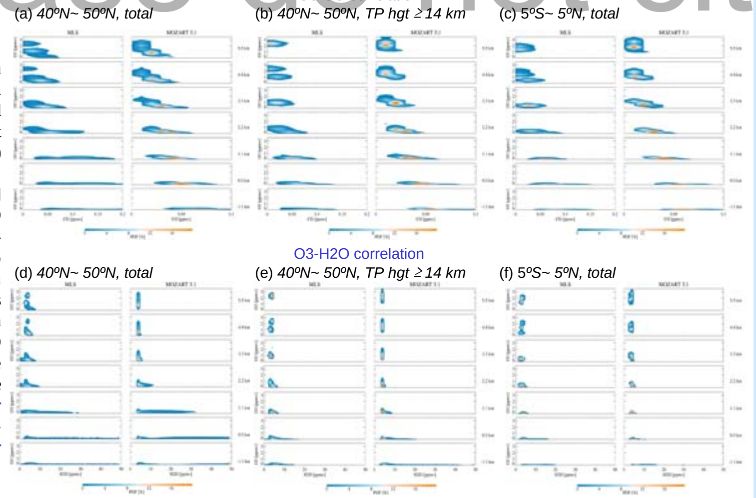

Figure 4. Two dimensional probability function showing the distribution of CO and O3 [(a) ~ (c)] for MLS and MOZART-3.1 result at relative altitude surface from -1.1 km to 5.5 km (from bottom to top) (a) in the NH mid-latitude (40°N~ 50°N), (b) for higher tp hgt (>=14km) and (c) in the tropics from July through September). (d) ~ (f) are same as (a) ~ (c) but for H2O and O3

Frequency of the higher tropopause as an index

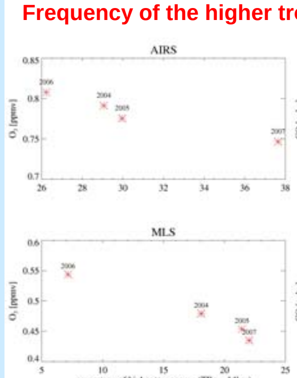

Figure 5. Scatter plot of higher tropopause index and zonal mean O3 at 100hPa from AIRS (upper) and MLS (lower) in 45°N in September.

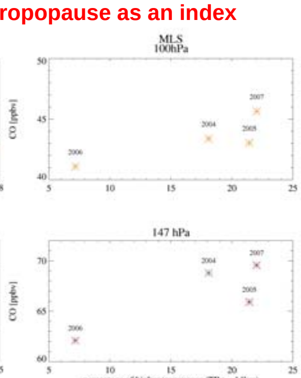

Figure 6. Scatter plot of higher tropopause index and zonal mean CO 100 (upper) and 147 hPa (lower) from MLS in 45°N in September.

For O3 and CO at mid-latitudes, there are actual distinguishable changes in vertical profiles not only in the relative altitude but also in the isobaric coordinate, by the changes of tropopause heights. We made simple index indicating the tropical air intrusion in 40° ~ 50°N each month.

$$\text{Index}\ (\%) = \frac{\text{number of higher tropopause}\ (\geq 14\text{km})\ \text{observed}}{\text{number of total observation}} \times 100$$

This simple index is related to observed O3 and CO in the UT/LS region. When there are more high tropopause occurrences at mid-latitudes, there is a decrease in O3 and an increase in CO at around 100hPa. However, our demonstration is limited by the amount of data. We are conducting modeling studies.

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