Ozone - water vapor interaction in the Arctic and the Antarctic

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In the present study, we focus on the correlation between ozone and water vapor in the Arctic and the Antarctic. The satellite data of the Improved Limb Atmospheric Infrared Spectrometer (ILAS) onboard the Advanced Earth Observing Satellite (ADEOS) were used for the period from 30 October 1996 to 30 June 1997. Clear anti-correlation is confirmed between ozone and water vapor distributions in their altitude-longitude maps for all seasons. The anti-correlation is also observed in the seasonal variations of the ozone and water vapor mixing-ratios in ozone layers. Furthermore, the differences in the altitude profiles inside and outside an ozone hole are studied for ozone and water vapor mixing-ratios and temperatures. The profiles of the differences are similar in the Arctic and the Antarctic; the ozone density is lower and the water vapor density is higher inside an ozone hole. Moreover, it is noticeable that the ozone mixing-ratio is proportional to the water vapor mixing-ratio inside an ozone hole at 20 km, while the ozone and water vapor mixing-ratios are in the anti-correlation outside the ozone hole at 20 km. The findings are discussed with chemical reaction schemes. Furthermore, the estimation of total column ozone from the ILAS data in the TOMS data unavailable region is discussed.
Key words: ozone hole; stratospheric ozone; Arctic; Antarctic, satellite experiment, ILAS, TOMS.

1. INTRODUCTION

Ozone chemistry is of great interest in view of environmental science. In general, it is known that HO_x, NO_x, and ClO_x cycles, are significant in stratospheric ozone chemistry. In particular, the NO_x and ClO_x cycles in ozone chemistry in the Arctic and the Antarctic have been extensively studied. In the present study, we focus on the HO_x cycle in ozone chemistry in the Arctic and the Antarctic.

For the present study on HO_x cycle, water vapor is investigated by the analysis of the Improved Limb Atmospheric Infrared Spectrometer (ILAS) data of the Advanced Earth Observing Satellite (ADEOS). The past studies on water vapor reported the dehydration process of water vapor as a specific chemical process in the Arctic and the Antarctic. Furthermore, water vapor has been used as a long-lived tracer for the study on the atmospheric circulation in these regions.

2. EXPERIMENTAL

In the present study, we used ILAS data (version 5.20) of satellite ADEOS. The ILAS data is available for the period of 30 October 1996 – 30 June 1997. For more details, see http://www-ilas.nies.go.jp/jindex.html.

3. RESULTS AND DISCUSSION

3.1 Longitude-Altitude Maps of Water Vapor and Ozone

Figure 1 shows the altitude-longitude maps of ozone and water vapor in the Antarctic on 17 November 1996. The maps indicate clear anti-correlation between the ozone and water vapor distributions at altitudes of 20-35 km. We confirmed the anti-correlation like this both in the Arctic and in the Antarctic for all seasons, while the altitudes for the anti-correlation depend on the season and the place (i.e., the Antarctic or the Arctic). The corresponding results have been reported in the maps of H_2O and ozone on the 655 K isentropic surface (approximately 25 km height) by MLS measurements on two consecutive days in November 1991 before breakup of the Antarctic vortex.

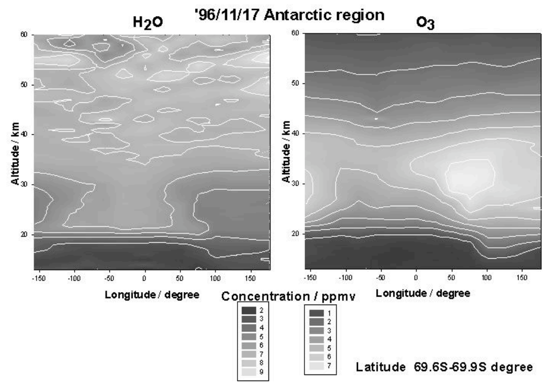

Fig.1 Altitude and longitude maps of water vapor and ozone concentrations (ppmv).

3.2 Seasonal Variation of Ozone and Water Vapor

Figure 2 shows the seasonal variation of ozone and water vapor densities in an ozone layer, which is defined as a layer of 9 km in thickness and of the highest ozone-mixing ratio. In this figure, the mixing ratios of ozone and water vapor are plotted as a function of date outside and inside the region of low ozone density. Such regions of low ozone density exist in the Arctic and the Antarctic for limited seasons. Both inside and outside the regions of low ozone density, anti-correlation is confirmed in these seasonal variations both in the Arctic and in the Antarctic. The anti-correlation is rather weak in the Arctic. It is remarked that the altitude of the ozone layer depends on season in the Antarctic, while it is invariable in the Arctic.

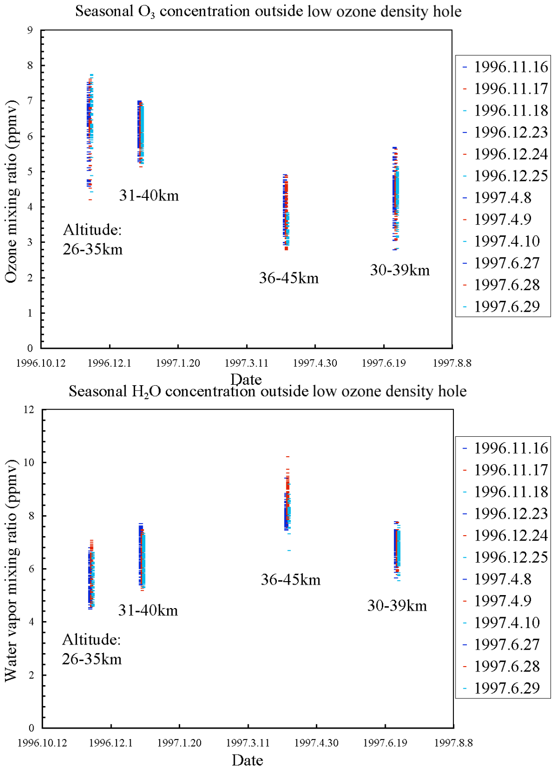

Fig.2 Seasonal variations of ozone and water vapor concentrations in ozone layers in the Antarctic.

3.3 Chemical Interaction between Water Vapor and Ozone in an Ozone Hole

For the comparison of the altitude profiles of ozone and water vapor mixing ratios and temperature inside and outside an ozone hole, the differences of these profiles are obtained at two observation points (44.8º and –163.7º in longitude, 74.4-74.8ºS in latitude). Figure 3 shows the differences of the profiles in the Antarctic. In this figure, the first point (44.8º in longitude) is in the center of the ozone hole and the second point (–163.7º in longitude) is close to the region of the maximum ozone density. The figure indicates that the ozone density is low and the water vapor density is high inside the ozone hole. The anti-correlation is confirmed between the difference profiles of water vapor and ozone. In the Arctic as well as the Antarctic, the ozone density is low and the water vapor density is high inside the ozone hole and hence the anti-correlation is confirmed between the difference profiles of water vapor and ozone.

However, figure 3 indicates that the anti-correlation is not simple. The low ozone density inside the ozone hole is observed at altitudes of 17-52 km in the Antarctic and 15-61 km in the Arctic, while the high density of water vapor inside the ozone hole is observed at altitudes of 19-39 km in the Antarctic and 15-38 km in the Arctic. Thus, the anti-correlation in the difference profiles is confirmed only at the altitudes of 17-38 km. At altitudes higher than 38 km, the ozone density is low inside the ozone hole, while the difference in the densities of water vapor inside and outside the ozone hole is zero. These facts suggest that the chemical processes of ozone with water vapor are significant at altitudes of 17-38 km. In particular, since the difference in density of water vapor is high at altitudes of 20-30 km, we need to study the chemical interaction between ozone and water vapor at the altitudes.

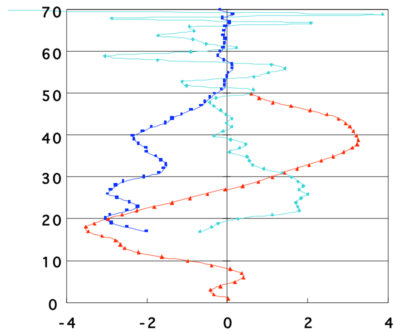

Fig. 3 the comparison of the altitude profiles of ozone and water vapor mixing ratios and temperature inside and outside an ozone hole

Figure 4(a) shows the ozone mixing-ratio as a function of water vapor mixing ratio at 25 km in the Antarctic on 1, 16, 17, 18 November, and 5 December 1996. The figure indicates clear anti-correlation for all data. This anti-correlation will be explained by chemical scheme 1[1]. On the other hand, Fig. 4(b) shows the ozone mixing-ratio as a function of water vapor mixing-ratio at 20 km in the Antarctic on 1, 16, 17, 18 November, and 5 December 1996. The figure indicates clear anti-correlation for the ozone mixing-ratio higher than 2 ppmv outside the ozone hole, as well as in Fig. 4(a). Yet, the ozone mixing-ratio is proportional to water vapor mixing-ratio for the ozone mixing-ratio less than 2 ppmv inside the ozone hole. The anti-correlation outside the ozone hole will be explained by chemical scheme 1, while the correlation inside the ozone hole will be explained by chemical scheme 2. H_2O is catalytic and reproduced in scheme 1, while it is not done in scheme 2. Formation of HNO_3 and PSC are essential in scheme 2.

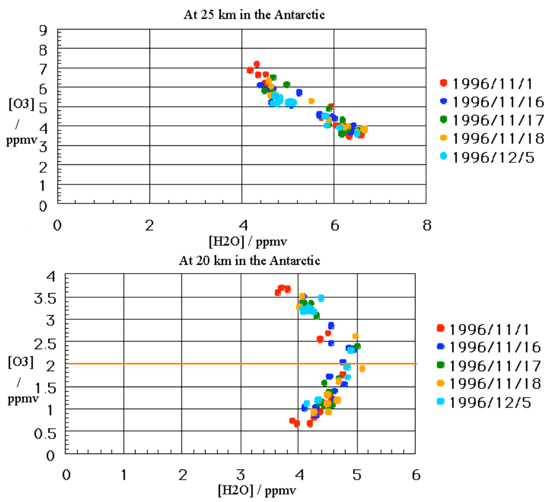

Fig. 4 O_3 concentration vs. H_2O concentration in an ozone hole in the Antarctic. (a) upper: at 25 km. (b) lower: at 20 km.

[1] Chemical schemes 1 and 2 will be described in the lecture.