Mem. Natl Inst. Polar Res., Spec. Issue, **45**, 13–18, 1986

DESCENDING MOTION OF ANTARCTIC STRATOSPHERIC AEROSOL LAYER IN WINTER: POSSIBLE EFFECT ON STRATOSPHERIC WATER VAPOR BUDGET

Yasunobu IWASAKA

Water Research Institute, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464

Abstract: Lidar measurements at Syowa Station (69°00′S, 39°35′E) revealed that the centroid of aerosol layer descended at the rate of 0.8 mm/s during winter. If this motion is a substantial movement of aerosol particles, the mass of water transported into the troposphere is about 5×10^7 t/winter, and the Antarctic winter stratosphere is an important sink of stratospheric water vapor. If it is a downword air motion carrying small ice crystals, the value is reduced to 5×10^4 t/winter.

1. Introduction

Satellite and lidar measurements showed that the Antarctic stratospheric aerosol is extremely enhanced during winter (MCCORMICK *et al.*, 1982, 1985; IWASAKA, 1985; IWASAKA *et al.*, 1985). A cold winter stratosphere activates absorption of water vapor by aerosol particles. STEELE *et al.* (1983) suggested that the enhancement of polar stratospheric aerosols was due to the growth of dilute particles which can be treated as pure ice through the deposition of water vapor molecules under the condition that atmospheric temperature dropped to below frost point. A large depolarization ratio of the winter stratosphere measured by lidar seems to support their hypothesis (IWASAKA, 1986a).

STANFORD (1973) suggested that the Antarctic stratosphere played a possible sink of the stratospheric water vapor through freeze-out effect of stratospheric cloud (Stratospheric "Cist") particles.

It is therefore of interest to consider whether or not the enhanced stratospheric particles can affect the water vapor budget in the stratosphere. In this paper we describe the downward motion of the winter enhanced stratospheric aerosol layer on the basis of lidar observation at Syowa Station (69°00′S, 39°35′E) and discuss the effect of this motion on the stratospheric water vapor balance.

2. Descending Motion of Antarctic Stratospheric Aerosol Layer during Winter

The backscattering coefficient of stratospheric aerosols was measured by lidar in 1983 at Syowa Station (IWASAKA, 1985; IWASAKA *et al.*, 1985). Here we define the centroid height of aerosol layer by,

$$h_B=\int_{Z_2}^{Z_1} Z\beta(Z)\,dZ \Big/ \int_{Z_2}^{Z_1}\beta(Z)\,dZ,$$

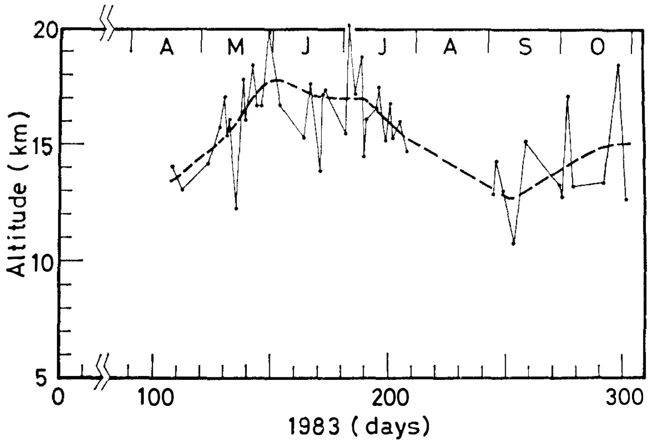

Fig. 1. The height of aerosol layer (h_B) defined by $\int Z\,\beta(Z)\,dZ/\int\beta(Z)dZ$, $\beta(Z)$ is aerosol backscattering coefficient. This value gradually decreased after early July.

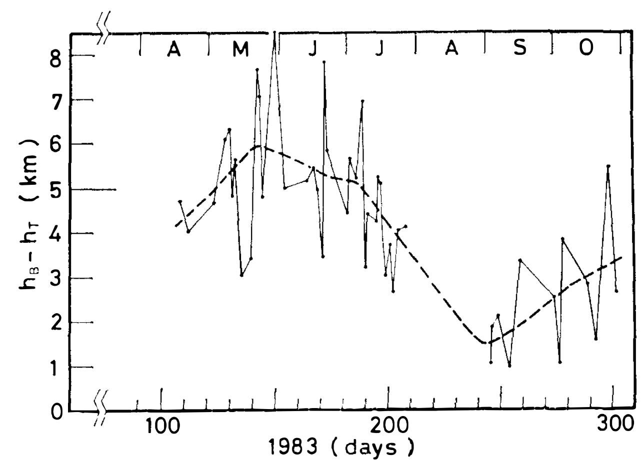

Fig. 2. Change of the layer center height measured from the tropopause. h_B and h_T are the layer center height and the tropopause height, respectively.

where Z_1 and Z_2 are the top and base of the aerosol layer height, respectively. $\beta(Z)$ is the backscattering coefficient of aerosol corresponds to the mass concentration of particulate matter (HOFMANN *et al.*, 1983). In Fig. 1, a temporal change of the centroid height is shown. Measurements on mid-latitude stratospheric aerosols show that the aerosol layer height frequently corresponds to the tropopause height. Thus it is necessary to clarify whether the winter descent in Fig. 1 is due only to the height variation of the local tropopause or not. The decrease of the difference between the centroid height and the tropopause suggests the descending motion of particle layer in Antarctic winter. The height of centroid measured from the tropopause is shown in Fig. 2. These figures show that the aerosol layer descends at a rate of about 0.8 mm/s during winter.

3. Transfer of Chemical Composition of Aerosols during Winter

Stratospheric aerosol particles are usually composed of sulfric acid droplets of 75% H_2SO_4 by weight. It is therefore reasonable to assume that Antarctic stratospheric aerosols also are the sulfuric acid solution before the winter enhancement since the temperature is not sufficiently low to make phase change of particles. As the temperature drops in winter, supersaturation of water vapor and sulfuric acid vapor occurs. The collision frequency of water vapor molecules and sulfuric acid molecules is little during the time scale of the winter enhancement (IWASAKA, 1986b). Therefore, it is reasonable to assume that the collision of water vapor molecules only contributes to the growth of aerosol particles and changes weight percent of particles (STEELE and HAMILL, 1981). According to the routinne radiosonde measurements at Syowa Station, the atmospheric temperature decreased frequently to $-85°C$ or lower in the winter stratosphere. Assuming the water vapor mixing ratio from 5 to 10 ppmv from data obtained in the mid and low latitudes stratosphere, it can be expected that the particles are diluted enough to be treated as pure ice under such a cold temperature (STEELE *et al.*, 1983). Lidar measurements showed a large depolarization (about 0.8 during mid-winter) ratio of the aerosol layer during winter (IWASAKA, 1986a, b). This observation seems to support the hypothesis presented by STEELE *et al.* (1983).

4. Possible Effect of the Winter Antarctic Stratosphere on the Global Budget of Stratospheric Water Vapor

It is worth noticing that the height of the layer center descended at the rate of about 0.8 mm/s in the winter season, and this motion was closely related with the descent of the cold region (IWASAKA, 1986a). MCCORMICK *et al.* (1985) also pointed out that descent of aerosol layer at the rate of 0.77 mm/s was found in the Antarctic stratosphere on the basis of satellite measurements and suggested that this motion was related with the large scale air motion in the winter stratosphere.

The interpretation of this motion is not yet certain, but the descending motion found by lidar and satellite is the important factor controlling the transport of particles if this motion means the substantial movement of particles.

Table 1. Source and sink of stratospheric water vapor.

Oxidation of CH_4		
Water vapor influx estimated by the CH_4 influx	CH_4 influx	
0.48×10^8 t/year	5×10^9 molec/cm²/s	NICOLET and PEETERMANS (1973)
$0.58–1.8\times10^8$ t/year	$6–19\times19^9$ molec/cm²/s	EHHALT (1978)
Hadley cell injection		
3.28×10^8 t/year		Ellsaesser's estimation using the date by NEWELL *et al.* (1969)
5.76×10^8 t/year		Ellsaeseer's estimation using the date by SISSENWINE *et al.* (1972)
11.3×10^8 t/year		ELLSAESSER (1974)
Hadley cell return out from stratosphere to troposphere		
8.3×19^8 t/year		ELLSAESSER (1974)
Transport of Antarctic stratospheric particles		
5×10^7 t/winter (sedimentation)		
5×10^4 t/winter (global circulation)		Present estimation

If we assume that the descending motion is due to the motion of air containing ~15 particles cm^{-3} (MORITA, private communication) and the average particle size to be about 0.2 μm, the flux of water due to this motion is about 4×10^{-14} g cm^{-2} s^{-1}. For the assumption that the particle sedimentation causes this descending motion, the particle size should be 2 μm or larger and the flux is about 4×10^{-11} g cm^{-2} s^{-1}. The horizontal scale of the event is unknown. Considering that the increase of particulate matter is highly correlated to the cold temperature field in winter, the area where the enhancement of stratospheric aerosol layer occurred is about 17×10^{6} km^2 (the polar area at latitude higher than 70°S). The lidar measurements show that the duration of the event is about 3 to 4 months. Assuming a constant flux at the tropopause level, we estimate the mass of water transported from the stratosphere to the troposphere to be 5×10^{4} and 5×10^{7} t per winter for the displacement due to subsidence and sedimentation, respectively. The mass of water transported through the global scale motion is in the order of 10^{8} t $year^{-1}$ (*e.g.*, ELLSAESSER, 1974, 1983). In Table 1, we compare the estimation with other values. The present rough estimations suggest the importance of the particle growth and transportation for global budge of stratospheric water vapor.

5. Summary and Discussion

Summarizing the lidar measurements at Syowa Station (69°00′S, 39°35′E), it can be concluded that (1) many ice particles are formed in the Antarctic winter stratosphere, and (2) the downward transport of the particles is a possible sink for the stratospheric water vapor balance.

The aerosol content fluctuates with relatively short periods, a few days to about ten days. These changes have good correspondence to the variations of stratospheric temperature, such as the appearance of very cold air, its duration, its spacial scale, and so on, but not to the wind field. However, it is necessary to gain more information on winds measured at many locations in addition to the measurements at Syowa Station in order to study the dynamical effect on aerosol layer motions and particle contents.

In the winter hemisphere, global transport of stratospheric minor constituents from the tropical zone to the polar region is active. The mixing ratio of surface ozone increases in Antarctic winter, and it may be due to descending motion of Antarctic stratospheric air relating to winter stratospheric air motion. The dscending motion of the aerosol layer may be partly due to the global air motion. However, it should be noticed that the descent of layer is active during the period when a large depolarization ratio is observed (IWASAKA *et al.*, 1985; IWASAKA, 1986a). This suggests the influence of active particles growing in solid state, possibly ice crystals, on the layer's descending motion.

Unfortunately, we were unable to observe the stratospheric aerosol layer in August 1983 owing to the system troubles (see dotted line in Figs. 1 and 2). So, the behavior of the layer centroid in this period is not clear. Here we speculate that the descending motion continued during the period, on the basis of a good correlation between the height of layer center and the location of very cold air (usually below −80°C). This speculation must be confirmed in the future.

Information is limited about the nature of the Antarctic stratospheric aerosols. The effects of the temperature decrease on the transformation of sulfuric acid droplets should be studied further. It is important to determine the mechanism of the descending motion of the aerosol layer in order to assess the effect of the particle content increase found in the Antarctic winter stratosphere on the global budget of the stratospheric water vapor. There are no data on humidity of the winter Antarctic stratosphere. Systematic measurements of the water vapor content are desired. The information on the horizontal scale of the enhancement also is essential to make a detailed discussion on the budget.

Acknowledgments

It is the author's pleasure to acknowledge the continuous encouragement given by Prof. T. HIRASAWA, National Institute of Polar Research. Members of the 24th Japanese Antarctic Research Expedition (leader: Prof. S. MAE, Hokkaido University) assisted author during the lidar measurements. The engineering staff of Nippon Electric Company rendered the technical support to him.

References

EHHALT, D. H. (1978): Source and sinks of atmospheric methan. Pure Appl. Geophys., **116**, 452–494.

ELLSAESSER, H. W. (1974): Water budget of the stratosphere. Third CIAP Conference, Rep. DOT-TSC-OST-74-15, Washington, D.C., U.S. Dep. Transp., 273–283.

ELLSAESSER, H. W. (1983): Stratospheric water vapor. J. Geophys. Res., **88**, 3897–3906.

HOFMANN, D. J., ROSEN, J. M., REITER, R. and JÄGER, H. (1983): Lidar- and balloon-borne particle counter comparisons following recent volcanic eruptions. J. Geophys. Res., **88**, 3777–3782.

IWASAKA, Y. (1985): Lidar measurement of the stratospheric aerosol layer at Syowa Station (69°00′S, 39°35′E), Antarctica. J. Meteorol. Soc. Jpn., **63**, 283–287.

IWASAKA, Y. (1986a): Lidar measurement on the Antarctic stratospheric aerosol layer; [II] The changes of layer height and thickness in winter. J. Geomagn. Geoelectr., **38**, 99–109.

IWASAKA, Y. (1986b): Large depolarization ratio of the winter Antarctic stratospheric aerosol layer; Lidar measurement at Syowa Station (69°00′S, 39°35′E), Antarctica. J. Meteorol. Soc. Jpn., **64**, 303–309.

IWASAKA, Y., HIRASAWA, T. and FUKUNISHI, H. (1985): Lidar measurement on the Antarctic stratospheric aerosol layer; [I] Winter enhancement. J. Geomagn. Geoelectr., **37**, 1087–1095.

McCORMICK, M. P., STEELE, H. M., HAMILL, P., CHU, W. P. and SWISSLER, T. J. (1982): Polar stratospheric cloud sightings by SAM II. J. Atmos. Sci., **39**, 1387–1397.

McCORMICK, M. P., HAMILL, P. and FARRUKH, U. O. (1985): Characteristics of polar stratospheric clouds as observed by SAM II, SAGE, and lidar. J. Meteorol. Soc. Jpn., **63**, 267–276.

NEWELL, R. E., VINCENT, D. G. and KIDSON, J. W. (1969): Interhemispheric mass exchange from meteorological and trace substance observations. Tellus, **21**, 641–647.

NICOLET, M. and PEETERMANS, W. (1973): On the vertical distribution of carbon monoxide and methan in the stratosphere. Pure Appl. Geophys., **106-108**, 1400–1416.

SISSENWINE, N., KANTOR, A. J. and GRANTHAN, D. D. (1972): How dry is the sky? A decade later and SST. Air Force Surv. Geophys., **240** (Rep. AFCRL-72-0294).

STANFORD, J. L. (1973): On the physics of stratospheric (nacreous) cloud formation. Tellus, **25**, 479–482.

STEELE, H. M. and HAMILL, P. (1981): Effects of temperature and humidity on the growth and optical properties of sulfuric acid-water droplets in the stratosphere. J. Aerosol Sci., **12**, 517–528.

STEELE, H. M., HAMILL, P., McCORMICK, M. P. and SWISSLER, T. J. (1983): The formation of polar stratospheric clouds. J. Atmos. Sci., **40**, 2055–2067.

(Received May 16, 1986; Revised manuscript received October 3, 1986)