A-3.3 Studies on Physics of Stratospheric Ozone Layer and Numerical Modeling

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Abstract To understand the variation of the ozone layer, modeling and studies on physical processes are important as well as photochemical ones. In this study, we examine a case in which ozone number density was low in the lower stratosphere. An one dimensional model has been developed. This model was applied to understand the seasonal variation in the upper stratospheric ozone measured with the ozone lidar at the National Institute for Environmental Studies (NIES). In order to model the stratospheric heterogeneous chemistry under disturbance by the Pinatubo eruption, the vertical distributions of the surface area of the stratospheric aerosols were estimated based on the aureolemeter and lidar data. Numerical studies on the breakdown of the polar vortex have been carried out to understand the variations of the stratospheric ozone.

Key Words One-dimensional model, Polar Vortex, Trajectory, Potential Vorticity, Pinatubo Aerosols

1. Introduction

To understand the variations of ozone layer and model the future of it, understanding the related physical processes is important as well as the photochemical processes. Present models have limitations with the heterogeneous chemistries and dynamics in the polar regions. There are still discrepancies with the absolute concentration of ozone at 40 km between models and observations. Thus, our understanding of the ozone layer is still insufficient and it should result in errors of the prediction of ozone depletion.

2. Objective

The goal of this study is to develop methods to understand and model the physical processes related to the observed variations of ozone layer.

3. Method

Analyses using meteorological and satellite data, numerical models, analyses of observed data with lidars and an aureolemeter have been developed and applied.

4. Results

4.1 A case study - low ozone concentration in the lower stratosphere over Japan

As variations of the total ozone over Japan, especially northern part of Japan, are large, to determine the causes of those variations for many cases and to clarify the statics of them is essential to understand " the recent decline of ozone concentration over Japan". As the first step for it, we carried out ozone sondes measurement for ten days at Sapporo (43°N, 141°E) and analyzed the case in which the ozone number density decreased dramatically in the lower stratosphere. Figure 1 is the vertical profiles of ozone measured with ozone sondes at 17 JST everyday from February 20 to March 1. The sudden decrease of ozone can be seen on February 26. To determine the cause of this decrease of ozone, we use potential vorticity (PV) maps, TOMS data, and so on (Taguchi et al., 1992). the potential vorticity maps were calculated from the JMA global analysis data. Potential vorticity (PV) and ozone have good correlation in the lower stratosphere and upper troposphere. Figure 2 is the PV map on February 26. The airmas with high PV was leaving and the sharp edge of it was just above Sapporo. TOMS data indicated that airmas with low ozone came from the lower latitude region. Therefore, the decrease of ozone in this case should be due to the transport effect.

4.2 Development of the NIES one dimensional model

A one dimensional stratospheric photochemical diffusion model has developed. This model can describe photochemistry, absorption and Rayleigh scattering of solar ultraviolet radiation and eddy diffusion. Simultaneous ordinary differential equations describing photochemical system are solved Gear method. Rayleigh scattering of ultraviolet radiation was calculated by use of the radiation transfer formula by Miller. The concentrations of minor constituents are averaged diurnally by our introducing parametrization of Turco and Whitten. We simplified the model and simulated the seasonal variation of vertical profiles of ozone and compared with the observed one with the NIES ozone lidar. The lidar data is shown in A-1.6 in this report. The highs where the phase of the seasonal variation change were simulated well.

4.3 Estimation of the surface area of the Pinatubo aerosols

As the heterogeneous reaction rates are proportional to the surface area of aerosol particles, it is important to estimate the surface area of aerosols to examine the effects of heterogeneous reaction on ozone depletion. The aureolemeter was developed to measure not only direct solar irradiance but sky radiance in the solar almucantar and can measure the size distribution of aerosols in the column air. Mie lidars measure the vertical profiles of aerosols. Therefore, the vertical distribution of the surface area can be determined if the size distribution of the aerosols in the column is homogeneous. We chose the conditions where optical thickness of the tropospheric aerosols is much smaller than that of the stratospheric ones. An example of the resultant profiles of the surface area is shown in Fig. 3. The peak value of the surface area was about 50. The details are described in Hayashida et al.(1992).

4.4 Numerical studies on the breakdown of polar vortex

The generation of Ozone hole has close relation to the existence of the polar vortex, and the breakdown of the polar vortex leads to the disappearance of the Ozone hole, together with the transportation of air of low-level Ozone concentration to middle latitude. Therefore, theoretical studies on the stability of the polar vortex is important not only for our understanding of the mechanism of Ozone-hole generation but also for the prediction of the decrease of Ozone in the global atmosphere. Recently, Juckes & McIntyre (1987) simulated the deformation process of the circular polar vortex perturbed by the wave- number 1 longitudinal forcing, using a barotropic and non-divergent horizontally two-dimensional model. They found that the simulated results agree at least qualitatively with the distribution of the potential vorticity obtained from observational studies. In this study, we will develop a more advanced version of their numerical model and study the stability of the polar vortex, for our final purpose of revealing the fundamental processes of the polar-vortex breakdown and also for the prediction of the phenomenon in the near future.

First, we have developed a spectral model for the two-dimensional horizontal fluid layer on a rotating sphere under the assumption that the fluid is barotropic and non-divergent. Using a vorticity equation for the fluid, we have computed the time-development of the initially non-axisymmetric polar vortex. We have used as an initial condition a polar vortex perturbed by wave-number 1, 2 or 3 longitudinal deformation. The results show that, due to the continual stripping off of the outer boundary of the polar vortex called "filamentation," the main body of the polar vortex becomes gradually circular. This agrees with the results obtained by adding an explicit wave-number 1 forcing term to the governing equations only until the circular vortex is sufficiently perturbed. This confirms that the polar vortex has a strong tendency to become axisymmetric in a long-time limit.

Second, we have investigated the differences in the time development due to the size, strength and the form of the initial polar vortex. At the same time, we have computed the growth rate of the energy component of each longitudinal wave number. We found the appearance of the tripolar vortex on the sphere recently identified in laboratory experiments (f-plane) in a rotating tank. This shows the stable existence of a low-level ozone concentration region embedded in a high-level ozone concentration region. To know the mechanism for the appearance of typical vortex deformation, theoretical studies on the stability of the polar vortex became necessary.

Finally, we have studied theoretically the linear stability of the baroclinic instability of the elliptic vortex when the air has a vertical stratification. We have used the quasi-geostrophic approximation on the f-plane for the Rossby wave and found that, the vortex which was stable in the barotropic fluid becomes sometimes becomes unstable if we consider the effect of the vertical stratification.

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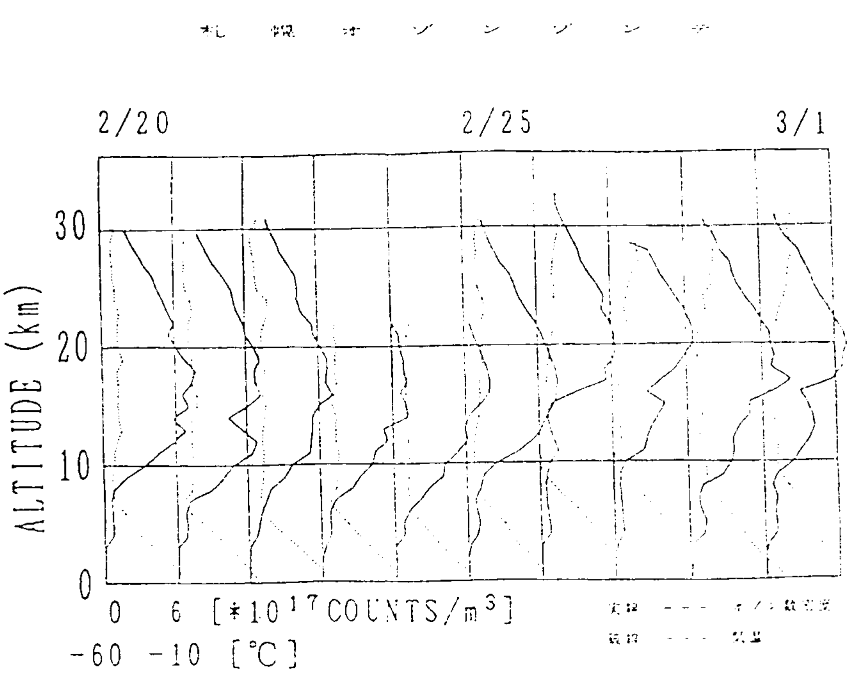

Fig. 1 Vertical distribution of ozone measured with ozone sondes at Sapporo in 1991.

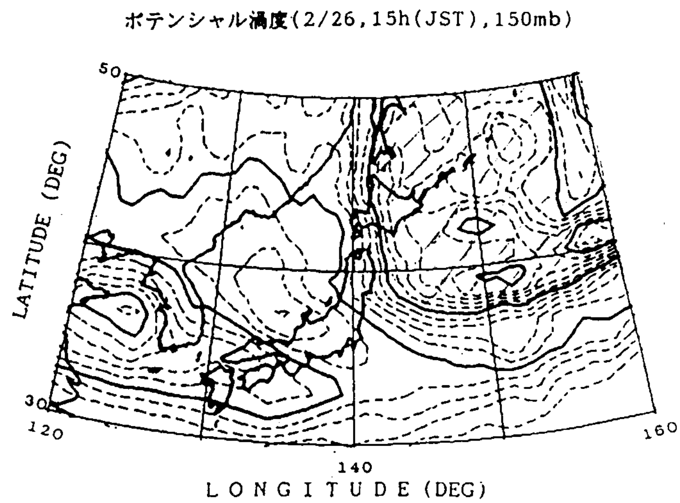

Fig. 2 Potential vorticity map on February 26, 1991.

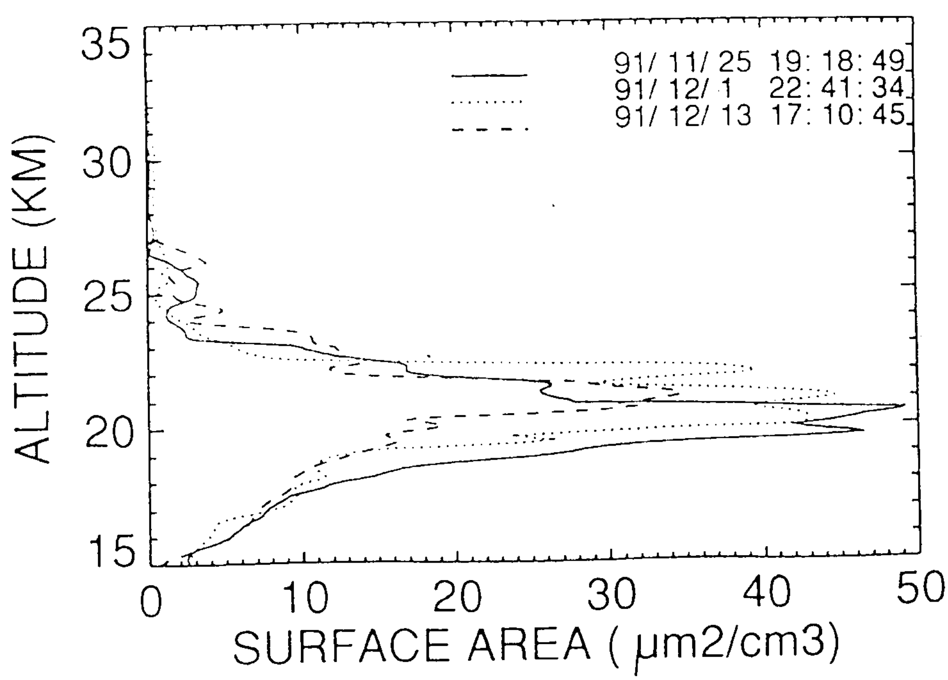

Fig. 3 The surface area of the stratospheric aerosols on November 25, December 1 and December 13, 1991calculated from the lidar and aureolemeter measurements.