A-1.4 Data Analysis and Modeling of Variability of the Ozone Layer

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Abstract

To understand the mechanism of variability of the ozone layer, we developed a software system working on a workstation for interactive analyses of observed data, trajectory analyses and calculation/display of potential vorticity and other meteorological parameters. The interrelation between the ozone variations in the two polar regions and a circulation change in the winter stratosphere were investigated using the daily total ozone data observed by Nimbus 7/TOMS (ver.6) and the geopotential height data analyzed by NMC. We also developed the numerical models for the study of the time development and the stability of the polar vortex.

Key Words Ozone depletion, Polar Vortex, SESAME, Planetary Wave, Sudden Warming

1.Introduction

Observed ozone data reflect both of variations by the chemical reactions and variations by the transport so it is important to develop an analysis to separate each effect in the total variations. Meanwhile, it is known that location of the polar vortex and interactions of the polar vortex with the middle-latitude air have large effects on the ozone variation. Therefore, it is quite useful to develop a software system for the data analysis, including software tools to draw potential vorticity(PV) maps, temperature maps and backward trajectories. In this sub theme, we developed a software system named as the Stratospheric Research Assisting System(STRAS) for a help to analyze data observed by ozone sondes during the Second European Stratospheric Research Assisting System (SESAME) campaign. We also investigated the interrelation between the ozone variations in the two polar regions using data observed by Nimbus 7/TOMS (ver.6) and by NMC(National Meteorological Center) and developed the numerical model to analyze the time development of the polar vortex.

2. Development of the Stratospheric Research Assisting System(STRAS)

The STRAS system working on a workstation has been developed at National Institute for Environmental Studies(NIES) for observational and data analysis research on stratospheric chemistry and dynamics. This software system consists of three subsystems: a subsystem for interactive analyses of observational data and their comparisons, a subsystem for trajectory analyses(Hayashida and Sasano, 1993) and a subsystem for calculation/display of potential vorticity (Taguchi et al., 1991) and other meteorological parameters. At present this software system can deal with observational data such as ozone lidar data, temperature lidar data, SAGE II satellite data, ozone sondes data (JMA and WMO) and aerological data (JMA) as well as CIRA 86 model atmosphere. Isentropic forward and backward trajectories can be calculated and displayed using JMA Global Analysis Data as a function of the second sub system. The third subsystem shows potential vorticity maps on isentropic surfaces, isobaric surfaces and meridional surfaces as well as heights, potential temperatures and temperatures using JMA Global Analysis DATA. In the framework of SESAME programme, we observed vertical profiles of aerosols, water vapor and temperature at Yakutsk (60N, 130E) in Eastern Siberia in cooperation with Central Aerological Observatory (CAO), Russia and Nagoya University. Analyses on the possible interactions between high- and mid-latitude region had been performed using trajectories(Fig.1), PV and temperature maps(Fig.2) obtained by the STRAS system.

3. Ozone variations in the two polar regions

The aims of the present study are to elucidate the interrelation between the ozone variations in the two polar regions and a circulation change in the winter stratosphere. The data used for analysis are the daily total ozone observed by Nimbus 7/TOMS(ver6) and the geopotential height data analyzed by NMC. The study has been made on the basis of the daily distributions of amplitudes and phases obtained from Fourier decomposition of the ozone amount and dynamic fields along latitude circles.

First analysis was made on the relationship of the total ozone variation to geopotential height fields. The year-to-year variations of amplitudes of wave numbers 1 to 5 for both total ozone and geopotential height at 200 hPa are has quite well shown a positive correlation. The positive correlations has been confirmed for December at latitudes from 45N to 55N. From the further analysis on the geopotential height in the troposphere (500 and 850 hPa), it is found that the year-to-year variation of amplitudes for wave numbers 1 to 5 has shown intimate connection of the stratospheric changes to the tropospheric changes even to wave number 5. The results suggest that the variations of 'total ozone wave' show a good indicator of dynamical wave field.

The second analysis has been made on the recent development of the Antarctic ozone hole, which low values has continued from 1989 to 1995. From daily distributions of 'total ozone wave', it is found that the recent development of the ozone hole has accompanied the amplification of monthly mean wave number 1 poleward of 50S. From the comparison of the amplitude of wave number 1 between 1987 and 92 in September, the amplitude in 92 is about 3 times larger than in 87 (Fig.3). Furthermore, the daily distribution of wave number 1 has shown that the eastward movement in 92 became slower than in 87, and its minimum tends to lie in southward end of South America. On the contrary to wave number 1 of 'total ozone wave' , the wave number 2 became faster eastward movement in 92 than in 87, being about 3 times. This result suggest that the recent continuing deepening of the Antarctic ozone hole has a relation to strengthening of westerlies in the Antarctic winter stratosphere, since the strong westerly jet surrounding the polar region can cause different behavior between wave number 1 and 2.

The third analysis has done on ozone depletion in the winter Northern Hemisphere. From the detailed analysis in January and February, the total ozone poleward of 30N is clear and as the higher the latitudes are, more the depletion of ozone occur. Tentative results are that the monthly standard deviation for each wave number, which are the mean deviation of the daily amplitudes from monthly mean, has recently damped along with the decrease of zonal mean and monthly mean ozone amount at 65,55 and 45N. The decrease in mid latitude in winter Northern Hemisphere may be due to decreasing activity of dynamical waves. This characteristics could be same features of the circulation in 'warm winter ', where the cold air in the polar region tend not frequently to flow out to mid latitudes.

4. Development of the numerical models for the breakdown of polar vortex

The generation of ozone hole has close relation to the dynamics of the polar-night vortex. For example the breakdown of the polar vortex leads to the disappearance of the ozone hole along with the transportation of the high-latitude air with low-level ozone to middle latitude. Therefore, theoretical studies on the stability of the polar vortex and the related numerical simulations are important not only for our understanding of the mechanism of ozone-hole generation but also for the prediction of the ozone depletion in the global scale. In this study, we have developed a horizontally two-dimensional high-resolution model for the study of the time development of the polar vortex and also investigated theoretically the stability of the polar vortex. These results will reveal the fundamental processes of the polar-vortex breakdown and will be useful for the prediction of the phenomena related to the ozone hole.

A high-resolution spectral model for the horizontally two-dimensional barotropic fluid has been developed. Using a conservation equation for the potential vorticity which includes the effect of the forcing due to the ultra-long Rossby waves, we have calculated the time development of the polar vortex(Fig.4). The ultra-long Rossby waves have their origin in the troposphere where they are excited for example by topographic effects. Only the waves with zonal-wave number 1 or 2 can propagate upward to the stratosphere because of the well-known dispersion relation of the Rossby waves. As initial conditions typical winter climatological zonal wind distributions are used. A forcing term with a zonal wave number 1 are used to perturb the initially circular-shaped polar vortex. Although we have added an artificial viscosity term of 6th-order derivative to the originally inviscid governing equation mainly for the numerical stability of the computation, the viscosity coefficient was chosen as small enough to avoid the significant viscosity effect until about 30 days after the beginning of the calculation. Due to the effect of the forcing term, the initially circular vortex is deformed significantly. On day 4 we get a typical winter stratospheric potential vorticity and streamline patterns. On day 6 we find transiently even the sudden-stratospheric-warming pressure distributions along with the intrusion of the warm mid-latitude air (with low potential vorticity) into the polar region. When the main polar vortex are deformed, many small filamentations occur at lower latitudes causing a mixing at much smaller scales. Since the forcing is terminated on day 12, the vortex returns to a circular shape before day 100. This shows that the forcing used in this study has not been so strong as to completely destroy the polar vortex. These results suggest that, to maintain the shape of the typical polar vortex shape, some moderate forcing strength and duration which has not yet to be identified are necessary.

References

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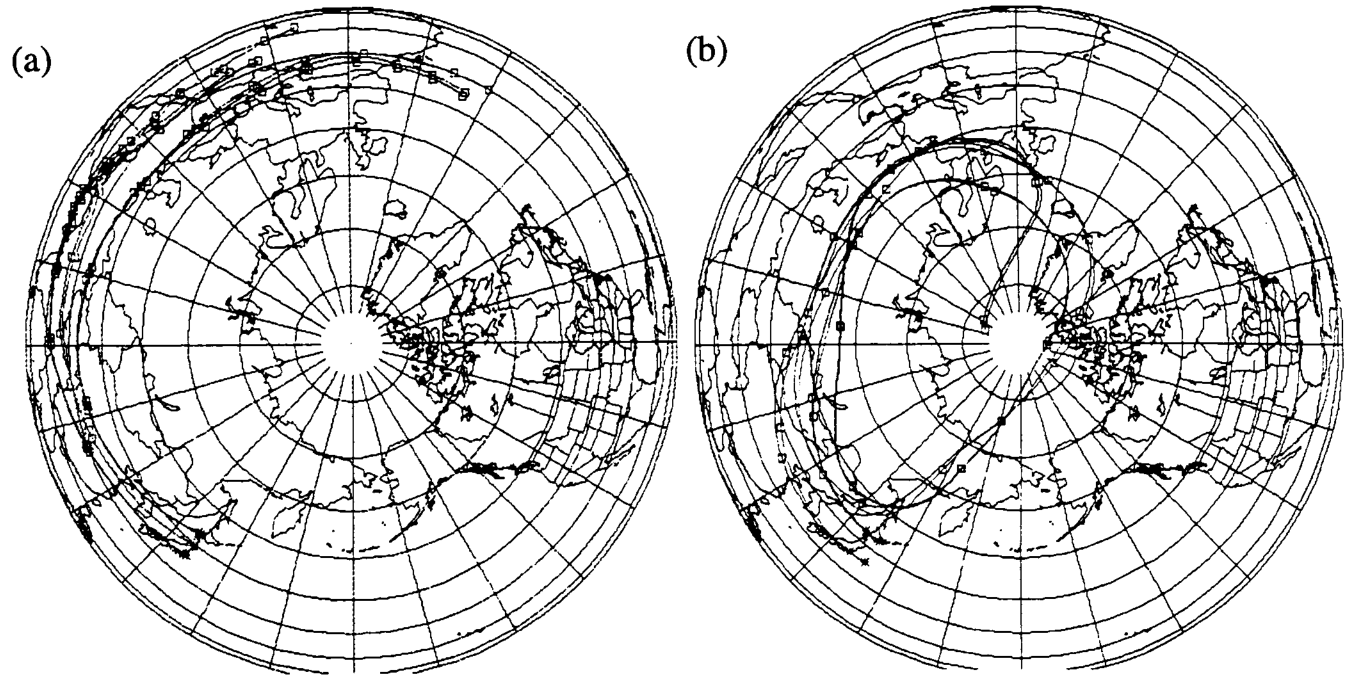


Fig.1 Backward trajectory for 10 days from Tsukuba on (a)Jan. 23, '95 and (b)Feb. 2, '95.

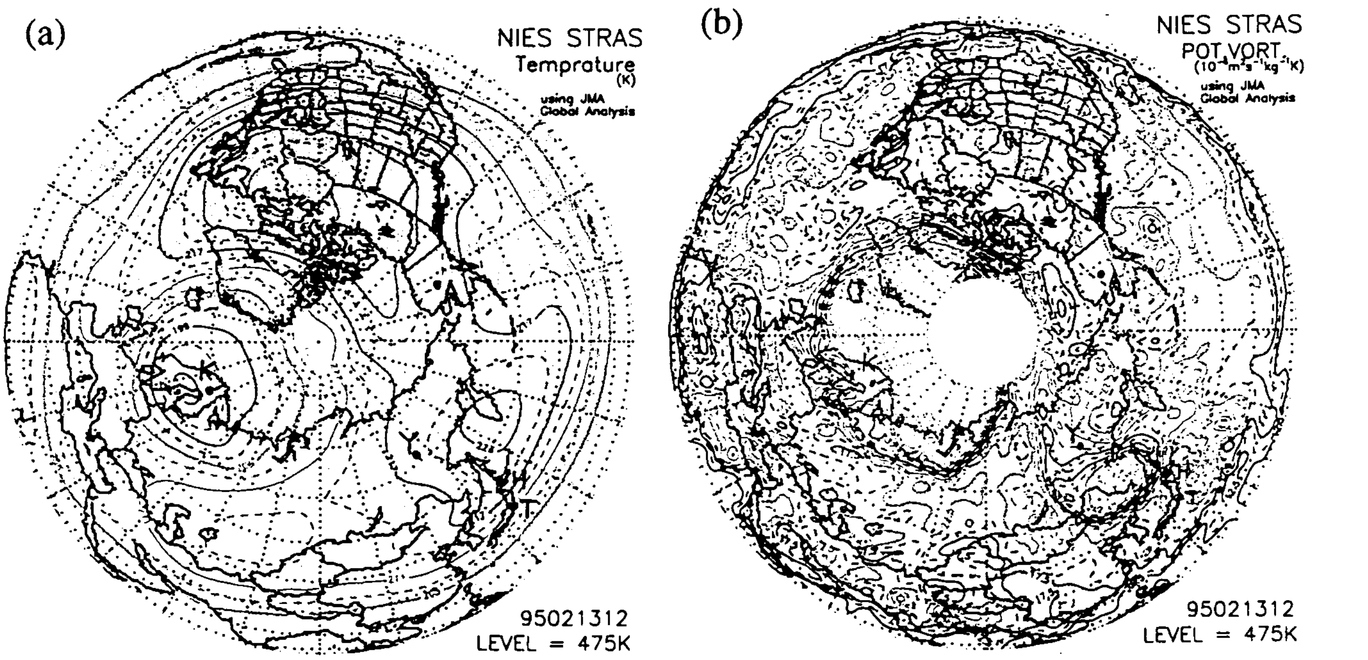
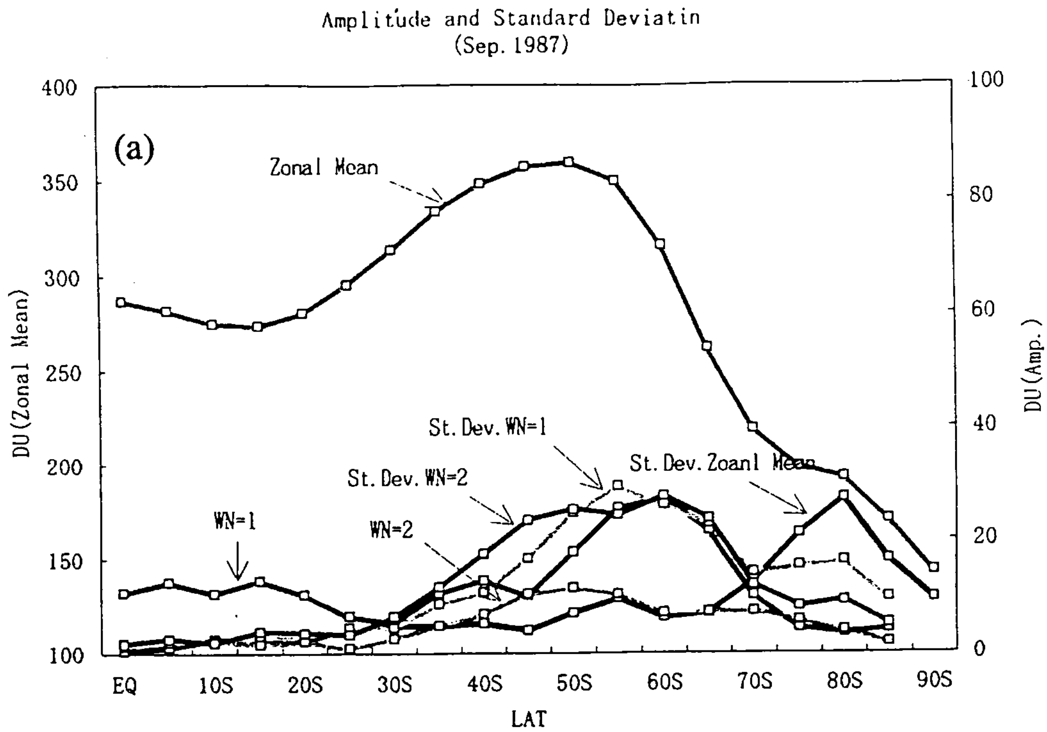


Fig.2 (a)Temperature and (b)PV maps on a isentropic surface of 475K in the Northern Hemisphere.



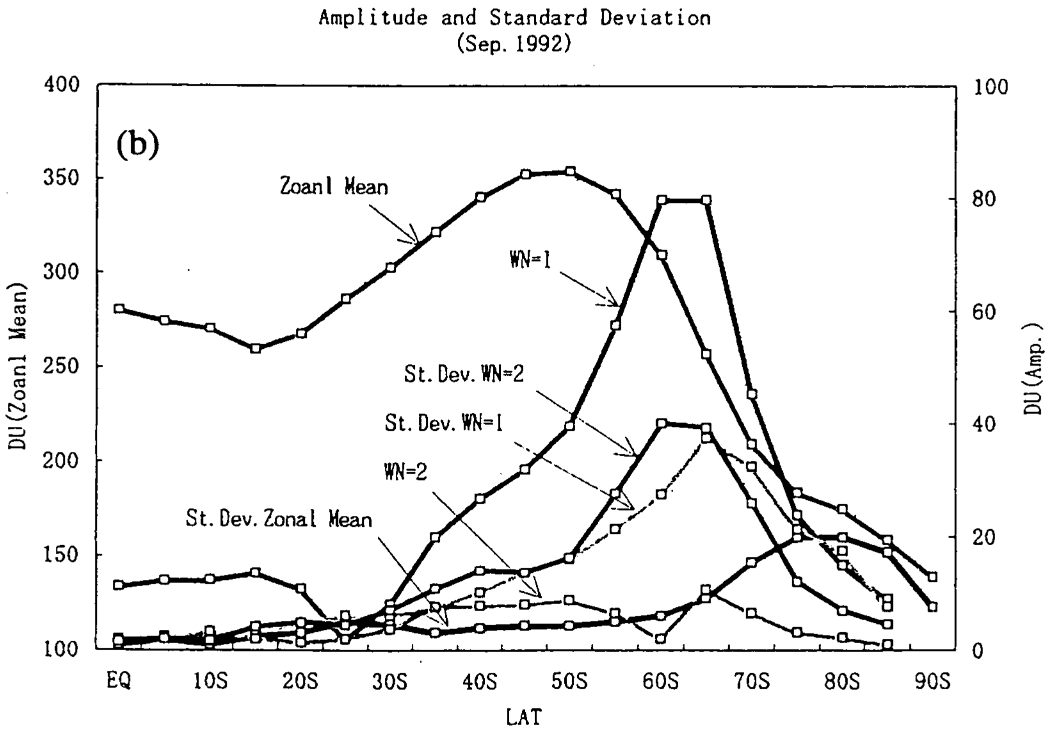


Fig.3 Zonal mean of the total ozone, amplitude of wave number 1 and 2 and the standard deviation in (a)Sep. 1987 and (b)Sep. 1992 in the Southern Hemisphere

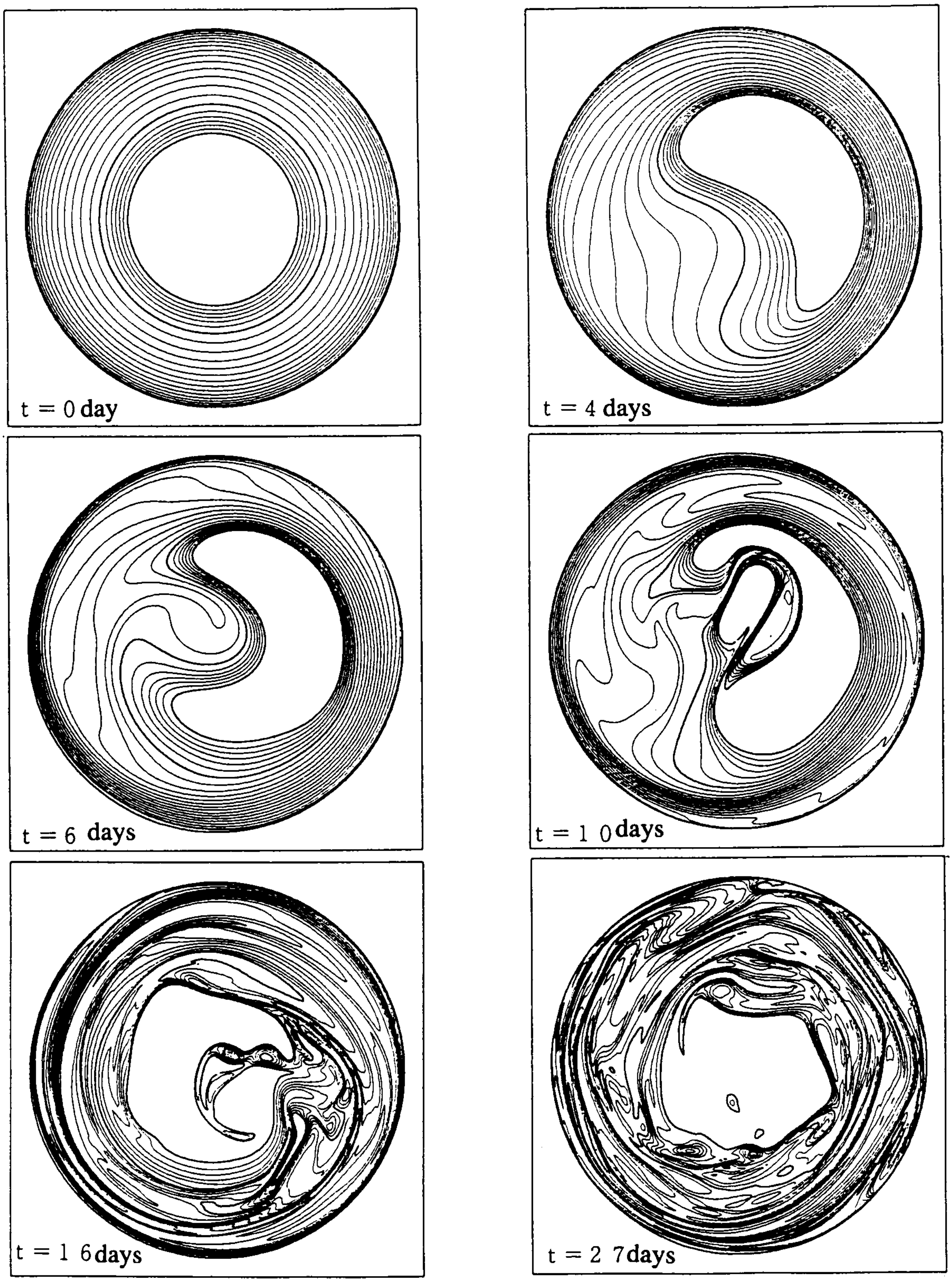


Fig.4 Time development of the potential vorticity. Two thick lines corresponds to potential vorticity of 2 and 1.4, respectively. Potential vorticity in the white region is higher than 2.