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LONG-TERM CHANGES IN THE QUASI-STATIONARY ZONAL DISTRIBUTION OF THE TOTAL OZONE IN THE ANTARCTIC REGION

A.V. Grytsai, A.M. Evtushevsky, G.P. Milinevsky, and A.V. Agapitov (*National Taras Shevchenko University of Kyiv, Ukraine*)

Abstract. Zonal distribution of the TOMS total ozone at the edge of the Antarctic stratospheric polar vortex is analyzed. The period of Antarctic late winter – spring – early summer (August-December) is considered. We study the changes in the zonal asymmetry of the total ozone for 1979-2004 using the TOMS daily data for 65°S and 70°S latitude circles. The 5-month average zonal distributions for the total wave number are considered. The results show that for the last 25 years the difference between zonal maximum and minimum of 5-month average total ozone increased to about 90 DU, or 30% compared to the zonal mean. The variations in the position of ozone maximum during the year are explored. A long-term eastward displacement of ozone minimum from the longitude of 45°W to 10°E is found. This displacement can be explained by interaction between the quasi-stationary components with zonal wave number 1 and 2.

1. Introduction

Long-wave atmospheric disturbances are regularly observed both as traveling and stationary planetary waves (Mechoso and Hartmann, 1982; Nogues-Paegle et al., 1992; Quintanar and Mechoso, 1995; Hood and Zaff, 1995). We consider a stationary component of the planetary waves, which causes a steady spatial distribution of atmospheric characteristics. In the real atmosphere some deviations from the steady distribution take place and these waves are named quasi-stationary ones.

This paper describes the quasi-stationary waves in the longitudinal distribution of the total ozone content above the Antarctic region. The TOMS data (Version 8) for the period of 1979-2004 are used (TOMS, 2005). The two latitude circles 65°S and 70°S are considered. This is an edge region of the stratospheric polar vortex (Lee et al., 2001) where the wave disturbances are the strongest during Antarctic winter/spring (Wirth, 1993; Quintanar and Mechoso, 1995). The data in the time interval of August-December (southern late winter, spring and early summer) are used. The long-term changes in the quasi-stationary planetary waves are analyzed from the 5-month average zonal distributions of the total ozone.

2. Analysis technique

The analysis technique described in (Grytsai et al., 2004) is used to obtain the quantitative parameters of the planetary waves. The daily longitudinal distributions of the total ozone at a certain latitude are selected from the TOMS global data to calculate the August-December average distribution and total ozone longitudinal profile (Fig. 1), which characterizes the steady ozone distribution at a given latitude for the 5-month interval. Although the wave activity in the southern stratosphere is high in winter (Fishbein et al., 1993; Hio and Hirota, 2002), the analysis for the high latitudes can be made only for August, because of the gap in the TOMS measurements during the polar night.

The 50°- window is applied to the 5-month average distribution to smooth the longitudinal profile. Then for 1979-2004, with excluding three years 1993-1995 because of the gap in the TOMS Version 8 data, the zonal wave amplitude and longitudinal position of the total ozone maximum and minimum are determined. The amplitude is calculated as a half a difference between the maximum and minimum values of total ozone. In this paper the results for the two latitude circles of 65°S and 70°S are presented.

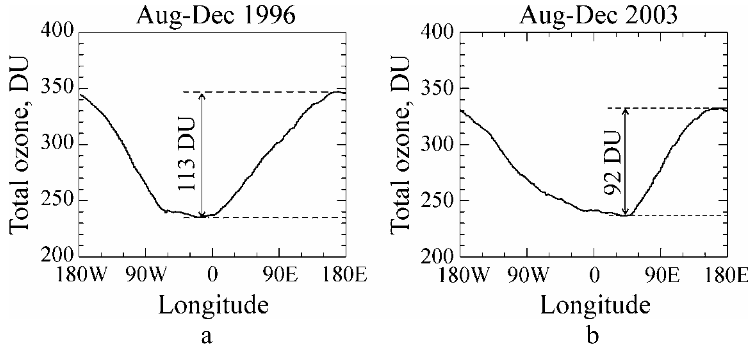


Fig. 1. August-December average distribution of total ozone along the latitude circle 65°S in 1996 (a) and 2003 (b).

Spectral analysis of the daily zonal distributions was performed and the quasi-stationary components of the zonal wave number 1-5 were calculated. Fig. 2 shows the first two harmonics (stationary wave numbers 1 and 2). Each plot gives a set of curves for the period of 1979-2004. In this case the amplitude was calculated as a maximum deviation from the zonal mean.

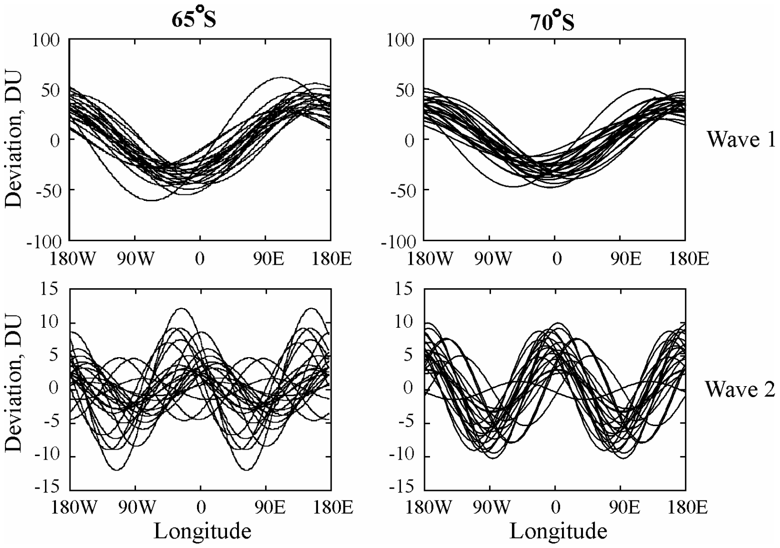


Fig. 2. The sets of the August-December average stationary wave 1 and 2 in the longitudinal distribution of the TOMS total ozone for the period 1979-2004, 65°S (left) and 70°S (right).

3. Long-term changes in the quasi-stationary wave characteristics

The changes in the maximum and minimum levels of total ozone in quasi-stationary zonal wave at the latitude circles 65°S and 70°S are shown in Fig. 3a. The negative trends are different for the ozone maximum and minimum. A higher negative trend of the total ozone minimum leads to the long-term increase in the wave amplitude (Fig. 3b).

During the last decade, the amplitude increased up to ~45 and ~35 DU at 65°S and 70°S, respectively, meaning the increase of about ~50% and ~25%, compared to the level of 1979.

In the last decade (1996-2004) the averaged low/high ozone values at 65°S were about 230/320 Dobson Units (DU). This difference is an evidence of the total ozone zonal asymmetry, which in 2000s reached 90 and 70 DU at the latitudes of 65°S and 70°S, respectively. It is about 30% compared to the zonal mean, and the asymmetry increases up to 40% in some of the years (see, for example, 1996 in Fig. 1a).

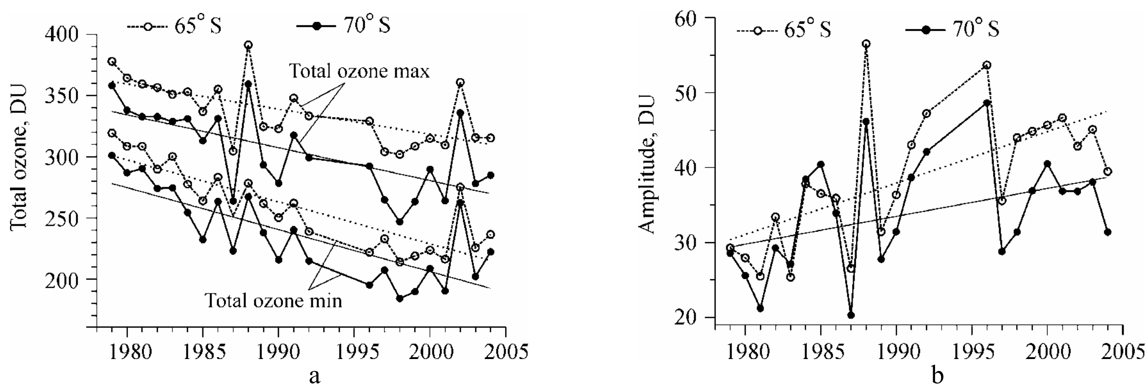


Fig. 3. Maximum and minimum levels of total ozone from 5-month average longitudinal distribution at 65°S and 70°S (a) and the zonal wave amplitude (b).

The changes in total ozone maximum and minimum longitudinal position are presented in Fig. 4. The longitude of the maximum varies close to the stable position of 162°E and 172°E at the latitudes of 65°S and 70°S, respectively. The position of the minimum shows a systematic eastward displacement from 45°W to 0° and from 40°W to 10°E, respectively.

On the average, for the two latitude circles a linear fit gives the drift velocity of 20±9°/decade (at the 95% confidence level). That is, our results reveal another feature of the zonal asymmetry, i.e. asymmetry in the longitudinal position of the total ozone extremes. This asymmetry varied for the last 25 years with nearly symmetric extreme position (the longitudinal distance of 180°) in the early 1990s (Fig. 4).

4. Spectral components of the quasi-stationary wave

To clarify, whether the wave processes are the cause of the difference in the behavior of ozone maximum and minimum (Fig. 4), the 5-month averages of the daily zonal wave number 1-5 have been analyzed for each latitude circles. As seen from Fig. 2, waves 1 and 2 are most often observed in nearly anti-phase combination around the zero longitude; it is especially evident from the plots for 70°S latitude (Fig. 2, right). We have compared the long-term changes of the phase of these quasi-stationary extremes. Fig. 5a shows that waves 1 and 2 exhibit different direction of the systematic longitudinal displacement. Wave 1 zonal drift is consistent with the eastward drift of the total wave number minimum (see Fig. 4) and wave 2 has the opposite drift to the west.

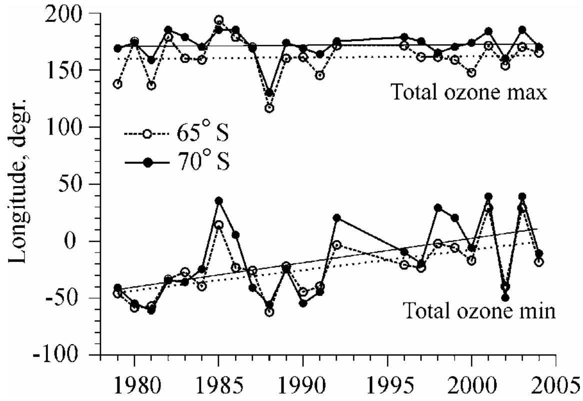
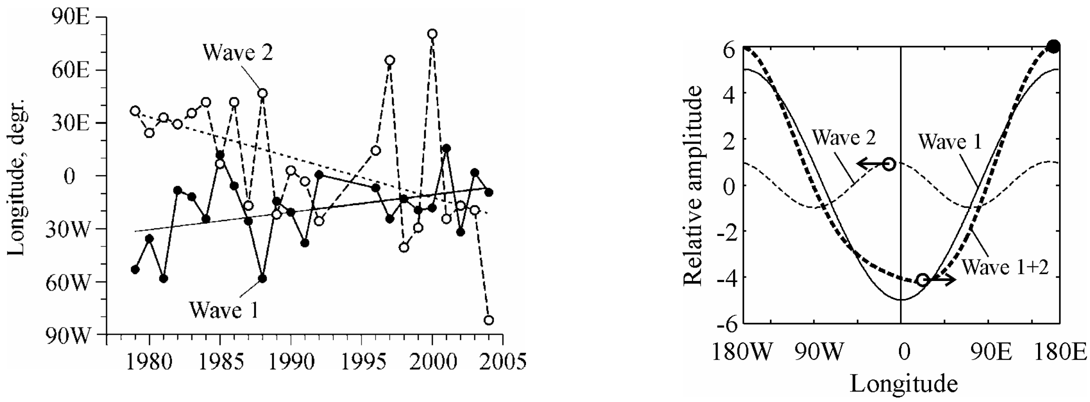


Fig. 4. Changes of the longitudinal position of the zonal maximum and minimum in the total ozone 5-month average distribution at 65°S and 70°S for 1979-2004.

Note, that nearly anti-phase combination of the wave extremes around the zero longitude is accompanied by their in-phase positions in the opposite longitudinal sector. The different drift direction of waves 1 and 2 causes an unstable position of the wave sum extreme in the 'anti-phase sector' and a stable one in the 'in-phase sector'.

Fig. 5b indicates that the zonal drift of wave sum minimum is much larger than that of maximum. As an example, wave 1 at the fixed longitude position is shown.

Wave 2 to wave 1 amplitude ratio corresponds to the average amplitude proportion in Fig. 2. If wave 2 maximum drifts to the west, then wave 1+2 minimum drifts to the east.



a B

Fig. 5. Interannual variations and trend of the 5-month average phase of zonal wave 1 minimum (the solid line) and wave 2 maximum (the dashed line) at 70°S for 1979-2004 (a), and the eastward displacement of wave 1+2 minimum due to the westward drift of wave 2 relative to wave 1 (b).

Within the relative phase displacement, which can be estimated from the long-term drift of the wave 1 and 2 extremes (Fig. 5a), the maximum of the sum of waves 1 and 2 takes almost unchanged position (small black circle in Fig. 5b).

We have calculated the sum of the first two spectral components by the 5-month averaging of their daily longitude deviations. The positions of the sum extremes reproduce nearly the whole picture of longitudinal variations of total wave number extremes presented by Fig. 4: ozone maximum takes in average the stable longitudinal position and the minimum displaces systematically to the east. For example, the average drift velocity for the wave 1+2 minimum is 20±10 °/decade, which almost exactly agrees with the value of 20±9 °/decade obtained above for the total wave number minimum. Wave 3 does not exhibit any systematic phase shift (not shown). Besides, wave number 3 has a much smaller 5-month average amplitude (of about 2 DU) and therefore gives no significant contribution to the ozone zonal asymmetry on this time scale.

5. Conclusion

The quasi-stationary zonal distribution of the total ozone along the two latitude circles of 65°S and 70°S is considered. Spectral analysis of the data shows that wave number 1 dominates in the August-December average zonal distribution of total ozone. It has been determined that during 1979-2004 the zonal asymmetry between the high and low levels of total ozone increased. In the last decade the asymmetry reached about 90 and 70 DU at 65°S and 70°S, respectively, which corresponds to the 5-month average asymmetry of ~30% relative to the total ozone zonal mean.

Another feature of the zonal asymmetry is changes in longitudinal position of the total ozone extremes. The longitude of the maximum varies close to the stable position of 162°E and 172°E at the latitudes 65°S and 70°S, respectively. The position of the minimum shows a systematic eastward displacement from 45°W to 0° at 65°S and from 40°W to 10°E 70°S. On the average, for the two latitude circles a linear fit gives the drift velocity 20±9°/decade.

The change in the 5-month average zonal asymmetry of the total ozone obtained in this paper can impact the longitudinal distribution of the surface UV-doses. Since the quasi-stationary waves in total ozone are formed in the lower stratosphere (Hood and Zaff, 1995), ozone zonal asymmetry can influence the temperature regime in this layer at the high southern latitudes. The tasks of the future work are an estimation of a possible impact of these effects on the Antarctic ecosystem and revealing the causes of the long-term drift of quasi-stationary wave total ozone minimum.

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