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ANTARCTIC TOTAL OZONE ANOMALY DURING 1988 AND 2002 SPRINGS

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Abstract. The total ozone content (TOC) variations in Antarctic region are considered using the TOMS satellite measurements. Main attention is devoted to ozone hole anomalous development in the 1988 and 2002 springs. The TOC planetary wave parameters in anomalous and typical years were compared. The TOC zonal mean increase relatively linear trend is equal 36 DU in 1988 and 60 DU in 2002. The evident TOC longitudinal contrast appeared in August of both anomalous years, one month before typical quasi-stationary wave development. The September zonal mean minimum was absent and TOC values exceeded typical at least from August to December. The first spectral components of zonal wave showed a considerable amplitude growing. Wave 1 amplitude in August and September was 2-3 times larger than in the neighboring years. In September 2002 the amplitude of wave 2 increased twice comparative to August in contrast to 1988. Characteristics of wave 3 did not change considerably relative to other years. Westward displacement of quasi-stationary wave minimum and maximum in 1988 and 2002 has been revealed. At 65°S the minimum for September-November averaged distribution shifted by 50° and 70°, respectively. This feature could be considered as indication of tropospheric changes.

Key words: total ozone content, planetary waves, Antarctic region, TOMS

Антарктична озонова аномалія навесні 1988 і 2002 рр. А.В. Грицай
Реферат. Варіації загального вмісту озону (ЗВО) в Антарктиці розглянуті з використанням супутникових (TOMS) вимірювань. Увага приділяється, головним чином, аномальному розвитку озонової діри навесні 1988 та 2002 рр. Проведене порівняння параметрів планетарних хвиль у ЗВО для аномальних та типових років. Зростання зонального середнього ЗВО відносно лінійного тренду становить 36 ОД у 1988 р. та 60 ОД у 2002 р. Суттєвий довготний контраст ЗВО спостерігався у серпні обох аномальних років, місяцем раніше типового розвитку квазістаціонарної хвилі. Вересневий мінімум зонального середнього був відсутній, а значення ЗВО перевищували звичайні принаймні з серпня до грудня. Перші спектральні компоненти зональної хвилі показали суттєве зростання амплітуди. Амплітуда хвилі 1 у серпні та вересні була в 2-3 рази більшою, ніж у сусідні роки. У вересні 2002 р. амплітуда хвилі 2 зросла вдвічі порівняно з серпнем, на відміну від 1988 р. Хвиля 3 суттєво не змінила своїх характеристик відносно інших років. Виявлений західний зсув мінімуму та максимуму квазістаціонарної хвилі у 1988 та 2002 рр. На широті 65°S мінімум усередненого за вересень-листопад розподілу змістився на 50° і 70°, відповідно. Ця особливість може розглядатися як прояв тропосферних змін.

Антарктическая озоновая аномалия весной 1988 и 2002 гг. А.В. Грицай
Реферат. Вариации общего содержания озона (ОСО) в Антарктике рассмотрены с использованием спутниковых (TOMS) измерений. Внимание уделяется, главным образом, аномальному развитию озоновой дыры весной 1988 и 2002 гг. Проведено сравнение параметров планетарных волн в ЗВО для аномальных и типичных лет. Возрастание зонального среднего ОСО относительно линейного тренда становит 36 ЕД в 1988 г. и 60 ЕД в 2002 г. Существенный долготный контраст ОСО наблюдался в августе обоих аномальных лет, месяцем ранее типичного развития квазистацилнарной волны. Сентябрьский минимум зонального среднего отсутствовал, а значения ОСО превышали обычные по крайней мере с августа по декабрь. Первые спектральные компоненты зональной волны показали существенное возрастание амплитуды. Амплитуда волны 1 в августе и сентябре была в 2-3 раза больше, чем в соседние годы. В сентябре 2002 г. амплитуда волны 2 увеличилась вдвое по сравнению с августом, в отличие от 1988 г. Волна 3 существенно не изменила своих характеристик относительно других лет. Обнаружен западный сдвиг минимума и максимума квазистационарной волны в 1988 и 2002 гг. На широте 65°минимум усреднённого за сентябрь-ноябрь распределения сместился на 50° и 70°, соответственно. Эта особенность может рассматриваться как проявление тропосферных изменений.

1. Introduction

At high latitudes of the Southern Hemisphere (SH) the strong variations of the total ozone content (TOC) take place during spring. Besides, in this region the considerable TOC interannual changes occur. The study of the observed changes is important for understanding the processes in ozone layer caused the ozone hole appearance and their possible prediction.

Ozone hole in the SH polar region has been observed from early 1980-s. Its area and duration change from year to year. The large deviations from average seasonal course happen sometimes. Such events were observed twice for the last 25 years – in 1988 (Kanzava and Kawaguchi, 1990) and in 2002 (Stolarski et al., 2005). The most considerable diminution of ozone hole area relative to the neighboring years was registered in 2002. The sudden stratospheric warming with zonal wind inversion unprecedented for the Southern Hemisphere took place (Allen et al., 2003; Harnik et al., 2005). Singularity of the phenomenon caused the appearance of "Journal of the Atmospheric Sciences" special issue (2005, Vol. 62, No. 3).

Ozone hole is usually defined as a region with ozone content smaller than 220 Dobson Units (DU) (Stolarski et al., 2005). The maximal area of the ozone hole determined in accordance with this definition reaches sometimes $25\text{-}30 \cdot 10^6$ km^2. The distinction from the neighboring years was very significant during the spring of 2002. The area of the ozone hole briefly reached $18 \cdot 10^6$ km^2, and then dropped rapidly in September to $2 \cdot 10^6$ km^2, or only about 10% of the normal area for that time. This event coincides with the vortex splitting into two pieces (22 September). In mid-October ozone hole recovered to the area of about $8 \cdot 10^6$ km^2 and finally disappeared in early November (Stolarski et al., 2005).

In ozone hole region a yearly minimum followed by the sharp increase is observed in early spring (usually in September). In anomalous 2002 the October average exceeded the 1990-2001 October average by 100-120 DU. This caused the exceeding of 2002 ozone content for the whole Southern Hemisphere by 2.5% (Stolarski et al., 2005). As a rule, ozone hole disappears in November and the TOC level recovers. Subsequently, in summer and in autumn, the ozone content decreases slowly. At the polar night end, in August, ozone hole appears again. A described seasonal cycle has taken place from the early 1980-s.

A distinctive feature of 2002 event consisted in the zonal wind rapid deceleration at 10 hPa level from 60 m/s westerly to 15 m/s easterly during 17-27 September (Allen et al., 2003). Such a scale of deceleration was never observed at least since 1979. Zonal wind remained easterly to 30 September, when it temporarily reversed to weakly westerly. Final warming at 10 hPa happened very early, on 31 October 2002.

Some researchers consider the effect of lower latitudes winds as a possible cause of the strong stratospheric warming in 2002. In that year a westerly phase of quasi-biennial oscillations in the lower stratosphere was observed (Gray et al., 2005). It is usually connected with undisturbed stratospheric polar vortex and deep ozone hole but in the upper stratosphere there was easterly wind anomaly in 2002. During January-September period strong easterly winds existed at the levels over 10 hPa. The possible impact of this phenomenon on high latitudes processes was studied using the simulation (Gray et al., 2005). At 30°S latitude the strong westerly wind deceleration with the following inversion of its direction began in May (Harnik et al., 2005). But the mere occurrence of the easterly winds in the lower-latitude stratosphere could not be the cause of sudden warming. Similar conditions were also observed in other years, for example in 1999, but ozone anomaly was not observed, suggesting that other factors are also required (Gray et al., 2005).

Planetary waves as the large-scale atmospheric disturbances have an important influence on ozone changes. In the southern high latitudes their maximal activity is observed in spring. Stationary planetary waves cause spatial redistribution and traveling planetary waves produce time variations. The length is one of the main characteristics of planetary waves. It is usually noted by zonal number which is equal the quantity of maxima or minima along the parallel (in zonal direction).

The planetary wave amplitude and time characteristics change considerably from year to year, amplitude ratio for waves with zonal number 1 and 2 varies too. It is shown that the traveling wave 1 is generated in the stratosphere through the wave-wave interaction (Hio and Yoden, 2004).

The increased planetary waves activity in high latitudes in some years can be caused by easterly winds domination at moderate and subtropical latitudes. Such stratospheric conditions result in poleward reflection of planetary waves (Harnik et al., 2005). The relationship between zonal mean flow and planetary waves exists, so, waves weaken zonal mean flow after that their amplitude decreases. This scenario was observed in the 2002 spring.

In (Harnik et al., 2005) it was determined that wave 1 and 2 heat fluxes in September 2002 were directed upward and exceeded usual values. The considerable increasing of heat fluxes was registered in the second half of September when sudden warming happened. In mentioned work main attention is devoted to simultaneous activity of the waves with both zonal numbers 1 and 2. Their joint developing is considered as the most important cause of the warming.

The considerable increase of heat flux at 100 hPa and 10 hPa in the spring of 2002 is noted in (Allen et al., 2003). At 10 hPa level an unusually persistent propagation of wave 2 was observed (Harnik et al., 2005). This traveling wave with period of about 12 days existed in the edge region of the stratospheric polar vortex during about 3 months (from July to October). A strong early planetary wave activity in 2002 was observed in ozone measurements also.

In 1988 the considerable stratospheric warming also took place from the end of August to the beginning of September. A strong stratospheric temperature increasing was observed during last week of August. Over Japanese station Syova the temperature at the level 30 mb (about 22 km) grew up by 59°C for 10 days (Kanzava and Kawaguchi, 1990). The temperature increasing in 1988 was accompanied by sudden growing of ozone content with a jump more than 200 DU over Syova station. The rate of temperature increasing was close to that during the major stratospheric warming in the Northern Hemisphere. But the spring warming in 1988 in the Southern Hemisphere does not satisfy the definition for a major warming as far as the disappearance of stratospheric polar vortex at 10 mb did not occur.

The unusual character of seasonal ozone course in 2002 and the similarity of the 1988 and 2002 events are noted in (Jadin and Vargin, 2004). The authors suppose that a connection between sea surface temperature anomalies and long-term variations of wave activity exists. It is assumed that wave amplitude depends on surface forcing mainly. A possible sea surface temperature influence in the eastern Pacific Ocean is considered in (Varotsos, 2003). It is assumed El Niño phenomenon can affect the intensity of high latitude oscillations.

Thus, the 1988 and 2002 anomalies in the Southern Hemisphere stratosphere were observed as the ones in TOC level, planetary wave activity, heat flux and temperature increase. But the anomalies intensity was larger in 2002 causing the major warming. The researchers assume the processes responsible for the Southern Hemisphere major warming are connected with the quasi-biennial oscillations and the influence of low-latitude wind and sea surface temperature. Further comparison of the 1988 and 2002 events could be useful for the identification of the most important factors leading to ozone hole anomalous development.

The aim of this work is to continue the search of the similarities and distinctions between 1988 and 2002 events analyzing the characteristics of the TOC zonal distribution. The edge and inner parts of the stratospheric polar vortex covering Antarctic region are considered. The study of planetary wave parameters in spring is carried out.

2. Data and methods

In this work satellite ozone observations are used. Satellite observations from Total Ozone Mapping Spectrometer (TOMS) have been carried out from 1979. The last, 8th data version is used. It includes the total ozone values for the years 1979-1992 and from 1996 hitherto. So, the measurements for 23 years in the 1979-2004 period are analyzed to estimate the anomaly level in 1988 and 2002 on the background of interannual variations and long-term tendencies. Besides, some parameters are compared with those for two neighboring years .

The TOMS observations give the global distribution of the daily ozone values. The spatial resolution is 1° for the latitude and 1.25° for the longitude (TOMS, 2005). The latitudes 55°S, 60°S, 65°S, 70°S and 75°S, which cover edge and inner regions of ozone hole, are considered. At the low Sun’s angular height over horizon the observations are not carried out, therefore whole August is covered by measurements up to 65°S only, but not at the higher latitudes.

The austral spring was taken for the analysis because the intense dynamical processes in stratosphere occur during this season. To obtain stationary wave parameters a time averaging of the ozone longitudinal distribution for 3 months (September-November) was realized. Zonal wave number characteristics were calculated by the spectral decomposition of the daily ozone distribution along each latitude circle. The components with wave number 1-3 are considered because the higher ones have very small amplitudes, especially for stationary waves.

3. Southern Hemisphere polar ozone variations and the peculiarities of 1988 and 2002

3.1. Interannual variations

The visualization of time-longitude ozone distribution at 65°S for anomalous and typical years reveals some details, which were distinctive in 1988 and 2002. Time-longitude distributions for 1987-1988-1989 and 2001-2002-2003 are shown in Fig. 1.

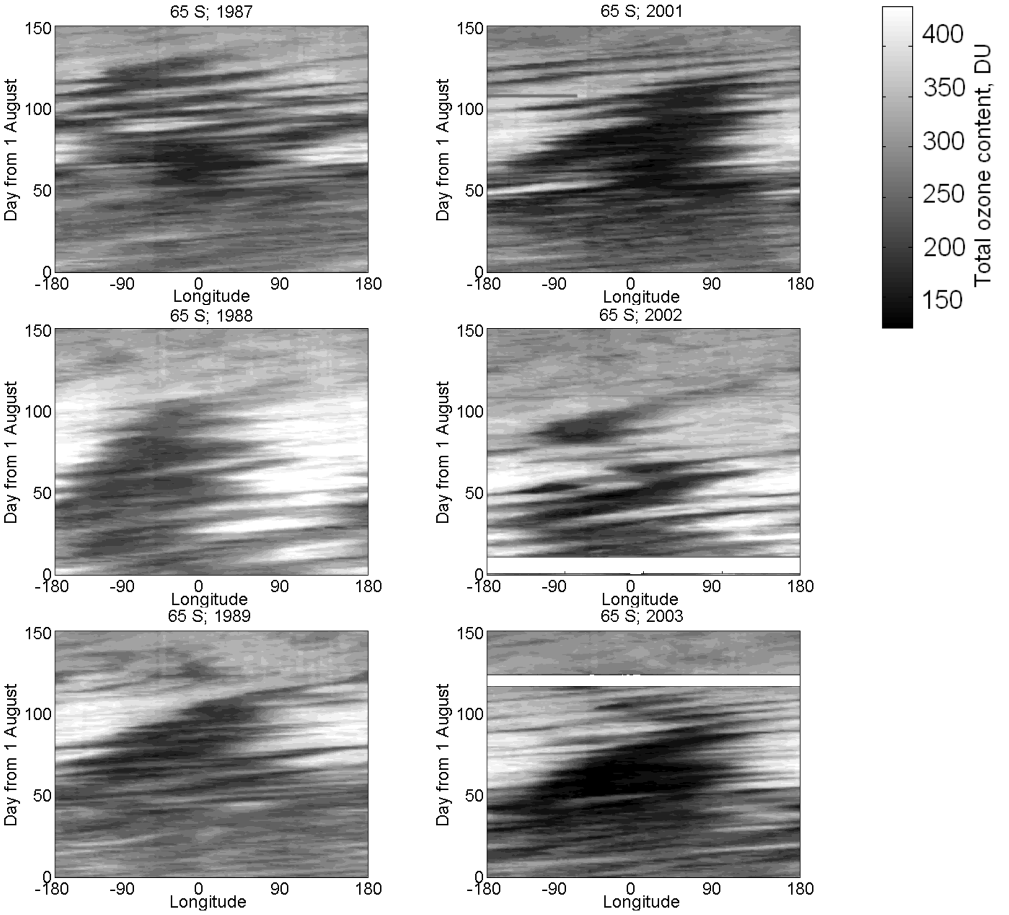

Fig. 1. Time-longitude variations of ozone content at 65°S in anomalous 1988, 2002 and adjacent years.

Firstly, the considerable increase of ozone content is noted in August-November 1988 and 2002 comparatively corresponding time interval of the adjacent years. It is seen from the lighter level of gray in the time-longitude plots for these years relatively other ones. The increase was registered in the longitudinal sectors both for the total ozone minimum and maximum. The sharp ozone increase is a result of moderate latitude air masses propagation to high latitudes. When this process occurs in a wide latitudinal band, this is an evidence of the stratospheric polar vortex destruction. The strong stratospheric warming is often observed in the Northern Hemisphere, but in the Southern Hemisphere event of 2002 spring is considered as an unprecedented phenomenon.

The significant contrast between the longitudinal maximum (white) and minimum (black) appeared in the August of the anomalous years. In the neighboring years this monthly distribution looked very uniform and longitudinal contrast increased beginning from September (Fig. 1). This is a manifestation of the earlier intensification of a quasi-stationary zonal wave in anomalous years. Traveling planetary waves, which are seen as inclined streaks in the August of 1988 and 2002, were observed in the adjacent years only from September too. This is an evidence of anomalous stratospheric regime, when sharp changes occurred about one month earlier than normally (Charlton et al., 2005).

Westward shift in longitudinal position of total ozone extremums is clearly seen in the anomalous years, especially in 1988 and it will be quantitatively estimated in the subsection 3.2.

From the beginning of regular satellite observations till the end of 1990-s the systematical considerable ozone decrease was fixed in SH high latitudes. The changes of the 3-month zonal mean at 65ºS confirm this tendency (Fig. 2). The positive deviations from the mean tendency in 1988 and 2002 were evident. The exceeding over linear trend (dashed line in Fig. 2) was equal 35.8 DU in 1988 and 59.7 DU in 2002. It is need to note the negative deviation in the preceding years, which in 1987 was even greater than positive one in 1988, whereas the interannual variations in the rest of years had approximately a half or third of amplitude relative to anomalous ones.

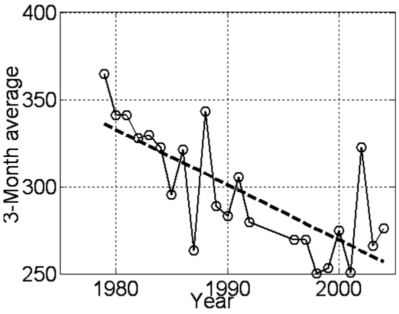

Fig. 2. Interannual variations and long-term trend of the September-November average of TOC zonal mean at 65° S.

Consequently, the jump between September-November average in 1987-1988 and 2001-2002 was about 80 and 72 DU, respectively. Distinction from the next year was smaller than from preceding one and equal to about 55 DU in 1988-1989 and 2002-2003.

Then, both cases exhibit a similar behavior of interannual variations, in which the next year after anomalous one shows the higher ozone level than preceding year. This feature could be a residual effect of anomalous ozone increasing, which lasted up to the next year and suggests that quasi-biennial oscillations had specific influence on anomalies 1988 and 2002 events (Gray et al., 2005).

3.2 Seasonal changes

The TOC seasonal course at latitudes covered by ozone hole has the spring ozone minimum. This minimum is observed in September and seen both in station data and in zonal mean. Illustration of typical seasonal changes during August-December is given in Fig. 3 by curves of 1987 and 1989 (left) and 2001 and 2003 (right). These curves are very close by pairs, especially during August-September. But in the anomalous 1988 and 2002 the seasonal minimum of zonal mean was absent that showed the atypical conditions existence. At 65°S the mean total ozone during all five months (August-December) of 1988 and 2002 remained greater than typical values. In the anomalous years the zonal mean before middle September was equal 280-320 DU exceeding the minimum level for adjacent years by about 50 DU (1988) and 80 DU (2002). After the mid-September increasing the exceeding was about 80 and 100 DU, respectively. So, as it is seen from the zonal mean, both in 1988 and 2002 the ozone anomaly lasted at least 5 months and was maximal in the second half of September.

Planetary wave activity has considerable monthly variations. In this subsection the main attention is given further to the wave activity monthly peculiarities and spectral characteristics. The wave amplitude increase in August and September of 1988 and 2002 was obtained in (Grytsai et al., 2005a) for the latitude 65°S.

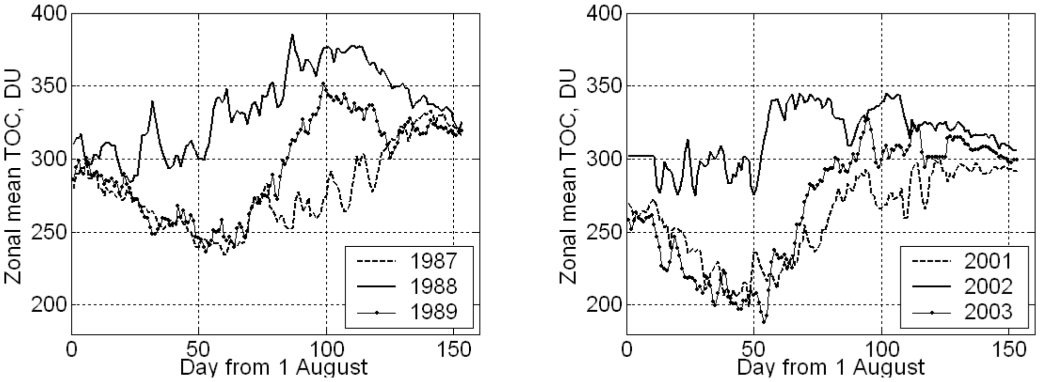

Fig. 3. Daily zonal mean TOC at 65°S for 1987-1989 (left) and for 2001-2003 (right).

Both the anomalous years 1988 and 2002 are characterized by an early planetary wave activity with large amplitudes relative to other years. In anomalous conditions the August amplitude of wave 1 exceeded the values for the preceding and next years 2-4 times. So, in 1988 August the wave 1amplitude reached 64 DU whereas in 1987 and 1989 it was equal 25 and 16 DU respectively. The same ratio took place in August 2002 too (85 DU in 2002 vs. 26 and 29 DU in the adjacent years). A similar pattern with a few lower amplitude ratios has been obtained for the wave 2 as well. On other hand, the wave with zonal number 3 does not show clear distinctions between three years (amplitude is 10-15 DU in August and a few lower in September), i.e., the increase of the most large-scale wave activity happened.

The comparison between two anomalous years shows that wave 1 in 2002 was of larger amplitude in August relative to 1988, whereas wave 2 had larger amplitude in September (57 and 29 DU correspondingly). This result indicates that the major warming was accompanied by earlier enhancement of wave 1. Wave 2 amplitude increased by factor of about 2 relative to August in September 2002 and decrease by factor 1.5 in 1988. This distinction is characteristic for the event of 2002, which is attributed to the “wave-2” type of the major warming (Charlton et al, 2005). Wave 2 is presented by traveling component dominantly (Grytsai et al., 2004) and the level of its activity can influence the strength of the stratospheric vortex on its final stage.

It is necessary to note that the large wave activity in the middle and upper stratosphere was observed throughout the 2002 late fall/winter (Allen et al, 2003). The planetary wave activity in total ozone was observed from late July when the ozone observations in edge region of stratospheric vortex were begun (Grytsai et al., 2004). In the late spring of 2002 the quick decrease of the wave activity in the total ozone data was observed due to early disappearance of ozone hole. Besides, in 1988 and 2002 the vortex had the smallest area and the vortex edge (and maximum of zonal wave in ozone) was placed at higher latitudes. In 2002 the November’s amplitude of wave 1 at 75°S (13 DU) was importantly smaller relatively other presented years (35-50 DU predominantly). In 1988 the diminution of planetary wave activity was not so strong and it became close to usual amount (39 DU for wave 1 at 75°S).

3.3. Longitudinal displacement of quasi-stationary wave extremums

Stationary (more precisely, quasi-stationary) planetary waves change slowly their phase from year to year. Spectral decomposition shows the domination of wave with zonal number 1 in the Southern Hemisphere (Hio and Hirota, 2002). Wave 1 is a sinusoidal component with one maximum and one minimum in zonal direction. But other components make some contribution in the decomposition therefore quasi-stationary wave is not symmetrical in longitudinal direction. The study of quasi-stationary wave extremums’ positions shows the long-term eastward drift of the minimum and the approximate invariability of the maximum’s longitude (Grytsai et al., 2005b). It is necessary to note that it is a mean tendency. In some years the deviations from the average position are observed.

The first estimation of the shift value along the 65°S latitude circle was given in (Grytsai et al., 2005b) using 5-month (August-December) average longitudinal distribution of total ozone. In this work the spring months September-November at 65°S and 70°S are considered and comparison with neighboring years is presented. As it is seen from Fig. 4, zonal wave 1 gives the main contribution to the westward longitudinal shift of the planetary wave extremums in anomalous years. Wave 1 phase shift in 1988 and 2002 had the close values relatively both the mean tendency and adjacent years values. Main tendency in the stationary wave 1 phase behavior consist in the eastward drift during last 25 years (Fig. 4, left). The considerable westward shift in the anomalous years, probably, can be connected with polar vortex (i.e., westerly zonal wind) weakness. Some westward shift was observed in 1981 and 1991, too, but the shift value relatively the mean tendency and adjacent years was lesser and closer to the displacements at typical interannual variations.

The stationary wave 2 phase did not show considerable shift in 1988 and 2002. At the same time, the evident wave 2 displacements occurred in 1997 (eastward), 2000 and 2004 (westward). So, the relationship between the stratospheric vortex state and wave 2 phase is not traced.

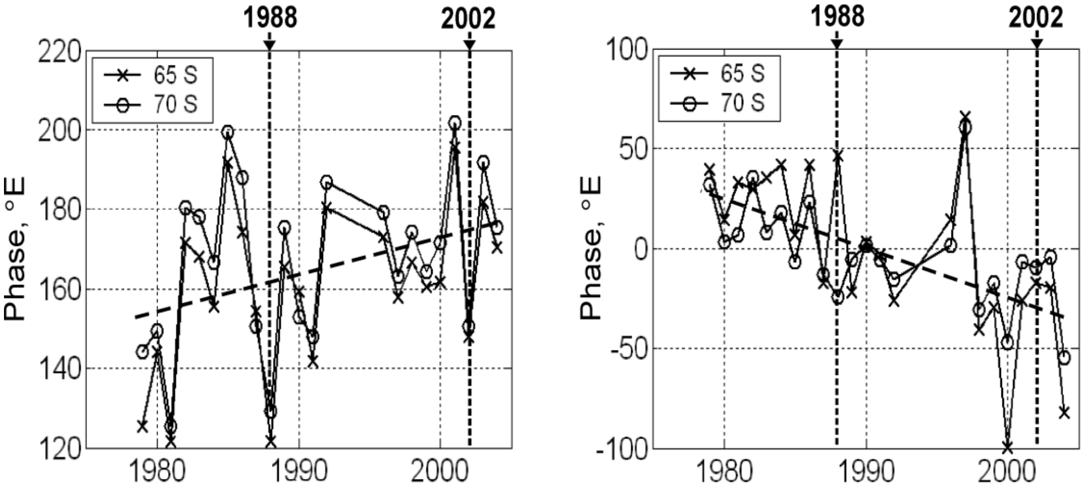

Fig. 4. The phase of September-November averaged stationary waves 1 (left) and 2 (right). The latitudes 65°S and 70°S are presented.

Quasi-stationary longitudinal dependence of the September-November average total ozone is presented in Fig. 5 as the total wave number distribution. Both 1988 and 2002 years were characterized by westward shift of extremums like shown in Fig. 4 for the wave 1 phase. At 65°S the westward quasi-stationary minimum shift relative to the adjacent years reached 50° in 1988 and 70° in 2002 (Fig. 5). The quasi-stationary wave maximum shifted westward by 60° in 1988 and by 15° in 2002.

The 3-month average total ozone in 1988 and 2002 exceeds the levels for neighboring years along the whole latitude circle. This feature is seen from the disposition of the curves in Fig. 5. For the minimum the difference relative to average for the two adjacent years is equal 30.6 DU in 1988 and 85.4 DU in 2002. For the quasi-stationary wave maximum the values 100.0 DU in 1988 and 40.8 DU in 2002 are obtained. This feature means the considerable quasi-stationary wave amplitude increasing in 1988 and its diminution in 2002. Physical cause of this phenomenon lies in a durable wave activity in 1988 and its quick decrease in 2002.

Thus, in 1988 and 2002 the westward shift of the quasi-stationary wave in total ozone was observed. This phenomenon took place at least in the latitudinal band of 55-75°S, which is studied in present work.

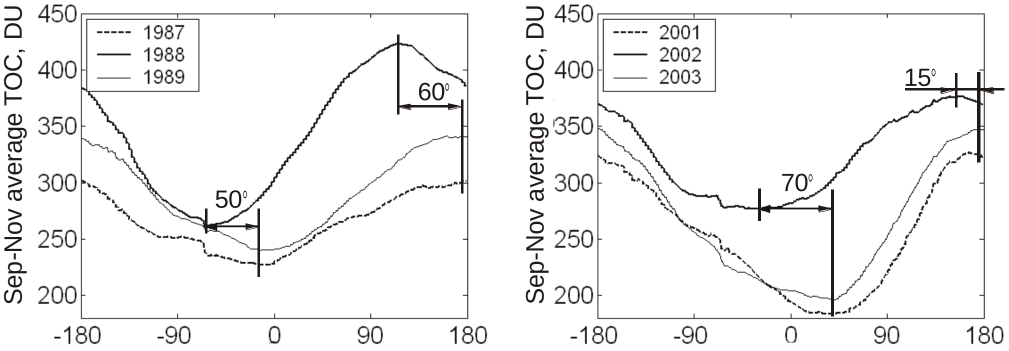

Fig. 5. September-November averaged longitudinal TOC dependence for 1987, 1988 and 1989 (left) and for 2001, 2002 and 2003 (right) at 65°S. The arrowheads show the longitudinal distance of the extremums position shift.

4. Conclusions

Anomalies in the Antarctic total ozone during the springs of 1988 and 2002 have been analyzed using the TOMS data. Main attention was devoted to anomalous features of these years in the zonal mean interannual variations and ozone seasonal course as well as in the parameters of planetary waves and their quasi-stationary component. Main features of variations of ozone content and planetary wave parameters in 1988 and 2002 are following.

1) The visible TOC increase occured in the anomalous 1988 and 2002 relative to the adjacent years (time-longitude plots in Fig. 1). The evident longitudinal contrast appeared in August of the anomalous years whereas in usual conditions this phenomenon occurred one month later. This is a manifestation of the earlier intensification of quasi-stationary zonal wave in the 1988 and 2002 winter/spring. Traveling planetary waves were observed in August as well (on typical conditions they appear only in September). Consequently, in 1988 and 2002 the stratospheric dynamical processes in Antarctic region developed approximately one month earlier than usually. Both stationary and traveling components of planetary waves were involved in this process.

The positive deviations in anomalous years from the mean tendency in the TOC zonal mean were estimated. In 2002 the deviation was larger than in 1988 (60 and 36 DU, respectively). In the previous years (1987 and 2001) the negative deviations up to some tens of Dobson Units were observed. The 3-month zonal mean in the next year is higher than in preceding one. This could be considered as possible prolonged effect of anomalous ozone increasing. For example, at 65°S the 1988-1987 and 2002-2001 differences are 80 and 72 DU, respectively, while relative to the next year analogous differences are about 55 DU in both cases. The described variations can be partially explained by the quasi-biennial variations impact.

2) Similarity of anomalies in 1988 and 2002 consists in absence of the September TOC minimum, which are observed regularly in the most of southern springs. Besides, their daily values of zonal mean exceeded typical ones at least during five months from August to December. The most evident anomaly was observed in mid-September.

Early activity of the planetary waves is confirmed by parameters of the zonal wave spectral components. In both anomalous years the August wave 1 amplitude was 2-3 times greater than that in the adjacent years. For wave 2 this ratio was smaller and wave 3 did not show noticeable features.

1988 and 2002 years show different relationship between wave 1 and 2. In 1988 wave 1 amplitude in September decreased by 1.5 in comparison with August. On the contrary, in 2002 wave 2 activity grew up and September to August amplitude ratio was equal 2. This result justifies quantitatively the attribution of the major warming 2002 as “wave 2” type event (Charlton et al, 2005).

3) Westward displacement of quasi-stationary wave extremums in the anomalous years was observed. In 1988 the longitudinal shift relative to the average position in the neighboring years 1987

and 1989 was equal 50° and 60° for the minimum and maximum, respectively. In 2002 such shift values relative to the average from 2001 and 2003 were 70° and 15°, respectively. This westward shift of quasi-stationary wave in the anomalous years was determined mainly by zonal wave 1. Stationary wave 2 did not have an anomalous longitudinal shift in both the years. Because stationary wave 1 in stratosphere has a surface origin, anomalous longitudinal position of its extremes can give additional indication of the troposphere changes causing the stratospheric anomalies.

Thus, in 2002 the major stratospheric warming was accompanied by large TOC increase with anomalous seasonal changes, longitudinal distribution and zonal wave behavior. Revealed 1988 and 2002 similarities and distinctions can be considered as indicators of the large-scale atmospheric processes involved in significant change of stratospheric dynamics in Antarctic region.

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