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QUASI-BIENNIAL OSCILLATION IN TOTAL OZONE: GLOBAL BEHAVIOUR DERIVED FROM GROUND-BASED MEASUREMENTS

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ABSTRACT

The quasi-biennial oscillation (QBO) in total ozone (TO) is studied on the basis of TO measurements at the world ground-based ozone network during 1972-1988. The TO content is on the whole greater in the tropical belt and smaller in high latitudes during the westerly phase of the QBO of the equatorial stratospheric 50 mb wind than during the easterly phase in all seasons. The appropriate TO difference (westerly category minus easterly category) displays certain space structures changing during a year. There are regions with the peculiar annual evolution of this difference, particularly in the Arctic and Antarctic. Spectral analysis reveals bimodality of TO power spectra in the frequency range of QBO periods, with spectral maxima corresponding to 17-23 months and 28-35 months. The large period oscillations are predominant on the whole. The small period oscillations are likely the consequence of interaction between an annual cycle and QBO.

1. INTRODUCTION

The QBO in global TO distribution was studied in detail on the basis of zonal mean data (Hasebe, 1983; Tolson, 1981; Hilsenrath and Schlesinger, 1981; Lait et al., 1989). For the more comprehensive study the analysis of latitude-longitude TO field is needed. Gruzdev and Mokhov (1992) have shown that characteristics of the TO QBO are structured on the globe and evolve with season. The aim of this paper is the further analysis of peculiarities in spatial-time distribution of different characteristics of the TO QBO. The monthly mean data of TO measurements at the world ozone measuring network during 1972-1988 (since 1973 for Soviet stations) are used. Stations with a duration of measurements less than 4 years are not considered. The paper includes: 1)the analysis of spatial distribution and annual evolution of the TO QBO anomalies determined as the long-term three-month mean TO difference (TOD) for the phases of the west and east equatorial stratospheric wind at the 50 mb level (west category minus east category); 2)the analysis of TO power spectra in the QBO frequency range.

2. ANALYSIS OF TOTAL OZONE QBO ANOMALIES

The TOD data were composed for four periods: January-March, April-June, July-September, and October-December. Such, rather than seasonal, composites enables us to separate possible influence of sudden winter stratospheric warmings in the northern extratropical latitudes since these occur primarily in the January-March period.

Fig.1 shows the TOD distribution for the four periods. The zero lines are thicken. Dashed lines correspond to regions with a sparse station distribution or short data series (duration of TO measurements is less than 8 years). All the differences exceeding 10 DU (5 DU in the tropics) by module are statistically significant at the 5% level. The TOD distribution is spatially inhomogeneous. There are seen negative and positive TOD anomalies in Fig.1 which are usually peculiar to certain regions. The anomalies evolve during a year. One can see negative TOD anomalies in the northern extratropical latitudes above the North Atlantic, north-east Asia, Siberia, North America, which are differently displayed in different periods. In the Southern Hemisphere (SH) the negative anomalies are noted over the New-Zealand and South American regions. It should be especially noted the extremely strong negative anomaly over the Antarctic in the October-December (late spring) period.

Positive anomalies are mainly peculiar to the tropics and usually seen

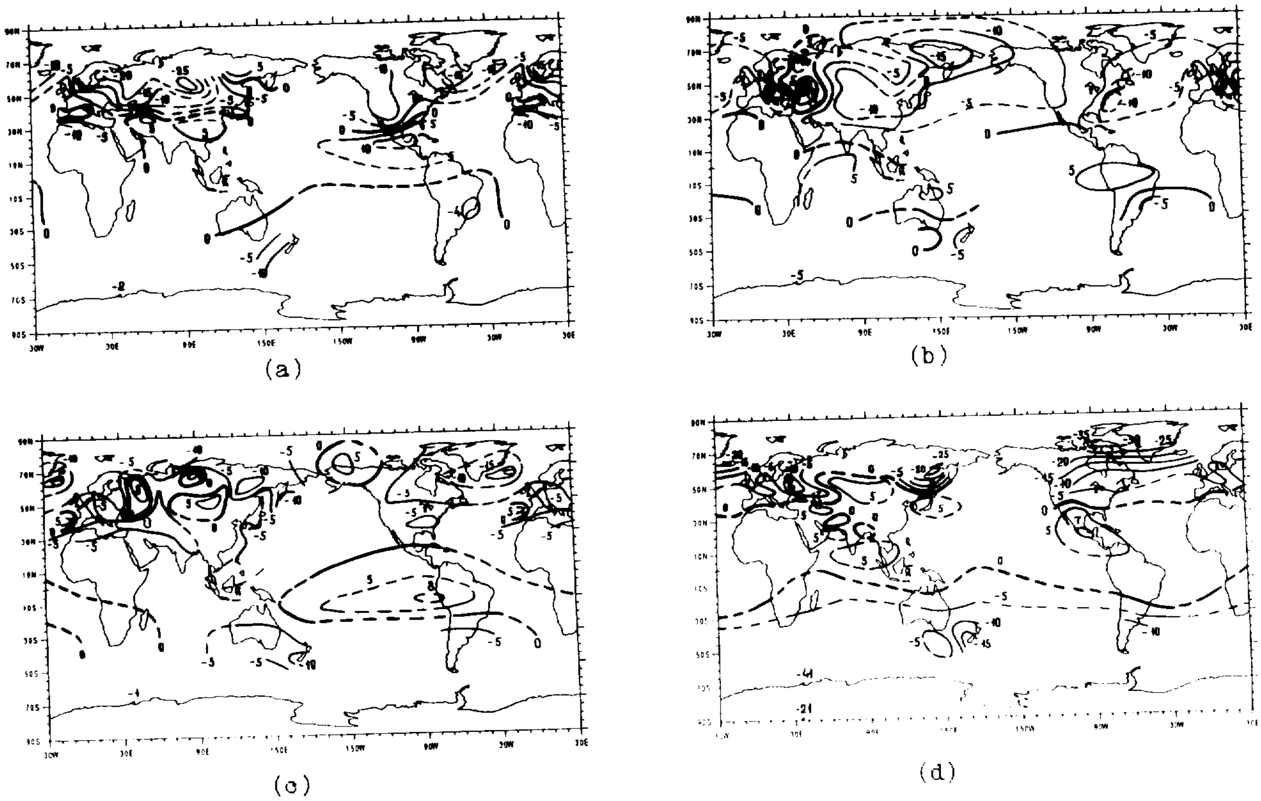

Fig.1. Total ozone difference (westerly category minus easterly category) for (a) January-March, (b) April-June, (c) July-September, and (d) October-December. Units: Dobson units.

over the American and Indian sectors. On the whole, one can distinguish the tropical belt with positive TODs and the areas of the extratropical latitudes, where "westerly" TO is usually less abundant than "easterly" TO. The boundary between the tropical belt and the area of negative TODs is strongly displaced during a year, sometimes stretching to extratropical latitudes.

As it is followed from Fig.1, the TO QBO can be described in the terms of TOD annual evolution. During October-December in the Northern Hemisphere (NH), when the boundary of the tropical area with positive TODs is shifted to the north into the middle latitudes, the strong negative TOD anomaly develops in the high latitudes and Arctic (Fig.1d). During the following January-March and April-June periods the anomaly spreads to the south, weakening in strength and changing zonal structure. A new center of negative TODs appears in January-March over Siberia (Fig.1a). By summer the NH negative anomalies are transformed to the less-scale structures (Fig.1c). The spread of the negative TOD area from the north displaces the tropical area of positive TODs to the south. In SH winter the negative middle-latitude anomaly in the Australian sector develops (Fig.1c). This, together with the departure of the northern boundary of the tropical positive area from the summer NH, results in penetration of the negative TOD area to the equator. The negative anomaly in the Australian sector retains its position during the following periods, intensifying in spring (Fig.1d), weakening in summer (Fig.1a) and intensifying again in autumn (Fig.1b). Quite different regime of TOD annual evolution is noted in the Antarctic: with very high negative TOD values in late spring and much smaller negative TOD values in all other seasons. The cyclic annual TOD evolution is seen well in Fig.1a-d.

3. SPECTRAL ANALYSIS OF TOTAL OZONE QBO

Annual evolution of the TOD seen in Fig.1 points out the possibility of interaction between the QBO and the annual cycle. This can result in appearing new periodicities in TO time evolution. Indeed, TO power spectra for the most of the stations have bimodal distribution in the frequency range of

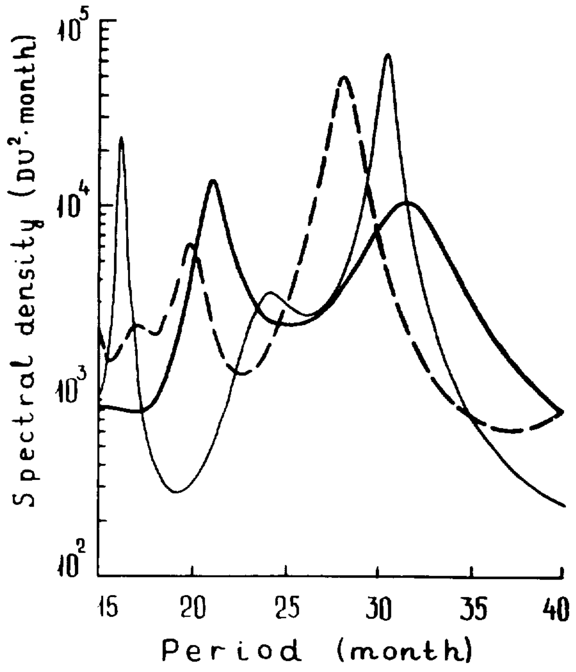

Fig.2. Total ozone power spectra for Boulder (40N, 105W, the thick full curve), Churchill (59N, 94W, the thin full curve), and Edmonton (53N, 114W, the dashed curve) stations.

QBO periods, with spectral maxima corresponding to 17-23 months (the small period (SP)) and 28-35 months (the large period (LP)). The high resolution spectral methods including the maximum entropy method were used for spectra calculations.

Fig.2 shows an example of TO spectra for three stations of the American sector. The detail spatial distributions of the SP and LP are described in Gruzdev and Mokhov (1992). The LP oscillations are predominant on the whole. The SP oscillations are most substantial in the regions where the annual evolution of the boundary between positive and negative TODs is essential (Fig.1). The SP oscillations are supposed to be the result of interaction between the QBO and annual cycle (Gruzdev and Mokhov, 1992).

4. DISCUSSION

The bimodality of TO spectra (in the range of QBO periods) was not found earlier because of insufficient spectral resolution of methods used (Hilsenrath and Schlesinger, 1981; Rightering, 1981; Oltmans and London, 1982). Inappropriate spectral methods led some authors (Hilsenrath and Schlesinger, 1981; Oltmans and London, 1982) to deduction about the latitudinal decrease of the TO QBO.

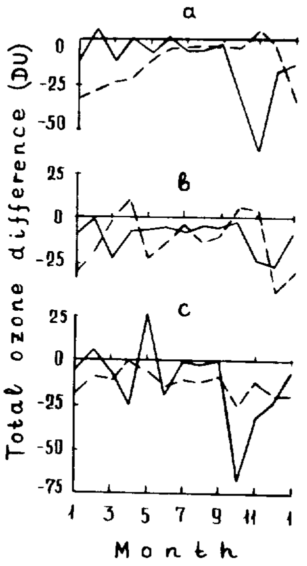

Fig.3. Total ozone difference as a function of month for (a) Resolute (75N, 95W, full curve) and Petropavlovsk- Kamchatsky (53N, 159E, dashed curve), (b) Edmonton (54N, 114W) and Oslo (60N, 11E), and (c) Syowa (69S, 40E) and Invercargill (46S, 168E).

The TO QBO is related to the QBO in atmospheric circulation. A number of features of the TOD distribution in NH extratropical latitudes in Fig.1 are in agreement with features of the distribution of analogous differences of 50 mb geopotential height (GHD). The January-March negative TOD anomalies over the region of North America and the North Atlantic and over Siberia (Fig.1a) correspond to the "troughs" in the January-March GHD distribution (Holton and Tan, 1982). The areas of positive GHD values over Europe and the North Pacific should be compared with the similar area of positive TODs in Fig.1a.

Different regimes of the TO QBO in the SH middle and polar latitudes are due to dynamical isolation of the Antarctic stratosphere during the period of the winter circumpolar vortex. Intensity and time of the spring reversal of stratospheric circulation (which supplies the SH polar region with ozone) are related to the phase of tropical stratospheric wind. So the quasi-biennial modulation of the spring TO minimum (ozone "hole") over the Antarctic is caused, explaining the high TOD values just in the same period (Fig.1d).

Existence of the TO QBO in the NH and SH extratropical latitudes in summer may be the consequence of spring anomalies degraded due to photochemical relaxation.

Large negative TOD values in the extratropical latitudes are observed during cold period when the planetary wave activity is large. Strong anomalies occur at different time in different regions (Fig.1). Fig.3 shows some examples of annual cycles of TODs for stations from different regions. Extreme negative TODs can occur in spring, in autumn, both in spring and autumn, when nonstationarity of planetary waves is essential, or in winter when planetary waves are stationary, or both in winter and spring.

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