N95- 10679

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OZONE AND STRATOSPHERIC HEIGHT WAVES FOR OPPOSITE PHASES OF THE QBO

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1. Introduction

The stratospheric quasi-biennial oscillation (QBO) provides an important source of interannual variations in the Northern Hemisphere. O'sullivan and Salby (1990) related extra-tropical eddy transports with the phase of the tropical QBO. When the tropical wind is easterly, the zero wind line is shifted into the winter hemisphere. Enhanced wave activity in middle latitudes acts to weaken the polar vortex. When the tropical wind is in the westerly phase the situation reverses. Heights at 30 mb and ozone configurations are contrasted in this paper for these two QBO phases.

When the winter vortex deforms due to the amplification of planetary waves 1 and 2, a band of air is drawn out of the vortex and extends westward and equatorward, the complementary band of low vorticity air spirals in toward the pole from lower latitudes. Sometimes, these planetary waves break (Juckes and McIntyre, 1987) and an irreversible mixing of air takes place between high and mid-latitudes. Global ozone patterns, as obtained from satellite observations, appear to be affected by planetary wave breaking (Leovy et al. 1985). This mixing results on regions with uniform ozone and potential vorticity.

In the Southern Hemisphere (SH), Newman and Randel (1988) using Total Ozone Mapping Spectrometer (TOMS) data and the NMC analyses have found strong spatial correlation between the October mean temperature in the lower stratosphere and total ozone for the 1979 through 1986 years. Recently Nogues-Paegle et al.(1992) analyzed SH ozone and height data from 1986 to 1989. They found that leading empirical orthogonal functions (EOFs) for both ozone and 50 mb heights exhibit zonal wave 1 and 2 and that the correlations between ozone and 50 mb principal components (PCs) are high. The results were found to be consistent with a linear planetary wave advecting a passive tracer. In this paper, the dominant patterns of variability for 30 mb NMC heights and TOMS total ozone are obtained for the winter to summer transition (January to May) in the Northern Hemisphere (NH) for the years 1987-1990.

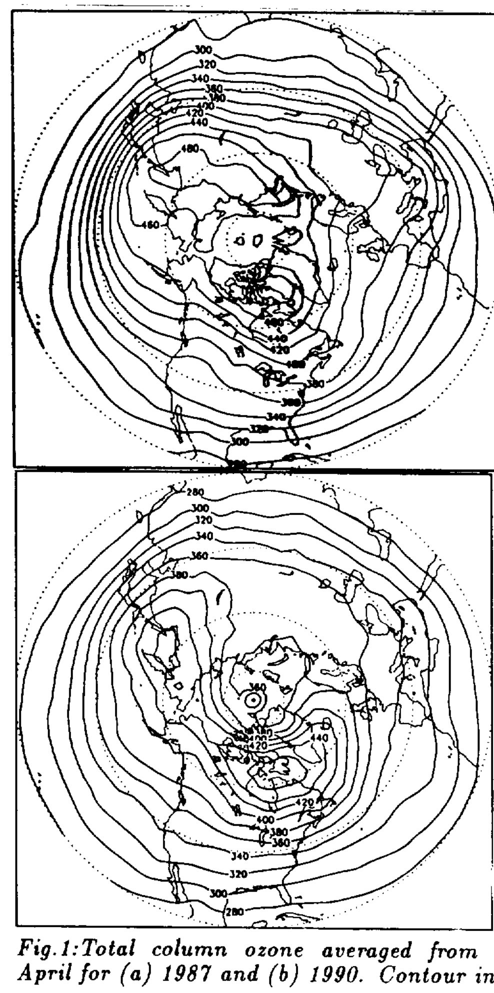

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Fig.1: Total column ozone averaged from February to April for (a) 1987 and (b) 1990. Contour interval 20DU

2. General description of ozone variability

Low January ozone values were found for all four years associated with a deep polar vortex. Most of the interannual variability is found from late winter (February) to spring. This is shown in Fig.1. During this period, the 1987 and 1989 years exhibited large ozone values, with peak values over 460 DU over the polar regions. Large ozone values can be found from the Sea of Okhotsk to the opposite side of the Arctic at 80 °W to 75 °N. In contrast, during 1988, regions with more than 460 DU of ozone were smaller than during 1987 and 1989. The 1990 was an ozone depletion year and a large ozone hole centered near the North Pole is apparent in the figure.

The zonal wind at Singapore at 30 mb is used to represent the quasi-biennial oscillation in the tropics and to link this to the ozone distribution. During the 1987 NH winter-spring, the QBO was in the easterly phase, while during 1990 it was in the westerly phase. Both 1988 and 1989 were in the transition phase, but winds were positive during 1988 and turned to negative during 1989. Low/high ozone values were found for the 1990/1987 years respectively. This is consistent with enhanced mid-latitude wave activity during the easterly phase of the tropical QBO. In the rest of the paper, we will examine wave activities in the extratropics and the ozone distribution during two extreme years: 1987 and 1990.

3. The 1987 case.

Fig.2 shows plots of the first two EOFs obtained for the 30 mb heights for each year and the associated PCs. The orthogonality of the PCs permits projection of the ozone grid point time series($O(x,t)$) onto PCs as follows:

$$O(x,t) = Omean(x) + \sum_k C_k(x) PC_k(t)$$

where $Omean(x)$ is the seasonal mean. The coefficient $C_k(x)$ for k=1,2 are given in Fig.2. Interpretation of the results obtained from the EOF analysis is facilitated with longitude-time diagrams of the zonally asymmetric component of the height field at 60 °N (Fig.4a).

PC 1 (Fig.2e) had large negative values during the first 20 days of January. During that period, the height mean shows a slightly off-center polar vortex and an Aleutian anticyclone similar to the EOF 1 pattern. This gives a large wave 1 at 60°N . Fig.4a shows that the wave 1 has both stationary and traveling components. In mid-January (Jan. 21), wave 1 starts to diminish and moves eastward. At the same time, the low pressure vortex was displaced to Russian Siberia. During this period, the PC 2 was strongest and the 30 mb height anomalies were similar to EOF 2 pattern (Fig.2b).

The ozone patterns (Fig. 2c, 2d) resemble the height EOFs. The EOF 1 pattern represents a seasonal trend of the 30 mb heights, which shows a weakening vortex as the season progresses. The ozone mean map from January 1 to 21 shows more ozone in the Pacific side and less ozone in the Atlantic side (Fig.2f) where the strong vortex was located. This is consistent with vertically propagating waves which tilt westward with height. As a result, the tropopause is found at low/high altitudes for stratospheric ridges/troughs, indicating a deeper stratosphere and therefore higher values of total ozone in ridges than in troughs. The ozone trend (Fig.2c) indicates that the ozone shifts from the Northern Pacific to the European side as the season shifts from winter to spring and the polar vortex weakens.

4. The 1990 case

The 1990 case is very different from 1987. A strong wave 1 persisted through the end of February (Fig.4b). During this time, large negative PC 1 (Fig.3e) indicated a strong zonal vortex (EOF 1, Fig.3a). A decrease of wave 1 was observed at the end of February with the amplification of PC 2 was large positive. EOF 2 (Fig.3b) also had a wave 1 structure with high pressure over the Atlantic ocean and lowest values close to the North Pole. The composite of heights during this period shows a near symmetric vortex located in the pole (Fig.3f). The vortex started to break during April, when PC 1 turned to large positive. This case displayed marked zonal symmetry and less mean flow-wave interaction than during 1987.

The ozone trend showed that when the vortex broke (Pc 1 becomes positive) during April, the ozone moved into the polar region to fill the ozone hole (Fig.3c).

Acknowledgements: This research has been supported by NASA grant NAG 5 127 and NSF grant 9114073

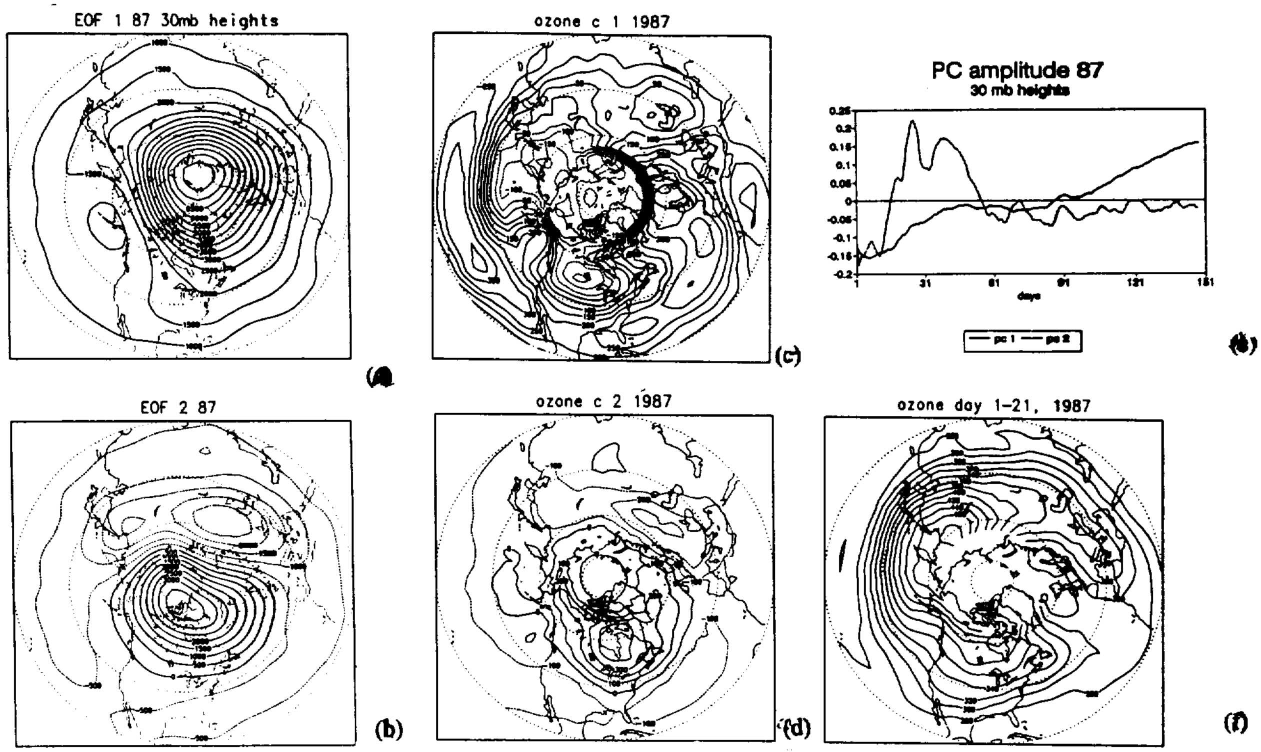

Fig.2: (a) EOF 1 and (b) EOF 2 for 30 mb heights for 1987.(c) C_1, (d) C_2, (e) Principal components PC 1 and 2 associated with EOF 1 and 2, and (f) total ozone averaged from January 1 to 21, 87

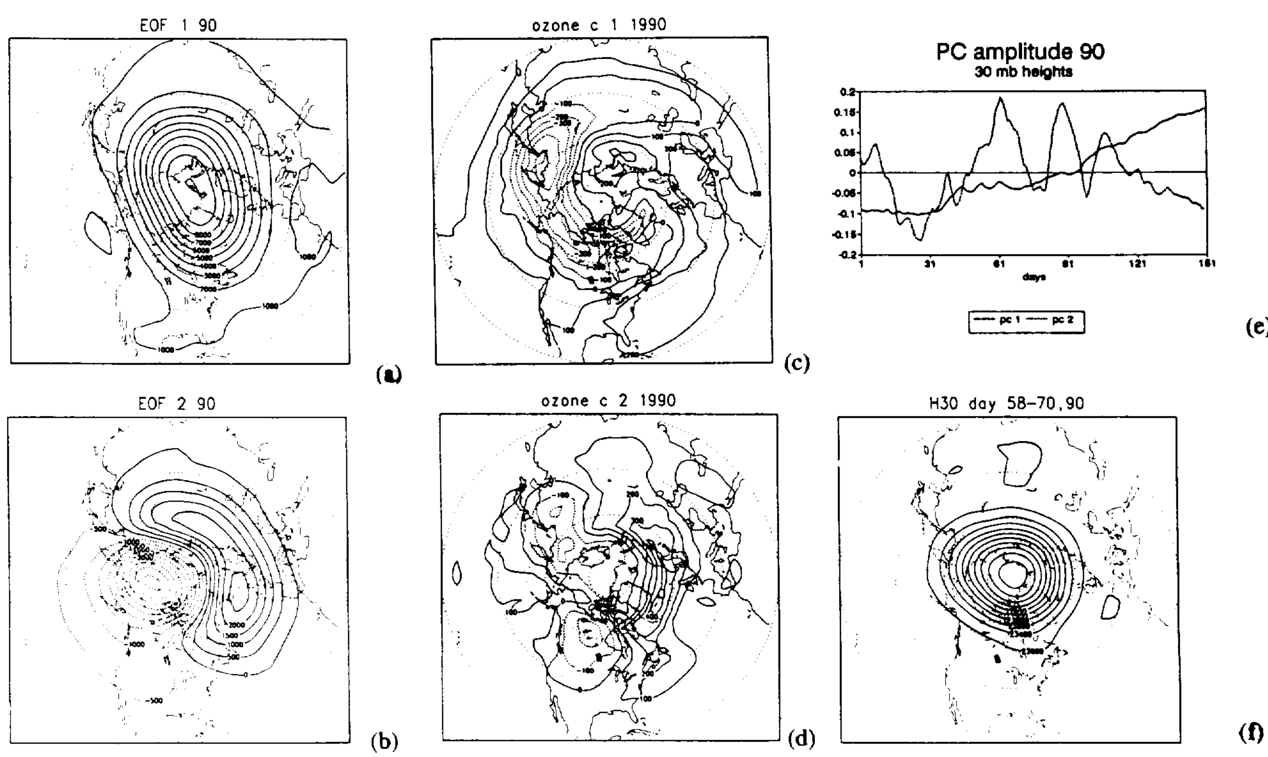

Fig.3: (a) -(e) Same as Fig.2, but for 1990, (f) 30 mb heights averaged over February 27 -March 11, 90

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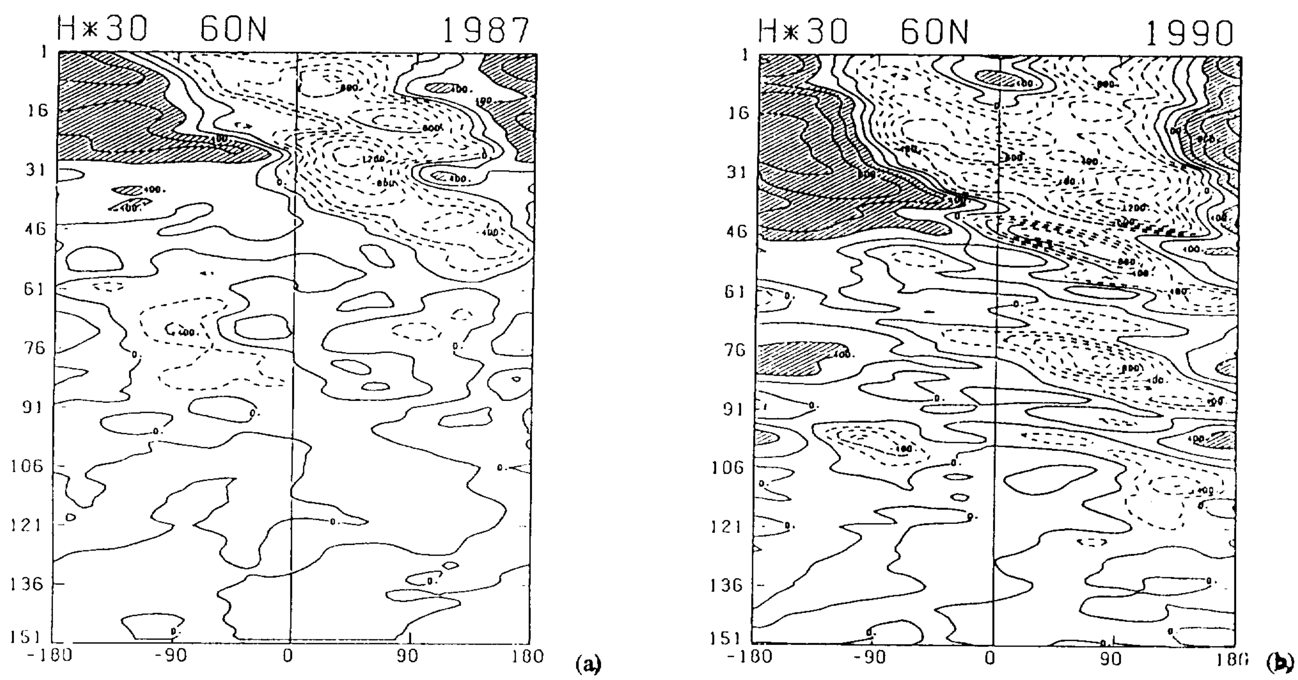

Fig.4 : Longitude-time diagram for the asymmetric part of 30 mb heights at 60N for (a) 1987 and (b) 1990.