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DISTRIBUTION OF MAJOR STRATOSPHERIC WARMINGS IN RELATION TO THE QUASI-BIENNIAL OSCILLATION

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Abstract. Data from 1953 to the present indicate that major warmings in the northern hemisphere winter have not occurred when the equatorial monthly mean zonal winds are deep westerly, i.e., westerly over more than about 5/8 of the 10-85 mb layer. Sixteen winters have had a major warming in the last 35 years. Six January-February periods had deep equatorial westerlies but did not experience a major warming.

Major warmings do not require deep equatorial easterlies, nor is the occurrence of a major warming significantly correlated with the sign of the zonal mean wind at any particular level between 10 and 50 mb, although as noted by previous investigators, more than half of the observed major warmings have occurred when the equatorial flow is easterly at a given level between 10 and 50 mb. We suggest that a more relevant QBO statistic may be found in the depth of QBO wind regimes.

The previously proposed connection between the equatorial quasi-biennial oscillation and the major warmings of the northern hemisphere winter is supported by these observations.

Introduction

It has been suggested that the quasi-biennial oscillation (QBO) in the equatorial lower stratosphere may affect the extratropical circulation during the northern hemisphere winter. Holton and Tan (1980, 1982) composited geopotential heights into easterly and westerly 50 mb QBO phase categories, and found a difference between the two such that in the composited westerly category the polar vortex was stronger, colder, and initially more zonally symmetric. The matter was explored further by Van Loon and Labitzke (1987). Following an earlier suggestion by Van Loon et al (1982) that the El Nino/Southern Oscillation (ENSO) phenomenon might instead be responsible for the observed difference, those authors attempted to extract a less ambiguous QBO signal by removing extreme ENSO years from the composites (i.e., about half the available years). A difference was again found, but mainly confined to the zonally symmetric component, at least in comparison to the extreme ENSO composites which exhibited a larger difference in the strength of the Aleutian high. This result is puzzling, in view of Labitzke's (1982) earlier suggestion that major midwinter warmings have occurred preferentially in the QBO easterly phase at 50 mb. Warmings involve a large asymmetric component as well as a mean flow change. Moreover, their association with the QBO is at least as strong as their association with ENSO (cf. Table 2 of Van Loon and Labitzke). Thus, a connection between the QBO and the zonally asymmetric component of the polar flow is to be expected. The purpose of this note is to demonstrate how this association might be strengthened by focusing on the depth of QBO wind regimes rather than the sign of the equatorial flow at a particular level.

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Deep Westerly Criterion

Following a suggestion by McIntyre (1982) that deep equatorial easterlies may favor the occurrence of a strong midwinter warming, we examined the record of equatorial winds from Naujokat (1986) for the period 1953-1985, together with more recent data, and compared the depth of QBO wind regimes to the historical data for major midwinter warmings (Schoeberl, 1978; Labitzke, 1981, 1982, 1987; Quiroz, 1986). The depth of QBO wind regimes as a function of time is indicated in Figure 1. The quantity shown is the fraction of log pressure altitude in the 10-85 mb layer occupied by westerly monthly mean zonal winds. Fractional, rather than total, depth was used because data above 10 mb were not routinely available and the QBO westerlies generally give way to time-mean easterlies in the tropical middle stratosphere anyway. A slight amount of upward extrapolation was used between 15 and 10 mb prior to 1956. Major warmings (excluding Jan 1987) are indicated by black dots.

Figure 1 suggests that neither the occurrence of a major warming, nor its strength (Schoeberl, 1978), depends on having deep equatorial easterlies. Rather, the non-occurrence of major warmings is associated with deep equatorial westerlies. Depths in excess of about 63 percent appear to prevent major warmings. Six winters met this criterion (Jan.-Feb. 1953, 1967, 1972, 1976, 1978, and 1983), and did not experience a major warming. All of these winters contained minor warmings, as most winters without major warmings apparently do.

Curiously, the winters with major warmings did not exhibit any preferential pattern of equatorial winds between 10 and 50 mb. Sometimes the winds were deep easterly, but more often a QBO transition was occurring, in either direction. For this reason, we cannot associate the occurrence of major warmings with the easterly phase of the QBO at a particular level, although as noted by Labitzke (1982) the majority of these warmings have occurred in this phase.

Figure 2 shows the distribution of Labitzke's (1982, 1987) 30 mb polar monthly mean temperatures (1956-1985) versus fractional depth of equatorial westerlies. Major warmings are denoted by open circles. Dotted circles indicate major warmings beginning in January and extending into February; these warmings resulted in the highest February

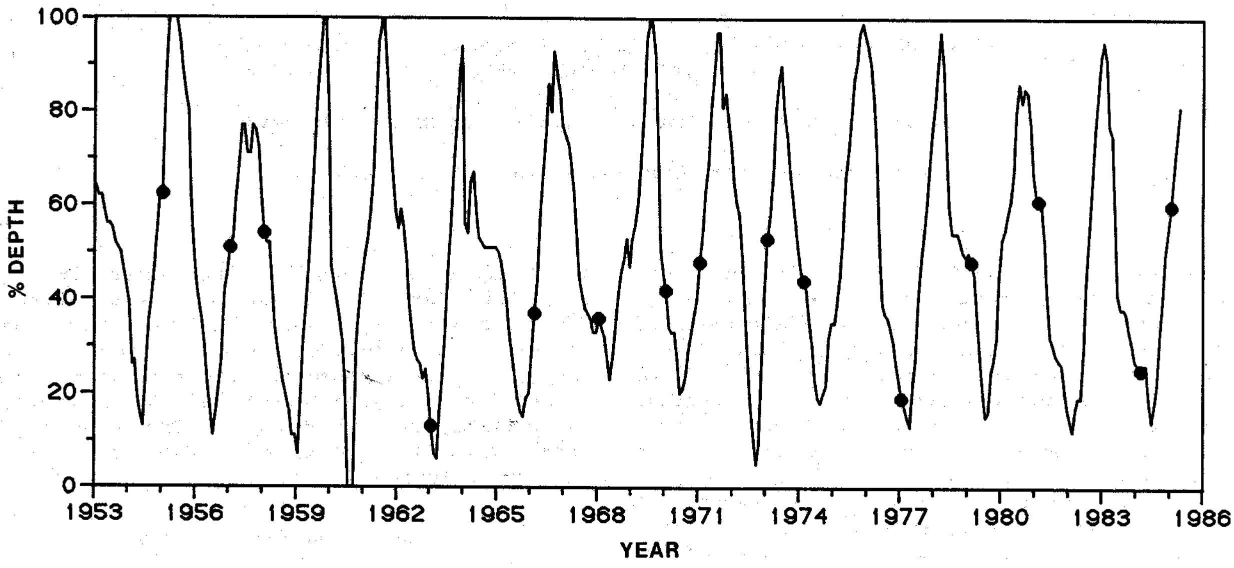

Fig. 1. Percent log-pressure depth of westerlies in the 10-85 mb layer (solid) and occurrence of major warmings (black dots).

monthly mean temperatures. Dots indicate years without major warmings. It is apparent that deep westerly months were cold and had no major warmings. February 1983 had no major warming but several minor warmings (Quiroz, 1986), and is the only example of an extremely deep westerly January or February that was not cold (Feb. 1978 being another possible exception). This is probably due to the partial displacement of the polar vortex off the pole.

The distribution of fractional depths, summarized in Figure 3 for January and February, has a broad maximum near the center, declining fairly symmetrically on either side. Deep easterlies and deep westerlies occurred equally often. The broad maximum near 50 percent depth is apparently due to the tendency of the QBO to stall in the descending easterly phase. These stalls seem to occur preferentially between July and February, typically beginning sometime around July and ending 6-9 months later.

As already noted, major warmings do not require deep equatorial easterlies. Nor do deep easterlies appear to prevent major warmings as in the case of deep westerlies. Incidentally, there was no apparent correlation between the fractional depth statistic and either ENSO or the solar cycle. Nor is the solar cycle related to the 30

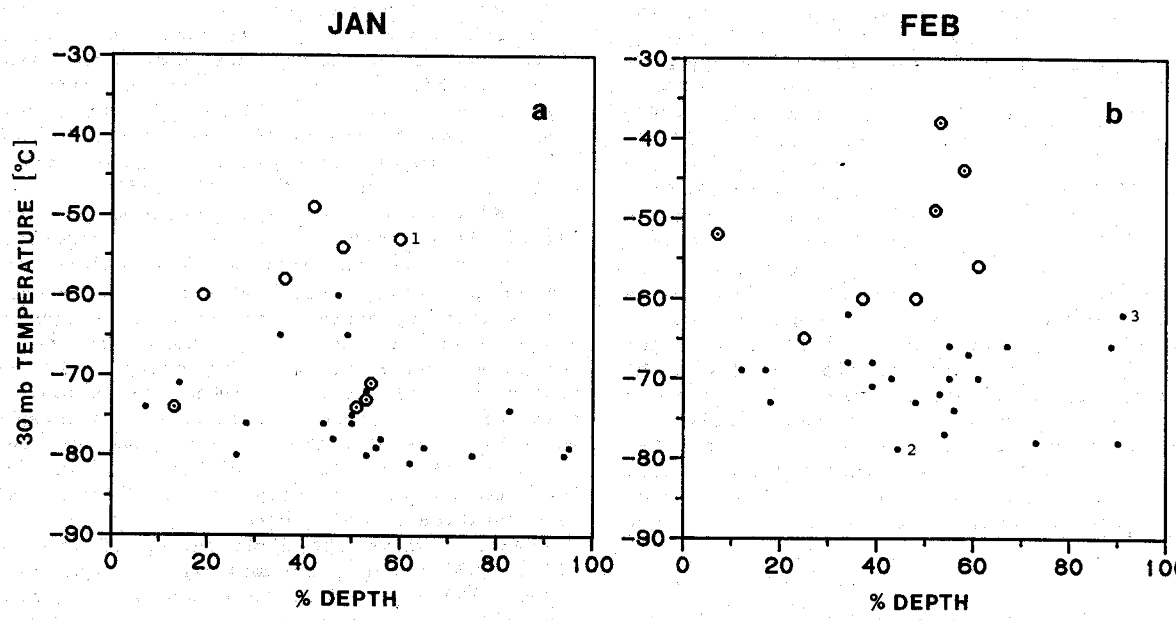

Fig. 2. Monthly mean temperature in the north polar region at 30 mb versus percent depth of equatorial westerlies. Circles denote major warmings, dotted circles indicate warmings beginning in January and extending into February, and dots indicate months without a major warming. Notes: (1) 1985 warming began in December 1984; (2) 1974 warming occurred mainly in March; (3) 1983 had several minor warmings.

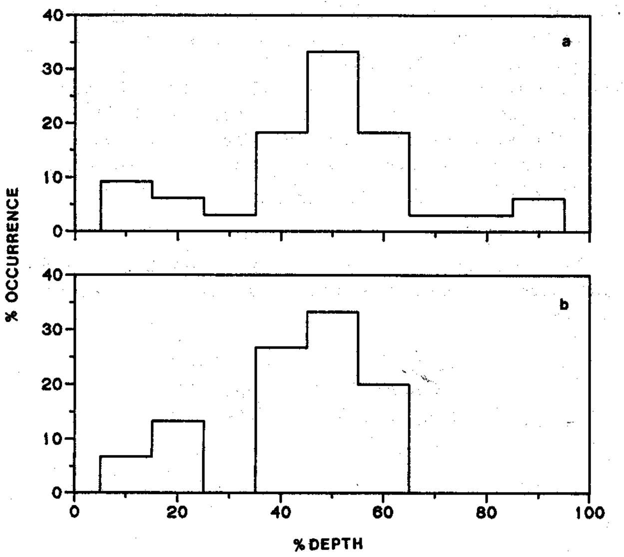

Fig. 3. (a) Percent occurrence of westerly depths in January and February and (b) percent occurrence when only years with major warmings are considered.

mb polar temperature during the QBO westerly phase when 30 mb, rather than 50 mb, QBO phases are used (contrast Labitzke, 1987).

The statistical significance of the observed non-occurrence of major warmings in deep equatorial westerlies was examined in two ways. First, the Wilcoxon rank-sum test was applied to the distribution of fractional depths with and without major warmings (using the fractional depth in the first month of the major warming, or the January depth if no warming occurred in that winter). This nonparametric test indicated that the observed separation of the means (due to the cold, deep westerly cases) was significant at the 3.3 percent level. Second, assuming a known distribution of fractional depths (Figure 3a), the probability of randomly having six deep westerly winters with no major warming was judged to be about 4.9 percent $[(29/35)^{16}]$, including 1986-1987 (Naujokat et al, 1987). The January distribution per se is more significant (2.7 percent) if the dotted circles and 1985 warming (which began in late December) are omitted, together with the 1955 warming which was uncertain due to a lack of Soviet data.

Other, less significant criteria can be constructed from Figure 1: e.g., the probability of randomly having no more than four major warmings outside the "intermediate" depth range (36-63%), as observed, is 23.1% according to the binomial theorem.

Conclusion

The data record from 1953 to the present supports the inference made by previous authors that the extratropical northern hemisphere wintertime circulation is in some way affected by the quasi-biennial oscillation in the equatorial lower stratosphere. The most relevant QBO statistic does not appear to be the wind direction at any particular level, but rather the depth of QBO wind regimes. As noted or implied by several earlier authors (e.g. Tung, 1979; Holton and Tan, 1980; McIntyre, 1982) the propagation of planetary Rossby waves depends, in part, on the position of the equatorial zero wind line which is modulated by the quasi-biennial oscillation. Admittedly, the fractional depth statistic presented here does not completely characterize the mean flow in the low-latitude part of the westerly waveguide, because the subtropical flow is also important (Dunkerton and Delisi, 1985). Thus, further observational as well as theoretical study is warranted of the apparent connection between the QBO and major warmings.

We recommend that the 50 mb index be employed only where its use can be justified a priori, as in the tropical ozone QBO (Oltmans and London, 1982), for example, in which the column amounts are heavily weighted by mixing ratios just above the tropopause. For other dynamical problems involving the QBO, a height-integrated statistic may be more useful.

To some degree, the 50 mb index and westerly depth statistic are similar, inasmuch as deep westerlies generally indicate that the 50 mb wind is either westerly or soon to become westerly. By implication, the deep westerly state is accompanied by relatively strong positive vertical wind shear in the lower stratosphere. On the other hand, neither the sign of the wind nor the strength of the shear requires deep westerlies. There are numerous examples of "stalled" descending easterlies underlain by a westerly regime. This makes the deep westerly criterion distinct from the 50 mb QBO index, as noted above.

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