On the Quasi-Decadal Modulation of the Stratospheric QBO Period

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ABSTRACT

The length of the westerly phase of the quasi-biennial oscillation (QBO) of zonal wind in the equatorial stratosphere is examined using the longest available record (1950–2001). An earlier finding by Salby and Callagan of a systematic quasi-decadal modulation of the QBO period is confirmed, although the earlier suggestion of a strong connection with the solar cycle is less clear in the extended record.

1. Introduction

In a recent paper Salby and Callaghan (2000, hereafter SC00) made an important and original contribution to the understanding of long-period variations in the extratropical middle atmospheric circulation. In particular, they noted that the observed tropical wind record near 50 hPa shows a quasi-decadal modulation of the length of the quasi-biennial oscillation (QBO) westerly phase, with anomalously long periods in the mid-1960s, mid–late 1970s and mid–late 1980s (SC00, their Fig. 3b). As SC00 note, this somewhat subtle effect can have a large influence on the modulation of tropical–extratropical interactions in the stratosphere since these interactions depend on the phase of both the QBO and the annual cycle (e.g., Holton and Tan 1980, 1982). This can help account for observations of quasi-decadal variability in the extratropical stratosphere (particularly in winter), and may even have implications for tropospheric climate variability.

More controversial, perhaps, is SC00's speculation relating the period modulation of the QBO to the 11-yr cycle of solar activity. There are other possible reasons for the variation in the QBO period, including variations in stratospheric aerosol loading associated with major volcanos, or systematic variations of tropospheric wave forcing. For example, Geller et al. (1997) were able to reproduce many features of the observed changes in QBO with a dynamical QBO model (based on that of Holton and Lindzen 1972) when they made particular assumptions relating the wave forcing to the observed tropical Pacific Ocean temperatures.

SC00 restricted their analysis to the well-known time series of monthly mean zonal wind at ''near-equatorial'' stations pieced together from observations at Kanton Island (2.8°N, 171.7°W); Gan, Maldives, (0.7°S, 73.1°E); and Singapore (1.4°N, 103.9°E); and distributed by the stratosphere group at the Free University of Berlin (FUB). The data record they used begins in January 1956, and it is not clear from SC00's Fig. 3b that the peaks in westerly phase length in the 1960s, 1970s, and 1980s were matched by one in the 1950s. In the present note a somewhat longer record will be examined.

2. Data analysis and discussion

Observations of 50-hPa wind at Balboa, Panama, in the former U.S. Canal Zone (9.0°N, 79.6°W) are available from late 1950 and were used in many early papers concerning the QBO. In fact, Quiroz (1981) looked for solar cycle effects in the Balboa data. As SC00 note, however, Quiroz's approach (using 12-month running means) tends to obscure his results.

Wallace (1973) plotted a time–height section of the Balboa winds (with long-term mean annual cycle removed) from late 1950 to July 1970, and his figure is the basis for the analysis reported here. The black dots in Fig. 1 show the duration of each westerly phase at 50 hPa determined from inspection of the Wallace time–height section. In Fig. 1 the durations are plotted at the midtime of each period of westerlies. The data record begins with anomalous westerlies at 50 hPa in late 1950, so the first point plotted is an underestimate of the length of the first westerly phase. The arrow shows the author's

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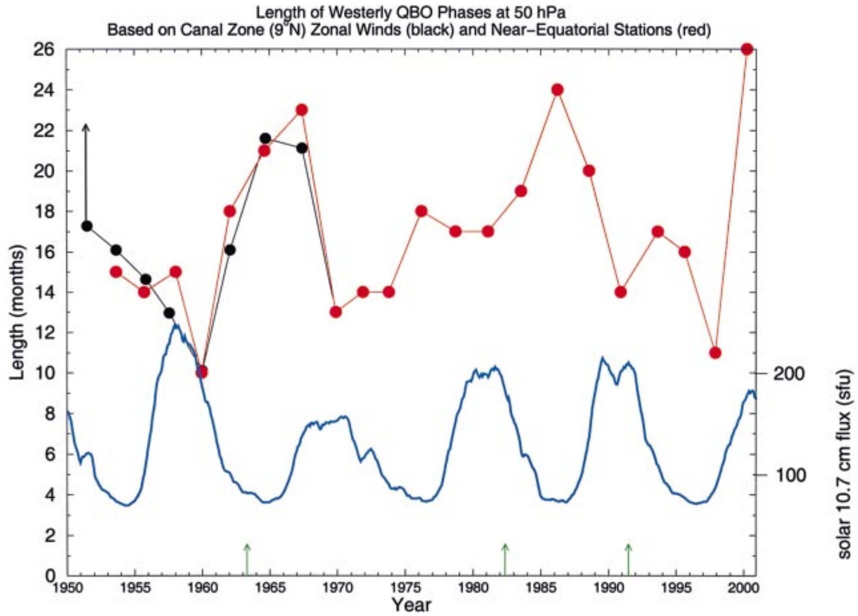

FIG. 1. The durations of westerly phases of the QBO in the 50-hPa zonal wind plotted at the time midway through each westerly phase. The red dots show estimates based on the near-equatorial FUB dataset for 1953–2001. The black dots show estimates based on inspection of the Balboa (9°N) wind anomalies plotted by Wallace (1973). The black arrow shows a subjectively determined range for the length of the first westerly phase in the record. The blue curve is an 11-month running mean of the observed 10.7-cm solar radio flux in solar flux units (1 sfu $= 10^{-22}$ m^{-2} Hz^{-1}). The green arrows at the bottom show the dates of the three most significant explosive volcanic eruptions during this period.

subjective estimate of a plausible range of actual length of this first westerly phase.

The red dots show the 50-hPa westerly phase durations from January 1953 to 2001, obtained by examination of an updated and extended version of the FUB near-equatorial dataset used by SC00. While the post-1956 data have been most widely distributed and analyzed, the Kanton Island data at 50 hPa are available starting in January 1953.

The results from the Balboa wind record and the near-equatorial wind record during the 1953–70 period of overlap are quite similar. The present post-1956 results also generally agree well with those of SC00 (who used 45-hPa winds to determine the westerly phase lengths). The biggest difference between the SC00 results and those in Fig. 1 is for the westerly phase centered in 1986 (24 months here versus 20 months in SC00). This difference is attributable to the slightly different pressure levels considered (see Naujokat 1986).

The results in the 1950s seem to indicate that the systematic quasi-decadal variations noted by SC00 had started at least circa 1950. However, as more data are added to the 1956–96 record analyzed by SC00, the possible connection with solar activity becomes less clear. The blue curve shows the 11-month running mean of the 10.7-cm solar radio flux. As noted by SC00, there is an overall negative correlation, with short westerly QBO periods occurring near times of solar maximum (particularly near 1970 and 1990). However, this relation is not strong for the solar maximum near 1981, and it appears that it may not be obeyed at all for the time around the solar maximum of 1948. In addition it seems that the relation will fail for the solar maximum at the beginning of the twenty-first century, since an extremely long westerly phase was observed extending from March 1999 to April 2001. The correlation coefficient between the westerly phase length and the 11-month mean solar radio flux is -0.46 when computed over the 17 westerly phases during 1956–96. However, the correlation coefficient is only -0.10 when computed over all 22 westerly phases shown in Fig. 1 (using the near-equatorial estimates, except for the first one, for which a period of 19 months was assumed).

Other explanations for the systematic long-term variations are not obvious. Investigators (e.g., Dunkerton 1983) have speculated that the stratospheric aerosol injected by tropical explosive volcanic eruptions may influence the progression of the QBO. The arrows at the bottom of Fig. 1 show the dates of the most significant of the explosive eruptions after 1950: Mount Agung (1963), El Chichon (1982), and Mount Pinatubo (1991). There is some apparent period lengthening following each of these eruptions. However, given the limited residence time expected for the aerosol, the effects attributable to volcanic eruptions should be largely confined to the first two years after each eruption. There have

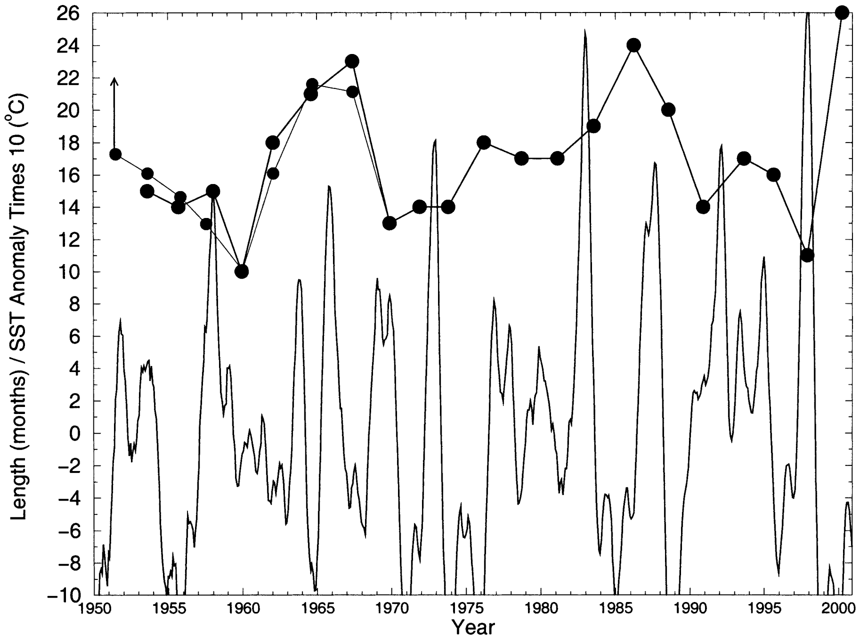

FIG. 2. The circles reproduce the determinations of the duration of each westerly QBO period in Fig. 1. The continuous curve shows a 5-month running mean of the Niño-3.4 index, i.e., the anomaly in the sea surface temperature averaged over 5°S–5°N and 120°–170°W.

been other speculations connecting aspects of the QBO in stratospheric winds with tropical sea surface temperatures and the Southern Oscillation (e.g., van Loon and Labitzke 1987; Geller et al. 1997; Kiladis et al. 2001). Figure 2 reproduces the QBO period estimates of Fig. 1 and compares them with a 5-month running mean of the familiar Niño-3.4 sea surface temperature index (i.e., anomalies in the sea surface temperature averaged over 5°S–5°N and 170°–120°W). While there may be subtle connections between the El Niño–Southern Oscillation phenomenon and the QBO, it is hard to discern any direct relation between the QBO period and the tropical sea surface temperatures.

3. Conclusions

As SC00 showed, an important key to understanding long-period variability in the extratropical circulation is the modulation of the tropical QBO period. In the lower stratosphere the length of the easterly phase is roughly constant from cycle to cycle, but the length of the westerly phase varies by over a factor of 2. The present analysis allows this period modulation to be studied in over a half century of data, providing five more westerly phase cases to be added to the record presented by SC00. It seems clear that the variations in QBO period length are not random, but rather have a quasi-decadal character. SC00 speculated that this aspect of QBO behavior may be explained in terms of solar flux variations. The present data record cannot conclusively rule out this kind of solar connection, but examination of the 1950–2001 data shows that the very strong apparent correlation between QBO period and solar activity may hold only for a part of the full record.

The present paper fits in a long history extending back at least to the work of Quiroz (1981), who believed that there was convincing evidence for solar modulation of the QBO period. With a somewhat longer record to examine, Dunkerton and Delisi (1985) rejected the reality of this connection. SC00 revived this idea based on the 1956–96 record. Now the present analysis of the 1950–2001 record again may cast some doubt on the solar–QBO connection. A conclusive answer may well await the availability of data over at least another one or two solar cycles.

Whether the solar cycle turns out to be important or not, seeking an explanation for the systematic variations in QBO period noted by SC00 should be a high priority for stratospheric research.

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