NOTES AND CORRESPONDENCE

Anomalous Short Duration of the Easterly Wind Phase of the QBO at 50 hPa in 1987 and Its Relationship to an El Niño Event

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1. Introduction

Reviewing a history over the past 35 years of the quasi-biennial oscillation (QBO) of zonal winds in the equatorial lower stratosphere, we find that the period of oscillation has varied from one cycle to another – the shortest was 22 months and the longest was 36 months at 50 hPa (~20.7 km). Inspection of each cycle at 50 hPa showed that the duration of the easterly wind phase was confined to a comparatively narrow range of 11 – 12 months, while that of the westerly wind phase widely varied from 10 to 22 months (Tsuneoka, 1984). Therefore, the period of the cycle at this level was considered to be determined mainly by the length of the westerly wind phase. When the wind field changes from westerly to easterly, we can expect reappearance of the westerly phase after about 12 months.

Quite contrary to our expectation, the latest easterly wind phase at 50 hPa, started in March 1987 and ended in September 1987. Its duration was only six months, the shortest since 1953. Geb and Naujokat (1987) also noted this extremely short easterly phase at this level. In this paper we report and discuss the anomalously short duration of the easterly phase of the QBO.

2. Data and notable features

In Table 1, we show the months when the easterly wind phase started and when it ended together with the duration in each cycle of the

QBO at 50 hPa. For convenience, a cycle number hereafter is given to each period from one easterly wind phase onset to the next. That is, the same number is given to an easterly wind phase and the following westerly wind phase. We can see in the table that the latest easterly wind phase (cycle 15) was abnormally short comparing with the easterly wind phases in the preceding 14 cycles, though relatively short in cycles 6 and 9. The data for the statistics are based on the observations at Canton Island (2.8S, 171.7W)

Table 1. The month when the easterly wind phase at 50 hPa started and ended, and the duration for each cycle.

Cycle	Easterly starting	Easterly ending	Easterly duration
1	Apr 1954	Mar 1955	11 mo.
2	May 1956	May 1957	12
3	Aug 1958	Aug 1959	12
4	Jun 1960	Jun 1961	12
5	Oct 1962	Oct 1963	12
6	Aug 1965	Jun 1966	10
7	Apr 1968	May 1969	13
8	May 1970	May 1971	12
9	Jun 1972	Mar 1973	9
10	Jun 1974	Jun 1975	12
11	Dec 1976	Dec 1977	12
12	Jun 1979	Jun 1980	12
13	Nov 1981	Oct 1982	11
14	Apr 1984	Mar 1985	11
Average			11.5
Standard deviation			1.0
15	Mar 1987	Sep 1987	6

Table 2. Monthly mean zonal wind velocity at 50 hPa ($\text{m}\cdot\text{s}^{-1}$, positive for westerly) with the number of missing data (in parentheses) for each estimate. Observations are at 00 GMT for Singapore, Tarawa and Nairobi, and at 12 GMT for Belem.

Month 1987	Singapore (1.4N, 104.0E)	Tarawa (1.3N, 172.9E)	Belem (1.4S, 48.5W)	Nairobi (1.3S, 36.8E)
Jan	3.2 (7)	4.4 (9)	3.3 (3)	1.3 (7)
Feb	2.9 (0)	0.4 (8)	2.5 (4)	2.7 (8)
Mar	1.6 (4)	-2.4 (8)	0.4 (8)	0.9 (17)
Apr	-7.6 (2)	-13.1 (9)	-9.0 (5)	-6.9 (8)
May	-19.3 (4)	-18.8 (8)	-17.5 (2)	-14.7 (4)
Jun	-23.6 (3)	-25.7 (11)	-20.7 (11)	-16.1 (7)
Jul	-27.3 (6)	-25.9 (21)	-23.7 (2)	-19.4 (3)
Aug	-22.6 (3)	-20.1 (25)	-17.3 (14)	-22.9 (4)
Sep	-5.1 (3)	-10.5 (26)	-9.7 (12)	-12.8 (6)
Oct	7.8 (4)	6.5 (29)	5.4 (6)	4.6 (10)
Nov	8.1 (2)	8.4 (26)	6.2 (11)	10.0 (15)
Dec	7.6 (2)	1.2 (28)	6.8 (6)	8.9 (13)

from 1953 to August 1967, at Gan (0.7S, 73.2E) from September 1967 to 1975, and at Singapore (1.4N, 104.0E) after 1976. It would be desirable for the analysis to use the data at the same station close to the equator throughout the whole time, but we could not complete it because of closure of the stations, Canton Island in 1967 and Gan in 1975. We have noticed only slight differences in the QBO phase shift by plus/minus one month or so between these stations. In Table 2, monthly mean zonal winds at 50 hPa in 1987 are shown for four stations close to the equator. We find, the reversal of wind direction from westerly to easterly occurred in February – March, and that from easterly to westerly in September – October. The duration of the easterly at Singapore is found to be a little shorter than that at other stations.

In Fig. 1, we show a time-height section of monthly mean zonal winds. The early part in the figure is after Reed (1965) for 1953 – 1963 and Kriester (1972) for 1964 – 1970. The data are based on those used in Table 1. We find in the figure that the deceleration rate of the easterly wind below the descending westerly regime for earlier years was not so large as that for later years. One of the reasons may be due to less

accurate data. In those years soundings did not frequently attain the higher levels and much data were missing. From the figure, the shortest duration of the easterly wind phase at 50 hPa shows two facts: (1) the preceding westerly wind phase was anomalously long (24 months); and (2) the westerly regime descent was very rapid (5 months from 10 hPa to 50 hPa).

The wind reversal from westerly to easterly at 50 hPa is likely to occur primarily in the months from April to June (Table 1). In northern winter months, the wind reversal from westerly to easterly is less likely to occur. If the wind reversal does not occur in months October to December, it may be expected to shift a few months later. Indeed, it occurred in March for the latest cycle. This prolongs the westerly wind phase at 50 hPa. On the other hand, the large descent rate of the westerly wind regime terminates the easterly wind phase in short time. The descent rate of the westerly wind regime from 10 hPa (30.5 km) to 50 hPa (20.5 km) for each cycle is shown in Table 3, and we find the descents in 1972 – 1973 and 1987 were the most rapid. The westerly wind regime descended between these two levels in 5 months. On the contrary, at higher levels above 20 hPa, a long easterly wind phase was observed. However, the

Fig. 1. Time-height section of monthly mean zonal winds in the equatorial lower stratosphere. Encircled numerals denote cycle numbers with which each cycle of the QBO is referred to in the text.

Table 3. The month when the reversal from the easterly wind phase to the westerly wind phase occurred at 10 hPa, and months which the descending easterly wind phase required from 10 hPa to 50 hPa for each cycle.

Cycle	The reversal from E to W at 10 hPa		Months required from 10 hPa to 50 hPa
3	Nov	1958	9 mo.
4	Oct	1960	8
5	Feb	1963	8
6	Oct	1965	8
7	May	1968	12
8	Jun	1970	11
9	Oct	1972	5
10	Jul	1974	11
11	Apr	1977	8
12	Aug	1979	10
13	Feb	1982	8
14	Jun	1984	9
15	Apr	1987	5

long easterly wind phase at higher levels was not always accompanied by the short easterly wind phase at lower levels.

3. Relationship with an El Niño event

Theoretical studies have explained that Kelvin wave activities carry the westerly momentum upward through the easterly wind regime, accelerate the above westerly wind component, and induce the descent of the westerly wind regime, while mixed Rossby-gravity wave activities produce upward flux of the easterly momentum through the westerly wind regime, and induce the descent of the easterly regime (see Lindzen’s review, 1987). Observationally, Maruyama (1979) showed, by analyzing the data at three stations over the Indian Ocean, that the intensities of Kelvin waves and mixed Rossby-gravity waves had a phase relationship with the QBO favorable to the theoretical explanation.

An El Niño event in 1986 – 1987 seems to have a connection with the rapid descent of westerly wind regime (cycle 15). If the El Niño event enhanced Kelvin wave activities, it may be possible to explain the rapid westerly wind descent. If the El Niño event suppressed mixed Rossby-gravity wave activities, it may be possible to explain the preceding long westerly wind phase and the short easterly phase. Support for this point of view comes from another rapid westerly wind descent in 1972 – 1973 (cycle 9) also falling upon an El Niño event. Since the definition of El Niño events has been ambiguous, here we select the years when the positive anomaly of sea surface temperature (SST) was widely observed over the central and eastern equatorial Pacific throughout the period longer than six months centered near Christmas Day (or a year-end) as El Niño years. The SST anomaly data referred here were compiled by Matsubayashi (1987). Sorting in this way we obtain 1957/1958, 1965/1966, 1969/1970, 1972/1973, 1976/1977, 1982/1983 and 1986/1987 as El Niño periods. Besides these years, the years 1953 and 1963 have been recognized as El Niño years but the SST was not enhanced at the year end.

Among these El Niño periods, the six cases 1963, 1965/1966, 1972/1973, 1976/1977, 1982/1983 and 1986/1987 synchronized with descent of the westerly wind regime for the cycles 5, 6, 9, 11, 13 and 15, respectively. In these cases, the easterly wind layer is found between the westerly wind layer above and that near the tropopause. Kelvin waves are favorable to propagate upward through this layer structure, and to accelerate the westerly layer above. Besides the two most rapid descents, cycles 9 and 15 (5 months from 10 hPa to 50 hPa), four other cases had a slightly increased descent rate (8 months from 10 hPa to 50 hPa), and El Niño events are considered to work partly on the descent rate of the westerly phase. All slower descents were out of El Niño events. On the other hand, as Fig. 1 shows, the lower level westerly wind regime has not always been prolonged during the period of El Niño events.

Dunkerton and Delisi (1985) made a detailed climatological study of the equatorial lower stratosphere using the data for the years from

1964 to 1983. They showed that the westerly accelerations appear first at the equator, while easterly accelerations at 50 hPa appear to propagate from the 'spring' hemisphere to the equator. Therefore the wind reversal from easterly to westerly can be explained as a result of vertical fluxes of westerly momentum from the troposphere, while the wind reversal from westerly to easterly may be due to the inflow of latitudinal momentum fluxes from the subtropics. This effect appears to synchronize the westerly wind phase onset at 50 hPa with tropospheric seasonal cycles, and the easterly wind phase onset at 50 hPa with stratospheric seasonal cycles whichever hemisphere the easterly wind phase propagates from.

It is an important problem as to how El Niño events accelerate the descent rate of the westerly wind regime in the equatorial stratosphere. The origin of equatorial waves has been sought in the troposphere. Yanai and Lu (1983) analyzed 200 hPa wind data for two summers, 1967 and 1972. They found that the Kelvin wave and the mixed Rossby-gravity wave were observed in 1967, but that the mixed Rossby-gravity wave was absent and the Kelvin wave was weak in 1972 when an El Niño event occurred. They suggested that all the westward moving equatorially trapped waves, such as the mixed Rossby-gravity waves, were excited by lateral forcing due to middle-latitude disturbances. Maruyama (1979)'s estimates also showed that the intensity of Kelvin waves at 50 hPa in 1972 was weaker than that in 1970. Furthermore, Lu (1987) showed, analyzing the data during the special observing periods (SOP – I and SOP – II) of the First GARP Global Experiment (FGGE), that the amplitudes of Kelvin waves and the convective activity are negatively correlated. So far as these results showed, we could not positively relate El Niño events to the Kelvin wave intensity. The absence of mixed Rossby-gravity waves in 1972 could be favorable to the relatively short duration of the easterly phase in cycle 9, because mixed Rossby-gravity waves contribute to the easterly momentum acceleration.

4. Concluding remarks

The latest easterly wind phase of the QBO at

50 hPa started in March 1987 and ended in September of the same year. Its duration was six months, that is the shortest since 1953, almost half of the average duration. This shows an anomalously long westerly wind phase at 50 hPa preceding the largest descent rate of the westerly regime above. An El Niño event is shown to relate with the rapid descent of the westerly regime, but not always with the prolongation of the westerly wind phase. From previous analyses of equatorial wave intensities, we have not yet been successful in relating the El Niño event directly with the intensity of Kelvin waves which have been considered to contribute to the westerly wind descent. This does not deny the role of Kelvin waves in the QBO, but the rapidity of the westerly descent could not be explained by Kelvin wave intensities. As another possible mechanism, the mean downward flow associated with the westerly regime descent should be also examined. A strong downward flow predicted theoretically can promote westerly acceleration (Plumb and Bell, 1982). The prolongation of the westerly wind phase and the following short easterly wind phase should also be analyzed in relation to the mixed Rossby-gravity waves which have been considered to contribute to the easterly momentum acceleration. Furthermore, timing of the wind direction reversal with seasonal cycles should be analyzed in relation to El Niño events, which are likely to control the global circulation patterns.

More detailed quantitative analyses of the relationship between the QBO and activities of the equatorial waves will be required by using data with high resolution from stations close to the equator, because the behavior of the QBO and the waves varies appreciably within a few degrees of latitude.

It is a noteworthy feature that the duration of the easterly wind phase at 50 hPa has been mostly around 12 months, though its behavior at other levels and that of westerly wind phase has

been different from one cycle to another. Therefore the latest easterly wind phase was remarkably anomalous, presenting many interesting problems in tropical meteorology.

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QBO に伴う 50 hPa 面の東風の継続期間が 1987 年に異常に短かったことと
エルニーニョとの関係について

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