Observations of Tropical Stratospheric Winds before World War II

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ABSTRACT

This paper discusses observations of the winds in the tropical stratosphere taken before the advent of regular operational balloon soundings in this region. These observations are at least broadly consistent with modern measurements, in the sense that they show that the winds in the tropical stratosphere have been undergoing some strong interannual variations over the last century. However, the available data appear to be too sparse to construct a detailed chronology of the quasi-biennial oscillation before about 1950.

1. Introduction

The circulation in the equatorial lower stratosphere is now known to display a remarkable interannual variation, with prevailing easterlies and westerlies alternating in a somewhat irregular cycle with average period around 27 months (e.g., Naujokat 1986). Near the equator the extremes seen in the monthly mean zonal wind during the quasi-biennial oscillation (QBO) can range from ~40 m s^{-1} easterlies to ~20 m s^{-1} westerlies (strongest near the 30-mb level). The reversals of the wind direction appear first at upper-stratospheric levels and then propagate downward to near the tropopause. The oscillation appears to be unrelated in any direct way to astronomical forcing or variations in the conditions at the earth's surface. The tropical stratosphere is unique in the atmosphere, both in having such a regular interannual cycle and in having the internal atmospheric "memory" that apparently accounts for almost all of the interannual variability in the circulation.

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Palmer (1954) summarized the then-standard view of the tropical stratospheric circulation that emphasized the steadiness of the winds throughout the annual cycle and from year to year. The presence of very pronounced interannual variability in the tropical stratospheric prevailing zonal winds was noted by Graystone (1959), McCreary (1959), and Ebdon (1960), and the existence of a quasi-regular biennial oscillation was first postulated by Reed et al. (1961) and Ebdon and Veryard (1961). The oscillation took so long to discover simply because very few observations of the wind in the tropical stratosphere were made until the 1950s. The U.S. government in the early 1950s began daily radiosonde observations extending into the stratosphere at some low-latitude stations. The earliest available regular stratospheric wind observations equatorward of 10° latitude appear to be those that began at Balboa (8.9°N, 79.6°W) in the middle of 1950 [available only to ~30 mb for the first six months (Wallace 1973)]. These were soon followed by observations at some tropical Pacific island stations such as Koror (7.3°N, 134.5°E), Majuro (7.1°N, 171.4°E), and Kwajalein (8.7°N, 107.7°E). These stations were joined in 1953 by Canton Island (2.8°S, 171.7°W). The radar-tracked balloon winds at Canton Island served as the primary basis for the initial identification of the QBO (Ebdon and Veryard 1961). The Canton Island observations were discontinued in 1967, but by employing data for later periods from other stations, it is possible to plot a detailed height–time section of the near-equatorial zonal wind up to ~10 mb starting from 1953 and continuing through the present, using only observations equatorward of 3° latitude (e.g., Naujokat 1986).

There has been some interest in searching for evidence of the tropical stratospheric winds in the period before these post–World War II systematic observations were taken. Soon after the discovery of the QBO, Ebdon (1963) examined some scattered in situ balloon observations of tropical stratospheric winds before 1920 in order to demonstrate the "permanence" of the oscillation. With the longer modern record now available, it seems clear that the QBO is indeed a reasonably stable presence in the circulation, but the possibility remains that its behavior could change systematically with time. Schove (1964, 1969) and Berson and Kulkarni (1968) examined the pre-1950 behavior of the tropical stratospheric winds in order to investigate possible solar cycle influence on the QBO. More recently the issue of QBO behavior over long periods has been investigated using indirect evidence by Hamilton (1983), Hamilton and Garcia (1984), Vial (1993), and Teitelbaum et al. (1995). They noted that the semidiurnal component of atmospheric surface pressure at low latitudes is systematically affected by the phase of the stratospheric QBO. Barometric data near the equator of sufficient quality to accurately determine the semidiurnal variation of pressure exist at least back to 1866. Other data of possible value for the inference of the QBO are measurements of total column ozone, some of which extend back to 1926. The ozone total column in the Tropics is known to be very strongly affected by the dynamical QBO, but the link between the tropical QBO and the ozone column in the extratropics (where the long observational records exist) is much less straightforward (e.g., Hamilton 1989; Tung and Yang 1994).

The last decade has seen renewed interest in possible effects of the stratospheric QBO on aspects of tropospheric climate (e.g., van Loon and Labitzke 1988; Labitzke and van Loon 1990, 1995; Gray 1984; Gray et al. 1992), and proposals for extending comparisons of tropospheric data with the stratospheric QBO into the pre-1950 period have recently been discussed. Thus it seems timely to critically review and extend earlier published compilations of the observations of stratospheric winds near the equator taken before World War II.

2. The Krakatoa easterlies

Russell (1888) discusses observations of the spread of the spectacular optical effects in the weeks following the explosive eruption of Mount Krakatoa (6.2°S, 105.4°E) in August 1883. Modern commentaries on these data are provided by Wexler (1951) and Palmer (1954). The observations indicated that the eastern edge of the volcanic dust cloud at high altitudes traveled westward at a very rapid rate (more than 30 m s^{-1}). The exact height of the dust cloud is not known, but observations following recent large explosive eruptions suggest that dust is initially injected into the lowest few kilometers of the stratosphere [contemporary estimates of the Krakatoa dust cloud height based on optical observations were somewhat higher (e.g., Russell 1888; Palmer 1954)]. The Krakatoa observations thus suggest that the QBO in the lower stratosphere must have been near its extreme easterly phase in August 1883.

3. Observations summarized in Ebdon

Ebdon (1963) examined pilot balloon observations taken at Batavia (present day Djakarta, 6.2°S, 106.8°E) during 1909–18. A total of 44 soundings reached at least 19 km (all between March 1911 and July 1918), with 37 of these between March 1911 and December 1913. While these observations are quite sparse, modern data indicate that the QBO fluctuations of the prevailing wind in the lower stratosphere are typically stronger than the day-to-day variations (e.g., Fig. 10 of Wallace 1973). Thus a relatively small number of soundings may be able to indicate the phase of the QBO with some degree of confidence. As noted by Ebdon (1963) the 1911–13 data display a clear QBO with even an indication of a descending westerly regime above easterlies in the first part of the period, and a descending easterly regime above westerlies in the period roughly from July 1912 to July 1913. Outside the 1911–13 period the scattered observations were used by Ebdon to construct a "suggested" chronology of QBO phase at 60 mb for 1909–18, but in light of the very limited data employed this has to be considered an extremely tentative proposal.

Ebdon (1963) also discusses pilot balloon observations of the winds taken by A. von Berson in an expedition to East Africa in 1908. According to Ebdon there were a total of three ascents near the southeast shore of Lake Victoria (about 1.5°S) in August and September that reached up to 19 km and one such flight at Dar es Salaam (6.8°S, 39.3°E) in October (reaching 22 km). These very limited data do not reveal a clear indication of the QBO phase.

4. Observations summarized by Berson and Kulkarni

Berson and Kulkarni (1968, hereafter BK) present a complicated diagram summarizing time series of 60-mb zonal wind, 60-mb temperature, and column ozone observations for several locations. They include points on their plot corresponding to the Batavia zonal wind observations discussed by Ebdon (1963) as well as observations in 1917 at Bandoeng, Indonesia (7°S, 109.6°E). In addition they include 60-mb wind observations in 1939 taken from a ship in the tropical Atlantic and wind observations from an Italian expedition in East Africa in 1932–33. Unfortunately BK provided no discussion of any of these data. There also appear to be some inaccuracies in the BK diagram. In particular, BK plot results for East Africa in 1931–32, while the observations actually appear to have been taken during 1932–33 (Bossolasco 1949). They also plot two westerly data points for August and October 1939 for the tropical Atlantic observations, while the actual observations (Vuorela 1948, 1950) are clearly easterly near 60 mb in the earliest near-equatorial observations (which are in early September, not August, as indicated by BK).

Bossolasco (1949) provides more details of the Italian pilot balloon measurements that were made at Mogadishu (2°N, 45.3°E) during August 1932 to July 1933. During this period a total of over 1200 balloons were launched, but only a small fraction could be followed up to stratospheric levels. Bossolasco focuses on the period 24 October–5 December when "the launches with pilot balloons reaching the high troposphere (and sometimes the stratosphere) were frequent and well-distributed." Unfortunately, the exact number of ascents at each level is not given. Bossolasco does describe three particular soundings that went to very high levels (near 30 km) on 9 November, 14 November, and 3 December. These soundings indicate the presence of very strong westerlies (up to 43 m s^{-1}) at midstratospheric levels. These very intense equatorial westerlies would seem to have no counterpart in modern observations. One can perhaps doubt the accuracy of the pilot balloon technique at high levels. Interestingly, Bossolasco noted that his finding of westerlies near 30 km contradicted the observations of the Krakatoa easterlies and the earlier pilot balloon observations at Batavia, but he offered no explanation for this.

Vuorela (1948, 1950) discusses pilot balloon observations of the wind taken on a commercial freighter that traveled from Finland to South America and back in the late summer and autumn of 1939. There were a total of 112 balloon flights during the voyage, and Vuorela (1950) presents the detailed wind soundings from each of these. There were four soundings within 10° of the equator that extended above 18 km. Two of these are around 5°S on 8 September (during the outward leg of the voyage). These show easterlies of 10–20 m s^{-1} from 18 to 25 km, with a hint of weak westerlies in a narrow region near 21 km. On the homeward leg of the voyage there were soundings taken near 5°S on 30 October and near 1°S on 31 October that each extended up to 22 km. These show strong (~20 m s^{-1}) westerlies above 18 km. These results are consistent with the easterly to westerly wind reversal descending through these levels in the intervening period (September and October). This also is supported by the cross sections of the zonal wind on outward and homeward legs published by Vuorela (1948).

5. The chronology of Schove

An intriguing paper relating to QBO history was published by Schove [1969, which is an updated version of Schove (1964)]. In this paper he asserts, "We have direct or indirect evidence for easterly phases at 60 mb (19.5 km) in 1883 . . ., 1909.7, 1911.8, 1914.1, 1916.2, 1918.2, . . . 1923, 1925, about 1928.2, . . . 1934, 1936, about 1939.2 and 1941.2, 1943, . . . about 1946.2 and 1948.2, 1950.1, 1952.4." Unfortunately the data sources are not spelled out [beyond a reference to the total column ozone observations given by Angell and Korshover (1967)], nor is "indirect evidence" defined. Even the exact meaning of the dates listed is not clear (so, e.g., the inclusion of "1918.2" would presumably refer to the presence of easterlies in February 1918, but "1923" in the list might mean that easterlies were present at the beginning of 1923, sometime during 1923, or throughout 1923). It is also odd that only times of easterlies are included. However, Schove (who passed away in 1986) made by far the most ambitious attempt at a premodern chronology for the QBO. The results for 1911–16 seem to be consistent with the QBO phases inferred from the Batavia observations discussed by Ebdon (1963), but the dates given by Schove during this period sometimes correspond to months with no stratospheric observations at Batavia (possibly indicating his use of some other data source during this period).

6. Observations in the tropical Atlantic, 1926–27

One source of in situ data that seems not to have been employed by earlier investigators is that provided by observations from the German research vessel *Meteor,* which conducted an extensive cruise of the Atlantic Ocean from April 1925 to June 1927. According to Speiss (1928), during this period a total of 814 pilot balloons were launched from the ship. While the majority of these balloons could only be followed up to heights near 10 km, some ascents extended above 20 km. Kuhlbrodt (1928) reports that near the equator at levels "above 16.5–17 km winds generally were observed to be easterly." The actual observations have not been found, but a detailed map of the ship track in Speiss (1928) shows the locations of each of the 814 soundings. Nearly all the soundings equatorward of 10° latitude were taken between early September 1926 and mid-February 1927. This included one near-equatorial section across the Atlantic in late December 1926 and early January 1927. Thus it seems reasonable to conclude that the prevailing equatorial winds between 17 and 20 km were easterly around the beginning of 1927 (and perhaps as early as September 1926). It is interesting that Schove (1969) lists February 1928 as a time of easterlies at 60 mb. In order to reconcile the Schove chronology with the *Meteor* observations, one needs to postulate either a very long easterly phase (at least December 1926 through February 1928) or a very short westerly phase intervening between January 1927 and February 1928. Interestingly, neither of these possibilities is consistent with the post-1953 documented behavior of the QBO near the equator, since the easterly phase at 60 mb has always been significantly shorter than the westerly phase (e.g., Naujokat 1986).

7. Discussion

A search of the literature has revealed a few dozen soundings taken with pilot balloons at various times between 1909 and 1939 that give results for the near-equatorial wind above the tropopause. The results are in broad agreement with modern observations, in the sense that the wind was found usually to be aligned zonally and that at some times easterlies were observed and at other times westerlies. There are even suggestions in some of the early balloon observations of the descending shear zones that are so prominent a feature of the QBO in modern data. However, with the exception of the 1911–13 observations at Batavia, the pre–World War II balloon data are very limited in their ability to reveal detailed QBO behavior. In addition, some of the observations (notably the very strong westerlies seen in the Mogadishu profiles) are difficult to reconcile with modern records. Of course, the manually tracked balloon techniques employed in these early soundings may have limited accuracy, particularly at high altitudes and in strong wind conditions.

The idea of using proxy data of various sorts to infer QBO phase has been discussed since the 1960s. It seems that some kinds of proxy data were employed by Schove (1964, 1969) in his ambitious (if mysterious) attempt to construct a QBO chronology. The extant extratropical total ozone records might provide some guidance in the post-1926 period. Similarly observations of the semidiurnal surface pressure oscillation near the equator could be employed. However, both the ozone and surface pressure records have their own limitations, and in any given year it is quite possible for non-QBO-related effects to swamp the QBO signal. Thus, while these proxies may be useful for examining general features of QBO behavior in the past (Hamilton 1983; Hamilton and Garcia 1984; Teitelbaum et al. 1995), they cannot be expected to provide reliable cycle-by-cycle QBO chronologies.

Unless a trove of hitherto unknown balloon observations emerges, it appears that the construction of a credible and detailed QBO chronology of the pre–World War II period will not be possible.

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