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Letters to the Editor

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QBO AND QTO IN TERRESTRIAL PARAMETERS: A BRIEF ASSESSMENT

1. A Quasi-biennial oscillation (QBO) in the equatorial stratospheric zonal winds was discovered by Veryard and Ebdon (1961) and others. Thereafter, several workers have studied and documented the characteristics of this wind QBO (Naujokat, 1986). For several months, the winds are westerly and then switch over rapidly to easterly and remain so for several months. The durations of the westerlies and easterlies change with altitude and latitude. The westerly accelerations appear first at the equator, spread with time to higher latitudes and are generally more intense than easterly accelerations. The maximum occurs later at lower altitudes, by 10-12 months from 10 hPa to 50 hPa. These characteristics are very well defined and from the data at any altitude, it is possible to determine the characteristics at other altitudes. A theoretical explanation of QBO was given first by Lindzen and Holton (1968) in terms of absorption in the stratosphere of vertically propagating equatorial Kelvin and Rossby-gravity waves generated in the troposphere. The wind QBO seems to affect other parameters, notably stratospheric temperatures and ozone.

The relationship between the tropospheric and stratospheric QBO seems to be controversial. Trenberth (1980) seems to feel that the two are unrelated, while Yasunari (1989) indicates possible links between the two. On the Earth's surface, there is another phenomenon *viz*. ENSO (El Niño/Southern Oscillation) which has predominantly a QTO (Quasi-triennial Oscillation) and larger periodicities but also has a biennial mode (Rasmusson *et al*., 1990) which may not be related to the stratospheric wind QBO. Barnett (1991) and Ropelewski *et al*. (1992) feel that tropospheric QBO is mainly related to ENSO. The parameters in the regions above the stratosphere (mesosphere, ionosphere, etc.) are known to have interannual variabilities. It would be interesting to know whether these have QBO and QTO and if so, whether these are in any way related to the stratospheric/tropospheric QBO/QTO, perhaps through upward moving gravity waves.

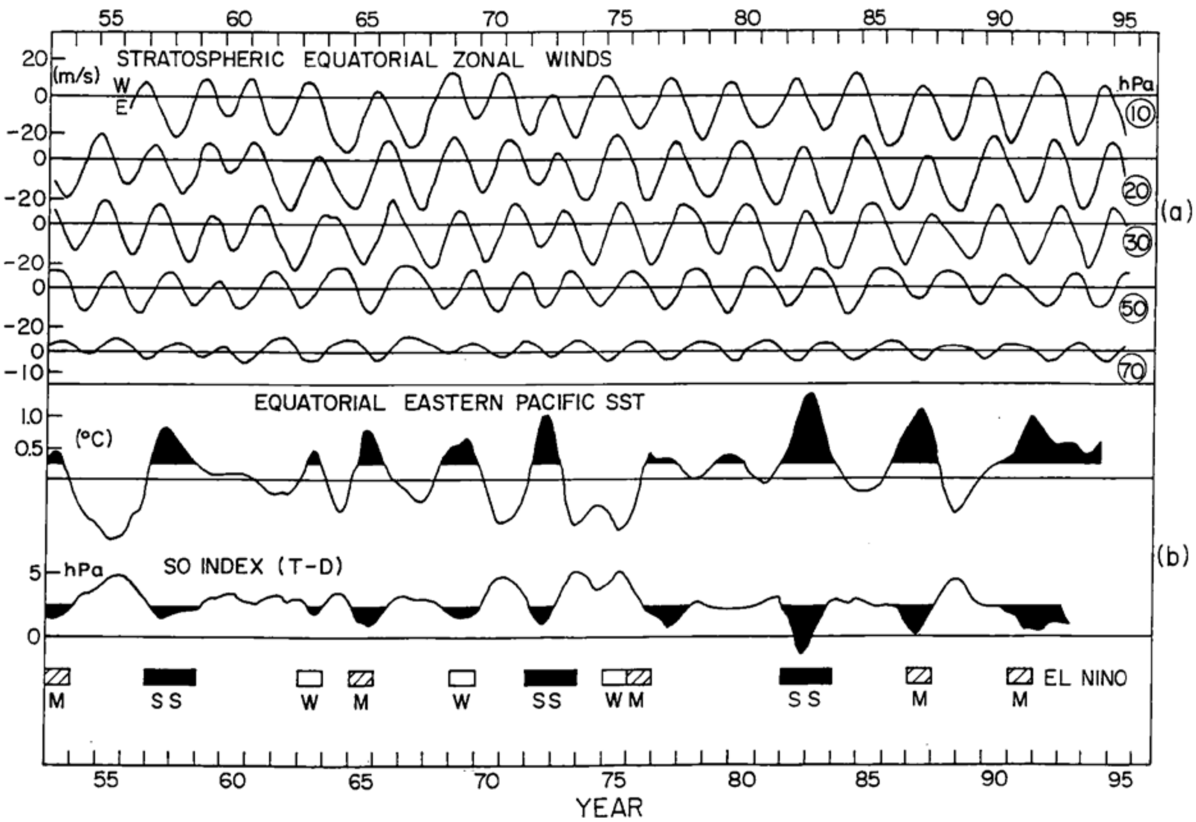
2. *Method of analysis* – For a study of QBO and QTO, the seasonal variations need to be eliminated or at least, minimized. This was achieved by obtaining 12-month running means. To eliminate the long-term trends and thus isolate the QBO and QTO, the 3-year running means were subtracted from the 12-month running means.

3. *Ionospheric parameters* – The series of ionospheric parameters foE, foF2 and hmF2 at Juliusruh (54.6º N, 13.4º E) were compared with those of solar parameters (sunspots, 10.7 cm radio emission). An 11-year oscillation was easily discernable. With 12-month running averages, ionospheric parameters showed oscillations with peak separations of 20-40 months (QBO, QTO). The 50 hPa tropical zonal wind showed peak separations of 20-35 months. In general, 50 hPa westerly wind peaks were ~6 months earlier than the ionospheric peaks. A spectral analysis of the ionospheric series by MEM (Maximum Entropy Method) confirmed significant peaks in the QBO region and a prominent peak near 11 years. The QBO peaks were also noticed in the range of the daily variation of the geomagnetic component H in the electro jet region where the ionization in the E-region is involved. The airglow emissions OI 6330 (red line, originating at ~250 km in the F-region) and OI 5577 (green line, its mesospheric component at ~95 km) observed at a low latitude location in Brazil also showed QBO and QTO. Thus, the stratospheric wind QBO seems to have an effect on the mesosphere and ionosphere.

4. *Stratospheric ozone and temperatures* - It is known since long that the stratospheric wind QBO affects stratospheric ozone and temperatures. Plots of ozone at North Polar, North Temperate, Tropical, South Temperate and South Polar regions as also a world averages showed QBO, with peak spacings of 21-36 months. Similarly, plots for stratospheric (100-30 hPa) temperatures also showed QBO. In the tropics, ozone maxima almost coincided with westerly wind maxima. In subtropics, (both north and south), there was a phase lag of ~3 seasons (9 months). For North Polar region, the westerly wind maximum seemed to coincide with temperature minima. For South Polar region, correlations were low.

Temperatures over, North Polar region had an inverse relationship with westerly wind. In contrast, the low latitude (10º N-10º S) temperatures had an excellent correlation (+0.8) with temperature maxima almost coinciding with the westerly wind maxima (Kane and Buriti, 1997). It was observed that the equatorial stratospheric wind affects ozone and temperatures not only in the low latitudes but also in the middle and high latitudes.

A spectral analysis of ozone in different geographical regions showed QBO with more than one peak (2.34, 2.66 etc.). Besides, there were peaks near 3.6 and 5.0 years and a weak 11-year peak in some cases. Thus, the solar cycle effect was not strong. Often, larger



Figs. 1(a&b). Time series of (a) stratospheric equatorial zonal wind (westerly positive, easterly negative) and (b) equatorial eastern Pacific SST, SO index Tahiti (T) minus Darwin (D) atmospheric pressure and El Niños (rectangles, full = strong, hatched = moderate, blank = weak)

peaks were observed (26, 32, 36, 44, 54, 66 months) which reflect long-term trends.

5. *Relationship between ENSO and stratospheric wind and temperature* - Since the stratospheric QBO is not, in general, well-related to the temperature variations in the troposphere, other factors may be playing a more dominant role here. An obvious candidate is the ENSO. El Niños (EN) are warm water episodes along the Peru-Ecuador coast and are related to Southern Oscillation (SO), an atmospheric pressure see-saw, *e.g*. the pressure difference between mid-Pacific Tahiti (T, 18º S, 150º W) and Australasian Darwin (D, 12º S, 131º E). Whenever (T-D) reaches minimum, it is mostly an El Niño year. For El Niño, there is no index as such, though temperature anomalies in Peru-Ecuador coast (Puerto Chicama) or the SST anomaly in the Central Pacific region Nino 3 could serve as an index. (Equatorial eastern Pacific) EEP-SST and the parameter (T-D) are available as regular time series. Fig. 1(a) shows the time-series of the stratospheric winds at several levels and Fig. 1(b) shows EEP-SST and the SO index represented by (T-D). The wind patterns [Fig. 1(a)] at various levels are similar and there is a phase shift of ~10 months from 10 hPa to 70 hPa. Also, amplitudes are largest near 20 hPa. The ENSO parameters [Fig. 1b)] have patterns very different from those of the winds, with large spacings in successive peaks. The EEP-SST maxima (shown black) coincide with SO index (T-D) minima (shown black) and with the occurrence of El Niños (shown by rectangles, strong = black; moderate = hatched; weak = blank). A cross-correlations between 50 hPa wind, EEP-SST and (T-D) showed that the wind had poor correlations with EEP-SST or (T-D). On the other hand, EEP-SST and (T-D) had an excellent negative correlation. Thus, EEP-SST and (T-D) on one hand and stratospheric wind on the other seem to be mostly unrelated parameters. A spectral analysis showed that the 50 hPa wind had 2.35 years as the most prominent peak and 2.70 years as a smaller peak, thus forming a QBO doublet. The EEP-SST and (T-D) peaks were similar and prominent at 3.5, 4.8 and 6.3 years. Rasmusson *et al.* (1990) emphasize a biennial (2 years) component of ENSO variability, which was not seen here.

A cross-correlation analysis showed that the upper troposphere and stratosphere temperatures were well related to the 50 hPa equatorial wind while lower troposphere temperatures were better related to equatorial eastern Pacific sea-surface temperatures. The spectral characteristics of all these temperatures showed that the stratospheric temperatures had major peaks in the QBO region while temperatures at lower altitudes had major peaks in the QTO and higher periodicity regions. The lower tropospheric temperatures seem to match with EEP-SST only.

6. *Tropospheric parameters* - Because of the concern about “greenhouse effects”, several “greenhouse gases” are being monitored for the last few decades. Measurements are available for water vapour (or cloudiness), carbon dioxide, carbon monoxide, ozone, nitrous oxide, methane and halocarbons. Since the movements of the trace elements are governed by global and local circulation patterns, some periodicities seen in the data of trace elements could be attributed to the circulation patterns. It was noticed that most of the trace element series showed QBO and QTO.

In the data for cloudiness of six broad regions of USA, all the series showed QBO, but 50 hPa wind effects were not predominant. A spectral analysis showed that all the series had prominent QBO, often with multiplets, but all of these also had prominent peaks in the QTO region (~3.3-3.6) and at ~4.2 years, indicating a complicated structure. In another set of data related to atmospheric water content, a spectral analysis showed that highly significant peaks were seen in the QBO region (2-3 years) as also in the QTO region (~3.6 years) and ~4.0 years. It was noticed that the 50 hPa wind and/or EEP-SST affect water content variations at different latitudes in different proportions.

Some meteorological series are known to show QBO. The QBO in Indian monsoon has been a subject of study since long (Parthasarathy and Mooley, 1978), with more recent studies as in Kane (1995). For many subdivisions of India, maximum rainfalls seem to be associated with the increasing westerly phase of the stratospheric zonal winds, and droughts seem to be associated with the easterly phase. However, droughts over India seem to be associated with El Niños also. There is a relationship of Indian monsoon rainfall with Eurasion snow cover also (Barnett *et al*., 1989). Thus, the stratospheric winds, the ENSO phenomenon, the Eurasian snow cover (and probably some other factors) are all involved in affecting the Indian monsoon, and these factors act at least partly independently of each other. For prediction schemes (Thapliyal and Kulshrestha 1992**)**, a dozen or more parameters are considered for regression equations, and the predictions have been satisfactory. Meehl (1987) identified a biennial signal in the coupled ocean-atmosphere system in the tropical Indian and Pacific regions and proposed a mechanism involving large-scale interaction between the ocean and atmosphere.

7. *Conclusions and discussion* - The paper examines the status of QBO/QTO in different terrestrial parameters. Two distinct phenomena seem to be involved, *viz*. (a) the stratospheric low latitude zonal wind QBO having a main peak at 2.35 and (b) the ENSO having a main peak at 4.8 years and a smaller peak at 3.5 years. From their spectral characteristics, these two phenomena seem to be almost independent. The stratospheric QBO seems to be associated with ionospheric, mesospheric, stratospheric and upper tropospheric parameters, while ENSO seems to be associated with middle and lower tropospheric parameters and surface phenomena.

In addition to the ENSO mode (40-60 month period), the zonal wind in the troposphere has a component of transient east-west circulation with the QBO time scale, which shows a totally eastward propagation (Yasunari, 1989). Thus, there is some evidence that the stratospheric and tropospheric QBO are coupled and these are, in turn, coupled to the QBO of the equatorial eastern Pacific SST, suggesting a dynamical link between stratospheric QBO and the large scale coupled atmosphere/ocean system. However, Trenberth (1980) mentions that the QBO shown by tropospheric ultralong waves of the Southern Hemisphere does not match with stratospheric QBO. Meehl (1987) identified a biennial signal in the coupled ocean-atmosphere system in the tropical Indian and Pacific regions which does not seem to be related to stratospheric QBO (Rasmusson *et al*., 1990). In any case, the ENSO mode (40-60 months) present in SST does seem to be an independent parameter.

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