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Interannual variability of precipitable water

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Abstract. The 12-month running means of the surface-to-500 mb precipitable water obtained from analysis of radiosonde data at seven selected locations showed three types of variability viz: (1) quasi-biennial oscillations; these were different in nature at different latitudes and also different from the QBO of the stratospheric tropical zonal winds; (2) decadal effects; these were prominent at middle and high latitudes and (3) linear trends; these were prominent at low latitudes, up trends in the Northern Hemisphere and downtrends in the Southern Hemisphere.

1 Introduction

Of the "greenhouse gases", water vapour is the most abundant. About half the warming expected from increases of CO_2 and other greenhouse gases is attributed to concomitant increases in water vapour, since the warming increases evaporation and the capacity of the air to hold moisture (Elliott *et al.*, 1991). Hence, monitoring water vapour is of great importance. Since water vapour has a residence time of only about 10 days and is not well-mixed in the troposphere, *global* changes are difficult to assess. Most of the estimates obtained so far are based on radiosonde humidity data. Bannon and Steele (1960) made a global analysis of precipitable water for 1951–55 and Tuller (1968) for 1964–68. Sellers (1965) estimated latitudinal and global averages. Global estimates are also given in Peixoto and Oort (1983). Using radiosonde data from a network, Elliott *et al.* (1991) calculated the precipitable water between the surface and 500 mb and estimated trends in water vapour at individual stations for 1973–86. In this note, we examine the interannual variability of water vapour at 7 selected stations for which Dr. Elliott kindly sent us monthly mean values for 1973–90.

2 Data

Worldwide radiosonde observations since 1973 are archived at the National Climatic Data Center, Asheville N.C. (USA) and compiled at the National Meteorological Center. Details of obtaining the precipitable water content from these data, biases and limitations of data etc. are described in Elliott *et al.* (1991). In this note, the data used are for Barrow (71°N, 157°W), Kiev (50°N, 30°E), Brownsville (26°N, 97°W), Majuro (7°N, 171°E), Tahiti (17°S, 149°W), Adelaide (35°S, 138°E) and Gough Island (40°S, 10°W) mostly for 00 and 12 UT (only 00 UT for Majuro and Tahiti), for which Dr. Elliott sent us the monthly values for 1973–1990.

At these locations, precipitable water shows a seasonal variation, with maxima in (local) summer and minima in winter. Since our purpose was to study interannual variability, the seasonal variation was eliminated by obtaining 12-month running means, which are plotted in Fig. 1 left half (solid lines), spaced 3 months apart. For each location, there are two plots, one for 00 UT and the other for 12 UT, except for Majuro and Tahiti for which only data for 00 UT were available.

3 Quasi-biennial oscillation (QBO)

A striking feature in all plots is a quasi-biennial oscillation (QBO), superposed on long-term variations represented by the thick lines, obtained as 3-year running means. To isolate the QBO, the 3-year running means were subtracted from the 12-month running means. The difference is plotted in Fig. 1, right half. QBOs are now clearly visible. Maxima are marked with arrows and the separation between successive peaks (in months) is indicated by numbers, which seem to be generally in the range 21–42 months. A power spectrum analysis of these series showed broad peaks near 30 months, significant at a 2 sigma (95%) level.

The phenomenon of QBO was strikingly noted first in the stratospheric zonal winds in the equatorial region (Reed *et al.*, 1961). In the bottom part of Fig. 1, right half, the 12-month running means of the 50 mb zonal wind (Venne and Dartt, 1990) are plotted and the vertical lines mark the maxima of the westerly phase (W) of these winds.

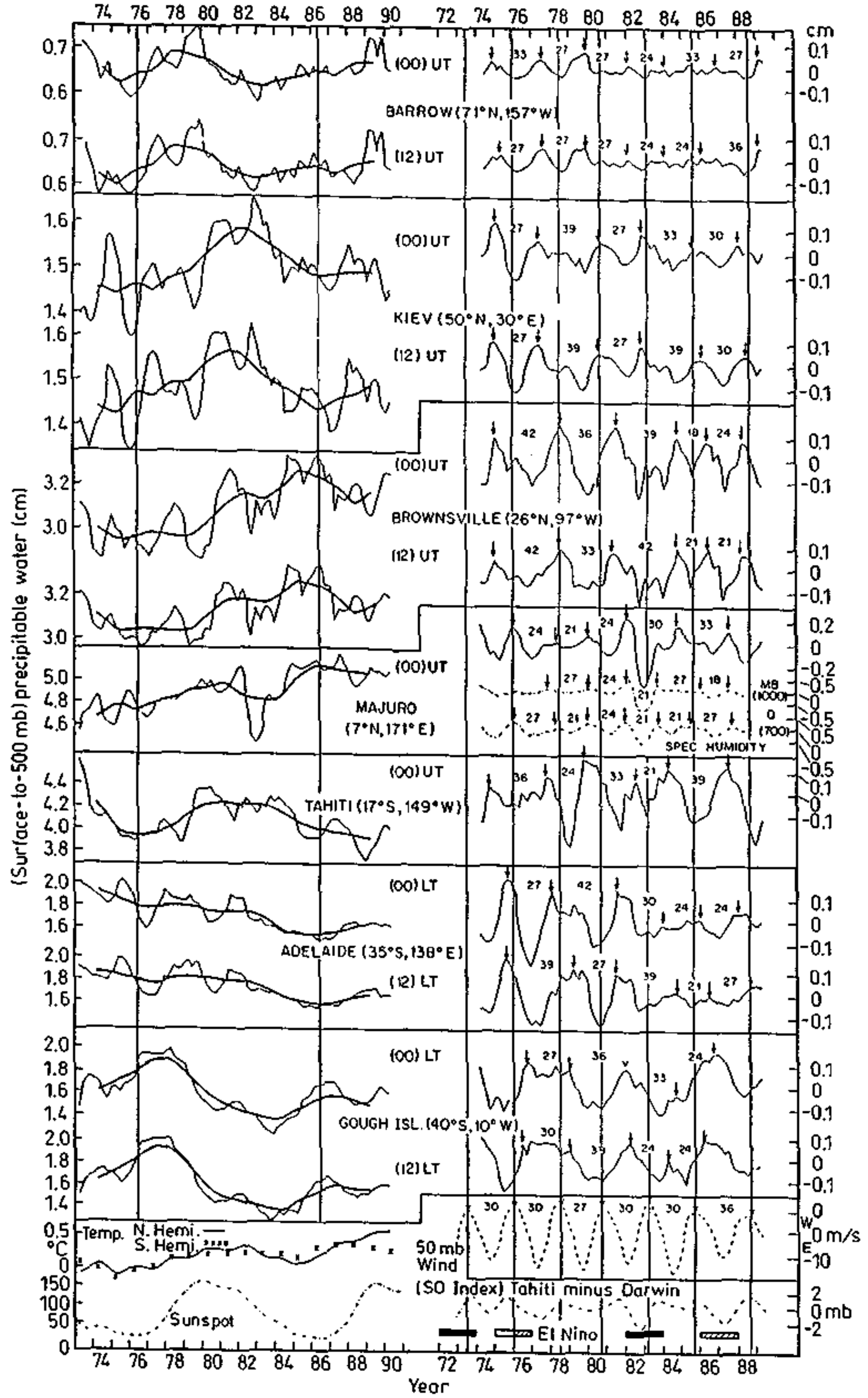

Fig. 1. *Left half*: 12-*month running means of precipitable water* (*surface-to*-500 mb) (*solid lines*) at 7 selected locations Barrow (71°N), Kiev (50°N), Brownsville (26°N), Majuro (7°N), Tahiti (17°S), Adelaide (35°S) and Gough Island (40°S), surface temperatures for the Northern (*solid lines*) and the Southern (*crosses*) Hemispheres, and sunspot number (*bottom plot*). *Thick lines* are 3-year running means. Observations refer to 00 UT and 12 UT every day. *Right half*: 12-*month means minus* 3-year means. *Arrows* indicate maxima of the quasi-biennial oscillations. Below Majuro, the *dashed lines* show specific humidity at 1000 and 700 mb (Gutzler, 1992). *Bottom plots* show 50 mb equatorial zonal wind (Venne and Dartt, 1990), SO index (Tahiti minus Darwin sea-level atmospheric pressure) and El Niño events as *rectangles* (*solid*, strong; *hatched*, moderate; *open*, weak)

The following may be noted:

1. The QBO maxima of precipitable water do not seem to match the 50 mb wind maxima or minima, not even with any fixed lag or lead. Thus, the origin of the tropospheric QBO (1000–500 mb) may not be the same as the origin of stratospheric QBO. Similar views have been expressed earlier by other workers (e.g. Trenberth, 1980; Rasmusson *et al.*, 1990)

2. The peaks in the QBO of precipitable water at different geographic locations are not similar i.e. there are no matches even with fixed lags or leads, nor similar spacings. If all these have a common origin, considerable distortions seem to occur. Alternatively, some very local effects might be the cause of considerable distortions.

4 Effects of El Niño

A well-known meteorological phenomenon is the occurrence of El Niño (warm water episodes in the Peru-Ecuador coast) with an average frequency of 3–4 years. The El Niños which occurred during 1972–88 are marked with rectangles (solid, strong; hatched, moderate; open, weak) at the bottom of Fig. 1 right half. The strong El Niño of 1982–83 seems to be associated with abnormally low precipitable water prominently at Majuro (7°N, 171°E) and weakly at Brownsville (26°N, 97°W). For the strong El Niño of 1972–73, no data are available. The moderate El Niños of 1976 and 1986–87 do not seem to have any striking influence on precipitable water. The bottom plot of Fig. 1 right half shows the Southern Oscillation (SO) index, represented by Tahiti minus Darwin atmospheric pressure. The El Niños coincide with SO minima. In addition to a 3–4 year periodicity, the SO index also has a QBO. It is likely that the QBO in precipitable water may have some relation with the QBO of SO.

Using data from four radiosonde stations namely Koror (7°N, 135°E), Truk (7°N, 152°E), Pohnpei (7°N, 158°E) and Majuro (7°N, 171°E), Gutzler (1992) defined indices of specific humidity (Q) for three levels 1000, 700 and 300 mb. Results for 1000 and 700 mb are shown in Fig. 1 right half, as dashed plots immediately below the full line plot of Majuro. As can be seen, there are indications of a QBO (more prominently at 700 mb).

5. Long-term trends

The thick lines in Fig. 1, left half indicate considerable long-term (period exceeding 3 years) fluctuations, that vary at different locations. There is an indication of decadal trends, probably a solar cycle association, at some locations. When compared with the sunspot cycle (Fig. 1, left half, bottom plot where vertical lines indicate sunspot minima), Barrow (71°N) and Gough Island (40°S) show water maxima *2–3 years before* the sunspot maxima (1979 and 1989). Kiev (50°N) and Tahiti (17°S) show water maxima a *year or two after* the sunspot maximum of 1980. Brownsville (26°N) and Majuro (7°N) show very little solar cycle association, but, instead, a 3–4 year wave superposed on a large upward linear trend. In contrast, Adelaide (35°S) shows a largely downward trend. The decadal trends (maximum to minimum of precipitable water) are as large as 0.1 cm (1 mm) for Kiev and 0.4 cm (4 mm) for Gough Island. The long-term linear trends are as large as $+0.3$ cm ($+3$ mm) per decade for Brownsville and -0.2 cm (-2 mm) per decade for Adelaide and Gough Island. The increase in water vapour in the Northern Hemisphere during 1973–88 is compatible with the rise in temperature during this period as shown in the bottom part of our Fig. 1, left half for the Northern Hemisphere (solid lines) and Southern Hemisphere (crosses) (data from Jones *et al*., 1986a, b and further private communication). However, the lowering of water vapour values in the Southern Hemisphere in spite of rise in temperature, needs explanation.

6 Conclusion and discussion

The precipitable water content obtained from analysis of radiosonde data at seven selected locations shows quasi-biennial oscillations which have spacings in the range 21–42 months. Individual waves at different latitudes do not correlate with each other or with the QBO waves of the 50 mb equatorial zonal winds, indicating that the QBOs of the troposphere and stratosphere have probably separate origins. The long-term trends are not linear. For some locations, decadal variations are larger than the linear trends.

Although these results do indicate striking QBO in the troposphere, their origin is somewhat puzzling. Yasunari (1989) reported evidence for a possible link between stratosphere, troposphere, and sea-surface temperature. However, earlier, Trenberth (1980) had indicated that the QBO of the stratospheric winds had no relationship with the QBO of ENSO (El Niño-Southern Oscillation) and recently Kane (1992) showed that this was true for some other parameters also. The present results show that precipitable water also shows that QBO does not match with stratospheric wind QBO but is related to strong El Niños. El Niños are associated with (SO) index (Tahiti minus Darwin atmospheric pressure) minima. In a recent communication (Kane and Gobbi, 1995) it was shown that for the United States cloudiness values showed quasi-biennial and quasi-triennial oscillations matching partly with similar oscillations in the SO index but not with QBO of the 50 mb wind. The SO index is also known to be related to the sea surface temperature (SST) index. Rasmusson and Carpenter (1990) showed a biennial component of ENSO variability. Meehl (1987, 1993) discussed the biennial mechanism and its relationship to interannual variability in the tropical region.

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