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Ionospheric response to the equatorial stratospheric wind

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RESUMEN

Utilizando datos ionosféricos de los meses de marzo y septiembre, registrados en Okinawa (26°N, 128°E), otro autor encontró una asociación entre la varianza de la frecuencia crítica de la capa F2, foF2var, y la oscilación cuasibienal de la media mensual del viento zonal (MMZW). En este trabajo se extiende este análisis, utilizando datos horarios mensuales de foF2 (entre las 12 y las 19 TL) para el periodo 1957-1989, para una estación ubicada en la cresta sur de la anomalía ecuatorial (Tucumán, 27ºS; 65ºW), para otra en el ecuador magnético (Huancayo, 12ºS; 75ºW) y otra estación de alta latitud (Slough, 51ºN; 0.6ºW). El coeficiente de correlación entre foF2var y MMZW es 0.05, 0.16 y 0.20 para Tucumán, Huancayo and Slough respectivamente, lo que indicaría que no hay asociación. Sin embargo dada la alta correlación encontrada en Okinawa (r=0.65), y en Tucumán cuando sólo se considera el período 1958-1968 (r=0.67), no descartamos completamente la posibilidad que la QBO del MMZW module la ionosfera en las crestas de la anomalía ecuatorial, sin buscar antes una explicación sobre la falta de correlación para Tucumán a partir de 1968. El análisis espectral de las tres estaciones muestra una significativa oscilación de alta frecuencia en foF2var (2.5-3.3 años) muy cercana, pero no coincidente con la QBO del MMZW, que también merece ser estudiada.

PALABRAS CLAVE: Oscilación cuasibienal, frecuencia crítica de la capa F2, media mensual del viento zonal, efecto dínamo.

ABSTRACT

Chen (1992) reports an association between the variance of the F2 layer critical frequency, foF2var, and the quasi-biennial oscillation, QBO, of the monthly mean zonal wind in the equatorial stratosphere (MMZW) at 40 mb, with data of March and September at Okinawa (26ºN, 128ºE). We search for such an association in other locations. Monthly-hourly foF2 data (between 12 and 19 LT) for the period 1957-1989 from Tucumán (27ºS; 65ºW), at the southern equatorial anomaly crest at the magnetic equator (Huancayo,12ºS; 75ºW), and in high latitude (Slough, 51ºN; 0.6ºW) were analyzed. The correlation coefficient between foF2var and MMZW is 0.05, 0.16 and 0.20 for Tucumán, Huancayo and Slough respectively, suggesting that there is no association. However, the correlation coefficient for Okinawa (r=0.65), and for Tucumán in the period 1958-1968 (r=0.67), is high. We do not rule out the possibility that the QBO of MMZW modulates the ionosphere at the crests of the equatorial anomaly. We look for an explanation of the loss of correlation for Tucumán after 1968. Spectral analysis, for all three stations, shows a significant high-frequency oscillation in foF2var (2.5-3.3 years) which is very close but not coincident with the QBO present in MMZW.

KEY WORDS: Quasi-biennial oscillation, F2 layer critical frequency, monthly mean zonal wind, dynamo effect.

INTRODUCTION

A quasi-biennial oscillation, QBO, of 26 to 28 months, is the main variation of the monthly mean zonal wind, MMZW, in the equatorial stratosphere (Reed *et al.*, 1961; Angell and Korshover, 1962; Hamilton, 1984; Dunkerton and Delisi, 1985; Naujokat, 1986; Randel *et al.*, 1999). The QBO prevails over seasonal variations at heights of 15 to 30 km (200 to 10 mb), but decays with time in alternating series of easterlies and westerlies that attain speeds of 20 to 30 m/s. The downward propagation occurs without loss of amplitude between 30 and 20 km. The QBO is symmetric with respect to the equator and is confined to latitudes of less than about 15° (Holton, 1982). The zonal wind presents longitudinal symmetry (Baldwin *et al.*, 2001).

This tropical phenomenon also affects the stratospheric flow from pole to pole by modulating the effects of extratropical waves (Holton and Tan, 1980; Baldwin *et al.*, 2001). The QBO affects the distribution and transport of trace constituents and may be a factor for stratospheric ozone depletion (Baldwin *et al.*, 2001). The QBO signal in column ozone is strong and statistically significant in the extratropics (Kinnersley and Tung, 1999).

The QBO has also been observed in the upper atmosphere. Satellite measurements of equatorial wind between 10 to 40 km and 50 to 115 km reveal a QBO in the upper mesosphere (Burrage *et al.*, 1996), called MQBO. The MQBO is centered near 85 km and extends out to ±30º latitude.

Based on ionospheric data from Okinawa (26°N, 128°E; geom.: 15.5°N, 196.9°E), located at the northern equatorial anomaly crest, Chen (1992) found that MMZW at 40 mb (20 km) is linearly correlated with the variance of the F2 layer critical frequency, foF2var (correlation coefficient r = 0.65). In the east phase of the wind, the foF2var increases and in the west phase the foF2var decreases. The planetary wave can modulate the tidal wind and the dynamo effect of the equatorial region can produce the fluctuation of the day-to-day variation of the electric fields in the E region. This fluctuating electric field can transfer to the F region along the geomagnetic field line thus generating the day-to-day variation of ionization (Chen, 1992). The QBO signature appears to be stronger in the ionosphere in spring and autumn (Chen, 1992; Keckhut and Chanin,1989).

Chen studied Okinawa, as well as Yamagawa (geomagnetic coordinates: 20.6°N, 199.1°E) and Kokobunji (geomagnetic coordinates: 25.7°N, 206.7°E). Yamagawa is located somewhat further away from the crest of the equatorial ionization anomaly, and the synchronization with MMZW is not as good as Okinawa. Kokobunji is much further away, and the synchronization is poor (Chen, 1992).

We study the association between foF2var data for three ionospheric stations and MMZW. One station in high latitude beyond the equatorial anomaly is Slough (51°N, 0.6°W; geom.: 54°N, 84.4°E); one at the magnetic equator (where the dynamo effect is dominant) is Huancayo (12°S, 75°W; geom.: 0.7°N, 355.2°E); and a third at the southern equatorial anomaly crest is Tucumán (27°S, 65°W; geom.: 15.6°S, 4.6°E).

DATA

Data of the monthly mean zonal wind, MMZW, at 40 mb, which is the concatenation of values at Canton Island (3°S, 172°W) for January 1957-August 1967, Gan/Meldives (1°S, 73°E) for September 1967-December 1975, and Singapore (1°N, 104°E) for January 1976-December 1989 were used (data obtained from http://dss.ucar.edu/pub/atmospheric_indices/qbo_winds/naujokat). The concatenation of the wind data is discussed in a paper by Naujokat (1986). This wind data series is the same as that used by Chen (1992) to find the QBO effects on the ionosphere over Okinawa.

Monthly hourly foF2 data of March, from 12 to 19 LT, of Tucumán (1958-1987), Huancayo (1957-1987) and Slough (1957-1989) were used to estimate foF2var. Since the foF2 distribution is not normal, the variance for each hour of the day was estimated as the difference between the upper and the lower quartile of all the daily values of the month. Depending on the year, the maximum variance appears between 12 and 19 LT. We used the same methodology as Chen (1992) to estimate the mean variance, foF2var*: the average of foF2var values between 12 and 19 LT, excluded the two maximum and two minimum values.

DATA ANALYSIS

In Figures 1 a, b and c the time behavior of MMZW and foF2var* for the three stations here analyzed, and high frequency oscillations in foF2var* can be seen. The spectral analysis confirm the presence of high frequency periodicities, being 2.8, 3.3 and 2.5 years for Tucumán, Huancayo and Slough, respectively (Figure 2). The amplitude of the high frequency oscillation, with respect to that of the 11 year oscillation, is greater for Tucumán, almost equal for Huancayo and lower for Slough. These high frequency oscillations do not follow the QBO in MMZW, as indicated by the correlation coefficients between foF2var* and MMZW which are 0.05, 0.16 and 0.20 for Tucumán, Huancayo, and Slough, respectively.

DISCUSSION AND CONCLUSION

For this study three stations were selected: one located in the southern crest of the equatorial anomaly (Tucumán), expecting a similar behavior to that observed in Okinawa by Chen (1992); a station located near the magnetic equator (Huancayo), where the dynamo effect is originated expecting that the day-to-day variability of the electric field also modulates the ionosphere of the region; and a high latitude station (Slough), out of the influence of the equatorial anomaly, expecting not to find any high frequency oscillation.

As the zonal wind presents longitudinal symmetry (Baldwin *et al.*, 2001), the concatenation of MMZW data used here, can be compared with ionospheric data from stations located at different longitudes. Although the geographical distribution of foF2 is characterized by a marked geomagnetic control (Davies, 1965), we expect that foF2var* reflects the QBO behavior, despite the data correspond to stations of different longitude.

Our results cannot confirm the modulation of the foF2 variability by MMZW found by Chen (1992) for the northern crest of the equatorial anomaly (Okinawa). The correlation coefficients between foF2var* and MMZW are low for all the stations here analyzed, even for that located at the southern crest of the equatorial ionization anomaly.

However, foF2var of Tucumán and MMZW are in phase for the period 1958-1968, being r = 0.67. This behavior changes from 1968 when the westerly wind intensity decreases to about 10 m/s (≅ 65%). Although the westerly wind

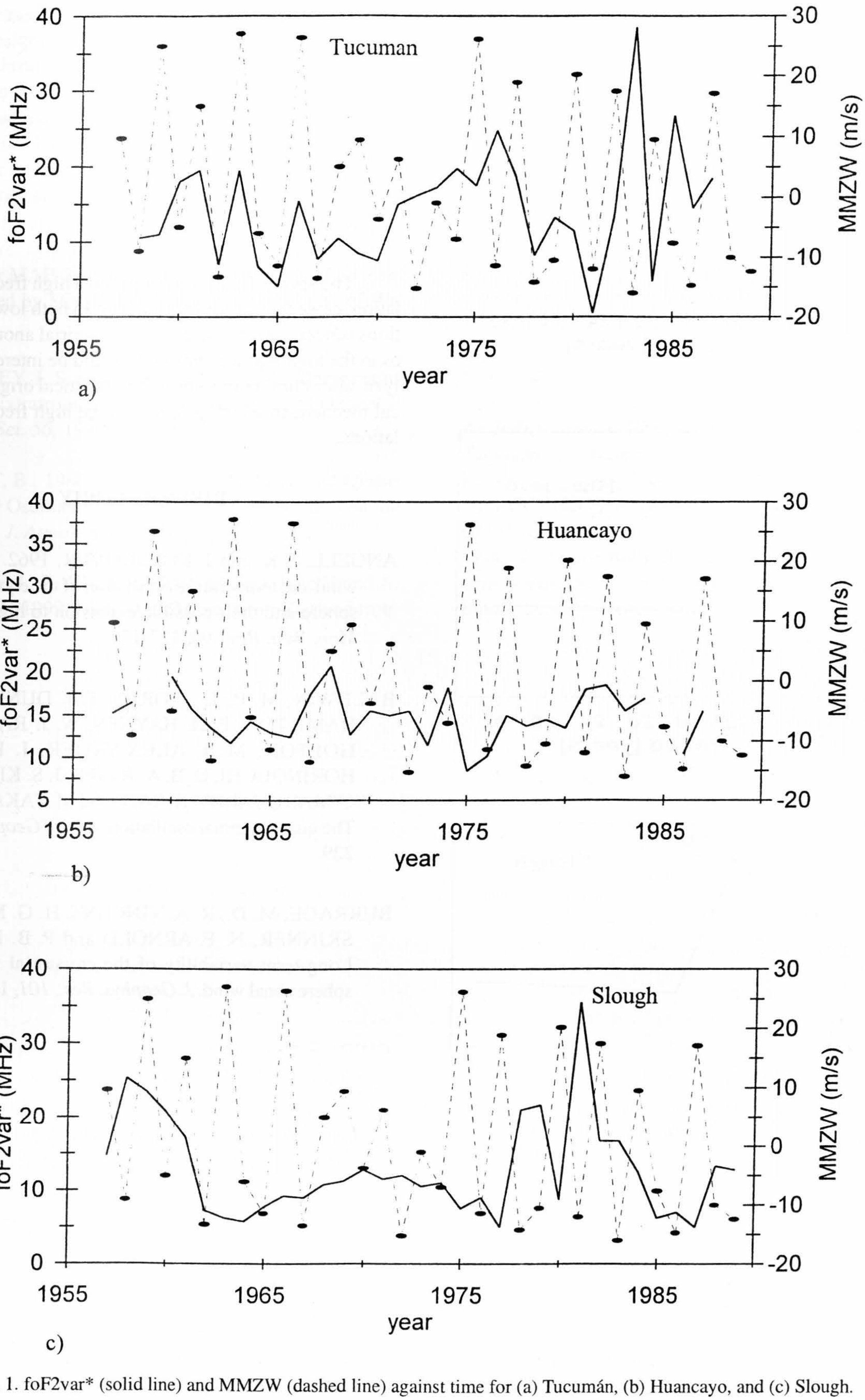

Fig. 1. foF2var* (solid line) and MMZW (dashed line) against time for (a) Tucumán, (b) Huancayo, and (c) Slough.

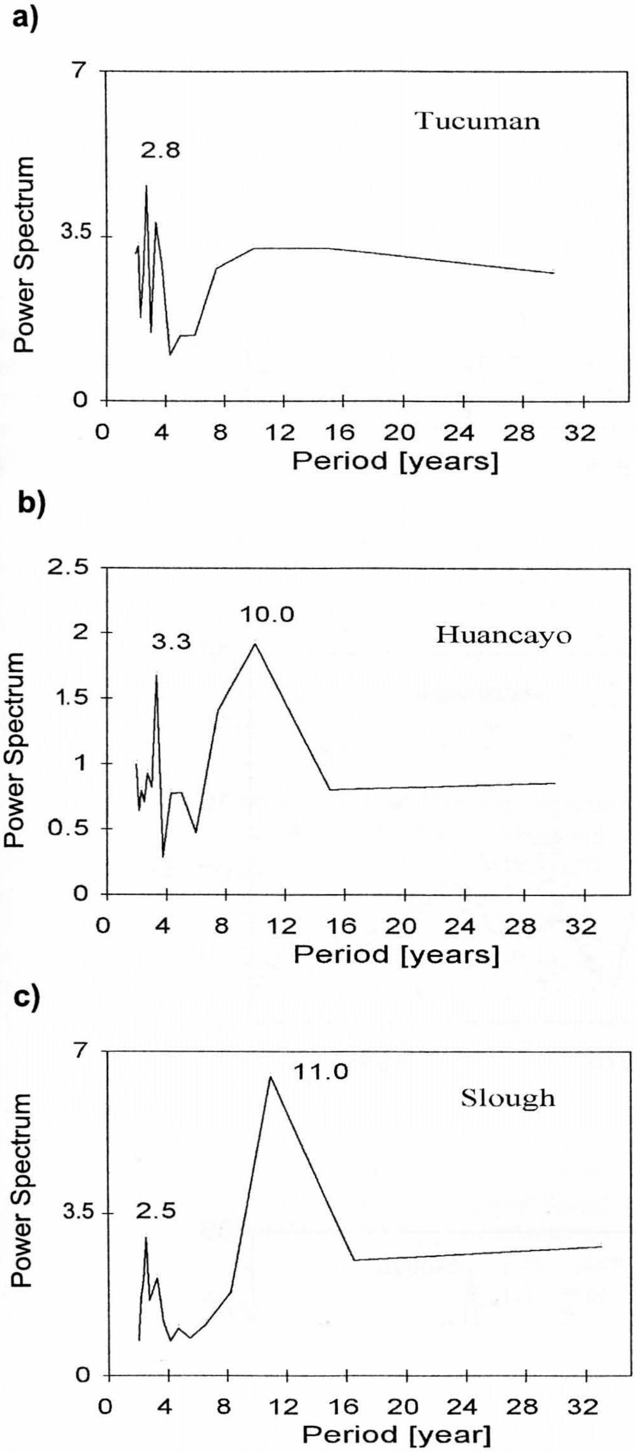

Fig. 2. Power spectrum for (a) Tucumán, (b) Huancayo, and (c) Slough.

intensity is again about 30 m/s from 1975, the correlation between fof2var and MMZW is low. Since we assume that the wind data series is well concatenated (Naujokat, 1986), we think that the cause of the unadjusment is not the changes in the stations' location.

We do not rule out completely the possibility that the QBO of MMZW modulates the ionosphere at the crests of the equatorial anomaly although for the complete data series of Tucumán the correlation is low. The correlation coefficient for the northern crest of the equatorial ionization anomaly is of the same order as for Tucumán when only the period 1958-1968 is considered (r around 0.65). This fact lead us to think that the results for Okinawa are not just a coincidence, and to look for an explanation about the lost of correlation for Tucumán after 1968.

The spectral analysis points out a high frequency oscillation, close to the QBO periodicity, in both low latitude stations (under the influence of the equatorial anomaly) as well as in the high latitude station. It would be interesting to analyze, after eliminating a possible statistical origin, the physical mechanism which produces these high frequency oscillations.

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