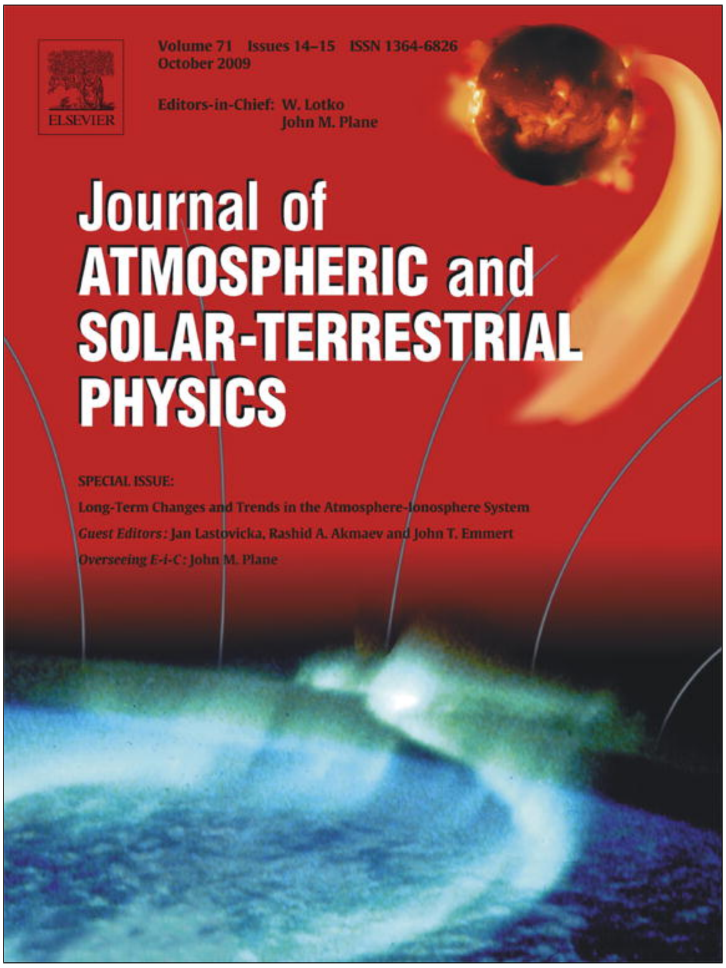
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Quasi-biennial oscillation in foF2 at the south crest of the equatorial anomaly

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ABSTRACT

The aim of this paper is to report some periodicities observed in the ionospheric parameter foF2 measured at Tucuman (26.9°S; 65.4°W), station placed near the southern crest of the equatorial anomaly. For that, monthly medians of foF2 at several hours of LT for the period 1958–1987 are used. The data are run with Fast Fourier Transform (FFT). Data gaps (~4–5 months) are filled by means of linear interpolation. Several periodicities are present. Besides the solar cycle dominant dependence (~11 years), semi-annual, annual, five years and quasi-biennial periodicities are also observed. A marked quasi-biennial periodicity is observed at daytime and nighttime hours being their greater amplitude at local noon and midnight. Different mechanisms or combined effects possibly cause them. It is suggested that the solar activity by means of extreme ultraviolet radiation (EUV), which present a quasi-biennial oscillation (QBO) and it is responsible for the ionization, could be the dominant mechanism for the diurnal quasi-biennial periodicity of foF2. At night, since the photoionization by extreme ultraviolet radiation is not significant and the F2 layer is lower than during daytime (~100 km) other mechanism may be operative for the quasi-biennial periodicity observed. Possibly the stratospheric QBO contributes to the modulation of the observed behaviour in foF2 at night. This result is preliminary because it needs to be extended to other stations so as to extract definite conclusions. Moreover, we cannot dismiss the possibility of a combined effect of both these mechanisms mainly at daytime and/or QBO influence of geomagnetic parameters.

1. Introduction

It is well known that some ionospheric parameters, such as the critical frequency of the F2 layer foF2, present variations on a wide range of time-scales: daily, day-to-day, month-to-month (seasonal), year-to-year (annual), solar cycle and long-term. These variations are mainly "solar-controlled", but the F2 layer is particularly influenced by the global thermospheric circulation. Thus, the solar zenith angle dependence causes the diurnal, annual and semi-annual variations on the ionosphere and on the solar photon radiation, which ionizes the major atmospheric constituents that varies with the 11-year solar cycle, with the quasi-27-day rotation of the sun, and perhaps even on a day-to-day basis (Forbes et al., 2000).

Moreover a quasi-biennial oscillation (QBO) has been found in several solar-terrestrial parameters. Zonal winds in the equatorial stratosphere (~16–50 km) show a very well-defined QBO, and is easily seen as downward propagating easterly and westerly wind regimes with an average period of 28 months. Although, QBO is a tropical phenomenon, it affects the stratospheric flow from pole to pole by modulating the effects of extratropical waves (for details see Baldwin et al. (2001) and references therein).

In particular, the presence of the QBO in the ionospheric parameter foF2 was investigated and their existence has been observed at different latitudes (e.g., Chen, 1992; Kane, 1995; Echer, 2007). Nevertheless, no conclusive result about if the cause of this variation is related to the solar–geomagnetic QBO, to the stratospheric QBO or to both has been found yet (Echer, 2007).

Thus, the aim of this paper is to report some periodicities observed in the ionospheric parameter foF2 measured at Tucuman (26.9°S; 65.4°W) near the southern peak of the equatorial anomaly, with particular emphasis in showing the QBO signal.

2. Results

The ionospheric station Tucuman is particularly interesting for its location, near the southern peak of the equatorial anomaly (geographical coordinates: 26.9°S, 65.4°W; magnetic coordinates: 15.5°S, 003.8°E). The first ionosonde was a vertical sounder conventional valve sweeping with a range of frequencies from 1 to 30 MHz. The ionograms were photographically recorded and

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manually scaled. It was operative between January 1958 and July 1987. Recently, at the end of August 2007 an Advanced Ionospheric Sounder (AIS), built at the Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy, was installed at Tucuman. That ionosonde is equipped with Autoscala, a software able to perform an automatic scaling of the ionograms.

In this paper, we consider only the monthly medians of foF2 for the period 1958–1987 (~3 solar cycles) at several hours of the day (00, 06, 12 and 18 h of LT).

The data were run with the Fast Fourier Transform (FFT). Data gaps (~4–5 months) were filled by means of linear interpolation. Figs. 1–4 show the FFT at 06, 12, 18 and 00 LT, respectively. Besides the solar cycle (~11 years) dominant dependence, semi-annual, annual, 5-year and quasi-biennial periodicities can also be observed. In comparison, the amplitudes of the beat periods associated with about 2-year are relatively greater than that about 3-year at 12, 18 and 00 LT (Figs. 1, 2 and 4), being the greater amplitude at local noon and midnight. That indicates the presence of a QBO signal in the ionosphere over Tucuman. But these figures show that these beat periods also appear in other features of the spectrum, and there they are larger in amplitude, such as 0.5 year (seasonal variation).

Among a variety of techniques available for analysing geophysical processes, wavelet analysis has emerged in the last decade as a useful statistical tool for this purpose. Thus, in order to see the QBO signal in foF2 during the considered period the monthly medians of foF2 were filtered out through the discrete wavelet analysis (DWT) using the Wavelet Toolbox for Matlab. We used the Daubechies function (see e.g., Kumar and Foufoula-Georgiou (1997) and Zossi de Artigas et al. (2006) for more details on this

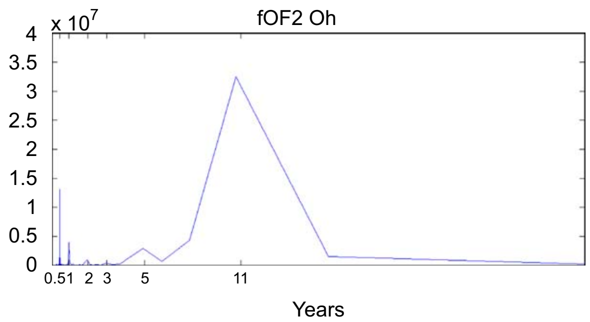

Fig. 1. Fast Fourier Transform for the monthly medians of foF2 at 00 LT (period 1958–1987).

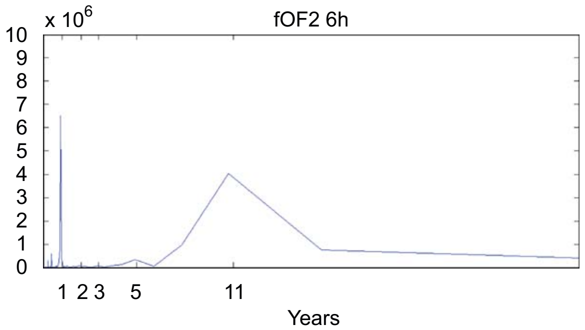

Fig. 2. Same as Fig. 1, but at 06 LT.

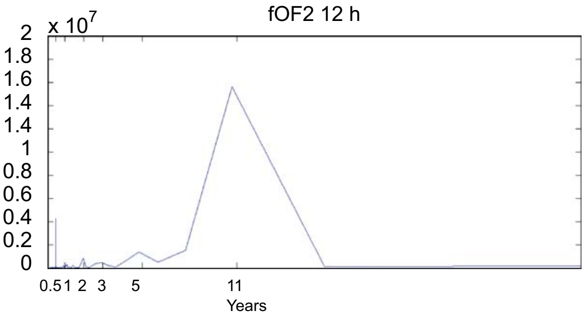

Fig. 3. Same as Fig. 1, but at 12 LT.

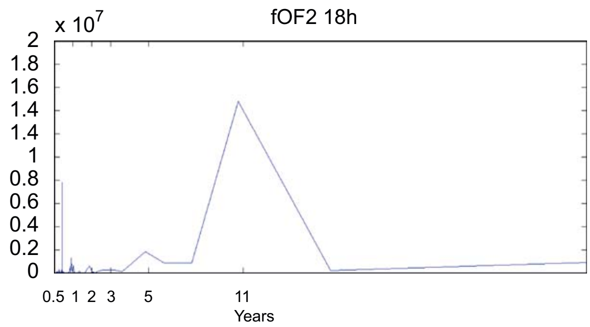

Fig. 4. Same as Fig. 1, but at 18 LT.

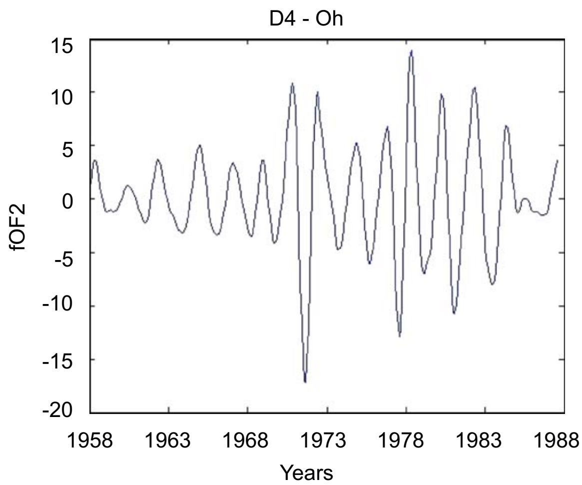

Fig. 5. Level D4 of the wavelet multi-resolution analysis for the monthly medians of foF2 at 00 LT (period 1958–1987).

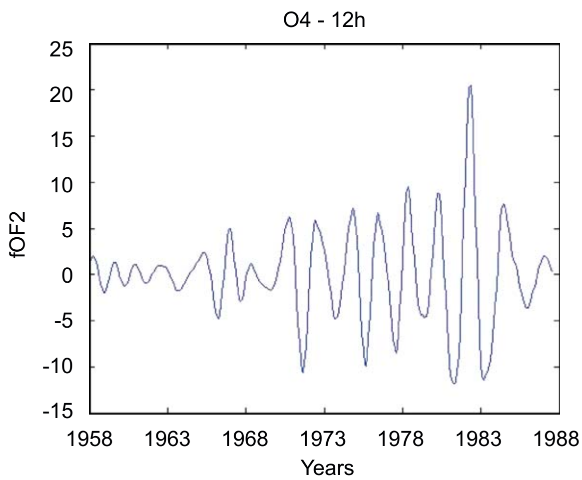

Fig. 6. Same as Fig. 5, but at 12 LT.

method). Figs. 5 and 6 depict level D4 which corresponds to the QBO signal at 00 and 12 LT. It can be seen clearly that a QBO-like signal is present in both these figures. No oscillation amplitude dependence with the solar cycle can be seen as was observed with sunspot numbers, which suggests that solar control is not the sole mechanism that produces the ionospheric variability in foF2.

3. Discussion and conclusions

This paper is concerned to show that the QBO signal is present in the ionospheric parameter foF2 over Tucuman, located near the southern crest of the equatorial anomaly. This is important because not all the low-latitude ionospheric stations show the presence of the QBO signal (see e.g., Echer, 2007).

The significant semi-annual periodicity observed is possibly due to the winter and/or equinox (higher values of foF2 during the equinoxes) anomalies, which are characteristic for the ionosphere over Tucuman (Mansilla et al., 2005).

The quasi-biennial periodicity in foF2 is observed at daytime and nighttime hours being their greater amplitude at local noon and midnight.

Possibly different mechanisms or combined effects cause that QBO. It is suggested that the solar activity by means of extreme ultraviolet (EUV) radiation, which present a QBO and it is responsible for the F layer ionization, could be the dominant mechanism for the diurnal quasi-biennial periodicity observed in foF2. As at daytime the plasma moves up at greater heights, foF2 is possibly less affected by a modulation of stratospheric origin. At night, the photoionization by extreme ultraviolet radiation is not significant and the F2 layer is lower than during daytime (of the order of about 100 km). Thus, other mechanism could also be operative for the observed quasi-biennial periodicity.

It is known that zonal winds in the equatorial stratosphere show a predominant QBO. Although this is a tropical phenomenon, it affects the stratospheric flow from pole to pole by modulating the effects of extratropical waves.

The responsible mechanism for the stratospheric QBO seems to be gravity waves convectively generated in the troposphere and propagating upwards, which drive the zonal winds in the tropical stratosphere (e.g., Lindzen and Holton, 1968; Holton and Lindzen, 1972; Shepherd, 2000). Moreover, the period and amplitude of the QBO are affected by the seasonal cycle of solar forcing (Mayr et al., 2003).

It was found that the relative sunspot numbers show a quasi-biennial oscillation. From the beginning of the solar cycle, the oscillation amplitude continuously increases, reaches its maximum value in the solar cycle maximum, and decreases in the declining phase reaching its minimum at the end of the solar cycle (Apostolov, 1985). As was mentioned, the ionospheric variability presents a strong solar control, so the quasi-biennial oscillation in solar activity would generate a similar variation in the ionospheric parameters. The fact that no clear (or significant) correlation between the quasi-biennial signal in foF2 with the solar cycle quasi-biennial oscillation at the end of the solar cycle is noted, it seems to indicate that another mechanism contributes to cause the foF2 variability.

Although in general the quasi-biennial oscillation in solar activity may be the predominant mechanism for the periodic fluctuation in foF2, possibly the stratospheric QBO contributes and/or promotes the modulation of the observed behaviour at daytime and also mainly at night since the F layer is closer to the stratosphere. Thus, the presence of QBO signatures in the ionosphere suggests a possible dynamical coupling between the lower and upper atmosphere through attenuated gravity waves propagating upwards.

This result is preliminary since it needs to be extended to other stations as to extract definite conclusions about the presence of the QBO signal in ionospheric parameters, mainly foF2. Different local times should be analyzed. Moreover, we cannot dismiss the possibility of a combined effect of both mechanisms suggested here (QBO in EUV and a dynamical coupling to the stratosphere) and also the influence of geomagnetic parameters which also present a QBO.

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