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Solar cycle and seasonal behaviour of quasi-two- and five-day oscillations in the time variations of f_0F2

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Abstract

Seasonal and solar cycle variations of the quasi-two- and five-day oscillation amplitudes of f_0F2 are evaluated by moving periodogram analysis. The 23 year time series (1964-1986) of f_0F2 hourly values of Kaliningrad (54.7°N, 20.62°E), covering the solar cycles 20 and 21, is used for the analysis. Long term variations of these amplitudes are modulated by the 11-year solar cycle and are simultaneously influenced by the geomagnetic activity. The annual variation of the quasi-two- and five-day oscillation amplitudes has very clear maxima near the equinoxes. The mechanism of the influence of the travelling planetary waves in the meteor wind region by vertical plasma drift to the $F2$-layer electron density maximum is discussed.

Key words *quasi-2 and 5-day oscillations – upper ionosphere – planetary waves*

1. Introduction

Wind measurements in the lower thermosphere from meteor radar observations indicate the existence of «planetary waves» with periods greater than 1 day and lower than 1 month (Muller, 1972). Subsequent observations of the meteor wind and temperature structure in the upper stratosphere, mesosphere and lower thermosphere show the presence of intensive quasi-two-day wave with large amplitude in the summer hemisphere (Kalchenko, 1979; Bulgakov, 1973; Glass *et al.*, 1975; Muller and Nelson, 1978; Craig *et al.*, 1980; Salby and Roper, 1980; Craig and Elford, 1981). Satellite radiance observations of the upper stratosphere and mesosphere give a global wave structure of the quasi-two-day temperature wave with wave number 3 and westward prevailing direction of the zonal propagation (Rogers and Prata, 1981). This result coincides with results obtained by the ground measurements of phase lags of the wind oscillations (Glass *et al.*, 1975; Muller and Nelson, 1978; Craig *et al.*, 1980). At low latitudes the zonal wind component has a weak amplitude while it can be greater than the meridional one at higher latitudes (Kalchenko, 1979; Bulgakov, 1973; Muller and Nelson, 1978; Craig and Elford, 1981). The amplitude of the quasi-two-day variation in the southern summer hemisphere is twice that of the northern one in the meridional wind (Craig and Elford, 1981) and in the temperature (Rogers and Prata, 1981). In the equatorial regions, a cross-equatorial leakage of the wave from summer to winter hemisphere has been suggested (Craig *et al.*, 1983). Typical wave periods are 51 h for the northern hemisphere (Muller, 1972; Glass *et al.*, 1975; Muller and Nelson, 1978; Salby

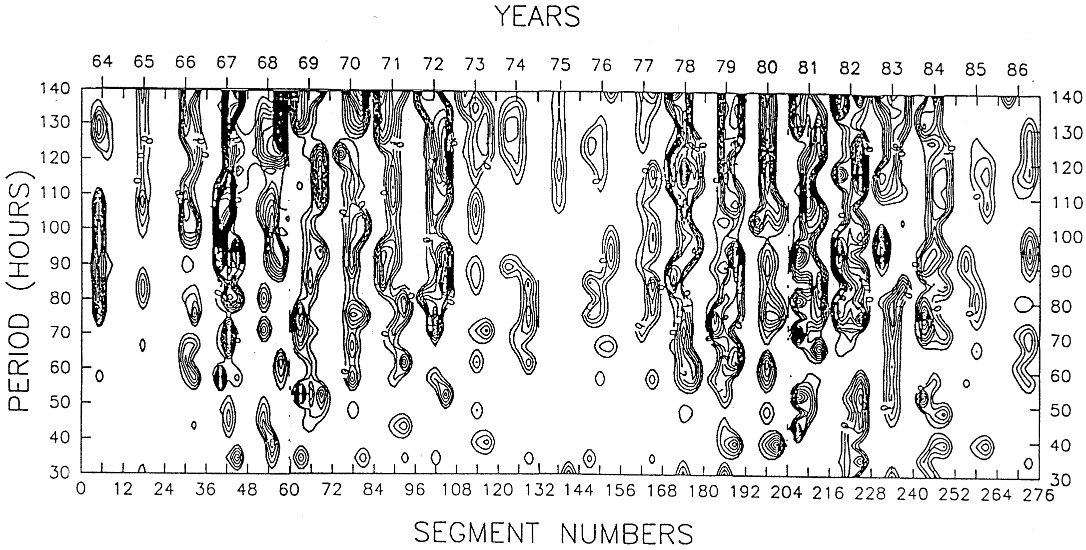

Fig. 1. Topographic map of the amplitude surface as a function of segment number and period in the periodic range 30-140 h for f_0F2 variations for the period 1964-1986 (solar cycles 20 and 21). Each segment has a length of 720 h.

and Roper, 1980) and 48-49 h for the southern hemisphere (Craig *et al.*, 1980; Craig and Elford, 1981).

Quasi-two-day temperature oscillations have maximum amplitudes in the mesosphere. Wind oscillations amplitudes are near constant in the lower thermosphere.

Investigations, referred to above, suggest prevailing maximum amplitudes to occur very close to the summer solstice and very weak amplitudes to happen near winter solstice for the northern hemisphere. In the southern hemisphere an inverse situation takes place. Salby and Roper (1980) note that the quasi-two-day wind amplitudes have minimum values in summer and maximum values in autumn.

A possible connection of quasi-two-day oscillations with the quasi-five-day oscillations in the meteor wind has been suggested (Muller and Nelson, 1978). The quasi-five-day oscillation has a westward propagation with a zonal wave-number 1.

Quasi-two-day oscillations have been detected in the electron concentration of the ionospheric *D*-region and in the upper ionosphere (Pancheva *et al.*, 1981; Pancheva and Lysenko, 1988; Pancheva *et al.*, 1991); their connection with analogous variations in the meteor region has been shown. Pancheva and Lysenko (1988) discuss two possible mechanisms to explain the quasi-two-day oscillations in the upper ionosphere electron concentration: 1) change of the neutral composition of the upper atmosphere by change of the dynamic regime at turbopause altitudes, and 2) change of the electron density by vertical plasma drift, generated by electric fields caused by the atmospheric dynamo effect (Ito *et al.*, 1986).

All these investigations concerning the influence of the planetary quasi-two-day oscillation on the lower and upper ionosphere utilize data of short time intervals, located near periods of intense quasi-two-day oscillation in the meteor winds, during summer.

The autocorrelation analysis and band-pass filtering (Apostolov *et al.*, 1993) and analysis of possible modulation effects in the domain 2-6 days (Altadill, 1993) of f_0F2 variations show that the real variations with great occurrence, and possibly related to the analogous meteor wind region variations, have quasi-two-day (from 45 to 55 h period) and quasi-five-day (from 110 to 140 h periods).

The object of this investigation is the seasonal and solar cycle occurrence of quasi-two- and five-day oscillations of the electron density at the $F2$-layer maximum.

2. Data and analysis

Investigation of the quasi-two-day oscillation requires data with sufficient density and completeness. We use f_0F2 hourly values of Kaliningrad (54.7°N, 20.62°E) for the period 1964-1986, covering the whole solar cycles 20 (1964-1976) and 21 (1976-1986). Row data only, without filtering are used for the analysis.

There are not many gaps in the time series of the data. Missing values are evaluated by a linear interpolation between the data of the preceding and following days at the same hour. For the evaluation of the temporal changes of the amplitudes of the investigated quasi-periodic oscillations it is convenient to use the moving periodogram analysis. The full time series (1964-1986) is divided into the 276 time segments, each with length of 730 h. Consecutively for each segment the periodogram in the periodic range from 30 to 140 h by step of 0.2 h is obtained. The periodograms are calculated by the method of the correloperiodogram analysis (Vitinsky *et al.*, 1986) allowing for each given period to obtain the amplitude and the respective probability of the existence (confidence level).

For each segment only amplitudes of the given period having the confidence level (probability) greater than 0.9 are taken; for the rest of the cases we consider it be zero, *i.e.* in this case we analyse only the statistical significant periods.

In fig. 1, the topographic map of the amplitude surface as a function of segment number and period is presented for the period range 30-140 h. It is clear that for the whole interval of the two solar cycles there are statistically significant oscillations from 2 to 6 days, predominantly in the summer half-year.

In detail, the maximum amplitudes are in the years near maximum solar activity and in the first years of the falling part of the cycle. For most of the years the maximum amplitudes are near one or the two equinoxes. The latter fact is very surprising for the quasi-two-day oscillations, taking into account the results of Pancheva *et al.* (1981), Pancheva and Lysenko (1988), Pancheva *et al.* (1991) and the clearly expressed maximum of quasi-two-day oscillation in meteor wind near summer solstice. However, in the investigations on the availability of quasi-two-day oscillations in the electron density of the lower and upper ionosphere only cases when the same oscillation is well developed in the meteor wind during the summer months are analysed. Up till now an investigation of the annual variation of the quasi-two-day oscillation amplitudes of the electron density in the ionosphere has not been made.

For a more detailed evaluation of the annual and solar cycle variations of the quasi-two- and five-day oscillation amplitudes all amplitudes irrespective of their probabilities are analysed. For each segment we find, by maximalization, the maximum amplitudes separately for the regions of 45-55 h and 110-140 h with the respective confidence levels (probabilities). The results for monthly mean amplitudes of the quasi-two- and five-day oscillations and their probabilities for solar cycles 20 and 21 are given in fig. 2. All amplitudes are in 0.1 MHz. In the same figure monthly mean values of the geomagnetic index ***aa***, sunspot numbers ***Rz*** and solar radio flux at 2800 MHz ($F10.7$) are also given for comparison. For smoothing the annual variation of all parameters, the 13-month smoothed averages of monthly means with half weights of the first and last

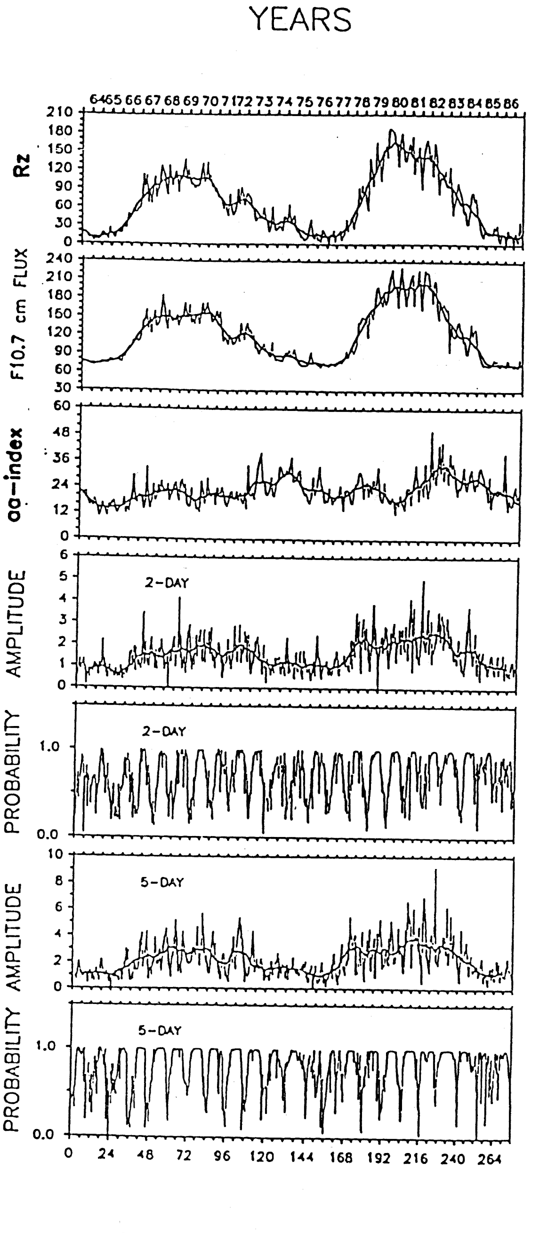

Fig. 2. Monthly mean amplitudes and probabilities of the quasi 2- and 5-day oscillations in f_0F2 for solar cycles 20 and 21 compared with monthly means of the geomagnetic index ***aa***, sunspot numbers ***Rz*** and solar radio flux at 2800 MHz.

months are calculated. The smoothing curves are presented by full lines in fig. 2.

The solar cycle dependence of the quasi-two- and five-day oscillation amplitudes is very complicated. The long-term variation of the quasi-two- and five-day amplitudes are modulated by the 11-year solar cycle variation. For solar cycle 20, with lower solar and geomagnetic activity than cycle 21, the quasi-two- and five-day amplitude variations (smoothed curves), especially the extrema, are very similar to those of the solar radio flux. The extrema of the solar cycle 21 nearly follow those of geomagnetic activity. For both solar cycles the coincidence with solar radio flux is better than the one with sunspot numbers.

It seems that there is a rival and combined influence of the ultraviolet radiation (*F*10.7 is a good indicator for UV-radiation) and of the geomagnetic activity. Probably, there is a definite level of geomagnetic activity above which the dominant influence of the geomagnetic field for the manifestation of these quasi-periodic oscillations begins.

We also obtained the annual mean variation of the quasi-two- and five-day oscillation amplitudes and respective confidence levels (probabilities) for the period 1964-1986 and separately for solar cycles 20 and 21 (fig. 3). The maximum amplitudes near equinoxes and maximum probabilities, greater than 0.9, in the summer half-year, centered in summer solstice, are very clearly expressed. Another important result of this analysis is that for the summer and winter solstice the quasi-two-day oscillation amplitudes are nearly equals. This indicates that the quasi-two-day oscillation has a continuous annual existence in spite of the very low confidence levels in the winter half-year.

A similar conclusion can be deduced for the quasi-five-day oscillation, for which, the amplitudes near the summer solstice are greater than that for the winter one.

The maximum amplitudes of the quasi-two- and five-day *F*2-region electron density oscillations near equinoxes show an important influence of the geomagnetic activity, since the semi-annual geomagnetic wave has

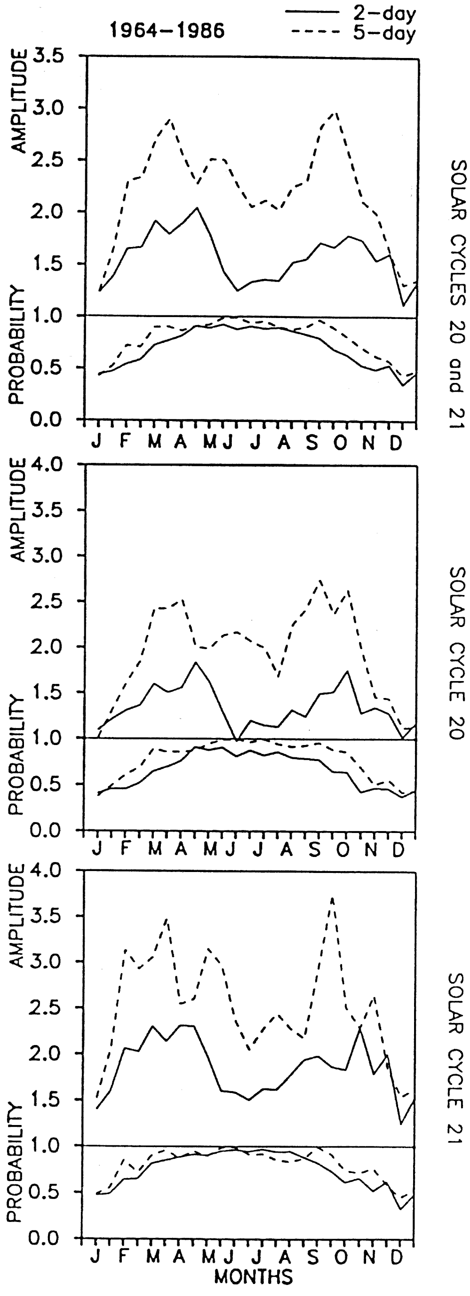

Fig. 3. Annual mean variation of the quasi 2- and 5-day oscillation amplitudes and probabilities of the f_0F2 for the period 1964-1986 and separately for solar cycles 20 and 21.

also equinox maxima. Pancheva and Lysenko (1988) propose a mechanism of vertical plasma drift as an explanation of the quasi-two-day oscillation in the electron density variation in the $F2$-region. The results presented here support this mechanism. First, the maximum amplitudes and probabilities of the quasi-two- and five-day oscillations are in the summer half-year, when the maximum meteor wind amplitudes of such oscillations are observed. Second, the vertical plasma drift generated by electric fields driven by an atmospheric dynamo effect (Ito *et al.*, 1986) depends on the geomagnetic activity. *I.e.*, the vertical plasma drift caused by an electric current system, primary, determines the existence of the quasi-two- and five-day oscillations in the $F2$-region electron density maximum, and secondary, the increase of the geomagnetic activity in the equinoxes and in the years near maximum and part of falling portion of the solar cycles cause the additional increase of the amplitudes.

For the station Poiters (46.57°N, 0.35°E) for 1964-1986 and Rome (41.9°N, 12.5°E) for 1976-1986 similar results have been obtained.

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