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Quasi-five- and ten-day oscillations in f_0F_2 and their possible connection with oscillations at lower ionospheric heights

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Abstract
The statistical analysis of the 5-day and 10-day oscillations inferred in the upper and lower ionosphere in Central Europe from f_0F_2 measured in Průhonice and the radio wave absorption in the lower ionosphere shows a remarkable degree of similarity for relative amplitudes of oscillations (not for absolute amplitudes). The relative amplitudes in both regions do not express a significant solar cycle effect and their seasonal variation is also similar except for winter. The typical relative amplitude of both 5- and 10-day oscillations in the F_2-region is about 4%, which is useful information for PRIME.

Key words *upper ionosphere – 5 and 10 day oscillations*

1. Introduction

One of the topics studied within PRIME are the planetary wave type oscillations in the F-region of the ionosphere in the period range of about 2-35 days (*e.g.*, Apostolov and Altadill, 1994). These studies show that at least sometimes such oscillations considerably affect the short-term variability of the F-region parameters. The mechanism of such effects is not known; the planetary wave modulation of upward propagating tides in the mesosphere or rather the lower thermosphere could play a role. Another possibility is a modulation of upward drifts at the same altitudes (Pancheva *et al.*, 1994).

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Planetary waves of periods around 5, 10 and 16 days are generally accepted to be the most important planetary waves in the middle atmosphere. The behaviour of quasi-five- and ten-day oscillations in the lower ionosphere over Europe has been extensively studied (*e.g.*, Laštovička, 1993; Laštovička *et al.*, 1994b). Also in the F_2-region, both over Europe and Southeastern Asia (*e.g.*, Apostolov *et al.*, 1994; Yi and Chen, 1993), the 5 and 10 day oscillations appear regularly in spectra as significant oscillations. Therefore, we will deal with these two periods, or strictly speaking, with periodic bands 4-6 and 9-11 days, since the above periods are quasi-periods with spectral peaks moving within these bands. We will study these oscillations in f_0F_2 and for comparison and partial explanation of the observed effects we will also use the results of radio wave absorption measurements in the lower ionosphere from the respective geographic area.

The purpose of the paper is to analyze the seasonal and solar cycle variations of amplitudes of quasi 5- and 10-day oscillations, to estimate typical absolute and relative values of these amplitudes and to contribute to clarifying the possible connection with similar oscillations in the lower ionosphere.

2. Data and method

We use f_0F_2 data from Průhonice (50°N, 15°E) over 1979-1989, and for some cases only over 1980-1988 due to data gaps and to the high occurrence rate of proton flares and strong magnetic storms in 1989. Two data sets of f_0F_2 are used: a) noon 10-14 UT median values; b) values at constant solar zenith angle $\chi = 75°$ (average from morning and evening values). The radio wave absorption data are also taken for Central Europe. We use the 6090 kHz absorption data measured at Panská Ves by the A3 method (oblique incidence on the ionosphere) at $\chi = 75°$ over the same period as f_0F_2. Characteristics of the 6090 radiopath: reflection point 50°N, 10.3°E, equivalent frequency 2.1-2.2 MHz.

The analysis is made by applying the correloperiodogram technique to consecutive 2-month long intervals for some first results. In order to have better resolution for analysis of seasonal variation, we use consecutive 1-month intervals for 5-day oscillation studies and 2-month intervals but shifted by 1 month relative to each other for 10-day oscillation studies (1 month contains only three 10-day waves, which is not enough for reliable determination of wave characteristics). In each interval we select maximum amplitudes in the 4-6 and 9-11 day bands and these data are then used as characteristics of oscillation strength in further analyses.

3. Seasonal variation

Figure 1 reveals different seasonal variations of the strength of oscillations in absorption and f_0F_2. While they are reasonably similar in the summer half of the year (March-September), they are strongly opposite in the late autumn-winter (November-January) for both 5- and 10-day oscillations, whose patterns

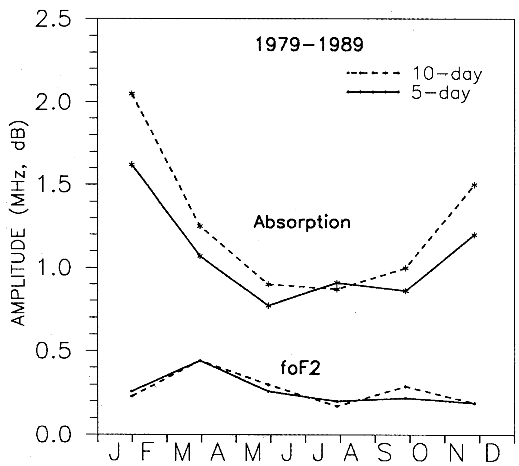

Fig. 1. Seasonal variation of the 5-day (full lines) and 10-day (dashed lines) wave amplitudes in absorption and f_0F_2, 1979-1989. Computed for consecutive 2-month intervals, noon f_0F_2 and absorption at $\chi = 75°$ (after Laštovička, 1995).

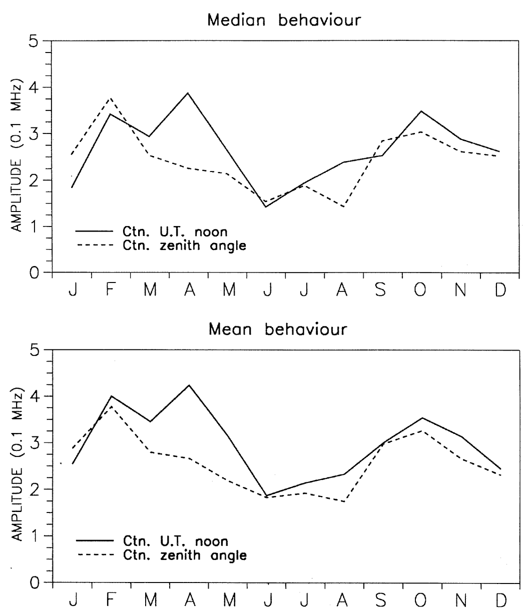

Fig. 2. Seasonal variation of amplitudes of the 5-day oscillation expressed in terms of mean and median values for f_0F_2 at noon (full line) and f_0F_2 at $\chi = 75°$ (dashed line). Computed for 1-month consecutive intervals.

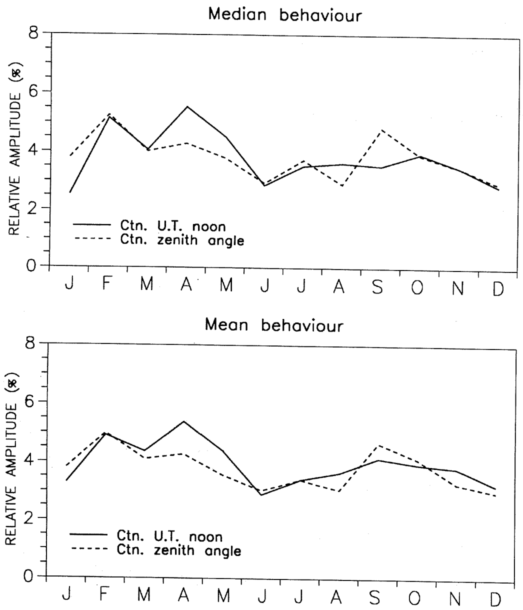

Fig. 3. The same as fig 2. but for amplitudes of oscillations divided by their absolute values, *i.e.* for relative amplitudes.

and strength do not differ much. These results are obtained for 2-month consecutive intervals. The difference between seasonal variations in f_0F_2 and absorption may be partially caused by the fact that noon f_0F_2 and absorption at $\chi = 75°$ are used, partly also by a different seasonal variation of absolute values of f_0F_2 and absorption.

In further analyses, 1-month consecutive intervals are used to calculating 5-day oscillations. Figure 2 shows the seasonal variation of the strength of 5-day oscillations expressed in terms of mean and median values for noon data and f_0F_2 at $\chi = 75°$. There are some rather minor differences between seasonal patterns based on mean and median values of f_0F_2. However, there is some difference between the seasonal pattern based on noon and that based on constant solar zenith angle. For χ = const. there is an evident shift of peak from April to February, *i.e.* compared with fig. 1 the only difference in the seasonal course of oscillations inferred from f_0F_2 and absorption at χ = const. consist in an opposite course in early winter (November-January); for the rest of the year there is a fairly good coincidence.

Figure 3 shows the same as fig. 2 but for amplitudes of oscillations divided by their absolute values, *i.e.* for relative amplitudes of oscillations in f_0F_2. The seasonal pattern provided by figs. 2 and 3 does not differ much. The main differences consist in a somewhat smaller magnitude of seasonal variation for relative amplitudes (*i.e.*, seasonal variation of absolute values of f_0F_2 to some extent contributed to the observed seasonal variation of amplitude oscillations), and in a very weak and smoothed variation in the second half of the year for noon values. Figure 3 allows us to estimate the relative amplitude of the 5-day oscillation. It is 4% on average with maximum equinoctial values (February-April) of about 5% and minimum summer values near 3%. Such an estimate is important for PRIME as an estimate of a typical possible inaccuracy introduced into short-term (days) predictions by neglecting such oscillations.

The seasonal variation of the relative amplitude of the 5-day oscillations for absorption in the lower ionosphere is plotted in fig. 4 and it

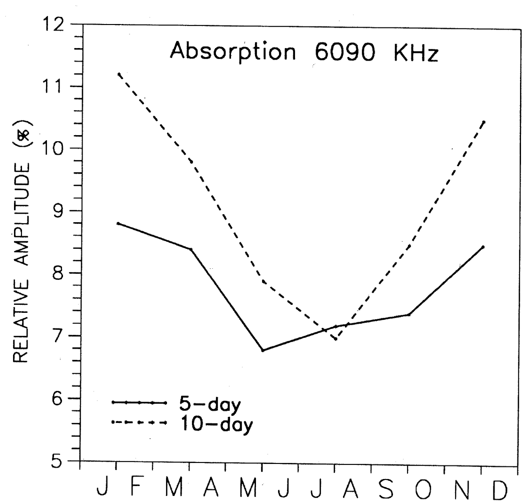

Fig. 4. Seasonal variation of relative amplitudes of the 5- and 10-day oscillations in absorption.

shape remains similar to the seasonal variation of absolute amplitude, but its magnitude becomes considerably smaller; instead of a factor ~2 for absolute amplitudes (fig. 1), the relative amplitudes increase only by a factor ~1.3%, from a summer minimum of 7% to a winter maximum of 9% (fig. 4). Thus, the contribution of seasonal variation of absolute values is significant.

In the case of 10-day oscillations, the 2-month long interval shifted by 1 month relative to each other are used in further analyses. Figure 5 shows the seasonal variation of the amplitude of 10-day oscillations expressed in terms of mean and median values for f_0F_2 at noon and at χ = 75°. The half-month shift of curves with respect to figs. 2 and 3 is due to the use of 2-month intervals centred on the last day of the given month, not in mid-month. There are some rather minor differences between seasonal patterns based on mean and median values of f_0F_2. However, there is some difference between the seasonal pattern based on noon values and that based on values at constant solar zenith angle. For χ = const. there is an evident shift of the peak from March to January-February and the seasonal variation in September-February is quite featureless. Compared with fig. 1, the only difference is in the seasonal course of magnitude of oscillations inferred from f_0F_2 and absorption at χ = const. consists in no seasonal variation in the F_2-layer in winter compared to strong winter peak in the lower ionosphere; for the rest of the year there is a fairly good coincidence.

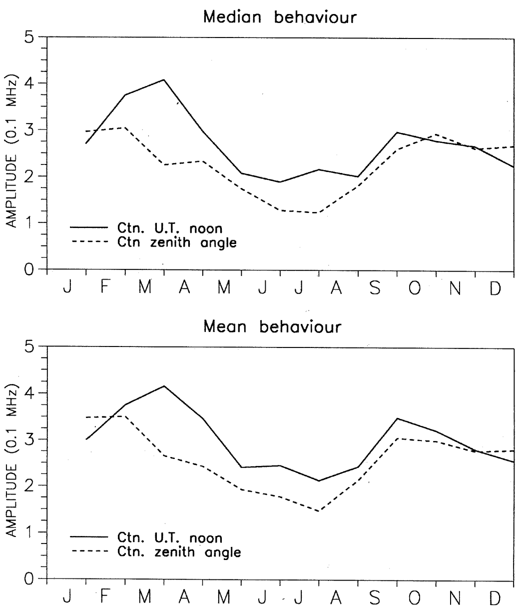

Fig. 5. Seasonal variation of amplitudes of the 10-day oscillations expressed in terms of mean and median values for f_0F_2 at noon (full line) and f_0F_2 at χ = 75° (dashed line). Computed for 2-month consecutive intervals shifted by 1 month relative to each other.

Figure 6 shows the same as fig. 5 but for relative amplitudes of oscillations in f_0F_2. The seasonal pattern provided by figs. 5 and 6 does not differ much. The main differences are in a smaller magnitude of seasonal variation for relative amplitudes, and in a very weak and smoothed variation in the second half of the year for noon values. Figure 6 allows the relative amplitude of the 10-day oscillation to be estimated. It is about 4% in average with a maximum in late winter/early spring of about 5% and a minimum in late summer with values near 3%. These values are roughly the same as those for the 5-day oscillation amplitude.

For absorption in the lower ionosphere, the shape of seasonal variation of the relative amplitude of the 10-day oscillation (fig. 4) remains similar but its magnitude becomes smaller – instead of a factor ~2 for absolute amplitudes (fig. 1), the relative amplitudes increase by a factor ~1.6 from a summer minimum of 7% to a winter maximum of 11% (fig. 4).

In summary, we can say that typical amplitudes of both oscillations are about 4% of absolute values of f_0F_2 changing seasonally from a late winter/early spring maximum of about 5% to a summer minimum of about 3%. Figure 1 shows that the amplitude of 10-day oscillations is slightly higher than of 5-day oscillations but the difference is rather marginal. The magnitude of seasonal variation (maximum/minimum) of relative amplitudes of oscillations in the F_2 region and in the lower ionosphere is comparable – a factor of about 1.6 for

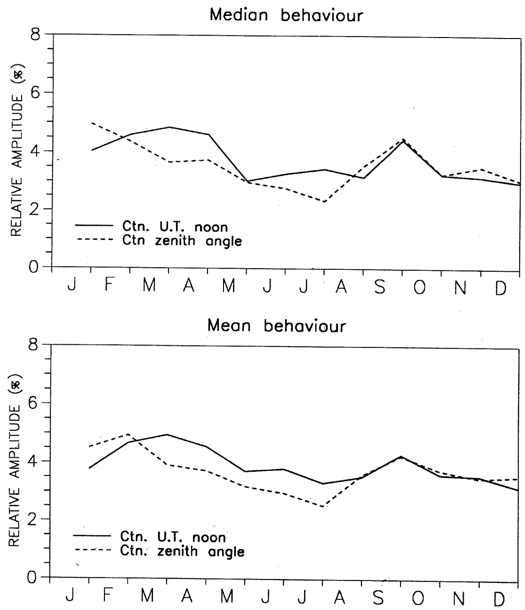

Fig. 6. The same as fig 5. but for amplitudes of oscillations divided by their absolute values, *i.e.* for relative amplitudes.

f_0F_2, factors of about 1.3 and 1.6 for absorption. Thus the different seasonal variations of absolute values of absorption and f_0F_2 considerably contributed to very different seasonal variations of oscillations shown in fig. 1. Another contribution to this difference is the use of noon values for f_0F_2 data versus constant zenith angle values for absorption data in fig. 1 – seasonal variations of oscillations in f_0F_2 for noon and χ = const. are to some extent different, and that for χ = const. is less distinct from that in absorption. A difference between seasonal variations of oscillations in the F_2-region and the lower ionosphere still persist in winter but the overall difference is remarkably smaller than that shown in fig. 1 and reported by Laštovička (1995).

4. Solar cycle effect

The long term amplitude variation of both oscillations in f_0F_2 seems to be modulated primarily by the 11-year solar cycle (*e.g.*, Apostolov *et al.*, 1994; Laštovička and Mlch, 1994), while there is practically no solar cycle variation of such oscillations in the lower ionosphere (*e.g.*, Laštovička, 1993), which represents another difference in the pattern of oscillations in the upper and lower ionosphere.

Figure 7 shows variations of amplitudes of 5-day oscillations over the period 1980-1989 separately for f_0F_2 at noon and at $\chi = 75°$. The noon and χ = const. curves display similar and already known solar cycle effects – much lower values at solar minimum (around 1986) than at solar maximum (1980-1982), the effect being slightly larger for noon values (factor > 2) than for χ = const. values (factor < 2). It should be noted that the solar cycle maximum was observed in essentially all solar parameters except for sunspot numbers just in 1981. Figure 7 also shows a quasi-persistent seasonal variation with summer minima.

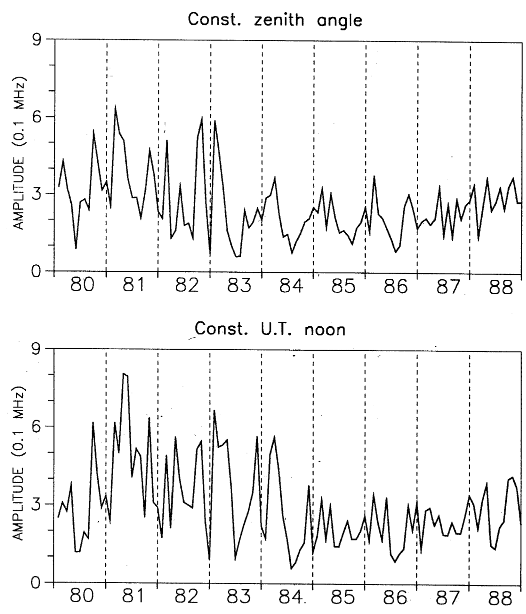

Fig. 7. Long-term (1980-1988) variation of amplitudes of the 5-day oscillations expressed in terms of mean and median values for f_0F_2 at noon (full line) and f_0F_2 at $\chi = 75°$ (dashed line). Computed for 1-month consecutive intervals.

For relative amplitudes, the pattern is quite different. Figure 8 does not exhibit any visible solar cycle effect in relative amplitudes of 5-day oscillations, which coincides with the result obtained for oscillations in absorption (*e.g.*, Laštovička, 1993). The characteristic value of the amplitudes of oscillations of 4% is confirmed, varying in individual months in the range of about 1%-8.5%.

A similar pattern of long-term variations of amplitudes for the 10-day oscillations is clearly visible in figs. 9 and 10. The solar cycle effect, which is more than a factor 2 in amplitudes of oscillations in fig. 9, disappears completely for relative amplitudes in fig. 10. The characteristic relative amplitude is again near 4%. Individual monthly relative amplitudes vary within the range of about 1.5%-10%.

Thus the strong solar cycle effect in amplitudes of oscillations in f_0F_2 is completely caused by the solar cycle variation of absolute values of f_0F_2.

In relative amplitudes of oscillations in f_0F_2 we do not see any detectable solar cycle effect, which cannot be seen in oscillations in absorp-

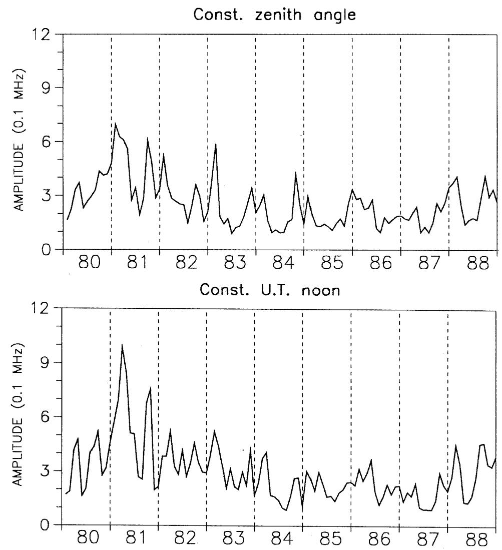

Fig. 9. Long-term (1980-1988) variation of amplitudes of the 10-day oscillations expressed in terms of mean and median values for f_0F_2 at noon (full line) and f_0F_2 at χ = 75° (dashed line). Computed for 2-month consecutive intervals shifted by 1 month relative to each other.

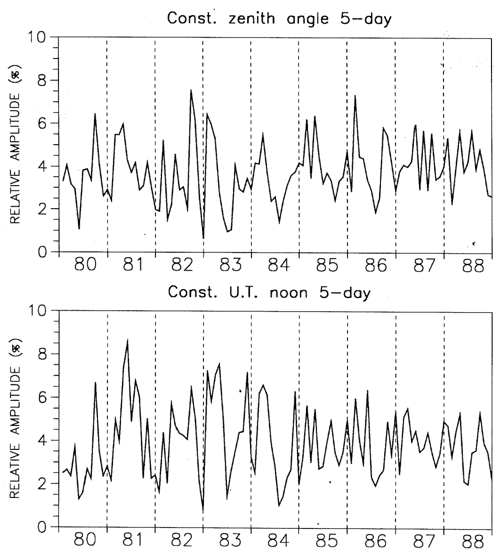

Fig. 8. The same as fig 7, but for amplitudes of oscillations divided by their absolute values, *i.e.* for relative amplitudes.

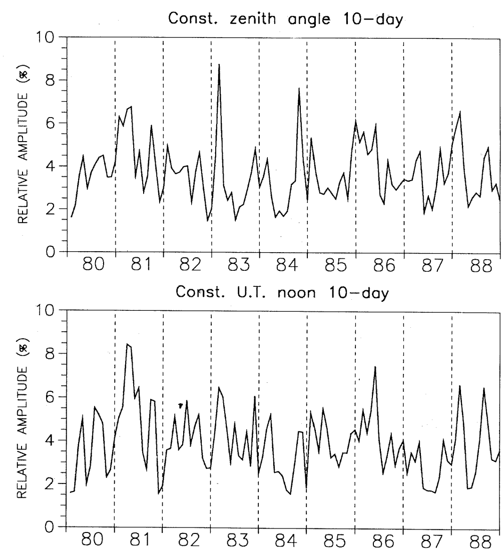

Fig. 10. The same as fig 9, but for amplitudes of oscillations divided by their absolute values, *i.e.* for relative amplitudes.

tion, either. Consequently, the solar cycle difference in the behaviour of oscillations in f_0F_2 and absorption in the lower ionosphere is explained and removed.

5. Discussion

Project PRIME requires estimates of amplitudes of oscillations as a source of possible uncertainty in predictions of the state of the ionosphere and conditions of radio wave propagation. Thus the typical amplitude of 4% as well as its seasonal course (maximum late winter/early spring of 5%, summer minimum of 3%), and range of monthly values of amplitudes, 1%-8.5% and 1.5%-10% for 5- and 10-day oscillations respectively, give useful information for the PRIME project.

It is of some interest to transform the amplitudes of the above oscillations into amplitudes of oscillations in electron density. Since $N_e \sim (f_0F_2)^2$, the 4% amplitude in f_0F_2 means an 8% amplitude in N_e at an altitude of the F_2-region maximum. The typical amplitude of oscillations in absorption is about 8%-9% (fig. 4). According to model calculations of Laštovička *et al.* (1994a), the 8% amplitude in absorption means about 10%-11% in N_e in the upper part of the lower ionosphere. Thus, the amplitudes of oscillations in the electron density in the upper and lower ionosphere appear to be comparable. Since atmospheric density is much lower at F_2-region heights than in the lower thermosphere and since the oscillations are expected to be caused by respective oscillations in the neutral atmosphere, it means that only a small fraction of planetary wave energy from the lower thermosphere reaches the F_2-region heights.

What might be the mechanism of the upward propagation of planetary wave forcing from the lower thermosphere to the F_2-region maximum height? According to both experimental data and model calculations (*e.g.*, Pancheva *et al.*, 1989; Laštovička *et al.*, 1994a), both 5- and 10-day oscillations in the lower ionosphere are caused by planetary waves propagating from below, which are mainly of tropospheric origin. This also accounts for the seasonal variation of amplitudes of oscillations in the lower ionosphere with winter maximum due to much easier winter propagation of planetary waves through the stratosphere.

The similar predominant periods of oscillations found in this paper, by Laštovička (1995) and by other authors, a similarly absent solar cycle effect in relative amplitudes of oscillations and except for winter a similar shape and magnitude of seasonal variation, indicate that the 5- and 10-day oscillations in both the upper and lower ionosphere are probably of common origin. According to various model estimates, planetary waves are unable to propagate (either at all or with sufficient efficiency) to the F_2-region maximum heights. Pancheva *et al.* (1994) consider two possible mechanisms to explain similar two-day oscillations in the lower and upper ionosphere: a) a generation of oscillations in the F-region vertical plasma drift by the ionospheric dynamo due to the influence of planetary waves in the lower thermosphere on the dynamo; b) a change in the neutral composition in the thermosphere due to changes of the mean vertical velocity near the turbopause. Teitelbaum *et al.* (1994) try to explain the QBO at F-region heights by an indirect upward propagation via modulation of tides. Such a mechanism might contribute to the upward propagation of planetary wave type oscillations as well. Nevertheless, the physical mechanism of the upward propagation of 5- and 10-day oscillations from the upper middle atmosphere remains an open question.

6. Conclusions

The above analysis of f_0F_2 from Průhonice and the radio wave absorption in the lower ionosphere in Central Europe allows us to draw the following conclusions concerning ~5- and ~10-day oscillations:

1) The typical relative amplitude of oscillations in f_0F_2 of 4% as well as its seasonal course (maximum late winter/early spring of 5%, summer minimum of 3%), and range of monthly values of amplitudes, 1%-8.5% and 1.5%-10% for 5- and 10-day oscillations, re-

spectively, represent a useful outcome of this paper for the PRIME project. The amplitude of 10-day oscillations is slightly higher than that of 5-day oscillations but the difference is marginal.

2) The magnitude of seasonal variation (maximum/minimum) of relative amplitudes of oscillations in the F_2 region and in the lower ionosphere is comparable by a factor of about 1.6 for f_0F_2, and factors of about 1.3 and 1.6 for absorption. The different seasonal variation of absolute values of absorption and f_0F_2 and to some extent the use of noon f_0F_2 instead of that at $\chi = 75°$ considerably contributed to the very different seasonal variations of oscillations shown in fig. 1. A difference between seasonal variations of oscillations in the F_2-region and the lower ionosphere still remains in winter but the overall difference is remarkably smaller than that shown in fig. 1 and reported by Laštovička (1995).

3) The strong solar cycle effect in amplitudes of oscillations in f_0F_2 is completely caused by the solar cycle variation of absolute values of f_0F_2. In relative amplitudes of oscillations in f_0F_2 we do not see any detectable solar cycle effect, which cannot be seen in oscillations in absorption either.

The physical mechanism of the upward propagation of the 5- and 10-day oscillations from the upper middle atmosphere to the F_2-region remains an open question. In future, it will be necessary to repeat such an investigation of oscillations with data from several other European stations to cover the PRIME area, and to search for mechanisms.

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