Solar cycle effect on oscillations in the period range of 2-20 days in the *F* region of the ionosphere

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Abstract
The results of Laštovička and Mlch (1994) and Altadill and Laštovička (1996) are extended by the use of f_0F_2 and $h'F$ data from Juliusruh, Lannion and Rome. There is a strong solar cycle effect in amplitudes of oscillations in f_0F_2 but none or a weak solar cycle effect in relative amplitudes of oscillations in f_0F_2 and in amplitudes of oscillations in $h'F$. The conditions when the planetary wave type oscillations should be taken into account in short-term predictions and when, on the other hand, they need not be taken into account, are partly specified.

Key words *ionosphere – planetary waves – solar cycle*

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 2-20 days. They have been observed in Europe (*e.g.*, Apostolov *et al.*, 1994; Laštovička and Mlch, 1994; Altadill and Laštovička, 1996) as well as in South-Eastern Asia (Yi and Chen, 1993). These studies show that at least sometimes such oscillations can considerably affect the short-term variability of the F-region parameters. Laštovička and Mlch (1994) and Altadill and Laštovička (1996) used only f_0F_2 from Průhonice over 1979-1989. Here we extend these investigations by the use of f_0F_2 and $h'F$ from Juliusruh, Lannion and Rome for the same period to obtain a rough cover of the PRIME area. The main goal is to check the Průhonice result on a very significant effect of the solar cycle on the magnitude and importance of the planetary wave type oscillations in f_0F_2 (Laštovička and Mlch, 1994) and, on other hand, no solar cycle effect in relative amplitudes ($\Delta f_0F_2/f_0F_2$) found by Altadill and Laštovička (1996), which means that the solar cycle effects in amplitudes of planetary wave type oscillations are caused by solar cycle changes of f_0F_2 itself without a significant change in planetary wave type forcing.

We performed the analysis for dominant upper middle atmospheric planetary waves of periods ~ 5 (4-6), ~ 10 (9-11) and ~ 16 (15-18) days and for oscillations near the half solar rotation period (12.5-14.5 days), which might be of solar origin. The analysis was made by applying the correloperiodogram technique to consecutive 2-month long intervals over the period 1979-1989. The input data were noon values (medians from 10-14UT) of f_0F_2 and $h'F$. The maximum amplitudes in each interval and each period band were used as characteristics of oscillations.

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2. Solar cycle effects

Figures 1 to 3 show the development of amplitudes of all four periods of ~5, 10, 13.5 and 16 days for the stations of Lannion, Juliusruh and Rome. Figures 2 and 3 also include solar activity indices R (sunspot number) and $F10.7$. Figures 1 to 3 clearly show a well-developed solar cycle variation of the magnitude of planetary wave type oscillations for all four periods (period bands) and all three stations. These oscillations are small, 0.1-0.3 MHz, during the low solar activity period (monthly mean R < 30-50) and with respect to the accuracy of f_0F_2 determination from conventional ionosondes (0.1-0.3 MHz depending on conditions) they can be neglected during the period of low solar activity. However, when solar activity becomes high (R well above 100), the amplitude of such oscillations may exceed 1 MHz and, particularly in the case of the ~ 5-day oscillation, they can significantly affect the accuracy of short-term predictions (a few days ahead) of f_0F_2. Figures 4 to 6 show the same as figs. 1 to 3 but for $h'F$ from Lannion, Juliusruh and Rome. Contrary to the f_0F_2 results, we do not see any clear dependence of planetary wave type activity on solar cycle in any of four period bands or for any station. The trend of increasing peak values of $h'F$ for Rome (fig. 6) was not confirmed by other stations and it is peculiar (its reality is highly questionable). The amplitude of oscillations in $h'F$ varies between about 1-10 km with typical values of about 3-4 km. With respect to the accuracy of the $h'F$ determination by conventional ionosondes, about 1-3 km depending on conditions, such oscillations cannot be neglected even though they are small compared with other changes caused by geomagnetic storms etc.

The solar cycle effect on planetary wave type oscillations in f_0F_2 may be caused or at least considerably affected by the solar cycle effect on f_0F_2 itself without a significant solar cycle dependence of planetary wave type forcing. Essentially, no solar cycle effect on plane-

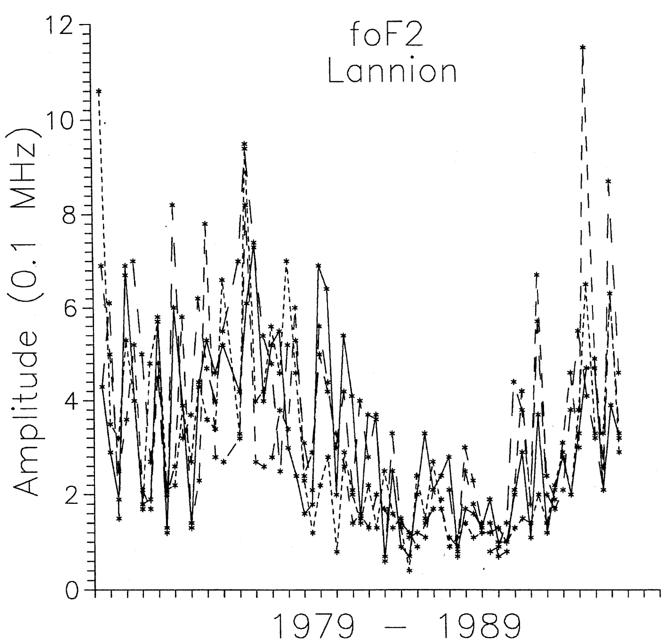

Fig. 1. Development of 4-6-day (short-dashed line), 9-11-day (medium-dashed line), 12.5-14.5-day (full line) and 15-18-day (long-dashed line) oscillations in f_0F_2 for Lannion (after Laštovička and Mlch, 1996).

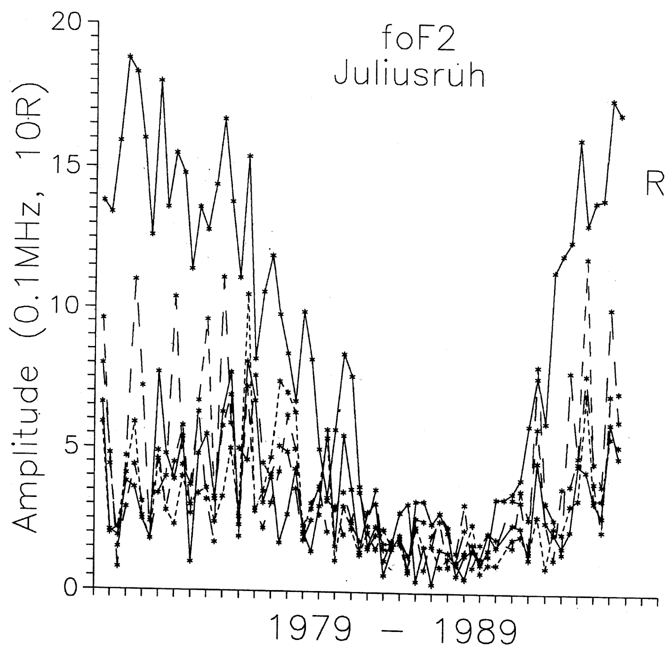

Fig. 2. The same as fig. 1 for Juliusruh; R = sunspot number (after Laštovička and Mlch, 1996).

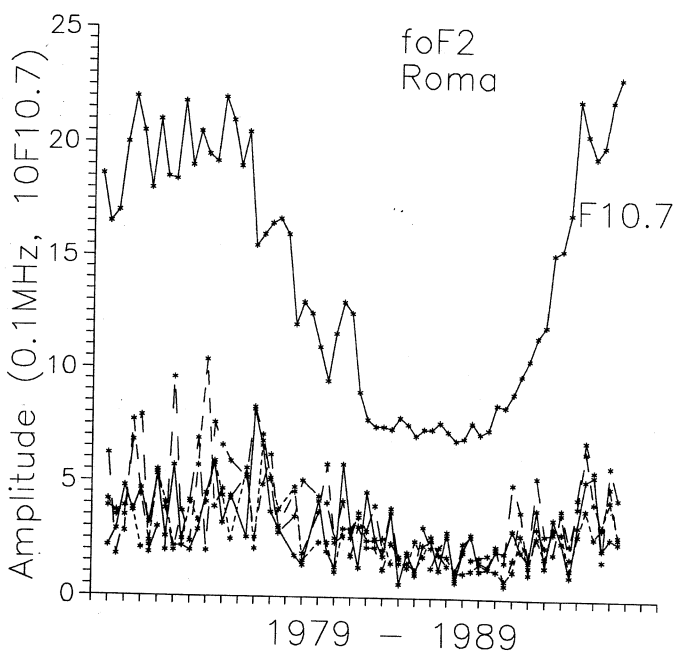

Fig. 3. The same as fig. 1 for Rome; $F10.7$ – λ = 10.7 cm solar radio noise (after Laštovička and Mlch, 1996).

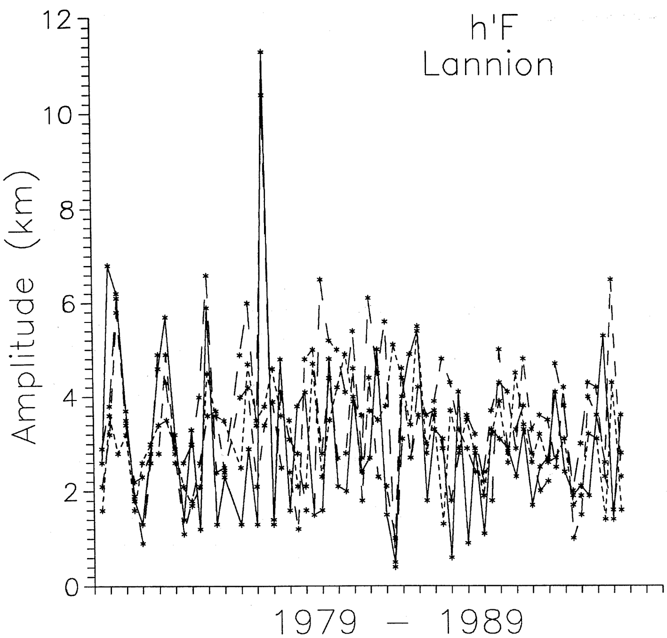

Fig. 4. Development of 4-6-day (short-dashed line), 9-11-day (medium-dashed line), 12.5-14.5-day (full line) and 15-18-day (long-dashed line) oscillations in *h'F* for Lannion.

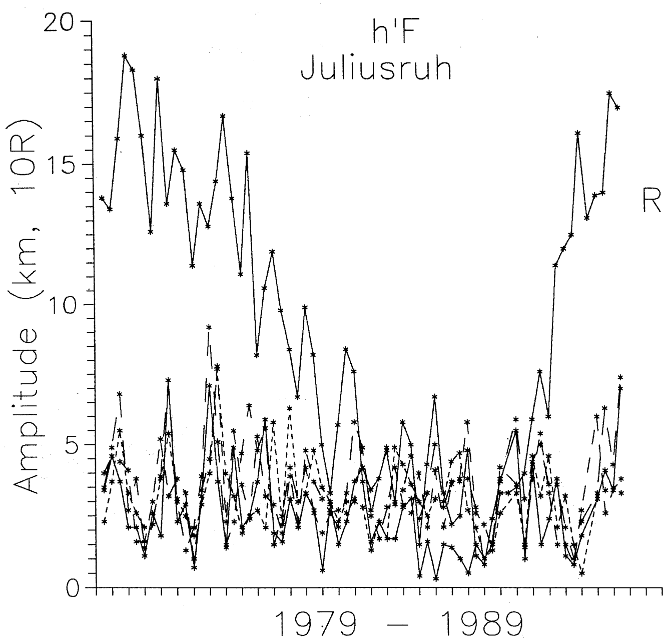

Fig. 5. The same as fig. 4 for Juliusruh. *R* = sunspot number.

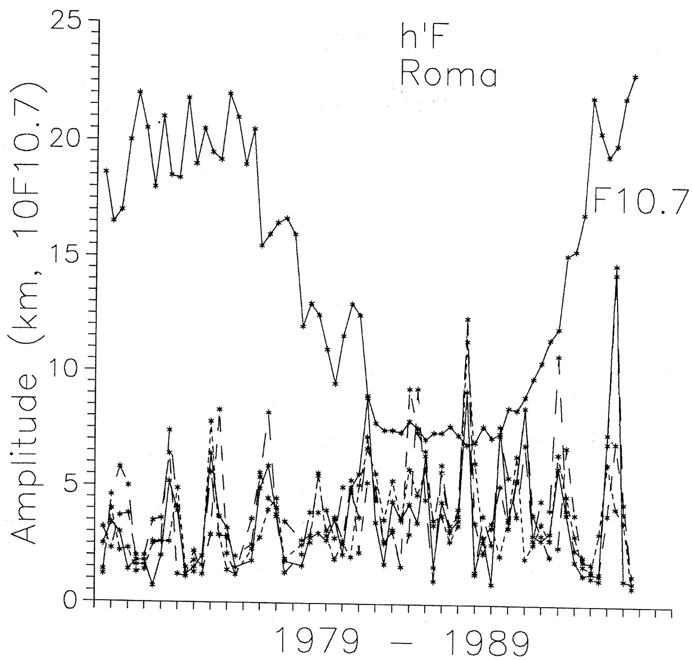

Fig. 6. The same as fig. 4 for Rome. $F10.7$ – λ = 10.7 cm solar radio noise.

tary wave type oscillations/forcing was found in the lower ionosphere (*e.g.*, Laštovička, 1993). In order to distinguish the effect of solar cycle variations on f_0F_2 and on thermospheric planetary wave type forcing, we will use the relative amplitudes ($\Delta f_0F_2/f_0F_2$), which are free of influence of f_0F_2 solar cycle variations. Figures 7 to 9 show the same as figs. 1 to 3 but for relative amplitudes ($\Delta f_0F_2/f_0F_2$) for Lannion, Juliusruh and Rome. Contrary to the absolute amplitudes of oscillations in f_0F_2 (figs. 1 to 3), but essentially in agreement with the $h'F$ oscillation pattern (figs. 4 to 6), we did not see any clear dependence of planetary wave type activity on solar cycle in any of four period bands for Rome (fig. 9), which is similar to Průhonice results (Altadill and Laštovička, 1996), and we observed a much weaker effect for Lannion and Juliusruh. This effect seems to be expressed only in maximum but not in minimum amplitudes (figs. 7 and 8) although in figs. 1 and 3 it is also expressed in minimum values. If we compare magnetic latitudes of stations, we find no significant solar cycle effect at lower latitudes (Rome and Průhonice), a minor effect at Lannion, and some, although not strong effect, at the highest latitudes studied in Juliusruh. Nevertheless, for all four stations the main contribution to the strong solar cycle effect observed in absolute amplitudes of oscillations was the solar cycle effect in values of f_0F_2 themselves. Extremely high relative amplitudes of oscillations do not appear to occur under low solar activity conditions. The level of solar activity itself is not sufficient information for predicting the amplitude of oscillations, we can only estimate an average value of possible amplitudes and corresponding range of values. The amplitudes are considerably affected by a strong and not very regular seasonal variation and by an irregular component. Nevertheless, for minimum solar conditions we need not take into account these oscillations in short-term radio wave propagation condition predictions unless we require accuracy better than that of f_0F_2 measurements by conventional ionosondes.

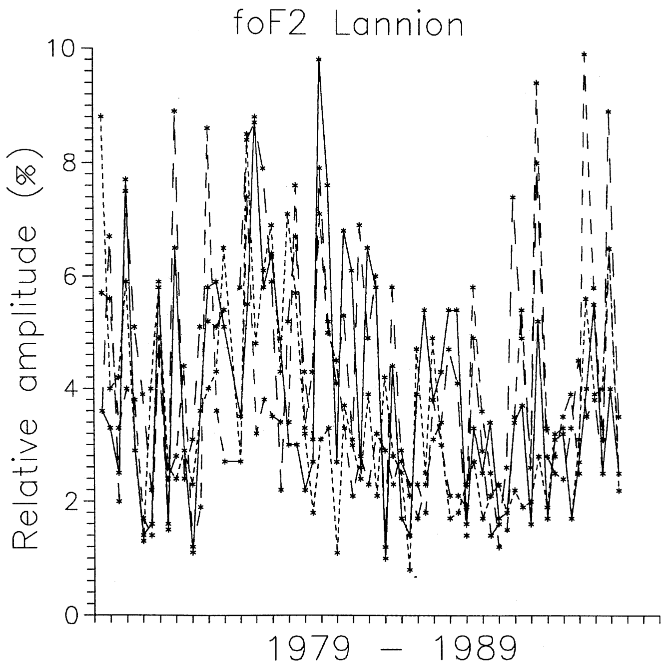

Fig. 7 Development of relative amplitudes of 4-6-day (short-dashed line), 9-11-day (medium-dashed line), 12.5-14.5-day (full line) and 15-18-day (long-dashed line) oscillations in f_0F_2 for Lannion.

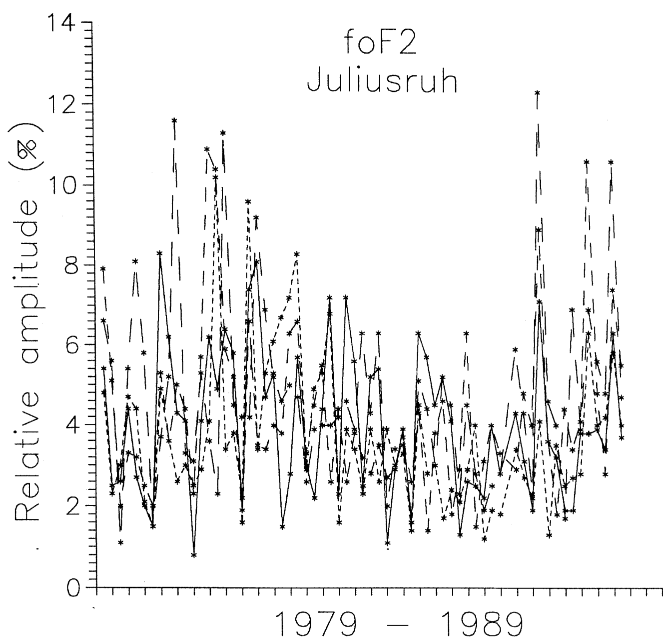

Fig. 8. The same as fig. 7 for Juliusruh.

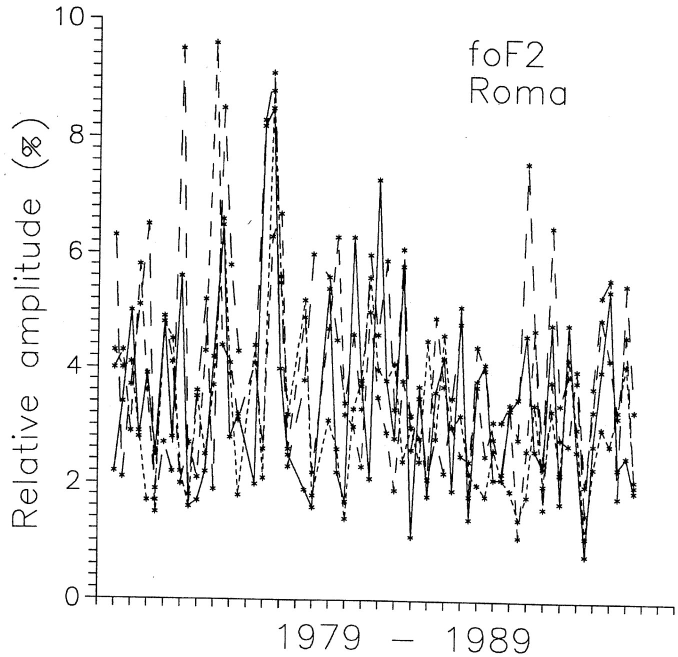

Fig. 9. The same as fig. 7 for Rome.

3. Possible mechanisms

A probable reason for the oscillations studied is planetary wave forcing. Correlations between oscillations in mesopause region winds and f_0F_2 (*e.g.*, Pancheva *et al.*, 1994; Yi and Chen, 1994) and oscillations in the lower ionosphere parameters and f_0F_2 (*e.g.*, Laštovička and Mlch, 1994; Altadill and Laštovička, 1996) have been established. According to both experimental data and model calculations (*e.g.*, Pancheva *et al.*, 1989; Laštovička *et al.*, 1994a), such oscillations in the lower ionosphere are caused by planetary waves propagating from below, which are mainly of tropospheric origin. Canziani (1994a) found 3-16 day oscillations in the tidal variability of meridional wind near 300 km.

How do such effects propagate upwards from the upper mesosphere/lower thermosphere to the F_2-region maximum heights? 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. Canziani (1994b) develops another possible mechanism based on non-linear wave-wave interaction. Calculations performed with a thermosphere-ionosphere-mesosphere-electrodynamic general circulation model (Roble and Ridley, 1994) clearly show that the thermospheric variability near 300 km is substantially influenced by couplings from below (from the middle atmosphere). Nevertheless, the physical mechanism of the upward propagation of the planetary wave type oscillations from the upper middle atmosphere remains an open question.

4. Conclusions

The planetary wave type oscillations (T = 2-20 days) in the F_2-region were studied in the range of about 4-18 days. The pattern of oscillations was in all four period sub ranges similar in gross features, *i.e.* from the point of view of a possible solar cycle effect. Mechanisms are not known, there are only some hypotheses.

Conclusions concerning f_0F_2:

1) The planetary wave type oscillations appear to be negligible under low solar activity conditions (monthly R < 30-50) but they can be very important and considerably affect the short-term predictions of f_0F_2 (by even more than 1 MHz) under high solar activity conditions (monthly sunspot number well above 100), and generally a large solar effect is observed (figs. 1 to 3).

2) In relative amplitudes of oscillations contrary to absolute amplitudes but essentially in agreement with the $h'F$ pattern, we did not see a clearly detectable solar cycle effect in Rome (and in Průhonice, Altadill and Laštovička, 1996), and we saw a much weaker effect in Lannion and Juliusruh (figs. 7 to 9). Thus, the main contribution to the solar cycle variation of absolute amplitudes of oscillations comes from the solar cycle variation of f_0F_2 itself.

Conclusions concerning $h'F$:

3) The oscillations in $h'F$ do not display an important dependence on the solar cycle. They are relatively small compared to other effects influencing $h'F$ but not quite negligible.

Acknowledgements

This work was supported by the Commission of European Union through grant ERBCIPECT926112.

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