HYSTERESIS IN DEPENDENCE OF $f_0F_2$ ON SOLAR INDICES

L. Trísková and J. Chum
Institute of Atmospheric Physics, Academy Science of the Czech Republic, Bocni II, 1401, 141 31 Praha 4, Czech Republic

ABSTRACT

The characteristics of hysteresis phenomena occurring in the relation between averaged $f_0F_2$ data and solar activity indices $R$ or $F_{10.7}$ have not the shape of a simple loop but that of an elongated figure eight. The sense of rotation is clockwise for lower and counterclockwise for higher indices. It seems difficult to incorporate this finding into existing prediction models.

INTRODUCTION

Hysteresis means a dependence of actual conditions from past history. In ferromagnetics for example the magnetic induction $B$ as function of the applied field $H$ shows lower values with increasing, higher values with decreasing $H$, so that the diagram is a counterclockwise rotating loop. It was shown in papers /1-3/ that the $F_2$-layer ionization at noon as function of the currently used solar indices $R$ or $F_{10.7}$ shows a comparable behaviour in solar cycles 20 and 21, in some months however with opposite sense of rotation. Clockwise rotation in the loop was also found when comparing annual means of both -parameters in solar cycle 17 /4/. Other solar activity measures have also been considered to obtain a unique relation between them and $f_0F_2$, e.g. the area of faculae /4/ or the area of Ca-@ages /5/. In the present paper we ask first whether the relation between $f_0F_2$ and $R$ or $F_{10.7}$ is systematically different in the ascending and descending phases of the solar cycle, and second whether such relation merits being included into prediction models.

DATA AND RESULTS OF PROCESSING

Stations listed in Table 1 cover a range of 54.6 N to 42.9 S (54.5 N to 53.6 S geomagnetic latitude). We have employed noon and midnight monthly medians of $f_0F_2$ and their annual means, the mean monthly and annual 10.7 cm flux, the mean monthly and annual sunspot number.

Figure 1 shows that for almost identical monthly values of $R$ or $F_{10.7}$ different diurnal curves are found in years of different solar phases. Thus, the monthly median $f_0F_2$ depends not only on $R$ in the given month, but also on the value of $R$ in the preceding month.

In the following we characterize the $F_2$-ionization by annual averages of monthly medians for local noon or midnight. Figure 2 shows the rather complicated dependence of noon values of the $f_0F_2$ medians on the average $R$ for solar cycles 20 and 21. Figure 3 indicates that this dependence is of the same nature for noon and midnight critical frequencies. The characteristic $f_0F_2$ vs. $R$ curves are not simple loops but 8-shaped. The sense of rotation is clockwise in the left hand and counterclockwise in the right hand loop. This holds for solar cycles 20, 21 and in the known part of cycle 22.
Fig. 1 Examples of monthly foF2 median diurnal variations in cases of equal R and equal or almost equal F10.7 in different years. (a) Dourbes (50.1 N, 04.6 E); (b) and (c) Průhonice (50 N, 15 E)

The results are summarized in Figure 4 which shows the coefficients of the linear regression lines to the dependence of the average annual median of foF2 on the annual average of R and on the annual average of F10.7 separately calculated for the ascending and descending branches of solar cycles 20 and 21. The linear regression of the dependence of F10.7 on R was also calculated for the ascending and descending branches of solar cycles 19 through 22.

The regression lines of the dependence foF2 vs. R display a greater slope in the descending branch (negative DB) and larger initial value of foF2 in the ascending branch (positive DA) for both solar cycles and all stations. This corresponds to the shape of the open-ended eight shown in Figures 2 and 3. Such a systematic difference of the ascending and descending branches of the solar cycles was not found for the foF2 vs. F10.7 dependence. However, the dependence of the radio flux on the sunspot number is similar to that of foF2 vs. R. Note that since the descending branch of the cycle 21 greater standard deviations occur than in the previous years.

Fig. 2 Dependence of the annual averages of the noon foF2 medians on the average R for solar cycles 20 and 21.

Fig. 3 Examples indicating that the foF2 vs. R dependence is of the same nature for noon and for midnight.
Fig. 4 $\Delta A = A_a - A_d$, $\Delta B = B_a - B_d$ and standard deviation $\sigma_{a,d}$ for regression lines of the type $y = A + Bx$, indices $a$ and $d$ corresponding to the ascending and descending branches of the solar cycles, respectively. (■ positive, □ negative value)
(a) annual average median of noon $f_{oF2}$ vs annual average $R$, cycles 20, 21
(b) annual average median of noon $f_{oF2}$ vs annual average $F10.7$, cycles 20, 21
(c) annual average $F10.7$ vs annual average $R$, cycles 19, 20, 21, 22
Numbers 1 through 7 are serial numbers of stations listed in Table 1

No systematic shape of the dependence of $f_{oF2}$ on $R$ or $F10.7$ was observed in the course of the solar cycle for the noon medians of the individual months (Figure 5). For some equinox months this dependence has the shape of a kind of loop, in April of cycle 20 and in March of cycle 21, with clockwise rotation, counterclockwise, however in September and October of cycle 21. Some months show a dependence similar to the annual (Figures 2 and 3), and the remaining months show no preference. An example of these curves is shown in Figure 5 which also indicates that the shape of the dependencies on $R$ and $F10.7$ is essentially the same.

**DISCUSSION**

This study could be carried out thanks to the station network of the International Geophysical Year (1957-59) which has been in operation during now nearly three whole solar cycles.

We find that the dependence of $f_{oF2}$ on $R$ has not the simple loop character of hysteresis. The 8-shape found in Figures 2 to 4 contradicts the result of Smith and King /4/ who for solar cycle 17 (1933-1943) described the dependence on $R$ of annual noon medians by an open-ended loop with clockwise rotation. The difference between their and our result can be explained by the fact that different $f_{oF2}$ characteristics were studied. If the true annual median over 365 noon values was dealt with in /4/, the authors in fact only worked with values around the equinoxes, the winter and summer values being eliminated. As indicated by Figure 5, clockwise loops are characteristic for spring, i.e. equinox months.

The contradiction between Figure 2 in /1/ and the curve $f_{oF2}$ vs $F10.7$ for August, cycle 21, in our Figure 5 is only apparent. The loop-like dependence in /1/ derives from the incomplete time series (1977 to 1984) while 11 years (1970 to 1986) were used in our Figure 5.

The systematic dependence of $F10.7$ vs. $R$ on the phase of the solar cycle could also be determined thanks to the sufficiently long series of data now available. The authors dare not speculate that this phenomenon might be explained by the different average heliographic latitude of sunspots on the ascending and descending branches. The change in the magnitude of the standard deviation of the $F10.7$ vs. $R$ dependence might be related to the change of the team responsible for calculating the sunspot numbers, and on techniques used.

As for the two questions formulated in the Introduction, the answer we received was affirmative for the $f_{oF2}$ vs. $R$ dependence. Not so, however, with the second question. Since the systematic dependence described appeared only in the annual characteristics of $f_{oF2}$, we see no possibility of including it into existing models.
CONCLUSION

Figures 2 to 4 demonstrate a particular shape of the graph between the ionization of the F2-layer and the sunspot number in the course of the solar cycle. The dependence is not loop-shaped but has the form of an open-ended figure eight. The regression line has a smaller slope on the ascending and a larger slope on the descending branch of the solar cycle. The same was found for the F10.7 vs R dependence. No way is seen to incorporate our findings into the existing prediction models.

Beginning the descending branch of cycle 21. The standard deviation of the regression between F10.7 and R has substantially increased since the descending phase of cycle 21. This might be related to the change in the technique of determining R.

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REFERENCES