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The effects of f_0F_2 variability on TEC prediction accuracy

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Abstract
In this paper hourly daily F_2-layer critical frequency data recorded at Rome and one minute daily TEC data recorded at Florence were used and the relevant variabiles were calculated. It was concluded that there was no clear evidence as to how they correlated. In order to obtain a measure of the f_0F_2 and TEC variability, the normalised differences df_0F_2 and dTEC from the relevant monthly median values were also considered. Since no clear evidence could be obtained as of how df_0F_2 and dTEC correlate, a new parameter, the $\Delta A_p/\Delta R$ ratio was tried. ΔA_p was taken as the difference between the maximum value of A_p measured at the relevant disturbance and that corresponding at the beginning of the disturbance. ΔR corresponded to the two above mentioned values of A_p. This parameter was compared to the differences of the corresponding df_0F_2 values called Δdf and dTEC values called ΔdT. In wintertime, when $\Delta A_p/\Delta R$ was negative, for the vast majority of the occurrences either Δdf or ΔdT was negative; Δdf and ΔdT were never observed to be negative at the same time whereas they were both positive in fewer than 10% of the observations. When $\Delta A_p/\Delta R$ was positive then either Δdf or ΔdT were negative. In summertime when $\Delta A_p/\Delta R$ was negative both Δdf and ΔdT were negative. When $\Delta A_p/\Delta R$ was positive, while a positive Δdf corresponded almost always to a positive ΔdT, a negative Δdf would equiprobably indicate either a positive or a negative ΔdT.

Key words *ionosphere – ionospheric modelling – ionospheric variability – Neural Networks*

1. Introduction

The prediction of ionospheric Total Electron Content (TEC) is a complex problem. The greatest contribution to the TEC is from the ionospheric F-layer, which in turn is a very variable ionised region of the higher atmosphere, whose electron concentration and distribution are governed (Kouris *et al.*, 1998, 1999) mainly by solar and geomagnetic phenomena. The introduction of f_0F_2 in Neural Network based, one-hour ahead, one-day ahead, two-days ahead and seven-days ahead TEC forecasting models has been recently investigated (Xenos, 1999) and proved very successful. In fact these models are far more accurate than the well known and widely used physical or empirical models that incorporate statistical or numerical methods. However, the TEC variability is not governed exactly by the same factors as f_0F_2 variability, since the topside ionosphere and influences from the plasmasphere above the F-region are important contributors to TEC. Although recently, the f_0F_2 was used successfully as an index in TEC prediction models (Xenos *et al.*, 2000), due to its strong variability (Kouris, 1999), it is reasonable to investigate the correlation between the f_0F_2 and TEC variability.

The present work, investigated the problem of the correlation between the f_0F_2 and TEC variability. Therefore, F_2-layer critical frequency data recorded at Rome and TEC data recorded at Florence have been used.

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2. Data and analysis

Hourly-daily TEC values produced from one minute Faraday-rotation measurements, from geostationary satellites, recorded at Florence (Spalla *et al.*, 1987) from the years 1975-1982 and 1989-1991 were correlated to f_0F_2 hourly-daily data measured at Rome. The daily A_p and R indices were used to define whether the ionosphere was quiet or disturbed. Therefore, f_0F_2, TEC, A_p and R graphs were compiled. When A_p exceeded 40 the ionosphere was characterised disturbed and the consequences of the disturbance on f_0F_2 and TEC were studied. For a more detailed analysis the time span of the study preceded and followed the disturbance occurrence by 24 h.

In order to obtain a measure of the f_0F_2 and TEC variability, the normalised differences df_0F_2 and dTEC from the relevant monthly median values were also considered. The formulas used for these calculations were

$$df_0F_2 = \frac{f_0F_{2\mathrm{obs}} - f_0F_{2\mathrm{med}}}{f_0F_{2\mathrm{med}}} \tag{2.1}$$

$$dTEC = \frac{TEC_{\mathrm{obs}} - TEC_{\mathrm{med}}}{TEC_{\mathrm{med}}} \tag{2.2}$$

where

$f_0F_{2\mathrm{obs}}$ the observed hourly daily f_0F_2 values;
$\mathrm{TEC}_{\mathrm{obs}}$ the observed hourly daily TEC values;
$f_0F_{2\mathrm{med}}$ the hourly monthly median f_0F_2 values;
$\mathrm{TEC}_{\mathrm{med}}$ the hourly monthly median TEC values.

Since no clear evidence could be obtained as to how df_0F_2 and dTEC correlated, a new parameter, the $\Delta A_p/\Delta R$ ratio was tried. ΔA_p was taken as the difference between the maximum value of A_p measured at the relevant disturbance and that corresponding at the beginning of the disturbance *i.e.* as soon as A_p exceeded 40. ΔR corresponded to the two above mentioned values of A_p. This new parameter was compared to the differences of the corresponding df_0F_2 values called Δdf and dTEC values called ΔdT.

3. Results and discussion

From figs. 1a-c it can be seen that when A_p increased and exceeded 40, *i.e.* when the ionosphere could be considered as disturbed, f_0F_2 showed a steep increasing trend whereas TEC usually, though not always, had an increasing one with respect to what was shown before the disturbance occurrence. A cross correlation analysis using a variable correlation period showed that the response time difference between the f_0F_2 and the TEC was of the order of 3-5 h, the f_0F_2 leading. The gradients measured between the f_0F_2 and TEC values corresponding to the start of the phenomenon and their maximum or minimum values, depending on the trend, were almost always proportional to the A_p values, more specifically to the A_p increase rate, and were stronger at high solar activity periods. It is worth mentioning that after the end of the disturbance, the f_0F_2 value reached a minimum, which almost always coincided with the minimum value of the month for the specific hour (Kouris and Fotiadis, 2000).

Since no clear evidence of the behavioural differences between f_0F_2 and TEC values could be obtained, a comparison between their variability was attempted. Using eqs. (2.1) and (2.2), the normalised differences df_0F_2 and dTEC for the above data set were obtained. Figures 2a-d show several characteristic cases. Again, no clear evidence could be obtained as to how df_0F_2 and dTEC correlate, since a positive df_0F_2 may be accompanied by a positive or negative dTEC and *vice versa*. Therefore, the $\Delta A_p/\Delta R$ ratio was compared to Δdf and ΔdT.

It can be observed (fig. 3a) that in winter and when the ionosphere is characterised as disturbed, the $\Delta A_p/\Delta R$ ratio is usually negative, whereas this ratio takes positive values for over 60% of the occurrences in summer (fig. 3b).

In wintertime, when $\Delta A_p/\Delta R$ was negative (fig. 4a), for the vast majority of the occurrences either Δdf or ΔdT was negative; Δdf and ΔdT were never observed to be negative at the same time whereas they were both positive in fewer than 10% of the observations. When $\Delta A_p/\Delta R$ was positive then either Δdf or ΔdT were negative.

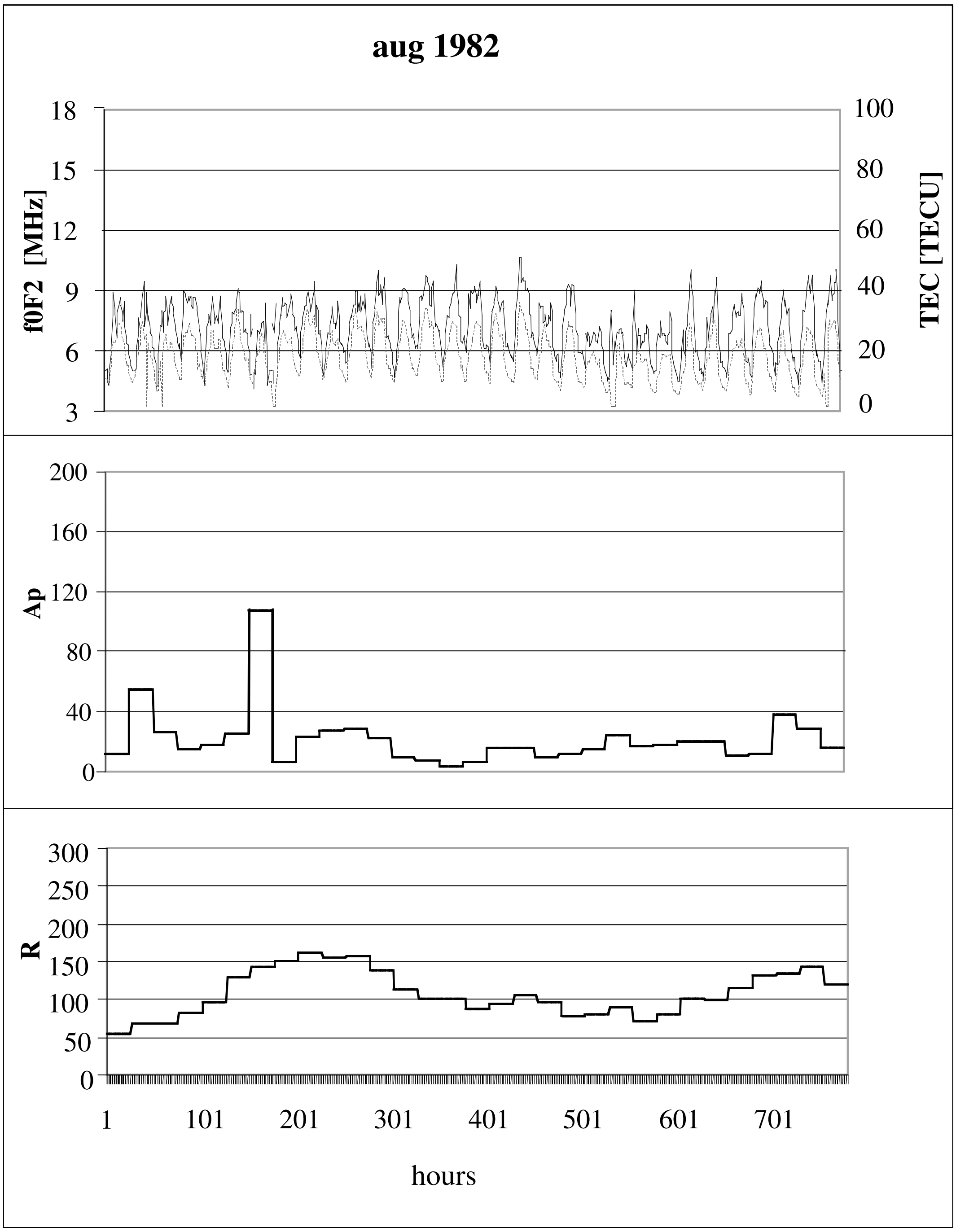

Fig. 1a. Characteristic month showing the f_0F_2 (solid line) and the TEC (dashed line), A_p and R values.

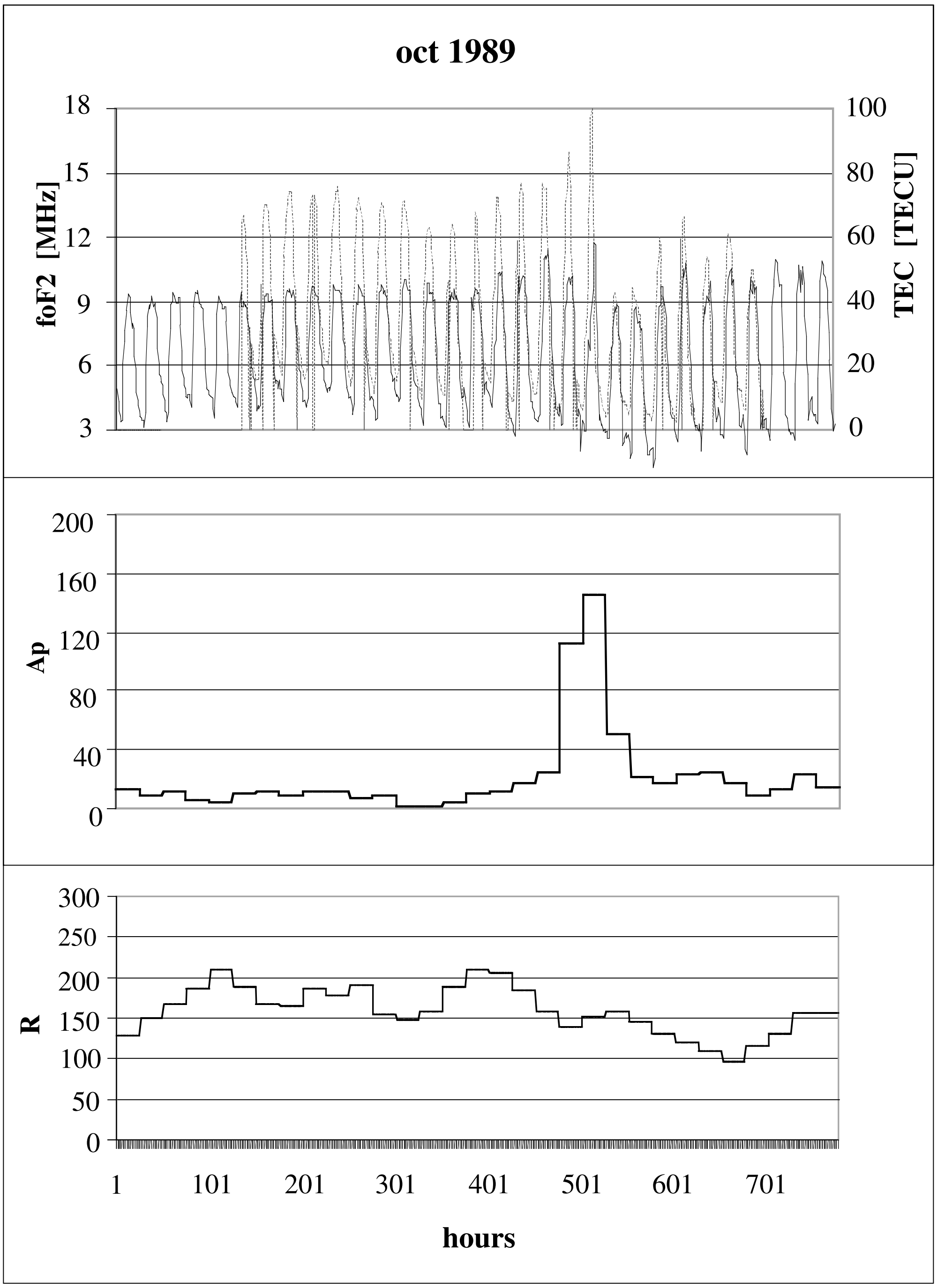

Fig. 1b. Characteristic month showing the f_0F_2 (solid line) and the TEC (dashed line), A_p and R values.

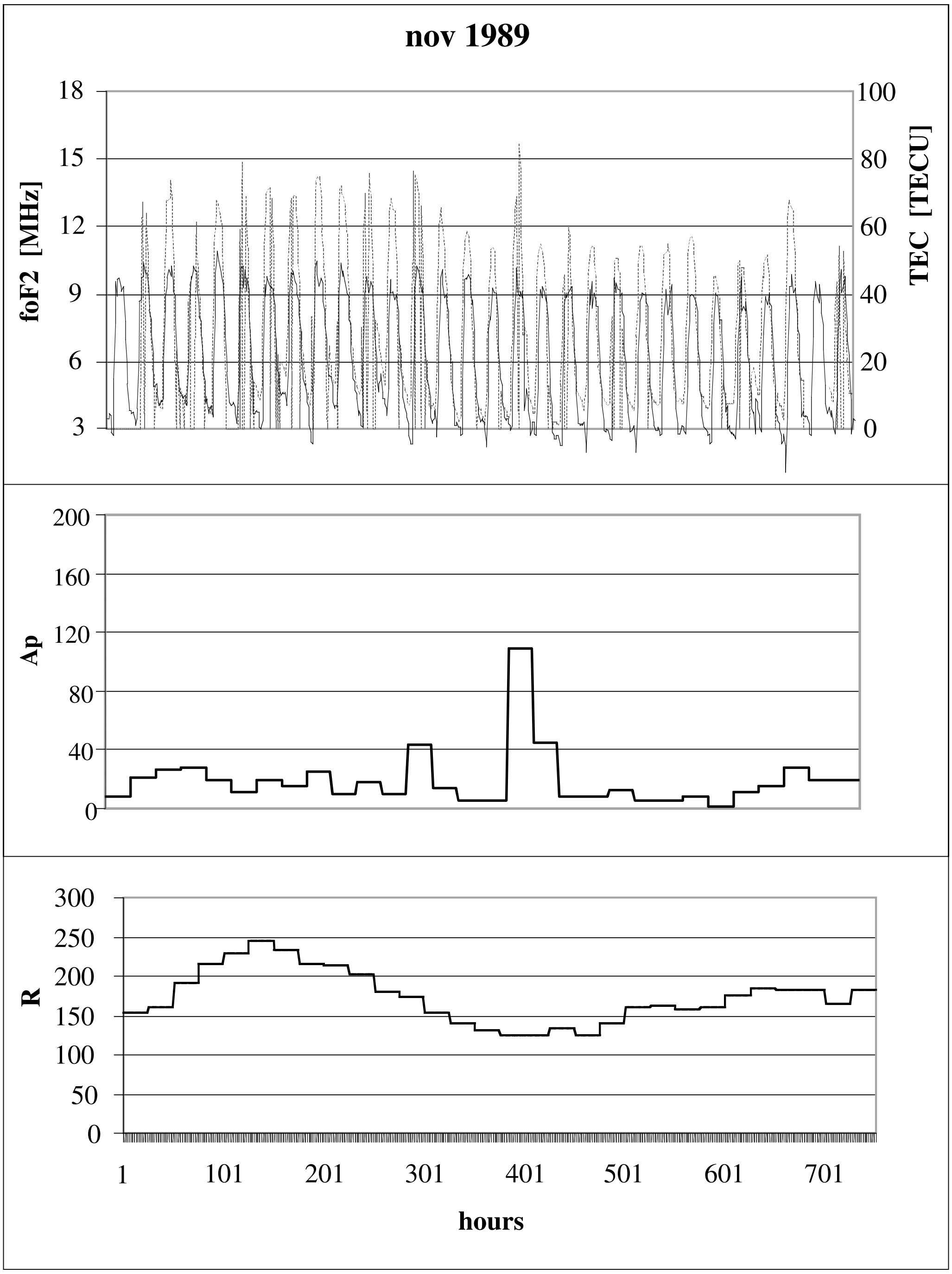

Fig. 1c. Characteristic month showing the f_0F_2 (solid line) and the TEC (dashed line), A_p and R values.

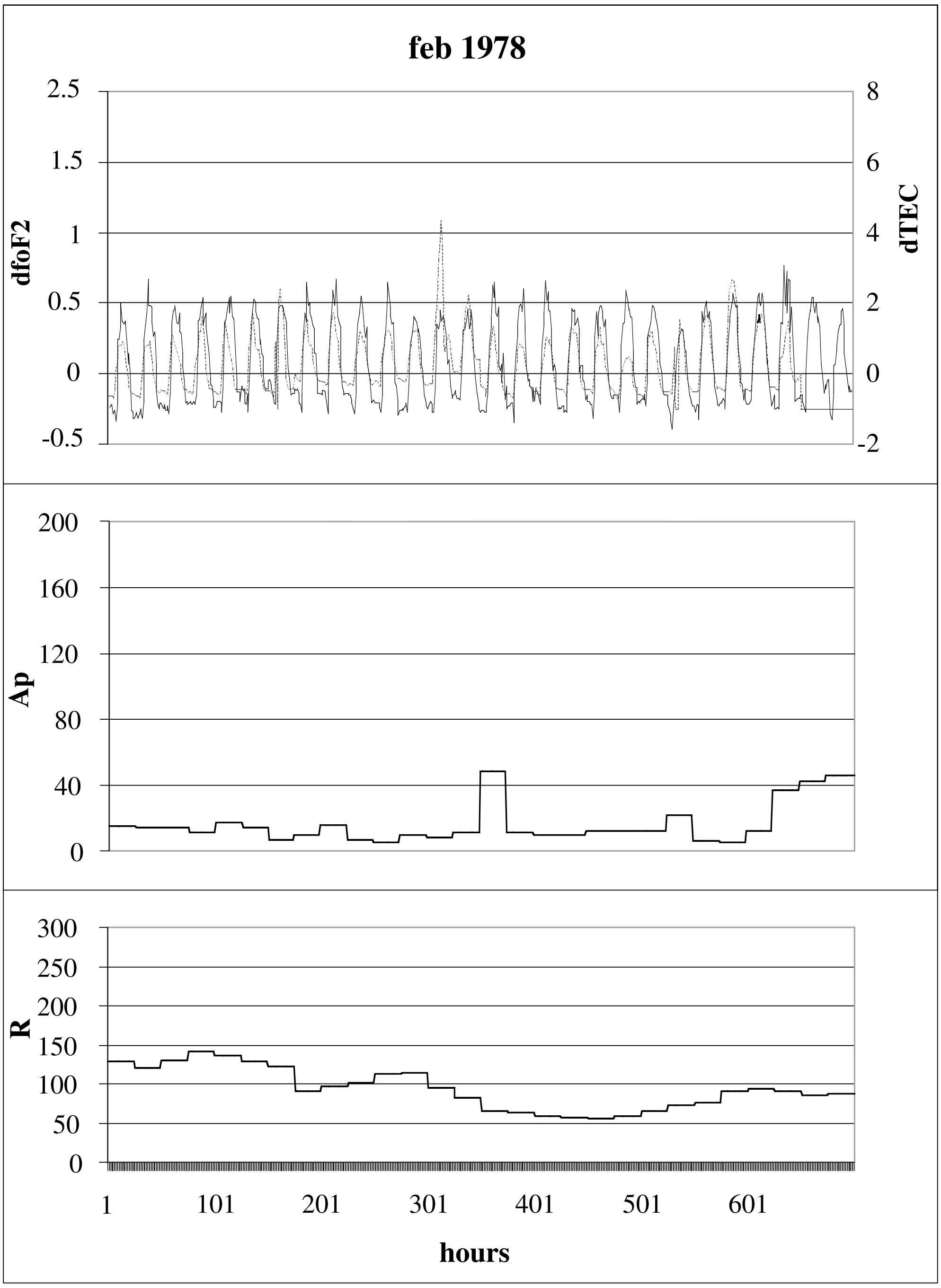

Fig. 2a. Presentation of df_0F_2 (solid line), dTEC (dashed line), A_p and R.

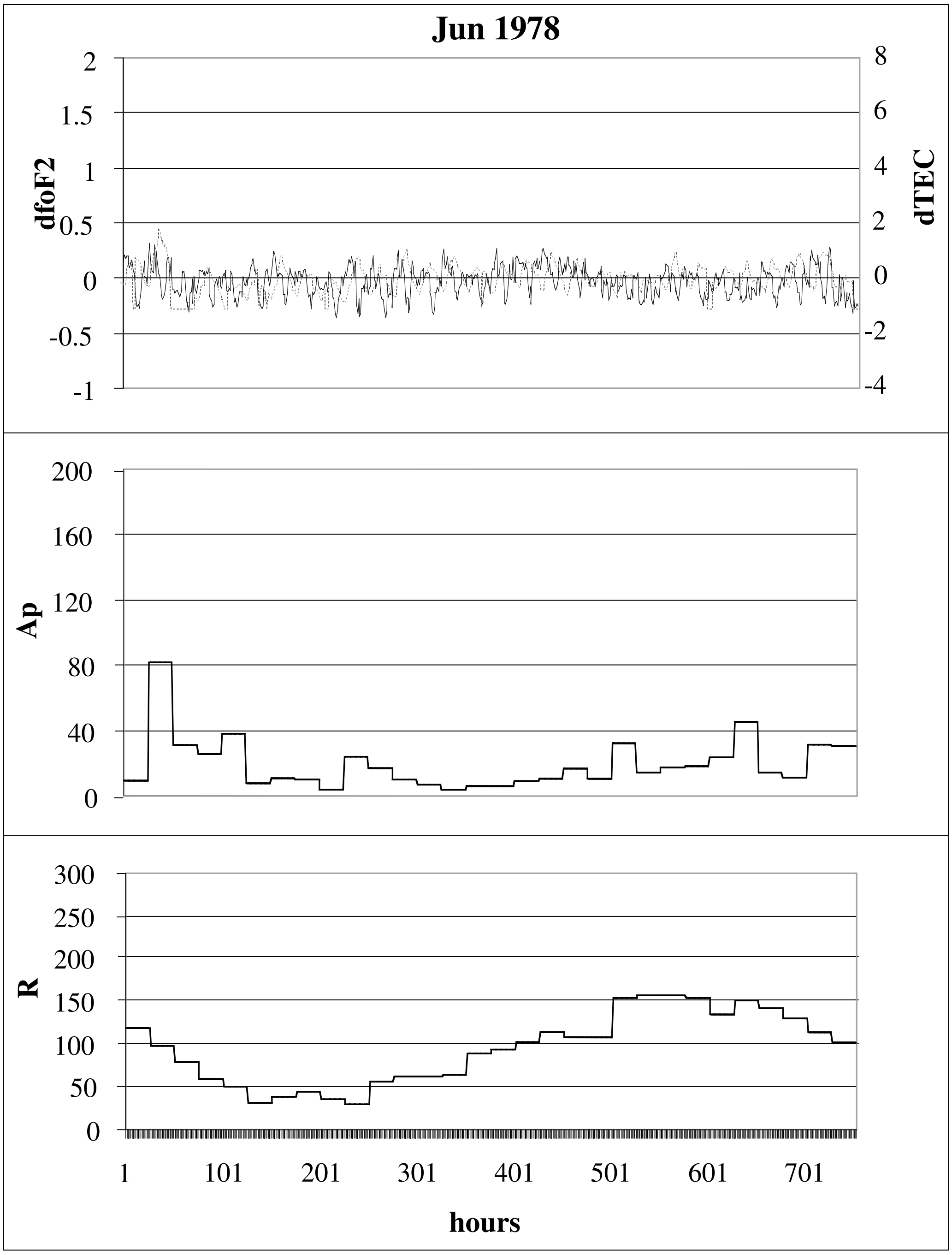

Fig. 2b. Presentation of df_0F_2, dTEC, A_p and R.

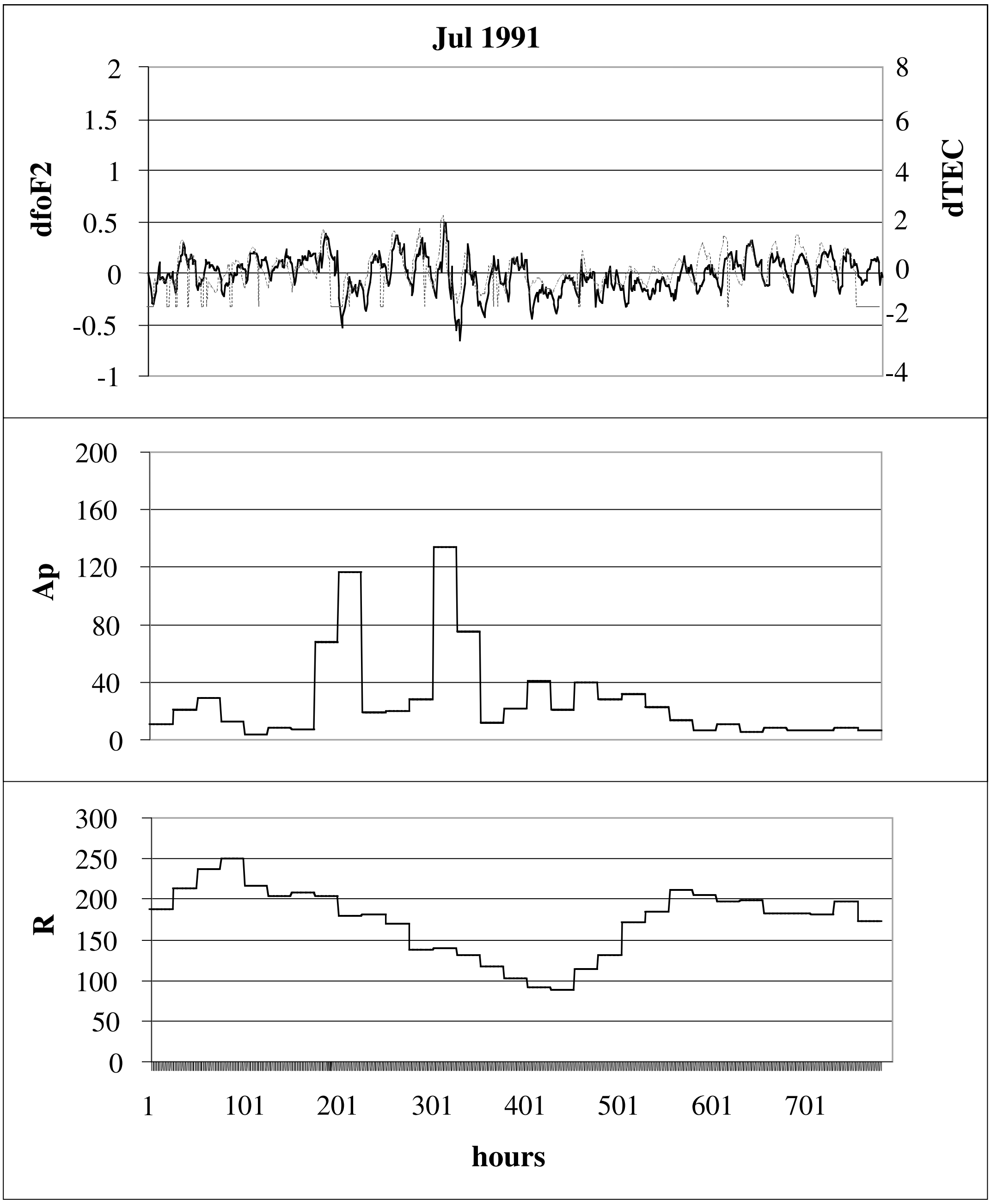

Fig. 2c. Presentation of df_0F_2, dTEC, A_p and R.

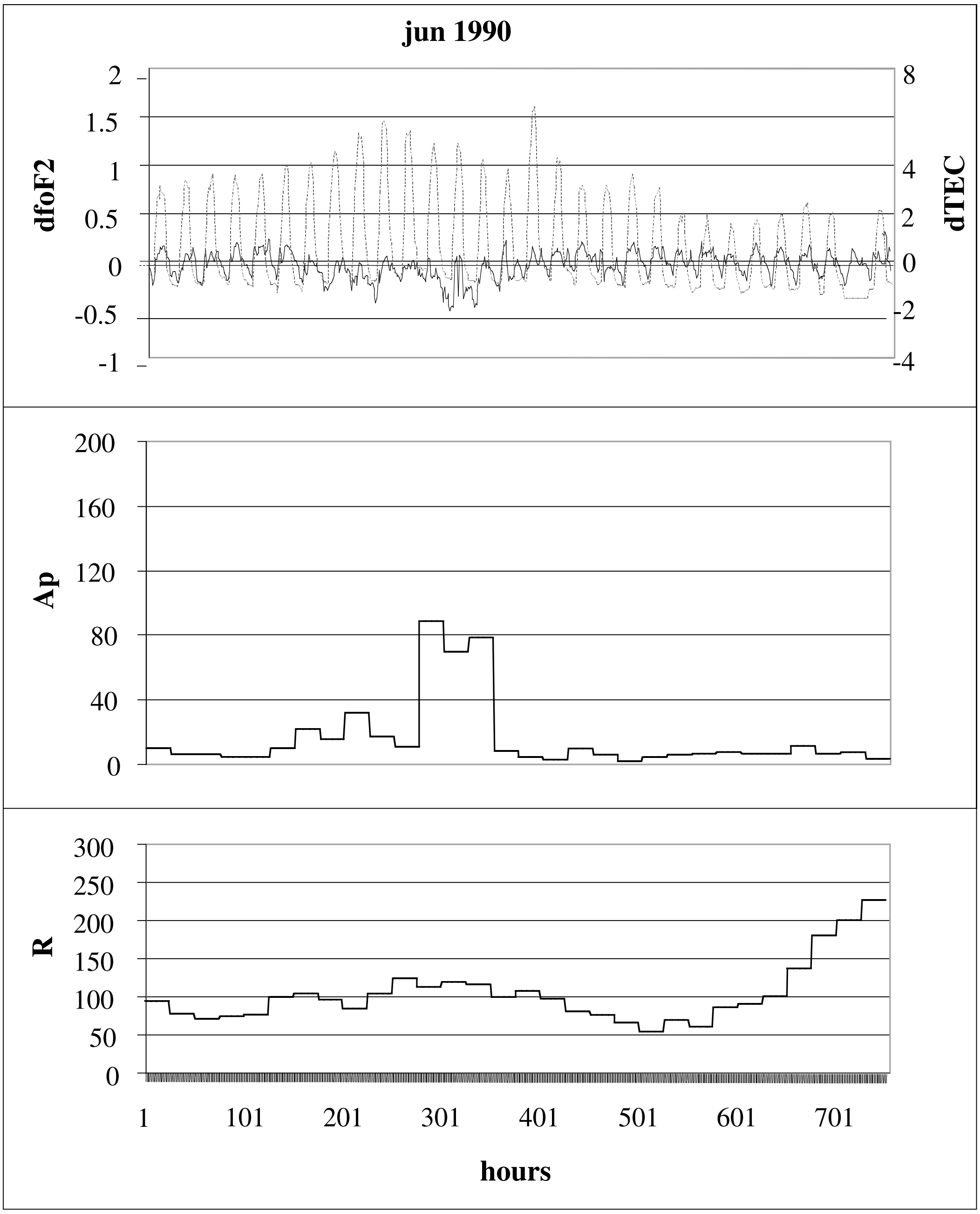

Fig. 2d. Presentation of df_0F_2, dTEC, A_p and R.

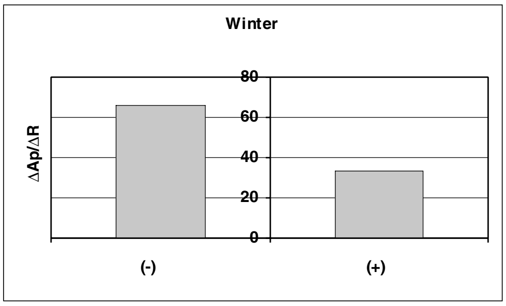

Fig. 3a. $\Delta A_p/\Delta R$ behaviour in winter.

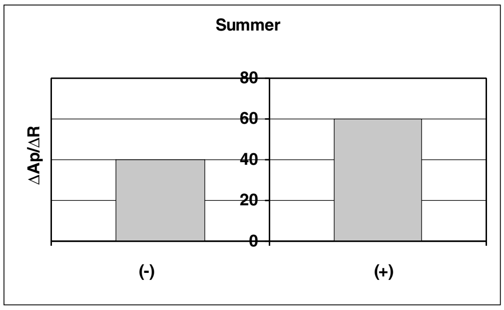

Fig. 3b. $\Delta A_p/\Delta R$ behaviour in summer.

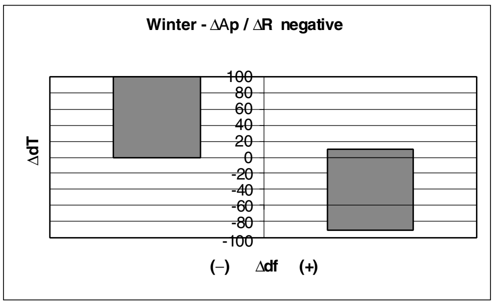

Fig. 4a. Δdf *versus* ΔdT behaviour in wintertime and when $\Delta A_p/\Delta R$ is negative.

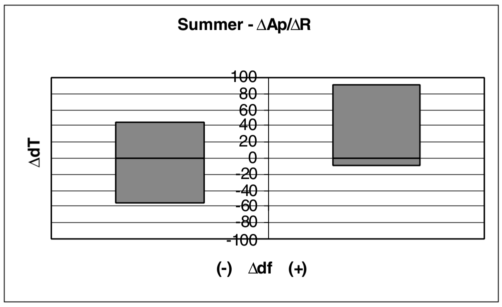

Fig. 4b. Δdf *versus* ΔdT behaviour in summertime and when $\Delta A_p/\Delta R$ is positive.

In summertime, when $\Delta A_p/\Delta R$ was negative both Δdf and ΔdT were negative. On the other hand, when $\Delta A_p/\Delta R$ was positive (fig. 4b), while a positive Δdf corresponded almost always to a positive ΔdT, a negative Δdf would equiprobably indicate either a positive or a negative ΔdT.

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