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 variables 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 $\Delta Ap/\Delta R$ ratio was tried. $\Delta Ap$ was taken as the difference between the maximum value of $Ap$ measured at the relevant disturbance and that corresponding at the beginning of the disturbance. $\Delta R$ 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 $\Delta df$ and $dTEC$ values called $\Delta dT$. In wintertime, when $\Delta A/\Delta R$ was negative, for the vast majority of the occurrences either $\Delta df$ or $\Delta dT$ was negative; $\Delta df$ and $\Delta dT$ were never observed to be negative at the same time whereas they were both positive in fewer than 10% of the observations. When $\Delta A/\Delta R$ was positive then either $\Delta df$ or $\Delta dT$ were negative. In summertime when $\Delta A/\Delta R$ was negative both $\Delta df$ and $\Delta dT$ were negative. When $\Delta A/\Delta R$ was positive, while a positive $\Delta df$ corresponded almost always to a positive $\Delta dT$, a negative $\Delta df$ would equiprobably indicate either a positive or a negative $\Delta dT$.

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.

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

$$df_0F_2 = \frac{f_{0F_2\text{obs}} - f_{0F_2\text{med}}}{f_{0F_2\text{med}}}$$

$$dTEC = \frac{TEC_{\text{obs}} - TEC_{\text{med}}}{TEC_{\text{med}}}$$

(2.1) (2.2)

where

$f_{0F_2\text{obs}}$: the observed hourly daily $f_0F_2$ values;

$TEC_{\text{obs}}$: the observed hourly daily TEC values;

$f_{0F_2\text{med}}$: the hourly monthly median $f_0F_2$ values;

$TEC_{\text{med}}$: the hourly monthly median TEC values.

Since no clear evidence could be obtained as to how $df_0F_2$ and $dTEC$ correlate, a new parameter, the $\Delta A_p/\Delta R$ ratio was tried. $\Delta A_p$ 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. $\Delta R$ 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 $\Delta df$ and $dTEC$ values called $\Delta dT$.

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 $\Delta df$ and $\Delta dT$.

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 $\Delta df$ or $\Delta dT$ was negative; $\Delta df$ and $\Delta dT$ 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 $\Delta df$ or $\Delta dT$ were negative.
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![Graph showing $f_0F_2$ and TEC values with Ap and R values.](#)

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.
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**Fig. 1c.** Characteristic month showing the \( f_0F_2 \) (solid line) and the TEC (dashed line), \( Ap \) and \( R \) values.
Fig. 2a. Presentation of $df_{F_2}$ (solid line), $d$TEC (dashed line), $A_p$ and $R$. 
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Fig. 2b. Presentation of $df_0F_2$, $d'\text{TEC}$, $A_p$ and $R$. 

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Fig. 2c. Presentation of $df_0F_2$, $d$TEC, $A_p$ and $R$. 
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Fig. 2d. Presentation of $df_0 F_2$, $d$TEC, $A_p$ and $R$. 

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

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