A single-station model suitable for f_0F_2 mapping

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Abstract
Ionospheric monthly-median values of the F_2 and E layer critical frequencies from 24 mid-latitude European stations are fitted to a second degree polynomial and their correlation is discussed. The resulting model is used to predict monthly-median f_0F_2 values for different ionospheric stations and for high, medium and low ionospheric activity. Finally, a potential application of the single station model developed for Slough to mapping the F_2-layer critical frequency is investigated. Thus prediction of the monthly median f_0F_2 values for eight mid-latitude European stations is attempted using the single-station model of Slough and the corresponding f_0E values of the station under investigation. The f_0F_2 values obtained are reasonably accurate. The main advantage of this method is its simplicity and the restricted number of parameters used.

Key words *radio wave propagation – ionosphere – ionospheric mapping – single station models*

1. Introduction

It is well known that height distributions of electron density for single locations find application in scientific investigations as well as in radio system performance assessment over neighbouring paths. These distributions may be obtained either by theoretical calculations or from measurements. The accuracy of these distributions in the immediate vicinity of the single station should be very good, the amount of data provided is very large while their cost is naturally very low. Therefore the development of single-station models is very popular among modelers.

Single-station models may be unique height distributions to particular locations, or they may result from standard regional or global distributions with locally generated anchor-point values. COST 238 (1995) activities in the field of single-station models development have been concerned with analyses of past vertical-incidence ionosonde data for specific locations. It has been shown (Stanislawska *et al.*, 1991, 1992, 1994; Bremer, 1991; Vasiljievic *et al.*, 1995) that monthly-median f_0F_2 can be described by functions that take into account the time-of-the-day, seasonal, solar and geomagnetic activity variations together with the specific ionospheric characteristics of the location. Yet the main drawback of the existing single station models is that though they can provide reliable results for the specific locations that they have been developed for, their prediction accuracy seems to diminish when applied elsewhere. This could be attributed to the fact that the variation of the parameters of each single station model seems to be substantial from station to station.

In this work a new technique for ionospheric f_0F_2 mapping is presented using the f_0F_2-f_0E single station model developed for a given ionospheric station. This method of ionospheric F_2-layer critical frequency mapping seems to have several advantages over the ITU-R map-

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ping technique (ITU-R, PI434, 1994). Its main advantage lies in the simplicity of the method and the restricted number of the necessary parameters. In fact it seems that for the European geographical area 35°-70°N and 10°W-60°E only one single station model developed for an ionospheric station with a rich and reliable f_0F_2 database is needed. This model gives reliable results whereas no further mathematical smoothing or «screen-point» artificial values in places where no measurement data exist is necessary.

2. Data and analysis

In this work hourly monthly-median values of the critical frequency f_0F_2 of the daytime F_2-layer and the night-time F-region, measured at 24 mid-latitude European stations are used (table I).

Second order polynomial regressions (Xenos *et al.*, 1996) employing the method of least squares were performed between the measured f_0F_2 data of each hour of each month at each station and the corresponding calculated f_0E

Table I. Statistical evaluation of the SSM model for the stations of COST251 area.

Station	Standard deviation	Average %	Scatter error	Systematic error
Arenosillo	0.478	5.638	0	0
Arkangelsk	0.394	6.735	0	0
Ashkhabad	0.404	4.563	0	0
Bekescaba	0.315	4.557	0	0
Dourbes	0.381	5.010	0	0
Ebro	0.494	5.224	0	0
Gorki	0.398	5.763	0	0
Juliusruh-Ruegen	0.393	5.626	0	0
Kaliningrad	0.381	5.373	0	0
Kiev	0.378	4.944	0	0
Lannion	0.375	4.935	0	0
Lycksele	0.431	7.475	0	0
Moskow	0.398	5.560	0	0
Nurmijarvi	0.551	8.630	0	0
Poitiers	0.385	4.761	0	0
Pruhonice	0.353	4.985	0	0
Rome	0.460	4.780	0	0
Rostov	0.347	4.373	0	0
Slough	0.392	5.362	0	0
Sofia	0.506	6.128	0	0
St. Petersburg	0.404	6.095	0	0
Sverdlovsk	0.389	5.543	0	0
Tbilisi	0.407	4.714	0	0
Uppsala	0.433	6.424	0	0

values raised at the 4^{th} power. The f_0E values were calculated using:

a) For the daytime values the formula proposed by Kouris (1981) and accepted by ITU-R (1994):

$$f_0E^4 = A\,S\,L\,D\,E \qquad (2.1)$$

where

$A = \cos^p \chi$
$p = 1.20$
$\chi =$ solar-zenith angle
$S = (1 + 0.0091\,R_{12})$
$L = 88 + 31 \cos \varphi$
$D = d^{-2}$
$d =$ the ratio of the Sun-Earth distance on the 15^{th} day of each month to the average value of the year.
$E = \cos^m \chi_{noon}$
$m = 0.11\text{-}0.49 \cos \varphi$.

b) For the night-time values the IRI-90 formula (Rawer and Biliza, 1990):

$$f_0E^4 = A\,B\,C\,D \qquad (2.2)$$

with

$A = 1 + 0.0094\,(COV_{12}\text{-}66)$
$B = \cos^m \chi_{noon}$
$m = 0.11\text{-}0.49 \cos \varphi$
$C = 92 + 35 \cos \varphi$
$D = \cos^m \chi_e$
$\chi_e = \chi - 3 \log\,(1 + \exp^{(\chi\text{-}89.98)/3})$
$COV_{12} = 63.7 + 0.728\,R_{12} + 0.00089\,R_{12}^2$.

3. Results and discussion

In order to investigate the accuracy of the models, the standard deviation, the average value of percentage deviation, the scatter error and

Table IIa. Statistical evaluation of the prediction ability of the SSM when the coefficients of the stations of table I are used.

Station	Standard deviation	Average %	Scatter error	Systematic error
Juliusruh-Ruegen	0.472	7.715	0.548	0.278
Kiev	0.502	7.080	0.581	0.292
Lannion	0.460	6.014	0.499	0.043
Moskow	0.439	6.762	0.498	0.236
Poitiers	0.497	5.398	0.548	0.168
Rome	0.487	6.010	0.522	0.186
Slough	0.516	6.515	0.540	0.157
Sverdlovsk	0.489	6.963	0.523	0.105

Table IIb. Statistical evaluation of the prediction ability of the SSM when the coefficients of Slough are used.

Station	Standard deviation	Average %	Scatter error	Systematic error
Juliusruh-Ruegen	0.658	11.131	0.678	0.163
Kiev	0.700	10.724	0.724	0.816
Lannion	0.733	10.465	0.741	−0.062
Moskow	0.736	12.282	0.742	0.088
Poitiers	0.786	11.568	0.851	−0.325
Rome	0.665	10.045	0.759	−0.366
Sverdlovsk	0.813	13.070	0.813	0.013

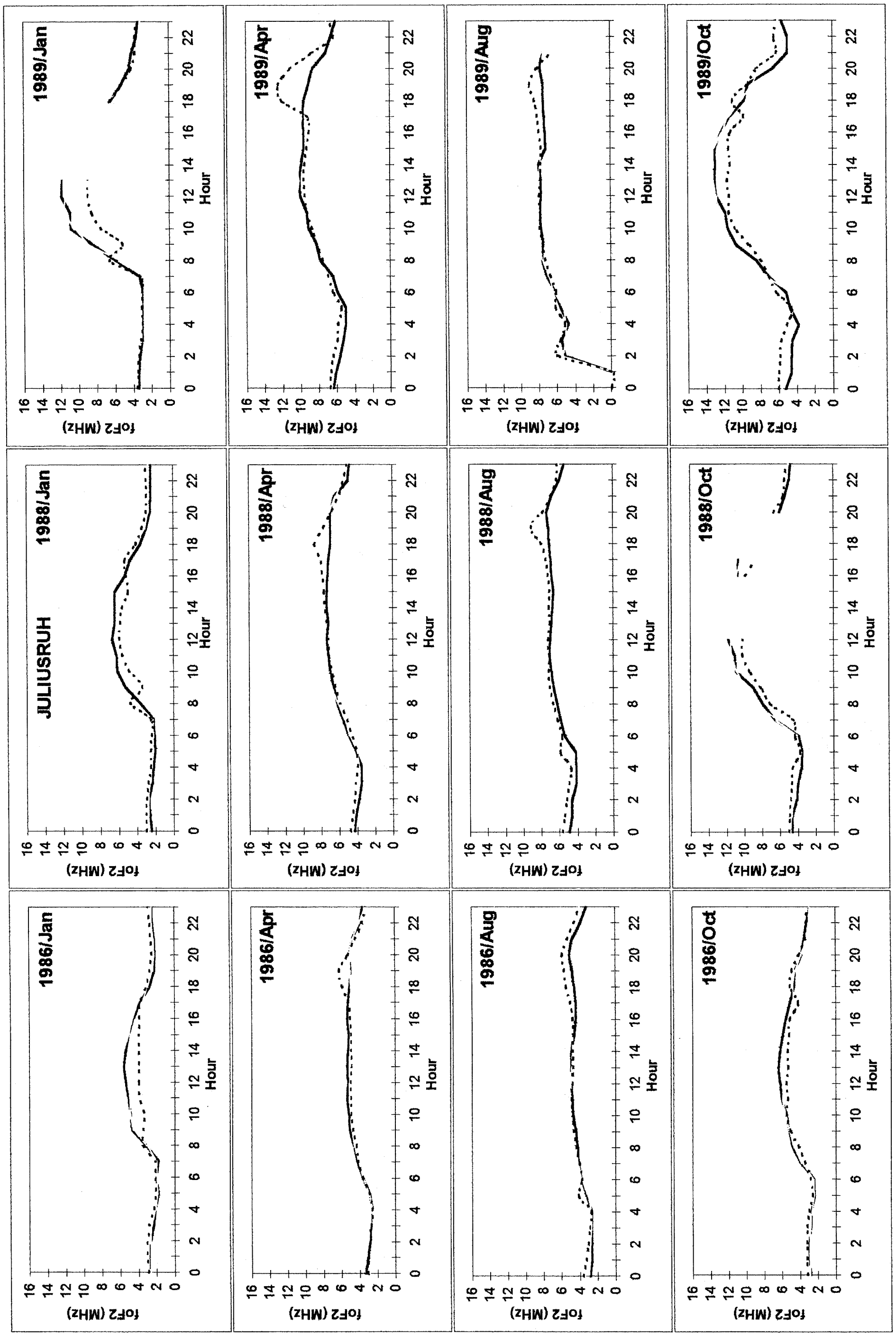

Fig. 1. Comparison of observed (——), predicted by the respective SSM (   ) and by the SSM of Slough (- - -) for JULIUSRUH, for January, April, August and October and for a year of low (1986), a year of medium (1988) and a year of high (1989) solar activity.

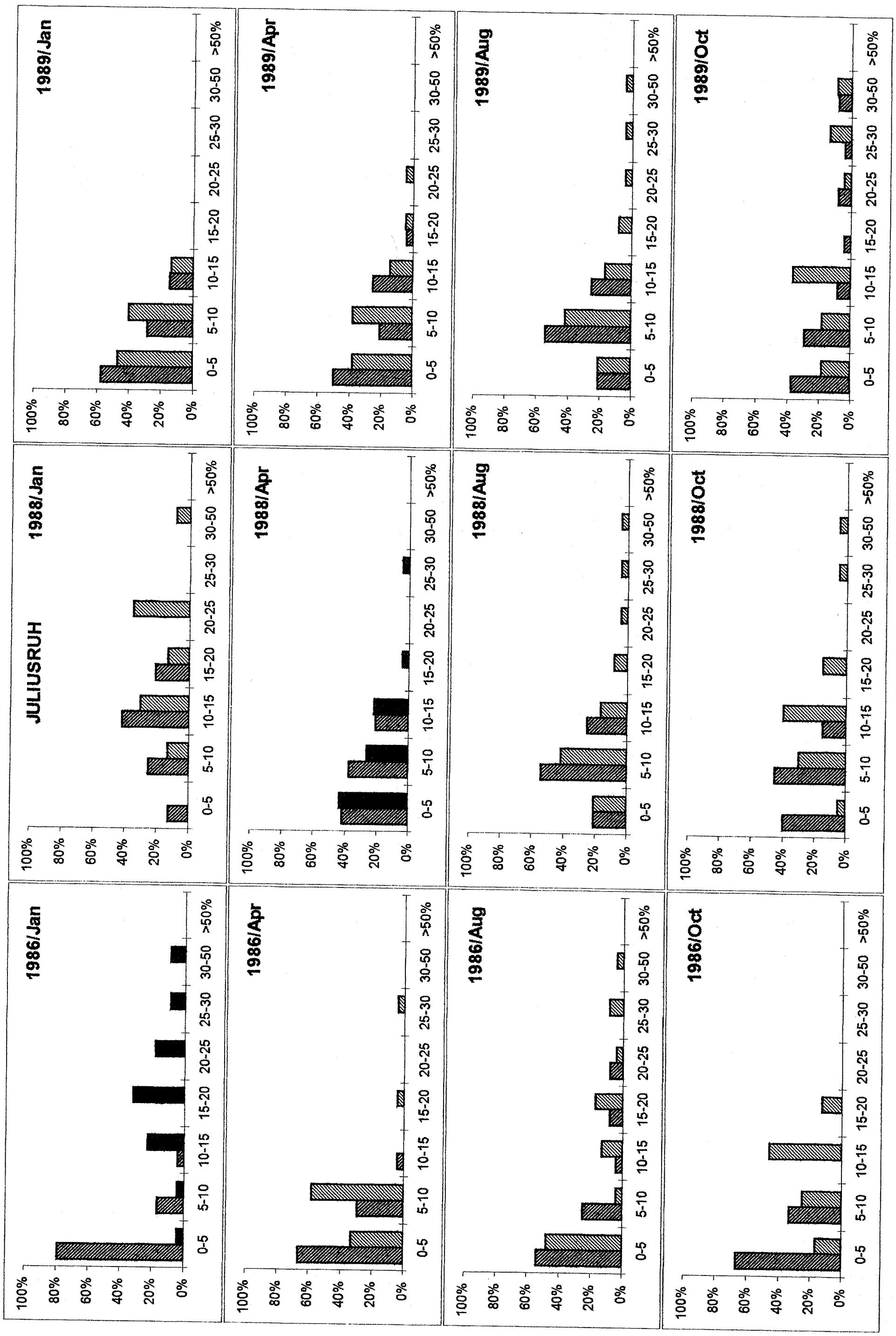

Fig. 2. Comparison of the normalized difference distribution for the f_0F_2 values predicted by the respective SSM ( ) and by the SSM of Slough ( ) for JULIUSRUH, for January, April, August and October and for a year of low (1986), a year of medium (1988) and a year of high (1989) solar activity.

the systematic error, as proposed by Stanislawska and Juchnikowski (1996), were calculated for each station. The results are listed in table I. It is evident that the retrospective accuracy of the model is reasonable.

To validate the single-station model, hourly-monthly median f_0F_2 values were predicted for eight arbitrarily selected stations and for a year of low (1986, $\overline{R_{12}}$ = 13.8), a year of medium (1988, $\overline{R_{12}}$ = 98.5) and a year of high solar activity (1989, $\overline{R_{12}}$ = 153.9) and the above mentioned statistical parameters have been calculated (table IIa). The unique criterion for the selection of the ionospheric stations was the availability of f_0F_2 values for these years. From table IIa it can be seen that all four parameters lie within acceptable accuracy margins and that the single-station model slightly overestimates the measured f_0F_2 values.

To assess the possibility of applying these single station models in ionospheric mapping of the F_2-layer critical frequency, an attempt was made to predict f_0F_2 values for the ionospheric stations of table IIa using the single station model developed for Slough and the corresponding f_0E values of the station. The resulting statistical parameters are presented in table IIb. From this table and from fig. 1, which highlights the hourly-monthly median values predicted by the single-station model and by the developed mapping technique on the one hand and the observed f_0F_2 values on the other hand at Juliusruh in 1986, 1988 and 1989 and for January, May, August and October, it can be seen that the agreement is very good. It can also be seen that the resulting errors are smaller for the year of low solar activity than for the year of high solar activity, whereas there is no clear correlation between the degradation of the reliability of the prediction and of the distance of the station where the single station model has been developed from Slough. On the other hand it is worth mentioning that the estimated f_0F_2 values are always larger than the observed ones in winter and summer whereas they are always smaller in the equinoxes.

Finally, from fig. 2 it can be seen that:

– When polynomial coefficients of the station are used to predict the f_0F_2 values, then the percentage error, with a few non-systematic exceptions, is almost always concentrated in the boundary of 0-5% in years of low solar activity, and is always concentrated in the boundaries 0-10% in years of high and medium solar activity.

– When the coefficients of Slough are used to predict the f_0F_2 values, then the percentage error is concentrated to a percentage larger than 60% in the boundaries 0-10%; a fact that is quite promising.

4. Conclusions

Ionospheric monthly-median values of the F_2- and E-layer critical frequencies from 24 mid-latitude European stations were fitted to a second degree polynomial and their correlation was discussed. The resulting model was used to predict monthly-median f_0F_2 values for different ionospheric stations and for high, medium and low ionospheric activity. Then an application of the single station model developed for Slough to mapping the F_2-layer critical frequency was investigated. Thus a prediction of the monthly median f_0F_2 values for eight mid-latitude European stations was achieved using the single-station model of Slough and the corresponding f_0E values of the station under investigation. The f_0F_2 values obtained are reasonably accurate. It seems that this method is suitable for ionospheric f_0F_2 monthly-median mapping in the sense that the only input required are the calculated f_0E values for a specific location and the relevant single-station model derived for Slough. It is evident that the main advantage of this method is its simplicity and the restricted number of parameters needed.

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