SPATIAL CORRELATION ASSESSMENT OF IONOSPHERIC PARAMETERS FOR LIMITED-AREA MAPPING

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ABSTRACT

Ionospheric parameters, like meteorological factors, are subject to great spatial and temporal variations, and whilst there are systematic changes with time-of-day, season and solar epoch as well as generally significant spatial changes over the orders of hundreds of kilometres that can be modelled there are also major variations on individual occasions, both from one day to the next at a given hour and also from minute to minute within an hour that must be regarded as irregular. Spatial gradients on single days are typically greater than the corresponding gradients in monthly median values. They also tend to be larger when day-to-day variability is most, such as at high and equatorial latitudes. In this paper the critical frequency of F2 layer *foF2* and the Total Electron Content *TEC* data are examined with the use of the statistical analysis. Particular attention is paid to the determination of a latitude/longitude relative scaling factor (*SF*) and the extent to which this changes for different occasions and for the separate mapped parameters. Scaling factor introduces the anisotropy of the region to the semivariogram from the speculation based on the physical knowledge of the region. Comparisons of the latitude/longitude scaling parameter *SF* used in map generation indicate that for the greatest accuracy *SF* should be separately determined for each parameter.

INTRODUCTION

Both parameters *foF2 and TEC* in order to assess radiopropagation effects over terrestrial HF and Earth-space links and for aeronomical studies there is importance to be able to produce so-called specific epoch instantaneous maps of ionospheric parameters [1], as well as monthly median maps. Instantaneous maps may relate to past occasions based on measured input data, or be derived from forecast parameter values for times in the future. Various approaches to the use of monthly median models to smooth between bottomside ionosphere instantaneous measurements in remote areas have been developed with some success [2], but this work remains a subject of ongoing activity not considered further here. In this paper maps are produced entirely from measurement data.

The ionospheric characteristic *foF2* and the *TEC* are generally correlated; however their spatial behaviour as observed on limited-area maps can show remarkable differences. Without recourse to theory, mapping structure provides a valuable means of examining measurement data and their spatial trends; significant systematic dependencies in space can be shown, as well as some occasional phenomena. The maps are an adequate substitute in most cases. But the required accuracy of the maps sometimes cannot be assessed on the basis of one-parameter data sets.

In this paper *foF2* and *TEC* data are examined in parallel during ionospheric quiet and disturbed conditions with the use of the statistical analysis. Additionally some remarks concerning the critical frequencies of F1 (*foF1*) and E (*foE*) layer are supplied. Than samples of the instantaneous maps are supplied. Maps of ionospheric parameters are constructed with the use of Kriging technique from limited location measurements. Kriging uses regional variable theory geostatistical techniques to calculate the autocorrelation between data points and is based on weighted averages, where the weights depend on the distance separation as given directly from the semivariogram. Maps of total electron content are compared with those of the corresponding ionospheric characteristic *foF2* derived from disparate data sources. Particular attention is paid to the determination of a latitude/longitude relative scaling factor (*SF*) and the extent to which this changes for different occasions and for the separate mapped parameters. Scaling factor introduces the anisotropy of the region to the semivariogram from the speculation based on the physical knowledge of the region. Comparisons between *foF2* and *TEC* maps for the same epochs reveal important differences in the shapes, positions and magnitudes of the associated isopleths, such that a simple slab thickness model could not be used to equate the two data sets.

MEASUREMENT SOURCES

Regular synoptic measurements using standardised procedures of key ionospheric parameters indicative of the bottom-side ionosphere peak densities and heights of the various layers (eg *foF2, M(3000)F2, foF1, foE*) are produced at least once an hour at upwards of a hundred locations world-wide [3]. Data bases of past ionospheric characteristics have been compiled, with European results assembled at Rutherford Appleton Laboratory (UK) on CD-ROM, also updated by data from the Ionospheric Despatch Centre of the SRC, Warsaw [4] (http://www.cbk.waw.pl/rwc/idce). Corresponding information is now becoming available in the form of co-ordinated measurements of the *TEC* within a vertical column of unit cross section between ground and geostationary or orbiting satellites such as those of the GPS system [5]. Although not as extensive in numbers of measuring locations or length of time over which such data have been produced, these latter are particularly important because they characterise the corresponding top-side ionosphere and many propagation phenomena experienced on Earth-space paths such as refraction, angular deviation, group-path delay, phase-path change, dispersion and polarisation rotation depend on *TEC*. The sources of *TEC* data are 24 GPS measuring stations within Europe from the International GPS Service for Geodynamics (IGS). *TEC* estimations along all GPS satellite links in view for elevation angles greater than 10^o are derived using a technique developed by Ciraolo [6]. Assuming a single-layer approximation for the ionosphere, these slant *TEC* data are then converted to equivalent vertical values at the pierce point of the raypath for an ionospheric shell fixed at 400km height. *TEC* data have been obtained from Rutherford Appleton Laboratory (UK) (http://www.rcru.rl.ac.uk/weather/tec). In this particular studies mainly ionospherically positively disturbed days in 1998 ware considered. Data were selected according to the catalogue available in IDCE [4].

SPATIAL STATISTICS AND MAPPING RESULTS

Correlation distances at middle latitudes are usually less in latitude than in longitude. This fact produces the elliptical shape of the curves on a plane described in degrees. One could expect this because the distance difference between 1 degree in latitude and one degree in longitude. However elliptical shapes can also be seen when the distance between the stations is described in kilometres. Some statistical studies for foF2 characteristics have been presented in [7].
Correlation coefficients for *TEC, foF2, foE* and *foF1* separately were calculated in order to build the correlation ellipses and to determine the scaling factor *SF* that illustrates the anisotropy of the medium.
The provided calculations are as follows: for every parameter for every epoch the correlation coefficient *K* is calculated for every pair of the stations for which the difference in their latitude (*dlat*) and longitude (*dlon*) is known. The set of *K, dlon and dlat* is obtained. This set is described by the Gaussian function, as *K'* should be 1 within the vicinity of the point (0,0) and should be going down to 0 at both sides:

$$K' = 1 / exp((dlon / A)^2 + (dlat / B)^2) \tag{1}$$

where *A* and *B* are the parameters of the distribution for two stations A and B for which the distances between the them in longitude and latitude is *dlon* and *dlat* respectively.

The best *K'* is found by varying *A* and *B* parameters to minimise the error between *K* and *K*' for the whole considered set of data. In such a case a and B parameters may be interpreted as the correlation radiuses: *A* – for longitude, *B* – for latitude. In the points (*dlon=A, dlat=0*), or (*dlon=0, dlat=B*) the function *K'* is equal 1/e.

Table 1. Scaling factor and the errors of optimalisation for *foE, foF1, foF2* characteristics and the *TEC*.

	foE	*foF1*	*foF2*	*TEC*
SF(dlon/dlat) for K =0.8	1 ($10^o/10^o$)	1 ($7^o/7^o$)	2 ($15^o/8^o$)	5 ($60^o/12^o$)
Error	0.48	0.70	0.56	0.25

In general, it is well known that correlation distances depend on direction and so can be regarded as anisotropic, with typically the ionosphere systematically correlated over appreciably greater distances E-W than N-S [8]. The scaling factor *SF* obtained for *foE* and *foF1* characteristics is about 1, what confirms the very well known fact that that at the heights of F1 and E layer all dynamic spatial changes of the electron density are connected with the influence of photoionisation. The influence of the factors as winds can be neglected and in the result the ionosphere is almost isotropic. *SF* in F2 layer is 2. This value is generally the same as appears in the paper [9] where *SF* is obtained from the kriging technique, from the behaviour of the semivariogram. *SF* values from both papers are the same, as in both only data from the mid-latitudes were considered. Comparing with the results of the paper [10] where for *foF2* characteristics at the low and equatorial latitudes the *SF* was found 0.8 we may say that however at these latitudes the magnetic field lines are almost paralleled to the F2 layer, and supposed to carry larger amount of plasma from higher latitudes, the vertical motion connected to the fountain effect is much more stronger and influences this region much more than the magnetic field. For the same selected periods the *SF* for *TEC* parameter is 5. It means that data are much more correlated in the latitude than in longitude, but the correlation is much more stronger than for *foF2* characteristic. The first explanation is that the F2 layer is much more connected with the motion of the plasma driven by winds etc, while upper ionosphere is driven mainly by magnetic field (motion of the plasma along the magnetic field lines). This drastic difference for the *SF* for *TEC* parameter shows the upper ionosphere very anisotropic. Scaling factors as shown above were used for the construction of the instantaneous maps for *foF2* and *TEC* parameters.

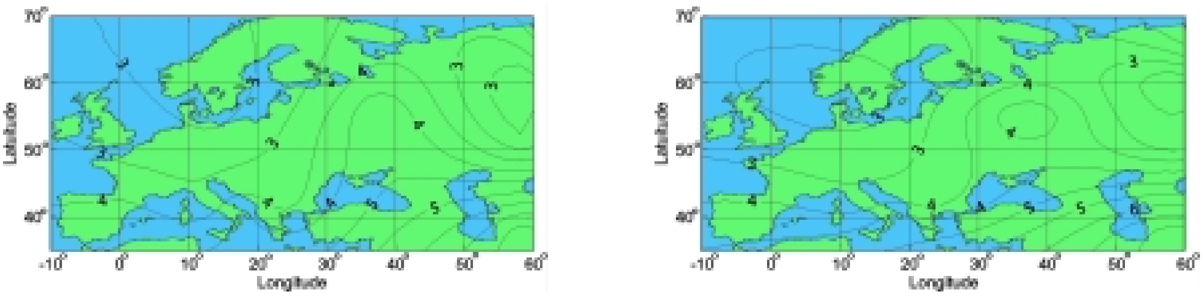

Fig.1. *foF2* maps for 27 January 1998 6UT. Left *SF*=1, right *SF*=2.

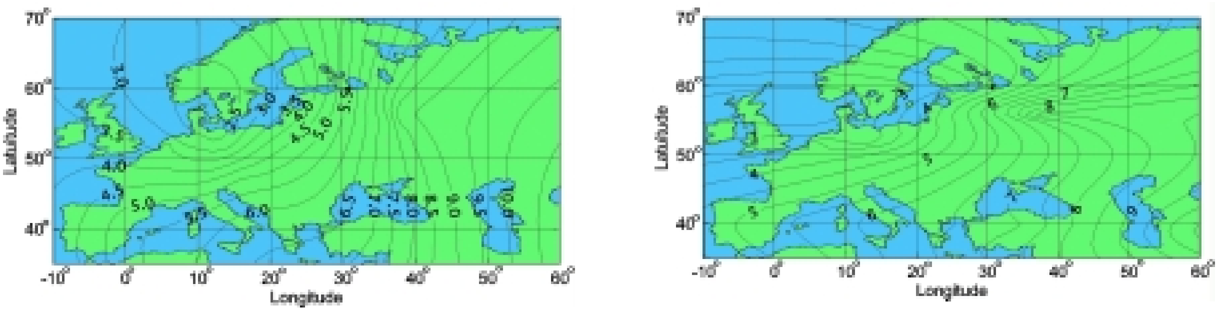

Fig. 2. *TEC* maps for 27 January 1998 6UT. Left *SF*=1, right *SF*=5.

Most mapping procedures among data-sparse isolated measurements involve the initial generation of values on a constant-spacing rectangular grid, in this case taken to be uniform in latitude and longitude, followed by contouring among the grid-point values. The grid values are derived by averaging among the data-point values with the application of appropriate weighting factors associated with each. These weighting factors depend on distance separation between measurement and grid-point locations and the degree of correlation associated with the variations over that area and in that direction. Various approaches to the determination of optimum weighting factors exist [11, 12, 13]. The particular approach followed in our case here has been initiated by [14] and further developed by [8]. So the concept of a relative scaling factor *SF* is introduced to distances in latitude and longitude before application of the kriging technique. *SF* can change over different parts of a single map and particularly it also varies with occasion [15], however the results presented there are not representative, as data used there consider only one quiet, and one disturbed day. In practice though it is necessary to take mean *SF* ratios over the whole area of a given map and over all hours of a given day, as determined by grouping measurement data.

Here we make comparisons of *TEC* and corresponding *foF2* maps for the same epochs. Figure 1 presents *foF2* maps for European area for two scaling factors (1 and 2). Figure 2 presents *TEC* maps for the same epoch for *SF*=1 and 5.

CONCLUSIONS

The kriging technique of instantaneous ionospheric mapping has been extended to include a variable correlation ellipse axial ratio for different days and as a function of time-of-day. *foF2* values from European vertical-incidence synoptic sounding stations and standardised *TEC* measurement data collected within the European chain of GPS stations have been used to generate instantaneous maps for particular epochs. These show much greater geographical structure than exists in the corresponding monthly median maps. *SF*=2 for foF2 characteristics has been applied to the COST 251 instantaneous mapping procedure [10]. Comparisons of the latitude/longitude scaling parameter SF shows that for the greatest accuracy SF should be separately determined for each parameter. The range of values encountered on different days of a month confirms that use of monthly median figures is not an acceptable approach. Proposed scaling factors have significance to communications, especially to Earth-space systems where either short-term propagation predictions or storm predictions are needed.

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