The ionospheric foF2 reconstruction in China region using the Kriging method

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Abstract

Hourly values foF2, observed at the ten ionosonde stations in China a have been used to investigate an ionospheric reconstruction method by introducing the CRI model as background in China region. In this method the regional-dependent variable is adopted as the relative difference between the estimated and the CRI modeled values of foF2. In this method the regional-dependent variable is adopted as the relative difference between the estimated and the CRI modeled values of foF2. The error analysis showed that this model performs well within the reasonable bounds, which is suitable in China region.

1. Introduction

Radio waves propagating through the Earth's ionosphere are greatly influenced by the F2 layer maximum electron density, which is simply related to the critical frequency foF2. The availability of the ionospheric reconstruction has got particular importance in HF propagation assessments and Earth-space communication. Many scientists have done much work to deal with the regional reconstruction for long time and have deduced several methods. One of the reconstruction methods that regard these circumstances of measurements is the Kriging method. The Kriging method is based on the characteristic variability demonstrations using the semivariogram, i.e. the function that illustrates the differentiation of the parameter value depending on the distance between the measurements. In the statistical meaning the Kriging method is an unbiased and optimum method for estimating values of regional-dependent variables in a given area based on the correlation of the variables. The Kriging method has minimum variances when applied to region-dependent variables [4]. Kriging consists in giving to the particular measurements the weighting factors that assure the most accurate estimation of the unknown parameter [5]. A computer contouring technique based upon this method is a useful tool in evaluation and interpretation of ionospheric data [1-2, 7].

2. The Kriging method

The Kriging method has recently received significant attention due to its excellent results reported for various applications. A brief description of the Kriging method [3] is given as follows.

Assuming Z(x) is a regional-dependent variable, satisfying the second order stationary distribution, which is the special distribution of the randomly variable Z(x) and is independent of the location, the exist corresponding covariance c(h) and the semivariogram (h) are dependent only on h, the distance between the two points.

Knowing the values of $Z(x_i)$ (i = 1, 2, 3 · · · , n) at several points in a given area, the Kriging method can be used to calculate the estimated value at any point x_0. The weighting factors λ_i is calculated and let the weighted average

$$Z_P(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \tag{1}$$

become the unbiased and optimum estimate of the unknown parameter $Z(x_0)$. The weighting factors λ_i and Lagrange factor μ should meet the following Kriging equations:

$$\begin{cases} \sum_{j=1}^{n} \lambda_i c(\gamma_i, \gamma_j) - \mu = c(\gamma_i, V) \\ \sum_{i=1}^{n} \lambda_i = 1 \end{cases} \tag{2}$$

where i=1,2,3,…, n. Solving the above n+1 linear equations, the weighting factors λ_i and Lagrange factor μ can be obtained and substituted into the Eq.(1) to get the Kriging estimated vales of $Z_P(x_0)$ at the point x_0.

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The Kriging method can be used to the ionospheric regional reconstruction. Assuming Z(x, y) is an ionospheric parameter, knowing the measured values of $Z(x_i, y_i)$, i = 1, 2, 3, · · · , n, at all of the ionosonde stations in a given area, the Kriging estimated values of $Z_P(x_0, y_0)$ at any given point (x_0, y_0) in the area. The result is a weighted average of all input values $Z(x_i, y_i)$, which can be expressed as follows:

$$Z_P(x_0, y_0) = \sum_{i=1}^{n} W_i Z(x_i, y_i) \tag{3}$$

where W_i is the weighting factor.

The semivariogram can be approximated by a linear function which crossed through the origin. Thus,

$$\gamma(x_i, y_i; x_j, y_j) = \gamma(D_{ij}) = kD_{ij} \tag{4}$$

Using the semivariogram instead of the covariance in Eqs.(2), the Kriging equations for the ionospheric regional reconstruction can be obtained from the system of n+1 Linear equations

$$\begin{cases} \sum_{j=1}^{n} D_{ij} \times W_i - \mu = D_{i0} \\ \sum_{i=1}^{n} \lambda_i = 1 \end{cases} \tag{5}$$

where i,j=1…,n. D_{ij} is the value of the semivariogram for the ionospheric distance between i-th and j-th points instead of the semivariogram; μ is Lagrange factor.

The 'ionospheric distance' D is introduced here. The term 'ionospheric distance' between two stations i and j is defined as follows:

$$D_{ij} = \sqrt{\{SK \times [\mathrm{Lon}(i) - \mathrm{Lon}(j)]\}^2 + \{SF \times [\mathrm{Lat}(i) - \mathrm{Lat}(j)]\}^2} \tag{6}$$

where Lon(i) and Lat(i) are the latitude and longitude of point i, respectively. *SF*, *SK* is the scaling factor to consider the ionospheric changes versus latitude and longitude. The equations are independent of the slope of the semivariogram. Therefore the resultant weights do not depend on the value of the slope.

3. Results and Discussion

In practice the ionospheric parameter is not an ideal steady randomly variable. By introducing a background ionosphere the reconstruction error will be considerable reduced, particularly in the condition that the available measurements are very few. Interpolation technique is applied to the deviations of the measurements from the monthly median model which is considered as a background for mapping. Specific ionospheric structures are more accurately reproduced together with the monthly median model (part of information about the physical gradients of electron concentration is retained even when the measurements are made far away from them. This technique helps to smooth out many discontinuities. Thus the values of the considered on the base of deviations demonstrate considerable improvement [6]. The China Reference Ionosphere (CRI) is adopted as the background in the ionospheric foF2 reconstruction in China region. This model could provide the ionospheric monthly medians of the electron density, electron temperature, and ion temperature and ion composition in altitudes from 60 to 1000 km in China and its surrounding area (65°N-40°S, 60°E,150°E) [8].

In the forming of the reconstruction method the regional-dependent variables are chosen as follows:

$$Z(x, y) = (\mathrm{foF2(x,y)} - \overline{\mathrm{foF2}}(x, y)) / \overline{\mathrm{foF2}}(x, y) \tag{7}$$

Where $\overline{\mathrm{foF2}}(x, y)$ is the background field calculated by the CRI model.

The Kriging method based the CRI model has been selected for the ionospheric reconstruction in China region. For the different indexes SF and SK, the computer simulations of the ionospheric reconstruction has been done for each hour, and in the solar minimum year (1981) and maximum year (1986) by using the systematic measured data from ten Chinese stations.

The cross validation are used here to test the method. Firstly, assuming the ionospheric parameter is unknown at a given ionosonde station, the estimated value of the parameter can be obtained by applying the Kriging method on the other stations. The performance of the reconstruction method is evaluated by the mean square deviation σ of the reconstruction values to the observed, which are calculated as

$$\sigma = \sqrt{\frac{1}{n} \sum (\mathrm{foF2_{obs}} - \mathrm{foF2_{pred}})^2}\,. \tag{8}$$

where n is the number of the samples in valuation,$foF2_{obs}$ and $foF2_{pred}$ represent the observed values and the forecasted values, respectively. σ is called as reconstruction error.

Table 1 the ionospheric reconstruction error σ of different indexes SF and SK in Beijing

year	σ (MHz)											
SF	1.0						0.8					
SK	0.7	0.6	0.5	0.4	0.3	0.2	0.7	0.6	0.5	0.4	0.3	0.2
1981	0.87	0.84	0.82	0.80	0.79	0.79	0.94	0.89	0.85	0.82	0.80	0.79
SF	1.2						2					
SK	1	0.8	0.6	0.4	0.3	0.2	1	0.8	0.6	0.4	0.3	0.2
1981	0.92	0.86	0.82	0.79	0.79	0.79	0.89	0.82	0.80	0.79	0.79	0.79
SF	1.0						0.8					
SK	0.7	0.6	0.5	0.4	0.3	0.2	0.7	0.6	0.5	0.4	0.3	0.2
1986	0.54	0.54	0.53	0.53	0.53	0..53	0.56	0.55	0.53	0.53	0.53	0.53
SF	1.2						2					
SK	1	0.8	0.6	0.4	0.3	0.2	1	0.8	0.6	0.4	0.3	0.2
1986	0.56	0.54	0.53	0.53	0.53	0.52	0.55	0.54	0.53	0.53	0.53	0.52

Table 1 shows one example in the ionospheric reconstruction error σ of different indexes *SF* and *SK* in Beijing stations. The reconstruction errors have been calculated according to Equation (7). The results presented in Tables 1 demonstrate that for the different indexes SF and SK, the reconstruction error σ is usually smaller when SF is 1.2 and SK is 0.3, respectively. So we choose these parameters in the ionospheric reconstruction model, which could better reflect the ionospheric foF2 changes along latitude and longitude.

Table 2 the reconstruction error σ of the ionospheric foF2 at ten stations in 2006 (unit: MHz)

	Haikou	Guangzhou	Chongqing	Lasa	Lanzhou	Qingdao	Beijing	Urumchi	Changchun	Manzhouli
January	1.12	1.03	0.81	1.01	0.56	0.61	0.62	0.67	0.62	0.57
February	1.28	1.10	0.74	0.86	0.45	0.52	0.50	0.65	0.58	0.50
March	1.32	1.20	0.91	1.16	0.49	0.45	0.43	0.70	0.50	0.47
April	1.31	1.18	0.93	1.13	0.49	0.47	0.41	0.86	0.49	0.51
May	1.11	1.07	0.83	0.98	0.56	0.46	0.46	1.01	0.41	0.44
June	1.07	0.82	0.66	0.89	0.49	0.43	0.41	1.08	0.37	0.41
July	1.10	0.96	0.67	0.84	0.52	0.45	0.44	1.00	0.39	0.44
August	1.27	1.05	0.73	0.90	0.48	0.44	0.45	1.07	0.39	0.46
September	1.42	1.15	0.82	1.05	0.43	0.48	0.38	1.01	0.39	0.56
October	1.33	1.15	0.87	1.01	0.50	0.50	0.45	1.44	0.52	0.54
November	1.42	1.08	0.79	1.05	0.46	0.46	0.42	1.50	0.58	0.53
December	1.27	0.88	0.72	0.83	0.48	0.48	0.42	1.16	0.52	0.55

Table 2 shows the evaluating results of the year 2006. It can be seen that the reconstruction errors are in the range of 0.3-1.0 MHz. The errors as a whole are different between the edgy and inner stations and between the lower and higher latitude stations. The RMS error is higher at low latitudes than at middle latitudes. These larger errors may be a result of the equatorial anomaly and the increased ionospheric variability in the low latitude region, due to complex electrodynamic interactions involving the neutral wind, the Earth's magnetic field and electric field in the F region. Alternately the larger errors may be due to the denser ionosphere in the low latitudinal region, which makes σ larger at low latitudes than at middle latitudes [1]. Therefore, the data from the edgy stations and lower latitude stations are very important in the ionospheric reconstruction in China region.

Figure 1 shows the contour maps of foF2 by used the data at 18UT on 18th February, 1979. In the Figures, the unit of the values is 0.1MHz, and the reconstruction area is range of 15°N-50°N and 80°E-130°E. It can be seen from the figures that reflect the ionospheric regional characters and improves the accuracy and stability of the reconstruction, but the reconstruction values of foF2 exist large difference in the southern China. The main reason might be that the southern China usually located in the northern hump of the equatorial anomaly in daytime, and most of the ionosonde stations of the network locate in the north of the hump. Therefore, it is difficult to reflect the features of the whole hump based on very few observations nearby.

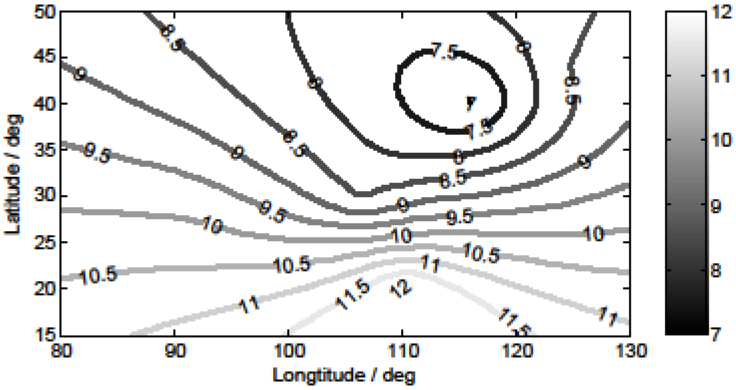

Fig.1 Figure 1 Contour map of foF2 at 18UT on 18th February, 1979

5. Conclusion

This paper has presented an ionospheric reconstruction method by introducing the CRI model as background when SF and SK are 1.2 and 0.3 respectively, which reflects the ionospheric foF2 changes better versus latitude and longitude. The Kriging method based the CRI model is used for interpolation of the ionospheric parameter foF2, which the results reflect the ionospheric regional characters and improves the accuracy and stability of the reconstruction. The error analysis shows that this model performs well within the reasonable bounds, which is suitable in China region. The data from low-latitude stations are very important in the ionospheric reconstruction and short-term forecasting in China.

6. Acknowledgments

This work was supported by the National Key Laboratory of Electromagnetic Environment, and the National Natural Science Foundation of China (Grant Nos. 61032009).

7. References

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