A new method for ionospheric short-term forecast using similar-day modeling

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***Abstract*—The conception of similar-day and its modelling of ionospheric short-term forecast are presented. The similar-day method not only has the merits of simpleness and facility, but also improves the forecast accuracy. A test of the method for 1h~24h f_0F_2 forecast of Manzhouli, Beijing, Urumchi and Haikou during the periods of the high level solar activities (in 1980) and a comparison with the autocorrelation method developed by LIU R. show that the method is realistic and reliable. The similar-day method betters the forecast result obviously for more than *N* h ahead（*N*=1 for winter and equinoxes, *N*=3 for summer）, and especially in winter, the relative error can be usually reduced by 2 percent or so. Finally, a new method for ionospheric short-term forecast is formed by combining the similar-day method and the autocorrelation method.**

I. INTRODUCTION

Variations in the ionosphere can affect a variety of ground-based and space-borne technological systems (e.g. high frequency (HF) communications, the Global Positioning System (GPS), over-the horizon radar, as well as ultra high frequency (UHF) satellite communications, etc.) These may have important military and socio-economical impacts, and hence the ability to forecast ionospheric conditions is valuable.

Besides diurnal, seasonal and solar cycle variations, the ionosphere experiences an obvious day-to-day variations and storm-time variations. For example, the day-to-day variation of f0F2 in mid-latitudes is usually as high as 15 percent of the monthly median value. During ionospheric storms the variation of f0F2 sometimes exceeds 30 percent. So the accurate prediction of the ionsphere for several hours or several days ahead is difficult.

Many techniques have been developed for ionospheric forecasting worldwide, among which are the auto-correlation method[1], the multiple linear regression method[2], and the artificial neural network method[3]. In China, several methods have been established for long-term forecast describing the ionospheric mean characteristics, such as the method of predicting the ionospheric F2 layer in the Asia-Oceania region[4]. While, the fruits about the short-term forecast are not very much. At present, the autocorrelation method developed by LIU R[5] (hereinafter the autocorrelation method) is practical. The method does not require any information about solar-geophysical activity. The only information needed is a long enough period of observations.

Borrowing ideas from the similar-cycle method[6] for sunspot number prediction and the similar-day conception[7] for load forecasting in power system, the similar-day method for ionospheric short-term forecast is presented. A test of the method to produce forecasting values of f_0F_2 from 1 h up to 24 h ahead at Manzhouli, Beijing, Wulumuqi and Haikou during the periods of the high level solar activities (in 1980) shows that the method is realistic.

II. SIMILAR-DAY METHOD

A. *Theory of similar-day modeling*

Due to the critical frequency of the F_2 layer(f_0F_2) having 24 h quasiperiodic variation, the similar-day forecasting method is put forward by introducing the similar-day conception for load forecasting in power system and borrowing ideas from the similar-cycle method for sunspot number prediction. We consider the ionospheric characteristics which is notated by z as a time series with a step of 1 h. First of all, the autocorrelation method is applied to produce predicted values of f_0F_2 from 1 h up to 24 h ahead, and the predicted values are denoted by $z(\tau)(\tau=1,\cdots,24)$. Then, among the historical f_0F_2 we search the series with the length of 24 h whose values and shapes are similar to those of $z(\tau)$, and call them similar-day series. Finally, these similar-day series are averaged to obtain the predicted values.

B. *Preprocess of the historical ionospheric data*

Before searching the similar-days, the historical ionospheric data should be collected and the data must be recent. Time series of ionospheric characteristics often display gaps due to various experimental problems. This can cause serious difficulties for short-term ionospheric predictions, which rely on good quality uninterrupted data. The short gaps can be filled by the method in [8], thus avoiding the need to discard slightly imperfect data.

C. *How to search the similar-day series*

Denote the predicted value series from 1 h up to 24 h ahead using the autocorrelation method as $z(\tau)(\tau=1,\cdots,24)$. Among the historical ionospheric data, the series with length of 24 h are chosen whose values and curves are similar to those of $z(\tau)$, and we name them similar-day series. We use the correlation coefficient to reflect the shape similarity between the predicted value series and the similar-day series, and adopt the absolute deviation to measure the vertical

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distance of them. Define the correlation coefficient E_{PA} and the absolute deviation E_{abs} as follows.

$$E_{PA} = \frac{\sum_{i=1}^{N}[(P_i - P_m)(O_i - O_m)]}{N \cdot S_P S_O} \quad (1)$$

$$E_{abs} = \frac{1}{N}\sum_{i=1}^{N}\left|P_i - O_i\right| \quad (2)$$

Where N is the length of the series and equal to 24 here, P_i is the evaluated series, P_m is the mathematical expectation of P_i, S_P is the standard deviation of P_i, O_i is the predicted value series, O_m is the mathematical expectation of O_i, and S_O is the standard deviation of O_i.

The correlation coefficient E_{PA} reflects the similarity of the evaluated series and the predicted value one and is set between -1 and +1. Larger absolute value means higher correlation. The absolute deviation E_{abs} reflects the vertical distance of the evaluated series and the predicted value one and is equal to zero when the two series are concurrent. So, if E_{PA} is close to 1 and E_{abs} is close to 0, the two series are similar. For given thresholds T_1 and T_2, if the evaluated series satisfies $E_{PA} > T_1$ and $E_{abs} < T_2$, it is chosen as similar-day series.

D. Practical calculating method for similar-day forecast

Considering the ionosphere shows seasonal variations, data in the nearest 30 days are selected as historical sample set. The gaps with length of less than 10 h are filled using the method in [8].

The similar-day forecast procedure is as follows.

1) A 1h~24h f_0F_2 forecast is produced by the autocorrelation method, and the predicted values are denoted by $z(\tau)(\tau = 1, \cdots, 24)$.

2) Among the nearest 30×24 historical f_0F_2 set (assuming f_0F_2 as a time series with a step of 1 h), the similar-day series of $z(\tau)$ are searched. First, the sequence with a fixed length of 24 h is shifted with a time step equal to 24 h from the beginning to the end of the set. The 30 shifts correspond to 30 f_0F_2 series with length of 24 h which are called historical-days. Then, the correlation coefficient E_{PA} and the absolute deviation E_{abs} for each historical-day series are calculated.

3) Sort the historical-day series by E_{abs} in ascending order and choose the first M ones. Among the M series, N series with large E_{PA} are selected as the similar-days of $z(\tau)$ （$M \geq N$, and $M = N = 6$ in this paper）.

4) The N similar-day series are averaged to acquire the final predicted result $\tilde{z}(\tau)(\tau = 1, \cdots, 24)$.

E. Prediction errors and discussion

We take a test of the similar-day method for 1h~24h ahead f_0F_2 forecast of Manzhouli, Beijing, Urumchi and Haikou in 1980 and draw a comparison with the autocorrelation method. The root mean square error and the one normalized by each measured value (hereinafter the relative error) are used as the predicted errors and are denoted by E_{RMSE} and E_{RM} respectively.

$$E_{RMSE} = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(meas(i) - fore(i))^2} \quad (3)$$

$$E_{RM} = \sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(\frac{meas(i) - fore(i)}{meas(i)}\right)^2} \quad (4)$$

where M is the total number of samples, $meas(i)$ is the measured value of f_0F_2 and $fore(i)$ is the predicted value of f0F2.

The result of the error analysis shows that for a forecast of 1~ N h ahead（$N = 1$ for winter and equinoxes，$N = 3$ for summer）, the similar-day method is a little worse than the autocorrelation method, but for more than N h ahead forecast, the former is better than the latter, and especially in winter, the relative error can be usually reduced by 2 percent or so. As an example Fig. 1 shows the prediction errors of f0F2 at Beijing in January 1980. The abscissa is marked the time in advance, from 1 h to 24 h. The ordinate shows the relative error. The value is calculated for the samples of all 31 days and 24 h in January. It can be seen that for 1 h ahead the prediction error of the autocorrelation method is smaller by 1 percent than that of the similar-day method, but for a forecast of 2 h to 24 h in advance, the latter is much better than the former, and the prediction error is reduced by 2.3 percent in average.

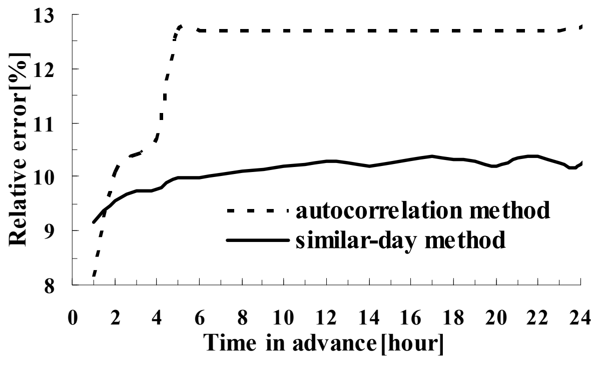

Fig. 1 Prediction errors of f_0F_2 using the similar-day method and the autocorrelation method at Beijing in January 1980.

We have also found that for the forecast of more than N h ahead, the improvement effect of the similar-day method is dependant on the season. Commonly, the improvement degree is significant in winter (November, December, January and February), general in equinoxes (March, April, September and October), and smallest in summer (May, June, July and August). Fig. 2 shows prediction errors (relative) of f0F2 in different seasons at Urumchi in 1980. Note that in winter and equinoxes, the similar-day method betters the forecast result for more than 1 h ahead, the relative errors are respectively reduced by 1.4 percent and 0.4 percent (averaged value), while in summer, the method improves just for more than 3 h ahead with the small improvement degree of 0.15 percent (averaged value).

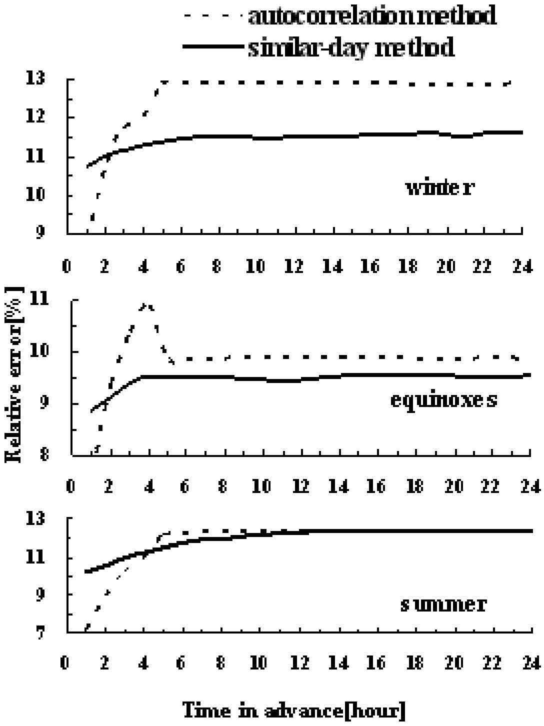

Fig. 2 Prediction errors of f_0F_2 at Urumchi in different seasons in 1980.

III. Conclusions

Based on the above analysis, we can combine the similar-day method and the autocorrelation method to form a new ionospheric short-term forecast technique, i.e. using the autocorrelation method for a forecast of 1 h to N h ahead and similar-day method for more than N h ahead. The new method has high calculating speed and high forecast accuracy, and is practical in China.

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References

[1] P. Muhtarov, I. Kutiev. Autocorrelation method for temporal interpolation and short-term prediction of ionospheric data[J].Radio Science, 1999, 34(2): 459-464.

[2] P. Muhtarov, I. Kutiev, L. Cander. Geomagnetically correlated autoregression model for short-term prediction of ionospheric parameters[J]. Inverse Problems, 2002, 18: 49-65.

[3] Lj R Cander, M Milosavljevic, S Stankovic, et al. Ionospheric forecasting technique by artificial neural network[J]. Electron. Lett.，1998, 34(6): 1573~1574.

[4] 孙宪儒. 亚大地区 F2 电离层预测方法. 通讯学报[J] . 1987, 8(6): 37-45.

[5] Liu R., Liu S, Xu Z, et al. Application of autocorrelation method on ionospheric short-term forecasting in China[J]. Chinese Science Bulletin. 2006, 51(3): 352-357.

[6] Wang Jialong, Han Yanben. “Similar Cycle” method and a discussion of predicted monthly sunspot numbers for solar cycle 23[J]. Chin. J. Space Sci.. 2000, 20(3):278-281.

[7] MO Weiren, ZHANG Boming, SUN Hongbin,, et al. Method to select similar days for short- term load forecasting[J]. Tsinghua Univ (Sci & Tech), 2004, 44(1):106-109.

[8] FENG Jing , LIU Wen, JIAO Peinan, et al. Autocorrelation method for interpolation of ionospheric characteristic parameters [J]. Chin. J. Space Sci. 2009, 29(2): 195-201.