Applicability Analysis of Kriging Methodology for China

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Abstract. A non-nominal condition of ionosphere likely makes the largest threat for aviation service of the Single Frequency (SF) Satellite-Based Augmentation System (SBAS). The Wide Area Augmentation System (WAAS) located in the mid-latitude region has updated the ionospheric grid correction technology from the Inverse Distance Weight (IDW) method to the Kriging methodology that was made primarily to improve system service availability and ensure system service integrity. The implementation of the Kriging methodology utilizes a dynamic fit domain to select a set of measurements and constructs two terms representing the threat of inaccurate model assumptions and the threat of spatial variations, respectively. The advantage of this methodology is that it not only reduces the dependence of the ionospheric augmentation information calculation on the distribution of reference stations but also improves system service performance. However, the BDSBAS (BeiDou Satellite-Based Augmentation System) service area, except for the terrain restricted the distribution of reference stations, has a larger latitude span. It has mid-latitude and low-latitude ionosphere characteristics, especially the irregularity of the low-latitude ionosphere will seriously affect the BDSBAS SF service performance. This paper analyzes the applicability of the Kriging methodology over China and constructs the quantitative relationship of observability between ionospheric measurements and the estimated location to solve the problem. The results show that the Kriging methodology can be used to calculate ionospheric delay augmentation information in the BDSBAS SF augmentation service. The search parameters of the dynamic fit domain in the Kriging can keep unchanged. The research of algorithm for China should focus on the analysis and modeling of ionospheric irregularities, develops the study of error uncertainty to meet the integrity requirements for aviation and improves the services of the system. Additionally, if there is no reference station in the overseas area, it is still difficult to implement effective monitoring of the integrity risk of edge grids caused by ionospheric irregularities, even under the conditions of multi-constellation.

Keywords: Kriging methodology · Ionosphere · Integrity · China

1 Introduction

For the Satellite-Based Augmentation System (SBAS) Single Frequency (SF) service operation capability, the ionospheric delay corrections and integrity parameters calculated by the master station and broadcast to aviation users via the SBAS GEO

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satellites must ensure the system service performance under any ionospheric environmental conditions. The calculation of ionospheric delay augmentation information in SF SBAS uses the grid correction technology [1]. Among them, the Inverse Distance Weight (IDW) method and the Kriging method have mature engineering applications in operational SBAS [2]. However, as shown in Table 1, some differences exist between them. The IDW method is being applied in the European Geostationary Navigation Overlay System (EGNOS). The Wide Area Augmentation System (WAAS) located in mid-latitude has updated the correction technology from the IDW to the Kriging to improve system service availability and ensure system service integrity. It should be noted that the tomographic method, which is a complex technology, is not suggested to apply in engineering due to limited correction accuracy [3].

Table 1. Comparison of IDW and Kriging algorithm

Name	IDW	Kriging
Corrections	Linear weighted (inverse distance) interpolation	Linear unbiased minimum mean square error estimate; 1-st order fit plus random field
Integrity parameters	The maximum value of the error limits of all IPP errors in the update period plus the absolute error is used to calculate integrity parameters	According to regional ionospheric irregularities, the undersampled threat term plus model non-conformance threat term is used to calculate the integrity parameters
Advantages	①The calculation of augmentation information is simple and straightforward ②High applicability between different regions	①Dynamic fit domain to select measurements, higher availability of grid points in the edge area, and higher system service availability ②Algorithm considers possible ionospheric integrity risk and includes ionospheric irregularity detector
Disadvantages	①Strict requirements on the number and distribution of IPPs around IGPs, and lower availability of edge grids ②It exist integrity risk caused by undersampled	The poorer applicability between different regions
Applications	EGNOS system	WAAS system

Compared with IDW, the integrity parameter calculated by the Kriging takes into account the effects of ionosphere irregularities at different scales on system service integrity and constructs an error model. It utilizes a dynamic fit domain to select a set of Ionospheric Pierce Points (IPPs) around an Ionospheric Grid Point (IGP). The advantage of Kriging is that it not only reduces the calculation of the ionospheric augmentation information dependent on the distribution of reference stations but also improves system service performance. However, the implementation of Kriging has regional applicability. The reason is that the augmentation information calculated by Kriging relates to the ionospheric characteristics. The mid-latitude ionosphere is usually smooth and easily estimated, such as the WAAS service area. The ionospheric irregularities affecting SBAS mainly consider caused by ionospheric storms. However, in the low-latitude region, various ionospheric anomalies exist and affect SBAS service performance, such as equatorial anomaly and plasma bubble, etc. Besides the terrain restricted the distribution of reference stations, the BeiDou Satellite-Based Augmentation System (BDSBAS) service area has a larger latitude span. It has mid-latitude and low-latitude ionosphere characteristics. Therefore, Kriging cannot simply apply in BDSBAS to estimate the ionospheric augmentation information.

We analyze the applicability of Kriging over China using the observations from WAAS and the Crustal Movement Observation Network of China (CMONOC). Chapter 2 gives the principle of Kriging. Chapter 3 discusses the applicability of Kriging. Chapter 4 gives conclusions and suggestions.

2 Kriging Methodology

Kriging estimates the vertical ionospheric delay at IGP using the IPPs within a circle centered upon it. We assume that there exist N IPPs lie within the fit radius around the IGP at the location x

$$\mathbf{I_{ipp}} = \begin{bmatrix} I(x_1) & I(x_2) & \cdots & I(x_N) \end{bmatrix}^T \tag{1}$$

where the vertical delay of IPP at the location $x_k = \left(x_{north,k}, x_{east,k}\right)$ (considered as the longitude and latitude) is given by

$$I(x_k) = a_0 + a_1 x_{north,k} + a_2 x_{east,k} + r(x_k) \tag{2}$$

Here, a_0, a_1 and a_2 are the model coefficient defined the planar trend of the ionospheric delay. $r(x_k)$ is a random field superimposed on the planar trend. It is used to characterize the correlation between neighboring measurements. The Grid Ionospheric Vertical Delay (GIVD) and the variance are given by

$$\hat{I}(x) = \sum_{k=1}^{N} \lambda_k I(x_k) = \mathbf{\Lambda}^T \mathbf{I}_{ipp} \tag{3}$$

$$\hat{\sigma}^2(x) = \mathbf{\Lambda}^T \mathbf{C}(\mathbf{h}) \mathbf{\Lambda} - 2\mathbf{\Lambda}^T \mathbf{C}(\mathbf{h_0}) + C(0) \tag{4}$$

where the Kriging coefficients $\mathbf{\Lambda} = \begin{bmatrix} \lambda_1 & \lambda_2 & \cdots & \lambda_N \end{bmatrix}^T$ are calculated based on the unbiased minimum mean square estimation error

$$\mathbf{\Lambda} = \left(\mathbf{W} - \mathbf{H}\mathbf{G}^T\mathbf{W}\right)\mathbf{C}(\mathbf{h_0}) + \mathbf{H}\mathbf{X}, \mathbf{H} = \mathbf{W}\mathbf{G}\left(\mathbf{G}^T\mathbf{W}\mathbf{G}\right)^{-1}, \mathbf{W} = \mathbf{C}^{-1}(\mathbf{h}) \tag{5}$$

where $\mathbf{C}(\mathbf{h})$ is the $N \times N$ spatial covariance matrix between IPPs. h represents the distance between IPPs. $\mathbf{C}(\mathbf{h_0})$ represents the spatial covariance vector between IPP and IGP. $\mathbf{G}$ is the $N \times 3$ observation matrix. $\mathbf{X}$ is the n-dimensional position vector. The more details of Kriging refer to the reference [4].

Integrity parameter, or named the Grid Ionospheric Vertical Delay Error (GIVE), represent the correction uncertainty and provide protection from the adverse influence of ionospheric irregularity [5]. GIVE is defined as

$$GIVE = \kappa_{99.9\%}\sigma_{GIVE} \tag{6}$$

$$\sigma^2_{GIVE} = R^2_{irreg}\hat{\sigma}^2_{Kriging} + \sigma^2_{undersampled} \tag{7}$$

In Eq. (7), the GIVE value fundamentally involves two terms:

(a) A term representing the threat of incorrect model assumptions: this error term is dependent on the ionospheric delay estimation methodology employed by SBAS and the number of measurements from reference stations. The inflated formal estimation error using an inflation factor R^2_{irreg} can protect the threat, which is the assumed ionospheric delay model incompatible with the actual caused by ionospheric irregularities. The inflation factor is defined as

$$R^2_{irreg} = \alpha_n \mathbf{I}^T_{ipp}\left(\mathbf{W} - \mathbf{WG}\left(\mathbf{G}^T\mathbf{WG}\right)^{-1}\mathbf{G}^T\mathbf{W}\right)\mathbf{I}_{ipp} \tag{8}$$

where α_n can be calculated from the integrity risk probability. A detailed introduction of the inflation factor can be found in the literature [5].

(b) A term representing the threat of spatial variations: this error term derived from the ionospheric spatial threat model, which is a function of the actual ionospheric threat space. The "threat" refers to the potential safety hazards in the SBAS caused by insufficient sampling for ionospheric irregularities [6]. This error term is defined as

$$\sigma^{raw}_{undersampler}\left(R_{fit}, RCM\right) = \max_{over\ k,T}\left(\sigma_{undersampled}\right) \tag{9}$$

$$\sigma_{undersampled} = \sqrt{\frac{\left|I(x_k) - \hat{I}(x_k)\right|^2}{K^2_{undersampled}} - \hat{\sigma}^2_k} \tag{10}$$

where $K_{undersampled}$ is the upper bound of the Gaussian error distribution that satisfies the predetermined integrity risk in SBAS [6]. R_{fit} and RCM are used to characterize the position relationship between the IPPs and the IGP, named the fit radius and the Relative Centroid Metric (RCM), respectively. The value of this term mainly depends on the number of observations provided by reference stations, the distribution of observations, and the magnitude of the estimation error term.

3 Applicability Analysis of Kriging Methodology

In SBAS, the ionospheric augmentation information includes ionospheric delay corrections (GIVDs) and integrity parameters (GIVEs). The broadcast GIVEs must bound the user vertical ionospheric delay residuals with a probability of 0.999.

$$P(GIVE(t) > |\hat{I}(t_k) - I(t)|) \geq 99.9\% \quad (11)$$

Different from the IDW, the integrity information calculated in Kriging is based on the integrity risk term caused by the irregularities in the regional ionosphere, in both sampled and undersampled conditions. It not only ensures aviation service integrity but also improves aviation service availability. In this section, we analyze the key parameters of Kriging based on ionospheric measurements from the WAAS and CMONOC, especially the empirical parameters, to verify the applicability of the Kriging over China.

3.1 IPP Search Algorithm

Kriging is a linear unbiased minimum mean square error estimation method. On the standard 350 km ionosphere thin shell model, the fit domain of Kriging, unlike the IDW using four grids around IGP, is defined to be a region within a circle centered upon the IGP [5], as shown in Fig. 1.

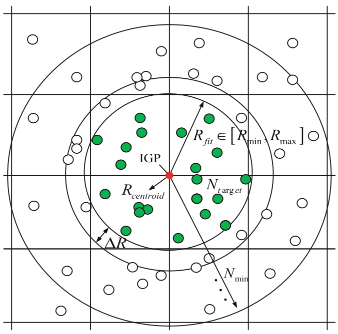

Fig. 1. Definition of the fit domain for Kriging

The implementation of Kriging in WAAS defines the IPP search algorithm to select IPPs for performing estimation. It includes four key parameters, which are the minimum search radius $R_{min} = 800$ km, the maximum search radius $R_{max} = 2100$ km, the number of target points $N_{target} = 30$, and the minimum number of target points $N_{min} = 10$ [5]. The configuration of the IPP search parameters, on the one hand, is related to GIVD estimation. It will also reflect the distribution of IPPs around IGP and affect the value of the spatial undersampled error term, that is, the calculation of GIVEs.

However, no relevant literature has been found to explain the reasons for how to define these parameters.

According to the definition of the fit domain, it can be considered that the four IPP search parameters are the result of a trade-off between the number of IPPs and the size of the search area. A larger search space will capture more IPPs, but it may result in reduced correction accuracy and introduced larger spatial uncorrelation errors, especially in low-latitude regions. A smaller search space will capture a small number of IPPs, but it will lead to greater uncertainty in the ionospheric delay estimation and increase model errors, as well as the system integrity risk.

3.1.1 Data Sources

In this section, the ionospheric observations from the WAAS and the CMONOC are used to analyze the applicability of Kriging. The thirty-eight WAAS reference stations are distributed in Fig. 2 (only one receiver is selected for display). Additionally, the green triangles in Fig. 2 are the stations unable to obtain observations in our study.

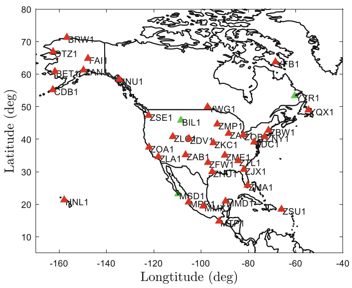

Fig. 2. Distribution of 38 WAAS receivers

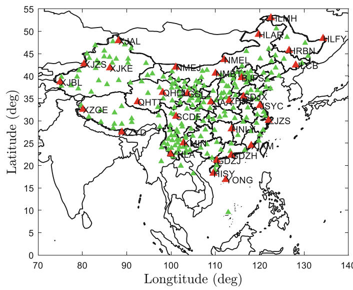

Fig. 3. Distribution of CMONOC receivers

The BDSBAS is being constructed. The location and number of reference stations have not yet determined. We select thirty-one reference stations from the CMONOC (see Fig. 3 red triangles) to simulate as BDSBAS reference stations [7]. Additionally, all CMONOC stations will be used (all triangles in Fig. 3) to simulate the impact of multi-constellation on the performance of Kriging.

3.1.2 Eligible Fit Measurements in Kriging

The implementation of the IPP search strategy in Kriging can be considered that the number of eligible fit measurements is the main index. The fit radius is not. Therefore, we should first determine the number of eligible fit measurements. In this section, two indicators are used to describe the relationship between the geometric relationship of IPPs and IGP with the increased measurements.

(1) Pseudo-Horizontal Dilution of Precision (Pseudo-HDOP): The DOP is calculated based on the relative position between the receiver and the satellite. We establish a quantitative relationship between the IGP and IPPs, named a pseudo-HDOP. We assume that the IPP used for fit is considered as a GPS satellite and IGP is considered as a user receiver. Based on the geodetic coordinate system, the

spherical distance between the IPP and IGP (the height is earth radius plus 350 km) is used to construct a geometric matrix related only to the geometric position of the IPP relative to the IGP, and further calculate the HDOP. Similarly, the magnitude of the pseudo-HDOP value is related to the geometric position between the IGP and IPPs.

(2) RCM: RCM is expressed as the ratio between the IGP and the weighted centroids of IPPs within the fit radius. RCM is used to describe the uniformity of the IPP distribution in the fit domain. The RCM index ranges from 0 to 1. The more RCM value is close to 1, the more IPP distribution is skewed to one side of the IGP, which increases the undersampled possibility of ionospheric irregularities. Therefore, the smaller the RCM value, the more uniform the IPP distribution near the grid points.

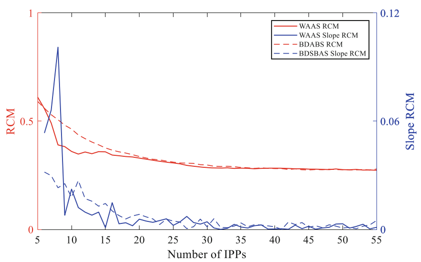

Fig. 4. Curve: RCM and its slope varies with the number of IPPs

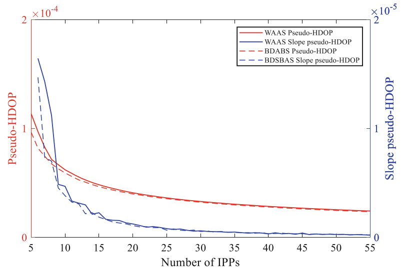

Fig. 5. Curve: Pseudo-HDOP and its slope varies with the number of IPPs

Figure 4 shows the curves of RCM values (red), the slope of neighboring RCM values (blue) with the number of IPPs around IGP. The solid line is WAAS data and the dotted line is BDSBAS data. Similarly, Fig. 5 shows the curves of pseudo-HDOP (red) and its slope (blue) values. It can be seen that when the number of IPPs around the IGP is less than 10, pseudo-HDOP and RCM values are both large. However, when the number of measurements exceeds 30, the RCM and the pseudo-HDOP value do not change significantly.

3.1.3 Fit Radius in Kriging

Based on the GPS observations from WAAS, we defined the ratio (Ratio_R) between the number of IGPs $(Total_{IGP_R})$ which exist the eligible IPPs within the Fit radius R_{fit} with all the augmentation information update epoch ($Total_{\text{epoch}}$, 300s interval) multiplied by total IGPs $\left(Total_{\text{igp}}\right)$. It is shown in Fig. 6.

$$\text{Ratio}_R = \frac{Total_{IGP_R}}{Total_{\text{igp}} \times Total_{\text{epoch}}} \tag{12}$$

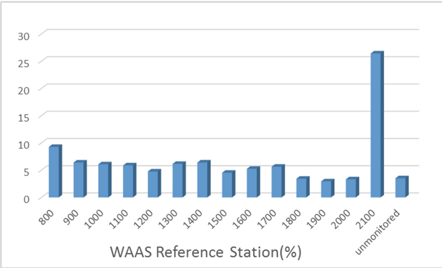

Fig. 6. The proportion of fit radius for WAAS(%)

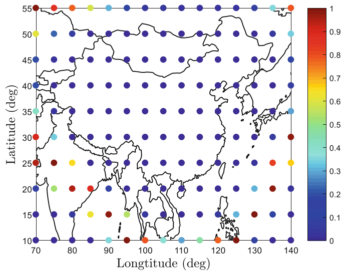

Fig. 7. Curve: SBAS ionospheric anomaly days per month in 2015

In Fig. 6, the y-axis represents the ratio $(Ratio_R)$, and the x-axis represents the fit radius (km). The results show that the ratio difference between each search radius is not obvious except for 2100 km. The fit radius of 2100 km and "unmonitored" is located at the edge area, while the 800 km is mainly concentrated in the CONUS (CONterminous United States). That is, the IGPs located in the middle of the service area requires a smaller cutoff radius to calculate ionospheric augmentation information, but marginal IGPs require a larger radius to provide sufficient measurements and to ensure its availability. Kriging expanded the fit radius to search eligible IPP numbers is the reason why it has higher marginal grid availability than IDW. In BDSBAS, the ratio of 2100 km fit radius is shown in Fig. 7. The fit radius of 800 km is mainly concentrated in the eastern continental regions. The distribution is similar to WAAS.

Table 2. IPP search parameter analysis in WAAS and BDSBAS

R_{max} (km)	R_{min} (km)	WAAS			BDSBAS		
		Residual error(m)		Availability	Residual error(m)		Availability
		RMS	Max		RMS	Max	
Quiet condition							
800	2100	0.1641	1.5747	86.77% (86.77%)	0.2359	2.9803	89.58% (89.58%)
500	2100	0.1641	1.5747	86.77% (86.77%)	0.2360	2.9803	89.58% (89.58%)
800	1500	0.1650	1.8406	65.18% (65.18%)	0.2335	2.6148	77.06% (77.06%)
500	1500	0.1650	1.8406	65.18% (65.18%)	0.2336	2.6184	77.06% (77.06%)
800	1200	0.1650	1.5747	49.86% (49.86%)	0.2316	2.6184	63.28% (63.28%)
500	1200	0.1651	1.5747	49.86% (49.86%)	0.2317	2.6184	63.28% (63.28%)
Storm condition							
800	2100	0.2855	4.7055	89.21% (85.79%)	0.2964	3.7421	88.88% (79.22%)
500	2100	0.2855	4.7055	89.21% (85.79%)	0.2969	3.7421	88.88% (79.25%)
800	1500	0.2844	6.0050	67.69% (65.44%)	0.2917	3.2546	76.27% (69.76%)
500	1500	0.2844	6.0050	67.69% (65.44%)	0.2922	3.2546	76.27% (69.80%)
800	1200	0.2811	1.8438	52.83% (51.28%)	0.2888	3.2546	63.81% (58.86%)
500	1200	0.2811	1.8438	52.83% (51.28%)	0.2893	3.2546	63.81% (58.90%)

The data from March 17, 2015 (storm condition, Kp = 8) and August 12, 2015 (quiet condition, Kp = 3) in Table 2 are used to analyze the correction performance and IGPs availability based on different combination of IPP search radius in WAAS and BDSBAS regions (IGPs availability in brackets is using the irregular detector, and the threshold is 3 [8]).

The IPP search parameters over WAAS in Table 2 shows that there is a positive correlation between the maximum fit radius and the availability of IGPs, especially the marginal IGPs. The system service availability will be reduced due to the poorer IGPs availability. The irregular detector is not triggered during the quiet period. Additionally, there is no significant correlation between the correction performance of Kriging with the minimum fit radius. For different combinations of search radius, the correction accuracy is in the thousandth during the quiet condition. However, in the storm period, these values tend to deteriorate with the changed fit radius. WAAS service area is located in mid-latitudes and ionosphere irregularities are mainly caused by the ionospheric storm. It should be noted that the variogram is used to characterize the spatial correlation of ionospheric measurements with distance. It has an impact on the correction performance and needs to be analyzed based on the measured ionospheric data in different areas [2, 9].

The results for BDSBAS in Table 2 are similar to WAAS. However, the residual error in BDSBAS is not obvious between the quiet and storm period. The reason is that not only geomagnetic activity but also solar activity can cause ionospheric irregularities over China, especially in the southern region. Furthermore, the insufficient measurements or outliers caused by non-ionospheric factors in the CMONOC may affect the result. Although the outlier detection technology [10] was used in this paper, the impact of data quality could not be completely removed. The chi-square irregularity detector in the BDSBAS area during storms is triggered more frequently (about 9%). In the southern region of China, the occurrence rate of ionosphere irregularities, such as equatorial anomaly and plasma bubbles which has an impact on the performance of the ionospheric grid correction, is relatively frequent. Additionally, Table 2 illustrates the assumption that if the fit radius unchanged will affect ionospheric correction performance for BDSBAS is not true. In contrast, if the density of reference stations is not increased and reference stations are not deployed overseas, the fit radius cannot be reduced to ensure the system integrity and the availability of edge grid points.

The BeiDou Navigation Satellite System (BDS) is under construction. With the development of multiple constellations, the number and geometric configuration of IPPs around IGP will be changed. Due to the difficulty to obtain BDS dual-frequency observations, we use more than 200 CMONOC stations to simulate the impact of multi-constellation (see Fig. 3). The measurements in this section were used data quality detection to reduce the effect of non-ionospheric factors [10].

Table 3 shows the correction result at quiet condition: June 20, 2016, December 16, 2016 (Kp = 1), and storm condition: March 17, 2015, June 23, 2015, (Kp = 8), under the condition of RCM < 0.5, to verify the impact of the multiple constellations on the applicability of Kriging.

Table 3. Correction performance analysis of quiet and storm condition

Radius (km)	Area	IPPs	Quiet condition			Storm condition		
			Residual error(m)		χ^2 Mean	Residual error(m)		χ^2 Mean
			RMS	95%		RMS	95%	
500	All	10	0.1790	0.3556	0.0455	0.4086	0.7012	0.2561
		30	0.1677	0.3343	0.0984	0.3636	0.6242	0.4284
		40	0.1673	0.3347	0.1121	0.3567	0.6128	0.4728
		50	0.1672	0.3330	0.1215	0.3544	0.6090	0.5124
	South	10	0.2165	0.4349	0.0595	0.6018	1.1680	0.5381
		30	0.1994	0.4097	0.1318	0.5336	0.9504	0.8803
		40	0.1975	0.4053	0.1493	0.5210	0.9430	0.9643
		50	0.1966	0.4020	0.1607	0.5169	0.9427	1.0397
	North	10	0.1579	0.3140	0.0387	0.2609	0.5175	0.1133
		30	0.1509	0.2976	0.0830	0.2392	0.4808	0.2061
		40	0.1515	0.3004	0.0950	0.2370	0.4737	0.2307
		50	0.1517	0.3000	0.1034	0.2355	0.4702	0.2511
800	All	10	0.1900	0.3764	0.0451	0.4536	0.7635	0.3318
		30	0.1720	0.3414	0.0933	0.3831	0.6543	0.4920
		40	0.1699	0.3385	0.1070	0.3711	0.6376	0.5153
		50	0.1690	0.3362	0.1167	0.3669	0.6328	0.5374
	South	10	0.2282	0.4550	0.0602	0.6695	1.3162	0.7153
		30	0.2066	0.4220	0.1273	0.5585	1.0163	1.0161
		40	0.2024	0.4117	0.1483	0.5398	0.9806	1.0565
		50	0.2003	0.4103	0.1601	0.5339	0.9745	1.0982
	North	10	0.1685	0.3378	0.3378	0.2857	0.5664	0.1355
		30	0.1530	0.3026	0.0773	0.2525	0.5034	0.2287
		40	0.1523	0.3025	0.0877	0.2470	0.4912	0.2449
		50	0.1521	0.3013	0.0964	0.2443	0.4833	0.2581

In Table 3, the boundary between the southern and northern in China is set to 30°N [2]. The results show that the geometric relationships between IPPs and IGP have an influence on the correction performance, especially under the storm condition. Additionally, under the conditions of good geometric configuration and the same fit radius, more measurements can improve the correction performance, but it not very noticeable. Similar to Figs. 4 and 5, the geometric values between 30, 40 and 50 are not visible and less impact on the correction performance.

In summary, the number of measurements is the key parameter in the Kriging IPP search algorithm. The dynamic fit radius is used to ensure sufficient IPPs around IGP. Among them, the maximum search radius is related to the availability of IGPs, especially at the edge area. The minimum cutoff radius mainly exists in the continental area where there exist dense IPPs. When the number of measurements reaches 30, the change of geometric values, as well as the correction performance, is not very noticeable. The chi-square irregularity detector triggered at storm conditions will further reduce the availability of IGPs than quiet. With the development of multiple constellations, the cutoff radius can appropriately reduce. However, two issues need to be noted. Firstly, the degradation of the minimum cutoff radius cannot be lower than the four grid around the IGP. The reason is that ionospheric augmentation information should characterize the changes of the ionosphere while ensuring the system integrity not only at grid locations but within the grid. A lower fit radius will increase the integrity risk. Additionally, the maximum cutoff radius cannot be reduced without overseas reference stations to achieve sufficient IGP availability and system integrity at the edge grids.

3.2 Inflation Factor

The normal or quiet ionospheric is smooth and can be well described by a hypothetical ionospheric model. However, the ionospheric irregularities will cause the hypothesized ionospheric model to be inconsistent with the actual and increase the integrity risk. Therefore, the inflation factor is used to increase the formal estimation error term in Kriging. It protects the user from the effect of integrity risk caused by inaccurate model assumptions. The inflation factor includes two types: a static inflation factor and a dynamic inflation factor. Compared with the static inflation factor, Literature [9] pointed out that the dynamic inflation factor can improve system availability. Figure 8 shows the curve of the dynamic inflation factor with the increased measurements on March 17, 2015, in the BDSBAS regional. It can be seen that the inflation factor gradually stabilizes. It will not be less than 1.4. This factor is related to the chi-square distribution. It characterizes the consistency between the model assumptions and the actual ionosphere. There exist a fixed formula to calculate. No regional applicability exists.

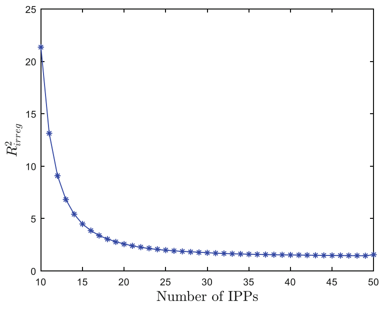

Fig. 8. Inflation factor

4 Conclusion

The aim of this paper was to analyze the applicability of Kriging over the BDSBAS service area. In order to solve this problem, the actual ionospheric observations derived from the WAAS and BDSBAS regions were used to quantitatively analyze the key parameters of Kriging, especially the selection of empirical parameters. And we construct the geometric quantitative relationship between ionospheric measurements and the estimated location. The results show that the Kriging methodology can be used to calculate ionospheric augmentation information in the BSDBSAS SF service. The IPP search parameters in the Kriging methodology which is based on first-order planar fit consist of two parts: the number of measurements and the fit radius. With increasing the number of IPPs or decreasing the fit radius, the ionospheric correction accuracy does not improve significantly, while the service integrity will be influenced. When Kriging is applied in BDSBAS, the IPP search parameters can keep unchanged and still maintain with WAAS. Additionally, with the development of multiple constellations, the fit radius can be appropriately reduced. But the minimum fit radius cannot be lower than the four grid around the IGP. The maximum cutoff radius is related to the availability of IGPs which located at the edge. If no reference stations exist overseas, the edge grid still exists a greater integrity risk. For the inflation factor, it is related to the chi-square distribution. This factor will gradually stabilize with the increased measurements. Therefore, the research on the implementation of the Kriging methodology in the BDSBAS area should focus on the temporal and spatial risk terms caused by the ionosphere irregularities, especially the low latitude ionosphere anomalies.

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