URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

The Spatial and Temporal Analysis of Hourly Computed TECs Derived by Ionospheric Climatology Models

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Abstract

Ionospheric total electron content (TEC) is the key factor for the media correction in Space Geodesy application. Ionospheric climatology models could provide TEC estimations. In this study, TECs hourly computed by three climatology models (IRI–2012, SPIM–2014 and NIC09) were validated by IGS final TEC maps in spatial and temporal domains. It was found that NIC09 overestimated TECs slightly with respect to IGS results. The accuracy during seasons was about 4 TECu. That was worse in winter than other seasons. SPIM–2014 overestimated TECs greatly. There were spring and autumn anomalies with the autumn anomaly more obvious. The accuracy was approximately 8 TECu. IRI–2012 underestimated TECs during all seasons except in autumn. The accuracy was nearly 7 TECu except in winter. As for the latitudinal domain, the performance of three models was better in middle and high latitudes than in low latitudes (especially equatorial regions). Overall, the accuracy of NIC09 was highest, which was followed by IRI–2012 and SPIM–2014. The accuracy of IRI–2012 was mostly better than SPIM–2014 except in summer north hemisphere and winter south hemisphere. The finding in this study could provide references for the specific application of the ionospheric climatology models.

1 Introduction

Since SA was turned off, the ionospheric correction was the main error source in the satellite geodesy. Ionospheric climatology models could provide the key parameters like electron density and total electron content (TEC). There were pretty many literatures which introduced the versions of ionospheric climatology models and discussed their performances (see references [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16]). However, the performance of models in high time resolution especially hour scale was little studied. In this study, the TECs hourly derived by three ionospheric climatology models (IRI–2012, SPIM–2014 and NIC09) were analyzed comprehensively. The accuracy of those models in spatial and temporal domains were achieved with respect to IGS final ionospheric products.

2 Methodology

The performance of three ionospheric climatology models such as IRI–2012, SPIM–2014 and NIC09 were investigated in this study. The input parameters for IRI–2012 and SPIM–2014 were set the same (like storm model and the parameters recommended by URSI). The input parameters for NIC09 were only the time and location.

The spatial and temporal analysis for hourly computed TECs were performed in this study. For spatial domains, the global region was divided into grids with 5-degree intervals from longitude -180 to 180 degrees and 2.5-degree intervals from latitude -87.5 to 87.5 degrees. For temporal domains, the seasons including equinoxes (spring and autumn) and solstices (summer and winter) in high solar activity year 2013 were selected. Four time sections surrounding those time points were further chosen, namely day of year (DOY) 077–081, 170–174, 263–267, and 353–357. For each day, TECs of global grids were computed for each time epoch with 2-hour intervals from UT 0 to 22.

The TECs derived by three models were accordingly compared with the references from IGS final ionospheric maps [17] which were in high accuracies for global regions [18]. The statistical indices were BIAS and RMSE, the method to calculate those indices were illustrated as follows:

$$\begin{aligned} BIAS &= <\Delta TEC_i> \\ RMSE &= \sqrt{<\Delta TEC_i^2>} \\ \Delta TEC_i &= TEC_{ref,i} - TEC_{mdl,i}, i = 1, n \end{aligned} \quad (1)$$

Wherein, $<>$ is the average of the variable, $TEC_{ref,i}$ is the reference, $TEC_{mdl,i}$ is the model TEC, n is the total number of samples.

3 Results and Discussion

3.1 Performance of models in the temporal domain

To investigate the temporal characteristics of three models, the performance of models for 12 time epochs was validated in this section. The statistics were performed for each equinox and solstice respectively. Figure 1 and 2 show the BIAS and RMSE for three models during different seasons. From BIAS subplot, there was a systematic offset for models comparing with IGS results. NIC09 was most close to IGS with a tiny positive bias. The BIAS was not affected by seasons. SPIM–2014 was overestimated for TECs. There were spring and autumn anomalies with autumn more noticeable. IRI–2012 underestimated TECs during all seasons except in autumn. There was an obvious underestimate in winter time. From RMSE subplot, the performance of three models in summer was better than in other seasons. The RMSE of NIC09 was roughly 4 TECu within the whole year except in winter. The accuracy was highest among models. The RMSE of SPIM–2014 was approximately 9 TECu with larger values in spring and autumn. Especially, the RMSE could arrive to about 12 TECu in autumn. The RMSE of IRI–2012 was mostly under 8 TECu. The accuracy of IRI–2012 was better than that of SPIM–2014 during the whole year except in winter. Furthermore, IRI–2012 was more stable than SPIM–2014 in performance.

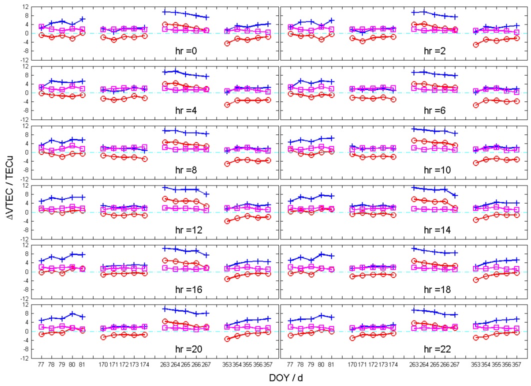

Figure 1. BIAS for three models in temporal domains (The X–axis for DOY, unit: day. The Y–axis for statistical values, unit: TECu. hr for each UT time epoch. Square for NIC09 model, cross for SPIM–2014 model and circle for IRI–2012 model. The dash line for zero offset)

The more comprehensive statistics were shown in Table 1. From the figure, the BIAS of NIC09 was the smallest, which was approximately 2 TECu. The bias kept stable within the year and there were no seasonal anomalies. The accuracy was in the level of about 4 TECu. That was worse in winter than in other seasons as well. SPIM–2014 was generally overestimated for the TECs. The BIAS was roughly 5 TECu. There were spring and autumn anomalies with the autumn anomaly more prominent. The accuracy was nearly 8 TECu during all seasons. IRI–2012 was overall underestimated for TECs within the year except in autumn. This is consistent with the discussions for different versions of IRI (see references [15, 16, 13, 9, 14]). The accuracy was almost 7 TECu except in winter. In addition, comparing with the indices of different hour epochs, the difference was not noteworthy. That seemed the hourly resolution for the TEC calculation by climatology models

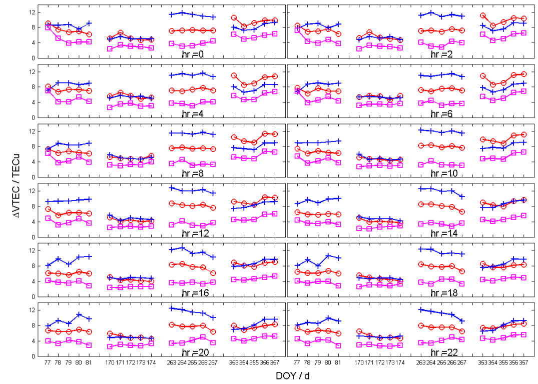

Figure 2. RMSE for three models in temporal domains (The X–axis for DOY, unit: day. The Y–axis for statistical values, unit: TECu. hr for each UT time epoch. Square for NIC09 model, cross for SPIM–2014 model and circle for IRI–2012 model. The dash line for zero offset)

could not be achieved, which can be related to the inner algorithms in the software.

3.2 Performance of models in the spatial domain

The spatial distribution of ionosphere was highly correlated to the latitude. The principal characteristics was the equatorial fountain or equatorial anomaly. To investigate the performance of three model in the spatial domain, the hourly computed TECs were validated in different latitudinal zones. Considering Section 3.1, the difference was not obvious by comparing with the statistical indices of various hour epochs. Therefore, the statistics for UT 0 were only shown in this section (see Figure 3). From the figure, the BIAS and RMSE of three models were better in middle and high latitudes than in low latitudes. There were equatorial anomalies, which was related to the complex changes of ionosphere near the equator. From the left subplot, the BIAS of NIC09 was the smallest. The model was a little overestimated except in winter south hemisphere. SPIM–2014 was mostly overestimated except in summer north hemisphere and winter south hemisphere. The IRI–2012 was underestimated for TECs except autumn globe and winter north hemisphere. From the right subplot, the accuracy of NIC09 was highest and almost not correlated with the latitude in summer. The accuracy of SPIM–2014 was the worst among three models except in summer north hemisphere and winter south hemisphere. The accuracy of IRI–2012 was better than the SPIM–2014 except in summer north hemisphere and winter north hemisphere.

4 Conclusions

The performance of three climatology models was investigated for the hourly computed TECs in this study. The validation was performed in spatial (latitudinal zones) and temporal domains (different equinoxes and solstices). From

Table 1. The statistical indices for three models in temporal domains (IRI for IRI–2012, SPM for SPM–2014, NIC for NIC09. Number 1–4 for different seasons. mbias for the mean of BIAS of all seasons. mrms for the mean of RMSE of all seasons. Unit: TECu)

HR	BIAS				RMSE			
UT	SEASON	IRI	SPM	NIC	SEASON	IRI	SPM	NIC
0	1	-1.15	4.49	1.94	1	7.32	8.54	5.08
	2	-1.84	1.89	1.81	2	5.31	5.12	2.85
	3	2.91	8.54	1.31	3	7.22	11.27	3.67
	4	-2.71	3.06	0.99	4	9.58	8.21	5.76
	mbias	-0.70	4.50	1.51	mrms	7.36	8.29	4.34
2	1	-1.12	4.44	2.01	1	7.28	8.50	4.81
	2	-2.17	1.62	1.80	2	5.43	5.23	2.86
	3	2.97	8.47	1.33	3	7.20	11.23	3.68
	4	-3.21	2.49	1.08	4	10.02	8.30	5.74
	mbias	-0.88	4.25	1.56	mrms	7.48	8.32	4.27
4	1	-1.05	4.44	2.04	1	7.32	8.58	4.96
	2	-2.46	1.37	1.95	2	5.61	5.37	3.19
	3	3.09	8.45	1.43	3	7.28	11.19	3.71
	4	-3.77	1.85	1.15	4	10.01	7.81	5.66
	mbias	-1.05	4.03	1.64	mrms	7.55	8.24	4.38
6	1	-1.01	4.47	1.95	1	7.12	8.45	5.01
	2	-2.40	1.44	2.06	2	5.41	5.29	3.44
	3	3.21	8.51	1.42	3	7.29	11.05	3.75
	4	-4.01	1.57	1.06	4	10.24	7.89	5.68
	mbias	-1.05	4.00	1.62	mrms	7.52	8.17	4.47
8	1	-0.72	4.83	1.81	1	6.61	8.37	4.66
	2	-2.10	1.68	1.95	2	5.07	5.14	3.33
	3	3.77	9.05	1.51	3	7.56	11.45	3.57
	4	-3.90	1.68	1.19	4	10.32	8.03	5.65
	mbias	-0.74	4.31	1.62	mrms	7.39	8.25	4.30
10	1	-0.06	5.49	1.74	1	6.63	9.13	4.41
	2	-1.73	1.94	1.78	2	4.70	4.94	2.95
	3	4.45	9.62	1.54	3	8.06	11.93	3.37
	4	-3.46	2.02	1.38	4	10.05	8.18	5.44
	mbias	-0.20	4.77	1.61	mrms	7.36	8.55	4.04
12	1	0.45	6.03	1.76	1	6.37	9.46	4.03
	2	-1.16	2.42	1.52	2	4.36	4.86	2.67
	3	4.69	9.83	1.45	3	8.25	12.10	3.41
	4	-2.63	2.77	1.61	4	9.44	8.34	5.06
	mbias	0.34	5.26	1.59	mrms	7.11	8.69	3.79
14	1	0.71	6.41	1.67	1	6.04	9.43	3.75
	2	-0.80	2.73	1.50	2	4.15	4.77	2.53
	3	4.45	9.69	1.21	3	7.95	11.91	3.38
	4	-1.83	3.57	1.59	4	8.86	8.59	4.76
	mbias	0.63	5.60	1.49	mrms	6.75	8.68	3.61
16	1	0.52	6.44	1.71	1	6.07	9.41	3.66
	2	-0.84	2.71	1.42	2	4.37	4.80	2.51
	3	3.80	9.23	1.33	3	7.68	11.58	3.59
	4	-1.59	3.88	1.42	4	8.51	8.76	4.73
	mbias	0.47	5.57	1.47	mrms	6.66	8.64	3.62
18	1	0.15	6.26	1.67	1	6.29	9.26	3.64
	2	-1.51	2.08	1.77	2	4.74	4.72	2.95
	3	3.40	9.04	1.31	3	7.72	11.64	3.88
	4	-1.57	4.15	1.44	4	8.06	8.65	4.62
	mbias	0.12	5.38	1.55	mrms	6.70	8.57	3.77
20	1	-0.16	6.09	1.56	1	6.55	9.21	3.59
	2	-1.81	1.85	1.64	2	5.09	4.82	2.86
	3	3.04	8.80	1.28	3	7.62	11.43	3.88
	4	-1.56	4.41	1.57	4	7.67	8.29	4.71
	mbias	-0.12	5.29	1.51	mrms	6.73	8.44	3.76
22	1	-0.57	5.74	1.55	1	6.57	8.87	3.81
	2	-1.73	2.00	1.49	2	5.23	5.05	2.82
	3	2.58	8.32	1.48	3	7.43	10.97	4.04
	4	-1.48	4.45	1.53	4	7.81	7.96	4.95
	mbias	-0.30	5.13	1.51	mrms	6.76	8.21	3.91

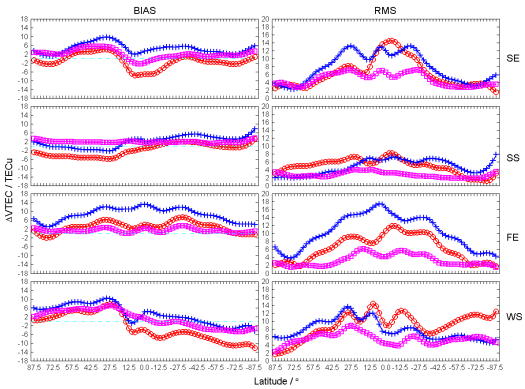

Figure 3. Statistical indices for three models in various latitudinal zones (left subplot for BIAS, right subplot for RMSE. X-axis for latitude, unit: degree. Y-axis for statistical values, unit: TECu. SE for spring equinox, SS for summer solstice, FE for autumn equinox, WS for winter solstice. Square for NIC09 model, cross for SPIM–2014 model and circle for IRI–2012 model. The dash line for zero offset)

the results, the accuracy of NIC09 was highest, which suggests the model could be used for the ionospheric correction in Space Geodesy. The accuracy of SPIM–2014 and IRI–2012 was worse than that of NIC09. There were seasonal and latitudinal characteristics taking account of the statistics. Additionally, there was no noticeable difference for the statistics of different hour epochs. That indicates the hourly resolution for the TEC calculation by ionospheric climatology models cannot be achieved currently.

On the other hand, NIC09 could only provide TECs although the accuracy for its hourly computed TECs was highest. SPIM–2014 and IRI–2012 could though produce more parameters (like electron density and temperature) besides TECs. That could be more available in the related studies of space weather.

5 Acknowledgements

The authors thank Dr. Bilitza, Dr. Gulyaeva and Dr. Scharoo for the help to use the models and solve related problems. The authors also thank the anonymous referees for their valuable suggestions. This study is supported by National Natural Science Foundation of China (Grant No. 11703066) and a scholarship fund from the China Scholarship Council (CSC). The authors declare that they have no conflict of interest.

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