Evaluation of nighttime VTEC variations in the Klobuchar ionospheric delay model from GIM

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Introduction

Klobuchar model, which is capable of providing a correction for approximately 50 percent root-mean-square (RMS) of the ionospheric range error, has been widely used by GPS navigation users to mitigate the effect of ionospheric delay [1]. The Nighttime Vertical Total Electron Content (NVTEC) average, as an important parameter in Klobuchar model, has been commonly set to a constant value of 9 TECU, while the NVTEC has greater variations depending on the solar activity cycle, season, and latitude [2]. Therefore finding the optimal NVTEC average in Klobuchar model is our objective of this study. Global Ionosphere Map GIM become an essential tool for the ionosphere studies such as ionosphere phenomenon at solar minimum [3].

the global spatial-temporal variations of NVTEC are analyzed in detail focusing on:

- Evaluating the rationality and reliability of the definition of NVTEC average
- Determining the suitable time span of NVTEC average
- Analyzing the dependence of NVTEC on solar activity, latitudinal and seasonal variations

DATA and Method

- GIM vertical TEC gridded values computed by IGS are used, covering the period from June 2, 1998 to December 31, 2010. The maps cover latitudes from -87.5 to 87.5 in step of 2.5 and longitudes from -180 to 180 in step of 5. The sampling interval is 2-hour
- The f10.7cm solar flux
- Five different periods (20:00-06:00 LT, 22:00-06:00 LT, 20:00-04:00 LT, 22:00-04:00 LT and 00:00-04:00 LT) are chosen as the candidates;the algorithm mean of NVTEC over nighttime at each grid point are calculated, being considered as the NVTEC average.Then the mean value of NVTEC average over all latitudes and longitudes are calculated, which are considered as globally-averaged NVTEC.

Rationality of NVTEC average and the suitable time span for calculation

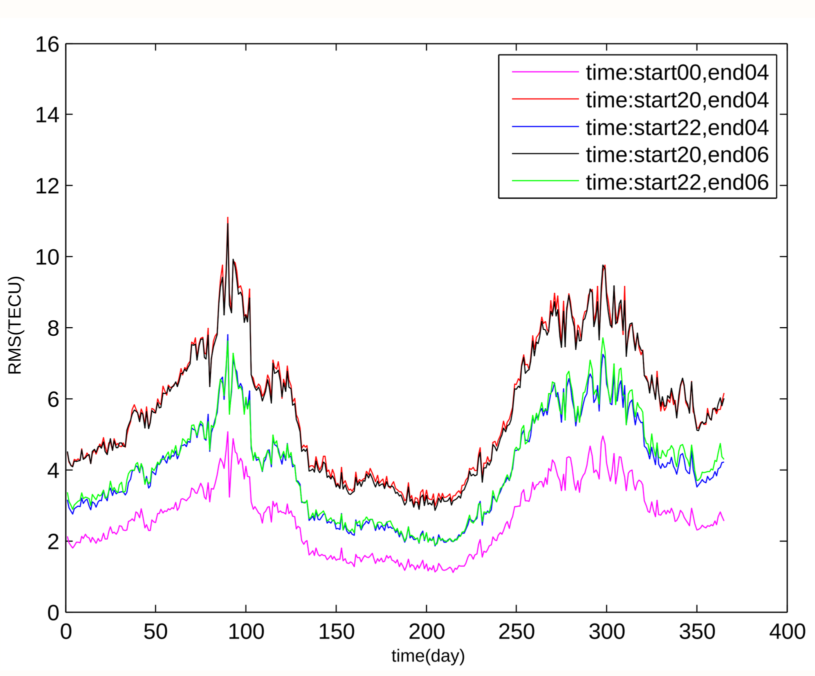

Figure 1: the globally-averaged RMS sequences during different suitable time spans in 2001

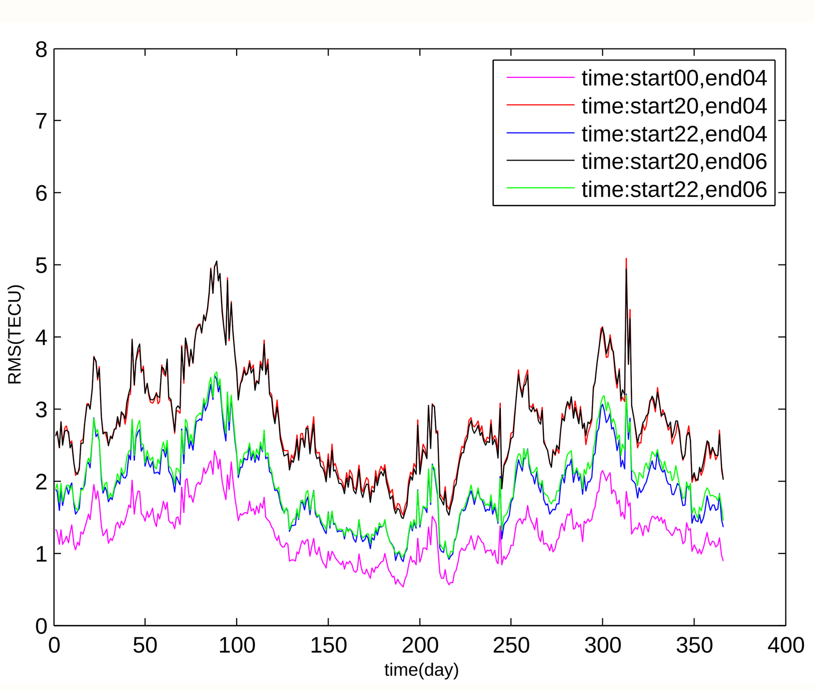

Figure 2: the globally-averaged RMS sequences during different suitable time spans in 2004

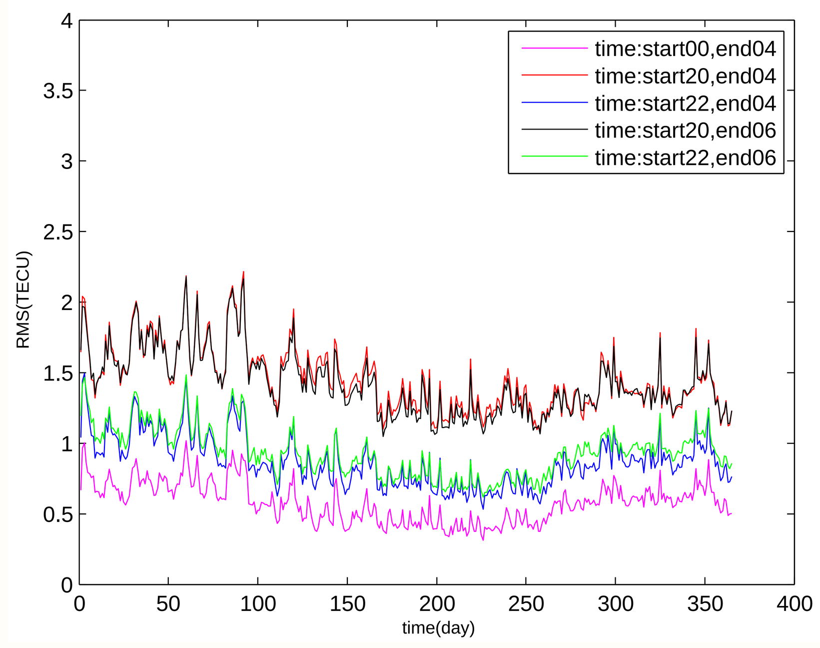

Figure 3: the globally-averaged RMS sequences during different suitable time spans in 2007

From Figure 1, 2 and 3, the following points can be made:

- The suitable time span can be set as 22:00-06:00 LT at solar maximum. For high precision requirements, the suitable time span can also be set as 22:00-06:00 LT.
- The ionosphere effect is increasing slowly between 04:00 LT and 06:00LT.
- The Klobuchar model based on optimal NVTEC average, chosen according to suitable time span, should meet the most requirements of ionospheric correction for GNSS navigation and positioning users. However, caution should be exercised as large errors are expected up to 10 TECU in spring and autumn at solar maximum.

Dependences of NVTEC on solar activity, latitudinal and seasonal variations

We analyzed the dependences of NVTEC on solar activity, latitudinal and seasonal variations, and set the suitable time span 22:00-06:00 LT,

Variations of NVTEC and solar activity

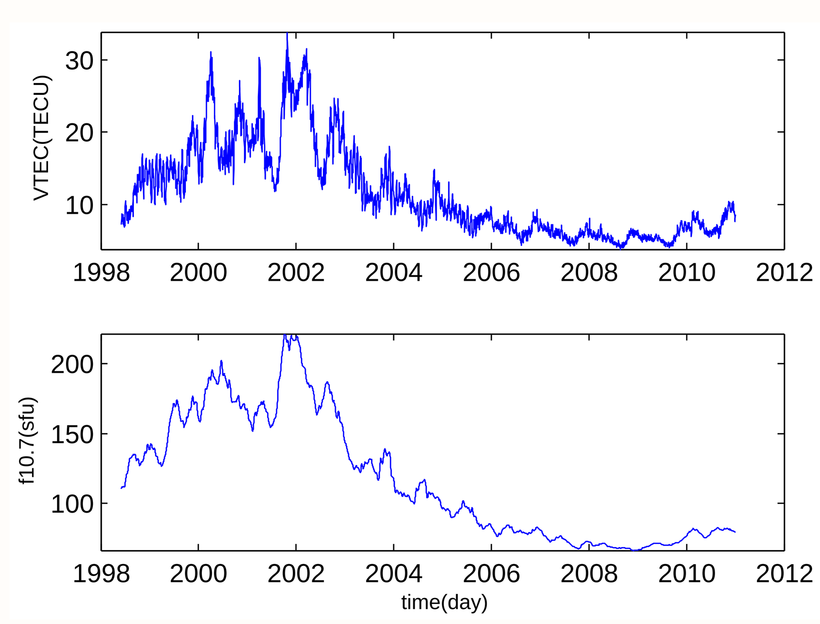

Figure 4: the variation of globally-averaged NVTEC and f10.7cm solar flux during1998-2010

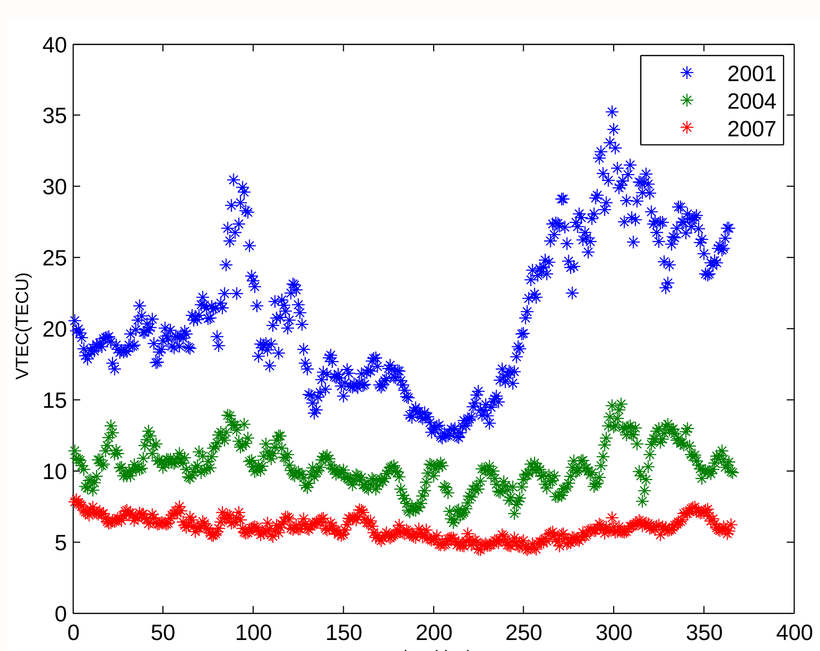

Figure 5: the globally-averaged NVTEC sequences in 2001, 2004 and 2007

From Figure 4 and 5 we can know that the daily globally-averaged NVTEC and f10.7cm solar flux of the radio emission from the sun reach their peaks in 2002, and valleys in 2008. From 2001 to 2007, there is a 17 TECU shape decrease, which simply implies that the solar flux is the single and most dominant parameter to which the observed variations in the nighttime ionospheric content could be attributed.

Seasonal variations of NVTEC

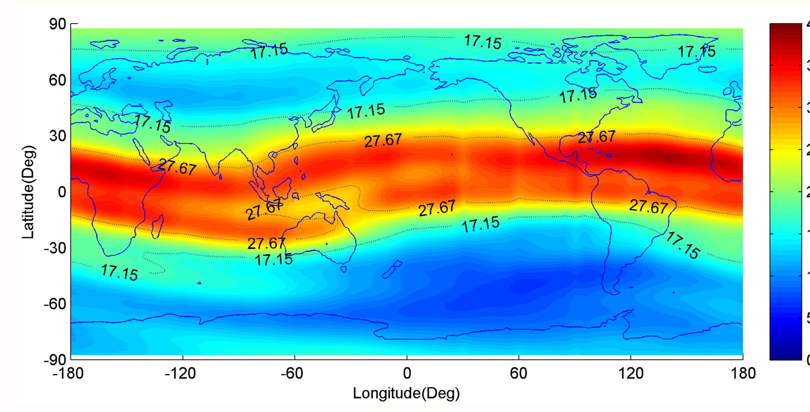

Figure 6: the global distribution of seasonal NVTEC average during 2001-2003 in spring (unit TECU)

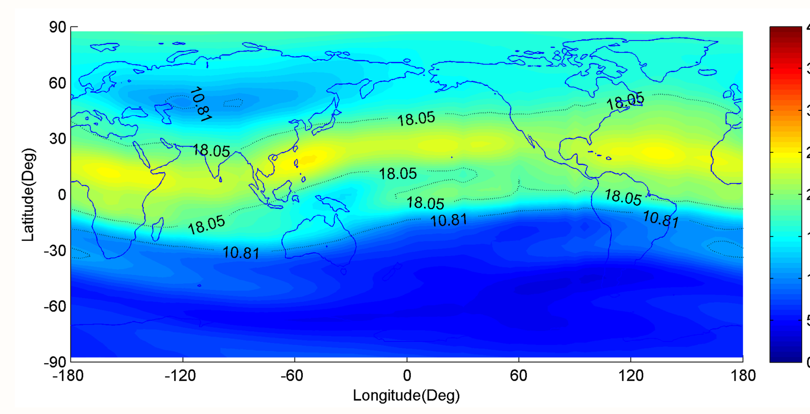

Figure 7: the global distribution of seasonal NVTEC average during 2001-2003 in summer (unit TECU)

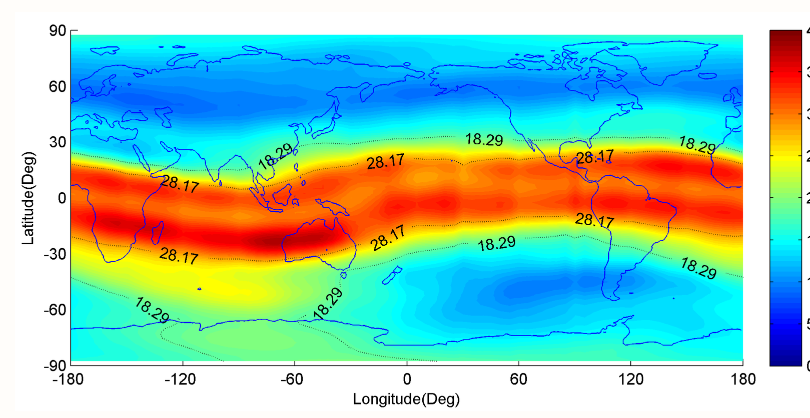

Figure 8: the global distribution of seasonal NVTEC average during 2001-2003 in autumn (unit TECU)

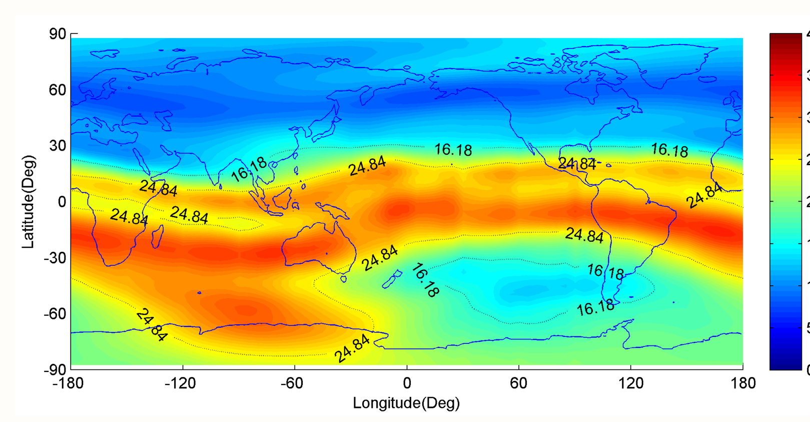

Figure 9: the global distribution of seasonal NVTEC average during 2001-2003 in winter (unit TECU)

From Figure 6,7,8,9, we can know that the constant value of 9 TECU in Klobuchar model really causes a greater deviation comparing with the NVTEC of different seasons. At solar maximum, the deviation is less in summer and winter than that in spring and autumn. And the deviation is about 17, 6, 21 and 12 TECU in spring, summer, autumn and winter respectively in 2001-2003. However, in 2008, which is at solar minimum, the deviation will be 1.44, 3.77, 2.02 and 2.07 TECU in spring, summer, autumn and winter in low-latitude zone and 4.1, 4.54, 4.04 and 4.26 TECU in high-latitude zone

Latitudinal variations of NVTEC

Figure 9,10 and Table1 present that it is very complex for the variations of NVTEC with the latitude in winter at solar maximum, and the NVTEC is about 29 TECU and it is greater in the southern hemisphere than in the north at low latitudes. At middle and high latitudes, the NVTEC is about 10 TECU in the northern hemisphere. While in the southern hemisphere, a large average value, 29 TECU, is found in the region of the south of Indian Ocean with longitude between -150deg and -30deg. Furthermore, the value in the center of this region, whose longitude and latitude is (-90deg, -60deg), can reach up to 32 TECU. In addition to the great value, there is a small average value, 15 TECU, found in the south of Pacific with longitude between 30deg and 150deg. In the winter seasons over 2005 to 2008, whose longitude and latitude is (90deg, -60deg), can go as low as 10 TECU, as shown in Figure 10.

These regional anomalies of NVTEC not only occur at solar maximum, but also can take place at solar minimum. As a known fact, the GPS receivers in the southern hemisphere are of less density, so the long term mapping of the NVTEC regional anomalies in the southern hemisphere still deserve more effort to study.

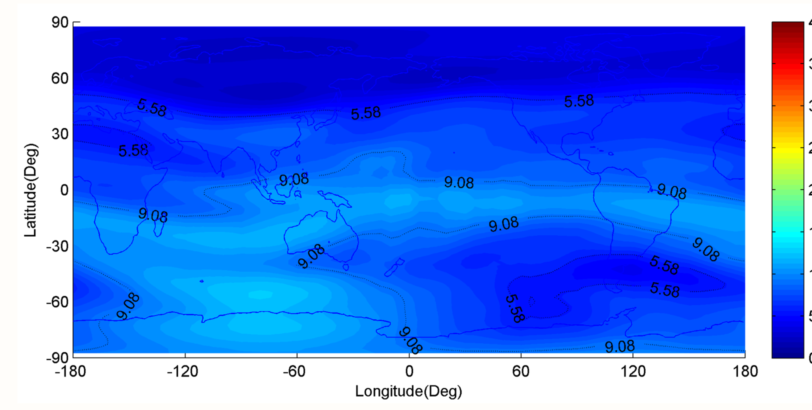

Figure 10: the global distribution of seasonal NVTEC average during 2005-2008 in winter (unit TECU)

Table 1: The NVTEC average in different latitude regions (2001-2010) (unit: TECU)

Year	Latitude range (deg)	Annual average value	Annual value spring	Annual value summer	Annual value autumn	Annual value winter
	40-60	15.93	14.55	12.21	19.65	17.4
2001	20-40	22.86	22.87	16.75	29.22	22.65
	0-20	30.61	32.10	20.31	40.31	29.8
	40-60	16.74	19.12	12.94	15.14	19.79
2002	20-40	23.69	28.22	17.46	23.20	25.94
	0-20	31.69	36.63	21.30	34.61	34.31
	40-60	9.97	9.98	8.52	9.54	11.86
2003	20-40	13.72	14.94	11.56	13.36	15.04
	0-20	19.45	22.97	14.46	20.2	20.21
	40-60	8.38	8.36	7.63	8.52	9.04
2004	20-40	10.96	11.56	9.80	11.27	11.20
	0-20	14.56	16.56	11.11	15.71	14.9
	40-60	7.00	6.98	6.42	6.61	8.02
2005	20-40	9.00	9.33	8.31	8.66	9.73
	0-20	11.25	12.63	9.28	11.32	11.79
	40-60	5.92	6.01	5.42	5.69	6.57
2006	20-40	7.51	7.90	6.81	7.46	7.88
	0-20	8.8	9.98	6.84	9.42	8.95
	40-60	5.44	5.38	5.01	4.96	6.41
2007	20-40	6.77	6.96	6.3	6.39	7.45
	0-20	7.51	8.22	6.21	7.42	8.23
	40-60	5.01	4.9	4.46	4.96	5.74
2008	20-40	6.28	6.5	5.56	6.36	6.75
	0-20	6.68	7.56	5.23	6.98	6.93
	40-60	5.22	4.94	4.62	5.45	5.90
2009	20-40	6.31	6.31	5.67	6.68	6.58
	0-20	6.49	6.74	5.21	7.45	6.6
	40-60	6.74	6.3	5.73	7.32	7.61
2010	20-40	8.21	8.02	7.15	9.19	8.48
	0-20	9.52	9.85	7.22	11.68	9.33

Conclusions

- In the Klobuchar model, the suitable period for nighttime VTEC can mostly be set as 20:00-06:00 LT.
- The NVTEC is the greatest at solar maximum with a very high dynamic range.
- Compared with 9 TECU used in Klobuchar ionospheric delay model, the deviation, caused by seasons and latitude, will be up to about 20 TECU at solar maximum and mostly around 3 TECU at solar minimum.
- Regional anomalies of NVTEC are shown in the winter of southern hemisphere. For both solar maximum and minimum, there are a pronounced high anomaly region in the southern Indian Ocean and a distinct low anomaly region in the southern Pacific Ocean.

References

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