

GPS Based Ionosphere Mapping Using PPP Method

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Key words: GIMs, IGS, Ionosphere mapping, PPP

SUMMARY

Mapping of the ionosphere is a very interesting subject within the scientific community due to its effects on various areas. Many studies have been performed for ionosphere mapping. In recent years GPS observations are widely used for this purpose. This paper demonstrates concept and practical examples of instantaneous mapping of the ionosphere, based on single station GPS observations using PPP technique. For doing this, different stations have been selected from the different ionospheric regions. Instantaneous maps have been generated for both quiet and stormy days by using Bernese 5.0 PPP modul. The quality of the ionosphere representation has been compared to the International GPS service(IGS) Global Ionosphere Maps(GIMs), which is generally used as a reference.

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1. INTRODUCTION

The ionosphere is a part of the upper atmosphere, starting at height of 50 km and extending to 1000 km. In that region free electron density affects the propagation of radio frequency electromagnetic waves.

Spatial and temporal characteristic effects of the ionosphere on radio wave propagation, interest various study areas including space-based observation systems as well as communication systems and safety-critical systems (Liu and Gao, 2004). The wide spread effect of the ionosphere on various areas has made ionospheric studies popular subject for about 40 years.

Ionospheric mapping is defined as a technique applying simultaneously measured total electron content(TEC) values to generate TEC maps referred to a specific time epoch (Stanislawska et. al. 2000).

With the help of large number of tracing stations, GPS observations can be used for monitoring ionospheric conditions during disturbed and quiet geomagnetic conditions. Ex: GNSS analysis centers provide GIMs(Global Ionosphere Maps) on a daily basis.

Many studies have been performed for regional ionosphere mapping. Wielgosz et. al.(2003) and Nohutcu et. al. (2010) are two of them.

In this study, two stations have been selected from high-latitude and mid-latitude regions. By the help of these stations, regional ionosphere maps have been generated for both quiet and stormy days by using Bernese 5.0 PPP modul(Dach and Hugentobler, 2007).

2. TEC MAPPING

Ionospheric information can be obtained from single station for the specific area. Dimension of this specific area can be expressed by the concept of “coverage circle “ which can be obtained for each station using equation 1 and 2(Hugentobler et. al. 2001).

$$\sin z' = \frac{R}{R+H} \sin z \quad (1)$$

$$\tan(z - z') = \frac{r}{R+H} \quad (2)$$

where, R is the radius of the earth, H is the single layer height, z and z' are satellite zenith angles at the receiver and IPP respectively, r is the radius of the coverage circle. When the $z = 75^\circ$, $R=6370$ km and $H= 450$ km is used, r is estimated as 1270 km.

The TEC maps have been generated with the Bernese software using PPP modul and output is in standard IONEX format. MSLM has been used for mapping the TEC. In this model it is assumed that all the free electrons are contained in a shell of infinitesimal thickness at altitude H . The altitude of this layer has been selected 450 km, which is generally used. Using MSLM noted above, vertical TEC map can be obtained at IPP.

ISTA and SODA IGS station, which are located in mid-latitude and high-latitude regions respectively, have been chosen. In order to determine the geographical location of the regional maps, $35^\circ - 45^\circ$ latitudes and $20^\circ - 40^\circ$ longitudes for ISTA and also $60^\circ - 70^\circ$ latitudes and $15^\circ - 35^\circ$ longitudes for SODA have been selected. For doing this both stormy (2003, DOY 302) and quiet (2003, DOY 285) days have been considered. In order to see the level of storm, K_p index values for pertinent days are given in figure 1 and 2.

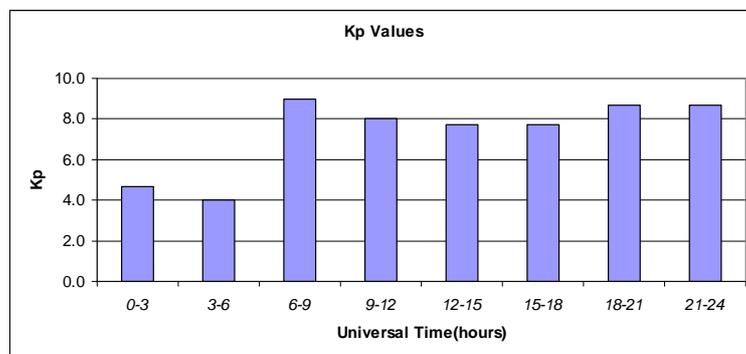


Figure 1. K_p values for 2003, DOY 302(URL-1)

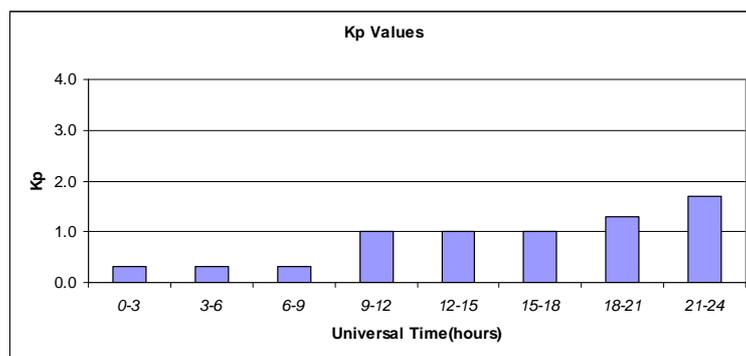


Figure 2. K_p values for 2003, DOY 285(URL-1)

As it can be seen in figure 1, geomagnetic storm is extreme for 6-9, 18-21 and 21-24 time periods and it is severe for 9-12, 12-15 and 15-18. However there is no storm occur for the DOY 285 (figure 2).

3. RESULTS

TEC maps cover a 24 hourly time period at intervals of 2 hours, starting from 00.00.00 hour. Figure 3 and 5 illustrate the vertical TEC map for mid-latitude station, ISTA on DOY 285 and 302 respectively which were produced with PPP technique with two-hour intervals between each map. For the comparison purpose, an area covering regional model was extracted from Global ionosphere Maps(GIM) which were downloaded from Centre for Orbit Determination in Europe (CODE)(URL-2) are given in figure 4 and 6 for DOY 285 and 302 respectively.

It can be seen in figure 3 and 4 the biggest difference between single station based regional model and GIMs are about 6 TECU. However differences can reach 10 TECU for the some time periods of stormy day(figures 5-6).

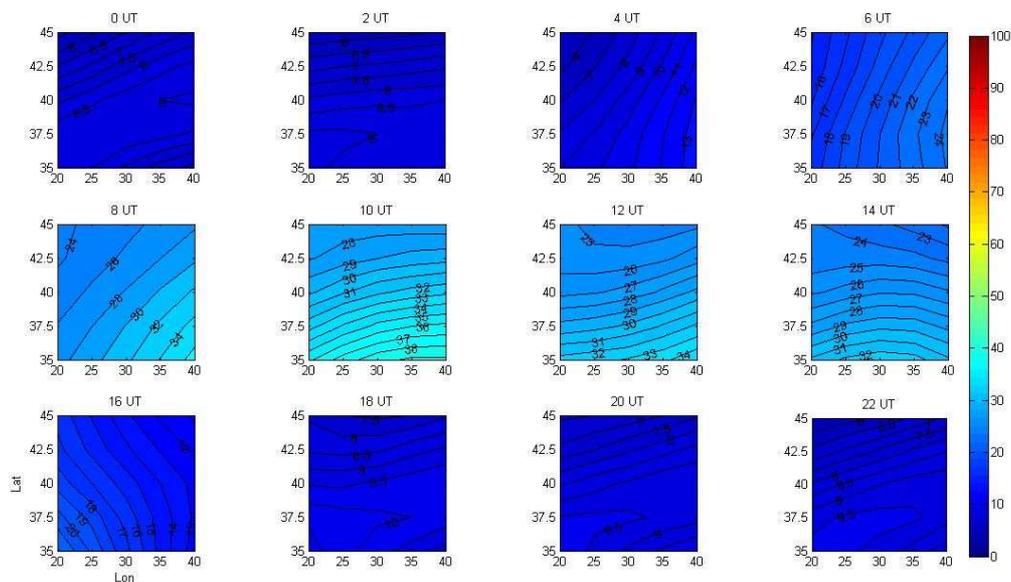


Figure 3. TEC maps for ISTA station, DoY 285-2003

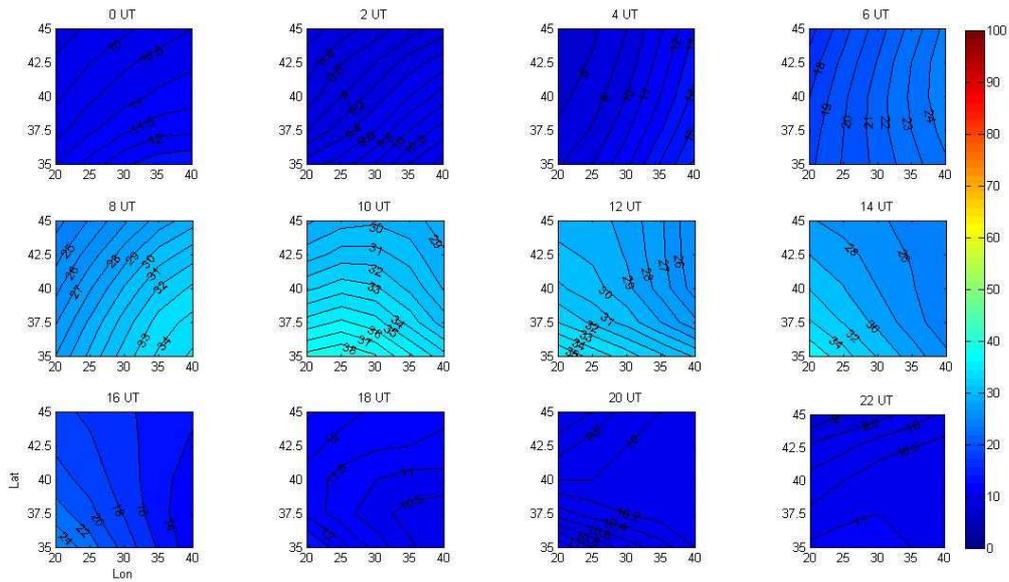


Figure 4. TEC maps from GIM, DoY 285-2003

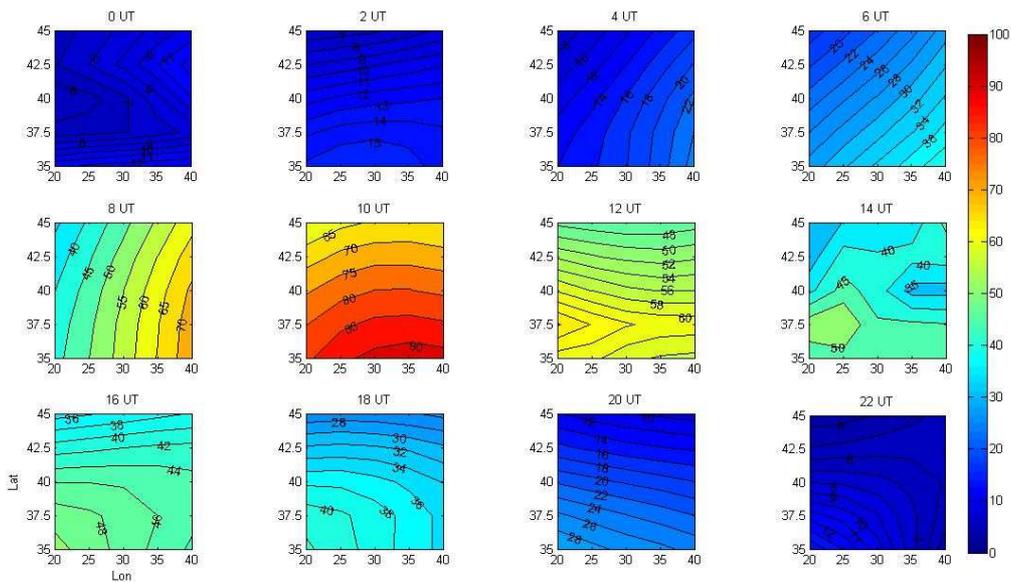


Figure 5. TEC maps for ISTA station, DoY 302-2003

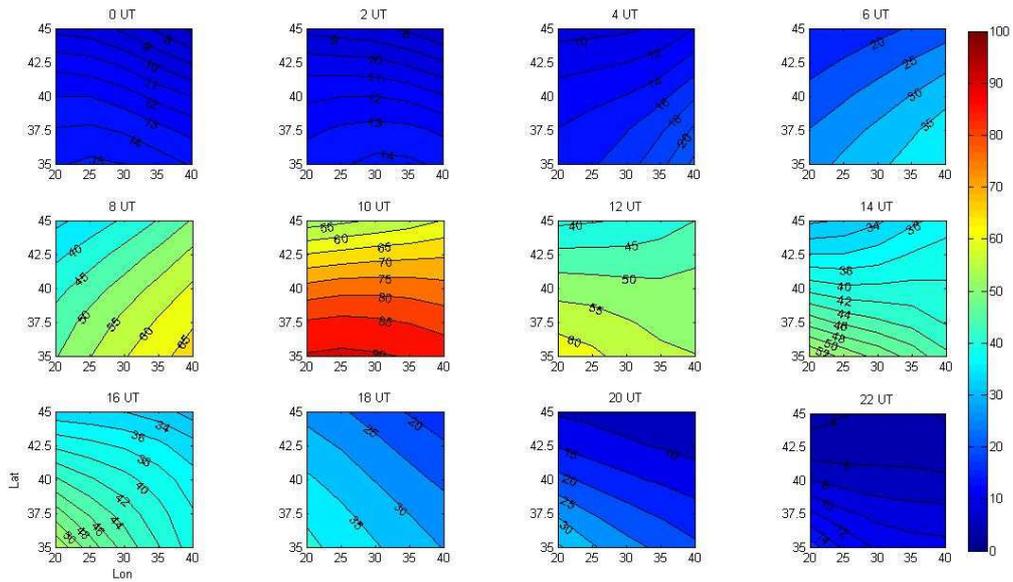


Figure 6. TEC maps from GIM, DoY 302-2003

Also comparison between GIMs and vertical TEC map for high-latitude station, SODA, is given in figures 7-8 and 9-10 for DOY 285 and 302 respectively.

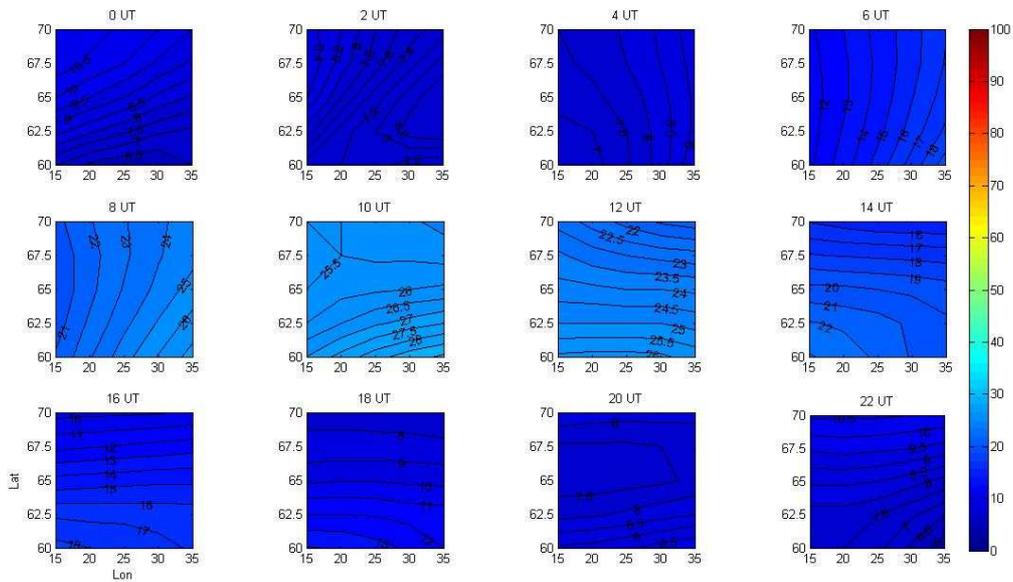


Figure 7. TEC maps for SODA station, DoY 285-2003

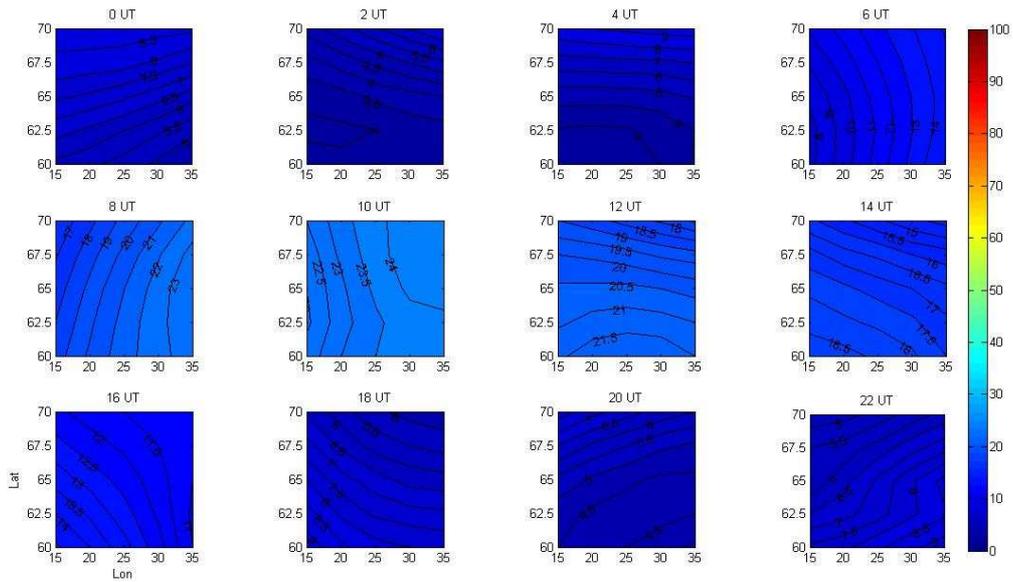


Figure 8. TEC maps from GIM, DoY 285-2003

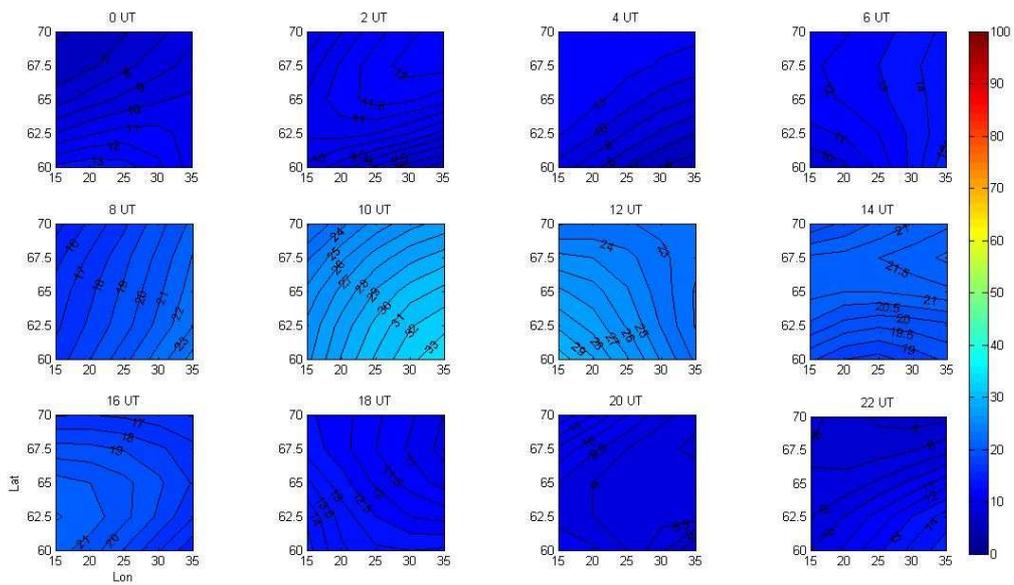


Figure 9. TEC maps for SODA station, DoY 302-2003

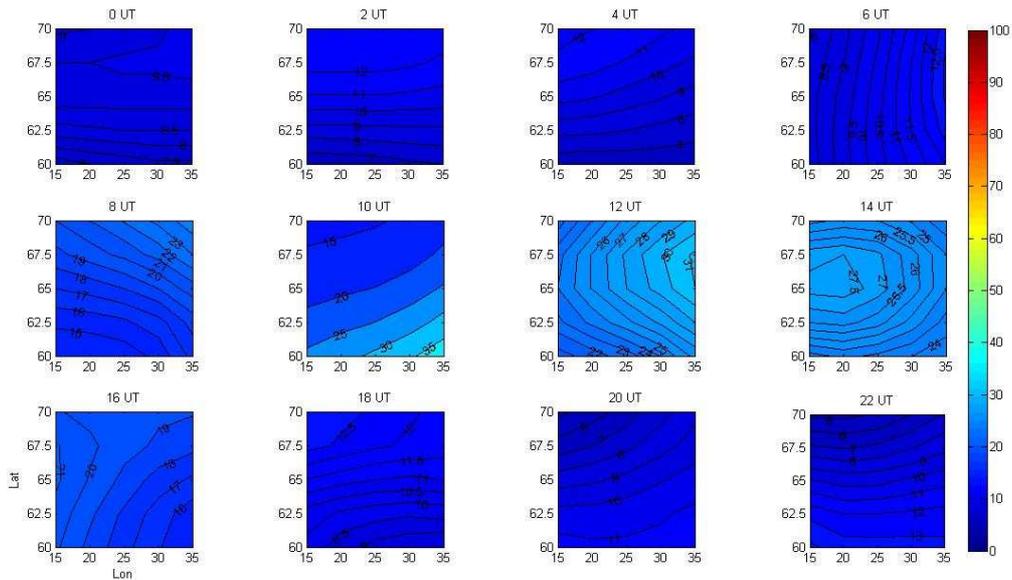


Figure 10. TEC maps from GIM, DoY 302-2003

As illustrated in figures 7-8 and 9-10, differences between GIM values and PPP results are similar to the mid-latitude results. In order to understand the difference between them whether they are systematic or random, we calculated mean and its standard deviations for each hour. Mean values and standard deviations have been calculated by 25 gridding points, which are also used for generating TEC maps, for each hour separately. Mean and standard deviation of differences between GIM values and PPP-derived can be seen in table 1.

Table 1: TECU difference between GIM and PPP-derived (TECU)

	Doy 285, 2003				DoY 302, 2003			
	ISTA		SODA		ISTA		SODA	
	Mean	Std.D.	Mean	Std.D.	Mean	Std.D.	Mean	Std.D.
0 ^h	3.0	1.1	-1.7	0.5	2.9	3.3	-0.7	3.0
2 ^h	1.5	0.9	-3.4	1.2	-0.5	1.3	-0.3	1.6
4 ^h	1.1	0.7	-2.7	2.2	-1.5	2.4	-0.6	1.1
6 ^h	1.3	0.8	-3.0	0.9	-1.5	1.6	-2.3	0.9
8 ^h	1.1	0.9	-2.7	0.8	-2.9	5.5	-0.8	3.7
10 ^h	0.6	2.4	-2.9	1.4	-2.4	4.2	-6.1	4.3
12 ^h	1.4	2.9	-3.8	0.4	-4.7	2.7	1.2	5.1
14 ^h	1.6	3.2	-2.2	1.3	-1.4	4.5	5.3	1.1
16 ^h	2.0	1.1	-1.9	2.5	-3.5	2.6	-0.1	1.8
18 ^h	2.3	1.4	-3.3	1.2	-4.9	3.1	-1.4	2.1
20 ^h	1.7	0.9	-2.9	1.3	-2.4	2.7	0.0	2.7
22 ^h	2.1	0.7	-1.6	2.6	0.5	1.7	0.0	1.8

Time series of the mean and standard deviations can be also seen in figure 11 and 12. In figure 11 and 12, blue and red represent quiet and stormy day, respectively. According to figures, it is evident that mean values are generally positive or negative. These indicate that there is an systematic behavior. However, this systematic behavior in terms of mean is not same character for quite and stormy day. It is clear in figure 12 that standard deviations in stormy day are bigger than in quite day. It can be seen that standard deviations for both days usually are bigger daytime other than at night.

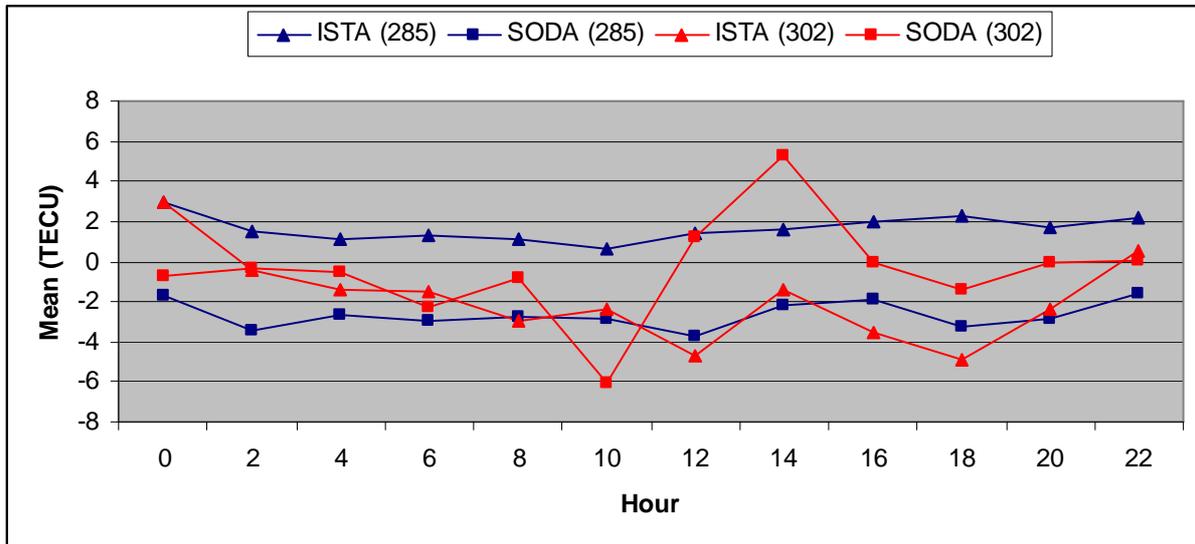


Figure 11. Mean of TECU difference between GIM and PPP-derived

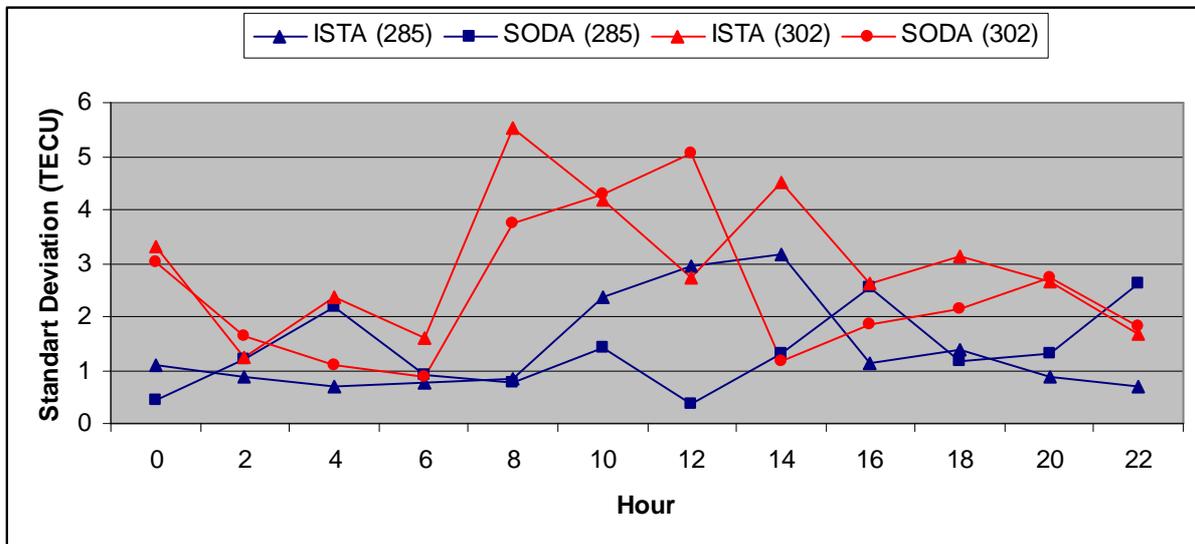


Figure 12. Standart Deviation of TECU difference between GIM and PPP-derived

4. CONCLUSION

In order to characterize the ionospheric behaviour, which is necessary in many ways (Ex: its importance for satellite based positioning), TEC maps are needed. Many studies have been performed for TEC mapping. In this study, single station based regional ionosphere models have been generated by PPP technique. In order to investigate the compatibility of these maps with GIMs, which is generally used as a reference, two stations have been selected from mid-latitude and high-latitude regions.

Regional vertical TEC maps have been obtained by using Bernese 5.0 PPP module for both quiet and stormy days. In order to determine the geographical location of the regional maps, coverage circle concept has been taken into consideration.

Results confirmed that, for both mid-latitude and high-latitude stations, regional vertical TEC maps are generally compatible with GIMs particularly when the quiet day is considered.

5. FUTURE STUDY

In this study, only GPS observations have been used. Addition of data from other satellite systems such as GLONASS, GALILEO, etc. may be more profitable in order to understand the ionospheric behaviour better.

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URL-2: <ftp://ftp.unibe.ch/aiub/CODE>

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