Ionosphere Continuous Monitoring Based on BDS GEO Satellites Measurements

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1. Abstract

Because of continuous covering, the Geostationary Earth Orbit (GEO) satellites play an important role in GNSS constellations like BDS. The advantage of using GEO satellites to monitor the ionosphere is the almost motionless ionosphere pierce point (IPP), which is analyzed by comparison with MEO and IGSO satellites. The results of observation data analysis using several tracking sites distributed different latitude show that the VTEC sequence derived from each GEO satellite at their respective fixed IPP is always continuous. The precision of calculated VTEC using BDS B1&B2, B1&B3 and B2&B3 dual-frequency combination was compared and analyzed. The $VTEC_{12}$ precision based on the carrier phase and code is 0.69 TECU and 5.54 TECU, respectively, which is slightly higher than $VTEC_{13}$, and much higher than $VTEC_{23}$. Furthermore, the variations of the correlation between the ionosphere and solar activity, and DST index were preliminary analyzed.

2. The information of satellites and sites

Table 1. The information of BDS GEO satellites.

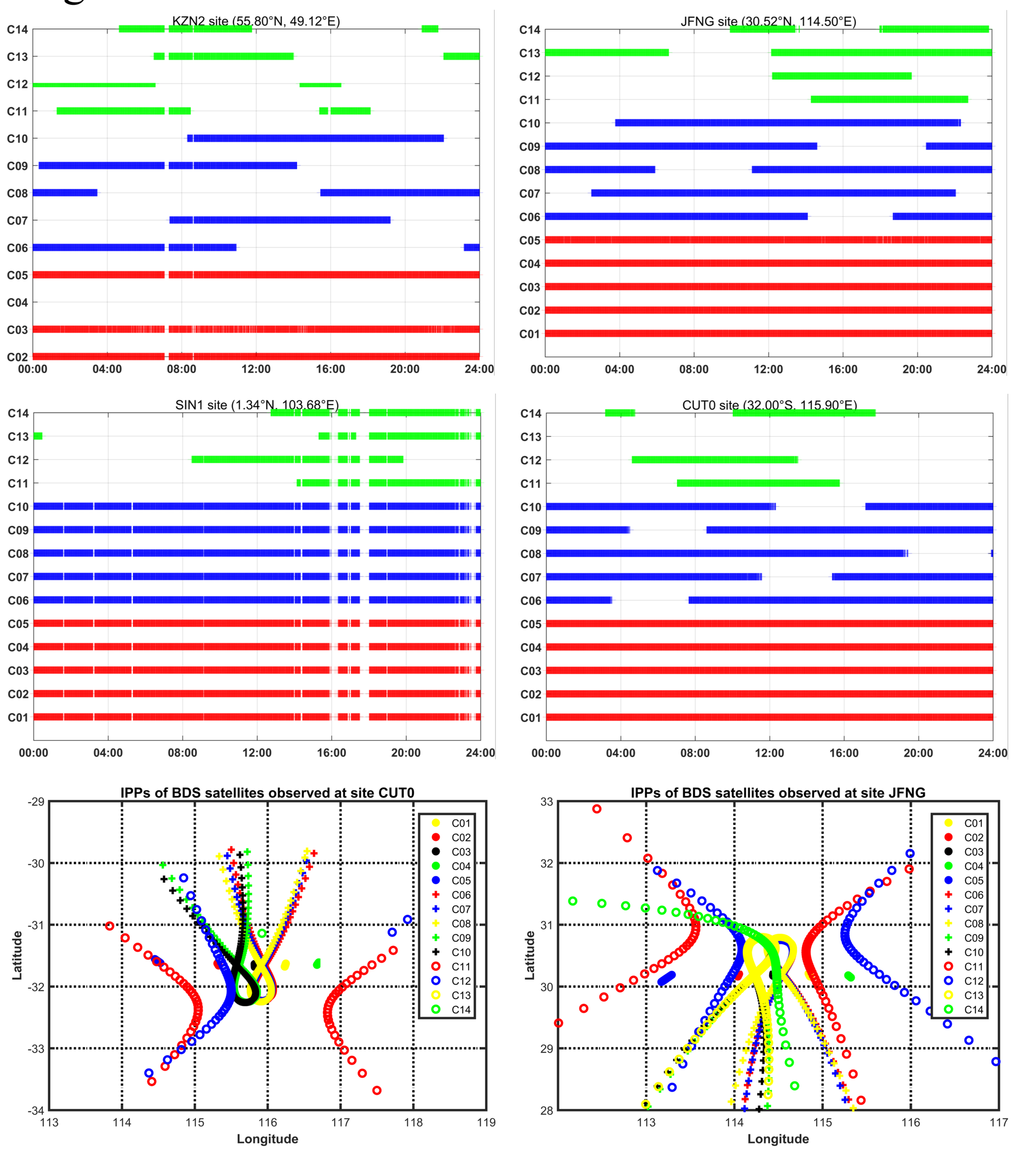
PRN	Satellite Name	Longitude deg.	Launch date
C01	BDS-G1	140°E	16/01/2010
C02	BDS-G6	80°E	25/10/2012
C03	BDS-G3	110.5°E	02/06/2010
C04	BDS-G4	160°E	31/10/2010
C05	BDS-G5	58.75°E	24/02/2012

Table 2. The information of selected sites.

No.	Site	Coordinates	Receiver type	Antenna type
1	KZN2	55.80° N, 49.12° E	TRIMBLE NETR9	TRM59800.00
2	JFNG	30.52° N, 114.50° E	TRIMBLE NETR9	TRM59800.00
3	SIN1	1.34° N, 103.68° E	TRIMBLE NETR9	LEIAR25.R3
4	CUT0	32.00° S, 115.90° E	TRIMBLE NETR9	TRM59800.00

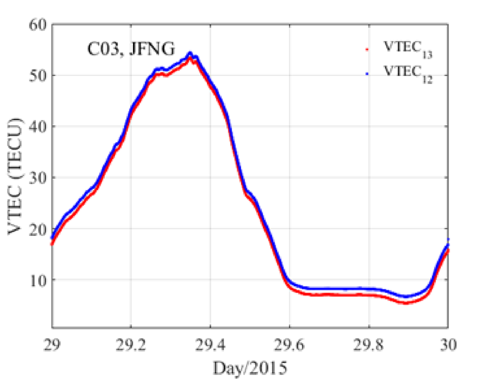
3. BDS satellites visibility & IPPs observed

- All GEO satellites C01-C05 are continuously tracked, except for the observation sites in the high latitude area.
- The IPPs of 5 BDS GEO satellites are almost stationary, their variation range is less than 0.1° both in latitude and longitude.

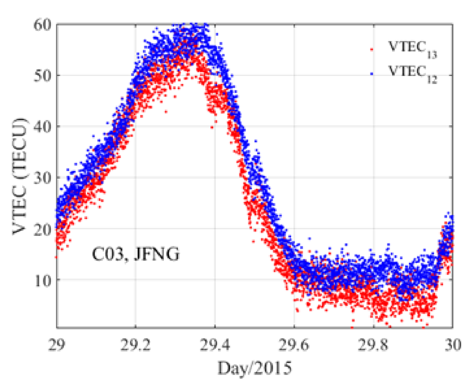


4. $VTEC_{12}$ and $VTEC_{13}$ for GEO satellites

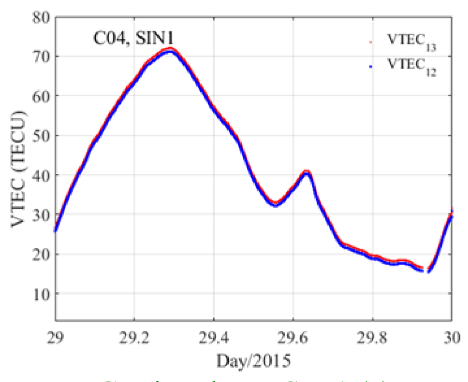
- $VTEC_{12}$ and $VTEC_{13}$ for GEO satellites on DOY 029/2015. Carrier phase: JFNG (a), SIN1 (c); Code: JFNG (b), SIN1 (d).
- There is little difference between $VTEC_{12}$ and $VTEC_{13}$ for the site at 029/2015.
- The multipath and measurement noise of Code are much larger than Carrier phase.



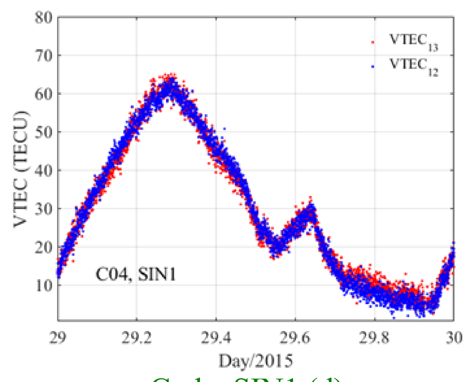
Carrier phase: JFNG (a)



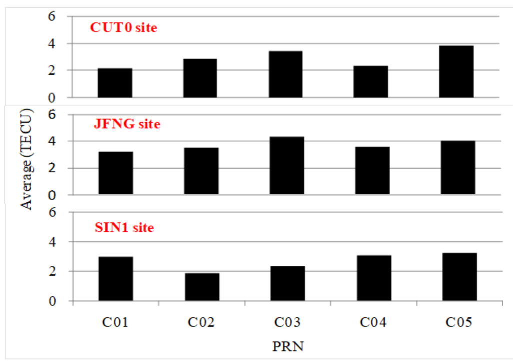
Code: JFNG (b)



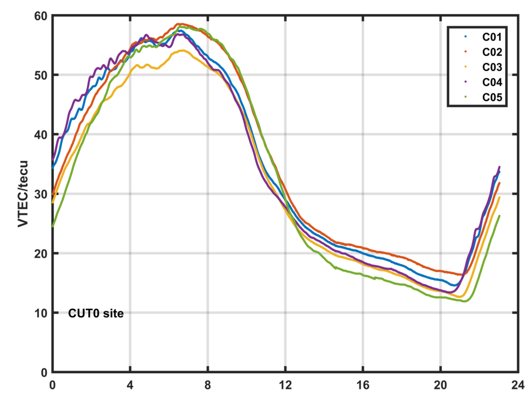
Carrier phase: SIN1 (c)



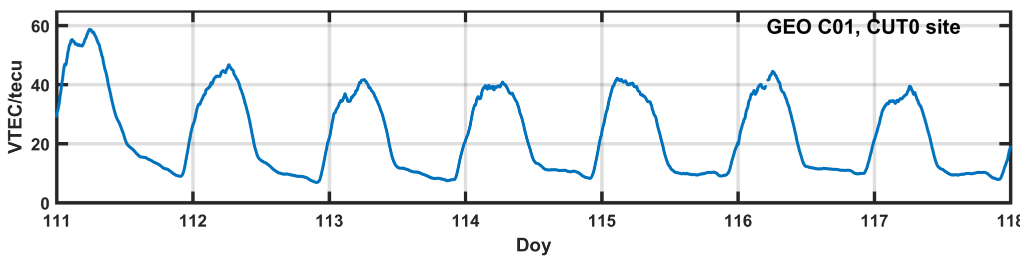
Code: SIN1 (d)



Differences of IGS GIM and $VTEC_{12}$ 2013/1/1—2015/12/31 (e)



VTEC of 5 GEO Satellites at CUT0 (f)

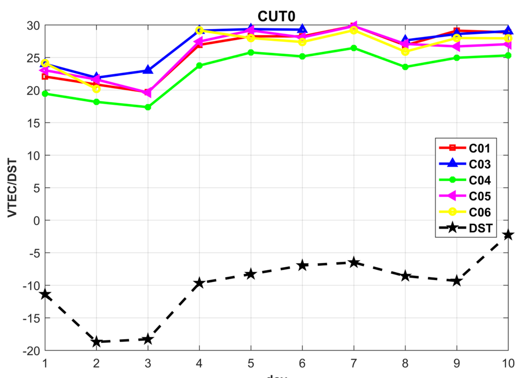


7 days $VTEC_{12}$ of GEO Satellite C01 at CUT0 (g)

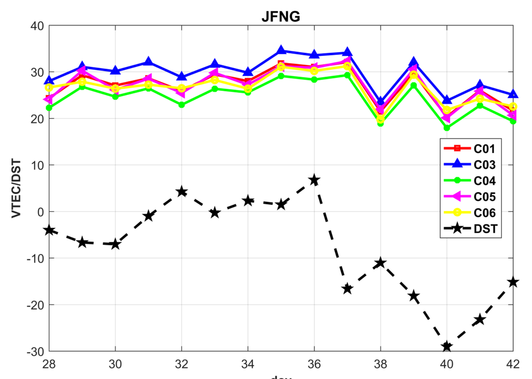
- The figure (e) shows that differences between IGS GIM and $VTEC_{12}$ for BDS GEO satellites at site CUT0, JFNG and SIN1 during 2013/1/1 to 2015/12/31.
- The calculation results show that the standard deviation of the difference between B1/B2 and B1/B3 Geometry-Free combination based on code observation is about 1.30 -3.02 TECU, whereas that of the carrier phase observation is less than 0.1 TECU.

5. Correlation of $VTEC_{12}$ and DST index

- The ionospheric data of IGS GIM may introduce model errors, so the VTEC sequences calculated from the GEO observations are more reliable.
- The left figure is a comparison between DST and $VTEC_{12}$ at CUT0 during 1-9 day of 2014, and the right figure is a comparison between DST and $VTEC_{12}$ at JFNG during 28-41 day of 2014.
- The trends of VTEC and DST index of the five GEO satellites show obviously consistent.



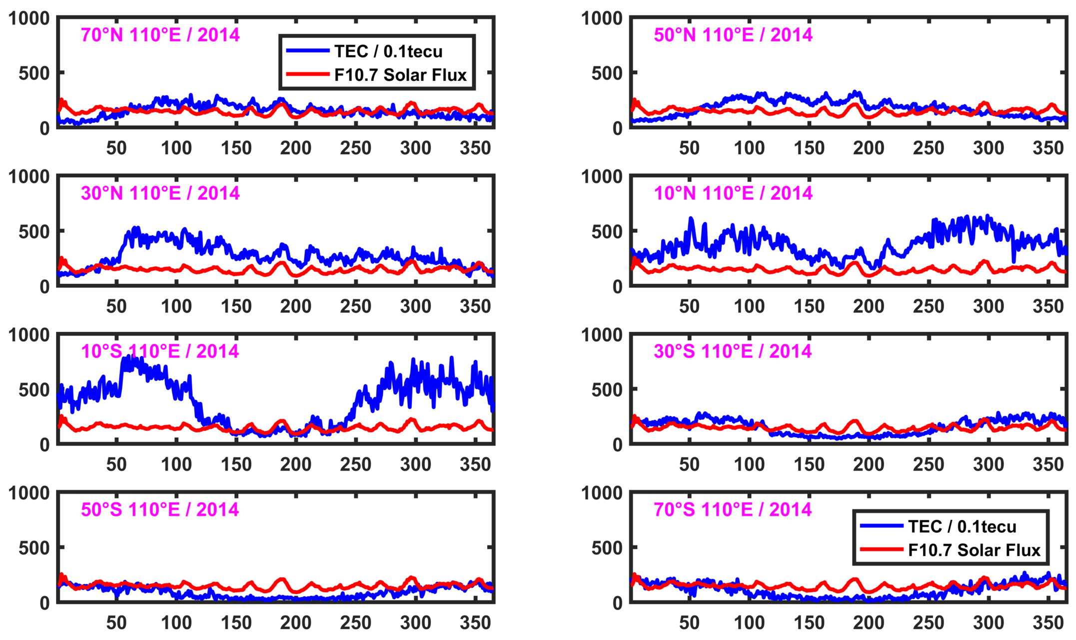
DST and $VTEC_{12}$ of C01-C05 at CUT0 2014/1—9 (left)



DST and $VTEC_{12}$ of C01-C05 at JFNG 2014/28—41 (right)

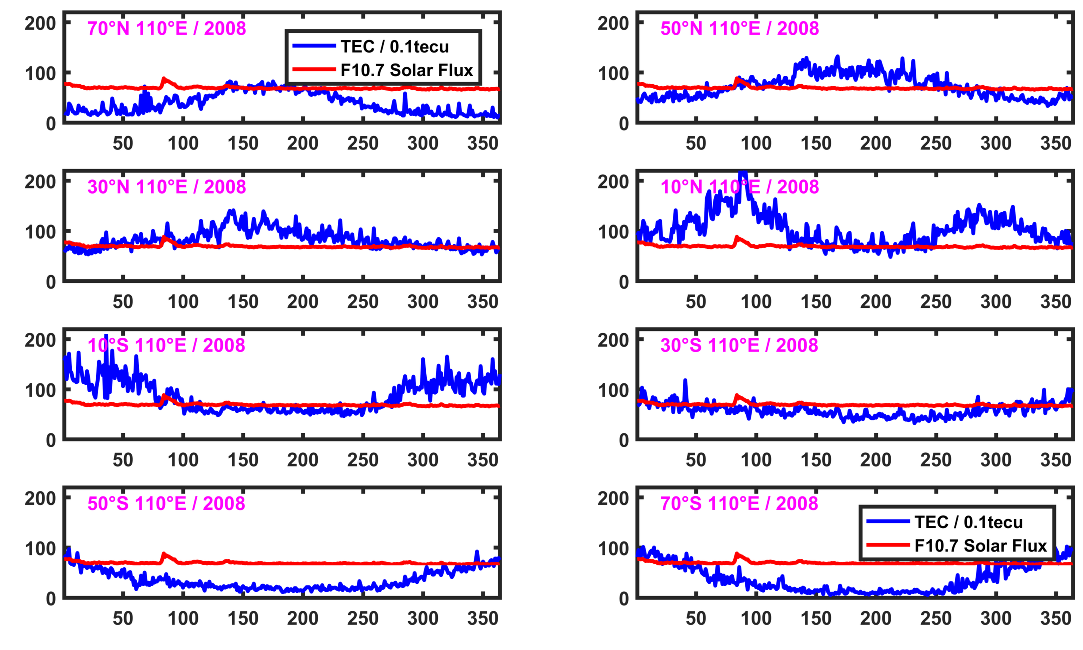
6. Correlation of TEC and F10.7 Solar flux

- The TEC data in figure below is derived from IGS GIM, and the solar activity index replaced the sunspot number with the adjusted F10.7 solar flux.
- The following figure shows the correlation between TEC and F10.7 solar flux at different latitudes throughout the year 2014, that is the Maximum year of the solar activity cycle. The ionosphere as a barometer can better reflect the changes of solar activity in Maximum year.
- The results show that there is a good agreement in mid-2014, and there is extremely abnormal in the lower latitudes in spring and autumn, which we call the ionospheric saturation during this period.



Correlation of TEC and F10.7 Solar flux in 2014

- Also the TEC data in figure below is derived from IGS GIM, and the solar activity index replaced the sunspot number with the adjusted F10.7 solar flux.
- The following figure shows the correlation between TEC and F10.7 solar flux at different latitudes throughout the year 2008, that is the Minimum year of the solar activity cycle. The ionosphere does not reflect the changes of solar activity very well in the Minimum year, that is possibly because the solar radiation energy is too little.
- The results show that the ionosphere is relatively calm in 2008 and does not change with solar activity. The reason for the initial determination is that ionization reaction of the sun to ionosphere does not reach the required energy threshold.



Correlation of TEC and F10.7 Solar flux in 2008

7. Conclusions

- The main advantage of using BDS GEO satellites is that the IPPs of GEOs is almost motionless compare to that of IGSOs and MEOs. The high-precision VTEC sequence derived from each GEO satellite at their respective fixed IPP is always continuous.
- The analysis results using a lot of measurements shows that the ionospheric monitoring continuously can be carried out at low and mid latitudes, but it is impossible in the polar region owing invisible.
- The $VTEC_{12}$ precision based on the carrier phase and code is 0.69 TECU and 5.54 TECU, respectively, which is slightly higher than $VTEC_{13}$, and much higher than $VTEC_{23}$.
- Because the VTEC sequence obtained has the advantages of continuity and reliability, it can be used to study correlation between the ionosphere and DST index, and between the ionosphere and the solar index.
- The preliminary results show that there is a similar behavior between the VTEC and DST index. And the relationship between TEC and the solar index in the Maximum and Minimum years of the solar activity cycle reflected more complex correlation. This research will be further analyzed in the future.

8. Acknowledgments

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9. References

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