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Zenith Tropospheric Delay Corrections of GNSS Satellite Signals

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ABSTRACT

The tropospheric delay is one of the main error causes of space geodetic techniques while their radio signals propagate through the atmosphere, e.g., (GPS) Global Positioning System. The tropospheric delay turns into an important issue for PPP (precise point position) of the aircraft on the runway using GPS and GNSS during landing under Instrument weather conditions which requires precision of less than 10 cm in real time. Tropospheric delay of the order of few decimeters can occur when the altitude difference between the aircraft and the specific station is about 0.5 km. In this paper selected 5 stations between Africa and Europe, 6 stations at America region and 6 stations between Asia and Austria, shows average of zenith tropospheric delay in low latitude over (Africa, America and Asia).

Keywords: GNSS – Zenith Tropospheric Delay (ZTD)

Introduction

The troposphere is the lower part of earth's atmosphere and begins at the Earth's surface and extends up to about 11 km (36,000 feet). It is non-dispersive and non-ionized middle with respect to radio waves up to 15 GHz. The troposphere affects the GNSS signals since the signals are both delayed and deflected. (Ashraf *et al.,* 2016).

The tropospheric delay is one of the main error causes of space geodetic techniques while their radio signals propagate through the atmosphere, e.g., (GPS) Global Positioning System. Today the total zenith tropospheric delay (ZTD) can be determined by GNSS (Global Navigation Satellite systems) and VLBI through mapping function (e.g., Niell, 1996; Behrend *et al.,* 2000; Niell *et al.,* 2001; Pacione *et al.,* 2002; Snajdrova *et al.,* 2006)) which plays an essential role in climatological and atmospheric science. (Haohan *et al.,* 2012). As the radio signals travels from satellite to receiver, it is affected by the atmosphere in two distinct ways: First, the signals are bent with respect to in gradients in the index of refraction of the atmosphere, traveling along a curved path (S) instead a geometrical straight line (G) the signal would travel in a region of constant refractivity. The difference between the lengths of these two paths is known as the geometrical delay. Second, the speed of propagation of signals is slower in a region of finite density than that in a vacuum. The increase in the time required to cover a given distance can also be expressed in terms of excess path length, yielding the optical delay. Both delays can be related to the variation of the refractive index, n, of the medium in the following manner (Yuan *et al.,* 1993):

$$\Delta L = \int_L n(s)ds - G \quad (1)$$

As S is the curved path length along L. In this equation, the first term of the equation coincides to optical delay and the second term corresponds to geometrical delay .The tropospheric delay is therefore often illustrated as a linear combination of the hydrostatic and wet components:

$$N(s) = [n(s) - 1] \times 10^6 \quad (2)$$

$$\Delta L = 10^{-6} \int_L N(s)ds - (S - G) \quad (3)$$

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As S is the curved path length along L. In this equation, the first term of the equation corresponds to optical delay and the second term corresponds to geometrical delay

$$\Delta L = 10^{-6} \int_L N_{Hyd}\, ds + 10^{-6} \int_L N_{wet}\, ds \quad (4)$$

The tropospheric delay (TD) is represented in terms of the delay calculated in the zenith direction over the antenna on the ground; hence the zenith tropospheric delay ZTD is a combination of (ZWD) the zenith wet delay and (ZHD) the zenith hydrostatic delay.

$$ZTD = ZHD + ZWD \quad (5)$$

The slant tropospheric delays (STD) at arbitrary elevation angles (ε) can be expressed in terms of the zenith delays (ZD) and mapping functions. This representation lets the use of separate mapping functions for the wet and hydrostatic delay components:

$$STD = m_h(\varepsilon) \times ZHD + m_w(\varepsilon) \times ZWD \quad (6)$$

Where

$m_h(\varepsilon)$ is the hydrostatic mapping function, and

$m_w(\varepsilon)$ is the wet mapping function.

Normally, the total zenith tropospheric delay (ZTD) is about 2.50 m, where about 90% of this value is caused by (ZHD) the zenith hydrostatic delay, and approximately about 10% of this value is caused by the zenith wet delay (Skone, 2001). As satellites reduction in elevation toward the horizon, the slant hydrostatic delay (SHD) or the slant wet delay (SWD) rises significantly.

The extent to which variations in solar activity affect climate has been the subject of Great achievement over many years and has often been the cause of guesswork and controversy. As observational and modeling techniques improve, and our understanding of the natural internal variability of the climate system advances, it is becoming more reasonable both to discover solar signals in climate records and to investigate the mechanisms whereby the solar impact acts. This subject is an interesting and difficult scientific area to study, but it is now also of considerable practical importance in terms of differentiating natural and anthropogenic causes of climate variation so that more reliable estimates can be made of the potential future influences of human activities on climate. (Haigh, 2002).

Table 1: List of stations used in the study, first column is Site ID , second column is latitude and third column is longitude. Shows geographic location and country

Country	Longitude	Latitude	Site ID
Ethiopia	38.7663017	9.0351340	ADIS00ETH
Egypt	29.910991	31.197066	ALX2
Cyprus	33.3964000	35.1409000	NICO00CYP
Kenya	40.1940000	-2.9960000	MAL200KEN
South Africa	20.8109111	-32.3814361	SUTM00ZAF
Colombia	-74.0809396	4.6400731	BOGT00COL
Virgin Islands, U.S.	-64.5843186	17.7568995	CRO100VIR
United States of America	-76.8268305	39.0217276	GODE00USA
Brazil	-63.8963198	-8.7093366	POVE00BRA
Peru	-71.4929041	-16.4654233	AREG00PER
Chile	-71.5320500	-37.3387028	ANTC00CHL
Philippines	121.0777306	14.6357194	PIMO00PHL
Taiwan	120.9873891	24.7979861	TCMS00TWN
china	116.2241278	40.2453250	BJNM00CHN
Australia	131.1327357	-12.8437107	DARW00AUS
Australia	133.8855132	-23.6701239	ALIC00AUS
Australia	144.9753402	-37.8294054	MOBS00AUS

Data and analysis

The value of zenith tropospheric delay over Africa and Europe, America, Asia and Australia. The metrological data were storage for 17 stations from web site (http://www.igs.org/network/). In this paper selected 5 stations between Africa and Europe, 6 stations at America region and 6 stations between Asia and Austria. Shows average of zenith tropospheric delay in low latitude over (Africa, America and Asia).

Result and Discussion

This study presents the characterization of Zenith tropospheric delay during maximum and minimum of the current solar cycle of years 2014 and 2017 respectively.

The result of solar maximum 2014, (solid line) in figure (1) shows the maximum value of tropospheric delay (ZTD) of about 0.86 meter during (May, July and October), the minimum ZTD value accord during (February, March and August). During 2017, (dash line) the result shows the maximum value of ZTD is 0.84 m (in April and June) and the minimum ZTD value is about 0.83 m in September. As a result, we found that the ZTD value are always much higher for the year 2014 which represent the solar maximum. The figure (2) shows the tropospheric delay of value at ADIS station in low latitude during maximum solar cycle in 2014 (solid line), and the maximum value of Zenith tropospheric delay is about 0.91 m (on March), the minimum value of ZTD on February. During minimum solar cycle in 2017 (dash line), the figure shows the maximum value of ZTD is 0.8742 m (on April), and the minimum value of ZTD is 0.6209 m (on September). The result shows, that the value of ZTD, is the maximum solar cycle higher than the minimum of solar cycle. In figure (3) it shows the maximum of solar cycle in 2014, (solid line) and the represents of the value of ZTD is almost stable all the year. During minimum solar cycle in 2017, dash line the figure shows the value of tropospheric delay is almost stable till September but the value of ZTD began to decrease 0.91 m on November. As a result, the value of ZTD is the maximum solar cycle (2014) higher than the minimum of solar cycle (2017). Figure (4) shows the average of tropospheric delay during maximum solar cycle 2014(solid line) , the maximum value of Zenith tropospheric delay is about 0.91 m (on September),the minimum value of ZTD is 0.82 m (on March) and on June it increase to 0.86 m .During 2017, the figure shows the maximum value of Zenith tropospheric delay (on March, MAY and September), the minimum value of Zenith tropospheric delay is 0.8243 m (on August).It observed over lapping of ZTD on April and another over lapping on June. As a result, the values of ZTD are always increasing in the maximum solar cycle and decrease in the minimum solar cycle.

In figure (5) it shows the mean of Zenith tropospheric delay during the maximum solar cycle in 2014, and the maximum value of Zenith tropospheric delay is 1.2332 m (on July) , the minimum value of Zenith tropospheric delay is almost stable from (January to march) and began to increase (on April). During 2017, the figure shows the maximum value of ZTD is about 1.14 m (on January) and the minimum of ZTD of about 0.89 m during (June, July and August).The observed data on MAY, that the value of ZTD were almost equal 1.1573 m (in 2014 and 2017).As a result, the ZTD value are always much higher for the year 2014 which represent the scale maximum. The maximum solar cycle 2014, in figure (6) shows (solid line) the maximum value of ZTD is about 0.99 m (on December), the minimum value of tropospheric delay of about 0.85 m (on August). During 2017(dash line) the figure shows the maximum value of ZTD is about 0.92m during (March, April and May) and the minimum value of ZTD in August. So, we can observed the over lapping between the maximum of solar cycle 2014 and the minimum of solar cycle in 2017 during (April and May).

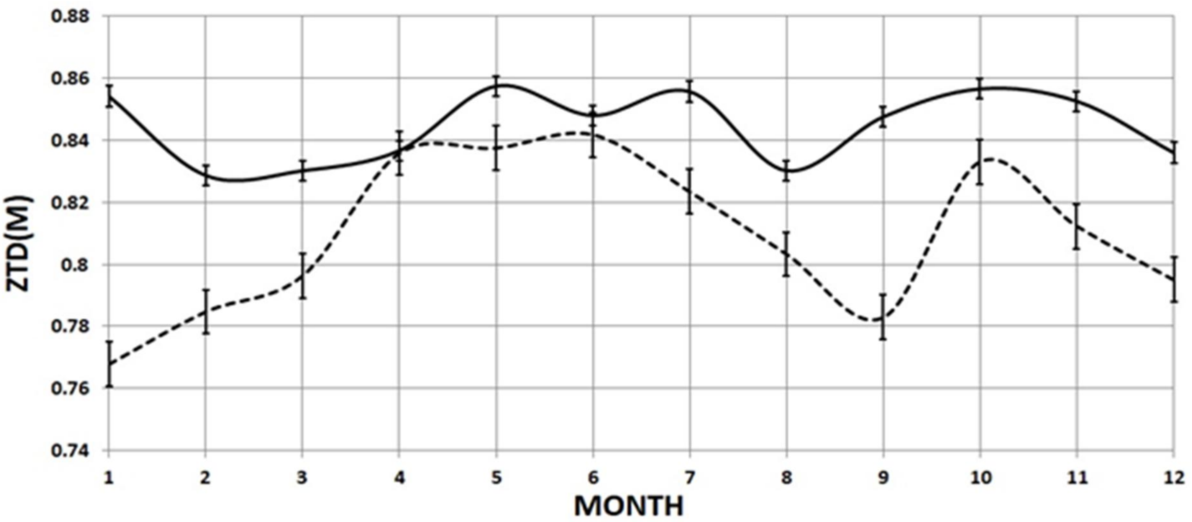

Fig. 1: Average of tropospheric delay during maximum solar cycle 2014 (solid line) and minimum solar cycle 2017 (dash line) at Africa and Europe regions (5 stations).

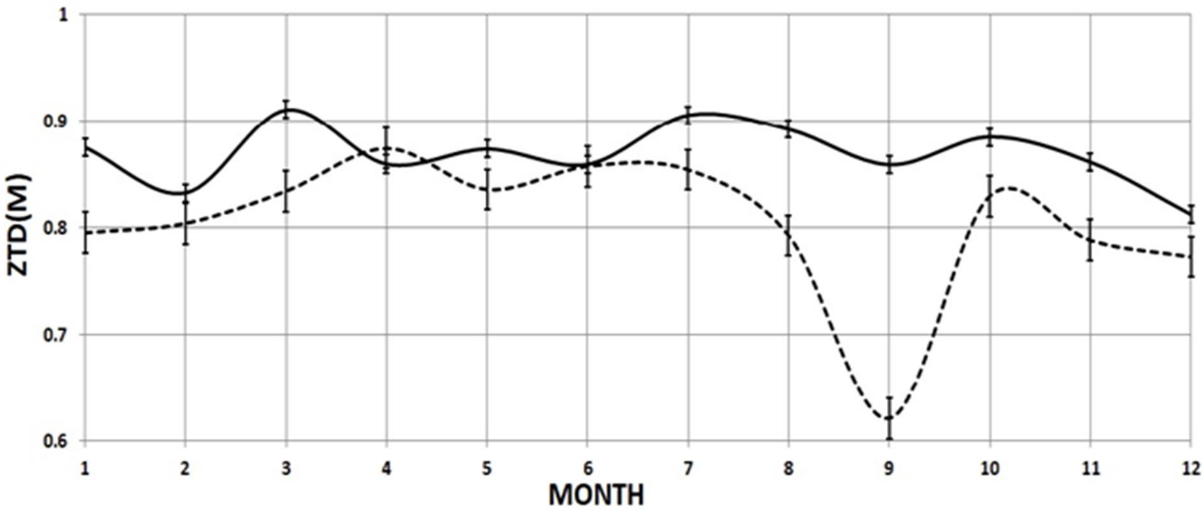

Fig. 2: Average of tropospheric delay during maximum solar cycle 2014(think line) and minimum solar cycle 2017 in low latitude (ADIS station).

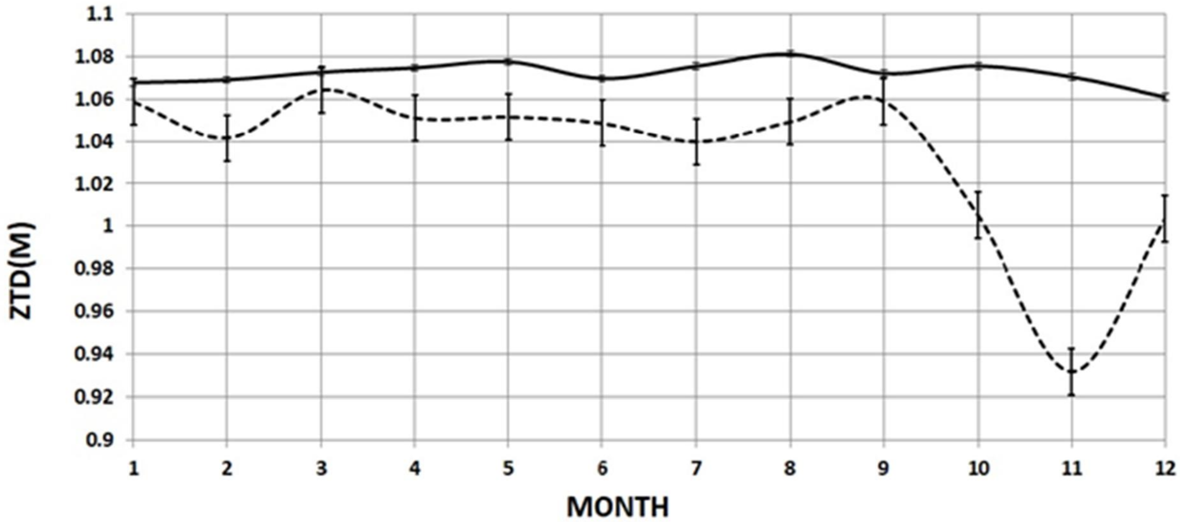

Fig. 3: Average of tropospheric delay during maximum solar cycle 2014(solid line) and (dash line) minimum solar cycle 2017 (6 stations) in American region.

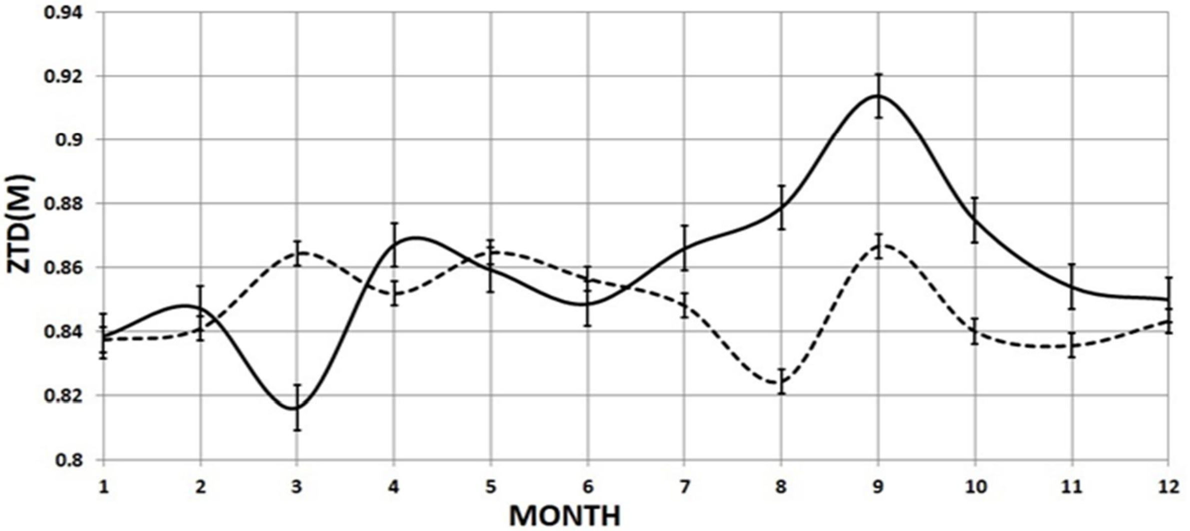

Fig. 4: Average of tropospheric delay during maximum solar cycle 2014(solid line) and(dash line) minimum solar cycle 2017 (dash line) in low latitude(BOGT station).

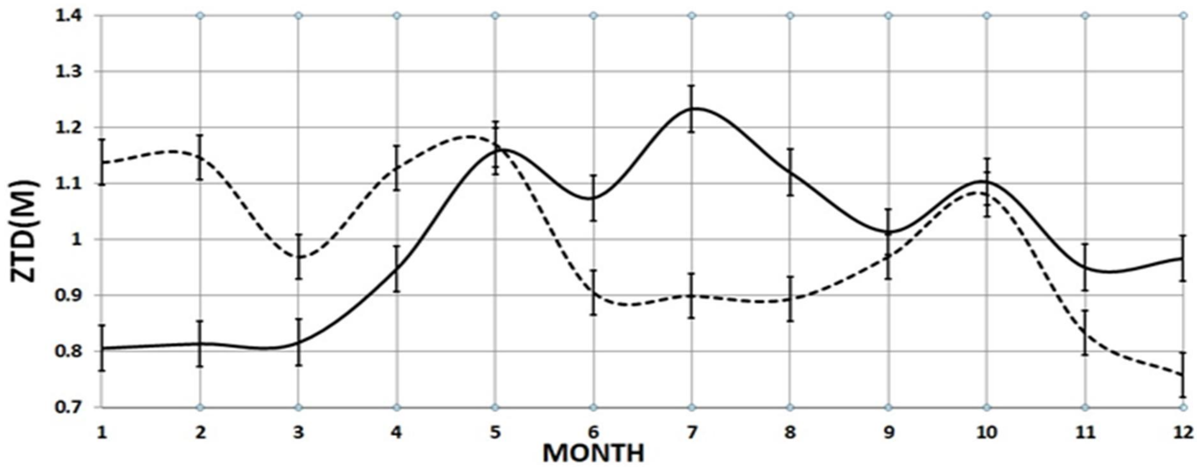

Fig. 5: Average of tropospheric delay during maximum solar cycle 2014 (think line) and (dish line) minimum solar cycle 2017 (6 station) between Asia and Australia.

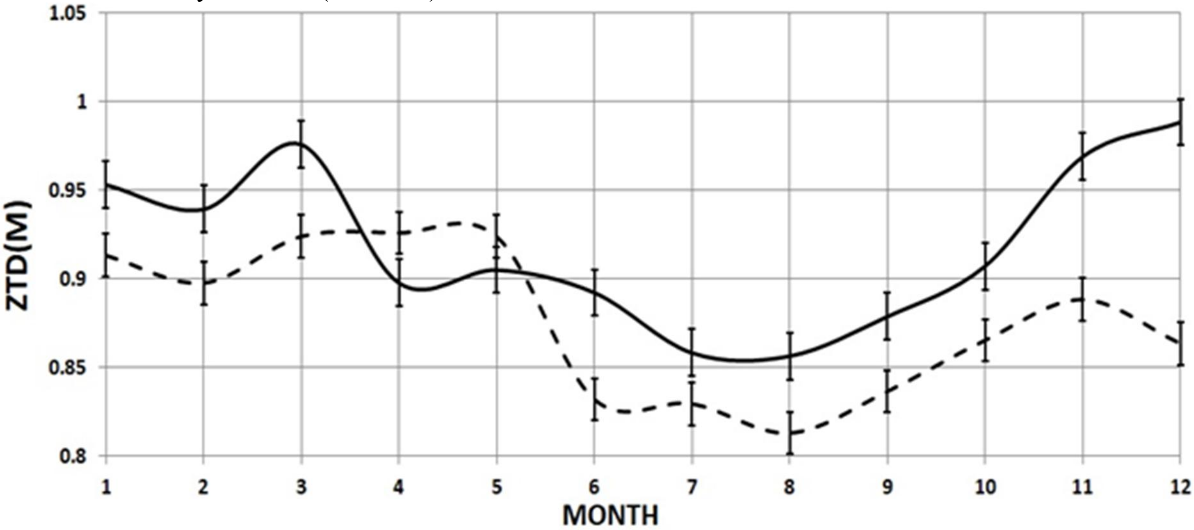

Fig. 6. Average of tropospheric delay during maximum solar cycle 2014 (solid line) and minimum solar cycle 2017 (dash line) at draw station in low latitude.

Conclusion

It could be concluded that the average of Zenith tropospheric delay during maximum solar cycle 24 (2014) and minimum solar cycle 24 (2015). Five stations were selected between Africa and Europe, six stations at America region and six stations between Asia and Austria. The average of zenith tropospheric delay in low latitude over (Africa, America and Asia). As Result, We found that the ZTD value are always much higher for the year 2014 which represent the solar maximum.

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