Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (44) No. (2) April. 2022

The Effect of Troposphere Delay on GPS Observations

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الملخص العربى :

إن نظام تحديد المواقع العالمي أصبح مكون أساسي في مختلف المجالات المحيطة بنا والتي تشمل المساحة ورسم الخرائط والملاحة وغيرها من التطبيقات الهامة. يعتمد النظام العالمي لتحديد المواقع على حساب زمن إنتقال الإشارات من القمر الصناعي إلى أجهزة الأستقبال، ولكن أثناء إنتقال هذه الإشارة تتعرض للعديد من العوارض التي تتسبب في تأخير وصولها لأجهزة الإستقبال مما يسبب زيادة في زمن إنتقال الإشارة مما يسبب أخطاء في تحديد المواقع. وتعتبر طبقة الغلاف الجوي من أكثر هذه العوارض تأثيرا على أرصاد نظام تحديد المواقع العالمي، فنتيجة إنتقال الإشارة خلال طبقة التروبوسفير قبل وصولها لجهاز الإستقبال يحدث لها تأخير. هذا التأخير يعتبر من أكبر مصادر أخطاء نظام تحديد المواقع العالمي. ولذا أجريت العديد من الدراسات على مدار الأعوام السابقة من أجل تقدير قيمة هذا الخطأ. وبناءا على ذلك فإن هذا البحث يقدم مراجعه شامله للعديد من الطرق التي يمكن إستخدامها لحساب التأخير الناتج عن طبقة التروبوسفير.

Abstract:

The use of GPS has become significant in many different applications, including mapping and surveying, as well as precise time determination, and ship navigation. It depends on an accurate measurement of the signal travel time, which is required to determine the distance between the satellite and the receiver. The accuracy of GPS positioning is lowered as a result of many error sources that affect GPS measurements. It is well recognized that atmospheric effects are the main source of spatially correlated inaccuracies in GNSS measurements. The GPS signals are delayed because they travel through the troposphere before being received by the antenna of the GPS receiver. This delay is considered one of the major error sources in GPS system. As a result, numerous studies have been carried out throughout the years to

calculate this error in GPS measurements. This article provides background on various methods that allow researchers and GPS users to calculate the troposphere delay.

Keywords: GPS; Atmospheric effects; Error sources; Troposphere delay.

Introduction:

According to their physical characteristics and effects on electromagnetic waves, the atmosphere is typically divided into various layers. The term spheres refer to the subregions of the atmosphere that share a common composition and set of characteristics. Pauses are the layers that define the boundaries between the spheres. The troposphere and ionosphere are the two spheres that have the biggest impact on satellite signals. The troposphere, which is the lowest layer of the atmosphere, is typically thought to exist up to an altitude of 10–12 km [Sickle, 2015]. The stratosphere and troposphere are separated by the tropopause. Up to around 50 kilometers, there is the stratosphere. The change in the medium's refractive index causes an additional delay in the measuring of the signal as it travels from the satellite to the receiver when Global Navigation Satellite System (GNSS) signals are transmitted through the atmosphere. The atmospheric effect is so strongly linked to GPS and is regarded as one of the most notable sources of all inaccuracies in point positioning when utilizing GPS technology. [Wolf and Ghilani, 2014].

The combined refraction in the stratosphere, tropopause, and troposphere is referred to as tropospheric delay in the GNSS community. The user's location, the day of the year, and climatic elements, such as the temperature, pressure, and humidity, all affect this delay. One of the biggest GPS positioning mistakes is brought on by this delay. This mistake can have a magnitude in the range of 2 meters [Hoffmann-Wellenhof et al., 2008]. To reflect the integrated tropospheric delay, numerous tropospheric models have been developed. Input for these models is typically required to include surface meteorological characteristics as pressure, temperature, and humidity [Shrestha, 2003]. About 85% of the overall tropospheric delay is contributed by the zenith hydrostatic delay [Skone, 2001]. With the assumption of hydrostatic equilibrium and the assumption that the zenith hydrostatic delay is a function of the surface pressure and, in

some situations, temperature, zenith hydrostatic delay models can be computed with accuracy better than 1% [Wang et al., 2017]. Zenith wet delay models have accuracy ranges between 10 and 20%, and they account for roughly 15% of the total delay. The wet component is dependent on water vapor, which is challenging to simulate because of its great spatial and temporal variability [Klos et al., 2018]. This article provides a general overview of various methods for calculating the troposphere delay on GPS observations.

Calculating the effects of the troposphere using numerical weather models:

In their 2007 paper, Andrei and Chen proposed an algorithm for computing the tropospheric delay based on the Numerical Weather Model. The National Centers for Environmental Prediction of the US National Oceanic and Atmospheric Administration created the Global Data Assimilation System (GDAS) model that was used in the inquiry. A conventional tropospheric model is utilized to derive atmospheric parameters from the GDAS model, such as pressure, temperature, and relative humidity. This study employs the Saastamoinen Model to compute zenith delays and, in conjunction with the Ifadis mapping function, to transform zenith delays into slant path delays. The outcomes were contrasted with tropospheric delays from the International GNSS Service.

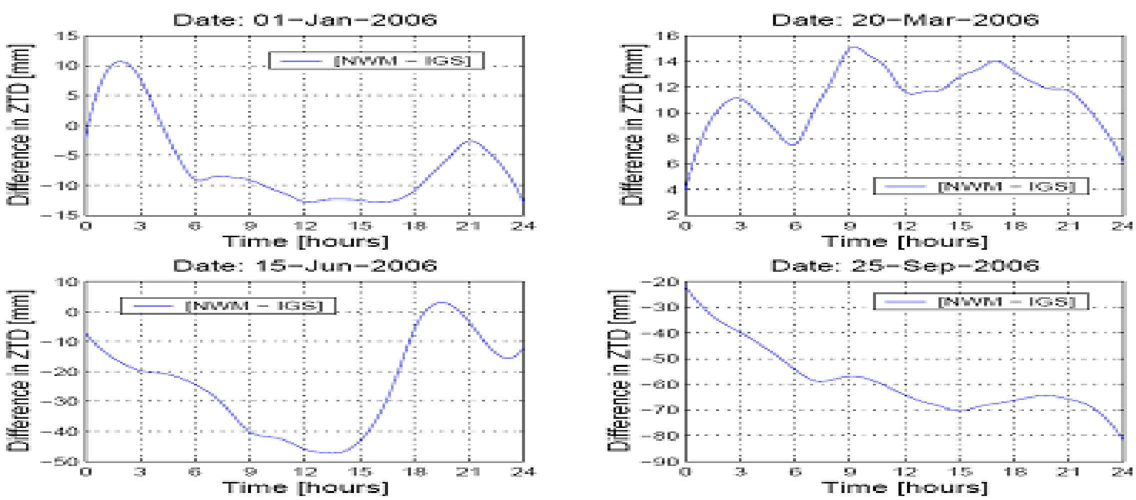

Fig. 1. The difference in zenith tropospheric delay between the suggested model's output and the IGS products at the METS, Finland, IGS station.

Table 1. Mean, standard deviation and RMS of the difference in (cm) between the proposed code's results and those from IGS.

DOY	Min	Max	Mean	Std.	RMS
1, January	0.8	-1.2	-0.6	0.7	0.9
20, March	1.5	0.8	1.1	0.2	1.2
15, June	0.2	-4.7	-2.5	1.6	2.9
25, September	-3	-7.3	-5.9	1.3	6

According to Fig. 1, the mean difference between zenith total delays calculated using the proposed model and IGS products ranges from -5.9 cm (on September 25) to +1.1 cm (March 20th). Twelve instances in time for the particular day were used to get these results. The standard deviations of the gap between the estimated tropospheric delay and IGS also range from 0.2 cm to 1.6 cm. As clarified for all four cases, Table 1 shows that the RMSE of the difference between the proposed code and the IGS results of the estimated tropospheric delay is between 0.9cm and 6.

Troposphere influence estimation using PPP post-processing softwares:

Astudillo et al. (2018) provide a comparison analysis of the estimated Zenith Tropospheric Delay (ZTD) achieved using the International GNSS Service tropospheric products and six Precise Point Positioning (PPP) post-processing softwares. The ZTD produced by IGS was compared to the predicted ZTD acquired with APPS, CSRS-PPP, MagicGNSS, POINT, RTKLIB, and gLAB. The Root Mean Square Error was used to evaluate the quality of ZTD estimates of each software, because it indicates how different the estimated value is from the true value. The RMSE of all the differences (ZTD measured from all stations using the same software minus IGS tropospheric product) was calculated. Table 2 demonstrates that, in most circumstances, the RMSE is equal to or less than 1 cm, the two online services CSRS-PPP and MAGIC estimate the ZTD to a value that is closer to the IGS tropospheric product than the three other software packages (except the case of January 2017). From the three PPP software run locally GLAB is the one that had the lowest RMSE.

Table 2. RMSE values for each software utilizing all data, expressed in centimeters.

Day of Year		CSRS	APPS	Magic	POINT	RTKLIB	gLAB
2016	27, January	0.78	17.13	1.01	16.23	12.29	3.62
	27, April	0.65	19.45	0.8	9.36	12.51	2.91
	27, July	0.69	15.06	1.00	13.68	9.42	2.40
	27, October	0.7	22.6	0.89	14.97	9.94	3.35
2017	27, January	4.77	15.67	4.85	16.75	13.96	3.21
	27, April	0.67	18.64	0.9	9.45	12.14	4.03
	27, July	0.66	17.39	0.78	12.67	8.71	2.74
	27, October	0.56	31.99	0.83	12.9	9.71	5.83

In this analysis, three trends were identified. The first was that ZTD estimates from CSRS-PPP and GLAB were highly similar to those from the IGS Tropospheric product. Furthermore, it was discovered that the tropospheric models currently used in POINT and RTKLIB do not accurately reflect the meteorological and atmospheric conditions in the equatorial region. Since CSRS-PPP and MAGIC's corrections are quite accurate, estimations that are closer to the actual value were discovered. Third, it was discovered that the ZTD estimation by PPP softwares was not significantly impacted by the change in season. This study suggests that CSRS-PPP can provide very accurate predictions for GNSS meteorology or numeric weather models, followed by MagicGNSS and gLAB.

Arief and Gatti (2020) present the open source goGPS software in order to calculate the ZTD. This software was applied on the BAKO station in Cibinong and the JOG2 station in Yogyakarta. In addition to GIPSY software, the IGS tropospheric products and commercial software Bernese version 5 were used to validate the results. Days of the year (DOY) 22–25, which represent the wet season in this study, and DOY 230–233, which overlap with August 17–20 and represent the dry season in 2018, are used as the epochs. The findings demonstrate that for Bako and Jog2 stations, the tendency of ZTD value in January is greater than the value of ZTD in August, with an average difference of 99,632 mm and 142,602 mm, respectively.

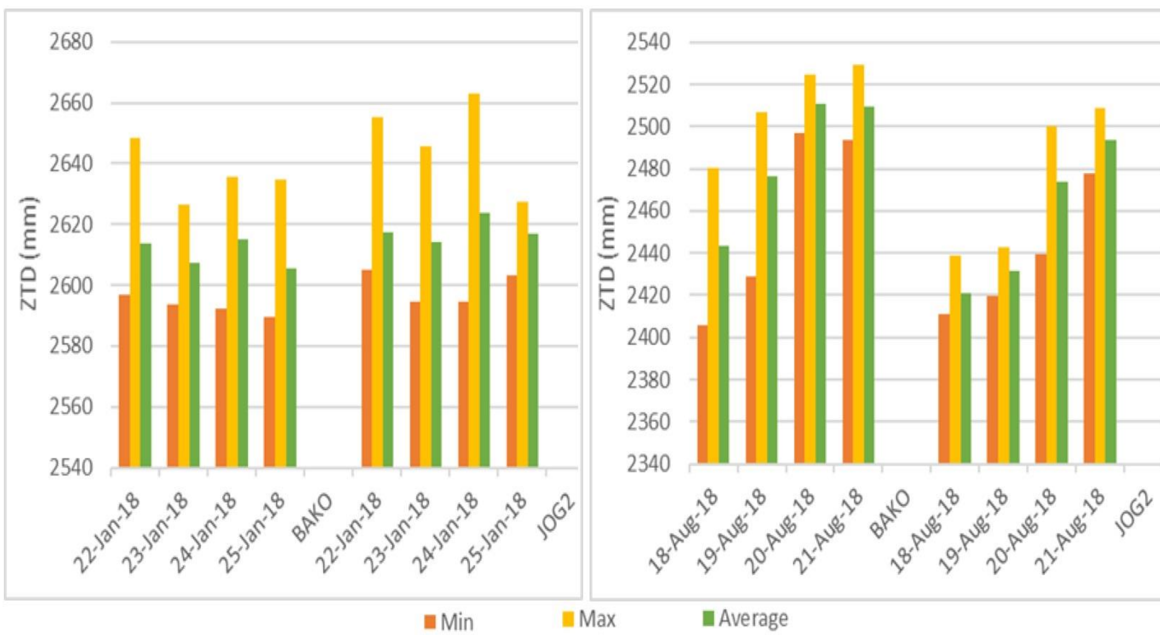

Fig. 2. The minimum, maximum, and average values for the years 2018-22-25 and 2018-18-21 at BAKO and JOG2 stations.

As shown in Fig. 2, the ZTD value's condition during January was more stable than it was in August, when there was a change in the ZTD value. When compared to January, which was rather consistent, the standard deviation in August was higher due to oscillations. The standard deviation for BAKO station is 18,025 mm in January and 48,118 mm in August. It was 22,986 mm at the JOG2 station in January and 42,988 mm in August. This reveals that ZTD is an indicator of conformity to the conditions of the rainy season and dry season since its value is higher during the rainy season than it is during the dry season. Hopefully, this phenomenon will be more beneficial for meteorological purposes. Results from the two BAKO and JOG2 stations, which were used to obtain ZTD values in both January and August, were reliable and consistent at various times and locations. At both BAKO and JOG2 stations, RMS measurements for the whole DOY show small values < 2 mm. As a result, free software like goGPS can be used as a substitute for paid software.

Utilizing Artificial Intelligence to Calculate the Troposphere's Effect:

Selbesoglu (2020) employed artificial intelligence technology and created a novel neural network model, as shown in Fig. 3, to forecast the wet troposphere delay with 10-minute intervals utilizing meteorological data from in-situ observations of The New Austrian Meteorological Measuring Network. To investigate how the ANN model responds to the various meteorological circumstances, predicted zenith wet delay (ZWD) values were performed on two reference stations that are part of the Austria GNSS Network of Austria during humid (August) and dry (December) seasons. A further investigation into the height influence on prediction was conducted using two GNSS stations at various altitudes. By comparing the outcomes with values calculated from Global Navigation Satellite System observations for validation, the developed neural network model for the zenith wet delay prediction based on TAWES meteorological data and EPOSA GNSS data was evaluated.

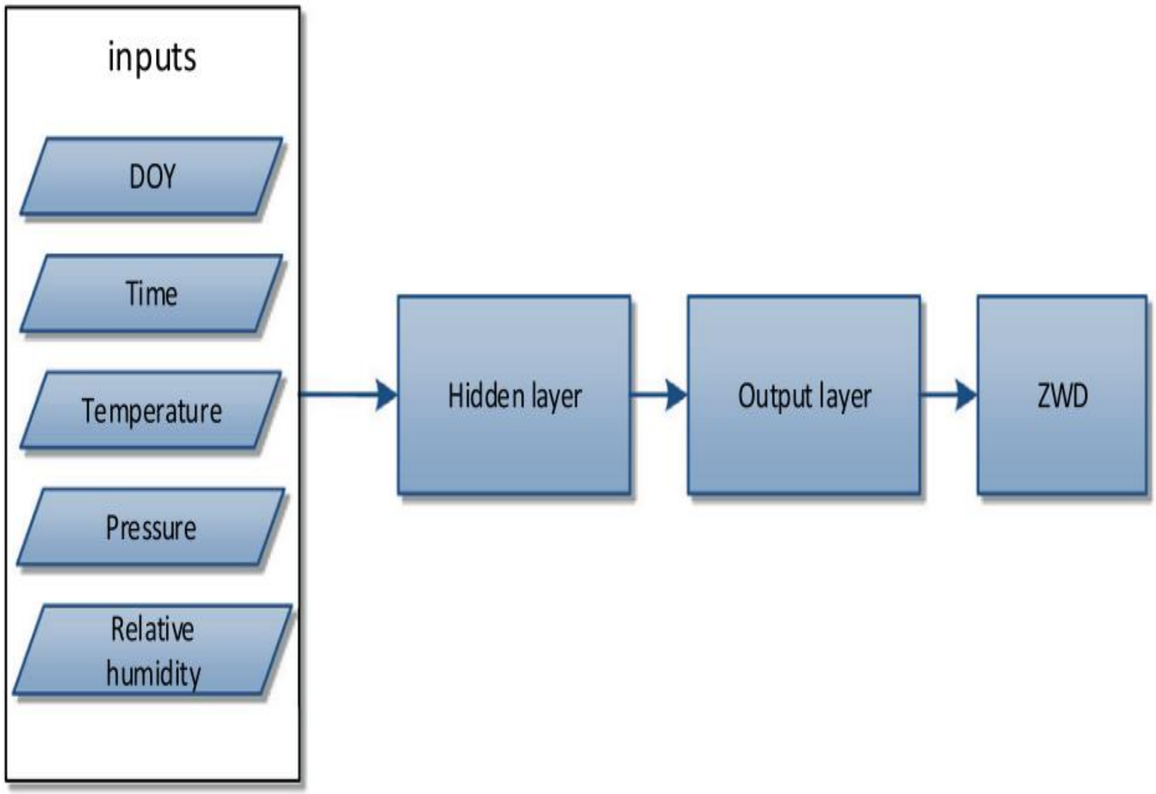

Fig. 3. Artificial neural network model design.

As shown in Fig. 4, the Root Mean Square Error was used to assess the accuracy of ZWD estimations produced by each software, as it shows how far the estimated value deviates from the actual value. The standard deviation of prediction between the forecasted ZWD and the GNSS ZWD is shown in Table 3 to be between 0.06 and 0.4 cm. Otherwise, the RMSE (Root Mean Square Error) ranges from 0.43 to 2.07 cm for the difference between the predicted and GNSS ZWD.

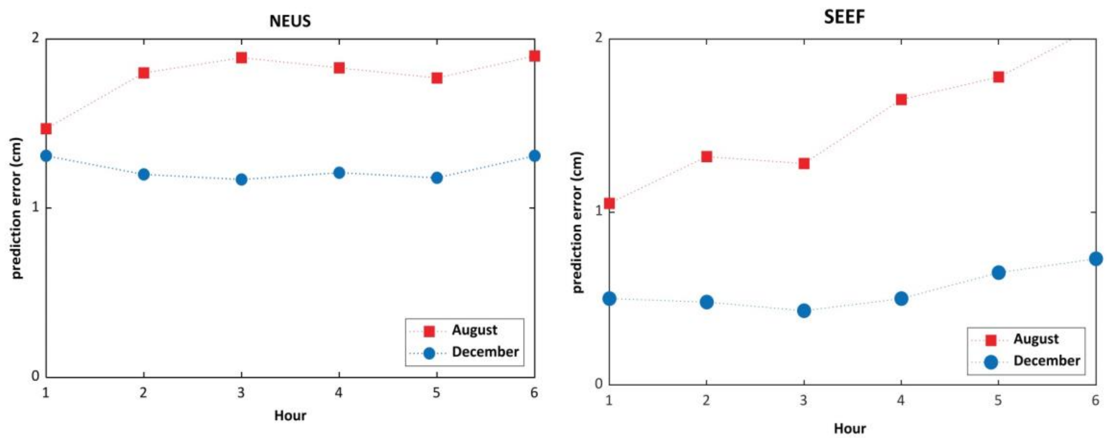

Fig. 4. The prediction error of the proposed ANN for SEEF and NEUS GNSS Stations up to 6 hours of prediction.

These findings indicate that the newly developed ANN model can deliver accurate ZWD predictions and that the accuracy of ZWD prediction by newly created ANN model is adequate for weather forecasts.

Table 3. The standard deviation and RMSE (in cm) for the difference between the anticipated ZWD and the GNSS ZWD, up to 6 hours of prediction.

Station Coor.			Hour		SD	RMSE		SD	RMS
NEUS	47,33 North	11,19 East	1	1 ST August, 2010	0.13	1.47	1 ST December, 2010	0.11	1.31
			2		0.26	1.8		0.16	1.2
			3		0.22	1.89		0.22	1.17
			4		0.25	1.83		0.18	1.21
			5		0.3	1.77		0.15	1.18
			6		0.32	1.9		0.22	1.31
SEEF	47,96 North	16,84 East	1		0.13	1.05		0.09	0.5
			2		0.17	1.32		0.06	0.48
			3		0..27	1.28		0.08	0.43
			4		0.16	1.65		0.08	0.5
			5		0.28	1.78		0.13	0.65
			6		0.4	2.07		0.15	0.73

Conclusions:

Due to the troposphere strata in the lower part of Earth's atmosphere, GNSS observations are impacted as they travel from satellites to receivers. The troposphere delay, which is the result of this action, is one of the main reasons of mistake in GPS point positioning. Thus, the topic of troposphere modelling gained popularity among researchers and technologists. A new era in the study of the troposphere has begun with the invention of the GPS, which offers precise tropospheric information of the GPS signals. Various methods for calculating the troposphere delay on GPS measurements are briefly summarized in this article. The results of the methodologies presented demonstrate that troposphere delay causes a delay into GPS measurements in the range of 2.0 m. Therefore, for all GPS users, the troposphere delay must be included in order to acquire precise coordinates. Additionally, the RMSE and standard deviation for each result are minimal. In light of this, this article provides a variety of additional resources for precisely tracking and calculating the tropospheric delay for GPS users.

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