Journal of Engineering Research

Volume 7
Issue 5 *This is a Special Issue from the Applied Innovative Research in Engineering Grand Challenges (AIRGEC) Conference, (AIRGEC 2023), Faculty of Engineering, Horus University, New Damietta, Egypt, 25-26 October 2023*

Article 61

2023

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Journal of Engineering Research (ERJ)
Vol. 7 – No. 5, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Study the Efficiency and Availability of GLONASS in Total Electron Content Mapping over Egypt

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***Abstract*- Global Navigation Satellite Systems (GNSS) are used for positioning and navigation, so the precision of its observations are crucial. The ionosphere has a significant impact on GNSS observations causing the biggest error. The free electrons in the ionosphere affect the navigation signals having electromagnetic properties. The ionosphere error can be eliminated by calculating Total Electron Content (TEC) using dual frequency receivers. On estimating TEC, a systematic error which is device (satellite and receiver) dependent is found called differential code bias (DCB).**

This article provides an overview of two GNSS systems: the Global Positioning System (GPS) and the GLObal NAvigation Satellite system (GLONASS). Moreover, data from four regional receivers in Egypt are used to investigate the availability of GPS and GLONASS satellites over Egypt on May 10, 2015 by comparing them with four European International GNSS Services (IGS) stations on the same day. Furthermore, the TEC values are calculated on 2-hour temporal resolution over the 24 hours of the day and validated using IGS TEC products. The results show that GLONASS satellites are covering Egypt efficiently; GLONASS observations compose around 42% of the total number of GNSS observations. The calculated TEC in Egypt are found less than IGS products over the most hours of the day with differences between 0.04 to 9.40 TECU.

***Keywords*- GPS, GLONASS, GNSS, DCB, TEC, Ionosphere.**

I. Introduction

Global uses for navigation and positioning have been multiplied with the implementation of the GPS by the United States and a comparable GLONASS system by the Soviet Union, which restored full constellation operation in April 2011. Along with GPS and GLONASS, China began developing (BeiDou) in the late 1990s and has been rapidly progressing in recent years. The European Union has also built their own satellite system (Galileo). Many other nations, such as Japan, have begun their own regional satellite navigation systems, the Quasi Zenith Satellite System (QZSS). The GNSS are made up of all of these satellite systems. Even though these systems have comparable qualities and may offer precise time and location information when their observations are combined, the majority of studies only included one GNSS constellation.

The ionospheric delay may be calculated using a variety of techniques [1, 2]. These studies used approximations, the DCB values of the satellites and receivers don't change throughout the course of a day, the ionosphere is modelled as a sphere with an incredibly small thin layer, and the TEC is uniform across tiny regions within a certain time interval in these investigations. Additionally, they stated that it is preferable to investigate low, mid, and high latitudes since the TEC cannot be regarded uniform in some regions due to latitude effects, such as the equatorial and auroral zones.

Ref. [3] calculated instrumental biases and TEC using self-calibration of pseudo-range errors (SCORE) process during geomagnetic storm in 2006. The most crucial idea in the SCORE method is that the same Vertical TEC (VTEC) is calculated on the junction between two satellites occurs. He discovered that compared to calm days, satellite DCB variation is higher on stormy days. Additionally, he stated that TEC may rise or fall as a result of ionospheric storms. Ref. [4] looked examined 270 stations' DCB values for GPS and GLONASS from 2000 to 2014. It was discovered that the DCBs of the GPS satellites shift by around 1 TECU year. The DCB fluctuations with GLONASS are more noticeable (between 5 and 10 TECU annually). Ref. [5] used 9 International GNSS Service (IGS) stations in South Korea to determine the DCB values and TEC using GPS and GLONASS data. Their study used data from the Center for Orbit Determination in Europe (CODE) Analysis Center, which it used to determine the receivers' DCBs and TEC. They discovered that the GLONASS readings can contribute to an almost TEC estimate method when the GPS signals are not seen in a brief period of time. According to Ref. [6], the ionospheric delay (containing both TEC and DCB in satellites and receivers) is larger at medium latitudes than high latitudes, but it is largest in both the north and south halves of the planet. Their ionospheric delay computation employed GPS and GLONASS readings from different latitudes and months in 2018.

In the current paper, an overview on GPS and GLONASS is presented focusing on the differences between them in Section (2). The TEC results are calculated using software developed on MATLAB using the Spherical Harmonic Model (SHM) introduced in Sections (3 & 4). A case study compares satellites visibility of the two constellations in Egypt and Europe is presented in Section (5) in addition to TEC mapping over Egypt. Section (6) includes a discussion of the results and presents the conclusions.

II. GPS and GLONASS Architecture:

Any GNSS constellation consists of three components: space, ground, and user segment. The term "space segment" refers to groupings of satellites that transmit electromagnetic signals. 32 satellites make up the GPS constellation, which are spread out across six orbital planes and orbits the Earth at a nominal height of 20200 km and an inclination of 55° with

Doi: 10.21608/erjeng.2023.243951.1287

Journal of Engineering Research (ERJ)
Vol. 7 – No. 5, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

respect to the equator during a period of around 12 sidereal hours. However, the GLONASS constellation consists of 24 satellites spread over three orbital planes at a height of 19140 kilometers. The orbital period of the planes is 11 hours, 15 minutes, and 44 seconds, with a distance between them of 120° and an inclination to the equator of 64.8° [7].

The ground segment includes Controlling ground facilities that follow the satellites, examining the data gathered, and offering guidance to modify satellite paths. Figure (1) illustrates an extremely sparse worldwide distributed monitoring network for GPS operation. Not just in Africa and the major oceanic regions, but also in China, Russia, and Europe. However, the whole ground component of GLONASS is situated on Russian land. To overcome the spreading shortage, monitor stations and SLR stations are used in addition to the control units as per Figure (2).

The GNSS receivers that can pick up, decode, and analyses the signals sent by these satellites are referred to as the user segment. One prominent user sector is IGS. It is made up of a voluntary union of more than 200 organizations from across the world that pool their resources and permanent GNSS station data to provide accurate products. IGS is the highest accuracy international civilian GNSS community [7].

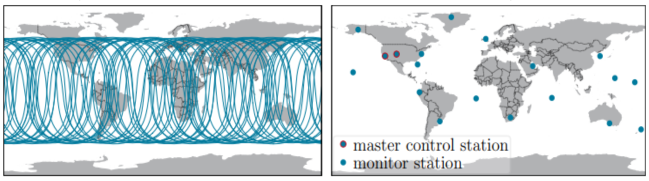


Figure (1): Ground tracks of GPS satellites on day 37 of year 2021 on the left and GPS ground segment on the right [8]

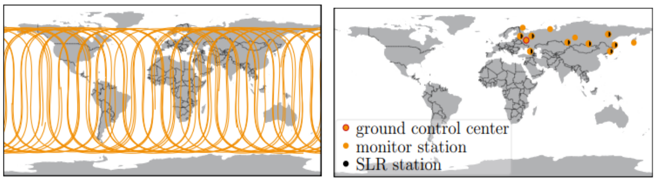


Figure (2): Ground tracks of GLONASS satellites on day 37 of year 2021 on the left and GLONASS ground segment on the right [8]

III. IONOSPHERIC DELAY:

Numerous errors, including bias in the satellite and receiver clocks, multi-path errors, orbital errors, tropospheric delay error, affects GNSS observations. However, the biggest error influencing GNSS observations is thought to be the ionospheric delay including TEC and DCB. The term "TEC" refers to the quantity of electrons within a tube with a one-meter square cross section that stretches from two sites the satellite to the receiver. The following equation describes how to compute the ionospheric TEC by integrating the location-dependent electron density N(s) along the path ds:

$$TEC = \int N_e\,(s)\,ds \quad (1)$$

DCB is a systematic error that is dependent on both the satellite and the receiver that occurs when measuring the TEC of the ionosphere using GNSS dual frequency pseudo-range data.

The geometry-free linear combination of GNSS observations, also known as the ionospheric observable, is traditionally used to estimate TEC. It is created by removing concurrent pseudo-range (P1-P2) or carrier phase observations (L1-L2) observations. This combination eliminates all frequency independent biases and the geometrical range between the satellite and receiver The pseudo-range measurements' geometry-free linear combination is achieved as shown in the following equation [9].

$$\text{P4} = P^s_{r,1}(i) - P^s_{r,2}(i) = I^s_1 - I^s_2 + DCB_s + DCB_r \quad (2)$$

$$\text{L4} = L^s_{r,1}(i) - L^s_{r,2}(i) = I^s_2 - I^s_1 + \lambda(N_2 - N_1) + \lambda(b_{r,2} - b_{s,2}) - \lambda(b_{r,1} - b_{s,1}) \quad (3)$$

With r, s, j, and *i* are the receiver, satellite, frequency, and epoch indices, and where: $\boldsymbol{P^s_{r,j}(i)}$, $\boldsymbol{L^s_{r,j}(i)}$ Pseudo-range and carrier-phase measurements, respectively, in meters, $\boldsymbol{I^s_{j,P}}$, $\boldsymbol{I^s_{j,L}}$ the ionosphere delay of pseudo-range and carrier-phase observations, respectively, in meters, $\boldsymbol{N_j}$ carrier-phase integer ambiguities, in cycles, $\boldsymbol{\lambda}$ carrier-phase wavelength, in meters, $\boldsymbol{b_{s,i}}$, $\boldsymbol{b_{r,i}}$ satellite and receiver instrument biases phase advance, respectively, in metric units, and $\boldsymbol{DCB_s}$, $\boldsymbol{DCB_r}$ are the satellite differential code bias and receiver differential code bias ,respectively, in metric units.

IV. SPHERICAL HARMONIC MODEL:

In order to represent the ionosphere, it is typically believed that all of the free electrons are concentrated in a single thin layer at height H. Slant TEC (STEC), which refers to the total electron content along the signal's course, intersects with the sent signal at the Ionospheric Pierce Point (IPP). It is simple to STEC using the smoothed P4 as following [9, 10]:

$$STEC = -\frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}(P_{4,sm} - c * DCB_r - c * DCB_s) \quad (4)$$

Where $\boldsymbol{f_1}$ and $\boldsymbol{f_2}$ refer to frequencies of the GNSS navigation signals. The frequencies are constant for all satellites in the case of GPS signals, f_1 and f_2 are 1575.42 MHz and 1227.60 MHz, respectively. On the other hand, GLONASS frequency differs depending on the satellite number. The two frequencies are determined to f_1 = (1602+ 9/16 k) MHz and f_2= (1246+ 7/16 k) MHz, respectively, where k refers to frequency channel number frequency [11].

An ionospheric spherical harmonic function can be concluded from the previous equations to calculate satellite and receiver DCBs for both GPS and GLONASS at any station from the smoothed P4 observations.

$$\sum_{n=0}^{N}\sum_{m=0}^{n} P_n^m sin(\beta)(a_n^m cos(ms) + b_n^m sin(ms)) = \text{Mp(z)}\left[-\frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}(P_{4,sm} - c * DCB_r - c * DCB_s)\right] \quad (5)$$

Doi: 10.21608/erjeng.2023.243951.1287

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

$$Mp(z) = \cos\left(\arcsin\left(\frac{R}{R+H}\sin(\alpha z)\right)\right) \quad (6)$$

Where: β is the geocentric latitude of IPP, n the degree of the spherical function, m the order of spherical harmonic function; fourth order for regional areas, eighth for continental, and fifteenth for global, P_n^m normalized legendre polynomials, a_n^m, b_n^m the estimated spherical harmonics coefficients, Mp(z) mapping function to convert STEC into Vertical TEC (VTEC) since STEC significantly varies depending on a satellite elevation angle z [12], R the radius of the Earth = 6,378,137 meters, H the attitude of the ionosphere electrons concentration = 506,700 meters and α a correction factor = 0.9782 .

V. TEC Modelling Over Egypt

The shortage of IGS stations in North Africa can make the IGS TEC products less precise in this area. In this section, four regional receivers namely ALAM, ASWN, MTRH and SAID, shown in Figure (3), are used to calculate TEC values over Egypt using GPS and GLONASS observations on 10 June 2015. Unlike DCB which is supposed to be the same during the same day, electronic density in the ionosphere changes rapidly. As a result, in this study, it is assumed that the TEC doesn't change during an interval of 2 hours (same as IGS IONEX data). Then the TEC results are interpolated to get the TEC values at grid points each 5° longitude (25°E to 35°E) and 2.5° latitude (from 20°N to 32.5°N) to compare them with data from IGS.

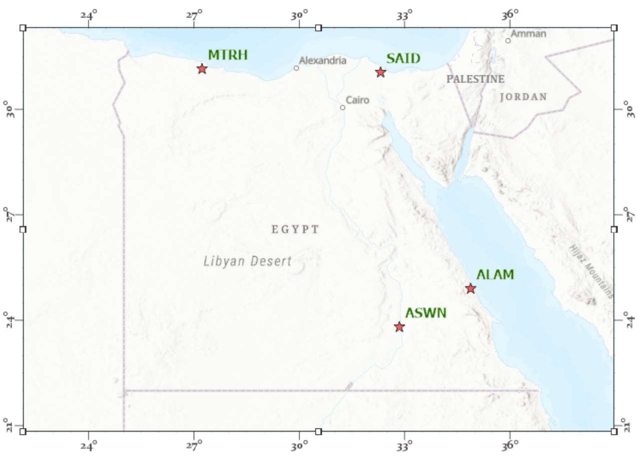


Figure (3): The location of the regional receivers in Egypt.

The most important question is to what extend is the GNSS visible in Egypt (mid latitudes), especially GLONASS because of the high inclination angle. In order to study that, a comparison is made between the number of observations received at four stations in Europe with those received at the receivers in Egypt (cut off angle for both is equal to 10°) in Figure (4). It is noticed that Egyptian stations receive less observations than European ones by about 20%. This could be due to various factors such as different receiver qualities, atmospheric conditions, and terrain. Despite the lower number of observations, GLONASS satellites appear to be visible in all four Egyptian receivers, with GLONASS observations occupying a significant percentage (ranging from 42% to 45%) except ASWN (which has 38%).

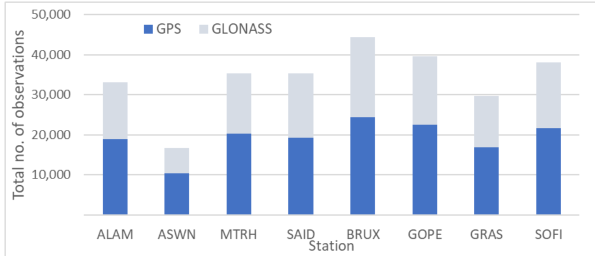


Figure (4): The number of GPS and GLONASS observations received at ALAM, ASWN, MTRH, SAID (Egypt) and BRUX, GOPE, GRAS, SOFI (Europe) on 10 June 2015 (cut off 10°).

The IPP tracks of GPS and GLONASS satellites for the first two hours of the day are shown in Figure (5). While GPS satellites cover the East and west Deserts, and Mediterranean Sea, GLONASS satellites cover Nile Valley, Delta, North Coast, and Red Sea. By using both GPS and GLONASS systems, the entire Egyptian territory is covered perfectly.

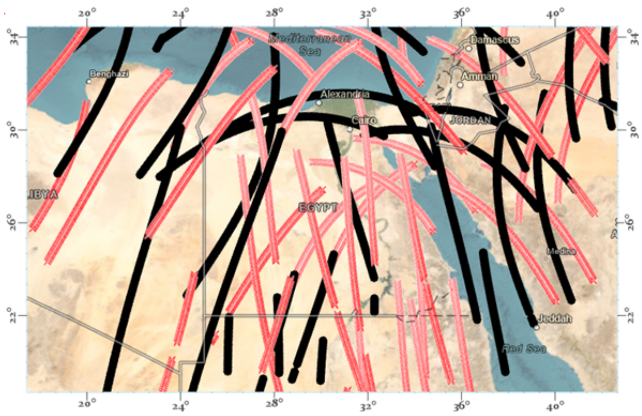
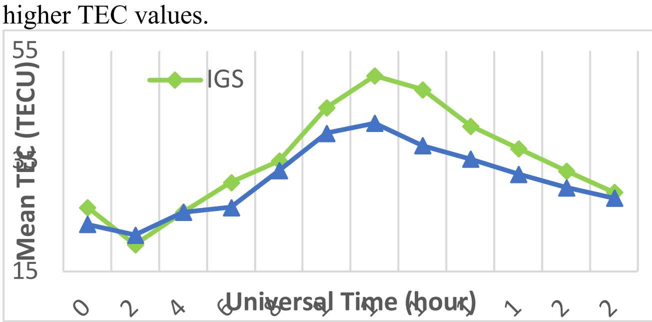


Figure (5): IPP tracks over Egypt for GPS and GLONASS satellites observed at 0-2 am on May 10, 2015, at ALAM, ASWN, MTRH, and SAID.

Mean 2-hour TEC values on May 10, 2015 in Figure (6) showing that IGS TEC values are greater than that calculated by SHM all over the day except at 2 am. The differences are between 0.04 and 9.40 TECU at 4 am and 2 pm, respectively. TEC has the at least value of 21.63 TECU at midnight (at 2 am), and the afternoon has the highest value of TEC by 41.90 TECU at 12 pm. This gradual rise in TEC values at the beginning of the day is due to the fact that when the sun rises above the horizon, the ionosphere is exposed to more solar radiation, leading to an increase in electron ionization and higher TEC values.



Doi: 10.21608/erjeng.2023.243951.1287

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ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Figure (6): Mean 2-hour TEC values on May 10, 2015, calculated using GPS and GLONASS observations at ALAM, ASWN, MTRH, and SAID and their corresponding IGS product values.

VI. Conclusions

This study introduces an overview of two GNSS constellations and an algorithm on MATLAB to estimate TEC values by SHM using GPS and GLONASS observations. The proposed software is used to calculate TEC values over Egypt from four regional receivers observing GPS and GLONASS satellites on 10 May 2015. The purposes of this study include satellites tracks over Egypt and their visibility, TEC trends during the day, and the difference between calculated TEC values and IGS products for the same region in Egypt. The results show that including GLONASS can increase the number of observations by about 80% compared to GPS observations only in Egypt. Additionally, when there is a limited number of receivers, GLONASS can be utilized to supplement GPS and achieve full coverage of a particular region.

Acknowledgment

The IONEX products were obtained through the online archives https://cddis.nasa.gov/archive/gnss/products/ionex/ of the Crustal Dynamics Data Information System (CDDIS), NASA Goddard Space Flight Center, Greenbelt, MD, USA.

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Doi: 10.21608/erjeng.2023.243951.1287