IONOSPHERIC ACTIVITY STUDIES IN THE TERRITORY OF LATVIA USING RINEX BASE STATION DATA

Atis Vallis[1]

[1]Lejaslīves SIA., Lejaslīves, Krimulda par., Sigulda distr., LV-2144, Latvia
e-mail: info@lejaslives.lv

1. Purpose

The purpose of this study is to develop a computer algorithm that would independently analyze and graphically display GNSS post-processing data from the LatPos network's Continuously Operating Reference Stations (CORS) in Latvia in order to obtain information about ionospheric activity.

The output of the algorithm, specifically the obtained information about ionospheric activity, will help increase work productivity and assist users when GNSS data is partially missing. It will support Global Navigation Satellite System (GNSS) Real-Time Kinematic (RTK) measurements by providing visually interpretable graphs that reflect Total Electron Content (TEC) fluctuations and their effect on the accuracy of GNSS observations [2, 4, 7, 8, 9, 10].

Provision of visually perceptible graphs that reflect Total Electron Content (TEC) fluctuations and their impact on the accuracy of GNSS measurements will help users of Global Navigation Satellite System's (GNSS) Real Time Kinematics (RTK) survey methods to increase work productivity and provide with missing information [2, 4, 7, 8, 9, 10].

2. Test data

The test data used in this study are RINEX (Receiver Independent Exchange) files from the LatPos GNSS reference station network. These files contain GNSS satellite signal observations, such as L1 and L2 carrier frequencies, C/A and L2C (M) code pseudorange data, as well as signal recording timestamps.

Only NAVSTAR (U.S. – Navigation System with Timing And Ranging) GPS (Global Positioning System) data obtained from this network were used in this work. The data processing, including extraction and calculation of relevant parameters, was carried out using the Python programming environment [5, 12].

3. Theoretical basis

TEC is the total number of electrons in the upper layers of the ionosphere (between the GNSS satellite and the receiver), which affects (most often hinders) the propagation and accuracy of GNSS signals. TEC calculations are used based on pseudorange and carrier phase differences for NAVSTAR satellites at two carriers L1 and L2 [3, 6, 9].

$$TEC = \int_{receiver}^{satellite} N \cdot ds \tag{1}$$

Each satellite transmits two carrier signals in the form of electromagnetic waves at the following carrier frequencies L1 = f_1 = 1575.42 MHz with a wavelength λ_1 = 19 cm and L2 = f_2 = 1227.60 MHz with a wavelength λ_2 = 24 cm.

4. TEC Calculation from GPS Observations

Pseudodistances obtained from the code (C/A, L2C (M)) travel time [2, 4, 7].

$$P = \rho + c \cdot (dT - dt) + \Delta i_i^{iono} + \Delta^{tropo} + b_i^{P,r} + b_i^{P,s} + m_i^P + \varepsilon_i^P \qquad (2)$$

Where:

i = 1, 2 corresponding to Pseudodistances P_1 (C/A) and P_2 (L2C (M))

P – is the code pseudorange measurement (in distance units)

ρ – is the geometrical range between satellite and receiver

c – is speed of light in vacuum

dT – is satellite clock offset from GPS time

dt – is receiver clock offset from GPS time

$\Delta i_i^{iono} = \frac{(40.3 \cdot TEC)}{f_i^2}$ ionospheric delay

f_i - is the carrier frequency Li

Δ^{tropo} – tropospheric delay

$b_i^{P,r}$ – are the receiver instrumental delays on P

$b_i^{P,s}$ – are the satellite instrumental delays on P

m_i^P – multipath effect on P

ε_i^P – receiver noise on P

Carrier phase observations are obtained from the carrier signal travel time [2, 4, 7, 9, 11].

$$\Phi_i = \lambda_i \cdot \phi_i = \rho + c \cdot (dT - dt) + \lambda_i + N_i - \Delta i_i^{iono} + \Delta^{tropo} + b_i^{\phi,r} + b_i^{\phi,s} + m_i^{\phi} + \varepsilon_i^{\phi} \qquad (3)$$

Where:

Φ_i – are carrier phase observation (in distance units)

ϕ_i – are carrier phase observation (in cycles)

$\lambda = c/f$ is the wavelength

N_i – are the unknown number of Li integer carrier phase ambiguities

$b_i^{\phi,r}$ – are the receiver instrumental delays on Φ

$b_i^{\phi,s}$ – are the satellite instrumental delays on Φ

m_i^{ϕ} – multipath effect on Φ

ε_i^{ϕ} – receiver noise on Φ

This formula describes the GPS pseudorange (P and Φ) measurement, including various factors that affect the signal path and time measurements.

TEC is the number of free electrons per square meter along the path of an electromagnetic wave traveling between a GPS satellite and a ground-based receiver. It is an important parameter in ionospheric studies and navigation corrections.

TEC is typically measured using GPS signals by analyzing the differences in pseudorange and carrier phase measurements between the two main GPS frequencies – L1 and L2.

Subtracting pseudorange measurements for L1 and L2 frequencies:

$$P_2 - P_1 = 40.3 \cdot TEC\ (1/{f_2}^2 - 1/{f_1}^2) \tag{4}$$

By rearranging this expression, TEC can be expressed as:

$$TEC = \frac{(P_2 - P_1)}{40.3 \cdot (1/{f_2}^2 - 1/{f_1}^2)} \tag{5}$$

When calculating a denominator containing known numerical values:

$$40.3 \cdot (1/{f_2}^2 - 1/{f_1}^2) = 1.05046 \times 10^{-5}$$

TEC simplifies to:

$$\mathrm{TEC} = (P_2 - P_1) \cdot 95215 \tag{6}$$

where 95215 is the scaling factor in TEC electrons/m².

TEC can be alternatively expressed as Total Electron Content Units (TECU). TECU is TEC expressed as 10^{16} electrons/m^2.

$$TEC\ (TECU) = (P_2 - P_1) \cdot 9.52 \tag{7}$$

This value is widely used in scientific literature [15, 16].

GPS pseudorange and carrier phase measurements can be used to calculate TEC in the ionosphere. If TEC is expressed in electrons/m², the factor 95215 is used, and if TEC is expressed in TECU units, the factor 9.52 is used.

TEC calculation based on pseudoranges (TEC P) and carrier phase differences (TEC Φ) is described below.

Combining the pseudorange observations *P*, we obtain the TEC value [2, 6, 10, 14]:

$$TEC\ P = 9.52 \cdot (P_2 - P_1) + various\ errors \tag{9}$$

In turn, combining the carrier phase observations Φ_i, we obtain:

$$TEC\ \Phi = 9.52 \cdot (\Phi_1 - \Phi_2) - (N_1\lambda_1 - N_2\lambda_2) + various\ errors \tag{10}$$

Calculating the difference between these two quantities resolves the uncertainty.

$$TEC\ L = TEC\ \Phi - (TEC\ \Phi - TEC\ P) \tag{11}$$

TEC is essential in geophysics and has applications in navigation measurement corrections for single-frequency receivers, as there is no way to calculate this uncertainty.

Traditionally, TEC was measured using the Faraday rotation effect on a linearly polarized plane wave.

5. Development progress

Python Software version 3.13.1 with georinex, numpy, pandas, matplotlib, gzip and other libraries were used to automate the calculations.

In order to test the operation of the algorithm time effectively, a 10-minute RINEX file was created.

Figure 1. displays test data analysis for a 10-minute RINEX file on 23.01.2025 LGIA (Latvian Geospatial Information Agency).

6. Results

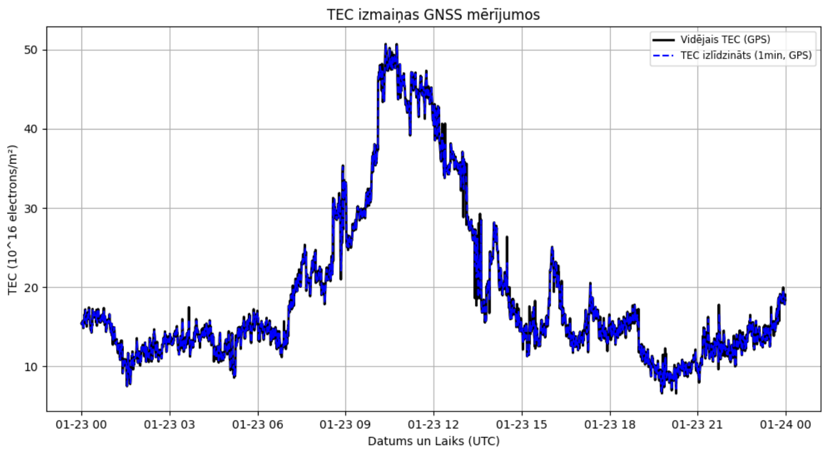

Fig. 1. Test data TEC graph of 23.01.2025

References:

[1] Leick, A. (1995). GPS satellite surveying (2nd ed.). John Wiley & Sons, Inc.

[2] Klobuchar, JA (1985). Ionospheric total electron content (TEC). In Handbook of Geophysics and the Space Environment.

[3] Hoffmann-Wellenhof, B., Lichtenegger, H., & Collins, J. (1994). GPS theory and practice. Springer-Verlag Wien.

[4] Komjathy, A. (1997). Global ionospheric total electron content mapping using the Global Positioning System (Doctoral dissertation).

[5] Gail, WB, Prag, B., Coco, DS, & Cooker, C. (1993). A statistical characterization of local mid-latitude total electron content. Journal of Geophysical Research, 98(A9), 15,717-15,727.

[6] Seeber, G. (1993). Satellite geodesy. Walter de Gruyter.

[7] Komjathy, A., & Langley, RB (1996). An assessment of predicted and measured ionospheric total

electron content using a regional GPS network. Retrieved from http://gauss.gge.unb.ca/grads/attila/papers/papers.htm (accessed 17 September 1998).
[8] Lanyi, GE, & Roth, T. (1988). A comparison of mapped and measured total ionospheric electron content using global positioning system and beacon satellite observations. Radio Science, 23, 483-492.
[9] Mannucci, AJ, Wilson, BD, & Edwards, CD (1993). A new method for monitoring the Earth's ionospheric total electron content using GPS global network. In Proceedings of ION GPS-93, Salt Lake City, UT, 22-24 September, The Institute of Navigation, Alexandria, VA, 1323-1332.
[10] Sardon, E., Rius, A., & Zarraoa, N. (1994). Estimation of the transmitter and receiver differential biases and the ionospheric total electron content from global positioning system observations. Radio Science, 29, 577-586.
[11] Klobuchar, JA (1996). Ionospheric effects on GPS. In BW Parkinson & JJ Spilker (Eds.), Global Positioning System: Theory and Applications (Vol. 1, pp. 370). American Institute of Aeronautics and Astronautics.
[12] Wilson, BD, & Mannucci, AJ (1993). Instrumental biases in ionospheric measurements derived from GPS data. In Proceedings of ION GPS-93, Salt Lake City, UT, 22-24 September, The Institute of Navigation, Alexandria, VA, 1343-1351.
[13] Kantor, IJ, de Paula, ER, & de Rezende, LFC (nd). TEC measurements with GPS data. INPE, Aeronomy Division, São José dos Campos, São Paulo - Brasil.
[14] Difar, KA (2019). Studying the relationship between TEC, I95 index and Wp index and their effect on ionosphere in Iraq, Romania and South Africa. Polytechnic University of Bucharest, Romania.
[15] Choi, B.-K., et al. (2010). Receiver DCB Estimation and Analysis by Types of GPS Receiver. Journal of Astronomy and Space Sciences, 27(2), 123–128.
[16] NOAA Space Weather Prediction Center. Total Electron Content.; https://www.swpc.noaa.gov/phenomena/total-electron-content