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# EVALUATION OF STATIC GNSS POSITIONING ACCURACY DURING SELECTED NORMAL AND HIGH IONOSPHERIC ACTIVITY PERIODS

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Abstract

This article presents the results of the experimental research into the ionospheric influences on the accuracy of the GNSS measurements by comparing single and dual frequency GNSS observations. In the research, GNSS data from three reference stations in central Poland were used. The selection of the observation period depended on the calm and disturbed ionospheric conditions. The purpose of the research was to determine the differences between the control coordinates of the stations and the coordinates of these stations received after processing the results of single and dual frequency GNSS observations. For a better visibility, these differences were presented as horizontal and vertical components. The values of these components are compared with the global magnetic activity and regional ionospheric index I95. The results obtained show that the ionosphere has a considerable impact on single frequency GNSS measurements according to the geodetic requirements, although this impact depends more on the state of ionosphere rather than on its space-time changes.

## Introduction

The main principle of the GNSS measurements is based on the determination of the amount of time it takes for an electromagnetic signal to travel from the satellite to the receiver. Because the signal travels through the heterogeneous atmosphere (ionosphere and troposphere), it will be distorted under its influence. One of the major errors in this case is the ionospheric delay.

The ionospheric impact on the distribution of the GNSS signals causes phase and group delays. The signal delay in the ionosphere depends on the

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solar activity, seasonal and daily variations, zenith distance and azimuth satellites, location of an observer. The measurement error of the pseudorange can be more than 50 m due to the delay of the GNSS signals in the ionosphere (SEEBER 2003).

Unlike the troposphere, that is not a dispersive medium and does not affect the propagation of the GNSS signals, the ionosphere is a dispersive medium and its impact depends on the satellite signal frequency. This factor helps minimize the measurement error in the computation of the ionospheric delay for the satellite signal.

The overall ionospheric impact on the satellite signal can be hypothetically divided into three components:

– 1st order impact (≈ 99%);
– 2nd order impact (≈ 0.8%);
– 3d order impact (≈ 0.2%).

The first order refractive index only accounts for the electron density within the ionosphere, while the effect of the Earth's magnetic field and its interactions with the ionosphere are considered in the higher order terms; i.e. the second and third terms.

The $1^{st}$ order impact of the ionosphere can be fully compensated due to the dispersion, namely 99% of its total impact if to use dual frequency (multifrequent) equipment (receiver and antenna). The detection and estimation of ionospheric impact during single frequency GNSS observation poses a special problem.

The main source of errors in single frequency equipment when measuring pseudorange is the signal propagation delay in the ionosphere that is caused by the total electron content (TEC) along the pass of the signal. This type of equipment does not allow to use the signals at the two coherent frequencies to avoid the ionospheric measurement error.

There are two methods to compute the ionospheric delay for single frequency equipment (SEEBER 2003). The first one is the correction of pseudoranges using ionospheric model parameters (KLOBUCHAR 1991) received in a GPS navigation message. The application of ionospheric model that is used in GPS allows to reduce ionospheric impact on the standard deviation when determining coordinates. It is experimentally proven that the real deviation reduction is possible only on approximately 50% (KAZANTSEV, FATEEV 2002). The second and the most promising method is the usage of properties of the received signals. According to this method, the calculation of the ionospheric signal delay is based on the fact that the phase and group ionospheric delays of the GNSS signals are equal in values but opposite in signs (GUOCHANG 2007).However, existing methods based on this approach have one common limitation – the additional identification of initial ambiguities in phase measurements (KRANKOWSKI et al. 2007). This problem complicates the implementation and reduces the efficiency of such method, which explains its limited use in practice.

Lately, the scientists actively work on the study of phase fluctuations and failures in GNSS phase and code measurements under conditions of geomagnetic disturbances (AFRAYMOVICH, USHAKOV 2003). Magnetospheric storms and substorms cause geomagnetic disturbances that result in a wide range of irregularities and processes in the Earth's ionosphere (HUNSUCKERET et al. 1996). Classic picture of ionospheric disturbances is proven by numerous observations (CHERNOGOR et al. 2014, BURMAKA, CHERNOGOR 2012). However, the physical nature of numerous mechanisms is not yet clear enough. The effects of a storm/substorm in the ionosphere depend on a great number of parameters such as local time, latitude, season, solar activity phase, storm/substorm intensity, and others. Thus, it is necessary to study the impact of signal propagation delay in the ionosphere on the measurement errors of defining coordinates, as this issue remains unexplored throughout the whole period of GNSS usage.

## Experiment description

For the study of the ionospheric impact, three stations with accurate coordinates (determined from long-term GNSS observations and adopted as control coordinates) are chosen. One station is used as a base station and two other are used as test stations to form 2 baselines for the computations. The distance between the stations depended on the possibility to determine the significant ionospheric impact. Thus, for short distances it would be more difficult to analyze the research results. That is why the approximate distances from the vector stations to the basic have to be 35–40 km and 85–90 km correspondingly. Based on hourly observations, the coordinate change had to be determined during the processing of single and dual frequency observations. For practical implementation of this research, we processed GNSS data from three reference stations in central Poland: BOGO (Borowa Gora), JOZE (Jozefoslaw), and LODZ (Lodz).The basic station in the research was JOZE. The distance between the BOGO and JOZE stations was approximately 40 km and between the JOZE and LODZ stations – 90 km. The observation period depended on the calm (2–6/12/2014, 9–15/02/2015, 16/03/2015) and disturbed (1, 7/12/2014, 17–22/03/2015) ionospheric conditions.

GNSS observation data was processed in Trimble Business Center.

Figure 1 shows the location of the stations on the map and Table 1 provides the control coordinate values (EPN 2015).

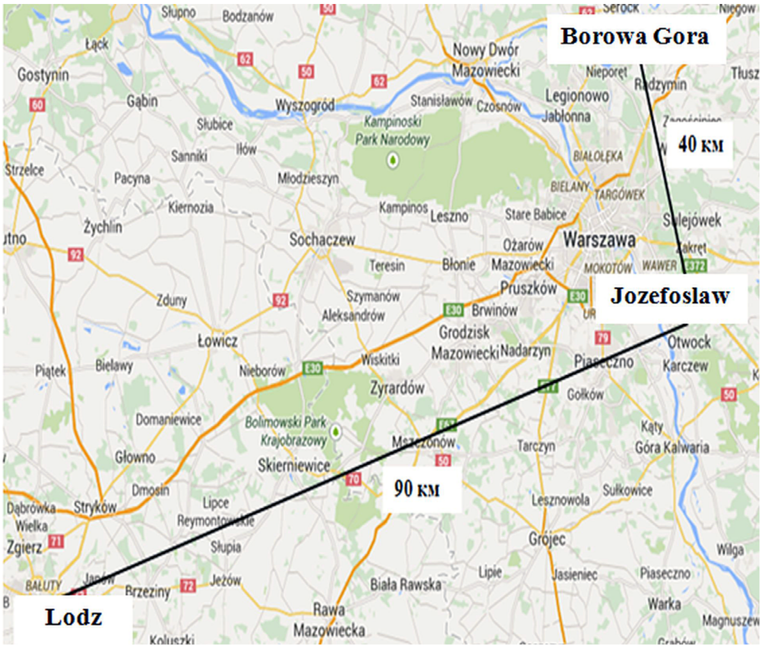


Fig. 1. Location scheme of the reference stations BOGO, JOZE, LODZ

Table 1

Control coordinates of the stations BOGO, JOZE, LODZ

| Station name | Coordinates [m] | | |
|---|---|---|---|
| | *X* | *Y* | *Z* |
| BOGO | 3633738.798 | 1397434.280 | 5035353.563 |
| JOZE | 3664939.989 | 1409154.013 | 5009571.472 |
| LODZ | 3728601.378 | 1317402.626 | 4987811.422 |

The purpose of the research is to compare station coordinates obtained after processing of single and dual frequency GNSS observations with the control coordinates provided in Table 1.

For a better clarity and visibility, the differences between the processed and control coordinates are converted into topocentric coordinates dN, dE, and dU, which are further represented as horizontal $H = \sqrt{N^2 + E^2}$ and vertical $V = U$ components. These components are the object of the analysis and are compared with the regional ionospheric index (I95) and global magnetic activity (MAG).

Using ionospheric index I95, the impact of the ionosphere on the determination of coordinates with the help of GNSS can be calculated with the accuracy up to 95% (WANNINGER 2004). Therefore, I95 is a statistic index that provides information about the value of differential ionospheric errors. Index is calculated using the GNSS observations results. One value of I95 includes differential ionospheric errors of all accessible satellite signals from at least three reference stations. The I95 value depends not only on the ionospheric conditions but also on other factors such as distance between the reference stations and elevation (SAPOS 2015).

Index values range between:

0–2 – normal level of ionospheric activity;

2–4 – moderate level ionospheric activity;

4–8 – high level of ionospheric activity.

Magnetic activity is a disturbance in Earth's magnetic field that is connected with the changes in magnetosphere-ionosphere current system. It is a part of the Sun-Earth connection physics and, correspondingly, the space weather. The main manifestations of the magnetic activity are strong disturbances – magnetic storms and substorms, and light disturbances – different kinds of magnetic pulsations (GFZ-Potsdam 2015).The condition of the magnetic field can be described using the Kp index:

$K \leq 2$ calm storm conditions;

$K = 2, 3$ minor disturbances;

$K = 4$ disturbances;

$K = 5, 6$ magnetic storm;

$K \geq 7$ strong magnetic storm.

The information about ionospheric conditions and the change in magnetic activity parameters can be obtained on the Internet (TESIS 2015).

## Calculation results

Figures 2, 3, 4, and 5 show the variations of *H* and *V* components for the BOGO station. Analysis of Figures 2 and 3 shows that there are considerable jumps in values of horizontal and vertical components for single frequency observations. These values are mostly positive and reach up to 40 cm. Figures 4 and 5 show that the values of horizontal and vertical components are smaller and do not exceed 5 and 10 cm, correspondingly.

Figures 6, 7, 8, and 9 illustrate variations of *H* and *V* components for the LODZ station. Figures 6 and 7 show that single frequency observations at a bigger distance have considerable influence on the way the vertical component changes. The values of these changes are both positive and negative and

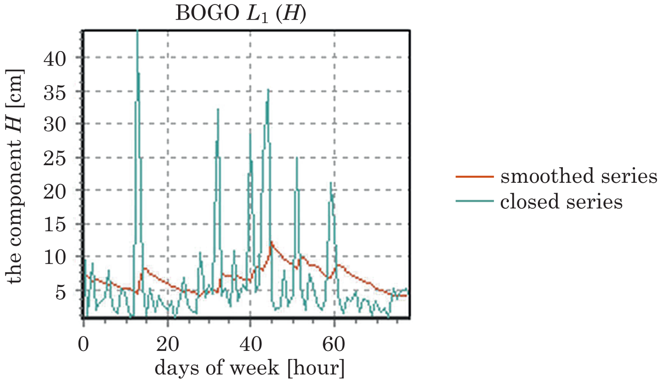


Fig. 2. *H* variations for single frequency observations

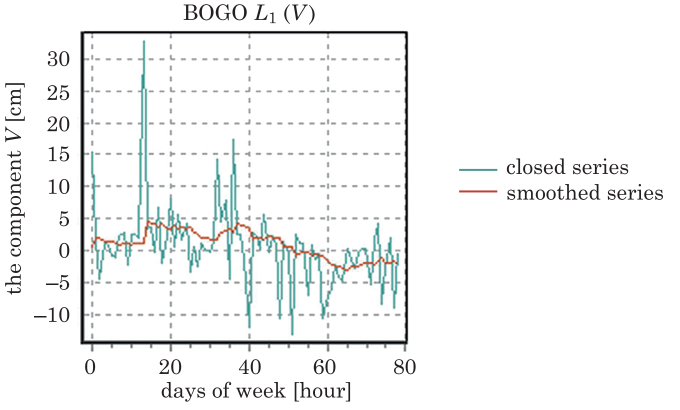


Fig. 3. *V* variations for single frequency observations

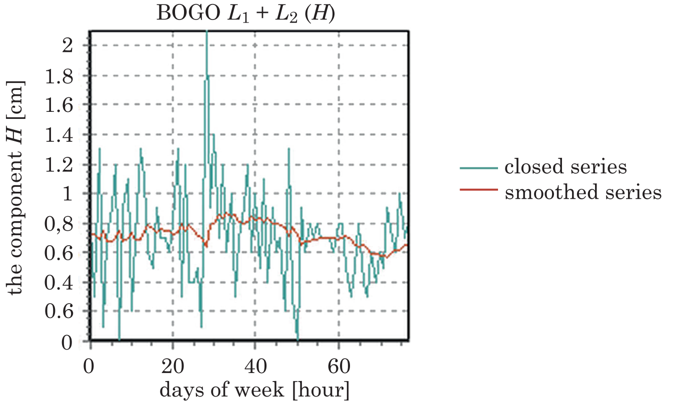


Fig. 4. *H* variations for dual frequency observations

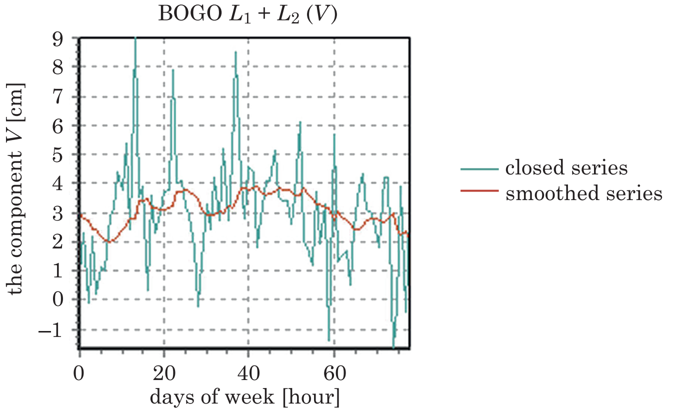


Fig. 5. $V$ variations for dual frequency observations

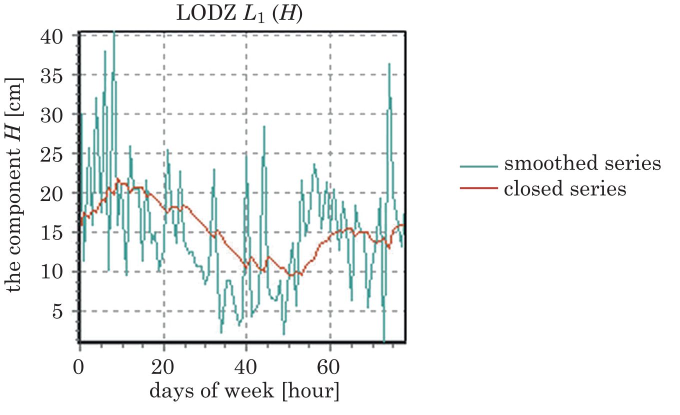


Fig. 6. $H$ variations for single frequency observations

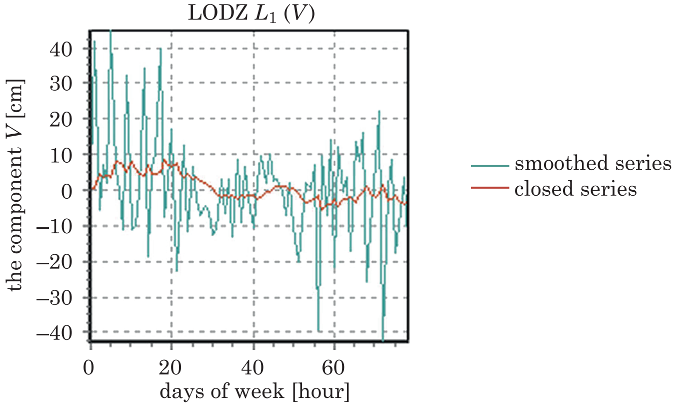


Fig. 7. $V$ variations for single frequency observations

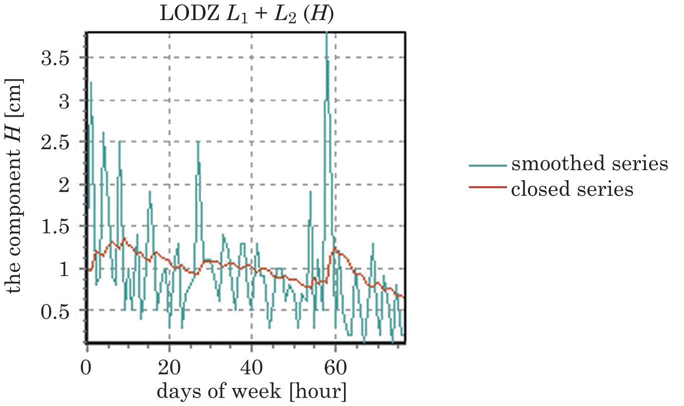


Fig. 8. *N* variations for dual frequency observations

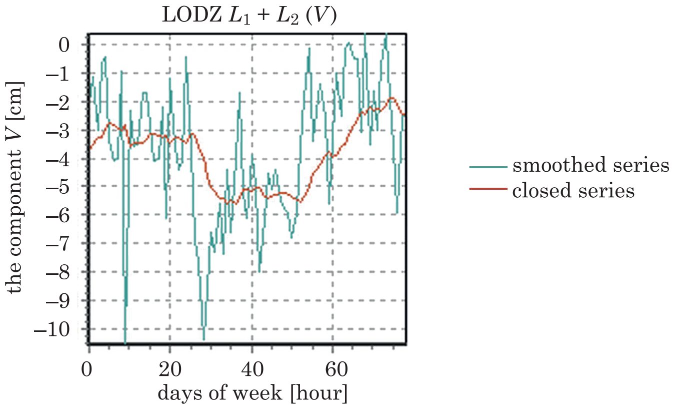


Fig. 9. *V* variations for dual frequency observations

range between -40 and 40 cm. Such fluctuations can be caused by the shift in ionosphere heterogeneity changes in space and time. Figures 8 and 9 show that bigger distance between the stations does not influence the results of dual frequency observations as the values of horizontal and vertical components do not exceed 5 and 10 cm correspondingly.

To our opinion, only the ionosphere can cause considerable deviations of single frequency observations discovered during the analysis of the obtained results.

Similar studies were conducted for three other reference stations in western Ukraine: MYKO (Mykolaiv), STRY (Stryi), and SKOL (Skole). The distances between these stations are similar to those in Poland. MYKO is used as a base station. The distance between the MYKO and STRY stations is approximately 35 km and between the MYKO and SKOL – 70 km. The observation period is 03/12/14. Figure 10 shows locations of the stations, and Table 2 provides their control coordinates.

Table 2

Control coordinates of the MYKO, STRY, and SKOL stations

| Station name | Coordinates [m] | | |
|---|---|---|---|
| | *X* | *Y* | *Z* |
| MYKO | 3790465.481 | 1685988.196 | 4828829.875 |
| STRY | 3812850.835 | 1687385.931 | 4810814.627 |
| SKOL | 3841562.710 | 1671363.028 | 4793846.225 |

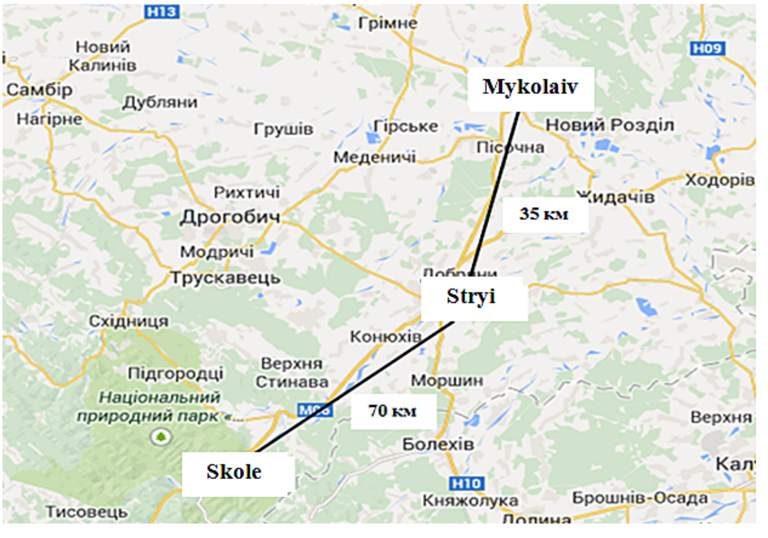


Fig. 10. Location scheme from MYKO, STRY, and SKOL reference stations

Considerable coordinate changes can be observed after the analysis of the obtained results from the reference stations in both Poland and Ukraine. Graphically the results are represented in Figures 11 and 12. The distance between the stations is 35–40 km. The similar results are obtained for the stations at the distance 70–90 km between each other (Fig. 13 and 14).

In general, 168 hourly observing sessions are processed. Approximately 5% of them did not result in a fixed solution. Most likely, this can be caused by the impact of the ionosphere.

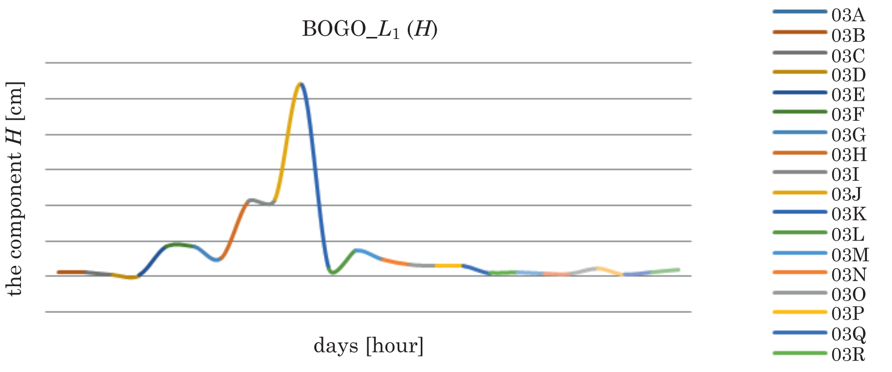


Fig. 11. $H$ variations for single frequency observations at the BOGO station

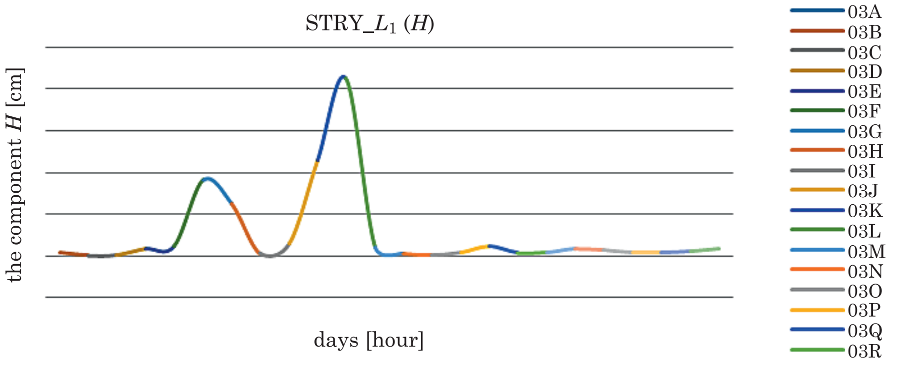


Fig. 12. $H$ variations for single frequency observations at the STRY station

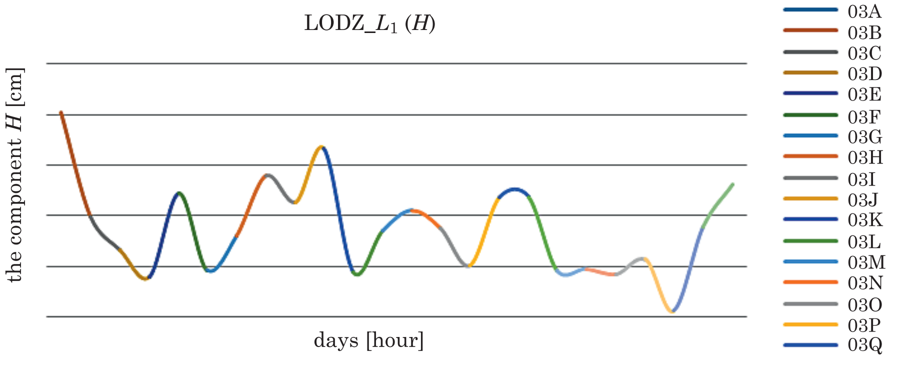


Fig. 13. $V$ variations for single frequency observations at the LODZ station

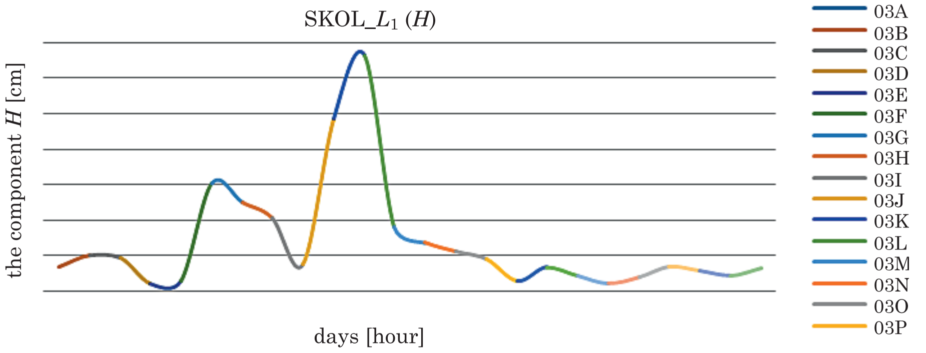


Fig. 14. *V* variations for single frequency observations at the SKOL station

The figures above show that the connection of the vertical and horizontal components with regional ionospheric impact is evident and with global magnetic activity is practically missing. This is due to the processing technology of the satellite observation results according to the relative method and the fact that the important factor is ionospheric space-time change and not its absolute indicators.

Table 3 includes the value percentage of the horizontal and vertical components obtained from the GNSS observations processing.

Thus, the ionospheric impact on the relative single frequency GNSS observations is essential to understand the geodetic practice requirements, especially with the distance between the stations of 40 km and more. The condition of the ionosphere (either calm or disturbed) is not as important as the space-time change.

Table 3

*H* and *V* percentage for single and dual frequency observations

| Value | Percentage [%] | | | |
|---|---|---|---|---|
| | $L_1$ | | $L_1 + L_2$ | |
| | *H* | *V* | *H* | *V* |
| ≈ 100 cm | 0 | 0 | 0 | 0 |
| ≈ 50 cm | 1 | 1 | 0 | 0 |
| ≈ 20 cm | 14 | 20 | 0 | 0 |
| ≈ 10 cm | 30 | 29 | 1 | 5 |
| ≈ 5 cm | 55 | 50 | 99 | 95 |

## Conclusions

The conducted research resulted in the following:

1. The accuracy of defining coordinates according to the single frequency observations is much worse. It ranges between 2 and 40 cm. The accuracy of the dual frequency observations is approximately 1–2 cm.

2. The distance between the research stations also influences the computation results. The ionospheric impact increases when the distance from the basic station gets bigger. For example, the errors for the BOGO station range between 1 and 50 cm for single frequency and between 0-3 cm for dual frequency observations. For the LODZ station, they range from 0 to 60 cm and 0–11 cm correspondingly.

3. Ionospheric disturbances slightly influenced the accuracy of the GNSS coordinates.

The errors are bigger for the calm condition of the ionosphere rather than for the disturbed. This indicates that the impact of the ionosphere is not driven by the absolute TEC level, but rather depends on its space-time dynamics, e.g., gradients in the TEC level, and the orientation of the processed baselines.

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