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The Influence of Condition of the Ionosphere on the Accuracy of Real Time Kinematic GPS Measurements

1. Introduction

This paper presents the results of how the ionosphere influence the accuracy of RTK GPS measurements. The RTK measurement technique significantly accelerates and improves the field work. A necessary condition for application of this technology is understanding the processes determining the accuracy, which is defined as the precision that must be measured by a particular amount. The result can be considered valid if the calculated value of the average measurement error does not exceed the assumed value of the maximum error. The accuracy of the measurement, indicates of the correctness of execution of the task. The value is recognized as correct when the correlations between results of measurement and estimate parameters are compiled. Also assumptions of mean error and correlations between measuring parameters are important. There are many factors affecting the quality of the received signal, conditioning the measurement accuracy, one of them is the ionosphere. The ionosphere is an upper layer of the atmosphere, which extends over 60 kilometers above the Earth's surface. The complex physicochemical processes that take place in it, have a profound effect on the propagation of electromagnetic waves, and thus they cause an ionospheric delay. A ionospheric delay is a direct cause of the decrease of accuracy of the RTK GPS measurements. In recent years, there has been an increasing interest in using the RTK GPS measuring methods, so it is very important to investigate the conditions of ionosphere on the accuracy of the measurement. There are many publications, which take into this topic in theoretical meaning, discussing the complexity of the propagation of electromagnetic waves in the ionosphere. The strongest factor influencing the accuracy RTK ionospheric delay, arising mainly during the transition of electromagnetic waves by a layer of F, which is characterized by the highest density of electron and the highest variation of this parameter [2]. Due to the unstable conditions of the

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ionosphere both the diurnal cycle and the 11 year cycle of solar activity, anticipating the size of ionospheric delay is a difficult issue. The attempt of solution of the problem can be the differential measurements observations based on a network of reference stations, assuming that a certain area of influence of the ionosphere is constant [4]. The research was conducted to find the correlation between the value of I95 index and the season of the year and the time of a day, and therefore to indicate the most beneficial time to carry out the measurement with the use of RTK GPS technique.

2. Materials and Methods

Ionospheric activity can be characterized by I95 index reflecting the intensity of the ionosphere, defined as the expected impact on the relative position of the receiver [3]. The index was elaborated in 1998 [5] and it is determined continuously to this day. For the Polish territory is determined in a consistent manner based on observations recorded by an active network of reference stations ASG-EUPOS. At first it was used as a support for the measurements performed on a single RTK station, but now it is calculated for the whole networks and is available for everyone on the RTK's technology providers websites (for instance: www.asgeupos.pl). I95 index informs about the standard ionospheric deviations model, which was based on observations from the networks.

Established ranges:

- 0–2 – negligible ionospheric disturbances,
- 2.1–4 – weak ionospheric disturbance,
- 4.1–8 – strong ionospheric disturbances,
- 8 – very strong ionospheric disturbances.

Index I95 is determined based on two coefficients ΔI_{lat} and ΔI_{lon} and is calculated from the formula:

$$\Delta I = \sqrt{\Delta I_{\mathrm{lat}}^2 + \Delta I_{\mathrm{lon}}^2} \tag{1}$$

where:

- ΔI – index I95,
- ΔI_{lat} – ionospheric biases in south-north directions,
- ΔI_{lon} – ionospheric biases in and west-east directions [4].

Then, the I95 index is identical to the 95% margin of all ΔI values in a predefined period of time. It was decided to use such a 95% margin since it can be expected that GPS carrier phase processing softwares are able to select and neglect those observations which are affected most [4].

Both factors are calculated for each signal by satellite-reference station and its value is the estimated hourly. I95 index is calculated based on the corrections determined for all GNSS satellites and a ASG-EUPOS network. It is assumed that the 5% of the marginal data is discarded. The index figure that exceed 4 can cause difficulties with the initialization of receiver on the ground.

The analyzed material was derived from the Technical Support Department ASG-EUPOS and it includes data on I95 index, indicating the activity of the ionosphere. The acquired data embraced the period from June 2011 to May 2012. During that period, the measurements were carried out every day and every hour, and therefore a numerous data was gathered. In total 8 675 features of I95 index were gathered, and then analyzed precisely.

To analyze the material, the graphs (Figs 1–12) of data from each month between June 2011 and May 2012 were drawn. On the graph, the features of I95 index were placed on vertical axis, whereas period of the particular month was placed on horizontal axis. To make the graph clearer, the key for Index I95 has a 0.5 interval, whereas on the horizontal axis one can find a next twenty four hours interval. Additionally, the graph of distribution of I95 index value according to time of day was drawn (figures marked as "b"). The measurement was recorded every hour, every day, every month from June 2012 to May 2012, for each month results show below (Figs 1–12).

a) b)

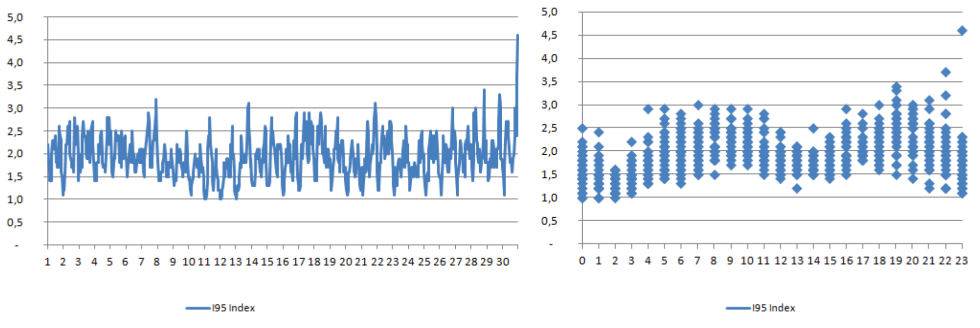

Fig. 1. Distribution of I95 index value in due course of June 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

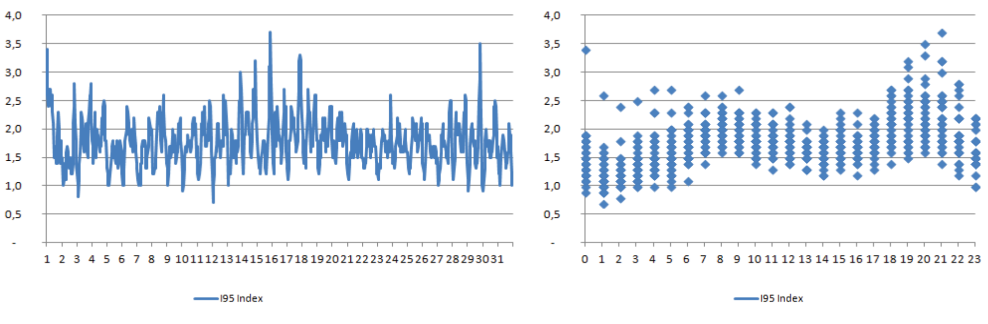

Fig. 2. Distribution of I95 index value in due course of July 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

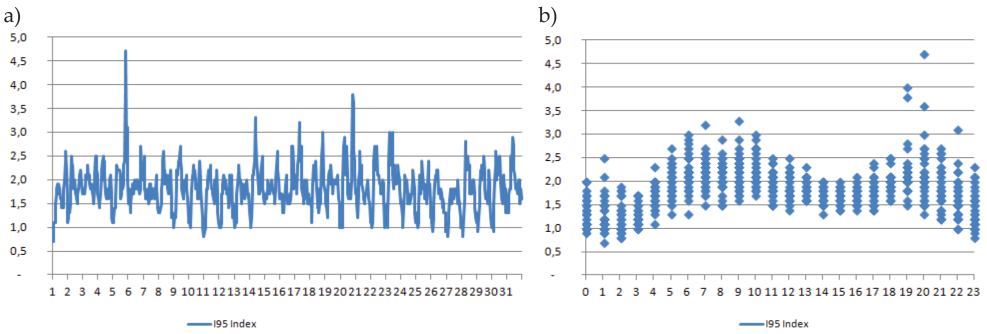

Fig. 3. Distribution of I95 index value in due course of August 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

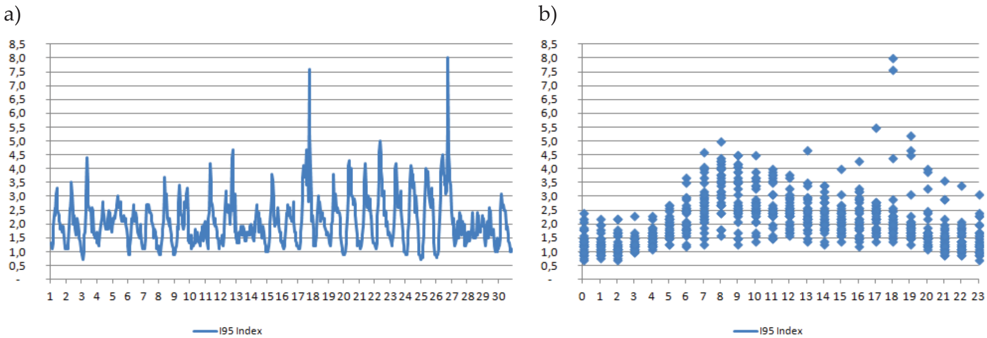

Fig. 4. Distribution of I95 index value in due course of September 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

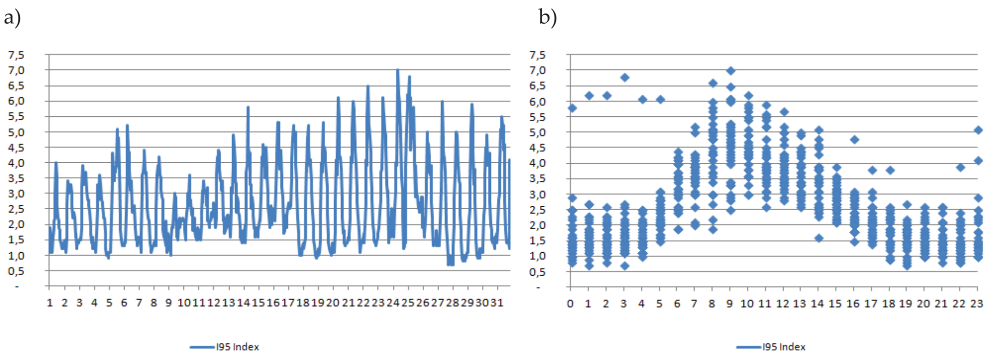

Fig. 5. Distribution of I95 index value in due course of October 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

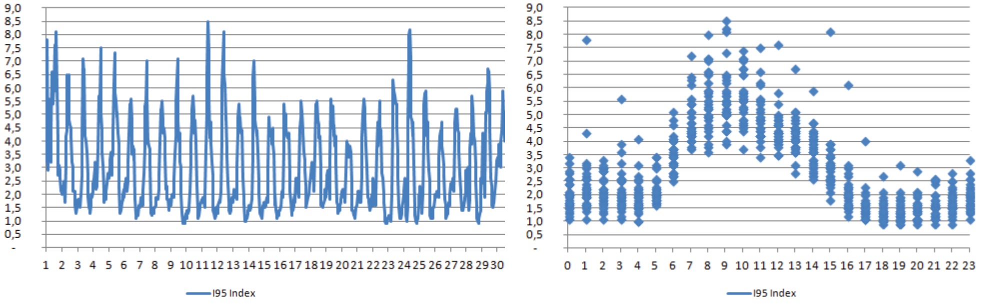

Fig. 6. Distribution of I95 index value in due course of November 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

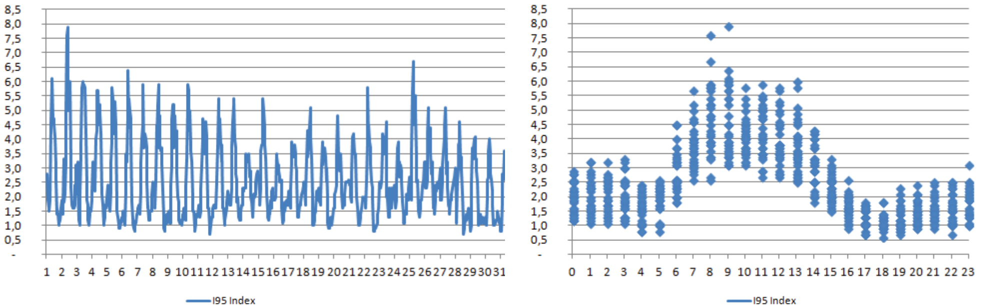

Fig. 7. Distribution of I95 index value in due course of December 2011 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

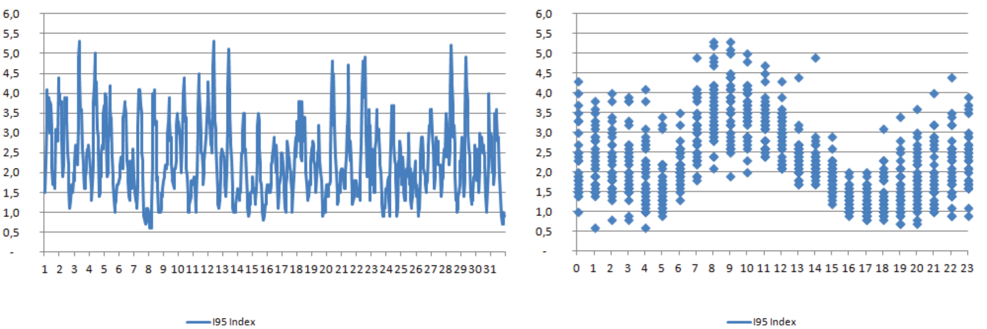

Fig. 8. Distribution of I95 index value in due course of January 2012 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

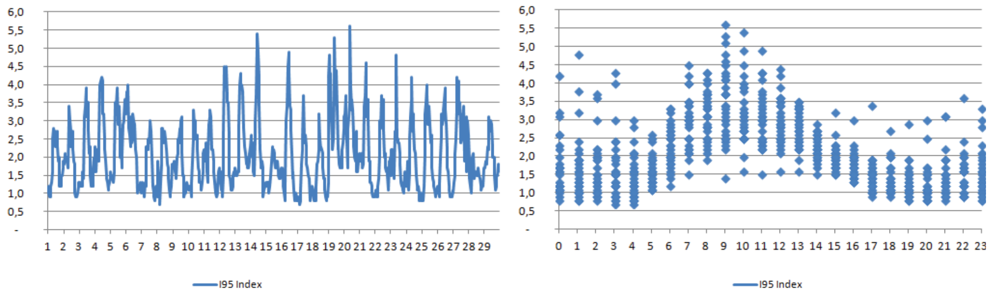

Fig. 9. Distribution of I95 index value in due course of February 2012 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

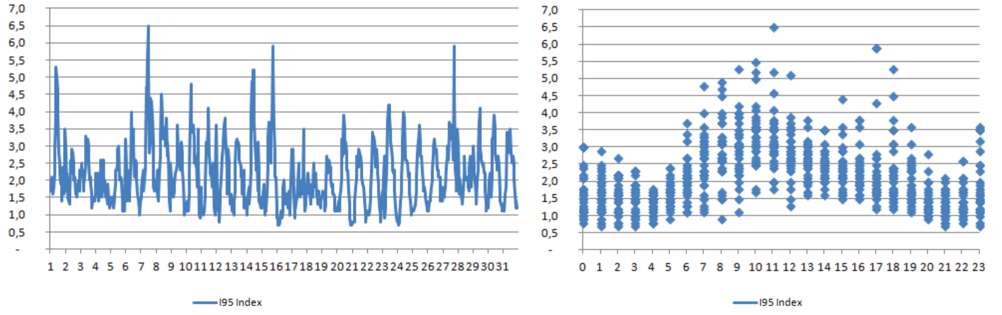

Fig. 10. Distribution of I95 index value in due course of March 2012 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

a) b)

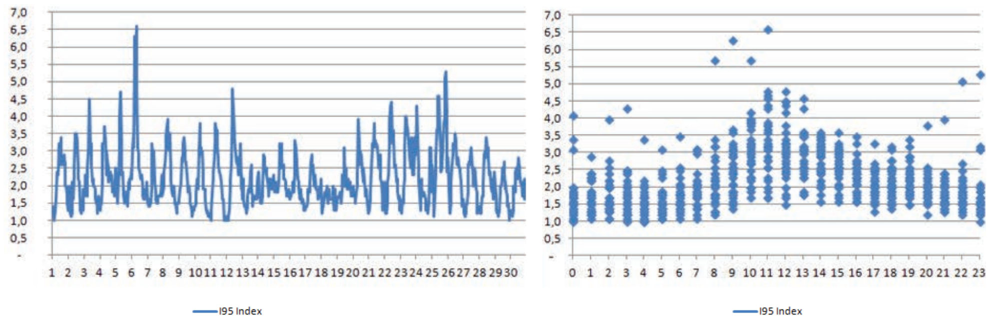

Fig. 11. Distribution of I95 index value in due course of April 2012 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

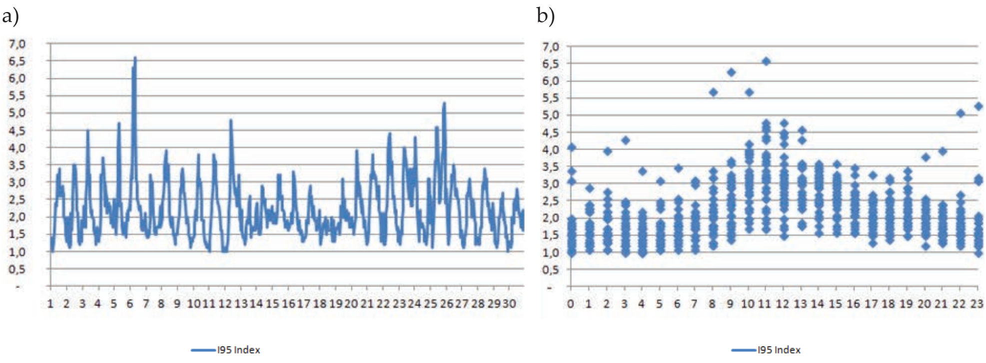

Fig. 12. Distribution of I95 index value in due course of May 2012 year (a) and distribution of I95 index value according to time of day (b)

Source: own elaboration based on data obtained from ASG-EUPOS [1]

3. Results

The results are included in the Table 1, which shows the minimum and maximum values of index I95, along with the time of their occurrence in the period from June 2011 to May 2012, as well as their average values and standard deviation. The chart is a compilation of research, which provides daily and annual ionospheric activity for Poland determined on the basis of the minimum, maximum, and average values I95, using data from an active geodetic network ASG-EUPOS, using VRS corrections of surface. Using the VRS corrections of surface, software in the receiver works with the data from the center, downloading the corrections of observation. Corrections of observations are determined by interpolation of observations from surrounding reference stations to approximate position of the receiver.

Table 1. Summary of results – daily and annual ionospheric activity for Poland, determined on the basis of the minimum, maximum, and average values I95

Month	Max	Hour	Min	Hour	Average	Standard deviation
1	*2*	*3*	*4*	*5*	*6*	*7*
June 2011	4.60	22:00	1.00	0:00	1.93	0.454
				1:00 a.m.		
				2:00 a.m.		
July	3.70	21:00	0.70	1:00 a.m.	1.77	0.423
August	4.70	20:00	0.70	1:00 a.m.	1.81	0.452
September	8.00	18:00	0.70	0:00	2.09	0.892
				2:00 a.m.		
				11:00 p.m.		

Table 1 cont.

1	2	3	4	5	6	7
October	7.00	9:00	0.70	1:00 a.m. 3:00 a.m. 7:00 p.m.	2.60	1.318
November	8.50	9:00	0.90	6:00 p.m. 7:00 p.m. 8:00 p.m. 9:00 p.m. 10:00 p.m.	2.99	1.636
December	7.90	9:00	0.60	6:00 p.m.	2.53	1.313
January	5.30	8:00 9:00	0.60	1:00 a.m. 4:00 a.m.	2.31	0.948
February	5.60	9:00	0.70	3:00 a.m. 4:00 a.m.	2.07	0.953
March	6.50	11:00	0.70	2:00a.m. 3:00 a.m. 9:00 p.m. 11:00 p.m.	2.15	0.912
April	6.60	11:00	1.00	4:00 a.m.	2.21	0.818
May 2012	4.70	09:00	1.10	2:00 a.m. 4:00 a.m.	2.31	0.604

Source: own elaboration based on data obtained from ASG-EUPOS [1]

Columns 2 and 4 of the Table 1 contain respectively the maximum and minimum values of I95 index in each month, columns 3 and 5 give the hours of specified maximum and minimum values for I95 index. Column 6 contains the average of I95 for each month, and column 7 contains standard deviations of I95 index calculated for each month.

4. Summary

Between the months of June 2011 and May 2012 one can distinguish the minimum and the maximum of the ionospheric activity per month, throughout a day and the stability of ionosphere throughout a day, as well as a year. The maximum activity of the ionosphere determined by the maximum of the value average of the I95 index was on month in November, the lowest ionosphere activity determined by the minimum of the value average of I95 index accounted for the month of July. Considering the activity of ionosphere over one day (Tab. 1), one can notice a relation between the minimum and the maximum annual activity of ionosphere. In the minimum of annual activity of the ionosphere (July 2011), the maximum daily activity of ionosphere was at 9:00 p.m, while the maximum annual activity of the ionosphere to (November 2011), the maximum daily activity was at 9:00 a.m. The minimum daily activity of ionosphere takes place during the night and it is constant. The reason of that is the disappearance of the ionization factor, namely the ionizing radiation. Therefore one can make a conclusion that the influence of the ionosphere on the accuracy of GPS RTK relies both on the season as well as the time of a day. For the period of one year, the main factor that determine the activity of ionosphere is the 11-year solar cycle, including the quantity and size of a solar flare. Predicting the impact of the ionosphere during the year is a much more difficult issue than forecasting it for forthcoming 24 hours. Knowing the structure of the ionosphere, determining its impact on the daily measurement accuracy is a matter of time of measurement. For the daily hours the impact is greater because of the existence of a factor, which is the form of ionizing radiation. During the night, the electrons content decreases, which increase the accuracy of measurements.

The analysis of the determined standard deviation for the particular populations helped to identify the largest and smallest periods of the stability of ionospheric conditions, throughout the interval of one year. The most stable ionospheric conditions were noticed during the month of July, where the standard deviation was the lowest. The lowest stability conditions were found during the months of November, where the standard deviation was the highest. One of the conclusions that emerges from these findings is that the smaller the scatter of value of I95 index is, the more stable the ionospheric conditions are. Figure 13 shows the distribution of the standard deviation of the coefficient of index I95 depending on the time over one day, determined on the basis of June 2011 – May 2012 (UTC +1:00 time)

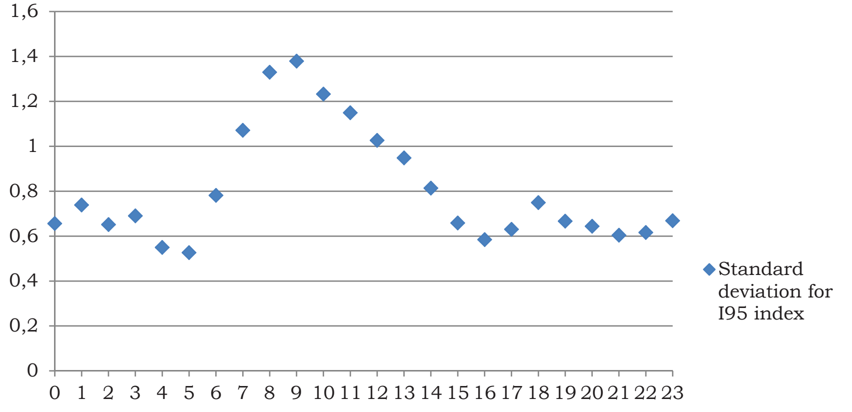

Fig. 13. Standard deviation for I95 index

Source: own elaboration based on data obtained from ASG-EUPOS [1]

The graph was created based on the values of the standard deviation of index I95, for the entire study period from June 2011 to May 2012, taking into account the consecutive hours. It may be considered that it is a representative, due to population and the fact that the standard deviation of scattered inform us about the mean observation. We see that the variation of ionospheric most marked in daylight hours between the hours of 5 a.m. and 4 p.m. Minimum stability falls at 9 a.m., then it is most active ionosphere.

5. Conclusions

Conducted research on a collection of data allowed to draw conclusions on the influence of the ionosphere on the accuracy of RTK GPS in the studied period. The best and the most vulnerable period for the purpose of measuring ionospheric conditions can be identified, after analyzing the data of I95 index, characterized by the activity of the ionosphere, which affects directly the accuracy of measurements. Taking into consideration the ranges of values for the coefficient of I95 index, one can conclude that 54% of the value of the coefficient of index I95 in the study population was in the range of 0–2, negligible ionospheric disturbances. Another 40% is in the range of 2.1–4.0, indicating a weak ionospheric disturbance, and 6% in the range of strong ionospheric disturbances, which may significantly hinder the process of initializing the receiver. It also should be noted that in most cases using RTK GPS technology in relation to the reference station network is outweighed ionosphere activity to such an extent that the measurement meets the accuracy requirements. In order to provide the best transmition condition of satellite signals should avoid hours, for which the value of standard deviation of the I95 index was the highest. According to Figure 13 the worst time is between are 7:00–12:00. At this time, the value of a standard deviation was above value 1. The measurement should be planning for the afternoon and evening, given that the change in the ionosphere based on a testing of I95 index depends on the time of day, but also on the period of 11 year cycle of solar activity.

Acknowledgements

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