UDC 528.2

Yu. PISHKO

Department of Engineering Geodesy. Lviv Polytechnic National University, 12, S. Bandery str., Lviv, Ukraine, 79013, tel. +38 (032) 258-23-87, e. mail: yupiro12@gmail.com.

THE EFFECT OF ABSOLUTE HUMIDITY ON GPS-POSITIONING ACCURACY

https://doi.org/10.23939/istcgcap2018.01.030

Objective. Investigate the effect of absolute humidity on the GPS accuracy for different durations of observation. **Methods**. The GPS observations with different durations over spring-autumn period at 17 permanent stations in France and 8 stations in Switzerland were chosen for initial data. These observations used four GPS networks with a different number of points (from 5 to 8) and lengths of vectors (average length varied from 5.1 to 48.6 km). Values of absolute humidity were determined using the average values of air temperature, atmospheric pressure, and relative humidity, obtained from 06:00 to 22:00. For our investigation we selected only those days when absolute humidity varied significantly. The observations were processed by the Trimble Business Center software, changing the duration of the observations (1, 2, 4 hours). In total, 1.200 sessions were processed. By comparing the values of true coordinates of the network points and those determined by the results of observations, we obtained the RMS (root-mean-square) errors of the positions of the points. **Results.** The analysis of RMS position errors showed that there is a tendency for deterioration of the point's position accuracy in the network when the absolute humidity is increasing. The values of the RMS, obtained at the lowest and highest values of absolute humidity, for all networks and the different durations of observations were compared. Thus, when the absolute humidity changed from 7.0 g/m^3 to 13,8 g/m^3 for the observation duration of 4 hours, the average values of RMS increased 1.6 times (from 4.4 mm to 7.0 mm), for the sessions of 2 hour duration the value of RMS increased 1.8 times (from 4.7 mm to 8.3 mm), and for a 1 hour duration – 2.1 times (6.1 mm to 13.0 mm). **Scientific novelty and practical significance.** The environment of satellite signals propagation remains one of the main sources of errors, in particular in the troposphere, which, in essence, "forms" the weather. Although today more attention is focused on weather forecasting using satellite navigation systems, there is also an inverse problem. The study suggests meteorological conditions, specifically absolute humidity, should be considered to increase the accuracy of GPS-measurements. The obtained results of the studies are quite reliable, since a large amount of data is used. It is advisable to choose the days for GPS observations, when the moisture content is minimal (no higher than 12 g/m^3). From a practical point of view – the possibility of using observable meteorological parameters obtained from the weather forecasts are feasible.

Key words: GPS; absolute humidity; duration of observation; points-positioning accuracy.

Introduction

Satellite technology is widely used in geodesy and navigation. This technology can provide efficient and fairly high accurate results during all weather. The accuracy, however, is regulated by a number of errors, the incidence of which can either be reduced, or completely eliminated. The sources of errors that affect the results of GNSS measurements can be divided into three groups, directly related to: satellites (inaccuracy of the clock, antenna offset, and antenna phase centre variations); medium of distribution (ionosphere propagation, neutral atmosphere propagation, and multipath); receivers (clock error, antenna offset, and antenna phase centre variations). Many leading scientists consider the troposphere to be one of the main sources of errors during GNSS observations [Azizov A. A. et al. 1997; Hutorova et al. 2010, Hofmann-Wellenhof B., Lichtenegger H., Collins J., 1994, Mendes V. B., Langley R. B., 1998]. Meteorological parameters, such as temperature, humidity, and atmospheric pressure have a significant effect on the distribution in the troposphere (also termed the neutral part of the atmosphere) of electromagnetic oscillations that are used in GNSS [Antonovich K. M., Frolova E. K., 2003]. Specifically, the delay of a radio signal depends primarily on the content of water vapor (one of the decisive factors affecting the formation of weather), its spatial-temporal distribution and, to a lesser extent, on the surface air temperature [Vahnin A. V., 2012; Ivanov V. A. et al. 2012; Kovorotnyj A. L. et al., 2014].

Today, not enough attention is devoted to the influence of meteorological parameters on the accuracy of GNSS measurements, since it is believed that observation can be performed in any weather [Zablotskyi F. D., 2013]. The issue of using GNSS technologies for research of weather and climate processes, which are aimed at improving weather forecasting, is being actively studied [Zablotskyi F. et al. 2011; Kablak N. I., 2009, Kablak N. I., 2011; Devis M. S., S. Businger, Herring T. A. et al., 1992; Schueler T., 2001]. On the other hand, if climate research and meteorology can rely heavily on GNSS measurements, then the reverse may also be looked at. Since the change in atmospheric pressure along the trajectory of the satellite signal changes the refractive index and the speed of this signal the least, the air temperature is slightly more influential and, most of all, the water vapor pressure. It is known that absolute humidity is the mass of water vapor divided by the mass of dry air in a certain volume of air at a specific temperature. The warmer the air is, the more water it can absorb. Absolute humidity is the measure of water vapor or moisture in the air, regardless of temperature. It is expressed as grams of moisture per cubic meter of air (g/m^3) [Absoliutna volohist. Wikipedia]. Therefore, the main focus of our study is precisely the clarification of the effect of absolute humidity on the accuracy of determining the position of points on the relative satellite observations.

Objective

The purpose of this study is to clarify the effect of absolute humidity on the GPS accuracy using different lengths of observation sessions.

Methodology and results

Research was conducted using GPS observations from permanent stations located in Switzerland and France. Data was taken from http://www.swipos.ch and http://rgp.ign.fr, which also shows the coordinates of these stations, used to calculate their coordinates in the Gauss-Kruger projection. They were accepted as true and compared to the adjusted coordinates of satellite networks, determined from observations of different durations.

Four networks were formed, their schemes are presented in Fig. 1. The first of these consist of 8 permanent stations and 17 vectors with lengths of 32.9 to 74.2 km, and the average length of a vector is 48.6 km. The second network consists of 7 stations and 14 vectors, the length of which varies from 8.6 to 46.7 km (the average is 20.2 km). The third network consists of 5 permanent stations and 9 vectors with lengths from 0.5 to 20.9 km (average is 11.0 km). And the fourth – from 5 permanent stations and 10 vectors with lengths from 0.9 to 11.4 km (average length is 5.1 km).

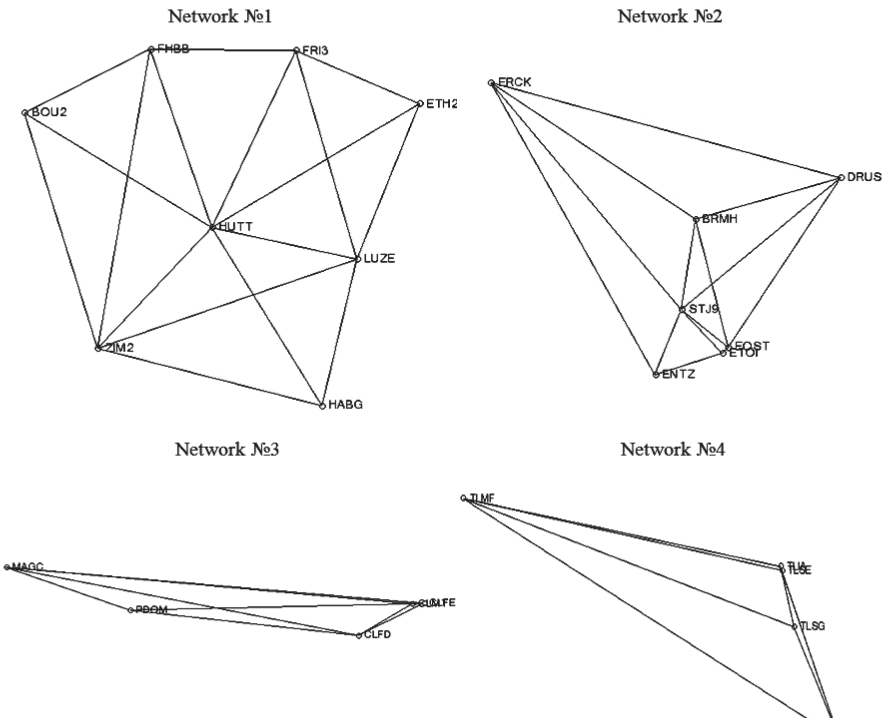

Fig. 1. Schemes of Geodetic GNSS Network

The observations were processed by the Trimble Business Center software. In this case, both broadcast and precise orbits were used with the same GPS data, and the elevation mask angle was set at 15º. All the processed data had an observation interval of 30 s. It is worth noting that the state of the ionosphere was also analyzed, the quality of the obtained observational results were checked (the necessary information was obtained from http://www.trimble.com/GNSS Planning Online), and the GDOP parameter was analyzed.

From observations with dual-frequency GPS receivers (using only GPS satellite signals), sessions of different durations were formed, namely, 1, 2 and 4 hours. Thus, for each network eight sessions lasting 1, 2 and 4 hours were processed. In total, 1 200 sessions were processed.

In addition, the values of absolute humidity were determined using the average values of air temperature, atmospheric pressure, and relative humidity from 6:00 to 22:00 hours for a certain period of time. These values were taken from http://www.eurometeo.com. For network No. 1, the absolute humidity for the two months of July and August 2014 was determined and the days were chosen when these values were the highest and lowest. Therefore, seven days were chosen when the absolute humidity varied from 13.7 to 16.3 g/m^3 and seven days when these values ranged from 8.7 to 11.1 g/m^3. For network No. 2, five days were chosen, namely: two days in August and September and one day in October 2016when the absolute humidity was equal to 16.6, 14.2, 11.8, 11.1 and 10.6 g/m^3. Also five days: three days in October 2016 and two days in January 2017, when these values were 6.6, 6.4, 6.3, 2.9 and 2.6 g/m^3. For network No. 3, the meteorological parameters were analyzed from April to June 2017. The absolute humidity was determined and seven days were chosen when the values were 15.6, 14.9, 14.2, 14.0, 13.9, 13.8, 12.9 g/m^3 and seven days when these values were 8.4, 6.6, 6.5, 6.2, 5.7, 5.1 and 4.5 g/m^3. For network No. 4, the absolute humidity change was determined in April, May, and June 2017 and six days were selected for each, when the absolute humidity was 14.6, 14.5, 13.0, 12.8, 11.3, 11.2 g/m^3 and 4.5, 4.7, 5.2, 6.3, 6.3, 6.7 g/m^3.

For the above range, changes in humidity values for all days (14 days) for network No. 1 were averaged to 12.7 g/m^3. Similarly, these average values were determined for other networks. For network No. 2 – 9.6 g/m^3, for network No. 3 – 10.1 g/m^3 and for network No. 4 – 9.6 g/m^3. The difference between the highest and the lowest absolute humidity values for network No. 1 was 7.6 g/m^3, for network No. 2 – 14.0 g/m^3, for network № 3 – 11.1 g/m^3, and for the last one – 10, 1 g/m^3.

According to the results of observations of 1, 2 and 4 hour durations for each network, we obtained the RMS for the horizontal components of relative position of the points. Table 1 shows the limits of their change, the lowest and the highest values (Δ), as well as the mean values. It should be noted that column “h” in the table shows the results obtained at high absolute humidity, higher than the average for each network, and in column “l” – low.

Table 1

RMSE of points position (mm), obtained at low and high absolute humidity

Session duration, h		network No. 1		network No. 2		network No. 3		network No. 4	
		h	l	h	l	H	l	h	l
1	Δ	84.1–4.8	27.9–2.7	15.1–1.2	7.7–4.1	17.7–0.6	8.4–0.5	13.7–0.0	8.0–0.5
	avg	29.5	12.3	6.2	4.1	6.6	3.8	6.1	4.0
2	Δ	28.8–4.4	15.2–2.2	12.6–1.2	7.0–1.4	15.8–0.7	7.4–0.6	11.6–0.4	7.5–0.4
	avg	13.6	8.4	5.2	3.5	6.4	3.6	5.5	3.8
4	Δ	20.2–2.2	12.2–1.6	10.8–1.1	6.3–1.3	15.6–0.5	7.0–0.8	11.5–0.0	7.7–0.0
	avg	10.3	7.3	4.8	3.3	6.3	3.5	5.3	3.7

In addition, the average values of the RMS for each observation time (1, 2, and 4 hours) and for each selected day were determined. Thus, for network No. 1, we obtained 14 values of the RMS for each duration of the observations (a total of 42), for network No. 2 – 10 values (in total 30), for network No. 3 – 14 values of the RMS (a total of 42), and for network No. 4 – 12 values of the RMS of the positioning (in total 36). Graphs were constructed for each network (see Fig. 2).

For all networks at different lengths of observations, the minimum values of RMS position errors occurred at the lowest absolute humidity. According to the graph (Fig. 2), for network No. 1, with a duration of observations of 4 hours and an absolute humidity greater than the average (12.7 g/m^3), the least accurate was obtained in five out of seven cases, and in six cases where the duration of sessions was 2 hours, whereas at a duration of 1 hour – only in four cases. Comparing the lowest and the highest values of RMS position errors, obtained with a duration of 4 hours for the lowest (8.7 g/m^3) and highest (13.8 g/m^3) absolute humidity, it was found that the points positioning accuracy deteriorated

2.5 times, with the duration of sessions of 2 hours and absolute humidity of 8.7 g/m^3 and 13.9 g/m^3 – 4.2 times, with a duration of 1 hour and an absolute humidity of 8.7 g/m^3 and 13.8 g/m^3 – 10.7 times. For network №2 with a duration of observations of 4 and 2 hours and absolute humidity greater than the average (9.6 g/m^3), the least accuracy was obtained in all cases, and when the duration of sessions was 1 hour – in four out of five cases. Comparing the lowest and highest values of the RMS, obtained at lower (6.6 g/m^3) and higher (14.2 g/m^3) absolute humidity, we found that accuracy deteriorated 2.3 times with a duration of 4 hours, 2.4 times – 2 hours and 2.6 times – 1 hour. For network No. 3 according to the graph (Fig. 2), with a duration of observations of 1, 2 and 4 hours and an absolute humidity greater than the average (10.1 g/m^3), inferior points positioning accuracy was obtained in six out of seven cases. Comparing the lowest and the highest values of RMS position errors, obtained at lower (5.1 g/m^3) and higher (13.9 g/m^3) humidity, we found that accuracy deteriorated 4.1 times with a duration of 4 hours, 3.9 times – 2 hours and 4 times – 1 hour. For network No. 4, with a duration of observations of 4 and 2 hours and an absolute humidity greater than the average (9.6 g/m^3), less accuracy was obtained in six out of seven cases, and for the duration of sessions 1 hour – in all cases. Comparing the lowest and the highest values of RMS, obtained with a duration of 4 hours for the lower (6.3 g/m^3) and higher (11.2 g/m^3) absolute humidity, we found that the accuracy deteriorated by 1.9 times, when the duration of sessions was 2 hours and humidity 4.5 g/m^3 and 11.2 g/m^3 – 2 times, with a duration of 1 hour and an absolute humidity of 6.3 g/m^3 and 11.2 g/m^3 – 2.2 times.

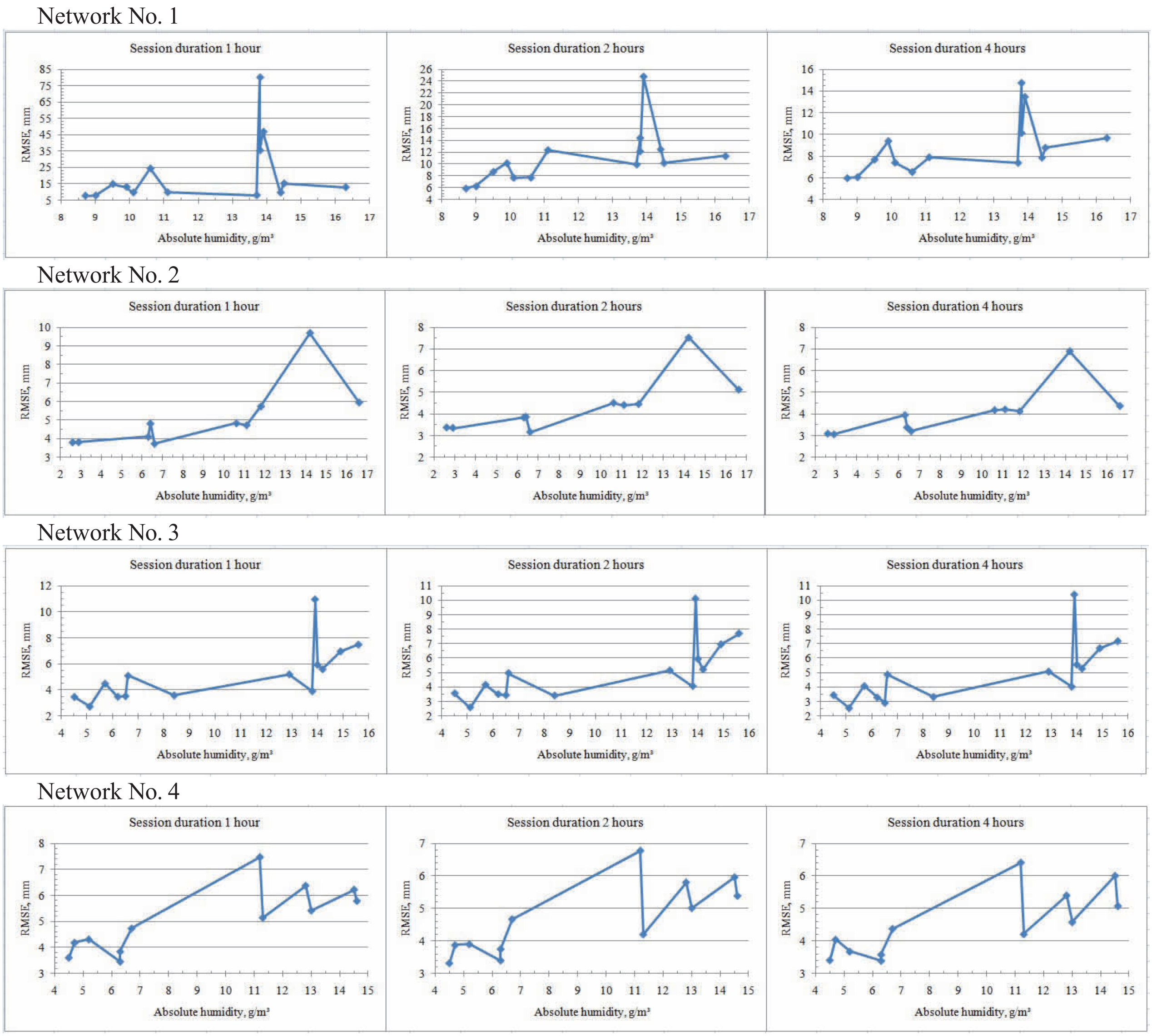

Fig. 2. The dependence of positioning accuracy for dual-frequency GPS-receivers on absolute humidity for 1, 2, and 4 hour durations of observations

In addition, we compared the values of RMS errors obtained with the lowest absolute humidity and the highest for all networks and different monitoring times. Thus, for network No. 1, with a duration of observations of 4 hours, the values of RMS obtained at low absolute humidity is 47.1 % less than the values obtained for the highest humidity. With a duration of 2 hours, respectively, 47.8 % less, and a duration of 1 hour – 34 %. For network No. 2 with a duration of sessions of 4 hours, the values of the RMS, determined at the lowest humidity, is only 0.2 % lower than the RMS, determined at the highest absolute humidity. Similarly, these values for the duration of 2 hours are 9.7 % and 1 hour – 23.3 %. For network No. 3 with a duration of observations of 4 hours this value is 41.4 %, 2 hours – 45.6 % and 1 hour – 39.8 %. Network No. 4 was similarly observed for a duration of 4 hours – 38.2 %, 2 hours – 43.3 %, 1 hour – 38.9 %.

Scientific novelty and practical significance

The propagation environment of satellite signals remain one of the main sources of errors, specifically, in the troposphere. In the earth's troposphere, more than 4/5 of the total mass of atmospheric air is concentrated along with almost all atmospheric water vapor. Also, the main meteorological processes occur there, in essence, this is where weather “forms”. The study suggests taking into account meteorological conditions, including absolute humidity, as a way to reduce the impact of the environment on the accuracy of GPS-measurements, to increase their quality. The obtained results of the conducted studies are quite reliable, since a large amount of data was used. It is advisable to choose days for observations when the moisture content is minimal (no higher than 12 g/m^3). From a practical point of view – the possibility of using observable meteorological parameters obtained from weather forecasting is feasible.

Conclusions

Having analyzed the obtained results, we see that there is a tendency of deterioration of the points positioning accuracy with the increase of absolute humidity. When the absolute humidity changed from 7.0 g/m^3 to 13.8 g/m^3 and the duration of observations was 4 hours, the average value of RMS increased by 1.6 times (from 4.4 mm to 7.0 mm), for the duration of sessions of 2 hours, the value of RMS increased by 1.8 times (from 4.7 mm to 8.3 mm), and for the duration of 1 hour – 2.1 times (from 6.1 mm to 13.0 mm). Today, more attention is focused on weather forecasting using satellite navigation systems, but as we see, there are other considerations. Therefore, to achieve greater accuracy in determining the position of GPS-receivers, it is advisable to take into account weather conditions, in particular to select the days for observations when the moisture content is minimal (no more than 12 g/m^3).

REFERENCES

Absoliutna volohist [absolute humidity. [Wikipedia, the free encyclopedia]. Available at: https://en.wikipedia.org/wiki/Humidity

Antonovich K. M., Frolova E. K. *Sovmestnoe ispol'zovanie meteodannyh nazemnyh i ajerologicheskih nabljudenij pri obrabotke sputnikovyh izmerenij* [The use of meteorological data from terrestrial and aerial observations in the processing of satellite measurements]. *Vestnik SGGA.* 2003, issue 8, pp. 8–13.

Azizov A. A., Gajkovich K. P., Kashkarov S. S., Chernjaeva M. B. *Ispol'zovanie signalov navigacionnyh ISZ dlja opredelenija parametrov atmosfery* [Use of navigation satellite signals to determine atmospheric parameters]. *Izv. VUZov. Radiofizika* [Radiophysics and Quantum Electronics], 1997, T. XLI, no. 9, pp. 1093–1110.

Devis M. S., Businger S., Herring T. A. et al. GPS meteorology: remote sensing of atmospheric water vapor using the Global Positioning System. *J. Geophys.* 1992, v. 97, pp. 15787–15801.

Hofmann-Wellenhof B., Lichtenegger H., Collins J. Global Positioning System. Theory and Practice. Wien; N. Y.: Springer-Verlag, 1994, 356 p.

Hutorova O. G., Vasil'ev A. A., Hutorov V. E. *O perspektivah issledovanija neodnorodnoj struktury troposfery s pomoshh'ju seti priemnikov GPS-GLONASS* [On prospects of investigation of the nonhomogeneous troposphere structure using the set of GPS-GLONASS receivers]. *Optika atmosfery i okeana* [Atmospheric and Oceanic Optics]. 2010, 23, no. 6, pp. 510–514

Ivanov V. A., Rjabova N. V., Zuev A. V., Kislicyn A. A., Ershov P. M. *Vlijanie klimaticheskih i geofizicheskih javlenij na pomehoustojchivost' priema radionavigacionnyh signalov sistem* GLONASS/GPS [Influence of climatic and geophysical phenomena on noise immunity reception of radio navigation signals of GLONASS/GPS systems]. *II Vserossijskie Armandovskie chtenija. Radiofizicheskie metody v distancionnom zondirovanii sred. Materialy V Vserossijskoj nauchnoj konferencii* [Materials of the All-Russian Scientific Conference] (Murom, 26-28 June 2012). Murom: *Izd. poligraficheskij centr MI VlGU*, 2012, 567 p.

Kablak N. I. *Monitorynh osadzhenoi vodianoi pary na osnovi obrobky HNSS-danykh* [Monitoring of the besieged water vapor on the basis of the processing of GNSS data]. *Kosmichna nauka i tekhnolohiia* [Space Science and Technology]. 2011, T. 17, no. 4, pp. 65–73.

Kablak N. I. *Suchasni pidkhody do vyznachennia ta vykorystannia troposfernykh zatrymok GNSS* *syhnaliv* [Questions of definition that uses of tropospheric delays of GNSS-signals at the present stage of development of satellite technologies are considered]. *Heodeziia, kartohrafiia i aerofotoznimannia* [Geodesy, Cartography and Aerial Survey"]. 2009, issue 72, pp. 22–27

Kovorotnyj A. L., Kivva F. V., Goncharenko Ju. V., Gorobec V. N., Gorb A.I. *Sravnitel'nyj analiz modelej dlja ocenki polnogo vlagosoderzhanija troposfery nad Har'kovskim regionom posredstvom GPS-izmerenij* [The comparative analysis of models for estimation of the total moisture content of the troposphere through the GPS measurements over Kharkov]. *Radiofizyka ta elektronika* [Radiophysics and electronics]. 2014, T. 5(19), no. 4, pp. 21–26.

Mendes V. B., Langley R. B. Tropospheric Zenith Delay Prediction Accuracy for Airborne GPS High-Precision Positioning. Proceedings of The Institute of Navigation 54th Annual Meeting, Denver, CO, U.S.A., 1–3 June 1998, pp. 337–347.

Schueler T. On Ground-Based GPS Tropospheric Delay Estimation Dissertation. T. Schueler. Schriftenreihe 73, Studiengang Geodäsie und Geoinformation Universität der Bundeswehr München, February 2001. Available at: http://137.193.32.1/ Forschung/ TropAC/ docs/phd/index.html.

Vahnin A. V. *Primenenie meteorologicheskoj informacii v navigacionnyh sistemah GLONASS/GPS: Magisterskaja dissertacija* [Application of meteorological information in navigation systems GLONASS. GPS: Master's thesis]. Vahnin Anton Vjacheslavovich. Sankt-Peterburg, 2012, 68 p.

Zablotskyi F. D. *HNSS-meteorolohiia* [GNSS meteorology]. lviv Polytechnic Publishing House, 2013, 96 p.

Zablotskyi F., Palianytsia B., Matviienko L., Turchyn N. *Sukha i hidrostatychna skladovi zenitnoi tropofernoi zatrymky* [On the dry and hydrostatic component of zenith tropospheric delay]. *Suchas. dosiahn. heodez. nauky ta vyr-va: zb. nauk. pr. Zakh. heodez. t-va UTHK* [Modern achievements of geodetic science and industry: Coll. Science pr. UTHK Western geodetic company]. Lviv Polytechnic Publishing House, 2011, issue II, pp. 92–95.

Ю. ПІШКО

Кафедра інженерної геодезії, Національний університет "Львівська політехніка", вул. Карпінського, 6, 79013, Львів; Україна, 79013, тел. +38 (032) 258-23-87, ел. пошта kaf.IGD@gmail.com.

ВПЛИВ АБСОЛЮТНОЇ ВОЛОГОСТІ НА ТОЧНІСТЬ ВИЗНАЧЕННЯ ПОЛОЖЕННЯ ПУНКТІВ GPS-ПРИЙМАЧАМИ

Мета. Дослідити вплив абсолютної вологості на точність визначення положення пунктів супутникових геодезичних мереж під час спостереження різної тривалості GPS-приймачами. **Методика.** Вихідними даними для дослідження послужили результати спостережень різної тривалості протягом 50 діб з квітня по жовтень місяць на 17 перманентних станціях Франції та 8 станціях Швейцарії. З цих спостережень сформовано чотири мережі з різною кількістю пунктів (від 8 до 5) та довжинами векторів (середня довжина сторін змінюється від 48,6 км до 5,1 км). Визначено значення абсолютної вологості, використовуючи середні значення температури повітря, атмосферного тиску та відносної вологості, отриманими за показниками з 6 по 22 год. Підібрані такі дні, коли значення абсолютної вологості, суттєво відрізнялися, тобто були найменшими та найбільшими. Опрацювання спостережень виконувалось програмним забезпеченням Trimble Business Center, змінюючи тривалість спостережень (4, 2, 1 год). Загалом нами опрацьовано 1200 сеансів. Порівнявши значення істинних та визначених за результатами спостережень планових координат пунктів мереж, отримані середні квадратичні помилки положення пунктів. **Результати.** Аналіз отриманих значень середніх квадратичних помилок положення пунктів, отриманих за результатами спостережень, показав що спостерігається тенденція погіршення точності визначення положення пунктів мереж за зростання абсолютної вологості. Порівнювалися значення СКП, отримані за найменших значень абсолютної вологості та найбільших для всіх мереж та різній тривалості спостережень. Таким чином, за зміни абсолютної вологості від 7,0 г/м^3 до 13,8 г/м^3 та тривалості спостережень 4 год, отримане середнє значення СКП зросло у 1,6 раза (від 4,4 мм до 7,0 мм), за тривалості сеансів 2 год значення СКП зросло у 1,8 раза (від 4,7 мм до 8,3 мм), а для тривалості 1 год – у 2,1 раза (від 6,1 мм до 13,0 мм). **Наукова новизна та практична значущість**. Середовище поширення супутникових сигналів і досі залишається одним з основних джерел помилок, зокрема тропосфера, у якій по суті "формується" погода. Хоча сьогодні більше увагу акцентують на прогнозуванні погоди використовуючи супутникові навігаційні системи, але існує і зворотний зв'язок. У дослідженні запропоновано враховувати метеорологічні умови, зокрема абсолютну вологість як спосіб зменшення впливу зовнішнього середовища на точність GPS-вимірювань, тобто підвищити їхню якість. Одержані результати проведених досліджень є досить достовірними, оскільки використано значну кількість даних, вони дають змогу рекомендувати вибирати такі дні для спостережень, коли значення вологості є мінімальними (не більшими ніж 12 г/м^3). З практичного погляду – це можливість за відомими метеопараметрами, отриманими з прогнозу погоди, встановлювати доцільність виконання спостережень.

Ключові слова: GPS; абсолютна вологість; тривалість сеансів спостережень; точність положення пунктів.

Received 15.02.2018