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METEOROLOGY MONITORING OF THE PRECIPITABLE WATER VAPOR DISTRIBUTION IN THE ATMOSPHERE BASED ON OPERATIONAL GNSS DATA PROCESSING AT REFERENCE STATION NETWORK ZAKPOS

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Abstract

Remote monitoring of the atmosphere is designed to obtain information about the state of the atmosphere. The principle of the remote monitoring system of the atmosphere is based on the registration and processing of spacecraft radio signals of the Global Navigation Satellite Systems (GNSS). The wet tropospheric delay component of the electromagnetic signal ($\Delta\rho_w^{tropo}$), which is derived from the GNSS observations data analysis, is used to calculate the water vapour content in the atmosphere. It is well known, that this parameter is critical to meteorologists, because the water vapour content in the atmosphere is a key parameter in the construction of numerical weather modelling. In this article the IWV - Integrated Water Vapour has been estimated and the expected accuracy of its determination on the basis of the operational GNSS data processing from reference station network ZAKPOS and the results of aerologic sensing of the atmosphere are given.

Key words: GNSS observations, tropospheric delay, water vapour.

Introduction

The principle of the remote monitoring system of the atmosphere is based on the registration and processing of spacecraft radio signals of the Global Navigation Satellite Systems (GNSS). The distribution of radio signals from navigation satellites to ground receivers through the atmosphere is accompanied by a propagation rate decrease. This is due to the presence of nitrogen, oxygen, carbon dioxide molecules and water vapour in the atmosphere. Under the influence of external radio waves, these molecules are polarized and provide additional electrical currents in the atmosphere. As a result, the total current is different from the currents in vacuum, which leads to decreases of phase velocity of the radio waves that directly depends on the concentration of molecules. Therefore, measurements of additional delay of signal passing in the atmosphere provide information on the integrated properties of the atmosphere along the propagation path of signal. When processing observational data from space vehicles, one gets additional information in the form of files of radio signal atmospheric delays that are registered by GNSS-receivers. Due to strong correlation between water vapour in the atmosphere and tropospheric delay of GNSS-signal propagation, one can estimate the IPWV - Integrated Precipitable Water Vapour in the atmosphere based on GNSS measurements.

The first has been created in Ukrainian network of active reference stations ZAKPOS / UA-EUPOS in Transcarpathia (Savchuk S. et al., 2008). Currently, there is an intensive ongoing research to identify and take into account the errors affecting GNSS observations in the network of active reference stations, including the investigation of lower atmosphere influence (tropospheric delays of the electromagnetic signal). Tropospheric delay errors in GNSS-measurements influence primarily the overall scale of geodetic measurements, the determination accuracy of the height point above the sea level and horizontal coordinates of the observation points. The wet tropospheric delay component of the electromagnetic signal allows to determine the amount of water vapour in the atmosphere that can be used for the purposes of meteorology.

In this article the concept of exploration of the existing infrastructure of the national network of active reference GNSS-stations for remote sensing of the atmosphere to determine the content of water vapour in the atmosphere as one of the main weather creating factors is presented. The accuracy of the integrated water vapour in the atmosphere (IWV) based on GNSS observations is estimated.

Analysis of recent research and publications on this issue

Currently, the troposphere exploration using GNSS - monitoring is aimed at deeper understanding of weather and climate processes, and ultimately, improving weather forecasting (J. Bosy et al., 2011).

Weather forecasting is largely dependent on the atmospheric circulation data, in which the physical processes of dynamic mass and energy mixing (including radiation, etc.) must be known. The atmosphere is unstable in both vertical and horizontal direction. The troposphere dynamics is considerably complicated due to fast changes of water vapour phases. The structure of the humidity field is reasonably complex and depends on many different processes in the atmosphere, so it is characterized by regular and random changes in the spatial and temporal scales. Large-scale inhomogeneities of the humidity field reach hundreds or thousands of meters. There are also small-scale humidity field inhomogeneities with dimensions from hundreds of meters to millimetres. Numerical characteristics of water vapour are used in operational meteorology for short-term weather forecasts (the distance between stations to 70 km) and for numerical weather prediction in climate applications for the whole region (the distance between stations > 100 km).

Operational weather forecast is usually based on relative humidity observations, along with pressure and temperature, determined by radiosondes and ground meteorological devices. Radiosondes are launched twice a day and determine the profiles of changes in atmospheric pressure (P, mbar), temperature (T, ˚C) and relative humidity (W, %) with height in the atmosphere. One of the main disadvantages of the radiosondes is the relatively low accuracy of the sensors as a result of contamination during their launch. On the other hand the amount of water vapour can be determined by radiometers. This tool generally provides very accurate data, but its measurements are unreliable during rainfalls, and this device is expensive. Radiosondes and ground or space water vapour radiometers are located at considerable distances from each other, and the measuring discretisation is low. For these measuring methods the vertical resolution determination of water vapour content in the atmosphere is sufficient, but spatial and temporal data distribution in these measurements is very loose and depends on weather conditions.

At the end of the last century a new method for evaluating and determining the integrated water vapour in the atmosphere (IWV) based on GNSS observations was developed. The method is based on the assessment of tropospheric delays ($\Delta\rho^{tropo}$) in the GNSS satellite signals. Preeminently $\Delta\rho^{tropo}$ can be directly related to the water vapour amount in the atmosphere and thus, it is a product that is essential for meteorologists. The advantage of this method is the possibility of its continuous implementation within the existing GNSS infrastructure (active reference station network with an exclusive control centre) and the fact that the derived water vapour estimates from the GNSS measurements do not depend on the rainfall and the presence of clouds.

Depending on the geographical location of the reference GNSS stations presently it is possible to study the detailed spatial and temporal distribution of water vapour in the atmosphere. Using GNSS allows long-term regional and global monitoring of the water vapour content in the atmosphere.

The tropospheric delay $\Delta\rho^{tropo}$ consists of two components: hydrostatic delay $\Delta\rho_d^{tropo}$ that depends on the state of the dry component of the atmosphere and the wet delay $\Delta\rho_w^{tropo}$ depending on humidity. These data values are $\Delta\rho_d^{tropo}$ - meters, $\Delta\rho_w^{tropo}$ - decimetres, IWV - millimetres. The IWV values vary from 0 to 40 mm and above. The error of 0.5 hectopascals corresponds to 0.2 mm for IWV and is acceptable for numerical weather prediction. The quality of results depends on the availability of meteorological estimations on the ground (Kablak N. et al., 2004).

Today, a number of meteorological projects have been completed: COST-71 "Exploitation of Ground-Based GPS for Operational Numerical Weather Prediction and Climate Applications" (1998-2003), TOUGH "Targeting Optimal Use of GPS Humidity Measurements in Meteorology" (2003-2006) and others. Currently an ongoing project in Central Europe, within which the zenith tropospheric delays in the regional network of GNSS stations are defined in near-real time, is E-GVAP. Its main analysis centre is located at the Royal Observatory of Belgium (ROB) (http://egvap.dmi.dk). The network currently has about 160 stations: most of them belong to the permanent network of EPN EUREF (*http://www.epncb.oma.be)* and the International GNSS Service IGS (http://igscb.jpl.nasa.gov). The continuity of water vapour determination on large areas allows to define and predict the dynamics of water vapour, and hence the rainfall in real time. Western part of Ukraine (Transcarpathian region) borders with Hungary, Slovakia, Romania and Poland. In the territory of those countries there are active reference station networks: SKPOS - Slovakia, GNSSNET.hu - Hungary, ROMPOS - Romania, ASG-EUPOS - Poland. Taking into account the geographical position of Ukraine (Transcarpathian region), and thus the station network ZAKPOS/UA-EUPOS, and cross-border cooperation with European countries, we can have accurate and frequent sample of IWV values on large areas, which allows us to define and predict the dynamics of water vapour in real time. Due to these statements the present research is caused.

Objective

The aim of this work is to evaluate the accuracy of the precipitable water vapour on the basis of operational GNSS data processing from reference station network ZAKPOS/UA-EUPOS for the purposes of meteorology.

The basic material

10% of the total tropospheric delay is the wet component of the tropospheric delay. The amplitude of the micro vibrations of the water vapour partial pressure has a random nature and can reach several millibars just in 10-20 seconds. The scale factor of partial pressure, which determines the height h_e, where e is reduced 2.72 times, varies widely – from 0.9 to 4.0 km. Within significant temperature inversion the height h_e reaches maximum values (h_e ~ 4 km). So the air humidity is difficult to model. And for accurate weather forecasting, one needs information of exclusive quality with high spatial and temporal distribution.

The equation for the phase method of observation is of the form (Hofmann-Wellenhof B.et al., 1997):

$$\Phi = \rho_R^S + \Delta\rho^{ion} + \Delta\rho^{tropo} - \Delta\rho^{rel} + c\cdot\Delta t^S - c\cdot\Delta t_R + \lambda N - v_R^S, \qquad (1)$$

where ρ_R^S is the distance between the position of the GPS-satellite in the t^s era (GPS) and the GPS-receiver position in the t_R era (GPS); $\Delta\rho^{ion}$ is the ionospheric delay; $\Delta\rho^{tropo}$ is the tropospheric delay; $\Delta\rho^{rel}$ is a relativistic correction; v_R^S is the noise measurement plus not modelling effects; c is the speed of light; N is the number of whole cycles; λ is the wavelength; $\Delta t^S, \Delta t_R$ are the satellite and receiver clock errors with respect to GNSS time system, respectively.

The phase of carrier frequency can be measured with an accuracy above 0.01 cycle, which corresponds to millimetre accuracy of the coordinates determination.

The total tropospheric delay can also be determined by means of aerologic sensing of the atmosphere using the formula (Mendes V.B. 1999):

$$\Delta\rho^{tropo} = \Delta\rho_d^{tropo} + \Delta\rho_w^{tropo} = 10^{-6}\cdot\int N_d^{tropo}dh + 10^{-6}\cdot\int N_w^{tropo}dh \qquad (2)$$

where $N_d^{tropo} = K_1\left(\frac{P_d}{T}\right)Z_d^{-1}$ are the coefficients of dry air refraction; $N_w^{tropo} = \left[K_2\left(\frac{e}{T}\right) + K_3\left(\frac{e}{T^2}\right)\right]Z_w^{-1}$ are the coefficients of wet air refraction; P_d is dry air pressure, mbar; e is partial pressure of water vapour, mbar; T is temperature, K_1 is the coefficient characterizing the polarization of dry air molecules, $K \cdot \text{mbar}^{-1}$; K_2 is the coefficient taking into account the polarization of water molecules, $\text{K}\cdot\text{mbar}^{-1}$; K_3 is the coefficient reflecting the effect of changing the electrical orientation of polar water molecules, $10^5\,\text{K}^2\cdot\text{mbar}^{-1}$.

Using the Mendeleev-Clapeyron equation we obtain:

$$N = K_1R_d\rho + \left[K_2'\left(\frac{e}{T}\right) + K_3\left(\frac{e}{T^2}\right)\right]Z_w^{-1} \qquad (3)$$

where

$$K_2' = K_2 - K_1\left(\frac{R_d}{R_w}\right) = K_2 - K_1\frac{\mu_w}{\mu_d},$$

R_d = 287,06 $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ is the specific gas constant of dry air, R_w = 461,525 $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ is the specific gas constant of water vapour, ρ is the overall air density, μ_d and μ_w is the molecular mass of dry air and water vapour, respectively.

The delay due to the influence of hydrostatic component of the atmosphere in the zenith direction is

$$\Delta\rho_d^{\,z} = 10^{-6}K_1R_d\int_{h_0}^{h}\rho dh. \qquad (4)$$

Atmospheric delay caused by the influence of water vapour in the zenith:

$$\Delta\rho_w^z = 10^{-6}\int_{h_0}^{h_{\max}}\left[K_2'\left(\frac{e}{T}\right)+K_3\left(\frac{e}{T^2}\right)\right]Z_w^{-1}dh \tag{5}$$

Using the value of the wet tropospheric delay, obtained in the GNSS observations processing, the integrated water vapour (IWV) as the total mass of water vapour in the column of air from the surface of the Earth to the end of atmosphere having the cross section of 1 m^2 can be determined by the formula:

$$IWV = \frac{\Delta\rho_w^{tropo}}{\xi}, \tag{6}$$

where

$$\xi = 10^{-6}R_w\left[K_2' + \frac{K_3}{T_m}\right].$$

In the last formula, the average temperature T_m can be determined by means of the relation (T.A. Herring et al,1992)

$$T_m = \frac{\int_{h_0}^{h_{\max}}\frac{e}{T}Z_w^{-1}dh}{\int_{h_0}^{h_{\max}}\frac{e}{T^2}Z_w^{-1}dh} \tag{7}$$

From the gas equation of state we obtain:

$$\left(\frac{e}{T}\right)Z_w^{-1} = \rho_w R_w$$

where ρ_w is water vapour density. Then the wet delay component will be:

$$\Delta\rho_w^{tropo} = 10^{-6}R_w\left[K_2' + \frac{K_3}{T_m}\right]\int_{h_0}^{h_{\max}}\rho_w dh. \tag{8}$$

The IWV value can be easily converted into units of length if we divide it by water density ($\rho(H_2O) \cong 10^3$ kg·m^{-3}). Then it is interpreted as the height (in mm) of water column of 1 m^2 cross section, derived from the condensed steam. It can be called a precipitable water vapour or just precipitable water (*PW*):

$$PW = \frac{1}{\rho_{H_2O}}\int_{h_0}^{h_{\max}}\rho_w dh. \tag{9}$$

It is obvious that 1 kg·m^{-2} of *IWV* corresponds to 1 mm of *PW*.
The IPWV value is calculated from the relation

$$IPWV = \frac{IWV}{\rho_w}. \tag{10}$$

Thus, for the transition from $\Delta\rho_w^{tropo}$ to the precipitable water vapour it is necessary to know the average temperature of the atmosphere above this point. The average temperature depends on the surface temperature with the correlation coefficient close to unity. For this purpose one needs to build a regression relation of the average temperature T_m and the Earth's surface temperature T_0 at the points of observation.

Experimental research

The value of the precipitable water vapour *IWV* (6) is definitely determined by $\Delta\rho_w^{tropo}$, which can be calculated by different methods:

- from GPS observations with the removal of the hydrostatic component;
- basing on aerologic sensing of the atmosphere;
- modelling representations using ground values of meteorological parameters.

Synchronous meteorological parameter measurements on the Earth's surface were used for the research, as well as aerologic sensing data of the atmosphere and delay values from network processing ZAKPOS during the year.

To estimate the errors of *IWV* determination we take into account the formulas (6), (7) and (8). The wet delay $\Delta\rho_w^{tropo}$ is determined by extracting from the total tropospheric delay $\Delta\rho^{tropo}$, obtained from GNSS measurements, and using the hydrostatic component of the atmospheric delay $\Delta\rho_{m,d}$ determined from the model:

$$\Delta\rho_w^{tropo} = \Delta\rho^{tropo} - \Delta\rho_{m,d} . \tag{11}$$

In most cases when processing GNSS data the Saastamoinen Model (Saastamoinen I.I., 1973) is used to calculate the hydrostatic component of the tropospheric correction $\Delta\rho_{d,c}$. According to the Saastamoinen Model the hydrostatic component of the tropospheric delay is calculated from the measured values of ground pressure at each station for which we know the latitude and altitude above sea level.

To explore the accuracy of *IWV* determination, the results of aerologic sensing of the atmosphere at UT=0^h i UT=12^h hours during the year in Uzhgorod were used. Based on these results the total delay $\Delta\rho_{aer}^{tropo}$ and separately the hydrostatic $\Delta\rho_{a,d}$ and wet $\Delta\rho_{a,w}$ components of the tropospheric delays were calculated. For the same time points the $\Delta\rho_m^{tropo}$, $\Delta\rho_{m,d}$ and $\Delta\rho_{m,w}$ were calculated based on ground meteorological parameters (temperature *T*, pressure *P*, humidity *W*) using the Saastamoinen Model and local model, as well as absolute tropospheric delays $\Delta\rho^{tropo}$ derived from GNSS observations on the same time points were found.

In the radio range, temperature inversions have a great influence on the tropospheric delay value, which cause the growth of the partial pressure of the atmosphere that affects the value of $\Delta\rho_{aer}^{tropo}$ and $\Delta\rho^{tropo}$. Modelling representations of tropospheric delays $\Delta\rho_m^{tropo}$ do not include the vertical distribution of meteorological parameters in the atmosphere, where temperature inversions are often observed. According to the sensing data of the atmosphere in Uzhgorod, there was explored that in 3 km height of the atmosphere, temperature inversions are observed in 73-97% of cases. Inversions in the layer of (8 – 18) km (upper layer) are observed in 20-40% of cases. Particularly strong inversions were observed at night in winter, mainly due to radiation inversions. The distribution of water vapour at different altitudes has irregular changes. There is no correlation between ground humidity values and its changes with heights. The average contribution of temperature inversions to the atmospheric delay ranges from 29 mm to 64 mm, humidity inversions: from 3 mm to 15 mm. Thus, the difference ($\Delta\rho_{aer}^{tropo} - \Delta\rho_m^{tropo}$) can reach 5-6 cm.

The $\Delta\rho_{aer}^{tropo}$ value cannot be considered completely accurate. The number of levels, on which the aerologic parameters were measured, depends on the frequency of the radiosonde query and the h_{ul} height of the upper limit of measurements. h_{ul} ranges from 5 to 20 km. The number of levels at one sensing ranges from 15 to 90. The measurement accuracy of aerologic parameters depends on the radiosonde type. In our case it is: $\Delta P = \pm 1$ mbar, $\Delta t = \pm 0.8\ ^0$C and $\Delta W = \pm 5\%$. This allows us to determine the refractive index of air with an error of $1 \cdot 10^{-6}$·. The error of $\Delta\rho_{aer}^{tropo}$ in the zenith, caused by measurement errors of the meteorological parameters, varies from 0.006 to 0.012 m.

To explore the accuracy of modelling representation $\Delta\rho_{m,d}$, the hydrostatic delay was calculated by the Saastamoinen Model ($\Delta\rho_{d,S}$), by a local model ($\Delta\rho_{d,l}$), which takes into account the regional, local and topographical features of observation points (Kablak N. 2011), and by aerologic sensing of the atmosphere ($\Delta\rho_{d,aer}$). The estimations of differences between them are given in the following table:

	Averaged values, m	Standard deviation, m
$\lvert \Delta\rho_{d,aer} - \Delta\rho_{d,l} \rvert$	0.0028	0.0048
$\lvert \Delta\rho_{d,aer} - \Delta\rho_{d,S} \rvert$	0.0092	0.0086

The $\Delta\rho_{d,l}$ value calculated by the local model is better consistent with the values calculated on the basis of aerologic sensing $\Delta\rho_{d,aer}$ than $\Delta\rho_{d,S}$. Only in 9 cases out of 56 $|\Delta\rho_{d,aer} - \Delta\rho_{d,l}|$ is greater than $|\Delta\rho_{d,aer} - \Delta\rho_{d,S}|$.

Thus, we can assert that the created local model of hydrostatic delay determination in Uzhgorod is better consistent with $\Delta\rho_{d,aer}$ than the Saastamoinen Model.

The differences of $\Delta\rho_{m,d}$ average values determined by two methods (by aerologic sensing data and by Saastmoinen model) reach 1 cm. This corresponds to the IWV difference - 1.5 mm. In some cases, when the $\Delta\rho_{d}$ determination accuracy by modelling representations is 3-4 cm, the precipitable water vapour will be determined with an error of 5-6 mm. Therefore, to improve the accuracy of the precipitable water vapour (*IWV*) determination on the basis of the operational GNSS data processing it is reasonable to use local modelling representations for the hydrostatic component of the tropospheric delay.

From the GNSS measurements we have the total tropospheric delay $\Delta\rho^{tropo}$. If the GNSS measurements were carried out only in the zenith direction (the satellite for this point is at the zenith), the accuracy of the $\Delta\rho^{tropo}$ determination would be estimated only by the accuracy of excluding the errors of the pseudo distance equation components. It is believed that the radio signal in GNSS observations passes through the Earth's atmosphere immediately. That is, the real state of unstable atmosphere at a given time is taken into account. However, the $\Delta\rho^{tropo}$ value is determined from the solution of the pseudo distance equation after exclusion of other errors and, besides, the $\Delta\rho^{tropo}$ is estimated not directly at the zenith, but at a certain zenith distance, which is reduced to the zenith by means of mapping functions. In most cases, while GNSS measurement processing the Neill's mapping function is used, which is not dependent on the meteorological parameters (Niell A. E., 2001). The error of the Neill's mapping function at $Z = 75^0$ is 5-6 cm and increases to 20 cm at $Z = 85^0$.

According to model representations of the mapping functions it is considered that the atmosphere is homogeneous, i.e. the horizontal gradients of refraction are not taken into account. Horizontal gradients of refraction bring error into the determination of the tropospheric delay at 3-5 cm at $Z = 83^0 - 85^0$ (N.Kablak et al, 2005).

To determine the precipitable water vapour (*IWV*) by the formulas (6) and (7), we need to know the average temperature T_m of the atmosphere above this point. At a certain atmosphere altitude *h* the meteorological parameters *e* and *T* can be determined by means of aerologic sensing of the atmosphere but it is not possible to carry out in every point, moreover, continuously and synchronously with GNSS-measurements. That is why the correlation between T_0 (ground temperature) and T_m which is calculated by the formula (7) in those moments when *e* and *T* are measured at different altitudes *h* within the troposphere is found. In determining the average temperature it is suggested to use this regression dependence on ground temperature:

$$T_m = a\, T_0 + b. \qquad (12)$$

Depending on the obtained coefficients when determining the average temperature in the troposphere by the values of ground temperature, the *IWV* value varies from 0.3 to 1.0 mm.

Therefore, to improve the accuracy of the precipitable water vapour determination on the basis of the operational processing of GNSS data it is reasonable to use local values of the correlation dependency coefficients of T_m on T_0.

The denominator of (5) ξ is determined by the constants R_w, K_2', K_3 and the average temperature T_m, which can be found by the formula (6). The maximum error value of the determination $K_2' = 17 \pm 10\ \mathrm{K\ mbar^{-1}}$ gives the error in determination $\Delta(IWV) = 0.3 - 0.9\ \mathrm{mm}$. The maximum error value of the coefficient determining $K_3 = (3.776 \pm 0.004) \cdot 10^5\ \mathrm{K\ mbar^{-1}}$ gives the error of $\Delta(IWV) \approx 0.02\ \mathrm{mm}$.

To assess the accuracy of the precipitable water vapour, the *IWV* value was also determined according to aerologic sensing of the atmosphere using the gas equation of state:

$$eV = \frac{m}{\mu} RT \,. \tag{13}$$

We accept that the volume V is a water vapour column in the atmosphere with height h, cross section S, and mass m. Then, for a homogeneous atmosphere (9) it takes the form:

$$eh = \frac{m}{S} \frac{R_w}{\mu} T \,.$$

As in the real atmosphere the quantities e and T are functions of height and integrated water vapor is

$$IWV = \frac{m}{S} \,,$$

then from the gas equation of state we get the following formula to calculate the integrated water vapour IWV_e by aerologic observations of water vapour pressure e and temperature T:

$$IWV_e = \frac{\mu}{R_w} \int_{h_0}^{h} \frac{e(h)}{T(h)} dh \,. \tag{14}$$

In the formula (12) the integration is carried out on the height of point h_0 to the height of wet atmosphere h.

During the research period of the precipitable water vapour calculated by this method varies from 2.3 mm in winter to 42.75 mm in summer.

The relative error (d) is:

$$d = \frac{IWV - IWV_e}{IWV_e} \,,$$

2,7% in average.

The IWV value determined by the results of GPS observations in average are larger than IWV_e, obtained by formula (14) based on aerologic observations. The differences between IWV and IWV_e values lie in the range from 0.2 to 1.6 mm. This is explained by the fact that IWV determination errors are laid in the very method of water vapour determination.

Thus, the IWV values based on operative data processing from the permanent station network ZAKPOS are calculated using ground meteorological data, such as temperature and pressure, as well as radio sensing data. The results are presented in a tabular form and in a variety of graphical forms. The figure provides IWV values determined on the basis of operational GNSS data processing from reference station network ZAKPOS in the form of isolines. Due to the implementation and ongoing operation of the Ukrainian network of active reference stations ZAKPOS / UA-EUPOS, now it is possible to process GNSS IWV data in real time with the discreteness of 1 min.

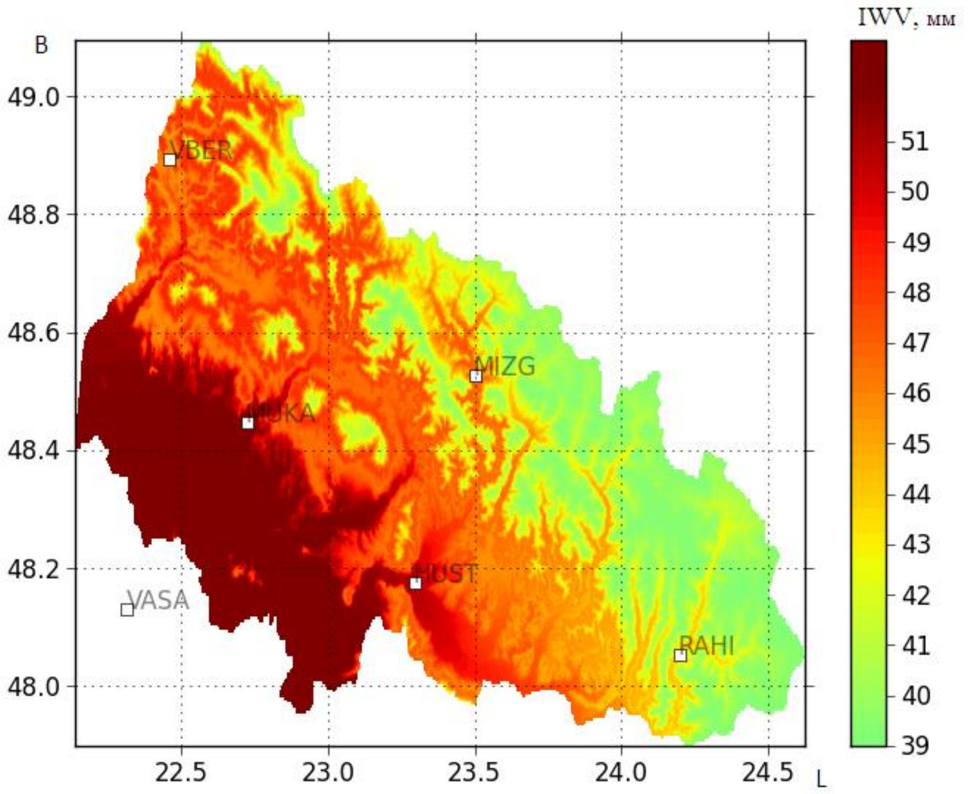

Fig. 1. Precipitable water vapour (15.07.2012, 00^h00^mUT).

Conclusions

The analysis of water vapour determination in the atmosphere during the year based on GNSS observations and aerologic sensing of the atmosphere showed:

- the average difference of the zenith atmospheric delays obtained by two methods used for the determination of water vapour in the atmosphere is about 1.5 cm; error of $\Delta\rho_{aer}^{tropo}$ in the zenith, which is caused by measurement errors of the meteorological parameters, varies from 0.006 to 0.012 m;
- the average differences of hydrostatic atmospheric delays calculated basing on aerologic sensing and the Saastamoinen Model, about 1 cm;
- the calculated *IWV* values vary from 0 to 43 mm. The differences of *IWV* values determined by the results of GNSS observations and IWV_e, derived from aerologic observations lie within the range of 0.2 to 1.6 mm.

To improve the accuracy of the precipitable water vapour values (*IWV*) on the basis of operational GNSS data processing it is needed to:

- use the local modelling representation for the hydrostatic component of the tropospheric delay;
- know the pressure and temperature on the ground;
- know the average temperature T_m, which correlates well with the ground temperature T_0;
- use appropriately the local values of coefficients of the correlation dependency of T_m on T_0.

Providing such conditions we should expect the increase of *IWV* accuracy to 1.5 mm.

This *IWV* error estimation applies to measurement at a particular time (single). Due to one-a-second (continuous) GNSS measurements, we should expect the increase of *IWV* accuracy. Basing on observations of GNSS network stations ZAKPOS and using cross-border cooperation with European countries, we can have accurate, dense and frequent sample of *IWV* values on large territories, which allow us to define and predict the dynamics of water vapour changes in real time.

In connection with importance of the given research we have elaborated the project HUSKROUA/1101/252 “SPACE EMERGENCY SYSTEM – cross-border system for pre-diction of natural disasters incidents on basis of exploitation of satellite technologies in Hungary, Slovakia, Romania and Ukraine” in the framework of the Cross-Border Cooperation Programme Hungary-Slovakia-Romania-Ukraine 2007-2013.

Within this project launch and stable operation of the system of cross-border area monitoring in real time is planned. It will assist solving the problem of timely pre-diction of natural disasters incidents, climate and environmental monitoring of the given area.

Thus, activities of this project as a multifunctional and integrated system will cause:

- carrying out international research and observations in field of geodynamics, meteorology, study of atmospheric processes etc;
- continuous atmosphere tomography;
- environmental monitoring (space-time changes of content of integrated water vapour in troposphere, pre-diction of thundershowers, floods etc);
- use of obtained data for improving accuracy of long-term weather forecasts.

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