Monitoring of Precipitable Water Vapor Over the Czech Republic by GPS

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Abstract. The paper is concerned with possibilities of usage Global navigation satellite system technology in another field of human existence, which is meteorology. Concretely it is focused on determining of predicted water vapor of the atmosphere whereas this parameter significantly influences actual status and development of weather. The paper stems from diploma thesis from 2007, which has achieved to prove that mentioned technology is really usable for existent purpose. The objective of this project is researching usability of ascertained fact within the scope of whole network of reference stations and judging predicted water vapor of the atmosphere values development over the Czech Republic. Except theoretical part attending to description of predicted water vapor of the atmosphere and generally most frequently used methods for its determination, the paper also includes description of practical tasks which means processing of GPS measurements for chosen time periods (time duration from two till three days) in selected network of terrestrial reference stations. Results from those computations are consequently represented in graphical form and compared with values of predicted water vapor of the atmosphere which were measured by Czech Hydrometeorological Institute with using conventional methods. At the conclusion are those comparisons commented and overall rating of GPS technology usability for described purpose is given, including suggestion of next progression at research of this questions.

Keywords: GPS, meteorology, predicted water vapor, Bernese GPS Software.

1 Introduction

People are dealing with the possibilities of Global Navigation Satellite Systems measurements usage not only for positioning and navigation purpose for two decades approximately. There exists an unexceptionable fact that signals emitted by satellites passing through the atmosphere are being affected by it. There were realized some researcher projects which have proven that it is possible to compute precipitable water vapor of the atmosphere (PWV) values from the GPS measurements. PWV has a huge influence on actual weather development so knowledge of its distribution is important for better initializing and constraining numerical weather prediction models. Up to now methods used for determination of this parameter are economically expensive and for definite reasons not very efficient.
There were defended a diploma thesis about GNSS meteorology at the Institute of Geoinformatics VSB – Technical University of Ostrava in 2007. The main goal of this thesis was to practically confirm the possibilities of GNSS technology usage for precipitable water vapor determination. However, the thesis was only comparing results gained from GPS signals computations with real information measured by Czech Hydrometeorological Institute for single stations.
The objective of my project was to pick up on this defended thesis and start to use the ascertained fact within a whole network of GPS reference stations.

2 Precipitable water vapor and methods of its determination

The precipitable water vapor of the atmosphere is one of the most important indicators about conditions of the troposphere. It is a basic component of the energy transfer and one of the most important factors which influence weather. It can be imagined as a total quantity of water contained in the atmosphere above a given position phrased in millimeters. However due to its own time and spatial variability it is even for contemporary meteorology difficult to describe it correctly.
It is possible to use a lot of methods and tools for water vapor determination presently. But the meteorological balloons equipped with radiosondes are the most frequent. Those balloons are rising in the atmosphere, radiosondes measuring some atmospheric parameters and sending measured values back to the earth. Those balloons are mostly being launched from one time to four times a day from

meteorological stations. In the Czech Republic there are two such meteorological stations, the first is situated in Praha-Libuš and the second one in Prostějov. Disadvantages of this method are that we can maximally get two or four values of PWV for two places in the Czech Republic a day and it is expensive because we have to launch new balloons all the time. The main advantage of it is that we are getting a precise vertical profile of the atmosphere and not only a total value of PWV.
One of the remote instruments which provide information about water vapor of the atmosphere on a global scale are satellites equipped with humidity sensors. Both NOAA and Meteosat satellites are being used for it.
But as it have been already said it is possible to determine PWV on the basis of GNSS measurements. Predicted water vapor of the atmosphere is then computed from the values of tropospheric refraction. [1], [3], [5]

3 Bernese GPS Software

Bernese SW represents a package of programmes for processing measurements of GPS signals which is still being developed by the Astronomical Institute at the University of Bern. It is a software with huge possibilities but unfortunately it can‘t be considered as user-friendly. Outputs from the processing which were executed in Bernese were values of the trophosferic refraction which were sequentially used for the PWV values determination. [4]

4 Processing

4.1 Selecting suitable network of GPS reference stations

Because the main goal of this project was to study results gained from GPS measurements for whole network of reference stations and compare them with real weather situation over Czech Republic it was necessary to select this network really properly. There were specified four requirements on the network and reference stations:

1. location of the particular stations within whole area of the Czech Republic and its close surroundings,
2. existence of the measurement of meteorological quantities at the reference GPS station (atmospheric temperature, pressure and humidity),
3. accessibility of measured data from the station (observation and meteo RINEX files),
4. involve stations with large differences in their altitude.

There are presently operated four networks of GPS reference stations in the Czech Republic (CZEPOS, TopNET, GEONAS, VESOG) but only stations from networks GEONAS and VESOG were suitable for this project because those networks are not commercial and data from them are free for researcher purposes. Finally was chosen a network shown at the Figure number one, which has contained fifteen stations.

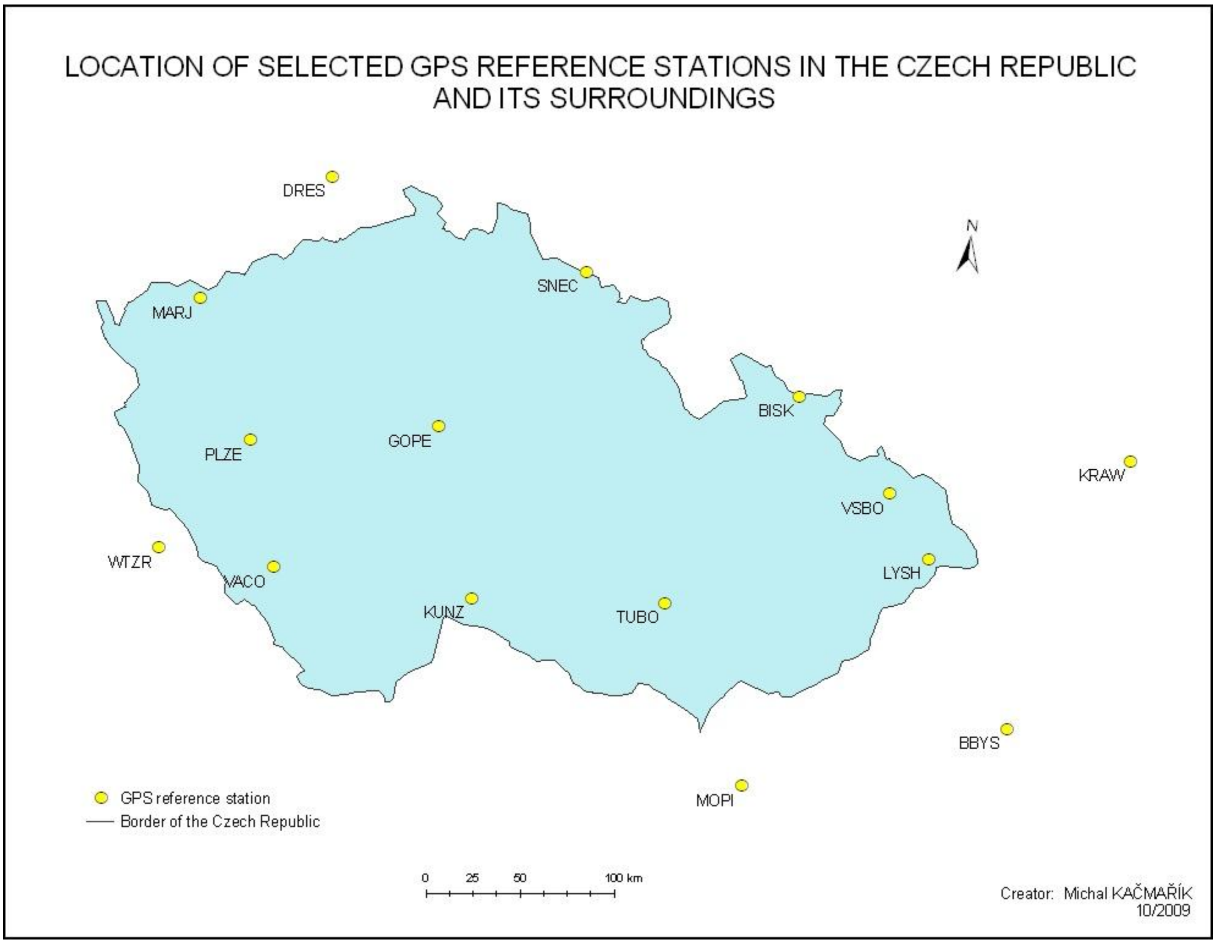

Fig. 1: Location of selected GPS reference stations in the Czech Republic and its surroundings

4.2 Selecting time periods suitable for processing

It was necessary to choose suitable time periods during which were over Czech Republic moving frontal systems of distinctive character in certain directions from the reason that I wanted to study a time development of PWV values for chosen network. On the basis of images from the Meteosat satellite were chosen two two-day time periods and one three-day time period:

1. from February 29th 2008 till March 1st 2008 (during these days were frontal systems moving over the Czech Republic approximately in the east-west direction and it is a time when the devastating windstorm Emma passed over this territory),
2. from March 23th 2008 till March 24th 2008 (during these days were frontal systems moving over the Czech Republic approximately in the north-south direction),
3. from September 29th 2008 till November 1st 2008 (during these days were frontal systems moving over the Czech Republic approximately in the east-west direction).

4.3 Visualization of computed results

Picture number 2 represents an example of results got from the executed computations. It shows PWV values computed from GPS measurements for the March 1st 2008 when windstorm Emma passed over the Czech Republic. Reference stations at the chart are aligned by their position approximately from the west to the east as the frontal systems were moving during this day. It is obviously visible that there exists a displacement in the start of the PWV values flopping among stations situated in the west and in the east. The beginning of the flopping always signifies an oncoming of the windstorm Emma above propriate reference station.

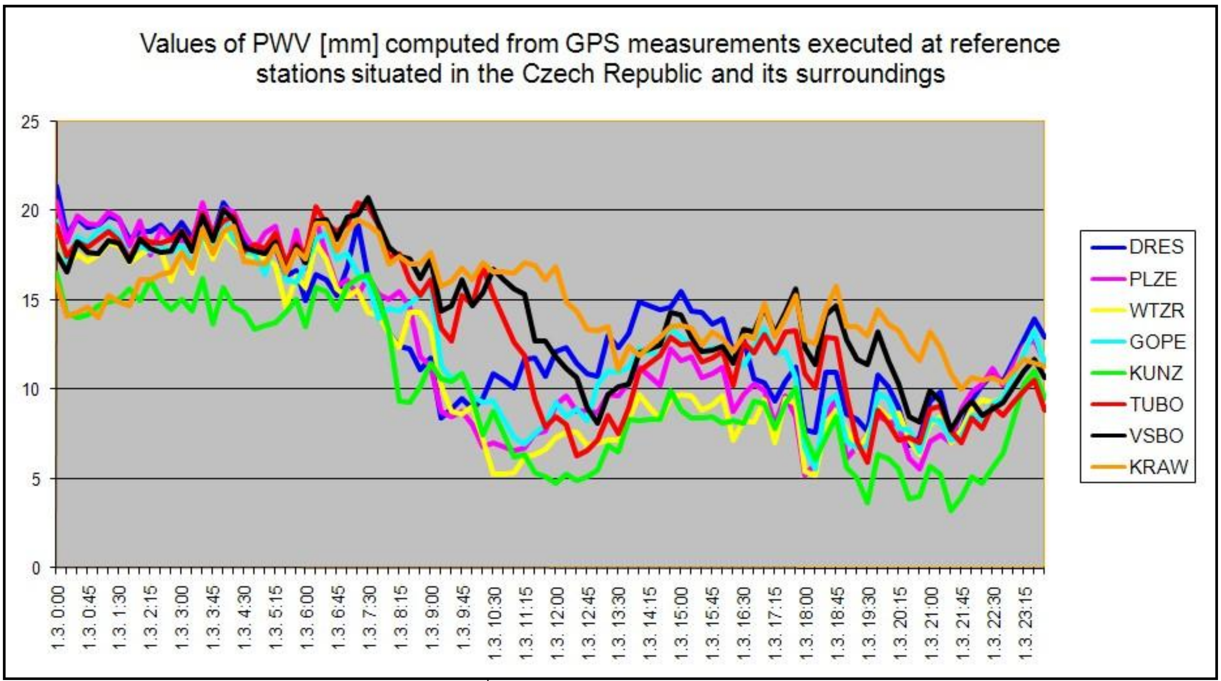

Fig. 2: PWV values [mm] for November 1st 2008 computed from data measured by GPS reference stations located in the Czech Republic and its surroundings

5 Confrontation of values got from GPS measurements with results from CHMI

The last goal of this project was make a comparison between results got from GPS measurements and the real weather situation over Czech Republic as it was described by CHMI. I have kept at disposition data from meteorological radiosondes and from meteorological radars.

5.1 Confrontation of values got from GPS measurements with the results from meteorological radiosondes

As it was mentioned in the Chapter 2 there is only one place in the Czech Republic from where meteorological balloons with radiosondes are being emitted and it is meteorological station Praha-Libuš. Balloons are being emitted at 0.00, 6.00, 12.00 and 18.00 UTC. Flight of such balloon takes about an hour and half so that is why we have to initiate a delay into the comparison (I used one hour). For confrontations with values got from radiosondes I used values of PWV computed from station GOPE. This GPS reference station is situated 32 kilometers far from meteorological station Praha-Libuš. This distance is enough high to be the cause of some differences between a pair of values. It is really important to realize that each meteorological balloon is being drifted by a wind all the time of its flight and because of this is moving not only in vertical direction.

Figures number three and four show results of made comparisons for time periods of March 1st 2008 and from September 29th 2008 till November 1st 2008. It is evident that results got from both technologies are very similar and this acknowledges that it is possible to use system GPS for correct PWV determination.

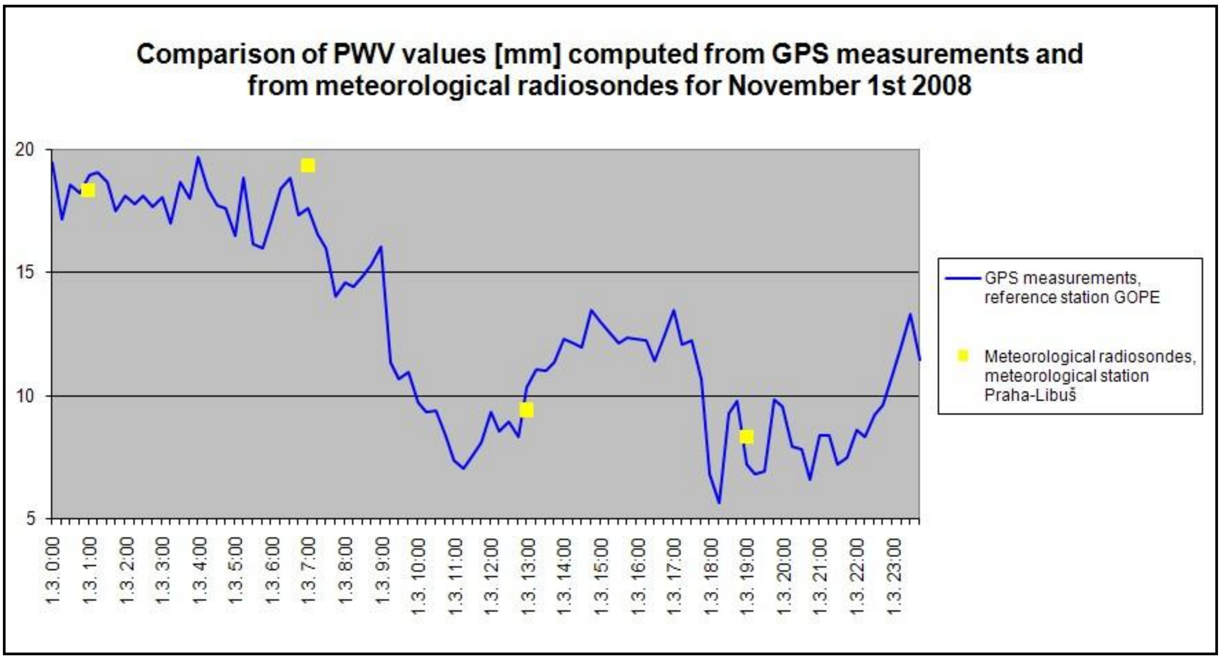

Fig. 3: PWV values [mm] for November 1st 2008 computed from data measured by GPS reference station GOPE and from meteorological radiosondes emitted from meteorological station Praha-Libuš

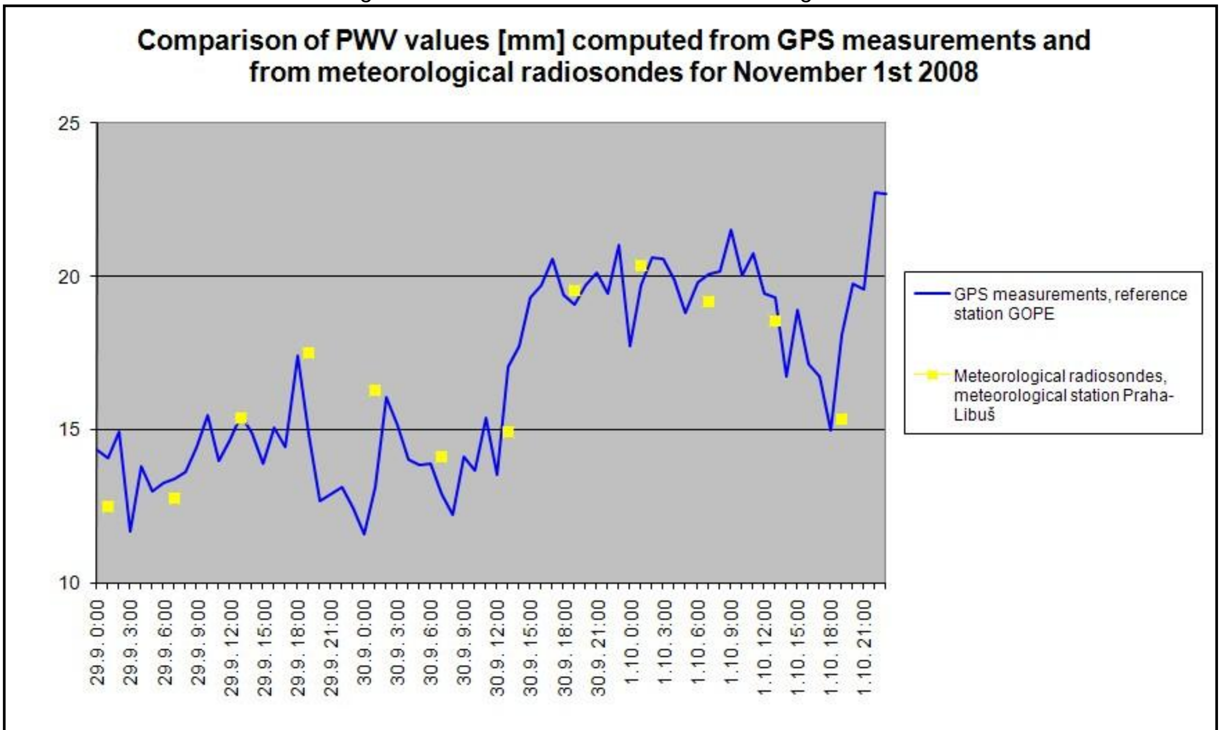

Fig. 4: PWV values [mm] for time period from September 29th 2008 till November 1st 2008 computed from data measured by GPS reference station GOPE and from meteorological radiosondes emitted from meteorological station Praha-Libuš

5.2 Confrontation of values got from GPS measurements with the results from meteorological radars for the windstorm Emma

Because we are studying PWV values development during the frontal systems movement over chosen area we are also able to determine the beginning of the precipitation falling from the curves of PWV values (depreciation in PWV values appears logically). From CHMI I got images from meteorological radars which were accurately prepared for GPS reference stations for the time when windstorm Emma have reached their position.

Following pictures show graphical outputs for selected reference stations. There is always marked a time when the meteorological radar image was taken at the curve of PWV values (green and yellow square) and the spatial position of appropriate station in the own image (red and white circle). Those outputs confirm that a course of the PWV values computed from GPS measurements corresponds to the real weather situation and that is why it can be said that the GPS technology is well suitable for such purpose.

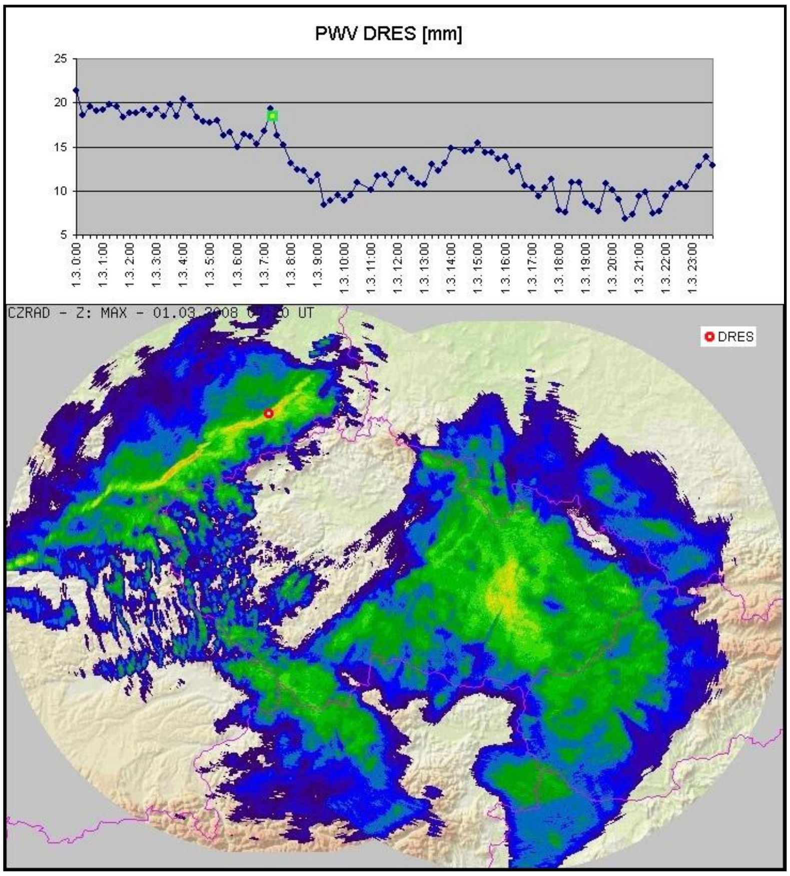

Fig. 5a: Comparison of the results got from GPS measurements at the DRES reference station with the image from meteorological radar at March 1st 2008

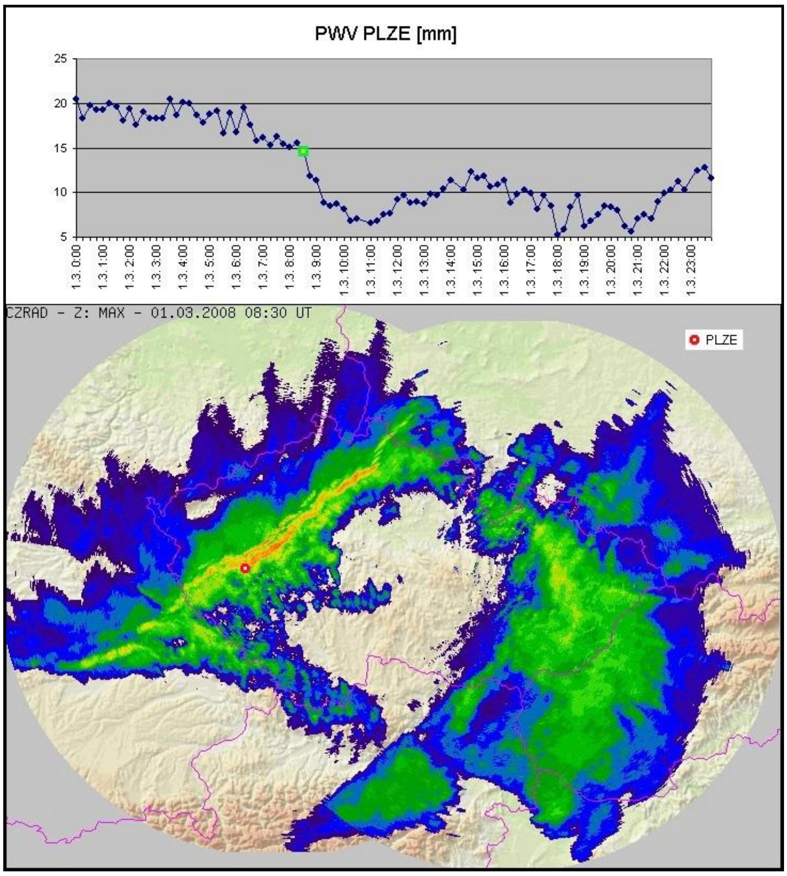

Fig. 5b: Comparison of the results got from GPS measurements at the PLZE reference station with the image from meteorological radar at March 1st 2008

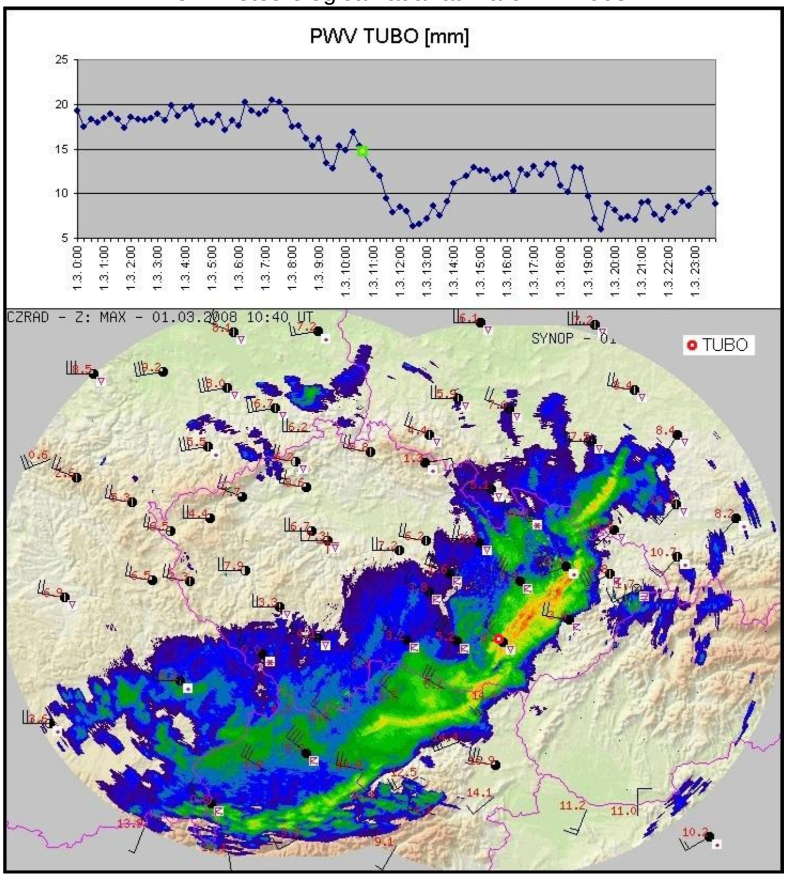

Fig. 5c: Comparison of the results got from GPS measurements at the TUBO reference station with the image from meteorological radar at March 1st 2008

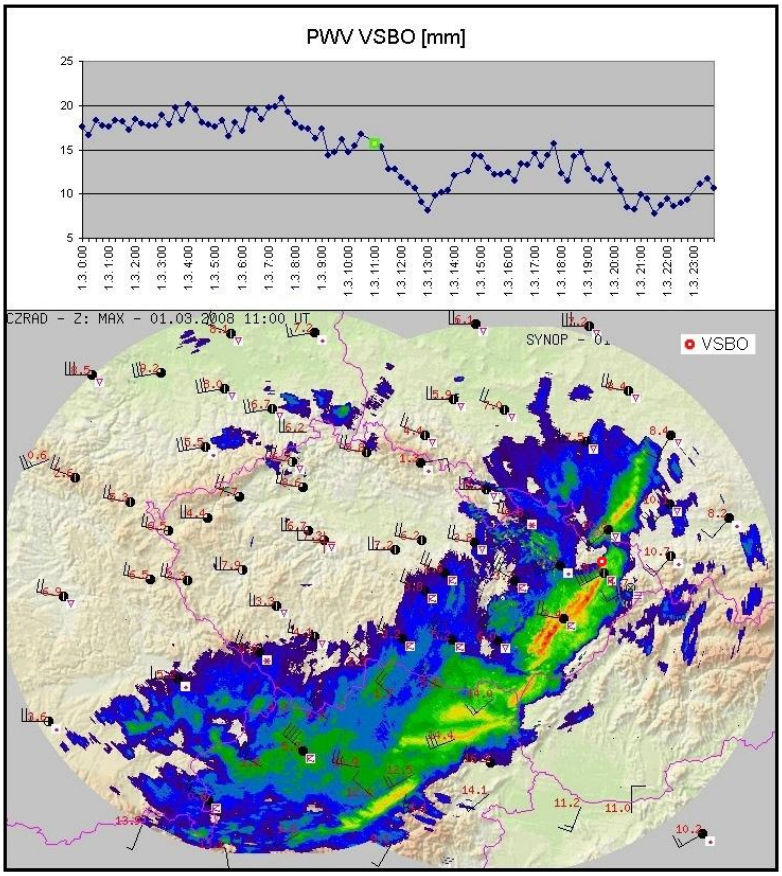

Fig. 5d: Comparison of the results got from GPS measurements at the VSBO reference station with the image from meteorological radar at March 1st 2008

6 Conclusion

Presented results of this project show that it is possible to use GPS technology for monitoring of water vapor in the atmosphere. Results got from GPS measurements achieve similar qualities as the contemporary used methods of CHMI do. But it is obvious that using meteorological balloons is not so efficient because we are able to get only four values of PWV a day for one place in whole Czech Republic. The GPS technology allows us to get for example twenty-four values of PWV a day for ten places in the Czech Republic. We also have to remember that each launching of such balloon costs money (concretely nearly 10 000Kč what is twelve millions crowns a year).

The main present disadvantage of using GPS technology for this purpose is a slowness of computations. It can be said that from the meteorological balloon we have the value of PWV until two hours from its launching. But a time needed to gain data from all GPS reference stations and make all computations is much longer. From this reason it is really necessary to establish an automatization of whole those processing.

Successful resolution of this problem could lead to practical usage of PWV values computed from GPS measurements for real applications, mainly as an input data for numerical weather prediction models like model ALADIN operated by CHMI.

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