INVESTIGATION OF UNCERTAINTY OF GNSS-BASED DISTANCE METROLOGY USING EPN DOUBLE STATIONS DATA

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Abstract

Nowadays surveyors and researchers in geosciences are facing the challenge of measuring distances over several hundreds of meters up to 1 kilometre with uncertainties at a single millimetre level and below. Electronic distance meters (EDM) and GNSS are available for this task and long length metrology complies with GNSS-based short distance measurements. Both approaches, however, are currently not capable of achieving traceability to the SI definition of the meter with one or even sub-millimetre uncertainty over the short distances.

The presented results were obtained in the framework of a research project aimed at fostering the measurements up to 1 kilometre traceability to SI units. The work is dedicated to a better understanding of the uncertainty of GNSS-based distance metrology. The influence of the troposphere, near-field effects and multipath on the distance measurements uncertainty was studied in optimized configurations.
Time series of vector components, derived from processing GNSS data from double EPN stations, were generated. They provide extremely rich information on variability of GNSS solutions that together with the external data enables qualitative and quantitative analysis of those variations as well as their reliable statistical estimate.

The experiments performed concerned the investigation of the response of the measuring system to tropospheric perturbations as well as to site specific effects vs. measured distance. Numerical experiments conducted indicate that the potentiality of GNSS positioning is not fully exploited in high-end applications. Also, analysis of time series of GNSS solutions may result in improvement of modelling of GNSS observations and GNSS-based distance metrology.

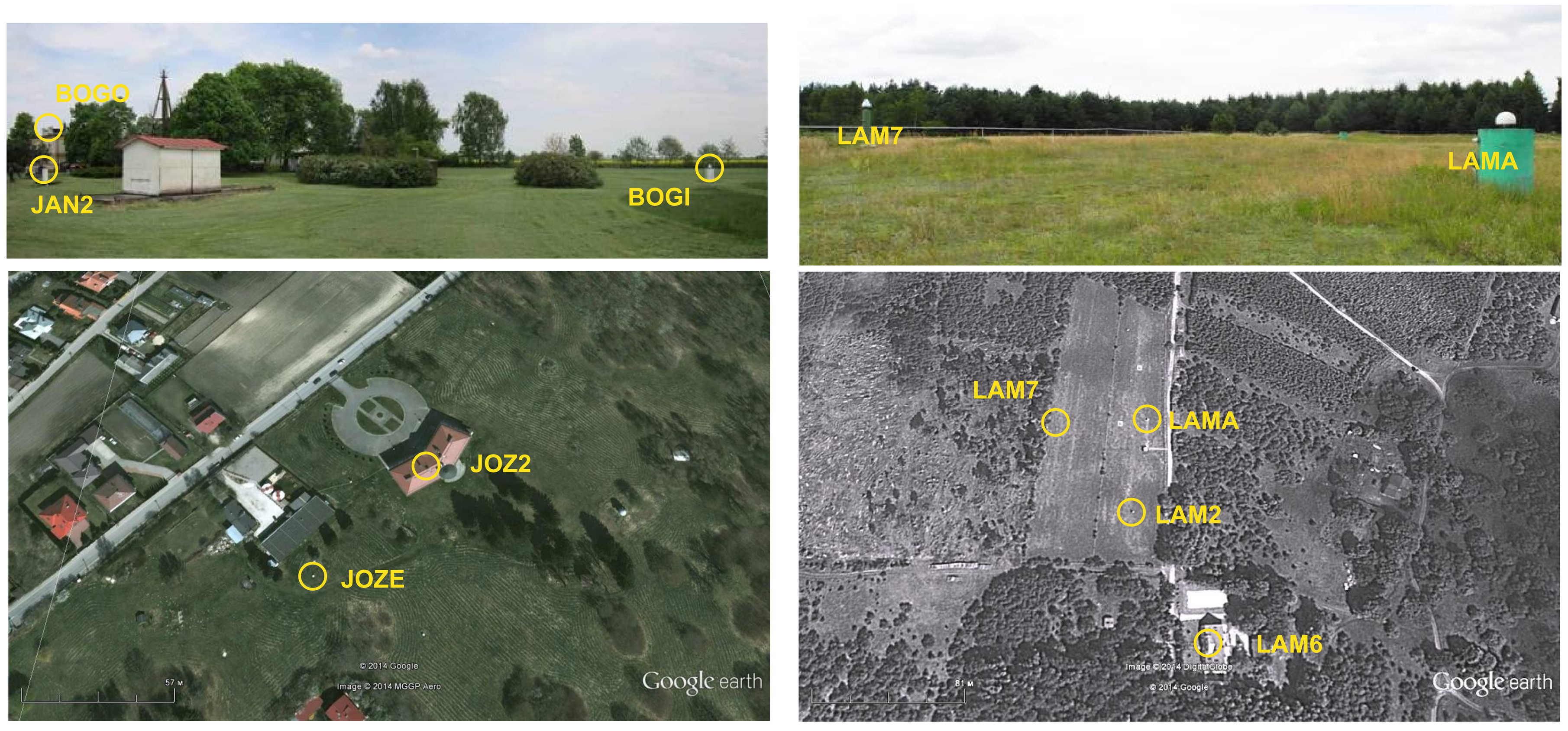

Fig. 1. EPN double stations in Poland: BOGO-BOGI, JOZE-JOZ2, LAMA-LAM7

Experiment

Time series of baseline components, derived from processing GNSS data from double as well as closely spaced EPN stations, were used to investigate random and systematic biases in the estimated short baseline lengths.

The test fields include three satellite observatories in Poland (Fig. 1):
1) **Lamkowko Observatory** - stations: LAMA, LAM6, and LAM7,
2) **Borowa Gora Observatory** - stations: BOGO and BOGI,
3) **Jozefoslaw Observatory** - stations: JOZE and JOZ2.

In addition, data from two other observatories were included:

4) **Wettzell Observatory** - stations: WTZA, WTZZ, WTZR and WTZS,
5) **Zimmerwald Observatory** - stations: ZIMM, ZIM2, WAB2.

The test baseline lengths varied from single metres up to 5 kilometres. In all tests performed within the presented research, choke ring type antennae on both ends of the measured baselines were used. Hence, the antenna PCV - dependent errors are greatly reduced. The GNSS data collected at the test baselines were processed in one hour long sessions using the Bernese scientific software and simple commercial software (GNSS Solutions).

This presentation shows the analysis of systematic errors caused by near field and multipath effects and their influence on results of short baseline determination with GNSS. It was confirmed that these effects have a period of sidereal day.
The results obtained with GNSS Solutions show three distance ranges with respect to the precision (repeatability) (Fig. 2). On the other hand, formal (internal) relative errors shows rather linear dependence on the baseline distance (Fig. 3).
In general, the evident mixture of random and systematic errors is presented in the plots. It is well-known that the later are the consequence, e.g. of the changes in the observed satellite constellation. Manifestation of this consequences is shown in Figure 10.
The antenna position residuals obtained with both scientific and commercial software are very similar and show regular and repeatable pattern (Figs 6-8), which still needs to be investigated. This pattern is also confirmed by the results of data processing in a kinematic mode (Fig. 4).

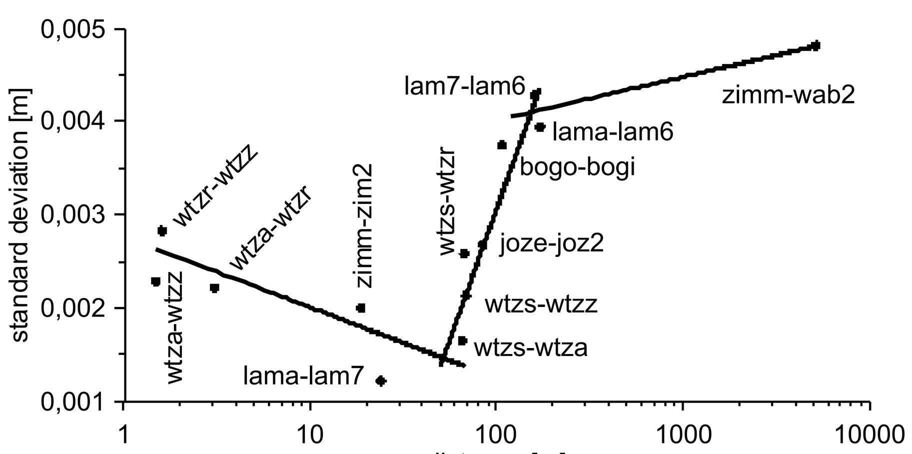

Fig. 2. Repeatability of the baseline lengths vs.their distances - calculated with GNSS Solutions in kinematic mode

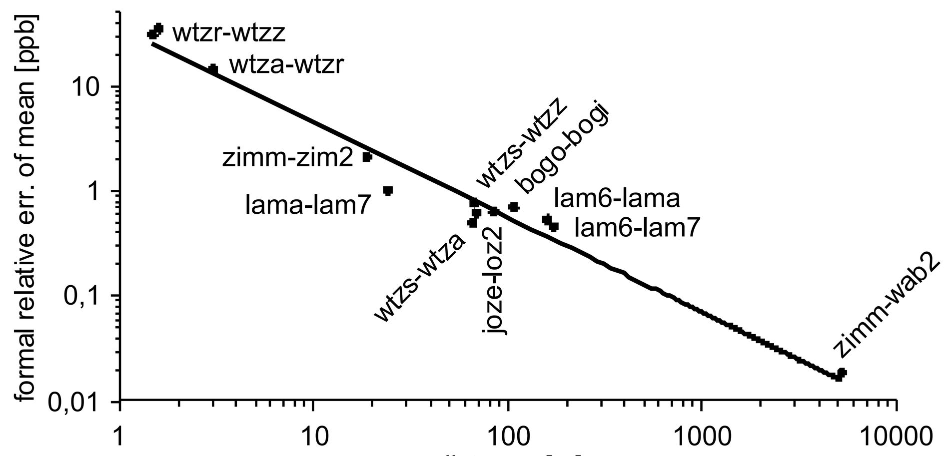

Fig. 3. Formal (internal) relative error of the baseline lengths vs.their distances - calculated with GNSS Solutions in kinematic mode (24-hour mean)

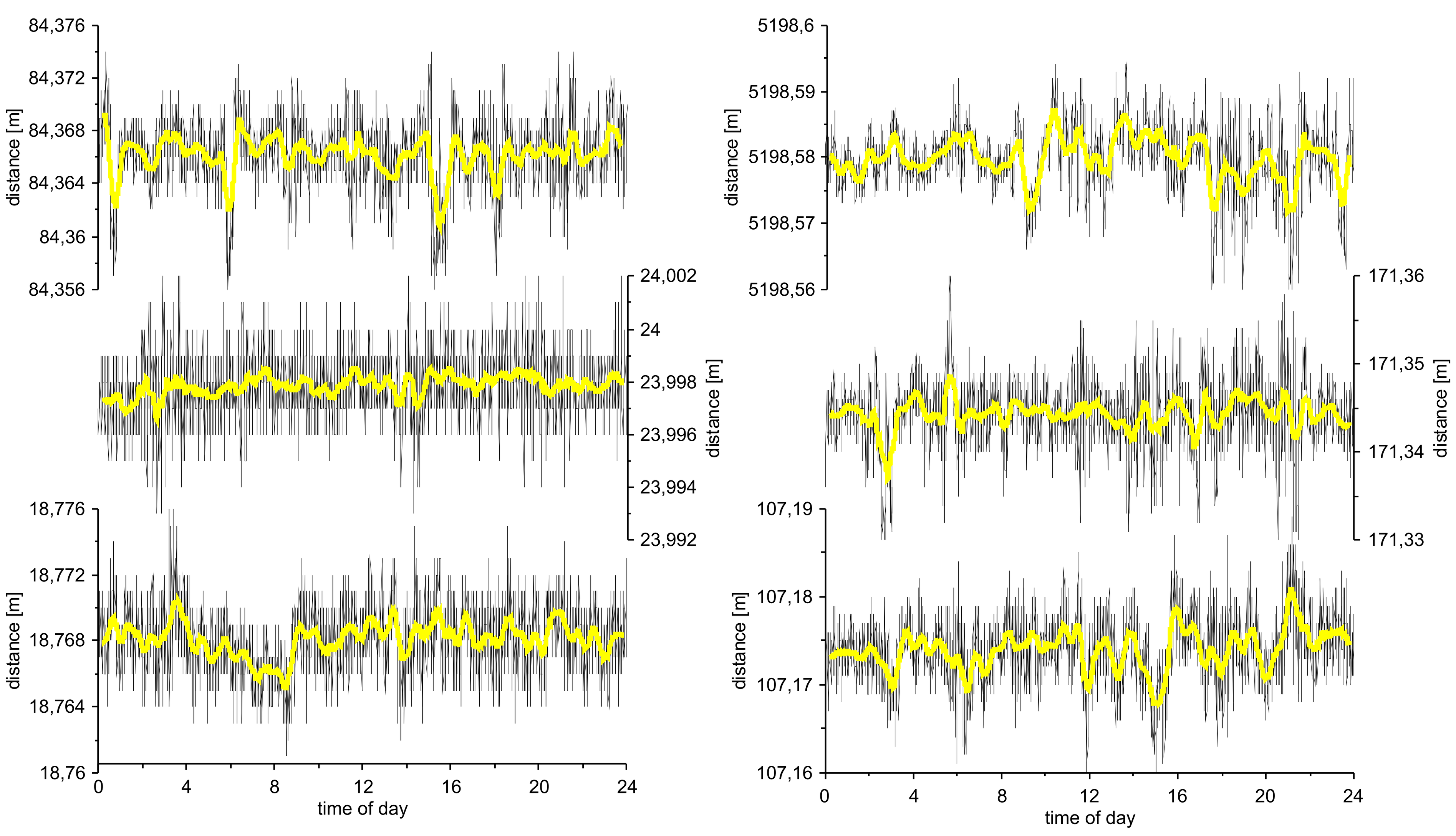

Fig. 4. Examples of the baseline length estimations in kinematic mode over 24-hour period (GNSS Solutions)

Acknowledgments

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Local gradients in the near ground troposphere

In addition, the results of original research on error sources that are usually neglected by the GNSS users were shown. These errors are connected with gradients in a ground layer of the troposphere that affect GNSS signals. At Lamkowko Observatory, a grassy meadow between the test baseline ends and a forest surrounding the test area leads to essential horizontal gradients of temperature and humidity of the ground layer of the troposphere (Fig. 5). Such gradients in a sunny summer day are very significant. In turn, they are practically absent in a rainy autumn night.
In case of some baselines, the arrangement of some test baseline antennae at different heights - around 1.5 m over the ground and 0.5 m over a building roof (Fig. 1) increases a problem of tropospheric gradients.

On the other hand, these effects are reduced in case of points of kilometre metrological range «Lipcy» of Kharkov NSC «Institute of Metrology» (Fig. 6). The majority of points is equipped with antennae of the same type. Also, the points are located on a homogeneous surface representing a grassy meadow that is the most desirable from the point of view of multipath effect minimization. Rare forest plantation and a ravine in vicinity of the metrological range have a rather weak impact on the presence of the tropospheric gradients, and therefore, the obtained results of baseline measurements.

Range points are equipped in such way that there is a possibility to coaxially mount (by means of force centering) two surveying instruments, e.g., a GNSS antenna and a EDM reflector. Such design is very seldom met on metrological ranges.

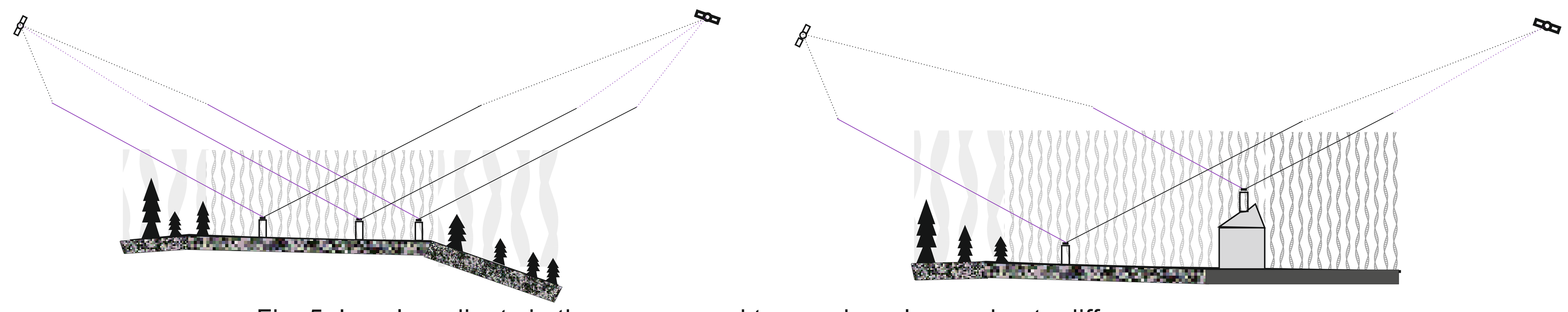

Fig. 5. Local gradients in the near ground troposphere layers due to differences in the surrounding ground surface

Fig. 6. Scetch and photo of the linear EDM test range "Lipcy" of NSC "Institute of Metrology" near Kharkiv. All points allows for forced co-centering of two geodetic instruments simultaneously - e.g., GNSS-antenna and EDM retroreflector

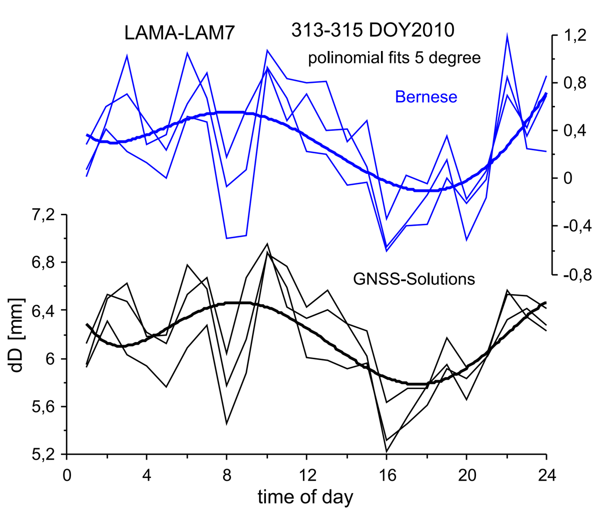

Fig. 9. Diurnal variations of LAMA-LAM7 distance over 3 days in 2010. Evident similarity of the results from two different software is clearly visible.

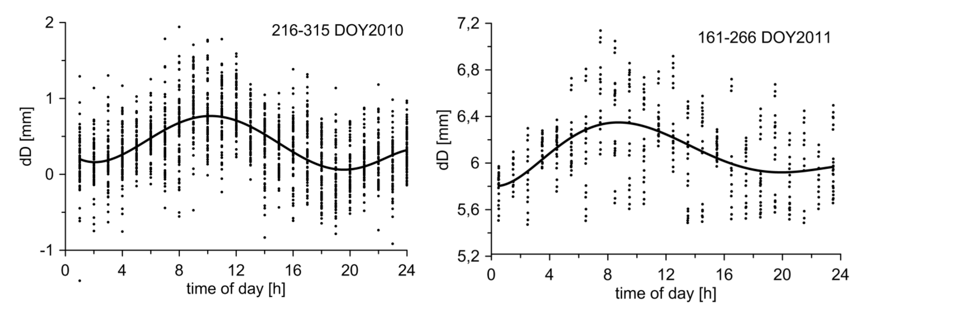

Fig. 7. Diurnal variations of LAMA-LAM7 distance over 100 days in 2010 and 2011. Dots mark 1-h sessions, lines - polinomial fits of 6 degree

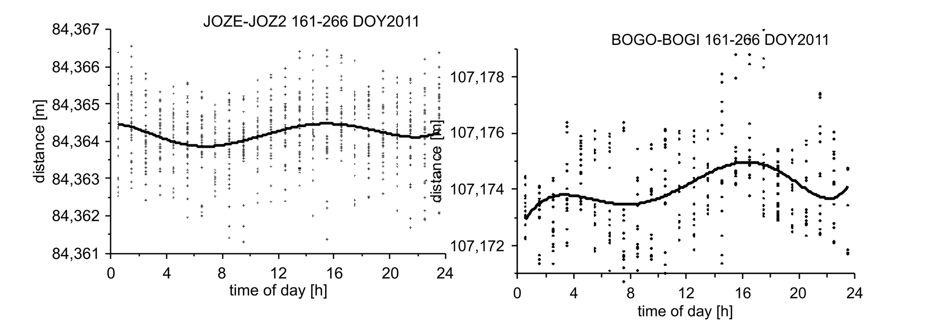

Fig. 8. Diurnal variations of JOZE-JOZ2 and BOGO-BOGI distance over 100 days in 2011. Dots mark 1-h sessions, lines - polinomial fits of 6 degree

Discussion and conclusions

The analysis of errors of GNSS length measurements on the basis of data from double EPN stations was carried out. It is shown that the results of calculations of the distances carried out by various programs differ at the level of units of millimetres (Fig. 9). It is obvious that the results received from scientific Bernese software have a higher level of confidence than the ones received from commercial software. For the discussion of metrological problems the expanded analysis on much greater amount of data obtained from various software packages is necessary. Similar comparisons are carried out by GNSS-community, however, without references to rather specific problem of measurement of the lengths in a range from single metres to a kilometre with sub-millimetre accuracy.

When analysing the possibilities of comparison of length measurements by EDM and GNSS methods the presence of significant differences in each of these measurement methods should be taken into account. Distances obtained by EDM are the result of direct measurement between two points, often repeated with the appropriate statistical treatment. On the other hand, GNSS measurements at the highest level of accuracy are always equivalent of repeated measurements at a number of physical points (located at the antenna phase center), followed by the adjustment, the process which determines the distance between the points.

It is necessary to underline the most accurate results of baseline determination with GNSS are obtained when processing long data time series (Fig. 10) by, e.g. different analysis centers and combining their results. Also, the highest accuracy is achieved in global networks, based on measurements by several independent methods. Such methods include very long baselines interferometry (VLBI), lunar laser ranging (LLR) and satellites laser ranging (SLR). These methods allow for the realization of the unit length by the velocity of electromagnetic waves for very long (global) distances. Hence, these techniques are used for scale calibrations for GNSS measurements.

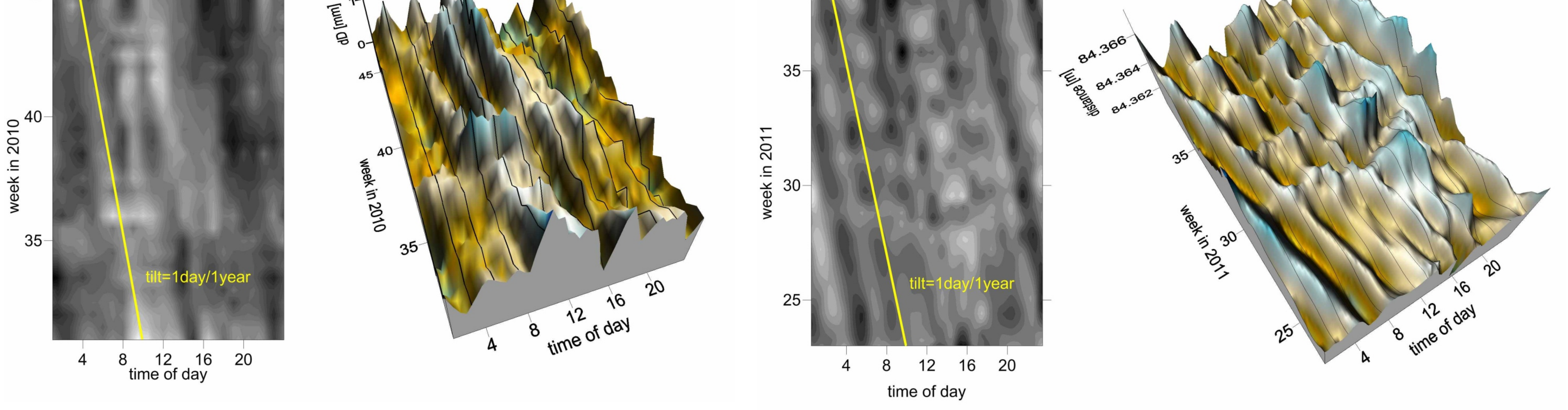

Fig.10. Variations of the LAMA-LAM7 baseline length (left) obtained with the Bernese software, 216-315 DOY 2010. Similar results were obtained for JOZE-JOZ2 baseline length (right) with GNSS Solutions, 161-266 DOY 2011. (Manifestation of changes in the GPS satellite constellation.)

Future studies

In further research we will compare GNSS baselines to EDM measurements at the metrological range of "Lipcy" of NSC "Institute of Metrology" in Kharkiv, Ukraine, where the GNSS antennae will be co-centered with EDM reflectors. This should help us to better understand the uncertainty of GNSS-based distance metrology. The research will be also continued in the Faculty of Geodesy and Land Management of Warmia and Mazury University as well as in the Institute of Geodesy and Cartography, Warsaw, Poland

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