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IMPACT OF SOME SITE DEPENDENT FACTORS ON GPS DISPLACEMENT MONITORING

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ABSTRACT

GPS is a convenient today´s universal technique which is currently used also for precise positioning applications like e.g. monitoring of 2D (3D) displacements in many fields of interest. Accuracy of GPS derived positional parameters is nearing the millimeter boundary provided that all relevant influencing factors are taken into account and properly modelled. Between many items in GPS error budget the influences of site dependent factors which have to do with receiving conditions at an individual GPS station are very important. Here we include the station monumentation and nearby surroundings, the antenna mounting, the obstacles in signal acquisition, the multipath sensitivity, and also the receiving characteristics of GPS hardware. The last factor includes actual position of GPS antenna receiving point – phase center – precise alignement of which to the station point is important especially in case of observation with different types of antennas. The factors mentioned have direct impact on the accuracy and reliability of resulting displacements.

The paper presents overview of some of the site dependent factors. Discussed are the possibilities of elimination/mitigation of some of the disturbing influences. Problems of relative calibration of GPS antennas at BUT, Department of Geodesy, are described in more detail, together with some examples of practical applications in evaluation of displacement measurements in Krkonoše and Sněžník networks.

KEYWORDS: geodynamics, displacement monitoring, GPS, site dependent factors

1. INTRODUCTION

GPS displacement measurement is considered as an alternative to conventional terrestrial measuring methods in present time, with some outstanding advantages. From methodological point of view the precise determination of horizontal and vertical displacements by the GPS is more complicated than by classical terrestrial methods. GPS is 3D positioning method which determines coordinates in global geocentric orthogonal system (WGS-84). From practical reasons the global rectangular coordinates X, Y, Z are often transformed into ellipsoidal coordinates φ, λ, h , and eventually into topocentric (local) horizontal coordinates n, e, u , see e.g. (Hefty, 2004). GPS measurements are influenced by many factors, and from well known reasons the vertical component is determined less accurately than the horizontal ones. The influences can be divided into the satellite associated errors (orbits, clock bias), the signal propagation errors (ionospheric/tropospheric delay), the receiver associated errors (clock bias, antenna phase center offsets/variations), the station associated errors (surroundings, centering, signal multipath, diffusion and diffraction), and others. When evaluating the epoch deformation measurements the uncertainties in referencing to successive reference frame realizations (ITRF, ETRF) also play an important role.

Between many items in GPS error budget the influences of site dependent factors which have to do with receiving conditions at an individual GPS station are very important. Here we include besides antenna phase center eccentricities and variations also other factors like multipath, diffusion and diffraction of satellite signals. These factors depend upon the station monumentation and nearby surroundings, the obstacles in signal acquisition, the multipath sensitivity, and also the receiving characteristics of GPS hardware. The last factor includes uncertainties in of GPS antenna phase center position and variations which are important especially in case of observation with different types of antennas. In most precise applications all the relevant systematic factors must be correctly modelled, and appropriate reduction or mitigation techniques employed, if the desired millimeter level accuracy and reliability of monitoring results have to be reached and guaranteed.

2. ANTENNA PHASE CENTER CALIBRATIONS

GPS antenna receiving characteristics are given by description of its phase center behavior in dependence of the incoming satellite signal.

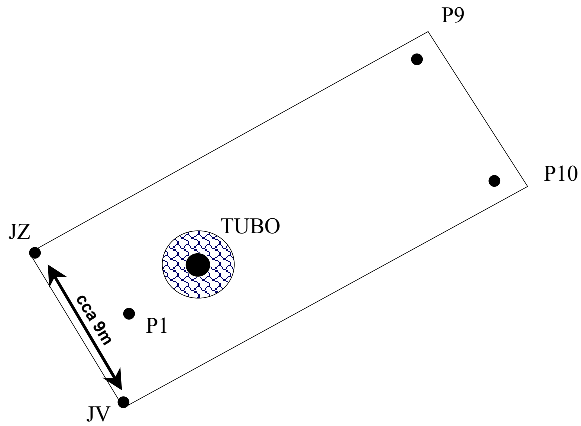

Fig. 1 GPS Antenna Test Base at BUT Brno

Fig. 2 Test Base Point JV

Practically it means the determination of complete set of antenna geometric calibration parameters – mean phase center eccentricities or offsets (PCO), and phase center variations (PCV).

Calibrations are performed in two principally different ways. Either it is absolute method which determines calibration parameters for single individual antenna, or it is relative method which works with antenna pair – one is the standard reference antenna (mostly AOAD/M_T type) and other is the calibrated antenna. In second case only relative parameters in respect to the reference antenna parameters are evaluated.

Absolute calibrations can be accomplished by anechoic chamber measurements with artificial signal, or by field measuring procedure with help of automated (robotic) antenna carrier enabling quick changes of antenna positions and tilt. The technology of field absolute antenna calibrations developed Geo++® GmbH Garbsen in cooperation with Institute for measurement of the Earth at University of Hannover, Germany. Advantages of absolute calibrations are the accuracy (average standard deviations 0.2 – 0.3 mm from several hours observation), the very good repeatability, the determination of complete elevation and azimuth dependent correction maps, no need for reference antenna, and the reliable PCV determination also for lower elevation angles (Böder et al., 2001). Disadvantageous is need for special equipment and know-how. One of the first facts revealed by absolute antenna calibrations was the description of the true receiving characteristics of AOAD/M_T, which is commonly used as reference antenna for relative calibrations. In (Schmitz et al., 2002) the influences of antenna construction, antenna housing, radomes, and ground planes are described and discussed.

Relative calibration procedures are less demanding, but strongly dependent upon the reference antenna used. The resulting parameters are also somewhat less accurate (especially the PCV) because antennas are stationary during tests and observations are not regularly distributed to all directions. Therefore the procedure is rather time consuming. Nevertheless, the results of relative calibrations are still currently officially used by many institutions.

Base for calibration of GPS antennas on the roof of BUT FCE building in Brno was established in 2002. It consists from 5 brick pillars with concrete top plates in close vicinity of the EPN station TUBO (Fig. 1). Each pillar is equipped with forced centering head for antenna mounting with repeating accuracy 0.1 mm, and with 12 V DC connection which enables long-term calibrations without need for external accumulator batteries. Most suitable for antenna testing are the corner pillars JV (Fig. 2) and JZ placed on southern side of the faculty building, which are well embedded in carrying construction, as well as the steel pillar of station TUBO. Mutual positions of the base points in local horizontal system (“ground truth”) were determined by conventional measuring techniques with accuracy better than 0.3 mm (horizontal), 0.2 mm (vertical).

Relative calibrations of single antennas are performed with respect to reference antenna Leica AT504 (LEIAT504) with choke ring construction elements, which has similar receiving parameters as the generally used Dorne Margolin type T antenna (AOAD/M_T). EPN station TUBO is equipped with similar antenna type TRM29659.00. Computations are performed with Bernese GPS Software ver. 4.2. Some preliminary results and experience from the calibrations at BUT Brno were published in (Kratochvíl et al., 2005). The accuracies (standard deviations) of phase center mean eccentricities obtained for 24 hours calibrations were 0.5 mm in horizontal component, and 0.8 mm in vertical component for both frequences L1, L2. For L1 frequency the accuracy is generally slightly better than for L2. From several days calibration the results are more accurate. 13 days solution gave L1 accuracy better than 0.1 mm for all three eccentricity components, respective L2 accuracy was about 0,2 mm. Elevation dependent phase center variations for tested LEIAT502 antenna were determined with accuracies about 0.3 mm (L1), respective 1.7 mm (L2) from 24 hours calibration. For 13 days solution the accuracy was about 0.1 mm (L1), and 0.5 mm (L2).

3. MULTIPATH, DIFFUSION AND DIFFRACTION

Typical site dependent factors influencing the GPS measurements are the multipath and diffusion effects, and the diffraction of satellite signals. Degree of actual disturbances caused by these factors is reflecting the site and hardware signal acquisition properties including the type of station monumentation, the site surroundings, the antenna mounting, the obstacles in signal acquisition, the nearby reflecting surfaces, and the antenna/receiver multipath sensitivity.

Multipath affects both code and phase measurements, and also the signal's amplitude. It is caused by reflections of signals from nearby surfaces, and can be divided into two parts. One part originates in the near vicinity of the antenna (pillar/tripod, tribrach, mounting adapter, station marker, antenna ground plane, etc.), second part comes from more distant reflections. Actual effect depends upon the multipath geometry (satellite-reflector-antenna configuration) which is changing in time, and also upon the reflector properties and the GPS hardware sensitivity. Periods of multipath are varying from hours for near reflectors (under 1 m) to minutes for greater reflector distances.

The multipath effect in measured carrier phase (single reflector case) is given by (Georgiadou and Kleusberg, 1988)

$$\psi = \arctan \frac{\alpha \cdot \sin \Theta}{1 + \alpha \cdot \cos \Theta} ,$$

where ψ is the phase difference between the multipath affected and direct signals of wavelength λ , α is the reflection coefficient (ratio of direct and reflected signal amplitudes), and Θ is the differential phase delay which depends upon the reflected signal delay path d

$$\Theta = \frac{2\pi}{\lambda} \cdot d .$$

In practice no station is free of multipath. The carrier phase error values are of millimeter – centimeter level. One way of multipath mitigation are the improvements in antenna construction (choke rings, special ground planes, gain characteristics etc.), another way is progress in receiver technology and signal filtering (advanced correlator techniques etc.) – see an overview in (Xia, 2004). Multiple reflections e.g. from rough surfaces in near vicinity of the antenna cause the diffusion effects.

Diffraction appears when the signal is permeating light obstructions like foliage, with subsequent more or less distinctive degradation of signal level. The SNR (signal to noise ratio) is strongly correlated with elevation angle of the incoming signal under normal receiving conditions. In case of attenuated signal f.e. from diffraction effect the correlation between SNR and elevation angle is distorted.

(Richter and Euler, 2001) proposed to down-weight the SNR attenuated signals after formula

$$\sigma_{\Delta}^2 = C_i \cdot 10^{-(SNR_{meas} - \alpha \cdot \Delta)/10}$$

where Δ is the difference between expected and actual SNR value, α is the empirical scaling factor, and C_i is the factor containing the carrier loop noise band width and a conversion term from cycles to mil-limeters. The procedure described was implemented into standard GPS processing software Leica SKI-Pro ver. 2.5.

In practice the observation conditions at many stations may be changing with vegetation progress which is accompanied by densification of the foliage and enlargement of the tree crowns. Typical example is the station TVDR of Sněžník network which was originally placed in open clearing, but now the near young trees are growing up with negative influence upon signal reception. Nice example of diffraction mitigation is the baseline VESE – MALI again of Sněžník network. While the station VESE has undisturbed horizon without any obstructions, the station MALI is situated at forest edge with severe observation blocking from this side. Fig. 3 shows differences between standard and diffraction modelled one hour solutions of the baseline height difference over 24 hours observation time. The baseline length is 3521 m, the height difference is 15 m. Evident here are the differences in means and standard deviations which favorize the SNR model based approach in this case.

4. EXAMPLES FROM KRKONOŠE MONITORING NETWORK

Some of the GPS measurements carried out in Krkonoše network (Švábenský and Weigel, 2004) were recomputed with respect to site dependent influences. Table 1 displays the development of the Krkonoše network local reference station ZLNA position in period of five years. Firstly the positions in particular realizations of ITRF (for the campaign epoch) were computed from 24 hours epoch observations with constraining of ZLNA to surrounding EPN stations GOPE, WROC, and TUBO. Resulting coordinates were then transferred into the ETRF89 system according to (Boucher and Altamimi, 2001). In the processing the preliminary testing values of the absolute antenna phase center eccentricities and variations published at

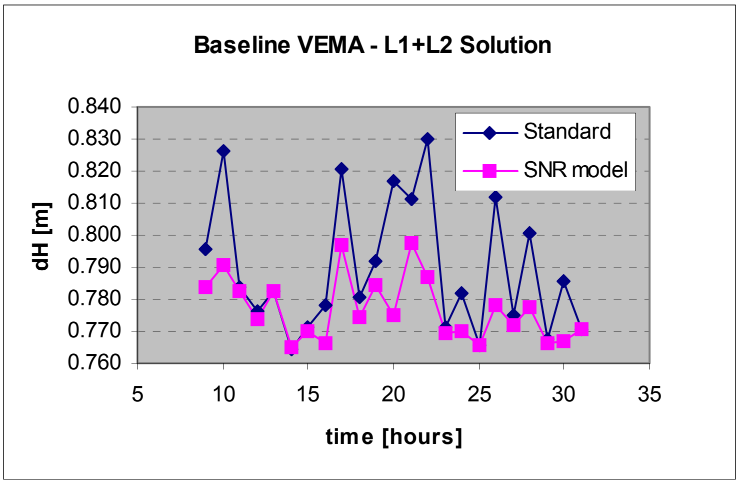

Fig. 3 Example of diffraction modelling effect

Table 1 Development of ZLNA position in ETRF89

Epoch	Latitude	Longitude	Height
2000.74	50° 45′ 23.98528′′	15° 32′ 21.16622′′	1438.817
2001.76	50° 45′ 23.98555′′	15° 32′ 21.16647′′	1438.817
2002.79	50° 45′ 23.98559′′	15° 32′ 21.16667′′	1438.832
2003.64	50° 45′ 23.98546′′	15° 32′ 21.16689′′	1438.835
2004.79	50° 45′ 23.98557′′	15° 32′ 21.16630′′	1438.824

ftp://igscb.jpl.nasa.gov/igscb/station/general/pcv_proposed/ were used. Average standard deviation of horizontal position was 2.6 mm. The results are not indicating any horizontal movements of the the station ZLNA (within 2 sigma confidence region). Application of different antenna model caused here differences in accuracy of horizontal component up to 2 mm.

Development of the station A1 horizontal position with respect to the reference station ZLNA for the same period is illustrated in Fig. 4. GPS antenna parameters obtained from individual calibration procedure were introduced. Average standard deviation of displacement components computed from 24 hours observations were 1.8 mm (laititude), 1.6 mm (longitude), and 3.4 mm (vertical). The displacements were not significant in respect to their 2 sigma confidence regions, and therefore no movements were detected for the station A1.

5. CONCLUSIONS

GPS measurement of displacements are influenced by various site dependent systematic factors like the uncertainties in phase center positions/variations of the GPS antennas, the multipath, diffusion, and diffraction of satellite signals. Most of these factors can be reduced or mitigated by ways of appropriate observing and/or processing techniques, taking advantage of progress in GPS hardware and software development.

Mean horizontal antenna phase center eccentricities may differ in values of several millimetres, vertical component differences may reach up to 10 mm and more (even for antennas of the same type). Inconsistencies caused by not taking the phase center variations into account may reach values up to several centimetres in vertical component. Accuracy of one day (24 hours) relative antenna calibrations is about 1 mm, in case of higher accuracy demands the calibrations must be extended over several days (Kratochvíl et al., 2005).

Important is also the elimination/mitigation of multipath effects especially for shorter observation times or for repeated short observations. The same is true also for diffraction or diffusion diluted signals in cases of GPS data collecting under not ideal circumstances. All these factors must be properly modelled and appropriate corrections have to be applied so as to ensure the accuracy and reliability of GPS determined displacements. For long time static observations it means another step to real one millimeter accuracy boundary, and also the shorter observations or repeated short sessions then may yield more accurate and reliable results.

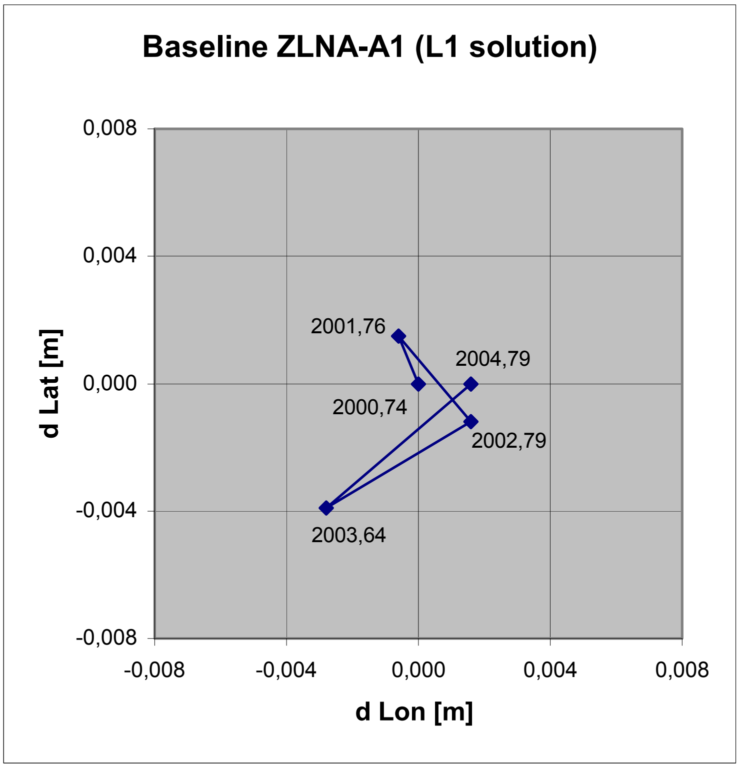

Fig. 4 Horizontal displacements of station A1

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