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Review article

SHORT-TERM AND LONG-TERM VARIABILITY OF ANTENNA POSITION DUE TO THERMAL BENDING OF PILLAR MONUMENT AT PERMANENT GNSS STATION

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Abstract

The variability of daily site coordinates at permanent GNSS station is a sum of many disturbing factors influencing the actual satellite observations, data processing, and bias modelling. In the paper are analysed possibilities of monitoring the instability of GNSS antenna pillar monument by the independent observations using the precise inclination sensor. Long-term series from three different types of pillars show specific features in amplitude and temporal evolution of monument bending. Correlations with daily temperature and/or solar radiation changes were proved.

Keywords: *precise inclination sensor observations, GNSS monument instability, thermal deformations*.

1. Introduction

Recent progress in observing technologies, software developments, etc. enables geodetic positioning with steady increasing precision. The actual accuracy of position is influenced besides the measurement itself by many environmental factors affecting the geodetic monument stability. These are: external temperature variability, direct solar radiation, wind strength and direction, underground water level changes, and seasonal variations of vegetation surrounding the monument. The building material and method of monumentation have also significant impact on the stability of the geodetic long-term observation series.

Monitoring of geodetic monument stability is based on regular measurements of its actual geometric and physical parameters to recognize the potential deformations. For the positional and geometric changes the methods of engineering surveying can be applied, e.g. regular repeated observations of lengths and/or angles by one or more total stations. If such monitoring system is fully automated, the continuous recording of monument movements are possible (Haas et. al, 2013). The GNSS permanent observations processed in various sampling intervals followed by noise analysis can also provide information about the monument stability (Beavan, 2005, Williams et. al, 2004). Another possibility is application of precise electronic inclinometers to monitor the slow movements of the GNSS antenna if placed on pillar or on top of building (Gerhatova et. al, 2015a, Gerhatova et. al, 2015b). The most effective approach is simultaneous observations by two or more independent techniques.

The continuous GNSS observations indicate positional changes of various origins. Long-term linear motions due to global and intraplate tectonics reach tens mm/year (Hefty, 2004). Periodic and short-term changes with amplitudes up to 10 mm are caused by various environmental sources, like seasonal and diurnal temperature, atmospheric pressure and humidity variability as well as the tidal phenomena. Moreover, if the GNSS monitoring is performed in seismic active regions, the sudden irregular positional displacements are observable (Hefty & Gerhatova, 2014).

The separation of sources and partial effects of various phenomena influencing the final time series of GNSS station coordinates is necessary for reliable interpretation of positional changes of geodynamical origin. Here, we will focus on detectable horizontal movements of GNSS antenna placed on pillar monument gained from independent long-term monitoring of the pillar instability using the precise inclination electronic sensor.

2. Experiment

We made set of experiments concerning the stability of permanent stations which are placed on concrete pillars of different height and diameter with different monumentation methods. According to previous experiments (Gerhatova et. al, 2015b) the most significant impact on concrete pillar movements has diurnal variability of temperature and the sunshine activity. Effects of these factors is warming up of pillar's sun-side and consequent inclination from the sun. Inclination's direction is determined by irregular thermal expansion of pillar. The magnitude depends on diameter and height of pillar, temperature difference between illuminated and shadow side of pillar and thermal expansion coefficient of building material (Lidberg & Lilje, 2007).

Measurements in experiment were realized by precise inclination sensor Leica Nivel220 (Leica Nivel manual). It is two-axis high precision sensor based on opto-electronic principle. In case of correct setup it is possible to measure inclination in north-south and west-east directions. During measurements sensor have to be connected to computer and values of inclination, temperature and time are recorded. Leica Nivel220 offers real-time data on a continuous basis with a long-range stability. Resolution of sensor is 0.001 mrad (0.6^{cc}) and zero-point stability is better than 3^{cc}/°C. Working temperature range is from -20 to +50 °C. According to manufacturer sensor has thermal compensation of measurements and regular drying of inside water vapour (up to 95%) to ensure constant sensor's condition.

The experiments were performed at two GNSS permanent stations: MOP2 (it is part of Slovak SKPOS and EUREF networks) and SUT1 (part of regional permanent network). At all stations the orientation of the inclination sensor was the same: X axis to east and Y axis to north.

Fig. 1. Pillar monument at station Modra-Piesok MOP2 (left) and detail with GNSS antenna and inclination sensor (right).

Permanent station MOP2 is situated in areal of Astronomic-geophysical observatory of Comenius University in Bratislava, Slovakia at Modra-Piesok locality in Little Carpathian Mountains approximately 530 meters above sea level (Fig. 1). The monument of MOP2 was built in 2007 as massive concrete pillar with height of 3 meters and diameter of 1 meter. Monument stands on concrete basement with dimension 1.5 m × 1.5 m × 0.5 m which is anchored to bedrock. Pillar’s body is made of circular shape concrete preforms filled up by concrete. At the top there is steel console joined to concrete part. GNSS antenna is mounted on steel rod screwed to console. Nivel220 sensor was placed next to console on the concrete surface during the experiment.

Fig. 2. Pillar monument of GNSS station SUT1 situated on a top of 6-floor building of Faculty of Civil Engineering in centre of Bratislava.

Permanent station SUT1 is located at the roof of block A building at Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovakia (Fig. 2). It is made as reinforced concrete pillar with height 1.21 m and diameter 0.40 m. In top part of pillar there is a steel console with screwed GNSS antenna. Nivel220 sensor is placed under the console.

The third place we used for our experiment is the massive pillar for geodetic astronomy observations (Fig. 3) situated in observatory on top of 5-floor historical building of Slovak University of Technology in centre of Bratislava (in following text

Fig. 3. Pillar for geodetic astronomy observations situated on top of 5-floor historical building of SUT in Bratislava. Inclination sensor is on the pillar in front of the Transit Instrument.

referenced as OBS). This building with observatory was built in 1946. Massive rectangular shaped concrete pillar with dimension 0.75 m × 0.50 m is joined with the building structure. Inclination sensor is placed on the pillar's top concrete surface in front of the old transit instrument. This pillar is covered by dome and is not directly suitable for GNSS observations; however it can serve for studies of tilt variation of monument at the top of building.

3. Data processing and analysis

As input to data processing we used raw measurements files from Leica Nivel220 sensors which contained time information, tilt in X and Y direction in mrad and temperature from internal sensor. In case of SUT1 station we used external measured temperature from the professional meteo-station close to monument due to better resolution and accuracy of measurements. Characteristics of used tilt long-term series can be found in Tab. 1.

Tab. 1. Used inclination's measurements series and their main characteristics

Monument	Data start	Data end	Data span (days)	Longest data gap	Gaps (%)	Recording interval
MOP2	31.3.2014	25.9.2014	178 days	9 days, 18 hr	11.63	16 s
SUT1	10.3.2015	1.3.2016	357 days	1 day, 4 hr	0.80	23 s
OBS	28.3.2013	1.3.2014	338 days	12 days, 4 hr	12.38	47 s

Data gaps were caused mainly by outages in electric supply. In such cases we had to repeatedly start communication software in PC and to refresh data logging. Data gaps are caused by maintenance of GNSS antenna on a pillar in some cases. For example at SUT1 station there was maintenance at 19. 9. 2015. This event caused jump in inclination's measurements. It was removed by estimation of mean values from data one week before and one week after jump and consecutive assignment of affected values to previous measurements level.

For long-term analysis it is not appropriate to use raw measurements. Better solution is to use interpolated values. We used linear interpolation with sampling interval of 5 minutes. Estimation of values in short outages was also performed. Data gaps longer than 1 hour were excluded from analysis.

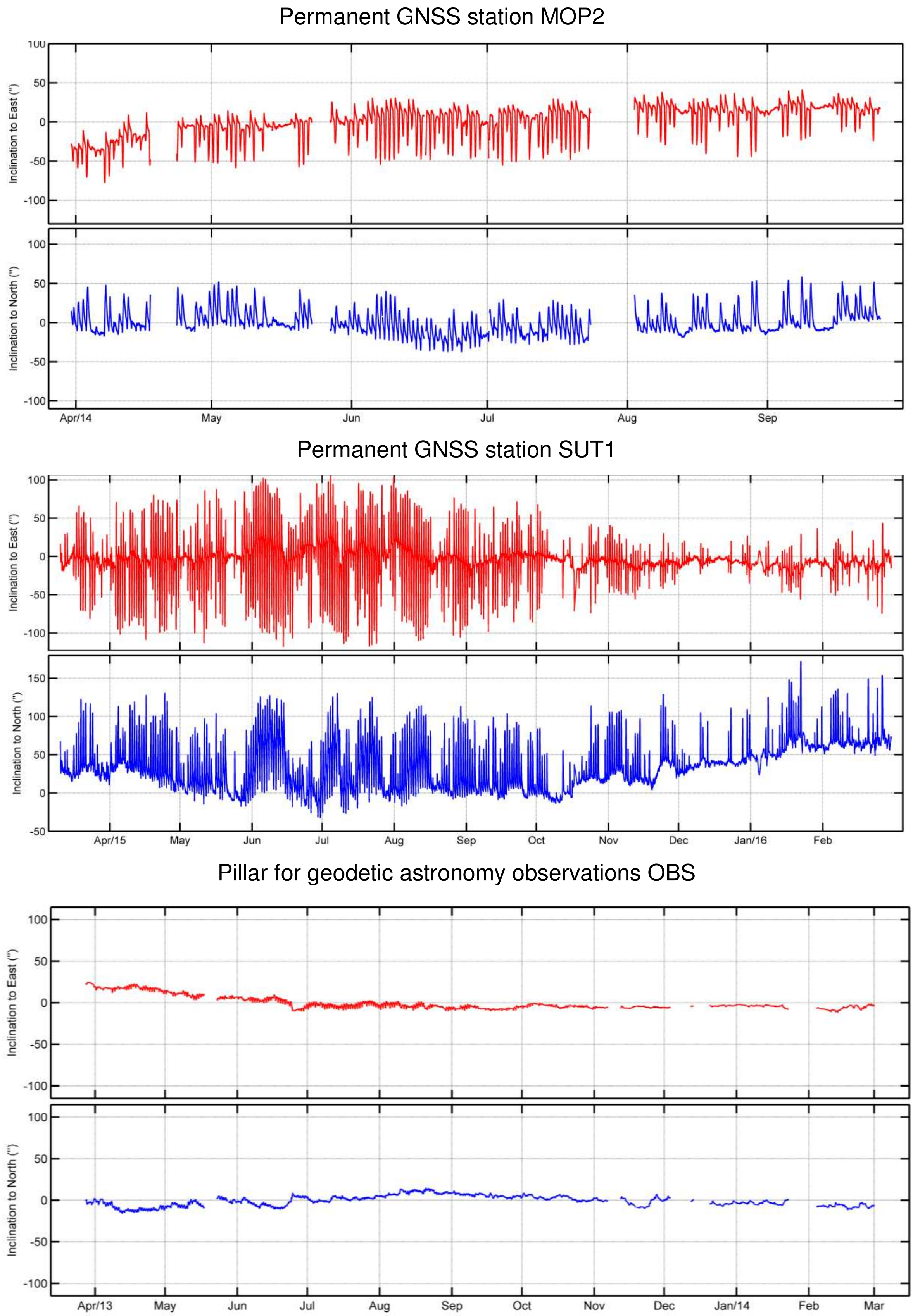


Fig. 4. Long-term time series of inclination observations. The scales for the inclination constituents are identical for all pillars.

The time series of inclination in east-west and north-south constituents for the three pillars mentioned are in plotted in Fig.4. It worth to mention that the zero value for all the series was defined according the procedure described below.

To estimate reference point of each set of measurements two-dimensional histograms were used (Fig. 5). We assume that measurements with the highest probability have also the highest count of occurrences in bin. For every histogram we determined bin with the most count of occurrences which represent reference point. Subsequently the interpolated measurements were reduced by this reference point's values.

It is evident that the inclination long-term and short-term behaviour is significantly different at each of the three analysed pillars. SUT1 has significantly changing daily variation depending on the season of the year. There is approximately twice times higher variation during the summer than through the winter. At MOP2 we cannot reliably evaluate seasonal variation due too short time series data. In case of OBS pillar we can clearly see the most stable long-term and short-term stability. We consider it is caused by dome coverage and then no direct impacts of weather conditions are possible. In long-term investigations we should point out to effect of long-term stability of precise inclination sensor, which would be crucial for this purpose.

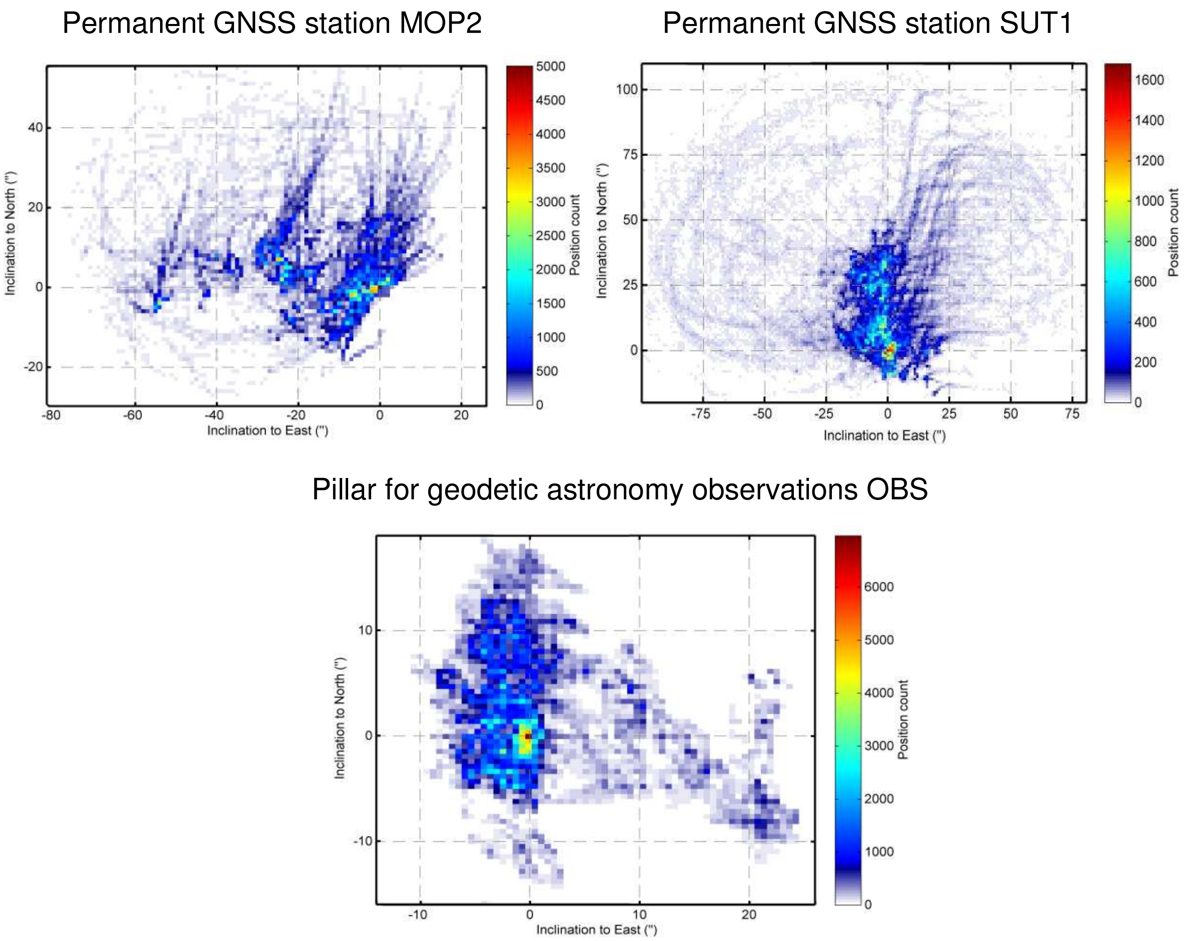


Fig. 5. Histograms of long-term inclination measurements with raw sampling intervals at three different pillars.

In the next part of processing we evaluated daily section from 0 to 24 UT in dependence of temperature and selected weather conditions (minimal, maximal temperature, daily sunshine hours, precipitation). Meteo data were obtained from www.weatheronline.co.uk or from meteo-station at SUT1. Plotted values are shown in arcseconds (in following text as ”) as relative values according to reference point. In case of MOP2 monument we can directly transform inclination to metric scale (80” inclination range at 3 m height represents 1.2 mm position variability). On the other monuments we cannot directly used this transformation, because the analysed pillars are tied to building structure and it is hard to separate proper pillar motion. Based on visual comparison we found several distinctive patterns in pillar’s movement.

In case of clear cloudless sunny weather with high daily temperature change the pillar performed regular elliptical movement (Fig. 6, right). With vague time delay after sunrise pillar starts to tilt from the sun. In some cases it came back to start position during night, in some cases not.

In case of cloudy, possibly rainy weather without sunshine with small diurnal temperature variability there is just small, nearly none pillar motion (Fig. 6, left).

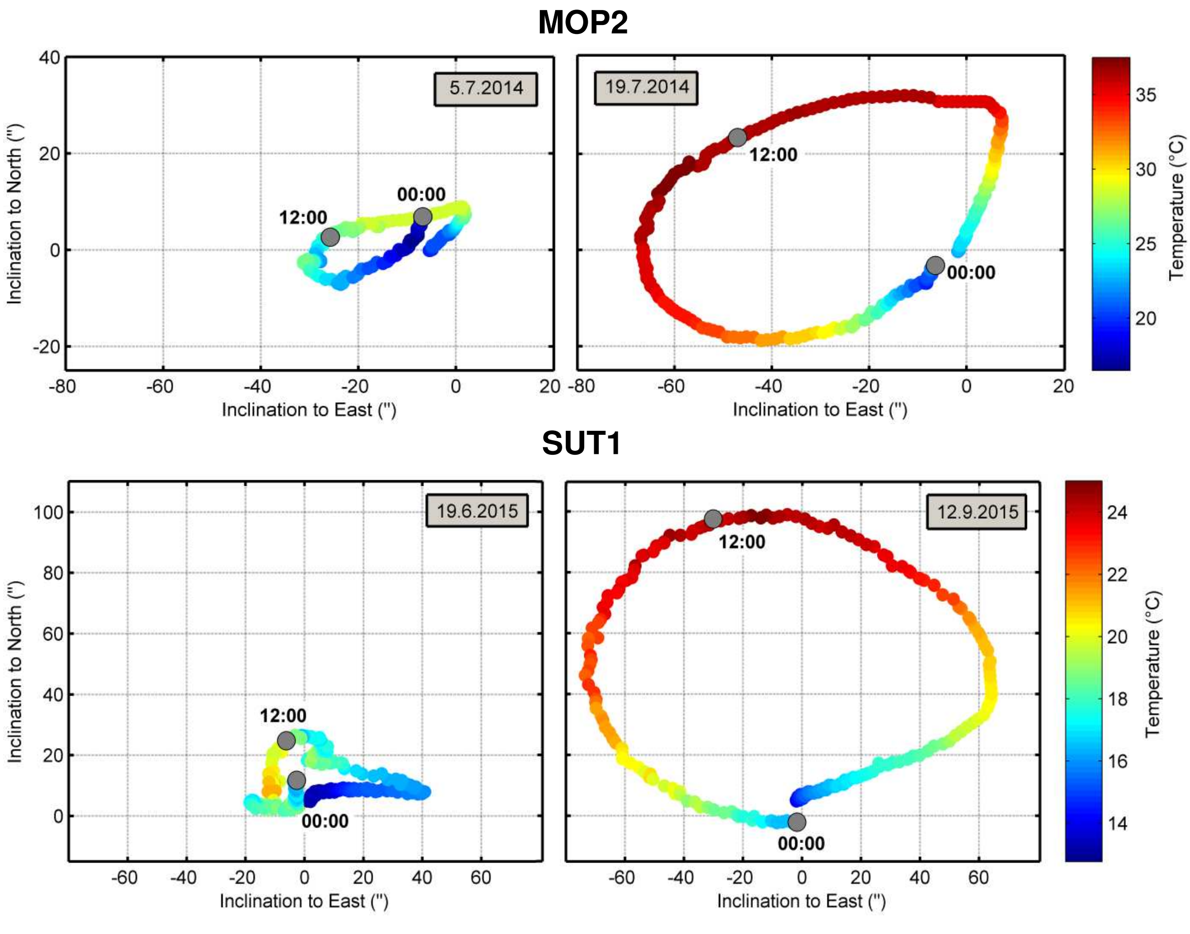
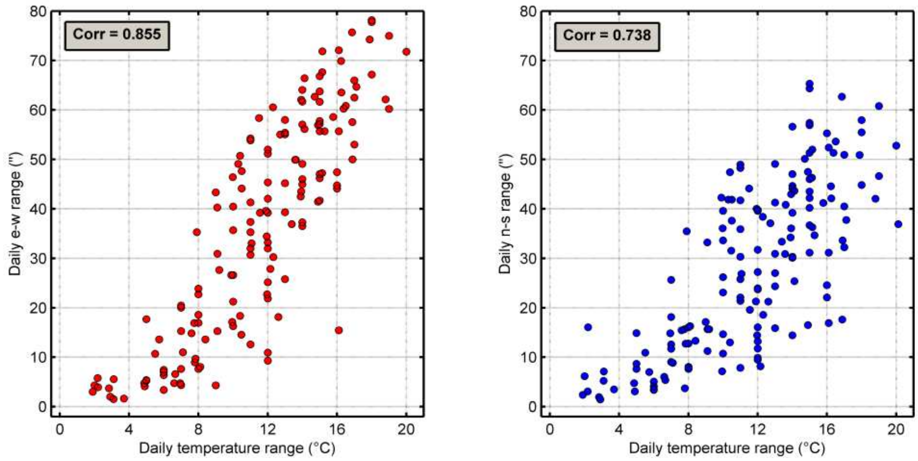


Fig. 6. Diurnal cycle of inclination observed at MOP2 and SUT1 in various temperature daily change (temperature course is represented by colours). On the left side are measurements during cloudy days and on the right side the days with all-day sunshine.

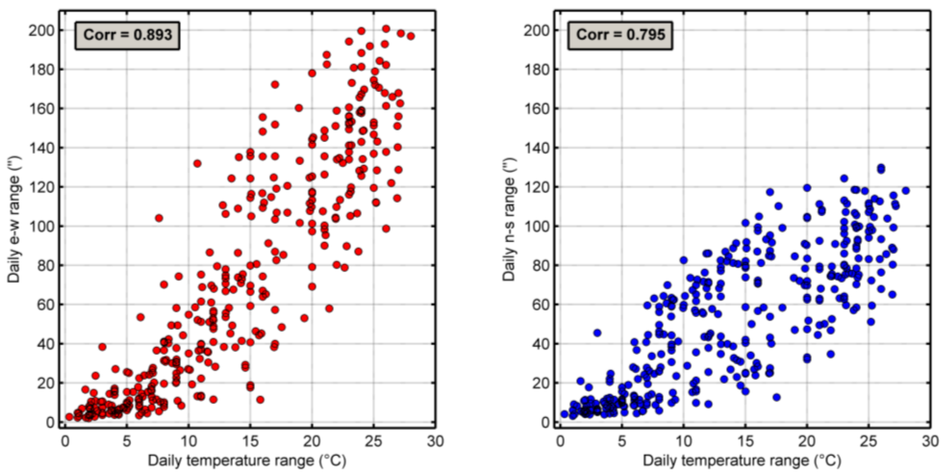
There is also big group of days with varying weather conditions (not sunny or cloudy all day long). These cases results to irregular pillar motion. During sunny period of the day it follows smooth curve with coincidence of delayed sun position. During cloudy parts of the day the motion is irregular without any significant pattern.

In the next analysis we focused on investigation of relationship between pillar's inclination and daily temperature variability, daily sunshine in hours.

Permanent GNSS station MOP2



Permanent GNSS station SUT1



Pillar for geodetic astronomy observations OBS

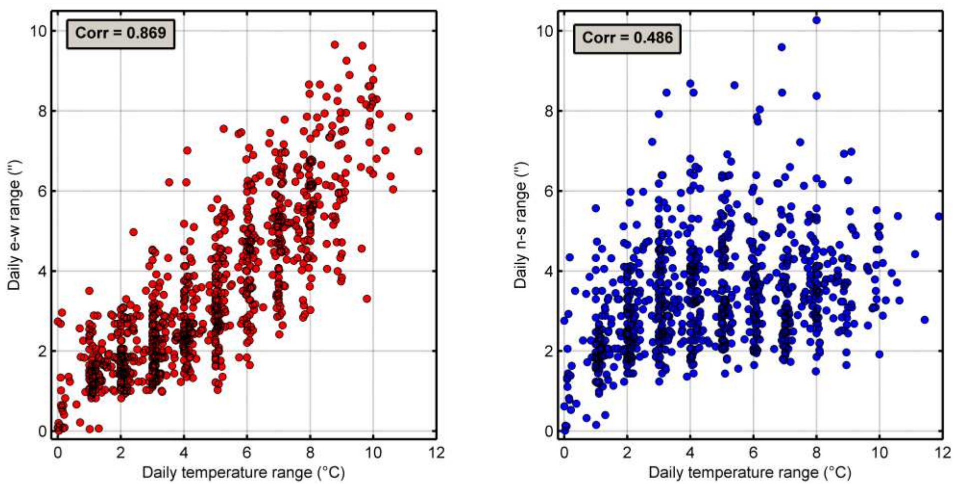


Fig. 7. Daily temperature range versus inclination ranges (east-west and north-south) observed at three various pillars.

MOP2: daily variability of temperature ranges from 2 to 20°C (experiment was made during spring and summer). To these values belong inclination values from 0” to 80” in east-west direction and from 0” to 65” in north-south direction. Magnitude of this inclinations concerns with pillar’s dimension (diameter of 1 m).

SUT1: daily variability of temperature ranges from 0 to 28°C (experiment was made throughout the year). To these ranges belong values from 0” to 200” in east-west direction and from 0” to 130” in north-south direction. Larger inclination’s ranges are linked to smaller pillar’s dimension (diameter 0.40 m), but especially with the fact that the pillar is situated on the top of building. We assume that in long-term view also the building itself make a movement in dependence of temperature changes due to changing of seasons throughout the year. This movement is partially part of measured inclinations. In both cases high value of correlation coefficient was computed, specifically 0.73 – 0.89, what represent strong correlation dependence.

OBS: to validate our assumptions we show results from pillar OBS where daily variability throughout whole year did not get over 12°C and inclinations in both directions did not get over 10”. Correlation coefficient has values 0.87 (east-west direction) and 0.49 (north-south direction).

Similar results we achieve also with analysis of inclination’s ranges and daily sunshine hours during day (Fig. 8). Used data are valid for Bratislava airport, approximately 7.5 km from SUT1. Value of sunshine hours during the day is just single number and we cannot perform in-depth analysis of daily sections.

At meteo-station close to SUT1 pillar we have measured values of global radiation (W.m^{-2}). These values partially reflect quantity of cludiness, but there does not exist clear formula between global radiation and sunshine hours.

Correlation between daily inclination’s range and sunshine hours is strong in case of stable sunny or cloudy weather throught the day, in case of varying weather the correlation is low.

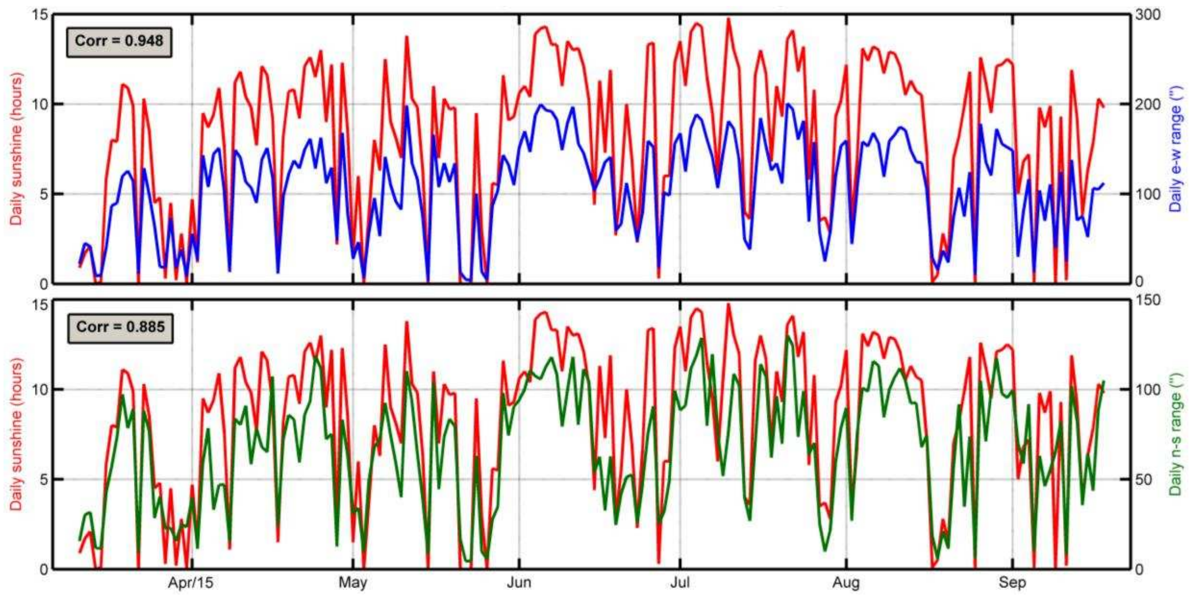


Fig. 8. Time series of daily inclination ranges in east-west (in blue) and north-south (in green) constituents observed at SUT1 pillar, and the duration of daily sunshine (in red).

4. Conclusions

Continuous measurements by precise inclination sensor are qualitatively different, independent method for determination of monument instability with comparison to existing GNSS or precise terrestrial methods. Results of experiment show that every investigated monument has very specific behavior. It does not depend only on dimension of monument, but also on method of monumentation and weather conditions (temperature, sunshine) and its temporal changes. Despite the fact that at two monuments experiment last nearly a year we can see that for properly estimation of long-term pattern it is not enough. Long-term measuring stability of precise inclination sensor seems to be a limiting factor in those analyses. For this purpose also verification by another monitoring method would be required. In the future we would like to develop complex model of pillar movement which would include local environment effects (shadows of near objects) according to actual weather conditions and solar activity.

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Leica Nivel220: Instruction manual

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