INVESTIGATING EFFECTS IN GPS TIME SERIES AND CASE STUDY ON TROPOSPHERIC EFFECTS

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SUMMARY

As the other discipline there are a lot of time series in geodesy. One of them is GPS data series. Generally the past and next values of physical magnitude are determined by using time series analysis.

IGNSS (International Global Navigation Satellite System Service) has been holding data of permanent GPS stations on the Earth since 1 January 1994. Analysis centers have been estimating daily positions of these stations using their data. Time series have been obtained by these changing positions. The time series are available on the internet freely for scientific aims.

The time series are used to estimate site coordinate and velocity, to observe solid Earth deformation, to determine sea level changing, to track Earth rotation parameters, to compute satellite orbits, to predict atmospheric parameters etc.

In this study, when height (Up) components of permanent GPS stations' coordinates are studied, seasonal effects are observed and it is researched if these Up constitutes have a relationship with temperature and pressure. To do this, correlations were analyzed and it is found that Up constitutes are related to temperature and pressure. A regression analysis was carried out to understand how much dependant is the height constitutes of the stations on temperature and pressure.

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1. INTRODUCTION

Time series that can find application in every area of science as related to its associated technology are often indispensable application area in the science of statistics and sometimes in econometrics. Time series are a set of values and observed measurements over a period of time, For example, a weekly amount of product exported from the factory, a highway accidents that occur annually, seasonal sea-level height, a fixed point is an example of an annual time series of coordinate changes. The use of time series can be expressed in the form of reporting results of the forward predictive with established by the mathematical models or in unknown time intervals in any way before the temporal data obtained from measurements made at regular intervals or with expected to occur in the future situation.

Time series analysis is of great importance in the field of engineering. we consider that a very high cost and labor-intensive seen in their realization of the plan-project phases and steps of structures such as dams, bridges, towers and to ensure the continuation of engineering structures. These structures show a different behavior in life expectancy under different loads, such as deformation and displacement. The necessary measures will be provided in time with continuous monitoring of behavior and with this pre-determination of the possible accidents that may occur.

2. TIME SERIES

At the periodic points of time, collecting data through observation of a response variable is called a time series (Sincich 1996). Time series appear while saving sequential values of variable in clear time space. Free variable can change content of study topic in time series. It can appear as in Geodesy science changes of coordinate components, in economy science this wholesale price index yearly, exporting of one product yearly for any firm. Data recording space is usually acceptable equal. However, in the practice usually come upon with no equal time series. This situation creates problems in analysis step.

Economists, businessman, administrators are usually need knowledge for make a decision with recording time period. Time series can use for future plans and estimation in long term periods as 5, 10, 20 years (Mann 1995). Time series analysis produces summarization properties of a series and outstanding of a series structure. This process can handle in frequency dimension like the time dimension. In other words, while frequency dimension periodic moves can consider, in the time dimension is given point to appearance of between different observations on time's different points. Both of the dimension analysis has properties vitals and same knowledge gives different ideas about a time series' qualitative in different ways.

In statistics, signal processing, econometrics and mathematical finance, a time series is a sequence of data points, measured typically at successive time instants spaced at uniform time intervals. Time series analysis comprises methods for analyzing time series data in order to extract meaningful statistics and other characteristics of the data. Time series forecasting is the use of a model to predict future values based on previously observed values. Time series are very frequently plotted via line charts.

2.1 Time Series Components

Analysis of time series requires decomposition of series component. For the purpose of decomposition of a series from components, clear a relation between four components must have conjecture. Generally, route of follow is conjecture which produce from total or multiplication of few components of a time series (Akalın, 1990).

In a classical model, time serial has a four component (Mann 1995).

1. Long-term common trend, T
2. Conjecture wave, C
3. Seasonal wave, S
4. Variation and irregular randomly motions, I

$$Y=T.C.S.I$$

Time series aim for statically is investigation of mentioned above each of four components how much effective take value on the event.

2.2 Trend

The data to be analyzed deviates more or less due to various reasons. However, a longer time trend of data may be a fixed value.
Trend is naming which a time series shows a clear route tendency. If trend components find in time series, conforming of line or curve equation with LSM could obtain for separation of this component from series.
Few method's using for calculate of Trend.

- The graphical method is one of them. Graphic method utilizes an orthogonal coordinate system. While the horizontal axis is marked as time, the values are marked on the vertical axis. When one combines with signs of series, the trend of time series occurs.
- Moving averages method is usually used in series, showing the rise and sudden drop in values. Therefore, by taking an average of previous and subsequent values of this degradation and increases the possibility of balancing occurs. Moving averages method is used to destroy the cyclical and seasonal fluctuations (Sincich 1996).
- A moving average is a set of numbers, each of which is the average of the corresponding subset of a larger set of data point. For example Mathematically, a moving average is a type of convolution and so it can be viewed as an example of a

low-pass filter used in signal processing. When used with non-time series data, a moving average filters higher frequency components without any specific connection to time, although typically some kind of ordering is implied. Viewed simplistically it can be regarded as smoothing the data.

- Principle of least squares method is to reveal the functional relationship between time and the results. Choosing the type of function best describe the trend of; the event graph is plotted by marking of time on the X axis and marking of event values on the Y axis. This graph indicates the development in the long run incident. So type of graph function can to be expressed and the degree of the curve is determined by the bending point.

When the type of function is not possible to determine by its graph, the standard errors of function types can be calculated. Thus function type is selected with according to the smallest standard deviation. function type is selected with own the smallest standard deviation (Akdeniz, 1998).

3 TYPES OF TIME SERIES

A time series is of a quantity of interest over time in an ordered set. The purpose of this analysis with time-series is face of the reality represented by a set of observation and over time in the future values of the variables to predict accurately (Allen 1964).

The different much examples are encountered when one examine types of time series such as autocorrelation function, partial autocorrelation function, the moving average (Moving Average, MA) series, autoregressive (auto regressive, R) series, difference equations, autoregressive moving average (ARMA) series, Holt-Winters exponential smoothing forecasting model, the Fourier technique and seasonal time series.

4 IN PERMANENT GNSS STATIONS FACTORS AFFECTING TIME SERIES

Over the time observation values of time series values, in the form of some changes are observed as increase or decrease. The various reasons, such as using receivers and antennas, reflective surfaces, atmospheric conditions change direction and intensity of time series. The changes in time series can be listed as trend, seasonal variations, cyclical variations and random variations. These changes are in general called the time series basic components, or factors. The other facors are the effect of satellites, long-term multipath effects, atmospheric effects, hardware effects, seasonal effect (ocean loading, streams of ocean) tidal effect etc.

The satellite effect: Effects related to the gravitational pull of the determination of satellite orbit can easily be modeled. Acceleration due to gravity is not and solar radiation pressure on satellite panels affects the satellite position **(**Urschl et al 2005**).**

The long-term multipath effects : The satellite signal reflected from the environment instead of the original source comes GNSS satellite receiver. This error is called multipath error. When GNSS receivers can not enough receive satellites signal or GNSS receiver can compute wrong own coordinates due to multipath error with reflected surface. Thus time series are affected by systematic multipath path error.

Atmospheric effect: GNSS uses radio waves. Waves sent by satellite to receivers on earth reaches the receiver along the way through the two main layers as ionosphere and troposphere. The ionosphere is the top layer of the atmosphere. The ionospheric effect may be modeled or eliminated by using different wavelengths. If two carrier phase measurements are used, the ionospheric effect is eliminated by the linear combination of these carries phase measurements. Because of water vapor, radio waves undergo the delay in the troposphere near ground layer of the atmosphere. Tropospheric effects are effectively irreducible by using double difference carrier phase observations of GPS solutions (Dai et al, 2006). To reduce tropospheric effects water vapor, humidity, temperature monitoring can be done more carefully. Thus results can be achieved with high accuracy. It is difficult to determine the correct long-term temperature trend and seasonal changes in the troposphere (Matthias et al, 2002). Thus this effect can change the results of time series (Piboon, 2002).

Hardware effect: Antennas meet signal moving in the atmosphere. To increase the accuracy of the height component, the calibration of the antennas is of great importance. The changing between electrical center of antenna and geometrical center antenna is not fixed and the changing can continuously be reduce or increase (Wübbena et al, 2006). Antenna radomes used to protect signal quality due to external factors affect the height component of the solution. So this problem is under investigation (Hugentobler et al, 2006), (Schmid, 2006).
In the case of several weeks of discontinuation of the data in a station, extraction station periodic movement is not possible. For this purpose, different locations on the same station would be obtained if a different provision of GPS equipment and data can be ensured the continuity of time series.

The other factors affecting the time series are as outlined below:

- The local meteorologic effect, snow effect on the radome, local refraciton etc
- The seasonal effect, ocean stream (golfstream, labrador) , tidal effect, glacial effect
- Earthquake effect (postsismic, co-sismic and inrtersismic effect), fault movements
- Global plate movements etc.

5 NUMERICAL APPLICATION

Time series raw data of ANKR (20805M002), TUBI (20806M001), ISTA (20807M001) and TRAB (20808M001) station have been used in application (Figure 1). The raw data of N (North), E (East) ve U (Up) local coordinates components of these stations have been provided from the Scripps Orbit and Permanent Array Center (SOPAC) GPS archive (web-1, 2009). These local coordinates are transformation of difference of Cartesian coordinates between reference epoch and measurement time epoch. These coordinates are composed of ITRF2005 reference epoch coordinates (X_0 , Y_0 , Z_0), daily local coordinates N, E, and U. Dates of the data cover the period from 26/06/1995 to 12/21/2008 in ANKR station, the period from 21/12/1995 to 08/05/1998 in TUBI station, the period from 26/12/1999 to 12/21/2008 in ISTA station, the period from 26/12/1999 to 28/11/2007 in TRAB station. For the N, E, and U coordinate components of the four stations time series graphic has been drawn by Microsoft

Excel on one graphic (Figure 2).

Figure 1: GNSS station Used in time series analysis

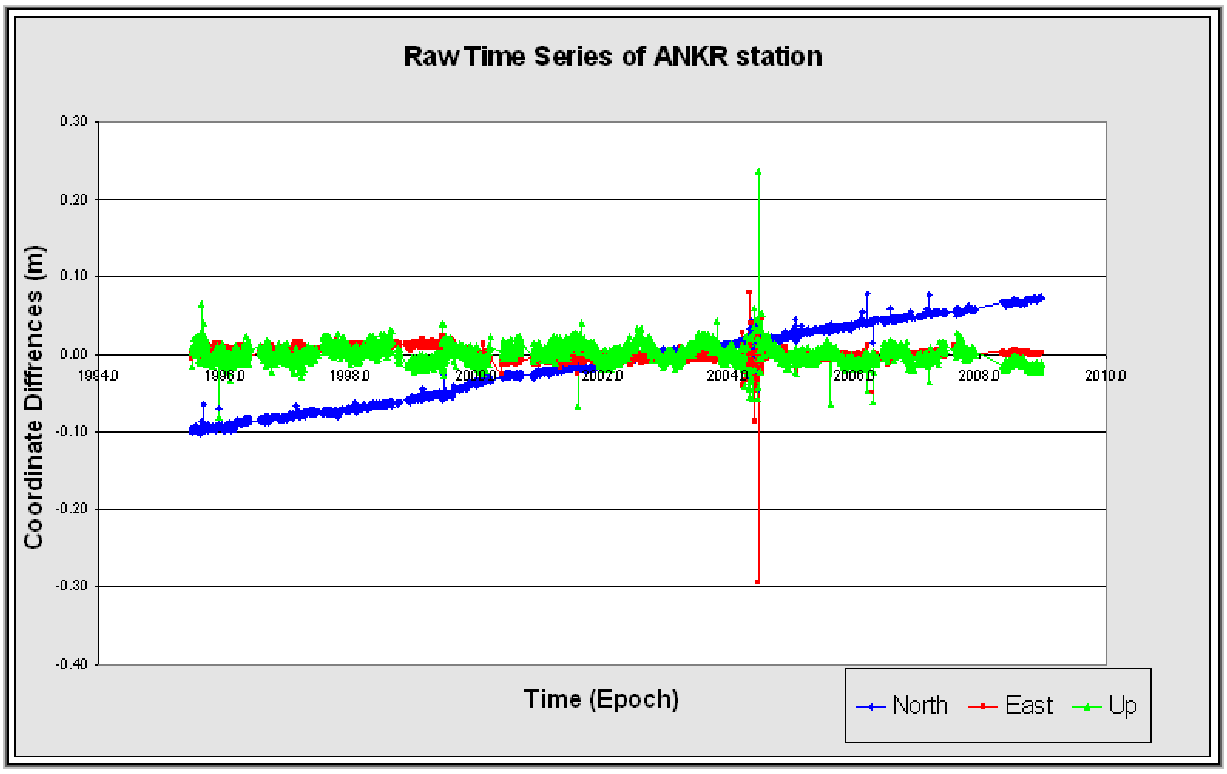

Figure 2: Time dependent changes in time series of ANKR station

Up component of four stations' coordinate time series is similar to the periodic due to seasonal effects and it appears to have been seen to act. In addition, the unusual changes were noticed in up component and these changes that changes caused by earthquakes are assumed. Firstly, the data interruptions of stations and gaps in time series were examined. For these gaps and interruptions, time series were analyzed. The long-term discontinuities in the stations were analyzed separately for different ranges of epochs. Then V-test was performed to determine outliers. Thus the outliers were eliminated from time series. Then, in height component of time series, periodic changes or seasonal effects were detected. So covering the years 1995 and 2008 daily average temperature and pressure values of four stations were obtained from General Directorate of State Meteorology Affairs. Regression analysis of height component was performed with according to the average pressure and average temperatures.

5. 1 V - Statistics

In the measures made for sample the elements x1, x2, ..., xn, V-statistics is used to examine the values showing the greatest difference whether belonging to the same set or not. (Yerci, 2002)
For the implementation of this test

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{X})^2} \qquad 5.1$$

value must be calculated.
Here V;

$$V = \frac{\left| X_E - \overline{X} \right|}{S} \qquad 5.2$$

The size of the test is calculated by equation 8.2. Hypothesis is established. If the hypothesis is smaller than V table values, the hypothesis will be considered valid according to the V table with n measurements and α significance level.

N, E and U components of stations’ coordinates divided periods of 6 months. V - Statistics were performed separately for every period of application because of big range of data. The purpose of this test, one can understand whether the series are stationary or not when one investigate the long periodic time series. As a result, values not outlying must stay in the own time series. According to V-statistics, outliers were extracted from time series of four station .In table 1 outliers of ISTA station are seen. There is much outlier in the other stations. But in this paper other outlier tables are not presented because of big tables.

5. 2 Regression Analysis of height components in ANKR, TUBI, ISTA ant TRAB GNSS Stations with average temperature and pressure

Each station’s average temperature and pressure values with height components are shown in the graphics e.g. in Figure 3 nad Figure 4 TRAB station height components with temperature and pressure values. In these graphics y column is no unit. Two variables multiplied by specific coefficients for better understanding of the visual. Then, regression analysis of height component was performed with according to the average pressure and average temperatures

Table 1. Outliers of ISTA station time series

Epoch	Year-Doy	N(m)	E(m)	U (m)
2001.223	2001 082	-0.0284	-0.0817	0.0198
2001.330	2001 121	-0.0211	-0.0851	0.0110
2002.484	2002 177	-0.0109	-0.0444	0.0054
2002.580	2002 212	-0.0218	-0.0266	0.0115
2002.596	2002 218	-0.0213	-0.0349	0.0393
2003.604	2003 221	-0.0168	-0.0185	0.0394
2004.062	2004 023	-0.0041	-0.0026	0.0169
2004.684	2004 251	0.0082	0.0086	0.0041
2005.722	2005 264	0.0051	0.0384	0.0231
2008.575	2008 211	0.0453	0.1026	0.0111
2008.578	2008 212	0.0509	0.1039	0.0107
2008.742	2008 272	0.0496	0.1128	-0.0089

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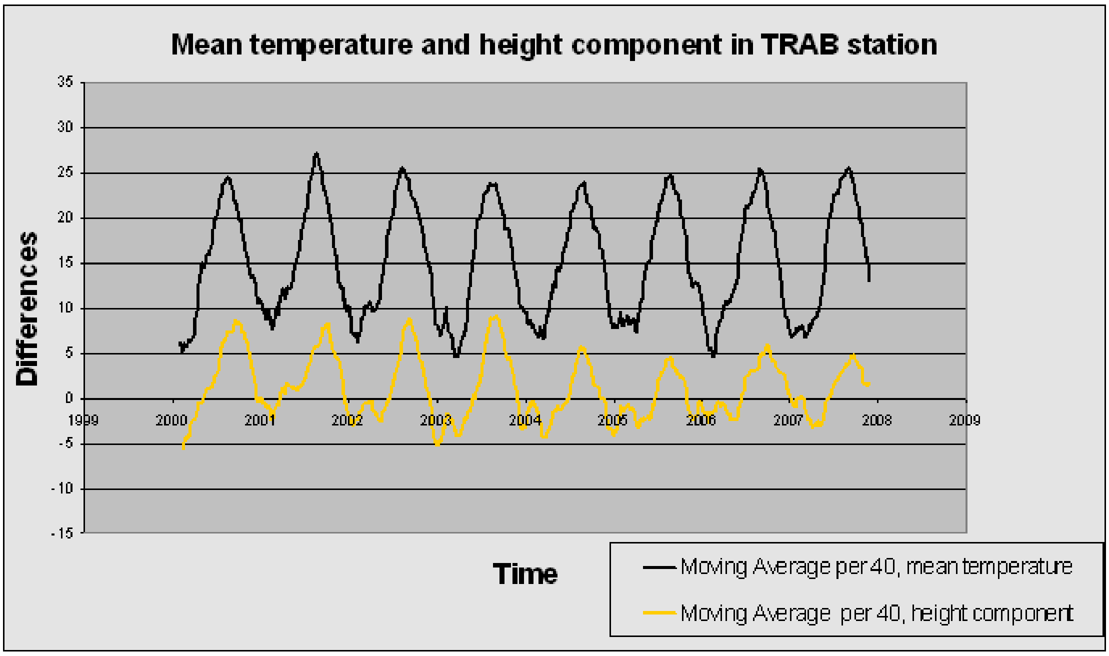

Figure 3. TRAB station's height component and temperature

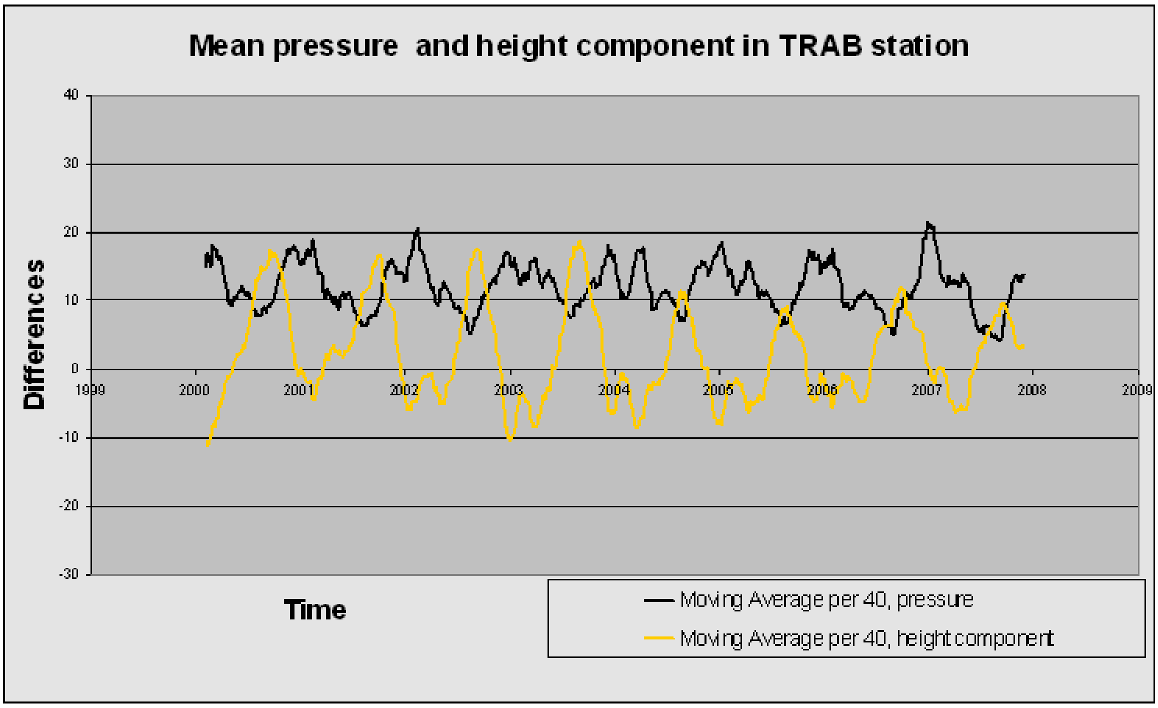

Figure 4. TRAB station's height component and pressure

Regression, setting up equality with the help of known is thought to predict the form for later cases. In other words, regression was used to measure the relationship between two or more variables. Regression provides both descriptive and inferential statistics. If X is the only variable point to an incident, and dependent variable Y, between these two variables Y = f (X) equation can be considered a link.

It is assumed that, according to the result of a series of measurement, (X1, Y1), (X2, Y2), ..., (Xn, Yn), values on plane are obtained from specified points in quantitative cases. If the frequency distribution of these points is examined, the maximum frequencies of the classes are different straight line from X and Y axes and the values are dispersed around the straight line.

The distribution of these series may be non linear distribution. If one has the impression that a suitable non-linear distribution, it is named suitable curve. But if the distribution is linear, it is named as the linear regression line or adjusting line.

5.3 Regression Analysis in ANKR Station

ANKARA station data was divided into three parts because of long term gaps and regression analysis was made separately for the three sections. The first part of ANKR station, the dates cover the period from 13.08.1999 to 26.06.1995. The second part, the dates cover the period from 17.03.2004 to 25.11.2000. The third part, dates cover the period from 30.11.2007 to 20.07.2004. In table 2, regression analysis coefficients and correlation coefficient with temperature are seen as y=ax+b regression equation. In table 3, regression analysis coefficients and correlation coefficient with pressure are seen as y=ax+b

Table 2. Regression Analysis of height components in ANKR Station with average temperature

Part number	a	b	Correlation coefficient, R
1	0.0006	-0.0067	0.4874
2	0.0008	- 0.0094	0.7575
3	0.0006	- 0.0081	0.6451

Table 3. Regression Analysis of height components in ANKR Station with average pressure

Part number	a	b	Correlation coefficient, R
1	-0.0006	0.5155	-0.2761
2	-0.0006	0.5404	-0.3029
3	-0.0007	0.6150	-0.3772

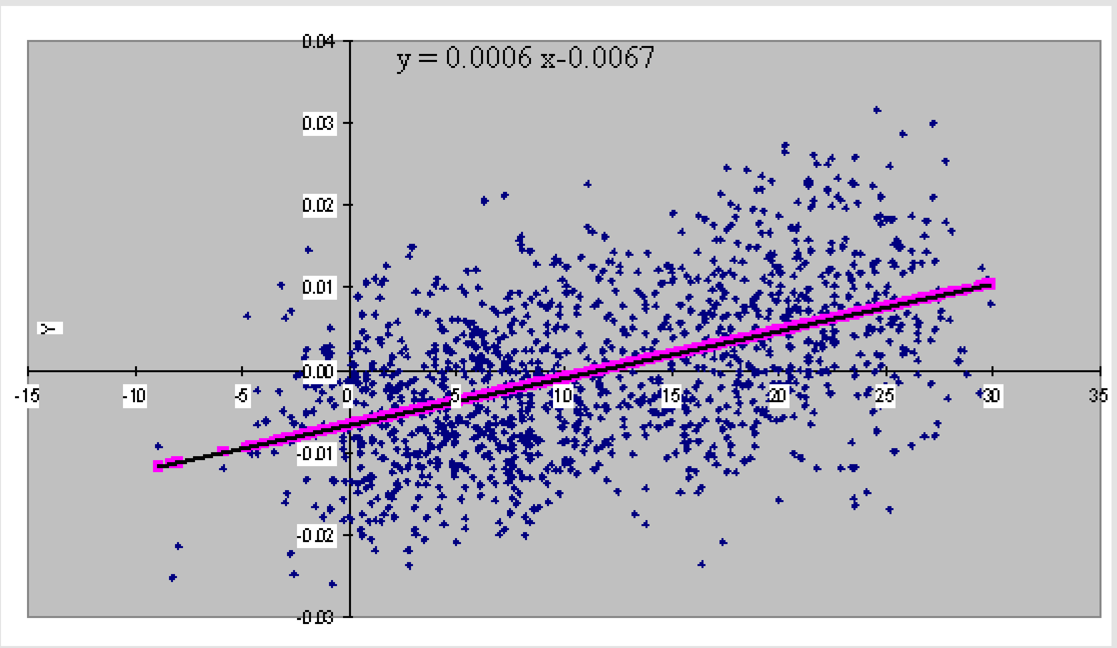

Figure 5. First part of ANKR Station regression line of height components with average temperature

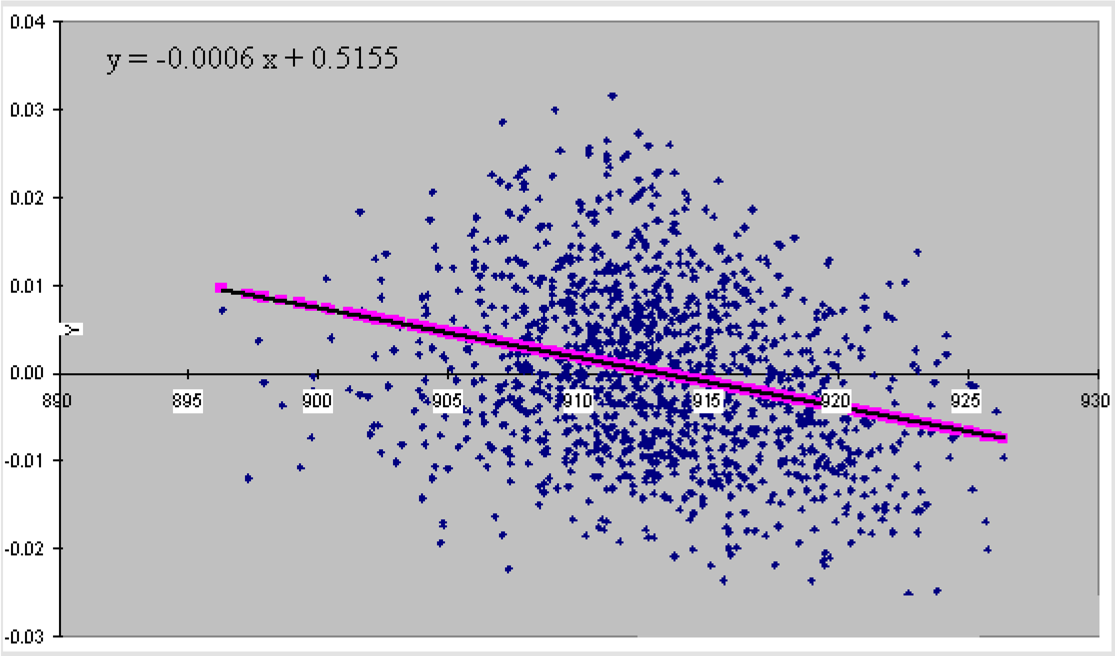

Figure 6. First part of ANKR Station regression line of height components with average pressure

5.4 Regression Analysis in Other Stations

In table 4, in TUBI, ISTA, TRAB station, regression analysis coefficients and correlation coefficient with temperature are seen as y=ax+b regression equation. In table 3, regression analysis coefficients and correlation coefficient with pressure are seen as y=ax+b

Table 4. Regression Analysis of height components in other stations with average temperature

Part number	a	b	Correlation coefficient, R
ISTA	0.0011	- 0.0162	0.7876
TRAB	0.0009	- 0.0134	0.6897
TUBI	0.0007	-0.0101	0.6370

Table 5. Regression Analysis of height components in other stations with average pressure

Part number	a	b	Correlation coefficient, R
ISTA	-0.0005	0.5047	-0.3124
TRAB	-0.0007	0.7063	-0.4691
TUBI	-0.0006	0.5924	-0.4605

6 CONCLUSIONS

One of the non secular behaviors often observed in GPS time series is the periodic variations with an annual period. The most obvious environmental factors with such period are temperature and pressure. Non-uniform temperature distributions and pressure of Earth surface due to solar radiation and tropospheric layer can cause thermal stress, expansion, subsidence and hence change in displacements and instability at the geodetic sites. In this study, we analyzed time series of GPS stations with temperature and pressure variations in a longer period of time. The GPS time series of stations lead us to assume that the displacement change of the GNSS station due to temperature and pressure. Also there is a linear correlation between height component of station coordinates and temperature. On the other hand inverse correlation between height component of station coordinates and pressure has been seen.

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