INTERACTION BETWEEN ATMOSPHERIC CONDITIONS AND GPS ACCURACY:

A CASE STUDY FROM ISTANBUL

by

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ABSTRACT

INTERACTION BETWEEN ATMOSPHERIC CONDITIONS AND GPS ACCURACY: A CASE STUDY FROM ISTANBUL

In this study, changes of the position data recorded by KANT permanent GPS station has been examined under the environmental conditions of the station. This cGPS station is situated in Kandilli Campus of Boğaziçi University and operated by Kandilli Observatory and Earthquake Research Institute. It is one of the sites of the Marmara GPS Network-MAGNET (TUBITAK), which was established for earthquake research in the Marmara Region. Data from KANT station has been continuously archived with thirty-second recording interval since 1999 in RINEX format. In this study, the position coordinates of the station have been obtained by GAMIT program with 2014 data. Data processing has been performed by selecting data from other short- and long-distance cGPS stations to minimize the potential errors and daily position GPS time series have been obtained.

Error sources at such a permanent GPS station can be listed as satellite clock, upper atmosphere (ionosphere), receiver clock, satellite orbit, lower atmosphere (troposhere) and multipath. In this study, changes in the position coordinates of the station have been compared with atmospheric conditions to understand whether the effects of atmospheric pressure, temperature, wind and humidity. Meteorological data obtained from Meteorology Laboratory of the Institute in daily base. According to the results, the coordinate displacements caused by environmental conditions can be significant and the effects should be taken into account, especially in high-precision geophysical research.

ÖZET

ATMOSFERİK KOŞULLAR VE GPS DOĞRULUĞU ARASINDAKİ ETKİLEŞİM: İSTANBUL'DAN BİR ÖRNEK

Bu çalışmada, KANT sabit GPS (sGPS) istasyonu tarafından kaydedilen konum verilerindeki değişiklikler istasyonun çevre koşulları dikkate alınarak incelenmiştir. Bu istasyon, Boğaziçi Üniversitesi Kandilli Kampüsü'nde bulunmaktadır ve Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü tarafından işletilmektedir. KANT, Marmara Bölgesi'ndeki deprem araştırmaları için kurulan Marmara GPS Ağı-MAGNET (TÜBİTAK) istasyonlarından biridir. KANT istasyonundan gelen veriler, 1999 yılından bu yana RINEX formatında otuz saniyelik kayıt aralığı ile sürekli olarak arşivlenmektedir. Bu çalışmada, istasyonun koordinatları 2014 yılı verileri kullanılarak GAMIT bilimsel yazılımı ile elde edilmiştir. Veriler, hata olasılıklarını en aza indirmek için kısa ve uzun bazda sGPS istasyonlarından elde edilen verilerle birlikte işlenmiş ve günlük GPS konum zaman serileri elde edilmiştir.

Sabit GPS istasyonundaki hata kaynakları; uydu saati, iyonosfer, alıcı saat, uydu yörüngesi, troposfer ve multipath hatası olarak sıralanabilir. Bu çalışmada, istasyonun koordinatlarındaki değişimlerde atmosferik basınç, sıcaklık, rüzgar ve nemin etkilerinin olup olmadığını gözlemlemek için bir karşılaştırma yapılmıştır. Meteorolojik veriler Enstitü'nün Meteoroloji Laboratuvarı'ndan günlük bazda elde edilmiştir. Karşılaştırma sonucunda, çevresel koşulların neden olduğu koordinat değişimleri gözlenmiştir. Bu koşulların etkileri özellikle yüksek hassasiyetli jeofizik araştırmalarda mutlaka dikkate alınmalıdır.

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Et	Irregular or Remainder Component
M	Earthquake Magnitude
S_t	Seasonal Component
T_t	Trend-Cyclic Component
Xt	Time Series

LIST OF ACRONYMS / ABBREVIATIONS

CfA	Center for Astrophysics
CORS	Continuously Operating Reference Stations
EOP	Earth Orientation Parameters
ERP	Earth Rotation Parameters
GMT	Generic Mapping Tools
GNSS	Global Navigation Satellite Systems
GLONASS	Global'naya Navigatsionnaya Sputnikovaya Sistema
GPS	Global Positioning System
IAU	International Astronomical Union
IGS	International GPS Service
ITRF	International Terrestrial Reference Frame
MAGNET	Marmara Continuous GPS Network
RMS	Root Mean Square
RINEX	Receiver Independent Exchange
RTK	Real Time Kinematic
SIO	Scripps Institution of Oceanography
SOPAC	Scripps Orbit and Permanent Array Center
TUSAGA	Türkiye Ulusal Sabit GNSS İstasyonları Ağı

1. INTRODUCTION

Global Positioning System (GPS) is a measuring system that contributes location, speed and time information of any point based on the measurement of at least 4 code-phase arrival times on 24 hours basis in all weather conditions on the Earth. Its high accuracy in determination of relative positioning availability increases the use of GPS in many fields.

GPS measurements are used actively to designate permanent stations' positions for geodetic purposes. Moreover, GPS measurements provide to evaluate the baselines of GPS processing. GPS measurements can be analyzed in two main methods as continuous and campaign measurements. Additionally, they support time series analyses, and also supply the observations which aimed at finding signal errors. Time series changes can be determined by using GPS data.

KANT is situated at the Kandilli Campus of Boğazici University. KANT has been accumulating data since July 6, 1999. The temporal resolution of GPS data is 24 hours, with a logging period of 30 seconds, the elevation mask is 10 degrees. Figure 1.1. shows the GPS sensor with a choke-ring model antenna.

Figure 1.1. GPS receiver named KANT functioning 24 hours/day (Trimble NETR9, now TOPCON Net-G5 with a choke-ring model antenna).

This study focuses on the effects of environmental conditions on GPS time-series of position changes. With this aim, position coordinates of the permanent GPS station KANT have been obtained by using scientific processing program-GAMIT. Time series graph has been derived for 2014 in daily base. Then, seasonal effects have been investigated by comparing the time series results.

16 IGS (International GPS Service) stations and 4 MAGNET stations have been selected for processing. The results of postfits nrms, which indicate primary quality of daily GAMIT processing, and observed meteorological parameters such as temperature, pressure, wind and humidity have been compared by taking into account the impact of natural (e.g. trees) and artificial (e.g. building) obstacles. Finally, the North and East displacement components of 4 MAGNET stations have been compared, as well.

2. LITERATURE REVIEW AND THEORY OF GPS

2.1. Past Studies Using KANT Data

First study on investigating long-term data from KANT was realized by (Turgut et. al., 2006). Turgut et al. (2006) evaluated the performance analysis of commercial GPS processing program (Trimble Geomatics Office) in medium and long-distance baselines. The results from this study show that, quality of the coordinate of starting point affects directly the result of the baseline solution quality. According to the loop closures, baseline solutions between permanent stations gives us better results comparing with campaign-based sites due to longer measurement time. Although Trimble Geomatics Office has well enough performance, as a commercial GPS processing software, for pre-co-post earthquake period baseline changes, this research suggests scientific software to obtain more precise results.

The GPS velocities with 3D concurrent time series' adjustment are calculated to get the interseismic velocities, based on GLOBK solutions. This research contains 900 days beginning from 18th August, 1999 (after the Izmit earthquake) until end of 2001. The TPGN (The Turkish Permanent GPS Network) is presented to the Earth Science community in (O. Lenk et al., 2003)'s paper. Data processing strategy and results from beginning analysis are examined. The interseismic velocities were compared with the pre-earthquake interseismic velocities (McClusky et al., 2000) in the epicentral region of the Izmit and Düzce earthquakes. This research's results produced to indicate velocity estimations' quality when there are at least two year observations for each station in TPGN.

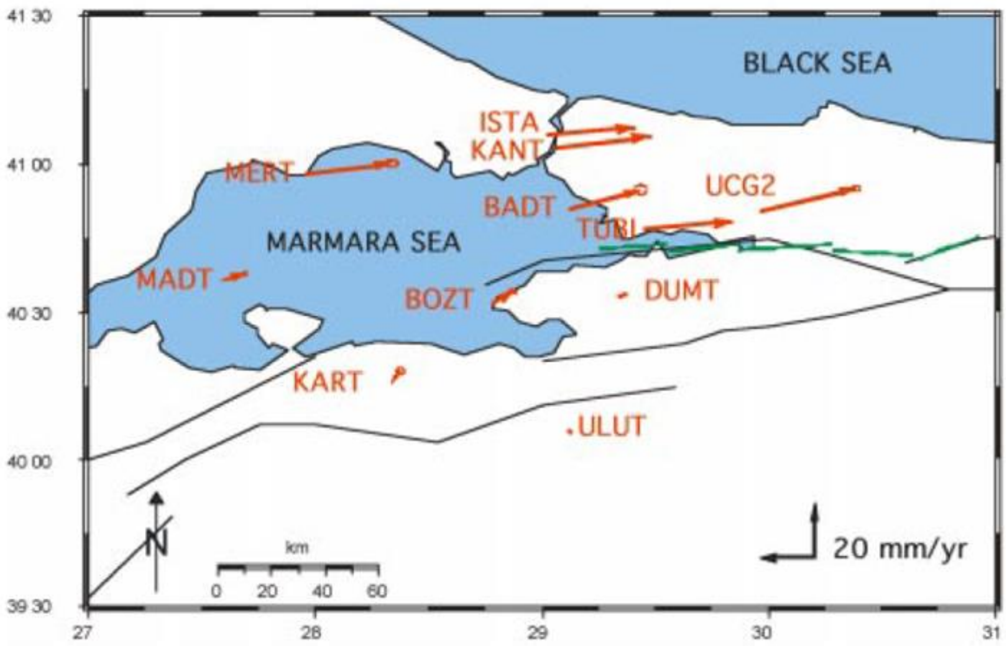

Figure 2.1. Interseismic velocities of MAGNET stations in ITRF96 reference system. Black marks show the active faults and green marks show the rupture of İzmit (17 August 1999) earthquake. (Ozener et al., 2009)

Ozener et al., (2009) specify solutions related to transforming data to information in earthquake studies. The continuous data of the GPS sensors were processed to produce geodetic velocities (Figure 2. 1.). KANT permanent station's data was processed. GPS velocities were created, then this data was processed to obtain strain assessment. The campaign-based stations' data were collected, then strain rate and velocity field maps were produced for hazard assessment. The strain map was evaluated from the continuous station data, additionally semiannual and annual strain maps were generated from campaign-based observations. It could be seen that deformation field was controlled by right-lateral strike-slip deformation on NAFZ. The eastern NAFZ was competent to generate major earthquakes. So, it is essential to computerise earthquake deformation maps to make determination on risk assessments and exigency managements.

In (Erol et al., 2006) research, the baseline solution between ISTA and KANT which are continuous reference stations was used for process. The both stations are on North Anatolian Fault (NAF). The characteristics of earthquakes like magnitudes, times and locations are generated from the Kandilli Observatory and Earthquake Research Institute. Therefore, GPS baseline analysis, changes and peaks of slope values can be interpreted. KANT is continuous reference station in Marmara Continuous GPS Network (MAGNET). Besides this station was installed on the ground. Determination the alteration of linear interaction coefficient of the time series is executed by autocorrelation function. In addition to this, the autocorrelation function leads to specify the interactions in a single time series. The correlations between two time series are evaluated by the cross correlation function. Least Squares Spectral Analysis (LSSA) and Wavelet Analysis (WA) technics are used to analyze GPS time series data from slope sensors and baseline processes from two permanent GPS stations. LSSA and WA are logical techniques to assess of inclination and GPS data. Thus, similarities and periodicities in time series can be found.

2.2 Time Series of GPS Studies

Time series are defined as the sequential ordering of data or signals depending on time space. Time series are one-dimensional signals. Many GPS time series analyses can be found in the literature review. First investigation of the permanent GPS station time series was made by (Wdowinski et al., 1997). This study (Williams et al., 2004) is about analyse of permanent GPS position time series. Maximum likelihood estimation method is used for noise content in nine various GPS solutions. We can understand the noise content of GPS data so realistic that uncertainties can be appointed to parameters estimated from them. This research's GPS observations were analyzed in SOPAC and the daily site coordinates were determined from the GPS data using GAMIT and GLOBK software. Noise types were also compared in the different graphic.

Researchers (King and Watson, 2010) investigated satellite geometry's effects and multipath signal. GIPSY PPP solutions were used to simulate time series. The antenna heights of reflectors are H=0.1 m , 0.2 m, 1.5 m below are simulated, besides GPS time series are analyzed. Therefore, the multipath effects' reflectors on GPS time series were examined and this study showed that the impact of responsive near field sources on GPS time series and impact of phase center modeling errors on station velocities.

The aliasing effect reviewed in (Penna and Stewart, 2003) is part of the plan of the GPS configuration. The processing term and tidal models' quality are used in the GPS station processing. This study procures the two changing effects for main diurnal and semidiurnal tidal constituent. The two kinds of signals in GPS time series is proved by modeled GPS data and examined for time series. Two aliased signals' consequences are clarified that spurious signs in time series with semi-annual and annual terms.

The most extensive time series analysis of (quasi) permanent GPS observations to date has been presented by (King et al., 1995) for a single 8-km baseline spanning the Hayward fault in northern California for nearly a 3-year period from 1991 to 1994. They did not detect a random walk signal in the estimated power spectral density and autocorrelation functions of their single relative position ("baseline") time series, although they identified its shortness compared to longer continuous geodetic time series may have made such a signal undetectable.

The periodic effects were calculated by continuous GPS stations' time series analysis and they were introduced as correction for the velocities which were obtained by the campaign type measurements (Kurt, 2009). Appropriate models and the velocities which obtained by campaign measurements were investigated to achieve more realistic velocities. GPS time series analysis were received by GAMIT/GLOBK software and tested with different types of noise models. The most suitable model is approved that the composition of white and flicker noise.

This paper (Tregoning and Watson, 2009) is about the effects on station coordinates of different methods to atmospheric loading deformation (ATML) and tropospheric delays. The GPS measurements were examined using the GAMIT/GLOBK program. Researchers also observed ZHD (Zenith hydrostatic delay) and mapping functions not only present time correlated noise but also important periodic intervals in annual and semiannual periods.

The most important error sources are multipath in GNSS positioning. Many researches have been executed about phase multipath mitigation technics: ones used with positioning algorithms. This study observes and produces new technics in this type (Lau and Cross, 2007). There are many different multipath mitigation technics for various applications, which have different multipath features. Thus, the hypothesis and analysis results of this technic and original program fixed phase multipath mitigation technics and also investigates phase multipath estimation using SNR-based models and ray-tracing method are studied. In addition to this, static and kinematic types for antenna and long-delay and short-delay multipath are also examined. Specular reflection is important multipath error source even the surface is rough in terms of results. The using of different phase multipath mitigation technics is suggested for different circumstances like static and kinematic types of antennas and long-delay and short-delay multipath.

Different geophysical and tectonic contributors and to classify the error spectrum of simultaneous GPS process on seasonal scales which make the seasonal deformation were explained in this study (Dong et al., 2002). The GAMIT software was used to process the daily GPS observation. The position changes of apparent seasonal station are originated from 4.5 years of global permanent GPS time series and “peering” way was investigated. The relatively seasonal sources are showed to collect insight into the known contributors by “peering” approach. Pole tide effects, ocean tide loading, atmospheric loading, nontidal oceanic mass and groundwater loading are assessed. Researchers investigated the significance of understanding seasonal variations in station positions. The nature of seasonal variations in position at global GPS stations are investigated in this study. Additionally, the research results show that global permanent GPS array studies can be observed seasonal signals, as signified by the similar patterns in the time series produced at the SOPAC and JPL analysis centers.

The impact of signals on geodetic velocities was analyzed in this research (Blewitt and Lavallee, 2002). Previous research about power law noise of coordinate time series was completed. A model was developed to compute the velocities that do not account for annual signals. Minimum velocity bias is suggested at integer-plus-half years, as approved by tests with real data. Below 2.5 years, the velocity bias can change intolerably large, and simultaneous estimation does not inevitably improve velocity assessments, which become changeable due to correlated parameters. It is recommended that 2.5 years be accepted as standard minimum data span for velocity solutions aimed for tectonic studies or reference frame preparation. Additionally, geophysical analysis of velocities received using shorter data intervals.

The unrealistic circumstance of the GPS antenna location and estimated parameters' number are remaining invariable with time, the GPS satellite constellation is invariably developing as satellites are commissioned and decommissioned. Additionally, it can be eliminated from the solution due to satellite eclipse or manoeuvre. Moreover, station specific obstacle like vegetation or man-made structures may alter with time, generating a new change in the observation geometry. Consequently, even though an unmodeled signal remains totally constant in time, the way in which it will generate is probably to change with time. If these differences are appropriately large, then the ensuring systematic error will probably bias the time series importantly, resulting in inaccurate explanation of geophysical signals like tectonic velocity, glacial isostatic adjustment, vertical movement of tide gauges or seasonal geophysical loading signals. Moreover, many errors would reduce the GPS contribution to the International Terrestrial Reference Frame (Altamimi et al., 2007).

In a research (Julaiti et al., 2016), 2-year span GPS data from 37 sites of TNPGN-Active were analyzed by using GAMIT/GLOBK to produce daily GPS time series of each station and related velocity estimates. For the GPS time series, mainly noise analysis was applied to distinguish which station is sufficient enough for using its velocity estimates. Two different combinations of noise types in the position time series were estimated, which are random walk noise model and white plus power law noise model. The results show that station has large amount of noise in its position time series and whether all the stations are reliable for velocity field estimates with 2-year data.

2.3 GPS and Errors

GPS which is the improved form of the transit system was developed by the NAVSTAR/GPS USA Defense Department. GPS receiver and satellite signals can be used continuously and instantly to determine position, velocity and time at any time and place in any atmospheric conditions and a global coordinate system. The GPS system is based on the principle of re-estimation, which is one of the basically known geodesic techniques. Re-estimation is observations and calculations to be which are made from known point to an unknown point. The GPS satellites are the location of points which are known in the GPS system. Conversely, the unknowns are the cartesian coordinates (X, Y, Z) of the station at which the measurements are made. At least 4 coordinates of satellites are needed to eliminate clock errors. Therefore, GPS is a 4 dimensional system (X, Y, Z, t). Spatial distances which are measured by radio waves, the triangulation points used are GPS satellites that can find certain coordinates by means of orbital (ephemeris) information.

There are some regular and irregular errors that affect GPS measurement results. It is the satellite-receiver distance that is essential for positioning with GPS.

2.3.1 Satellite Ephemeris Errors

If the accuracy of the satellite position information broadcast in the GPS navigation message is low or deliberately mispublished, the error is called ephemeris error. Satellite ephemeris error requires more responsive calculation of satellite orbits. This is due to very well measured and modeled fault affecting the satellites. The effect of the ephemeris error is too small for bases of several kilometers. As the base grows, the size of this error also increases.

2.3.2. Satellite Clock Errors

GPS sets the time base for location determination. For this reason, atomic clocks are used in GPS satellites. The fact that the satellite and receiver clocks are not synchronised to the correct time according to the GPS time is the principle of clock faults. Satellite clock errors are constantly monitored by the control department and the ephemeris loads the clock corrections daily as part of the navigation message. The important issue is to reduce the total error in calculating the receiver-to-receiver distance, which provides about 30 nanosecond synchronization between the satellite clock and the GPS time. At the moment, the GPS information signals traveling at a speed of about 3.108m travel about 30cm at 1ns. A 1 nanosecond error is a 1 second error in about 30 years on a digital clock, and this error rate is good. However, the GPS system causes a 30 cm error, which causes the coordinate to be determined with a 30 cm error. For this reason, atomic clocks are used in GPS satellites and control centers. Even though sensitive clocks are used in the sundials, it is still a matter of time to grow this mistake. For this reason, the calculated satellite time is loaded from the loading stations in accordance with the errors and delivered to the users with the posted navigation message.

2.3.3. Ionospheric Effect

Ionosphere is all of the high atmospheric regions where the air molecules are extensively concentrated and electrically conductive. The ionosphere is defined as the upper atmosphere layers (70-3000km) with free electron density that can affect the spreading of electromagnetic waves. Ionization and free electron density are directly dependent on the solar charge. For this reason, the effect of ionosphere on electromagnetic waves is more than daytime.

2.3.4. Troposphere Effect

GPS satellites broadcast signals from space are moving in the space before entering the atmosphere. These signals pass through the ionosphere. Then mesosphere, passing through the stratosphere and the troposphere they reach the destination. The troposphere is the lowest layer of air that comes into contact with the earth. The thickness is 8 km in the poles and 18 km in the equator. Air events are generally seen in the lower parts of the troposphere 3- 4 km.

2.3.5. Satellite Slope Angle

Low slope angles are problematic due to atmospheric refraction. However, it is desirable to keep this angle small so that more measurements can be used to increase positional accuracy and more satellites.

2.3.6. Signal Reflection (Multipath) Effect

Signal propagation is called multipath effect when the signals emitted from the satellite are mixed into the main signal by following one or more paths to the receiving antenna. The effects caused by the satellites and the effects caused by the surfaces around the receiving antenna are largely eliminated by the method of relative positioning because the effects on the short-edge networks will be the same for both antennas on both sides. Possible sources of reflections caused by the surroundings of the receiving antenna are structures, trees, water surfaces and other reflective surfaces. The magnitude of the signal reflection impact is proportional to the wavelength. The size of the effect in the code measurement of the antenna signal reflection is 29.3 m for the P code and 293. 2 m for the C / A code. For phase measurement, this error amount is about 4.8 cm for L1 frequency.

2.3.6.1. GPS Signal Reflection Geometry. There are 3 types of signal reflection mode:

F-mode signal reflection (Forward):

The F-mode represents the signal which reflects forward by bouncing from the floor and the signal considered to be smooth reflection. After GPS signals reflects, they polarize to left direction. GPS antennas easily detect that it is a reflected signal.

BA-mode signal reflection:

The BA-mode represents the signals reaching by reflecting backwards from above the antenna level. After GPS signals reflects, they polarize to left direction like F-mode.

BB-mode signal reflection:

BB-mode indicates signals coming from below and reflected backwards. The signal strength is reduced because it is reflected twice. The first reflection is perceived as a normal GPS signal since the left second reflection has right-hand polarization. It is considered the most dangerous reflection mode (Tiryakioglu, 2009).

2.3.7. Receiver Antenna Phase Center Error

The receiving antenna is the point at which the phase center GPS signals reach the antenna. The phase center of an ideal GPS antenna must be independent of the way of arrival of the signal arriving at the antenna. In practice, small changes are observed in the phase centers of the antennas depending on the azimuth and elevation angle of the satellite signal. These variations are different for L1 and L2 signals. Antenna phase center variations range from a few millimeters to a few centimeters depending on the antenna structure.

2.3.8. Selective Availability (SA)

Selective accuracy access (Selective Availability) was produced for unauthorized users by United States. Positioning accuracy was intentionally worsened by the US. This situation has been removed since 1 May 2000. Differential GPS (DGPS) technique is used to protect against SA effect at short base lengths.

2.3.9. Carrier Wave Phase Uncertainty and Phase Interruptions

The GPS receiver measures only the phase between the measurement signal and the receiver signal at the time of measurement. As soon as the receiver is switched to a counter which is activated when the receiver phase integer ranging from 0 to $2\boldsymbol{\pi}$ increases or decreases +1 or -1. Thus, the first measure of the integer phase wave length change is determined from the observation epoch. It is not known how many full waves the carrier wave phase between the satellite and receiver for the first epoch (start moment) contains. This is known as 'carrier wave phase start uncertainty' or briefly ambiguity. Phase uncertainty is indicated by N. GPS receivers should maintain observations on every observed satellite without any measurement interruption. As long as there is no signal interruption in observations, N will be constant.

2.3.10. Sensitivity Loss (DOP) Factors

Another factor that affects three-dimensional position in GPS navigation measurements is satellite geometry in the sky. Satellite geometry is a main source of error in locating. The position of the satellite relative to each other and to the receiver on the earth is expressed by the error contribution loss (DOP) factors in determining the receiver antenna coordinates. The DOP factors are measures of the effects of satellite geometry on the accuracy obtained from the navigation solutions, generally obtained as the function of the diagonal components of the cofactor and variance-covariance matrix obtained after balancing. The high DOP value specifies that the satellite geometry is not suitable for accurate positioning (the satellites are very close to each other) and the low DOP value designates that the satellite distribution is very suitable. The types of DOP factors are defined as follows:

GDOP: Specifies the total effect of the satellite geometry on the calculated point coordinates and the receiver clock is unknown.

PDOP: Specifies the effect of satellite geometry on the computed horizontal and vertical coordinates.

HDOP: Specifies the effect (latitude, longitude) of the satellite geometry on the computed horizontal coordinates

VDOP: Affects the computed point height of the satellite geometry.

TDOP: Expresses the effect of satellite geometry on computed time information.

2.4. Mitigation Errors

Base lengths less than 100 km in the IGS standards are local, between 500 km and 1000 km are regional and more than 1000 km are called global bases. Many effects can be overlooked in relative positioning by phase observations in basins less than 100 km. Some distorting effects that are ignored in localized networks (<100 km), but which are important for global measurement networks, geophysical and geodynamic purpose networks, and for precise point positioning (PPP) are explained below. The solar and moon locations must also be known so that some of these effects can be calculated, additionally this information is taken from planets ephemeris tables (Kahveci, 2010). These effects:

Earth Rotation Parameters: The route of the earth's motion axis changes depending on time. The rotation of earth is not a regular movement, because of precession, nutation, pole travel and universal time (UT1). The appropriate coordinate systems are necessary to define for the geodetic sizes (point coordinates, base components etc.) which can be obtained by modeling and evaluation of GPS observations.

During the assessment of GPS data, the point coordinates and satellite coordinates must be defined in the same reference system. Therefore, the conversion parameters between ITRF and ICRF systems must be known. These conversion parameters are known as EOP (Earth Orientation Parameters). Earth orientation parameters X_P, Y_P, d_Ψ, d_ε, UT1-UTC ensure that ITRF is routed to the ICRF depending on time. From these parameters, X_P and Y_P parameters determine the position of Celestial Ephemeris Pole in ITRF system. d_Ψ ve d_ε parameters which are defined according to the 1980's nutation model of IAU (International Astronomical Union) determine the difference between CEP and normal CEP. In addition to this, UT1-UTC describes IERS reference meridian's direction in ICRF (Castrique, 1996). In the practice, three of these parameters (X_P, Y_P and UT1) are used in evaluation of GPS data and these are called ERP: Earth Rotation Parameters. Therefore, ERP includes polar motion components and UT1 time scale (McCarthy and Petit, 2003).

Consequently, the direction of the earth's motion axis changes with time. The direction of the transformation vector equals the instantaneous motion axis' direction, at the same time the size of the transformation vector is equal to the motion speed of the earth.

The earth's rotation is not a regular movement, the reasons for this; precession, nutation, polar travel and universal time (UT1). In other words, as a result of changes in the earth rotation vector, the impacts of the sun, the moon and the attraction of the planets and the ocean and underground water movements on earth, atmospheric effects (Kahveci, 2002).

These parameters provide the conversion between inertial reference frame (ICRF) and the terrestrial reference system (ITRF). As a result of this conversion satellite orbits are obtained in the ITRF system. In order to make the specified transformation more precise in scientific software, half a day ERP is considered in the changes. Because the ERP is significantly influenced by the daily and half-day periods of ocean loading. This effect is 0.1 mas (3 cm) in size on earth.

Polar Motion and Polar Tides: Due to minor changes in the potential of ground-based centrifugal force, movement of the rotation axis with consider to the solid ground is known as pole travel. Consequently, gravity effects of moon and sun cause periodic changes in station coordinates. Likewise, the rotation axis of the globe, displacement relative to solid ground (lithosphere) causes periodic deformations.

Ocean Loading: Ocean loading can be described as the pressure of the oceanic tides below the earth's crust. Meanwhile, it shows a half-day or day periods. Ocean loading's impact is smaller than earth tide. Additionally, it does not have fixed part and shows local effect. Ocean loading can be overlooked in 24-hour static observations and the account of distant (>1000) stations on the ocean coast. If the station is near to the ocean and the tropospheric wet component and receiver clock fault are to be calculated, this effect must be taken into consideration even in 24-hour static observations (Kouba, 2009). Otherwise, the oceanic tropospheric effect is reflected in the solutions as receiver clock defects. (Dragert et al., 2000)

Solid Earth Tides: The solid earth is actually as flexible as the gravitational makes that cause the ocean tide. The station displacements in vertical and horizontal directions due to tides are expressed by spherical harmonics (Love Number h_{nm} and Shida number l_{nm}). It is an effect that should be allowed if accuracy of 1mm is aimed at station positions (McCarthy and Petit, 2003). Taking the tide term up to the second degree and making the height correction is sufficient for the 5mm accuracy (McCarthy, 1989). Conversely, tide correction can be defined by two components, latitude dependent stable part and periodic part. This correction reaches 5 cm in the horizontal direction and 30 cm in the radial direction in the absolute position of the measurement point. The periodic part is brought to an average value by performing a 24-hour static observation. However, the fixed part (about 12 cm in the middle latitudes) can not be corrected by the 24-hour static observation. For this reason, tidal effects must be considered in accordance with the ITRF in calculations. Neglecting this effect will result in a significant systematic fault, especially in the case of precise point positioning (Kouba, 2009). If this effect is not taken into account in the calculations, it is possible that there is a systematic error of 12 cm in the radial route and 5 cm in the north route and absolute position of the measurement point even if a long period of static observation is made in the determination of the precise point position. On the other hand, this effect is substantially eliminated as it can be assumed to be the same on both ends of the base in determining the relative position where the base length is less than 100 km (Kouba, 2009).

Satellite Antenna Phase Shifts: The basis of satellite-based corrections is the difference between the satellite center of gravity and the phase center of the satellite antenna. Because the forces acting on the satellites used in the satellite orbit calculation are modeled according to the satellite center of gravity. Likewise, the IGS results orbits and clock information also point to the satellite center of gravity. However, the satellite navigation message is directed to the antenna phase center. In addition, satellite observations are based on the antenna phase center. Consequently, offset values between weight and phase centers must be modeled and taken into account for calculations. (Kouba, 2009) The phase center of L1 and L2 carriers is accepted to be the same. Satellites can not orient themselves correctly to the sun as they pass through the shadow of the Earth (about 55 minutes) and thus errors of up to 10 cm for very long bases at satellite receiver distances will arise due to the incorrect orientation of the satellites. This is also called geometric effect. Moreover, there is also dynamic effect. Due to the incorrect direction that occurs when the satellite enters the shadow of the earth, because the solar panels can not be vertical to the sun satellite way, the modeling of the radial composition parameters used in satellite orbit calculations becomes almost impossible (Hugentobler et al., 2001). Zero values were used for these offsets until November 5, 2006. Since this date, satellite and receiver antennas have started to use absolute phase center values.

Receiver Antenna Phase Shifts (PCV: Phase Center Variations): GPS satellite signals come from every direction, so the situation for receiving antennas becomes more complicated than satellite antennas. Receiver antenna phase center position also varies depending on these directions. This direction dependency is called “receiver antenna phase center changes”. These changes are different for L1 and L2 in contrast to the satellites. Because these changes vary depending on the antenna type. If the different antenna models are used in the same network, this effect becomes even more important. Taking into account this effect makes error up to 10 cm at the station height regardless of the base length. If the same antenna model is used in the network, this effect shows itself as a scale factor and its amount is given as nearly 0.015 ppm (Hugentobler et al., 2001).

If the file “igs05.atx” which contains PCV values is used in the calculations and there is no information in this file about the antenna model used in the measurement, the best solution is to use “zero” or “relative PCV” values. If the relative, absolute satellite and receiver antenna phase center values are used as mixed, there are faults up to 10 cm in height component. If different type and model antennas are used in the GPS network and tropospheric parameters are to be calculated, PCV files which contain phase center changes must be used. Besides, PCV files must be used again if the location is determined by the PPP method.

Phase Wind Up: The GPS satellites broadcast right-polarized signal (RHCP: Right Hand Circularly Polarized). Therefore, carrier wave phase observation depends on the reciprocal placement of the receiver and satellite antennas. The receiver’s or a satellite antenna’s turning a tour around its own vertical axis causes carrier wave phase’s sliding up to 1 wavelength. This impact is called the “phase rotation effect” (Wu et al., 1993). Receiver antennas are generally directed to the north in static measurements, except for real time GPS measurements to avoid these error sources in GPS measurements. But this situation is different for satellite antennas. When the satellite antennas and the sun panels are setting towards the sun, they are exposed to small rotation. Thus, the geometry of the satellite stations is affected negatively. Furthermore, satellite solar panels are arranged towards the sun when a certain period of stay in the dark. As a result, the phase rotations which correspond to a complete rotation within nearly half an hour for the satellite antenna consist. In these cases, the phase measurement should be adjusted (Bar-Sever 1996, Kouba 2008). This effect can be disregarded in base lengths of 100 km and in relative position determinations. For instance, this effect causes error about 4 cm at a base length of 4000 km (Wu et al., 1993). For this reason, it is important to consider this effect in PPP applications. Because IGS clock information is considered to be correct in this method and it may correspond to nearly half wavelength as an error in calculations. All IGS analysis centers have implemented these adjustments in their calculations since 1994. This is disregarded and also IGS orbital/clock information are accepted correct, so it causes errors at dm range in location and receiver time calculations. Additionally, this error source is eliminated as a binary phase source in kinematic GPS measurements and they are included the parameter in the receiver clock calculation.

Station Velocities (Location Changes): GPS stations are generally exposed to periodic movements. Most of the periodic site movements are accepted the same for important part of the world. These effects are considered to have been destroyed for small base lengths less than 100 km in relative positioning. Their size is nearly in the range of dm.

But;

a. If users want to use the PPP method and determine the ITRF compatible station coordinates
b. If relative positioning is to be used in some cases longer than 500 km
c. If studies are doing to determine geophysical and country datum

These station movements should be modeled as applied in IGS standards. On the other hand, other effects that cause station movements below 1 cm (atmospheric loading, underground water/soil moisture, snow mass effect etc.).

Coherence with IGS/IERS (International Earth Rotation Service) Standards: IGS/IERS standards and definitions must be observed when using fixed IGS products and solutions in high-precision GPS assessments. This situation is especially important in PPP solutions and long base solutions. In this context, if IGS/IERS products are used while GPS analyzes are performing;

- Using the latest version of ITRF
- Compatibility of IGS orbital information and IGS Earth rotation parameters (ERP: Earth Rotation Parameters)
- It is important to examine the IGS station log files (antenna phase center values, antenna change information etc.)

Reference Frame (Datum): IGS orbit and clock information which are used in calculations (constant received) determined the location reference system. To give an example, the network is directed precisely and its scale is determined for the free or minimum relative position determining (IGS orbit/time information is considered as constant). Consequently, all solutions to be included in GPS network solutions must be in the same reference system. ITRF solutions, except for high frequency tidal models, it can be considered that there is linear motion in the stations. That is why the station coordinates and their velocities are given in ITRF solutions.

2.5. D-GPS (For Correlated Errors)

Surveyors and geodesists have selected differential GPS for the ways of data processing. Frequently, the differential GPS processing technics relies on two receivers laying at a control point whose location is predicted: the base. The positional error at the other end of the baseline can be calculated according to adjustment between the biases at the base and the biases at the rover. Adjustments are produced that eliminate the three-dimensional positional error in unknown station by mitigating the degree of biases there with differential GPS processing. Carrier phase observations which processed differentially can achieve precisions of a few centimeters. These circumstances have caused to the structure of networks of CORS stations on control sites to support differential processing.

Differential correction is made to obtain more accurate positioning information in a short time. This is called Differential GPS (DGPS). Dual-frequency GPS receivers are used to execute the geodetic observations. It gets very important to post-process this data using programme that gives the desired accuracy for evaluating the crustal deformations (Likhar, 2002). Two receivers are used in this method. One of the receivers are put in a known point coordinates, the other receiver is at the point where the coordinates are to be specified. In DGPS technic, there must be at least two receivers, one of which is stable and the other is rover. Navigation applications (such as navigation of land, sea and air vehicles) demands high accuracy. This situation limits the facilities to use without instant location. The desired navigation accuracy can be reached by DGPS technique. Firstly, the corrections of the lengths (pseudorange corrections) which are obtained from the receivers at the reference point in DGPS. If the reference point’s and satellite’s location coordinates are thought to be known, these corrections are the difference between the calculated length and the measured length. These corrections are the different values for each GPS satellite that is in the receiver’s field of view at the time of measurement. These corrections which were obtained are broadcasted with radio signals from each reference point. The automobiles, airplanes and ships etc. which carry the DGPS receiver take adjustments of DGPS by collecting these signals. Then, DGPS corrected lengths are determined by these adjustments’ being made to the lengths of the satellites entering the field of view of the DGPS receiver on the vehicle. By using these obtained lengths and the orbit data of the satellites, the position of these vehicles in the measuring position is calculated.

2.6. Linear Combination of Measurements (LC) (Ionosphere)

The ionosphere is the ionised form of air molecules. The ionosphere is the high atmospheric regions that air molecules have taken electrical conductivity. The signal transfer of GPS is impacted with the variation in the deflective content in the ionosphere, because of the motion of electrons in the extension medium. These refractile content alterations effect the velocity of the waves, making the notable impacts of first-order ionospheric phase promote and group retardation (Hoffman et al., 2008) The part of ionospheric retardation to the pseudorange errors is important owing to its potential magnitude and its large variance (Mazzella et al., 1996) Hence it is the main error sources of satellite based location. Based on diffusive effect of the ionospheric retardation, about 99% of ionospheric error can be reduced by making the “ionosphere free” linear combination (LC) (Xie and Han, 2000)

GPS observations have precise linear combinations and they play a main role in the problem of ambiguity resolution. In terms of ambiguity resolution one normally focus on those integer linear conjuction that generate a phase predictable which has a comparatively long wavelength, low noise behavior and an acceptable little ionospheric delay. These types of features are very profitable to the ambiguity adjusting analyze.

The linear combination reinforced while differencing two of phrases has nearly the best conceivable incertitude measure as the both phrases' sum has almost the worst undetermined. Two types of linear combinations are known in the GPS research literature.

"Wide laning" method is a very profitable way. The narrow, the wide and extra wide-lane are often used. On the other hand different wide-lane data have been analyzed. Nevertheless, the different integer linear data that are examined, are limited to the single-channel dual frequency way.

The method has been developed by different technics to provide cycle-slip adjustment before processing term. The formulas use two dual frequencies, double-difference carrier phase and pseudorange geometry-free linear combinations. These conjunctions are eliminated to let for high-resolution cycle slip detection. After that, correlation with least-squared depends on Chebyshev polynomials for cycle-slip resolution.

The measurements include linear combinations of undifferenced or double-differenced L1 and L2 carrier-phase and pseudorange investigations. Sample of compositions beneficial for kinematic measurement are the ionospheric phase delay (the geometry-free phase is scaled type) (Goad, 1986; Bastos and Landau, 1988, Blewitt, 1990; Gao and Li, 1999), sequence remaining (Bastos and Landau, 1988), and widelane phase minus narrow lane pseudorange (Blewitt, 1990; Han, 1997; Gao and Li, 1999).

The double-difference technique observes receiver and transmitter clocks as nuisance parameters that can be reduced by the appropriate linear combination of data (Wu, 1984), precisely analogous to eliminating ionospheric impacts by producing the ionosphere-free combinations described earlier.

Ionosphere has different effects on system and phase observations which made with GPS. In other words, while the ionosphere group delay effect is concerned with code measurements, phase acceleration is claimed for phase measurements. Ionosphere has a feature that distributes radio waves, this destructive effect varies depending on the frequency of the radio waves. Accordingly, when these effects are modeled, the ionospheric refraction index must be determined and then it is necessary to find correction to be measured by integrating along the signal way between the receiver and the satellite. (Tiryakioglu, 2005)

2.7. GPS Baseline

The receivers which are used to survey are expensive and composite for daily work. The GPS receivers use two frequencies broadcast due to the satellites. The GPS signal's properties and complicated calculation approach to develop the accuracy of the positions received. Generally, the receivers have different high-quality antenna.

Two types of GPS receivers are used for GPS baseline, with one at each end of the line to be evaluated. They simultaneously gather GPS observations from the satellites. The time of coincident data changes by the line's length and the precision required. The distinction in location (latitude, longitude and height) between the two stations is computed with specialized program. GPS positioning has many uncertainties, and they can be reduced in the computations because the defects in the data are the same in the baseline.

The precision of data is received from this approach rely on the measurements' circumstance, but is nearly about 1 part per million (1 milimeter per kilometer) so a distinction in location can be estimated over 30 kilometers with an uncertainty of about 30 mm, or about 100 mm over 100 kilometers.

While a known position's single baseline provide the location at the different end of the baseline, extra GPS baselines to different stations are evaluated to control on the consequences and an assess the uncertainty of the computed location.

The sub-optimal data processing algorithms are used by the commercial software, as processing data on a single baseline mode (at the same time more than two receivers were performing), however the scientific program has multi-baseline and multi-session competence. The baseline vectors that derived from GPS require scale and rotation parameters.

The observation noise of GPS, EGNOS and GIOVE-A/B pseudo range and carrier phase measurements, functional circumstances can be determined by short and zero baseline dimensions (H. van der Marel et al., 2009).

3. POSITIONING TECHNIQUES

Location information is obtained by two basic methods: absolute and relative positioning in GPS measurement methods. The position of a point can be defined by GPS method as absolute, relative and differential.

3.1. Precise Point Positioning (PPP)

Precise Point Positioning first appeared in 1970 and the theoretical basis was given by (Zumberge et al.,1997). PPP is a positioning technic that reduces or simulates GPS system errors to supply a greater level of position accuracy from a single receiver and charge a fee to access the corrections. The basis of PPP is composed by Relative Point Positioning methods. Especially, the Differential GPS method is quite advanced can be used in narrow and wide area in real-time applications. In addition to this, CORS Network which provides real-time solutions for engineering purposes was established. In non-real time studies, owing to precise satellite clock and the availability of orbital information; Precise Point Positioning (PPP) provides decimeter-centimeter accuracy results with one device and these results are independent of any DGPS network. Dual-frequency component is necessary in PPP. Thus, there are two measurement formulas, for pseudorange and carrier phase. A PPP solution relies on GPS satellite clock and orbit adjustments, produced from a network of global reference sites. Formerly the adjustments are computed, they are distributed to the last user with satellite or over the Internet. These corrections are used by the receiver, resulting in decimeter-level or better positioning with no base station expected.

The PPP method needs a period of time to merge to decimeter precision for resolving any local biases like the meteorological circumstances, multipath environment and satellite geometry. The actual accuracy executed and the convergence time required is relied on the feature of the adjustments and how they are used in the receiver. Up to 3 centimeter accuracy is credible.

3.2. Relative Positioning

The other sites' coordinates are defined in accordance with a known point of coordinates. Particularly, the base vector between two sites is defined by the relative position determination. Coincident code or phase observation with two receivers installed in two separate locations are in the same case. The accuracy which is obtained by relative positioning is much better than absolute positioning. The accuracy which is obtained depending on receiver type, dimension time, observed satellite geometry, satellites number and used ephemeris information changes between 0.001 and 100 ppm. The application of each of the difference observations is possible in relative positioning, the double difference method is preferred as a result observation in geodetic studies.

Relative Positioning with NAVSTAR/Global Navigation Satellite System (GPS) satellite signals, using double-difference method, has been applied by the surveying association for some time. This method is agreeable because satellite clock compensates and receiver clock compensates are eliminated. Additionally, carrier phase double-difference processing presents different accuracy, after carrier cycle ambiguities have been determined.

Coincident code or phase measurements are made in the identical surroundings with receivers installed in two different locations in relative positioning. The accuracy is better than absolute positioning. The accuracy of the measured value changes from 0.01ppm to 100ppm depending on the receiver type, the satellite geometry observed, the number of satellites and the ephemeris information. The position of the reference point should be known with an accuracy of 15-20 mm in the WGS-84 system.

3.3. Comparison Between PPP and Relative Positioning

Precise Point Positioning (PPP) and Relative Positioning provide an important part to geodynamic observations. PPP method's principal advantage is that positions are severally obtained. However in relative positioning, an error in the base site coordinates would change the different sites (Perez et al., 2003).

Dual-frequency GPS component is necessary in PPP. Hence, there are two observation formulas, for both pseudorange and carrier phase. (Zumberge et al., 1997)'s study shows that it is feasible to get accuracy of a few millimeters and a few centimeters in the horizontal and vertical data with PPP method. Various precision can be received for static point positioning, using a period of 24 hours of measurements. (Monico and Perez, 2001; Monico, 2000a)

PPP currently has disadvantages. The time is essential to determine the cycle ambiguity. The time necessity to move from a float to a fixed result is increased because the ambiguity cannot be accepted to be an integer as it is in a different solution. The convergence can take

20 minutes or more. The condition may be developed by the raise in satellite noticeables that will begin the addition of GLONASS in the IGS PPP result.

3.4. Double Differences

Double differences can be defined as the difference of binary singular difference. In other words, the difference between the single differences are created for two different satellites in the same epoch. Double differences technic is used to eliminate satellite clock and orbit errors, localized atmospheric errors and receiver clock errors. It is accepted by the final carrier phase GPS resolution. The most popular GPS technic presently in use for precise positioning is double differencing. This method is popular because ordinary mode errors cancel for short baselines or their effect is radical reduced in the case of long baselines. This is specifically true for satellite orbital errors and receiver clock errors.

Another distinctive characteristic of double differencing is the relative ease of restrictive double difference ambiguities to integer values. Some ambiguity fixing strategies have become accessible that characteristically rely on statistical tests and search strategies.

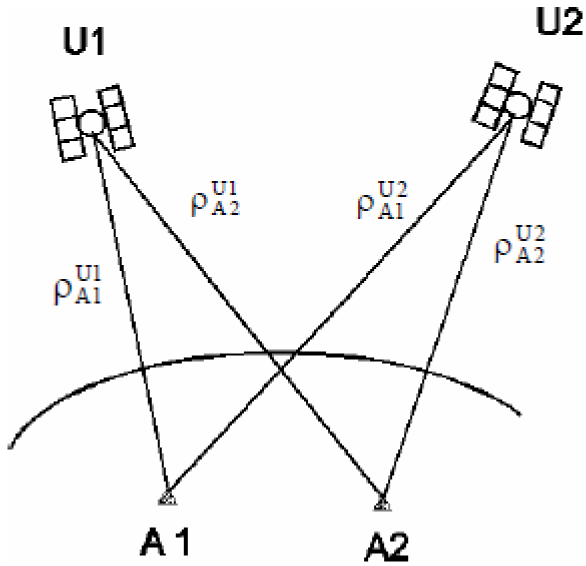

Figure 3. 1. Receiver – satellite double differences.

Double difference observations;

$$\Delta\Delta_{A1A2}^{U1U2}(t) = \Delta_{A1A2}^{U1}(t) - \Delta_{A1A2}^{U2}(t) \tag{3.1}$$

expressed by this equation. In this method, both satellite and receiver clock errors are eliminated. Generally, it has been used as the basic observation equation in GPS measurements evaluation software. In this method, tropospheric and ionospheric effects are also eliminated or shortened at short baselines. (İ. Kalaycı, 1997)

The Double Differences model is usually constituted by taking one satellite as constant. Fixed satellite is usually selected as the satellite with the smallest vertical angle and the maximum measurements collected satellite during the observation period. The satellite array that makes the Double Difference measure specifies functional model mostly and depending on this, the stochastic model on the long baselines. (O. Kurt, 2010)

DD (Double Differences, observations taken twice a difference) which is relative positioning mathematical model is chosen in many commercial and academic software. The most important features of DD mathematical model are its removing some of the errors in the GPS observations, reducing some of its effects significantly and independent of the epochs (O. Kurt, 2010).

Evaluation the various stochastic features of the examinations, and classification the predicted stochastic features with respect to the noise features were executed by zero, single, double and time differences.

4. DATA PROCESSING, METHODOLOGY AND ANALYSIS

GPS has high (sub centimeter) positioning accuracy, like in the velocity field assessment of tectonic plates. Currently, Relative Positioning or Precise Point Positioning (PPP) used for such applications (Arslan, 2004).

The main GPS measurements used for evaluating position, velocity and time are:

Pseudorange and carrier phase or dissimilarity of carrier phase. Dual frequency data is required since ionosphere related errors can be eliminated by using data combinations based on two different frequencies.

Pseudorange multipath is principally controlled by these factors:

- The antenna's location: is a ground plane or choke ring accessible, are higher conducting obstacles nearby,
- The antenna's quality: does the antenna have low precision for low elevation signals,
- The receiver's property: do the tracking algorithms of the receiver channels poses multipath reduction technics.

The dissimilarities between the pseudo-range data and the carrier phase data are:

a) The ambiquity terms,

b) The importantly larger noise term associated with pseudo-range data. The multipath conditions are not contained, however, the pseudo-range data is more responsive to multipath (thus a larger magnitude term) than carrier phase data.

4.1. Data Acquisition

16 IGS points (BUCU, GLSV, BAHR, GRAS, GRAZ, NICO, ORID, MAT1, KIT3, ZECK, NSSP, NOT1, ONSA, POTS, VILL, ZWE2) were added to the processing (Figure 4. 1.). And MAGNET sites (BOZT, DUM2, TUBI and KANT) were used in this process (Figure 4. 2.).

Figure 4. 1 Study Area (includes KANT) and selected IGS stations.

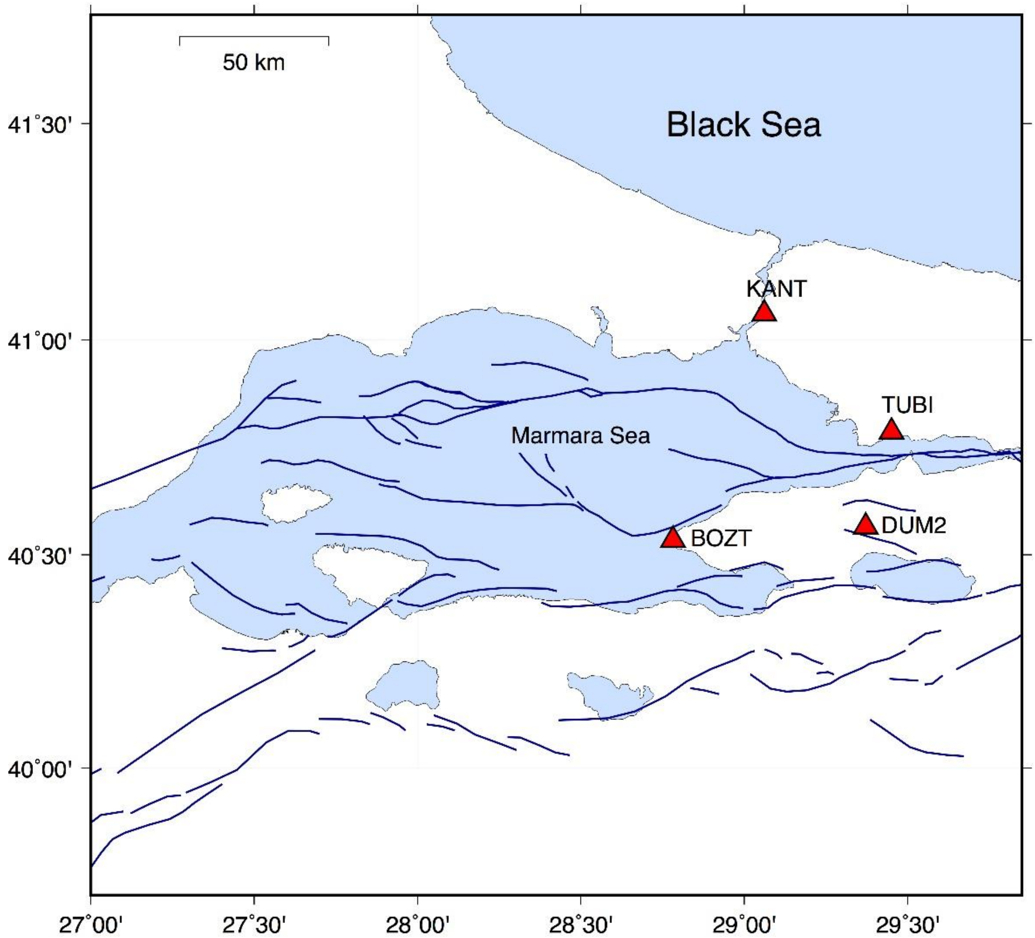

Figure 4.2. MAGNET Stations used in this study.

4.2. Data Processing

Data gathered from sixteen permanent IGS sites have been analyzed on a daily base using GAMIT GPS processing program (Herring 2000 ; King&Back, 1998)

The scientific program has more featured simulating and processing strategies, such as the ability to arrange orbital parameters, evaluate tropospheric scale factors, process more than one observation session.

In GPS data processing, two types of software are used; commercial and scientific. Commercial software is used in common engineering applications and various types of GPS data collected by any surveying method can be processed. Scientific software is generally used in crustal deformation studies but any kind of study which requires GPS data processing can be executed by scientific software. A list of scientific software and its supporting institution is given in Table 4.1. (Havazlı, 2012)

Table 4.1. Scientific GPS data processing software and supporting institutions.

Software	Institute
Bernese	AIUB
GAMIT/GLOBK	MIT-SIO
GIPSY/OASIS II	JPL (NASA)
PAGE5	NOAA
GEONAP	University of Hannover
MURO.COSM	University of Texas-Van Martin System
DIPOP	University of New Brunswick

GAMIT/GLOBK (Herring et al., 2010a) software is chosen in this study for data process. The software works under two main modules. First module is GAMIT and it consists of various programs to process GPS data and results return as the position estimates. The second main module is GLOBK which is a Kalman filter. Its main purposes is to merge various geodetic ways from the analyzing of main data from space geodetic or terrestrial researches.

The main GAMIT modules necessitate seven input types:

- Raw phase and pseudo-range data in the form of ASCII X-files (one for each site within each session)
- Site coordinates in the form of an L-file
- Receiver and antenna data for each site (file station.info)

- The list of satellite and scheme (file session.info)
- Primary status for the satellites' orbits in a G-file (or a arranged ephemeris in a T-file)
- Satellite and site clock values (I-, J- and K-files)
- Control files for the examination (sestbl. and sittbl.)
- "Standard" tables to supply lunar/solar ephemeris, the Earth's rotation, geodetic datums and spacecrafts and the information of observation devices (Herring *et. al.*, 2010b)

GAMIT/GLOBK is an inclusive software program applied to complete GPS analysis models, which has been developed by the Massachusetts Institute of Technology (MIT), the Harvard-Smithsonian Center for Astrophysics (CfA), Scripps Institution of Oceanography (SIO), and Australian National University (ANU). GAMIT is short for GPS Analysis at MIT with purpose that is classifying the data, both station log sheets and receiver production, with the method which it can be processed adequately by the program modules, such as makex, fixdrv, arc and model. GLOBK stands for Global Kalman filter VLBI and GPS analysis software, which is designed to combine solutions from quasi-observations by using Kalman filter (Herring et al., 2015).

4.2.1. Gamit Processing

GAMIT is a software which used for analyzing GPS data. This program uses the GPS broadcast carrier phase and pseudorange predictables to evaluate three dimensional relative positions of good sites and satellite orbits, atmospheric zenith delays and earth orientation parameters. The program is organized to operate in UNIX system. The users have to define the correct information about data set, so the directory named tables is important for GAMIT processing. It contains several types of files, such as:

(1) station.info, this file supplies receiver and antenna information for each site; (2) sestbl., session control table, this file determines the earlier measurements errors and satellite constraints and the main method of analysis (Appendix B); (3) process.defaults, these files give the directory names of processing sources and solution, and other control environment parameters (Appendix C). (4) sites.defaults, these files are used to operate the use of stations in the processing, specifically the global stations whose data can be downloaded remotely (Appendix D); (5) apr file and L-file both of them include the coordinates of all the stations to be used in the GAMIT, all files help to get appropriate coordinates for the processing.

In this study, the all GAMIT daily solutions have been run by using SH-GAMIT command for data from 2014 of KANT stations; 16 IGS sites (i.e. BUCU, GLSV, BAHR, GRAS, GRAZ, NICO, ORID, MAT1, KIT3, ZECK, NSSP, NOT1, ONSA, POTS, VILL, ZWE2) and (BOZT, DUM2, TUBI) MAGNET stations. In the processing, we used International Terrestrial Reference Frame 2008 (ITRF08) as the reference system and fixed the orbits by setting the mode of experiment as BASELINE. Examining the last result from the processing saved in GAMIT summary files, in "sh_gamit_ddd.summary" file in each day directory (ddd refers to Julian day). Generally, we found that KANT station's one year data are "good" marked for daily data set and they are also acceptable. Every one of daily data has values of 6-14 mm of one-way post-fit root mean squares (RMS) residuals by satellite and station.

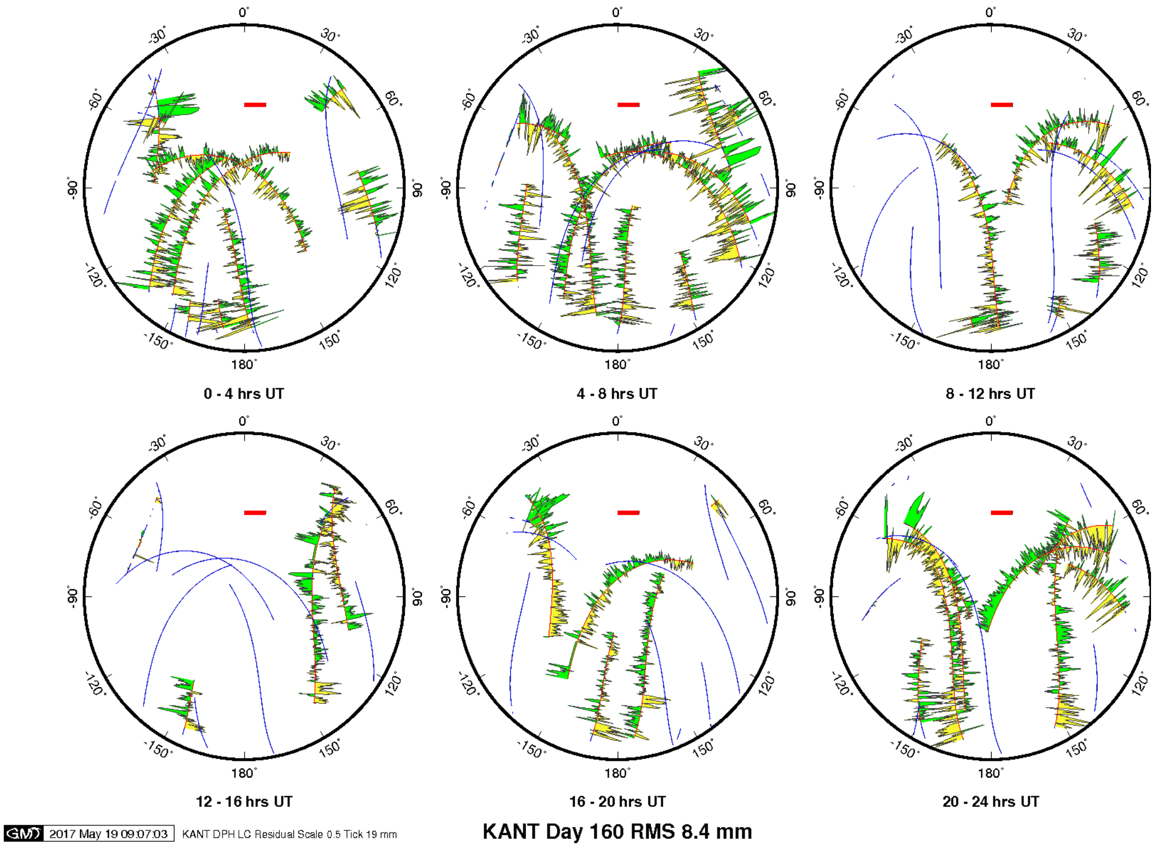

Figure 4. 3. Sky plots of KANT station on June 9th, 2014, which shows phase residuals of GAMIT daily solution. The tick circle describe the site's azimuth from 0 ~ 360°, 0° is in the north way. Blue points indicate the received satellites array in this day from elevation 0 ~ 90°.

Sky plots are used to assess multipath, water vapor and antenna phase center model. Additionally, these sky plots graphics show residuals to eliminate ionospheric error from GPS signals (Figure 4. 3.).

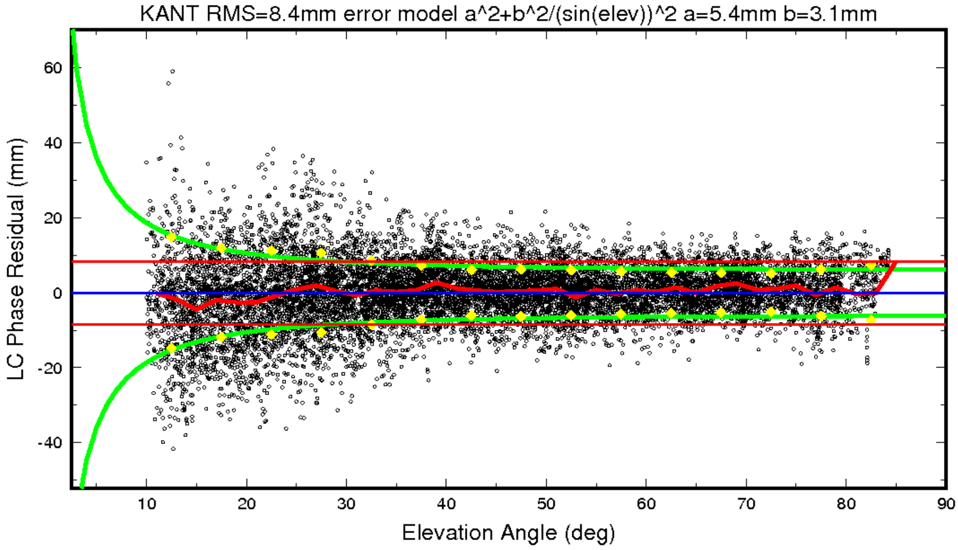

Figure 4. 4. KANT 160th day of antenna phase center graphic.

The last part of red line is smoothing in antenna phase center (Figure 4. 4.). Additionally, green line shows error model depends on elevation. This graphic does not have a problem for antenna phase center (Figure 4. 6.).

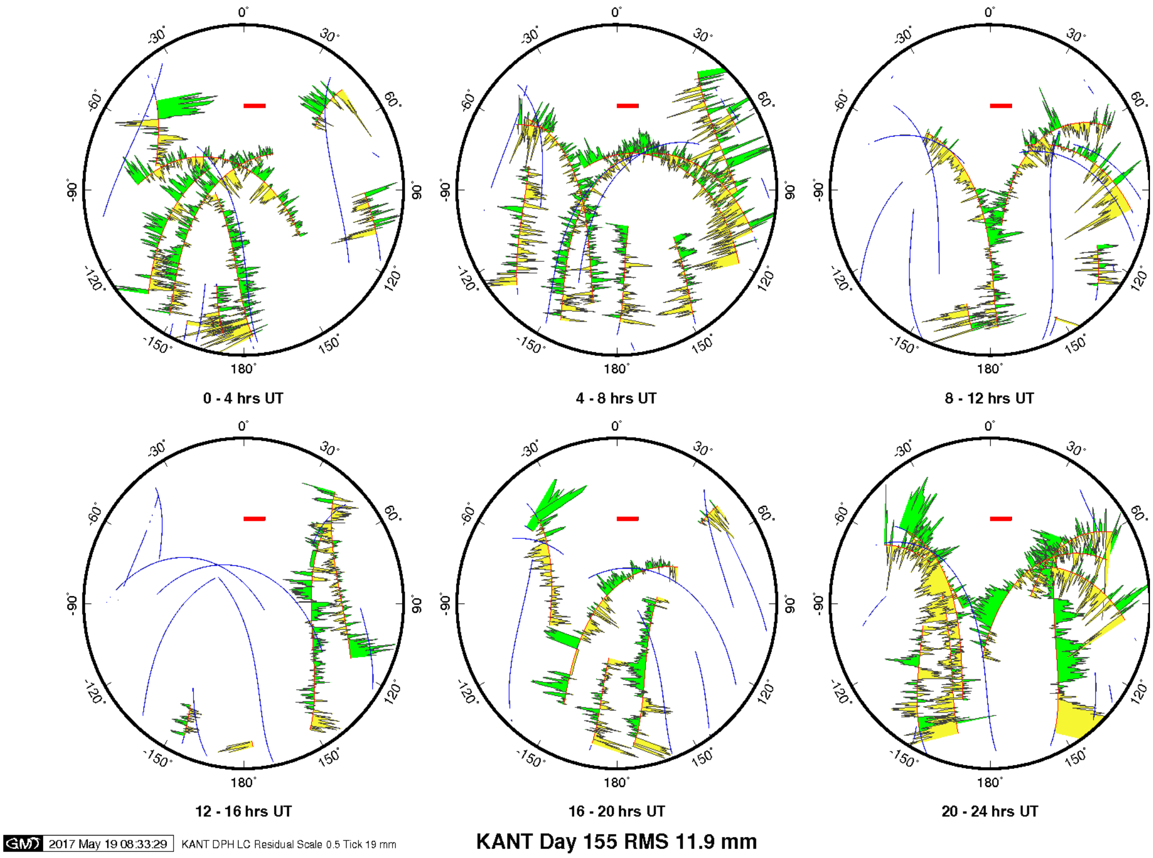

Figure 4. 5. Sky plots of KANT station on June 4th, 2014, which has an acceptable daily solution.

Sky plot is used to investigate phase noises in a signal which comes from the satellite (Figure 4. 5.). Sky plot is created every 4 per hour. Blue line shows the satellite route in the figure, yellow fluctuations means positive phase noises and green fluctuations indicates negative phase noises. Additionally, red rectangle indicates the amount of scale. High residuals in the same place at different times suggest multipath. Besides, high residuals appearing in a given place only at one time indicate water vapor.

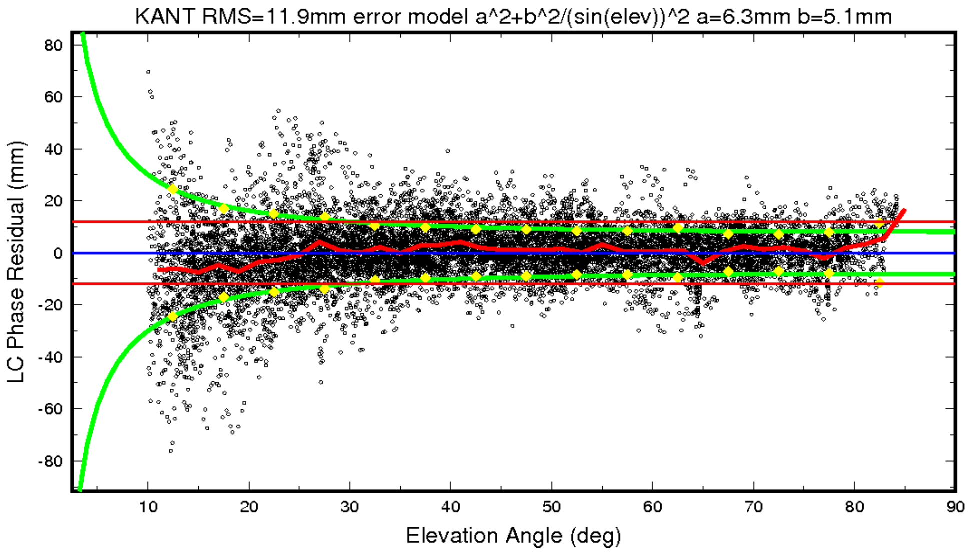

Figure 4. 6. KANT 155th day of antenna phase center graphic.

4.3. GPS Time Series

The time series refers to a series of position data points which consists of consecutive measurements made over a successive time interval with at most one data point in each unit. Time series analysis consists of multiple methods to break down time series data for purpose of extracting significant statistics and other meaningful characteristics of the data. Those methods can be usually divided into two sections, which are time-domain methods and frequency-domain methods, involving the concepts of Fourier transform, power spectral density and, sometimes, Wavelet analysis in signal processing.

GPS time series are related with changing position of target place. Clearly, GPS time series usually consist of four main components (i) Trend, which exists as there is a long term increase or decrease in the data; (ii) Seasonal, which is a long-term regular pattern existing in data due to seasonal factors; (iii) Cyclic, any pattern showing up rises and falls without regular period; (iv) Irregular, other unpredictable random variable existing in data (Mann 1995).

However, in practice, GPS time series X_t are usually regarded as comprising three components: a seasonal component St, a trend-cyclic component Tt which is contacting both trend and cyclic, and an irregular or remainder component Et. Then, a proper model will be established for decomposing those three components from time series to achieve a purpose that all of them except irregular one can be given appropriate explanation. There is a common model for GPS time series, the additive model (Friedman and Stuetzle, 1981):

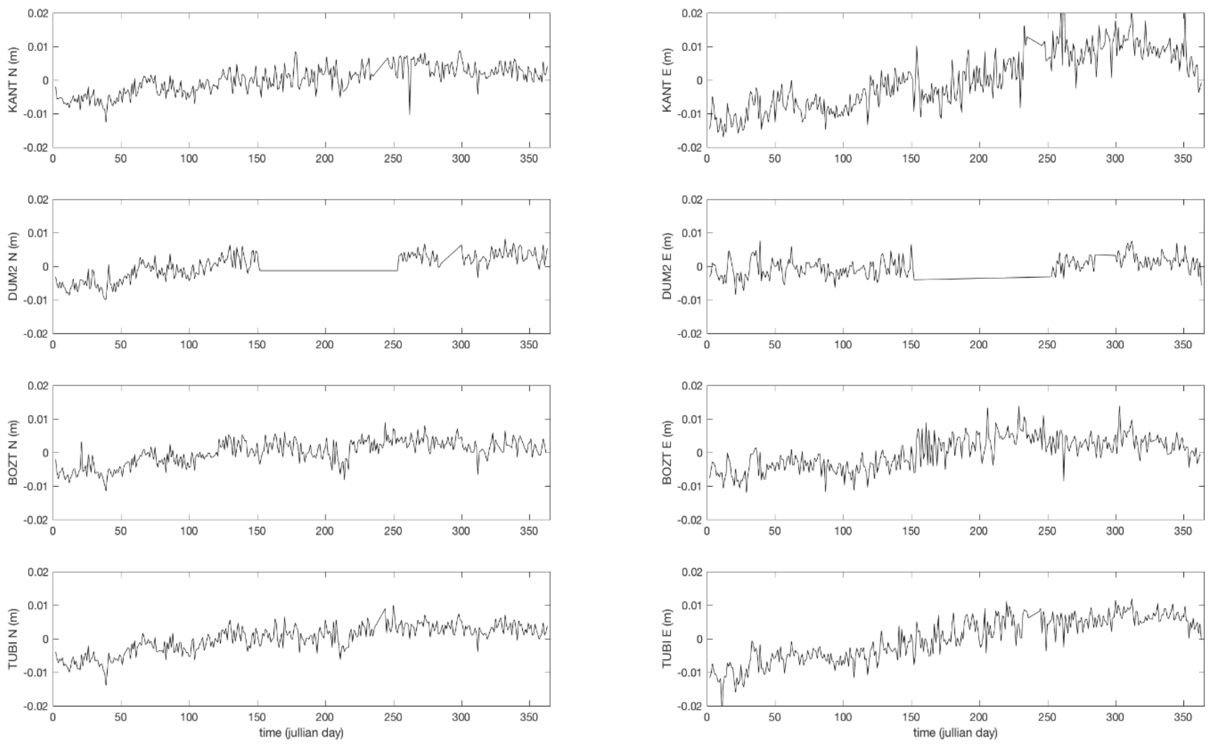

Figure 4. 7. MAGNET Stations' North, East Time Series Graphics.

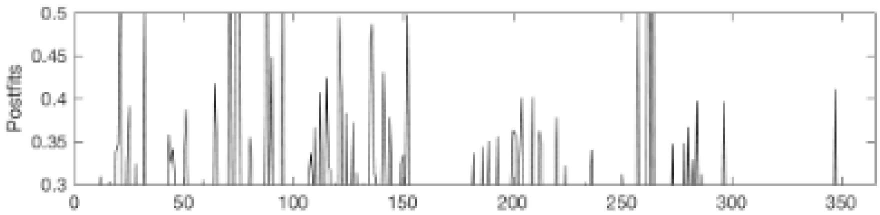

Figure 4. 8. KANT station's Postfits graphic.

The comparisons in these table are done according to the North (N), East (E), Up (U) values. Although the concept of N, E, U values are different from latitude and longitude values, when the results are converted to each other it can be seen that there is no significant difference. (Arslan, 2007)

In the analyzing of a time series, typically the reasonable trend, which may adjust linear, quadratic, ascending and so on indications, is classified and eliminated in the first path (Pytharouli et al. (2004), Pagiatakis (1999)).

High-precision geodetic measurements with GPS play vital roles for evaluating station coordinate and velocities, probabilistic or fundamental interpretation of inter-seismic deformation, satellite orbits, atmospheric delays and Earth orientation parameters.

Table 4. 2. IGS Active Stations used in this study.

St. Name	**Location**
BUCU	Bucharest, Romania
GLSV	Golosiiv, North of Ukraine
BAHR	Manama, Bahrain
GRAS	Caussols, France
GRAZ	Graz, Austria
NICO	Nicosia, Cyprus
ORID	Ohrid, Macedonia
MAT1	Matera, Italy
KIT3	Kitab, Uzbekistan
ZECK	Zelenchukskaya, Russian Federation
NSSP	Yerevan, Armenia
NOT1	Noto, Italy
ONSA	Onsala, Sweeden

POTS	Potsdam, Germany
VILL	Villafranca, Spain
ZWE2	Zwenigorod, Russian Federation

Table 4. 3. MAGNET Stations used in this study.

BOZT	Bozburun
DUM2	Dumanlı
KANT	Kandilli
TUBI	TUBITAK

RINEX data from 16 IGS Stations (Table 4. 2.) are selected in the same baseline distance from KANT permanent station. Besides, 4 MAGNET stations are chosen to be processed (Table 4. 3.). SOPAC web site uses the Hatanaka file compression strategy for all those RINEX data files. Conversion program CRX2RNX from Geospatial Information Authority of Japan (GSI) can be operated in the UNIX system to convert the Hatanaka files into RINEX observation files. Then these files were processed by GAMIT v.10.6 to obtain high-precision coordinates of stations and relevant solutions (Herring et al, 2015). Saastamoinen troposphere model was used for zenith delay. Besides, ocean tide loading was Sherneck model. It took 4 days to process 365-day data. After time series graphics were composed, KANT station's Postfits graphic was obtained (Figure 4. 8.).

Time series graphics include North, East and Up velocity values. Up graphics were not put in this tables to observe, because certain comments can not be made in up velocity graphics. Besides, the accuracy of Up graphic is lower than North and East values.

The Reviews of Stations:

KANT rises linearly on North direction. KANT and TUBI points in the northern region of the NAF are moving north-east direction on the velocity value graphics (Figure 4. 7.). The route of KANT and TUBI stations in the graphics depend on NAF tectonic movement.

There is no data between 150-250 days in DUM2 station. The north and east component of DUM2 are not observed any movement. Hence, east graphics are noisier. BOZT and DUM2 which locate in the south of the NAF are around 0. There is no linear rising and obvious movement on the velocity value graphics. Generally, the range of deviations are from -0.02 to 0.02. Deviations exceed over 0, after 230.

DUM2, BOZT, TUBI stations' East RMS values change similarly from -0.02 to 0.02. There is no significant deviation. The calendar (Appendix A) shows the Julian days and the date of 2014 to analyze the time of processing results. The standard deviations of North and East DUM2 graphs are 0 in the range from 150 to 250 days. Fluctuation on the eastern component is more than the north component.

5. CONCLUSIONS

5.1. Results

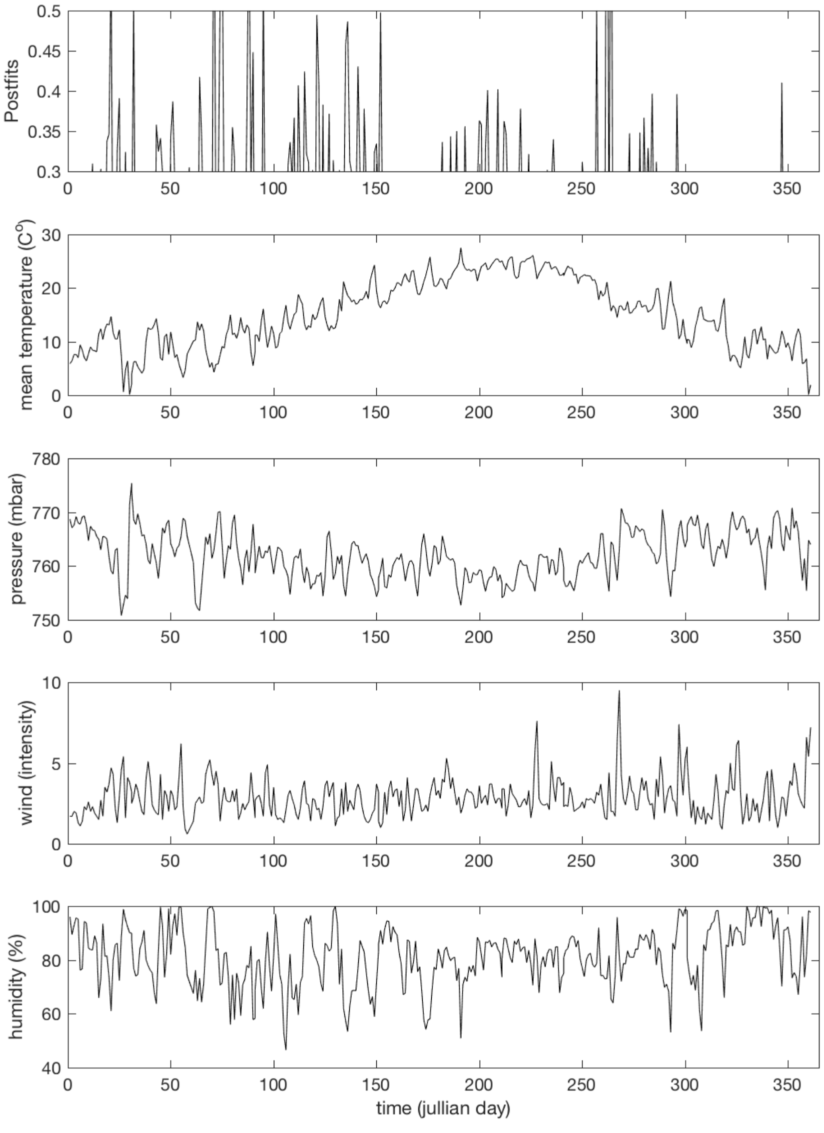

Figure 5.1. KANT postfits and meteorological graphics for 2014.

Regarding the meteorological graphics (Appendix E), atmospheric conditions can be observed the averaged of each month for the period of 2014. The seasonal value graphics show that the temperature graphical curve increased in the summer term. On the contrary, the pressure values decrease with temperature highness. Wind value did not change for a few days in the year. Humidity values changed like increasing and decreasing suddenly in a few days. This alteration could be observed especially in the spring and summer months during the year. There is precipitation in periods of % 100 humidity value. Additionally, the weather is foggy or rainy in the high humidity period.

The north graph of KANT station followed approximately a linear movement for velocity values (Figure 5. 1.). The east graph of KANT is observed fluctuations (noise) especially in the summer period when the temperature increased. There is not fluctuations in North and East values in DUM2 station graphics in the summer days. It is observed “0” in this term. Accordingly, it is clearly seen that DUM2 station has no data in this time period. The trend movement is generally linear in the other time periods during the year. The noise values in the North graph for the BOZT station progressed linearly. A small amount of noise increased for East graphic in the summer term because of high temperature. The values of the north graph are linear on TUBI station. In the east graph, noise activity is observed in some days due to temperature increase and pressure reduction.

5.2. Discussion

The seasonal effect of KANT station can be observed with great accuracy, since the meteorological station is located in the region of KANT. For this reason, the postfits graphic of KANT station was composed. Postfits values are better on summer and autumn days. Postfits values are getting worse on the graphic part where humidity rises.

The values on the postfits graph should be less than 0.2. If the postfits value is less than 0.2 in the graph, most of the data is processed. The results show that the postfits graphic is affected mainly by humidity in the meteorological data. According to the graphical results, the best time for measurement is June, October, November and until the mid-December. The postfits values are acceptable accuracy between 150 and 180 days; 300 and 350 days.

The value of KANT has the effect of wind correlation with the GPS signal on the day when the wind intensity increases. The directions of wind should be researched to define types of wind from meteorological data. For instance, the direction of wind went south from north between 260 and 270 days. The alteration of wind's direction and increased intensity reflected directly in the postfits graphic which shows the GPS measurement. When the meteorological data is observed, it shows that the wind intensity is high on 18th August, 28th September and 27th October, so postfits values are high on these date. Lodos wind blowed from south direction on 22nd, 23rd and 24th September, so the motion of tree leaves around KANT affected postfits values negatively.

Humidity affects the electromagnetics. The KANT postfits values are worse in the winter months, between 0-150 days because of precipitation. The pressure gets the lowest value by snowfall effect when the temperature is 0 degrees Celcius. For this reason, the postfits value turns out higher on 20. Day.

5.3. Conclusion

GPS positioning accuracy decreases on the day when the wind direction and intensity increases. All stations' east components were observed more fluctuation of coordinate values on the time series graphics. Spectral analysis should be made to detect periodic components.

The overall results indicate that more yearly data have to be observed to get the precise results. Further research in this study might produce seasonal effects on the time series graphics well.

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APPENDIX A: GPS CALENDAR

Bundesamt für
Kartographie und Geodäsie

GPS Calendar 2014

January				February				March				April				May				June			
Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day
1 Wed	1	1773 3	56 658	1 Sat	32	1777 6	56 689	1 Sat	60	1781 6	56 717	1 Tue	91	1786 2	56 748	1 Thu	121	1790 4	56 778	1 Sun	152	1795 0	56 809
2 Thu	2	4	659	2 Sun	33	1778 0	56 690	2 Sun	61	1782 0	56 718	2 Wed	92	3	749	2 Fri	122	5	779	2 Mon	153	1	810
3 Fri	3	5	660	3 Mon	34	1	691	3 Mon	62	1	719	3 Thu	93	4	750	3 Sat	123	6	780	3 Tue	154	2	811
4 Sat	4	6	661	4 Tue	35	2	692	4 Tue	63	2	720	4 Fri	94	5	751	4 Sun	124	1791 0	56 781	4 Wed	155	3	812
5 Sun	5	1774 0	56 662	5 Wed	36	3	693	5 Wed	64	3	721	5 Sat	95	6	752	5 Mon	125	1	782	5 Thu	156	4	813
6 Mon	6	1	663	6 Thu	37	4	694	6 Thu	65	4	722	6 Sun	96	1787 0	56 753	6 Tue	126	2	783	6 Fri	157	5	814
7 Tue	7	2	664	7 Fri	38	5	695	7 Fri	66	5	723	7 Mon	97	1	754	7 Wed	127	3	784	7 Sat	158	6	815
8 Wed	8	3	665	8 Sat	39	6	696	8 Sat	67	6	724	8 Tue	98	2	755	8 Thu	128	4	785	8 Sun	159	1796 0	56 816
9 Thu	9	4	666	9 Sun	40	1779 0	56 697	9 Sun	68	1783 0	56 725	9 Wed	99	3	756	9 Fri	129	5	786	9 Mon	160	1	817
10 Fri	10	5	667	10 Mon	41	1	698	10 Mon	69	1	726	10 Thu	100	4	757	10 Sat	130	6	787	10 Tue	161	2	818
11 Sat	11	6	668	11 Tue	42	2	699	11 Tue	70	2	727	11 Fri	101	5	758	11 Sun	131	1792 0	56 788	11 Wed	162	3	819
12 Sun	12	1775 0	56 669	12 Wed	43	3	700	12 Wed	71	3	728	12 Sat	102	6	759	12 Mon	132	1	789	12 Thu	163	4	820
13 Mon	13	1	670	13 Thu	44	4	701	13 Thu	72	4	729	13 Sun	103	1788 0	56 760	13 Tue	133	2	790	13 Fri	164	5	821
14 Tue	14	2	671	14 Fri	45	5	702	14 Fri	73	5	730	14 Mon	104	1	761	14 Wed	134	3	791	14 Sat	165	6	822
15 Wed	15	3	672	15 Sat	46	6	703	15 Sat	74	6	731	15 Tue	105	2	762	15 Thu	135	4	792	15 Sun	166	1797 0	56 823
16 Thu	16	4	673	16 Sun	47	1780 0	56 704	16 Sun	75	1784 0	56 732	16 Wed	106	3	763	16 Fri	136	5	793	16 Mon	167	1	824
17 Fri	17	5	674	17 Mon	48	1	705	17 Mon	76	1	733	17 Thu	107	4	764	17 Sat	137	6	794	17 Tue	168	2	825
18 Sat	18	6	675	18 Tue	49	2	706	18 Tue	77	2	734	18 Fri	108	5	765	18 Sun	138	1793 0	56 795	18 Wed	169	3	826
19 Sun	19	1776 0	56 676	19 Wed	50	3	707	19 Wed	78	3	735	19 Sat	109	6	766	19 Mon	139	1	796	19 Thu	170	4	827
20 Mon	20	1	677	20 Thu	51	4	708	20 Thu	79	4	736	20 Sun	110	1789 0	56 767	20 Tue	140	2	797	20 Fri	171	5	828
21 Tue	21	2	678	21 Fri	52	5	709	21 Fri	80	5	737	21 Mon	111	1	768	21 Wed	141	3	798	21 Sat	172	6	829
22 Wed	22	3	679	22 Sat	53	6	710	22 Sat	81	6	738	22 Tue	112	2	769	22 Thu	142	4	799	22 Sun	173	1798 0	56 830
23 Thu	23	4	680	23 Sun	54	1781 0	56 711	23 Sun	82	1785 0	56 739	23 Wed	113	3	770	23 Fri	143	5	800	23 Mon	174	1	831
24 Fri	24	5	681	24 Mon	55	1	712	24 Mon	83	1	740	24 Thu	114	4	771	24 Sat	144	6	801	24 Tue	175	2	832
25 Sat	25	6	682	25 Tue	56	2	713	25 Tue	84	2	741	25 Fri	115	5	772	25 Sun	145	1794 0	56 802	25 Wed	176	3	833
26 Sun	26	1777 0	56 683	26 Wed	57	3	714	26 Wed	85	3	742	26 Sat	116	6	773	26 Mon	146	1	803	26 Thu	177	4	834
27 Mon	27	1	684	27 Thu	58	4	715	27 Thu	86	4	743	27 Sun	117	1790 0	56 774	27 Tue	147	2	804	27 Fri	178	5	835
28 Tue	28	2	685	28 Fri	59	5	716	28 Fri	87	5	744	28 Mon	118	1	775	28 Wed	148	3	805	28 Sat	179	6	836
29 Wed	29	3	686					29 Sat	88	6	745	29 Tue	119	2	776	29 Thu	149	4	806	29 Sun	180	1799 0	56 837
30 Thu	30	4	687					30 Sun	89	1786 0	56 746	30 Wed	120	3	777	30 Fri	150	5	807	30 Mon	181	1	838
31 Fri	31	5	688					31 Mon	90	1	747					31 Sat	151	6	808				

Bundesamt für
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GPS Calendar 2014

July				August				September				October				November				December			
Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day	Gregor. Date	Day Num-ber	Week / Day	Modif. Julian Day
1 Tue	182	1799 2	56 839	1 Fri	213	1803 5	56 870	1 Mon	244	1808 1	56 901	1 Wed	274	1812 3	56 931	1 Sat	305	1816 6	56 962	1 Mon	335	1821 1	56 992
2 Wed	183	3	840	2 Sat	214	6	871	2 Tue	245	2	902	2 Thu	275	4	932	2 Sun	306	1817 0	56 963	2 Tue	336	2	993
3 Thu	184	4	841	3 Sun	215	1804 0	56 872	3 Wed	246	3	903	3 Fri	276	5	933	3 Mon	307	1	964	3 Wed	337	3	994
4 Fri	185	5	842	4 Mon	216	1	873	4 Thu	247	4	904	4 Sat	277	6	934	4 Tue	308	2	965	4 Thu	338	4	995
5 Sat	186	6	843	5 Tue	217	2	874	5 Fri	248	5	905	5 Sun	278	1813 0	56 935	5 Wed	309	3	966	5 Fri	339	5	996
6 Sun	187	1800 0	56 844	6 Wed	218	3	875	6 Sat	249	6	906	6 Mon	279	1	936	6 Thu	310	4	967	6 Sat	340	6	997
7 Mon	188	1	845	7 Thu	219	4	876	7 Sun	250	1809 0	56 907	7 Tue	280	2	937	7 Fri	311	5	968	7 Sun	341	1822 0	56 998
8 Tue	189	2	846	8 Fri	220	5	877	8 Mon	251	1	908	8 Wed	281	3	938	8 Sat	312	6	969	8 Mon	342	1	999
9 Wed	190	3	847	9 Sat	221	6	878	9 Tue	252	2	909	9 Thu	282	4	939	9 Sun	313	1818 0	56 970	9 Tue	343	2	57 000
10 Thu	191	4	848	10 Sun	222	1805 0	56 879	10 Wed	253	3	910	10 Fri	283	5	940	10 Mon	314	1	971	10 Wed	344	3	001
11 Fri	192	5	849	11 Mon	223	1	880	11 Thu	254	4	911	11 Sat	284	6	941	11 Tue	315	2	972	11 Thu	345	4	002
12 Sat	193	6	850	12 Tue	224	2	881	12 Fri	255	5	912	12 Sun	285	1814 0	56 942	12 Wed	316	3	973	12 Fri	346	5	003
13 Sun	194	1801 0	56 851	13 Wed	225	3	882	13 Sat	256	6	913	13 Mon	286	1	943	13 Thu	317	4	974	13 Sat	347	6	004
14 Mon	195	1	852	14 Thu	226	4	883	14 Sun	257	1810 0	56 914	14 Tue	287	2	944	14 Fri	318	5	975	14 Sun	348	1823 0	57 005
15 Tue	196	2	853	15 Fri	227	5	884	15 Mon	258	1	915	15 Wed	288	3	945	15 Sat	319	6	976	15 Mon	349	1	006
16 Wed	197	3	854	16 Sat	228	6	885	16 Tue	259	2	916	16 Thu	289	4	946	16 Sun	320	1819 0	56 977	16 Tue	350	2	007
17 Thu	198	4	855	17 Sun	229	1806 0	56 886	17 Wed	260	3	917	17 Fri	290	5	947	17 Mon	321	1	978	17 Wed	351	3	008
18 Fri	199	5	856	18 Mon	230	1	887	18 Thu	261	4	918	18 Sat	291	6	948	18 Tue	322	2	979	18 Thu	352	4	009
19 Sat	200	6	857	19 Tue	231	2	888	19 Fri	262	5	919	19 Sun	292	1815 0	56 949	19 Wed	323	3	980	19 Fri	353	5	010
20 Sun	201	1802 0	56 858	20 Wed	232	3	889	20 Sat	263	6	920	20 Mon	293	1	950	20 Thu	324	4	981	20 Sat	354	6	011
21 Mon	202	1	859	21 Thu	233	4	890	21 Sun	264	1811 0	56 921	21 Tue	294	2	951	21 Fri	325	5	982	21 Sun	355	1824 0	57 012
22 Tue	203	2	860	22 Fri	234	5	891	22 Mon	265	1	922	22 Wed	295	3	952	22 Sat	326	6	983	22 Mon	356	1	013
23 Wed	204	3	861	23 Sat	235	6	892	23 Tue	266	2	923	23 Thu	296	4	953	23 Sun	327	1820 0	56 984	23 Tue	357	2	014
24 Thu	205	4	862	24 Sun	236	1807 0	56 893	24 Wed	267	3	924	24 Fri	297	5	954	24 Mon	328	1	985	24 Wed	358	3	015
25 Fri	206	5	863	25 Mon	237	1	894	25 Thu	268	4	925	25 Sat	298	6	955	25 Tue	329	2	986	25 Thu	359	4	016
26 Sat	207	6	864	26 Tue	238	2	895	26 Fri	269	5	926	26 Sun	299	1816 0	56 956	26 Wed	330	3	987	26 Fri	360	5	017
27 Sun	208	1803 0	56 865	27 Wed	239	3	896	27 Sat	270	6	927	27 Mon	300	1	957	27 Thu	331	4	988	27 Sat	361	6	018
28 Mon	209	1	866	28 Thu	240	4	897	28 Sun	271	1812 0	56 928	28 Tue	301	2	958	28 Fri	332	5	989	28 Sun	362	1825 0	57 019
29 Tue	210	2	867	29 Fri	241	5	898	29 Mon	272	1	929	29 Wed	302	3	959	29 Sat	333	6	990	29 Mon	363	1	020
30 Wed	211	3	868	30 Sat	242	6	899	30 Tue	273	2	930	30 Thu	303	4	960	30 Sun	334	1821 0	991	30 Tue	364	2	021
31 Thu	212	4	869	31 Sun	243	1808 0	56 900					31 Fri	304	5	961					31 Wed	365	3	022

APPENDIX B: SESSION TABLE

```
Session Table

Processing Agency = MIT

Satellite Constraint = Y         ; Y/N  (next two lines are free-format
but 'all' must be present)
                 all       a      e      i     n       w       M     rad1
rad2  rad3  rad4  rad5  rad6  rad7  rad8  rad9;
                          0.01  0.01   0.01   0.01    0.01    0.01   0.01
0.01  0.01  0.01  0.01  0.01  0.01  0.01  0.01

  << Controls must begin in column 1 >>

Choice of Experiment = BASELINE   ; BASELINE/RELAX./ORBIT
Type of Analysis = 1-ITER         ; 1-ITER(autcln prefit and conditional
redo) / 0-ITER (no postfit autcln) / PREFIT
AUTCLN redo = Y                   ; Y/N; 3rd soln only if needed, assume
'Y' if 'Type of analysis = 1-ITER'
Choice of Observable = LC_AUTCLN  ; LC_AUTCLN (default), LC_HELP
(codeless L2), L1_ONLY (L1 soln from dual freq),
                                    L2_ONLY (L2 soln from dual freq),
L1,L2_INDEPENDENT (L1 + L2 from dual freq)
                                    L1&L2 (same as L1,L2_INDEPENDENT but
with ion constraint);
                                    L1_RECEIVER (must add 'L1only' in
autcln.cmd)
Station Error = ELEVATION 10 5    ; 1-way L1, a**2 +
(b**2)/(sin(elev)**2) in mm. default = 10. 0.
AUTCLN reweight = Y               ; Y/N; reweight data from autcln rms;
replaces  'Use N-file' in releases < 10.32
AUTCLN Command File = autcln.cmd  ; Filename; default none (use default
options)
Decimation Factor = 4             ; FOR SOLVE, default = 1
Quick-pre decimation factor = 10  ; 1st iter or autcln pre, default same
as Decimation Factor
Quick-pre observable = LC_ONLY    ; for 1st soln, default same as Choice
of observable

Ionospheric Constraints =  0.0 mm + 8.00 ppm
Ambiguity resolution WL = 0.15 0.15 1000. 99. 15000. ; for LC_HELP,
ignored for LC_AUTCLN
Ambiguity resolution NL = 0.15 0.15 1000. 99. 15000. ; allow long
baselines with LC_AUTCLN

Zenith Delay Estimation = Y     ; Yes/No  (default No)
Interval zen = 2                ; 2 hrs = 13 knots/day  (default is 1 ZD
per day)
Zenith Constraints = 0.50       ; zenith-delay a priori constraint in
meters (default 0.5)
Zenith Variation = 0.02 100.    ; zenith-delay variation, tau in
meters/sqrt(hr), hrs (default .02 100.)
Elevation Cutoff = 0              ; default 0 to use value in autcln.cmd
Atmospheric gradients = Y       ; Yes/Np  (default No)
```

```
Number gradients = 2           ; number of gradient parameters per day
(NS or ES); default 1
Gradient Constraints = 0.01     ; gradient at 10 deg elevation in meters;
default 0.03 m

Update T/L files = L_ONLY       ; T_AND_L (default), T_ONLY, L_ONLY, NONE
Update tolerance = .3           ; minimum adjustment for updating L-file
coordinates, default .3 m

Met obs source = GPT 50         ; hierarchical list with humidity value
at the end; e.g. RNX UFL GPT 50 ; default GTP 50
                                   if [humid value] < 0, use RNX,
UFL(VMF1), or GPT2 if available
Output met = N                  ; write the a priori met values to a z-
file (Y/N)
Use met.list = N                ; not yet supported
Use met.grid = N                ; not yet supported
DMap = GMF                      ; GMF(default)/VMF1/NMFH; GMF now invokes
GPT2 if gpt.grid is available (default)
WMap = GMF                      ; GMF(default)/VMF1/NMFW; GMF now invokes
GPT2 if gpt.grid is available (default)
Use map.list = N                ; VMF1 list file with mapping functions,
ZHD, ZWD, P, Pw, T, Ht
Use map.grid = N                ; VMF1 grid file with mapping functions
and ZHD
Yaw Model = Y                   ; Y/N  default = Y
Radiation Model for ARC = BERNE  ; BERNE/BERN2/UCLR1/UCLR2/NONE  default
= BERNE
Earth radiation model = NONE     ; NCLE1/NCLE2/TUME1/TUME2/NONE  default
= NONE; MIT repro2 = NCLE1
Antenna thrust model = NONE      ; ANTBK/NONE  default = NONE; MIT repro2
= ANTBK
Inertial frame = J2000           ; J2000/B1950 default = J2000
Reference System for ARC = EGM08 ; WGS84/EGM96/EGM08/EGR08  default =
EGM008; MIT repro2 = EGR08 (relativity)

Tides applied = 31               ; Binary coded: 1 earth  2 freq-dep  4
pole  8 ocean  16 remove mean for pole tide
                                 ; 32 atmosphere ;  default = 31
Use otl.list = N                 ; Ocean tidal loading list file from OSO
Use otl.grid = Y                 ; Ocean tidal loading grid file, GAMIT-
format converted from OSO
Etide model = IERS03             ; IERS96/IERS03
Earth Rotation = 11              ; Diurnal/Semidirunal terms: Binary
coded: 1=pole 2=UT1 4=Ray model; 8=IERS2010 16=include libration terms;
default=11
Apply atm loading = N            ; Y/N for atmospheric loading
Use atml.list = N                ; Atmospheric (non-tidal) loading list
file from LU
Use atml.grid = N                ; Atmospheric (non-tidal) loading grid
file from LU, converted to GAMIT format
Use atl.list = N                 ; Atmospheric tides, list file, not yet
available
Use atl.grid = N                 ; Atmospheric tides, grid file

Antenna Model = AZEL             ; NONE/ELEV/AZEL  default = ELEV   Use
AZEL for IGS absolute ANTEX files
SV antenna model = ELEV          ; NONE/ELEV       default = NONE   Use
ELEV for IGS ANTEX files
```

```
SV antenna off = N              ; Y/N to estimate satellite antenna
offsets (default N)

Delete AUTCLN input C-files = Y  ; Y/N ; default Y to force rerun of
MODEL
Scratch directory = /tmp

 << List of additional controls not commonly - blank first column to
indicate a comment >>

  Simulation con                  : s-file name
  Inertial frame = B1950          ; B1950/J2000 (default = J2000)

  Initial ARC                     ; Y/N  default = Yes
  Final ARC                       ; Y/N  default = No
  Radiation Model for ARC         ; SPHRC/BERNE/SRDYB/SVBDY  default =
SPHRC
  Reference System for ARC        ;
WGS72/WGS84/MERIT/IGS92/EGM96/EGM08(incremental_updates) (default =
EGM08)
  Reference System for ARC = EGM08 ;
WGS72/WGS84/MERIT/IGS92/EGM96/EGM08/EGR08  default = EGM008; MIT repro2 =
EGR08 (relativity)

  Tabular interval for ARC        ; 900. seconds (new default), 1350.
seconds (old default)
  Stepsize for ARC                ; 75. seconds (new default), 168.75
seconds (old default)
  Arc debug flag                  : Turn on various print and test
options (see arc.f) (default = 0 )

  Earth Rotation                  ; Diurnal/Semidirunal terms: Binary
coded: 1=pole 2=UT1 4=Ray model; 8=IERS2010 ; default=11
  Estimate EOP                    ; Binary coded: 1 wob   2 ut1   4 wob
rate   8 ut1 rate
  Wobble Constraint = 3. 0.3      ; Default 3. (arcsec) 0.3 (arcsec/day)
  UT1 Constraint = 0.00002 0.02   ; Default .00002 (sec) 0.02 (sec/day)

  Number Zen = 4                  ; number of zenith-delay parameters
(default 1)
  Zenith Constraints = 0.50       ; zenith-delay a priori constraint in
meters (default 0.5)
  Zenith Model = PWL              ; PWL (piecewise linear)/CON (step)
  Zenith Variation = 0.02 100.    ; zenith-delay variation, tau in
meters/sqrt(hr), hrs (default .02 100.)
  Gradient Constraints = 0.03     ; gradient at 10 deg elevation in
meters
  Gradient Variation = .01 100    ; gradient variation
  Tropospheric Constraints = NO   ; YES/NO   (spatial constraint)

  Ion model = NONE                ; NONE/GMAP (default NONE) use 2nd/3rd
order ionsopheric corrections
  Mag field = IGRF12              : IGRF12/IGRF11/IGRF10/DIPOLE (default
IGRF12)

  Yaw Model                       ; YES/NO  default = YES
  I-file = N                      ; Use I-file (Y/N)  (default Y)
```

```
  AUTCLN Postfit = Y              ; Assume 'Y' if 'Type of analysis = 1-
ITER' (autcln.cmd.postfit file also)
  Delete AUTCLN input C-files = Y ; YES/NO/Intermediate (default no)
  AUTCLN Command File             ; Filename; default none (use default
options)
  Delete eclipse data = POST      ; ALL/NO/POST (Default = NO)
  SCANDD control                  ; BOTH (default) /NONE/FIRST/FULL/IFBAD
see manual sec. 5.2
  Iteration                       ; CFILES / XFILES (default)
  Edit AUTCLN Command File        ; YES/NO; default = NO  (For clocks, no
longer needed)

  Ambiguity resolution WL         ; default = 0.15 0.15 1000.  10. 500.
  Ambiguity resolution NL         ; default = 0.15 0.15 1000.  10. 500.
  Type of Biases                  : IMPLICIT (default for quick),
EXPLICIT (default for full)
  H-file solutions                ; ALL ; LOOSE-ONLY
  Skip loose                      : Y / N (default) sometimes necessary
for short baselines
  Station Error = BASELINE 10. 0.   ; 1-way L1, a**2 + (b**2)(L**2) in
mm, ppm, default = 10. 0.
  Station Error = UNIFORM 10.       ; 1-way L1 in mm, default = 10.
  Station Error = ELEVATION 4.3 7.0 ; 1-way L1 , a**2 + b**2/sin(elev)**2
in mm, default = 4.3 7.0
  Satellite Error = UNIFORM 0.      ; 1-way L1 in mm (added quadratically
to station error) default = 0.
  Select Epochs                   ; Enter start and stop epoch number
(applies only to SOLVE)
  Decimation Factor               ; FOR SOLVE, default = 1
  Elevation Cutoff = 15.          ; For SOLVE, overrides the MODEL or
AUTCLN values if they are lower
  Correlation print               ; Threshhold for printing correlations
(default 0.9999)

  Export Orbits                   ; YES/NO  default = NO
  Orbit id                        ; 4-char code read only if Export
Orbits = YES
  Orbit Format                    ; SP1/SP3 (NGS Standard Products)
  Orbit organization              ; 3-char code read only if Export
Orbits = YES
  Reference System for Orbit = ITR93 ; ITR92/ITR91/ITR90/WGS84/MERIT (for
SP3 header)
  Reference System for ARC = EGM08 ; WGS84/EGM96/EGM08/EGR08  default =
EGM008; MIT repro2 = EGR08 (relativity)

  Lunar eclipses = Y               ; Set = N to turn off lunar eclipses
in ARC to match model of GAMIT < 10.2 (default Y)
                                    (no longer supported: see arc_debug
below)
  Delete all input C-files        ; YES/NO  default = NO
  Delete MODEL input C-files      ; YES/NO  default = NO
  Delete AUTCLN input C-files     ; YES/NO  default = NO
  Update T/L files                ; T_AND_L (default), T_ONLY, L_ONLY,
NONE
                                   (Applies only to update for final
solution after initial )
  Update tolerance                ; minimum adjustment for updating L-
file coordinates, default .3 m
  SOLVE-only = YES                ; YES/NO  default = NO
```

```
  X-compress = YES                ; Uncompress/compress X-files  default
= NO
  SCANDD control                  ; FULL (default), FIRST, BOTH, IFBAD,
NONE
  Run CTOX = YES                  ; Make clean X-files from C-files
default = NO
  Bias apriori = 100.             ; Optional constraint on biases for
LC_AUTCLN (default 0 -> no constrint)
  SOLVE print  = Y                ; Turn on SOLVE output to screen
(default N)

  Bias apriori = 1000.            ; Optional constraint on biases for
LC_AUTCLN (default 1000, 0 -> constraint)
  Bias rcond = 10000.             ; Condition number ratio for fixing
dependent biases (default 10000.)
```

APPENDIX C: PROCESS.DEFAULTS

```
# process.defaults
#
#  Do not remove any of these entries. To by-pass a function, set the
value to null: ""

## LOCAL DIRECTORIES
# Directory for translation of raw data
 set rawpth = "$procdir/raw"
# Directory path for raw archives (search all levels); e.g. /data18/simon
 set rawfnd = ""
# Input files for RINEX translators
 set mpth = "$procdir/mkrinex"
# RINEX files directory
 set rpth = "$procdir/rinex"
# Directory path for RINEX archives (search all levels); e.g.
/data18/simon
 set rnxfnd = ""
# Broadcast orbit directory
 set bpth = "$procdir/brdc"
# IGS files directory
 set ipth = "$procdir/igs"
# G-files directory
 set gpth = "$procdir/gfiles"
# GAMIT and GLOBK tables directory
 set tpth = "$procdir/tables"
# Output gifs directory
 set gifpth = "$procdir/gifs"
# Globk solution directory
 set glbpth = "$procdir/gsoln"
# Globk binary h-file directory
 set glfpth = "$procdir/glbf"
# Directory path for other h-files (LA, LB, LC options; search all
levels)
#  e.g. "/raid1/tah/SIO_GLL"; ( /raid6/ftp/pub/MIT_GLL/H07
/raid2/simon/gps_analysis/cgps_hfiles )
 set hfnd = ""
# Template files
 set templatepth = "$procdir/templates"
# Place to store temporary control files
 set cpth = "$procdir/control"
# Archive root directory (cannot be null)
 set archivepth = "$procdir/archive"

## FTP INFO FOR REMOTE FILES
# Raw data archive
# set rawarchive = 'chandler.mit.edu'
# set rawdir = 'pub/continuous/mitnet'
# set rawlogin = "anonymous simon@chandler.mit.edu"
# Addresses for CDDSI, SOPAC, IGSCB, UNAVCO, BKG, IGN, USNO are given in
template/ftp_info

##GAMIT
# Set sampling interval, number of epochs, and start time for processing
 set sint = '30'
```

```
 set nepc = '2880'
 set stime = '0 0'
# Variables for updating tables
 set stinf_unique = "-u"
 set stinf_nosort = "-nosort"
 set stinf_slthgt = "2.00"
# Set "Y" to use RINEX header coordinates not in lfile or apr file
 set use_rxc      = "N"
# Broadcast orbits
 set brdc = 'brdc'
# Minimum x-file size to be processed (Def. 300 blocks; most OS use 1 Kb
blocks)
 set minxf = '300'
# Set search window for RINEX files which might contain data for day -
default check the previous day
 set rx_doy_plus = 0
 set rx_doy_minus = 1
# Default globk .apr file
 set aprf = itrf08_comb.apr
# Set compress (copts), delete (dopts) and archive (aopts) options.
(Don't forget to set the archivepth.)
# Possible d-, c-, and a- opts: D, H, ao, ac, as, b, c, d, e, g, h, i, j,
k, l, m, o, p, q, t, x, ps, all"
 set dopts = ( c )
 set copts = ( x k ao )
 set aopts = ''
# Set the rinex ftp archives (defined in ftp_info) you would like to look
for data in.
# (Default archives searched are: sopac, cddis and unavco).
set rinex_ftpsites = (sopac cddis unavco)


## RESOURCES
# Minimum raw disk space in Mbytes
 set minraw = '100'
# Minimum rinex disk space in Mbytes
 set minrinex = '100'
# Minimum archive disk space in Mbytes
 set minarchive = '100'
# Minimum working disk space in Mbytes
 set minwork = '500'

## SYSTEM-DEPENDENT SETTINGS
# UNIX df command must be set to return the correct form
# Most machines (
 set udf = 'df -mk'
#   but note that if you have free > 1 Tb, you will need to change this
to Mb
# set udf = 'df -m'
# HP
# set udf = 'bdf'
# UNIX mail command
#  Most machines
 set umail = 'mail -s'
#  HP
# set umail = 'mailx -s'
# Mail address for sending the processing report (if '' will default to
`whoami` in sh_gamit)
 set mailto = ''
```

```
# Host name for email and anonymous ftp password use (if '' will default
to `hostname` in sh_gamit)
 set machine = ''
# Ghostscript path
set gspath = '/usr/bin'
# ImageMagick path fir gif conversion
# set impath = '/usr/bin/X11'
set impath = '/usr/bin'
```

APPENDIX D: SITES.DEFAULTS

```
# Format: site expt keyword1 keyword2 ....
#
#  where the first token is the 4- or 8-character site name (GAMIT uses only
#  4 characters, GLOBK allows only 4 unless there are earthquakes or renames),
#  the second token is the 4-character experiment name, and the remaining
#  tokens, read free-format, indicate how the site is to be used in the processing.
#  All sites for which there are RINEX files in the local directory will be used
#  automatically and do not need to be listed.
#
#  ftprnx = sites to ftp from rinex data archives.
#  ftpraw = sites to ftp from raw data archives.
#  localrx = site names used to search for rinex files on your local system.
#              (required in conjunction with rnxfnd path variable set in process.defaults).
#  xstinfo = sites to exclude from automatic station.info updating.
#  xsite   = sites to exclude from processing, all days or specified days
#
# Replace 'expt' with your experiment name and edit the following to list sites needed from
external archive
 all_sites ayca  xstinfo
 nico_gps ayca ftprnx
 zeck_gps ayca ftprnx
 orid_gps ayca ftprnx
 mat1_gps ayca ftprnx
 bucu_gps ayca ftprnx
 not1_gps ayca ftprnx
 onsa_gps ayca ftprnx
 pots_gps ayca ftprnx
 gras_gps ayca ftprnx
 graz_gps ayca ftprnx
 vill_gps ayca ftprnx
 zwe2_gps ayca ftprnx
 bahr_gps ayca ftprnx
 kit3_gps ayca ftprnx
 nssp_gps ayca ftprnx
 glsv_gps ayca ftprnx
# templates for removing sites
# ttth_gps  expt xsite:1999_256-1999_278 xsite:1999_300-1999_365
```

APPENDIX E: METEOROLOGICAL GRAPHICS

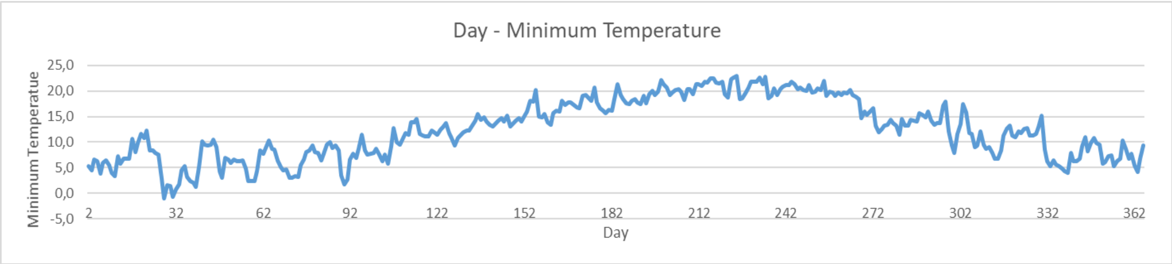

Figure E. 1. 30-day average of minimum temperature graphic in 2014.

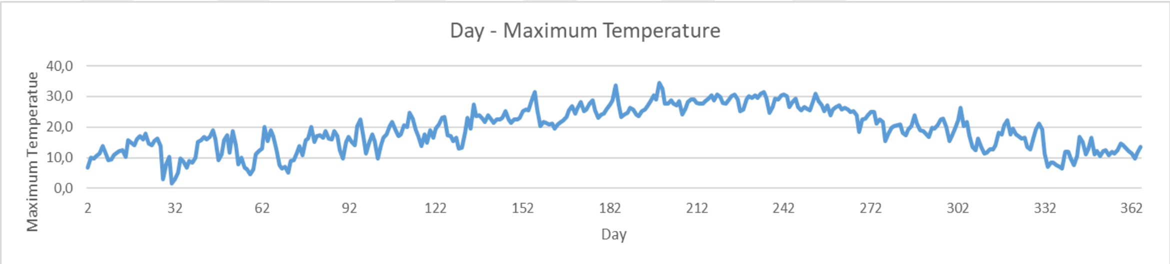

Figure E. 2. 30-day average of maximum temperature graphic in 2014.

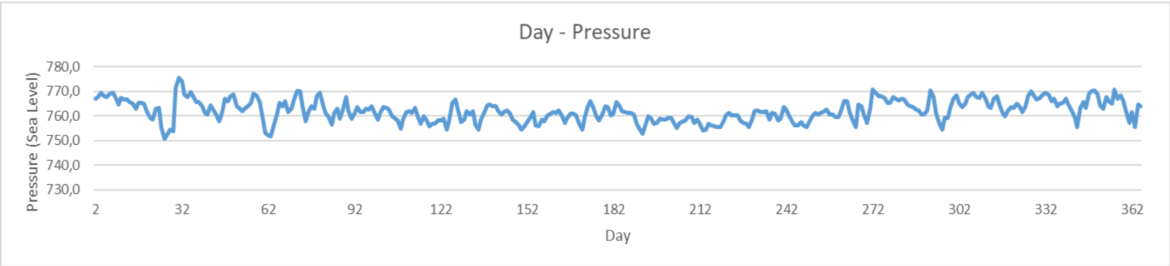

Figure E. 3. 30-day average of pressure graphic in 2014.

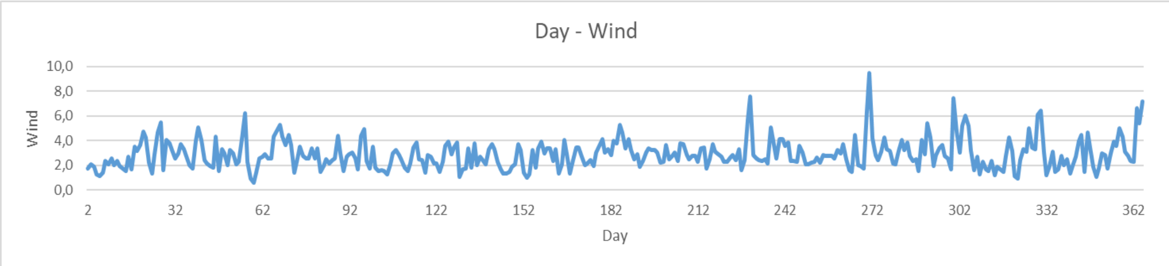

Figure E. 4. 30-day average of wind graphic in 2014.

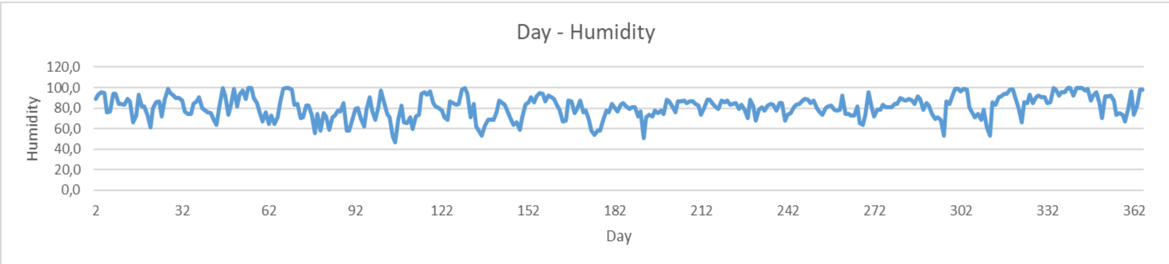

Figure E. 5. 30-day average of humidity graphic in 2014.