Sudan University of Science and Technology

College of Graduate Studies

Effect of Epoch on Global Positioning System Observations

أثر لحظة الرصد علي إرصادات نظام الموقع العالمي

A thesis submitted as a partial fulfillment to the admission of the degree of Master in Geodesy and GIS

Prepared by:

Mohammed alnour yagoub

Supervised by:

Dr. Alhadi Alnazier Ibrahim

August 2017

بسم الله الرحمن الرحيم

وَأَلْقَىٰ فِي الْأَرْضِ رَوَاسِيَ أَن تَمِيدَ بِكُمْ وَأَنْهَارًا وَسُبُلًا
لَّعَلَّكُمْ تَهْتَدُونَ(15) وَعَلَامَاتٍ وَبِالنَّجْمِ هُمْ يَهْتَدُونَ (16)

صدق الله العظيم

الآيتان (15) و (16) من سورة النحل

Acknowledgements

First and foremost, I must mention and thanks for Allah, and to my guide and supervisor **Dr. Elhadi Elnazier Ibrahim**, Who led me with patience, The research would not have been possible without his advices and assistance Beside of many colleagues and friends. Without him, I may not have started my research . The research would not have become a reality without the encouragement of many colleagues and friends.

A lot of thanks are to:
My family and community
The staff of Surveying Engineering Department .
My colleagues and friends for Khartoum State Survey.

المستخلص

نظم الاحداثيات مهمة جدا لتحديد المواقع علي الاسطح، علي سبيل المثال نظم الاحداثيات الارضية مرجعها سطح الارض.

يمكن ان تتغير الاحداثيات الارضية مبنية علي عدة عوامل من اهمها تحركات القشرة الارضية والزلازل الارضية ، ولتجنب هذه الاسباب يجب رصد نقاط الضبط في فترات زمنية متفاوته والمقارنة بين تلك الارصادات .

يهدف هذا البحث الي المقارنة بين ثلاث فترات زمنية (2007-2005-2000) ، وتم رصد عدد 30 نقطة موزعة داخل ولاية الخرطوم ، باستخدام طريقة الرصد الثابت، واستخدمت طريقة الجزر ألتربيعي لمتوسط مربعات الأخطاء للمقارنة بين النتائج في الفترات الثلاث.

Abstract

Coordinate system is very important to determine positions on the surfaces, for example ground coordinate system depends on the earth surface. It can be change depends on several factors, the most important is earth crust move and earth quake, to avoid this reasons must be observe some of control points in different epochs to compare between epochs.

This research aims to compare between three epochs (2000-2005-2007) , by observed 30 points distributed in Khartoum state , the method for observation were static GPS observation , Root Mean Square Error(RMSE) was used for comparison between epochs.

TABLE OF CONTENT

Contents ***page***

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 General

The Global Positioning System (GPS) is a navigation system based on satellite technology. Its fundamental technique involves measuring the ranges between the receiver and a few simultaneously observed satellites, and the positions of the satellites are forecasted and broadcasted along with the GPS signal to the user.

Through several known positions (of the satellites) and the measured distances between the receiver and the satellites, the position of the receiver can be determined.

The position change, which can also be determined, is then the velocity of the receiver. The most important applications of GPS are positioning and navigation.

Through its evolution over the past few decades, GPS has now come to be known even by school children. It has been extensively applied in several areas, including air, sea, and land navigation, low-earth orbit (LEO) satellite orbit determination, static and kinematic positioning, and flight-state monitoring, as well as surveying.

Its wide utility has made GPS a necessity for industry, research, education, and daily life.

To describe the motion of the GPS satellites, an inertial coordinate system must be defined.

The motion of the satellites follows Newtonian mechanics, and Newtonian Mechanics is valid and expressed in an inertial coordinate system.

The Conventional Celestial Reference Frame (CRF) is suitable for our purpose.

The xy-plane of the CRF is the plane of the earth’s equator; the coordinates are celestial longitude, measured eastward along the equator from the vernal equinox, and celestial latitude.

The vernal equinox is a crossover point of the ecliptic and the equator.

Thus, the right-handed earth centered inertial (ECI) system uses the earth center as the origin, the CIO as the z-axis, and its x-axis is directed to the equinox of J2000.0 (Julian date for 1 January 2000 at 12 h).

Such a coordinate system is also called equatorial coordinates of date.

Because of the motion (acceleration) of the earth’s centre, ECI is indeed a quasi-inertial system, and the general relativistic effects must be taken into account.

The system moves around the sun, however, without rotating with respect to the CIO.

This system is also called the earth-centred space-fixed (ECSF) coordinate system.

The International Terrestrial Reference Frame (ITRF) is formed through Cartesian coordinates and linear velocities of a global set of sites equipped with various space geodetic observing systems. If geographical coordinates (ellipsoidal latitude, longitude, and height) are required instead of Cartesian coordinates (X, Y, Z), use of the GRS80 ellipsoid is recommended .The ensemble of coordinates implicitly define the CTP (Z-axis) and the GMO (X-axis).

1.2 Problem statement

Ground coordinates are effected by several factors , the most important of the earth’s crust move , so must observe the reference points at specified intervals.

1.3 Research Objectives

This research aims to:

- Compare between epochs.
- Evaluate the magnitude of error.

1.4 Thesis Layout

This research contains of five chapters. Chapter one includes this introductory, Chapter two global positioning systems, chapter three describes Reference Coordinate Systems, chapter four explain methodology and results, Chapter five Conclusion of this work and recommendations.

CHAPTER TWO

GLOBAL POSITIONING SYSTEM (GPS)

The Navigation Satellite System with Time And Ranging (NAVSTAR) Global Positioning System (GPS) is a satellite-based radio navigation system providing precise three dimensional position, navigation, and time information to suitably equipped users. the system is continuously available on a world-wide basis, and is independent of meteorological conditions. GPS has been under development in the U.S.A. since 1973, and is primarily a military system, with limited access to civil users.

It has been used for the solution of geodetic problems since about 1983. in its final configuration, available since 1995, the system nominally consists of 24 satellites placed in orbits of about 20 200 km altitude above the Earth’s surface.

The arrangement of satellites has been planned in such a way that at least four satellites are simultaneously visible above the horizon, anywhere on Earth, 24 hours a day.

GPS is primarily a navigation system. the fundamental navigation principle is based on the measurement of so-called pseudo ranges between the user and four satellites.

Starting from the known satellite coordinates in a suitable reference frame the coordinates of the user antenna can be determined. from the geometrical point of view three range measurements are sufficient.

A fourth observation is necessary because GPS uses the one-way ranging technique, and the receiver clock is not synchronized with the satellite clock. This synchronization error is the reason for the term “pseudorange”.

The description of the GPS system follows the division that is customary for navigation satellites:

Space Segment: with active satellites.
Control Segment :for system and time control, and for the prediction of orbits .
User Segment *:* with different receiver types .

2.1 Space Segment

The basic constellation, when fully implemented, consists of 24 space vehicles. The satellites are placed in almost circular orbits in six orbital *planes,* with an orbital inclination of 55 degrees.

The orbital height is about 20 200 km, corresponding to about 26 600 km for the semi-major axis. the orbital period is exactly 12 hours of sidereal time, and provides repeated satellite configurations four minutes earlier each day with respect to universal time.

The arrangement of satellites in the full constellation, the so-called baseline constellation, the orbital position of each satellite in one of the six orbital planes *A* to *F* is indicated by its plane position number, also named *slot.* four slots are assigned to each plane. six additional slots, *A*5 through *F*5, are provided on the basis of need for active spares. the separation in right ascension between two orbital planes is 60◦.the position of a satellite within the particular orbital plane can be identified by the argument of the latitude , although the baseline constellation includes 24 satellites, the number of active satellites on orbit may vary due to failures, launches,

or maintenance requirements, and since 1995 has exceeded 24. on January 1, 2003, the constellation comprised 28 satellites. with the augmented constellation, most users will have six to eight, or at times even more, satellites in view instead of the minimum of four satellites.

Three generations of satellites have been launched:

Block I development satellites,
Block II/IIa production satellites, and
Block IIR replenishment satellites.

2.2 Control Segment

The tasks of the Control Segment are to (e.g. Russell, Schaibly, 1980; Misra, Enge, 2001)

− continuously monitor and control the satellite system,
− determine the GPS system time,
− predict the satellite ephemerides and the behavior of the satellite clocks,
− periodically update the navigation message for each particular satellite and,
− command small maneuvers to maintain orbit, or relocate to substitute an unhealthy satellite.

Within the Control Segment are the Master Control Station (MCS), several unmanned monitor stations (MS) located around the world, and *ground antennas* (GA) for uploading data to the satellites. the Operational Control Segment (OCS) for GPS consists of the MCS near Colorado Springs (U.S.A.), four monitor stations and co-located ground antennas in Ascension Island, Cape Canaveral, Diego Garcia and Kwajalein, and two more monitor stations in Colorado Springs and Hawaii. the monitor stations and ground antennas are operated remotely from the Master Control Station.

The monitor stations receive all satellite signals, from which they determine the pseudoranges to all visible satellites, and transmit the range data along with local meteorological data via data link to the Master Control Station.

From these data the MCS precomputes satellite ephemerides and the behavior of the satellite clocks and formulates the navigation data (message). The message data are transmitted to the ground antennas and uplinked via S-band to the satellites in view.

Shows this process schematically. because of the global distribution of the upload antennas at least three contacts per day can be realized between the control segment and each particular satellite. Signals transmitted by GPS satellites are based on GPS System Time. until June1990 this was the time given by the cesium oscillator at one of the monitor stations.

The Global Positioning System (GPS) Figure (2.1). Data flow in the determination of the broadcast ephemeris .

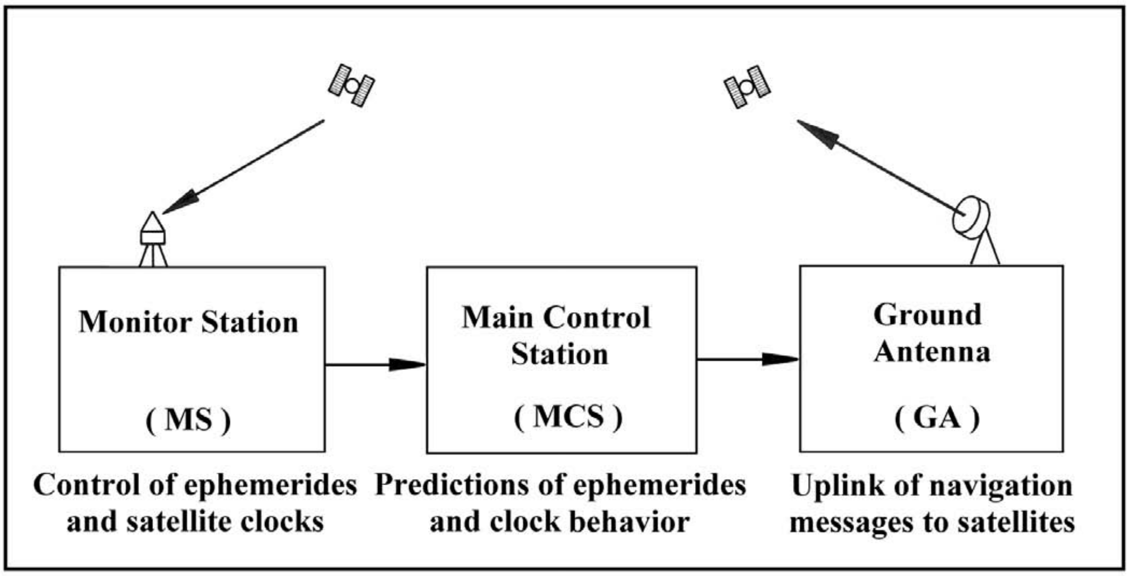


Figure 2.1: Data flow in the determination of the broadcast ephemeris

2.3 Observation Principle and Signal Structure

NAVSTAR GPS is a one-way ranging system, i.e. signals are only transmitted by the satellite.

The fundamental observable is the signal travel time between the satellite antenna and the receiver antenna.

The signal travel time is scaled into a range measurement using the signal propagation velocity.

One-way ranging means that a clock reading at the transmitter antenna is compared with a clock reading at the receiver antenna. in general, it cannot be assumed that the two clocks are strictly synchronized.

The observed signal travel time thus contains a systematic synchronization error (time bias).

Biased ranges are also called *pseudo ranges*. Hence, the basic observation principle of GPS can be regarded as the determination of pseudo ranges. Fig (2.2) demonstrates that the simultaneous observation of four pseudo ranges is required to derive the three coordinates of the user antenna and the clock synchronization error.

As an additional requirement, it is also necessary to know the satellite position and the satellite time

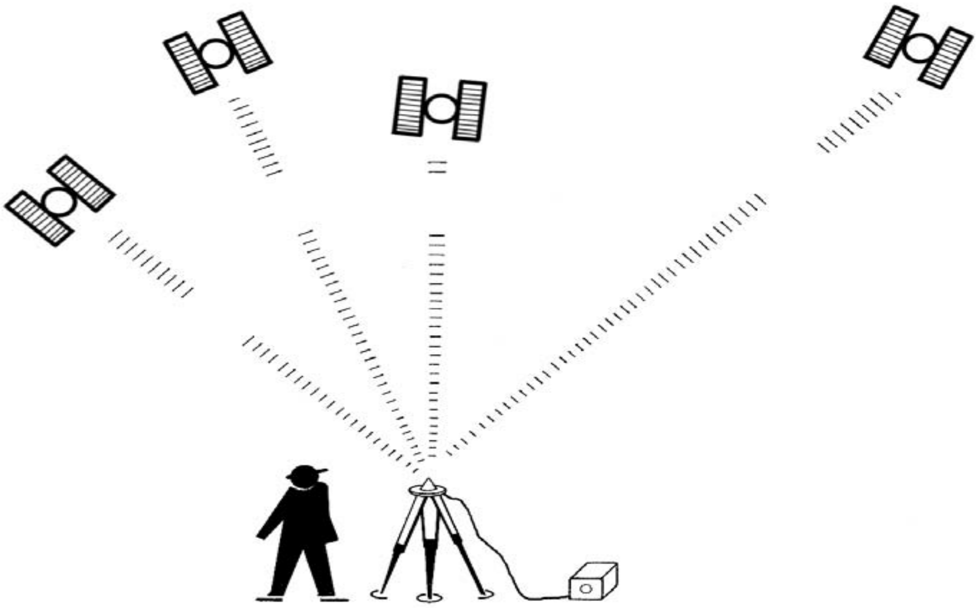


Figure2.2 : Basic principle of positioning with GPS

GPS signals must provide a means for determining positions in real-time. This is achieved by modulating the carriers with pseudorandom noise (PRN) codes.

These are sequences of binary values (zeros and ones, or +1 and−1) which appear to have random character, but which can be identified unequivocally. Their most important property is a low autocorrelation value for all delays except those that coincide exactly the pseudo ranges are derived from the travel time of an identified coded PRN signal.

Two different codes are in use, the P-code and the C/A-code. P means precision or protected, and C/A means clear/acquisition.

The *P-code* has a frequency of 10.23 MHz, i.e. a sequence of 10.23 million binary digits or *chips* per second.

This frequency is also referred to as the *chipping rate* of the P-code. the corresponding "wavelength" of one chip is about 30 m. the P-code sequence is extremely long; it only repeats after 266 days (38 weeks). Portions of seven days each are assigned to the various satellites. as a result, all satellites can transmit on the same frequency and can be identified by their unique one-week PRN segment. This technique is also called *code division* multiple access (CDMA).

The code segments are set back to zero each week at midnight (0h UT) from Saturday to Sunday. the P-code is the principle code for navigation and available on both carrier frequencies L1 and L2.

Note that with the implementation of Anti-Spoofing the P-code has been encrypted for non-authorized users.

The *C/A-code* has a length of only one millisecond and is generated at a chipping rate of 1.023 MHz The corresponding wavelength is about 300 m. the C/A-code is currently only transmitted on the L1 carrier.

The epochs of both codes are synchronized. for detailed information on the structure and the generation of the codes, to determine the signal propagation time, the user needs a copy of the code sequence in the receiver.

This code sequence is phase-shifted in time step by step, and correlated with the received code signal until maximum correlation is achieved. the necessary phase shift in the two sequences of codes is a measure of the signal travel time between the satellite and receiver antennas.

This technique can be described as code phase observation.

For precise geodetic applications the pseudo ranges have to be derived from phase measurements on the carrier signals because of the much better resolution. This technique requires, however, a solution to the problem of ambiguity determination and is discussed in more detail. The third type of signal transmitted from a GPS satellite is the broadcast message .

2.4 Orbit Determination and Orbit Representation

Determination of the Broadcast Ephemerides

In order to solve the navigation task the user must have real-time access to the satellite positions and satellite system time.

This is made possible by the orbit information, the navigation message, that is contained in the data signal. the navigation message is determined by the Control Segment and “broadcast” to the users via the GPS satellites.

These broadcast ephemerides are generated in two steps. First, a reference ephemeris, based on several days of observations from the monitor stations, is generated(*off-line*) using a highly sophisticated software package for orbit determination In the second step (*on-line*) the discrepancies between the current observations at the monitor stations and the reference ephemeris are derived, and are processed in a linear Kalman filter algorithm to predict corrections to the reference ephemeris.

For this purpose, code-pseudo range and carrier observations are made of all visible satellites at all monitor stations.

The data are corrected for ionospheric and tropospheric delays, for Earth rotation and for relativistic effects. the corrected measurements and carrier-aided smoothed observations are input into the Kalman filter process and are used to estimate the following states(Parkinson et al., 1996, chap. 10):

- satellite position at epoch,
- satellite velocity at epoch,
- three clock parameters per satellite,
- solar radiation pressure coefficients per satellite,

− y-axis acceleration bias,
− two clock parameters per monitor station, and
− one tropospheric scale factor per monitor station.

The estimated perturbations in the elements are used to correct the satellite reference ephemeris and to generate the broadcast ephemerides. In a similar way the satellite clock behavior is predicted and included in the data signal in the form of a second order polynomial.

Computation of the satellite trajectories is based on the gravity field parameters and the station coordinates of the World Geodetic System 1984 (WGS 84).

In order to improve the accuracy of the ephemeris the WGS 84 station coordinates were replaced by (ITRF 91) coordinates in 1994, and by (ITRF 94) coordinates in 1996. Earth orientation parameters are taken from the IERS Rapid Service.

The process of orbit determination is still based on the technology of the 1980s (Russell, Schaibly, 1980; Swift, 1985) but will be upgraded along with the Accuracy Improvement Initiative.

2.5 Orbit Representation

The satellite positions estimated in the Kalman filter process are next represented in the form of Keplerian elements with additional perturbation parameters.

Summarizes all parameters that describe the satellite orbit and the state of the satellite clock. the parameters refer to a given reference epoch, $t0e$ for the ephemeris and $t0c$ for the clock, and they are based on a four hours curve fit (ICD, 1993).

Hence, the representation of the satellite trajectory is achieved through a sequence of different disturbed Keplerian orbits.

At present, a fresh data set is broadcasted every two hours, causing small steps between the different overlapping representations. These steps can reach a few decimeters but may be smoothed by suitable approximation techniques, e.g. Chebyshev polynomials.

2.6 GPS Receivers (User Segment)

Appropriate satellite receivers are required to use the GPS signals for navigation purposes and/or geodetic positioning. first- and second-generation user equipment has already disappeared from the market, and new models frequently appear.

The number of manufacturers is growing fast which makes a complete treatment of makes and models impossible and meaningless within the scope of this book. Consequently only the basic aspects of GPS receivers will be discussed here.

A general review is given, including some models for geodesy, surveying, and GIS/navigation currently available.

2.7 Receiver Concepts and Main Receiver Components

A GPS receiver detects the signals transmitted from a GPS satellite and converts the signals into useful measurements (observables). The GPS signals, when they arrive at the user antenna, are extremely weak.

A particular technique, named spread spectrum, is used to transmit and detect the signal information. the name is due to the fact that the power of the signal to be transmitted is “spread” over a much larger bandwidth (e.g. 20 MHz for GPS) than that of the navigation message (50 bps). The *bandwidth* of a signal is the frequency domain in which about 99% of the signal power is transmitted.

For GPS the pseudorandom code sequence (P-code or C/A- code) is used as the spreading function. This technique is also named binary phase shift keying (BPSK).

In the receiver the spreading function is known, so the signal can be de-spread by correlating the received signal with the locally generated signal. One advantage of the technique is that the signals are quite resistent against disturbances, and can be detected within a noisy environment. It is through this process that rather small antennas can provide the necessary signal-to-noise ratio (SNR) for the GPS receiver.

The basic components of a generic GPS receiver are:

- antenna with (optional) preamplifier
- radio-frequency (RF) and intermediate-frequency (IF) “front-end” section,
- signal tracker and correlator section
- microprocessor for receiver control, data sampling, and data processing (navigation solution)
- oscillator
- power supply
- memory, data storage
- user interface

The antenna detects the electromagnetic waves arriving from the satellites, converts the wave energy into an electric current, amplifies the signal strength and hands the signals over to the receiver electronics.

The GPS signal structure requires that all GPS antennas must be right-handed circularly polarized. the antenna has to be very sensitive because of the rather weak satellite signal, and the gain pattern must allow signal reception from all elevations and azimuths of the visible hemisphere.

CHAPTER THREE

ERRORS IN GPS

GPS pseudo range and carrier-phase measurements are both affected by several types of random errors and biases (systematic errors). These errors may be classified as those originating at the satellites, those originating at the receiver, and those that are due to signal propagation (atmospheric refraction) . Figure 3.1 shows the various errors and biases.

The errors originating at the satellites include ephemeris, or orbital, errors, satellite clock errors, and the effect of selective availability. The latter was intentionally implemented by the U.S. DoD to degrade the autonomous GPS accuracy for security reasons. It was, however, terminated at midnight (eastern daylight time) on May 1, 2000 . The errors originating at the receiver include receiver clock errors, multipath error, receiver noise, and antenna phase center variations. The signal propagation errors include the delays of the GPS signal as it passes through the ionospheric and tropospheric layers of the atmosphere. In fact, it is only in a vacuum (free space) that the GPS signal travels, or propagates, at the speed of light.

In addition to the effect of these errors, the accuracy of the computed GPS position is also affected by the geometric locations of the GPS satellites as seen by the receiver. The more spread out the satellites are in the sky, the better the obtained accuracy (Figure 3.1).

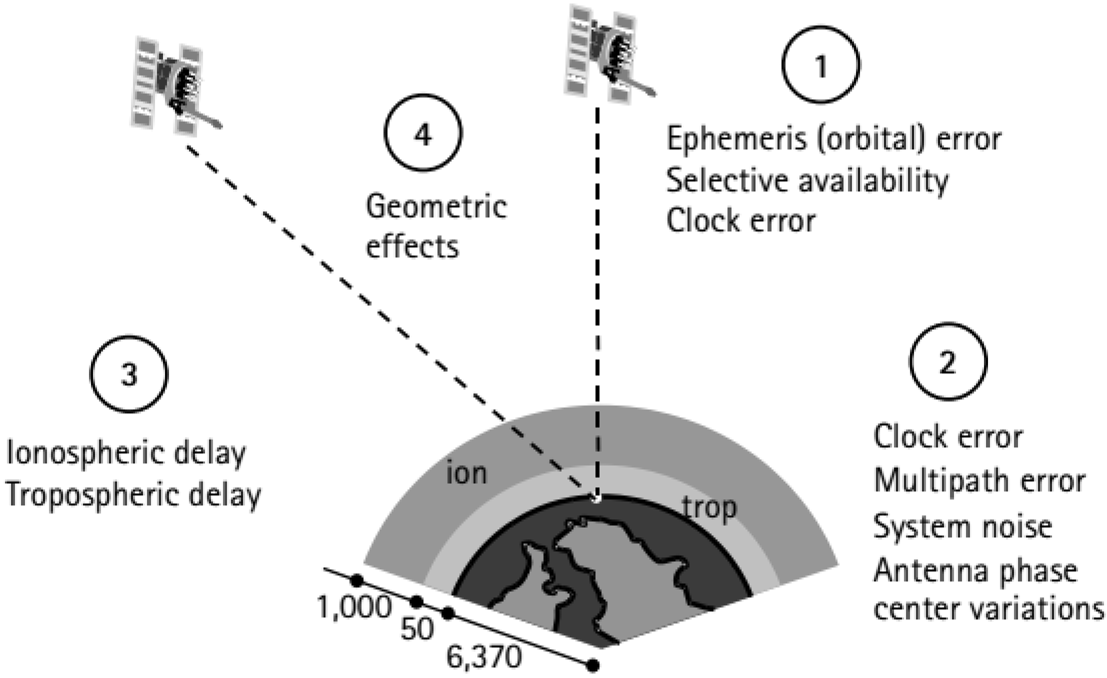


Figure 3.1: GPS errors and biases

Some of these errors and biases can be eliminated or reduced through appropriate combinations of the GPS observables. For example, combining L1 and L2 observables removes, to a high degree of accuracy, the effect of the ionosphere. Mathematical modeling of these errors and biases is also possible. In this chapter, the main GPS error sources are introduced and the ways of treating them are discussed.

3.1 GPS **ephemeris errors**

Satellite positions as a function of time, which are included in the broadcast satellite navigation message, are predicted from previous GPS observations at the ground control stations. Typically, overlapping 4-hour GPS data spans are used by the operational control system to predict fresh satellite orbital elements for each 1-hour period. As might be expected, modeling the forces acting on the GPS satellites will not in general be perfect, which causes some errors in the estimated satellite positions, known as ephemeris errors. Nominally, an ephemeris error is usually in the order of 2m to 5m, and can reach up to 50m under selective availability. The range error due to the combined effect of the ephemeris and the satellite clock errors is of the order of 2.3m.

An ephemeris error for a particular satellite is identical to all GPS users worldwide. However, as different users see the same satellite at different view angles, the effect of the ephemeris error on the range measurement, and consequently on the computed position, is different. This means that combining (differencing) the measurements of two receivers simultaneously tracking a particular satellite cannot totally remove the ephemeris error. Users of short separations, however, will have an almost identical range error due to the ephemeris error, which can essentially be removed through differencing the observations. For relative positioning, the following rule of thumb gives a rough estimate of the effect of the ephemeris error on the baseline solution: the baseline error / the baseline length = the satellite position error / the range satellite. This means that if the satellite position error is 5m and the baseline length is 10 km, then the expected baseline line error due to ephemeris error is approximately 2.5mm.

Some applications, such as studies of the crustal dynamics of the earth, require more precise ephemeris data than the broadcast ephemeris. To support these applications, several institutions [e.g., the International GPS Service for Geodynamics (IGS), the U.S. National Geodetic Survey (NGS), and Geomatics Canada have developed post mission precise orbital service. Precise ephemeris data is based on GPS data collected at a global GPS network coordinated by the IGS. At the present time, precise ephemeris data is available to users with some delay, which varies from 12 hours for the IGS ultra rapid orbit to about 12 days for the most precise IGS precise orbit. The corresponding accuracies for the two precise orbits are in the order of a few decimeters to 1 decimeter, respectively. Users can download the precise ephemeris data free of charge from the IGS center.

3.2 Selective availability

GPS was originally designed so that real-time autonomous positioning and navigation with the civilian C/A code receivers would be less precise than military P-code receivers. Surprisingly, the obtained accuracy was almost the same from both receivers. To ensure national security, the U.S. DoD implemented the so-called selective availability (SA) on Block II GPS satellites to deny accurate real-time autonomous positioning to unauthorized users. SA was officially activated on March 25, 1990.

SA introduces two types of errors. The first one, called delta error, results from dithering the satellite clock, and is common to all users world-wide. The second one, called epsilon error, is an additional slowly varying orbital error. With SA turned on, nominal horizontal and vertical errors can be up to 100m and 156m, respectively, at the 95% probability level. Figure 3.2 shows how the horizontal position of a stationary GPS receiver varies over time, mainly as a result of the effect of SA. Like the range error due to ephemeris error, the range error due to epsilon error is almost identical between users of short separations. Therefore, using Differential GPS (DGPS) would overcome the effect of the epsilon error. In fact, DGPS provides better accuracy than the standalone P-code receiver due to the elimination or the reduction of the common errors, including SA.

Following extensive studies, the U.S. government discontinued SA on May 1, 2000, resulting in a much-improved autonomous GPS accuracy. With the SA turned off, the nominal autonomous GPS horizontal and vertical accuracies would be in the order of 22m and 33m (95% of the time),

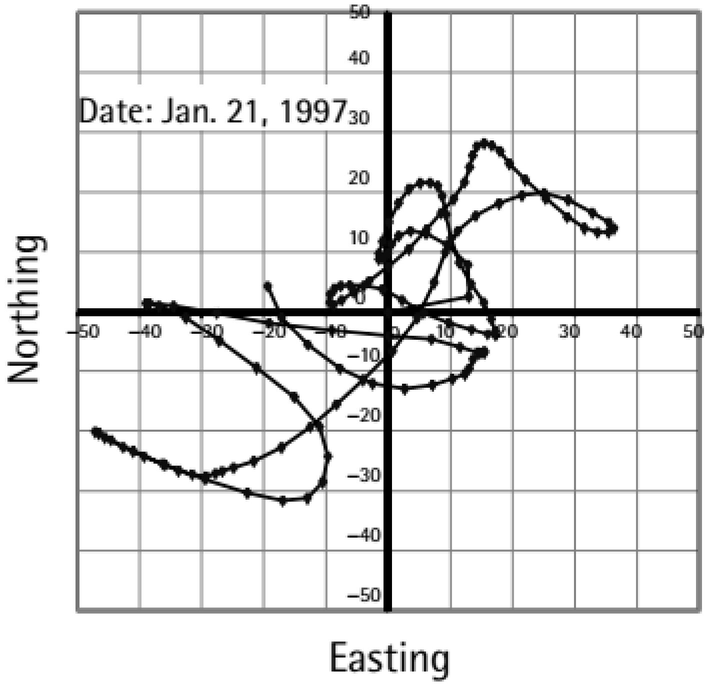


Figure 3.2: Position variation of a stationary GPS receiver due to SA

Respectively. Figure 3.3 shows the GPS errors after SA was turned off. The elimination of SA will open the door for faster growth of GPS markets (e.g., vehicle navigation and enhanced-911). Although the removal of SA would have little impact on the DGPS accuracy, it would reduce the cost of installing and operating a DGPS system. This is mainly because of the reduction in the required transmission rate.

3.3 Satellite and receiver clock errors

Each GPS Block II and Block IIA satellite contains four atomic clocks, two cesium and two rubidium. The newer generation Block IIR satellites carry rubidium clocks only. One of the onboard clocks, primarily a cesium for Block II and IIA, is selected to provide the frequency and the timing requirements for generating the GPS signals. The others are backups.

The GPS satellite clocks, although highly accurate, are not perfect. Their stability is about 1 to 2 parts in 10^{13} over a period of one day. This means that the satellite clock error is about 8.64 to 17.28 ns per day. The corresponding range error is 2.59m to 5.18m, which can be easily calculated by multiplying the clock error by the speed of light (i.e., 299,729,458 m/s). Cesium clocks tend to behave better over a longer period of time compared with rubidium clocks. In fact, the stability of the cesium clock.

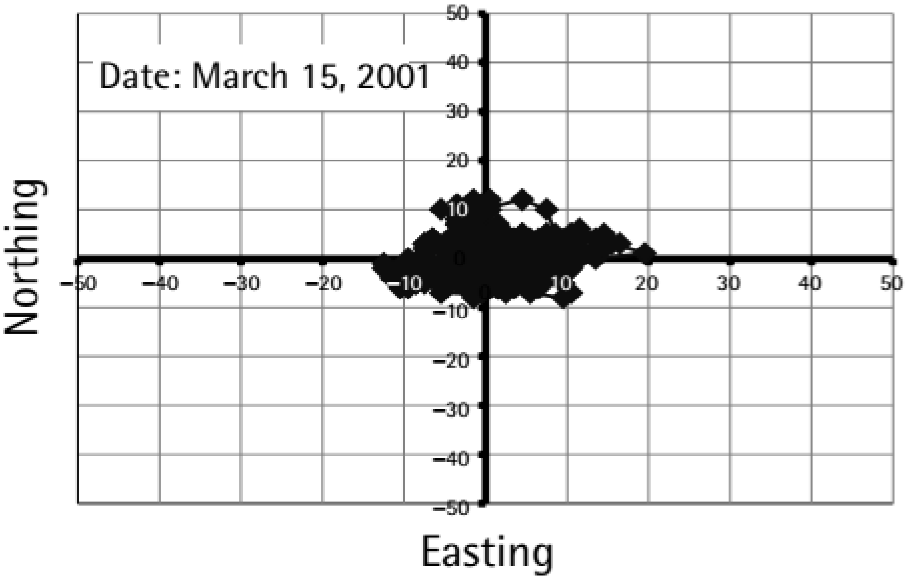


Figure 3.3: Position variation of a stationary GPS receiver after terminating SA.

Over a period of 10 days or more improves to several parts in 10^{14}. The performance of the satellite clocks is monitored by the ground control system. The amount of drift is calculated and transmitted as a part of the navigation message in the form of three coefficients of a second-degree polynomial [3, 8].

Satellite clock errors cause additional errors to the GPS measurements. These errors are common to all users observing the same satellite and can be removed through differencing between the receivers. Applying the satellite clock correction in the navigation message can also correct the satellite clock errors. This, however, leaves an error of the order of several nanoseconds, which translates to a range error of a few meters (one nanosecond error is equivalent to a range error of about 30 cm) .

GPS receivers, in contrast, use inexpensive crystal clocks, which are much less accurate than the satellite clocks. As such, the receiver clock error is much larger than that of the GPS satellite clock. It can, however, be removed through differencing between the satellites or it can be treated as an additional unknown parameter in the estimation process. Precise exter-nal clocks (usually cesium or rubidium) are used in some applications instead of the internal receiver clock. Although the external atomic clocks have superior performance compared with the internal receiver clocks, they cost between a few thousand dollars for the rubidium clocks to about $20,000 for the cesium clocks.

3.4 Multipath error

Multipath is a major error source for both the carrier-phase and pseudorange measurements. Multipath error occurs when the GPS signal arrives at the receiver antenna through different paths. These paths can be the direct line of sight signal and reflected signals from objects sur-rounding the receiver antenna (Figure 3.4).

Multipath distorts the original signal through interference with the reflected signals at the GPS antenna. It affects both the carrier-phase and pseudorange measurements; however, its size is much larger in the pseudorange measurements. The size of the carrier-phase multipath can reach a maximum value of a quarter of a cycle (about 4.8 cm for the L1 carrier phase). The pseudorange multipath can theoretically reach several tens of meters for the C/A-code measurements. However, with new advances in

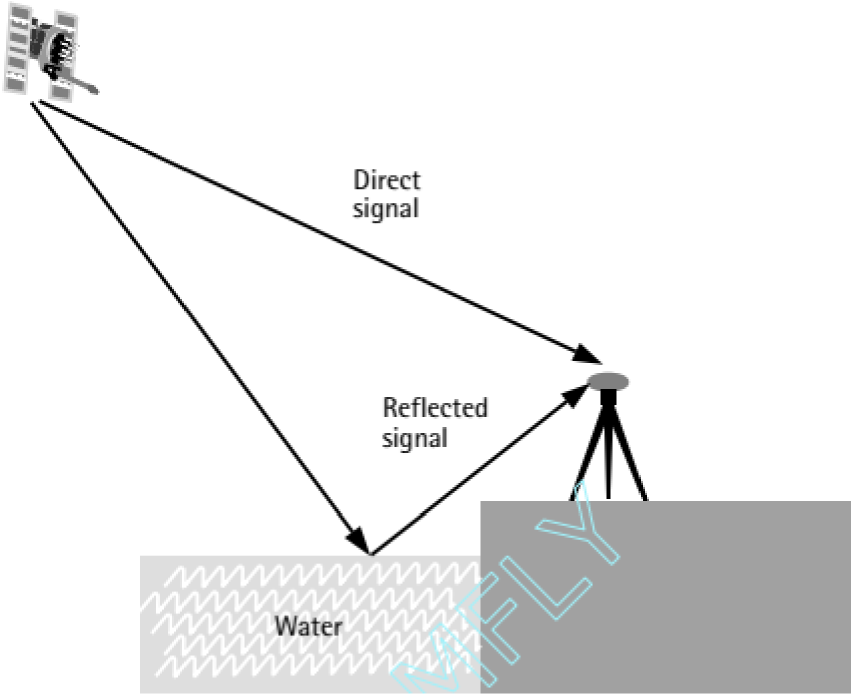


Figure 3.4: Multipath effect

Receiver technology, actual pseudorange multipath is reduced dramatically. Examples of such technologies are the Strobe correlator (Ashtech, Inc.) and the MEDLL (NovAtel, Inc.). With these multipath-mitigation techniques, the pseudorange multipath error is reduced to several meters, even in a highly reflective environment.

Under the same environment, the presence of multipath errors can be verified using a day-to-day correlation of the estimated residuals . This is because the satellite-reflector-antenna geometry repeats every sidereal day. However, multipath errors in the undifferenced pseudo range measurements can be identified if dual-frequency observations are available. A good general multipath model is still not available, mainly because of the variant satellite-reflector-antenna geometry. There are, however, several options to reduce the effect of multipath. The straightforward option is to select an observation site with no reflecting objects in the vicinity of the receiver antenna. Another option to reduce the effect of multipath is to usea chock ring antenna (a chock ring device is a ground plane that has several concentric metal hoops, which attenuate the reflected signals). As the GPS signal is right-handed circularly polarized while the reflected signal is left-handed, reducing the effect of multipath may also be achieved by using an antenna with a matching polarization to the GPS signal (i.e., right-handed). The disadvantage of this option, however, is that the polarization of the multipath signal becomes right-handed again if it is reflected twice.

3.5 Antenna-phase-center variation

As stated in Chapter 2, a GPS antenna receives the incoming satellite signal and then converts its energy into an electric current, which can be handled by the GPS receiver. The point at which the GPS signal is received is called the antenna phase center [3]. Generally, the antenna phase center does not coincide with the physical (geometrical) center of the antenna. It varies depending on the elevation and the azimuth of the GPS satellite as well as the intensity of the observed signal. As a result, additional range error can be expected.

The size of the error caused by the antenna-phase-center variation depends on the antenna type, and is typically in the order of a few centimeters. It is, however, difficult to model the antenna-phase-center variation and, therefore, care has to be taken when selecting the antenna type . For short baselines with the same types of antennas at each end, the phase-center error can be canceled if the antennas are oriented in the same direction. Mixing different types of antennas or using different orientations will not cancel the error. Due to its rather small size, this error is neglected in most of the practical GPS applications.

It should be pointed out that phase-center errors could be different on L1 and L2 carrier-phase observations. This can affect the accuracy of the ionosphere free linear combination, particularly when observing short baselines. As mentioned before, for short baselines, the errors are highly correlated over distance and cancel sufficiently through differencing. Therefore, using a single frequency might be more appropriate for short baselines in the static mode.

3.6 Receiver measurement noise

The receiver measurement noise results from the limitations of the receiver's electronics. A good GPS system should have a minimum noise level. Generally, a GPS receiver performs a self-test when the user turns it on. However, for high-cost precise GPS systems, it might be important for the user to perform the system evaluation. Two tests can be performed for evaluating a GPS receiver (system): zero baseline and short baseline tests.

A zero baseline test is used to evaluate the receiver performance. The test involves using one antenna/preamplifier followed by a signal splitter that feeds two or more GPS receivers (see Figure 3.5). Several receiver problems such as interchannel biases and cycle slips can be detected with this test. As one antenna is used, the baseline solution should be zero. In other words, any nonzero value is attributed to the receiver noise. Although the zero baseline testsprovide useful information on the receiver performance, it does not provide any information on the antenna/preamplifier noise. The contribution of the receiver measurement noise to the range error will depend very much on the quality of the GPS receiver.

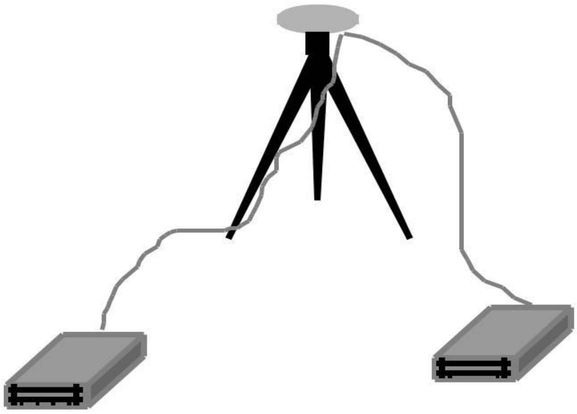


Figure 3.5: Zero baseline test for evaluating the performance of a GPS receiver

Typical average value for range error due to the receiver measurement noise is of the order of 0.6m (1s-level).

To evaluate the actual field performance of a GPS system, it is necessary to include the antenna/preamplifier noise component. This can be done using short baselines of a few meters apart, observed on two consecutive days (see Figure 3.6). In this case, the double difference residuals of one day would contain the system noise and the multipath effect. All other errors would cancel sufficiently. As the multipath signature repeats every sidereal day, differencing the double difference residuals between the two consecutive days eliminates the effect of multipath and leaves only the sys-tem noise.

3.7 Ionospheric delay

At the uppermost part of the earth's atmosphere, ultraviolet and X-ray radiations coming from the sun interact with the gas molecules and atoms. These interactions result in gas ionization: a large number of free "negatively charged" electrons and "positively charged" atoms and molecules. Such a region of the atmosphere where gas ionization takes place is called the ionosphere. It extends from an altitude of approximately 50 km to about 1,000 km or even more (see Figure 3.1). In fact, the upper limit of the ionospheric region is not clearly defined .

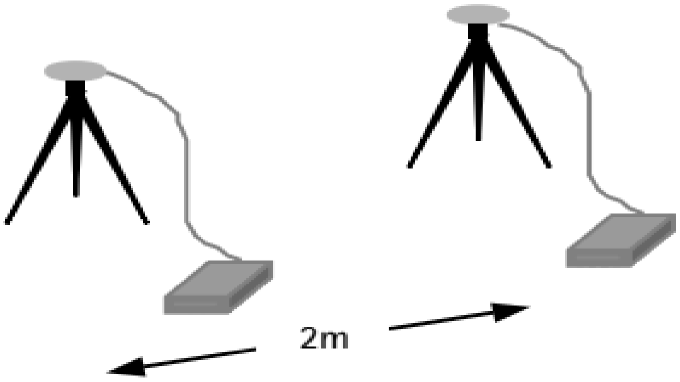


Figure 3.6: Short baseline test for evaluating the performance of a GPS system.

The electron density within the ionospheric region is not constant; it changes with altitude. As such, the ionospheric region is divided into sub regions, or layers, according to the electron density. These layers are named D (50–90 km), E (90–140 km), F1 (140–210 km), and F2 (210–1,000 km), respectively, with F2 usually being the layer of maximum electron density. The altitude and thickness of those layers vary with time, as a result of the changes in the sun's radiation and the Earth's magnetic field. For example, the F1 layer disappears during the night and is more pronounced in the summer than in the winter.

The question that may arise is: How would the ionosphere affect the GPS measurements? The ionosphere is a dispersive medium, which means it bends the GPS radio signal and changes its speed as it passes through the various ionospheric layers to reach a GPS receiver. Bending the GPS signal path causes a negligible range error, particularly if the satellite elevation angle is greater than 5°. It is the change in the propagation speed that causes a significant range error, and therefore should be accounted for. The ionosphere speeds up the propagation of the carrier phase beyond the speed of light, while it slows down the PRN code (and the navigation message) by the same amount. That is, the receiver-satellite distance will be too short if measured by the carrier phase and too long if measured by the code, and compared with the actual distance. The ionospheric delay is proportional to the number of free electrons along the GPS signal path, called the total electron content (TEC). TEC, however, depends on a number of factors:

(1) The time of day (electron density level reaches a daily maximum in early afternoon and a minimum around midnight at local time);

(2) The time of year (electron density levels are higher in winter than in summer);

(3) The 11-year solar cycle (electron density levels reach a maximum value approximately every 11 years, which corresponds to a peak in the solar flare activities known as the solar cycle peak—in 2001 we are currently around the peak of solar cycle number 23); and

(4) The geographic location (electron density levels are minimum in mid latitude regions and highly irregular in polar, and equatorial regions). As the ionosphere is a dispersive medium, it causes a delay that is frequency dependent. The lower the frequency, the greater the delay; that is, the L2 ionospheric delay is greater than that of L1. Generally, ionospheric delay is of the order of 5m to 15m, but can reach over 150m under extreme solar activities, at midday, and near the horizon.

This discussion shows that the electron density level in the ionosphere varies with time and location. It is, however, highly correlated over relatively short distances, and therefore differencing the GPS observations between users of short separation can remove the major part of the ionospheric delay. Taking advantage of the ionosphere's dispersive nature, the ionospheric delay can be determined with a high degree of accuracy by combining the P-code pseudo orange measurements on both L1 and L2. Unfortunately, however, the P-code is accessible by authorized users only. With the addition of a second C/A-code on L2 as part of the modernization program, this limitation will be removed . The L1 and L2 carrier-phase measurements may be combined in a similar fashion to determine the variation in the ionospheric delay, not the absolute value. Users with dual-frequency receivers can combine the L1 and L2 carrier-phase measure-ments to generate the ionosphere-free linear combination to remove the ionospheric delay [5]. The disadvantages of the ionosphere-free linear combination, however, are: (1) it has a relatively higher observation noise, and (2) it does not preserve the integer nature of the ambiguity parameters. As such, the ionosphere-free linear combination is not recommended for short baselines. Single-frequency users cannot take advantage of the dispersive nature of the ionosphere. They can, however, use one of the empirical ionospheric models to correct up to 60% of the delay. The most widely used model is the Klobuchar model, whose coefficients are trans-mitted as part of the navigation message. Another solution for users with single-frequency GPS receivers is to use corrections from regional net-works. Such corrections can be received in real time through communication links.

3.8 Tropospheric delay

The troposphere is the electrically neutral atmospheric region that extends up to about 50 km from the surface of the earth (see Figure 3.1). The troposphere is a nondispersive medium for radio frequencies below 15 GHz As a result, it delays the GPS carriers and codes identically. That is, the measured satellite-to-receiver range will be longer than the actual geometric range, which means that a distance between two receivers will be longer than the actual distance. Unlike the ionospheric delay, the tropospheric delay cannot be removed by combining the L1 and the L2 observations. This is mainly because the tropospheric delay is frequency independent.

The tropospheric delay depends on the temperature, pressure, and humidity along the signal path through the troposphere. Signals from satellites at low elevation angles travel a longer path through the troposphere than those at higher elevation angles. Therefore, the tropospheric delay is minimized at the user's zenith and maximized near the horizon. Tropospheric delay results in values of about 2.3m at zenith (satellite directly overhead), about 9.3m for a 15°-elevation angle, and about 20–28m for a 5°-elevation angle .

Tropospheric delay may be broken into two components, dry and wet. The dry component represents about 90% of the delay and can be predicted to a high degree of accuracy using mathematical models. The wet component of the tropospheric delay depends on the water vapor along the GPS signal path. Unlike the dry component, the wet component is not easy to predict. Several mathematical models use surface meteorological measurements (atmospheric pressure, temperature, and partial water vapor pressure) to compute the wet component. Unfortunately, however, the wet component is weakly correlated with surface meteorological data, which limits its prediction accuracy. It was found that using default meteorological data (1,010 mb for atmospheric pressure, 20°C for temperature, and 50% for relative humidity) gives satisfactory results in most cases.

3.9 Satellite geometry measures

The various types of errors and biases discussed earlier directly affect the accuracy of the computed GPS position. Proper modeling of those errors and biases and/or appropriate combinations of the GPS observables will improve the positioning accuracy. However, these are not the only factors that affect the resulting GPS accuracy. The satellite geometry, which represents the geometric locations of the GPS satellites as seen by the receiver(s), plays a very important role in the total positioning accuracy. The better the satellite geometrystrength, the better the obtained positioning accuracy. As such, the overall positioning accuracy of GPS is measured by the combined effect of the unmodeled measurement errors and the effect of the satellite geometry.

Good satellite geometry is obtained when the satellites are spread out in the sky. In general, the more spread out the satellites are in the sky, the better the satellite geometry, and vice versa. Figure 3.7 shows a simple graphical explanation of the satellite geometry effect using two satellites [assuming a two-dimensional (2-D) case]. In such a case, the receiver will be located at the intersection of two arcs of circles; each has a radius equal to the receiver-satellite distance and a center at the satellite itself. Because of the measurement errors, the measured receiver-satellite distance will not be exact and an uncertainty region on both sides of the estimated distance will be present. Combining the measurements from the two satellites, it can be seen that the receiver will in fact be located somewhere within the uncertainty area, the hatched area. It is known from statistics that, for a certain probability level, if the size of the uncertainty area is small, the computed receiver's position will be precise. As shown in Figure 3.7(a), if the two satellites are far apart (i.e., spread out), the size of the uncertainty area will be small, resulting in good satellite geometry. Similarly, if the two satellites are close to each other [Figure 3.7(b)], the size of the uncertainty area will be large, resulting in poor satellite geometry.

The satellite geometry effect can be measured by a single dimensionless number called the Dilution Of Precision (DOP). The lower the value of the DOP number, the better the geometric strength, and vice versa [3, 8]. The DOP number is computed based on the relative receiver-satellite geometry at any instance, that is, it requires the availability of both the receiver and the satellite coordinates. Approximate values for the coordinates are

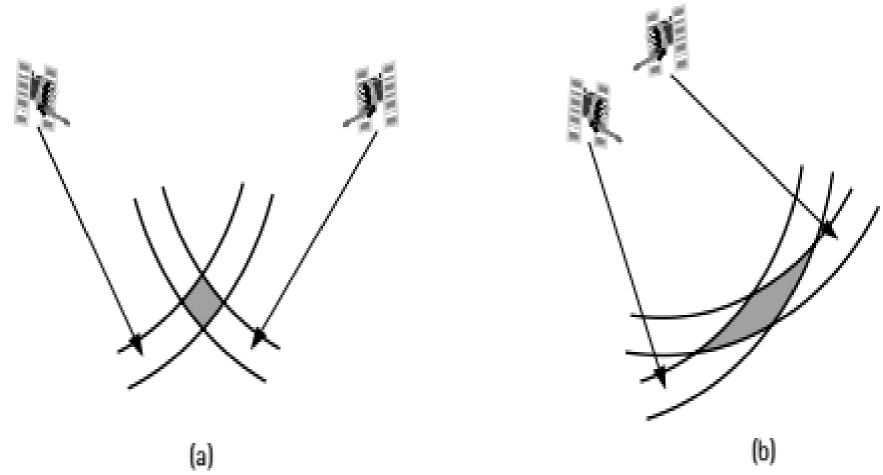


Figure 3.7: (a) Good satellite geometry; and (b) bad satellite geometry.

Generally sufficient though, which means that the DOP value can be determined without making any measurements. As a result of the relative motion of the satellites and the receiver(s), the value of the DOP will change over time. The changes in the DOP value, however, will generally be slow except in the following two cases: (1) a satellite is rising or falling as seen by the user's receiver, and (2) there is an obstruction between the receiver and the satellite (e.g., when passing under a bridge).

In practice, various DOP forms are used, depending on the user's need. For example, for the general GPS positioning purposes, a user may be interested in examining the effect of the satellite geometry on the quality of the resulting three-dimensional (3-D) position (latitude, longitude, and height). This could be done by examining the value of the position dilution of precision (PDOP). In other words, PDOP represents the contribution of the satellite geometry to the 3-D positioning accuracy. PDOP can be bro-ken into two components: horizontal dilution of precision (HDOP) and vertical dilution of precision (VDOP). The former represents the satellite geometry effect on the horizontal component of the positioning accuracy, while the latter represents the satellite geometry effect on the vertical component of the positioning accuracy. Because a GPS user can track only those satellites above the horizon, VDOP will always be larger than HDOP. As a result, the GPS height solution is expected to be less precise than the horizontal solution. The VDOP value could be improved by supplementing GPS with other sensors, for example, the pseudolites (see Chapter 9 for details). Other commonly used DOP forms include the time dilution of precision (TDOP) and the geometric dilution of precision (GDOP). GDOP represents the combined effect of the PDOP and the TDOP.

To ensure high-precision GPS positioning, it is recommended that a suitable observation time be selected to obtain the highest possible accuracy. A PDOP of five or less is usually recommended. In fact, the actual PDOP value is usually much less than five, with a typical average value in the neighborhood of two. Most GPS software packages have the ability to predict the satellite geometry based on the user's approximate location and the approximate satellite locations obtained from a recent almanac file for the GPS constellation. The almanac file is obtained as part of the navigation message.

CHAPTER FOUR

REFERENCE COORDINATE SYSTEMS

Appropriate, well defined and reproducible reference coordinate systems are essential for the description of satellite motion, the modeling of observables, and the representation and interpretation of results.

The increasing accuracy of many satellite observation techniques requires a corresponding increase in the accuracy of the reference systems.

Reference coordinate systems in satellite geodesy are global and geocentric by nature, because the satellite motion refers to the center of mass of earth. Terrestrial measurements are by nature local in character and are usually described in local reference coordinate systems.

The relationship between all systems in use must be known with sufficient accuracy. Since the relative position and orientation changes with time, the recording and modeling of the observation time also plays an important role.

It should be noted that the results of different observation methods in satellite geodesy refer to particular reference coordinate systems which are related to the individual methods. These particular systems are not necessarily identical because they may be based on different data and different definitions. Often the relationship between these particular systems is known with an accuracy lower than the accuracy of the individual observation techniques. The establishment of precise transformation formulas between systems is one of the most important tasks in satellite geodesy.

4.1 Cartesian Coordinate Systems and Coordinate Transformations

In a Cartesian coordinate system with the axes *x*, *y*, *z* the position of a point *P* is determined by its position vector

$$\begin{pmatrix} \mathbf{x}_P \\ y_P \\ z_P \end{pmatrix} = x_P \qquad (4.1)$$

where x_P, y_P, z_P are real numbers.

The transformation to a second Cartesian coordinate system with identical origin and the axes x^r, ,y^r,z^r,which is generated from the first one by a rotation around the *z*-axis by the angle γ , can be realized through the matrix operation

$\boldsymbol{x}_P=\boldsymbol{R}3(\gamma)\boldsymbol{x}P$(4.2)

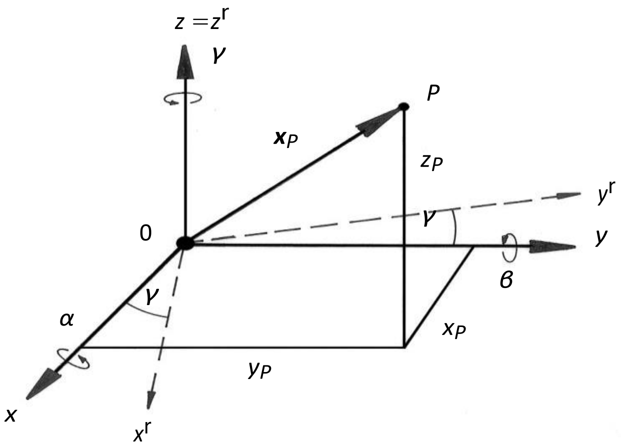


Figure4.1: Cartesian coordinate system

with

$$\boldsymbol{R}_3(\gamma) = \begin{pmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\boldsymbol{R}_2(\beta) = \begin{pmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{pmatrix}$$

$$\boldsymbol{R}_1(\alpha) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{pmatrix}$$

Therepresentationisvalidforaright-handedcoordinatesystem.Whenviewedtowardstheorigin,acounter-clockwiserotationispositive,anycoordinatetransformationcan be realized through a combination of rotations. the complete transformation is

$$\boldsymbol{x}_P = \boldsymbol{R}_1(\alpha)\boldsymbol{R}_2(\beta)\boldsymbol{R}_3(\gamma)\boldsymbol{x}_P \quad (4.3)$$

The mathematical properties of rotation matrices are described using linear algebra, the following rules are of importance:

(1) Rotation does not change the length of a positionvector.

(2) Matrix multiplication is notcommutative.

$\boldsymbol{R}_i(\mu)\boldsymbol{R}_j(\nu)=\boldsymbol{R}_j(\nu)\boldsymbol{R}_i(\mu)$.(4.4)

(3) Matrix multiplication isassociative

$\boldsymbol{R}_i(\boldsymbol{R}_j\,\boldsymbol{R}_k) =(\boldsymbol{R}_i\boldsymbol{R}_j)\boldsymbol{R}_k$.(4.5)

(4) Rotations around the same axis areadditive

$\boldsymbol{R}_i(\mu)\boldsymbol{R}_i(\nu) = \boldsymbol{R}_i(\mu+\nu)$.(4.6)

(5) Inverse and transpose are relatedby

$\boldsymbol{R}^{-1}_i(\mu) = \boldsymbol{R}^T_i(\mu)=\boldsymbol{R}_i(-\mu)$.(4.7)

(6) The following relationship alsoholds

$(\boldsymbol{R}_i\boldsymbol{R}_j)^{-1}=\boldsymbol{R}^{-1}_j\boldsymbol{R}^{-1}_i$. (4.8)

The polarity of coordinate axes can be changed with reflection matrices

$$s1=\begin{pmatrix}-1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{pmatrix}\quad s2=\begin{pmatrix}1 & 0 & 0\\ 0 & -1 & 0\\ 0 & 0 & 1\end{pmatrix}\quad s3=\begin{pmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & -1\end{pmatrix} \tag{4.9}$$

Finally, the matrix for a general rotation by the angles α, β, γ is

$$\boldsymbol{R}=\begin{pmatrix}\cos\beta\cos\gamma & \cos\beta\sin\gamma & -\sin\beta\\ \sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma & \sin\alpha\sin\beta\sin\gamma+\cos\alpha\cos\gamma & \sin\alpha\cos\beta\\ \cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma & \cos\alpha\sin\beta\sin\gamma-\sin\alpha\cos\gamma & \cos\alpha\cos\beta\end{pmatrix} \tag{4.10}$$

Therelationbetweenthepositionvectorsintwoarbitrarilyrotatedcoordinatesystems isthen

$\gamma^{rrr}{}_P = \boldsymbol{R}\boldsymbol{x}_P$; $\boldsymbol{x}_P = \boldsymbol{R}^T\,\boldsymbol{x}^{rrr}$. *(4.11)*

In satellite geodesy the rotation angles are often very small, thus allowing the use ofthelinearizedformfor**R**.Withcos$\alpha\simeq 1$andsin$\alpha\simeq\alpha$(in radians),neglecting higher order terms, it follows that

$$R(\alpha,\beta,\gamma) = \begin{pmatrix} 1 & \gamma & -\beta \\ -\gamma & 1 & \alpha \\ \beta & -\alpha & 1 \end{pmatrix} \qquad (4.12)$$

Although matrix multiplication does not commute (4.4) the infinitesimal rotation matrix (4. 12) does commute.

4.2 Reference Coordinate Systems and Frames in Satellite Geodesy

In modern terminology it is distinguished between

- reference systems.
- reference frames.
- conventional reference systems and frames.

A reference system is the complete conceptual definition of how a coordinate system is formed. It defines the origin and the orientation of fundamental planes or axes of the system. It also includes the underlying fundamental mathematical and physical models. A conventional reference system is a reference system where all models, numerical constant sandalgorithmsare explicitly specified. reference frame means thepracticalrealizationofareferencesystemthroughobservations.Itconsistsofaset ofidentifiablefiducialpointsonthesky(e.g.stars,quasars)oronEarth'ssurface(e.g. fundamental stations). It is described by a catalogue of precise positions and motions (if measurable) at a specific epoch.
In satellite geodesy two fundamental systems are required:

- aspace -fixed, Conventional Inertial reference System(CIS) for the description of satellite motion ,and - an Earth-fixed,
Conventional Terrestrial reference System(CTS) for the positions of the observation stations and for the description of results from satellite geodesy.

4.3 Conventional Inertial Systems and Frames

Newton's laws of motion are only valid in an inertial reference system, i.e. a coordinate system at rest or in a state of uniform rectilinear motion without any acceleration. Thetheoryofmotionforartificialsatellitesisdevelopedwithrespectto such a system.

Spacefixedinertialsystemareusuallyrelatedtoextraterrestrialobjectslikestars, quasars (extragalactic radio sources), planets, or the Moon.

They are therefore also named celestial reference systems(CRS).

The definition of a CRS can be based on kinematic or dynamic considerations. Akinematic CRSis defined by stars orquasars with well known positions and, if measurable, proper motions. A dynamical CRS is based on the motion of planets, the Moon, or artificial satellites.

The establishment of conventional celestial reference systems is under the responsibility of the International Astronomical Union(IAU).

From January 1, 1988, until December 31,1997, the conventional celestial reference system was based on the orientation of the equator and the equinox for the standard epoch J2000.0, determined from observations of planetary motions in agreement with the IAU (1976) system of astronomical constants as well as related algorithms (cf. Seidelmann (ed.) (1992)). The corresponding reference frame was the Fifth Fundamental Catalogue (FK5) (Fricke et al.,1988).

The equatorial system at a given epoch $T0$ which has been used in spherical astronomy for many years yields a rather good approximation to a conventional inertial reference system. The origin of the system is supposed to coincidewiththegeocentric$M$.Thepositive$Z$-axisisorientedtowardsthenorth pole and the positive X-axis to the First Point of Aries♈. The Y -axis completes a right-handed system. Since Earth’s center of mass undergoes small accelerations because of the annual motionaround the Sun, the termquasi-inertial systemis also used.

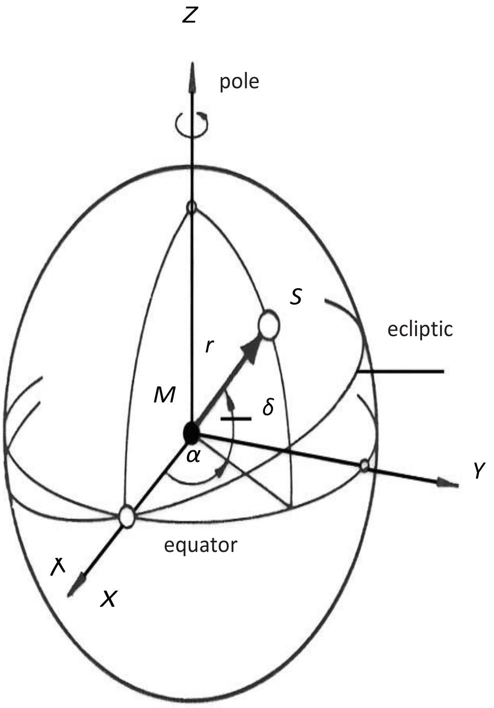


Figure 4.2: Equatorial system in spherical astronomy

The traditional materialization of the above definition for practical purposes is through a catalogue of the positions and proper motions of a given number of fundamental stars. The FK5 is a catalogue of 1535 bright stars, compiled from a large number of meridian observations. The formal uncertainties of the FK5 star positions were about 20 to 30 milliarc seconds at the time of publication (1988). The quality of the FK5 frame is time dependent and is continuous lygettingworse(deVegt,1999;Walter,Sovers,2000).

Star positions are usually given as spherical coordinates right ascension α and *declination* δ.

The transformation of spherical coordinates α, δ, r into Cartesian coordinates X, Y , Z is

$X = r\cos\delta\cos\alpha,\quad Y = r\cos\delta\sin\alpha,\quad Z = r\sin\delta.$ (4.13)

The reverseformulasare

$$r=\sqrt{X^2+Y^2+Z^2},\ \alpha=\arctan\frac{Y}{X},\ \delta=\arctan\frac{Z}{\sqrt{X^2+Y^2}}$$

Insphericalastronomy$r$isusuallydefinedastheunitradius.Wemayconsiderthe celestialsphereinFig(3.2)astheunitsphereandapplythebasicformulasofspherical geometry.DetailedinformationonsphericalastronomycanbefoundinGreen(1985) *orintextbooksongeodeticastronomy*(e.g.Mackie,1985;Schödlbauer,2000).

Theaccuracyofthecelestialreferencesystem,realizedthroughtheFK5catalogue, is by far insufficient for modern needs. Considerable improvement, by several orders of magnitude, was achieved with the astrometric satellite mission HIPPARCOS(Kovalevskyetal.,1997),and with extra galactic radio sources (quasars) via the technique of Very Long Baseline Inter ferometry (VLBI) which use sradiotele scopes.

In 1991 the IAU decided to establish a new celestial reference system based on a kinematicratherthanonadynamicdefinition(McCarthy,2000).Thesystemiscalled the International Celestial Reference System(ICRS) and officially replaced the FK5 fundamental system on January 1, 1998. The axes of the ICRS are no longer fixed to theorientationoftheequatorandthevernalequinox,butwithrespecttodistantmatter in the universe. The system is realized by a celestial reference frame, defined by the precise coordinates of extragalactic objects (mainly quasars) with no measurable transversemotion.TheoriginoftheICRSiseitherthebarycenterofthesolarsystem, or the geocenter. the ICRS, hence, consists ofthe:

- Barycentric CelestialReference System(BCRS).
- Geocentric CelestialReference System(GCRS).

The relation between them makes use of general relativity (geodesic precession, Lense- Thirring precession), see McCarthy(2000);Capitaine, etal.(2002).

TheInternationalCelestialReferenceFrame(ICRF)isacatalogueoftheadopted positionsof608extragalacticradiosourcesobservedviathetechniqueofVLBI.212 of these objects are defining sources. They establish the orientation of the ICRS axes. The typical position uncertainty for a defining radio source is about 0.5 milliarc seconds (mas). The resulting accuracy for the orientation of the axes isabout0.02 mas (Ma et al., 1997).

Inordertomaintaincontinuityintheconventionalcelestialreferencesystemsthe orientationsoftheICRSaxesareconsistentwiththeequatorandequinoxatJ2000.0, as represented by the FK5. Since the accuracy of the FK5 is significantly worse than thenewrealizationsoftheICRS,theICRScanberegardedasarefinementoftheFK5 system.

TheHipparcosCatalogueisarealizationoftheICRSatopticalwavelengths.This catalogue contains 118 218 stars for the epoch J1991.25. the typical uncertainties at catalogueepochare1masinpositionand1mas/yearinpropermotion.Fortheepoch.

4.4 Reference Coordinate Systems

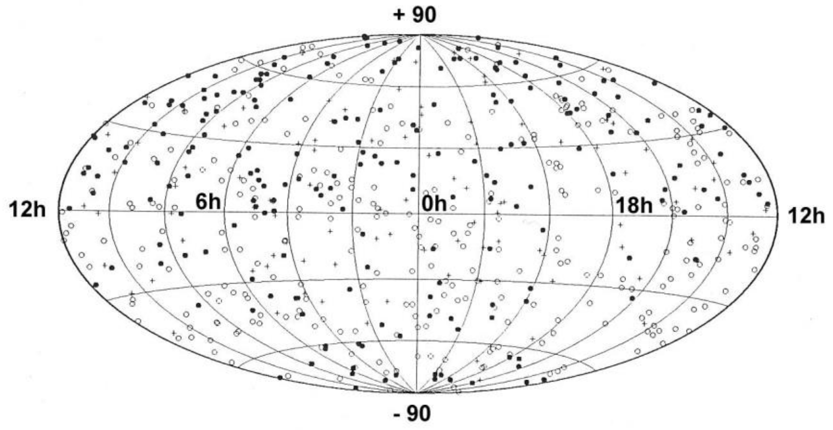


Figure4.3.InternationalCelestialReferenceFrameICRF;distributionofthe212best-observed extragalactic sources (after Maetal.(1998))

J2000.0typicalHipparcosstarpositionscanbeestimatedintherangeof5to10mas (Kovalevsky et al., 1997; Walter, Sovers,2000).

With forthcoming astrometric space missions like FAME and GAIA (Walter, Sovers,2000),further improvement the optical realization of the ICRS to the level of 10 micro arc seconds (μas) is expected. Also the link between the ICRF based on radio stars and frames a topical wavelengths will be improved.

For more information on conventional inertial reference systems and frames seee.g.Moritz,Mueller(1987,chap.9),Seidelmann(ed.)(1992,chap.2),Walter,Sovers (2000), Schödlbauer (2000, chap. 3), Capitaine, et al. (2002) .

4.5 Conventional Terrestrial Systems and Frames

A suitable Earth-fixed reference system must be connected in a well defined way to Earth's crust. Such a Conventional Terrestrial System(CTS) can be realized through a set of Cartesian coordinates of fundamental station sor markers with in a global network.

The origin of an ideal conventional terrestrial reference system should be fixed to the geocentric, including the mass of the oceans and the atmosphere. the*z*-axis should coincide with the rotational axis of Earth. Since the geocentric and the rotationalaxisarenotdirectlyaccessibleforobservationstheidealsystemisapproximated by conventions.

The classic al convention for the orientation of axes was based on as- trinomial observations and has been developed and maintained since 1895 by the International Latitude Service (ILS), and since 1962 by the International Polar Motion Service (IPMS) (Moritz,Mueller,1987). It is established through the conventional direction to the mean orientation of the polar axis over the period 1900–1905Conventional Terrestrial Pole(CTP), also named Conventional International Origin(CIO) and a zero longitude on the equator Green which Mean Observatory (GMO). GMO is defined through the nominal longitudes of all observatories which contributed to the former international time service BIH (Bureau International del' Heure).

In 1988 the responsibility for establishing and maintaining both the conventional celestial and terrestrial reference system sand frames, was shifted to the International Earth Rotation Service(IERS), Although the IERS results are based on modern space techniques like *SLR* ,*VLBI*,*GPS* , and *Doppler* , the traditional convention has been maintained within the accuracy range of the classical astronomical techniques in order to provide continuity.

The conventional terrestrial reference system, established and maintained by the IERS, and nearly exclusively used for today's scientific and practical purposes is the International Terrestrial Reference System (ITRS); its realization is the International Terrestrial Reference Frame(ITRF). The ITRS is defined as follows (Boucher et al., 1990; McCarthy,2000):

It is geocentric, the center of mass being defined for the whole Earth, including oceans and atmosphere.

The length unit is the SI meter; the scale is in context with the relativistic theory of gravitation.

- The orientation of axes is given by the initial BIH orientation at epoch 1984.0. The time evolution of the orientation will create no residual global rotation with regard to Earth's crust (no-net-rotation condition).

These specifications correspond with the IUGG resolution no. 2 adopted at the 20th IUGG General Assembly of Vienna in 1991. The orientation of axes is also called IERS Reference Pole(IRP) and IERS Reference Meridian(IRM).

TherealizationoftheITRS,theInternationalTerrestrialReferenceFrame(ITRF) is formed through Cartesian coordinates and linear velocities of a global set of sites equipped with various space geodetic observing systems. If geographical coordinates (ellipsoidal latitude, longitude, and height) are required instead of Cartesian coordinates *(X, Y, Z)*, use of the GRS80 ellipsoid is recommended .The ensemble of coordinates implicitly define the CTP (*Z*-axis) and the GMO(*X*-axis).

Nearly every year a new ITRF is realized based on new observations with geodetic space techniques (e.g. Doppler [6], GPS [7], SLR [8], VLBI). The result is published under the denomination ITRFxx, where xx means the last digits of the year whose data were used in the formation of the frame. The most recent solution is ITRF2000, Alta Mimi et al. (2001). Each particular ITRF is assembled by combining sets of results from independent techniques as analyzed by a number of separate groups. The use of as many different techniques as possible provides a significant decrease of systematic errors.

The establishment of a terrestrial reference frame is not an easy task because Earth's crust continuously undergoes various deformations. Since today's geodetic space techniques provide station coordinates at the 1 cm or sub centimeter level, it is necessary to model the various deformations at the mm-level. The main influences are:

- Global plate tectonics.
- Solid Earth tides.
- Ocean and atmospheric loading effects.
- Polar tides.
- Regional and local effects.

Detailed models and algorithms for these effects are given in the IERS Conventions (McCarthy, 2000).

The largest effect comes from global plate tectonics, in order to maintain the orientation of the coordinate axes stable on the dynamic Earth, the orientation rate of the ITRF is defined, by convention, so that there is no rotation of the frame with respect to Earth's lithosphere. In practice, the ITRF orientation rate is aligned to the plate tectonic model NNR-NUVEL-1A (Argus, Gordon, 1991; DeMets et al., 1994).

This procedure is based on the assumption, that the model fulfills the condition of no-net-rotation, i.e. the integral of model velocities over the entire surface of Earth becomes zero (Drewes, 1999).

Regional realizations of the ITRS are e.g. the ETRF89 for Europe and SIRGAS for South America. a particular global realization of a terrestrial reference system is the World Geodetic System *1984* (WGS84).

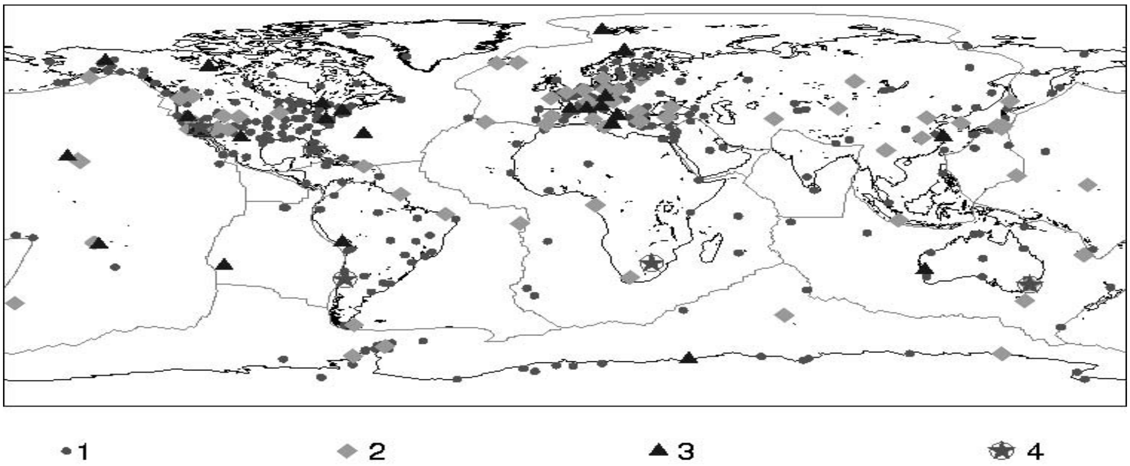


Figure 4.4: International Terrestrial Reference Frame ITRF2000Symbols indicate the number of different space techniques collocated at the particular.

4.6 Relationship between CIS and CTS

The transition from the space-fixed equatorial system Conventional Inertial System (CIS) to the Conventional Terrestrial System (CTS) is realized through a sequence of rotations that account for :

- **Precession**
- **Notation**
- **Earth rotation including polar motion.**

These can be described with matrix operations. For a point on the celestial sphere, described through its position vector r, we can write

$\boldsymbol{r}\text{CTS}= \boldsymbol{SNPr}\text{CIS}$

Theelementsoftherotationmatricesmustbeknownwithsufficientaccuracyforeach observation epoch. These rotations are now considered in more detail.

4.6.1 Precession and Nutation

Earth's axis of rotation and its equatorial plane are not fixed in space, but rotate with respecttoaninertialsystem.ThisresultsfromthegravitationalattractionoftheMoon andtheSunontheequatorialbulgeofEarth.Thetotalmotioniscomposedofamean secular component (precession) and a periodic component (nutation).

4.6.2 Earth Rotation and PolarMotion

Forthetransitionfromaninstantaneousspace-fixedequatorialsystemtoaconventional terrestrial reference system we need three further parameters. They are called Earth Rotation Parameters(ERP) or Earth Orientation Parameters(EOP).

As shown in Fig. 4.5, the polar motion is defined as the angles between the pole ofdateandtheCIOpole.Thepolarmotioncoordinatesystemisdefinedby*xy*-plane coordinates, whose x-axis is pointed to the south and is coincided to the mean Green wich meridian, and whose y- axis is pointed to the west. x_p and y_p are the angles of the pole of date,

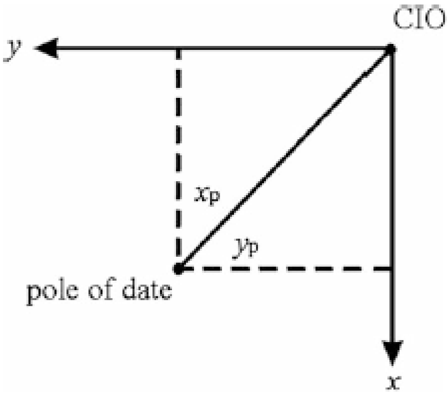


Figure 4.5 : Polar motion

The IERS determined x_p and y_p can be obtained from the home pages of IERS.

CHAPTER FIVE

OBSERVATION and METHODOLOGY

5.1 Study area

Khartoum State was chosen to be the Study area which is located between LAT (16°15'40.81024",15°12'11.03337") **N and** LONG (32°48'50.85061",32°18'29.84451") **E** respectively and surrounded with six States Nile valley in the North, White Nile and Algezera in the South, North Kordofan in the West and Kassala and Algedarif in the East.

The control network of 30 points spaced approximately ten kilometers extending at least five kilometers east and west the river Nile in Khartoum state.

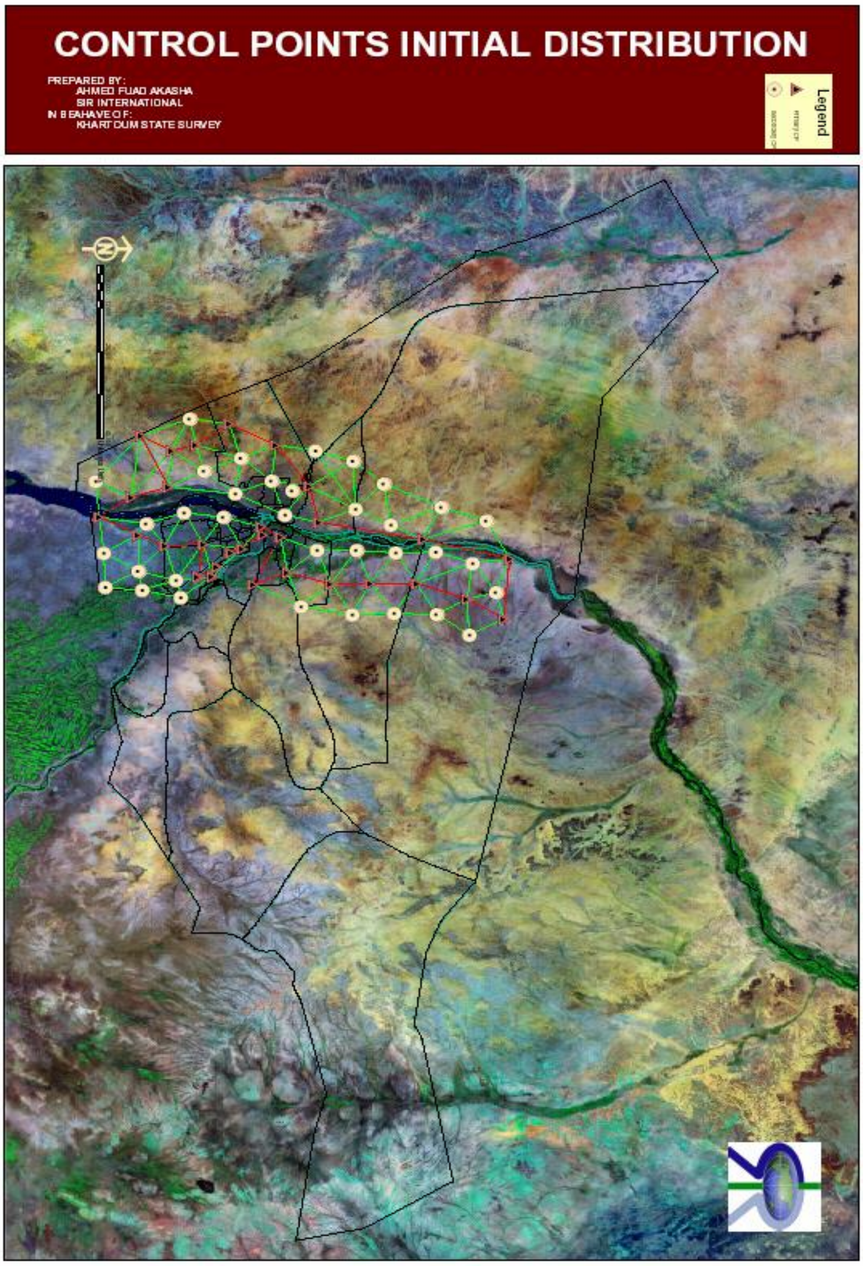


Figure 5.1 The points network

5.2 Observation

The chosen method for observation were Static GPS observations because high-accuracy positioning is required and various systematic errors to be eliminated. Static procedures are used to measure baselines between stationary GPS receivers by recording data over an extended period of time. An hour long sessions was adopted to avoid multi-path effects and minimize the number of the re-observed baselines, because of the long traveling time to and from the new points.

5.3 Reference WGS84 coordinates

The continuous operating base station at the Ministry of physical planning's headquarters was used as an accurate WGS84 coordinate source. Reference point was observed for 24 hours then the observation file was submitted to (AUSPOS) an online service operated by the Australian government for GPS data processing. The collected data was processed with three International Geodetic Station (IGS) stations. Precise satellite orbit data was used for the processing yielding a sub- centimeter RMS in coordinates. During the base station establishment a baseline was observed between it and the above mentioned point. Then the base station was used for referencing the new project points. The detailed processing report for the reference point can be found in the appendices.

5.5 Data collection

5.5.1 Crew

Surveying consisted of two KSS surveyors equipped with the necessary laptops and software/hardware tools as detailed in the following sections. The work started with a training course to discuss the aspects of the project and the fundamentals of GPS surveying. The course was held in the ministry's headquarters and contained five power point presentations covering the following topics in details:

1. GPS fundamental.
2. GPS observables.
3. Code measurements Vs. Phase shift measurements.
4. GPS error sources.
5. GPS calibration and error sources.
6. GPS network design.

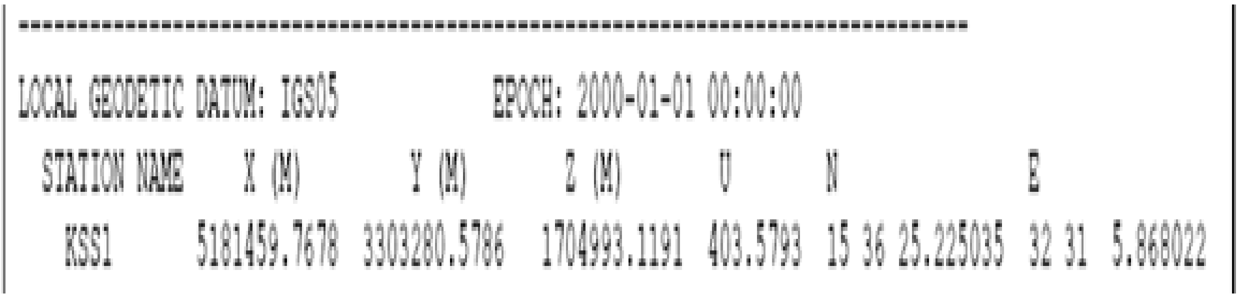
The main objective of the course was to assure the common understanding of the project and increase the level of communication between the field crew.

5.5.2 Equipment

Trimble v5800 survey grade GPS receivers were used for data collection. The continuous operating base station was using a Trimble 5700 survey grade GPS receiver with a Zephyr Geodetic antenna with a ground plan. Data was processed using Trimble Business Center.

5.5.3 Control points

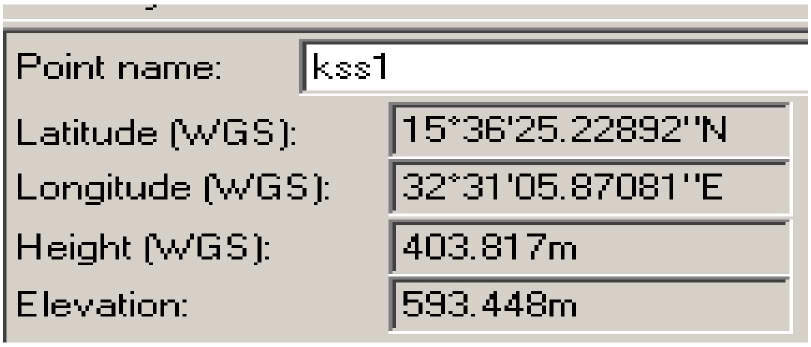
The project depended on the primary loop surveyed by Khartoum State Survey (KSS) for control and to provide the transformation parameters. The following reference points was supplied by the (KSS) with the following coordinates:



```
-------------------------------------------------------------------------------

LOCAL GEODETIC DATUM: IGS05            EPOCH: 2000-01-01 00:00:00
  STATION NAME     X (M)          Y (M)         Z (M)       U        N                 E
    KSS1       5181459.7678  3303280.5786  1704993.1191  403.5793  15 36 25.225035  32 31  5.868022
```

Figure 5.2 Reference point in epoch 2000



Point name: kss1

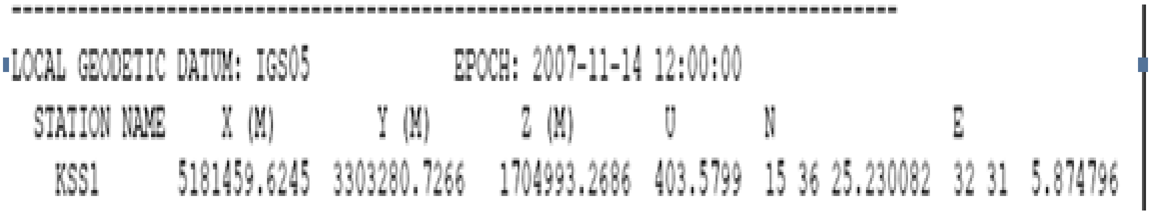
Latitude (WGS): 15°36'25.22892"N

Longitude (WGS): 32°31'05.87081"E

Height (WGS): 403.817m

Elevation: 593.448m

Figure 5.3 Reference point in epoch 2005



```
-------------------------------------------------------------------------------

LOCAL GEODETIC DATUM: IGS05            EPOCH: 2007-11-14 12:00:00
  STATION NAME     X (M)          Y (M)         Z (M)       U        N                 E
    KSS1       5181459.6245  3303280.7266  1704993.2686  403.5799  15 36 25.230082  32 31  5.874796
```

Figure 5.4 Reference point in epoch 2007

5.6 Data Processing

5.6.1 Baseline processing

Baseline processing took place in the TBC (Trimble Business Center) Software. Initially an elevation mask of 13° (Trimble default) was used; elevation mask was raised in case of unacceptable processing results. Baselines were accepted when having Root Mean Square(RMS) of less than 0.02m and a ratio of more than 3 and a reference variance of less than 5. Any baseline solution failed to meet the above mentioned criteria was re-processed and if reprocessing didn't solve the problem the baseline was rejected. Broadcast satellite orbit data (ephemeris) was used for processing because the main source of error was the setup errors and the ephemeris error seemed to be negligible.. Loop closure was accepted to be less than 10ppm although the average of loop closures was 1.72ppm.

Three epochs had been used to compare with them (epoch2000-2005)&(2005-2007) respectively .

5.7 Network adjustment

Least squares adjustment was conducted in the TBC software for the error estimation of the network. Minimally constrained adjustment or free adjustment was done in WGS84 datum holding the base station in the ministry's (head quarter) to assure the internal consistency of the network.

5.8 Results

The result has been calculated between (epoch2000 - epoch 2005 - epoch 2007) (different between easting)shown as table below:

V1=mean – epoch 2000
V2= mean – epoch 2005
V3=mean – epoch 2007

Table 5.1: Result of easting different between three epochs

Point	Epoch 2000	Epoch 2005	Epoch 2007	Mean	V1	V2	V3	RMSE (V1)	RMSE (V2)	RMSE (V3)
1	448361.75	448361.833	448361.952	448361.845	0.095	0.012	-0.107	0.0003	0.0003	0.0002
jeblawlia	445730.230	445730.313	445730.432	445730.325	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss12	445691.758	445691.842	445691.961	445691.8537	0.096	0.012	-0.107	0.0003	0.0003	0.0002
kss13	445500.131	445500.214	445500.333	445500.226	0.095	0.012	-0.107	0.0003	0.0003	0.0002
Kss14	449159.960	449160.043	449160.162	449160.055	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss14s	449159.954	449160.038	449160.157	449160.0497	0.096	0.012	-0.107	0.0003	0.0003	0.0002
kss15	454220.449	454220.532	454220.651	454220.544	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss16	461487.182	461487.265	461487.384	461487.277	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss17	468174.736	468174.819	468174.938	468174.831	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss17s	468174.722	468174.805	468174.924	468174.817	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss18	466389.071	466389.153	466389.273	466389.1657	0.095	0.013	-0.107	0.0003	0.0003	0.0002
kss19	464906.401	464906.483	464906.603	464906.4957	0.095	0.013	-0.107	0.0003	0.0003	0.0002
kss20	454890.226	454890.309	454890.428	454890.321	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss21	457812.899	457812.982	457813.102	457812.9943	0.095	0.012	-0.108	0.0003	0.0003	0.0002
kss22	463107.443	463107.526	463107.646	463107.5383	0.095	0.012	-0.108	0.0003	0.0003	0.0002
kss-12	445691.779	445691.862	445691.981	445691.874	0.095	0.012	-0.107	0.0003	0.0003	0.0002
Kss 16	461487.207	461487.290	461487.409	461487.302	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss-bh9	454906.190	454906.273	454906.392	454906.285	0.095	0.012	-0.107	0.0003	0.0003	0.0002
Kss-bh10	454804.663	454804.746	454804.866	454804.7583	0.095	0.012	-0.108	0.0003	0.0003	0.0002
kss-bh11	455545.393	455545.476	455545.595	455545.488	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss-bh12	455706.832	455706.915	455707.034	455706.927	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss-bh13	460291.107	460291.189	460291.309	460291.2017	0.095	0.013	-0.107	0.0003	0.0003	0.0002
kss-bh14	464724.578	464724.661	464724.780	464724.673	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss-bh15	477815.619	477815.701	477815.821	477815.7137	0.095	0.013	-0.107	0.0003	0.0003	0.0002
kss-bh16	472514.972	472515.055	472515.174	472515.067	0.095	0.012	-0.107	0.0003	0.0003	0.0002
kss-bh17	468380.966	468381.048	468381.168	468381.0607	0.095	0.013	-0.107	0.0003	0.0003	0.0002
kss-bh18	470666.549	470666.631	470666.751	470666.6437	0.095	0.013	-0.107	0.0003	0.0003	0.0002
Kss-bh19	472419.438	472419.520	472419.640	472419.5327	0.095	0.013	-0.107	0.0003	0.0003	0.0002
KssO15	433502.428	433502.512	433502.630	433502.5233	0.095	0.011	-0.107	0.0003	0.0003	0.0002
KssO18	436447.247	436447.330	436447.449	436447.342	0.095	0.012	-0.107	0.0003	0.0003	0.0002

The result has been calculated between (epoch2000 - epoch 2005 - epoch 2007) different between northing shown as table below:

Table 5.2: Result of northing different between three epochs

Point	Epoch2000	Epoch2005	Epoch2007	Mean	V1	V2	V3	RMSE(V1)	RMSE(V2)	RMSE(V3)
1	1725523.865	1725523.984	1725524.019	1725523.956	0.091	-0.028	-0.063	0.0005	0.0009	0.0005
jeblawlia	1684467.280	1684467.400	1684467.434	1684467.371	0.091	-0.029	-0.063	0.0005	0.0009	0.0005
kss12	1715726.919	1715727.039	1715727.074	1715727.011	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
kss13	1706285.677	1706285.797	1706285.832	1706285.769	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
Kss14	1694734.795	1694734.916	1694734.950	1694734.887	0.092	-0.029	-0.063	0.0005	0.0009	0.0005
kss14s	1694734.793	1694734.914	1694734.948	1694734.885	0.092	-0.029	-0.063	0.0005	0.0009	0.0005
kss15	1720981.362	1720981.482	1720981.517	1720981.454	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
kss16	1712795.255	1712795.374	1712795.409	1712795.346	0.091	-0.028	-0.063	0.0005	0.0009	0.0005
kss17	1705071.159	1705071.279	1705071.314	1705071.251	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
kss17s	1705071.161	1705071.281	1705071.316	1705071.253	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
kss18	1695756.483	1695756.603	1695756.637	1695756.574	0.091	-0.029	-0.063	0.0005	0.0009	0.0005
kss19	1685396.921	1685397.042	1685397.076	1685397.013	0.092	-0.029	-0.063	0.0005	0.0009	0.0005
kss20	1686222.922	1686223.043	1686223.077	1686223.014	0.092	-0.029	-0.063	0.0005	0.0009	0.0005
kss21	1695141.342	1695141.462	1695141.496	1695141.433	0.091	-0.029	-0.063	0.0005	0.0009	0.0005
kss22	1704143.612	1704143.732	1704143.766	1704143.703	0.091	-0.029	-0.063	0.0005	0.0009	0.0005
kss-12	1715726.912	1715727.032	1715727.067	1715727.004	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
Kss 16	1712795.274	1712795.394	1712795.429	1712795.366	0.092	-0.028	-0.063	0.0005	0.0009	0.0005
kss-bh9	1739809.061	1739809.179	1739809.215	1739809.152	0.091	-0.027	-0.063	0.0005	0.0009	0.0005
Kss-bh10	1750412.519	1750412.637	1750412.673	1750412.61	0.091	-0.027	-0.063	0.0005	0.0009	0.0005
kss-bh11	1760381.011	1760381.129	1760381.166	1760381.102	0.091	-0.027	-0.064	0.0005	0.0009	0.0005
kss-bh12	1770278.394	1770278.512	1770278.549	1770278.485	0.091	-0.027	-0.064	0.0005	0.0009	0.0005
kss-bh13	1779072.664	1779072.781	1779072.819	1779072.755	0.091	-0.026	-0.064	0.0005	0.0009	0.0005
kss-bh14	1781646.433	1781646.550	1781646.588	1781646.524	0.091	-0.026	-0.064	0.0005	0.0009	0.0005
kss-bh15	1778892.221	1778892.338	1778892.376	1778892.312	0.091	-0.026	-0.064	0.0005	0.0009	0.0005
kss-bh16	1770095.276	1770095.394	1770095.431	1770095.367	0.091	-0.027	-0.064	0.0005	0.0009	0.0005
kss-bh17	1760310.973	1760311.091	1760311.128	1760311.064	0.091	-0.027	-0.064	0.0005	0.0009	0.0005
kss-bh18	1747357.125	1747357.243	1747357.279	1747357.216	0.091	-0.027	-0.063	0.0005	0.0009	0.0005
Kss-bh19	1737011.813	1737011.932	1737011.968	1737011.904	0.091	-0.028	-0.064	0.0005	0.0009	0.0005
KssO15	1750427.988	1750428.107	1750428.143	1750428.079	0.091	-0.028	-0.064	0.0005	0.0009	0.0005
KssO18	1756585.881	1756585.999	1756586.036	1756585.972	0.091	-0.027	-0.064	0.0005	0.0009	0.0005

The result has been calculated between (epoch2000 - epoch 2005 - epoch 2007) different between elevation shown as table below:

Table 5.3: Result of elevation different between three epochs

Point	Epoch2000	Epoch2005	Epoch2007	Mean	V1	V2	V3	RMSE(V1)	RMSE(V2)	RMSE(V3)
1	401.583	401.801	401.564	401.649	0.066	-0.152	0.085	0.0007	0.0004	0.0004
jeblawlia	438.887	439.103	438.866	438.952	0.065	-0.151	0.086	0.0007	0.0004	0.0004
kss12	381.473	381.691	381.454	381.539	0.066	-0.152	0.085	0.0007	0.0004	0.0004
kss13	382.569	382.787	382.550	382.635	0.066	-0.152	0.085	0.0007	0.0004	0.0004
Kss14	382.774	382.991	382.754	382.84	0.066	-0.151	0.086	0.0007	0.0004	0.0004
kss14s	382.708	382.925	382.688	382.774	0.066	-0.151	0.086	0.0007	0.0004	0.0004
kss15	384.807	385.025	384.788	384.873	0.066	-0.152	0.085	0.0007	0.0004	0.0004
kss16	385.512	385.729	385.493	385.578	0.066	-0.151	0.085	0.0007	0.0004	0.0004
kss17	385.594	385.811	385.575	385.66	0.066	-0.151	0.085	0.0007	0.0004	0.0004
kss17s	385.592	385.810	385.573	385.658	0.066	-0.152	0.085	0.0007	0.0004	0.0004
kss18	387.402	387.619	387.382	387.468	0.066	-0.151	0.086	0.0007	0.0004	0.0004
kss19	389.142	389.360	389.123	389.208	0.066	-0.152	0.085	0.0007	0.0004	0.0004
kss20	387.339	387.556	387.319	387.405	0.066	-0.151	0.086	0.0007	0.0004	0.0004
kss21	386.559	386.776	386.540	386.625	0.066	-0.151	0.085	0.0007	0.0004	0.0004
kss22	385.834	386.052	385.815	385.9	0.066	-0.152	0.085	0.0007	0.0004	0.0004
kss-12	381.521	381.738	381.501	381.587	0.066	-0.151	0.086	0.0007	0.0004	0.0004
Kss 16	385.455	385.672	385.436	385.521	0.066	-0.151	0.085	0.0007	0.0004	0.0004
kss-bh9	381.315	381.534	381.297	381.382	0.067	-0.152	0.085	0.0007	0.0004	0.0004
Kss-bh10	379.768	379.986	379.749	379.834	0.066	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh11	380.801	381.020	380.783	380.868	0.067	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh12	378.124	378.343	378.106	378.191	0.067	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh13	396.591	396.811	396.574	396.659	0.068	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh14	402.385	402.605	402.368	402.453	0.068	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh15	457.292	457.512	457.275	457.36	0.068	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh16	427.095	427.314	427.078	427.162	0.067	-0.152	0.084	0.0007	0.0004	0.0004
kss-bh17	409.831	410.050	409.813	409.898	0.067	-0.152	0.085	0.0007	0.0004	0.0004
kss-bh18	405.605	405.823	405.587	405.672	0.067	-0.151	0.085	0.0007	0.0004	0.0004
Kss-bh19	404.038	404.257	404.020	404.105	0.067	-0.152	0.085	0.0007	0.0004	0.0004
KssO15	444.503	444.721	444.484	444.569	0.066	-0.152	0.085	0.0007	0.0004	0.0004
KssO18	429.644	429.862	429.625	429.71	0.066	-0.152	0.085	0.0007	0.0004	0.0004

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From results the epochs it found:

- Average different in easting from (2000-2007) is = 0.0003M.
- Average different in northing from (2000-2007) is = 0.0006M.
- Average different in elevation from (2000-2007) is = 0.0005M.

The RMSE in northing change randomly (0.0005- 0.0009- 0.0005) but systematic in (easting and elevation).

- The main effect of change coordinates is:

- Earth's crust movement.
- Earthquakes movement.

6.2 Recommendations

- Measurement the reference points at specified interval.
- Using mathematical model to calculate different between parameter.

References

1- **AfraimovichEL,KosogorovEA,LeonovichLA**(2000)Theuseoftheinternational GPSnetworkas the global detector (GLOBDET) simultaneously observing sudden ionospheric disturbance.

2- **Al-Haifi Y, Corbett S, Cross P** (1997) Performance evaluation of GPS single-epoch on-the-fly ambigu-ity resolution.

3- **Angermann D, Baustert G, Klotz J** (1995) The impact of IGS on the analysis of regional GPS- network.

4- **Bastos L, Landau H**(1988) Fixing cycle slips in dual-frequency kinematic GPS-application using Kalman filtering

5- **B.hofmann- wellenhof&H.lichtenegger and J. collins**(1997, 2001). global positioning system(theory and practice).

6- **Bock Y, Prawirodirdjo L, Melbourne TI** (2004) Detection of arbitrarily large dynamic ground motions with a dense high-rate GPS network.

7- **Cannon E, Weisenburger S** (2000) The use of multiple receivers for constraining GPS carrier phase ambiguity resolution.

8- **Cai C, Gao Y** (2013) Modeling and assessment of combined GPS/GLONASS precise point positioning. GPS Solutions.

9- **Casotto S, Zin A** (2000) An assessment of the benefits of including GLONASS data in GPS-based precise orbit determination

10- **Chen CS, Chen Y-J, Yeh T-K** (2000) The impact of GPS antenna phase center offset and variation on the positioning accuracy.

11- **Chen H, Dai L, Rizos C, Han S** (2005) Ambiguity recovery using the triple-differenced carrier phase type approach for long-range GPS kinematic positioning.

12- **Cong, L.; Li, E.; Qin, H.; Ling, K.V.; Xue, R.** A performance improvement method for low-cost land vehicle GPS/MEMS-INS attitude determination. *Sensors* **2015 .**

13- **Guochangxu** (second edition)(2003-2007). GPS (theory, algorithms and applications).

14- **Jiang N, Xu Y, Xu T, Xu G, Sun Z, Schuh H** (2016) GPS/BDS short-term ISB modeling and prediction. GPS Solutions.

Li, R.; Qu, X.H. Study on calibration uncertainty of industrial robot kinematics parameters. Chin. J. Sci. Instrum. **2014**

15- **Seo, S.H.; Lee, B.H.; Jee, G.I**. Position error correction using waypoint and vision sensor. In Proceedings of the International Symposium on GNSS, Jeju, Korea, 18–20 October 2014 .

16- **Söderholm, S., Bhuiyan, M. Z. H., Thombre, S., Ruotsalainen L. and H. Kuusniemi** (2016). An L1 CDMA multi-GNSS software receiver,

17- **XuG,SchwintzerP,ReigberCh**(1998)KSGSoft Kinematic/StaticGPSSoftware

Papers:

- **Faisal abdelrahman ali** (2009) . The Sudan - Ethiopia boundary dispute: Associate professor of law .University of Khartoum.
- **Hilde f. Johnson** (2011).waging peace in Sudan .
- **Working paper no.2(**January 1994) (geodetic appreciation) university of east London.

Appendix

List of points in epoch 2000

ID	*Easting (Meter)*	*Northing (Meter)*	*Elevation (Meter)*
18- 1	**19-** 448361.75	**20-** 1725523.865	**21-** 401.583
22- jeblawlia	**23-** 445730.230	**24-** 1684467.280	**25-** 438.887
26- kss12	**27-** 445691.758	**28-** 1715726.919	**29-** 381.473
30- kss13	**31-** 445500.131	**32-** 1706285.677	**33-** 382.569
34- Kss14	**35-** 449159.960	**36-** 1694734.795	**37-** 382.774
38- kss14s	**39-** 449159.954	**40-** 1694734.793	**41-** 382.708
42- kss15	**43-** 454220.449	**44-** 1720981.362	**45-** 384.807
46- kss16	**47-** 461487.182	**48-** 1712795.255	**49-** 385.512
50- kss17	**51-** 468174.736	**52-** 1705071.159	**53-** 385.594
54- kss17s	**55-** 468174.722	**56-** 1705071.161	**57-** 385.592
58- kss18	**59-** 466389.071	**60-** 1695756.483	**61-** 387.402
62- kss19	**63-** 464906.401	**64-** 1685396.921	**65-** 389.142
66- kss20	**67-** 454890.226	**68-** 1686222.922	**69-** 387.339
70- kss21	**71-** 457812.899	**72-** 1695141.342	**73-** 386.559
74- kss22	**75-** 463107.443	**76-** 1704143.612	**77-** 385.834
78- kss-12	**79-** 445691.779	**80-** 1715726.912	**81-** 381.521
82- Kss 16	**83-** 461487.207	**84-** 1712795.274	**85-** 385.455
86- kss-bh9	**87-** 454906.190	**88-** 1739809.061	**89-** 381.315
90- Kss-bh10	**91-** 454804.663	**92-** 1750412.519	**93-** 379.768
94- kss-bh11	**95-** 455545.393	**96-** 1760381.011	**97-** 380.801
98- kss-bh12	**99-** 455706.832	**100-** 1770278.394	**101-** 378.124
102- kss-bh13	**103-** 460291.107	**104-** 1779072.664	**105-** 396.591
106- kss-bh14	**107-** 464724.578	**108-** 1781646.433	**109-** 402.385
110- kss-bh15	**111-** 477815.619	**112-** 1778892.221	**113-** 457.292
114- kss-bh16	**115-** 472514.972	**116-** 1770095.276	**117-** 427.095
118- kss-bh17	**119-** 468380.966	**120-** 1760310.973	**121-** 409.831
122- kss-bh18	**123-** 470666.549	**124-** 1747357.125	**125-** 405.605
126- Kss-bh19	**127-** 472419.438	**128-** 1737011.813	**129-** 404.038
130- KssO15	**131-** 433502.428	**132-** 1750427.988	**133-** 444.503
134- KssO18	**135-** 436447.247	**136-** 1756585.881	**137-** 429.644

List of points in epoch 2005

ID	*Easting (Meter)*	*Northing (Meter)*	*Elevation (Meter)*
138- 1	**139-** 448361.833	**140-** 1725523.984	**141-** 401.801
142- jeblawlia	**143-** 445730.313	**144-** 1684467.400	**145-** 439.103
146- kss12	**147-** 445691.842	**148-** 1715727.039	**149-** 381.691
150- kss13	**151-** 445500.214	**152-** 1706285.797	**153-** 382.787
154- Kss14	**155-** 449160.043	**156-** 1694734.916	**157-** 382.991
158- kss14s	**159-** 449160.038	**160-** 1694734.914	**161-** 382.925
162- kss15	**163-** 454220.532	**164-** 1720981.482	**165-** 385.025
166- kss16	**167-** 461487.265	**168-** 1712795.374	**169-** 385.729
170- kss17	**171-** 468174.819	**172-** 1705071.279	**173-** 385.811
174- kss17s	**175-** 468174.805	**176-** 1705071.281	**177-** 385.810
178- kss18	**179-** 466389.153	**180-** 1695756.603	**181-** 387.619
182- kss19	**183-** 464906.483	**184-** 1685397.042	**185-** 389.360
186- kss20	**187-** 454890.309	**188-** 1686223.043	**189-** 387.556
190- kss21	**191-** 457812.982	**192-** 1695141.462	**193-** 386.776
194- kss22	**195-** 463107.526	**196-** 1704143.732	**197-** 386.052
198- kss-12	**199-** 445691.862	**200-** 1715727.032	**201-** 381.738
202- Kss 16	**203-** 461487.290	**204-** 1712795.394	**205-** 385.672
206- kss-bh9	**207-** 454906.273	**208-** 1739809.179	**209-** 381.534
210- Kss-bh10	**211-** 454804.746	**212-** 1750412.637	**213-** 379.986
214- kss-bh11	**215-** 455545.476	**216-** 1760381.129	**217-** 381.020
218- kss-bh12	**219-** 455706.915	**220-** 1770278.512	**221-** 378.343
222- kss-bh13	**223-** 460291.189	**224-** 1779072.781	**225-** 396.811
226- kss-bh14	**227-** 464724.661	**228-** 1781646.550	**229-** 402.605
230- kss-bh15	**231-** 477815.701	**232-** 1778892.338	**233-** 457.512
234- kss-bh16	**235-** 472515.055	**236-** 1770095.394	**237-** 427.314
238- kss-bh17	**239-** 468381.048	**240-** 1760311.091	**241-** 410.050
242- kss-bh18	**243-** 470666.631	**244-** 1747357.243	**245-** 405.823
246- Kss-bh19	**247-** 472419.520	**248-** 1737011.932	**249-** 404.257

250- KssO15	**251-** 433502.512	**252-** 1750428.107	**253-** 444.721
254- KssO18	**255-** 436447.330	**256-** 1756585.999	**257-** 429.862

List of points in epoch 2007

ID	***Easting (Meter)***	***Northing (Meter)***	***Elevation (Meter)***
258- 1	**259-** 448361.952	**260-** 1725524.019	**261-** 401.564
262- jeblawlia	**263-** 445730.432	**264-** 1684467.434	**265-** 438.866
266- kss12	**267-** 445691.961	**268-** 1715727.074	**269-** 381.454
270- kss13	**271-** 445500.333	**272-** 1706285.832	**273-** 382.550
274- Kss14	**275-** 449160.162	**276-** 1694734.950	**277-** 382.754
278- kss14s	**279-** 449160.157	**280-** 1694734.948	**281-** 382.688
282- kss15	**283-** 454220.651	**284-** 1720981.517	**285-** 384.788
286- kss16	**287-** 461487.384	**288-** 1712795.409	**289-** 385.493
290- kss17	**291-** 468174.938	**292-** 1705071.314	**293-** 385.575
294- kss17s	**295-** 468174.924	**296-** 1705071.316	**297-** 385.573
298- kss18	**299-** 466389.273	**300-** 1695756.637	**301-** 387.382
302- kss19	**303-** 464906.603	**304-** 1685397.076	**305-** 389.123
306- kss20	**307-** 454890.428	**308-** 1686223.077	**309-** 387.319
310- kss21	**311-** 457813.102	**312-** 1695141.496	**313-** 386.540
314- kss22	**315-** 463107.646	**316-** 1704143.766	**317-** 385.815
318- kss-12	**319-** 445691.981	**320-** 1715727.067	**321-** 381.501
322- Kss 16	**323-** 461487.409	**324-** 1712795.429	**325-** 385.436
326- kss-bh9	**327-** 454906.392	**328-** 1739809.215	**329-** 381.297
330- Kss-bh10	**331-** 454804.866	**332-** 1750412.673	**333-** 379.749
334- kss-bh11	**335-** 455545.595	**336-** 1760381.166	**337-** 380.783
338- kss-bh12	**339-** 455707.034	**340-** 1770278.549	**341-** 378.106
342- kss-bh13	**343-** 460291.309	**344-** 1779072.819	**345-** 396.574
346- kss-bh14	**347-** 464724.780	**348-** 1781646.588	**349-** 402.368
350- kss-bh15	**351-** 477815.821	**352-** 1778892.376	**353-** 457.275
354- kss-bh16	**355-** 472515.174	**356-** 1770095.431	**357-** 427.078
358- kss-bh17	**359-** 468381.168	**360-** 1760311.128	**361-** 409.813
362- kss-bh18	**363-** 470666.751	**364-** 1747357.279	**365-** 405.587
366- Kss-bh19	**367-** 472419.640	**368-** 1737011.968	**369-** 404.020

370- KssO15	**371-** 433502.630	**372-** 1750428.143	**373-** 444.484
374- KssO18	**375-** 436447.449	**376-** 1756586.036	**377-** 429.625