VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

APLINKOS INŽINERIJOS FAKULTETAS

GEODEZIJOS IR KADASTRO KATEDRA

Vilma Zubinaitė

SAULĖS AUDRŲ ĮTAKOS PRECIZINEI PADĖČIAI NUSTATYTI PASAULINE NAVIGACINE PALYDOVINE SISTEMA TYRIMAS

INVESTIGATION AND ANALYSIS OF THE INFLUENCE OF SOLAR STORMING ON PRECISE POSITIONING BY GNSS

Baigiamasis magistro darbas

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Pavadinimas: Saulės audrų įtakos precizinei padėčiai nustatyti pasauline navigacine palydovine sistemas tyrimas
Autorius: Vilma Zubinaitė

Kalba:

	lietuvių
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Anotacija

Baigiamajame magistro darbe nagrinėjama saulės audrų įtaka precizinei padėčiai nustatyti pasauline navigacine palydovine sistema, analizės būtinumas ir tikslai. Išnagrinėti pagrindiniai principai, kuriais remiantis nustatomas saulės audros poveikis precizinei padėčiai nustatyti. Pateiktas saulės radiacijos ir geomagnetinių audrų klasifikavimas.

Projekto efektyvumas apskaičiuojamas analizuojant apskaičiuojant saulės aktyvumo efektą palydovų orbitoms remiantis žemės pozicija. Tyrimo procesas - palyginti palydovų ir imtuvo padėtis tą dieną, kai saulės aktyvumas siekė griežčiausia kategoriją ir kaip kontrolinį tašką pasirinkus artimiausia dieną, kai nebuvo užfiksuoti jokie saulės aktyvumo reiškiniai.

Išnagrinėjus teorinius ir praktinius saulės audros įtakos aspektus, pateikiamos baigiamojo darbo išvados ir siūlymai.

Darbą sudaro trys dalys: įvadas, teorija, praktinė tiriamoji dalis, išvados ir siūlymai, literatūros sąrašas.

Darbo apimtis – 78 p. teksto be priedų, 20 iliustr., 23 lent., 27 bibliografiniai šaltiniai.

Atskirai pridedami darbo priedai.

Prasminiai žodžiai: precizinė padėtis, navigacinė palydovinė sistema, palydovų padėties sistema, referencinė stotis, tikslumas

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Annotation

The nature of this Project has started from an understanding of the error sources that affect GNSS positioning, as well as the details of positioning using code or phase measuring technigues. The ability to be able to visualise satelite positioning in three dimensions as related to the Sun has been essential.

Theoretically, the Project has also demanded learning the theory of computing with respect to satelite orbits and their interpolation, date/time conversions, coordinate system conversions anp positional extraction. These in turn have demanded detailed understanding and interpretation of various data file formats and layouts. Only when all of these theoretical aspects have been brought together has it been possible to make detailed computations to arrive at comparative data for analysis.

Computation experiments have been concentrated on the developing of algorithms and test data which can later be used to validate special purpose software These test computations have of necessity been extensive, in an attempt to cover all possible configurations.

A number of surprises have emerged from the results, especially having regard to the size of the results encountered. Many quations have arisen, and not a few of them remain unanswered. These unexplained questions amply demontrate that more work is required in this area.

Structure: introduction and background, theorethical aspects of solar storming on precise positioning by GNSS, practical experimets of investigation and analysis of the influence of solar storming on precise positioning by GNSS, conclusions and suggestions, references.

Thesis consist of: 78 p. text without appendixes, 20 pictures, 10 tables, 27 bibliographical entries.

Appendixes included.

Keywords: precise positioning, global navigation satelite system, satelite positioning systems, reference station, accuracy.

CONTENT

SUMMARY IN LITHUANIAN

Saulės energija yra žemės planetos šaltinis – tai nenuginčijama. Tačiau šiuolaikinė moderni civilizacija tampa vis labiau priklausoma nuo infrastruktūros sąlygų bei galimybių, kurios yra pažeidžiamos tuo pačiu šaltiniu – saulės aktyvumu, kuris taip pat yra žinomas kaip kosminis oras (angl. *space weather*). Paskutiniais metais tai yra aktyviai nagrinėjama.

Saulės įvykiai, kurie gali veikti navigacinius palydovus ir palydovų navigaciją, yra geomagnetinės audros ir saulės radiacijos audros. Šie yra skirstomi į griežtas kategorijas nuo 1 iki 5 (5 kategorija yra griežčiausia) ir yra pranešama reguliariai kiekvieną savaitę aplinkos centro (angl. *SEC - Space Environment Center*). Tikslius šių kategorijų apibrėžimus galima rasti SEC internatiniame puslapyje www.sec.noaa.gov/NOAAScales. Svarbu tai, kad geomagnetinės audros kategorijos G2-G5 ir saulės radiacijos audros kategorijos S2-S5 gali veikti palydovų navigaciją, o tiksliau sakant gali veikti palydovų orbitas.

Saulės įvykiai taip pat trukdo radijo perdavimui ir priėmimui ir todėl tai yra žinoma kaip „radijo nutraukimu“. Palydovų navigacija gali palengvinti signalų transliaciją, „radijo nutraukimo“ (angl. *Radio Blackouts*) paplitimo priežastis geomagnetinėmis ar saulės radiacijos audromis gali taip pat veikti palydovų navigaciją. Radijo nutraukimo aktyvumas taip pat yra skirstomas į kategorijas nuo 1 iki 5.

Gali būti užtikrintai teigiama, kad kiekvienas iš ankščiau minėtų reiškinių iš dalies gali sumažinti tikslumą ir patikimumą palydovų navigacijos ir padėties sistemoms. Taigi, tai argumentuojama, kad saulės aktyvumas yra svarbus matininkams, dirbantiems milimetrų tikslumu.

Kosminio oro (angl. *Space weather*) įtaka palydovų navigacijai ir padėties pozicijai vertinama dviem būdais.

Pirmasis yra reikšmingiausias ir dėl jonosferos trukdymų. Šis viršutinysis žemės atmosferos regionas turi keletą savybių, kurios apsaugo žemės paviršių nuo žalingos saulės radiacijos. Taip pat per ją veikia radijo dažnių perdavimas – įsiterpia anomalijos į palydovų padėčių paklaidų biudžetą.

Antrasis efektas - tai palydovų orbitų judėjimų trukdymai, kurie priklauso nuo saulės vėjo ir radiacijos slėgimo. Navigacijos palydovų orbita palyginti yra aukštai, už jonosferos, todėl palydovai yra nepaveikti trinties iš žemės atmosferos. Palydovai yra pažeidžiami išorinių jėgų, kaip skleidžiamų iš žemės gravitacijos, mėnulio, planetų ir saulės efektų ir įvykių.

Pozicijų apskaičiavimai priklauso nuo žinomų palydovų padėčių. Palydovų padėtys yra skaičiuojamos iš parametrų, kurie apibūdina jų orbitas. Tie parametrai yra prognozuojami ir gali būti papildyti tiksliai apdorotais judėjimo parametrais. Tačiau eilinis matininkas yra suinteresuotas matuoti realiu laiku ir tai jam kliudo pasinaudoti tiksliomis jų efemeridėmis.

Remiantis visuomenės informavimo pranešimais, kitas saulės aukšto aktyvumo ciklas yra numatomas stipresnis nei paskutinieji ciklai. Saulės efektai yra susiję su aukštu saulės aktyvumu galinčiu fiziškai „pastūmėti“ palydovus. Tai gali būti argumentuojama tuo, jog jeigu visi palydovai būtų stumdomi ta pačia kryptimi, tai veikimas ant žemės pozicijos pradingtų. Arba vis dėlto skirtumai nėra susiję, tada kyla klausimas, kokie trukdymų padariniai turi įtakos imtuvo pozicijai.

Baigiamojo darbo uždavinys yra ištirti saulės aktyvumo poveikį palydovų bei žemės padėties pozicijoms. Šiuo tikslu tyrimo procesas buvo:

- Naudojantis gautais duomenimis iš aplinkos centro (angl. *Space Envirinment Center*), buvo siekiama identifikuoti paskutinįjį didesnį saulės audros aktyvumą;
- Naudojantis transliuojamomis efemeridėmis ir tiksliai siunčiamomis efemeridėmis, buvo bandoma apskaičiuoti trijų dimensijų momentines GPS ir GLONASS palydovų padėtis;
- Buvo palyginti transliuojamų ir tikslių efemeridžių nustatytų padėčių iškreipimo mastą.

Mananoma, kad anomalus palydovų išėjimas iš pranašaujamos orbitos yra dėl saulės vėjo spaudimo. Išėjimo apimtis gali būti išgaunama, lyginant suskaičiuotas orbitos padėtis iš dviejų šaltinių:

- Iš transliuojamų efemeridžių kaip išrašai iš referencinės stoties (RINEX formatas);
- Iš tiksliai transliuojamų orbitų iš IGS (SP3 formatas).

Kitaip sakant, tokie pradiniai pranašaujamų ir tikslių efemeridžių padėčių skaičiavimai, duos orbitos trukdymų dydį. Kitas tyrimo etapas tarpusavyje susieti palydovų orbitų trukdymus. Esmė yra ta, jog bus bandoma saulės audros poveikiu modeliuoti visus palydovus.

Šiam tikslui baigiamojo darbo idėja buvo išanalizuoti, kokia yra saulės audrų įtaka precizinei padėčiai nustatyti pasauline navigacine palydovine sistema. Eksperimentiniais objektais buvo pasirinkta iš aplinkos centro (angl. *Space Environment Center*), kur yra pranešama apie saulės aktyvumą. Pasirinkome 2005 metų rugsėjo 11 dieną, kadangi šio centro duomenimis saulė buvo ypač aktyvi - geomagnetinės audros buvo aukščiausio lygio (G5). Kaip kontrolinis taškas buvo pasirinkta artimiausia diena, kai nebuvo užfiksuoti jokie saulės aktyvumo reiškiniai. Tai buvo 2005 metų rugsėjo 29 dieną. Atsitiktinai buvo nuspręsta ištirti sistemos funkcionavimą 10 valandų intervale, pradedant 02:00 UT ir baigiant 12:00 UT (audra buvo 0645 UTC).

Pirmasis tyrimo etapas prieš skaičiuojant palydovų padėtis naudojant stebėtas efemeridžių ir tikslius efemeridžių parametrus, apima tokius žingsnius:

- Perskaičiuoti civilinį laiką į GPS laiką (rezultatai pateikiami 3.1 ir 3.2 lentelėse):
- Identifikuoti regimus palydovus iš RINEX formatų (rezultatai pateikiami 3.3 ir 3.4 lentelėse)

Siekiant apskaičiuoti transliuojamiems palydovų padėtims trijų dimensijų žemės centro koordinates, buvo naudota darbe aprašytomis formulėmis, skyriuje 2.1. Rezultatų ištraukos pateiktos 3.5 ir 3.5 lentelėse, kur pilni spaudiniai yra pateikti 6 ir 7 prieduose.

Imtuvo transliuojamų padėčių skaičiavimai buvo atliekami naudojantis parametrais iš RINEX formato stebėjimo ir navigacijos failų, naudojantis skaičiavimo procedūromis aprašytomis skyriuje 2.2. Rezultatai pateikti 3.7 ir 3.8 lentelėse.

Palydovų padėtys buvo skaičiuojamos tik GPS palydovams. GLONASS palydovų padėčių buvo atsisakyta (3.10 ir 3.12 lentelės), kadangi bandomųjų skaičiavimų rezultatai buvo labai dideli ir kadangi buvo ribotas baigiamojo darbo laikas.

Apskaičiuojanti tikslias palydovų padėtis, buvo naudotasi parametrais iš IGS centro. Rezultatai pateikiami 8 ir 9 prieduose.

Grafiniai pavaizdavimai palydovų išsidėstymų rugsėjo 11 ir 29 dienų, pateikiami baigiamajame darbe 3.4-3.15 paveiksluose.

Tiksli imtuvo padėtis buvo apskaičiuota naudojant apskaičiuotas imtuvo transliuojamos padėties duomenis ir tikslias efemerides iš SP3 failų. Rezultatai pateikti 3.13 ir 3.14 lentelėse, o grafiniai vaizdai – 3.16-3.18 paveiksluose.

Palyginus imtuvo padėčių skaičiavimų rezultatus su Gjøviko universiteto referencine stotimi „GJOV“, skirtumai tarp šios stoties parametrų ir mūsų apskaičiuotų rezultatų yra pateikti 3.15 ir 3.16 lentelėse. Rezultatai yra:

- X koordinatės yra nedidelis skirtumas;

- Y koordinatės rodo apie 15% didesnės nei dienos, kada nebuvo jokių saulės aktyvumo požymių (2005.09.29);
- Z koordinatės – didesnės 80% nei 2005.09.29.

Parametrai, kuriuos gavome apskaičiavus imtuvo padėtį ir tikslias efemerides iš SP3 failų yra kur kas geresni. Palyginus 2005.09.29 ir 2005.09.11 dienų apskaičiuotus parametrus, gavome:

- X koordinatės - 2005.09.29 didesni 40% nei 2005.09.11;
- Y koordinatės - 2005.09.29 didesni 30% nei 2005.09.11;
- Z koordinatės - 2005.09.29 didesni 80% nei 2005.09.11.

Palyginus transliuojamą ir apibrėžtą imtuvo padėtis (1. pav.), apskaičiavome skirtumus tarp tikslios (SP3) ir transliuojamos (RINEX) parametrus ir skirtumus tarp nagrinėjamų dienų (2005.09.11 ir 2005.09.29).

	11.09.2005			29.09.2005			Skirtumai tarp 11.09 ir 29.09		
	X	Y	Z	X	Y	Z	X	Y	Z
Tiksli (SP3)	6			2,7			3,3		
		9,5			6,4			3,1	
			25			9,5			7,0
Transliuojamat (RINEX)	23,5			23,7			0,2		
		55			46,6			8,4	
			82,8			46,5			36,3
Skirtumai	17,5			21,0					
		45,5			40,2				
			57,5			37,0			

1. pav. Transliuojamos ir tikslios imtuvo padėties palyginimai

Analizuojant šiuos duomenis matome, jog palydovų padėčių skirtumai tarp transliuojamos ir tikslios padėčių nėra tokie žymūs kaip skirtumai tarp dienų. Didžiausias skirtumas yra tarp tikslios ir transliuojamos padėčių Z koordinatės – 20 metrų, X ir Y – apie 5 metrus. Skirtumai tarp 2005.09.29 ir 2005.09.11 yra labiau pastebimi. Z koordinatės skiriasi apie 20 metrų.

Išnagrinėjus teorinius ir praktinius saulės audros įtakos aspektus galima daryti išvadas. Skaičiavimų rezultatai nustebino. Panagrinėjus grafikus yra matoma, kad palydovų padėčių kreivės yra išsidėsčiusios netvarkingai, kai buvo veikiami saulės audros, o tuo tarpu kreivių išsidėstymai tą dieną, kai audros nebuvo, yra tolygūs. Iš to galima daryti išvadą, kad palydovų padėtys yra veikiamos saulės aktyvumo. Tačiau konkrečių įvykių tą valandą, kai buvo saulės audra nėra, bet iš grafikų yra matoma, jog penkios valandos prieš audrą palydovų, taip pat ir imtuvų kreivės šokteli. Kodėl taip yra, šiuo metu negalima to paaiškinti. Todėl šiam tikslui, yra siūloma apskaičiuoti padėtis veikiant skirtingų saulės audrų kategorijoms ir tipams, ištirti padėtis paimant didesnį laiko tarpą ir apskaičiuojant palydovų orbitas kas penkias minutes ar net sekundes, nes šiame baigiamajame darbe buvo skaičiuojama kiekvieną valandą. O kad būtų galima atlikti tokius tikslius skaičiavimus, tam tikslui bendradarbiaujant su Gjøviko universiteto dėstytojais yra rašoma programa, pagal kurią bus galima atlikti skaičiavimus automatizuotai.

FIGURES

TABLES

ABBROVIATION

ASCII - American Standard Code for Information Interchange

EUREF 89 - European Reference Frame 1989

GHA - Greenwich Hour Angle

GNSS - Global Navigation Satellite Systems

GPS - Global Positioning System

GST - Greenwich Sidereal Time

IGS - International Geosynthetics Society

ILS - Instrument Landing Systems

LHA - Local Hour Angle

LST - Local Sidereal Time

MLS - Microwave Landing Systems

RINEX - Receiver Independent Exchange Format

SEC - Space Environment Center

SP3 - Standard Product 3 Format

UT - Universal Time

UTC - Coordinated Universal Time

1. INTRODUCTION AND BACKGROUND

1.1. Solar Storming and Precise Satellite Positioning

Solar energy is the source of life on Planet Earth – this is indisputable. However, the modern highly technical civilization is becoming increasingly dependent on infrastructural facilities, which turn out to be vulnerable to disturbance by the very same source – vulnerable to solar activity, which is otherwise becoming known as "space weather".

That this is so is clearly evidenced by the growing research activity of recent years including the launching of a number of appropriately instrumented satellites in order to monitor (provide early warning of) the Sun's motions and improve the understanding of the phenomena involved.

The solar events that can affect navigation satellites and satellite navigation are primarily Geomagnetic Storms and Solar Radiations Storms. Such events are categorized in severity on a scale of 1 to 5 (five most severe) and are reported regularly in weekly summaries distributed by the Space Environment Center (SEC). The definitions of these severity categories are available on the SEC web site (www.sec.noaa.gov/NOAAScales) (Appendix 1). Essentially, geomagnetic storm categories G2 to G5 and solar radiation storm categories S2 to S5 can affect satellite navigation in one way or another, and specifically have the effect of altering satellite orbits.

The solar events also interfere with radio transmission and reception and cause what are known as "radio blackouts". Clearly, since satellite navigation by its nature relies on the transmission of signals, the incidence of radio blackouts caused by geomagnetic or solar radiation storming can also have an effect on satellite navigation. Radio blackout activity is also categorized on a scale from one to five, and the current Category R5 Radio Blackout definition states.

The incidence of geomagnetic and solar radiation phenomena and radio blackouts are regularly advised and reported by the SEC.

How Satellite Positioning System Users are affected

At the outset, it can safely be assumed that each of the above-described phenomena will at the very least degrade the accuracy (and thus reliability) of satellite navigation and positioning systems. The severity of such degradation depends on the level of accuracy required by the user, and surveyors are among those with the most stringent accuracy requirements. Therefore, it is argued that solar activity is of greater significance to the surveyor working at the (hopefully) millimeter accuracy level than it is to the operator or navigator who is much pleased to obtain one-meter reliability.

Notwithstanding the thought that surveyors and geodesist are those most likely to be affected by solar radiation, it must also be remembered that other specialized users are emerging. A prime example of this is the development of aircraft landing guidance aids based on differential satellite navigation systems as an alternative to the conventional (and purportedly much more expensive) Instrument Landing Systems (ILS) and Microwave Landing Systems (MLS).

There are undoubtedly other examples where very high accuracy and/or reliability are required, either already existing or under development.

How satellite Positioning is degraded

Leaving aside the radio blackout phenomenon with its more electronic effects, space weather impacts satellite navigation and positioning in two ways.

The first is usually thought of as most significant, and concerns the disturbance of the Ionosphere. This upper region of the Earth's atmosphere has a number of properties, which serve to protect the surface from the Sun's damaging radiations. In so doing, it also affects the passage of radio frequencies through it – thus injecting anomalies into the satellite positioning error budgets. Ionosphere error has long been thought of as the most awkward and serious difficulty facing high precision users, and much research has been done (and continues) in this area.

The second effect concerns the disturbance of satellite orbit tracks due to solar wind and radiation pressures. Navigation satellites orbit relatively high, well outside the Ionosphere, and therefore largely unaffected by friction drag from the Earth's atmosphere. They are thus vulnerable to external forces such as those that emanate from the gravitational effects of the Earth, the Moon, the planets and the Sun – and solar events. Knowing the relative motions of the heavenly bodies concerned – the proper business of astronomers – gravitational effects are readily taken into account. However, solar events are by nature unpredictable, and high accuracy users to be concerned to know what consequences they are facing.

Rather less work appears to have been done to investigate the practical consequence of navigation satellite orbit perturbation due to solar events.

Consequences of Orbit Disturbance

Position computation depends on knowing the positions of the used satellites. Satellite positions are computed from parameters that describe their orbits. These parameters are in turn predictive and can be replaced by precise parameters post-processed from tracking. However, the average surveyor is interested in (and prepared to pay for) real time, which obviously precludes the use of these precise ephemeredes.

Most production uses of GNSS surveying systems, whether for positioning, setting out or machine guidance, rely on the principles of differential positioning, where differencing techniques are used to eliminate errors. Indeed, it can (and has) been argued that these differencing techniques will safely remove any residual errors there may be in the predictive orbit parameters sets transmitted by the satellites.

On the other hand, having to operate together with some from of reference system – be it a local reference station or a virtual reference station system – can only be considered to be an "expensive necessity". Publicly stated objectives for the future are to improve the single point positioning capabilities significantly, so that a large proportion of survey users will no longer need to operate against reference stations. (GALILEO aims to provide one-meter accuracy for single point positioning). Reducing to single point positioning starts to remove the rather more concealed advantage of differential positioning obtained from differencing techniques. Therefore, errors in satellite orbit parameters can suddenly start to be significantly interesting again. In addition, it has to be remembered that orbit parameters are only uploaded to the satellites "every so often".

Meanwhile, the media report that the next solar-high-activity cycle is predicted (confidence in the high nineties percentile) to be very significantly stronger than in recent cycles. 30% to 50% stronger has been mentioned. The storming effects associated with high solar activity are able to physically "push" satellites off course, rendering their predictive orbital parameters in error. It can be argued that if all satellites are pushed off course in the same direction by the same amount, then the effect on the differentially produced ground position will disappear due to differencing. If however differencing is not involved, then the question becomes what affects such course disturbance has on the ground receiver's position.

The situation is perhaps further complicated by the consequences of satellites passing through eclipse. Here, if the Sun decides to storm, then all satellites visible to the Sun can be assumed to be similarly affected. Satellites in partial eclipse might be less affected, while those actually in full umbra would logically be completely unaffected. On the other hand, GNSS is a 24-hour system, and there is nothing to say, at least at present, that surveyors will only use satellites when they are illuminated by the Sun. Therefore, the question arises as to what effect there might be on a ground receiver's position if not all satellites are pushed off course.

1.2. Project "HiGarus"

The proposed name is a combination of two separate names or parts of names. The first – "HiGarus" – written as here, is the official abbreviation for "Høgskolen i Gjøvik", being the formal Norwegian language name of Gjøvik University College. The proposition is that HiG will carry out this project, and therefore including the abbreviation in the project name indicates the active participants and their "ownership".

The second part of the name – "arus" – is borrowed from Icarus, the son of Deadelus, who flew too close to the sun while escaping from Crete. The wax, which attached him to, the wings that his father had made for him melted. He fell into the Aegean Sea and drowned. Naturally, everyone is well aware of this legend from mythology, and has hopefully learned the associated lessons. Thus borrowing a part of Icarus' name brings forth the project's association with the Sun. The association is perhaps reinforced by the less well know fact that the asteroid whose orbit is said to take it closest to our Sun is, perhaps not unnaturally, called Icarus.

The uniqueness of "HiGarus" can be almost guaranteed in that the combination of the Norwegian abbreviation for rather small university college together with the second half of the name of a mythical figure is more than somewhat unlikely. Meanwhile, it will not go unnoticed that the name "HiGarus" sounds quite similar to "Icarus" and will as a consequence be easy to remember.

Finally, it is suggested that 'HiGarus" is comfortably short, catchy, and will cause little difficulty either in Norwegian or in English.

1.3. The Aim

To investigate the effect of solar activity can have on satellite based ground positioning:

- Single point;
- Differential;
- Code;
- Phase.

Assuming that solar activity does affect positioning results, answer the following consequential issues:

- How big can the effect be – linked to solar weather scales?
- What are identifiable consequences?
- What observing procedures should be invoked?
- What warning procedures should be invoked?

Process:

- Using broadcast ephemeredes or post-processed precise ephemeredes, compute the instantaneous position in three dimensions of each GPS and GLONASS satellites;
- Given a fictitious ground positions specified with high precision, simulate both pseudo range and phase observations at these same instants;
- Similarly, using actual observations extract pseudo range and phase observations;
- Using these either actual or simulated observations, compute the instantaneous receiver positions and compare with the defined positions;
- Using data obtained from the Space Environment Center in USA, identify recent major solar storming activity, and extract live observations from two own records for the same period;
- Compare broadcast and precise ephemeredes to determine the amount of orbit distortion and the time taken to correct the broadcast ephemeredes;
- Using these data develop a model connecting orbit distortion (with consequential ground positions distortion) with solar storming severity scales;
- Pursue these avenues particularly to include visible satellites to the operator, which are in eclipse to determine the effects of eclipsing satellites under solar storming conditions upon ground positions.

1.4. Explanation of the Aim

Assume that abnormal departure of satellite from its predicted orbit is due to solar wind pressure. The amount of departure can be obtained by comparing orbital positions computed from two sources:

- From published almanacs normally intended for mission planning, on from broadcast ephemeredes as recorded by tracking stations;
- From precise post-processed orbits available thought the IGS.

These comparisons need to be made for selected periods of time when it is separately reported that the Sun has been particularly active. In other words, a search through solar activity records will indicate periods of storming, and these will in turn suggest the periods during which predicted and precise ephemeris based satellite positions should be compared. Such initial comparisons will give indications of the size of the orbital disturbances, as well as how long it normally takes before the predicted parameters are update and corrected.

A next relevant investigation is to correlate the orbit disturbances for different satellites at the same solar event. The point here is to attempt to model solar storm effect on all satellites in the GNSS constellations. This would enable reliable simulation.

A further expected outcome of this second analysis is to determine whether solar storming affects satellites as they go through their eclipse periods. Logically, it might be expected that a satellite in eclipse at the time a solar storm attacks the Earth would be unaffected and this should be discernable from comparisons as above. (It should be however be noted that this particular aspect will involve preparing a system of determining whether a satellite's position is on Earth shadow or not).

Finally, conclusions need to be drawn to relate the amount of orbital disturbance to the numerical space weather severity scales that are currently published by the SEC.

Having above experimentally determined the amount by which satellites can have departure from their predicted positions, the questions becomes how far the resulting positions on the ground are removed from the truth. At least two possible approaches suggest themselves here. On is to go directly to simulation, and the second is to work with archived observational data.

Archived data consists of downloaded predicted ephemeredes to visible satellites, together with observed pseudo-ranges and phase measurements on both frequencies. It is thus proposed to compute the ground antenna position at each epoch for the period selected using the actual observed ranges and phases, but based on firstly predicted satellite positions and secondly on actual measured satellite positions as obtained above.

The nature of GNSS is that positional quality depends in the geometry of visible satellites. This is made more awkward at high latitudes (i.e. at the HiG latitude) because of there never being satellites visible in the North apart from those that are very low averring the Northern horizon. It has been suggested that this can lead to a measure of positional distortion, particularly in the North-South ordinate, but not so much in the East-West component.

2. THEORETHICAL ASPECTS OF SOLAR STORMING OF PRECISE POSITIONING BY GNSS

2.1. Computation of Satellite Position

The latest ephemeris parameters extracted above are applicable at the Time of Ephemeris, defined by the parameter t_{oe}. Meanwhile, the epoch of observation t as at some other time. It is therefore necessary that the ephemeris parameters are corrected so that they will be applicable at the epoch of observation. Once this is done, the satellite's co-ordinates can be calculated. The sequence of the computation is as shown in the following list of equations. All that is necessary is to apply the extracted parameters with their correct signs in their corrected places, and in the end, the satellite's co-ordinates will be obtained.

The semi-major axis length of the orbital ellipse comes immediately from:

$$a = \left(\sqrt{a}\right)^2 \qquad (2.1.)$$

According to Kepler's Third Law, the mean motion n_0 - angular velocity – of a satellite is given by:

$$n_0 = \sqrt{\frac{\mu}{a^3}} \qquad (2.2.)$$

This is the theoretical value of the satellite's motion, and to be corrected by the Δn parameter obtained from the satellite message.

$$n = n_0 + \Delta n \qquad (2.3.)$$

No of seconds between t_{oe} and epoch of obs (t) - therefore the number of seconds that the ephemeris has to be updated with:

$$t_k = t - t_{oe} \qquad (2.4.)$$

So that it is now possible to correct the satellite's Mean, Eccentric and True Anomalies up to the epoch concerned:

$$M_k = M_0 + nt_k \qquad (2.5.)$$

$$E_k = M_k + e\sin E_k \tag{2.6.}$$

$$\upsilon_k = 2\arctan\left\{\sqrt{\frac{(1+e)}{(1-e)}}\tan\left(\frac{E_k}{2}\right)\right\} \tag{2.7.}$$

Note that the value of E_k is determined in equation (2.6.) dependent on E_k itself. This is solved by iteration, where in the first attempt, $\sin M_k$ is used on the right of the equals sign. The resulting first value of E_k is then used in the form $\sin E_k$ to evaluate the equation again. This process is repeated until the resulting value of E_k does not alter further (often three or four iterations will be sufficient). Thereafter, once υ_k has been evaluated. The value of E_k can be confirmed from equation (2.8.)

$$E_k = \arccos\left\{\frac{e+\cos\upsilon_k}{1+e\cos\upsilon_k}\right\} \tag{2.8.}$$

The angular distance around the orbit from the Ascending Node crossing the Equatorial Plane going north to the satellite's position - Φ_k - is then obtained by adding the True Anomaly υ_k and Argument of Perigee ω:

$$\Phi_k = \upsilon_k + \omega \tag{2.9.}$$

Next, the Argument of Perigee, orbit radius and orbit inclination are corrected up to the epoch of observation by producing respectively $\delta u_u, \delta r_k$ and δi_k:

$$\delta u_k = C_{us}\sin 2\Phi_k + C_{uc}\cos 2\Phi_k \tag{2.10.}$$

$$\delta r_k = C_{rs}\sin 2\Phi_k + C_{rc}\cos 2\Phi_k \tag{2.11.}$$

$$\delta i_k = C_{is}\sin 2\Phi_k + C_{ic}\cos 2\Phi_k \tag{2.12.}$$

Applying δu_k to the previously computed True Anomaly (equation (2.9.)):

$$u_k = \Phi_k + \delta u_k \tag{2.13.}$$

While the orbit radius and inclination at epoch, including corrections, are obtained from:

$$r_k = a(1 - e\cos E_k) + \delta r_k \qquad (2.14.)$$

$$i_k = i_0 + \delta i_k + (idot)t_k \qquad (2.15.)$$

So far, the satellite's position has been described with respect to how far it has moved around its orbit since it crossed the Equatorial plane going north. The whole is now transformed so that the final resulting satellite position is given in the required three-dimensional Earth-centre Cartesian co-ordinate system. Two intermediate parameters - x'_k and y'_k - are first evaluated:

$$x'_k = r_k \cos u_k \qquad (2.16.)$$

$$y'_k = r_k \sin u_k \qquad (4.17.)$$

Now, Ω_k comes out as the total angular distance in the Equatorial plane from the free-dimensional co-ordinate x-axis – in other words the satellite's longitude:

$$\Omega_k = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_e)t_k - \dot{\Omega}_e t_{oe} \qquad (2.18.)$$

And the final satellite co-ordinates: [19]

$$x_k = x'_k \cos\Omega_k - y'_k \cos i_k \sin\Omega_k \qquad (2.19.)$$

$$y_k = x'_k \sin\Omega_k + y'_k \cos i_k \cos\Omega_k \qquad (2.20.)$$

$$z_k = y'_k \sin i_k \qquad (2.21.)$$

2.2. Computation of Receiver Position

The actual receiver measurements will have been recorded and developed into the standard RINEX Observation Forma. Different types of measurements may have been made, for example, code pseudo-range, phase or Doppler, and the measures might be made on a single frequency or on more than one frequency. Each of these different measurements types can be used to produce a number, which represents the distance in meters from the receiver's antenna centre to the actual satellite is transmitting antenna. (This distance is also often known as "range").

The simple measurement situation:

The demonstration following will develop the position of a satellite receiver antenna in the following circumstances:

- At one defined epoch – instant of time;
- Using one receiver;
- With more than enough satellite visible;
- Using pseudo-range observations on two frequencies;
- Taking into account satellite clock errors;
- Taking into account receiver clock errors.

Available data:

The data to be used in computing the receiver position is:

- The date and time of the observation – the epoch of observation;
- Which specific satellites have been observed;
- The approximate position of the receiver;
- The previously computed positions of the satellites at this epoch;
- The individual satellite's clock error parameters;
- The measured pseudo-ranges on two frequencies to the visible satellites at this epoch.

Symbols:

TX	Refers to a signal transmitter
RX	Refers to a signal receiver
D	A distance, which is directly measured or computed
PR	A pseudo-range – a distance derived from a measured time interval multiplied by the speed of light
t	An instant in time – an epoch
Δt	A time interval – the difference in time between two different instants in time (in other words, Δt will be equal to t_2 minus t_1)
$f(\ldots)$	A mathematical; function

$\delta\ldots$	A small correction to something
c	The Speed of Light
a_1, a_2, a_3	Coefficients
$\frac{\delta\ldots}{\delta x}$	The partial derivative of an expression involving a number of variables but with respect to only one of those variables (in this case x), and treating the remaining variables as fixed quantities

Otherwise,

- Names and symbols for parameters that are extracted from RINEX files use the parameter names that are to be found in the RINEX documentation.
- Additional parameters referring to satellites are given in upper case capitals. A suffix is used to indicate which satellite. In other words, the tree-dimensional co-ordinates of satellite $PRN26$ would be represented by X_{26}, Y_{26} and Z_{26}.
- Lower case symbols are used for parameters referring to the receiver.

Constants:

The only constant necessary, once the actual satellite co-ordinates have been computed, is the Speed of Light. The value used here is:

$$c = 2.99792458000E + 08 \text{ meters per second}$$

Using Algebraic Representations:

To start with, then, the distance between two points in three dimensions is a function of the three-dimensional co-ordinate of those two points. Of on of those two points is treated as being fixed and immovable, then the distance between it and the other becomes merely a function of the co-ordinates of the other.

In this case, let the instantaneous co-ordinates of the satellite be considered as fixed and immovable. Then:

Statement 1:

Distance RX to TX = f *(receiver co-ordinates)*

$$ {}_{RX}D_{TX} = f(x_{RX}, y_{RX}, z_{RX}) \tag{2.22.} $$

Suppose now that the receiver co-ordinates are estimated from other sources of information – as for example a map – then a new mathematical function statement can be made:

Statement 2:

Estimated distance RX to TX = f (estimated receiver co-ordinates)

$$ \left({}_{RX}D_{TX}\right)_{estimated} = f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right) \tag{2.23.} $$

However, the final correct receiver co-ordinates are equal to the estimated receiver co-ordinates plus unknown small corrections. Therefore, *Statement 1* above can now be rewritten to incorporate these unknown corrections:

Statement 3:

Correct distance RX to TX = f (corrections to estimated receiver co-ordinates + estimated co-ordinates)

$$ \left({}_{RX}D_{TX}\right)_{correct} = f\left\{\left(\delta x_{RX} + x_{RX_{estimated}}\right), \left(\delta y_{RX} + y_{RX_{estimated}}\right), \left(\delta z_{RX} + z_{RX_{estimated}}\right)\right\} \tag{2.24.} $$

Note that the corrections are the unknowns in *Statement 3*, while the estimated co-ordinates of the receiver are treated as being fixed.

Now that the unknowns are focused as small corrections to estimated values, it is necessary to apply Taylor's Theorem to the mathematical function described in *Statement 3*. This yields the following new statement:

Statement 4:

Correct distance RX to TX = f (estimated co-ordinates) + Partial first derivatives of Statement 2 with respect to each of the individual co-ordinate correction.

$$ \left({}_{RX}D_{TX}\right)_{correct} = \begin{array}{l} f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right) + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial x_{RX_{estimated}}} \cdot \delta x_{RX} \\ + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial y_{RX_{estimated}}} \cdot \delta y_{RX} \\ + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial z_{RX_{estimated}}} \cdot \delta z_{RX} \end{array} \tag{2.25.} $$

On examining *Statement 4*, the mathematical function of the estimated receiver co-ordinates can be seen to be the estimated distance from receiver to satellite, as given in *Statement 2*. Now therefore, *Statement 4* above can be simplified:

Statement 5:

Correct distance RX to TX = Estimated distance RX to TX + Partial first derivatives of Statement 2 with respect to each of the individual co-ordinate correction.

$$\left({}_{RX}D_{TX}\right)_{correct} = \begin{array}{l} \left({}_{RX}D_{TX}\right)_{estimated} + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial x_{RX_{estimated}}} \cdot \delta x_{RX} \\ + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial y_{RX_{estimated}}} \cdot \delta y_{RX} \\ + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial z_{RX_{estimated}}} \cdot \delta z_{RX} \end{array} \qquad (2.26.)$$

It is perhaps advisable to turn *Statement 5* around so that the unknowns – the co-ordinate corrections – come at the beginning of the statement, because this will then better reflect in the algebraic construction of the equations:

Statement 6:

Partial first derivatives of Statement 2 with respect to each of the individual co-ordinate correction = Correct distance RX to TX - Estimated distance RX to TX .

$$\begin{array}{l} \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial x_{RX_{estimated}}} \cdot \delta x_{RX} \\ + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial y_{RX_{estimated}}} \cdot \delta y_{RX} \\ + \dfrac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial z_{RX_{estimated}}} \cdot \delta z_{RX} \end{array} = \left({}_{RX}D_{TX}\right)_{correct} - \left({}_{RX}D_{TX}\right)_{estimated} \qquad (2.27.)$$

The last stage in constructing the observation equations is to look at the actual observation. The actual raw observation is a measurement of the time taken – the time interval – by a signal to travel from satellite to receiver. This measurement is made using the GPS Timescale, so that the time interval is equal to the GPS time of arrival of the signal minus the GPS time at which the signal departed from the satellite. Each of these two time statements naturally need to include the respective clock errors, so that:

Statement 7:

Observed signal travel time = Receiver clock time of arrival – Satellite time of departure.

$$\Delta t_{observed} = t_{in_{RX}} - t_{out_{RX}} \tag{2.28.}$$

Clock time is however equal to GPS Time plus clock error, thus:

$$t_{in_{RX}} = t_{in_{GPS}} + \delta t_{RX} \tag{2.29.}$$

And

$$t_{out_{TX}} = t_{out_{GPS}} + \delta t_{TX} \tag{2.30.}$$

Therefore, expanding in terms of satellite and receiver clock and their respective errors:

Statement 8:

Observed signal travel time = GPS tome of arrival + Receiver clock error – (GPS time of departure + Satellite clock error)

$$\Delta t_{observed} = \left(t_{in_{GPS}} + \delta t_{RX}\right) - \left(t_{out_{GPS}} + \delta t_{TX}\right) \tag{2.31.}$$

This can also be written:

Statement 9:

Observed signal travel time = Signal travel time in GPS time + Receiver clock error – Satellite clock error.

$$\Delta t_{observed} = \Delta t_{GPS} + \delta t_{RX} - \delta t_{TX} \tag{2.32.}$$

Multiply this by the speed of light to convert to distance, and the statement it terms of pseudo-range distances becomes (note that the observation is of a time interval and not directly of a distance, and this is why the observed "distance" is called "pseudo-range", here using the symbol PR):

Statement 10:

Observed pseudo-range = Correct distance + Speed of Light x receiver clock error – Speed of Light x satellite clock error.

$$c \cdot \Delta t_{observed} = c \cdot \Delta t_{GPS} + c \cdot \delta t_{RX} - c \cdot \delta t_{TX} \tag{2.33.}$$

$$\left({}_{RX} PR_{TX}\right)_{observed} = \left({}_{RX} D_{TX}\right)_{correct} + c \cdot \delta t_{RX} - c \cdot \delta t_{TX} \tag{2.34.}$$

Completing the development of the observation equation structure, now substitute of the correct distance D in *Statement 6*:

Statement 11:

Partial first derivatives of Statement 2 with respect to each of the individual co-ordinate correction = Observed pseudo-range – Speed of Light multiplied by receiver clock error + Speed of Light multiplied by satellite clock error – Estimated distance RX to TX.

$$\begin{aligned} &\frac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial x_{RX_{estimated}}} \cdot \delta x_{RX} \\ &+ \frac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial y_{RX_{estimated}}} \cdot \delta y_{RX} = \left({}_{RX} PR_{TX}\right)_{observed} - c \cdot \delta t_{RX} + c \cdot \delta t_{TX} - \left({}_{RX} D_{TX}\right)_{estimated} \\ &+ \frac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial z_{RX_{estimated}}} \cdot \delta z_{RX} \end{aligned} \tag{2.35.}$$

The result of *Statement 11* above is a rather complicated looking affair, and, to aid understanding, some further discussion is appropriate:

- Initially, remember that anything, which is “estimated” or “observed” in the above equation, is already something to which actual number can readily be attached.
- Leaving these aside, then, there are five quantities to which numbers cannot be easily allocated from any of the sources of data discussed so far. These are: $\delta x_{RX}, \delta y_{RX}, \delta z_{RX}, \delta t_{RX}$ and δt_{TX}.
- Fortunately, the value δt_{TX} is actually available by computation from parameters that are provided in the navigation message, and this leaves four unknown quantities.
- Meanwhile, the partial derivatives on the left of the equals sign also need to be expanded before actual numbers can be entered.
- Also, note that each term of the above equation is in distance units – this is merely to reinforce the contention that it is entirely arithmetically correct to use an equal’s sign.

Collecting up unknowns on the left, and known and observables into an absolute term on the right (given in the conventional least squares order), the *Statement 11* equation will become:

Statement 12:

$$\begin{aligned}&\frac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial x_{RX_{estimated}}}\cdot \delta x_{RX}\\&+\frac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial y_{RX_{estimated}}}\cdot \delta y_{RX}\\&+\frac{\partial f\left(x_{RX_{estimated}}, y_{RX_{estimated}}, z_{RX_{estimated}}\right)}{\partial z_{RX_{estimated}}}\cdot \delta z_{RX}\\&+c\cdot \delta t_{RX}\end{aligned} = \left\{-\left({}_{RX}D_{TX}\right)_{estimated}+\left({}_{RX}PR_{TX}\right)_{observed}+c\cdot \delta t_{TX}\right\} \quad (2.36.)$$

Notice now that this equation consists on the left of a series of unknown quantities, each multiplied by some coefficient, and, on the right in curly brackets, an absolute term. Both the left hand side coefficients and the right hand side absolute term are based on available numbers, and can therefore be evaluated. The *Statement 12* equation is now simplified yet further by a form of substitution, and will end up looking very similar to any observation equation in any survey adjustment process by the method of least squares. (Note also that the word “estimated” has been replaced with the word “computed” again to accord with conventional surveying least terminology – not unnaturally, since to estimate the provisional co-ordinates of a new point inevitably involves some computations).

Statement 13:

$$a_1\cdot \delta x_{RX}+a_2\cdot \delta y_{RX}+a_3\cdot \delta z_{RX}+c\cdot \delta t_{RX} = \left\{-\left({}_{RX}D_{TX}\right)_{computed}+\left({}_{RX}PR_{TX}\right)_{observed}+c\cdot \delta t_{TX}\right\} \quad (2.37.)$$

Where the four unknowns have coefficients, which are evaluated as follows:

$$a_1 = \frac{\partial f\left(x_{RX_{computed}}, y_{RX_{computed}}, z_{RX_{computed}}\right)}{\partial x_{RX_{computed}}} \quad (2.38.)$$

$$a_2 = \frac{\partial f\left(x_{RX_{computed}}, y_{RX_{computed}}, z_{RX_{computed}}\right)}{\partial y_{RX_{computed}}} \quad (2.39.)$$

$$a_3 = \frac{\partial f\left(x_{RX_{computed}}, y_{RX_{computed}}, z_{RX_{computed}}\right)}{\partial z_{RX_{computed}}} \quad (2.40.)$$

$c =$ the speed of light (a given constant)

Judging now by the number of times the concept of least squares adjustment has been mentioned so far; it is implicit that normal positioning will involve observations to more than enough satellites – more than the minimum required four satellites. Therefore, the above *Statement 14* equation to an individual satellite is most unlikely to be an exact equality. There are always going to be residual errors, and these are normally called "v". Therefore, to now make the equation confirm to standard survey least squares usage, a little moving around is necessary, and the residual v needs to be introduced:

Statement 14:

$$a_q \cdot \delta x_{RX} + a_2 \cdot \delta y_{RX} + a_3 \cdot \delta z_{RX} + c \cdot \delta t_{RX} - \left\{ -\left({}_{RX} D_{TX} \right)_{computed} + \left({}_{RX} PR_{TX} \right)_{observed} + c \cdot \delta t_{TX} \right\} = v \qquad (2.41.)$$

Which, after tidying up (removing the curly brackets becomes):

Statement 15:

$$a_1 \cdot \delta x_{RX} + a_2 \cdot \delta y_{RX} + a_3 \cdot \delta z_{RX} + c \cdot \delta t_{RX} + \left({}_{RX} D_{TX} \right)_{computed} - \left({}_{RX} PR_{TX} \right)_{observed} - c \cdot \delta t_{TX} = v \qquad (2.42.)$$

All that remains now before the actual putting in of numbers can begin is to work out how the three "a" coefficients can be computed. Returning to *Statement 1*, repeated here for convenience:

Statement 1:

$${}_{RX} D_{TX} = f\left(x_{RX}, y_{RX}, z_{RX} \right) \qquad (2.43.)$$

In addition, expanding geometrically – the clue is Pythagoras in three dimensions – and remember that the satellite (TX) co-ordinates are regarded as fixed in this context:

Statement 16:

$$f\left(x_{RX}, y_{RX}, z_{RX} \right) = \sqrt{\left(X_{TX} - x_{RX} \right)^2 + \left(Y_{TX} - y_{RX} \right)^2 + \left(Z_{TX} - z_{RX} \right)^2} \qquad (2.44.)$$

The partial derivative of this expression with respect to x_{RX} becomes

Statement 17:

$$\frac{\partial f\left(x_{RX_{computed}}, y_{RX_{computed}}, z_{RX_{computed}}\right)}{\partial x_{RX_{computed}}} = \frac{\partial\sqrt{\left(X_{TX}-x_{RX}\right)^2+\left(Y_{TX}-y_{RX}\right)^2+\left(Z_{TX}-z_{RX}\right)^2}}{\partial x_{RX_{computed}}}$$

$$= \frac{1}{2}\left\{\left(X_{TX}-x_{RX}\right)^2+\left(Y_{TX}-y_{RX}\right)^2+\left(Z_{TX}-z_{RX}\right)^2\right\}^{-\frac{1}{2}} \cdot 2\left(X_{TX}-x_{RX}\right) \cdot -1$$

$$= -\frac{1 \cdot 2\left(X_{TX}-X_{RX}\right) \cdot (-1)}{2\sqrt{\left(X_{TX}-x_{RX}\right)^2+\left(Y_{TX}-y_{RX}\right)^2+\left(Z_{TX}-z_{RX}\right)^2}}$$

$$= -\frac{\left(X_{TX}-x_{RX}\right)}{\sqrt{\left(X_{TX}-x_{RX}\right)^2+\left(Y_{TX}-y_{RX}\right)^2+\left(Z_{TX}-z_{RX}\right)}} \qquad (2.45.)$$

If now the computed estimated values for the receiver co-ordinates have been used as in *Statement 14*, then this partial derivative becomes:

Statement 18:

$$\frac{\partial f\left(x_{RX_{computed}}, y_{RX_{computed}}, z_{RX_{computed}}\right)}{\partial x_{RX_{computed}}} = -\frac{\left(X_{TX}-x_{RX_{computed}}\right)}{\sqrt{\left(X_{TX}-x_{RX_{computed}}\right)^2+\left(Y_{TX}-y_{RX_{computed}}\right)^2+\left(Z_{TX}-z_{RX_{computed}}\right)^2}} \qquad (2.46.)$$

Simplifying, note that the square root term is actually equal to the computed estimated distance between the receiver and the satellite based on the computed estimated receiver co-ordinates.
Therefore:

Statement 19:

$$\frac{\partial f\left(x_{RX_{computed}}, y_{RX_{computed}}, z_{RX_{computed}}\right)}{\partial x_{RX_{computed}}} = -\frac{\left(X_{TX}-x_{rx_{computed}}\right)}{{}_{RX}D_{TX}} \qquad (2.47.)$$

Using similar arguments, the expression for the other two partial derivatives can also be developed.

In conclusion, and partly repeating, the conventional observation equation is:

Statement 15:

$$a_1 \cdot \delta x_{RX} + a_2 \cdot \delta y_{RX} + a_3 \cdot \delta z_{RX} + c \cdot \delta t_{RX} + \left({}_{RX}D_{TX}\right)_{computed} - \left({}_{RX}PR_{TX}\right)_{observed} - c \cdot \delta t_{TX} = v$$

Where the four coefficients are evaluated:

Statement 20:

$$a_1 = -\frac{\left(X_{TX} - x_{RX_{computed}}\right)}{{}_{RX}D_{TX_{computed}}} \tag{2.48.}$$

$$a_2 = -\frac{\left(Y_{TX} - y_{RX_{computed}}\right)}{{}_{RX}D_{TX_{computed}}} \tag{2.49.}$$

$$a_3 = -\frac{\left(Z_{TX} - z_{RX_{computed}}\right)}{{}_{RX}D_{TX_{computed}}} \tag{2.50.}$$

$c =$ the speed of light (a given constant)

While the full equation would be written as: [20]

$$\begin{aligned} -\frac{\left(X_{TX} - x_{RX_{computed}}\right)}{{}_{RX}D_{TX}}\delta x_{RX} - \frac{\left(Y_{TX} - y_{RX_{computed}}\right)}{{}_{RX}D_{TX_{computed}}}\delta y_{RX} - \frac{\left(Z_{TX} - z_{RX_{computed}}\right)}{{}_{RX}D_{TX}}\delta z_{RX} + c\cdot\delta t_{RX} + \\ + \left\{\left({}_{RX}D_{TX}\right)_{computed} - \left({}_{RX}PR_{TX}\right)_{ocserved} - c\cdot\delta t_{TX}\right\} = v \end{aligned} \tag{2.51.}$$

2.3. Computation of the eclipse

Its altitude above the horizon and its azimuth from the north, as seen by an observed on the Earth's surface, most conveniently specifies the position of a heavenly body in the sky. It is essentially a comparison between the observed and calculated values of altitude and azimuth that makes possible the determination of position and direction on the Earth's surface from astronomical observations. It is not practicable to tabulate the rapidly changing altitudes and azimuths of the heavenly bodies for all positions on the Earth, but they can be calculated for any position, by direct solution of a spherical triangle, from knowledge of the geocentric position of the heavenly body referred to the Earth's equator.

In fact the quantities which the observer requires from the almanac are the Greenwich hour angle (GHA), namely the arc of the equator (or the angle at the pole) westwards from the Greenwich meridian, and the declination, or arc of the meridian from the equator to the body. Both are independent will in practice either be combined with a known, or assumed, longitude to give hour angle (LHA) or be used to derive longitude from a value of LHA deduced from observation.

The rotation of the Earth on its axis west to east causes the heavenly bodies to appear to revolve round the Earth from east to west. Owing to the real motion of the Earth in its annual orbit about the Sun, the latter appears to alter its position with respect to the stars and so appears to revolve in a different period; moreover, owing to the varying motions of the Earth in its orbit, this period is not constant. Universal time (UT), which is the mean solar time of the meridian of Greenwich, is such that the average period of rotation of the Earth with respect to the Sun taken throughout the year is precisely 24 hours; this is mean solar day. (The mean solar day is now slightly longer than a day of 86400 atomic seconds; the accumulated effect of this difference amounts to about one second each year). The hour angle of the Sun increases at a rate which is, on the average, precisely that of mean solar time. The differences between the Greenwich hour angle of the Sun and universal time oscillates slowly and with small amplitude, it is convenient to tabulate this difference (denoted by E) and to obtain the Greenwich hour angle of the Sun from the relation:

$$\text{Greenwich hour angle (GHA) Sun} = \text{UT} + \text{E} \qquad (2.52.)$$

In which multiples of 24 hour may be omitted. The Sun transits over the Greenwich meridian when UT = 24 hours – E.

The period of rotation of the Earth with respect to the stars is approximately 23:56:01, 1 of mean solar time, so that the hour angles of the stars increase more rapidly than that of the Sun. It is convenient to relate the positions of the stars to the is the vernal equinox, or the first point of Aries, which is the intersection of the Earth's equator and the ecliptic. The hour angle of this point increases by approximately 24:03:56, 6 each mean solar day. By analogy with the treatment of the Sun, a quantity R is defined such that is the difference between GHA Aries and UT; R increases by 3:56, 6 (minutes, seconds) a day. Thus:

$$\text{GHA Aries} = \text{UT} + \text{R} \qquad (2.53.)$$

In addition, is Greenwich (apparent) sidereal time (GST).

The hour angle of a star differs from that of Aries by the arc of the equator, or the angle at the pole, between the meridian of Aries and the meridian of the star, this difference is measured eastwards from the meridian of Aries to that of the star and is known as right ascension (RA).

The apparent right ascensions (and declinations) of stars are nearly constant, varying slightly owing to the real motions of the stars and to precession, and periodically owing to nutation and aberration. The GHA of a star is obtained from that of Aries by subtracting the right ascension:

$$\text{GHA Star} = \text{GHA Aries} - \text{RA Star} = \text{GST} - \text{RA Star} \qquad (2.54.)$$

Whence the formula for the GHA of star is:

$$\text{GHA Star} = \text{UT} + \text{R} - \text{RA Star} \qquad (2.55.)$$

It will be seen that when a star (or other heavenly body) is on the Greenwich meridian, its right ascension is equal to the Greenwich sidereal time:

Knowledge of UT will enable the GHA of the Sun and stars to be calculated from tabulated values of E, R and RA of the stars. Standard radio time signals give coordinates universal time (UTC), which differs from international atomic-time scale by an exact number of seconds. Step adjustment is made as required (normally at 0 hour on January 1 and July 1) so that the difference between the time signal and UT does not exceed zero, 9 seconds.

In the same way as UT, GHA and GST are related to the meridian of Greenwich, there exist mean solar times, hour angles and sidereal times related to the meridian of the observer and termed local mean time

(LMT), local hour angle (LHA) and local sidereal time (LST). Each of these differs from the corresponding UT, GHA and GST by the longitude of the observer, if necessary expressed in time. Thus:

$$Longitude = LMT - UT = LHA - GHA = LST - GST \qquad (2.56.)$$

Where the sign convention east longitude is positive is used. Similarly,

$$LMT = UT + longitude(east) \qquad UT = LMT - longitude(east) \qquad (2.57.)$$

$$LHA = GHA + longitude(east) \qquad LST = GST + longitude(east) \qquad (2.58.)$$

Combination of (2.56.) and (2.58.) with (2.52.) and (2.55.), together with the tabulated declination, will provide the data to enable positions to be determined from astronomical observations.

In practice, local mean and sidereal times are used primarily in connection with local phenomena such as rising and setting and meridian passage, as such, they are mainly used for planning programmers. Just as the Greenwich meridian passage of the Sun occurs when UT=24 hours – E, the local meridian passage occurs when LMT is 24 hours – E, similarly corresponding to the LHA of a star whose right ascension is zero, is frequently used as an argument for such tables as the Pole Star Table, it may be obtained by combining longitude with R and UT as:

$$LST = R + UT + longitude(east) \qquad (2.59.)$$

If mean (UT or LMT) is required for a given sidereal time (GST or LST) it may be obtained from:

$$UT = GST - R; \qquad LMT = LST - R \qquad (2.60.)$$

Where R is to be taken for the (approximate) UT concerned. [26]

2.4. Conversion of Coordinates

Geocentric coordinates are Earth centered three-dimensional Cartesian co-ordinates. In other words, they come in sets of three numbers – meters – and are conventionally known as x, y and z. The three axes, again conventionally are:

- x-axis parallel to the conventional zero meridian of longitude at Greenwich and in the equatorial plane;
- y-axis at 90º to the x-axis in the easterly direction and in the equatorial plane;
- z-axis parallel to the mean axis of Earth rotation in the northerly direction.

Geodetic coordinates also come in sets of three numbers to define uniquely a position on the selected Figure of the Earth (the “ellipsoid” also sometimes called the “spheroid”). To make sense of this type of coordinates it is necessary to also specify which ellipsoid is being used, usually in the form of announcing:

- "a" - the length in meters of the ellipsoid’s semi-major axis;
- "e^2" - the square of the eccentricity of the ellipsoid.

Many, instead of quoting the eccentricity, specify the ellipsoid’s flattening, which is given by:

$$f = \frac{(a-b)}{a} \tag{2.61.}$$

(b is the length of the ellipsoid’s semi-minor axis)

In addition, the relationship between f and e^2 is given by:

$$e^2 = 2f - f^2 \tag{2.62.}$$

Thereafter, the tree numerical position descriptors in the geodetic coordinate system are as follows:

- Latitude – symbol ϕ - in degrees, minutes and seconds of arc;
- Longitude – symbol λ - in degrees, minutes and seconds of arc;
- Height over the defined ellipsoid – symbol H - in meters – also known as the ellipsoidal height – and equal to the sum of orthometric (leveled) height (h) and geoidal separation (N). [24]

2.4.1. Converting from Latitude, Longitude and Height to Geocentric Coordinates

This is straightforward and involves three closed formulae. No iteration is required, although it is necessary to take care that enough significant figures are held.

Given a position in terms of latitude (ϕ), longitude (λ) and orthometric height (h), with its associated geoidal separation (N), then the geocentric coordinates are given by:

$$x = (v + N + h) \cdot \cos\phi \cdot \cos\lambda \qquad (2.63.)$$

$$y = (v + N + h) \cdot \cos\phi \cdot \sin\lambda \qquad (2.64.)$$

$$z = \{(1 - e^2) \cdot v + N + h\} \cdot \sin\phi \qquad (2.65.)$$

Where v, the length of the normal terminated by the ellipsoid's minor axis (the ellipsoid's meridional radius), is given by:

$$v = \frac{a}{\sqrt{(1 - e^2 \cdot \sin^2\phi)}} \qquad (2.67.)$$

2.4.2. Converting from Geocentric Coordinates to Latitude, Longitude and Height

The reverse conversion is rather complicated for two reasons:

- The first is that the computation involves evaluation of v, the length of the normal terminated by the ellipsoid's minor axis, which is itself a function of the so far unknown latitude;
- The second is that the function to determine latitude is itself a function of a combination of v and latitude.

However, suitable iterations based on a provisional value for latitude converge rapidly.

The longitude is determined directly from:

$$\tan\lambda = \frac{y}{x}\text{, or in other words}$$

$$\lambda = \tan^{-1}\left(\frac{y}{x}\right) \qquad (2.68.)$$

Using latitude can now be calculated using the provisional latitude and the meridional radius just calculated:

$$\tan\phi = \frac{z + e^2 \cdot v \cdot \sin\phi}{\sqrt{(x^2 + y^2)}}, \text{ so that}$$

$$\phi = \tan^{-1}\left\{\frac{z + e^2 \cdot v \cdot \sin\phi}{\sqrt{(x^2 + y^2)}}\right\} \quad (2.69.)$$

Now use the results of formulae 2.69. to repeat from formulae 2.68. again, repeating until the value of latitude has fully stabilized.

Ellipsoidal height $((N + h)$ now comes from:

$$(N + h) = \frac{\sqrt{(x^2 + y^2)}}{\cos\phi} - v \quad (2.70.)$$

In high latitudes, it may be preferable to use the following: [21]

$$(N + h) = \frac{z}{\sin\phi} - (1 - e^2) \cdot v$$

2.5. RINEX Format

The first proposal for the "Receiver Independent Exchange Format" RINEX has been developed by the Astronomical Institute of the University of Berne for the easy exchange of the GPS data to be collected during the large European GPS campaign EUREF 89, which involved more than 60 GPS receivers of 4 different manufactures. The governing aspect during the development was the following fact:

Most geodetic processing software for GPS data uses a well-defined set of observables:

- The carrier-phase measurement at one or both carriers (actually being a measurement on the beat frequency between the received carrier of the satellite signal and a receiver-generated reference frequency).

- The pseudo range (code) measurement, equivalent to the difference of the time of reception (expressed in the time frame of the receiver) and the time of transmission (expressed in the time frame of the satellite) of a distinct satellite signal.
- The observation time being the reading of the receiver clock at the instant of validity of the carrier-phase and/or the code measurements.

Usually the software assumes that the observation time is valid for both the phases and the code measurements, and for all satellites observed.

Consequently, not all these programs need most of the information that is usually stored by the receivers: they need phase, code, and time in the above-mentioned definitions, and some station-related information like station name, antenna height, etc.

2.5.1. General Format Description

Currently the format consists of six ASCII file types:

- Observation Data File (often known as "O-files")
- GPS Navigation Message Files (often known as "N-files")
- GLONASS Navigation Message File (often known as "G-files")
- GEO Navigation Message File (often known as "H-files")
- Meteorological Data File (often known as "M-files")
- Satellite and Receiver Clock Data File (often known as "C-files")

2.5.2. The RINEX File Naming Convention

The recommendation in the RINEX Standard is to use a file naming convention, which is compatible with the most common operating system currently to be found. To achieve this, the convention calls for file names of no more than eight characters before the file name separator, and with file extensions of three characters.

The naming format is then designed to provide a workably unique system, which clearly identifies the following critical details:

- The station or point at which the observational data were recorded;
    - Four characters allowed

- The date on which the observations were recorded;
    - Three characters allowed in the file name, and two characters allowed in the file name extension
- The sequence number of the file(s) if three are more than one file on the same date;
    - One character allowed
- The type of data included in the file;
    - One character allowed.

2.5.3. The RINEX File Name Structure

The eleven character positions in the recommended RINEX standard file name are represented as follows: [22]

ssssdddf.yyt	ssss:	4 characters station name can be either numerical or alphabetical, but punctuation symbols should preferably not be used.
	ddd:	The Day of Year (DoY) number of the first record in the file. Always a number. If the DoY requires less than three digits, than the three characters need to e filled with zeoes.
	f:	The file sequence number within the day. Usually, alphabetical characters are used (with one exception) such that, for example, the third file at the same station within a particular day would use the letter “c”. The exception is where there is only one file during the day, in which case the numeral zero “0” is used.
	yy:	The last two digits of the year – “05” means the year 2005. (Clearly. Years before 1980 are not relevant since before that time there was no GPS to exchange data from. Meanwhile, this convention will therefore be unique up to 2079, by which time undoubtedly new systems will have led to completely new and different standards – almost certainly).
	t:	The type of data in the file, indicated by an alphabetical letter which is the first letter of an English language word that describes the contents – more or less: O: Observation file N: Navigations file for GPS G: GLONASS Navigation file for GLONASS

H: Navigation file for Geostationary GPS payload
M: Meteorological data file
C: Satellite and Receiver Clock data fie.

2.5.4. RINEX Observation File

The original RINEX Version 2 needed one major supplement, the explicit definition of the time system:

GLONASS is basically running on UTC (or, more precisely, GLONASS system time linked to UTC (SU)), i.e. the time tags are given in UTC and not GPS time. In order to remove possible misunderstandings and ambiguities, the header records "TIME OF FIRST OBS" and (if present) "TIME OF LAST OBS" in GLONASS and GPS observation files *can*, in mixed GLONASS/GPS observation files *must* contain a time system identifier defining the system that all time tags in the GLONASS UTC time system. Pure GPS files default to GPS and pure GLONASS files default to GLO.

Hence, the two possible time tags differ by the current number of leap seconds.

In order to have the current numbers of leap seconds available recommend including a LEAP SECOND line into the RINEX header.

If there are known non-integer biases between the "GPS receiver clock" and "GLONASS receiver clock" in the same receiver, they should be applied. In this case the respective code and phase observations have to be corrected, too (c * bias if expressed in meters).

The small differences (modulo 1) between GLONASS system time, UTS (SU), UTC (USNO) and GPS system time have to be dealt with during the post-processing and not before the RINEX conversion. It may also be necessary to solve for remaining differences during the post-processing.

Table 2.1 Observation data file – header section description

HEADER LABEL (Columns 61-80)	DESCRIPTION	FORMAT
RINEX VERSION / TYPE	- Format version (2.10) - File type ('O' for Observation Data) - Satellite System: blank or 'G': GPS 'R': GLONASS 'S': Geostationary signal payload 'T': NNSS Transit 'M': Mixed	F9.2, 11X, A1, 19X A1, 19X
PGM / RUN BY / DATE	- Name of program creating current file - Name of agency creating current file - Date of file creation	A20, A20, A20
COMMENT	Comment line (s)	A60
MARKER NAME	Name of antenna marker	A60
MARKER NUMBER	Number of antenna marker	A20
OBSERVER / AGENCY	Name of observer / agency	A20, A40
REC # / TYPE / VERS	Receiver number, type, and version (Version: e.g. International Software Version)	3A20
ANT # / TYPE	Antenna number and type	2A20
APPROX POSITION XYZ	Approximate marker position (WGS84)	3F14.4
ANTENNA: DELTA H/E/N	- Antenna height: Height of bottom surface ant antenna above marker - Eccentricities of antenna center relative to marker to the east and north (all units in meters)	3F14.4
WAVELENGHT FACT L1/2	- Default wavelength factors for L1 and L2 L1: Full cycle ambiguities L2: Half cycle ambiguities (squaring) 0 (in L2): Single frequency instrument - Zero or blank The default wavelength factor line is required and must preceed satellite – specific lines.	2I6, I6
WAVELENGHT FACT L1/2	-Wavelength factors for L1 and L2 1: Full cycle ambiguities 2: Half cycle ambiguities (sugaring) 0 (in L2): Single frequency in instrument - Number of satellites to follow in list for which these factors are valid. - List of PRNs (satellites numbers with system identifier) These optional satellite specific lines may follow, if they identify a state different from the default values. Repeat record if necessary.	2I6, I6, 7 (3X, A1, I2)
# / TYPES OF OBSERV	- Number of different observation types stored in the file - Observation types If more than 9 observation types: Use continuation line (s) The following observation types are defined in RINEX Version 2.10: L1, L2: Phase measurements on L1 and L2	I6 9(4X, A2) 6X, 9(4X, A2)
	C1 : Pseudo range using C/A-Code on L1 P1, P2: Pseudo range using P-Code on L1, L2 D1, D2: Doppler frequency on L1 and L2 T1, T2: Transit Integrated Doppler on 150 (T1) and 400MHz (T2) S1, S2: Raw signal strengths or SNR values as given by the receiver for the L1, L2 phase observations Observations collected under Ant spoofing are converted to “L2” or “P2” and flagged with bit 2 of loss of lock indicator Units: Phase : full cycles	

Table 2.1 (continued)

INTERVAL	Observation interval in seconds	F10.3
TIME OF FIRST OBS	- Time of first observation record (4-digit-year, month, day, hour, min, sec) - Time system: GPS (=GPS time system) GLO (=UTC time system) Compulsory in mixed GPS/GLONASS files Defaults: GPS for pure GPS file GLO for pure GLONASS files	5I6, F13.7, 5X, A3
TIME OF LAST OBS	- Time of last observation record (4-digit-year, month, day, hour, min, sec) - Time system: Same values as in time of first obs record	5I6, F13.7, 5X, A3
RCV CLOCK OFFS APPL	Epoch, code, and phase are corrected by applying the real-time-derived receiver clock offset: 1=yes, 0=no; default: 0=no Record required if clock offsets are reported in the epoch/sat records	I6
LEAP SECONDS	Number of leap seconds since 6-Jan-1980 Recommended for mixed GPS/GLONASS files	I6
# OF SATELLITE	Number of satellites, for which observations are stored in the file	I6
PRN / # OF OBS	PRN (sat. number), number of observations for each observation type indicated in the "# / types of observ " – record. If more than 9 observation types: Use continuation line (s) This record is (these records are) repeated for each satellite present in the data file	3X, A1, I2, 9I6 6X, 9I6
END OF HEADER	Last record in the header section	60X

Table 2.2 Observation data file – data record description

OBS. RECORD	DESCRIPTION	FORMAT
EPOC/SAT or EVENT FLAG	- Epoch: - year (2 digits, padded with 0 if necessary) - month, day, hour, min, - sec - Epoch flag 0: OK 1: power failure between previous and current epoch >1: event flag - Number of satellites in current epoch - List of PRNs (sat. numbers with system identifier) in current epoch - Receiver clock offset (seconds, optional) If more than 12 satellites: Use continuation lines(s) If epoch flag 2-5: - Event flag: 2: start moving antenna 3: new site occupation (end of kinem. data) (at least MARKER NAME record follows) 4: header information follows 5: external event (epoch is significant, same time frame as observation time tags) - "Number of satellites" contains number of special records to follow. Maximum number of records: 999 - For events without significant epoch the epoch fields can be left blank If epoch flag = 6: 6: cycle slip records follow to optionally report detected and repaired cycle slips (same format as OBSERVATIONS records; slip instead of observation; LLI and signal strength blank or zero)	 1X, I2.2, 4(1X,I2), F11.7, 2X, I1, I3, 12 (A1, I2), F12.9 32X 12 (A1, I2) [2X, I1,] [13}
OBSERVATIONS	- Observation | rep. within record for	m (F14.3

Table 2.2 (continued)

	- LLI | each obs. type (same seq	I1,

	- Signal strength | as given in header) If more than 5 observation types (=80 char): continue observations in next record. This record is (these records are) repeated for each satellites given in EPOCH/SAT – record Observations: Phase: Units in whole cycles of carrier Code: Unites in meters Phase values overflowing the fixed format F14.3 have to be clipped into the valid interval (e.g. add or subtract 10**9), set LLI indicator. Loss of lock indicator (LLI). Range: 0-7 0 or blank: OK or not known Bit 0 set: Lost lock between previous and current observation: cycle slip possible Bit 1 set: Opposite wavelength factor to the one defined for the satellite by a previous WALENEGHT FACT L1/L2 line. Valid for the current Antispoofing Bit 2 set: Observation under Antispoofing (may suffer from increased noise) Bits 0 and 1 for phase only. Signal strength projected into interval 1-9: 1: minimum possible signal strength 5: threshold for good S/N ratio 9: maximum possible signal strength 0 or blank: not known, don't care	I1)

2.5.5. RINEX Navigation File

Table 2.3 Navigation message file – header section description

HEADER LABEL (Columns 61-80)	DESCRIPTION	FORMAT
RINEX VERSION / TYPE	- Format version (2.10) - File type ('N' for navigation data)	F9.1, 11X, A1, 19X
PGM / RUN BY/ DATE	- Name of program creating current file - Name of agency creating current file - Date of file creation	A20, A20, A20
COMMENT	Comment line(s)	A60
ION ALPHA	Ionosphere parameters A0-A3 of almanac	2X, 4D12.4
ION BETA	Ionosphere parameters B0-B3 of almanac	2X, 4D12.4
DELTA-UTC: A0, A1, T, W	Almanac parameters to compute time in UTC A0, A1: terms of polynomial T : reference time for UTC data W : UTC reference week number. Continuous number, not mod (1024)!	3X, 2D19.12, 2I9
LEAP SECONDS	Delta time due to leap seconds	I6
END HEADER	Last record in the header section	60X

Table 2.4 Navigation message file – data record description

OBS. RECORD	DESCRIPTION	FORMAT
PRN / EPOCH / SV CLK	- Satellite PRN number - Epoch: Toc – time of clock Year (2 digits, padded with 0 if necessary) Month Day Hour Minute Second - SV clock bias (seconds) - SV clock drift (sec/sec) - SV clock drift rate (sec/sec2)	I2, 1X, I2.2, 1X, I2, 1X, I2, 1X, I2, 1X, I2 F5.1, 3D19.12 *
BROADCAST ORBIT – 1	- IODE issues of data, Ephemeris - Crs (meters) - Delta n (radians/sec) - M0 (radians)	3X, 4D19.12
BROADCAST ORBIT – 2	- Cuc (radians) - e Eccentricity - Cus (radians) - sqrt (A) (sqrt (m))	3X, 4D19.12
BROADCAST ORBIT – 3	- Toe Time of Ephemeris (sec of GPS week) - Cic (radians) - OMEGA (radians) - Cis (radians)	3X, 4D19.12
BROADCAST ORBIT – 4	- i0 (radians) - Crc (meters) - Omega (radians) - OMEGA DOT (radians/sec)	3X, 4D19.12
BROADCAST ORBIT – 5	- IDOT (radians/sec) - Codes on L2 channel - GPS week # (to go with TOE) Continuous number, not mod (1024)! - L2 P data flag	3X, 4D19.12
BROADCAST ORBIT – 6	- SV accuracy (meters) - SV health (bits 17-22 w 3 sf 1) - TGD (seconds) - IODC Issue of Data, Clock	3X, 4D19.12
BROADCAST ORBIT – 7	- Transmission time of message ** (sec of GPS week, derived e.g. from Z-count in Hand Over Word (HOW) - Fit interval (hours) Zero if not known - Spare - Spare	3X, 4D19.12

As the GLONASS navigation message differs in contents from the GPS message too much, a special GLONASS navigation message file format has been defined.

The header section and the first data record (epoch, satellite clock information) are similar to the GPS navigation file. The following records contain the satellite position, velocity and acceleration, the clock and frequency biases as well as auxiliary information health, satellite frequency (channel), age of the information. [8]

Table 2.5 GLONASS navigation message file – header section description

HEADER LABEL (Columns 61-80)	DESCRIPTION	FORMAT
RINEX VERSION / TYPE	- Format version (2.10) - File type ('G' = GLONASS nav mess data)	F9.2, 11X A1, 39X
PGM / RUN BY / DATE	- Name of program creating current file - Name of agency creating current file - Date of file creation (dd-mmm-yy hh:mm)	A20, A20, A20
COMMENT	Comment line(s)	A60
CORR TO SYSTEM TIME	- Time of reference for system time corr (year, month, day) - Correction to system time scale (sec) to correct GLONASS system time to UTC (SU) (-TauC)	3I6, 3x, D19.12
LEAP SECONDS	Number of leap seconds since 6-Jan-1980	I6
END OF HEADER	Last record in the header section.	60X

Table 2.6 GLONASS navigation message file – data record description

OBS. RECORD	DESCRIPTION	FORMAT
PRN / EPOCH / SV CLK	- Satellite number: Slot number in sat. constellation - Epoch of ephemeredes - year (2 digits, padded with 0, if necessary) - month, day, hour, minute, - second - SV clock bias (sec) (-TauN) - SV relative frequency bias (+GammaN) - Message from time (tk) (0 .le. tk. lt. 86400 sec of day UTC) The 2-digit year in RINEX 1 and 2.xx files are understood to present 80-99: 1980-1999 and 00-79: 2000-2079	I2, 1X, I2.2, 4(1X, I2), F5.1, D19.12, D19.12, D19.12
BROADCAST ORBIT – 1	- Satellite position X (km) - velocity X dot (km/sec) - X acceleration (km/sec2) - health (0=OK) (Bn)	3X, 4D19.12
BROADCAST ORBIT – 2	- Satellite position Y (km) - velocity Y dot (km/sec) - Y acceleration (km/sec2) - frequency number (1-24)	3X, 4D19.12
BROADCAST ORBIT - 3	- Satellite position Z (km) - velocity Z dot (km/sec) - Z acceleration (km/sec2) - Age of oper. information (days) (E)	3X, 4D19.12

2.6. SP3 Format

The original Standard Product 3 format (SP3-a) was proposed in (Remondi, 1989) and modified and adopted in (Remondi, 1991). The SP3 format is similar to the original NGS Standard Product 1 format described in (Remondi, 1989 and 1985) but includes additional information: satellite clock corrections, orbit accuracy exponents, comment lines, the GPS week and seconds of week associated with the first epoch, and more flexible header structure. [9]

On line one character, two is the format version identification character. The first released version has been designated version "a". Subsequent versions will use lower case letters in alphabetical order. The first line comprises the Gregorian date and time of day of the first epoch of the orbit, the number of epochs in the ephemeris file (up to 10 million), and the data used descriptor, the orbit type descriptor, and the agency descriptor. The data used descriptor was included for ease in distinguishing between multiple orbital solutions from a single organization. This will have primary use for the agency generating the orbit. A possible convention is given below, this is not considered final and suggestions are welcome.

u	undifferenced carrier phase
du	change in u with time
s	2-receiver/1-satellite carrier phase
ds	change on s with time
d	2-receiver/2-satellite carrier phase
dd	change in d with time
U	undifferenced code phase
dU	change in U with time
S	2-receiver/1-satellite code phase
dS	change in S with time
D	2-receiver/2-satellite code phase
dD	change in D with time
+	type separator

Combinations such as "__ u+U" seem reasonable. If the measurements used were complex combinations of standard types, then one could use "mixed" where mixed could be explained on the comment line.

Orbit type is described by a three-character descriptor. At this time, only three have been defined: FIT (fitted), EXT (extrapolated or predicted), BCT (broadcast), and HLM (fitted after applying a Helmert transformation). Naturally, others are possible. The computing agency descriptor allows four characters (e.g. _NGS, _IGS, etc.).

The second line has: the GPS week (which was exceed 1000 in the year 1999); the seconds of the GPS week elapsed at the start of the orbit (0.0 <= seconds of week < 604800.0) in seconds; the modified Julian Day Start (where 44244 represents GPS zero time – January 6, 1980); and fractional part of the day (0.0 <= fractional <1.0) at the start of the orbit.

The third lines to the seventh lines indicate the number of satellites followed by their respective identifiers. The identifiers must use consecutive slots and continue on lines 4-7, if required. The value 0 should only appear after all the identifiers are listed. Satellite identifiers may be listed in any order. However, for ease in reviewing satellites included in the orbit file it is recommended that numerical order be used.

The eight lines to the twelfth lines have the orbit accuracy exponents. The value 0 is interpreted as accuracy unknown. A satellite's accuracy exponent appears in the same slot on lines 8-12 as the identifier on lines 3-7. The accuracy is computed from the exponent as in the following example. If the accuracy exponent is 113, the accuracy is 2**13 mm or 8 m. The quoted orbital error should represent one standard deviation and be based on the orbital error in the entire file for the respective satellite. This may lead to some distortion when orbit files are joined together.

Lines 13-18 allow the SP3 ASCII file to be modified, since the SP3 format has been designed so that additional parameters may be added.

Lines 19-22 are free form comments.

Line 23 is the position and clock line, and the first character is P indicating a position line. The positional values are in kilometers and are precise to 1 mm. A precision of 0.5 mm can be accommodated if rounding is used, i.e., the value shown is never more than 0.5 mm from computed value. The clock values are in microseconds and are precise to one picoseconds. Bad or absent positional values are to be set to _999999.9999__ . The six integer nines are required, whereas the fractional part nines are optional. When the position/velocity mode flag is set to V in line one, a velocity record for the same satellite follows each position record for a given satellite. The first character of the velocity record is a V. The velocity components are given in decimeters/second and have a precision of 10**-4 mm/seconds. The last column of a velocity record is the rate-of-change of clock correction given in units of 10**-four microseconds/second. The precision of this parameter is 10**-16 second/second. [18]

3. PRACTICAL EXPERIMENT OF INVESTIGATION AND ANALYSIS OF THE INFLUENCE OF SOLAR STORMING OF PRECISE POSITIONING BY GNSS

3.1. Search for Solar Storms Events

The solar events that can affect broadcast and ephemeris positions are primarily geomagnetic storms and solar radiation storm. Such events are categorized in severity on a scale of 1 to 5 and are reported regularly in weekly summaries distributed by the Space Environment Center (SEC). Essentially, geomagnetic storm categories G2 to G5 and solar radiation storm categories S2 to S5 can affect satellite navigation and specifically have the effect of altering satellite orbits.

Visits to the SEC web site quickly indicated that an "extreme" geomagnetic storm was recorded at about 0600-0900 UTC on 11 September 2005, see Figure 3.2 and 3.3. The SEC warning is produced at Figure 3.1. This storm was selected as the object for experimentation. As a control a "benchmark" a period was 29 September was the nearest to the storm period. The point being that the visible satellites and their geometry would not have changed very much. Was chosen a 29 September where information clearly indicated no solar activity.

Space Weather Message Code:	ALTK09
Serial Number:	5
Issue Time:	2005 Sep 11 0646 UTC
ALERT:	Geomagnetic K-index of 9
Threshold Reached:	2005 Sep 11 0645 UTC
Synoptic Period:	0600-0900 UTC
Station:	Boulder
Active Warning:	Yes
NOAA Scale:	G5 - Extreme

Figure 3.1 Alerts issued by SEC in 11 September 2005

Somewhat arbitrarily, we decided to examine the behavior of the system for a period of 10 hours, starting at 02:00 UT up until 12:00 UT on these two dates.

In the first experiment stages, we aim to prepare sets of a test results at one-hour intervals using easily checkable methods, in other words hand and simple spreadsheet computations. These test data would then be invaluable for confirming that the behavior of later computer programs would be correct.

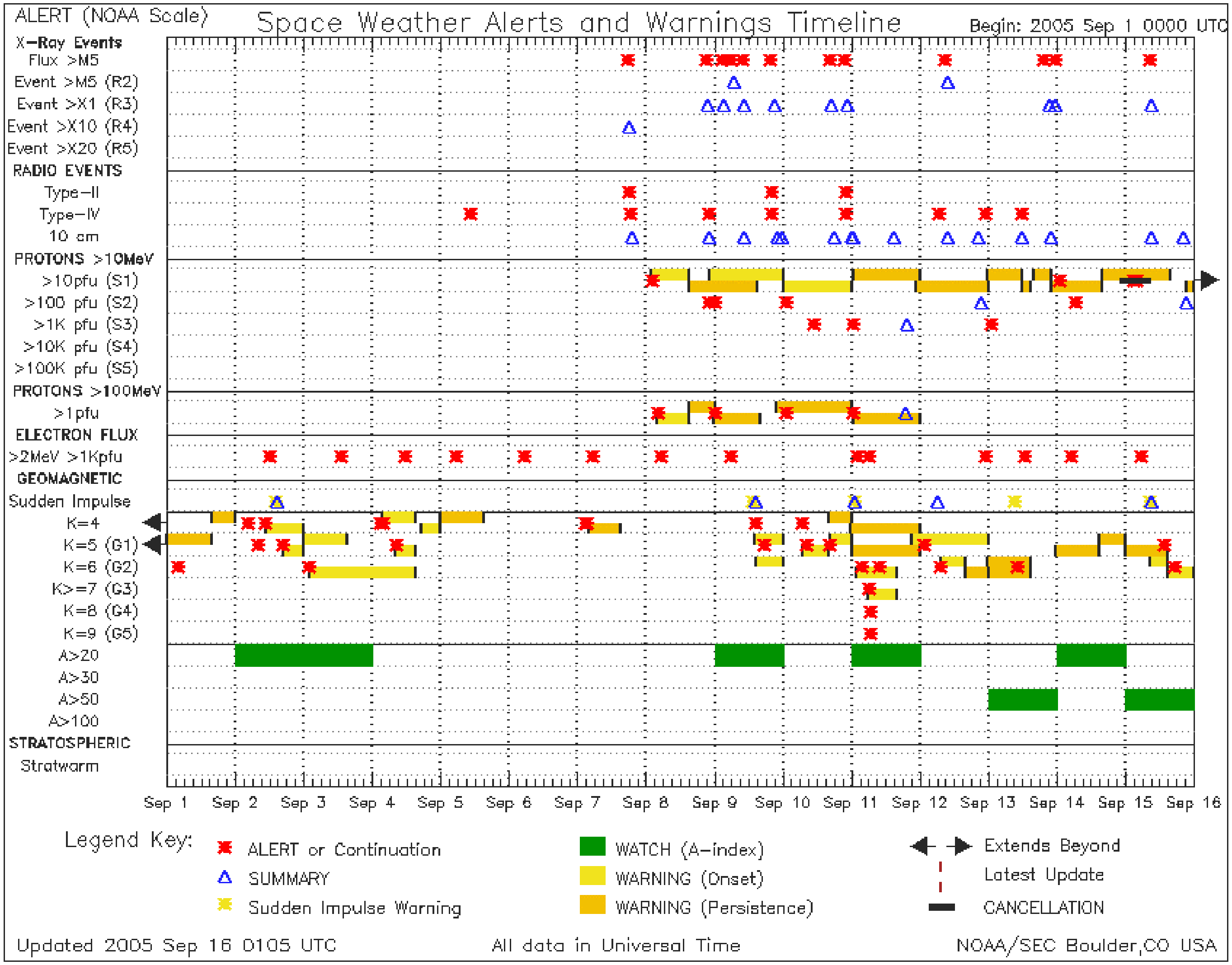

Figure 3.2 Space Weather Alerts Timelines for September 1-15, 2005

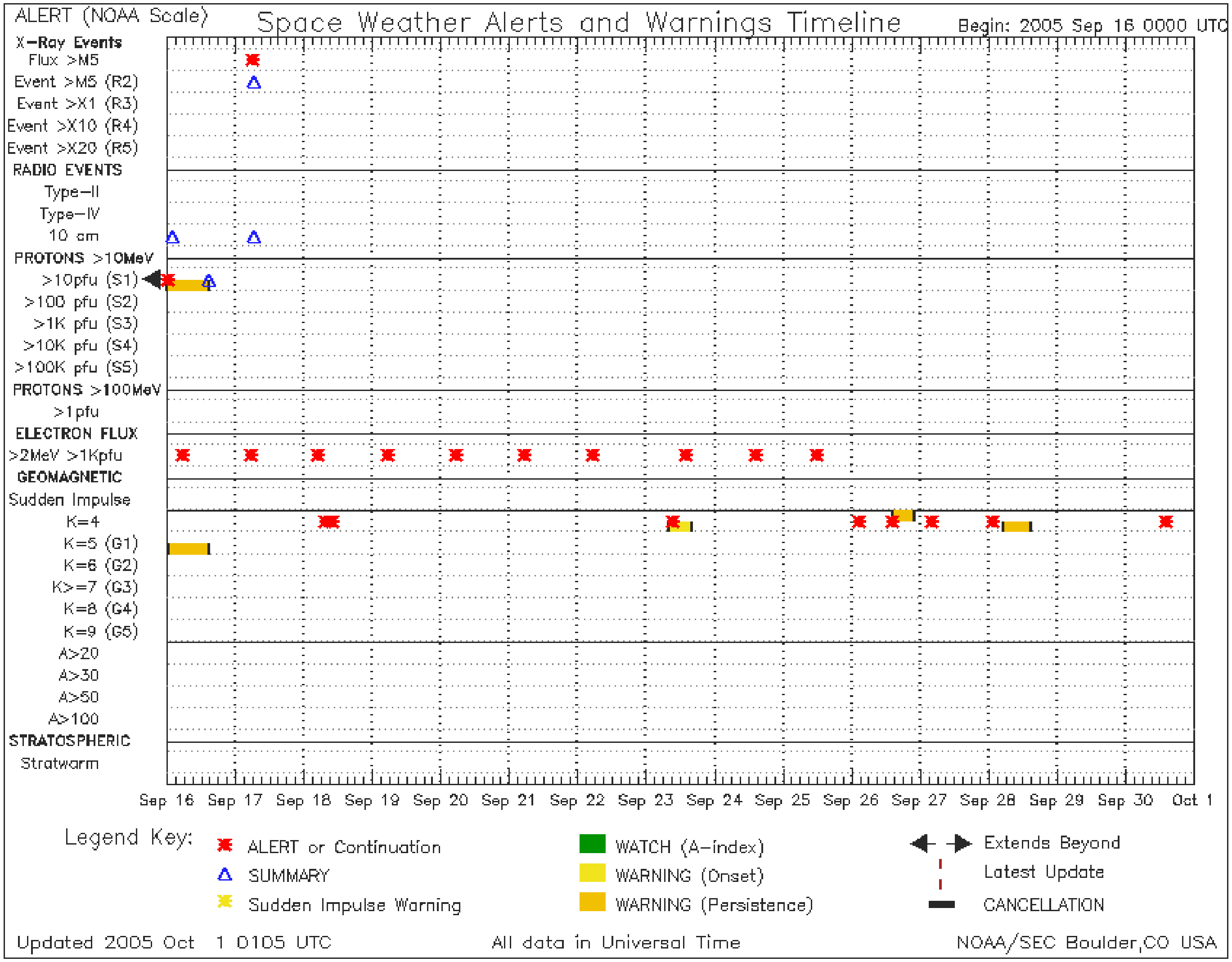

Figure 3.3 Space Weather Alerts Timelines for September 16-31, 2005

3.2. Extract Observed Ephemeris Covering these Events

Before starting the computation of the satellite position using observed ephemeredes or precise ephemeredes parameters, we have to:

- Convert civil date to GPS week and Second-in-Week;
- Identify visible satellites from the RINEX observation file;
- Check, which observables are logged.

The satellites observed at each of the epochs listed in Tables 3.1 and 3.2 where extracted from the appropriate RINEX observation files, and are listed at Table 3.3 and 3.4.

Table 3.1 Converting Civil Data 11th September 2005 to GPS week Second-in-Week. CN*-2; GPSW**-316; GLOW***-1340; Day - Sunday

Date	Epoch Time	Sec-in-W
11. 9. 2005	2 0 0.0000	7200
11. 9. 2005	3 0 0.0000	10800
11. 9. 2005	4 0 0.0000	14400
11. 9. 2005	5 0 0.0000	18000
11. 9. 2005	6 0 0.0000	21600
11. 9. 2005	7 0 0.0000	25200
11. 9. 2005	8 0 0.0000	28800
11. 9. 2005	9 0 0.0000	32400
11. 9. 2005	10 0 0.0000	36000
11. 9. 2005	11 0 0.0000	39600
11. 9. 2005	12 0 0.0000	43200

Table 3.2 Converting Civil Data 29th September 2005 to GPS week Second-in-Week. CN*-2; GPSW**-318; GLOW***-1342; Day - Thursday

Date	Epoch Time	Sec-in-W
29. 9. 2005	2 0 0.0000	352800
29. 9. 2005	3 0 0.0000	356400
29. 9. 2005	4 0 0.0000	360000
29. 9. 2005	5 0 0.0000	363600
29. 9. 2005	6 0 0.0000	367200
29. 9. 2005	7 0 0.0000	370800
29. 9. 2005	8 0 0.0000	374400
29. 9. 2005	9 0 0.0000	378000
29. 9. 2005	10 0 0.0000	381600
29. 9. 2005	11 0 0.0000	385200
29. 9. 2005	12 0 0.0000	388800

* The GPS Week cycle (one cycle has 1024 week).
** GPS Week.
*** GLONASS Week.

Table 3.3 RINEX observations files at 11^{th} September 2005

Observation files	Sec-in-W	No of satellites	Satellites observed*
GJOV254C.05O	7200	12	G24 G19 G14 G11 G20 G07 G28 R05 R22 R21 R06 R23
GJOV254D.05O	10800	12	G25 G2 4G23 G14 G11 G20 G07 G01 R22 R06 R08 R23
GJOV254E.05O	14400	13	G25 G24 G23 G04 G11 G20 G07 G01 R22 R24 R06 R08
GJOV254F.05O	18000	12	G25 G24 G23 G04 G20 G07 G01 R01 R24 R17 R08 R23
GJOV254G.05O	21600	11	G24 G23 G04 G13 G20 G16 G27 R01 R24 R17 R08
GJOV254H.05O	25200	12	G10 G23 G04 G06 G13 G16 G27 R01 R18 R17 R08 R02
GJOV254I.05O	28800	10	G10 G02 G23 G13 G08 G16 G27 R01 R18 R02
GJOV254J.05O	32400	11	G10 G26 G29 G28 G13 G08 G21 G27 R01 R03 R02
GJOV254K.05O	36000	11	G10 G19 G26 G29 G28 G08 G21 G27 R04 R03 R02
GJOV254L.05O	39600	12	G10 G19 G26 G29 G28 G18 G08 G27 R04 R03 R21 R22
GJOV254M.05O	43200	11	G26 G29 G28 G18 G08 G22 R23 R04 R03 R22 R05

Table 3.4 RINEX observation files at 29^{th} September 2005

Observation Files	Sec-in-W	No of satellites	Satellites observed*
GJOV272C.05O	352800	12	G11 G24 G23 G20 G01 G14 G07 G04 R01 R02 R24 R08
GJOV272D.05O	356400	12	G11 G24 G23 G20 G01 G30 G07 G04 R01 R18 R02 R08
GJOV272E.05O	360000	10	G02 G24 G23 G20 G04 G13 R01 R18 R02 R03
GJOV272F.05O	363600	12	G02 G24 G23 G20 G27 G16 G04 G13 R18 R02 R03 R04
GJOV272G.05O	367200	13	G02 G08 G23 G10 G27 G06 G16 G04 G13 R02 R03 R04
GJOV272H.05O	370800	10	G02 G08 G10 G27 G16 G13 R05 R03 R04 R21
GJOV272I.05O	374400	13	G08 G26 G10 G27 G28 G21 G29 G13 R05 R23 R03 R04
GJOV272J.05O	378000	13	G19 G08 G26 G10 G27 G28 G21 G29 R05 R23 R24 R06
GJOV272K.05O	381600	12	G19 G08 G26 G10 G28 G29 G18 R05 R23 R24 R06 R17
GJOV272L.05O	385200	10	G09 G26 G07 G28 G22 G29 G18 R24 R06 R17
GJOV272M.05O	388800	14	G09 G05 G26 G11 G07 G28 G22 G29 G18 R18 R08 R24

3.2.1. Satellite Broadcast Position

The three – dimensional Earth - centered co-ordinates of each observed satellite at each epoch of observation were computed by Microsoft Excel. Orbit ephemeredes were taken from the appropriate RINEX navigation files and the computing procedures described in chapter 2.1 were used.

A small extract of results are at Tables 3.5 and 3.6, which complete listings are in Appendixes 6 and 7.

* GPS satellites – prefix *G*; GLONASS satellites – prefix *R*.

Table 3.5 Satellite position at 11^{th} September 2005

Epoch	Satellite	X, meters	Y, meters	Z, meters
7200	PRN07	-2667013.6421	-1634346.471	2122022.314
	PRN11	1773323.071	1201427.615	1975032.388
	PRN14	3475114.082	1547234.366	2136875.640
	PRN19	2554423.721	7291857.807	3839515.919
	PRN20	2118080.854	-1068524.121	1185068.493
	PRN24	6381471.152	-2038798.778	1591478.596
	PRN28	9891529.219	-2174520.877	1148499.554
10800	PRN01	7389890.739	1420181.858	2138825.659
	PRN07	6763469.410	-1584543.840	2061958.670
	PRN11	2111982.501	8438513.936	1385048.481
	PRN14	-6387074.915	1441870.854	2141852.855
	PRN20	1755263.880	-4243164.086	1939170.078
	PRN23	2662710.442	-5746983.745	4849655.651
	PRN24	9982240.271	-1264357.720	2134482.653
	PRN25	7359497.613	2307892.889	1119382.664
14400	PRN01	-2379101.641	1548224.995	2162934.821
	PRN04	3694915.928	-1658005.323	2032242.336
	PRN07	1470288.127	-1686436.013	1464640.325
	PRN11	2318594.024	1247512.716	4243814.353
	PRN20	1442951.076	4902914.927	2167220.948
	PRN23	2403008.675	8520715.301	1133921.784
	PRN24	1573986.768	-4847841.723	2113600.873
	PRN25	1978873.685	1879639.108	1902156.341

Table 3.6 Satellite position at 29^{th} September 2005

Epoch	Satellite	X, meters	Y, meters	Z, meters
352800	PRN01	5164473.932	1429367.716	2197594.199
	PRN04	-9234055.427	-2125233.531	1567313.169
	PRN07	8515166.469	-1601092.588	1979935.468
	PRN11	2180231.157	9616533.089	1191248.599
	PRN14	-8583093.304	1447217.898	2059473.079
	PRN20	1670091.353	-2208872.374	2045135.634
	PRN23	2643855.319	-2951726.383	3161981.688
	PRN24	1109700.942	-1084246.238	2179978.939
356400	PRN01	-4487264.812	1605086.330	2085777.067
	PRN04	5293254.076	-1521797.142	2104676.901
	PRN07	1584447.535	-1722760.112	1286358.774
	PRN11	2326551.439	1292534.182	1804039.662
	PRN20	1394643.818	7228963.854	2133879.823
	PRN23	2281217.538	1494454.164	1354658.010
	PRN24	1716129.893	-3400521.939	2030074.619
	PRN30	-1570560.403	3118968.978	2090688.276
360000	PRN02	-1520115.715	-1665046.520	2039257.967
	PRN04	1346811.097	-9857111.623	2071767.249
	PRN13	2229044.303	-4322933.623	1365933.493
	PRN16	-1967545.113	2577077.672	6017905.165
	PRN20	1318329.546	1609545.368	1643764.732
	PRN23	1607680.398	5755500.651	2028325.765
	PRN24	2309483.163	1501177.995	1347038.366
363600	PRN02	7963629.717	-1376839.823	2097180.056
	PRN04	2114939.205	-6715974.373	1483121.940
	PRN13	1662699.837	1394682.177	2057489.613
	PRN20	1354815.374	2170043.698	7084807.919
	PRN23	8944550.442	1253515.484	2152649.547

3.2.2. Receiver Broadcast Position

The ground position's co-ordinates have been computed using Microsoft Excel spreadsheet taking observation and navigation data from RINEX files, and computing procedures in Chapter 4.4 were used.

The results are shown below (table 3.7 and table 3.8).

It will be seen in Tables 3.9 and 3.11 (see Appendix 8 and 10) above that satellite co-ordinate have only been computed for the observed GPS satellites. GLONASS satellite position computations are not repotted for the following reasons:

- Trial computations appeared to indicate very large differences (km level) when compared directly with published post processed precise positions;
- These differences were difficult to explain within the terms of this study;
- Nevertheless, initial investigations showed that GPS and GLONASS use different time scales (UTC-USNO and UTC Moscow), and that GLONASS time is held to UTC Moscow using leap seconds, while GPS time is must to connect. This could have contributed to the above unexplained difficulty; [6]
- Meanwhile, there was also some lack of clarity as to the timescales used in the various ephemeris data file, which also could have contributed to this anomaly.

Table 3.7 Receiver position at 11^{th} September 2005

Epoch	X	Y	Z
7200	3066629.707	578501.917	5543835.001
10800	3066683.189	578430.686	5544213.258
14400	3066665.527	578418.277	5544099.465
18000	3066676.237	578447.873	5544041.694
21600	3066783.546	578481.446	5544230.577
25200	3066678.264	578433.335	5544085.301
28800	3066633.891	578409.072	5544067.617
32400	3066657.937	578451.781	5544212.424
36000	3066674.932	578410.965	5544150.040
39600	3066664.105	578430.323	5544075.596
43200	3066686.844	578429.366	5544113.294

Table 3.8 Receiver position at 29^{th} September 2005

Epoch	X	Y	Z
352800	3066669.872	578448.435	5544187.946
356400	3066678.365	578419.870	5544108.825
360000	3066682.588	578443.725	5544143.683
363600	3066721.606	578421.211	5544180.999
367200	3066669.454	578418.154	5544149.724
370800	3066635.007	578414.385	5544046.663
374400	3066648.706	578449.660	5544207.267
378000	3066657.714	578409.156	5544075.025
381600	3066664.372	578432.643	5544086.187
385200	3066751.212	578421.227	5544386.418
388800	3066655.749	578427.025	5544095.461

3.3. Extract Precise Ephemeris Covering these Events

3.3.1. Precise Satellite Position

To compute the precise ephemeris satellite position, we used:

- Precise ephemeris parameters from IGS (Sp3 format).

Precise ephemeredes are obtained by post processing tracking observation. In other words, precise ephemeredes are a statement of where the satellites "were" at given epochs. By contrast, broadcast ephemeredes are a statement of where the satellites "are expected to be" at some epoch in the future. In both cases, the ephemeris data available needs to be processed to convert it from the form in which it is given into actual and meaningful three-dimensional Earth-centered coordinates.

Unlike the broadcast ephemeredes and precise ephemeredes are presented in files of coordinates for each satellite at regular 15 minutes intervals. All that is therefore necessary is to interpolate to the actual epochs that are wanted. In this experiment, the wanted epochs at one-hour intervals on the hour, and therefore ephemeredes could be directly read without interpolation.

Nevertheless, we note that simple linear interpolation is most unlikely to be adequate. Orbit paths are by nature curved, and the satellites are moving at enormous speeds. According to the literature, LaGrange interpolation would be recommended using preferably eight data points to define the curve.

The small extracts of results of precise ephemeris satellite positions are at Table 3.9 and 3.12, with complete listings are at Appendixes 8 and 11.

Table 3.9 Precise satellite position at 11^{th} September 2005 of GPS satellites

Epoch	Satellite	X, meters	Y, meters	Z, meters
		RINEX-SP3	RINEX-SP3	RINEX-SP3
7200	PRN07	-0.001240	-0.000152	-0.000854
	PRN11	-0.000784	-0.001310	-0.000980
	PRN14	-0.000777	-0.001192	-0.001337
	PRN19	0.000205	-0.000279	-0.002874
	PRN20	-0.001154	-0.000802	-0.001864
	PRN24	-0.000745	-0.000747	-0.001345
	PRN28	0.000291	0.000474	-0.002616
10800	PRN01	0,002723	-0,001486	-0,002002
	PRN07	-0.001953	-0.000190	0.000002
	PRN11	-0.000702	-0.001557	-0.000489
	PRN14	-0.000436	-0.001027	-0.001892
	PRN20	-0.000399	-0.001096	-0.001859
	PRN23	0,000234	0,000522	0,001643
	PRN24	-0,000414	-0,000930	-0,001025
	PRN25	-0,001394	-0,001395	0,000590
14400	PRN01	0.002608	-0.001090	-0.000957
	PRN04	-0.000538	0.000065	-0.000401
	PRN07	-0.001942	-0.000123	0.001105
	PRN11	-0.000668	-0.001512	-0.000320
	PRN20	0.000191	-0.001742	-0.001617
	PRN23	-0.000452	0.000993	0.001085
	PRN24	-0.001121	-0.002082	-0.000637

Table 3.10. Precise satellite position at 11^{th} September 2005 for GLONASS satellite

Epoch	Satellite	X, kilometers	Y, kilometers	Z, kilometers
		RINEX-SP3	RINEX-SP3	RINEX-SP3
8100	PRN05	-15,04170	24,137770	-33,50889
	PRN06	-24,96278	32,947342	1,646365
	PEN21	9,731435	-1,220365	-45,17007
	PRN22	34,512995	2,443713	-25,03689
	PRN23	39,508357	4,792194	11,429832
11700	PRN06	-12,34536	33,612837	-23,42839
	PRN08	-9,848248	20,269540	38,898425
	PRN22	17,090978	-4,781105	-41,97057
	PRN23	38,548661	-6,764013	-14,17040
15300	PRN06	-0,316771	19,385589	-41,26598
	PRN08	-4,814896	36,942932	19,548721
	PRN22	-5,194708	-0,171722	-46,16967
	PRN24	37,127195	-16,80035	-4,902317
18900	PRN01	3,804249	32,533542	28,065280
	PRN08	6,733618	40,191065	-5,741108
	PRN17	31,758603	-25,45862	5,532196
	PRN23	3,192319	-5,447300	-46,04053
	PRN24	24,227197	-21,37040	-28,58648
22500	PRN01	16,551643	37,419593	4,196654
	PRN08	14,369351	28,505602	-29,30640
	PRN17	21,014414	-30,59741	-19,70470
	PRN24	6,584596	-12,54099	-43,60068
26100	PRN01	23,980584	27,789838	-20,98581
	PRN02	23,867387	31,428120	13,997141
	PRN08	10,109549	8,969925	-43,98347
	PRN17	6,236297	-21,44856	-38,95086

Table 3.11 Precise satellite position at 29^{th} September 2005 for GPS satellites

Epoch	Satellite	X, meters	Y, meters	Z, meters
		RINEX-SP3	RINEX-SP3	RINEX-SP3
352800	PRN01	0,002213	-0,000837	-0,002073
	PRN04	0,001866	0,000758	0,000074
	PRN07	-0,000954	0,000520	0,000285
	PRN11	-0,001462	0,000149	-0,000537
	PRN14	0,000828	-0,001388	-0,000923
	PRN20	-0,000619	-0,000937	-0,001369
	PRN23	0,000368	0,000558	-0,000643
	PRN24	-0,000847	-0,001683	-0,000860
356400	PRN01	0,001686	-0,001217	-0,001060
	PRN04	0,001620	0,001351	-0,000103
	PRN07	-0,001426	0,000411	0,001656
	PRN11	-0,001453	-0,000078	-0,000021
	PRN20	-0,000871	-0,001420	-0,000760
	PRN23	0,000771	0,000283	-0,000987
	PRN24	-0,001179	-0,001283	-0,000376
	PRN30	0,001105	0,000170	-0,000450
360000	PRN02	-0,000243	-0,000229	0,000210
	PRN04	0,000329	0,001366	-0,000337
	PRN13	-0,000325	-0,000858	-0,002275
	PRN16	-0,035345	0,055035	-0,022757
	PRN20	-0,001158	-0,001476	-0,000119
	PRN23	0,000685	0,000431	-0,000634
	PRN24	-0,001666	-0,000961	0,000121

Table 3.12 Precise satellite position at 29^{th} September 2005 for GLONASS satellite

Epoch	Satellite	X, kilometers	Y, kilometers	Z, kilometers
		RINEX-SP3	RINEX-SP3	RINEX-SP3
353700	PRN01	-12,58554	38,992095	3,273055
	PRN02	-10,41944	25,445848	34,830529
	PRN08	-8,116938	30,347145	-29,98600
	PRN24	12,493191	-4,802784	-43,91756
357300	PRN01	-0,605917	36,318267	-21,80115
	PRN02	-3,130803	39,571203	13,080942
	PRN08	1,587286	12,675358	-44,25426
	PRN18	36,239303	-18,49707	3,596850
360900	PRN01	6,320377	19,691155	-40,27342
	PRN02	8,503147	38,879704	-12,75020
	PRN03	7,066131	34,454647	23,590492
	PRN18	26,189402	-25,17170	-21,37435
364500	PRN02	13,870558	24,030924	-34,65155
	PRN03	19,519452	35,937818	-1,033919
	PRN04	12,375356	28,246370	31,105602
	PRN18	9,773061	-18,51600	-40,02522
368100	PRN02	6,488062	3,876280	-45,87269
	PRN03	24,419608	24,076802	-25,43009
	PRN04	26,744850	30,755562	7,884134
371700	PRN03	15,634971	7,388605	-42,19001
	PRN04	32,387492	20,315406	-17,77255
	PRN05	31,215077	20,120138	19,632516
	PRN21	1,599396	-40,81674	-4,377054
375300	PRN03	-4,427553	-3,379533	-46,13414
	PRN04	23,386157	5,770807	-37,92885

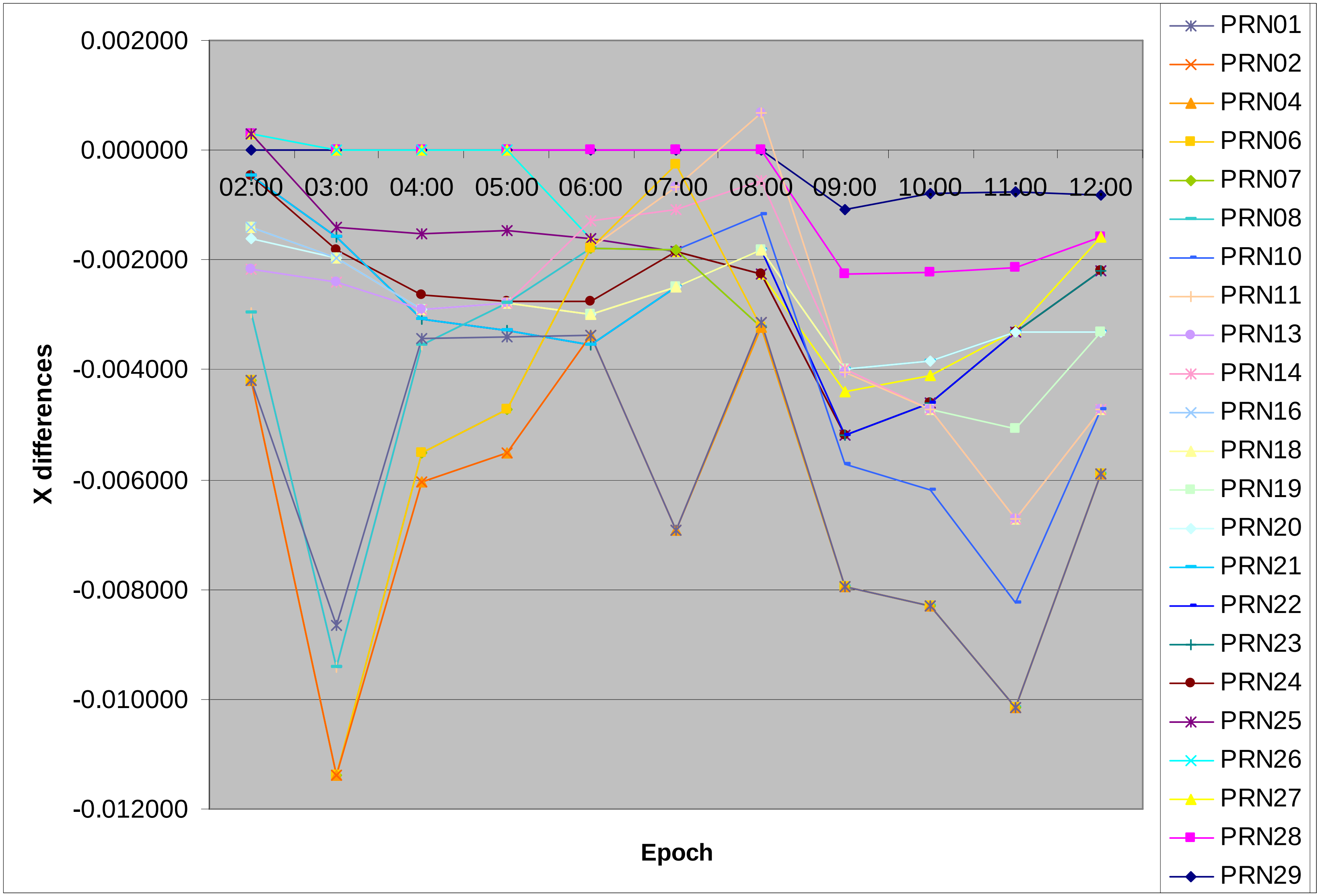

Figure 3.4. GPS satellite position at September 11, 2005

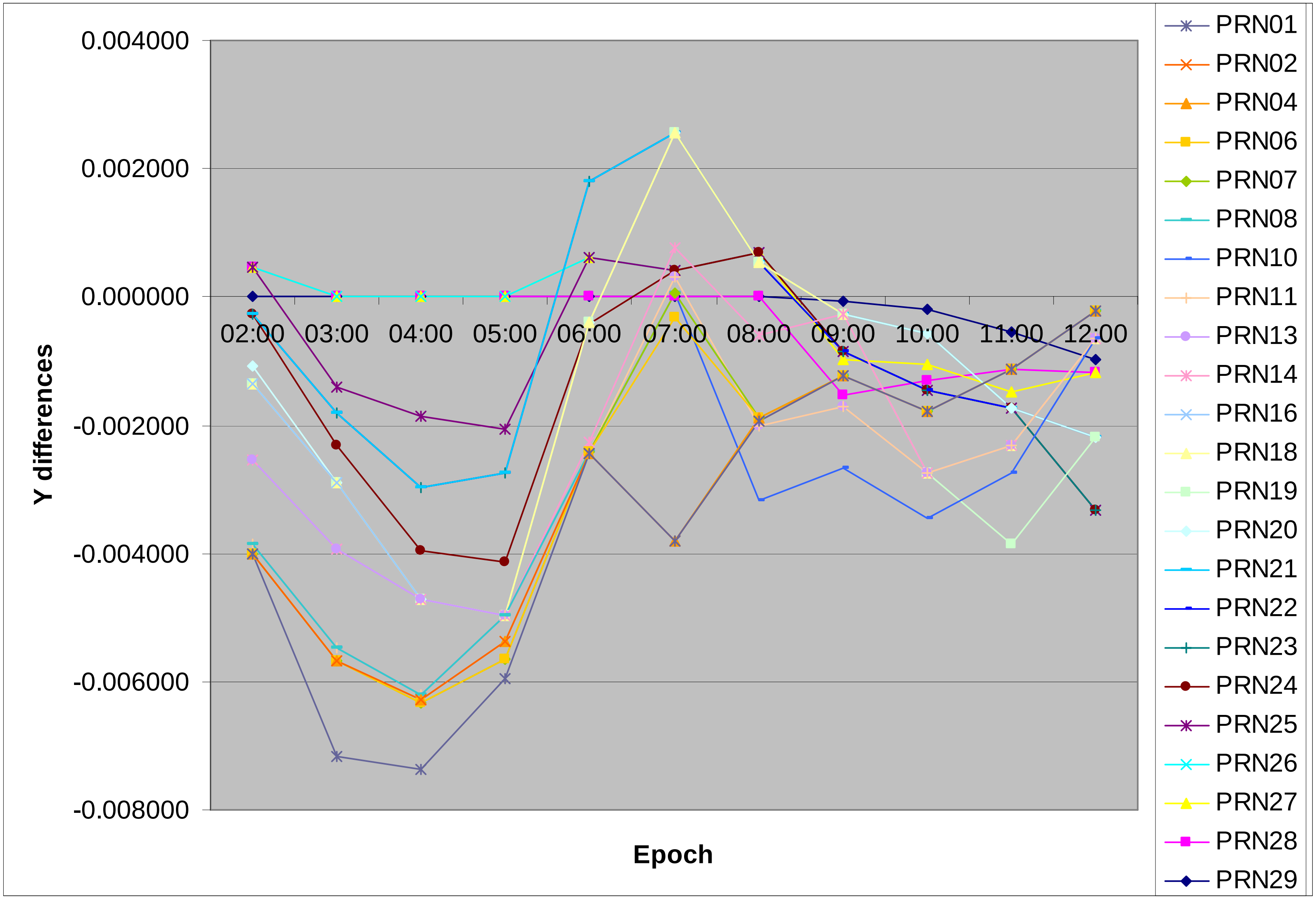

Figure 3.5 GPS satellite position at September 11, 2005

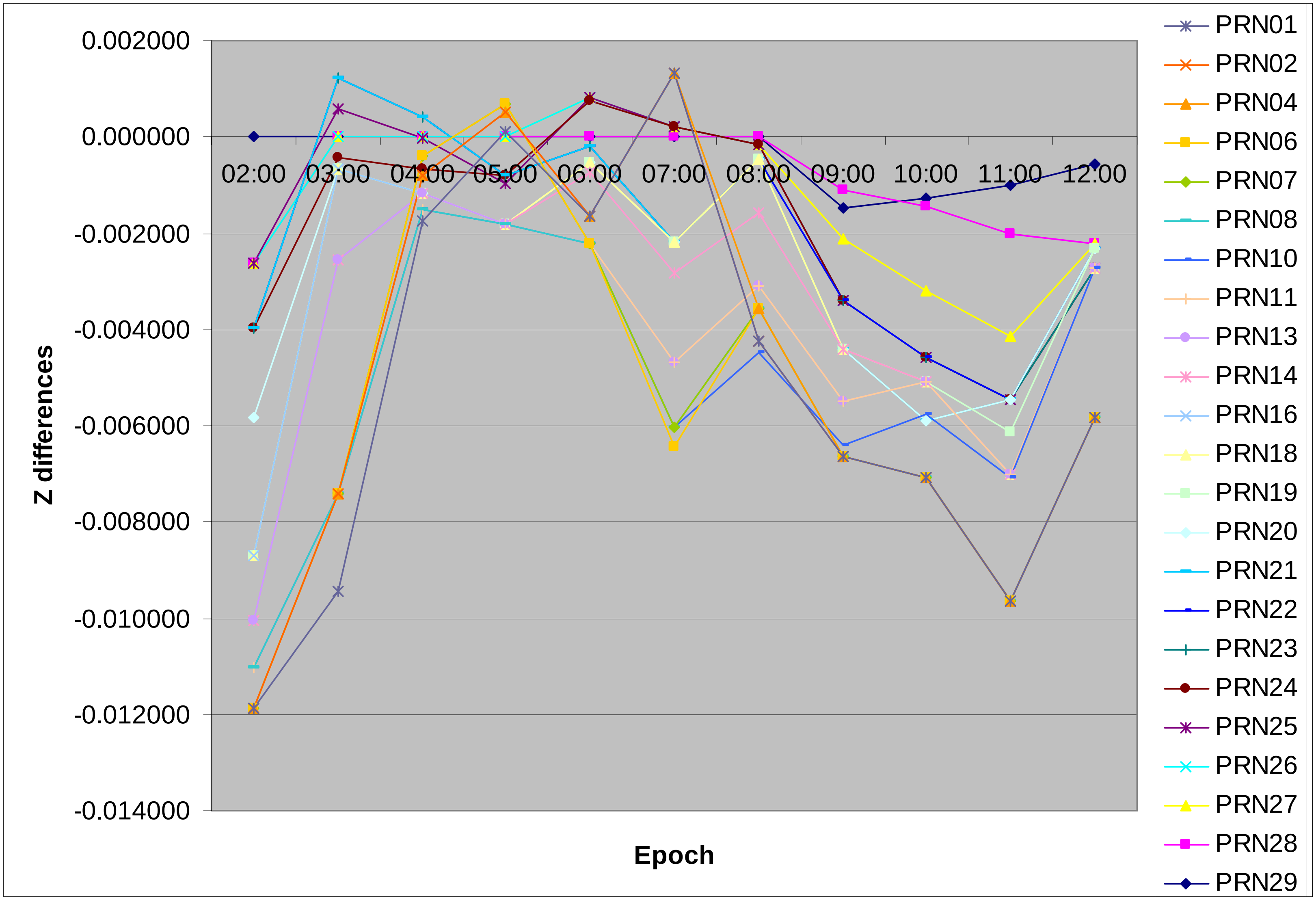

Figure 3.6 GPS satellite position at September 11, 2005

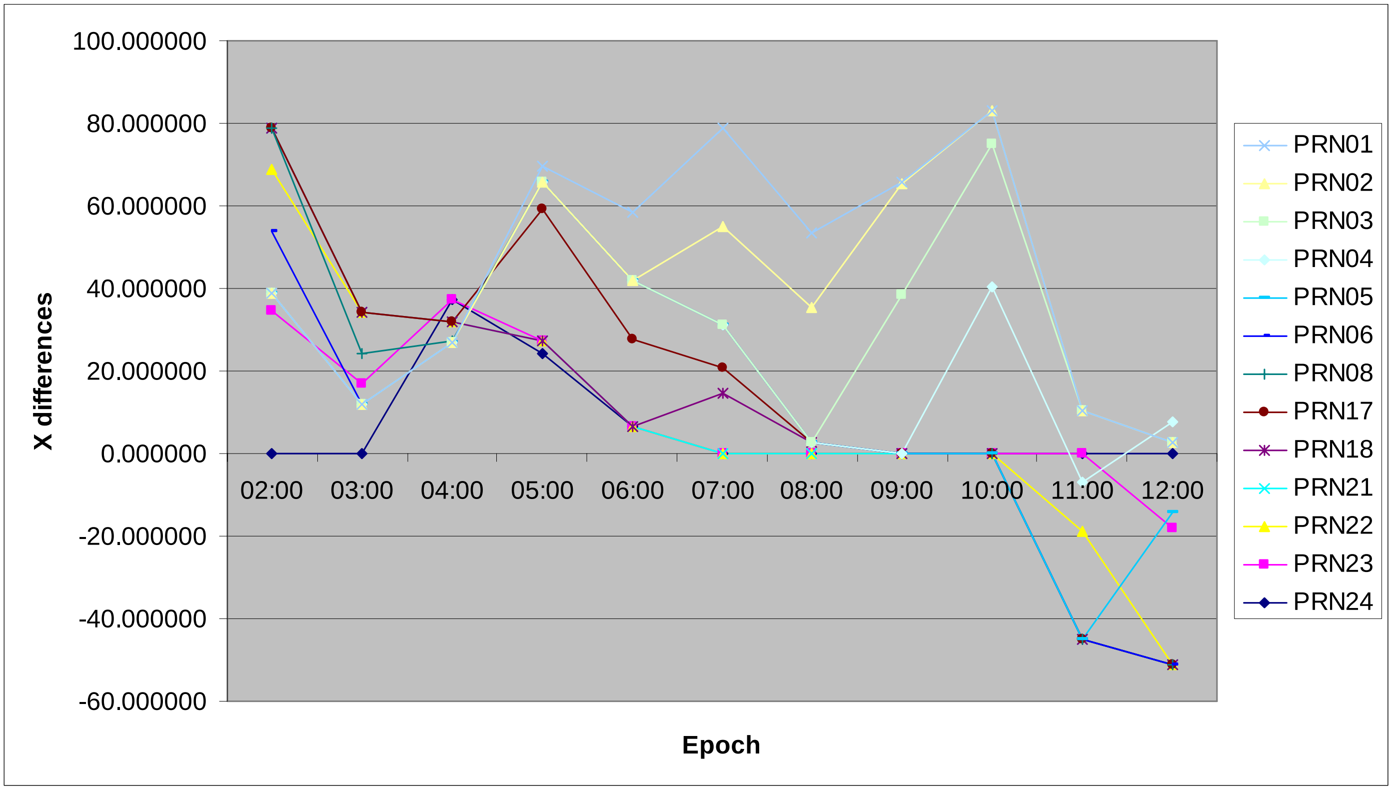

Figure 3.7 GLONASS satellite position at September 11, 2005

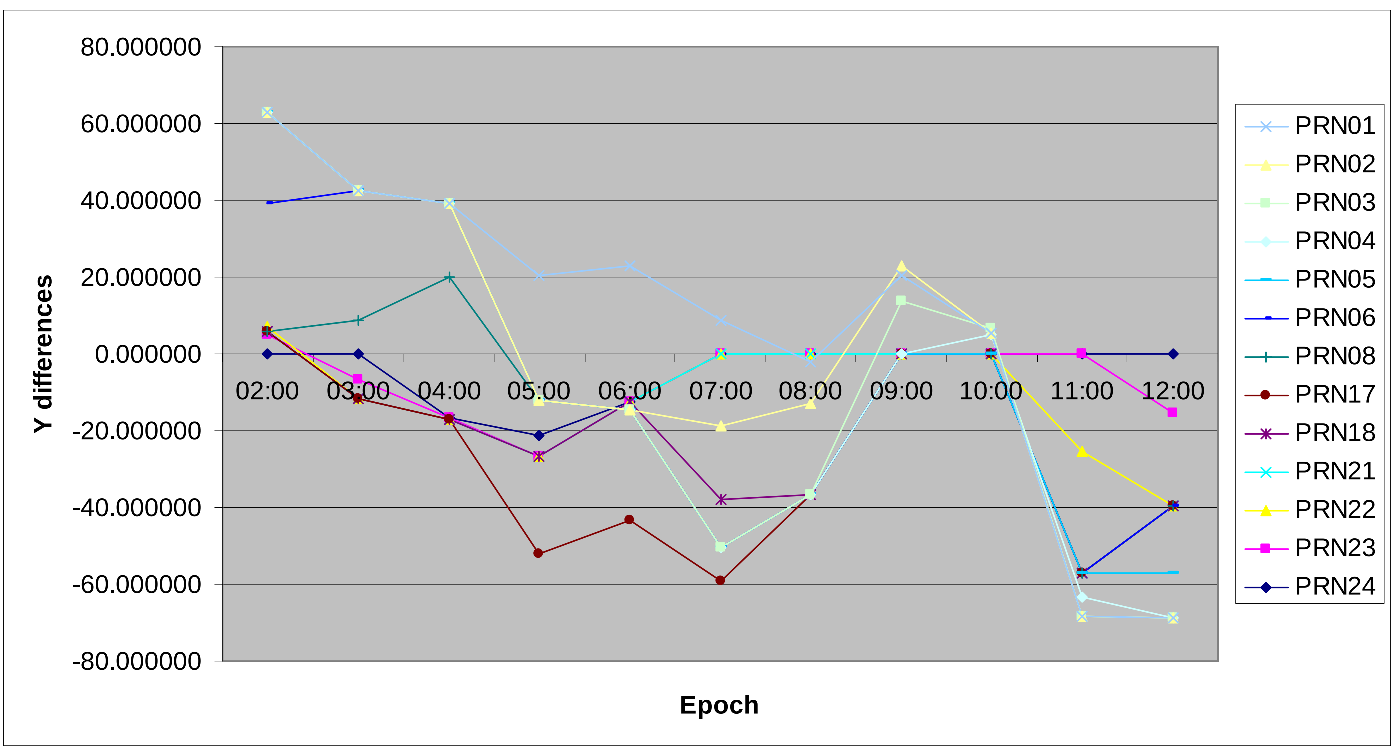

Figure 3.8 GLONASS satellite position at September 11, 2005

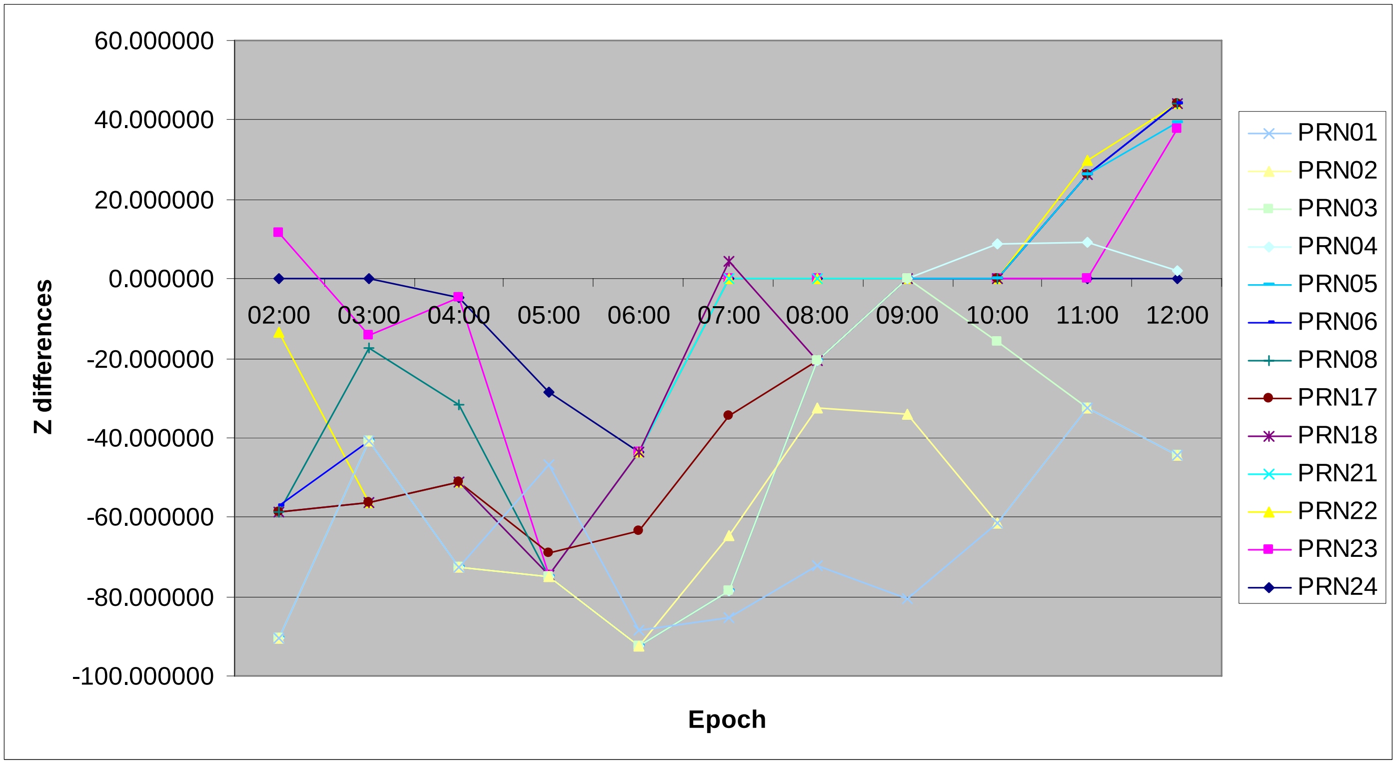

Figure3.9 GLONASS satellite position at September 11, 2005

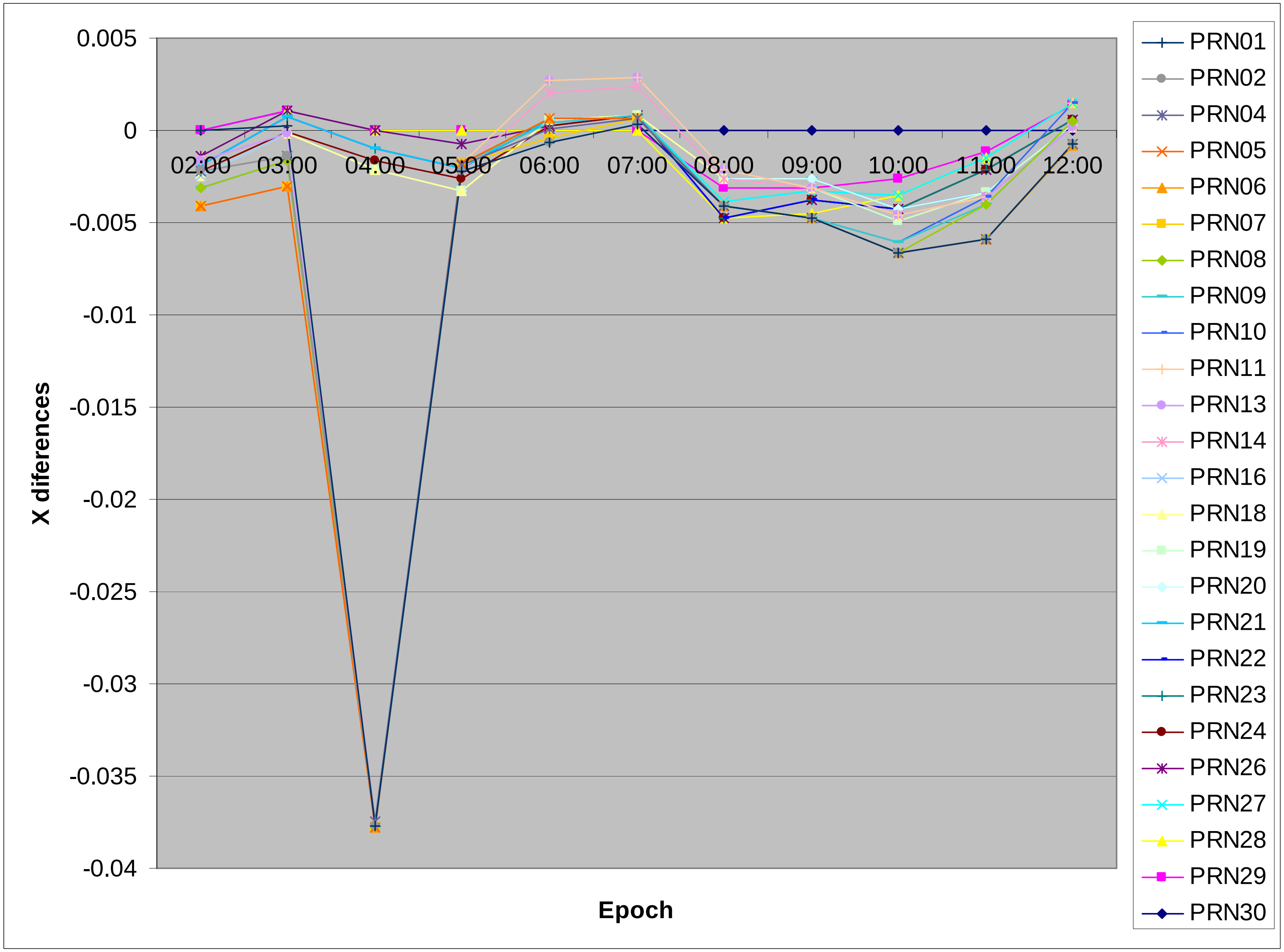

Figure 3.10 GPS satellite position at September 29, 2005

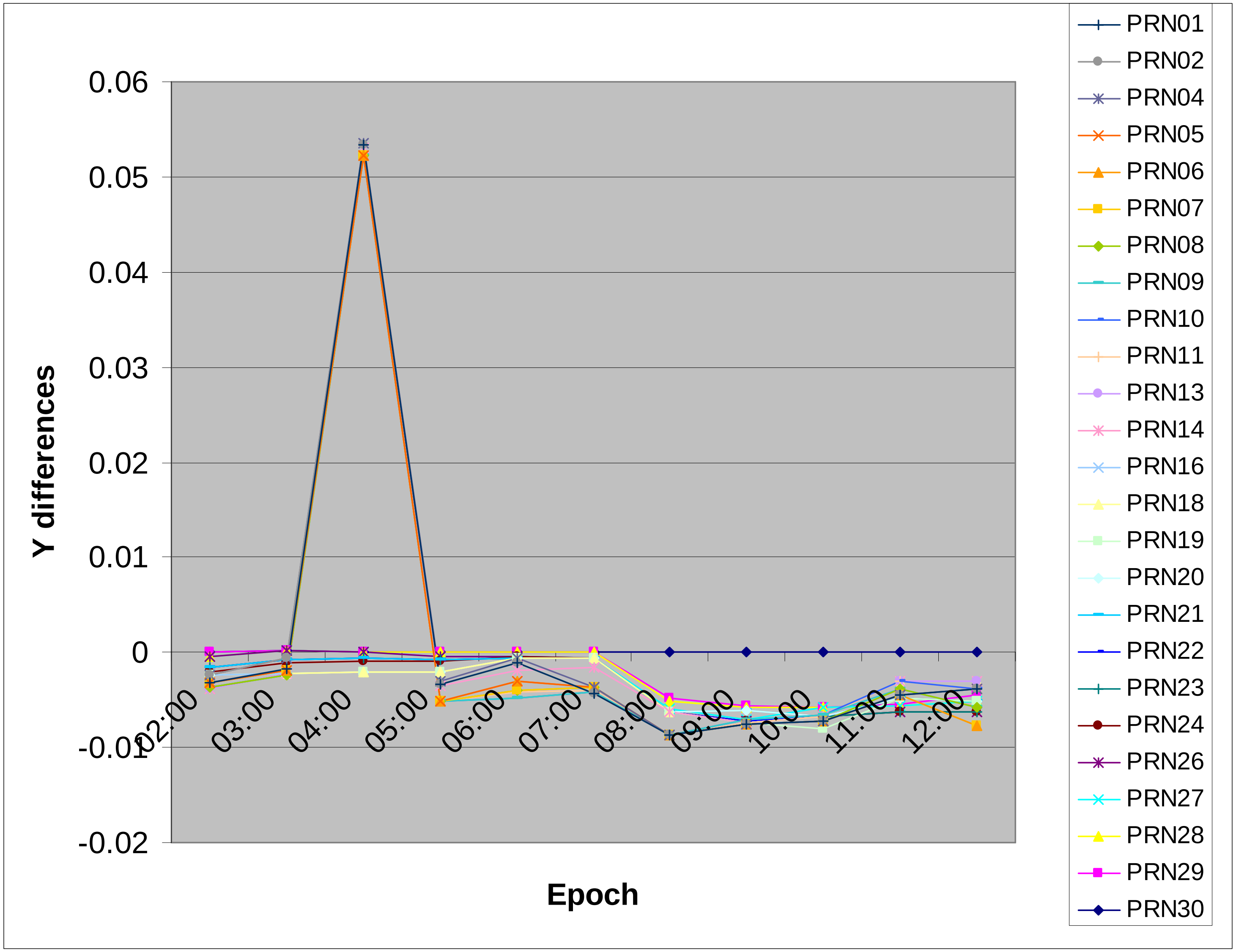

Figure 3.11 GPS satellite position at September 11, 2005

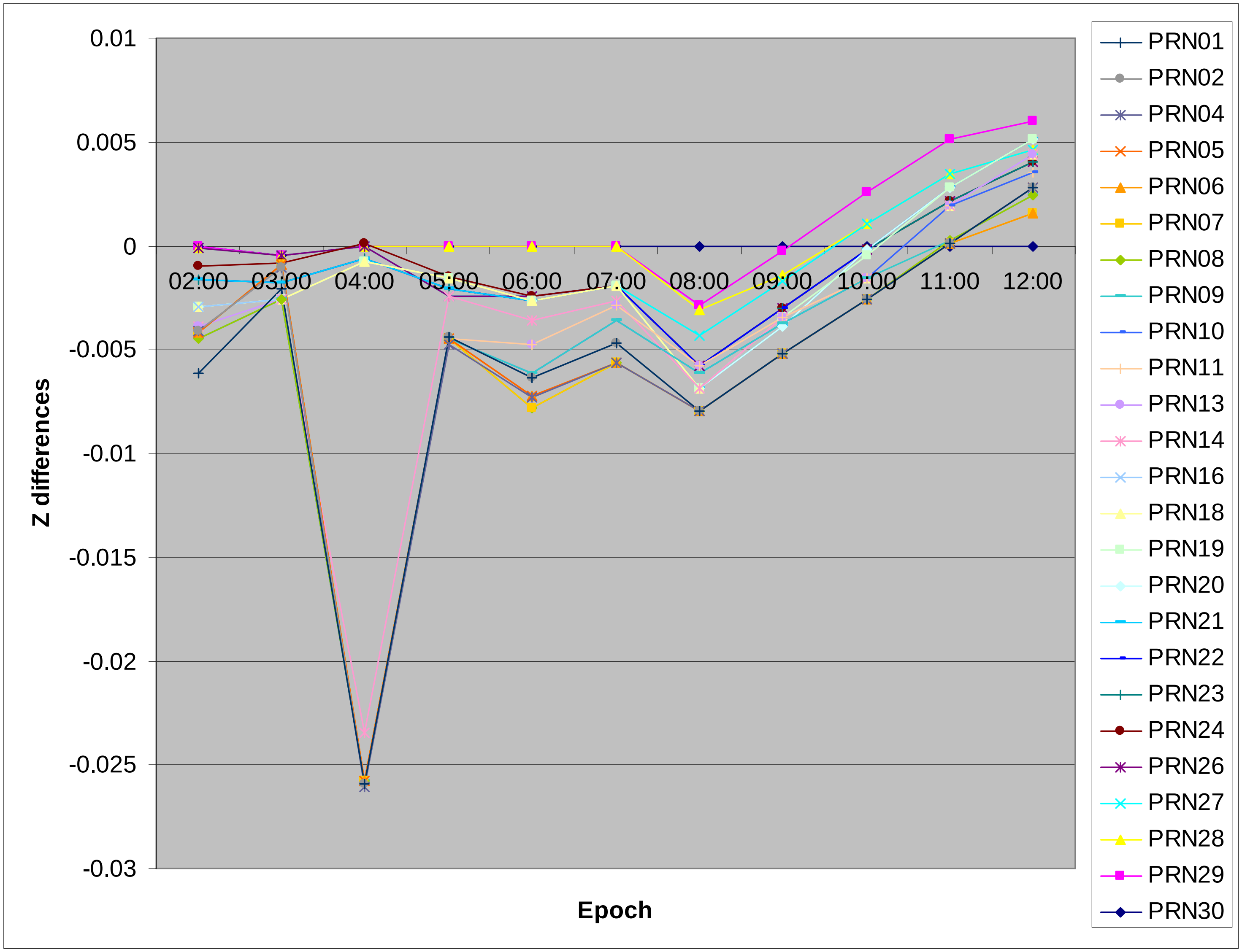

Figure 3.12 GPS satellite position at September 11, 2005

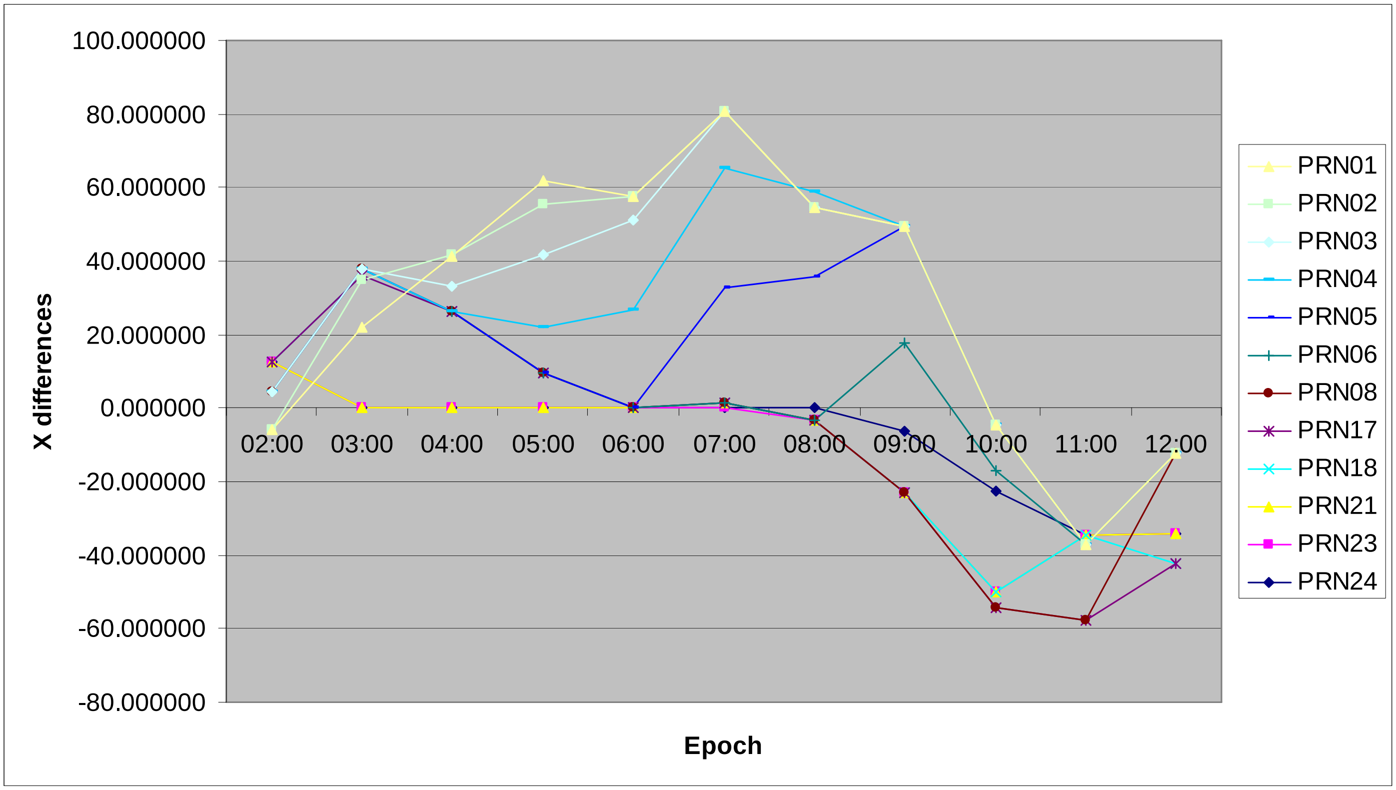

Figure 3.13 GLONASS satellite position at September 29, 2005

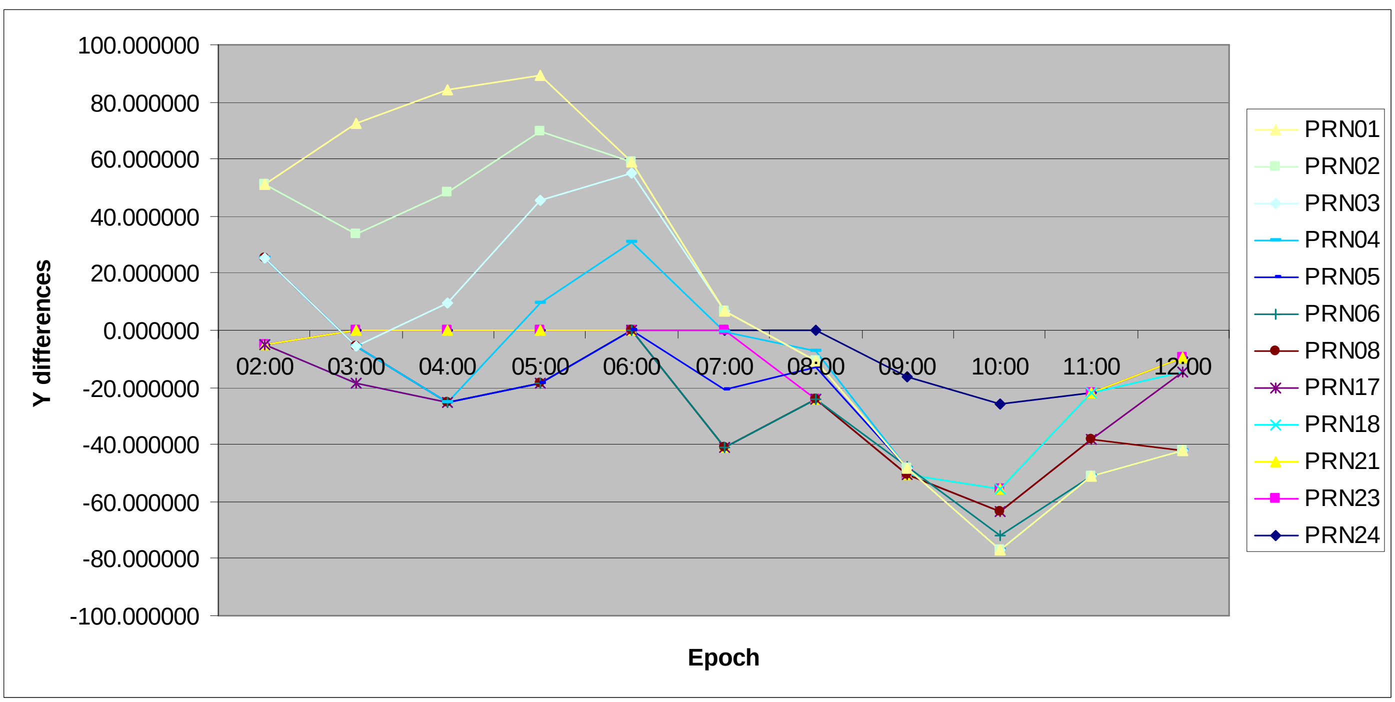

Figure 3.14 GLONASS satellite position at September 29, 2005

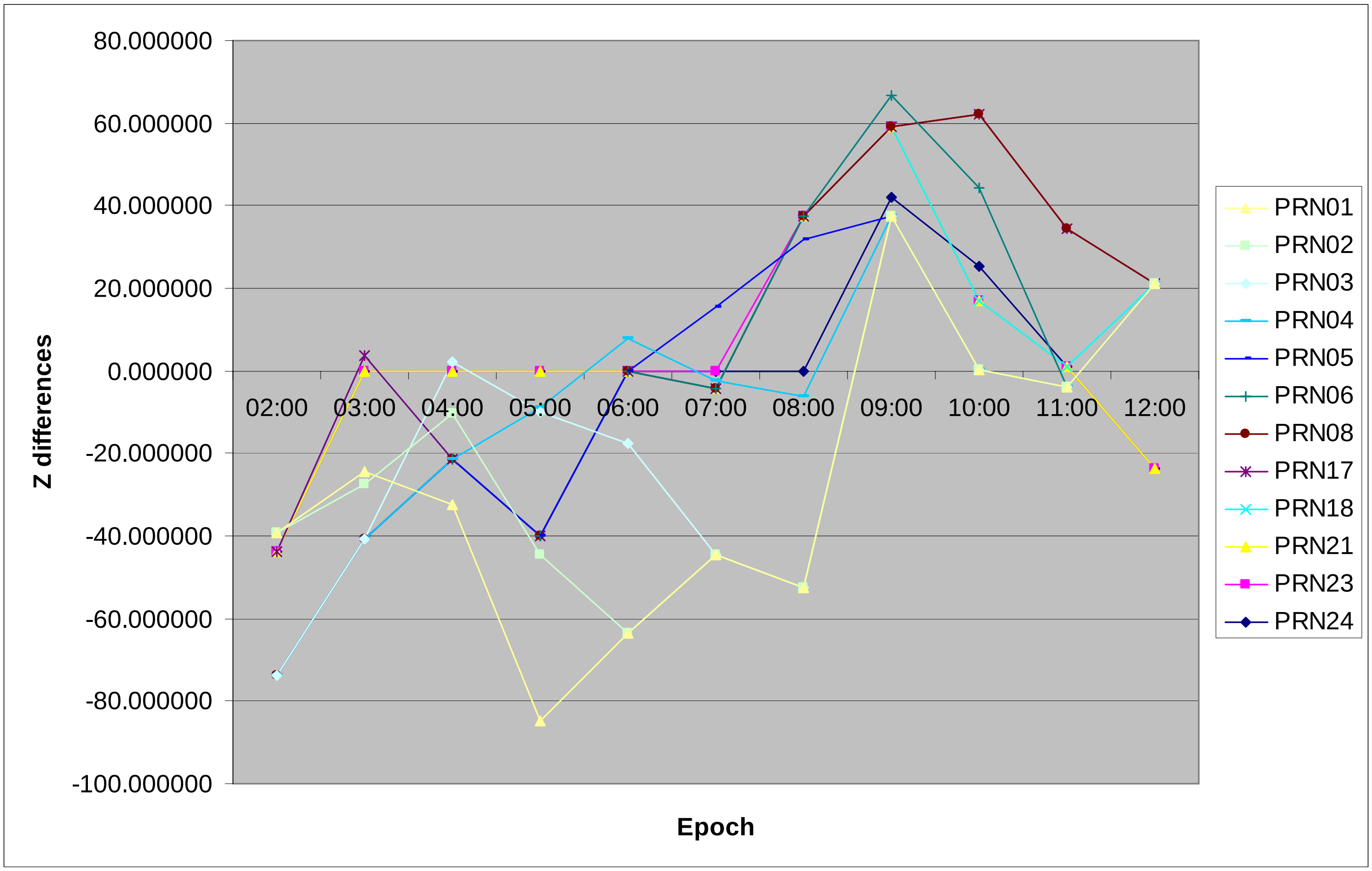

Figure 3.15 GLONASS satellite position at September 29, 2005

3.3.2. Precise Receiver Position

The precise receiver position was computed using dates of computed receiver broadcast position and precise ephemeredes from SP3 files. Results are shown below in Table 3.13 and 3.14.

Table 3.13 Precise receiver position at 11th September 2005

Epoch	X, meters	Y, meters	Z, meters
	RINEX-SP3	**RINEX-SP3**	**RINEX-SP3**
7200	-31.157	63.722	-229.122
10800	5.860	6.984	0.093
14400	0.894	-0.134	0.205
18000	10.648	23.838	-8.775
21600	1.326	1.347	2.749
25200	6.458	1.787	-20.417
28800	-0.652	-0.408	-2.746
32400	0.724	3.677	-3.136
36000	0.162	0.459	1.036
39600	-7.411	-1.622	-6.509
43200	-1.563	0.320	-0.019
	6.078	**9.481**	**24.888**

Table 3.14 Precise receiver position at 29th September 2005

Epoch	X, meters	Y, meters	Z, meters
	RINEX-SP3	**RINEX-SP3**	**RINEX-SP3**
352800	0.113	-0.172	-1.402
356400	6.140	-4.881	14.010
360000	-0.130	-0.188	-0.089
363600	6.452	-4.504	7.975
367200	1.029	0.594	-0.306
370800	0.697	0.114	-3.815
374400	0.302	0.330	-0.225
378000	-3.761	3.259	-13.180
381600	-1.313	1.545	-0.170
385200	8.805	-50.017	33.579
388800	-0.526	4.716	-29.864
	2.661	**6.393**	**9.510**

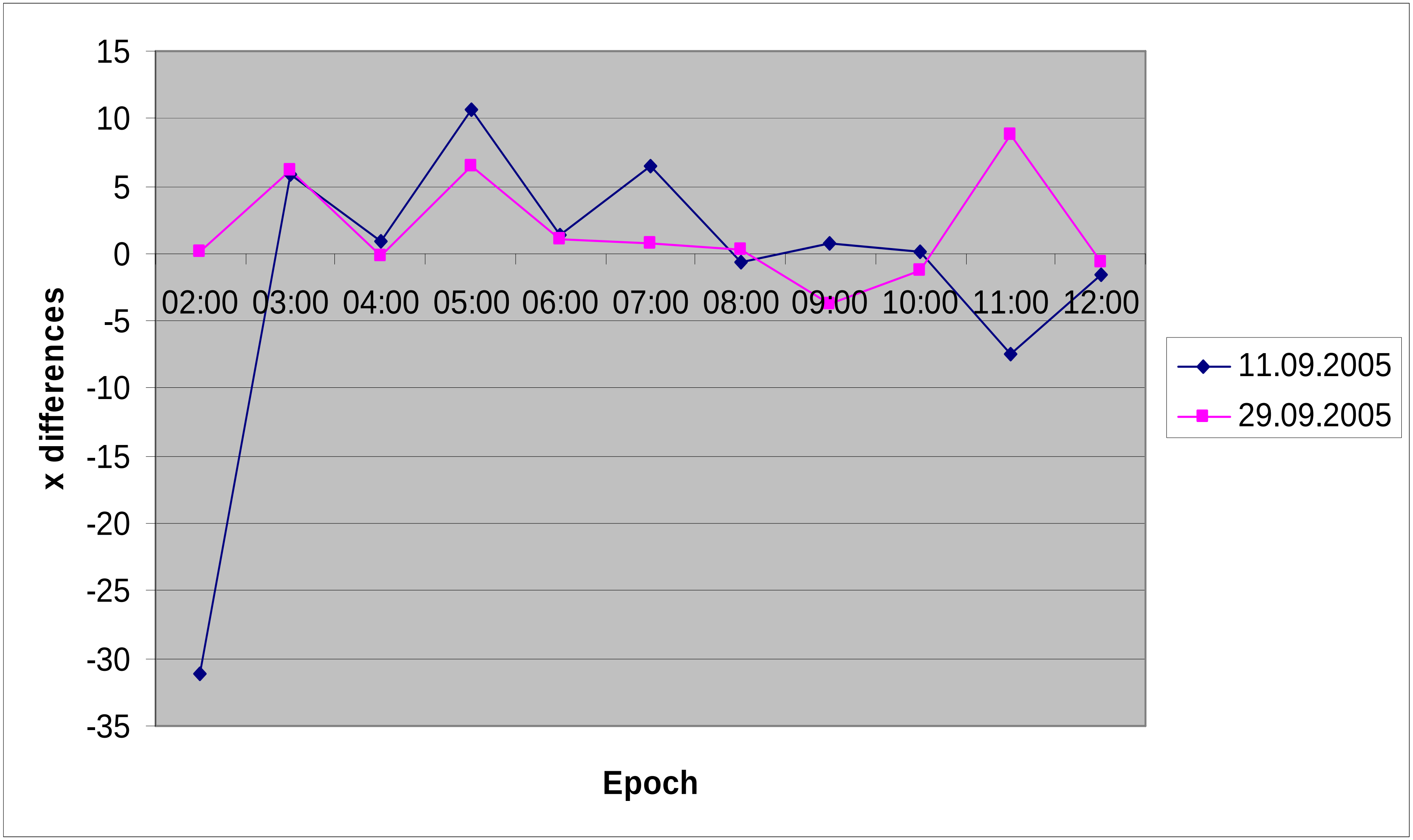

Figure 3.16 Differences of September 11, 2005 and September 29, 2005

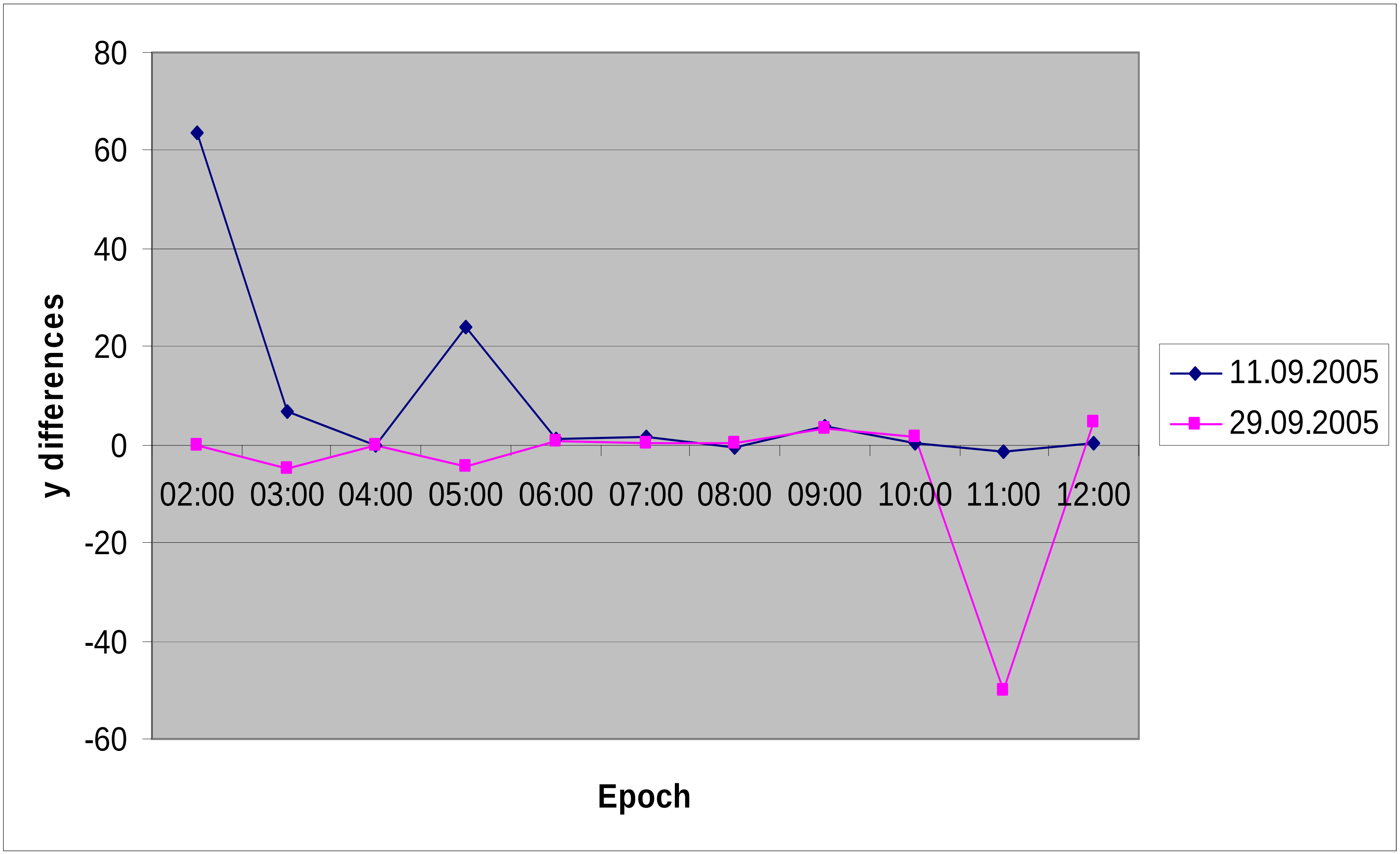

Figure 3.17 Differences of September 11, 2005 and September 29, 2005

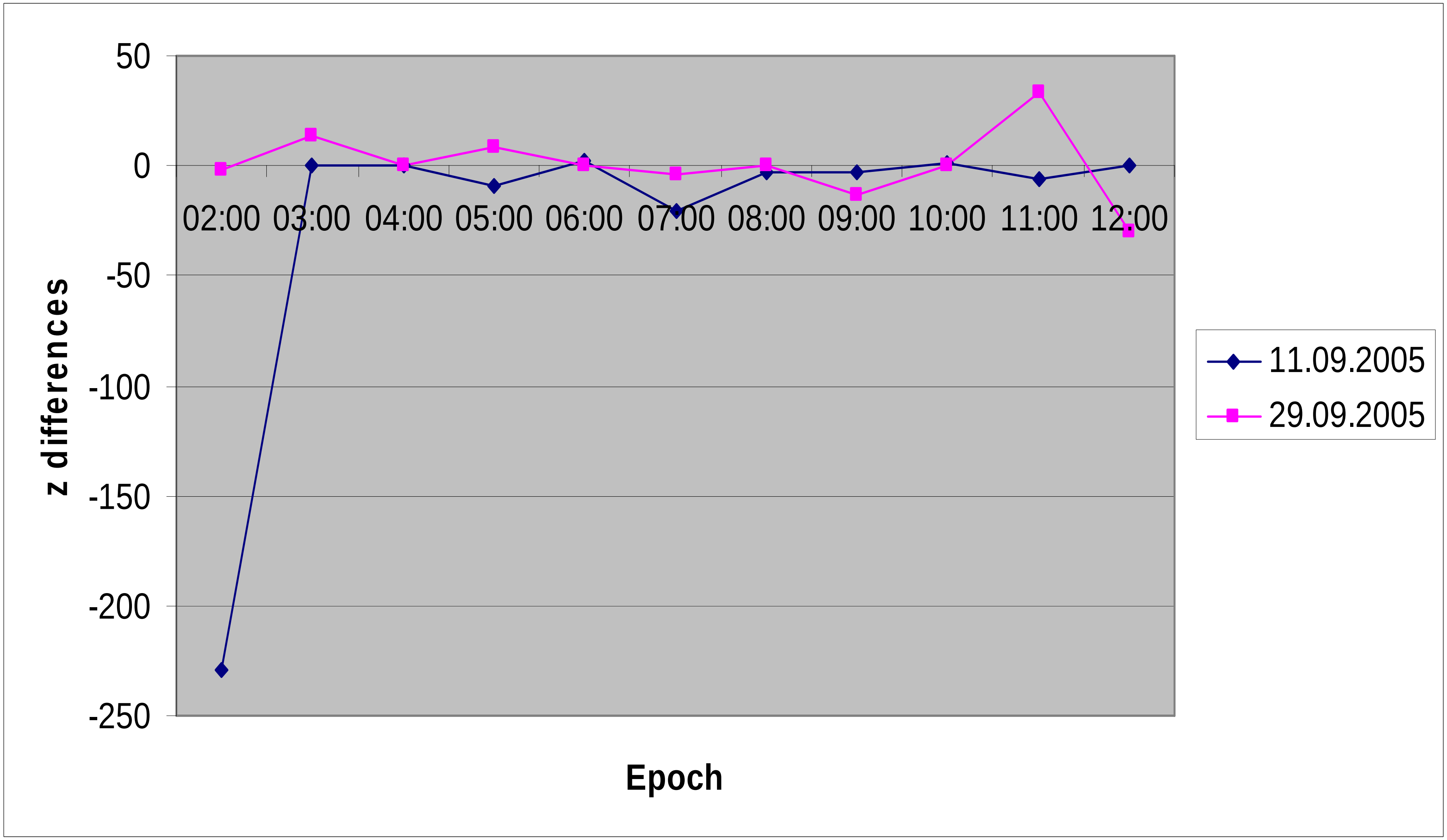

Figure 3.18 Differences of September 11, 2005 and September 29, 2005

3.4. Results analysis and recommendations

After some practical experiment, results are and can be interpreted as:

The first experiment, we did, was computing observed ephemeris three-dimensional Earth centered co-ordinates of each observed satellite at each epoch of observation were taken from appropriate RINEX navigation files and ground position's co-ordinates were taken from RINEX files observation and navigations dates. In addition, the results are given in meters.

The receiver broadcast positions results we can compare with Gjøvik University College station "GJOV" (see Figure 3.19).

Coordinates:

EUREF89 epoch 1989 January 01

	X (m)	RMS (m)	Y (m)	RMS (m)	Z (m)	RMS (m)
XYZ	**3066676.0470**	±0.00072	**578381.1270**	±0.00057	**5544140.8300**	±0.00121

Latitude	Longitude	Height
60º 47´ 22.1536´´ North	**10º 40´ 50.2921´´ East**	**238.321 m (ellipsoid)**

Antennehoyde til BCR (= "Base Choke Ring) er 0.180 m over punktet.
Hoydereferansen pa stasjonen er flaten pa toppen av soylen for antenne

	North	East	
UTM	**6740511.182**	**591492.701**	**(sone 32)**

Geoidhyde (VREF1996) over ellipsoiden er +38.849 m (jfr WSKTRANS version 4.0)

Beregning basert pa kontinuerlige GPS malinger fra 14.09.00 tik 31.12.00 og er utfort av Statens kartverk (jfr e-post fra Oddgeir Kristiansen datert 14 Februar 2001)

Antennetype:

ASH701946.013 SNOW, seria nr CR32000-1601
(Ashtech P/N 701946-01 REV 3 med "conical snow radome"

Figure 3.19 Gjøvik University College station "GJOV"

Differences between station "GJOV" and broadcast receiver position are given in Tables 3.15 and 3.16.

Table 3.15 Broadcast receiver position at 11th September 2005 ("dirty")

Epoch	X, meters	Y, meters	Z, meters
7200	-46.340	120.790	-305.829
10800	7.142	49.559	72.428
14400	-10.520	37.150	-41.365
18000	0.190	66.746	-99.136
21600	107.499	100.319	89.747
25200	2.217	52.208	-55.529
28800	-42.156	27.945	-73.231
32400	-18.110	70.654	71.594
36000	-1.115	29.838	9.210
39600	-11.942	49.196	-65.234
43200	10.797	48.239	-27.536
Average*	**23.457**	**54.946**	**82.802**

Table 3.16 Broadcast receiver position at 29th September 2005 ("clean")

Epoch	X, meters	Y, meters	Z, meters
352800	-6.175	67.308	47.116
356400	2.318	38.743	-32.005
360000	6.541	62.598	2.853
363600	45.559	40.084	40.169
367200	-6.593	37.027	8.894
370800	-41.040	33.258	-94.167
374400	-27.341	68.533	66.437
378000	-18.333	28.029	-65.805
381600	-11.675	51.516	-54.643
385200	75.165	40.100	-54.412
388800	-20.298	45.898	-45.369
Average*	**23.731**	**46.645**	**46.534**

These results we have got from computation of receiver broadcast position minus station "GJOV" (HiG) parameters. Comparing the "clean" and "dirty" averages:

- In X, there is little differences;
- In Y, "dirty" appears some 15% more than "clean";
- In Z, "dirty" appears some 80% more than "clean".

To explain parameters of precise receiver position at "dirty: (11th September 2005) and "clean" (29th September 2005) time (see Table 3.16 and 3.17), we can:

* Numerical average, disregarding sign

Table 3.13 Precise receiver position at 11th September 2005

Epoch	X, meters	Y, meters	Z, meters
	RINEX-SP3	**RINEX-SP3**	**RINEX-SP3**
7200	-31.157	63.722	-229.122
10800	5.860	6.984	0.093
14400	0.894	-0.134	0.205
18000	10.648	23.838	-8.775
21600	1.326	1.347	2.749
25200	6.458	1.787	-20.417
28800	-0.652	-0.408	-2.746
32400	0.724	3.677	-3.136
36000	0.162	0.459	1.036
39600	-7.411	-1.622	-6.509
43200	-1.563	0.320	-0.019
Average*	**6.078**	**9.481**	**24.888**

Table 3.14 Precise receiver position at 29^{th} September 2005

Epoch	X, meters	Y, meters	Z, meters
	RINEX-SP3	**RINEX-SP3**	**RINEX-SP3**
352800	0.113	-0.172	-1.402
356400	6.140	-4.881	14.010
360000	-0.130	-0.188	-0.089
363600	6.452	-4.504	7.975
367200	1.029	0.594	-0.306
370800	0.697	0.114	-3.815
374400	0.302	0.330	-0.225
378000	-3.761	3.259	-13.180
381600	-1.313	1.545	-0.170
385200	8.805	-50.017	33.579
388800	-0.526	4.716	-29.864
Average*	**2.661**	**6.393**	**9.510**

These parameters we have got of computing receiver broadcast position and precise ephemeredes from SP3 files. As we see, the parameters are two times better at “clean” day than “dirty”. Comparing the “clean” and “dirty” averages:

- In X, “dirty” appears some 40% more than “clean”;
- In Y, “dirty” appears some 30% more than “clean”;
- In Z, “dirty” appears some 80% more than “clean”.

To compare the broadcast and precise receiver position (see Figure 3.20), we calculated differences of precise (SP3) and broadcast (RINEX) parameters and differences between “dirty” and “clean” days.

* Numerical average, disregarding sign

	11.09.2005			29.09.2005		
	X	Y	Z	X	Y	Z
Precise (SP3)	6			2,7		
		9,5			6,4	
			25			9,5
Broadcast (RINEX)	23,5			23,7		
		55			46,6	
			82,8			46,5

Diff 11.09 to 29.09		
X	Y	Z
3,3		
	3,1	
		7,0
0,2		
	8,4	
		36,3

Diff Precise to Broadcast	17,5			21,0		
		45,5			40,2	
			57,5			37,0

Figure 3.20 Comparison of broadcast and precise receiver position

To explain these parameters, we can:

- The differences between precise and broadcast positions are not so much clearly then differences between days. The biggest difference is for Z co-ordinate of precise and broadcast positions. It is 20 meters, and for X and Y co-ordinates are – about 5 meters.
- The differences between “dirty” and “clean” days are biggest and more appreciable. Z co-ordinate differs almost 20 meters at these days.

4. CONCLUSIONS AND RECOMMENDATIONS

The main task of this project, which we called “HiGarus” were to investigate and analyze the influence of solar storming on precise positioning by satellites. The concept was to examine observations during two periods, one, which was free of solar storming activity, and one that was infested by a severe storm. For each of these two periods, the idea was to compare the positions of satellites and of ground receivers using data from two sources:

- From broadcast ephemeredes as recorded by a tracking station;
- From precise post-processed orbits available thought the IGS.

The time frames for these experiments were chosen by examining the Space Environment Center (SEC) web site, which shows solar activity levels. A Category 5 Geomagnetic Storm was noted on 11 September 2005 – the “dirty” period – and a totally “clean” period was selected on 29 September 2005. The following emerged:

- Comparing satellites positions and plots, we see that satellites positional differences very a lot over the time frame and from satellite to satellite. These variations are significantly smaller for the “clean” time frame. The satellites’ curves approx to move disorderly. The satellites’ positions are jumping, but there are some satellites, which differ at 02:00-04:00 UT. The same events repeat looking at the receiver position plot at the same epoch. The differences of satellite positioning X, Y and Z for 11^{th} September 2005 are, respectively, -0.010, -0.006, -0.012 meters;

- There are some satellites, which depart on the “clean” day at 03:00-05:00 epoch. The biggest differences in X, Y and Z are, respectively, -0.035, -0.050 and -0.025 meters. This phenomenoe is unexplained, and it is important to mention, that similar investigations in Gjøvik University College in 2006, showed similar phenomena;

- The above observation and conclusions suggest that it is important to investigate the effects of orbit disturbances for different satellites at the same solar events. The point is to attempt to model solar storms effects on all satellites in the GNSS constellations, and to investigate more storms of different categories and types.

- Computing GLONASS satellites positions, we have got huge differences:
    - Broadcast ephemeredes gives satellite positions directly at given epochs;

- Precise ephemeredes also gives satellites positions directly at given epochs (in other words by choosing the same epoch for broadcast and precise positions, direct satellite position comes without any computation. Therefore – no possible errors in computing theory) ;
- Different between broadcast and precise very large – why? Possibly:
  - GLONASS and GPS time;
  - PZ90 – WGS84 different parameters;
  - Different definitions of basic parameters.
- Based on these factions, we decided not to pursue GLONASS further in this study;
- However, because of the GLONASS as a supplement to GPS, particularly in high latitudes and in horizontions/forested terrain, we recommend that these GLONASS aspects are taken up in future investigations.

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APPENDIX 1

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	**Power systems:** : widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp = 9	4 per cycle (4 days per cycle)
G 4	Severe	**Power systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp = 7	200 per cycle (130 days per cycle)
G 2	Moderate	**Power systems:** high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp = 6	600 per cycle (360 days per cycle)
G 1	Minor	**Power systems:** weak power grid fluctuations can occur. **Spacecraft operations:** minor impact on satellite operations possible. **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp = 5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

Solar Radiation Storms			Flux level of >= 10 MeV particles (ions)*	Number of events when flux level was met (number of storm days**)
S 5	Extreme	**Biological:** unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	**Biological:** unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** blackout of HF radio communications through the polar regions and increased navigation errors over several days is likely.	10^4	3 per cycle
S 3	Strong	**Biological:** radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	**Biological:** passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** **Satellite operations:** infrequent single-event upsets possible. **Other systems:** small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	**Biological:** none. **Satellite operations:** none. **Other systems:** minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2}. Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle measurements (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	**HF Radio:** Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R 4	Severe	**HF Radio:** : HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions

APPENDIX 2

Observation Data File

```
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
     2              OBSERVATION DATA    M                   RINEX VERSION / TYPE
GBSS                Univ Coll of Gjųvik  02/16/2007 13:17   PGM / RUN BY / DATE
Ashtech GBSS ref st software v. 3.1.01 (Apr 2000)           COMMENT
--                                                          COMMENT
Antenna height is measured to BCR                           COMMENT
GJOV                                                        MARKER NAME
10332M001                                                   MARKER NUMBER
George Preiss       University College of Gjųvik            OBSERVER / AGENCY
ZX199909121         Ashtech Z18         0065      ZT16      REC # / TYPE / VERS
CR32000-1601        ASH701946.013 SNOW                      ANT # / TYPE
  3066676.0470   578381.1270  5544140.8300                  APPROX POSITION XYZ
        0.1800        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
     7    L1    L2    C1    P1    P2    D1    D2            # / TYPES OF OBSERV
    60                                                      INTERVAL
    13                                                      LEAP SECONDS
  2005     9    11     2     0    0.000000      GPS         TIME OF FIRST OBS
  2005     9    11     2    59   59.000000      GPS         TIME OF LAST OBS
                                                            END OF HEADER
 05  9 11  2  0  0.0000000  0 12G24G19G14G11G20G07G28R05R22R21R06R23-0.000000087
  -3465586.604 7  -2700456.055 5  23611077.741    23611077.741    23611081.812
      3205.082        2497.453
   6607439.347 7   5148654.074 5  24027286.435    24027286.435    24027287.182
     -3764.760       -2933.574
 -15918625.503 9 -12404120.224 7  21743044.916    21743044.916    21743046.566
      -884.605        -689.304
 -17034213.309 9 -13273411.768 8  20349054.806    20349054.806    20349055.799
      -389.516        -303.498
 -12913050.674 9 -10062114.648 6  22257989.068    22257989.068    22257991.001
      3090.260        2407.986
  -8462461.988 8  -6594119.932 5  23671403.308    23671403.318    23671406.377
      2561.615        1996.037
  -3623214.871 7  -2823274.609 4  24075051.062    24075051.062    24075052.857
     -2370.432       -1847.132
   9632733.527 7   7492125.995 7  22034924.126    22034924.126    22034919.346
     -3768.797       -2931.271
 -21627639.513 9 -16821491.817 9  19839290.804    19839290.804    19839294.580
       199.994         155.558
   5728926.603 6   4455830.032 7  21172746.806    21172746.806    21172748.693
     -3734.622       -2904.711
 -28454054.309 9 -22130927.838 8  19136137.947    19136137.947    19136133.722
      -361.378        -281.082
  -4527706.578 8  -3521545.943 7  22680762.464    22680762.464    22680765.847
      3957.982        3078.437
 05  9 11  2  1  0.0000000  0 12G24G19G14G11G20G07G28R05R22R21R06R23-0.000000061
  -3657542.452 7  -2850031.979 5  23574550.027    23574550.027    23574553.701
      3194.013        2488.827
   6833637.989 7   5324912.718 5  24070330.720    24070330.720    24070331.413
     -3774.473       -2941.129
 -15864298.510 9 -12361787.453 7  21753383.010    21753383.010    21753384.691
      -925.656        -721.290
 -17009785.338 9 -13254376.990 8  20353703.300    20353703.300    20353704.245
```

```
      -424.157         -330.501
 -13097843.332 8 -10206108.906 6  22222823.993    22222823.993    22222826.036
      3070.028         2392.246
  -8615429.650 8  -6713315.492 5  23642294.264    23642294.264    23642297.481
      2537.806         1977.520
  -3480188.566 7  -2711825.557 4  24102268.028    24102268.028    24102269.935
     -2396.379        -1867.267
   9859295.353 7   7668340.703 7  22077292.358    22077292.358    22077287.639
     -3782.543        -2941.975
 -21637923.083 9 -16829490.178 9  19837373.158    19837373.158    19837376.862
       143.337          111.487
   5953983.479 6   4630874.237 7  21214789.355    21214789.355    21214791.150
     -3766.398        -2929.403
 -28431040.009 9 -22113027.823 6  19140443.188    19140443.188    19140438.976
      -405.112         -315.085
  -4764422.630 8  -3705658.419 7  22636634.512    22636634.512    22636637.933
      3932.930         3058.954
 05  9 11  2  2  0.0000000  0 12G24G19G14G11G20G07G28R05R22R21R06R23-0.000000062
  -3848891.228 8  -2999134.875 5  23538137.558    23538137.558    23538141.017
      3184.284         2481.284
   7060345.540 7   5501567.946 5  24113471.852    24113471.852    24113472.435
     -3782.327        -2947.269
 -15807576.188 9 -12317588.291 7  21764176.909    21764176.909    21764178.596
      -964.995         -751.936
 -16983342.497 9 -13233772.177 8  20358735.242    20358735.242    20358736.107
      -457.249         -356.288
 -13281479.519 9 -10349202.018 7  22187879.190    22187879.190    22187881.164
      3051.177         2377.558
  -8767023.824 8  -6831440.836 5  23613446.634    23613446.634    23613450.087
      2515.308         1959.996
  -3335681.534 7  -2599222.636 4  24129766.870    24129766.870    24129768.797
     -2420.398        -1886.025
  10086610.001 7   7845140.924 7  22119801.389    22119801.389    22119796.626
     -3794.481        -2951.226
 -21644868.979 9 -16834892.531 9  19836077.858    19836077.858    19836081.581
        88.216           68.615
   6180881.274 6   4807350.268 7  21257175.870    21257175.870    21257177.680
     -3796.539        -2952.835
 -28405469.211 9 -22093139.459 6  19145226.752    19145226.752    19145222.528
      -447.165         -347.783
  -4999684.469 8  -3888639.771 7  22592777.770    22592777.770    22592781.092
      3908.959         3040.285
 05  9 11  2  3  0.0000000  0 12G24G19G14G11G20G07G28R05R22R21R06R23-0.000000060
  -4039584.527 8  -3147726.993 5  23501849.666    23501849.666    23501853.221
      3173.342         2472.772
   7287579.319 7   5678633.212 5  24156713.111    24156713.111    24156713.699
     -3790.818        -2953.882
 -15748431.517 9 -12271501.578 7  21775431.796    21775431.796    21775433.489
     -1005.204         -783.254
 -16954849.766 9 -13211570.048 8  20364157.260    20364157.260    20364158.067
      -491.288         -382.823
 -13463910.218 9 -10491355.785 7  22153163.801    22153163.801    22153165.800
      3031.022         2361.860
  -8917190.454 8  -6948453.715 6  23584870.780    23584870.780    23584874.429
      2491.420         1941.364
  -3189678.995 7  -2485454.360 4  24157550.174    24157550.174    24157552.070
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
```

APPENDIX 3

Navigation Data File

```
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
          2         NAVIGATION DATA                         RINEX VERSION / TYPE
GBSS                Univ Coll of Gjųvik  02/16/2007 13:17   PGM / RUN BY / DATE
Ashtech GBSS ref st software v. 3.1.01 (Apr 2000)           COMMENT
--                                                          COMMENT
Antenna height is measured to BCR                           COMMENT
     .1211D-07   .1490D-07  -.5960D-07  -.1192D-06          ION ALPHA
     .9626D+05   .8192D+05  -.1966D+06  -.3932D+06          ION BETA
     .372529029846D-08  .888178419700D-14   147456     1340 DELTA-UTC: A0,A1,T,W
    13                                                      LEAP SECONDS
                                                            END OF HEADER
 7 05  9 11  2  0  0.0  .325586181134D-03  .175077730091D-10  .000000000000D+00
     .620000000000D+02  .344375000000D+02  .515092884258D-08 -.314004276503D+01
     .180862843990D-05  .133950671880D-01  .876374542713D-05  .515376334000D+04
     .720000000000D+04  .307336449623D-06 -.244202701723D+01 -.158324837685D-06
     .935889290837D+00  .192750000000D+03 -.177674251077D+01 -.798676125209D-08
    -.315370279295D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.186264514923D-08  .318000000000D+03
     .687000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
 9 05  9 11  1 59 44.0 -.737700611353D-05 -.181898940355D-11  .000000000000D+00
     .218000000000D+03 -.485937500000D+02  .463876465174D-08  .671142568810D+00
    -.261515378952D-05  .172932356363D-01  .824034214020D-05  .515365752220D+04
     .718400000000D+04 -.197440385818D-06  .176594886857D+01  .670552253723D-07
     .956904704453D+00  .222468750000D+03  .118625813799D+01 -.828891669522D-08
     .281797452281D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.558793544769D-08  .218000000000D+03
     .654000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
11 05  9 11  2  0  0.0  .263985712081D-03  .341060513165D-11  .000000000000D+00
     .630000000000D+02  .878125000000D+02  .597024868482D-08  .165013308502D+01
     .475347042084D-05  .449402933009D-02  .653602182865D-05  .515370130730D+04
     .720000000000D+04  .149011611938D-07 -.146960942706D+01  .119209289551D-06
     .900090501937D+00  .220656250000D+03  .232908148919D+00 -.876000774663D-08
    -.223937899341D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .100000000000D+01  .000000000000D+00 -.121071934700D-07  .319000000000D+03
     .630000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
 7 05  9 11  2  0  0.0  .325586181134D-03  .175077730091D-10  .000000000000D+00
     .620000000000D+02  .344375000000D+02  .515092884258D-08 -.314004276503D+01
     .180862843990D-05  .133950671880D-01  .876374542713D-05  .515376334000D+04
     .720000000000D+04  .307336449623D-06 -.244202701723D+01 -.158324837685D-06
     .935889290837D+00  .192750000000D+03 -.177674251077D+01 -.798676125209D-08
    -.315370279295D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.186264514923D-08  .318000000000D+03
     .687000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
14 05  9 11  2  0  0.0 -.265482813120D-04  .568434188608D-12  .000000000000D+00
     .138000000000D+03 -.717812500000D+02  .369301097159D-08 -.291592043689D+01
    -.369362533092D-05  .189529696945D-02  .645779073238D-05  .515375836563D+04
     .720000000000D+04 -.633299350739D-07  .762480371111D+00  .167638063431D-07
     .983605774054D+00  .267812500000D+03 -.206248455908D+01 -.767960560068D-08
     .992898501065D-10  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .100000000000D+01  .000000000000D+00 -.931322574615D-08  .394000000000D+03
     .630000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
 9 05  9 11  1 59 44.0 -.737700611353D-05 -.181898940355D-11  .000000000000D+00
     .218000000000D+03 -.485937500000D+02  .463876465174D-08  .671142568810D+00
```

```
    -.261515378952D-05  .172932356363D-01  .824034214020D-05  .515365752220D+04
     .718400000000D+04 -.197440385818D-06  .176594886857D+01  .670552253723D-07
     .956904704453D+00  .222468750000D+03  .118625813799D+01 -.828891669522D-08
     .281797452281D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.558793544769D-08  .218000000000D+03
     .654000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
19 05  9 11  2  0  0.0 -.260104425251D-04 -.227373675443D-12  .000000000000D+00
     .930000000000D+02  .409687500000D+02  .467626621383D-08 -.163682636608D+01
     .222772359848D-05  .338168255985D-02  .904686748981D-05  .515373323059D+04
     .720000000000D+04 -.111758708954D-07 -.232835114929D+01  .122934579849D-06
     .958815358851D+00  .205000000000D+03 -.151567883715D+01 -.790318634229D-08
    -.241081470582D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.144354999065D-07  .930000000000D+02
     .627000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
11 05  9 11  2  0  0.0  .263985712081D-03  .341060513165D-11  .000000000000D+00
     .630000000000D+02  .878125000000D+02  .597024868482D-08  .165013308502D+01
     .475347042084D-05  .449402933009D-02  .653602182865D-05  .515370130730D+04
     .720000000000D+04  .149011611938D-07 -.146960942706D+01  .119209289551D-06
     .900090501937D+00  .220656250000D+03  .232908148919D+00 -.876000774663D-08
    -.223937899341D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .100000000000D+01  .000000000000D+00 -.121071934700D-07  .319000000000D+03
     .630000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
20 05  9 11  2  0  0.0 -.489125959575D-04  .147792889038D-11  .000000000000D+00
     .188000000000D+03  .581250000000D+01  .458197657200D-08 -.894913858057D+00
     .292435288429D-06  .250260788016D-02  .323913991451D-05  .515364105034D+04
     .720000000000D+04  .149011611938D-07 -.299015781379D+00  .149011611938D-07
     .960572578012D+00  .314812500000D+03  .147556540836D+01 -.832713257278D-08
    -.157863718515D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.698491930962D-08  .444000000000D+03
     .660000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
14 05  9 11  2  0  0.0 -.265482813120D-04  .568434188608D-12  .000000000000D+00
     .138000000000D+03 -.717812500000D+02  .369301097159D-08 -.291592043689D+01
    -.369362533092D-05  .189529696945D-02  .645779073238D-05  .515375836563D+04
     .720000000000D+04 -.633299350739D-07  .762480371111D+00  .167638063431D-07
     .983605774054D+00  .267812500000D+03 -.206248455908D+01 -.767960560068D-08
     .992898501065D-10  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .100000000000D+01  .000000000000D+00 -.931322574615D-08  .394000000000D+03
     .630000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
22 05  9 11  2  0  0.0  .391430221498D-04  .204636307899D-11  .000000000000D+00
     .730000000000D+02  .137812500000D+02  .448875840338D-08 -.221347323813D+01
     .637024641037D-06  .487381406128D-02  .332109630108D-05  .515368113136D+04
     .720000000000D+04  .132247805595D-06 -.237666181716D+00  .745058059692D-08
     .958382673034D+00  .315750000000D+03 -.158783187324D+01 -.814283918194D-08
    -.173935816553D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .100000000000D+01  .000000000000D+00 -.181607902050D-07  .329000000000D+03
     .627000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
19 05  9 11  2  0  0.0 -.260104425251D-04 -.227373675443D-12  .000000000000D+00
     .930000000000D+02  .409687500000D+02  .467626621383D-08 -.163682636608D+01
     .222772359848D-05  .338168255985D-02  .904686748981D-05  .515373323059D+04
     .720000000000D+04 -.111758708954D-07 -.232835114929D+01  .122934579849D-06
     .958815358851D+00  .205000000000D+03 -.151567883715D+01 -.790318634229D-08
    -.241081470582D-09  .000000000000D+00  .134000000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00 -.144354999065D-07  .930000000000D+02
     .627000000000D+04  .000000000000D+00  .000000000000D+00  .000000000000D+00
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
```

APPENDIX 4

GLONASS Navigation Data File

```
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
     2.01           GLONASS NAVMESS DATA                        RINEX VERSION / TYPE
GBSS                Univ Coll of Gjųvik  02/16/2007 13:17       PGM / RUN BY / DATE
Ashtech GBSS ref st software v. 3.1.01 (Apr 2000)               COMMENT
--                                                              COMMENT
Antenna height is measured to BCR                               COMMENT
  2005     9    11     .447034835815D-06                        CORR TO SYSTEM TIME
    13                                                          LEAP SECONDS
                                                                END OF HEADER
 5 05  9 11  1 45  0.0  .203650444746D-03  .000000000000D+00  .630000000000D+04
    -.168114892578D+04 -.178241920471D+01  .931322574615D-09  .000000000000D+00
     .158582954102D+05  .206463146210D+01  .186264514923D-08  .200000000000D+01
     .198889824219D+05 -.179888629913D+01  .000000000000D+00  .000000000000D+00
 6 05  9 11  1 45  0.0 -.275103375316D-03 -.272848410532D-11  .630000000000D+04
     .128698803711D+05 -.216026306152D+01  .931322574615D-09  .000000000000D+00
     .153753955078D+04  .212039852142D+01  .186264514923D-08  .100000000000D+01
     .218469755859D+05  .111108875275D+01  .000000000000D+00  .000000000000D+00
21 05  9 11  1 45  0.0  .132270157337D-03  .363797880709D-11  .630000000000D+04
     .228675634766D+05  .154115009308D+01  .931322574615D-09  .000000000000D+00
     .345654296875D+02  .216543197632D+00  .186264514923D-08  .500000000000D+01
     .113276850586D+05 -.311381721497D+01  .000000000000D+00  .000000000000D+00
22 05  9 11  1 45  0.0 -.429768115282D-04  .454747350886D-11  .630000000000D+04
     .955992138672D+04  .295328140259D+01  .931322574615D-09  .000000000000D+00
    -.842226904297D+04  .663198471069D+00  .186264514923D-08  .100000000000D+02
     .220947890625D+05 -.102551460266D+01 -.931322574615D-09  .000000000000D+00
23 05  9 11  1 45  0.0  .116560608149D-03  .000000000000D+00  .672000000000D+04
    -.102793740234D+05  .263390254974D+01  .000000000000D+00  .000000000000D+00
    -.121609941406D+05  .727052688599D+00  .931322574615D-09  .110000000000D+02
     .199313271484D+05  .179611778259D+01 -.279396772385D-08  .000000000000D+00
 5 05  9 11  1 45  0.0  .203650444746D-03  .000000000000D+00  .630000000000D+04
    -.168114892578D+04 -.178241920471D+01  .931322574615D-09  .000000000000D+00
     .158582954102D+05  .206463146210D+01  .186264514923D-08  .200000000000D+01
     .198889824219D+05 -.179888629913D+01  .000000000000D+00  .000000000000D+00
 6 05  9 11  1 45  0.0 -.275103375316D-03 -.272848410532D-11  .630000000000D+04
     .128698803711D+05 -.216026306152D+01  .931322574615D-09  .000000000000D+00
     .153753955078D+04  .212039852142D+01  .186264514923D-08  .100000000000D+01
     .218469755859D+05  .111108875275D+01  .000000000000D+00  .000000000000D+00
21 05  9 11  1 45  0.0  .132270157337D-03  .363797880709D-11  .630000000000D+04
     .228675634766D+05  .154115009308D+01  .931322574615D-09  .000000000000D+00
     .345654296875D+02  .216543197632D+00  .186264514923D-08  .500000000000D+01
     .113276850586D+05 -.311381721497D+01  .000000000000D+00  .000000000000D+00
22 05  9 11  1 45  0.0 -.429768115282D-04  .454747350886D-11  .630000000000D+04
     .955992138672D+04  .295328140259D+01  .931322574615D-09  .000000000000D+00
    -.842226904297D+04  .663198471069D+00  .186264514923D-08  .100000000000D+02
     .220947890625D+05 -.102551460266D+01 -.931322574615D-09  .000000000000D+00
23 05  9 11  1 45  0.0  .116560608149D-03  .000000000000D+00  .672000000000D+04
    -.102793740234D+05  .263390254974D+01  .000000000000D+00  .000000000000D+00
    -.121609941406D+05  .727052688599D+00  .931322574615D-09  .110000000000D+02
     .199313271484D+05  .179611778259D+01 -.279396772385D-08  .000000000000D+00
 5 05  9 11  2 15  0.0  .203660689294D-03  .000000000000D+00  .720000000000D+04
    -.433187402344D+04 -.115708923340D+01  .931322574615D-09  .000000000000D+00
     .194287753906D+05  .185495471954D+01  .931322574615D-09  .200000000000D+01
     .159226279297D+05 -.257955074310D+01  .000000000000D+00  .000000000000D+00
```

```
 6 05  9 11  2 15  0.0 -.275108963251D-03 -.363797880709D-11  .720000000000D+04
     .916218896484D+04 -.191998672485D+01  .186264514923D-08  .000000000000D+00
     .576168164062D+04  .253835296631D+01  .186264514923D-08  .100000000000D+01
     .229652807617D+05  .123019218445D+00  .000000000000D+00  .000000000000D+00
21 05  9 11  2 15  0.0  .132276676595D-03  .363797880709D-11  .720000000000D+04
     .249483676758D+05  .745619773865D+00  .931322574615D-09  .000000000000D+00
     .116529296875D+03 -.910167694092D-01  .931322574615D-09  .500000000000D+01
     .535773193359D+04 -.347645664215D+01  .931322574615D-09  .000000000000D+00
22 05  9 11  2 15  0.0 -.429674983025D-04  .454747350886D-11  .720000000000D+04
     .146518208008D+05  .265492248535D+01  .931322574615D-09  .000000000000D+00
    -.766329492188D+04  .188941955566D+00  .186264514923D-08  .100000000000D+02
     .194183623047D+05 -.192900085449D+01 -.931322574615D-09  .000000000000D+00
23 05  9 11  2 15  0.0  .116560608149D-03  .000000000000D+00  .720000000000D+04
    -.513091748047D+04  .304189872742D+01  .000000000000D+00  .000000000000D+00
    -.111554829102D+05  .366696357727D+00  .931322574615D-09  .110000000000D+02
     .223521723633D+05  .876106262207D+00 -.279396772385D-08  .000000000000D+00
 5 05  9 11  2 15  0.0  .203660689294D-03  .000000000000D+00  .720000000000D+04
    -.433187402344D+04 -.115708923340D+01  .931322574615D-09  .000000000000D+00
     .194287753906D+05  .185495471954D+01  .931322574615D-09  .200000000000D+01
     .159226279297D+05 -.257955074310D+01  .000000000000D+00  .000000000000D+00
 6 05  9 11  2 15  0.0 -.275108963251D-03 -.363797880709D-11  .720000000000D+04
     .916218896484D+04 -.191998672485D+01  .186264514923D-08  .000000000000D+00
     .576168164062D+04  .253835296631D+01  .186264514923D-08  .100000000000D+01
     .229652807617D+05  .123019218445D+00  .000000000000D+00  .000000000000D+00
21 05  9 11  2 15  0.0  .132276676595D-03  .363797880709D-11  .720000000000D+04
     .249483676758D+05  .745619773865D+00  .931322574615D-09  .000000000000D+00
     .116529296875D+03 -.910167694092D-01  .931322574615D-09  .500000000000D+01
     .535773193359D+04 -.347645664215D+01  .931322574615D-09  .000000000000D+00
22 05  9 11  2 15  0.0 -.429674983025D-04  .454747350886D-11  .720000000000D+04
     .146518208008D+05  .265492248535D+01  .931322574615D-09  .000000000000D+00
    -.766329492188D+04  .188941955566D+00  .186264514923D-08  .100000000000D+02
     .194183623047D+05 -.192900085449D+01 -.931322574615D-09  .000000000000D+00
23 05  9 11  2 15  0.0  .116560608149D-03  .000000000000D+00  .720000000000D+04
    -.513091748047D+04  .304189872742D+01  .000000000000D+00  .000000000000D+00
    -.111554829102D+05  .366696357727D+00  .931322574615D-09  .110000000000D+02
     .223521723633D+05  .876106262207D+00 -.279396772385D-08  .000000000000D+00
 8 05  9 10 18 45  0.0  .927988439798D-04 -.818545231596D-11  .675600000000D+05
    -.148365068359D+05 -.147317028046D+01 -.186264514923D-08  .000000000000D+00
    -.659277587891D+04 -.225817966461D+01  .931322574615D-09  .600000000000D+01
     .196617055664D+05 -.186986541748D+01  .000000000000D+00  .000000000000D+00
 8 05  9 11  2 15  0.0  .925632193685D-04 -.818545231596D-11  .864000000000D+04
     .151783154297D+05 -.182806015015D+00  .000000000000D+00  .000000000000D+00
    -.205073920898D+05 -.465087890625D-01  .000000000000D+00  .600000000000D+01
     .503711914062D+03  .357317161560D+01  .000000000000D+00  .100000000000D+01
 5 05  9 11  2 15  0.0  .203660689294D-03  .000000000000D+00  .810000000000D+04
    -.433187402344D+04 -.115708923340D+01  .931322574615D-09  .000000000000D+00
     .194287753906D+05  .185495471954D+01  .931322574615D-09  .200000000000D+01
     .159226279297D+05 -.257955074310D+01  .000000000000D+00  .000000000000D+00
 6 05  9 11  2 15  0.0 -.275108963251D-03 -.363797880709D-11  .810000000000D+04
     .916218896484D+04 -.191998672485D+01  .186264514923D-08  .000000000000D+00
     .576168164062D+04  .253835296631D+01  .186264514923D-08  .100000000000D+01
     .229652807617D+05  .123019218445D+00  .000000000000D+00  .000000000000D+00
 8 05  9 11  2 15  0.0  .925632193685D-04 -.818545231596D-11  .864000000000D+04
     .151783154297D+05 -.182806015015D+00  .000000000000D+00  .000000000000D+00
    -.205073920898D+05 -.465087890625D-01  .000000000000D+00  .600000000000D+01
     .503711914062D+03  .357317161560D+01  .000000000000D+00  .100000000000D+01
21 05  9 11  2 15  0.0  .132276676595D-03  .363797880709D-11  .810000000000D+04
     .249483676758D+05  .745619773865D+00  .931322574615D-09  .000000000000D+00
     .116529296875D+03 -.910167694092D-01  .931322574615D-09  .500000000000D+01
```

```
      .535773193359D+04 -.347645664215D+01  .931322574615D-09  .000000000000D+00
22 05  9 11  2 15  0.0 -.429674983025D-04  .454747350886D-11  .810000000000D+04
      .146518208008D+05  .265492248535D+01  .931322574615D-09  .000000000000D+00
     -.766329492188D+04  .188941955566D+00  .186264514923D-08  .100000000000D+02
      .194183623047D+05 -.192900085449D+01 -.931322574615D-09  .000000000000D+00
23 05  9 11  2 15  0.0  .116560608149D-03  .000000000000D+00  .810000000000D+04
     -.513091748047D+04  .304189872742D+01  .000000000000D+00  .000000000000D+00
     -.111554829102D+05  .366696357727D+00  .931322574615D-09  .110000000000D+02
      .223521723633D+05  .876106262207D+00 -.279396772385D-08  .000000000000D+00
 5 05  9 11  2 45  0.0  .203660689294D-03  .000000000000D+00  .900000000000D+04
     -.585963623047D+04 -.553090095520D+00  .931322574615D-09  .000000000000D+00
      .223700522461D+05  .137000846863D+01  .931322574615D-09  .200000000000D+01
      .107227011719D+05 -.316056632996D+01  .000000000000D+00  .000000000000D+00
 6 05  9 11  2 45  0.0 -.275116413832D-03 -.363797880709D-11  .900000000000D+04
      .607604394531D+04 -.148388767242D+01  .186264514923D-08  .000000000000D+00
      .105271489258D+05  .271014690399D+01  .186264514923D-08  .100000000000D+01
      .222833510742D+05 -.875832557678D+00  .000000000000D+00  .000000000000D+00
 8 05  9 11  2 45  0.0  .925473868847D-04 -.818545231596D-11  .900000000000D+04
      .144450288086D+05 -.593187332153D+00  .000000000000D+00  .000000000000D+00
     -.198932915039D+05  .743434906006D+00  .931322574615D-09  .600000000000D+01
      .683294531250D+04  .341368103027D+01  .000000000000D+00  .100000000000D+01
21 05  9 11  2 45  0.0  .132283195853D-03  .363797880709D-11  .900000000000D+04
      .254935375977D+05 -.146479606628D+00  .931322574615D-09  .000000000000D+00
     -.155245117188D+03 -.170272827148D+00  .931322574615D-09  .500000000000D+01
     -.102605712891D+04 -.357062435150D+01  .186264514923D-08  .000000000000D+00
22 05  9 11  2 45  0.0 -.429581850767D-04  .454747350886D-11  .900000000000D+04
      .189531875000D+05  .208388423920D+01  .186264514923D-08  .000000000000D+00
     -.767964648438D+04 -.181946754456D+00  .186264514923D-08  .100000000000D+02
      .152400576172D+05 -.268341922760D+01  .000000000000D+00  .000000000000D+00
23 05  9 11  2 45  0.0  .116559676826D-03  .000000000000D+00  .900000000000D+04
      .495687500000D+03  .315842342377D+01  .931322574615D-09  .000000000000D+00
     -.108958457031D+05 -.847148895264D-01  .931322574615D-09  .110000000000D+02
      .230440302734D+05 -.112518310547D+00 -.186264514923D-08  .000000000000D+00
 6 05  9 11  2 45  0.0 -.275116413832D-03 -.363797880709D-11  .900000000000D+04
      .607604394531D+04 -.148388767242D+01  .186264514923D-08  .000000000000D+00
      .105271489258D+05  .271014690399D+01  .186264514923D-08  .100000000000D+01
      .222833510742D+05 -.875832557678D+00  .000000000000D+00  .000000000000D+00
 8 05  9 11  2 45  0.0  .925473868847D-04 -.818545231596D-11  .900000000000D+04
      .144450288086D+05 -.593187332153D+00  .000000000000D+00  .000000000000D+00
     -.198932915039D+05  .743434906006D+00  .931322574615D-09  .600000000000D+01
      .683294531250D+04  .341368103027D+01  .000000000000D+00  .100000000000D+01
21 05  9 11  2 45  0.0  .132283195853D-03  .363797880709D-11  .900000000000D+04
      .254935375977D+05 -.146479606628D+00  .931322574615D-09  .000000000000D+00
     -.155245117188D+03 -.170272827148D+00  .931322574615D-09  .500000000000D+01
     -.102605712891D+04 -.357062435150D+01  .186264514923D-08  .000000000000D+00
22 05  9 11  2 45  0.0 -.429581850767D-04  .454747350886D-11  .900000000000D+04
      .189531875000D+05  .208388423920D+01  .186264514923D-08  .000000000000D+00
     -.767964648438D+04 -.181946754456D+00  .186264514923D-08  .100000000000D+02
      .152400576172D+05 -.268341922760D+01  .000000000000D+00  .000000000000D+00
23 05  9 11  2 45  0.0  .116559676826D-03  .000000000000D+00  .900000000000D+04
      .495687500000D+03  .315842342377D+01  .931322574615D-09  .000000000000D+00
     -.108958457031D+05 -.847148895264D-01  .931322574615D-09  .110000000000D+02
      .230440302734D+05 -.112518310547D+00 -.186264514923D-08  .000000000000D+00
----|---1|0---|---2|0---|---3|0---|---4|0---|---5|0---|---6|0---|---7|0---|---8|
```

APPENDIX 5

SP3 Data File

```
#aP2005  9 11  0  0  0.00000000      96 ORBIT IGb00 HLM  IGS
## 1340      0.00000000   900.00000000 53624 0.0000000000000
+   29     1  2  3  4  5  6  7  8  9 10 11 13 14 15 16 18 19
+         20 21 22 23 24 25 26 27 28 29 30 31  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         3  3  3  3  4  3  3  3  3  3  3  3  3  3  3  3  4
++         3  3  3  3  3  3  3  3  3  5  3  3  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
%c cc cc ccc ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%c cc cc ccc ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%f  0.0000000  0.000000000  0.00000000000  0.000000000000000
%f  0.0000000  0.000000000  0.00000000000  0.000000000000000
%i    0    0    0    0      0      0      0      0         0
%i    0    0    0    0      0      0      0      0         0
/* FINAL ORBIT COMBINATION FROM WEIGHTED AVERAGE OF:
/* cod emr esa gfz jpl mit ngs sio
/* REFERENCED TO IGS TIME AND TO WEIGHTED MEAN POLE:
/* CLK ANT Z-OFFSET (M): II/IIA 1.023; IIR 0.000
*  2005  9 11  0  0  0.00000000
P  1  20816.869527  15324.034851  -6018.714967      7.801944
P  2 -14550.021020  -5668.110128 -21770.852640    -27.405463
P  3  23091.642992   8518.628298  10206.358230     33.142935
P  4  -7489.709107 -18953.040733 -16861.363671    -40.537011
P  5 -21565.531391  13799.327713  -6904.718529     -3.733541
P  6  -1932.058859  17620.288754 -19556.164790    817.048907
P  7 -15894.470835 -20277.355617   7166.164514    325.466039
P  8  -1575.829358 -23638.674440  11437.481431    -40.983688
P  9 -14103.383856  15837.173013  15273.222580     -7.351526
P 10 -24798.590235    -83.797501  -9984.365977     69.938834
P 11  13951.825436 -16376.240817  15408.491346    263.977147
P 13   -308.344234 -18185.592477 -19452.549780     13.204219
P 14  16005.880688  20478.373734   5637.100903    -26.535365
P 15   1912.228831  23036.578812  12578.857797    487.579014
P 16  22858.111113   2878.523816 -13197.529456      8.428028
P 18  -6635.274721  16108.436119  20041.946466   -186.540939
P 19  18607.273733    200.246964  19065.754418    -25.996794
P 20  20553.285070 -13613.725157  -9948.480227    -48.908693
P 21  -6089.179724  25531.196713   1464.102168    128.383106
P 22   7142.776020  13905.547140  21630.979401     39.135263
P 23  10942.971319 -10503.552953 -21905.803142    175.384289
P 24   3762.249830 -25627.798674  -5122.194043     45.669560
P 25  11224.381494  14892.555838 -18497.001191    102.967424
P 26 -19773.442327  -3350.411513  17360.020367      8.662267
P 27   3776.270052 -26062.906555   1079.742615     14.698108
P 28  -4946.241816 -14546.495517  21918.987483     41.957491
P 29 -21530.832154  -6730.123486  14429.050575    303.985328
P 30 -12516.469615  16825.039066 -16495.509971    376.550986
P 31  -9113.999995 -20629.634661  13480.208026     18.563573
*  2005  9 11  0 15  0.00000000
```

```
P  1  21089.774868  15830.003406  -3181.515798      7.804377
P  2 -14040.519534  -8024.425261 -21368.325067    -27.405381
P  3  23747.640221   9378.290499   7695.039848     33.145621
P  4  -6888.537423 -20695.239152 -14928.818604    -40.560885
P  5 -22261.414412  13745.960265  -4183.037431     -3.759168
P  6  -3805.914219  16212.129027 -20476.915919    817.060440
P  7 -15001.176693 -19933.362365   9738.130417    325.481712
P  8  -1066.560113 -24744.639492   8877.178301    -40.985705
P  9 -13989.433524  13874.162268  17140.513356     -7.354150
P 10 -23642.188733   -613.907429 -12454.988419     69.938850
P 11  14097.817910 -14468.123671  17108.284977    263.980225
P 13   1415.523873 -16701.732322 -20694.387019     13.205755
P 14  15297.394429  20080.980112   8385.156844    -26.534976
P 15   1310.852906  24254.985944  10134.260574    487.583092
P 16  21356.173688   3571.129386 -15348.372309      8.428664
P 18  -8797.195754  16595.500687  18739.902017   -186.543315
P 19  19983.426092   1757.466583  17522.552565    -25.997122
P 20  21555.120956 -13710.911239  -7327.568542    -48.907429
P 21  -6415.459432  25451.916900  -1391.972194    128.386888
P 22   4782.823459  14578.788755  21838.408020     39.137120
P 23  12786.299934  -8862.923940 -21642.475616    175.382433
P 24   4130.083760 -26003.694156  -2292.421553     45.671694
P 25  10822.744477  16962.790973 -16912.214196    102.968560
P 26 -21115.828645  -4714.480115  15444.949024      8.659004
P 27   4064.426750 -25919.739582  -1787.384677     14.699281
P 28  -2605.451481 -15268.460963  21799.877272     41.957114
P 29 -22561.839233  -7787.954768  12111.643056    304.004720
P 30 -14220.931061  17237.887987 -14529.224773    376.563946
P 31  -7590.638164 -19766.894302  15529.763983     18.563617
*  2005  9 11  0 30  0.00000000
P  1  21141.659983  16109.971928   -289.541765      7.808924
P  2 -13662.887129 -10338.971577 -20607.792134    -27.405303
P  3  24201.815182  10045.668286   5052.841699     33.148493
P  4  -6412.311368 -22235.455044 -12735.607651    -40.584941
P  5 -22680.620780  13586.415383  -1388.851102     -3.785295
P  6  -5811.790175  14844.089356 -21038.623449    817.072062
P  7 -13867.366021 -19473.268152  12146.615978    325.497109
P  8   -670.425941 -25577.935959   6159.703408    -40.985868
P  9 -13953.404917  11709.550237  18697.537559     -7.355231
P 10 -22267.890613  -1302.603937 -14715.287650     69.939395
P 11  14320.815542 -12394.716264  18510.731295    263.982985
P 13   3314.724190 -15242.393413 -21582.961025     13.207181
P 14  14330.333429  19535.617975  10989.548575    -26.534457
P 15    835.339360  25219.029106   7510.432413    487.587504
P 16  19679.067678   4426.362061 -17234.495018      8.429258
P 18 -10777.146479  17139.371519  17114.396130   -186.546267
P 19  21295.762185   3115.522865  15680.372205    -25.997259
P 20  22270.349199 -13744.099186  -4580.778775    -48.906000
P 21  -6685.667542  25068.832075  -4223.326651    128.388738
P 22   2458.823342  15375.067491  21675.498008     39.138991
P 23  14673.643018  -7354.528443 -21010.662568    175.380241
P 24   4413.782774 -26079.484366    577.417520     45.675778
P 25  10535.360681  18849.781734 -15027.161637    102.970550
P 26 -22350.355937  -5848.490888  13264.721827      8.655874
P 27   4337.180267 -25464.783569  -4622.765418     14.700903
P 28   -334.122474 -16101.513173  21313.254593     41.956695
EOF
```

APPENDIX 6

Table 3.5 Satellite position at 11^{th} September 2005

Epoch	Satellite	X, meters	Y, meters	Z, meters
7200	PRN07	-2667013.6421	-1634346.471	2122022.314
	PRN11	1773323.071	1201427.615	1975032.388
	PRN14	3475114.082	1547234.366	2136875.640
	PRN19	2554423.721	7291857.807	3839515.919
	PRN20	2118080.854	-1068524.121	1185068.493
	PRN24	6381471.152	-2038798.778	1591478.596
	PRN28	9891529.219	-2174520.877	1148499.554
10800	PRN01	7389890.739	1420181.858	2138825.659
	PRN07	6763469.410	-1584543.840	2061958.670
	PRN11	2111982.501	8438513.936	1385048.481
	PRN14	-6387074.915	1441870.854	2141852.855
	PRN20	1755263.880	-4243164.086	1939170.078
	PRN23	2662710.442	-5746983.745	4849655.651
	PRN24	9982240.271	-1264357.720	2134482.653
	PRN25	7359497.613	2307892.889	1119382.664
14400	PRN01	-2379101.641	1548224.995	2162934.821
	PRN04	3694915.928	-1658005.323	2032242.336
	PRN07	1470288.127	-1686436.013	1464640.325
	PRN11	2318594.024	1247512.716	4243814.353
	PRN20	1442951.076	4902914.927	2167220.948
	PRN23	2403008.675	8520715.301	1133921.784
	PRN24	1573986.768	-4847841.723	2113600.873
	PRN25	1978873.685	1879639.108	1902156.341
18000	PRN01	-1052682.542	1842394.909	1613382.217
	PRN04	1160116.796	-1086491.983	2130823.076
	PRN07	1913115.975	-1779110.220	4808930.602
	PRN20	1322757.882	1418207.634	1807178.480
	PRN23	1780850.809	4469387.444	1914305.582
	PRN24	2192379.599	7148509.916	1537411.056
	PRN25	-6144070.174	1437219.462	2186508.897
21600	PRN04	1963500.049	-7176979.608	1656625.456
	PRN13	1799473.942	-2084432.543	1943755.250
	PRN16	-3116002.521	2263037.751	1356615.494
	PRN20	1350823.390	2073789.699	9573909.882
	PRN23	1053315.458	1077635.731	2176774.799
	PRN24	2590918.684	3398939.063	5570719.081
	PRN27	2632285.660	4919462.677	6169831.173
25200	PRN04	2506008.787	-5634088.032	7411797.946
	PRN06	-1256807.107	-1009557.591	2129859.602
	PRN10	3543800.695	-1847797.585	1855120.638
	PRN13	1234339.105	7736452.981	2213285.281
	PRN16	-6936651.009	1572485.658	2030990.386
	PRN23	4763175.956	1831755.101	1847333.798
	PRN27	2378953.791	5812021.033	1132950.532
28800	PRN02	2118435.095	-1303584.919	8821043.508
	PRN08	2460518.520	7929548.349	1029112.108
	PRN10	9718226.987	-1121516.289	2194686.973
	PRN13	8611933.413	1657986.512	1882401.482
	PRN16	-1318345.818	8273954.671	2160906.405
	PRN23	1641069.638	2437502.409	1014091.833

Table 3.5 (continued)

	PRN27	1741509.011	7966274.412	1913086.431
32400	PRN08	1859053.103	3988811.162	1853742.835
	PRN10	1739346.373	-5314610.139	1938669.862
	PRN13	7266069.964	2332138.784	1042108.766
	PRN21	-9349062.422	-1252502.328	2152473.511
	PRN26	8334017.986	-2097651.174	1314832.490
	PRN27	9454315.787	1243426.675	2205137.840
	PRN28	2333946.622	1306334.092	2730579.458
	PRN29	1074066.487	-1705729.232	1743399.622
36000	PRN08	1117395.954	9957043.282	2178188.346
	PRN10	2391013.508	-2121611.959	1161297.051
	PRN19	-9744026.956	1600515.220	1893067.631
	PRN21	-1535575.693	-1804150.741	1929250.583
	PRN26	1017948.893	-1303859.412	2027110.051
	PRN27	2488783.368	1849057.523	1931802.086
	PRN28	2064847.936	1305247.226	1108110.310
	PRN29	1271618.473	-8255608.367	2203387.695
39600	PRN08	5013502.008	1745683.632	1907313.808
	PRN10	2669204.525	-9896933.094	7417092.898
	PRN18	-2672253.659	-1519536.311	2171773.700
	PRN19	-1344253.375	7328992.644	2181343.001
	PRN26	1438883.612	-3849329.816	2169433.134
	PRN27	-1880140.498	2390056.227	115479.329
	PRN28	1380162.962	1299189.689	1898843.059
	PRN29	1685813.570	5783432.915	2081533.523
43200	PRN08	1500069.373	2380330.806	1110163.675
	PRN18	6943676.748	-1617062.777	1988267.951
	PRN22	-6821518.621	-1398947.415	2168089.112
	PRN26	1996247.448	3553366.932	1711351.273
	PRN28	4621818.012	1463840.855	2192462.398
	PRN29	2167925.797	6888332.252	1412613.026

APPENDIX 7

Table 3.6 Satellite position at 29^{th} September 2005

Epoch	Satellite	X, meters	Y, meters	Z, meters
352800	PRN01	5164473.932	1429367.716	2197594.199
	PRN04	-9234055.427	-2125233.531	1567313.169
	PRN07	8515166.469	-1601092.588	1979935.468
	PRN11	2180231.157	9616533.089	1191248.599
	PRN14	-8583093.304	1447217.898	2059473.079
	PRN20	1670091.353	-2208872.374	2045135.634
	PRN23	2643855.319	-2951726.383	3161981.688
	PRN24	1109700.942	-1084246.238	2179978.939
356400	PRN01	-4487264.812	1605086.330	2085777.067
	PRN04	5293254.076	-1521797.142	2104676.901
	PRN07	1584447.535	-1722760.112	1286358.774
	PRN11	2326551.439	1292534.182	1804039.662
	PRN20	1394643.818	7228963.854	2133879.823
	PRN23	2281217.538	1494454.164	1354658.010
	PRN24	1716129.893	-3400521.939	2030074.619
	PRN30	-1570560.403	3118968.978	2090688.276
360000	PRN02	-1520115.715	-1665046.520	2039257.967
	PRN04	1346811.097	-9857111.623	2071767.249
	PRN13	2229044.303	-4322933.623	1365933.493
	PRN16	-1967545.113	2577077.672	6017905.165
	PRN20	1318329.546	1609545.368	1643764.732
	PRN23	1607680.398	5755500.651	2028325.765
	PRN24	2309483.163	1501177.995	1347038.366
363600	PRN02	7963629.717	-1376839.823	2097180.056
	PRN04	2114939.205	-6715974.373	1483121.940
	PRN13	1662699.837	1394682.177	2057489.613
	PRN20	1354815.374	2170043.698	7084807.919
	PRN23	8944550.442	1253515.484	2152649.547
	PRN24	2626681.943	3650972.054	3096524.809
	PRN27	2619902.539	4971896.982	2976536.142
367200	PRN02	1675713.797	-1283381.359	1575262.277
	PRN04	2569067.735	-5485496.796	5000910.319
	PRN06	-1165679.061	-1196203.940	2083239.559
	PRN08	2669869.901	-2373329.682	1823616.307
	PRN10	4559556.437	-1698325.522	1973813.555
	PRN13	1126061.776	9783389.109	2190486.107
	PRN16	-8433854.248	1370477.621	2119631.290
	PRN23	3751774.446	1998263.191	1691181.259
	PRN27	2273946.101	5988191.458	1329026.336
370800	PRN02	2217093.619	-1295870.512	6183119.291
	PRN08	2354125.890	1230216.928	1244607.748
	PRN10	1124890.878	-9838075.076	2189893.900
	PRN13	8104365.542	1841151.372	1729554.295
	PRN16	-1504747.839	6495601.572	2099384.973
	PRN27	1582656.910	8629298.949	2019653.518
374400	PRN08	1697934.118	5051883.839	1974381.409
	PRN10	1894320.860	-4493267.081	1812843.000
	PRN13	7153974.584	2429782.752	8009122.785
	PRN21	-7231289.632	-1380628.951	2151527.801
	PRN26	8638817.770	-1934131.266	1528315.139

Table 3.6 (continued)

	PRN27	7900068.047	1359109.475	2195057.911
	PRN28	2309580.022	1322524.511	2900005.842
	PRN29	1099572.676	-1519684.541	1896611.233
378000	PRN08	9645974.391	1154489.047	2169890.024
	PRN10	2486480.099	-1874297.774	9492418.886
	PRN19	-1028081.096	1425662.068	2001733.114
	PRN21	1048467.479	-1945234.509	1788875.809
	PRN26	1099829.478	-1080371.370	2117253.680
	PRN27	1430919.347	1976342.393	1806284.433
	PRN28	1936956.323	1299076.146	1326874.483
	PRN29	1349607.733	-6116573.989	2228585.159
381600	PRN08	4029283.826	1905624.572	1770863.455
	PRN10	2665864.884	-9427944.350	-1671880.527
	PRN18	-2759214.725	-1525854.978	2181592.762
	PRN19	-1447202.382	5565593.429	2167431.567
	PRN26	1566921.656	-1776555.297	2112604.242
	PRN28	1176298.209	1320434.079	2016628.749
	PRN29	1798084.354	2326190.750	1973036.741
385200	PRN07	1516388.807	1985696.542	9634191.949
	PRN09	1399396.532	-1373075.216	1724910.068
	PRN18	9027470.295	-1662236.066	1860696.876
	PRN22	-4719457.200	-1460533.166	2183676.121
	PRN26	2121273.800	4899514.399	1526088.873
	PRN28	2430630.955	1532431.472	2177977.617
	PRN29	2260513.232	7853641.064	1199156.320
388800	PRN05	2236817.807	-1226044.877	6893858.759
	PRN07	9271616.222	1774386.403	1794996.129
	PRN09	1454121.718	-4270804.808	2127085.701
	PRN11	-1560682.509	5505127.163	2072629.541
	PRN18	1550034.820	-1875463.774	1037254.105
	PRN22	3915839.817	-1833249.221	1897441.354
	PRN26	2500881.645	8062789.196	5285675.936
	PRN28	-5813255.583	1906046.246	1763905.265
	PRN29	2472185.093	9981045.549	1095141.590

APPENDIX 8

Table 3.9 Precise satellite position at 11th September 2005 of GPS satellites

Epoch	Satellite	X, meters	Y, meters	Z, meters
		RINEX-SP3	RINEX-SP3	RINEX-SP3
7200	PRN07	-0.001240	-0.000152	-0.000854
	PRN11	-0.000784	-0.001310	-0.000980
	PRN14	-0.000777	-0.001192	-0.001337
	PRN19	0.000205	-0.000279	-0.002874
	PRN20	-0.001154	-0.000802	-0.001864
	PRN24	-0.000745	-0.000747	-0.001345
	PRN28	0.000291	0.000474	-0.002616
10800	PRN01	0,002723	-0,001486	-0,002002
	PRN07	-0.001953	-0.000190	0.000002
	PRN11	-0.000702	-0.001557	-0.000489
	PRN14	-0.000436	-0.001027	-0.001892
	PRN20	-0.000399	-0.001096	-0.001859
	PRN23	0,000234	0,000522	0,001643
	PRN24	-0,000414	-0,000930	-0,001025
	PRN25	-0,001394	-0,001395	0,000590
14400	PRN01	0.002608	-0.001090	-0.000957
	PRN04	-0.000538	0.000065	-0.000401
	PRN07	-0.001942	-0.000123	0.001105
	PRN11	-0.000668	-0.001512	-0.000320
	PRN20	0.000191	-0.001742	-0.001617
	PRN23	-0.000452	0.000993	0.001085
	PRN24	-0.001121	-0.002082	-0.000637
	PRN25	-0.001507	-0.001873	-0.000019
18000	PRN01	0,002109	-0,000599	-0,000411
	PRN04	-0,000792	0,000277	-0,000181
	PRN07	-0,001947	-0,000670	0,002513
	PRN20	0.000504	-0.002236	-0.001004
	PRN23	-0.000514	0.001389	-0.000005
	PRN24	-0.001310	-0.002070	0.000157
	PRN25	-0,001453	-0,002055	-0,000962
21600	PRN04	-0,001565	-0,000026	0,000568
	PRN13	-0.000508	-0.000165	-0.001476
	PRN16	0.001693	-0.001858	-0.000204
	PRN20	0.000566	-0.002217	-0.000336
	PRN23	-0.000793	0.002240	-0.000951
	PRN24	-0,001136	-0,001039	-0,000050
	PRN27	-0,001613	0,000612	0,000807
25200	PRN04	-0,006667	-0,003484	0,007743
	PRN06	0,001565	-0,000361	-0,000397
	PRN10	-0,001138	-0,000252	-0,001342
	PRN13	0,000395	-0,000473	-0,001870
	PRN16	0,001410	-0,001788	-0,000639
	PRN23	-0,000648	0,002162	-0,002387
	PRN27	-0,001836	0,000402	0,000211
28800	PRN02	0.000104	-0.000040	-0.000673
	PRN08	-0.002071	0.001274	0.000879
	PRN10	-0.001837	-0.001151	-0.001369
	PRN13	0.001218	-0.001428	-0.001507
	PRN16	0.001270	-0.001131	-0.001113

Table 3.9 (continued)

	PRN23	0,000437	-0,000142	-0,000303
	PRN27	-0,002248	0,000686	-0,000174
32400	PRN08	-0,002242	0,001449	-0,000232
	PRN10	-0,001652	-0,000967	-0,000919
	PRN13	-0,000087	-0,001435	-0,001075
	PRN21	0,001206	0,000581	-0,001017
	PRN26	-0,000775	0,000119	-0,001278
	PRN27	-0,002158	0,000568	-0,000993
	PRN28	-0,001154	-0,001480	0,000370
	PRN29	-0,001092	-0,000062	-0,001491
36000	PRN08	-0,002110	0,001667	-0,001324
	PRN10	-0,001480	-0,000716	-0,000687
	PRN19	-0,000870	-0,002183	0,000828
	PRN21	0,000754	0,000887	-0,001302
	PRN26	-0,000490	-0,000411	-0,001389
	PRN27	-0,001888	0,000265	-0,001754
	PRN28	-0,001422	-0,001109	-0,000168
	PRN29	-0,000796	-0,000200	-0,001287
39600	PRN08	-0,001903	0,001617	-0,002592
	PRN10	-0,001536	-0,000418	-0,000037
	PRN18	-0,001650	0,001549	-0,000887
	PRN19	-0,001749	-0,002132	-0,000675
	PRN26	-0,000049	-0,000247	-0,001330
	PRN27	-0,001139	-0,000344	-0,002115
	PRN28	-0,001359	-0,000587	-0,001019
	PRN29	-0,000770	-0,000554	-0,001002
43200	PRN08	-0,001190	0,000426	-0,003106
	PRN18	-0,001405	0,001539	-0,000404
	PRN22	-0,001119	0,001149	0,000386
	PRN26	-0,000596	-0,002142	-0,000500
	PRN28	-0,000788	-0,000206	-0,001660
	PRN29	-0,000804	-0,000984	-0,000561

APPENDIX 9

Table 3.10 Precise satellite position at 11th September 2005 for GLONASS satellite

Epoch	Satellite	X, meters	Y, meters	Z, meters
		RINEX-SP3	RINEX-SP3	RINEX-SP3
8100	PRN05	-15,04170	24,137770	-33,50889
	PRN06	-24,96278	32,947342	1,646365
	PEN21	9,731435	-1,220365	-45,17007
	PRN22	34,512995	2,443713	-25,03689
	PRN23	39,508357	4,792194	11,429832
11700	PRN06	-12,34536	33,612837	-23,42839
	PRN08	-9,848248	20,269540	38,898425
	PRN22	17,090978	-4,781105	-41,97057
	PRN23	38,548661	-6,764013	-14,17040
15300	PRN06	-0,316771	19,385589	-41,26598
	PRN08	-4,814896	36,942932	19,548721
	PRN22	-5,194708	-0,171722	-46,16967
	PRN24	37,127195	-16,80035	-4,902317
18900	PRN01	3,804249	32,533542	28,065280
	PRN08	6,733618	40,191065	-5,741108
	PRN17	31,758603	-25,45862	5,532196
	PRN23	3,192319	-5,447300	-46,04053
	PRN24	24,227197	-21,37040	-28,58648
22500	PRN01	16,551643	37,419593	4,196654
	PRN08	14,369351	28,505602	-29,30640
	PRN17	21,014414	-30,59741	-19,70470
	PRN24	6,584596	-12,54099	-43,60068
26100	PRN01	23,980584	27,789838	-20,98581
	PRN02	23,867387	31,428120	13,997141
	PRN08	10,109549	8,969925	-43,98347
	PRN17	6,236297	-21,44856	-38,95086
	PRN18	14,683223	-37,86583	4,417737
29700	PRN01	18,409236	10,881264	-39,81219
	PRN02	32,426502	23,483634	-11,83752
	PRN18	2,801875	-36,53704	-20,63015
33300	PRN01	0,249005	-2,306967	-46,52678
	PRN02	26,938837	8,915796	-34,02639
	PRN03	38,511841	13,820489	-0,110991
36900	PRN02	8,239572	-1,345020	-45,724543
	PRN03	34,699776	1,726727	-24,660257
	PRN04	40,286625	5,123882	8,838313
40500	PRN03	17,313286	-5,051728	-41,80867
	PRN04	38,014891	-6,462670	-16,88192
	PRN21	-26,02501	-31,55524	-3,448077
	PRN22	-18,85307	-25,36498	29,691416
44100	PRN03	-4,828439	0,060071	-46,25933
	PRN04	21,922501	-11,55381	-37,37620
	PRN05	36,752819	-17,71323	-4,708064
	PRN22	-32,85338	-23,97007	6,268017
	PRN23	-18,21071	-15,40673	37,850345

APPENDIX 10

Table 3.11 Precise satellite position at 29^{th} September 2005 for GPS satellites

Epoch	Satellite	X, meters	Y, meters	Z, meters
		RINEX-SP3	RINEX-SP3	RINEX-SP3
352800	PRN01	0,002213	-0,000837	-0,002073
	PRN04	0,001866	0,000758	0,000074
	PRN07	-0,000954	0,000520	0,000285
	PRN11	-0,001462	0,000149	-0,000537
	PRN14	0,000828	-0,001388	-0,000923
	PRN20	-0,000619	-0,000937	-0,001369
	PRN23	0,000368	0,000558	-0,000643
	PRN24	-0,000847	-0,001683	-0,000860
356400	PRN01	0,001686	-0,001217	-0,001060
	PRN04	0,001620	0,001351	-0,000103
	PRN07	-0,001426	0,000411	0,001656
	PRN11	-0,001453	-0,000078	-0,000021
	PRN20	-0,000871	-0,001420	-0,000760
	PRN23	0,000771	0,000283	-0,000987
	PRN24	-0,001179	-0,001283	-0,000376
	PRN30	0,001105	0,000170	-0,000450
360000	PRN02	-0,000243	-0,000229	0,000210
	PRN04	0,000329	0,001366	-0,000337
	PRN13	-0,000325	-0,000858	-0,002275
	PRN16	-0,035345	0,055035	-0,022757
	PRN20	-0,001158	-0,001476	-0,000119
	PRN23	0,000685	0,000431	-0,000634
	PRN24	-0,001666	-0,000961	0,000121
363600	PRN02	-0,000329	-0,000222	0,000398
	PRN04	-0,000135	0,002041	-0,000302
	PRN13	0,000405	-0,001627	-0,002047
	PRN20	-0,001191	-0,001403	0,000489
	PRN23	0,000535	0,000240	-0,000532
	PRN24	-0,001864	-0,000579	0,000898
	PRN27	-0,000758	-0,000371	-0,002423
367200	PRN02	-0,000770	-0,000507	0,000945
	PRN04	-0,000532	0,002381	-0,000093
	PRN06	0,001036	0,001038	0,000597
	PRN08	-0,000806	0,000766	-0,001666
	PRN10	-0,002318	-0,000659	-0,001357
	PRN13	0,000679	-0,002250	-0,001215
	PRN16	0,001485	-0,001221	-0,000904
	PRN23	0,000330	-0,000188	-0,000208
	PRN27	0,000222	-0,000467	-0,002459
370800	PRN02	-0,000264	-0,000521	0,000918
	PRN08	-0,000211	0,000389	-0,002063
	PRN10	-0,002044	-0,000163	-0,000731
	PRN13	0,000476	-0,002400	-0,000221
	PRN16	0,001610	-0,000959	-0,000703
	PRN27	0,000798	-0,000605	-0,001916
374400	PRN08	0,000030	0,000029	-0,001777
	PRN10	-0,002006	-0,000081	-0,000383

Table 3.11 (continued)

	PRN13	0,000481	-0,002433	0,001051
	PRN21	0,002153	0,000108	-0,001032
	PRN26	-0,000894	-0,000335	-0,001490
	PRN27	0,000910	-0,000905	-0,001237
	PRN28	-0,001666	-0,000230	-0,000249
	PRN29	-0,003111	-0,004852	-0,002838
378000	PRN08	-0,000044	-0,000495	-0,001427
	PRN10	-0,001643	0,000279	-0,000311
	PRN19	-0,000505	-0,001327	0,000401
	PRN21	0,001170	0,001228	-0,000877
	PRN26	-0,000458	-0,000167	-0,001293
	PRN27	0,001175	-0,001355	-0,000240
	PRN28	-0,001326	-0,000075	-0,001190
	PRN29	-0,003143	-0,005695	-0,000263
381600	PRN08	-0,000561	-0,000789	-0,000998
	PRN10	-0,001483	0,000194	0,000015
	PRN18	0,000309	0,001325	-0,001117
	PRN19	-0,000596	-0,001234	-0,000317
	PRN26	-0,000739	-0,001050	-0,00118
	PRN28	-0,000931	0,000030	-0,00154
	PRN29	-0,002626	-0,005791	0,002565
385200	PRN07	-0,001869	0,000049	-0,000112
	PRN09	-0,000395	-0,000671	-0,001660
	PRN18	-0,000278	0,001722	-0,000918
	PRN22	-0,001180	0,001446	0,000682
	PRN26	-0,000694	-0,000630	-0,001289
	PRN28	-0,000341	-0,000165	-0,001729
	PRN29	-0,001128	-0,005462	0,005148
388800	PRN05	0,000123	0,003845	0,001248
	PRN07	-0,001288	0,000127	-0,000903
	PRN09	-0,000984	-0,001952	-0,001111
	PRN11	0,001284	-0,000741	-0,000839
	PRN18	-0,000134	0,002046	-0,000765
	PRN22	-0,000280	0,001237	0,001145
	PRN26	-0,000896	-0,001220	-0,000627
	PRN28	0,000103	-0,000645	-0,001346
	PRN29	0,001376	-0,004469	0,005979

APPENDIX 11

Table 3.12 Precise satellite position at 29th September 2005 for GLONASS satellite

Epoch	Satellite	X, meters	Y, meters	Z, meters
		RINEX-SP3	RINEX-SP3	RINEX-SP3
353700	PRN01	-12,58554	38,992095	3,273055
	PRN02	-10,41944	25,445848	34,830529
	PRN08	-8,116938	30,347145	-29,98600
	PRN24	12,493191	-4,802784	-43,91756
357300	PRN01	-0,605917	36,318267	-21,80115
	PRN02	-3,130803	39,571203	13,080942
	PRN08	1,587286	12,675358	-44,25426
	PRN18	36,239303	-18,49707	3,596850
360900	PRN01	6,320377	19,691155	-40,27342
	PRN02	8,503147	38,879704	-12,75020
	PRN03	7,066131	34,454647	23,590492
	PRN18	26,189402	-25,17170	-21,37435
364500	PRN02	13,870558	24,030924	-34,65155
	PRN03	19,519452	35,937818	-1,033919
	PRN04	12,375356	28,246370	31,105602
	PRN18	9,773061	-18,51600	-40,02522
368100	PRN02	6,488062	3,876280	-45,87269
	PRN03	24,419608	24,076802	-25,43009
	PRN04	26,744850	30,755562	7,884134
371700	PRN03	15,634971	7,388605	-42,19001
	PRN04	32,387492	20,315406	-17,77255
	PRN05	31,215077	20,120138	19,632516
	PRN21	1,599396	-40,81674	-4,377054
375300	PRN03	-4,427553	-3,379533	-46,13414
	PRN04	23,386157	5,770807	-37,92885
	PRN05	39,117489	11,231772	-5,603154
	PRN23	-3,469106	-24,26328	37,319416
378900	PRN05	31,936964	-0,571027	-29,16580
	PRN06	40,701985	2,765777	7,677890
	PRN23	-16,91211	-34,27405	17,034849
	PRN24	-6,279554	-16,20844	42,100484
382500	PRN05	12,575948	-5,094128	-43,88487
	PRN06	37,222695	-8,579251	-17,99706
	PRN17	-4,230015	-7,663045	45,412746
	PRN23	-27,63671	-29,48310	-8,454104
	PRN24	-22,39106	-16,20844	42,100484
386100	PRN06	20,485328	-12,38289	-38,12358
	PRN17	-23,22877	-16,51556	33,426072
	PRN24	-34,60247	-21,96070	0,928982
389700	PRN08	30,145509	-27,87755	0,151833
	PRN18	-8,412394	-4,947973	44,945531
	PRN24	-33,93156	-9,417263	-23,77529