CHAPTER 1 *INTRODUCTION*

1.1 The problem and its precedents

The earth's surface is affected by numerous movements and deformations that are, between others: tectonic and fault movements, earthquakes and volcanism induced changes, ground erosion and other geodynamic phenomena, landsliding, subsidences, etcetera. A convenient method to follow these phenomena is the monitoring of the ground and water pressures, and also of the displacements.

In the geomatic study of such problems, the relative movement of a point respect to others is obtained through the measurement of angles, distances, elevations and their variation along the time. To describe the movement of a body, we need the position of several points in a well-defined time epochs, expressed in a certain reference system (i.e. x, y, z) defined with the aid of other points inner or external to the body, however connected with this through precise geometric relations. When monitoring certain phenomena or several features spread on the territory, the measurements are done with different frequencies that depend on the rate of the movement and the potential risk that they represent.

The nature of the movement and, especially, of the attended deformation, can ask for an elevated number of points to follow the evolution of the changes along the time. Usually, these points are linked through closed figures, called nets or networks. The shape of the net can be different as long as the observables (measurements) remain greater than the number of unknown quantities (the spatial coordinates of the measured points). In this way, in fact, it is possible to perform a compensation (or adjustment) of the raw measurements, in order to identify gross errors and to minimize the random ones. Otherwise, such errors could introduce errors in the results and induce to a bad interpretation of the behaviour.

Recently, the GPS technique is being used more and more to monitor the behaviour of wide areas (Gili et al, 2000). The reason is that this system can cover huge extensions (from a county to a whole continent) with a reasonable effort, giving the results coordinate variations) with a convenient level of accuracy (ranging from several millimetres to few centimeters), well balanced in the three axes.

The present '*tesina'* (final degree work) describes the application of the GPS system to the monitoring of network that has been built within the '*Comarca del Bages*' (county or sub region in the central part of Catalonia, Spain). This area, named *Conca Potàssica Catalana* (Potassic Salt Catalan Basin) is affected by a set of subsidence processes caused by precedent intensive mining exploitation. Although now is under recession, the potash salts have been traditionally exploited since ancient times, being still the most important mining activity in Catalonia. Balsareny, Cardona, Sallent and Súria are the main towns in the Bages area with mining activities.

The collapses and the subsidence problem that arose in the last decade of the XX century explain the realization of many technical studies in the Bages area. Firstly, the I.C.C. (Institut Cartogràfic de Catalunya), and later the I.G.C. (Institut Geològic de Catalunya) with the help of local authorities (municipalities), have been working to investigate these phenomena. In the most active areas, several local networks have been established. For example, in Sallent several techniques have been applied, ranging from precision levelling and Automatic Total Station (see Prats, 2008, for a recent overview), up to Ground Based SAR (described in Pipia et al., 2007 &2008 among others). Also in Súria and Cardona local GPS networks have been installed and observed since 1997 (UPC-DETCG, 2007).

The spread of the movements in the Bages county (along an area of about 40 Km in the East-Weast, and around 25 Km North-South) lead to consider the possible correlation of the problem with the geologic formation in deep (the potassic salts underground). To assess the risk of a generalized movement, or to discard it, under the leadership of the IGC and with the help of the UPC, a medium GPS network has been proposed and established in the last part of 2007 (UPC-DETCG, 2007b). The network is named "*Xarxa de la Conca Potàssica Catalana* (Potassic Salt Network), or "CK network" in short. The first GPS field campaign has been carried out in December 2007.

1.2 Aims of this work

In this previous context, this '*tesina'* , after the general study of the problem and of the area, has been devoted to establish the 'best processing' of the GPS field data.
To achieve this general goal, the original collected RINEX GPS files have been processed following different strategies and using two softwares: one scientific, the *Bernese GPS Software* and one commercial, the *Trimble Geomatics Office*. Obviously, the basis of each program has had to be gained in advance. Finally, the results of the processing with the different strategies and parameters have been compared, along with the advantages and drawbacks of each option. The conclusions of the present 'tesina' will be taken into account in the future work in that area.

1.3 **Overview and contents of the report**

We explain at the beginning (Chapter 2) the geological situation of the area and the localization of the zone affected by the subsidence movement. Next Chapter address the techniques used in mining monitoring, introducing the GPS system, and giving the general reader a summary description of the technique. After that, in the Chapter 4, the CK network is briefly described, along with the field and processing procedure to be used. The next chapter is devoted to the actual processing of the December 2007 campaign with the BERNESE and with the TGO softwares. There is a description of the model and parameters used to process the field data and to adjust the network. The results are compared at the end, leading to the last Chapter (#6), where several conclusions are highlighted.

CHAPTER 2 *GEOLOGICAL CONTEXT OF THE PROBLEM*

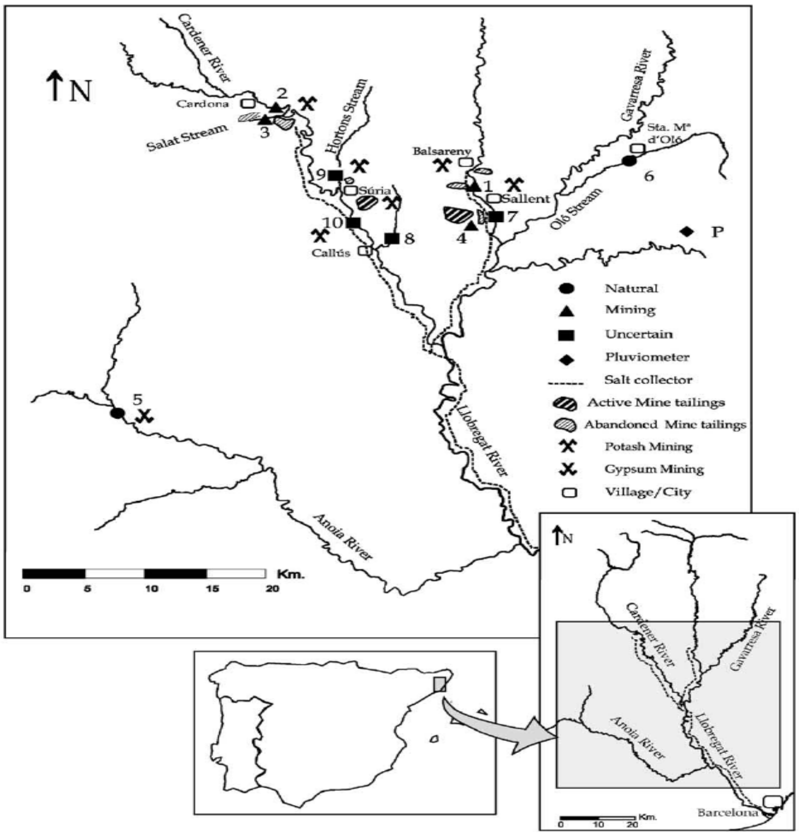
2.1 Geographical situation of the area

Catalonia is an autonomous community of Spain. The country displays a notable geographical diversity on a relatively reduced area of about 32.000 km^2. It borders France and Andorra to the north, Aragon to the west, the Valencian community to the south, and the Mediterranean sea to the east (580 km coastline). The capital city is Barcelona. Catalonia is organized into four '*provinces*' (Barcelona, Tarragona, Lleida and Girona); this subdivision overlaps with the one used by the Catalan Administration into 41 '*comarcas*' (regions).

The largest comarca within the Barcelona province is the Bages, situated to the west of the province (figure 1). It is a mountainous area away from the coast, dotted with villages, farmhouses and small towns. The capital of the region is the town of Manresa, surrounded by mountains including the Sant Llorenç del Munt and the Montserrat natural parks.

The Bages is the most important region of Spain in potash mining, accounting for about three quarters of the Spanish production of this mineral. The main extractive shafts are located along the Cardener river in Cardona (until 1990) and Suria; and in Sallent-Balsareny, along the Llobregat river (see figure 2). The mining of potash began in the 1920's in the Cardener valley, and in the 1930's in the Llobregat.

<u>Figure 1</u>: the Bages Comarca, in the west part of the Barcelona Province, within the Catalonia autonomic region of Spain, (from the web site: http://www.property-net-spain.com/provinces/barcelona/)



<u>Figure 2</u> : Llobregat River Basin, showing major tributaries and sample location. (from the article:"Sulphur isotopes as tracers of the influence of potash mining in groundwater salinisation in the Llobregat Basin (NE Spain)", N.Otero et al., 2002).

2.2 Extension and Geology of the "Potash Basin" (CK)

Geographically and geologically, the Bages Comarca and the Conca Potàssica Catalana (Potash Basin, CK) belong to the Central Catalonian depression which is the eastern sector of the basin of the river Ebre. This low lands region borders on the mountain range of Pyrenees by the north, on the Catalonian Coastal range by the east and on the Iberian range by the south-west. The study of the rocks that emerged to the surface of the Bages Comarca reveals their conditions and dates of origin. In a geological point of view, the rocks in Bages are not too ancient. Most of them belong to the Tertiary period and some to the Quaternary.

The Conca Potàssica Catalana is made of a great saline unit. The potash salts were traditionally exploited since ancient times, being still an important mining activity in Catalonia. The Enrique mine, located in the city of Sallent, was under exploitation until 1974. This mine had a maximum depth of 260 metres and in 1954 a cavity of approx 120 meters high and 40 meters wide was found while mining works were being done. This cavity, caused by water circulation, is located under the South-East part of Sallent, in the neighbourhood known as 'Barri de l'Estació', close to the Llobregat River. Water floods in 1957 and 1962 forced to abandon this part of the mine, filling up the cavity with saturated salty water. During the 90s the strong subsidence caused damages in the structures of most of the buildings and some of them had to be demolished. The rest are still under continuous observation (Prats, 2008).

The mining sites that exist in the localities of Sallent, Suria, Balsareny and Cardona produce large salt mining tailings, which are stored around the mining sites, with no waterproofing. The potash mine tailings mainly consist of halite with minor amounts of sulphates (gypsum, polihalite and anhydrite) and are considered by law as a resource and not as waste, as halite can be reused for the chlorine industry. Some aquifers near the mining zones have much salinity. The origin of the salinity is controversial, as it can be related to natural water interaction with saline formations, or it could be due to contamination from mine tailing effluents. Fertilisers could also contribute to groundwater salinisation, as agriculture is an important economic activity in the Llobregat Basin.

In the middle section of the Llobregat River, besides the main flow, there are three tributaries, all of which have several evaporitic outcrops in their catchments.

The Cardona area is composed dominantly of halite, sylvite, carnallite and gypsum of Late Eocene age. Along the Llobregat River different sulphate formations outcrop: gypsum of Oligocene age, and both anhydrite and gypsum of Late Eocene age. These evaporite materials cause high natural values of salinity (14% in weight) in some of the small tributaries of the rivers. On the other hand, the salinity of the Llobregat River has increased significantly since the early 1920's due to the extensive development of potash and salt mining.

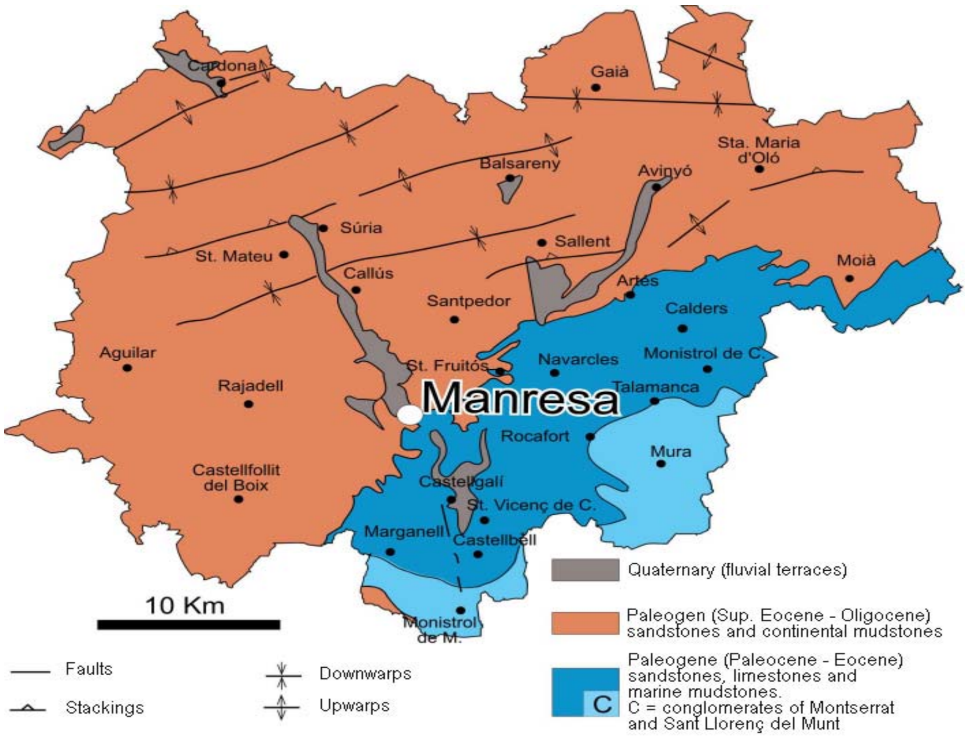


Figure 3 : Geological map of the district of Bages (Catalonia), from the web site: http://ichn.iec.cat/bages/hist-geologica/imatges.

2.3 Short history of salt mining and associated problems

Until 1980, the mines were all owned and operated by private capital. The Suria concession belonged to the Belgium-based multinational company Solvay, where as Cardona and Sallent-Balsareny were owned respectively by the Spanish companies, ‘Explosivos Rio Tinto’ and ‘Cros’. The 1980’s brought about several rounds of restructuring that ended in the closure of most of the Cardona site and the transfer to public owner ship of the other concessions. Thus, in 1985, Solvay sold the Suria mine to the publicly-owned ‘Instituto National de Industria’ (INI). In 1987, ‘Explosivos Rio Tinto’ and ‘Cros’ were purchased and merged by KIO (Kuwait Investment Office) adopting the name of ‘Ercros’. In turn, ‘Ercros’ was sold to the IN1 in 1991. Therefore, today all extractive activities in the area are owned and operated by a single, public company named ‘Potasas de1 Llobregat’ (renamed recently to ‘Iberpotash’).

It now seems likely that more and more of the miners will abandon Cardona and settle in Sallent-Balsareny or in other more accessible places such as the Bages capital, Manresa. Therefore, direct depopulation could affect about a fifth of the current population of Cardona, although indirect effects might be much greater due to the fact that those leaving the area are also those with the best paid jobs. Besides direct socioeconomic impacts on a number of small firms that did subcontracted work for the mine, other services such as retailing and commerce, and banking activities are experiencing losses and, in some cases, they have closed their operations. This situation is aggravated by the regressive demographic trends peculiar to this area and of the rest of the Bages as well leading towards an ageing population subsisting with retirement or welfare money. Overall, the future for Cardona looks quite problematic unless alternatives are found to redress the decline of the locality. The situation in the other extractive centers of the Bages area is perhaps less severe than in Cardona but steady curtailments in labour numbers are also under way.

On the other hand, the mine ‘Enrique’, in Sallent, exploited the potash between the years 1932 and 1974, at a medium depth of 260 meters. The method of exploitation was intensive, with the opening of chambers sustained by pillars. Already at its beginning, the mine suffered an entry of water due to the torrent of Soldevila. So, on the year 1954 and the following, were opened two galleries to intercept the course of water and to pump it, but with any results. The mining exploitation continued in direction north, leaving a border of protection that borders the Llobregat. In years 1957 and 1962, under the neighborhood of the Rampinya, the mine suffered both new entries of water; these probably related with the Llobregat. The difficulties in controlling these arrivals of water poured the mine Enrique into the closing in year 1973. The mine zone spreads to the right of the Llobregat, under the neighborhoods from the Estació and of the Rampinya, and in west direction going up the valley of Sant Antoni.

During the years there was some projects based on the measures of the movement due to the mining activities (i.e. Pipio, 2007 & 2008). This set of measurements does not indicate the occurrence of collapses or short-term collapses in the near future, like those that have happened in Cardona.

In Súria area the phenomena of subsidence and of formation of sinkholes can have also a natural origin in the sudden dissolution of the carnal·lita. The mineral carnal·lita-chloride of potassium and of hydrated magnesium is the most soluble salt in water of among those that constitute the geological formation of Cardona. In the course of the years, in Súria have been several episodes of sinkholes formation, due to the dissolution of the carnal·lita in the water. At the present, the only zone of sinkholes formations that is active in Súria is near the stream of the Tordell, at the exit of Súria for the neighborhood of Joncarets heading to Balsareny. This field zone is located in the left of the stream, luckily without houses.

At the geological complexity of Cardona, with the risk of collapses due to the dissolution of the carnal·lita for the presence of water, it is necessary to add the historical interferences of the mining activity.

In the basin of the Cardener we can found the first two waste dumps of Cardona, that are the new one in exploitation and the old one abandoned. More down, in Súria, there is the small waste dump of Cabanasses , that in 2004 was covered with earth, and the big one (and in fast growth) of 'the Fusteret' or 'of Súria'. In the valley of the Llobregat there are the two neglected waste dumps of Vilafruns (Balsareny) and of the Botjosa (Sallent); and the biggest and most visible of all of them, the mountain of waste that grows day by day, the waste dump of 'the Cogulló' or 'of Sallent' remain.

The estimate for the group of the waste dumps of the Bages was, when starting the year 2004, of about 70 million tons of saline residuals that is increased annually in 3 more million, accumulated in 100 hectares of land. The mining of the potash of the Bages, it alone, generates a mass of salt of equivalent rejection to the total of the urban residual or waste, or the group of all the industrial waste of Catalunya. These cause dangerous environmental impacts on the landscape and the waters, that is denounced by the civic Platform MontSalat (Montsalat, 2008).

CHAPTER 3 *MONITORING OF SURFACE DISPLACEMENTS INDUCED BY MINING*

3.1 Short review of real cases and techniques

The Earth's surface is subject to small but important displacements as subsidence, lateral movement, rotation, distortion, dilation, that affect elevation, horizontal position or both. Such movements may result from the active tectonic processes; collapse into underground cavities; compaction of superficial materials; seismically mass movement (e.g. liquefaction); volcanic activity; and swell behaviour of clays. Sudden movements may be caused by faulting associated with earthquakes and from the collapse of rock or sediment into natural holes in soluble rocks (e.g. salt, gypsum, limestone, or into cavities produced by extraction of near-surface mineral deposits by conventional (especially coal) or solution mining (especially salt).

Underground mining activities very often cause changes to the surface and causing a risk for people and infrastructure. The main risk is induced by sudden falls of the surface. In contrast to surface deformations induced by active mining these deformations are difficult to predict. The risk justifies the monitoring of ground movements in historical mining areas.

In the past, different surveying techniques have been used to monitoring the superficial movements of unstable areas. It is very frequent the use of levels, theodolites, electronic distance meter (EDM), and total stations measurements to obtain the coordinates, to control the points and landslide features (table 3.1).

Table 1: Main techniques used to monitor ground movements, according to Gili et al. (2000).

Method	Results	Typical range	Typical precision
Precision tape	Δdistance	< 30 m	0.5 mm/30 m
Fixed wire extensometer	Δdistance	< 10–80 m	0.3 mm/30 m
Rod for crack opening	Δdistance	< 5 m	0.5 mm
Offsets from baseline	ΔH, ΔV	< 100 m	0.5–3 mm
Surveying triangulation	ΔX, ΔY, ΔZ	< 300–1000 m	5–10 mm
Surveying traverses	ΔX, ΔY, ΔZ	Variable	5–10 mm
Geometrical levelling	ΔZ	Variable	2–5 mm/km
Precise geometrical levelling	ΔZ	Variable	0.2–1 mm/km
Electronic distance measurement (EDM)	Δdistance	Variable (usual 1–14 km)	1–5 mm + 1–5 ppm
Terrestrial photogrammetry	ΔX, ΔY, ΔZ	Ideally < 100 m	20 mm from 100 m
Aerial photogrammetry	ΔX, ΔY, ΔZ	$H_{flight} < 500$ m	10 cm
Clinometer	$\Delta \alpha$	$\pm 10°$	0.01–0.1°
GPS	ΔX, ΔY, ΔZ	Variable (usual < 20 km)	5–10 mm + 1–2 ppm

Aerial or terrestrial photogrammetry provides point coordinates contour maps and cross-sections of the landslides. Photogrammetric compilation enables a quantitative analysis of the change in slope morphology and also the determination of the movement vectors. During the last decade of the 20th century, GPS has increasingly become an indispensable tool for high precision positioning. Current GPS capabilities permit the determination of inter-receiver distances at the sub-cm accuracy level, for receiver separations of tens to hundreds of kilometres, from which can be inferred the rate-of change of distance between precisely monumental ground marks. This is the basic geodetic measure from which can be inferred the ground deformation. The pattern of ground subsidence due to mining, determined from the analysis of such measures across a GPS network, is an important input to models that seek to explain the mechanisms for such deformation, and hopefully to mitigate the damage to society caused by such (slow or fast) ground movements.

3.2 Monitoring of surface displacement with the GPS

Thanks to the use of the GPS system it is possible to monitoring the displacements of the surface with new procedure and methods, and to use advanced software to acquire the data and post processing the same.

The GPS permit to measure the coordinates, distances, or angles of a series of targets from fixed points selected as reference or base points. After that the difference between the value obtained and the previously coordinates values shows the movements of the target. The frequency of field survey is given (i.e. monthly, weekly) and the values obtained are discontinuous but related to the cumulative movements of surface points. Very interesting is the possibility to automate the monitoring of the displacements with the use of permanent GPS stations, or computer operated servo-total station. In the early 1980s the use of GPS precise application (static methods) was developed. Gervaise et al. (1985) wrote about the work with the GPS in a control network, the CERN Large Electron Positron (LEP) ring near Geneva. After a 3 days campaign, an overall RMS error of about 4 mm was obtained for a set of six baselines ranging from 3 to 13 km (i.e. about 0.5 ppm).

Bock et al. (1986) used the GPS for a set of baselines from 71 to 313 km, in California. The results were a repeatability of 3 to 10 parts in 108, or 0.03 to 0.1 ppm. After the comparison of the results with those of very long baseline interferometry (VLBI), the accuracy was established as 0.1 to 0.2 ppm. A network of a similar scale was built by Grellet et al. (1993) and Goula et al. (1996). In this case, to measure natural deformation in the range 1 mm/year/10 km for seismic risk assessment in the Eastern Pyrenees, a set of 24 fixed points were established. Also for longer baselines, better precision figures may be obtained, such as those used to measure crustal deformation (Larson and Agnew, 1991). Global baselines crossing the earth (about 12 750 km) can be measured with repeatabilities of 5 cm, i.e. 0.004 ppm (Rius et al., 1995). Very successfully is the use of the GPS system to establish control networks around open cuts, mining areas and gasfield exploitations (Joass, 1993). In instrumented landslides located in the Swiss Alps, Bonnard et al. (1996), with the simultaneously use of receivers, obtained a precision of about 1 cm. This precision is higher than that achieved perforusing ordinary surveying techniques of triangula- tion. Vaccaro (1998) additionally reports a six times saving in GPS surveying time in relation to the classical survey when monitoring a mudslide.

In the areas with crustal deformation or special tectonic activity (Moss et al., 1997) the GPS measurements are very important to assist the study and prediction of earthquake or volcanic eruption.

But the use of the GPS has also been improved to measure vertical movements, which are considered the less precise component for measuring. In Ashkenazi et al. (1994), the study of the vertical land displacements and mean sea level in Western Europe was carried out with the use of GPS network. Krijnen and de Heus (1995) and Augath and Strerath (1995) explain the use of GPS with subcentimetre accuracy for subsidence monitoring and coastal level changes.

On the other wise, the kinematic use of the GPS has been applied to monitor the deformations of a reservoir embankment (Collier, 1993) or the movement of a cable stayed bridge (Leach and Hyzak, 1992). In addition to that, designs and tests have been made to obtain continuous monitoring of offshore platforms, gas field areas (Flouzat et al., 1995) and dams (Hudnut and Behr, 1998), or to predict the possible movements in real time (or near real time) in order to avoid disasters in mining areas or due to gliding slopes or avalanches (Hein and Riedl, 1995).

3.2.1 Summary description of the GPS system

Global Navigation Satellite System (GNSS) is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. A GNSS allows small electronic receivers to determine their location (longitude, latitude, and altitude) to within a few meters using time signals transmitted along a line of sight by radio from satellites.

The Global Positioning System (GPS) is the only functional Global Navigation Satellite System (GNSS). The first applications for GPS were for national defence and GPS remains an essential part of national defence for both the United States and its allies. In parallel with its military uses, the GPS signal has become an essential element for many other applications.

Every satellite consists of three components:

- space segment;
- control segment;
- user segment.

The space segment consists of different types of GPS satellites. Each type is defined as a block. Every new block keeps improvements from the previous block and adds new functionally. The satellite transmits a number of coded messages called the Pseudo Random Noise code that are utilized by the receiver to determine the range between the satellite and the receivers. By now 30 GPS satellites are active, turning around the earth in a orbit at a height of 20240 Km. There are six orbits and at least four satellites per orbit, spaced 30°.Each orbit creates an angle with the equator of approximately 55 degrees. The responsible of the operational status of the space segment is the control segment. The Master control station near Colorado Spring (USA), five monitoring station and four uplink stations, make up this segment (see figure 3.2.1.2). The task of this station is to follow the satellites in their orbits and to predict these orbits for the near future. In addition to that the time synchronisation between the satellites is verified and correction messages are transmitted. The user segment consists of the GPS receiver equipment, which receives the signals from the GPS satellites and uses the transmitted information to calculate the user's three-dimensional position and time. In the GPS the satellites are a reference point and our receiver given the distance between the satellite and the receivers antenna. In particular are measured the travel time of a radio signal. After the multiplying of this by the speed of light a range measurement is obtained. Each GPS satellite transmits unique ranging code signals on two frequencies: 1575.42 MHz (L1) and 1227.60 MHz (L2). The Coarse Acquisition (C/A) code is transmitted on L1 and can be received by any type of GPS receiver. The C/A code consists of 1023 bits and is repeated every millisecond. The Precision (P-code) code is transmitted on L1 and L2. P-code is encrypted and available only to users with appropriate decryption equipment provided by the USA Department of Defence. The P-code is transmitted at 10.23 MHz and repeats every 267 days. Both codes are synchronized to the satellite's atomic clocks.

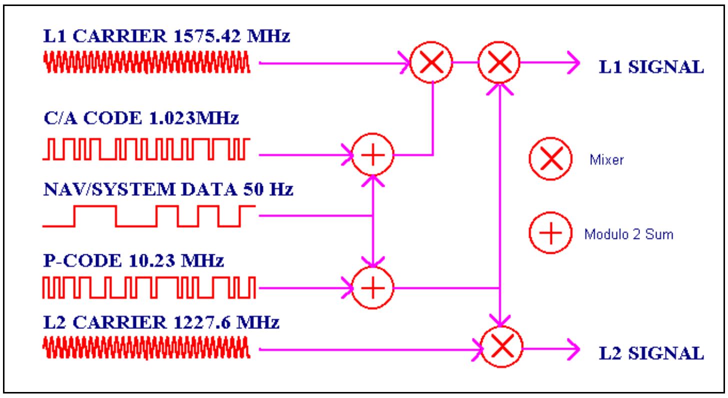


Figure 4 : structure of the GPS satellite signals according to P. Dana (http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

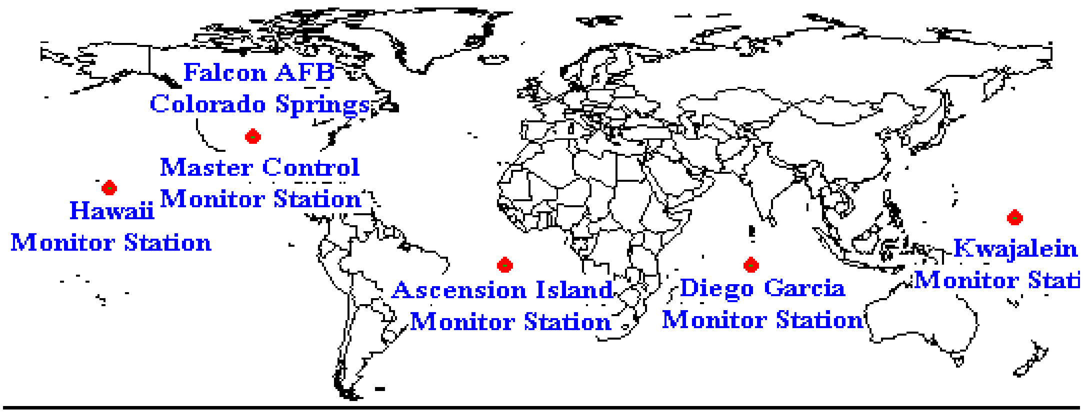


Figure 5 : Global Positioning System (GPS) Master Control and Monitor Station Network, according to P. Dana http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html)

There are two main types of measurements that can be made on the GPS signals:

• range observations based on the PRN codes, sometimes referred to as "code range" or "code phase";

• carrier phase observations, which are more precise range-type measurements, but which have a much higher degree of "ambiguity" than the code ranges.

GPS works by timing how long it takes coded radio signals to reach the earth from its satellites. A receiver does this by generating a set of codes that are identical to those being transmitted by the system’s satellites. It calculates the time delay between its codes and the codes received from the GPS satellites by determining how far it has to shift its own codes to match those transmitted by the satellites. This travel time is then multiplied by the speed of light to determine the receiver's distance to the satellites. A GPS receiver could, in theory, calculate its three dimensional position by measuring its distance from three different satellites, but in practice a fourth satellite is necessary because there is a timing offset between the clocks in a receiver and those in a satellite. The fourth measurement allows a receiver's computer to solve for the timing offset and eliminate it from the navigation solution.

GPS velocity measurements are made by taking the rate of change of pseudorange measurements over time. These pseudorange rate measurements are performed by noting the difference in phase measurements (i.e. the average Doppler frequency) over a given time interval.

GPS receivers maintain an 'almanac' stored in their computer, which is used to determine where each satellite will be in the sky at any given time. Each of the satellites passes over one of the five monitoring stations twice a day.

This provides the opportunity to precisely measure the altitude, position and speed of the satellites. Variations between the almanac and the actual satellite position are known as ephemeris errors. They are usually very minor and are caused by factors such as gravitational pull from the moon and sun and by the pressure of solar radiation falling on the satellites. Once a satellite's position is measured, that data is relayed back to the satellite which broadcasts the corrections, if any, along with timing information. Thus the satellites transmit both a timing signal and a "data message" regarding exact orbital locations and the "health" of the satellite.

To assure that the satellite and receiver are synchronized, an accurate clock is needed. Each satellite has four precise atomic clocks while the receivers use less expensive, moderately accurate clocks. Even with accurate atomic clocks, some sources of error are inevitable - such as ionospheric and tropospheric delays. By using established models of the atmosphere, these errors can be largely eliminated by civilian GPS receivers. Military receivers, which can access the C/A code on two separate frequencies, are able to correct for actual atmospheric effects in real-time.

The GPS signals that arrive at that location contain errors (e.g., atmospheric delays, and satellite clock errors) that misrepresent the receiver's position. These errors can be estimated by comparing the site's known position with its position according to GPS. Once the errors are identified, correction terms can be communicated to nearby users with other "roaming" GPS receivers. Each satellite monitored and in view of both the reference and roaming receivers will generate its own error corrections. Those correction terms allow the roaming user to eliminate the bias errors in the GPS signals from the satellites they are using. Reference stations can be relatively inexpensive, as in the case of a single station used for simple land surveys or part of extensive networks that provide accurate corrections over large areas for international transportation needs.

CHAPTER 4 ***NETWORK FOR MONITORING THE SUBSIDENCE AT THE 'CK' AREA***

4.1 General description of the network

The following section want to give a general overview to project and elaborate a net GPS with high precision having little o middle baselines with a length approximately of 10-70 Km.

The procedure to elaborate net GPS is based on the calculation of the baselines.

One of the many applications of the GPS is to control the crustal deformations as subsidence, volcanic deformations, landslip movements, and etcetera. So using the GPS it is possible to obtain a good precision and reliability of the results.

To choose the point is important to respect the rules:

- open sky: above an angle of elevation of about 15° it is possible to avoid the obstacles along the path of the signal;
- far from reflective superficial: for example metallic superficial, water superficial or traffic street in order to avoid the multipath effect;
- Far from electric installation: for example transmitting antenna to avoid the disturb due to the generation of magnetic wave.

The zone object of the study occupies the central position of the Catalonia, in particular the Bages area. The stations used for the campaign are 36 and the observations for these stations are available for nine days. All the days of the observations are of the year 2007 from December 11 to 15 and from December 17 to 20.

The points that described the network are different e we can see this in the following pictures.

Figure 6: one point that belong to the net

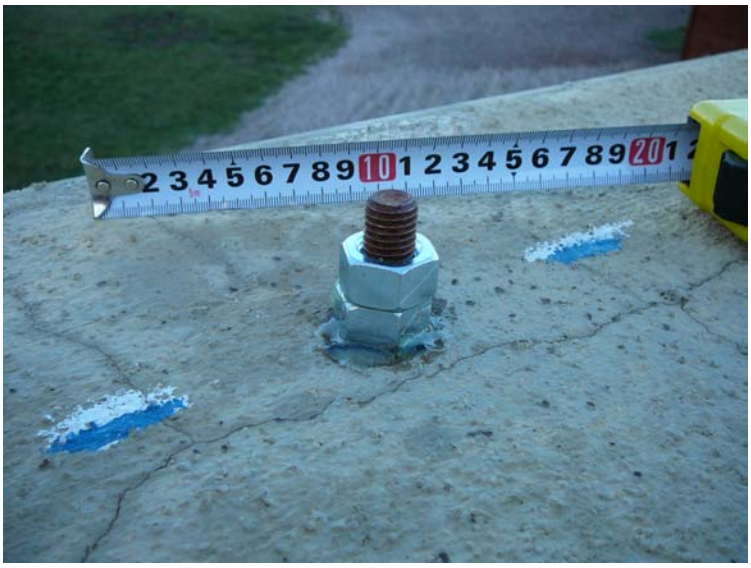


Figure 7: one point that belong to the net

Figure 8 : one point that belong to the net

In order to obtain more information about the points that describes the network see the annex I for a general description of the geodetic points.

<u>Table 2</u>: Vertex points belonging to the CK network

punti di controllo	nomi
CK01	Pinós
CK02	Sant Gabriel
CK03	Sant Diumenge
CK04	Sant Quintí
CK05	Borrelles
CK06	Comabella
CK07	El Remei
CK08	La Garriga
CK09	Serrat d'Obaga Negra
CK10	El Castellot
CK11	Montbordó
CK12	les Pinasses
CK13	Sant Genis
CK14	Sant Sadurní
CK15	Turó de Cal Ponç
CK16	Camprodon
CK17	Serrat de la Rodoreda
CK18	Les Eretes
CK19	Goberna
CK20	Ca l'Ase Negre
CK21	Puigdellivol
CK22	El Putxó
CK23	Puig-alter
CK24	el Cogulló
CK25	El Puig de Calders
CK26	Substitut de Turò de Buixadors
CK27	Substitut de Linya
CK28	Substitut de Collbaix
CK29	Parador (Cardona)
CK30	Vilar Rural (Cardona)
CK31	Les Comes (Súria)
CK32	Súria-K (Súria)
CK33	Salmorres (Sallent)
CK34	Castell (Sallent)
CK35	Castell Vell (Balsareny)
CK36	Serrat d'Alou (Balsareny)

4.2 Data acquisition procedure at each epoch

The duration of the sessions is designed to obtain a high precision in the calculation but also depend on the geometric stability of the net.

The satellites geometry is very important during the survey with the GPS in fact when we have a homogeneity distribution above the point we can obtain better measurements.

There are some parameters that can influence the duration of measurement session:

- length of baseline;
- number of visible satellites;
- geometric configuration of the satellites;
- relation signal/noise (S/N).
-

It is very important for this project the request of very elevated precisions, so the methodology of relief is static with varying duration of the sessions from point to point.

In the CK project the numbers of the sessions of the measurements are 13 during which the point observed are different in time and number.

Table 3: Sessions of measurements

Session 1	CK07 – CK09 – CK29 – CK06 – CK30 – CK04
Session 2	CK11 – CK10 – CK 08 – CK07 – CK29 – CK09
Session 3	CK16 – CK13 – CK12 – CK11 – CK10 – CK08
Session 4	CK15 – CK35 – CK17 – CK16 – CK13 – CK12
Session 5	CK36 – CK14 – CK25 – CK15 – CK35 – CK17
Session 6	CK34 – CK33 – CK24 – CK36 – CK14 – CK25
Session 7	CK12 – CK31 – CK23 – CK34 – CK33 – CK24
Session 8	CK07 – CK30 – CK05 – CK03 – CK02 – CK27
Session 9	CK05 – CK03 – CK02 – CK27 – CK04 – CK01
Session 10	CK01 – CK06 – CK20 – CK19 – CK26 – CK18
Session 11	CK21 – CK22 – CK28 – CK19 – CK26 – CK18
Session 12	CK20 – CK32 – CK23 – CK21 – CK22 – CK28
Session 13	CK06 – CK08 – CK31 – CK32

In this project the double frequency GPS receivers and the corresponding antennas are six, of the same model and make. In particular we have six receivers Leica System-1200 and six antennas AX1203.

Table 4: Type of receiver and antenna to monitor the network

Receiver GPS Leica GX 1230	R1	460157
Receiver GPS Leica GX 1230	R2	463159
Receiver GPS Leica GX 1230	R3	451945
Receiver GPS Leica GX 1230	R4	460183
Receiver GPS Leica GX 1230	R5	459743
Receiver GPS Leica GX 1230	R6	459748
Antenna GPS Leica AX 1202	A1	04130086
Antenna GPS Leica AX 1202	A2	04330303
Antenna GPS Leica AX 1202	A3	04470080
Antenna GPS Leica AX 1202	A4	04470090
Antenna GPS Leica AX 1202	A5	05420065
Antenna GPS Leica AX 1202	A6	05420075

4.3 Post-processing strategies of the raw data

The GPS measurements are usually stored in computer memory in the GPS receivers, and are subsequently transferred to a computer running the GPS post-processing software. The software computes baselines using simultaneous measurement data from two or more GPS receivers. The baselines represent a three-dimensional line drawn between the two points occupied by each pair of GPS antennas. The post-processed measurements allow more precise positioning, because most GPS errors affect each receiver nearly equally, and therefore can be cancelled out in the calculations.

GPS data collected for high precision applications must be post processed to provide millimetre to meter level precision. Typically, the post-processing involves differential processing relative to a fixed base location. For certain survey types, such as stop-and–go kinematic, it is essential to process the data while still in the field as a data quality check. This allows for a re-survey if there are problems with the data. For more robust data collection methods such as static surveys, data processing in the field is not required. For many high accuracy applications final data processing in the field is not possible. Advanced data processing methods typically require internet access to continuous station data, precise satellite orbits, and on-line data processing services. A common process is to field process data as a quick quality check, then spend more time back in the office to rigorously develop the final results.

When processing GPS data, the positions are typically referenced to a precisely defined ellipsoid, such as IRTF 98 or WGS-84. These ellipsoids are mathematical representations of the shape of the Earth, and do not reflect the constant-gravity defined geoid (mean sea-level) surface of the Earth. As a result, the ellipsoidal elevations are usually significantly different from the corresponding geoid, or sea-level elevations. If the user is ultimately interested in geoid elevations, a gravity model such as EGM96 must be applied. The user may also want to apply a coordinate transformation to other reference frames or map projections.

4.3.1 General overview of the SW to process the GPS data

The end of the years ’80, with the determination of precise algorithmic for the postprocessing of GPS data, see the development of many software for the same.

This software can be organized as the following:

- *scientific software*: created in order to adopt every receivers and observables measurements;

- *commercial software*: developed by the various commercial houses of receivers, which use is subordinate at the same receiver.

In the following table we have the most famous software used to elaborate the GPS data.

Table 5: Commercial and Scientific software to process the GPS data

Software	**typology**	**Developed to**
BA.M.BA	Scientific	University of Milano, Italia
Bernese GPS Software	Scientific	A.I.U.B. (Astronomisches Institut Universität Bern), Svizzera
DI.PO.P (Differential Positioning Program)	Scientific	University of New Brunswich, Canada
GAMIT	Scientific	M.I.T. (Massachussets Institute of Technology), USA
GEONAP	Scientific	University of Hannover, Germania
GEOTRACER	Commercial	Geotronics
GIPSY (Groningen Image Processing SYstem)	Scientific	J.P.L (Jet Propulsor Laboratory)
PRISMA	Commercial	Ashtech
Ski	Commercial	Leica
Trimble Geomatics Office	Commercial	Trimble
TopconTools	Commercial	TOPCON P.S.
TOPAS	Scientific	University of Federal Armed Force

In general, the structure of various software is very similar; what mostly distinguishes them, besides the possibility to effect some operations with one in comparison to the others, it is their user interface: very friendly in the case of the commercial software, of difficulty understanding, for non experienced user, in the case of the scientific software.

Actually the software are continuously up-to-date for the development of the various applications of the GPS, that is about the method of relief (static relief, static-rapid, cinematic, differential, RTK), or the use of the GPS in the fotogrammetry, or the integration of GPS and GIS.

This up-to-date also is due to development of computer science and operative system.

In particular we want to speak about the Leica Geo Office (LGO).

Leica Geo Office includes the following standard functionality:

- data management;

- view and edit ;
- TPS processing;
- flexible reporting
- flexible import and export;
- tools for GNSS, TPS and levels.

The additional powerful options are the following:

- coordinate transformations;
- GNSS post processing;
- level data processing;
- network adjustment;
- GIS/CAD export;
- surfaces & volumes.

It is possible to have different management components for every projects, coordinate systems, GPS antennas, report templates in order to create a separation of important information and a clear overview of all data. The LGO software give the possibility to work as you want, so you can configure and set the software for your preferences and requirements.

The TPS Processing module allows you to manage and process your TPS data. It is possible to re-calculate TPS setups to update station coordinates and orientations. Setups and traverses can be defined and processed with different parameters. Traverse results can be displayed and archived in HTML-based reports. The LGO software permits to import data from CompactFlash cards, directly from receivers, total stations and digital levels, or from reference stations and other sources via the Internet.

The software has a complete range of libraries and tools for defining coordinate systems and transforming coordinates from one system to another:

- libraries of ellipsoids;
- projections and geoidal models,
- convert ellipsoidal to orthometric heights and vice.

The GNSS Post Processing module processes all types of GPS and GLONASS raw data. One of the main applications is the classical processing of baselines in geodetic control networks. It is also used for processing kinematic data, especially for “filling in gaps” when RTK coordinates are not available due to breaks in the radio link.

Leica Geo Office post processing allows extended user control over what has to be processed and how it is processed. For routine baseline computations, processing can be set to run fully automatically using default settings. For critical lines or special investigations, processing can be manually controlled, in which case advanced users have ample scope to set parameters and use their own processing preferences.

The Network Adjustment module allows to combine all types of measurements: GPS, TPS and level. Or you can handle them separately in a rigorous least squares adjustment in order to obtain the best possible set of consistent coordinates and verify that they fit with the coordinates of known control points. An optional statistical testing identifies blunders and outliers.

Network Adjustment is based on the powerful MOVE3 kernel with rigorous algorithms. It will adjust:

- 3D GPS networks;
- 2D TPS traverse nets,
- 3D TPS traverse and height networks;
- 1D level line networks;
- as well as combined GPS;
- TPS and level networks.

An advantage of Network Adjustment is that it permits the user to design and analyze networks in order to test their suitability before going into the field, establishing markers and taking measurements.

Another important aspect of this software in the surfaces and volumes module that permit you to calculate digital terrain models from points stored in your project.

The surfaces can be visualized in a 2D or in a 3D view with a wide range of graphical possibilities. Using the Surfaces module you can calculate volumes above a reference height or between two surfaces.

4.3.2 Trimble Geomatics Office (TGO) software

The *Trimble Geomatics Office 1.5* is a commercial software developed by the commercial house of the receiver Trimble.

The structure is very similar to the other commercial software; the scheme of his working is the following:

- import GPS data from Trimble receiver;
- conversion of data (from raw to RINEX);
- import of broadcast or precise ephemeris;
- process GPS baselines;
- adjust the network;
- to transform the coordinates from one system to an other .

It is possible to use the TGO software with the following type of measurements:

- static and static - rapid;
- cinematic: Stop&Go, RTK, On-The-Fly.

In general with the commercial software the elaboration of the network is completely automatic in front of the scientific software, in order to give the possibility to the user to modify and to choose different parameters.

Though commercial software is limited, about the complexity of the algorithm, they try to adopt recent algorithm to use GPS data.

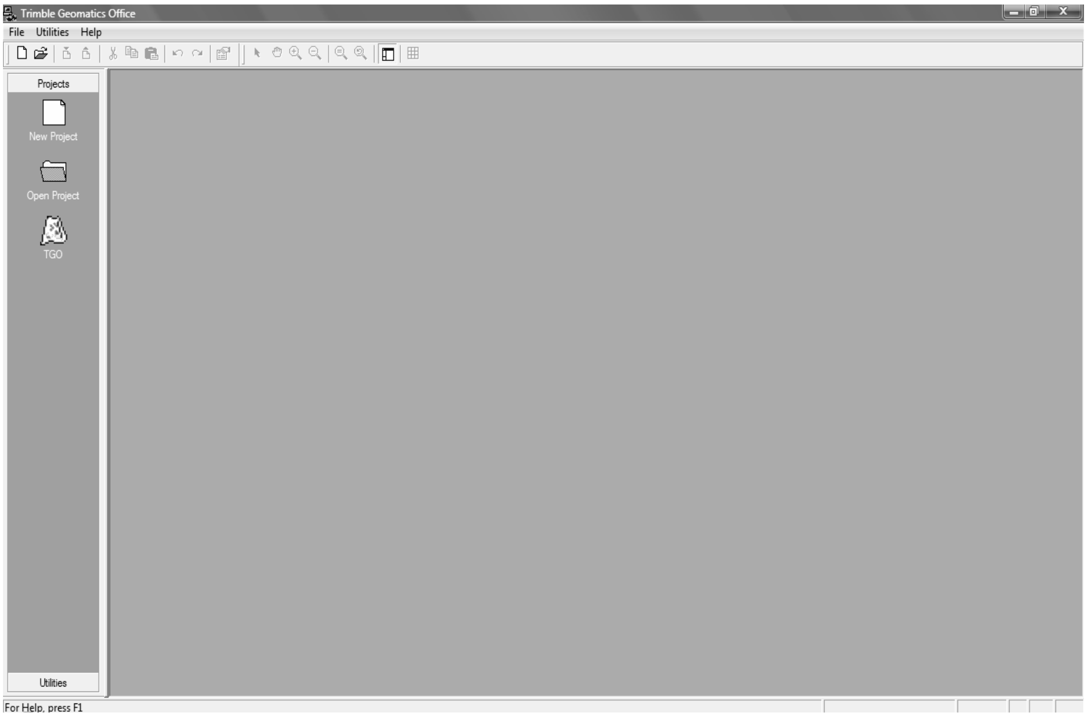


Figure 9: Trimble Geomatics Office

The software gives the possibility to choose or to select the right parameters for the different type of measurements:

- elevation mask;
- type of ephemeris (precise o broadcast);
- elimination of problematic satellites;
- type of frequency: L1, L2, L3 (ionofree), L5 (wide line), Ln (narrow lane);
- type of solution: only code, float, fix;
- troposphere model: *Hopfield, Goad-Goodman, Saastamoienen, Black, Niell* or no model;
- parameters to control the quality of datas (*edit multiplier, ratio test*).

The TGO software use two different module to elaborate the data that are:

1. module WAVE (*Weighted Ambiguity Vector Estimator*) to elaborate the baselines; it also permit to manipulate the observations L1 and L2 of all the satellites “clasped” and to have a graphic representation;
2. module *Network adjustment* to adjust thee network (estimation of final coordinates and rms errors): it works with the method of least square estimation.

The module Wave processes the baselines at the beginning with the solution of codes, after with the double differences and at the end with the triple differences; obviously the procedure depend of the availability of the dates in double or triple differences.
In case of availability of both frequencies, the program makes different linear combinations to obtain the better solution.
The software tries to solve the ambiguities using the combination L5 (wide-lane) and after uses the combination L3 (narrow-lane), in order to obtain an ionofree fixed solution.
If it is impossible to have a “narrow-lane” solution, the program will give the solution ionofree float.
The “wide-lane” solution isn’t the best solution for the short baselines (< 15 Km), because it is more noise that “ionofree fixed. On the other wise it is a good solution for baseline of about 15-30 Km.

It is impossible to accept the “ionofree float” solution for the baselines of middle length (more of 30 Km); while for the long baselines (from 100 to 1000 Km) it is the best solution that we can obtain.
For long observations (more of 4 hours) the solution “ionofree float” gives the possibility to have results geometrically correct.
With the use of L1 solution, for the short baselines (5-8 Km), the software tries to give an “ionofree fixed” solution using the “wide-lane” and the “narrow lane”.
When the TGO software processes the data in single frequency, it tries to fix the ambiguities.
There are two parameters that permit to control the quality of the obtained solution from the elaboration of the baselines:

- the ratio: defined as the relationship among the variance of the second good solution and the variance of the best solution, among those calculated by the software; low values of the ratio means that the two best solutions can indifferently be used; contrarily, the found solution is the most suitable;
- the reference variance, defined as the relationship between the calculated precision and the foreseen precision based on the length of the baseline and the duration of the observation; values less than unit show that we have obtained a solution better of that foreseen.

Generally it is difficult to establish an optimum range for the variance and for the ratio, because they are the parameters to test the quality of the data. The usual approach is to suspect of the baselines that have a high variance and a low ratio (i.e. ratio < 5).

4.3.3 Bernese software

The Bernese GPS Software is a sophisticated tool meeting highest quality standards for

geodetic and further applications using Global Navigation Satellite Systems (GNSS). Both of the currently active GNSS are supported: the American Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS).

The Bernese GPS Software, is a software written in language Fortran 77. Created in the year 1988 (Bernese GPS Software Version 3.0), subsequently it has been modified completely and suited for the operational systems MS DOS, VMS and UNIX (Bernese Second Generation GPS Software). The version MS DOS is endowed with a system of menu for the management of the files of input and the programs of elaboration.

It is a packet open to the consumers and to the scientific search. The Bernese GPS Software has been developed during the years in seven different versions that are: 3.1, 3.2, 3.3, 3.4, 3.5, 4.0, 4.2 and 5.0.

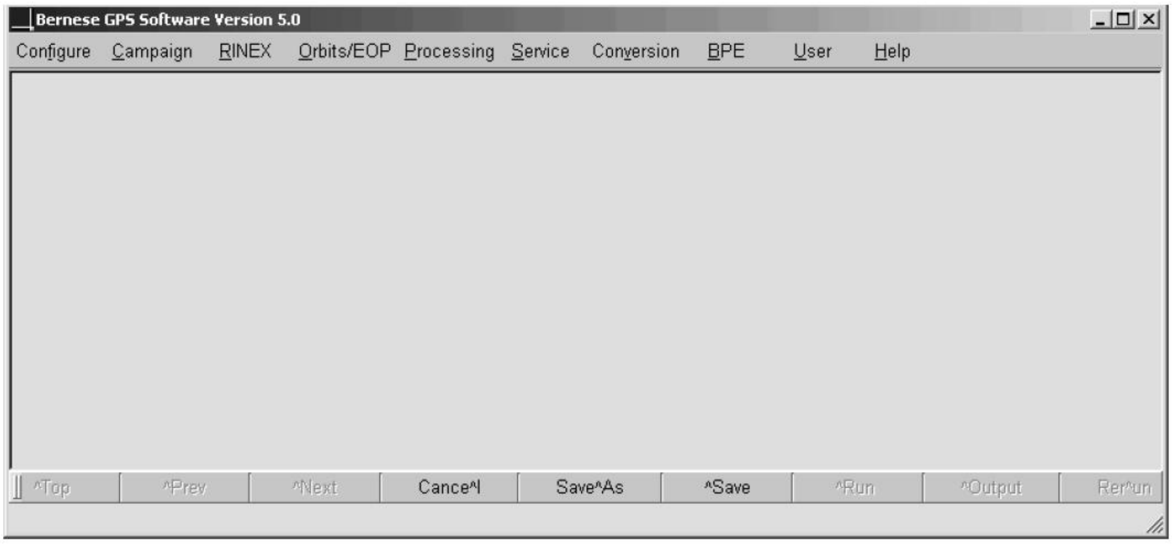


Figure 10: Bernese GPS Software 5.0

The Bernese GPS Software is particularly well suited for:

- rapid processing of small-size single and dual frequency surveys,
- automatic processing of permanent networks,
- processing of data from a large number of receivers,
- combination of different receiver types, taking receiver and satellite antenna phase center variations into account,
- combined processing of GPS and GLONASS observations,
- ambiguity resolution on long baselines (2000 km and longer),
- generation of minimum constraint network solutions,
- ionosphere and troposphere monitoring,
- clock offset estimation and time transfer,
- orbit determination and estimation of Earth orientation parameters.

General features of the software are:

- all principal observables recorded by high precision geodetic receivers, code and phase data on both carriers may be processed;
- different linear combinations of L1 and L2 may be used;
- single and dual frequency data may be processed in the same estimation step;
- the processing programs support the simultaneous estimation of a large number of different parameter types;
- the parameter estimation programs may be used for baseline-, session-, campaign-, multiple campaign processing;
- the data can either be processed in double-difference mode or in zero-difference mode;
- different ambiguity resolution strategies allow fixing of phase ambiguities on up to very long (several thousand kilometres) baselines;
- different troposphere mapping functions are available.

The Bernese GPS Software Version 5.0 contains nearly 100 programs which are grouped

logically into six parts represented as items in the menu bar of the menu program:

I. the Transfer Part includes all programs related to the transfer of RINEX files (observations, navigation messages, meteorological files, clock files) into Bernese format or vice versa, and to manipulate RINEX files such as cutting to a specific time window or concatenation of files;
II. the Orbit Part contains all programs related to satellite orbits and Earth orientation parameters (EOPs). This includes the generation of an internal orbit representation (so-called standard orbit) starting from precise ephemerides o broadcast

information, update orbit information, creation of precise orbit files, concatenation of precise files, comparison of orbits, conversion of EOP information from IERS format to Bernese format, and extraction of pole information;

III. the Processing Part contains the main processing programs. This includes code pre processing and receiver synchronization (program CODSPP), generation of baseline files (program SNGDIF), dual frequency phase pre-processing (program MAUPRP), parameter estimation based on GPS and/or GLONASS observations (program GPSEST) and on the superposition of normal equation systems (program ADDNEQ2).

IV. The sub-menu contains a simulator for GNSS observations (Simulation Part, program GPSSIM) as well as the Service Part as a collection of a number of tools to browse binary observation files, check residuals, compare and manipulate coordinates, for automated processing, and many more. This menu item also provides the possibility to browse program output and error message files.

V. The Conversion Part collects programs to convert binary files into ASCII format and vice versa. Additional programs allow to convert SINEX files into normal equation files, to extract station information from SINEX, or to manipulate troposphere SINEX files.

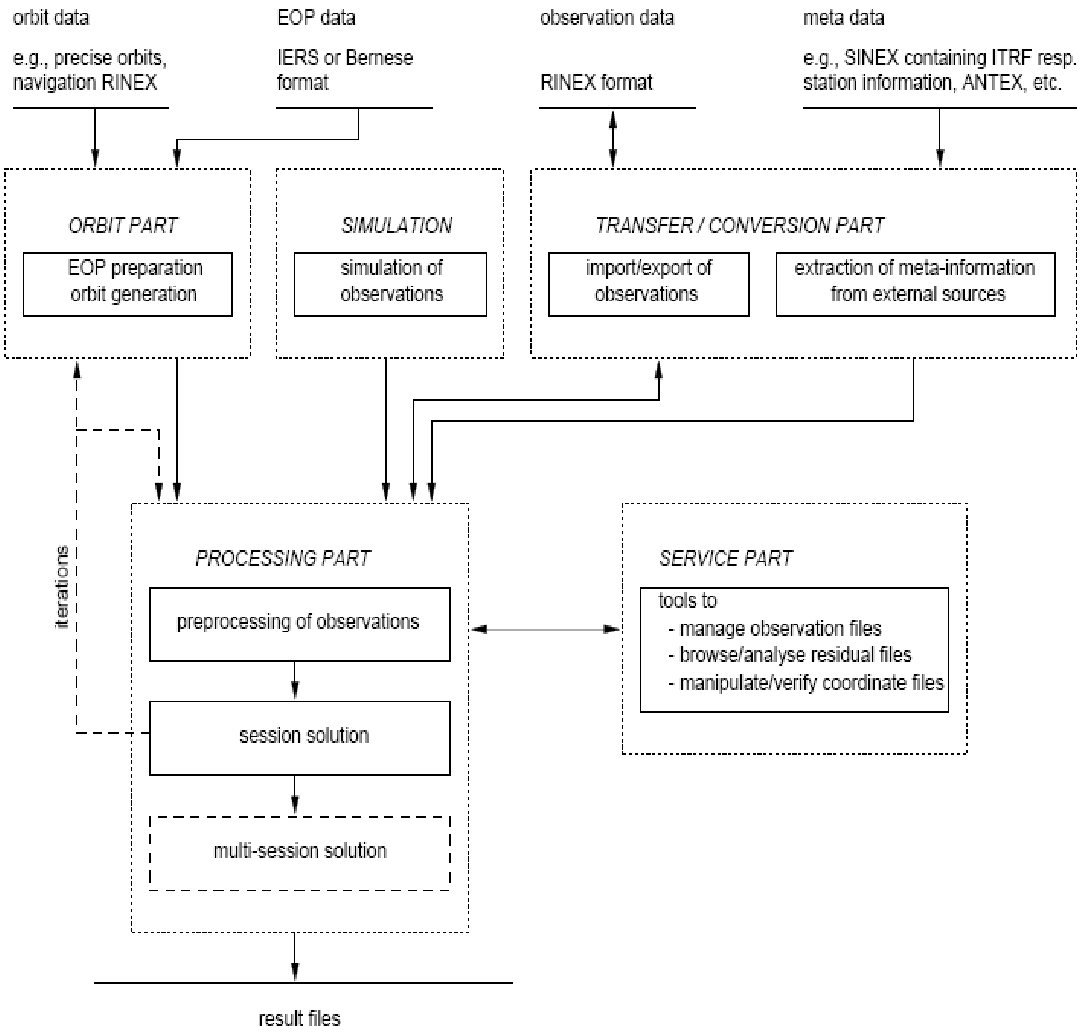


Figure 11: functionall flow diagram of standard processing in Bernese GPS Software Version 5.0 (from the Bernese manual 5.0)

CHAPTER 5 *DECEMBER 2007 CAMPAIGN AT THE 'CK' NETWORK*

5.1 Description of the data acquired

In the Bernese software we work with the days of observations while in the TGO software we work with the session.

The sessions of measurement are in total 13 in number and the days in with the point are observed are 9. The observation of the network beginning on December 11 2007 to 15 with an interruption in the 15th day, and restart on the December 17 2007 to 20.

The data acquired are observation file in a RINEX format that we imported in both the software in order to post processing the same.

The rinex format consists of three ASCII file types:

- observation data file;
- navigation message file;
- meteorological data file.

Each file type consists of a header section and a data section. The header section contains global information for the entire file and is placed at the beginning of the file.

The time of the measurement is the receiver time of the received signals. It is identical for the phase and range measurements and is identical for all satellites observed at that epoch. For single-system data files it is by default expressed in the time system of the respective satellite system. Else the actual time can be indicated in the Start Time header record.

The format of the generation time of the RINEX files is now defined to be:

- yyyymmdd = year, mouth, day;
- hhmmss = hour, minute, second.

GPS time is usually expressed in GPS weeks and GPS seconds past 00:00:00 (midnight) Saturday/Sunday. GPS time started with week zero at 00:00:00 UT (midnight) on January 6, 1980. The GPS week is transmitted by the satellites as a 10 bit number. It has a roll-over after week 1023. The first roll.-over happened on August 22, 1999, 00:00:00 GPS time. In order to avoid ambiguities the GPS week reported in the RINEX navigation message files is a continuous number without roll-over, i.e. …1023, 1024, 1025, … We use GPS as time system identifier for the reported GPS time.

```
     2              OBSERVATION DATA    G                   RINEX VERSION / TYPE
LEICA GEO OFFICE 6.0                    24-1-8 09:05        PGM / RUN BY / DATE
                    GPS Global                              OBSERVER / AGENCY
CK04                                                        MARKER NAME
CK04                                                        MARKER NUMBER
451945              LEICA GX1230        5.50                REC # / TYPE / VERS
                    LEIAX1202                               ANT # / TYPE
  4753809.6456   134710.1171  4237048.1865                  APPROX POSITION XYZ
        0.1000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
L1PhaOff:   0.0648  L2PhaOff:   0.0622                      COMMENT
     1     1                                                WAVELENGTH FACT L1/2
     6    C1    L1    D1    P2    L2    D2                  # / TYPES OF OBSERV
  2007    12    11    17    12    0.000000                  TIME OF FIRST OBS
  2007    12    12     5    50   30.000000                  TIME OF LAST OBS
    14                                                      LEAP SECONDS
    27                                                      # OF SATELLITES
          C1    L1    D1    P2    L2    D2                  COMMENT
   G 1   653   653   653   653   653   653                  PRN / # OF OBS
   G 2  1203  1203  1203  1203  1203  1203                  PRN / # OF OBS
   G 3   153   153   153   153   153   153                  PRN / # OF OBS
   G 4  1373  1373  1373  1371  1371  1371                  PRN / # OF OBS
   G 5   408   408   408   408   408   408                  PRN / # OF OBS
   G 6     0     0     0     0     0     0                  PRN / # OF OBS
   G 7     0     0     0     0     0     0                  PRN / # OF OBS
   G 8  1489  1489  1489  1489  1489  1489                  PRN / # OF OBS
   G 9   889   889   889   889   889   889                  PRN / # OF OBS
   G10  1441  1441  1441  1441  1441  1441                  PRN / # OF OBS
   G11  1015  1015  1015  1015  1015  1015                  PRN / # OF OBS
   G12   564   564   564   564   564   564                  PRN / # OF OBS
   G13  1592  1592  1592  1592  1592  1592                  PRN / # OF OBS
   G14   472   472   472   469   469   469                  PRN / # OF OBS
   G15  1328  1328  1328  1327  1327  1327                  PRN / # OF OBS
   G16     0     0     0     0     0     0                  PRN / # OF OBS
   G17  1923  1923  1923  1923  1923  1923                  PRN / # OF OBS
   G18   821   821   821   821   821   821                  PRN / # OF OBS
   G19   422   422   422   422   422   422                  PRN / # OF OBS
   G20  1380  1380  1380  1380  1380  1380                  PRN / # OF OBS
   G21   455   455   455   454   454   454                  PRN / # OF OBS
   G22   506   506   506   505   505   505                  PRN / # OF OBS
   G23  1486  1486  1486  1486  1486  1486                  PRN / # OF OBS
   G24   814   814   814   814   814   814                  PRN / # OF OBS
```

Figure 12: a RINEX file

The network object of this study is formed by 36 point distributed in the central part of the Catalunia. The choice of this point is due to a necessity to minimize the time spent in this project and the cost. So we used same points that belong to the ICC/IGN Institute.

The following image show the network formed by the observations of these vertexes

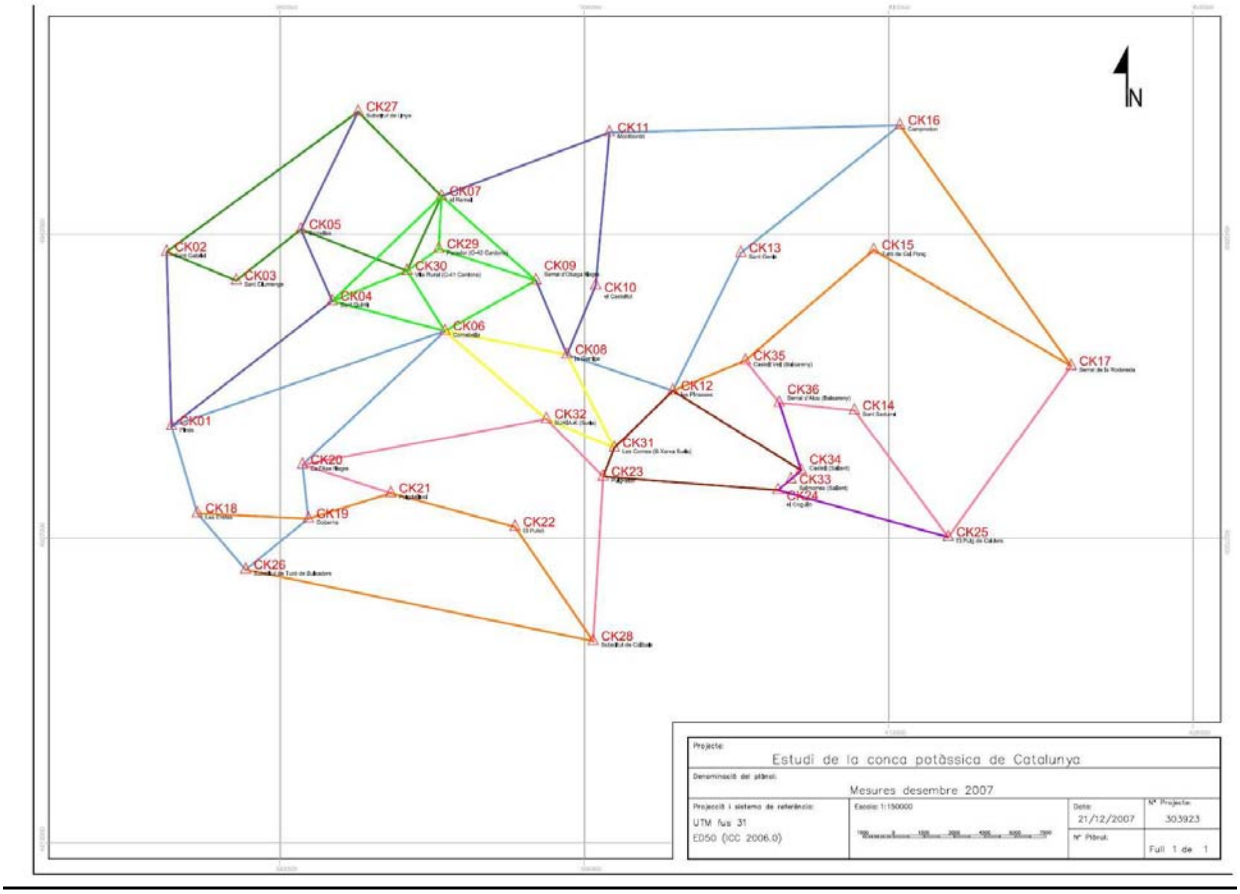


Figure 13: The network scheme

The different colours in the network identified the different sessions that are doing during the month of December 2007.

5.2 The different strategies with BERNESE

To post-processing the GPS data we used two different strategies in order to obtain a high quality of results.

In the first strategy we adjust the net as completely free. To obtain the final values of the coordinates, using the ADDNEQ2 program, it is necessary to fix a point that can belong or not to the network.

In our case the point choose to be fixed is the CK07 (el Ramie). However the possibility to fix a point is real if this point is present in all the session of campaign.

To cross this problem, in the first run of the ADDNEQ2 program, we decide not to fix but to constrain the point CK07 only in the sessions that observed this point.

The second step was to extrapolate the obtained coordinates of an other point in order to constrain this point for the other session.

In particular we processed the days: 345, 346, 351 and 352 constrained the point CK07.

After this we extrapolate the obtained coordinates of the point CK06 (Comabella) that we constrained in the days 353 and 354. With these run we obtained the coordinates of the point CK023 (Puig-alter) that constrained in the days 348 and 349. The last point constrained for the day 347 is CK35 (Castell Vell-Balsareny) just obtained from the processing of the day 348.

The strategy is to constrain at the beginning the net, using this type of bond, in order to limit the network and at the and to fix the point CK07.

On the other side the second strategy is based on the use of two permanent stations that are monitoring by the ICC (Institut Cartogràfic de Catalunya). The two stations are:

- les Planes. Pallejà (Baix Llobregat) ;
- Bellmunt de Segarra. Talavera (Segarra).

We following the same strategy used in the Bernese manual in particular we use a minimum constraint solution in the datum definition for station coordinates.

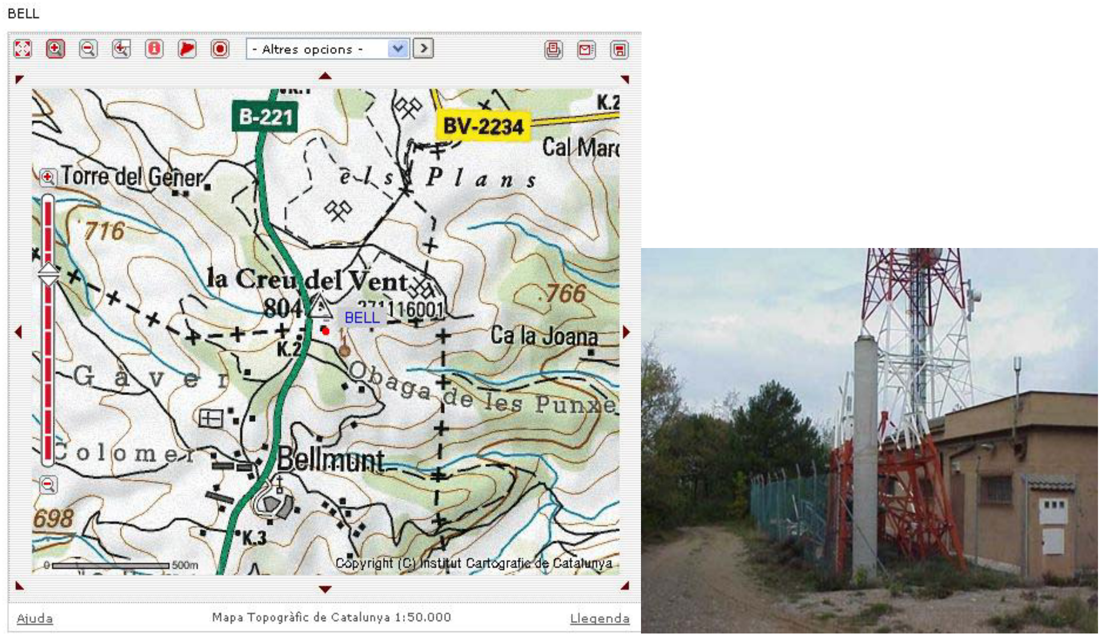


Figure 14: Bellmunt de Segarra. Talavera (Segarra), from the web site :

(http://www.icc.es/web/content/en/prof/geodesia/catnet.html)

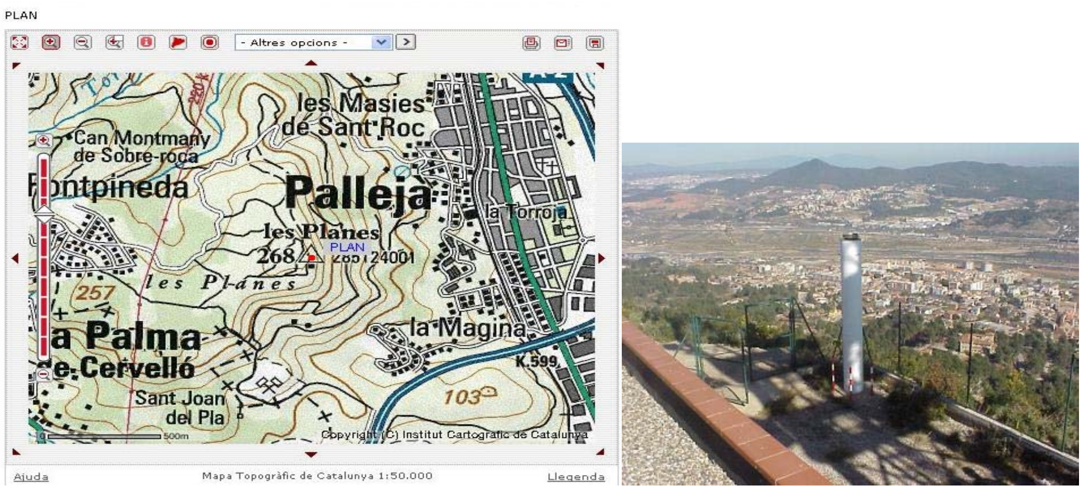


Figure 15: les Planes. Pallejà (Baix Llobregat), from the web site :

(http://www.icc.es/web/content/en/prof/geodesia/catnet.html)

5.2.1 Definition of the project

In the Bernese GPS Software the operations to define the project are the following:

1. denominations of the campaign : the name for the Conca Potassica project is: BCN;

2. creation of the directory in which we have the input files (observations files in RINEX format in the directory P:\BCN\RAW, precise ephemeris files in P:\BCN\ORB and the approximate coordinates files in P:\BCN\STA) and the output file, becomes after the different phases of elaborations in (directory P:\BCN\OUT);

3. definition of the sessions of the measurements, specifying the data and the hour of the beginning for every sessions;

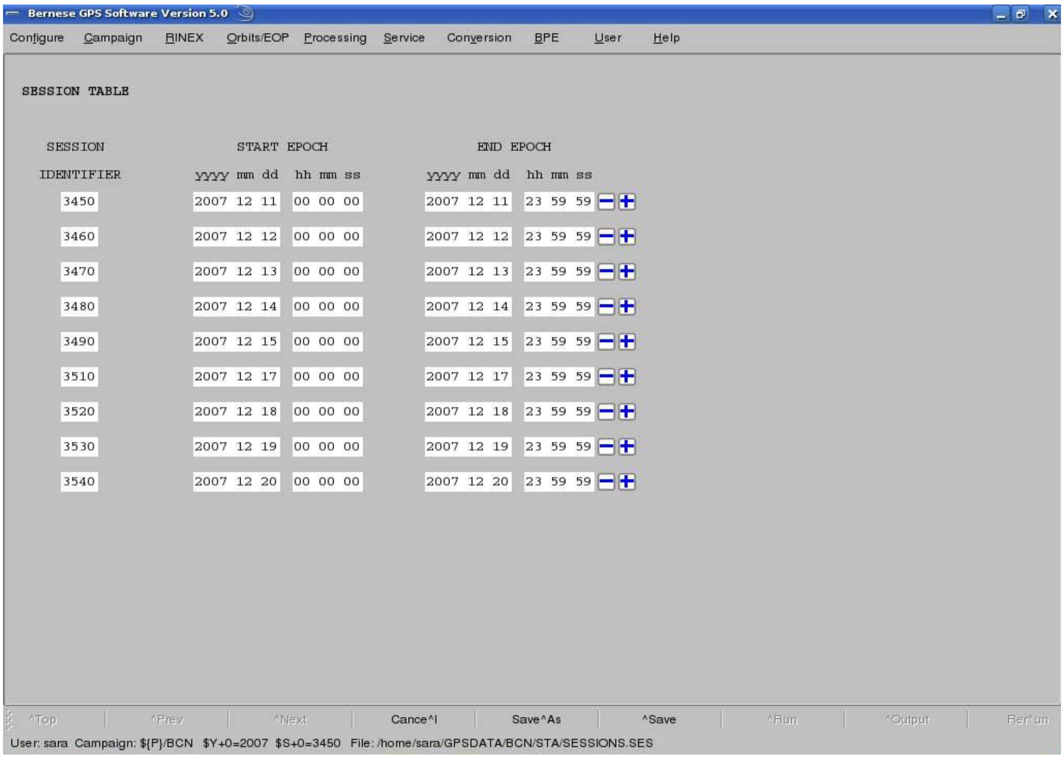


Figure 16: The session table in the Bernese GPS software

4. choice of the file to use during the elaboration : it is important to use the up-to-date of these files, in particular of the files SATELLIT.TTT and SAT_*.CRX, that have the information about all satellites, BULLET_A.ERP that is the file about the parameters of the rotation of the earth and PHAS_IGS.05, in which there are the positions and the variations of the phases center of the different antenna;

5. it is fundamental to create the file with the approximately coordinates of every stations (APRIORI.CRD). In this case we haven't the coordinates, so we used the only heading of the file in order to write this file after the importation of the RINEX.

```
IGS00 COORDINATES BASED ON IGS01P37_RS54.SNX                  29-MAY-08 11:15
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS00...........

NUM  STATION NAME           X (M)          Y (M)          Z (M)     FLAG

  1  CK04              4753809.6456    134710.1171   4237048.1865    R
  2  CK06              4754524.8622    140310.8285   4235964.6760    R
  3  CK07              4750119.4281    139905.8702   4240933.5215    R
  4  CK09              4752721.4650    144710.3955   4237910.2013    R
  5  CK29              4751790.9061    139862.6276   4238934.8497    R
  6  CK30              4752596.8345    138342.0791   4238127.5313    R
  7  CK08              4754956.4028    146362.6330   4235071.2058    R
  8  CK10              4752754.5115    147660.5741   4237746.0363    R
  9  CK11              4747775.4285    148074.5159   4243429.7269    R
 10  CK12              4756018.6437    151641.0228   4233882.1201    R
 11  CK13              4751303.6399    154755.4151   4238935.3237    R
 12  CK16              4746944.3638    162374.6603   4243837.0974    R
 13  CK14              4756262.0367    160619.9260   4233214.0383    R
 14  CK15              4750954.2395    161294.0224   4239121.2932    R
 15  CK17              4754512.0317    171228.2031   4235086.2824    R
 16  CK25              4760232.1029    165460.3119   4228577.0552    R
 17  CK35              4754729.1184    155156.6725   4234887.5769    R
 18  CK36              4756031.6098    156896.2011   4233345.8087    R
 19  CK23              4758919.1980    148353.6934   4230605.3168    R
 20  CK24              4758972.7369    156988.3468   4230162.7372    R
 21  CK31              4757907.8851    148852.8814   4231639.2143    R
 22  CK33              4758441.8044    157607.1045   4230433.7984    R
 23  CK34              4758187.9360    158095.6651   4230825.7327    R
 24  CK02              4752617.0131    126467.6989   4238851.8326    R
 25  CK03              4753381.7553    129947.2343   4237800.3944    R
 26  CK05              4751475.3269    133040.2075   4239621.1373    R
 27  CK27              4747462.5203    135652.3410   4243943.3497    R
 28  CK01              4758384.9458    127009.5371   4232503.8718    R
 29  CK18              4761116.2525    128425.9513   4229207.2069    R
 30  CK19              4761173.7633    133910.9900   4229162.2306    R
 31  CK20              4759297.6697    133525.0162   4231037.6171    R
 32  CK26              4762900.9417    130907.7673   4227186.7494    R
 33  CK21              4760164.9460    137930.2911   4230135.0191    R
 34  CK22              4760804.2709    144099.9681   4228759.9799    R
 35  CK28              4764350.8188    148142.1324   4224566.7699    R
 36  CK32              4757016.6625    145453.1495   4232605.6615    R
```

Figure 17: file of approximate coordinates of all the stations

5.2.2 Import file

In the Bernese GPS software thanks to the program RXOBV3 it is possible to import the observables files that are in the Bernese format (binary). In the field “Input Files: COORDINATES” there is the file of approximate coordinates. After this it is possible to chose the options to import the data: in this case we used the “Sampling: SAMPLING INTERVAL” for the Bernese observations files.

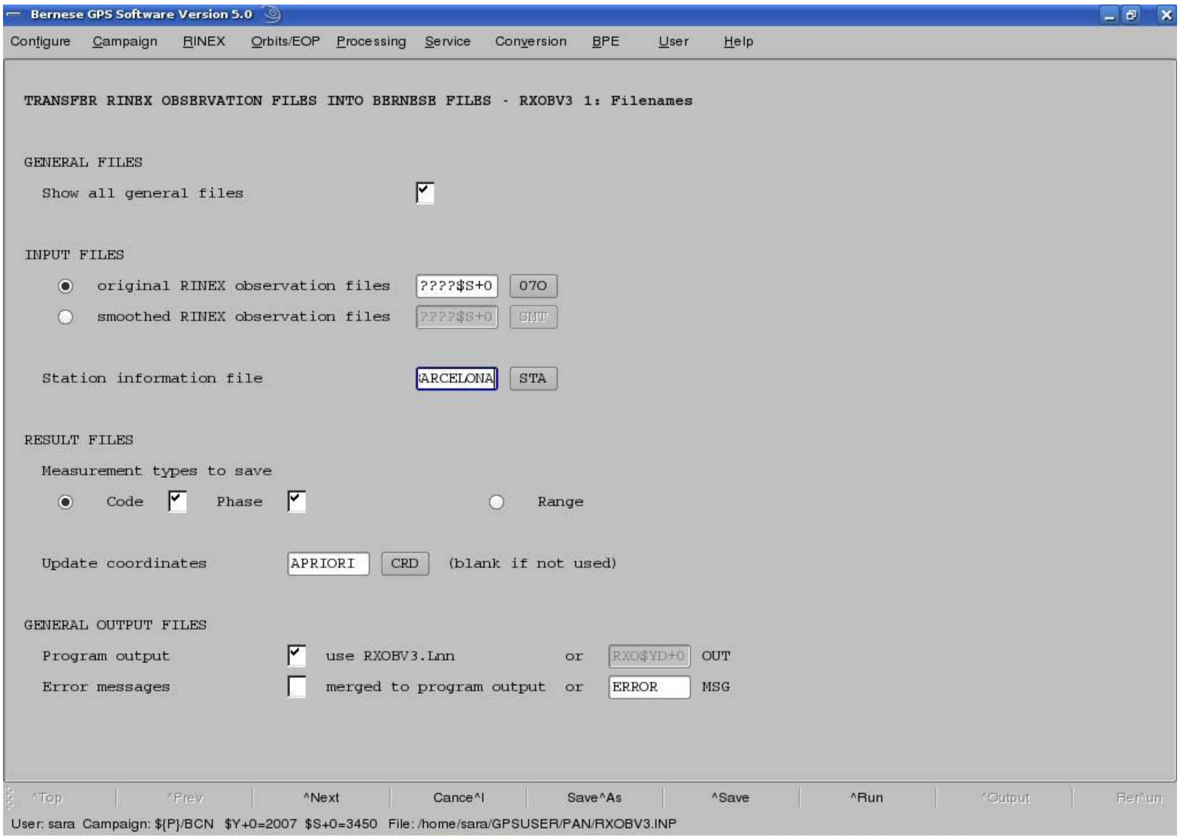


Figure 18: Import the RINEX file

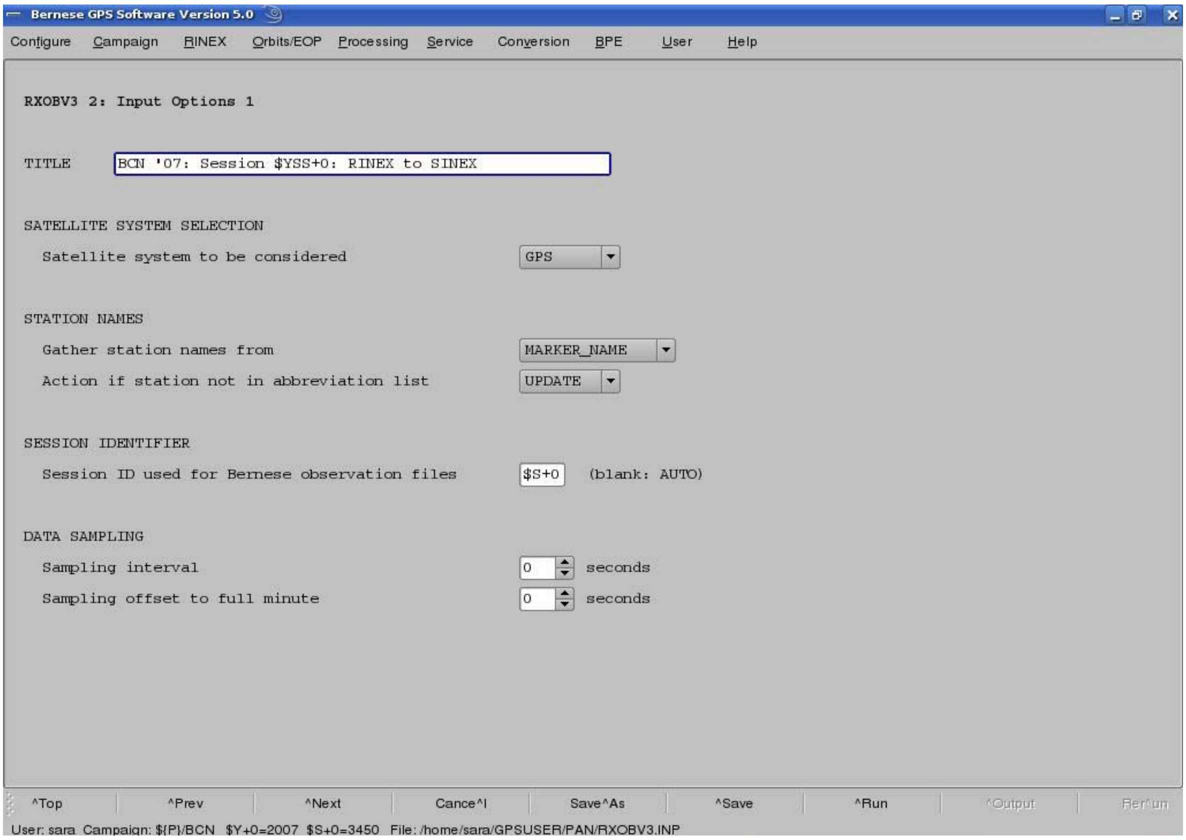


Figure 19: RXOBV3 program

The PRETAB program, permits to import the ephemeris and to create the tabular orbit files, changing the precise orbits from the terrestrial into the celestial reference frame and to

generate a satellite clock file (CLK). The clock file will be used in program CODSPP if no broadcast orbits are used.

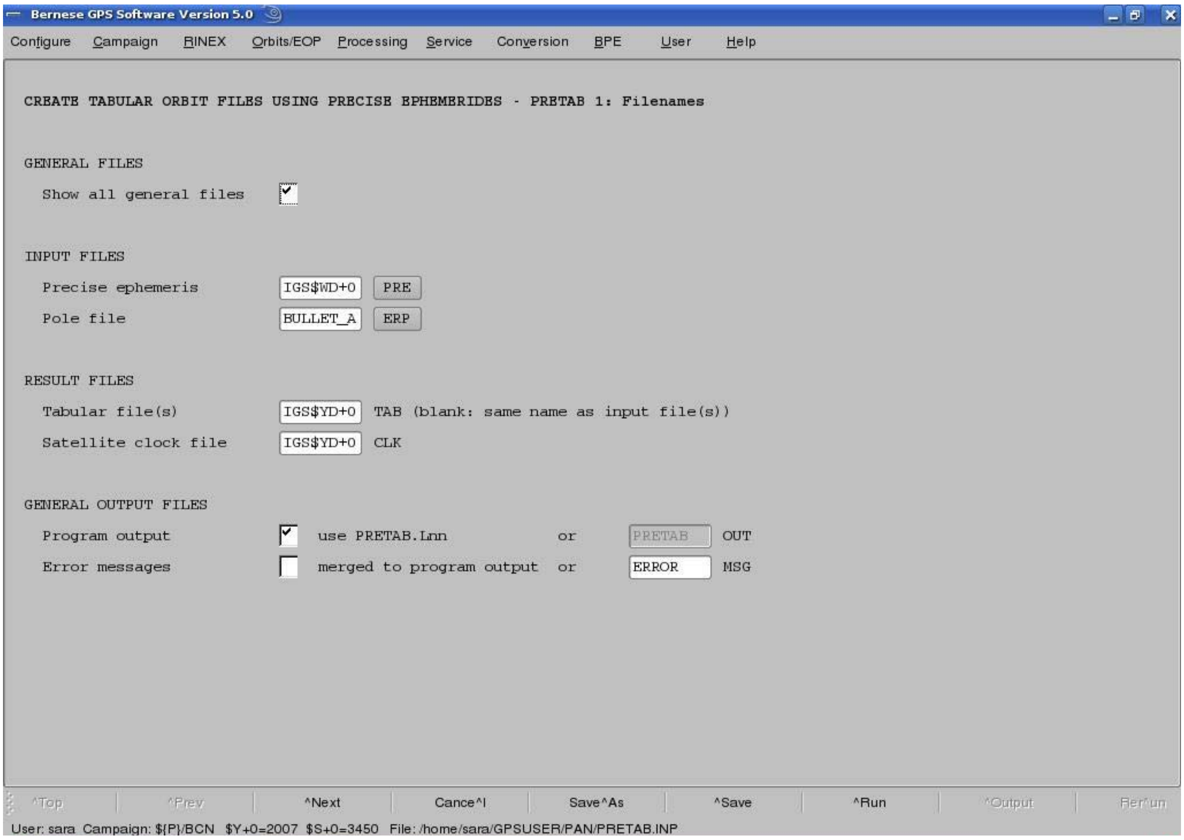


Figure 20: The tabular orbit

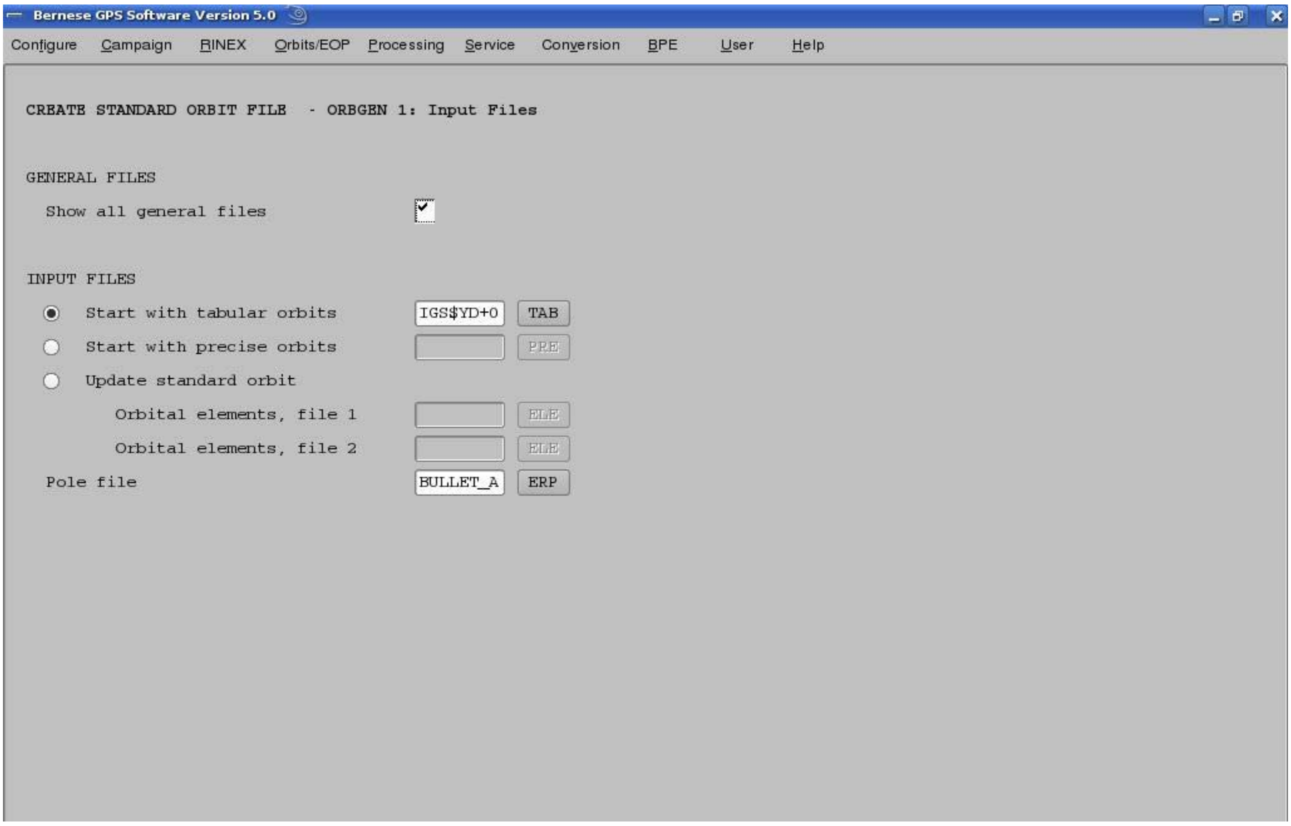


Figure 21: The standard orbit

The ORBGEN program uses the tabular orbit files to create the standard orbit files, using the tabular orbit files as pseudo–observations for a least–squares adjustment. Both programs are use separately for every session.

5.2.3 Data Preprocessing

In the Bernese GPS software to process the baselines we must run three programs for every session.

The first program is called CODSPP and its main task is to compute the receiver clock corrections.

In this case we haven't the precise coordinates, so the Apriori coordinates files is overwrite, and the esteemed coordinates are saved ("Output files: COORDINATES > APRIORI <").

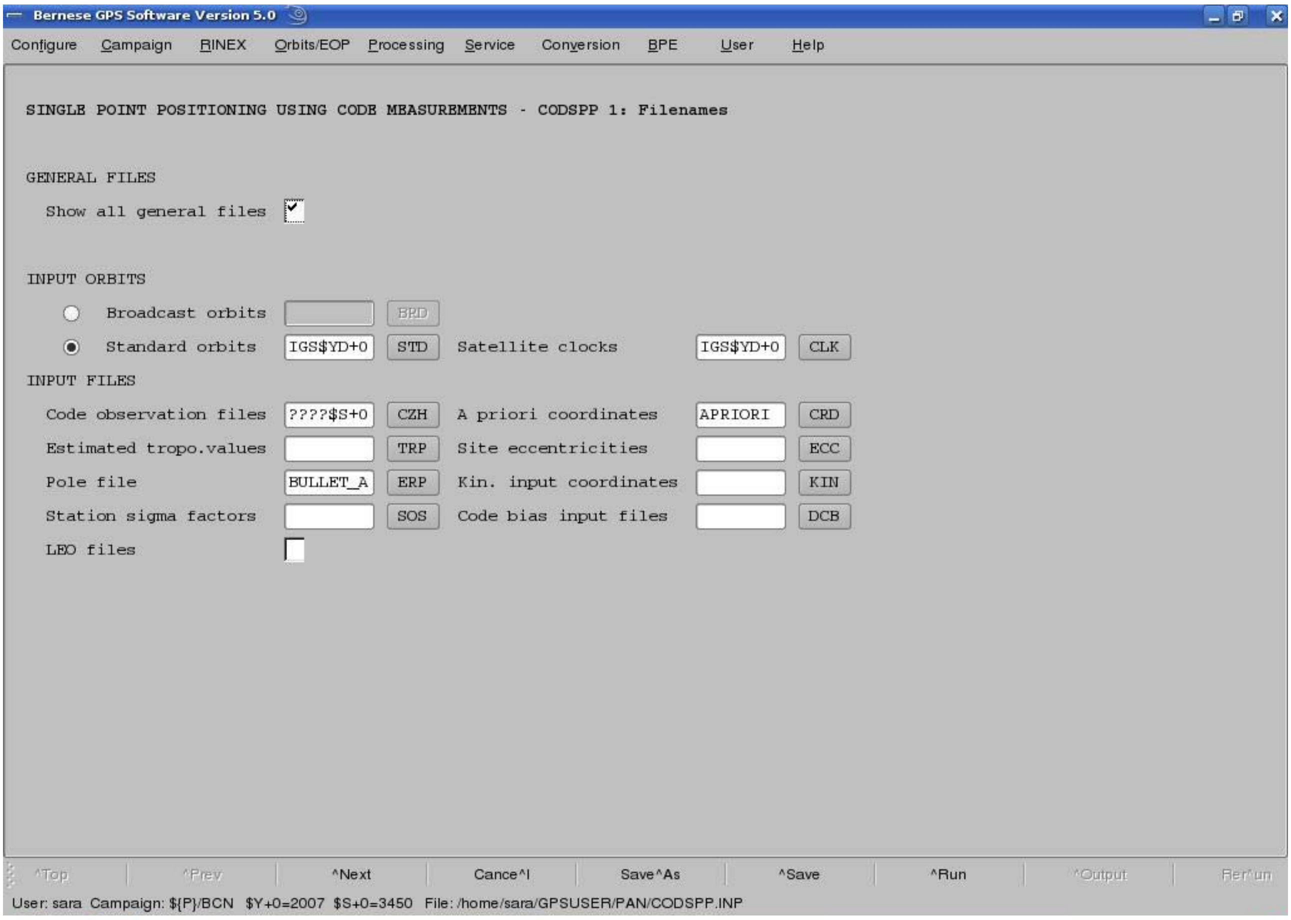


Figure 22: CODSPP program

To Eliminate the ionospheric path delay we used the linear combination Ionosphere Free ("Parameters: FREQUENCY > L3 <"), so in this case it is possible to not specified the ionosphere model ("Atmosphere Models: IONOSPHERE > NO <"); while the troposphere model used is Hopfield ("Atmosphere Models: TROPOSPHERE > HOPF <").

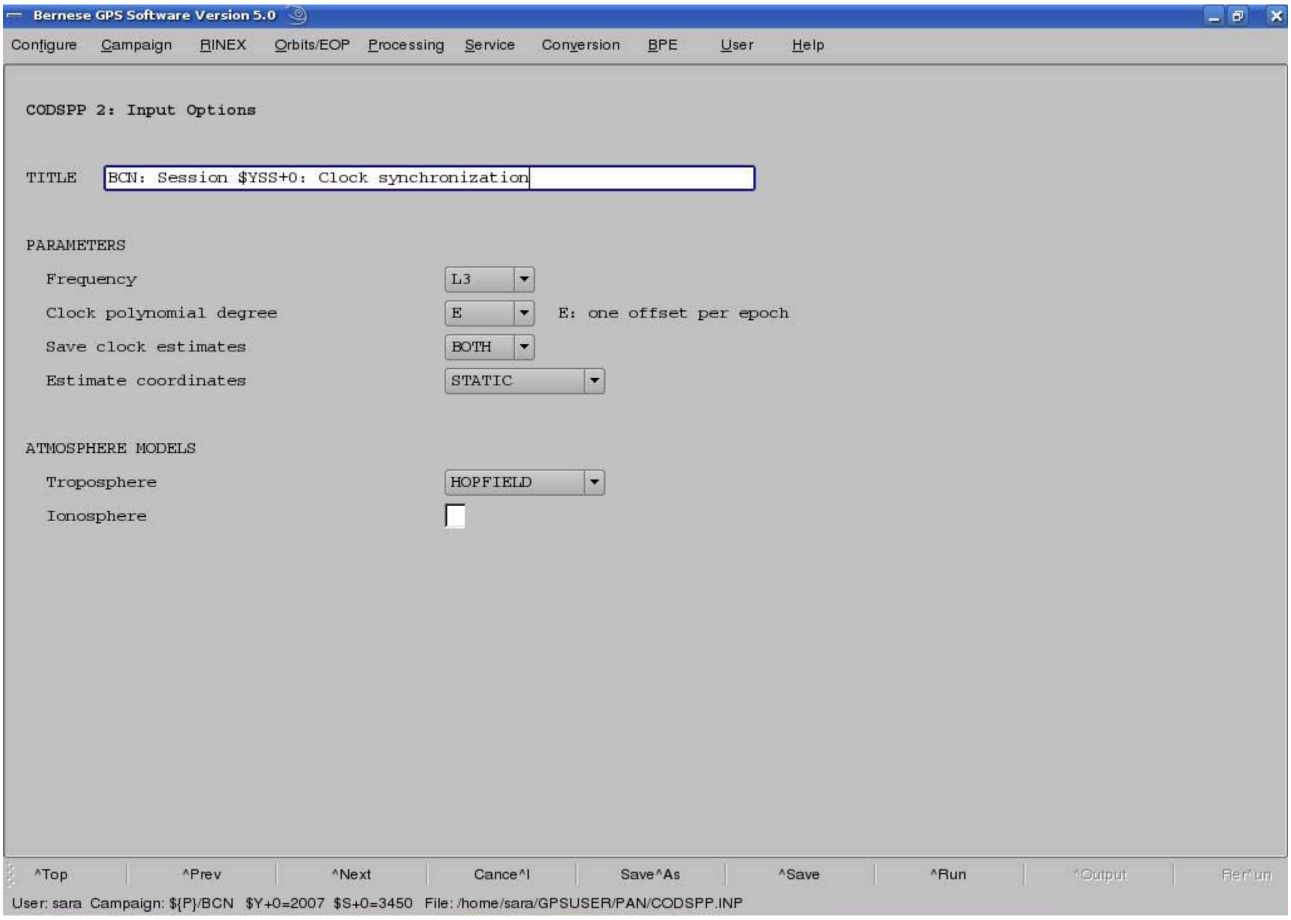


Figure 23: The clock synchronization

The second processing program is called SNGDIF that creates the single differences and stores them into files. We use the strategy OBS-MAX for phase observation files (“STRATEGY > OBS-MAX <”) so it is possible to optimize the single difference thanks to the number of common observations of both stations of each baseline.

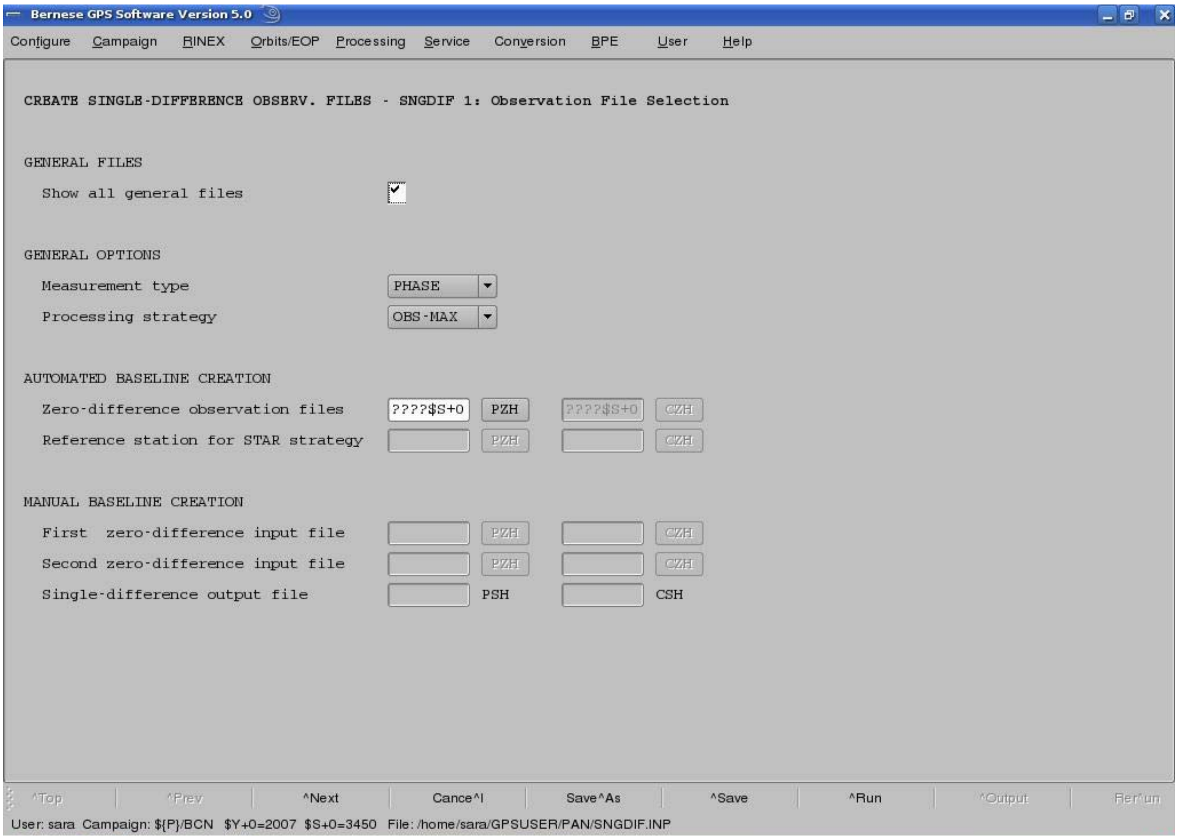


Figure 24: The SNGDIF program

The third program used is MAUPRP that analyze the cycle slips.

We used the linear combination Ionosphere Free (“Triple Diff. Solution: FREQUENCY > L3 <”) to identify the same (“FREQUENCY TO CHECK > COMBINED <”). With this technique the observations within the L1 or L2 measurements are avoided (“Marking of Observation: MARK UNPAIRED OBSERVATION > YES <”).

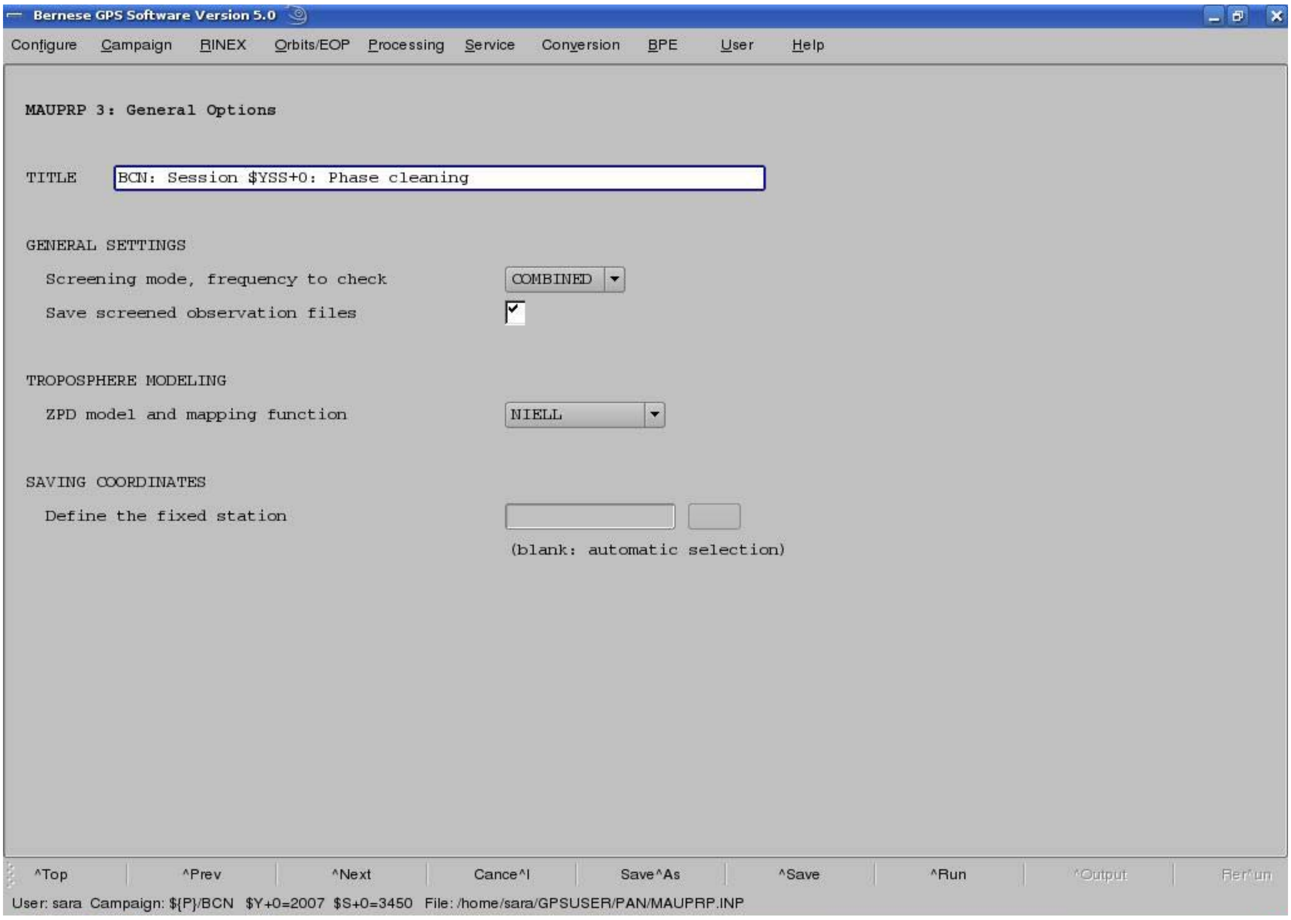


Figure 25: The MAUPRP program

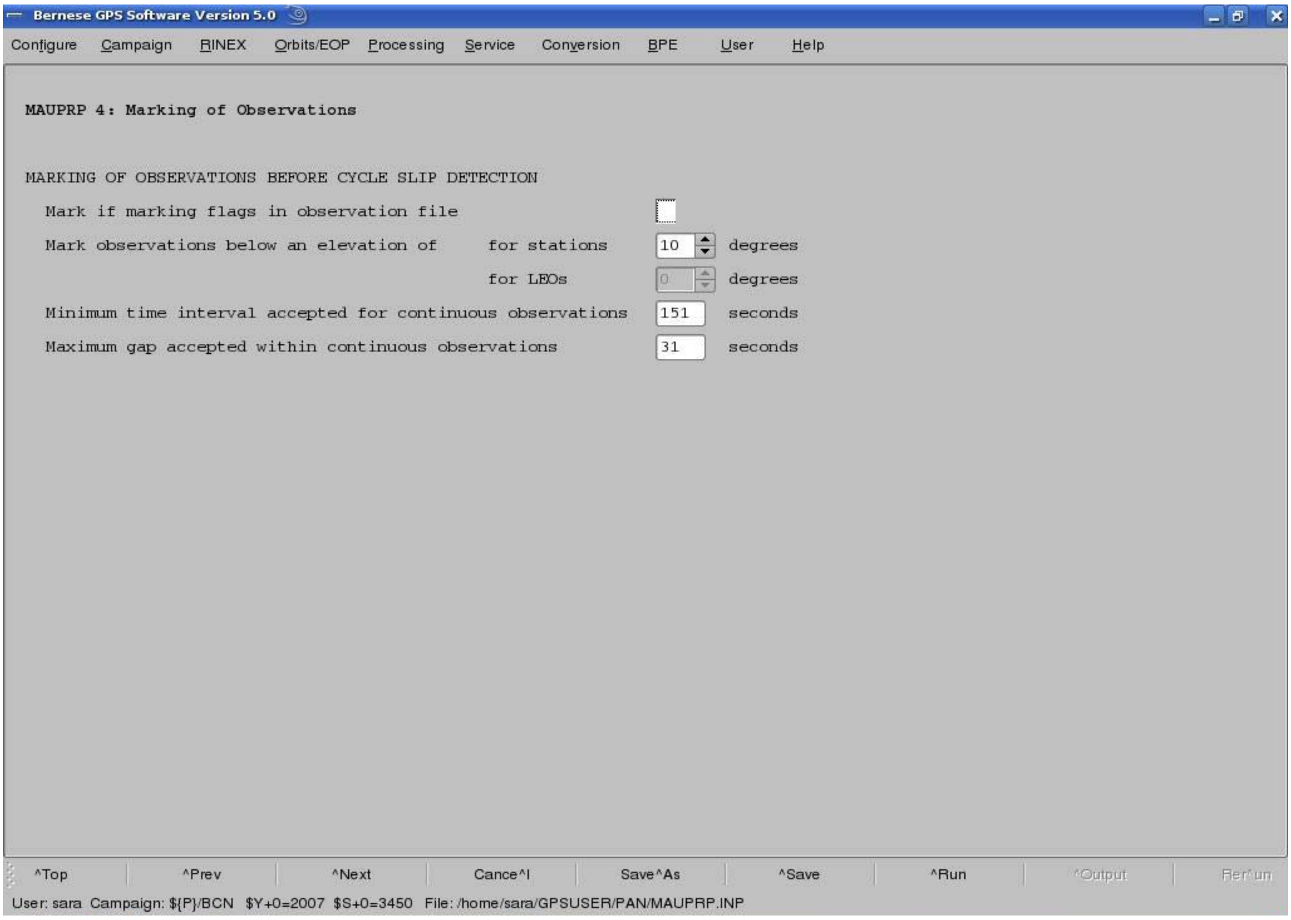


Figure 26: General options of the MAUPRP program

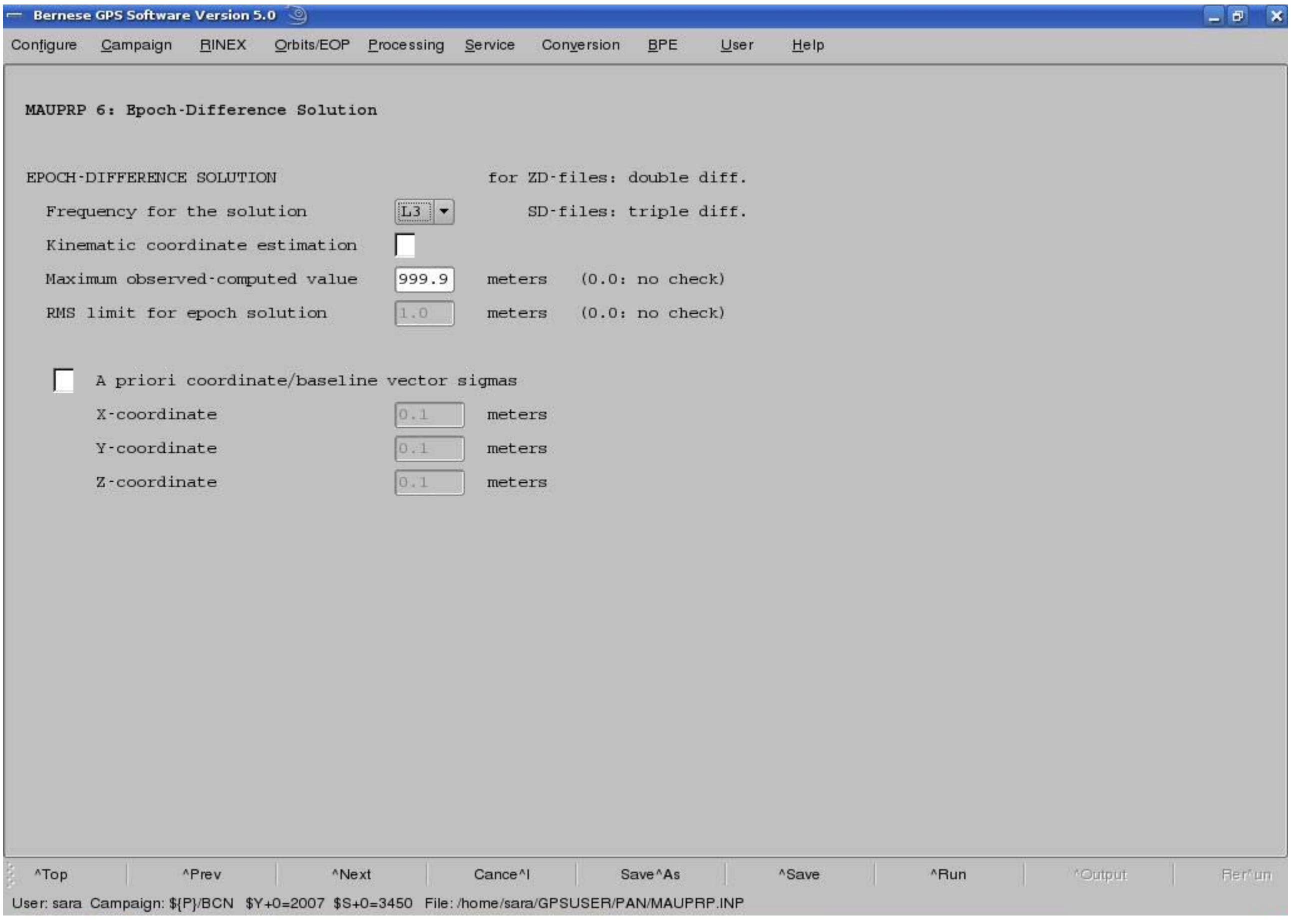


Figure 27: General options of the MAUPRP program

This phase has been performed twice; in fact, in the first execution, as done in the first phase, not having accurate coordinates, the file of the previously coordinates Apriori is overwrite and the precise coordinates esteemed save (“Output file: COORDINATES > APRIORI <”), but not saving the changes in the file of the observations (“General Parameters: SAVE SCREENED FILE > NO <”). In the first execution the program utilized the new precise coordinates in the previously execution, not overwriting them, and saving the new values in the observation files.

5.2.4 ***Data Processing***

The least–squares adjustment is the task of program GPSEST. It is a good idea to start GPSEST first in the SESSION mode and to produce an ambiguity–free L3 solution. We do not expect any final results from this run but we want to check the quality of data and save the residuals after the least–squares adjustment (“Output Files: RESIDUALS > RES02143 <”). The program also creates a file with the troposphere parameter (“Output Files: TROPOSPHERE PARAM. > TRO02143 <”), that are utilized after in the second execution of the GPSEST. To test the observations files is necessary to put the value zero for the sampling rate (“Observation selection: SAMPLING RATE > 0 <”).

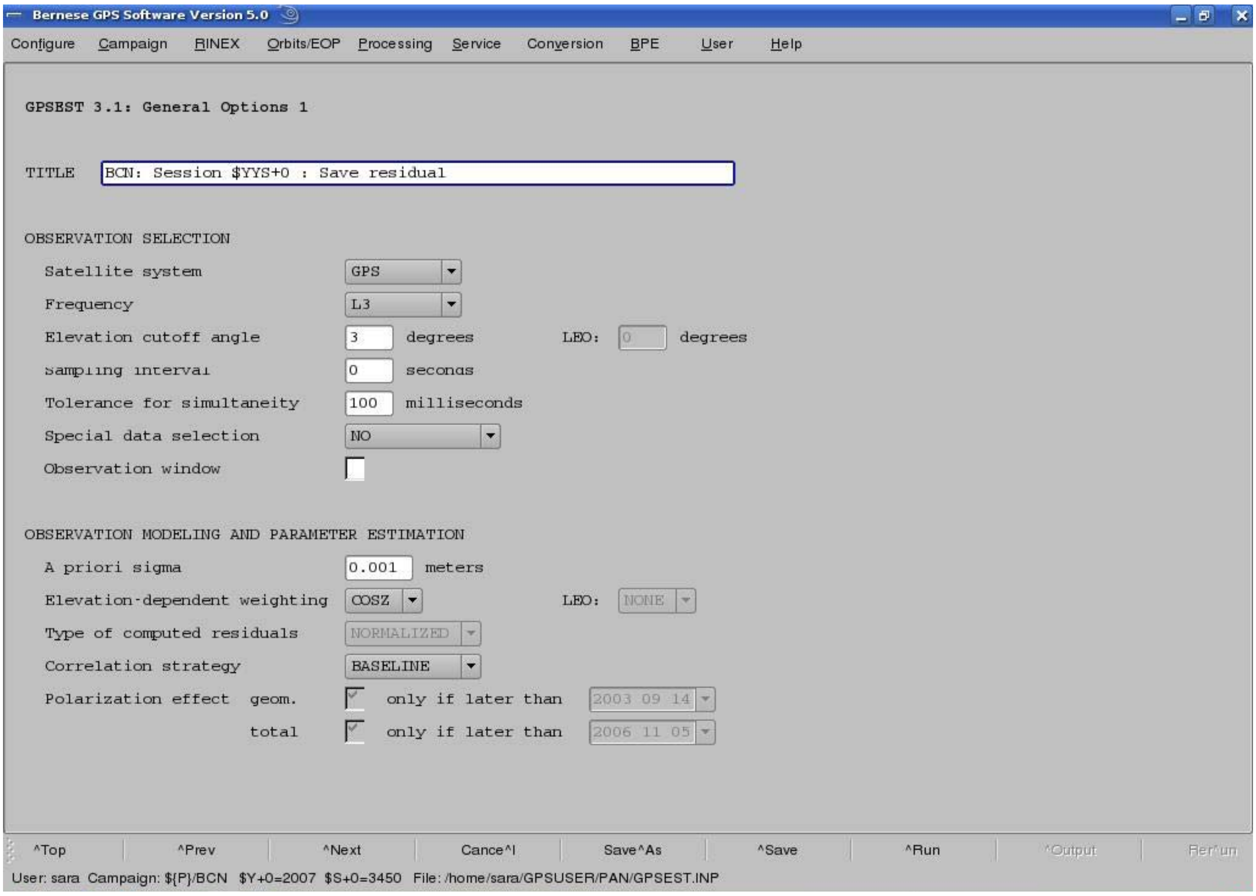


Figure 28: The GPSEST program

To resolve the ambiguities, in the second run of the GPSEST program, we process the baselines separately one by one using the QIF (quasi–ionosphere–free) strategy (“Ambiguities: RESOL. STRATEGY > QIF <”; “Ambiguities: SAVE AMBIGUITIES > YES <”). This strategy need the stochastic ionosphere parameters (“Special Request: STOCHASTIC IONOSPHERE PARAMETERS > YES <”). The program uses the estimate troposphere parameters that became from the first execution for each station (“Input Files: TROPO. ESTIMATES > YES <”, “Special Request: SITE-SPECIFIC TROPOSPHERE PARAMETERS > YES <”).

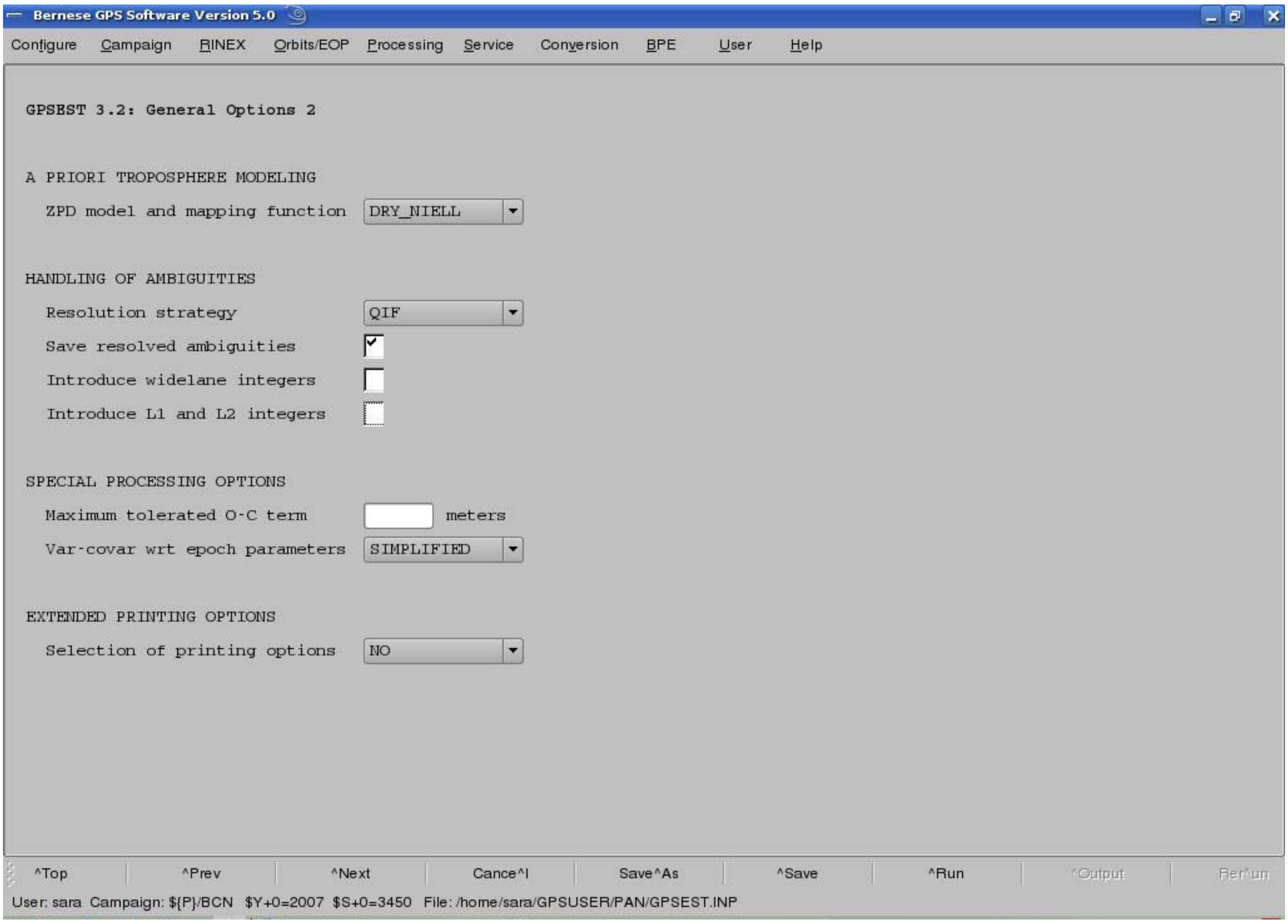


Figure 29: General options of the GPSEST program

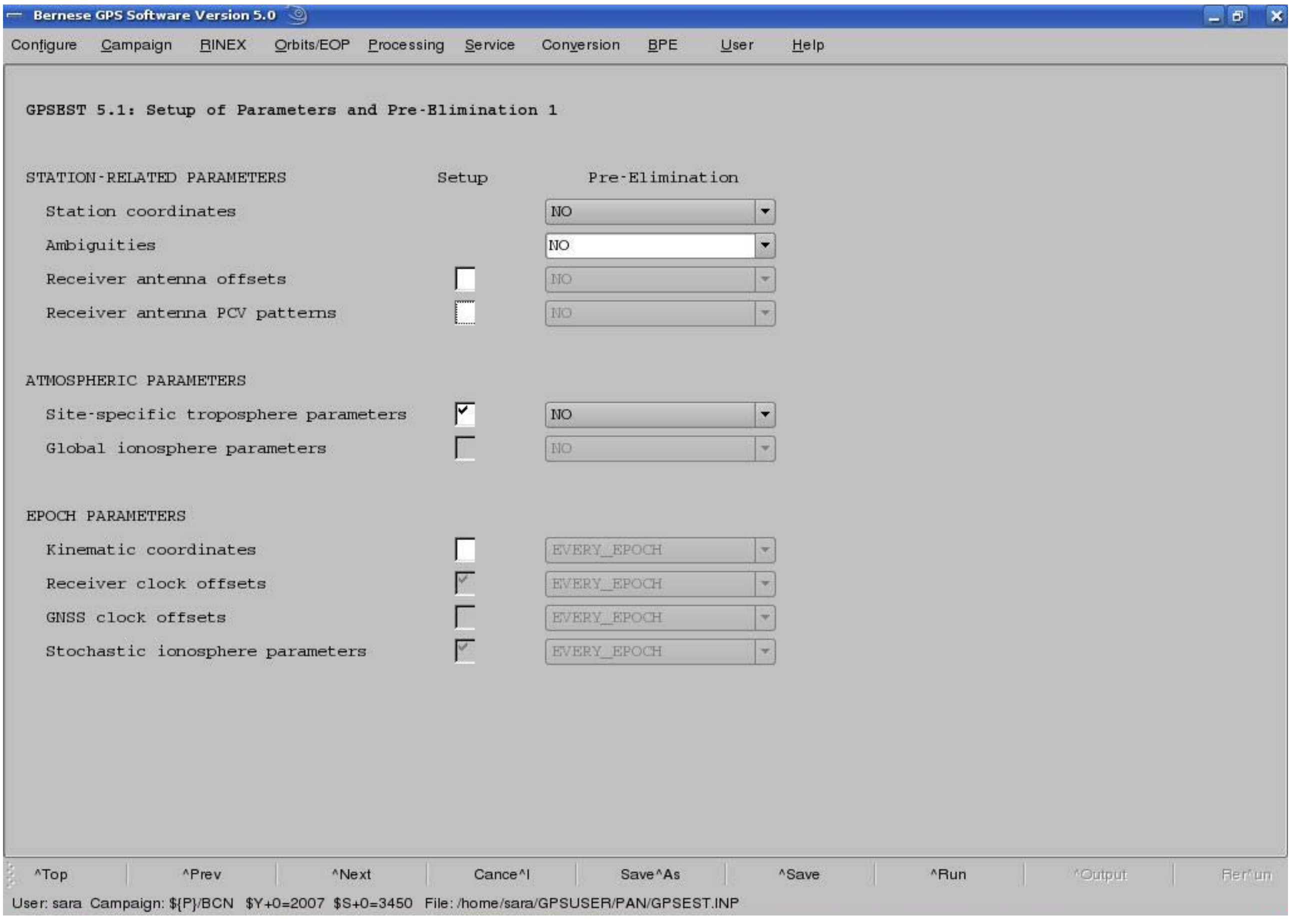


Figure 30: General options of the GPSEST program

After the resolution of the ambiguities, we run again the program in the SESSION modality to generate the final coordinates ("Output Files: COORDINATES") and the normal equation for all the session ("Output Files: NORMAL EQUATIONS"). Also in this case we chose the linear combination Ionosphere-Free ("Frequency: FREQUENCY > L3 <"); the solved ambiguities obtained in the previously execution are introduced are know parameters ("Ambiguities: INTRODUCE L1 AND L2 > YES <"), while the unsolved ambiguities are eliminated ("Ambiguities: RESOL. STRATEGY > ELIMIN <").

It is import to underline that the ad just of the net is completely free, without any fixed stations "Fixed Station(s): STATION > NONE <", to give a flexibility to the net in case of changes of reference system used in the ADDNEQ program.

After the loop over all baselines is completed and the ambiguities are resolved we used again (fourth execution) the program in formality CORRECT to produce the files of the normal equations ("Output Files: NORMAL EQUATIONS > FIX$YD+0.NQ0") for every session. The linear combination Ionosphere-Free is still chosen ("Observation Selection: FREQUENCY > L3"); the ambiguities resolved in the preceding execution as known parameters are introduced ("Handling of Ambiguities: It introduces L1 AND L2 INTEGERS > YES"), while those not resolved are eliminated. It is possible, in this phase, to use a tall speed of sampling; nevertheless we preferred to use the zero value to take all the observations.

The program that allows to get the final solution is ADDNEQ2 that elaborates the files (one for every session) of the normal equations previously gotten. In the first execution the final coordinates and the tropospheric results is esteemed ("Output Files: STATION COORDINATES > FIN$YD+0.CRD"); ("Output Files: TROPOSPHERE ESTIMATES > FIN$YD+0.TRP"). In the second execution the new normal equations are produced ("Output Files: NORMAL EQUATIONS > RED$YD+0.NQ0"), that are used in input in the third execution of the program. In this phase the final coordinates are esteemed ("Output Files: STATION COORDINATES => FINAL.CRD").

The following image show the different use of the ADDNEQ2 program for the two different strategies.

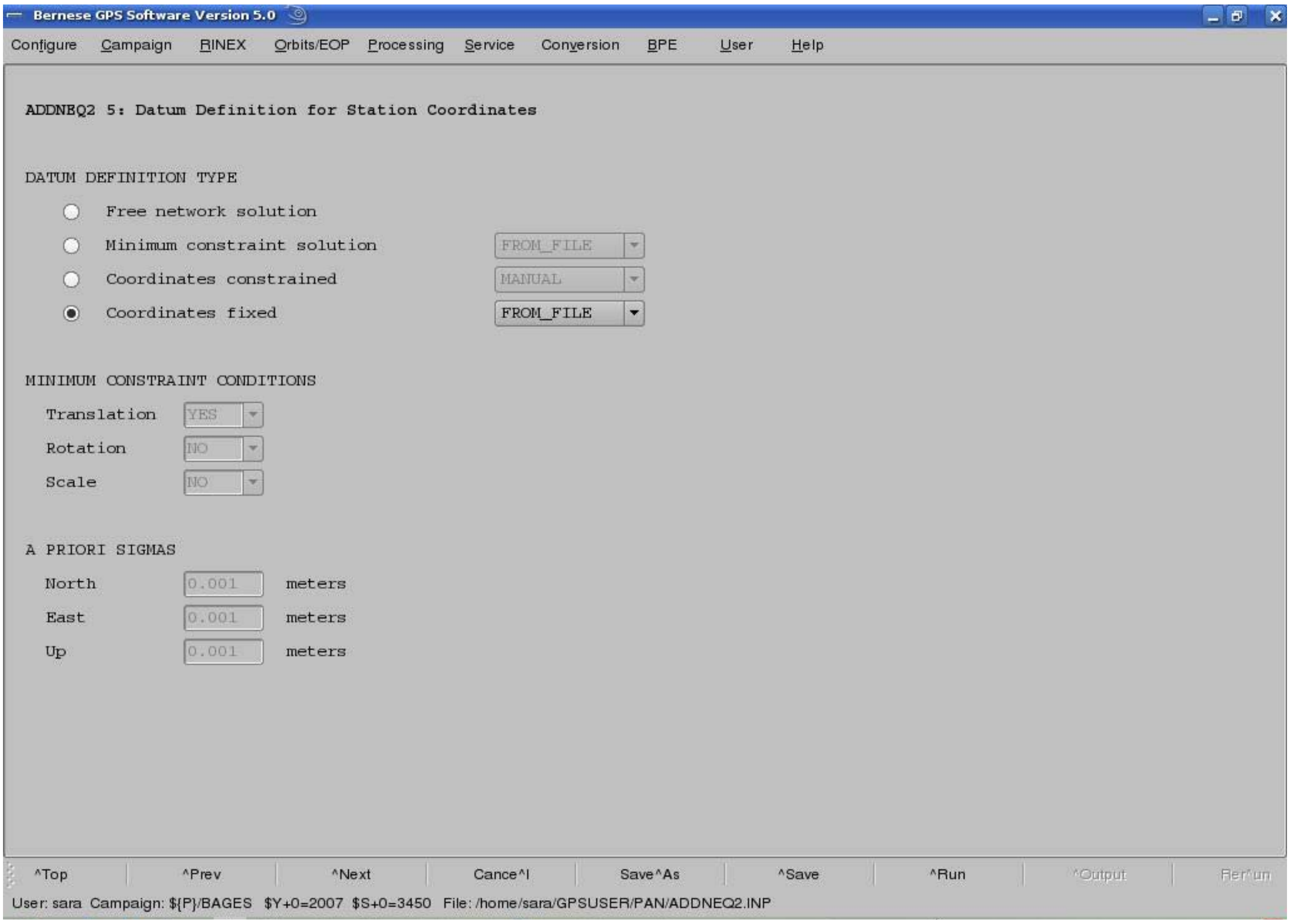


Figure 31: The ADDNEQ2 program

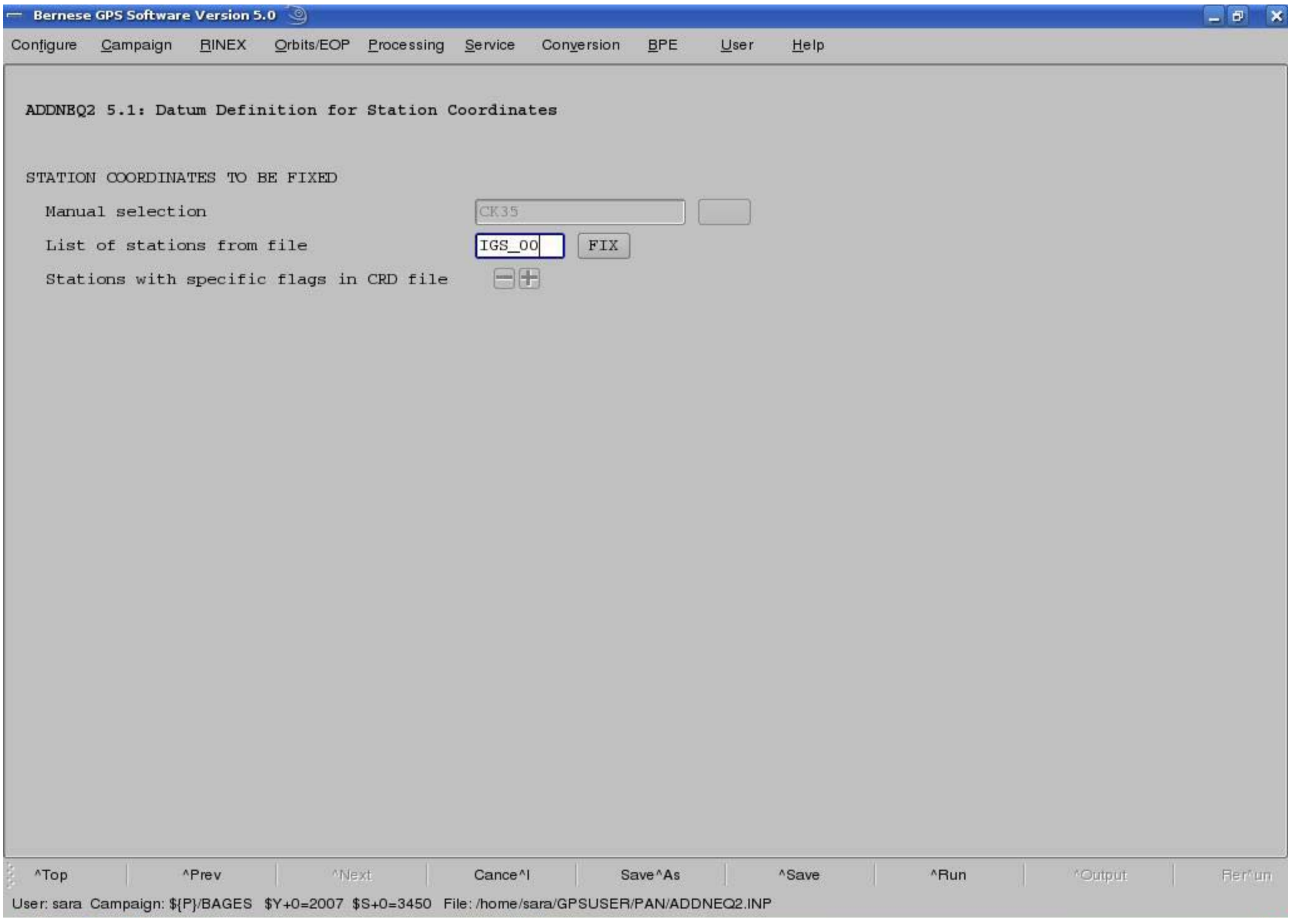


Figure 32: General options of the ADDNEQ2 program

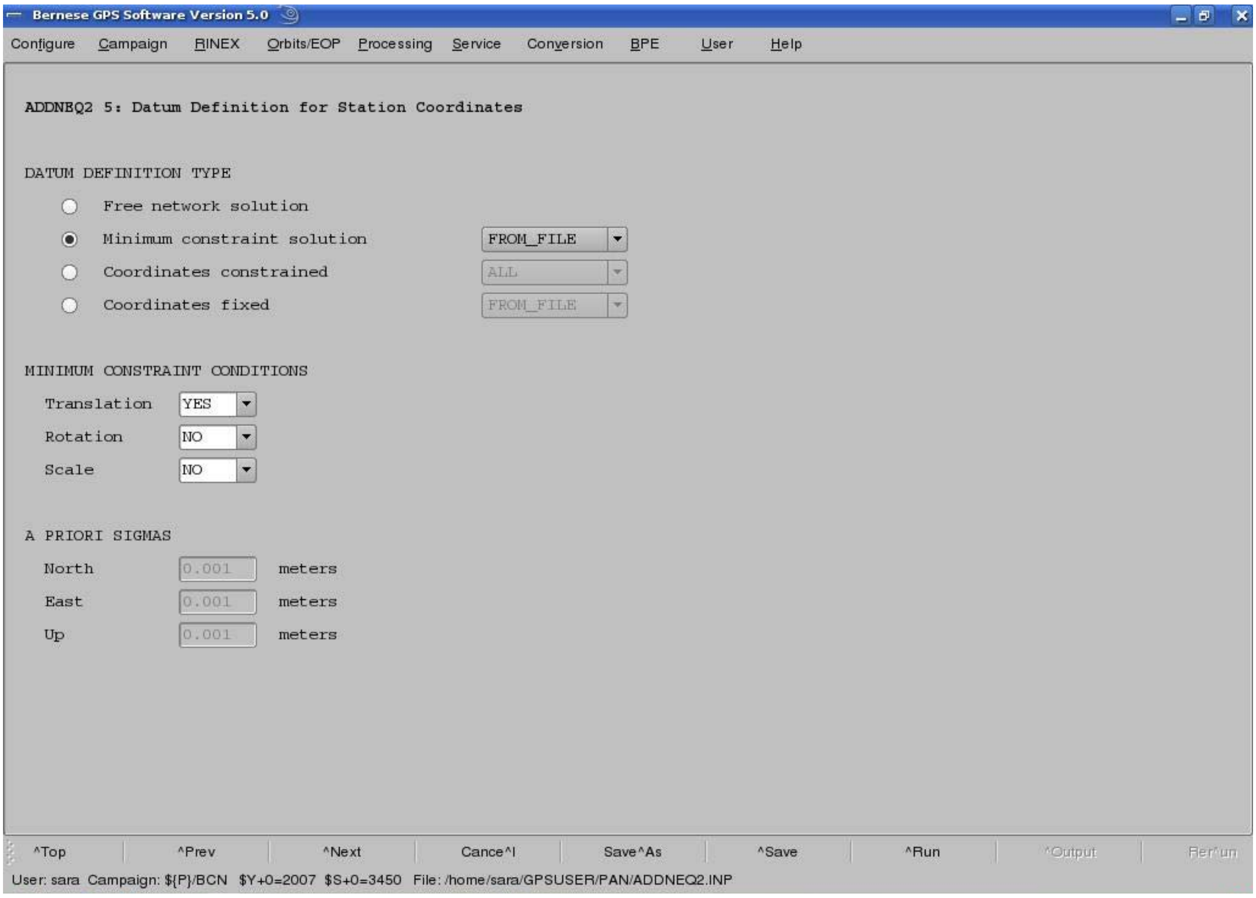


Figure 33: General options of the ADDNEQ2 program

5.3 Post processing with the TGO

To elaborate the data with the TGO software it is necessary to follow same phases that are:

- define the project (characteristic parameters of the measurements as system of reference, used files, number and duration of the sessions of measure, et cetera);

- import the data in the project and the inherent information of all the single stations of the net (measures of phase or code) and the satellites (ephemeris broadcast or precise);

- process the baselines following the most opportune strategy to adopt;

- adjust the net using the least squares adjustment;

- show the results (the compensate coordinates, relative errors and point error ellipses, etcetera).

5.3.1 Definition of the project

Is it, therefore, necessary at first to create a new project (*File* → New Project....) defining the proprieties of the same (additional information, system of coordinates, unity of measure and formats, et cetera).

Through the panel *Project Properties* is possible to plan the system of coordinates (*Coordinate System Settings*) to adopt for the elaboration.

With the command *Change* it is possible to define the type of projection (*system*), the zone (*zone*), the datum or the ellipsoid of reference (*datum*) and the model of geoide (*geoid model*).

It is possible to observe in the following the choice performed for the net object of study.

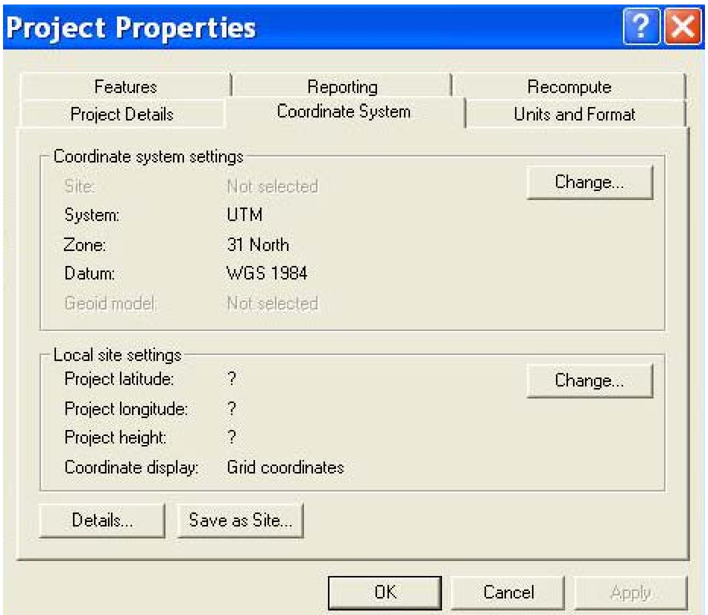


Figure 34: The project properties in the TGO software

To import in the software the observable data use the option (*File → Import)* and select the extension of the data.

In our case the imported file are in the RINEX format:

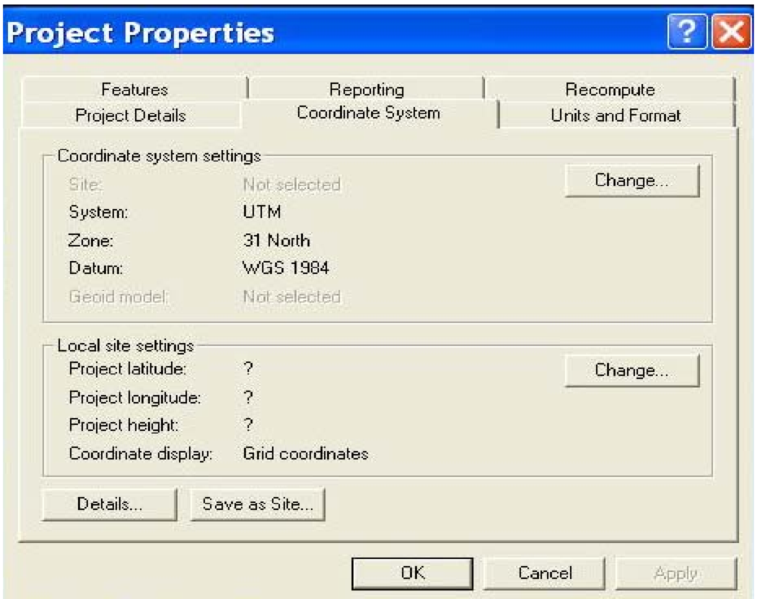
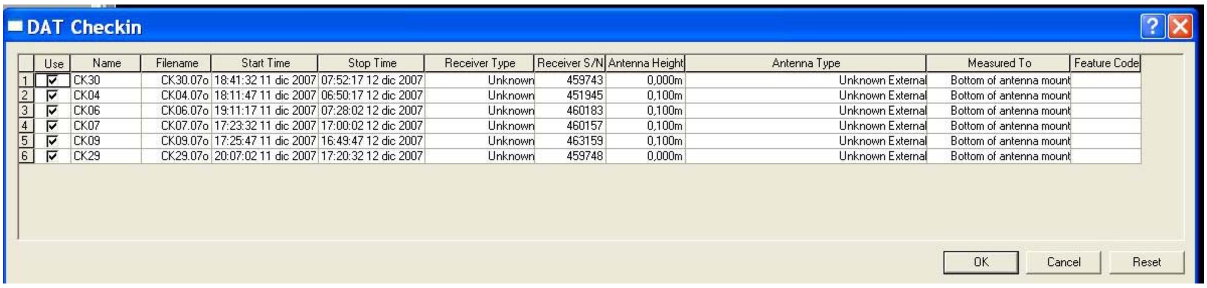


Figure 35: Other parameters defined in the project with the TGO

5.3.2 Import file

After the importation of the RINEX file (observations data and navigations data) appears a dialog (*Dat Checkin*) in which it is possible to change the value of each GPS station (name, antenna type, antenna height).



DAT Checkin

	Use	Name	Filename	Start Time	Stop Time	Receiver Type	Receiver S/N	Antenna Height	Antenna Type	Measured To	Feature Code
1	☑	CK30	CK30.07o	18:41:32 11 dic 2007	07:52:17 12 dic 2007	Unknown	459743	0,000m	Unknown External	Bottom of antenna mount	
2	☑	CK04	CK04.07o	18:11:47 11 dic 2007	06:50:17 12 dic 2007	Unknown	451945	0,100m	Unknown External	Bottom of antenna mount	
3	☑	CK06	CK06.07o	19:11:17 11 dic 2007	07:28:02 12 dic 2007	Unknown	460183	0,100m	Unknown External	Bottom of antenna mount	
4	☑	CK07	CK07.07o	17:23:32 11 dic 2007	17:00:02 12 dic 2007	Unknown	460157	0,100m	Unknown External	Bottom of antenna mount	
5	☑	CK09	CK09.07o	17:25:47 11 dic 2007	16:49:47 12 dic 2007	Unknown	463159	0,100m	Unknown External	Bottom of antenna mount	
6	☑	CK29	CK29.07o	20:07:02 11 dic 2007	17:20:32 12 dic 2007	Unknown	459748	0,000m	Unknown External	Bottom of antenna mount	

OK Cancel Reset

Figure 36: The imported data

Subsequently we can import the precise ephemeris of the our measurements sessions, (*Precise ephemeris files*), downloaded by the IGS (*International GPS Service* http://igscb.jpl.nasa.gov/ components/prods_cb.html).

At this point, the software shows the point and all the potential baselines formed between the vertexes. The possibility to interact with the graphical elements of the net permits to kwon everything about the point and to change the same.

The TGO choose in automatic way, in base to the time of observation, the optimal verse of all the baselines (if, for example, among two stations A and B, the station A. has once of greater observation, the toward some baseline will be from A to B; however the user can change the verse).

In this phase it is possible to represent, in a graphic way, with a temporal reference system, the observations done pick up by every station (View → Timeline) to disable, eventually, those affects by cycles slips (it is better to perform such operation after the process of the baselines).

It is possible, besides, to represent graphically, for every station, information related to the PDoP and to the satellite constellation.

If there is the knowledge of the precise coordinates of a station (as this case) it is possible to plan manually them modifying the ownerships of the same station.

The following windows show same parameters that permit to the user to test the quality of the measure.

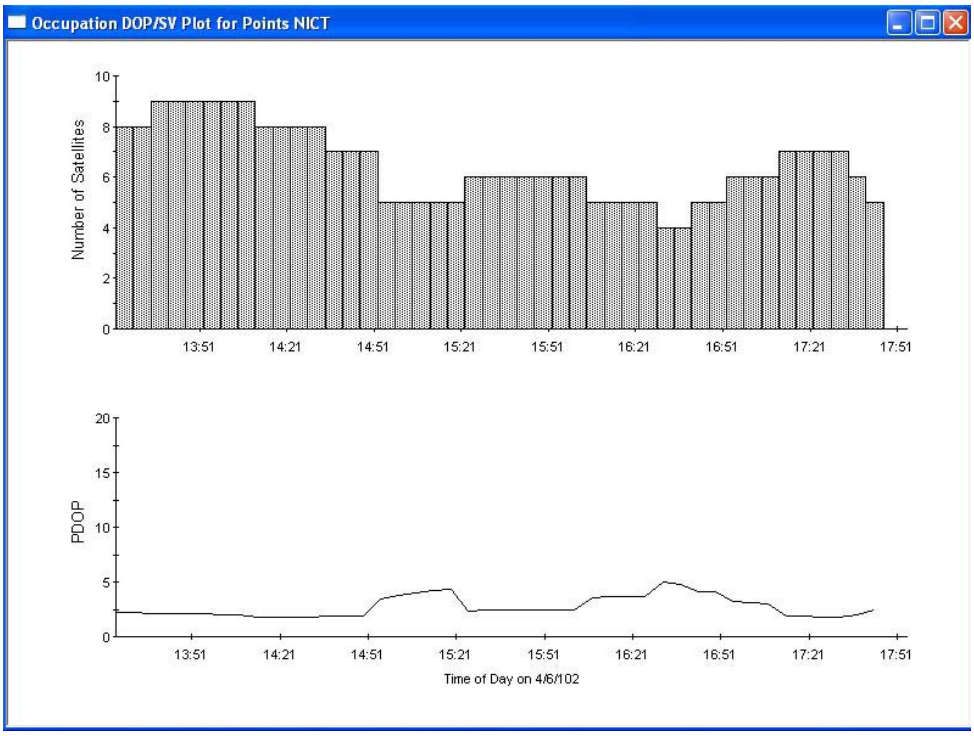


Figure 37: Occupation DOP/SV

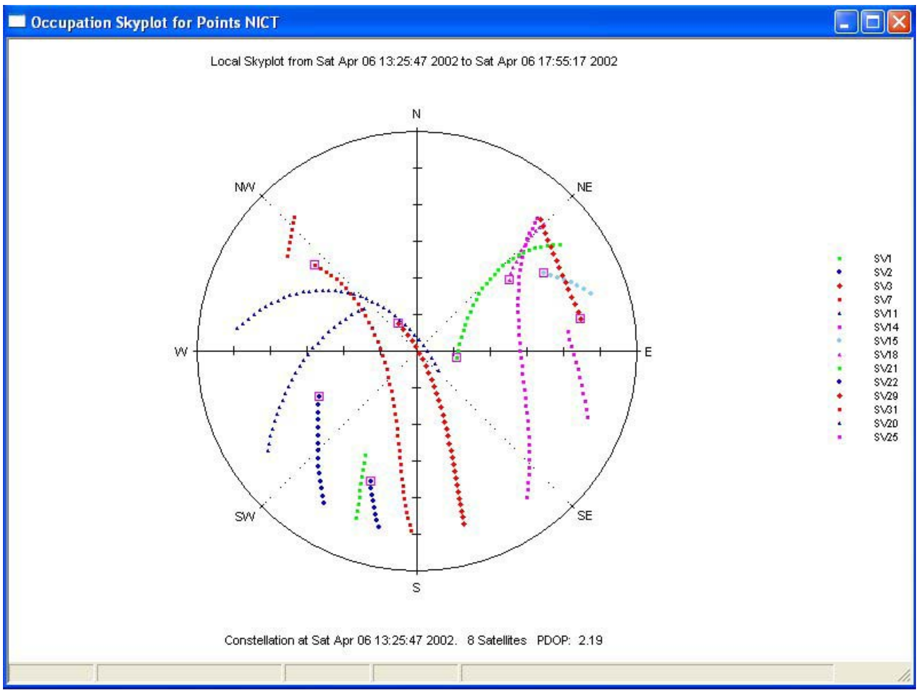


Figure 38: Occupation Skyplot

Before to process the baselines with the TGO software (*Survey* → *Process GPS Baselines)* it is necessary to define the processing strategy through the window *Survey* →*GPS Processing Style.*

The software allows to solve the ambiguity with different combinations: L_5 (*wide-lane*), L_3 (narrow-lane), L1 and L2.

Some parameters as the ratio and the reference variances give the possibility to the user to check the quality of the obtained solution.

The following parameters are used for our project:

- ✓ Ephemeris type (Ephemeris): Precise;
- ✓ cut-off angle (Elevation mask): 15°;
- ✓ solution type (Solution type): Fixed.

Figure 39: Parameters of the TGO

With the option *Advanced* , it is possible to select other parameters as the troposphere model (Hopfield, Saastamoinen, ecc.) and the parameter to accept the processed baselines.

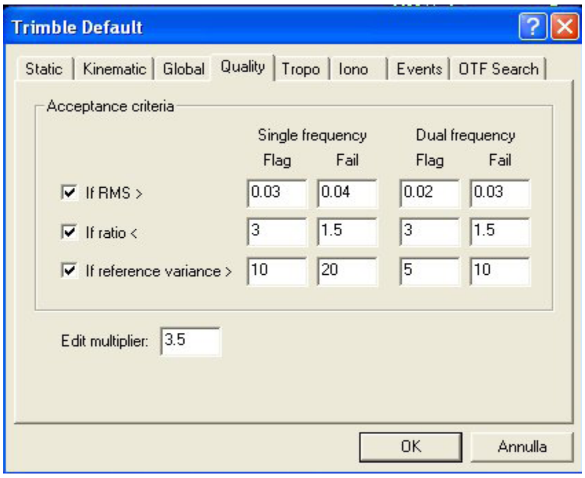


Figure 40: parameter of the project

Defined the strategy we can process all the baselines (*Survey* → *Process GPS Baselines)* as the following:

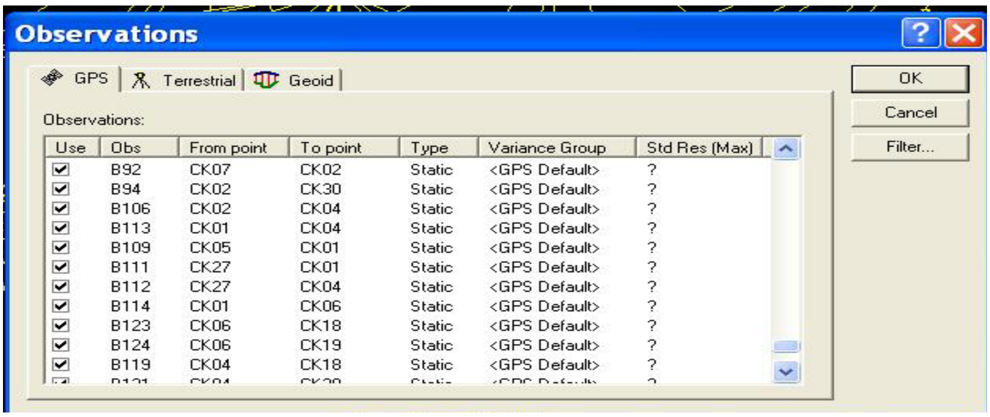


Figure 41: Observations file

5.3.3 Data processing

In the Trimble Geomatics Office the adjust of the net (*Adjustment* → *Adjust*) must be precedes from three consecutive operations: choice of the style of compensation (*Adjustment* → *Adjustment Styles*), tie of the stations (*Adjustment* → *Points*) and choice of the independent baselines (*Adjustment* → *Observations*).

The default styles of compensation are three: the element of distinction is the scalar sigma, a mathematical function that describes the behaviour of a one-dimensional casual error (*univariate scalar sigma*) and two- dimensional (*bivariate scalar sigma*).

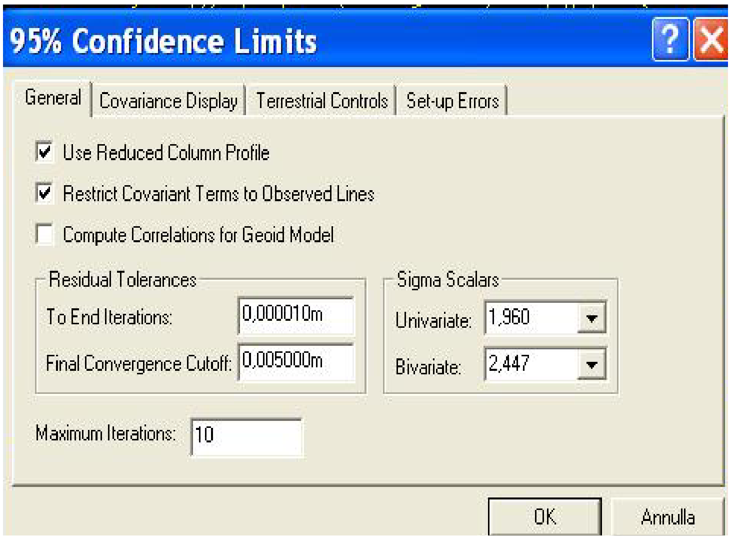


Figure 42: Network Adjustment Styles

In this case we chose the *95% Confidence Limits*, in with the propagation of the errors is showed in terms of the standard error equal to 2σ.

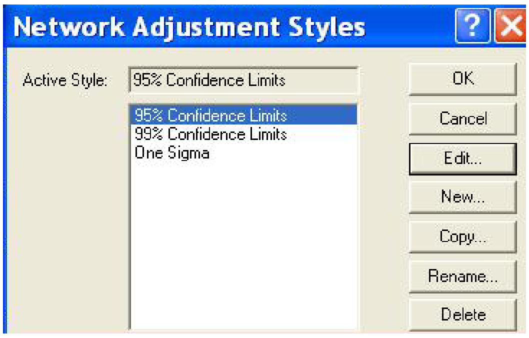


Figure 43: Windows of the Network Adjustment Styles

At the and we select the independent baselines that satisfied better the following preferential criterions:

1. type of solution: *ionofree fixed*;
2. more elevated values of the ratio;
3. lower values of the reference variance and of the rms.

The use of independent baselines assures that the compensation of the net isn't affected from strong redundancies, due to an excessive number of degrees of liberty that could turn in a low valuation of the error in the compensated coordinates.

the results of the elaboration are saved in a HTML file (*Reports → Network Adjustment Report*) with a summary of the styles chosen to adjust the net. There are also some statistic information as the Chi – Quadro test, standard error of the unity of weight of the net and the single baselines, degrees of liberty, number of redundancies, the geographical coordinates compensated of the various stations with the relative ellipses of error and the histograms of the standardized residues.

The histogram of the standardized residues visualizes the following characteristics: distribution of the frequency of the standardized residues, excluded observations, curve of the normal distribution (of Gauss), critical value of Tau.

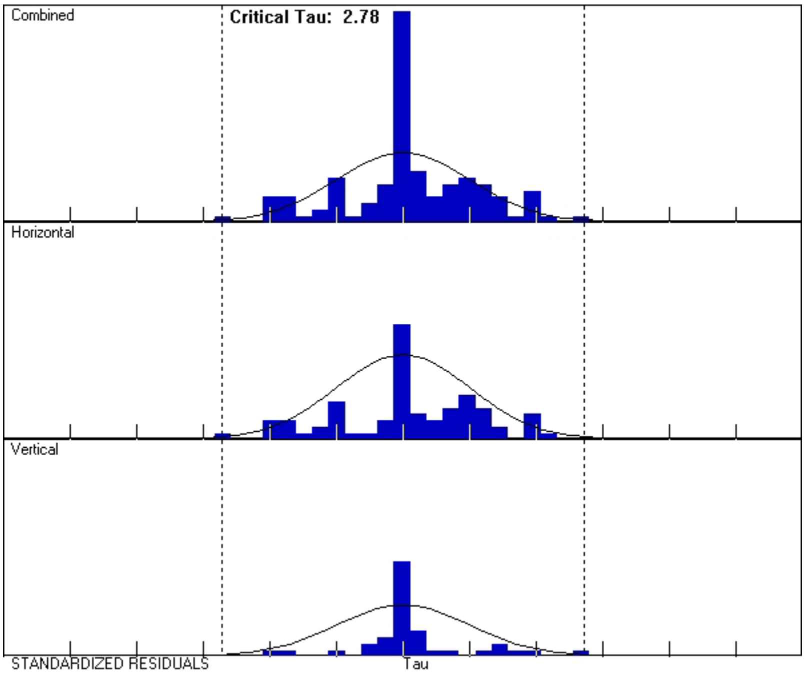
Besides, such histograms contain the following graphic information:

- combined: diagram combined of both the standardized residuals of the horizontal and vertical observations;

- horizontal: diagram of the standardized residuals of the horizontal observations;

- vertical: diagram of the standardized residuals of the vertical observations.

These show graphically the distribution of the frequency of the standardized residuals of the observation of the adjust. The statistics of the compensated observations underline the standardized residuals for every observation; the central vertical line is the residual zero.



. Figure 44: Standard residuals

Based on the normal distribution, the smallest residues are gathered in it and they show the tallest frequency. The greatest residues are lost around the value zero and they get further to decrease of frequency.

If the residues of the compensation are distributed to "random", the diagram of distribution frequency approximates the curve of normal distribution..

The vertical lines to the left and to the right of the line zero represent the critical Tau value; every standardized residue that it goes beyond the line of the curve it is "outlier."

the *Network Reference Factor* represents the relationship among the s.q.m. apriopri (preadjustment) and the s.q.m. a posteriori (post-adjustment).

The Chi – Quadro test underlines the goodness of the adjustment. If the value E.F. is good and the degrees of liberty of the net are acceptable, the net is mathematically approved, and the Chi – Quadro test isn't fail. The Chi – Quadro test represents the first indicator of the happened mathematical closing of the net, for an adjust to the least squares estimation.

The degrees of liberty underline the global entity of the redundancies of the net. They show the number of the independents observations, used as overestimate solutions.

5.3 The final solution

The following tables shows the results obtained with the postprocessing with the two softwares:

- Bernese GPS software;
- TGO GPS software.

Table 6: The N obtained coordinates of the stations with the Bernese GPS software using the two permanent station: Bellmunt de Segarra and les Planes.

STAZIONE	N	Rms [m]
CK01	41°50'0.862026"	0.0006
CK02	41°54'39.079232"	0.0007
CK03	41°53'55.142189"	0.0007
CK04	41°53'24.872166"	0.0006
CK05	41°55'18.454916"	0.0007
CK06	41°52'39.757686"	0.0007
CK07	41°56'15.178198"	0.0006
CK08	41°52'4.920700"	0.0006
CK09	41°54'2.847501"	0.0007
CK10	41°53'56.209789"	0.0007
CK11	41°58'0.735275"	0.0007
CK12	41°51'9.682870"	0.0006
CK13	41°54'51.399934"	0.0007
CK14	41°50'41.925066"	0.0007
CK15	41°54'58.739389"	0.0007
CK16	41°58'18.424078"	0.0008
CK17	41°51'56.938971"	0.0007
CK18	41°47'41.421723"	0.0006
CK19	41°47'35.830956"	0.0006
CK20	41°49'1.881793"	0.0007
CK21	41°48'18.636521"	0.0006
CK22	41°47'27.666121"	0.0006
CK23	41°48'50.129904"	0.0006
CK24	41°48'32.300607"	0.0006
CK25	41°47'20.605360"	0.0006
CK26	41°46'12.613469"	0.0006
CK27	41°58'27.930209"	0.0007
CK28	41°44'27.102433"	0.0006
CK29	41°54'50.835417"	0.0007
CK30	41°54'14.888811"	0.0007
CK31	41°49'36.608714"	0.0006
CK32	41°50'21.474001"	0.0007
CK33	41°48'49.872388"	0.0006
CK34	41°49'4.472474"	0.0006
CK35	41°51'59.374544"	0.0007
CK36	41°50'52.771561"	0.0007
BELL	41°35'58.615287"	0.0002
PLAN	41°25'6.689605"	0.0002

Table 7 : The S obtained coordinates of the stations with the Bernese GPS software using the two permanent station: Bellmunt de Segarra and les Planes.

STAZIONE	E	Rms [m]
CK01	1°31'44.237357"	0.0004
CK02	1°31'27.415254"	0.0004
CK03	1°33'57.411450"	0.0004
CK04	1°37'23.402559"	0.0004
CK05	1°36'13.837553"	0.0004
CK06	1°41'25.295615"	0.0004
CK07	1°41'13.366836"	0.0003
CK08	1°45'47.025928"	0.0004
CK09	1°44'38.369952"	0.0004
CK10	1°46'46.240090"	0.0004
CK11	1°47'10.920240"	0.0004
CK12	1°49'34.304422"	0.0003
CK13	1°51'55.886320"	0.0004
CK14	1°56'2.936975"	0.0005
CK15	1°56'39.942845"	0.0005
CK16	1°57'32.752772"	0.0005
CK17	2°3'45.156321"	0.0005
CK18	1°32'42.400119"	0.0004
CK19	1°36'39.776972"	0.0004
CK20	1°36'25.347240"	0.0004
CK21	1°39'35.025729"	0.0004
CK22	1°44'1.294445"	0.0004
CK23	1°47'7.959879"	0.0004
CK24	1°53'21.748123"	0.0004
CK25	1°59'26.626472"	0.0005
CK26	1°34'27.716115"	0.0004
CK27	1°38'12.114649"	0.0004
CK28	1°46'51.485405"	0.0004
CK29	1°41'9.356490"	0.0004
CK30	1°40'2.391661"	0.0004
CK31	1°47'30.944730"	0.0004
CK32	1°45'4.881026"	0.0005
CK33	1°53'49.298618"	0.0004
CK34	1°54'10.818306"	0.0004
CK35	1°52'8.440030"	0.0004
CK36	1°53'21.959236"	0.0004
BELL	1°24'4.094214"	0.0003
PLAN	1°59'13.026097"	0.0003

Table 8: The U obtained coordinates of the stations with the Bernese GPS software using the two permanent station: Bellmunt de Segarra and les Planes.

STAZIONE	U [m]	Rms [m]
CK01	9.817.860	0.0017
CK02	9.146.511	0.0018
CK03	8.511.807	0.0018
CK04	7.659.204	0.0016
CK05	7.128.394	0.0017
CK06	6.953.632	0.0017
CK07	7.281.293	0.0014
CK08	5.559.678	0.0016
CK09	7.506.038	0.0017
CK10	7.330.666	0.0017
CK11	8.385.431	0.0018
CK12	6.763.332	0.0014
CK13	6.161.066	0.0017
CK14	6.312.659	0.0021
CK15	6.422.349	0.0019
CK16	8.408.708	0.0019
CK17	8.533.794	0.0018
CK18	8.471.027	0.0017
CK19	9.726.067	0.0018
CK20	8.167.473	0.0019
CK21	9.547.556	0.0018
CK22	6.508.583	0.0018
CK23	5.737.333	0.0015
CK24	5.249.081	0.0017
CK25	6.201.364	0.0017
CK26	8.815.407	0.0020
CK27	6.737.540	0.0017
CK28	5.943.109	0.0019
CK29	6.347.965	0.0018
CK30	6.619.562	0.0017
CK31	5.214.492	0.0018
CK32	4.239.695	0.0019
CK33	3.253.571	0.0017
CK34	4.096.407	0.0016
CK35	4.717.875	0.0018
CK36	4.550.521	0.0018
BELL	8.534.015	0.0004
PLAN	3.199.604	0.0004

Table 9: The N obtained coordinates of the stations with the Bernese GPS software, fixing the CK07 point.

STAZIONE	N	Rms [m]
CK01	41°50'0.871413"	0.0007
CK02	41°54'39.088682"	0.0004
CK03	41°53'55.151626"	0.0005
CK04	41°53'24.881575"	0.0005
CK05	41°55'18.464354"	0.0004
CK06	41°52'39.767091"	0.0005
CK07 (FIX)	41°56'15.178089"	0.0000
CK08	41°52'4.930024"	0.0006
CK09	41°54'2.856850"	0.0004
CK10	41°53'56.219086"	0.0006
CK11	41°58'0.744547"	0.0006
CK12	41°51'9.692121"	0.0007
CK13	41°54'51.409175"	0.0006
CK14	41°50'41.934319"	0.0008
CK15	41°54'58.748610"	0.0007
CK16	41°58'18.433294"	0.0007
CK17	41°51'56.948191"	0.0007
CK18	41°47'41.431092"	0.0009
CK19	41°47'35.840322"	0.0009
CK20	41°49'1.891272"	0.0008
CK21	41°48'18.645854"	0.0008
CK22	41v47'27.675421"	0.0009
CK23	41°48'50.139138"	0.0008
CK24	41°48'32.309881"	0.0008
CK25	41°47'20.614632"	0.0009
CK26	41°46'12.622830"	0.0010
CK27	41°58'27.939657"	0.0005
CK28	41°44'27.111788"	0.0011
CK29	41°54'50.844757"	0.0004
CK30	41°54'14.898204"	0.0004
CK31	41°49'36.617990"	0.0008
CK32	41°50'21.483251"	0.0007
CK33	41°48'49.881646"	0.0008
CK34	41°49'4.481726"	0.0008
CK35	41°51'59.383794"	0.0007
CK36	41°50'52.780826"	0.0008

Table 10: The S obtained coordinates of the stations with the Bernese GPS software, fixing the CK07 point.

STAZIONE	E	Rms [m]
CK01	1°31'44.258101"	0.0008
CK02	1°31'27.436012"	0.0008
CK03	1°33'57.432231"	0.0006
CK04	1°37'23.423426"	0.0004
CK05	1°36'13.858373"	0.0005
CK06	1°41'25.316509"	0.0004
CK07 (FIX)	1°41'13.367401"	0.0000
CK08	1°45'47.046854"	0.0005
CK09	1°44'38.390807"	0.0004
CK10	1°46'46.260959"	0.0005
CK11	1°47'10.941124"	0.0005
CK12	1°49'34.325251"	0.0007
CK13	1°51'55.907187"	0.0008
CK14	1°56'2.957802"	0.0010
CK15	1°56'39.963705"	0.0010
CK16	1°57'32.773642"	0.0011
CK17	2°3'45.177118"	0.0014
CK18	1°32'42.420857"	0.0007
CK19	1°36'39.797750"	0.0005
CK20	1°36'25.368172"	0.0006
CK21	1°39'35.046483"	0.0005
CK22	1°44' 1.315245"	0.0005
CK23	1°47'7.980445"	0.0006
CK24	1°53'21.768915"	0.0009
CK25	1°59'26.647254"	0.0012
CK26	1°34'27.736862"	0.0006
CK27	1°38'12.135508"	0.0004
CK28	1°46'51.506414"	0.0006
CK29	1°41'9.377376"	0.0003
CK30	1°40'2.412522"	0.0003
CK31	1°47'30.965595"	0.0007
CK32	1°45'4.901479"	0.0005
CK33	1°53'49.319408"	0.0009
CK34	1°54'10.839090"	0.0009
CK35	1°52'8.460913"	0.0008
CK36	1°53'21.980094"	0.0009

Table 11: The U obtained coordinates of the stations with the Bernese GPS software, fixing the CK07 point.

STAZIONE	U [m]	Rms [m]
CK01	9.821.330	0.0017
CK02	9.150.000	0.0016
CK03	8.515.291	0.0015
CK04	7.662.689	0.0014
CK05	7.131.893	0.0015
CK06	6.957.078	0.0015
CK07 (FIX)	7.281.569	0.0000
CK08	5.563.097	0.0016
CK09	7.509.514	0.0014
CK10	7.334.114	0.0017
CK11	8.388.884	0.0018
CK12	6.766.765	0.0018
CK13	6.164.516	0.0019
CK14	6.316.111	0.0024
CK15	6.425.796	0.0023
CK16	8.412.167	0.0021
CK17	8.537.211	0.0023
CK18	8.474.508	0.0019
CK19	9.729.540	0.0019
CK20	8.170.932	0.0019
CK21	9.551.069	0.0019
CK22	6.512.115	0.0020
CK23	5.740.750	0.0019
CK24	5.252.508	0.0022
CK25	6.204.773	0.0023
CK26	8.818.893	0.0020
CK27	6.741.037	0.0015
CK28	5.946.626	0.0020
CK29	6.351.441	0.0014
CK30	6.623.070	0.0013
CK31	5.217.913	0.0020
CK32	4.243.188	0.0019
CK33	3.257.004	0.0021
CK34	4.099.837	0.0021
CK35	4.721.334	0.0023
CK36	4.553.941	0.0023

Table 12: The N obtained coordinates of the stations with the TGO GPS software, fixing the CK07 point.

STAZIONE	N	Rms [m]
CK04	41°53'24,87213"	0,002
CK09	41°54'02,84754"	0,002
CK07 (FIX)	41°56'15,17809"	0,000
CK02	41°54'39,07917"	0,002
CK30	41°54'14,88882"	0,002
CK05	41°55'18,45490"	0,002
CK01	41°50'00,86198"	0,002
CK27	41°58'27,93017"	0,002
CK06	41°52'39,75781"	0,002
CK18	41°47'41,42176"	0,002
CK20	41°49'01,88202"	0,002
CK19	41°47'35,83100"	0,002
CK22	41°47'27,66612"	0,002
CK21	41°48'18,63656"	0,002
CK23	41°48'50,12986"	0,002
CK29	41°54'50,83517"	0,001
CK08	41°52'04,92039"	0,001
CK11	41°58'00,73504"	0,000
CK12	41°51'09,68249"	0,000
CK13	41°54'51,39963"	0,000
CK16	41°58'18,42378"	0,000
CK15	41°54'58,73900"	0,001
CK35	41°51'59,37423"	0,000
CK25	41°47'20,60501"	0,001
CK36	41°50'52,77126"	0,001
CK17	41°51'56,93876"	0,001
CK34	41°49'04,47214"	0,001
CK33	41°48'49,87212"	0,000
CK24	41°48'32,30028"	0,000

Table 13: The S obtained coordinates of the stations with the TGO GPS software, fixing the CK07 point.

STAZIONE	E	Rms [m]
CK04	1°37'23,40292"	0,001
CK09	1°44'38,37044"	0,002
CK07 (FIX)	1°41'13,36740"	0,000
CK02	1°31'27,41558"	0,001
CK30	1°40'02,39216"	0,001
CK05	1°36'13,83798"	0,002
CK01	1°31'44,23771"	0,001
CK27	1°38'12,11506"	0,001
CK06	1°41'25,29601"	0,002
CK18	1°32'42,40044"	0,002
CK20	1°36'25,34774"	0,002
CK19	1°36'39,77733"	0,002
CK22	1°44'01,29486"	0,002
CK21	1°39'35,02601"	0,002
CK23	1°47'07,96017"	0,002
CK29	1°41'09,35703"	0,001
CK08	1°45'47,02657"	0,001
CK11	1°47'10,92079"	0,000
CK12	1°49'34,30497"	0,000
CK13	1°51'55,88696"	0,000
CK16	1°57'32,75339"	0,000
CK15	1°56'39,94345"	0,001
CK35	1°52'08,44055"	0,000
CK25	1°59'26,62708"	0,001
CK36	1°53'21,95982"	0,001
CK17	2°03'45,15691"	0,000
CK34	1°54'10,81890"	0,000
CK33	1°53'49,29917"	0,000
CK24	1°53'21,74866"	0,000

Table 14: The U obtained coordinates of the stations with the TGO GPS software, fixing the CK07 point.

STAZIONE	U	Rms [m]
CK04	765,95	0,011
CK09	750,63	0,012
CK07 (FIX)	728,157	0,000
CK02	914,684	0,009
CK30	661,998	0,011
CK05	712,872	0,013
CK01	981,819	0,011
CK27	673,782	0,012
CK06	695,398	0,012
CK18	847,144	0,012
CK20	816,78	0,013
CK19	972,643	0,013
CK22	650,904	0,013
CK21	954,792	0,014
CK23	573,772	0,013
CK29	634,821	0,004
CK08	555,981	0,004
CK11	838,558	0,002
CK12	676,346	0,002
CK13	616,122	0,002
CK16	840,883	0,003
CK15	642,243	0,005
CK35	471,804	0,003
CK25	620,14	0,004
CK36	455,059	0,005
CK17	853,38	0,001
CK34	409,635	0,001
CK33	325,357	0,001
CK24	524,906	0,001

CHAPTER 6 ***CONCLUSION***

The use of the Bernese software isn't very simple even if its results are sure more dependable that the TGO software, that is more userfriendly. The short time available to study all the advantages that the Bernese offers is a limit in an approach with this scientific software. In you are more confidence in the post processing with the Bernese, this software will help you in the choice of a singular parameters in order to obtain a high quality of results.

On the other hand also with the TGO it is possible to adopt the parameter that represent our project, but the options are less than in the Bernese software. Another aspect that I want to underline is the time spend to elaborate the campaign in both softwares. In fact with the TGO software it is very immediate to import the data, to select the parameters, to adjust the network and to obtain the final coordinates, final goal of our study.

While with the Bernese the same task is very long, because sometimes the software ask you to run more time the same program or to process the independent baselines singularly. In addition to that the Bernese choices automatically the best baselines in our network and while in the TGO you can select all ore more independent baselines. After the elaboration of the campaign in the Bernese software, the output file show a correction between the a priori value and the estimated value that has a millimetric order, and the rms error that have the same order. So we can see how the GPS system is the best methodology to use in the monitoring of the surface movements if the aim is to obtain a results of this level.

However in my point of view just a single campaign of measurement is not enough to give certain answers because with the help of another or more set of observations we can verify the quality of the data and of the probable movements. And advanced idea is to add to the network other points, in order to have more observations measurements, so in this case we can adopt a different scheme the zona affected by movements due to salt mining activities. On the other hand just in this work, we use two additional permanent stations. With this strategies, the results obtained in the postprocessing with the Bernese GPS software are very satisfactory.

In addition, if the aim of the work is to test and verify the presence of certain movements we will use sure one or more fixed points to monitoring the network. So it is necessary to observe these point for all the days that make our network, in order to get same advantages in the use of the post- processing software, that as the case of the Bernese, need of this situation.