UNIVERSIDADE DA BEIRA INTERIOR
Faculdade de Engenharia

Automatic Local Coordinates
Evaluating and automating methods to estimating 3D coordinates with respect to a specific Datum

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Dissertação para obtenção do Grau de Mestre em
Engenharia Informática
(2º ciclo de estudos)

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Covilhã, Outubro de 2016

To my parents Maria da Graça and António Jorge and to my girlfriend Maria Domingues.

Acknowledgments

First and foremost, I would like to thank my supervisor Prof. Rui Fernandes for all his support, availability, for believing in me and for his never ending patience. His guidance and teaching along the course of this dissertation was crucial for understating definitions and methods from such a different but extremely interesting research area. It was extremely important to count with his vast experience and knowledge.

I must also thank my family and girlfriend who have always been extremely supportive on all steps of my life, without them I wouldn't be writing this dissertation. To my parents, Maria da Graça and António Jorge, for everything they have done for me, for all the headaches I must have caused and for always believing in me, they definitely did the best job in raising me and always pointing me in the right direction. To my girlfriend Maria Domingues who since the beginning also always supported me and believed in me, thank you for all your comprehension, support and love. Last but not least, I would also like to thank my sister for all the support.

I would also like to thank the members of SEGAL, specially Hugo Valentim for his friendship and encouragement that led me to do this work. Still from SEGAL I would like to also specially thank Machiel Bos and André de Sá for sharing their knowledge and experience with me. Finally, I would also like to thank Prof. Carlos Barrico, Prof. Paul Crocker and João Apolinário for their support.

I couldn't finish the acknowledgments without referring ReNEP (http://www.dgterritorio.pt/cartografia_e_geodesia/geodesia/redes_geodesicas/renep/), SERVIR (https://www.igeoe.pt/ index.php?id=45), NASA/JPL (http://www.gdgps.net), NRCAN (http://nrcan.gc.ca), AUSPOS (http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos) and also EOARD - US Air Force (Project SOGRA) for their openness and availability to provide data to support this dissertation.

Abstract

The physical location of a specific point in the globe does not has the same coordinates as time passes by. This is due to the movement of the tectonic plates. The physical point, observed in a specific day, changes as function of time and consequently its precise coordinates change as well.

However, for many geo-referencing applications (mapping, navigation, etc.) it is preferable to consider static reference frames such as the system currently in force in Portugal (PT-TM06 / ETRS). To obtain the coordinates of a point in relation to a static reference frame it is necessary: (1) processing the observation data, and (2) convert this data for the selected reference datum. For processing the observation data it is possible to use online GNSS data processing services. These are simple to use and provide this type of post-processing to groups with lower financial resources and / or specific expertise. However, these require converting the results of the online services from the used datum (usually the materialization of the last ITRF at the time of observation) to the desired reference datum. This is accomplished through the calculation and application of transformation parameters to the coordinates obtained in the online processing.

This thesis presents in detail the implementation of a solution that aims to automate the entire process of calculating coordinates in a given datum reference (usually national) using online processing services. The application to Portugal was used as case study, using the National Network of GNSS Permanent Stations (ReNEP), which is managed by the Direcção Geral do Território to materialize the reference datum. The focus of this work has been more focused on informatics component, however other studies were also conducted that allowed to the evaluation of the quality of the obtained coordinates and to define some of the parameters required to optimize these. To obtain the coordinates of the final system (for Portugal, the national materialization of ETRS89) it was necessary to develop several tools, which were subsequently tested and validated, and consist in:

- Automatic GNSS data processing using online processing services;
- Gross error detection (*outliers*) and formal error normalization given by online services;
- Calculation and subsequent application of coordinate transformation parameters;
- Development of a web service to be provided to the community.

In the developed tools there is still room for expansion (such as adding more online services) and improvement of some features (such as automatic integration with the MGN application (GNSS Networks Management) and automatic detection of errors in the reference stations). However, the objectives have been achieved and currently, the tool and the web service are available in operating mode (although not yet officially released), hosted in SEGAL servers ready to be tested by the community. It also planned to test the implementation of the ALC in other countries (eg. Mozambique, Bhutan).

Palavras-chave

Process Automation, Web Services, Coordinate Estimation

Resumo Alargado

A localização física de um determinado ponto no globo não tem sempre as mesmas coordenadas, isto porque, devido ao movimento das placas tectónicas o ponto físico, observado num determinado dia, muda em função do tempo e consequentemente as coordenadas precisas desse ponto também.

No entanto, para muitas aplicações de geo-referênciação (mapeamento, navegação, etc) é preferível considerar referenciais estáticos como é o caso do sistema atualmente em vigor em Portugal (PT-TM06/ETRS). Para obter as coordenadas de um ponto em relação a um referencial estático é necessário: (1) processar os dados de observação e (2) converter os resultados para esse o datum de referência selecionado. Para processamento dos dados de observação pode-se recorrer a serviços online de processamento de dados GNSS, pois estes são simples de usar e permitem tornar este tipo de pós-processamento mais acessível a grupos com menores recursos financeiros e/ou conhecimentos específicos. No entanto, exigem converter os resultados destes serviços do datum utilizado (normalmente a materialização do último ITRF à época da observação) para o datum de referência pretendido. Isso é realizado através do cálculo e aplicação de parâmetros de transformação às coordenadas obtidas no(s) processamento(s) online.

Nesta dissertação é apresentada em detalhe a implementação de uma solução que visa automatizar todo o processo de calcular coordenadas num dado datum de referência (normalmente nacional) utilizando serviços de processamento online. A aplicação a Portugal foi usada como objecto de estudo, tendo-se utilizado a Rede Nacional de Estações Permanentes GNSS (ReNEP), que é gerida pela Direcção Geral do Território para materializar o datum de referência. O foco deste trabalho concentrou-se mais na componente informática, sendo que foram também realizados estudos que permitiram avaliar a qualidade das coordenadas obtidas e decidir alguns dos parâmetros necessários para otimizar estas. Para obtenção de coordenadas no sistema final (no caso de Portugal, a materialização nacional do ETRS89), foi necessário desenvolver várias ferramentas, que foram posteriormente testadas e validadas e, que consistem em:

- Processamento automático de dados GNSS usando serviços de processamento online;
- Detecção de erros grosseiros (*outliers*) e normalização dos erros formais dados pelos serviços online;
- Cálculo e posterior aplicação de parâmetros de transformação de coordenadas;
- Desenvolvimento de um serviço web para disponibilização do sistema à comunidade.

Nas ferramentas desenvolvidas existe ainda possibilidade de expansão (tal como adicionar mais

serviços online) e melhoria de algumas funcionalidades (como integração automática com a aplicação MGN (Management GNSS Networks) e deteção automática de erros nas estações de referência). Contudo, os objectivos foram atingidos e atualmente, a ferramenta e o serviço web encontra-se disponível em modo operacional (embora não ainda disponibilizada oficialmente), alojada nos servidores do SEGAL podendo ser testada pela comunidade. Pretende-se também testar a implementação do ALC em outros países (e.g. Moçambique, Butão).

Palavras-chave

Automatização de Processos, Serviços Web, Estimação de Coordenadas

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Acronyms

ALC	Automatic Local Coordinates
API	Application programming interface
AUSLig	Geoscience Australia
CSRS	Canadian Spatial Reference System
CSRS-PPP	Canadian Spatial Reference System Precise Point Positioning
DD	Double Difference
ECEF	Earth Centered Earth Fixed
ETRS	European Terrestrial Reference System
GDA	Geocentric Datum of Australia
GDGPS	Global Differencial GPS System
GDGPS-APPS	Global Differencial GPS System - Automatic Precise Positioning Service
GLONASS	Russian Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IGEoE	Instituto Geográfico do Exército
IGS	International GPS Service
IQR	Interquartile range
ITRF	Internacional Terrestrial Reference Frame
LAT	Latitude
LON	Longitude
MGN	GNSS Network Management System

NAD	North American Datum
NRCan	Natural Resources Canada
PPP	Precise Point Positioning
PT-TM06/ETRS89	Portuguese - Transverve Mercator 2006 - European Terrestrial Reference System 1989
ReNEP	Rede Nacional de Estações Permanentes GNSS
RINEX	Receiver Independent Exchange Format
RMS	Root Mean Square
RTK	Real Time Kinematic
SEGAL	Space & Earth Geodetic Analysis Laboratory
UBI	Universidade da Beira Interior
VCV	Variance-covariance Matrix
WGS84	World Geodetic System 1984
WRMS	Weighted Root Mean Square

Chapter 1

Introduction

This dissertation elaborates on the subject of geographic coordinates estimation and correction using a static reference frame and its integration with a GNSS network management system. The next section presents the problem statement, motivation and scope behind this work, the next-to-last section presents the main contributions to integrate the developed services and making them available to the users, finally the last section describes the contents of each chapter of this dissertation.

1.1 Motivation and problem statement

The physical location of a determined point in the globe doesn't has the exact same coordinates in two different moments since the physical location of that point changes as a result of movement of the tectonic plates. However, for many geo-referencing applications (like mapping), it is preferable to consider static reference frames (i.e., that do not change in time). The reference frame (materialization of the datum) is defined by a set of points on a region, country, continent, or even on the entire planet for which their precise coordinates are calculated and then used as reference. This set of coordinates is then used as official coordinates to relate to for the determination of coordinates of other points even if they are observed at different epochs. The position of a point observed in a different epoch can be converted to the reference epoch by application of transformation parameters like the Helmert transformation method[Wat06].

Supposing that a farmer wants to accurately measure the extents of his vineyards and the vineyards are too far away to use directly the observations of the existing network of permanent stations in the country. The solution is to densify the network by installing a new reference point in the area to be measured (which can also be used later for other projects). Using data from reference stations of the official datum (normally permanent stations like the stations from ReNEP), someone can compute the position of the station with respect to the official datum. Later (or even simultaneously, depending of the selected method but always acquiring data at the reference station), he uses GNSS rovers to get measurements at the corners of the area to be measured that can be used as input in a processing software to acquire the coordinates of all points of interest.

A major condition to guarantee that the coordinates of the corners of field(s) are precisely coordinated with respect to the official datum is to ensure the quality of coordinates of the new reference station. Any deviation on the coordinates of this station will be directly transferred to the coordinates of the other points. In the example of the vineyards, and using the current techniques, observations at the reference station would need to be done for several hours (or even days if sub-centimeter accuracy is required) whereas the field corners can be observed only during few minutes. A straight rule for the time of observations does not exist since it depends of several parameters (distance and number of reference stations in vicinity, accuracy needed, local environment, etc.).

This work focuses on the simplification and automatization of the computation of the coordinates of stations that can be used as reference, or by other words, on the computation of the coordinates of points to densify the network of reference coordinates in a country or region. The target end-users are experts (like geodetic technicians) that are not able to access very special processing software (e.g., GIPSY-OASIS, GAMIT, BERNESE) that should be used when the densification (i.e., maintaining the same order of accuracy) of the existing reference frame is required. It is not intended to be used to compute the positions of the corners of the vineyard fields.

This way, the main motivation of this dissertation was to develop a platform and methods to make use of currently available online tools (that compute precise positions relative to a global reference frame at the epoch of observation) in order to automate the estimation of the coordinates of points with respect to a particular regional or national datum. The transformation between the daily global datum and the reference datum for any computed point solution is done by applying transformation parameters which are automatically estimated using a network of reference points with coordinates known on the target datum.

The implications of using daily, weekly or monthly transformation parameters were analyzed for identification of the most accurate approach. The influence of using rapid or precise orbits in the online precise positioning computation were also analyzed. In the end, an application, called ALC - Automatic Local Coordinates, based on web services, was developed using the national reference stations of Portugal - ReNEP[dT] as a case study (even if the ultimate goal is that it can be used for any datum on the globe).

In order to develop this solution, Figures 1.1 and 1.2 present flowcharts with the representation of the main tasks that have been developed in order to obtain accurate coordinates with respect to a specific reference datum. The flowcharts are constituted of small boxes where each represent a specific step/task that was developed/implemented.

Figure 1.1, describes the workflow of the tasks that are automatic carried out (on a daily basis) at the background by ALC in order to obtain the transformation parameters between the daily global datum and the target datum. Namely:

1. **National Network Files** Collection of observation files from the national reference network;
2. **Processing in Online Services** Tools to process the observation files in the different online services (see section 4.5);
3. **Detect Outliers** Methods to detect outliers on the provided solutions from the online services (see chapter 4);
4. **Normalize Formal Errors** Methods to normalize the retrieved solutions from the different online services (see chapter 5);
5. **Merge Solutions** Methods to merge the individual online solutions into a single solution (see chapter 5);
6. **Transformation Parameters** Methods for determination of the Helmert coordinate transformation parameters (see chapter 6).

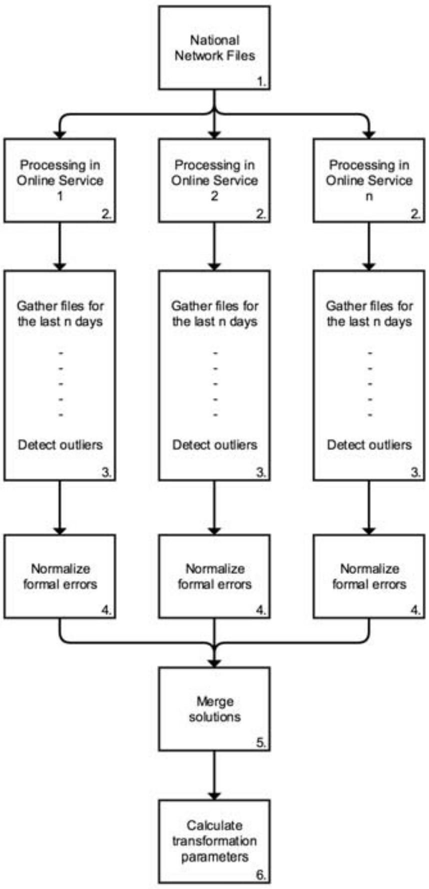


Figure 1.1: ALC background main tasks.

Figure 1.2, shows the workflow of the component of the ALC that interacts with the end-user through a web service that input a user observational file on a given point and outputs the coordinates of this point in the defined reference frame of ALC. The main tasks are:

1. **User File** Observation file that was uploaded by a registered user of the web service;
2. **Processing in Online Services** As defined before;
3. **Normalize Formal Errors** As defined before;
4. **Merge Solutions** As defined before;
5. **Transformation Parameters** Methods for the application of the previously determined Helmert coordinate transformation parameters (see chapter 6);
6. **Generate Report** Tools to generate reports on the estimated final coordinates with a high level of detail (see section 8.2.13).

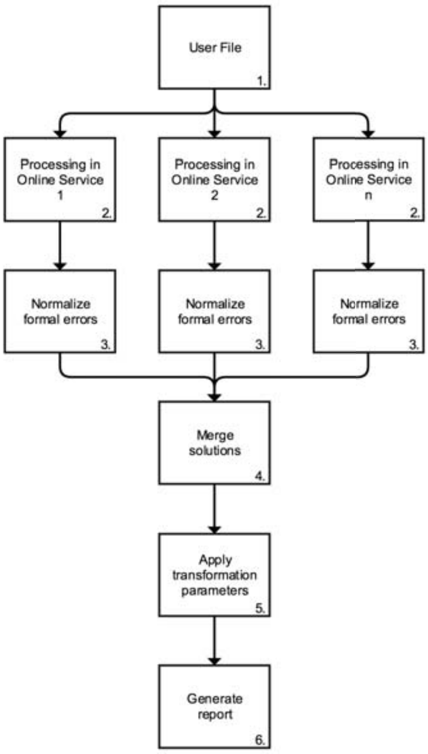


Figure 1.2: ALC webservice main tasks.

1.2 Main contributions

In order to manage GNSS networks, SEGAL has developed MGN - GNSS network management system, a software consists of a complex set of tools and a web platform for GNSS stations network management. This software is very useful to assist the following scenarios:

- Storage of raw GNSS data and generation of RINEX files;
- Availability of RINEX files to users registered in the web platform;
- GNSS stations connection state monitoring;
- Received GNSS data quality assurance.

However, despite the existence of such software and other software to compute positions with respect to a specific reference frame, there is no solution that integrates both, since both exist but do not cooperate with each other.

The main contribution of this dissertation aims to the development of a solution that complements the GNSS network management system (MGN) and enables the community to computes positions with respect to the selected reference frame materialized by the reference network (which is managed by MGN). ALC will enable users to quickly and automatically determine precise and official coordinates (when endorsed by the national authority) for physical points in compliance with the country's current datum.

It also provides a detailed study and comparison of two of the most reliable online precise positioning systems using a network of fifty-five stations displaced worldwide. This study was presented on the *9^a Asamblea Hispano Portuguesa de Geodesia y Geofísica - Universidad Complutense Madrid*[ucm].

This dissertation also elaborates on the engineering and implementation of these integrated systems and the delivery of a functional prototype.

1.3 Dissertation overview

This dissertation is organized in 9 chapters. The contents of such chapters can be summarized as follows:

1. **Chapter 1 - Introduction** Contextualizes the subject that is addressed in this dissertation. It includes the motivation behind this work and a brief introduction about the adopted approach as well as the main contributions;
2. **Chapter 2 - Geodetic Reference System** Introduces the area of Geodesy by describing the various different coordinate systems and a quick introduction to the Geodetic systems, as well as to the terrestrial reference frames;

3. **Chapter 3 - State-of-the-Art in Processing Software** The state of the art in processing methods of GNSS data is presented. The theoretical concepts behind processing GNSS data is introduced and the various tools are also introduced;

4. **Chapter 4 - Outlier Detection** Describes the contemplated methods to detect and remove outliers, the conducted tests as well as the conclusion about the adopted outlier detection methods and parameters;

5. **Chapter 5 - Formal Error Normalization** Analyzes the research conducted to normalize the formal errors between solutions provided by the online services as well as the method adopted to do so. The conducted tests are also described and analyzed;

6. **Chapter 6 - Coordinate Transformation** Describes the methods adopted for calculation of the transformation parameters from one reference frame to another and its application. The conducted tests are discussed and its accuracy analyzed;

7. **Chapter 7 - Software Engineering** Analyzes the requirements needed for the development of this work as well as the presentation of the use cases and discussion of the diagrams of the proposed database;

8. **Chapter 8 - Automatic Local Coordinates Software** Discusses all the components that comprise the Automatic Local Coordinates solution and analyzes them in detail. It describes what was developed and how it was developed;

9. **Chapter 9 - Conclusions and Future Work** Presents the main conclusions of this dissertation as well as some directions regarding future developments related with this work.

Chapter 2

Geodetic Reference System

2.1 Introduction

As mentioned in the introduction, the objective of this research work was to provide a simple solution to compute an accurate position relative to a specific reference coordinate system using GNSS observations.

In this chapter, the most important geodetic concepts related with this work are briefly presented, in particular the various types of coordinate systems that are being used these days with the advent of the Global Navigation Satellite Systems, which have revolutionized how the position of points are computed. The chapter is structured in the following manner:

- Section 2.2 presents some basic definitions about the different coordinate systems;
- Section 2.3 describes the story behind the necessity of the creation of the World Geodetic System;
- Section 2.4 introduces the Global Navigation Satellite System;
- Section 2.5 introduces the International Terrestrial Reference Frame;
- Section 2.6 introduces the Portuguese adoption of the European Terrestrial Reference System.
- Section 2.7 concludes this chapter with the main conclusions.

In order to determinate coordinates on Earth's surface accurately a specific research field has evolved: Geodesy. In a very broad sense Geodesy may be defined as the science of meticulous measurement and understanding of three fundamental properties of planet Earth: the geometric shape, the orientation in space, and the gravity field. These three properties are only meaningful when associated with time. With the usage of current positioning technology, geodesists can permanently monitor movement of any point in the globe [OA14].

2.2 Coordinate systems

In a simple way, the classic definition of a coordinate system is defined by a set of points previously marked on the Earth's surface which will allow that any other geographic point may be localized on its surface. The geometric location of any point on the space (including the Earth's surface) can be defined by a triplet of coordinates, which can be represented using different conventions: Cartesian (X,Y,Z); Geodetic (Latitude, Longitude, Ellipsoidal Height); Planimetric (East, North) + Vertical; etc..

At the end of the twentieth century, the classic geodetic reference systems based on triangulations were substituted by geodetic spatial technologies like the VLBI (Very Long Baseline Interferometry), the LLR (Lunar Laser Ranging, the SLR (Satellite Laser Ranging) and the most well known GPS (Global Positioning System). The classic geodetic reference systems, normally defined at national level, were then replaced by geodetic coordinates referred to global geocentric reference frames.

In this work, only the geometric (ellipsoidal) height is taken into account. The orthometric height used in many countries is more complex and different conventions are being used to materialize the height of a point on Earth's surface [Smi97]. The orthometric height is normally defined as the height above mean sea level which is an equipotential surface so-called geoid (its materialization at each country is done by using tide-gauges). Space geodetic techniques on the other hand provide geometrical positions relative to the centre of the Earth. In order to convert the heights obtained by space-geodesy (ellipsoidal height) into orthometric height (with respect to geoid), models of the difference (called geoid undulation) are normally applied.

2.2.1 Earth Centered Earth Fixed

Earth Centered Earth Fixed (ECEF) coordinates gives a set of three values to precisely determinate any point in the globe. Its representation is the same as the classic algebraic 3D space set of coordinates: X, Y, Z, as seen in Figure 2.1 with green lines. The origin position (0,0,0) is defined by the center of mass of planet Earth. Each axis, are perpendicular to each other, the Z axis coincident with the Earth rotation axis pointing positively to North pole; the X axis, rotating with the Earth, points positively to the intersection of the equatorial plane and the meridian of Greenwich (by convention); and the Y axis pointing positively in order to create a 3D right-handed orthonormal system [PL10].

In fact, due to the slight inclination of the rotational axis of planet Earth, the Z axis does not precisely coincides with the rotational axis but instead ”wobbles” around it, thus providing a stable and precise axis set to ECEF that can allow measurements at any time on a fixed point always with the same coordinates.

The unit of these coordinates are represented using the IS standard, meters.

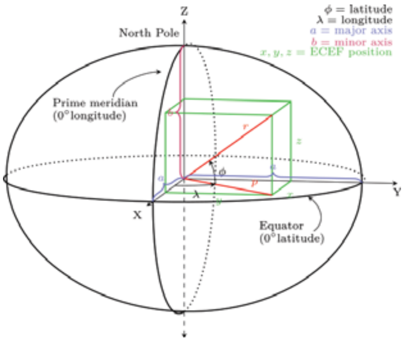


Figure 2.1: ECEF coordinates system ilustration.

In this work all computations are done using ECEF coordinates as a starting point. The use of other representations, such as Geodetic Coordinates (subsection 2.2.2) or Local Coordinates (subsection 2.2.3) are only done for human representation and understanding convenience.

2.2.2 Geodetic coordinates

Geodetic coordinates give positions of points with respect to a select ellipsoid of reference. The reference ellipsoid is an approximated mathematical representation of the globe's surface. The one used by the GNSS technology, WGS84, is described in more detail in section 2.3.

The two ellipsoid coordinate components, represented in Figure 2.2 with orange lines, measures the rotational angles between reference plans and the point of interest. By convention, in planet Earth, these coordinates are measured in degrees with ranges depending of the used convention. Complementing the surface ellipsoidal components there is also a vertical component which is discussed further down this section.

Two elements make up the surface component: latitude and longitude. Latitude (represented in Figure 2.2 by symbol Φ) is the angle between the equatorial meridian and the measured point varying between -90° and +90°. By default, latitude measurements are positive in the northern hemisphere and negative in the southern hemisphere, having a 0° measurement over the equatorial meridian. Longitude (represented in Figure 2.2 by symbol Λ) is the angle between the prime meridian and the measured point varying between -180° and +180°. By default, longitudinal measurements are positive to West of the prime meridian and negative to the East of the prime meridian, having a 0° measurement over the prime meridian.

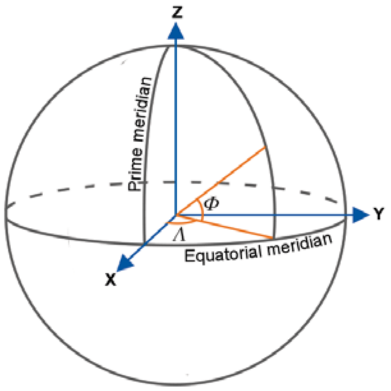


Figure 2.2: Geodetic coordinates system ilustration.

2.2.3 Local Coordinates

Local (East North Up - ENU) coordinates is a geographical coordinate system that is normally used to represent the positions of points locally. This type of coordinate system, represented in Figure 2.3 with green lines, comprises three components that are formed using a plane tangent to the globe's surface centralized on the area of interest in order to minimize the deformations caused by considering the Earth's surface plane. East represents a position along the eastern axis, North represents a position along the northern axis where positive values mean a position north of the equatorial meridian, and finally Up, represents the vertical position of the tangent plane. Note that this is also a Cartesian frame but that the origin is now located at the area (or point) of study.

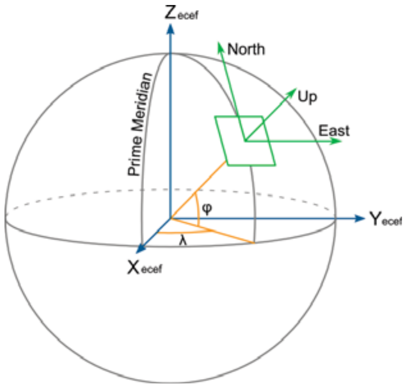


Figure 2.3: Local ENU coordinates system ilustration.

2.3 World Geodetic System

By the late 1950's the military felt the need to realize a global reference frame. Later on, the U.S. Department of Defense had generated a geocentric reference system which might be used as standard and applied to different networks worldwide. This effort lead to the creation of the first World Geodetic System (WGS), the WGS60, as seen in Figure 2.4. Since then, multiple iterations have been made in order to update and keep-up with the most recent surveying and mapping technology as well as with the alterations in the Earth surface. The most recent iteration occurred in 1984 where WGS84 has been published.

The World Geodetic System 84 was derived from a network of points fixed with extreme precision by satellite observations and statistical methods. This adjustment resulted in an ellipsoid that minimize the misfit with the Earth's real surface globally. All other regional datums worldwide can refer to WGS once a precise surveying has been made in that region.

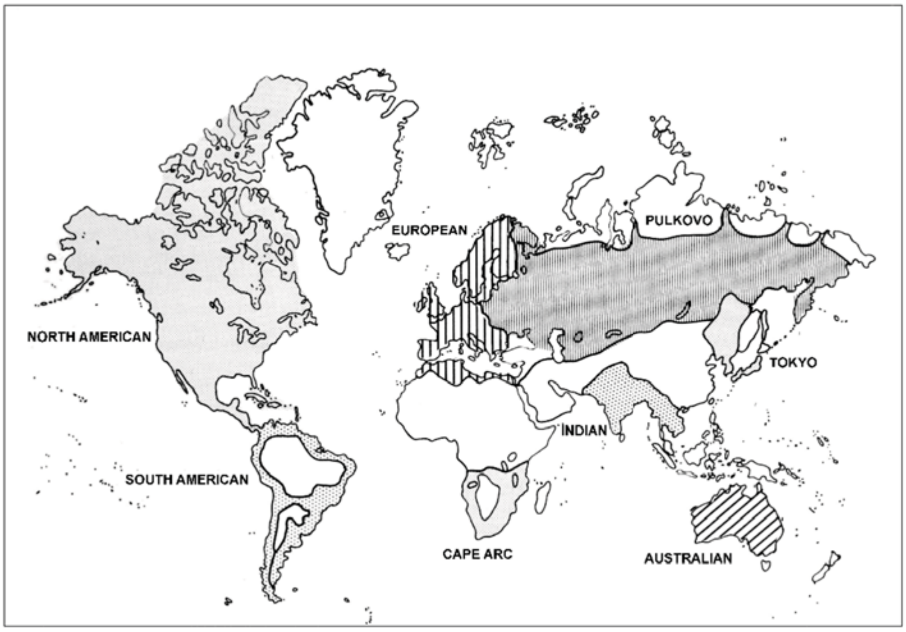


Figure 2.4: Major geodetic datum blocks of WGS60.

2.4 Global Navigation Satellite System

In recent years the usage of satellite positioning services has become more common and more spread, leading to nowadays, almost every mobility device having equipped some sort of satellite navigation system, e.g. smartphones, cars, smartwatches, etc. The Global Navigation Satellite System, more widely known as GNSS, is a technology that includes all the satellite navigation systems. The aggregation of the Global Positioning System (GPS) from the United States of America, the Russian Global Navigation Satellite System (GLONASS), China's BeiDou-2 Navigation Satellite System and Europe's Global Navigation Satellite System (Galileo) all together form the Global Navigation Satellite System (GNSS). The combination of these systems allow anybody to know his or her exact location in the planet in almost every part of the globe at anytime, revolutionizing the old traditional paper maps into digital solutions with higher accuracy than previously.

In order for this technology to work, a set of satellites orbiting the planet, a dense ground reference station infrastructure and user equipment is necessary. The GPS satellite network consists of a set of 24 satellites arranged in 6 orbital planes where each plane contains 4 satellites, providing users positioning and velocity data. The GLONASS satellite network consists of a set of 24 satellites arranged in 3 orbital planes with 8 evenly spaced satellites on each plane and is of great importance as it performs well in high latitudes where the GPS has lower coverage. The Chinese BeiDou-2 satellite network consists of a set of 21 satellites and, finally, the European Galileo satellite network consists of a set of 24 satellites arranged in 3 orbital planes with 8 satellites per orbital plan which was developed as an European initiative for having a backup in case of disablement of the other networks.

Using this kind of technology, in order to trilaterate the position of a specific individual a set of a minimum of three satellites is necessary to determine a location, however a fourth one is also necessary due to the uncertainty of the time value, unless the signal receiver is connected to an atomic clock [Gro13]. Nevertheless, nowadays it is common to observe simultaneously 20+ GNSS satellites, permitting to obtain higher quality positions than when a single GNSS constellation is used.

2.5 International Terrestrial Reference Frame

The International Terrestrial Reference Frame (ITRF) [IGN16] is the realization of the International Terrestrial Reference System (ITRS). In a simple way, the ITRS is a mathematical method and theoretical representation of Earth's terrestrial reference system that comprises positions and velocities of more than 800 stations, that are estimated by combination of VLBI, SLR, GPS and DORIS individual terrestrial reference frame solutions. The ITRS is realized and maintained by the International Earth Rotation and Reference Systems Service (IERS) [fCG13].

This way, the ITRF is the realization of the ITRS, where its mathematical method and theoretical system are applied allowing the determination of a location/position as a function of time with great accuracy. These frames are used for precise orbit determination on GNSS, altimetry, oceanography, gravity, cartography, for navigation and also for national/regional geodetic systems. In the context of space geodesy, the origin of an ITRF is the center of mass of the Earth and its orientation for X and Y axis are equatorial whereas the Z axis is an approximation to the Earth pole. The most recent realization of the ITRS is the ITRF2008 which is now used by most processing systems.

2.6 PT-TM06/ European Terrestrial Reference System 1989

The European Terrestrial Reference System (ETRS) [eur16]. is the European version of the ITRS but is based solely on the Eurasian plate and its movement. Its first realization was performed in 1989, leading to the creation of the ETRS89.

Since 1989, international campaigns have been conducted in order to establish the ETRS89 in Portugal (mainland) for the creation of the PT-TM06/ETRS89. These campaigns, conducted in 1989, 1995, 1997 and 1999 had the purpose to connect the Portuguese network to the European network. In the campaign of 1989, Portugal has participated in the EUREF European campaign contributing with only 2 stationary points, in 1995 with 12 stations for the IBERIA95, in 1997 with its first order network of 119 points and in 1999 with its second order network of 832 points [VBKC07].

So, in 2006, using the results of all the previous campaigns it was possible to establish the Portuguese Geodetic Reference Frame, PT-TM06/ETRS89, by calculation of the precise coordinates of a set of stations in relation to the ETRS89 reference epoch datum.

2.7 Conclusion

In this chapter, a brief introduction to some geodetic concepts necessary for the understanding of the topics addressed in this dissertation were discussed. The different used reference systems were presented and their differences analyzed. The developments in surveying technology were also briefly introduced with the description of the World Geodetic System, the Global Navigation Satellite System and the Terrestrial Reference Frames that are used in this dissertation.

As a side note, it is important to mention that this chapter does not represent an extensive review of the addressed topics, but instead a brief introduction. Interested readers should refer to more specific literature, in the addition to the mentioned ones, for a more broad perspective and understanding, such as:

- Geodesy general concepts: [Mor80] and [Van14];
- GNSS concepts: [Lei96] and [HWLC01];
- Reference Systems: [RDB11].

Chapter 3

State-of-the Art in Processing Software

3.1 Introduction

In this chapter, the state-of-the art in processing methods of GNSS data with some basic definitions and some applications are discussed. The different applications and methods are presented. The chapter is structured in the following manner:

- Section 3.2 presents some of the processing methods used in GNSS post-processing;
- Section 3.3 briefly describes the main existing offline softwares for post-processing;
- Section 3.4 introduces the main existing online softwares for post-processing;
- Section 3.5 concludes this chapter with the main conclusions.

3.2 Processing methods

For GNSS data processing, the two most used methods are discussed in this section: Double Difference (DD) and Precise Point Positioning (PPP).

3.2.1 Double Difference

Double Difference (DD) is a method that processes GNSS data in batch, i.e. a set of stations simultaneously. The approach behind this method is to form baselines between GNSS stations and thus eliminate clock errors. This method results with the combination of two methods:

- **Between-Receivers Single Difference** - A technique where two GNSS receivers are listening in sync to the same satellite. By subtracting each receiver observations equation, this method is able to provide better positioning since common error sources, such as those caused by the ionosphere and the water vapor in the atmosphere, are canceled when the difference is removed [SD14].
- **Between-Satellites Single Difference** - A technique that consists in one receiver listening in sync to two satellites. In this case instead of subtracting two solutions from two different receivers, here the code and/or phase from one satellite is subtracted to the other satellite. This technique is able to eliminate the receiver clock error but does not provide

a better position estimate [SD14].

Combining the two techniques it is possible to highlight the best of both. In this case, from the ”Between-Receivers Single Difference” method it is possible to have improved position estimates and from the ”Between-Satellites Single Difference” method it is possible to eliminate the clock error, leading this combination to a better resulting solution.

3.2.2 Precise Point Positioning

Precise Point Positioning (PPP) is a method that processes GNSS data using a single GNSS station independently. This positioning method relies on precise products (GNSS orbits and clock products) with centimeter-level accuracy. GNSS orbits and clock products represent two of the biggest error sources in GNSS positioning and they needed to be minimized (one of the roles of IGS - International GNSS Service) in order to obtain the best possible positions using PPP [Gao06]. For dual-frequency GNSS receivers combined with satellite clocks and precise positions, PPP provides highly accurate solutions with accuracies of about 1 centimeter. This way, several applications requiring this kind of data may see their quality increased using this method. Also note that PPP can be used for stations that are not near to other stations (distance larger than 100km) and which therefore cannot profit from the Double Difference technique to eliminate error sources.

The PPP technique (even for real-time, if products with enough quality will be made available at the epoch of the observations) might be the preferred method in the future to compute solutions globally since it has some advantages:

- With PPP it is possible to obtain precise positioning using only one GNSS receiver without a base station. This fact eliminates the need of using the RTK/baselines to obtain precise positioning;

- Cost efficiency, as this technique requires less computational resources since the processing of networks using the DD approach increases exponentially with the number of stations.

3.3 Offline processing software

Offline GNSS processing software have been around for a long period of time, some are free and others are commercial, but they all have one thing in common, the need to have a dedicated system to run the software and a large amount of knowledge needed in order to interact with the software. These needs are the possible drawbacks for many groups with smaller financial resources and/or specific knowledge. Therefore, online services, where the whole analysis process is automated, are probably more suitable for these users. Even though this dissertation

Table 3.1: Offline processing software

Software	Distribution	License Details
RTKLib	Open-Source	BSD 2-clause license
GPSTk	Open-Source	GNU LGPL
GAMIT	Commercial with free license for academic or personal use	-
GIPSY/OASIS	Commercial with free license for academic or personal use	-
BERNESE	Commercial (focused on large networks and scientific use)	-
Leica Geo Office	Commercial (focused on small surveying networks)	-
Trimble Business Center	Commercial (focused on small surveying networks)	-

does not verse about offline processing software, in Table 3.1 a list with the main products in the GNSS processing software industry are presented.

3.4 Online processing software

Online GNSS data processing services have been gaining more and more users, largely due to its simplicity of use and the fact that this type of post-processing technique is more accessible to groups with smaller financial resources and/or specific knowledge. This type of service is characterized by its precise calculation (centimeter level) in a global reference frame (currently ITRF2008) without the need to specify a set of reference stations. Currently, there are various free online services that perform this type of post-processing, each one with its peculiarities and using different processing models, which makes it difficult to choose which service fits best the needs of the user (in terms of access and precision). In this dissertation three online services where chosen and studied: CSRS-PPP (NRCAN - Canada), GDGPS-APPS (NASA/JPL - USA) and AUSPOS (AUSLIG - Australia). Other services, free and commercial, are also available (e.g., [GS13]) but are not used here.

3.4.1 Natural Resources of Canada - Canadian Spatial Reference System PPP

The Natural Resources of Canada (NRCAN) is a Canadian governmental entity that is responsible for natural resources, energy, mining and materials, forests, earth sciences, hazards and explosives in Canada [oC16]. They provide the CSRS-PPP service, which is an online application for GNSS data post-processing enabling users to compute accurate solutions with respect to NAD83 (North American Datum 1983) and ITRF2008. The service uses precise GNSS satellite orbit ephemerides to produce corrected coordinates with a high level of accuracy for any point in the globe.

Using this service, users can upload RINEX observation data from receivers with single or dual-frequency either in static or kinematic mode receiving in return the positions in national and international reference frames. The user can access the service at
https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en.

3.4.2 Jet Propulsion Laboratory - Global Differential GPS

The Jet Propulsion Laboratory (JPL) is a research facility in the United States of America that conducts research on robotics, space and Earth sciences [nas16]. The JPL is a federal funded research and development center managed for NASA by Caltech, and employs one of the largest ground network of real-time reference receivers (for each SEGAL has been actively contributing) with an innovative network architecture and real-time data processing software.

The GDGPS-APPS (Global Differential GPS - Automatic Precise Positioning Service) service provided by JPL is based on the GIPSY-OASIS software also available offline. Therefore, it is able to also compute solutions for static and kinematic (including high-speed) observations. For the occasional user a web platform is provided at http://apps.gdgps.net/apps_file_upload.php and for the more heavy-duty costumer, more advanced systems are provided for an easier incorporation of this system. Currently the GDGPS-APPS service supports RINEX 2, RINEX 2.11 and GIPSY TDP files.

3.4.3 Geoscience Australia - AUSPOS

The Geoscience Australia (AUSLIG) is the Australian entity responsible for research and development on minerals, natural resources, energy, forests, earth sciences and protection of critical infrastructures [GA14b]. AUSLIG has maintained a service (AUSPOS) that runs 24/7 for online GNSS processing which provide users access to coordinates in the GDA94 Australian datum and ITRF2008 datum.

The AUSPOS service, contrary to the other services, does not use the PPP approach. Instead, it uses the BERNESE software package (based on the DD methodology) to compute the coordinates of the station by processing it together with the data of the 15 nearest stations [GA14a].

The initial objective was also to include this service (which is still are on the future plans). However, the AUSPOS service performed badly with only an average of 4% files processed (see 4.5). This situation was investigated and the team responsible for AUSPOS service was enquired about this low performance and their reply invoked an incapacity to attend a large number of simultaneously requests.

Consequently, it was not possible to process data with the AUSPOS service timely (for the planned tests) and it was decided to not include this service since there were no guarantees that it could be used reliably by the system on the operational mode.

3.5 Conclusion

In this chapter the state-of-the art in processing methods with some brief definitions were discussed. The used processing methods were also presented and their differences explained.

The usage of the PPP GNSS processing technique is more cost efficient than double difference, as it is demonstrated by the fact that the AUSPOS service has difficulties to provide timely solutions. This chapter, namely the processing methods section was widely influenced from chapter 3 of [Val16].

Chapter 4

Outlier Detection

4.1 Introduction

In this chapter, the research regarding the methods to detect and remove outliers is discussed. The studied methods are analyzed and a series of conducted tests are described as well as a conclusion about the adopted outlier detection methods and parameters. The chapter is structured in the following manner:

- Section 4.2 presents the initial problem detected with the results of the observation files;
- Section 4.3 explains the Interquartile Range method ;
- Section 4.4 explains the Weight Root Mean Square method;
- Section 4.6 analyzes the results of the application of the methods explained before;
- Section 4.7 concludes this chapter with the main conclusions.

4.2 Motivation

In short, the definition of an outlier can be defined as *"(...) an observation which deviates so much from the other observations as to arouse suspicions that it was generated by a different mechanism (...)"* [Haw80]. At first sight, it is possible with fair ease to predict outliers by simply looking to a set of data, however, this vulgar prediction can be erroneous since no model of factual proofing was performed to precisely detect outliers. The need of analog models to precisely detect outliers lead, over the years, to the development of several methods and models. The more common methods to detect outliers are related to statistical models, these methods use statistical distribution models for prediction, meaning that outliers are the points that have a low probability to be generated by the original mechanism (e.g. deviate more than three times the standard deviation from the mean).

It is normal that one or more of the daily estimated solutions for the positions are outliers - i.e. the residual of the value is too far away from what is considered "normal" due to unknown or known causes that cannot be corrected. In this case, these solutions must be removed because otherwise they will bias the final coordinated solution when merged together. Another interesting addition to this topic is the usage of data snooping [Smi11], because every time a day is removed from the merging set of solutions, their residuals must be recalculated since they change with the influence of the presence of outliers.

From the existing methods to detect outliers, two are commonly referred and were chosen for the detection mechanism, all of them using statistical models: the interquartile range method (IQR) and the weighted root mean square (WRMS).

4.3 Interquartile Range Method

Assuming that the data set is clustered around a central value, the interquartile range method (IQR) measures how spread the data is around that value, also allowing the determination if values are "too far" from the central value. Potential outliers are considered all values that fall outside the predicted range, i.e. that are "way too far" from the central value.
The IQR method is based in an initial division in quartiles of a sorted list of data, each of the quartiles representing a quarter of the data. Using this division it is possible to observe four quarters and three quartile references as seen in Figure 4.1.

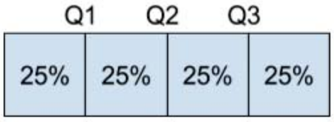


Figure 4.1: Quarters and quartiles on IQR method.

After determination of Q1 and Q3 the IQR value is the difference between both as seen in Formula 4.1.

$$IQR = Q3 - Q1 \quad (4.1)$$

This value then represents how spread the values are around the central value Q2. For exemplification, in Figure 4.2 is a representation of IQR using a box and whisker plot, where the colored area represents the spread of values around Q2.

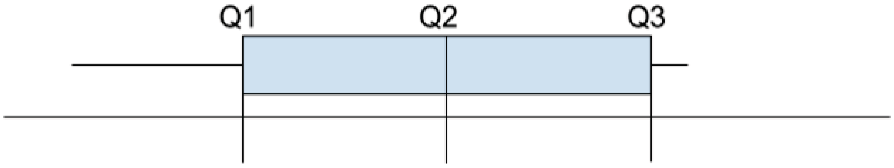


Figure 4.2: Box and Whisker plot representing the IQR

Even though at first sight it is possible to interpret that all values that reside outside the IQR (colored area) are outliers, in fact, this does not imply that all values are necessarily outliers. In outlier detection methods it is commonly accepted to include some values outside the IQR. The IQR is meant to be used as an indication of where most values are, but for outlier detection a factor needs to be applied in order to include some outside values which are not true outliers, but rather part of the valid set of data.

In the 70's the mathematician John W. Tukey [Tuk77] has created the box and whisker representation to depict groups of numerical data, which is the case of the IQR, and with the aid of this representation he also denoted what were “acceptable” and “unacceptable” values of a set of data using a factor that would be applied to the IQR. For John Langbein [Lan04], when using the IQR method to detect outliers a good factor to use in the threshold equation is 3 times the value of the IQR.

Using these threshold values it is then possible to detect outliers that fall behind or after the IQR by evaluating Equation 4.2.

$$-threshold_{IQR} \leq X_i \leq threshold_{IQR} \quad (4.2)$$

4.4 Weight Root Mean Square Method

Another method for outlier calculation is recurring to the Weight Root Mean Square (WRMS) calculation and the application of a demarcation criterion over the WRMS value. This method, like the IQR method is also ”negatively” influenced by the real outliers, if any, since the presence of such outliers will increase the calculated threshold. The WRMS method is a method that determines the square root of mean of a set of values and then applies specific independent weights to each of the values in the set as described in Formula 4.3.

$$WRMS = \sqrt{\frac{\sum_1^n X_i^2 \cdot W_i}{\sum_1^n W_i}} \quad (4.3)$$

In this formula, X is the set of values to be evaluated and W the corresponding set of weights. Using the WRMS value is possible to find the outliers that are in the set X. For this, a factor for the threshold value needs to be considered. Exemplifying, if a factor of 2.5 is used, this means that, following a normal distribution representation, any value that is more than 2.5 times away from the reference would be considered an outlier.

With the WRMS value and the factor, the threshold criterion is given by Equation 4.4.

$$WRMS \cdot (-2.5) \leq X_i \leq WRMS \cdot 2.5 \quad (4.4)$$

4.5 Outlier Detection Testing Methodology

In order to study the application of the methods presented above for the ALC outlier detection mechanism a set of IGS stations was chosen and one entire year of of data, 2015, was processed. The IGS network possesses an open and high-quality network of GNSS stations globally distributed with about 500 stations [igs]. All data from this GNSS station network is access-open and available to the end-user. Taking into account the accountability and stability of this network, a set of 51 IGS stations with global geographical distribution was selected for this study, as shown in Figure 4.3.

Figure 4.3: Distribution of selected 51 IGS stations used in study.

Using the network of stations illustrated in Figure 4.3 it was possible to to analyze a set of approximately 18'000 RINEX daily files with an average of 358 files per station (98%) for the 365 days of 2015, as shown in Figure 4.4.

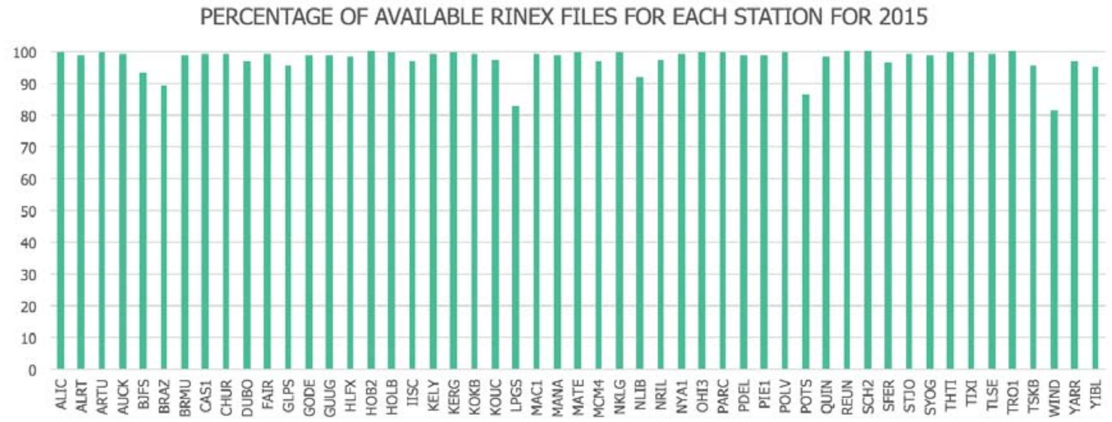


Figure 4.4: Percentage of available RINEX files for each station for 2015.

A script was developed, described in more detail in section 8.2.3, that submitted all the available RINEX files to the online services and collected the results (this script was also adopted for the normal operation of ALC). Figure 4.5 shows the percentage of RINEX files for which results were returned. Both GDGPS-APPS and CSRS-PPP performed satisfactorily with an average of 95% files processed using the GDGPS-APPS and an average of 100% files processed using the CSRS-PPP service. The performance of the AUSPOS service is also shown: an average of 4% files processed. This justifies why the service was not included as initially planned.

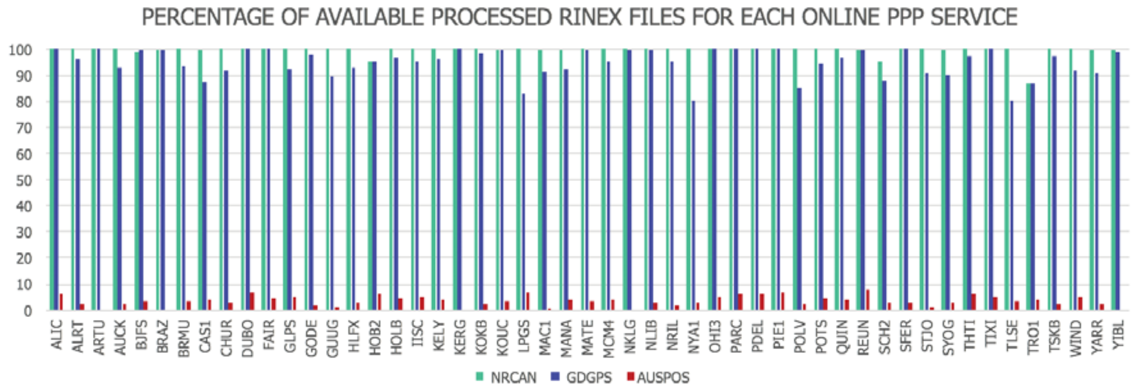


Figure 4.5: Percentage of available RINEX files that were processed by the online services.

The total data set of daily solutions estimated for this global sub-network of IGS was also used for the normalization of the errors between the different online services, which is discussed in the Chapter 5.

4.6 Analysis of the results of the outlier detection methods

The main objective of studying these methods is due to the fact that the daily solutions have to be merged into a single solution to estimate the transformation parameters (see 1.1) considering a specific duration period. This is carried out for each station and each online service separately.

The determination of the most correct value for the threshold value to be used on both methods was the objective of the particular tests that are described in this section.

The analysis was carried out for three specific periods: 7, 15, and 31days, which corresponds to the periods that were studied for the estimation of the Helmert transformation parameters, as it is described in detail in Chapter 6. Consequently, the 7-period was tested 52 times for each station and each service, whereas the 31-period was tested 12 times for each station and each service.

Tables 4.1 and 4.2 show the summary of the detected outliers using the different periods and the two online services when the threshold scale value were 2.5 and 3.0, respectively. A more detailed view of the detected outliers can be analyzed in appendix A. Naturally, when the period increases, the number of detect outliers also increase. However, the number is quite small, even when the value of 2.5 is used. And the number of outliers detected in the two online services is also almost the same, which indicated that they perform consistently. Table 4.1 shows that the WRMS method is detecting more outliers than it should since it is usually acceptable to find about 1% to 2% of outliers in a set of large data [Lan04]. Therefore, it was decided to use the value of 3.0 as default for outlier detection. Nevertheless, as it is shown on section 8.3.2.8, these values can be configured by the user. In fact, the user can select to only use one detection outlier method, IQR or WRMS, instead of both (default) using the standard or any other value.

Table 4.1: Percentage of outlier detection for multiple time intervals.

Duration	Average Outliers			
	CSRS-PPP		GDGPS-APPS	
	IQR	WRMS	IQR	WRMS
7 Days	2%	0%	2%	0%
15 Days	2%	2%	2%	2%
31 Days	2%	5%	2%	3%

Table 4.2: Percentage of outlier detection for multiple time intervals with revised WRMS factor.

Duration	Average Outliers			
	CSRS-PPP		GDGPS-APPS	
	IQR	WRMS	IQR	WRMS
7 Days	2%	0%	2%	0%
15 Days	2%	0%	2%	0%
31 Days	1%	1%	2%	0%

4.7 Conclusion

In this chapter, the research regarding the methods to detect and remove outliers was discussed. The initial issue regarding the possibility of presence of outliers was considered and research was conducted in order to find the best suitable outlier detection methods for unidimensional sets of data. The selected methods, IQR and WRMS, were explained. One year of data from a global network of IGS stations was used in order to evaluate which was the default value to be used as threshold value. It was decided to select a conservative value (3.0) for outlier detection both with the IQR and WRMS methods. Nevertheless, this value can be changed by the user.

Chapter 5

Formal Error Normalization

5.1 Introduction

In this chapter, the research regarding the normalization of formal errors between solutions provided by the online services and the method adopted to normalize the formal errors is discussed. The data used to perform this study will also be analyzed and, finally, there will be a concluding discussion about the results of this study. The chapter is structured in the following manner:

- Section 5.2 presents the initial problem detected with the usage of the online processing services;
- Section 5.3 quickly introduces formal errors and describes the process to assess the ratio between the online services;
- Section 5.4 explains how the performance of vertical and horizontal components of the solutions from the online services was determined;
- Section 5.5 describes the method developed to normalize formal errors across the multiple processing service solutions;
- Section 5.6 concludes this chapter with the main conclusions.

5.2 Motivation

The analysis of the first solutions obtained using the GDGPS-APPS and the CSRS-PPP online services showed an odd behavior: the solutions retrieved from the GDGPS online service were (considering the associated uncertainty given by the standard deviation of the coordinate) about ten times more precise than solutions from NRCAN. The reason is due to the processing methods and the uncertainties considered for the used models. This value is not representative of a true error, since each model expresses its variables (e.g. delay in atmosphere, ionosphere, multipass, error in the GPS orbits, etc.) with distinct weights between them, this, theoretically, justifies that formal errors only represent what they are, formal errors, they do not represent necessarily the reality value but rather a reference/theoretical value. In this sense, they can be internally (solutions from the same service) compared but not externally (solutions from different services).

A GNSS station is utterly stable, being influenced mainly only from tectonic plate and seasonal deformation caused by loadings which may create some small variations in the position. Therefore, the variation around the mean position is a more realistic estimate of the error.

In order to find a more realistic estimate for the formal error, a set of tasks were performed to study the relation between online services and the formal errors, these tasks are comprehended by:

- Computation of the ratio of formal errors between the online services;
- Computation of the WRMS of the residuals between daily positions and trend (i.e., misfit all over the year) for each service and compute the ratio between them;
- Development of a method to correct formal errors of solutions in order to provide a proper relative weighted mean using the previously computed ratio.

5.3 Ratio between services

5.3.1 Quick Introduction to formal errors

As mentioned above, the GNSS signal is affected by several error sources, e.g. delay in the atmosphere, ionosphere, multi-path, error in the orbits, etc.. The size of these error sources are given by models that differ for each software package, which explains why the formal error is different between the solutions from the different online services.

Figure 5.1 shows two very simplified representations of a series of points where each point has an associated ”formal error” represented by a vertical line crossing each point. If linear regression was performed in order to estimate the best fit, the error associated with the left line would be smaller than the error associated with the right one, despite the residuals (distance to the line) are smaller for the right case than for the left one. This was caused because the formal error of the derived trend would be only function of the number and formal errors of the input data points. This means that even though a model suggests that it has a smaller formal error, does not necessarily mean that it is closer to the real position.

Figure 5.1: Formal errors versus dispersion of the data points

So, what comes out of the GNSS software analysis software is just a formal error of the position which does not take all physical error sources into account[SGBCW11]. Therefore, the best approach is to increase the errors of the observations to better reflect the influence of the physical sources.

5.3.2 Calculation of ratio between services

Figure 5.2 shows the ratio of the average formal error between the two analyzed services using the 3D norm of the X, Y, and Z components of the standard deviation for each analyzed IGS station (see Figure 4.3) - a more detailed view of the data can be analyzed in appendix B.1.

The average ratio of formal errors between CSRS-PPP and GDGPS-APPS solutions is 5.61, i.e. the formal errors of the GDGPS-APPS solutions are approximately 5 times lower than the formal errors of the CSRS-PPP solutions. It was decided to use this value of 5.61 as the default ratio since it best represents the average ratio between both services on a global scale. In fact, although this value depends of the quantity of stations (and data) used, Figure 5.2 shows that the computed value is quite robust since there is a clearly tendency for the stabilization of the ratio in-between 5 and 6.

Since the CSRS-PPP solutions average formal errors are in average higher than the GDGPS-APPS solutions average formal errors, it was decided to take a more conservative step and only scale up the formal errors of the GDGP-APPS solutions instead of weight-averaging both solutions, or scaling down CSRS-PPP solutions.

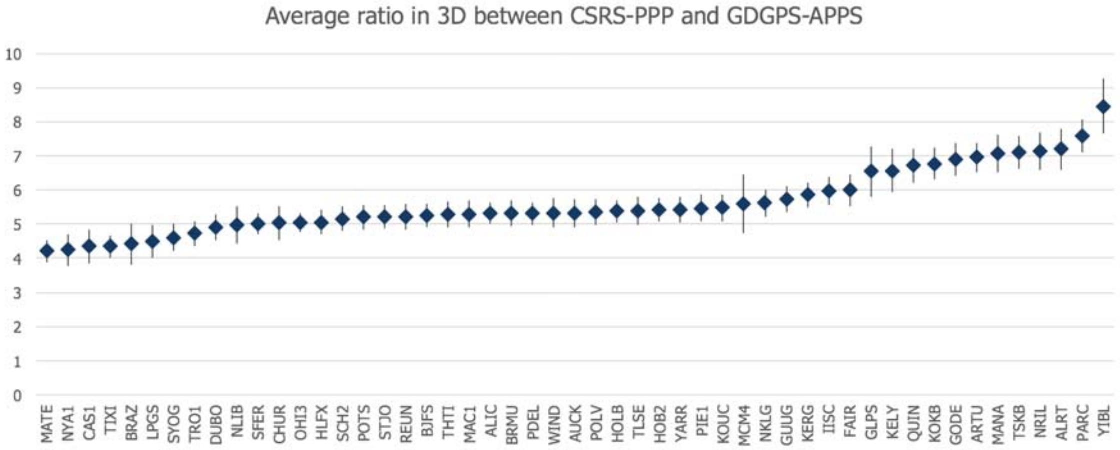


Figure 5.2: Average ratio in 3D between CSRS-PPP and GDGPS-APPS.

5.4 Analysis of components performance using Hector residuals

To study the normalization of the formal errors between online processing services another tool, developed at SEGAL, called HECTOR[BFWB12] was used. HECTOR is a software used to estimate linear trends in time-series (and other parameters as seasonal deformations). This software outputs a set of data including the residuals obtained between the fitted/optimal solution determined by Hector and the observed data.

5.4.1 Assessment of ratio between services

With the residuals outputted by HECTOR, the root mean square (RMS) for each component of each service was computed. The comparison between both services shows there is slightly better RMS in the horizontal components for CSRS-PPP and slightly better RMS in the vertical component of GDGPS-APPS. These difference, however, are not significantly different: the difference of the RMS between services is approximately 0.5mm for the horizontal components and approximately 1.5mm for the vertical component. This is illustrated by Figures 5.3 and 5.4. The plots show a graphical representation for half a year in 2015 for the Ponta Delgada's (PDEL) station in the Azores. Figure 5.3 shows that the horizontal component from the CSRS-PPP solutions, marked in green, have slightly bigger residuals than the GDGPS-APPS solutions, marked in red. On the other hand, Figure 5.4 shows that the vertical component from the GDGPS-APPS solutions have bigger residuals than the CSRS-PPP solutions.

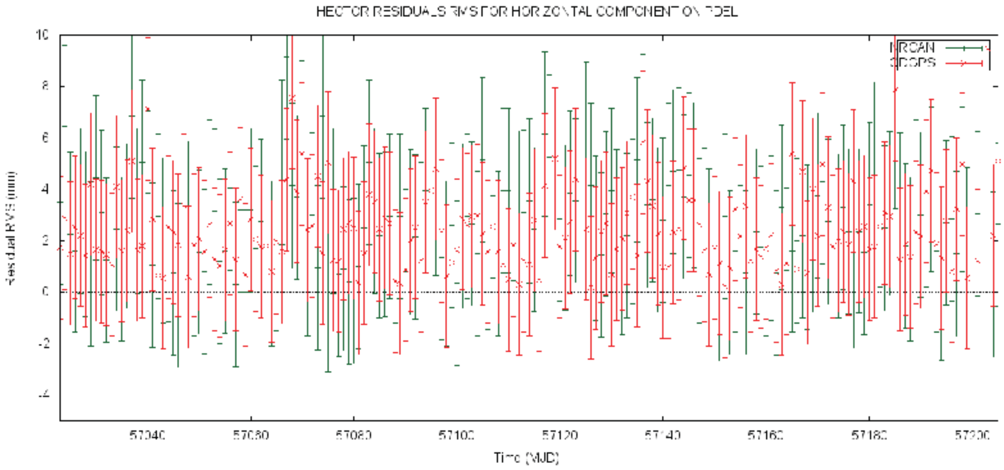


Figure 5.3: Hector residuals with RMS for horizontal component on PDEL.

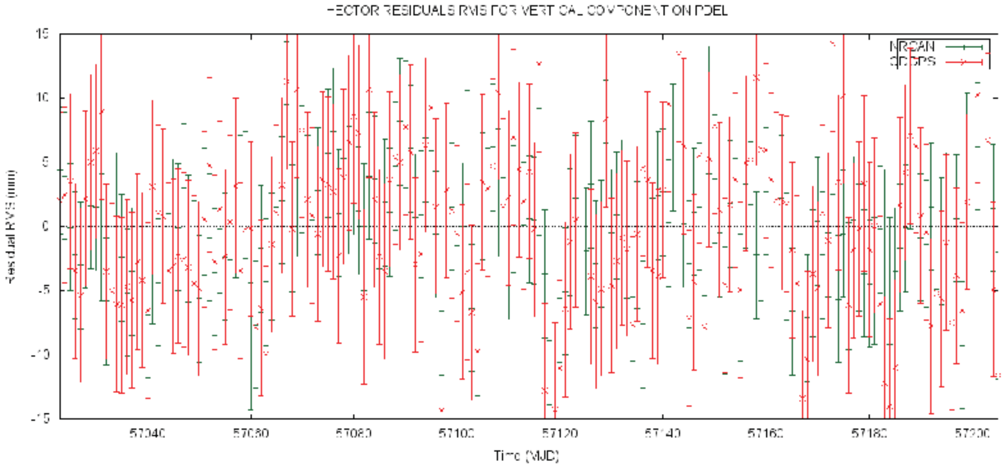


Figure 5.4: Hector residuals with RMS for vertical component on PDEL.

Although this only represents half a year for only one station, this behavior spans across all year for all stations as numerically shown in Table 5.1.

To find the average ratio between both services for the horizontal and the vertical components independently, the RMS of the residuals was computed and its average calculated in order to find reasonable scale factors between the services. A more detailed view of a summary of the residuals RMS across all stations can be analyzed in appendix C on TableC.1.

Table 5.1: Average RMS of residuals for both services

Service	Horizontal	Vertical
GDGPS-APPS	2.73 mm	6.69 mm
CSRS-PPP	3.26 mm	5.15 mm

By observation of Table 5.1 it is possible to see the low value of the average residuals, this is the justification that the solutions provided by the online processing services are equivalent and should have the same weight. This also means that the formal errors are wrong and should be scaled to be more realistic as the existing difference is now proven to be unrealistic.

So, finally, in order to find a reasonable scale factor between the services, the ratio between the average RMS of the residuals was calculated which then translates into our scale factor. The final scale factors can be observed in Table 5.2, where CSRS-PPP solutions should be scaled 0.8354 and 1.2985 times for horizontal and vertical components, respectively, and GDGPS-APPS solutions should be scaled 1.1970 and 0.7701 times for horizontal and vertical components, respectively.

Table 5.2: Ratio between average RMS for both services (Scale factor)

Service	Horizontal	Vertical
$\frac{CSRS-PPP}{GDGPS-APPS}$	0.8354	1.2985
$\frac{GDGPS-APPS}{CSRS-PPP}$	1.1970	0.7701

Since Hector outputs results in Local system (ENU) and the solution files retrieved by the online services are in Cartesian system (XYZ), a coordinate transformation operation is needed in order to achieve independent scaling operations between horizontal and vertical components with the now calculated ratios.

5.5 Development of method to normalize formal errors on both services

Now that the ratio of formal errors between both services and the performance on the different components was analyzed, it was possible to develop a method that normalizes formal errors on both services in order to remove the initial disparity. As described before, the solutions generated on the CSRS-PPP service have more conservative formal errors than the solutions generated on the GDGPS-APPS service, as the first give more room for position fluctuation. However, it is wrong to scale down formal errors from solutions generated by the CSRS-PPP service in order to make them closer to the formal errors of the solutions generated by the GDGPS-APPS service, since in that way the operation would not represent the errors properly.

So, there were multiple possible approaches in order to perform the normalization, namely:

- Replace the original sigmas in the solution files by the RMS of the residuals looking for long time-series of both solutions. This approach has the disadvantage that an outlier in one of the solutions (which can be detected by internal comparison of the formal errors) will have the same weight as a good solution;

- Normalize the solutions in XYZ by scaling one (or both in order to approach the real uncertainties) of the solution files. The internal relative uncertainties (considering solutions for different days of the same online service) will still be maintained. This is the easiest approach since only one scalar operation is necessary;

- Weight separately the horizontal and vertical components. The tests showed that the GDGPS-APPS service performs better in the vertical component and the CSRS-PPP in the horizontal component. Therefore, it is possible to provide different weights to different components. This would imply to transform the VCV (variance-covariance) matrix from XYZ to ENU, apply the different weights, and transform back to XYZ in order to have two normalized solutions.

The adopted approach for error scaling was the last one, which follow the recommendations from Soler [SC85] who presented a paper that describes the procedures necessary to transform covariance matrices between coordinate systems.

Namely, in order to proceed to the normalization of the formal errors on solution files according to the adopted approach the following steps need to be executed:

- After extraction of data from the solution files it is possible to fill equation 5.1 to calculate the variance-covariance matrix in Local coordinates. Here formal errors will be scaled by 5.61 if it is a GDGPS-APPS solution file or scaled by 1 if it is a solution file from CSRS-PPP;

$$C_{ENU} = \begin{pmatrix} -sin(\lambda) & cos(\lambda) & 0 \\ -sin(\phi)cos(\lambda) & -sin(\phi)sin(\lambda) & cos(\phi) \\ cos(\phi)cos(\lambda) & cos(\phi)sin(\lambda) & sin(\phi) \end{pmatrix} \begin{pmatrix} s\sigma_x & 0 & 0 \\ 0 & s\sigma_y & 0 \\ 0 & 0 & s\sigma_z \end{pmatrix} \begin{pmatrix} 1 & \rho_{xy} & \rho_{zx} \\ \rho_{xy} & 1 & \rho_{zy} \\ \rho_{zx} & \rho_{zy} & 1 \end{pmatrix} \begin{pmatrix} s\sigma_x & 0 & 0 \\ 0 & s\sigma_y & 0 \\ 0 & 0 & s\sigma_z \end{pmatrix} \begin{pmatrix} -sin(\lambda) & cos(\lambda) & 0 \\ -sin(\phi)cos(\lambda) & -sin(\phi)sin(\lambda) & cos(\phi) \\ cos(\phi)cos(\lambda) & cos(\phi)sin(\lambda) & sin(\phi) \end{pmatrix}^T \quad (5.1)$$

$$s = 5.61 \vee s = 1$$

- Using the VCV matrix in ENU calculated in the previous step it is possible to extract the correlation and scaling matrices and calculate the scaled variance-covariance matrix in Local coordinates using equation 5.2;

$$S_{ENU} = \begin{pmatrix} \sqrt{\mathbf{C}_{EE}} \cdot H & 0 & 0 \\ 0 & \sqrt{\mathbf{C}_{NN}} \cdot H & 0 \\ 0 & 0 & \sqrt{\mathbf{C}_{UU}} \cdot V \end{pmatrix} \begin{pmatrix} 1 & \frac{\mathbf{C}_{EN}}{\sqrt{\mathbf{C}_{EE}}\sqrt{\mathbf{C}_{NN}}} & \frac{\mathbf{C}_{EU}}{\sqrt{\mathbf{C}_{EE}}\sqrt{\mathbf{C}_{UU}}} \\ \frac{\mathbf{C}_{EN}}{\sqrt{\mathbf{C}_{EE}}\sqrt{\mathbf{C}_{NN}}} & 1 & \frac{\mathbf{C}_{UN}}{\sqrt{\mathbf{C}_{UU}}\sqrt{\mathbf{C}_{NN}}} \\ \frac{\mathbf{C}_{EU}}{\sqrt{\mathbf{C}_{EE}}\sqrt{\mathbf{C}_{UU}}} & \frac{\mathbf{C}_{UN}}{\sqrt{\mathbf{C}_{UU}}\sqrt{\mathbf{C}_{NN}}} & 1 \end{pmatrix} \begin{pmatrix} \sqrt{\mathbf{C}_{EE}} \cdot H & 0 & 0 \\ 0 & \sqrt{\mathbf{C}_{NN}} \cdot H & 0 \\ 0 & 0 & \sqrt{\mathbf{C}_{UU}} \cdot V \end{pmatrix} \quad (5.2)$$

$$\mathbf{C} = \mathbf{C}_{ENU}, H = Horizontalscalefactor, V = Verticalscalefactor$$

- With the VCV matrix in Local coordinates properly scaled it is now necessary to revert back to Cartesian coordinates. To do that, equation 5.3 is used;

$$S_{xyz} = \begin{pmatrix} -sin(\lambda) & cos(\lambda) & 0 \\ -sin(\phi)cos(\lambda) & -sin(\phi)sin(\lambda) & cos(\phi) \\ cos(\phi)cos(\lambda) & cos(\phi)sin(\lambda) & sin(\phi) \end{pmatrix}^{-1} S_{ENU} \begin{pmatrix} -sin(\lambda) & cos(\lambda) & 0 \\ -sin(\phi)cos(\lambda) & -sin(\phi)sin(\lambda) & cos(\phi) \\ cos(\phi)cos(\lambda) & cos(\phi)sin(\lambda) & sin(\phi) \end{pmatrix}^{T^{-1}} \quad (5.3)$$

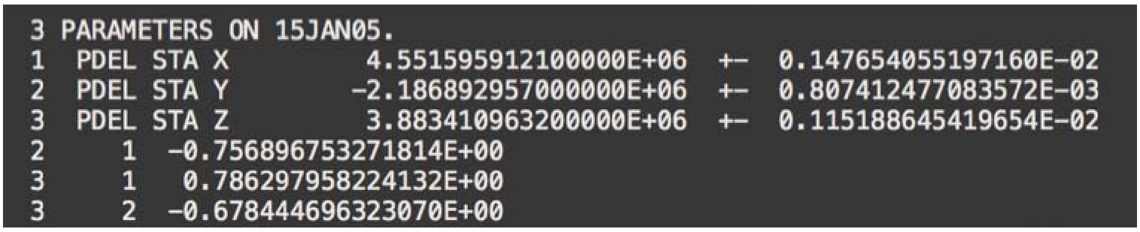
- With results from the previous step it is time to extract the correlation and standard-deviation matrices in order to update each solution file. With equation 5.4 it is possible to extract the VCV matrix and with equation 5.5 it is possible to extract the new scaled formal errors.

$$S\rho_{xyz} = \begin{pmatrix} 1 & \frac{\mathbf{S}_{xy}}{\sqrt{\mathbf{S}_{xx}}\sqrt{\mathbf{S}_{yy}}} & \frac{\mathbf{S}_{xz}}{\sqrt{\mathbf{S}_{xx}}\sqrt{\mathbf{S}_{zz}}} \\ \frac{\mathbf{S}_{xy}}{\sqrt{\mathbf{S}_{xx}}\sqrt{\mathbf{S}_{yy}}} & 1 & \frac{\mathbf{S}_{zy}}{\sqrt{\mathbf{S}_{zz}}\sqrt{\mathbf{S}_{yy}}} \\ \frac{\mathbf{S}_{xz}}{\sqrt{\mathbf{S}_{xx}}\sqrt{\mathbf{S}_{zz}}} & \frac{\mathbf{S}_{zy}}{\sqrt{\mathbf{S}_{zz}}\sqrt{\mathbf{S}_{yy}}} & 1 \end{pmatrix}, \mathbf{S} = \mathbf{S}_{xyz} \quad (5.4)$$

$$S\sigma_{xyz} = \begin{pmatrix} \sqrt{\mathbf{C}_{xx}} & 0 & 0 \\ 0 & \sqrt{\mathbf{C}_{yy}} & 0 \\ 0 & 0 & \sqrt{\mathbf{C}_{zz}} \end{pmatrix}, \mathbf{S} = \mathbf{S}_{xyz} \quad (5.5)$$

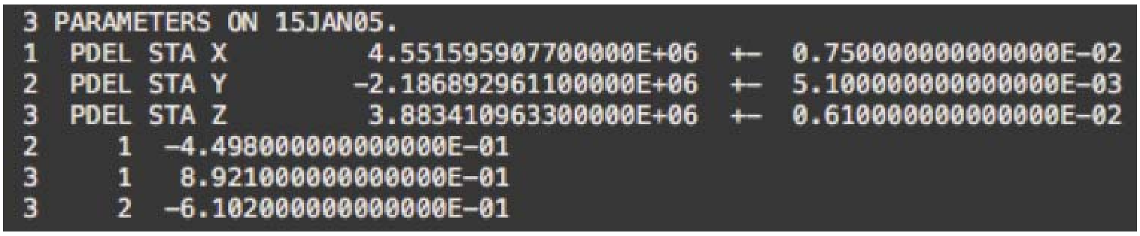
5.5.1 Comparision of results

With the previously described method it is possible, to normalize/equalize solutions processed by the online services. In figures 5.5 and 5.6 it is possible to observe a solution file (in the STACOV file format, the default solution file format of the GIPSY/OASIS software) from the station in Ponta Delgada (PDEL), Azores, where it is visible the big discrepancy of the formal errors between the online services. In fact, in a 3D representation, as used in section 5.3 to represent the ratio between services, in this case there is a ratio of approximately 5.4. After processing the files using the method in this section it is visible in figures 5.7 and 5.8 that the formal errors are now closer and the ratio between services is now is lower being only approximately 1.6, which represents a more balanced ratio.



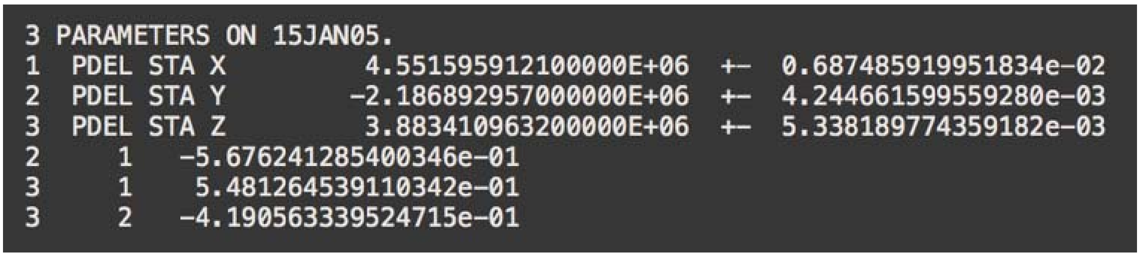
```
3 PARAMETERS ON 15JAN05.
1  PDEL STA X         4.551595912100000E+06  +-  0.147654055197160E-02
2  PDEL STA Y        -2.186892957000000E+06  +-  0.807412477083572E-03
3  PDEL STA Z         3.883410963200000E+06  +-  0.115188645419654E-02
2     1  -0.756896753271814E+00
3     1   0.786297958224132E+00
3     2  -0.678444696323070E+00
```

Figure 5.5: PDEL STACOV file from the GDGPS-APPS service before normalization method.



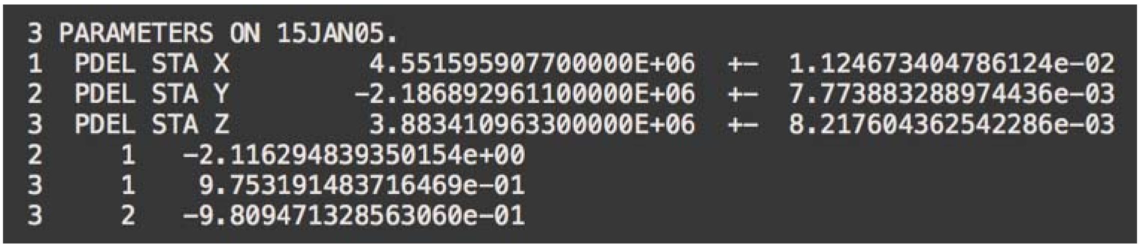
```
3 PARAMETERS ON 15JAN05.
1  PDEL STA X         4.551595907700000E+06  +-  0.750000000000000E-02
2  PDEL STA Y        -2.186892961100000E+06  +-  5.100000000000000E-03
3  PDEL STA Z         3.883410963300000E+06  +-  0.610000000000000E-02
2     1  -4.498000000000000E-01
3     1   8.921000000000000E-01
3     2  -6.102000000000000E-01
```

Figure 5.6: PDEL STACOV file from the CSRS-PPP service before normalization method.



```
3 PARAMETERS ON 15JAN05.
1  PDEL STA X         4.551595912100000E+06  +-  0.687485919951834e-02
2  PDEL STA Y        -2.186892957000000E+06  +-  4.244661599559280e-03
3  PDEL STA Z         3.883410963200000E+06  +-  5.338189774359182e-03
2     1   -5.676241285400346e-01
3     1    5.481264539110342e-01
3     2   -4.190563339524715e-01
```

Figure 5.7: PDEL STACOV file from the GDGPS-APPS service after normalization method.



```
3 PARAMETERS ON 15JAN05.
1  PDEL STA X         4.551595907700000E+06  +-  1.124673404786124e-02
2  PDEL STA Y        -2.186892961100000E+06  +-  7.773883288974436e-03
3  PDEL STA Z         3.883410963300000E+06  +-  8.217604362542286e-03
2     1   -2.116294839350154e+00
3     1    9.753191483716469e-01
3     2   -9.809471328563060e-01
```

Figure 5.8: PDEL STACOV file from the CSRS-PPP service after normalization method.

5.6 Conclusion

In this chapter, the study that was conducted in order to normalize formal errors between solutions provided by the online services and the method adopted to normalize the formal errors was discussed. The initial problem detected regarding the discrepancy between the formal errors from the results of the online providers was an issue that would skew the results obtained, so there had to be something done in order to correct the discrepancy. After studying the ratio of formal errors between the two online services it was concluded that there was a ratio of 5.61:1 regarding the weight of both solutions, which bias the end results when the solutions are merged.

An additional analysis was made with the study of the performance of horizontal and vertical components for both online services and there was an obvious difference in the results which indicated that the GDGPS-APPS service showed lower residuals in the horizontal component and the CSRS-PPP service showed lower residuals in the vertical component. Therefore, a method to normalize the associated uncertainties of the position solutions given by the online services was developed. This method involves the use of a series of coordinate conversion methods and scaling operations, resulting in a normalized/equivalent solutions.

Chapter 6

Coordinate Transformation

6.1 Introduction

As described in the introduction, the coordinates of a point are always given in an adopted reference frame. In this chapter, the transformation from the reference frame of the epoch of observation into the local reference frame is discussed and its accuracy will be analyzed. The chapter is structured in the following manner:

- Section 6.2 presents the initial problem with constantly changing coordinates;
- Section 6.3 describes the process to determinate the Helmert transformation parameters;
- Section 6.4 analyzes the methods conducted to test the transformation parameters;
- Section 6.5 concludes this chapter with the main conclusions.

6.2 Motivation

All global reference frames have their origin at the centre of mass of the solid Earth, however they differ in their orientation and rotation in space. An example of such a reference frame is the International Terrestrial Reference Frame 2008 (ITRF2008). As introduced before, as time passes, a specific point on the Earth's surface changes its position within ITRF2008 because the tectonic plates are constantly moving. So, in order to achieve static coordinates, the orientation of the adopted (for example ETRS89, http://etrs89.ensg.ign.fr) reference frame should follow the tectonic plate. In order to solve this problem, coordinate transformation parameters are determined and applied. Examples of methods to transform coordinates in the space are:

- **Molodensky-Badekas transformation** A method that directly converts coordinates between geodetic coordinate systems of different datums [1] without the need of converting to geocentric ECEF (Earth Centered, Earth Fixed) coordinates;
- **Helmert transformation** A method that transforms between different systems without changing the shape of the objects.

---

[1] The correct term is data (plural of datum). But for disambiguity purpose the term datums was used.

In this work, due to the simplicity and wide-usage for global coordinate systems, the adopted coordinate transformation method is the Helmert Transformation Parameters method which is described in detail in the next section.

6.3 Helmert transformation parameters

One way to obtain the transformation parameters needs pairs of known coordinates in the two systems. The Helmert Transformation Parameters method, also known as Bursa-Wolf, consists in a series of matrix operations, graphically represented in Figure 6.1 in order to estimate 7 parameters: 3 translation parameters in the cartesian axis(ΔX, ΔY and ΔZ), 3 rotation parameters (α, β and γ) and a scale factor (S).

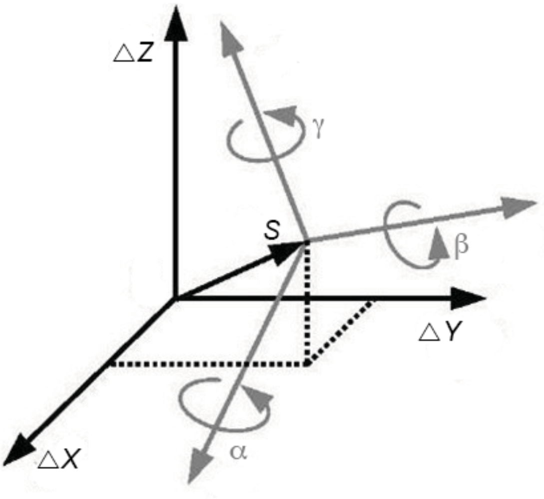


Figure 6.1: Graphical representation of the coordinate transformation parameters.

The determination of the Helmert Transformation Parameters starts with a matrix representation of the transformation, given by equation 6.1.

$$\begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} = S \cdot \begin{bmatrix} 1 & \gamma & -\beta \\ -\gamma & 1 & \alpha \\ \beta & -\alpha & 1 \end{bmatrix} \cdot \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad (6.1)$$

where X_T, Y_T, Z_T and X_S, Y_S and Z_S are coordinates in meters in the target and source coordinate systems, respectively. α, β and γ are the rotation angles in radians on the X, Y and Z axes, respectively, and those angles are considered to be very small. ΔX, ΔY and ΔZ are the translation movements in meters from the origin. Finally, S is the scale change, in ppm, given by the following formula $S = (1 + \delta \cdot 10^{-6})$, and that transforms equation 6.1 into equation 6.2

$$\begin{bmatrix} X_T - X_S \\ Y_T - Y_S \\ Z_T - Z_S \end{bmatrix} = \begin{bmatrix} \delta & \gamma & -\beta \\ -\gamma & \delta & \alpha \\ \beta & -\alpha & \delta \end{bmatrix} \cdot \begin{bmatrix} X_S \\ Y_S \\ Z_S \end{bmatrix} + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \qquad (6.2)$$

where δ, α, β, γ, ΔX, ΔY and ΔZ are the seven transformation parameters, which are computed using the previously mentioned known points in both reference systems. The minimum number of common points needs to be equal to three, only then the least square method can be applied and the seven transformation parameters can be obtained [Kar07] [Kni09].

6.4 Determination and application of transformation parameters

Different types of tests were conducted to test the application of the transformation parameters when influenced by some constraints. These tests include the study of the influence of using different time-window frames and the influence of using GNSS post-processed data with different types of orbits.

6.4.1 Influence of different time-window frames

To calculate the transformation parameters in this work, first, three steps must be performed beforehand: outlier detection (chapter 4), error scaling (chapter 5) and the merging of the solutions. Only after these three steps it is possible to calculate the transformation parameters because this is when all the data is normalized. However, when merging the solutions a question rises that relates to the amount of data necessary to estimate good transformation parameters. In order to find the best amount of data necessary, i.e. the best number of days with observations, several tests were conducted to study the best approach by comparing the transformation parameters using 1 day, 7 days, 15 days and 30 days backwards worth of data starting from the day of the calculation, which for this study involved the following steps:

- Everyday and for a specific date interval, estimation of 1, 7, 15 and 30 days window transformation parameters using data from the set of reference stations;

- Using data from the same date interval, apply the corresponding calculated transformation parameters of the four time-windows to the same stations;

- Calculate de position difference between the transformed coordinates and the reference coordinates of the set of stations.

In this study, the stations used were all the stations from the RENeP network and the date interval was one month from August 2016. The official reference frame for the RENeP stations was determined with respect to the ETRS89 datum, so, this means that all the post-processed GNSS solutions (given by the online services in ITRF2008 at the epoch of observation) had to be transformed to ETRS89 in order to best-fit the grid of that epoch. After calculation of the transformation parameters, these resulting transformation parameters were used to transform observed coordinates into ETRS89 and then compared to their reference coordinates in ETRS89. For the results listed in Table 6.1 all stations in the network were used, each consisting out of 30 days of observations. The map in Figure 6.2 presents the graphical representation of the RMS for each station on the ReNEP network using the calculated transformation parameters with a 15 day window.

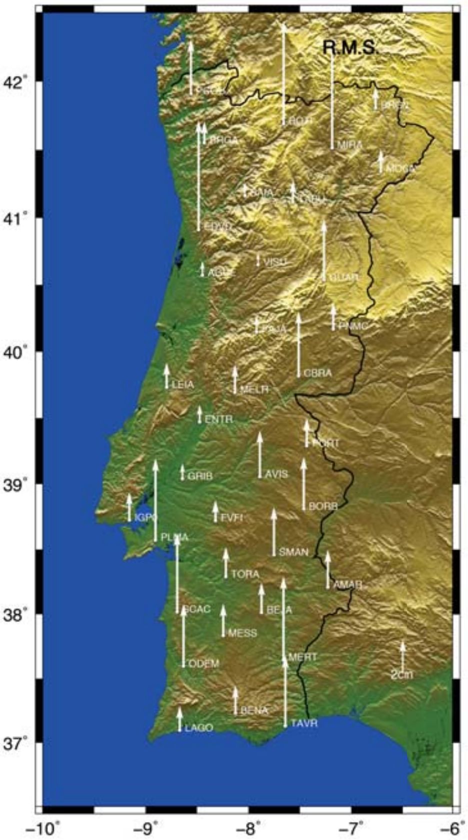


Figure 6.2: 3D RMS for the entire dataset of reference stations (36).

Table 6.1: RMS for the entire dataset of reference stations (36) using different time-window frames.

Duration	E (mm)	N (mm)	U (mm)	3D (mm)
1 Day	9.8	7.2	29.4	31.8
7 Days	9.8	7.0	29.3	31.7
15 Days	9.8	7.0	29.2	31.6
30 Days	9.8	7.1	29.3	31.6

Taking into account the results determined above, it is possible to observe that there is no significant difference between the different time window frames: the difference is less than

0.2mm (in 3D). The solutions determined using 15 and 30 day windows only show slight better values. However, there are practical advantages to select the 15 day window: (1) it performs well on the outlier detection (see chapter 4); (2) and improves the probability of available data for all stations in networks with low reliability (inconstant availability of the daily GNSS files). Therefore, the 15 day window was selected to estimate a single combined solution (at the epoch of observation) for the estimation of transformation parameters into the coordinates at the official reference frame. The variation of the values showed in Table 6.1 are also confirmed using other subsets of reference stations, as it is shown in the next sections.

The detailed analysis of the residuals showed that 6 stations had their RMS value 2 times higher than the total RMS of the individual RMS in either one of the horizontal components or on the vertical component. Since the number of used ReNEP stations is quite high (36 stations with available data and known coordinated), it was decided to have a conservative approach and consider these six stations as outliers, namely `AVIS`, `BORB`, `BOTI`, `CBRA`, `EDVD` and `MIRA` (see also Figure 6.2).

Notice that the reason for these outliers is not completely clear but it is probably caused by an incorrect estimation of the reference coordinates with respect to PT-TM06/ETRS89, particularly for the stations with large residuals on the vertical component.

The transformation parameters were calculated again, with the results observed in Table 6.2 and graphically displayed in Figure 6.3.

Table 6.2: RMS for the best dataset of reference stations (30) using different time-window frames.

Duration	E (mm)	N (mm)	U (mm)	3D (mm)
1 Day	7.8	6.1	23.1	25.1
7 Days	7.8	5.9	22.8	24.8
15 Days	7.8	5.9	22.6	24.7
30 Days	7.7	6.0	22.7	24.7

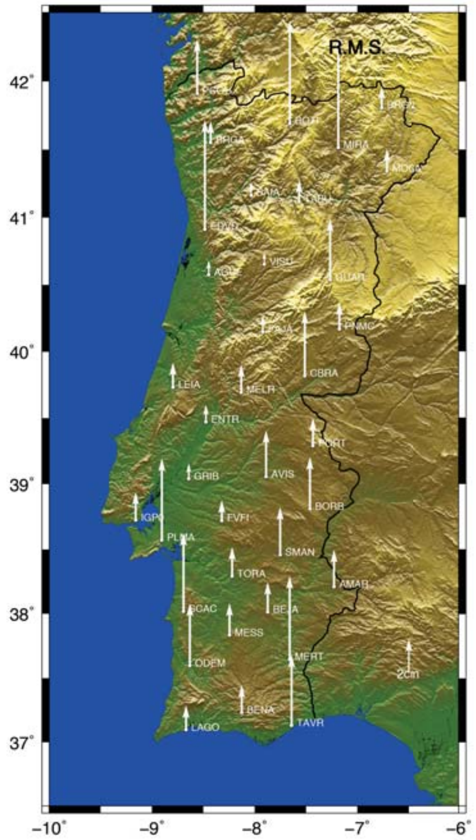


Figure 6.3: 3D RMS for the best dataset of reference stations (30)

As it is visible, the difference to the reference coordinates when considering the selected 15 days period has now dropped from 31.6mm (in 3D) to 24.7 mm (in 3D), representing an improvement of about 7mm in the final position. It was decided to, based in these results, to use this set of 30 reference stations to estimate the transformation parameters in the remaining tests.

6.4.2 Influence of orbits in user's post-processed GNSS data

When post-processing GNSS raw data it is possible to process the data using different orbit products depending on the urgency of the data to be processed. Usually there are 3 types of orbits: ultra-rapids, rapids and precise/final. The difference between them is the accuracy of the orbit of the satellite travel and the time it takes to make them available publicly, but mostly what matters the most is the accuracy of the orbit, which as more time passes by the more accurate it gets. Usually, ultra-rapid orbits are available within 90 minutes and less than a day after the observation has been recorded, rapid orbits are available after 1 day and precise/final orbits are available after 8 to 13 days, depending on the online service. In order to find the most suitable orbits to best handle the incoming requests, a test was conducted to study which would be the best orbits to wait for in order to apply coordinate transformation. This study involved the following steps:

- Everyday and for a specific date interval, estimation of 15-day window transformation parameters using data from a set of stations;

- Using data from the same date interval but processed using different orbit types, apply the calculated transformation parameters to all solutions of the same stations;

- Calculate de position difference between the transformed coordinates and the reference coordinates of the set of stations for all solutions.

In this study only the rapid and precise/final orbits were considered as this kind of data is not usually processed in the same day of the observation recording. The stations used were all the RENeP network stations and the date interval was one month in August 2016. The available reference frame for the RENeP stations was determined using the ETRS89 epoch datum, so, this means that all the post-processed GNSS data had to be transformed to ETRS89 in order to best-fit the grid of that epoch. After calculation of the transformation parameters, these resulting transformation parameters were used to transform observed coordinates to ETRS89 and then compared to their reference coordinates in ETRS89. The data in Table 6.3 is the summary, for the whole network, of the RMS of the difference between the transformed position in ETRS89 and the reference position in ETRS89 for 1 month of post-processed GNSS data for each station using Precise and Rapid orbits. Figure 6.4 presents the graphical representation of Table 6.3.

Table 6.3: RMS of the network difference between transformed positions in ETRS89 and reference positions in ETRS89 for 1 month of GNSS data processed using different orbits.

Orbits	E (mm)	N (mm)	U (mm)	3D (mm)
Precise	8.00	5.81	24.38	26.32
Rapid	8.20	6.02	23.25	25.37

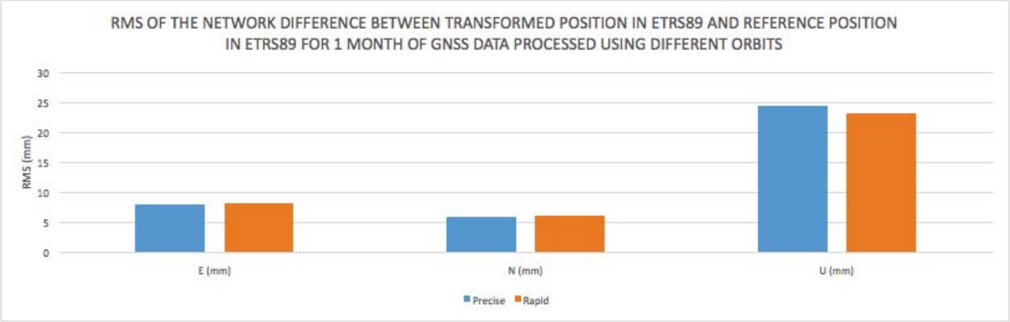


Figure 6.4: RMS of the network using data from table 6.3.

Taking into account the results determined above, it is possible to observe that there is practically no difference on the positions estimated using precise and rapid orbits, since the difference is less than 1mm, which means that, in practice, there is no real need to wait for precise orbits in order to estimate and apply transformation parameters to obtain more *accurate* observed and post-processed coordinates.

6.4.3 Variations on density and performance of GNSS stations network

Other tests were conducted regarding the density and reliability of the GNSS stations considering subsets of the used network of 36 ReNEP stations.

6.4.3.1 Calculation of transformation parameters using a network with low density

A test regarding variations on performance and density of the GNSS stations network was conducted to test how the transformation parameters of a network of only 6 stations would perform. In order to conduct this test a small network was set by choosing 6 stations well distributed from the ReNEP network. The same routine as in the *influence of different time-window frames test* was used and the results are shown in Table 6.4 and graphically represented in Figure 6.7.

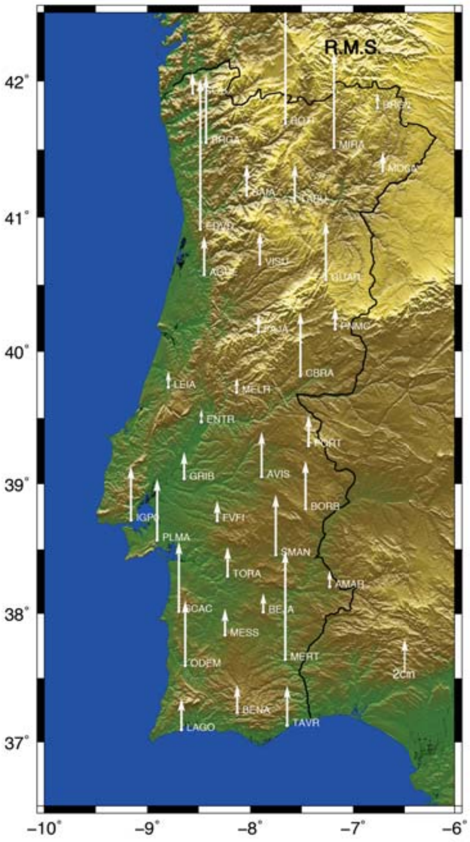


Figure 6.5: 3D RMS for the small dataset of reference stations (6)

Table 6.4: RMS for the small dataset of reference stations (6) using different time-window frames.

Duration	E (mm)	N (mm)	U (mm)	3D (mm)
1 Day	10.2	7.4	33.2	35.5
7 Days	9.9	7.2	32.4	34.7
15 Days	9.9	7.2	32.2	34.5
30 Days	9.9	7.2	32.3	34.5

6.4.3.2 Calculation of transformation parameters using a small network with low reliability

Another test was performed to test the influence of using a network with a small amount of stations (low density) and, on top of that, stations that are not reliable, i.e. with an inconsistent availability of GNSS observation files. In order to conduct this test a small network of 10 stations, from ReNEP, was selected, well distributed across Portugal (mainland) and its reliability was artificially manipulated in order to simulate a non-reliable environment where there were no observations files for everyday for every station (minimum of 5 stations). Once again the same routines as in the *influence of different time-window frames test* were used and the results are available in Table 6.5 and graphically represented in Figure 6.6.

Table 6.5: RMS for the variable dataset of reference stations (between 5 and 10) using different time-window frames.

Duration	E (mm)	N (mm)	U (mm)	3D (mm)
1 Day	10.1	7.7	33.1	35.5
7 Days	9.7	7.5	32.9	35.1
15 Days	9.7	7.6	32.5	34.8
30 Days	9.7	7.7	32.7	35.0

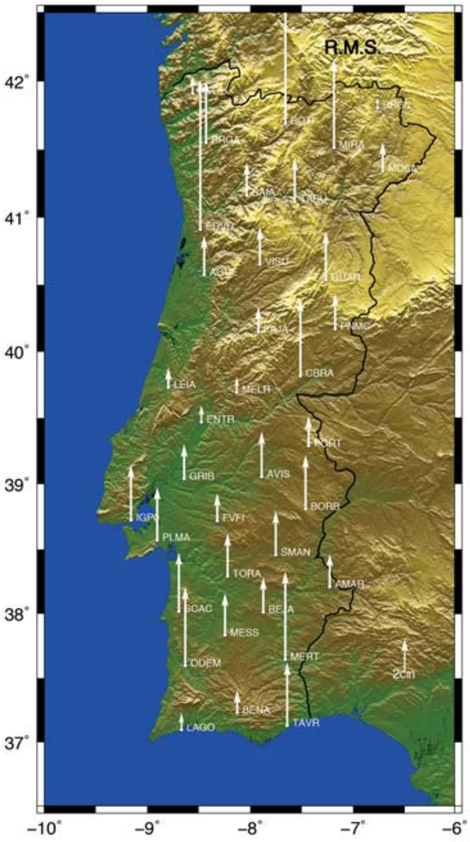


Figure 6.6: 3D RMS for the variable dataset of reference stations (between 5 and 10)

In this test it is possible to observe that the performance of the computed transformation parameters is a little worse when compared with the whole ReNEP network. This is very natural to occur as the density of the network and the amount of data changes in a negative way. However, the performance of the computed transformation parameters is not that much worse and this fact is believed to be related to the small area of the Portuguese mainland. These results would probably be worse if the same amount of stations were used in a significantly larger country/region, but this test is only a simulation to reproduce the possible effects in such case.

6.4.3.3 Calculation of transformation parameres using a worst case scenario

This last variation consisted in calculating the transformation parameters using the six stations that performed worst in the *influence of different time-window frames test* (subsection 6.4.1). So, stations `AVIS`, `BORB`, `BOTI`, `CBRA`, `EDVD` and `MIRA` were used to calculate the transformation parameters. The same routine as in the *influence of different time-window frames test* was used and the results are to be seen in Table 6.6 and graphically represented in Figure 6.7.

Table 6.6: RMS for the worst dataset of reference stations (6) using different time-window frames.

Duration	E (mm)	N (mm)	U (mm)	3D (mm)
1 Day	13.8	10.8	75.3	77.3
7 Days	12.5	11.5	68.5	70.6
15 Days	13.3	11.5	69.8	71.9
30 Days	12.2	11.6	68.1	70.2

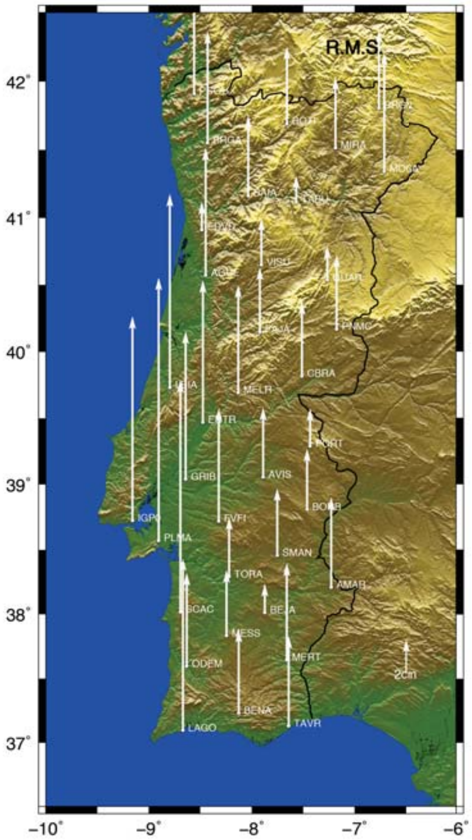


Figure 6.7: 3D RMS for the worst dataset of reference stations (6).

In this test it is possible to see, as already expected, that the performance of the approximations is highly negative influenced due to lack of density in the reference stations network and due to the poor quality of the used data. As observed, the RMS of the differences are larger than 70mm (in 3D) to the reference positions, with some having more than 100mm (in 3D) of difference.

6.4.4 Usage of the multiple calculated transformation parameters and its influence on stations outside the network

The last test carried out was based on the usage of all the previously computed transformation parameters and the analysis of the robustness of the parameters between each other. In order to process this test, the network of IGEoE stations was used. It is comprised of 27 stations well distributed across Portugal (mainland). For this series of tests, the following steps were performed:

1. Application of the different sets: best set (30 stations), entire set (36 stations), low reliability (5-10 stations), low density (6 stations); worst case scenario (6 *outlier* stations) of transformation parameters with a 7 day window to observation files of all Sundays during a period of 5 weeks;

2. After application of the different sets of transformation parameters to all files, each group was merged in a single combined solution for the specific transformation parameter set;

3. Using the best set (30 stations) as reference, the differences in East, North and Up for the other sets of transformation were determined.

6.4.4.1 Entire ReNEP network transformation parameters

Figure 6.8 shows, in white, the estimated differences for the horizontal (left) and vertical (right) components. Marked with green circles are the best set (30 stations) network, and in red triangles the entire set (36 stations).

The results showed that the differences in the horizontal component increases in the south of the Portuguese mainland with a North-Eastern direction and higher negative vertical differences along the coast line, indicating increase of deformation towards south on the horizontal component and essentially a rotation on the vertical component. Nevertheless, the differences are of few millimeters on the horizontal component (maximum of 5.5mm in `FARO`) and few centimeters in the vertical component (maximum of -3.6cm in `CAMI`). This implies that the use of the entire set of reference stations would also provide acceptable solutions.

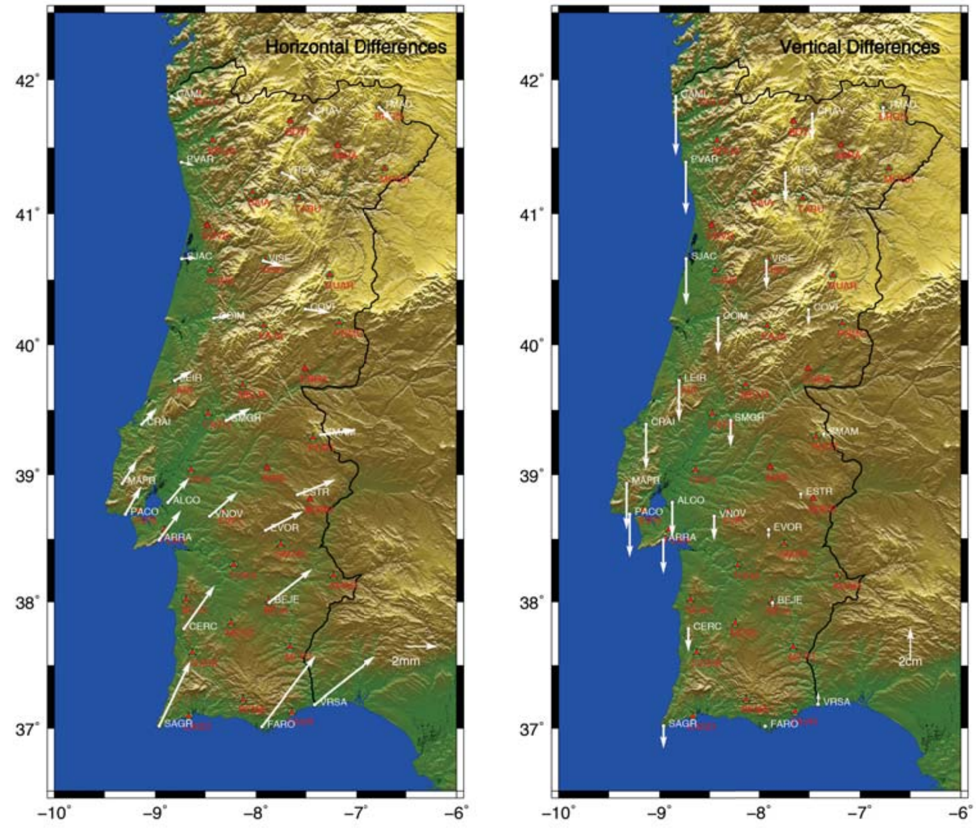


Figure 6.8: Differences between the entire set (36 stations) and the best set (30 stations).

6.4.4.2 Low reliability network transformation parameters

Figure 6.9 shows, in white, the estimated differences for the horizontal (left) and vertical (right) components. Marked with green circles are the best set (30 stations) network, and in red triangles the low reliability set (10 stations).

In the analysis of the performance and robustness of using transformation parameters from a low reliability network, the results show first that the differences are much smaller than when the possible outliers stations are included. Nevertheless, it is observed that there was a tendency of most stations for their horizontal differences to face a direction to South-East, and larger towards south (maximum of 2.5mm in `FARO`), and negative differences for all stations (maximum of -0.8cm in `FARO`) in the vertical component.

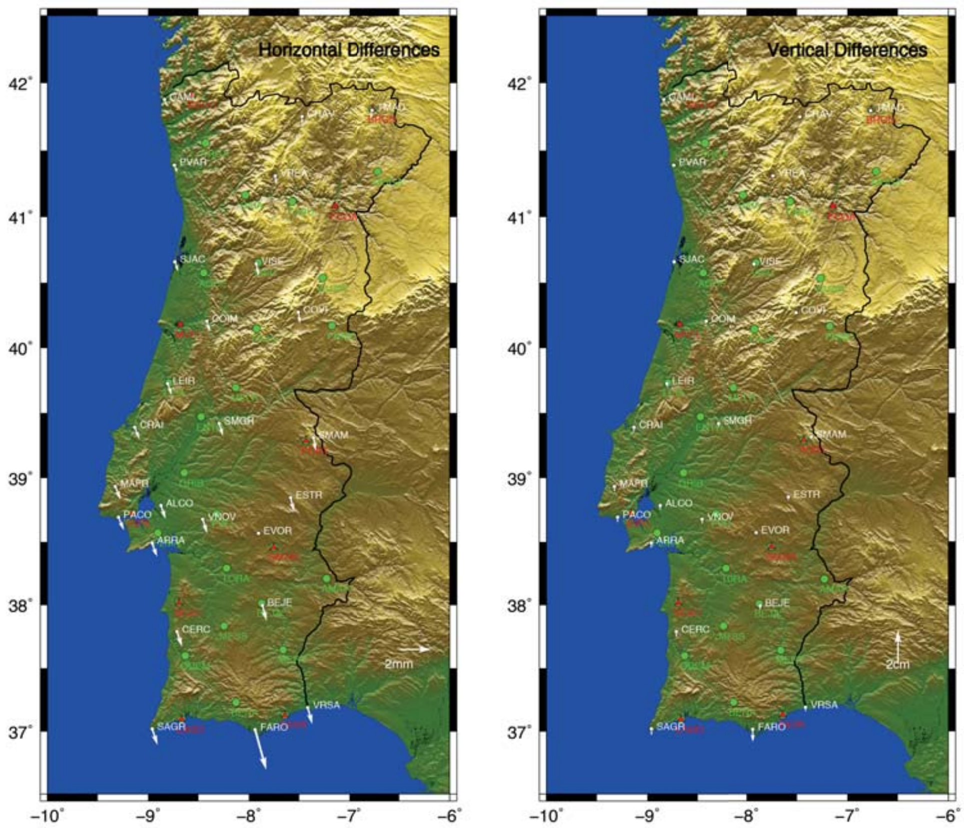


Figure 6.9: Differences between the low reliability set (5-10 stations) and the best set (30 stations).

6.4.4.3 Low density network transformation parameters

Figure 6.10 shows, in white, the estimated differences for the horizontal (left) and vertical (right) components. Marked with green circles are the best set (30 stations) network, and in red triangles the low density set (6 stations).

As for the analysis using a low density network, the results showed a worse performance with a considerable tendency of horizontal differences facing towards South-East, particularly for the stations located in the center-south and south of the Portuguese mainland (maximum of 6.7mm in `FARO`). In the case of the vertical velocities, it is possible to observe a moderate tendency of a positive velocity of the stations located in the center and north region but only in the coast line (maximum of 2.3cm in `FARO`).

Comparing with the other two previous solutions, it is possible to conclude that this small set of stations perform worse than the one with low reliability, indicating that a reduced number of reference stations can significantly affect the quality of the transformation.

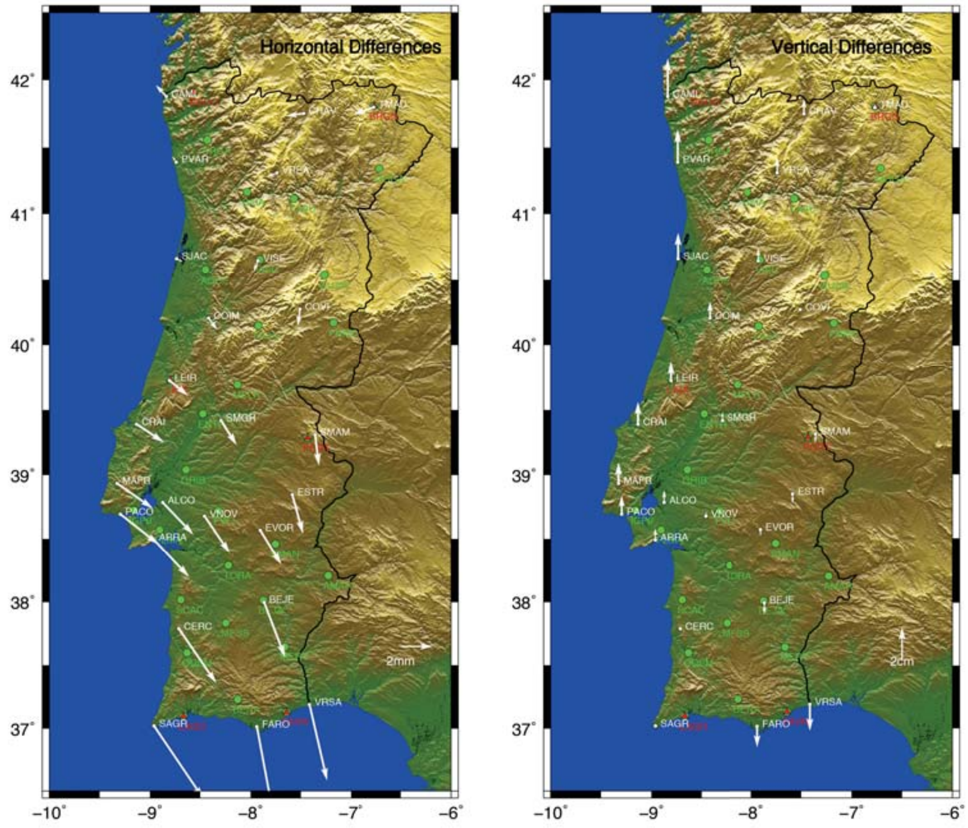


Figure 6.10: Differences between the low density set (6 stations) and the best set (30 stations).

6.4.4.4 Worst case scenario network

Finally, Figure 6.11 shows, in white, the estimated differences for the horizontal (left) and vertical (right) components. Marked with green circles are the best set (30 stations) network, and in red triangles the worst case scenario (6 stations).

Regarding the worst case scenario network, the results clearly show that these stations are completely unreliable to be used to estimate the tranformation parameters for the Portuguese mainlan. This was expected since they were considered outliers and their number were reduced. Last, but not least, their spatial distribution is very bad with two clusters (in North and Center) of 3 stations each. This implies that for a larger portion of the territory, the transformation parameters were also being extrapolated. For sake of curiosity, the maximum difference in the horizontal component was 22.5mm in `SAGR` (minumum of 4.1mm in `SMAM`), and maximum difference in the vertical component was -17.0cm in `MAFR` (minumum of -0.2cm in `ESTR`)

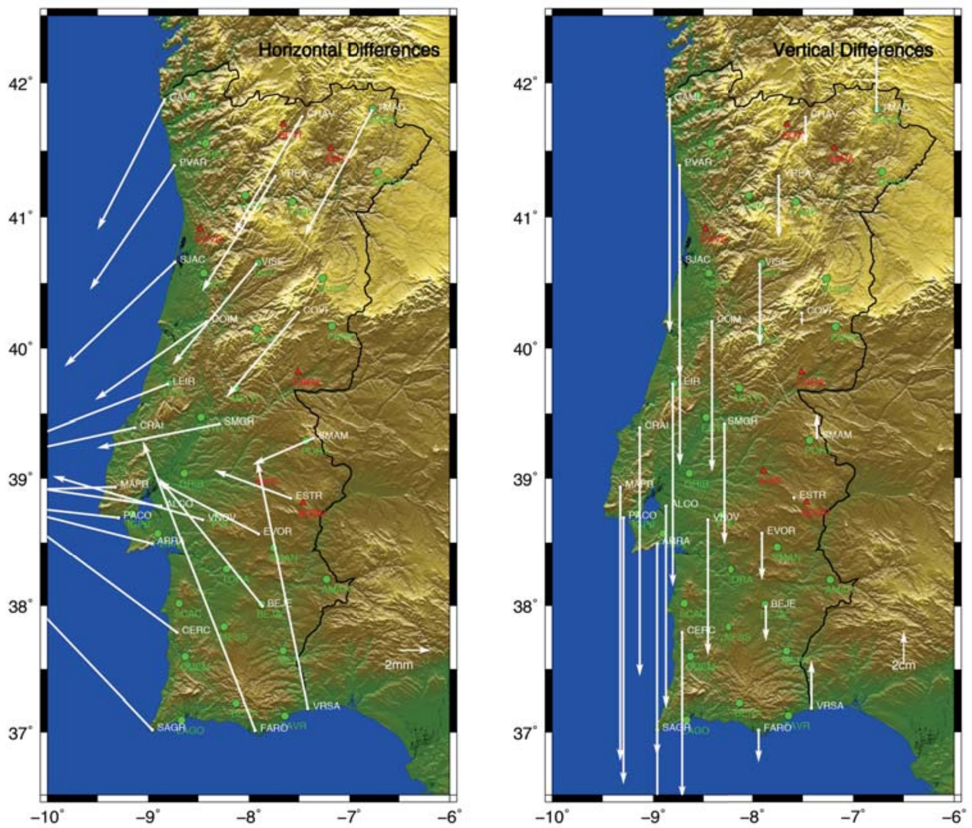


Figure 6.11: Differences between the worst case scenario (6 stations) and the best set (30 stations).

6.5 Conclusion

In this chapter, the coordinate transformation method to map from the ITRF2008 at the epoch of observation into the local official reference frame and its analysis were discussed. This section is crucial for the whole system, since the automation of the coordinate transformation is the core element of this work. Using the Helmert transformation, it was possible to achieve good results with differences to the original reference of 10mm in the horizontal component and 30mm in the vertical component, which are misfits perfectly acceptable.

The influence of the quantity of data used in the calculation of the transformation parameters was studied and it was possible to observe that the best option is 15 days which represent the previously mentioned difference of approximately 25mm (in 3D) to the original coordinates.

However, in the first try of the calculation of the transformation parameters, it was possible to observe that 6 stations of the ReNEP network were causing a higher discrepancy to the reference coordinates, these stations were then removed and the parameters recalculated, improving the overall statistics.

The influence of the orbits in the post-processed GNSS solutions was also analyzed concluding that there is no significant differences between Rapid and Precise orbits: the differences are situated below 1mm.

The influence of using low reliability, low density and worst case scenario networks were also tested and it was concluded that the usage of a (simulated) low reliability network has an influence in the positioning of approximately 35mm (in 3D) when compared with a more reliable network (like the best set of ReNEP stations). The usage of a low density network had an influence of also approximately 35mm (in 3D) when compared with the the best set of ReNEP stations. Finally the worst case scenario presented an influence of approximately 72mm (in 3D) when compared with the best set of ReNEP station coordinates.

Another set of tests were also performed, where the robustness of the transformation parameters were evaluated using stations external to the reference network and it was possible to conclude that the variation on density, reliability and in a worst case scenario is greater in the low density and worst case scenario and moderate in the low reliability network.

Finally and overall, the performed tests validated that the developed solution is in fact a good solution for the transformation of the solutions provided by the online services into the official reference frame, namely for the Portuguese mainland as the results are quite satisfactory.

Chapter 7

Software Engineering

7.1 Introduction

This chapter discusses the software engineering of the ALC solution that was developed. The requirement analysis are presented as well as use cases and database diagrams. The chapter is structured in the following manner:

- Section 7.2 presents the requirements analysis;
- Section 7.3 describes the general use cases;
- Section 7.4 explains the database structure and how it was designed;
- Section 7.5 concludes this chapter with the main conclusions.

7.2 Requirements analysis

The requirement analysis is one of the most important parts of any software engineering project, these requirements will, on a high level of abstraction, define what the project is about and how it has to be perceived by others. These requirements can be organized in two categories: the functional and non-functional requirements, which are analyzed in subsections 7.2.1 and 7.2.2.

7.2.1 Functional requirements

- Transformation of positioning coordinates of different datums to a defined datum;
- Calculation of coordinate transformation parameters between datums;
- Post-process observation files using online PPP services;
- Provide a web service where users can register and submit their own collected observation files and later collect the results;
- Transform coordinates of the user submitted data;
- Manage users in the platform;

- Monitor activity in the web service;

7.2.2 Non-functional requirements

- The web service platform should be easy to understand and intuitive;
- The appearance should be clean and simple;
- The platform layout should be easy to navigate and functionalities of the same family should be grouped together;
- The area for non-administrators should be of the most ease usage;
- The area for administrators should immediately present the most relevant information in the first screen.

7.3 Use cases

In the case of the ALC web service, two actors were considered, the *User* which is a non-administrator user of the web service, and the *Administrator* which is an administrator user of the web service and has access to more advanced features.

In figures 7.1 and 7.2 it is possible to observe an overview of the main features that can be found in the ALC web service. Each diagram represents the interaction with the ALC web service of a different type of user. The first diagram is a representation of the main features that the regular user can execute and the second diagram a representation of the features that the administrators of the platform can have access to. Independently of the type of user, all have to be successfully log in the platform in order to use their available functionalities.

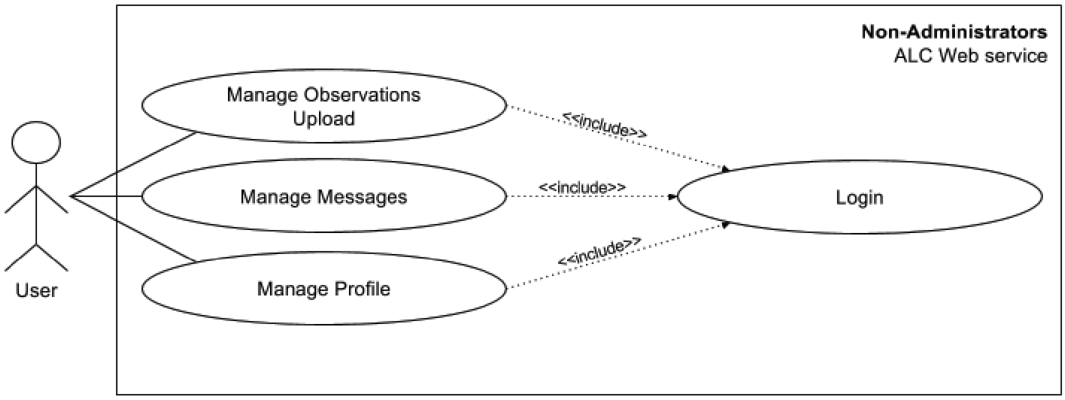


Figure 7.1: Use case diagram for non-administrators.

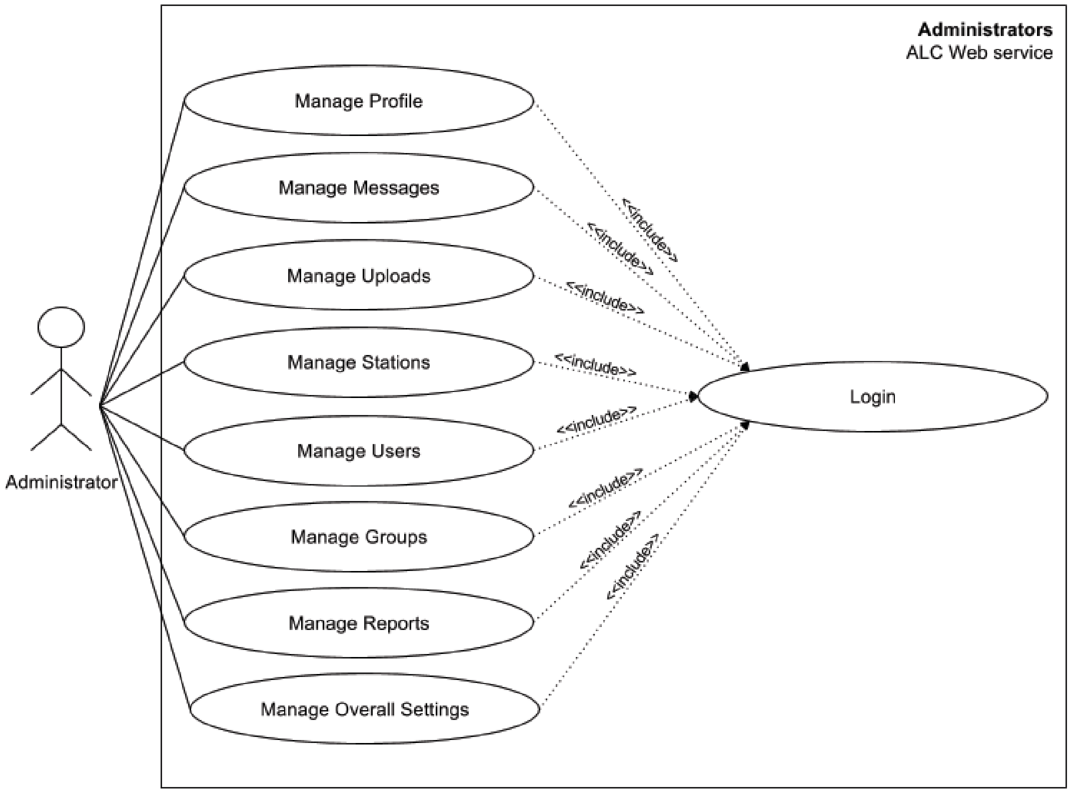


Figure 7.2: Use case diagram for administrators.

7.4 Database design

Given that it was necessary to store information for the web service to work, it was decided that the development of a local database was the best approach. The relational model of the developed database can be seen in Figure 7.3, which shows in detail the tables that were created in the database, as well as the fields that every table contains. In the design of the database, the future integration with the MGN software was also taken into account. Therefore, some of the tables contain more fields than the strictly necessary ones.

The `users` table holds the information of the users able to access the web service and also the pre-registered users. The stored information includes full name, username, password, status of the account, organization, and more. A unique identifier for each user is also included.

The `groups` table contains the information of the various groups configured, the groups provide different permission levels inside the platform. The table contains a name, the attributed permission level and timestamps. It includes the unique identifier for each group.

The `users_groups` table contains the keys that relate users and groups, because every user can belong to more than just one group.

The `tokens` table holds the temporary randomly generated token necessary to reset the password from users. The stored information includes the token, a link to a specific user and a timestamp. The token also works as the unique identifier.

The `loginAttempts` table is a control table that monitors the failed login attempts and ultimately blocks users of logging in the platform. The stored information is simply the link to a specific user and the timestamp of the last login attempt.

The `timeInterval` table contains the time window restriction information on which the user is able to login to the platform. The table contains the link to a user, the date on which the user may start to log in the platform and the date on which the user loses access. It includes a unique identifier for each period.

The `messages` table holds all the messaging the users may exchange with the administrators of the platform. The table contains the link to the sender and receiver as well as the message and the status of the message. Each message is identified by a unique identifier.

The `uploads` table contains the information of the files uploaded by the users to be processed. The stored information includes the link to the user that uploaded the file, file name and location, status and notification settings of the job, the transformation parameters used, and also positioning information which is filled after the job is done. A unique identifier for each upload is also included.

The `transformationParameters` table holds all the transformation parameters that are calculated. The table contains the location of the transformation parameters file, the amount of data used to generate the parameters and also the rotation, translation and scaling parameters. Each transformation parameters entry has a unique identifier.

The `stations_transformationParameters` table contains the keys that relate stations and transformation parameters, because every set of transformation parameters was calculated using a set of stations.

The `stations` table holds the most recent information of all stations existing in the configured network. The table contains identification information like marker name and positioning information, but also the responsible entities and on-server raw file processing settings. A unique identifier for each station is also included.

The `stationsRevision` table, holds exactly the same information as the `stations` table, however the difference in this table is that it holds all the history of the changes made to the stations. Also a link to the original station in the `stations` table is included as well as a unique identifier.

As for the `rinexFiles` table, it holds the information regarding the processed observation files. The table contains information like the file name, the station it belongs to, the type of data that was stored, the date of the observation and the percentage of completeness of the observation file.

Lastly, the `stacovFiles` table holds the post-processed observation files. The stored information includes the RINEX file it relates to, the file name and the post-processing service used. A unique identifier is as always included in this table as well.

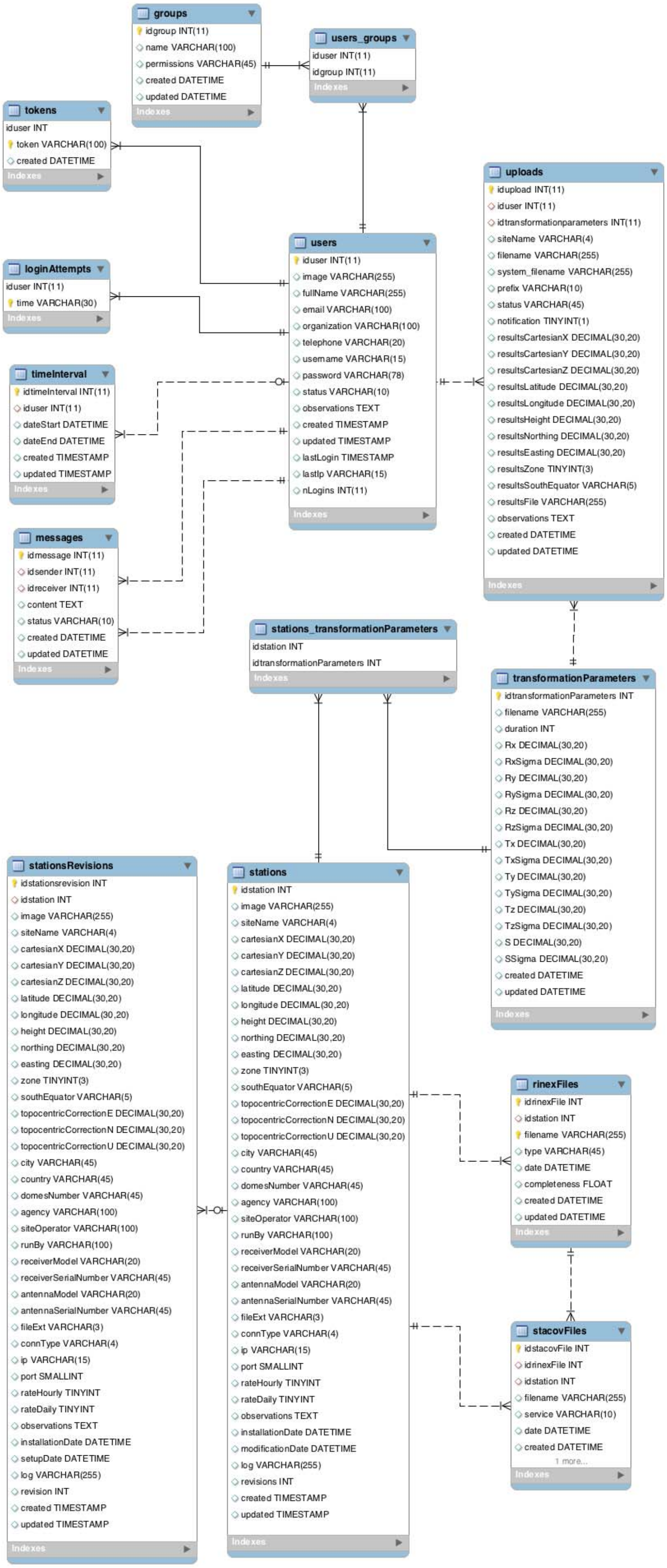


Figure 7.3: Relational model diagram of the ALC database.

7.5 Conclusion

The present chapter discussed the software engineering of the ALC solution. It included the definition of the solution itself as for what it should be and how it should be, by describing the functional and non-functional requirements. Also the two main use case diagrams where introduced so that a better perception of what each user can do can be perceived and, finally, the database scheme was introduced and each table described. With this chapter in mind it was possible to solidly develop the ALC solution which is described in detail in chapter 8.

Chapter 8

Automatic Local Coordinates Software

8.1 Introduction

In this chapter, the developed coordinate datum correction solution is discussed. This solution was named **A**utomatic **L**ocal **C**oordinates (ALC). ALC is divided in two products: one is a set of background processes that work locally to process data, the other is a web solution that allows registered users to easily submit observation files and automatically retrieve the corrected coordinates for the observation files they submitted. It also allows the management of users, activity, generation of automatic reports, and more. The chapter is structured in the following manner:

- Section 8.2 presents the different components that run in the background;
- Section 8.3 presents the web solution and describes how it works;
- Section 8.4 concludes this chapter with the main conclusions.

8.2 ALC background processing components

In order for ALC to work properly a set of background processes must run everyday so that all the necessary data to correct observation solutions are up-to-date. These background processes comprise the following major tools:

- **StartDailyNetworkTasks** a background process that runs everyday to keep the system up-to-date;
- **AppsFromService** a tool to process RINEX files in the online processing services;
- **ScaleRetrievedStacov** where the STACOVs retrieved from the online services are normalized and balanced;
- **MergeStacovPeriod** a tool to merge existing STACOV files into a single STACOV file;
- **DeleteMergeOutliers** an important auxiliary tool to detect outliers when merging STACOVs;

- **GetTransformationParameters** a process that determines the transformation parameters using the Helmert transformation parameters method;

- **DetectTransformationOutliers** similarly to DetectMergeOutliers this tool is an important auxiliary tool to detect possible outliers during the calculation of the transformation parameters;

- **ProcessUserData** a tool that scans the folder with the user RINEX files submitted by users in the online platform and processes them;

- **TransformCoordinates** a process that applies the previously calculated transformation parameters in order to correct coordinates to a specific datum.

8.2.1 StartDailyNetworkTasks component

This component is a background process that is intended to be executed everyday to process the available RINEX observation files from the day before using the configured online processing services, it also starts the merging process and calculation of transformation parameters whenever the day of week is Sunday. This task is achieved by following flowchart 8.1.

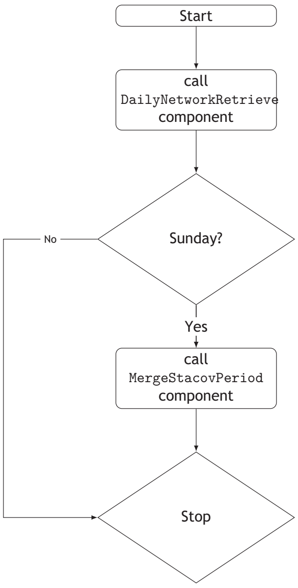


Figure 8.1: General flowchart of StartDailyNetworkTasks component.

As flowchart 8.1 shows, every day the `DailyNetworkRetrieve` component is called in order to process the most recent RINEX files available in the system, after processing all the observation files, if the day of the week is a Sunday the `MergeStacovPeriod` component is called and the configured merge duration is fed to the component so that the already processed observation files get merged together and the most recent transformation parameters get calculated.

The command line options for this component are as described in Table 8.1.

StartDailyNetworkTasks command line options	
`-h`	produce help message
`-c`	specification of location of configuration file with stations network list

Table 8.1: StartDailyNetworkTasks command line options.

8.2.2 DailyNetworkRetrieve component

The DailyNetworkRetrieve component is responsible for finding new available RINEX files and process them using the configured online processing services. This component is called by the StartDailyNetworkTasks component and screens the configured RINEX files folder and checks for all files received the day before so that they get processed using the AppsFromService component. This task is achieved by following flowchart 8.2.

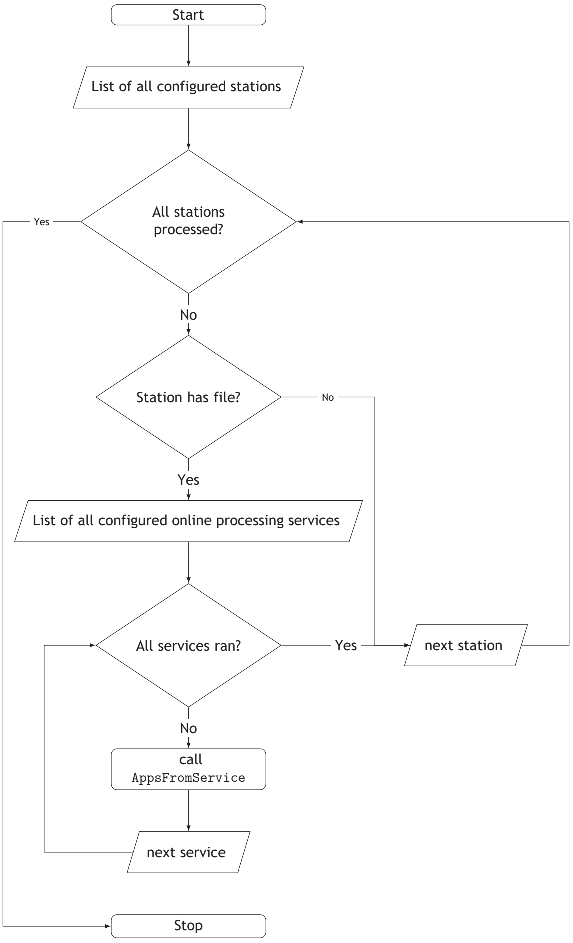


Figure 8.2: General flowchart of DailyNetworkStacovRetrieve component.

As flowchart 8.2 shows, all stations from the configured network are put in queue and processed to retrieve the daily STACOV file from each configured online service. The task of submitting the observation files and retrieving the STACOV results is done using the `AppsFromService` component.

The command line options for this component are as described in Table 8.2.

DailyNetworkRetrieve command line options	
`-h`	produce help message
`-d`	specification of operation date in format YYYYDOY (YYYY = Year, DOY = Day of year)
`-c`	specification of location of configuration file with stations list

Table 8.2: DailyNetworkRetrieve command line options.

8.2.3 AppsFromService component

This component has the purpose to submit the referenced observation files to the configured online processing services and retrieve the resulting STACOV files that will be used later in the creation of the station network transformation parameters. This task is achieved by following flowchart 8.3.

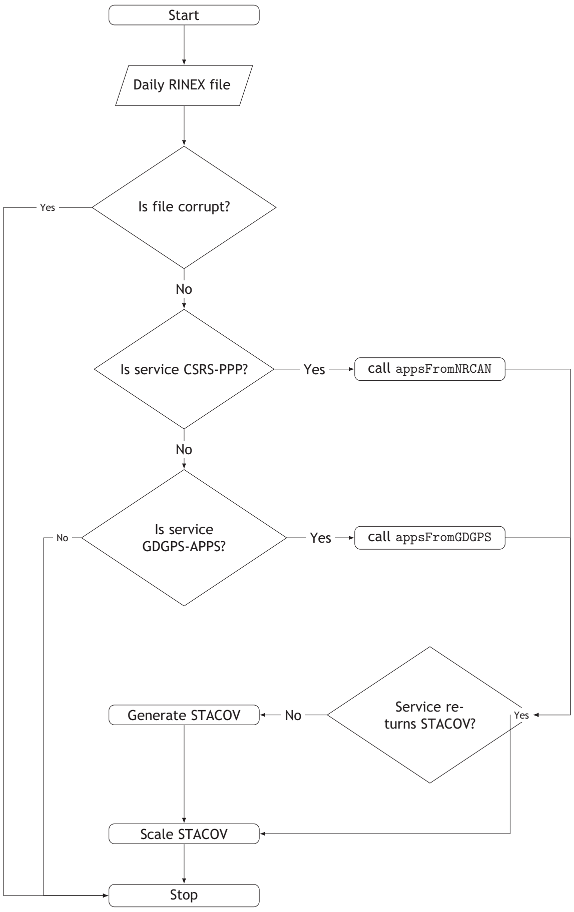


Figure 8.3: General flowchart of AppsFromService component.

As flowchart 8.3 shows, the provided RINEX file is uploaded to the online processing services by calling the `appsFromNRCAN` or `appsFromGDGPS` scripts, depending on which service is being processed. These scripts interact with the online services and collect the results. If the results include a STACOV file, then the STACOV file is scaled, due to the issue with the formal errors discrepancy described in chapter 5, using the `scaleRetrievedStacov` component, if a STACOV file is not included then the `AppsFromService` component will call the `nrcanToStacov` script and generate a STACOV file using the summary file provided by the service.

The command line options for this component are as described in Table 8.3.

AppsFromService command line options	
`-h`	produce help message
`-d`	specification of operation date in format YYYYDOY (YYYY = Year, DOY = Day of year)
`-i`	specification of the location of the RINEX file
`-o`	specification of the location for the result STACOV file
`-s`	specification of the online service
`-c`	specification of location of configuration file with stations list

Table 8.3: AppsFromService command line options.

8.2.4 AppsFromGDGPS and AppsFromNRCAN components

The `AppsFromGDGPS` and `AppsFromNRCAN` components are ultimate responsible components for submitting the provided observation files and for collecting the results of the processing done in the online processing services. The `AppsFromGDGPS` component interacts with the online public accessible Instant Positioning Tool [NASa]. This component fills and submits the form with the pre-configured data and provided observation file, and enters in a waiting cycle until the results are ready to be collected to the provided output folder. The `AppsFromNRCAN` component interacts with an API, kindly provided by the NRCAN office [?]. This component exchanges a few calls with the API where some pre-configured data and the provided observation file are sent. It then enters in a waiting cycle until the results are ready to be collected to the provided output folder.

Both components command line options are as described in Table 8.4.

AppsFromGDGPS and AppsFromNRCAN command line options	
`-i`	specification of the location of the RINEX file
`-d`	specification of the location for the output folder where the results will be stored

Table 8.4: AppsFromGDGPS and AppsFromNRCAN command line options.

8.2.5 ScaleRetrievedStacov component

Due to the scaling issue found in chapter 5, this component was developed to be responsible for scaling the STACOV files. With the provided STACOV file the component calls a function that executes the scaling methods described in detail in chapter 5. With the results of this function a new STACOV file is generated as specified by the `-o` option.

The command line options for this component are as described in Table 8.5.

ScaleRetrievedStacov command line options	
`-h`	produce help message
`-i`	specification of location of the input STACOV file
`-o`	specification of location of the output STACOV file
`-s`	specification of service that processed the STACOV file

Table 8.5: ScaleRetrievedStacov command line options.

8.2.6 MergeStacovPeriod component

The `MergeStacovPeriod` component is a very important component since it is here that more core tasks are performed. This task is achieved by following flowchart 8.4.

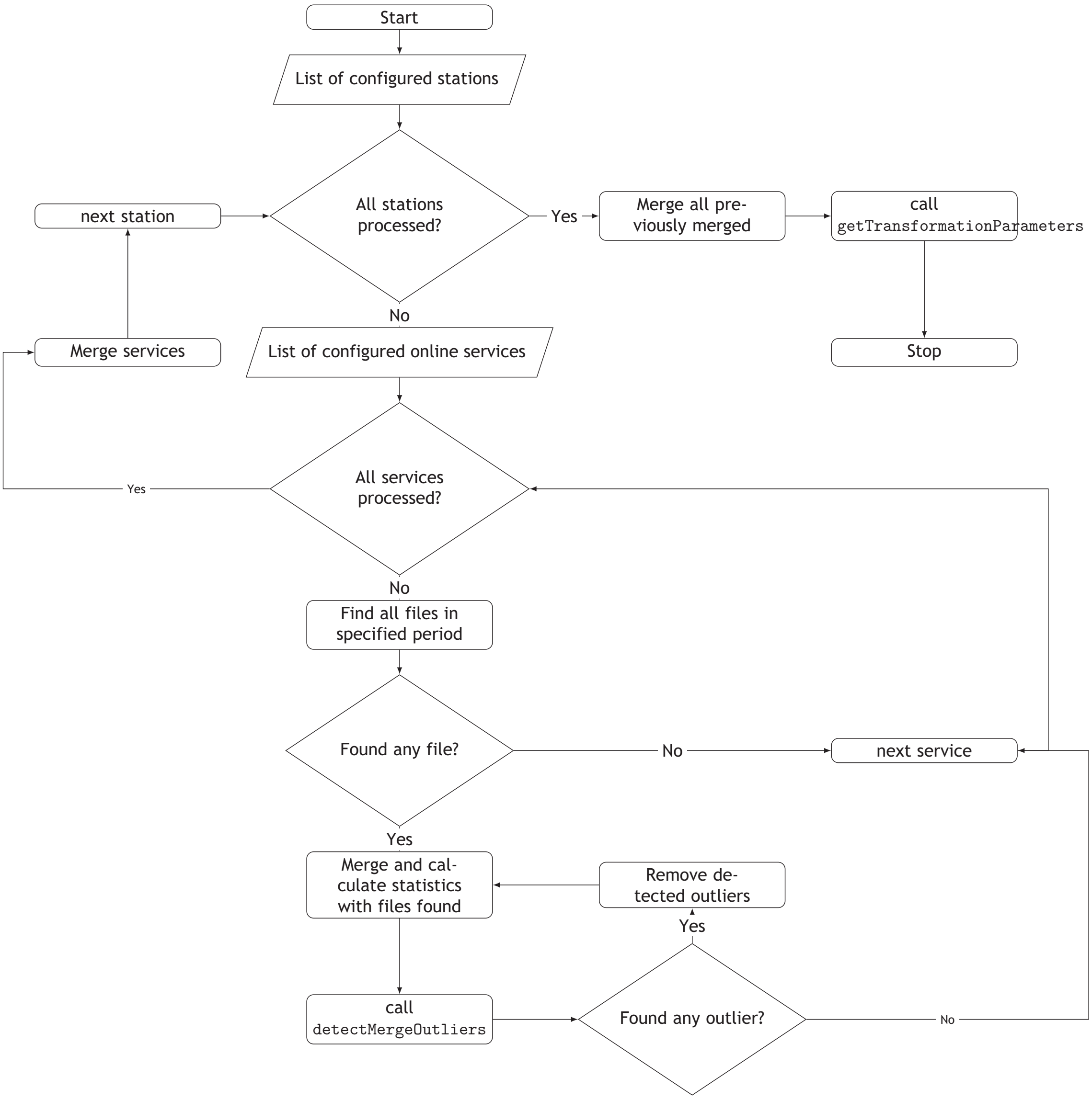


Figure 8.4: General flowchart of MergeStacovPeriod component.

As flowchart 8.4 shows, these core tasks are the outlier detection mechanism which will find all the available STACOV files available for the specified time interval, merge them together, using the `detectMergeOutliers` component, and for each component (lat, long and rad) calculate the residuals between the merged filed. With the calculated residuals it is then possible to determine if the set of files contains any outlier, and if so, the outlier file is removed and the process of merging and residuals calculation restarts. After all outliers removed and all services and all stations are processed, the solutions for all stations are merged into one file and the transformation parameters are calculated by calling the `getTransformationParametrs` component.

The command line options for this component are as described in Table 8.6.

MergeStacovPeriod command line options	
`-h`	produce help message
`-r`	specification of the initial reference date in YYYDOY (YYY = Year, DOY = Day of Year)
`-d`	specification of the duration in days to go back in time
`-c`	specification of location of configuration file with stations list

Table 8.6: MergeStacovPeriod command line options.

8.2.7 DetectMergeOutliers component

This component is responsible for the detection of outliers using the output of the statistics calculations (A tool provided by the NASA/JPL's GIPSY/OASIS [NASb] software package called `statistics`) determined in the `MergeStacovPeriod` component. The output of those statistics consist in 3 files, one for each component (LAT, LON and RAD), inside those files are the residuals between the files merged and the main purpose of this component is to find any outliers in this set of residuals. In order to do that the methods presented in chapter 4 are applied by calling the `detectOutliersIQR`, and `detectOutliersWRMS` functions. This task is achieved by following flowchart 8.5.

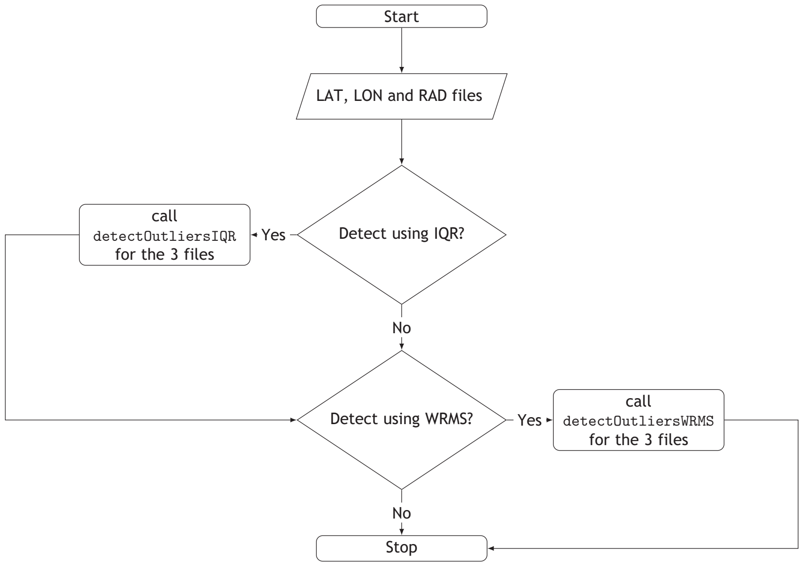


Figure 8.5: General flowchart of DetectMergeOutliers component.

The command line options for this component are as described in Table 8.7.

DetectMergeOutliers command line options	
`-h`	produce help message
`-lat`	specification of the location of the LAT file
`-lon`	specification of the location of the LON file
`-rad`	specification of the location of the RAD file
`-m`	specification of the detection method
`-site`	specification of site name
`-w`	specification of the GPSWEEK of submitted data
`-s`	specification of the online processing service

Table 8.7: DetectMergeOutliers command line options.

8.2.8 DetectMergeOutliersIQR and DetectMergeOutliersWRMS components

These 2 components are responsible for applying all the theory, described in chapter 4, to practice. The inputs for theses functions are their demarcation factors and the set of values where the auditory should be performed, In the end, their output is the highest outlier found.

The command line options for this component are as described in Table 8.8.

DetectMergeOutliers command line options	
`int`	specification of the demarcation factor for the applied method
`array`	set of residuals to be processed

Table 8.8: DetectMergeOutliersIQR and DetectMergeOutliersWRMS command line options.

8.2.9 GetTransformationParameters component

This component is responsible for the determination of the transformation parameters. The component uses a tool provided by the NASA/JPL's GIPSY/OASIS [NASb] software package called `transform` which calculates the Helmert transformation parameters between a datum reference network and an observed network merge. This task is achieved by following flowchart 8.6.

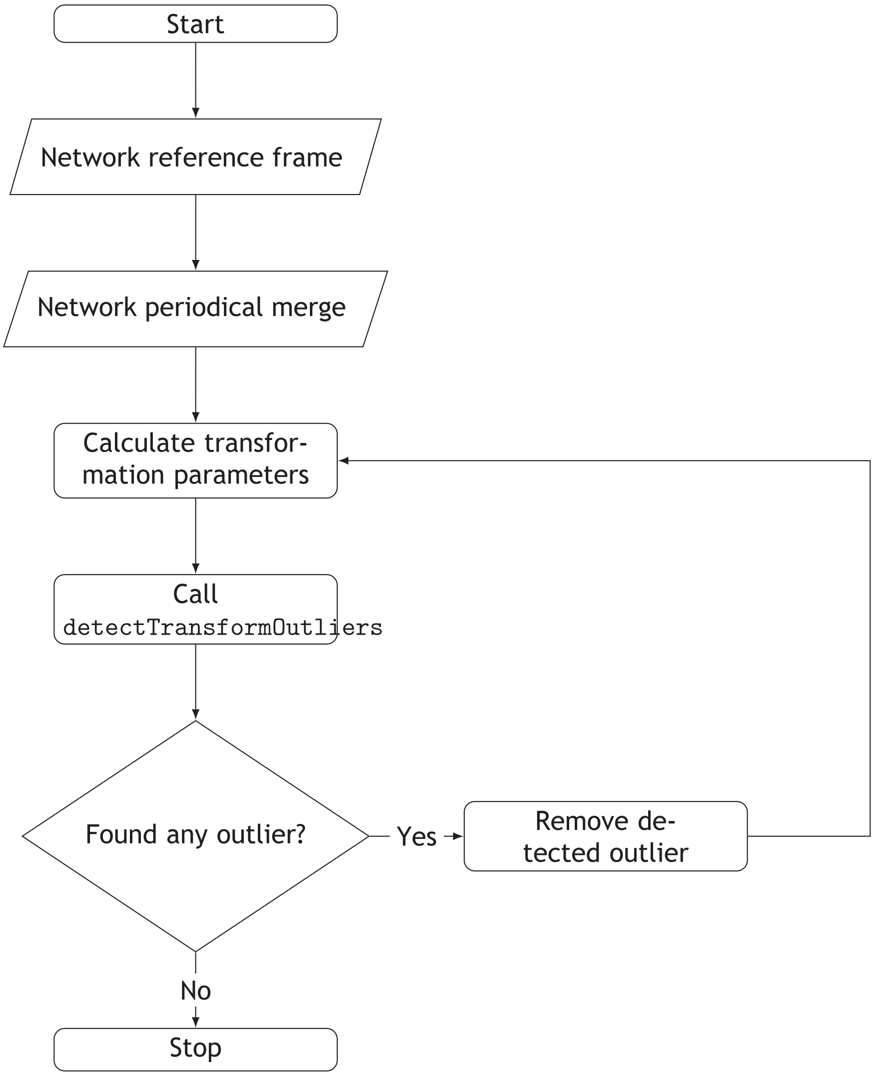


Figure 8.6: General flowchart of GetTransformationParameters component.

As illustrated in flowchart 8.6, after determination of the transformation parameters, a set of residuals is presented together with the parameters and, once again, outlier detection methods come to action in order to find any gross errors with the calculated data, if any outlier is detected the station is removed and the transformation parameters are recalculated again, until there's no more outliers being detected. In the end, a solution with the transformation parameters is stored in the predefined file.

The command line options for this component are as described in Table 8.9.

GetTransformationParameters command line options	
`-h`	produce help message
`-f`	specification of the location of the network datum reference frame
`-i`	specification of the location of the network period merge
`-o`	specification of the location for the output of the transformed network
`-p`	specification of the location for the output of the transformation parameters

Table 8.9: GetTransformationParameters command line options.

8.2.10 DetectTransformOutliers component

The working flow for this component is the same as for the `detectMergeOutliers` component with the exception that in this component the geodesic components that are studied are E, N and V instead of LAT, LON RAD, regarding everything else, the operation of this component is the same. So, for the sake of not having repeated text in this dissertation, please refer to subsection 8.2.7 of this very chapter and main section for a more detailed explanation of the operation of this component.

The command line options for this component are as described in Table 8.10.

DetectTransformOutliers command line options	
`-h`	produce help message
`-p`	specification of the location for the input transformation parameters file
`-m`	specification of the outlier detection method

Table 8.10: DetectTransformOutliers command line options.

8.2.11 ProcessUserData component

This component is responsible for making a bridge between the online platform and the background processes. This component runs every minute and monitors a shared folder between the background processes and the online platform in order to find new uploads the users may have submitted. This task is achieved by following flowchart 8.7.

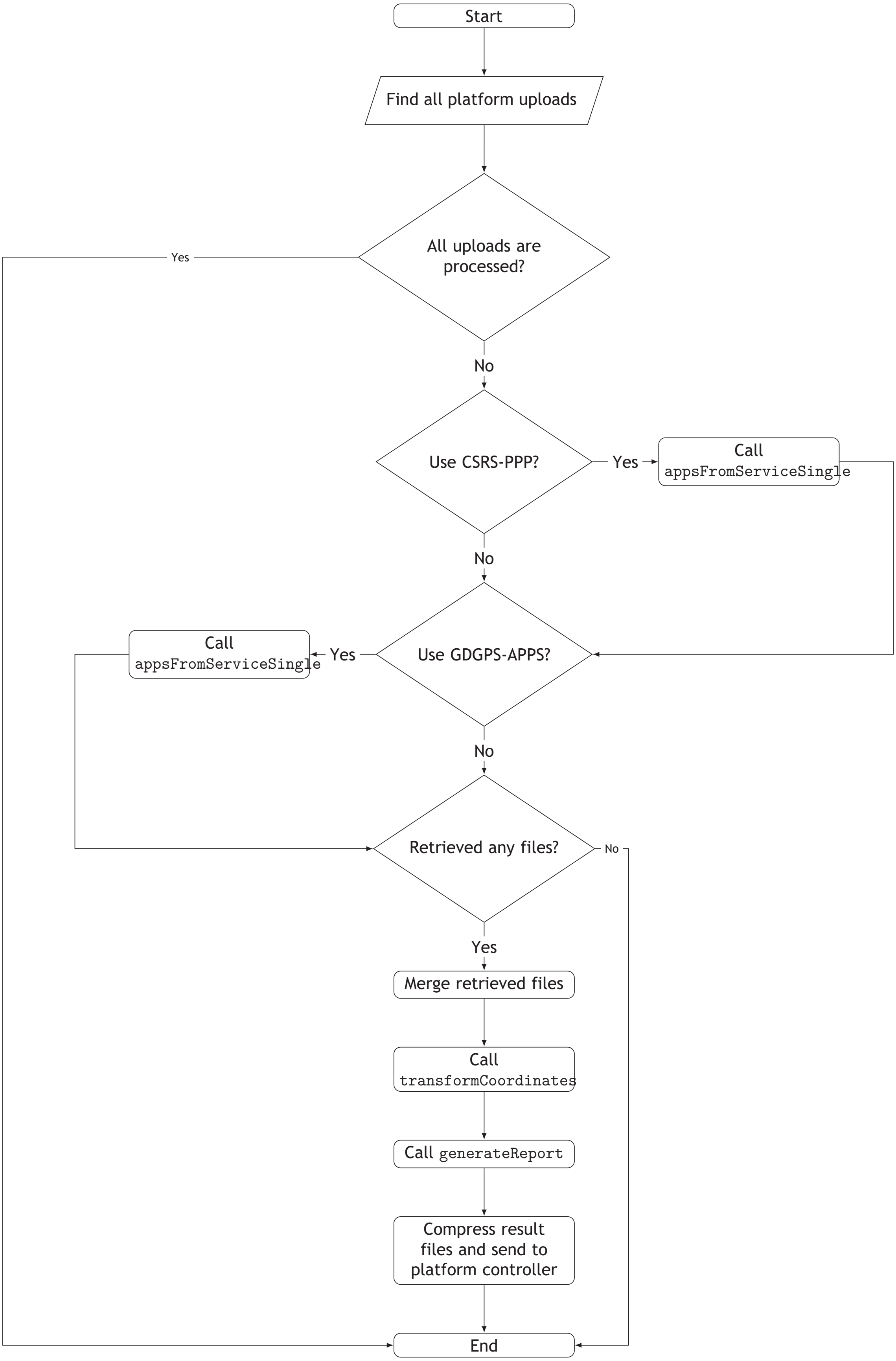


Figure 8.7: General flowchart of ProcessUserData component.

As illustrated in flowchart 8.7, if any observation file has been found, the component submits the file to the configured online services and then merges them together. In this case, no outlier detection method is run since it is only dealing with files of the very same day and they are all scaled to have balanced weights. It is then possible to apply the transformation parameters, to this last generated file and extract the corrected coordinates from the observation file that was originally submitted by the user. A report is also generated where a series of details are presented. Finally, the results are compressed in a tarball and sent to another shared folder between the background processes and the online platform where the results are monitored by the platform controller.

The command line options for this component are as described in Table 8.11.

ProcessUserData command line options	
`-h`	produce help message

Table 8.11: ProcessUserData command line options.

8.2.12 AppsFromServiceSingle component

The working flow for this component is the same as for the `appsFromService` component with the exception that in this component the output is not a folder with files but rather a STACOV file, regarding everything else, the operation of this component is the same. So, for the sake of not having repeated text in this dissertation, please refer to subsection 8.2.3 of this very chapter and main section for a more detailed explanation of the operation of this component.

The command line options for this component are as described in Table 8.12.

AppsFromServiceSingle command line options	
`-h`	produce help message
`-i`	specification of the location of the input RINEX observation file
`-o`	specification of the location of the output STACOV file
`-s`	specification of the online processing service

Table 8.12: AppsFromServiceSingle command line options.

8.2.13 GenerateReport component

The `GenerateReport` component is responsible for the generation of a report about the details of the operations that took place in order to calculate the datum corrected coordinates of the observation file submitted by the user in the web platform. A more detailed view of an example of a report generated by this component can be analyzed in appendix D.

The command line options for this component are as described in Table 8.13.

GenerateReport command line options	
`-h`	produce help message
`-i`	specification of the location of the file with the report bulk data
`-o`	specification of the location of the output report file

Table 8.13: GenerateReport command line options.

8.2.14 TransformCoordinates component

This component applies a specified set of transformation parameters to a network periodical merge, in order to transform the network periodical merge coordinates into coordinates referring to the datum of where the transformation parameters are originally from. The application of the transformation parameters is done using a tool provided by the NASA/JPL's GIPSY/OASIS [NASb] software package called `apply` which applies transformation parameters using the Helmert transformation method.

The command line options for this component are as described in Table 8.14.

TransformCoordinates command line options	
`-h`	produce help message
`-p`	specification of the location of the transformation parameters file
`-i`	specification of the location of the network period merge
`-o`	specification of the location of the transformed network

Table 8.14: TransformCoordinates command line options.

8.3 ALC web solution

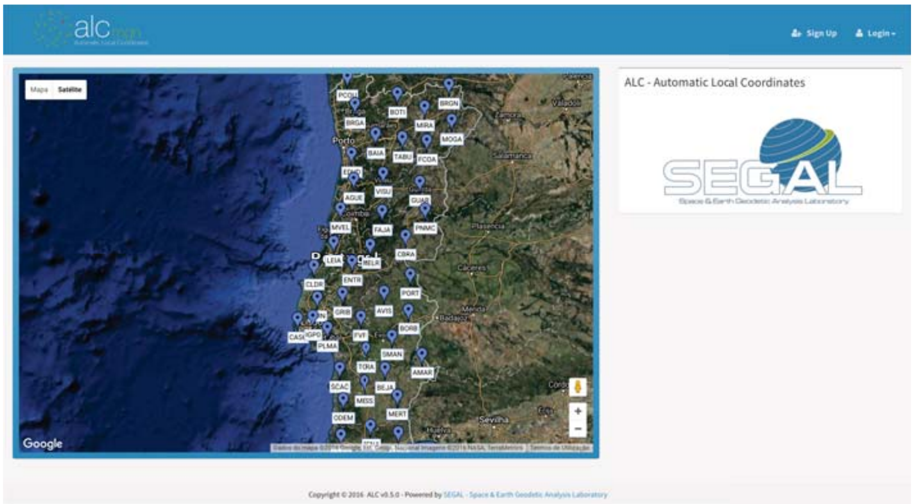


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Figure 8.8: ALC - Homepage.

The ALC web solution (welcome screenshot in Figure 8.8) is an online web platform that is intended to be used as an interface for users who want to process RINEX (observation files) and calculate the coordinates of their observation files to a specific datum. This web solution is provided with a registered users area in order to control access and monitor activity. The solution is divided in 3 parts:

- **Registered Users Area** area where registered users can submit their RINEX and monitor the evolution of its processing;

- **Administration Area** area reserved only for administrators where it is possible to manage most of the functions of the platform;

- **Background Processes** a set of tools that run in the background that monitor the evolution of the users requests.

In Figure 8.9 a graphical representation of the platform's site map is illustrated.

8.3.1 Registered users area

The registered users area is a area where the users that are registered to the platform can submit their observation files for coordinate correction and collect results. This area is divided in 3 functionalities:

- **Observation Files** relates to the functionalities of upload, monitoring and results download of the submitted observation files;

- **Profile** relates to the functionality of personalization of the users profile;

- **Messages** relates to the functionality of being able to send messages to the administrators.

However, in order to use the ALC web platform the first step to get access is to request an account, in order to do that it is necessary to fill the sign up form, which is illustrated in Figure 8.10. After requesting the account an administrator will receive a notification that someone is requesting an account. After validation from the administrators the account is created and the user can start using the platform.

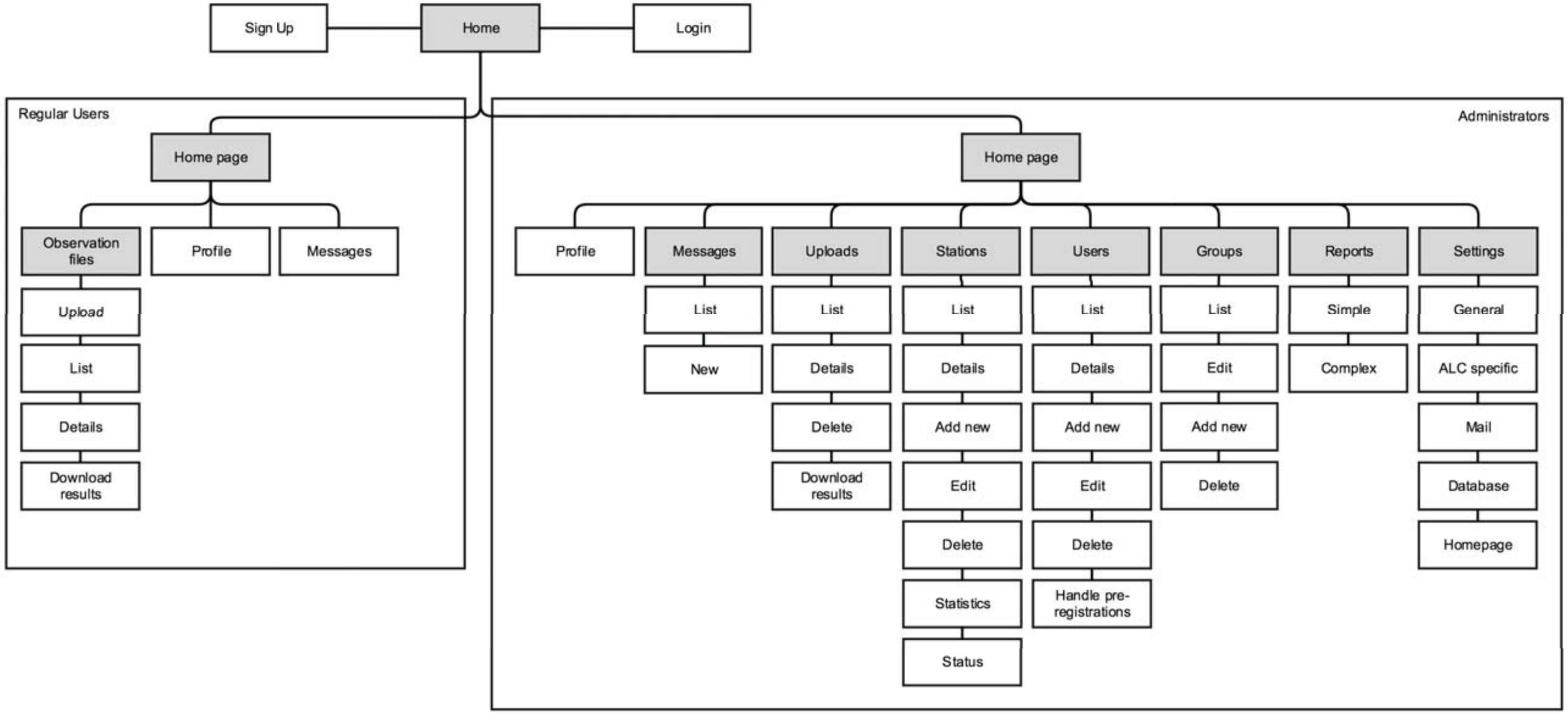
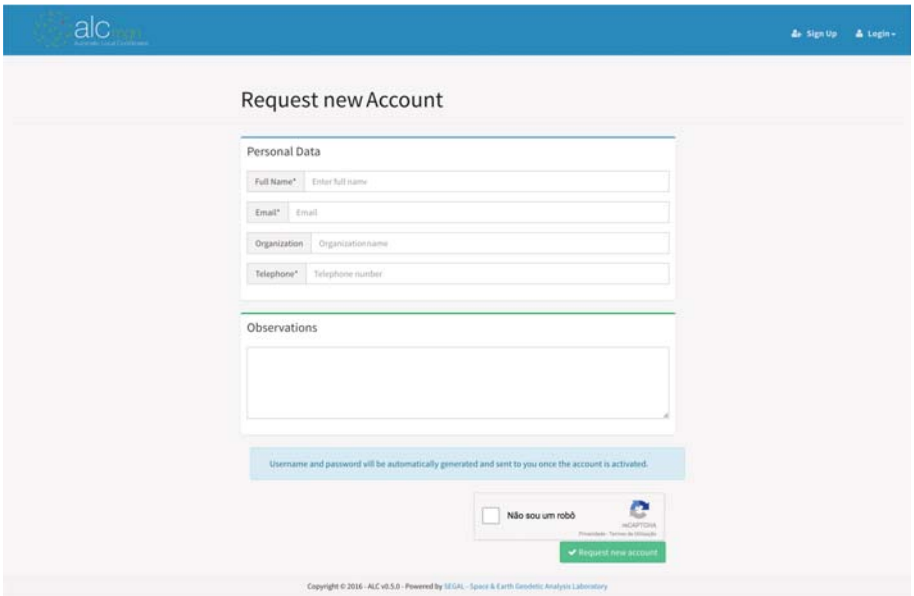


Figure 8.9: ALC - Site map.



Request new Account

Personal Data

Full Name* Enter full name

Email* Email

Organization Organization name

Telephone* Telephone number

Observations

Username and password will be automatically generated and sent to you once the account is activated.

☐ Não sou um robô

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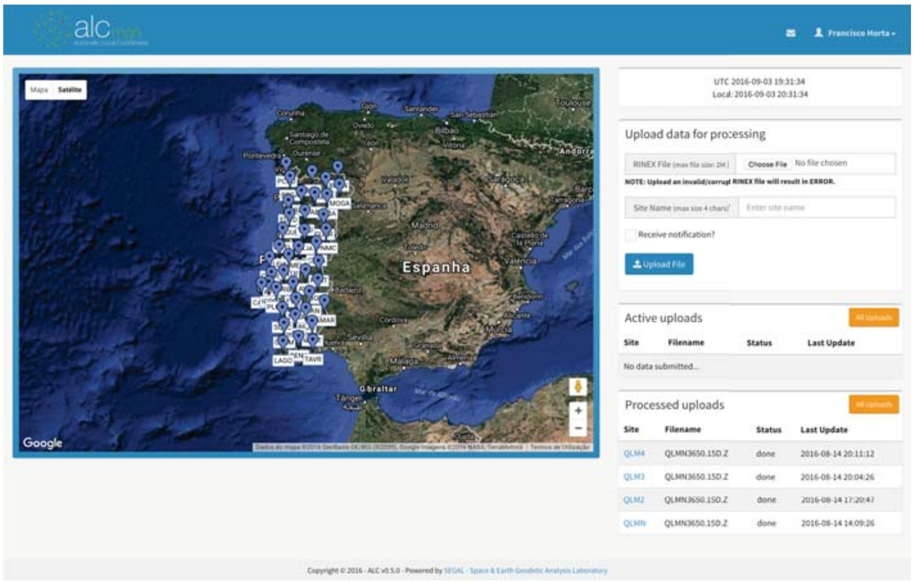
Figure 8.10: ALC - Sign-up page.

After a successful login the initial screen is displayed, as illustrated in Figure 8.11, in this screen the user is able to see the active network that is used as reference, submit observation files for processing, check on on-going submitted data, edit his profile and send messages to the administrators of the platform.



UTC 2016-09-03 19:31:34
Local: 2016-09-03 20:31:34

Upload data for processing

RINEX File (max file size: 2M) Choose File No file chosen

NOTE: Upload an invalid/corrupt RINEX file will result in ERROR.

Site Name (max size 4 chars) Enter site name

☐ Receive notification?

Active uploads

Site	Filename	Status	Last Update
No data submitted...			

Processed uploads

Site	Filename	Status	Last Update
QLM4	QLMN3650.15D.Z	done	2016-08-14 20:11:12
QLM3	QLMN3650.15D.Z	done	2016-08-14 20:04:26
QLM2	QLMN3650.15D.Z	done	2016-08-14 17:20:47
QLMN	QLMN3650.15D.Z	done	2016-08-14 14:09:26

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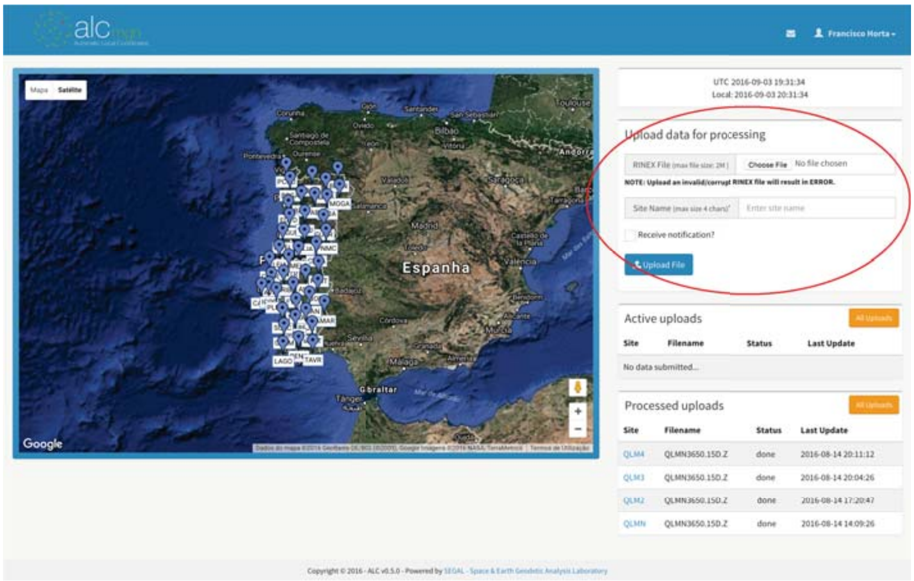
Figure 8.11: ALC - Registered user home page.

8.3.1.1 RINEX files

The registered users are able to submit their observation files for processing by filling and submitting the form highlighted in Figure 8.12. After submitting the form the progress of the process can be tracked in the tables that are presented below, where the "Active uploads" table show the on-going uploads and the "Processed uploads" table shows the last five processed uploads.



UTC 2016-09-03 19:31:34
Local: 2016-09-03 20:31:34

Upload data for processing

RINEX File (max file size: 2M) Choose File No file chosen

NOTE: Upload an invalid/corrupt RINEX file will result in ERROR.

Site Name (max size 4 chars)* Enter site name

☐ Receive notification?

Active uploads

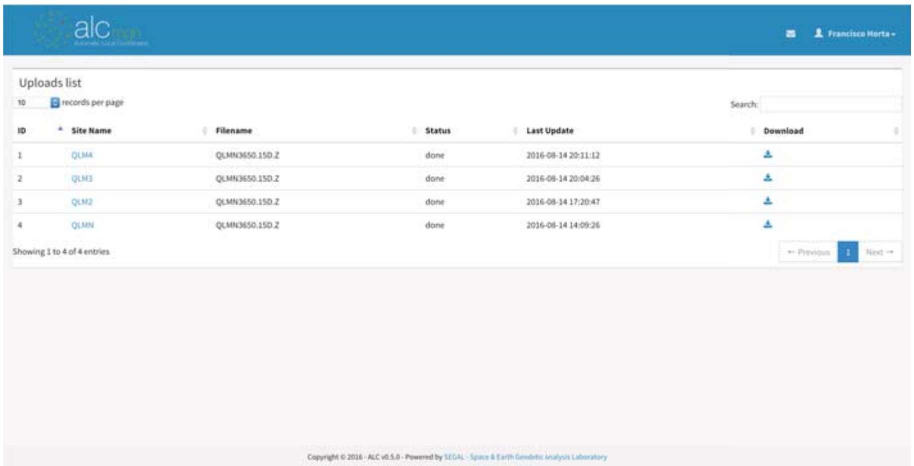
Site	Filename	Status	Last Update
No data submitted...			

Processed uploads

Site	Filename	Status	Last Update
QLM4	QLMN3650.15D.Z	done	2016-08-14 20:11:12
QLM3	QLMN3650.15D.Z	done	2016-08-14 20:04:26
QLM2	QLMN3650.15D.Z	done	2016-08-14 17:20:47
QLMN	QLMN3650.15D.Z	done	2016-08-14 14:09:26

Figure 8.12: ALC - Submit observation files.

The users can also check on details of the submitted data by clicking on the name of the self-defined "Site Name" in the tables below the submit form or through the list of uploads the user has sent, illustrated in Figure 8.13. In both cases, by clicking in the "Site Name", a new screen with a quick summary about the extracted information is presented to the user, as illustrated in Figure 8.14.



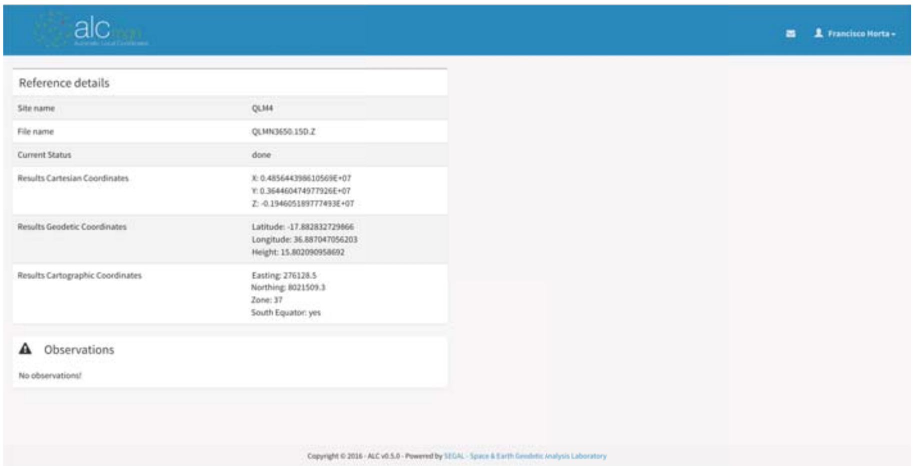
Uploads list

10 records per page

ID	Site Name	Filename	Status	Last Update	Download
1	QLM4	QLMN3650.15D.Z	done	2016-08-14 20:11:12	⤓
2	QLM3	QLMN3650.15D.Z	done	2016-08-14 20:04:26	⤓
3	QLM2	QLMN3650.15D.Z	done	2016-08-14 17:20:47	⤓
4	QLMN	QLMN3650.15D.Z	done	2016-08-14 14:09:26	⤓

Showing 1 to 4 of 4 entries

Figure 8.13: ALC - User uploads list.



Reference details

Site name	QLM4
File name	QLMN3650.15D.Z
Current Status	done
Results Cartesian Coordinates	X: 0.485644398610569E+07 Y: 0.364460474977926E+07 Z: -0.194605189777493E+07
Results Geodetic Coordinates	Latitude: -17.882832729866 Longitude: 36.887047056203 Height: 15.802090958692
Results Cartographic Coordinates	Easting: 276128.5 Northing: 8021509.3 Zone: 37 South Equator: yes

Observations

No observations!

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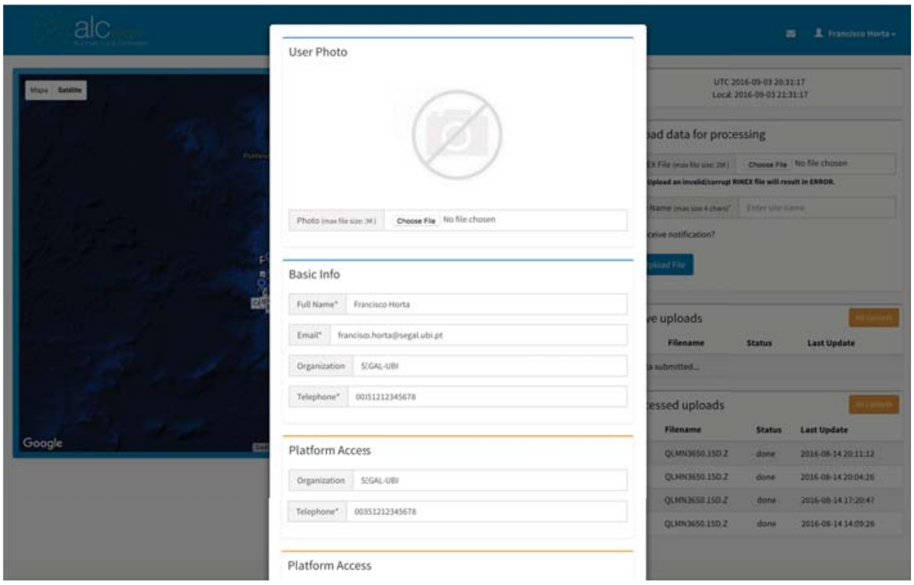
Figure 8.14: ALC - User upload details.

8.3.1.2 Profile

The user can also edit his own profile, giving him the ability to edit personal information like the email, organization, password, etc. To access this functionality, the user has to click in the upper right corner over his name, followed by another click on the "Profile" option. Immediately a pop-up will appear with a pre-filled form containing all the user data, as illustrated in Figure 8.15. The user may then change the data at will and then click in the option "Edit User" to persist changes.



User Photo

Photo (max file size: 3M) No file chosen

Basic Info

Full Name*: Francisco Horta

Email*: francisco.horta@segal.ubi.pt

Organization: SEGAL-UBI

Telephone*: 00351212345678

Platform Access

Organization: SEGAL-UBI

Telephone*: 00351212345678

Platform Access

UTC 2016-09-03 20:31:17
Local: 2016-09-03 21:31:17

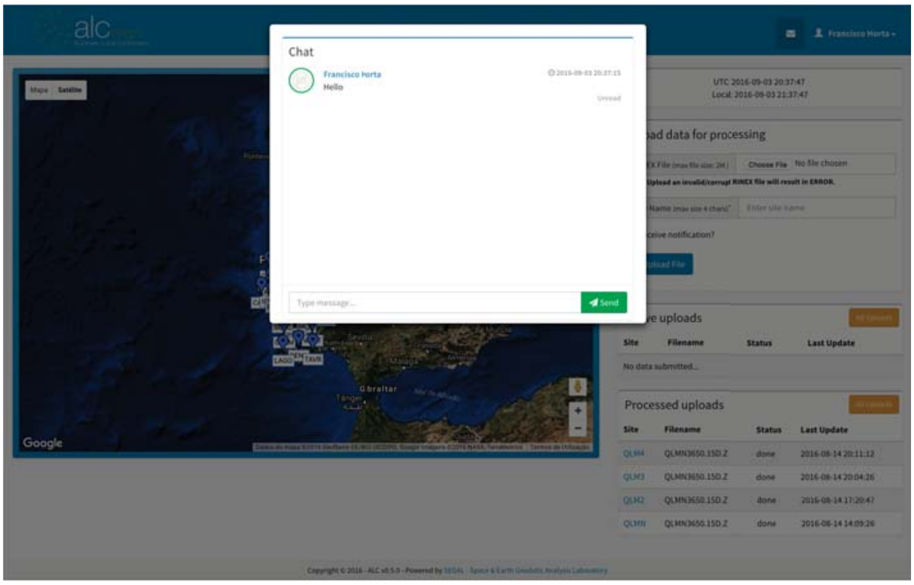
Filename	Status	Last Update
QLMN3650.15D.Z	done	2016-08-14 20:11:12
QLMN3650.15D.Z	done	2016-08-14 20:04:26
QLMN3650.15D.Z	done	2016-08-14 17:20:47
QLMN3650.15D.Z	done	2016-08-14 14:09:26

Figure 8.15: ALC - User profile edition.

8.3.1.3 Messages

The last functionality for regular registered users is the communication with the administrator. In case a user wants to communicate with an administrator of the ALC platform, he can do it using this functionality.

In order to access this functionality, the user needs to click the button with an envelope symbol located right next to the user's name. By clicking on that button, a pop-up is shown with the current conversation, as illustrated in Figure 8.16. This chat works just like any other chat, in order to send a message to the administrator it is just needed to fill out the text field on the bottom of the pop-up and then press the "Send" button once the user has finished typing the message.



Francisco Horta
Hello
2016-09-03 20:37:15
Unread

UTC 2016-09-03 20:37:47
Local 2016-09-03 21:37:47

Site	Filename	Status	Last Update
No data submitted...			

Site	Filename	Status	Last Update
QLM4	QLMN3650.15D.Z	done	2016-08-14 20:11:12
QLM3	QLMN3650.15D.Z	done	2016-08-14 20:04:26
QLM2	QLMN3650.15D.Z	done	2016-08-14 17:20:47
QLMN	QLMN3650.15D.Z	done	2016-08-14 14:09:26

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Figure 8.16: ALC - User messaging exchange.

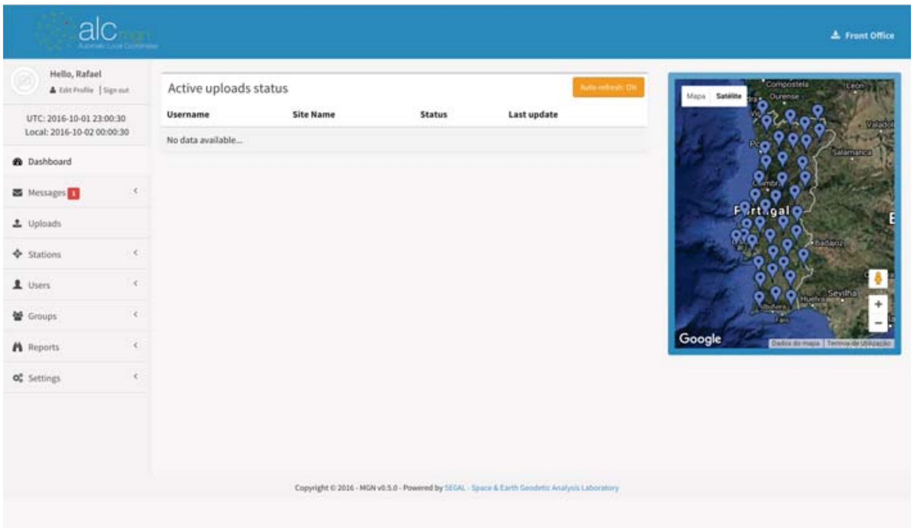
8.3.2 Adminstration area

The administration interface is only accessible for platform administrators. This level of permissions allows users to manage on-going uploads, the reference stations, users, user groups and to customize several software definitions. In case the user that has performed login in the platform has administration permissions, this user will be automatically redirected to the administration area, as illustrated in Figure 8.17. This area is divided in 8 functionalities:

- **Dashboard** relates to the entry page of the administration panel where a general overview is displayed;

- **Messages** relates to the functionality of receiving and sending messages to the users of the platform;

- **Uploads** relates to the functionality of management of the users uploads;
- **Stations** relates to the functionality of management of the stations of the reference network;
- **Users** relates to the functionality of management of the users that have access to the platform;
- **User groups** relates to the functionality of management of the user groups, in order to give users different kind of permissions in the platform;
- **Reports** relates to the functionality of generation of reports for monitoring activity in the platform;
- **Settings** where multiple settings can be customized.



UTC: 2016-10-01 23:00:30
Local: 2016-10-02 00:00:30

Active uploads status

Username	Site Name	Status	Last update
No data available...			

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Figure 8.17: ALC administration panel - Dashboard.

8.3.2.1 Dashboard

After login as administrator, the user is redirected to the administration panel, as illustrated in Figure 8.17. In this area the user can perform several administration tasks, which will be detailed in the following topics.

In the top right corner, the administrator will find a button “Front Office”, this button when pressed, allows the administrator to access the regular users area. By clicking in that button, the administrator will be redirected to the regular registered users area and the administrator will be presented with the same screen as for the regular users, but with a button that allows him to go back to the administration panel.

In the left side of 8.17, the user is presented with a navigation menu, where he can access several functionalities as:

- **Edit Profile** access to profile edition form;
- **Sign Out** end session;
- **Dashboard** access to initial screen;
- **Messages** access to user<>admin messages management;
- **Messages** access to user submitted observation files management;
- **Stations** access to stations management;
- **Users** access to users management;
- **Groups** access to user groups management;
- **Reports** access to report generators;
- **Settings** access to ALC software settings management.

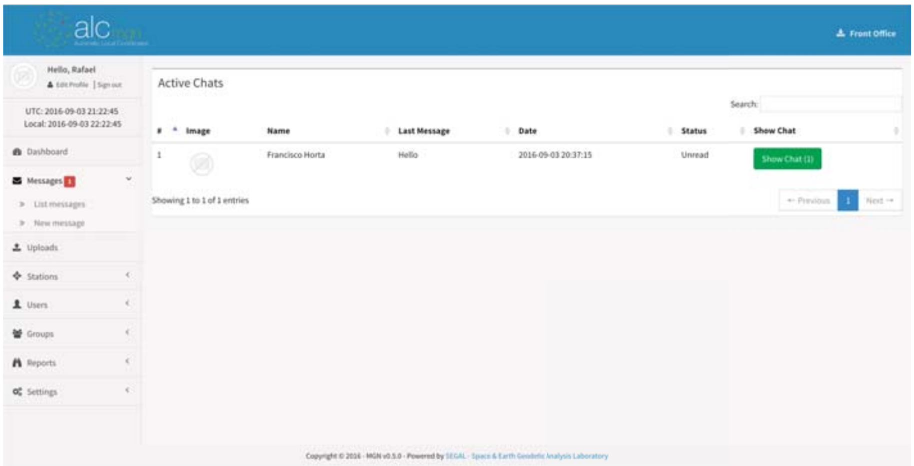
On the right an interactive map is presented with all the stations of the reference network.

Finally, in the middle of the page, a table with all uploads and stations is presented. In the first table a list of all on-going uploads is presented where it is possible to check the user that has made the upload as well as the status of the on-going process, and in the table below it is possible to check reference station details, statistics and the most recent RINEX files received.

8.3.2.2 Messages

In message management its possible to communicate with the various users of the web platform. Once the administrator accesses the message management, a view with all the open conversations is shown to the user, as illustrated in Figure 8.18. Starting from this view it is possible to create new conversations, reply and checkout existing conversations.

In the conversation listing its possible to check multiple information about the conversations with each user.



Active Chats

#	Image	Name	Last Message	Date	Status	Show Chat
1		Francisco Horta	Hello	2016-09-03 20:37:15	Unread	Show Chat (1)

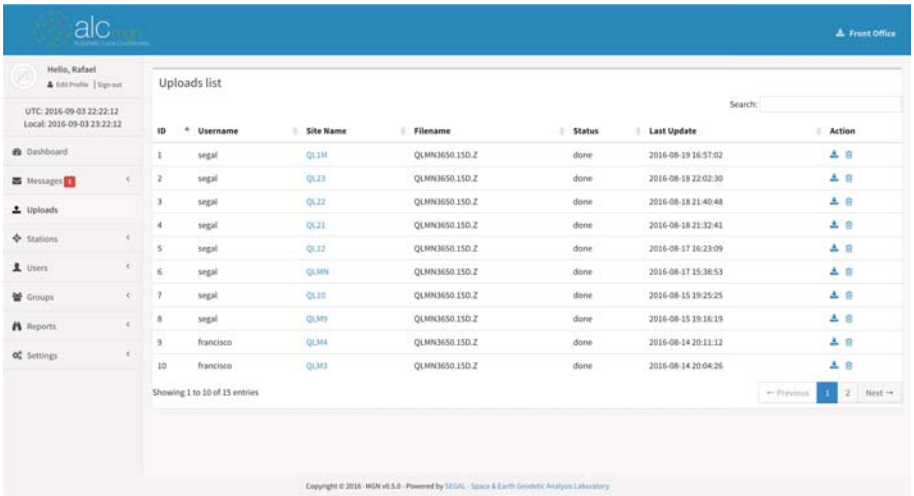
Showing 1 to 1 of 1 entries

Figure 8.18: ALC administration panel - Messages list.

8.3.2.3 Uploads

This functionality has the purpose to manage the observation files that have been submitted by the users. This functionality allows the administrator to check on progress of the uploads, download results of the processed data, and delete old data.

By accessing the uploads management area, the administrator is presented with a list of all the submitted data, as illustrated in Figure 8.19. From this view, the administrator is able to check on progress, download and delete data.



Uploads list

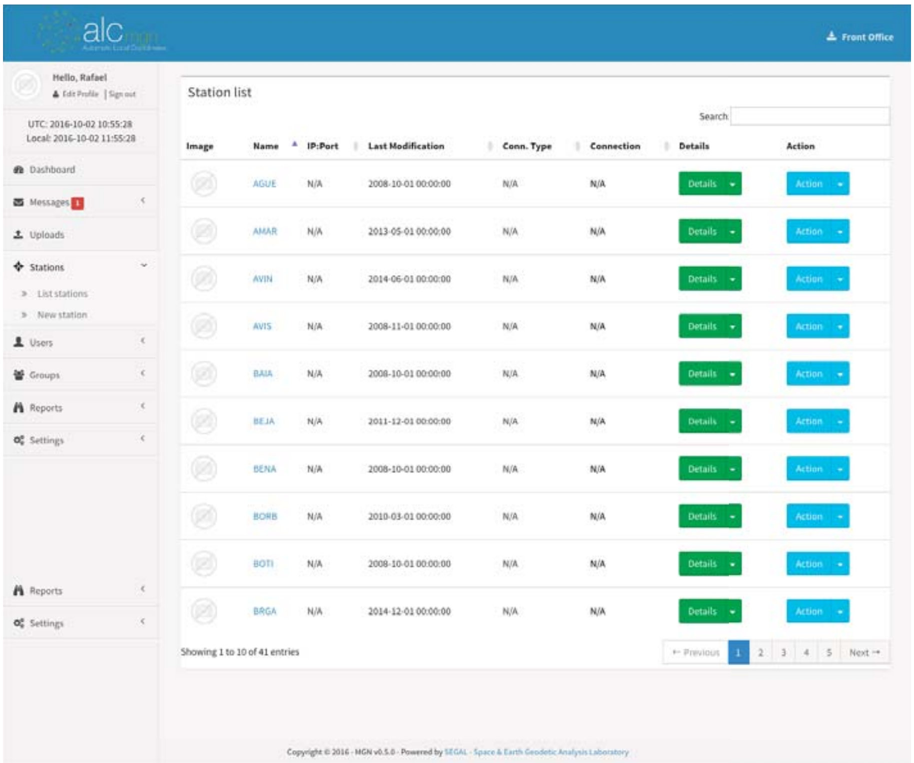
ID	Username	Site Name	Filename	Status	Last Update	Action
1	segal	QL1M	QLMN3650.15D.Z	done	2016-08-19 16:57:02	
2	segal	QL23	QLMN3650.15D.Z	done	2016-08-18 22:02:30	
3	segal	QL22	QLMN3650.15D.Z	done	2016-08-18 21:40:48	
4	segal	QL21	QLMN3650.15D.Z	done	2016-08-18 21:32:41	
5	segal	QL12	QLMN3650.15D.Z	done	2016-08-17 16:23:09	
6	segal	QLMN	QLMN3650.15D.Z	done	2016-08-17 15:38:53	
7	segal	QL10	QLMN3650.15D.Z	done	2016-08-15 19:25:25	
8	segal	QLM9	QLMN3650.15D.Z	done	2016-08-15 19:16:19	
9	francisco	QLM4	QLMN3650.15D.Z	done	2016-08-14 20:11:12	
10	francisco	QLM3	QLMN3650.15D.Z	done	2016-08-14 20:04:26	

Showing 1 to 10 of 15 entries

Figure 8.19: ALC administration panel - Uploads list.

8.3.2.4 Stations

This functionality has the purpose to manage stations that integrate the currently defined network, once they are correctly configured. By accessing this area the user is presented with a comprehensive list of all stations, as illustrated in Figure 8.20. Starting from this page it is possible to add new stations, visualize, edit and/or delete existing stations. It is also possible to check out some information about the stations as well to perform various actions like for example check connection (if feature is available) and review the last revisions made to the stations.



Station list

Image	Name	IP:Port	Last Modification	Conn. Type	Connection	Details	Action
	AGUE	N/A	2008-10-01 00:00:00	N/A	N/A	Details	Action
	AMAR	N/A	2013-05-01 00:00:00	N/A	N/A	Details	Action
	AVIN	N/A	2014-06-01 00:00:00	N/A	N/A	Details	Action
	AVIS	N/A	2008-11-01 00:00:00	N/A	N/A	Details	Action
	BAIA	N/A	2008-10-01 00:00:00	N/A	N/A	Details	Action
	BEJA	N/A	2011-12-01 00:00:00	N/A	N/A	Details	Action
	BENA	N/A	2008-10-01 00:00:00	N/A	N/A	Details	Action
	BORB	N/A	2010-03-01 00:00:00	N/A	N/A	Details	Action
	BOTI	N/A	2008-10-01 00:00:00	N/A	N/A	Details	Action
	BRGA	N/A	2014-12-01 00:00:00	N/A	N/A	Details	Action

Showing 1 to 10 of 41 entries

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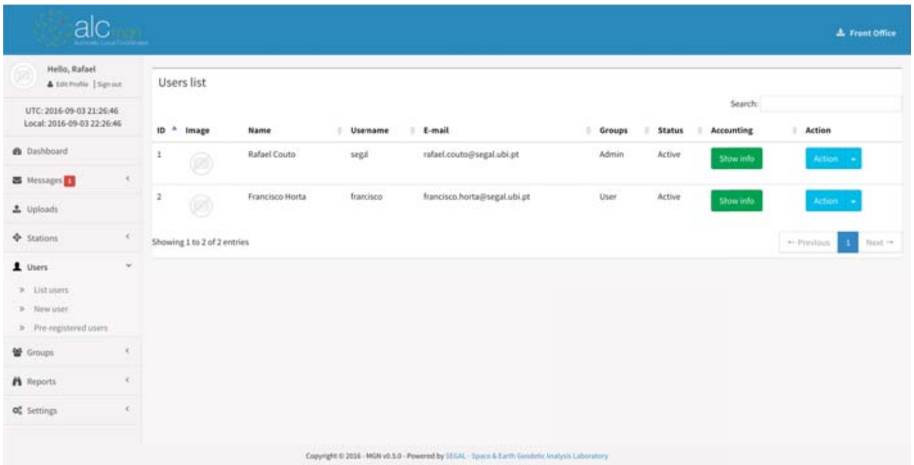
Figure 8.20: ALC administration panel - Stations list.

8.3.2.5 Users

This functionality has the purpose to manage the users who have access to the ALC web platform. This functionality allows the administrator to add, edit or delete users, as well as to define the users permissions, check user's activity profiles and to review the pre-registration accounts.

By accessing the user's management area, the user is presented with a list of all the registered users, as illustrated in Figure 8.21. From this view, the administrator is able to create, edit and delete users, consult users activity report, his permissions and also review pre-registration accounts.

By default, there is at least one user with a maximum permissions level. This user cannot be deleted if there isn't any other user with the same maximum permissions level. It is also impossible to remove the user from its maximum permissions level if there isn't any other user with the same maximum permissions level.



Users list

ID	Image	Name	Username	E-mail	Groups	Status	Accounting	Action
1		Rafael Couto	segl	rafael.couto@segal.ubi.pt	Admin	Active	Show info	Action
2		Francisco Horta	francisco	francisco.horta@segal.ubi.pt	User	Active	Show info	Action

Showing 1 to 2 of 2 entries

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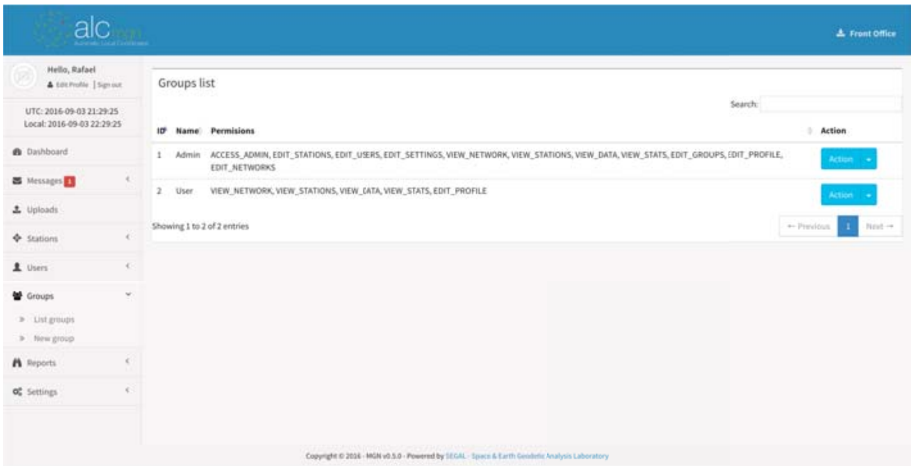
Figure 8.21: ALC administration panel - Users list.

8.3.2.6 User groups

This functionality has the purpose to manage user groups. These user groups are important because they define different permission levels inside the web platform, which allows to distinguish the users from one another.

By accessing the user groups management, the administrator is presented with a list of all the existing user groups, as illustrated in Figure 8.22. From this view, it is possible for the administrator to create new user groups, edit or delete existing user groups. By default, a group called "Admin" exists and cannot be edited neither deleted, since it represents the maximum level of permissions and if this group was deleted, there is no way that this level of permissions could be reached again.



Groups list

ID	Name	Permisions	Action
1	Admin	ACCESS_ADMIN, EDIT_STATIONS, EDIT_USERS, EDIT_SETTINGS, VIEW_NETWORK, VIEW_STATIONS, VIEW_DATA, VIEW_STATS, EDIT_GROUPS, EDIT_PROFILE, EDIT_NETWORKS	Action
2	User	VIEW_NETWORK, VIEW_STATIONS, VIEW_DATA, VIEW_STATS, EDIT_PROFILE	Action

Showing 1 to 2 of 2 entries

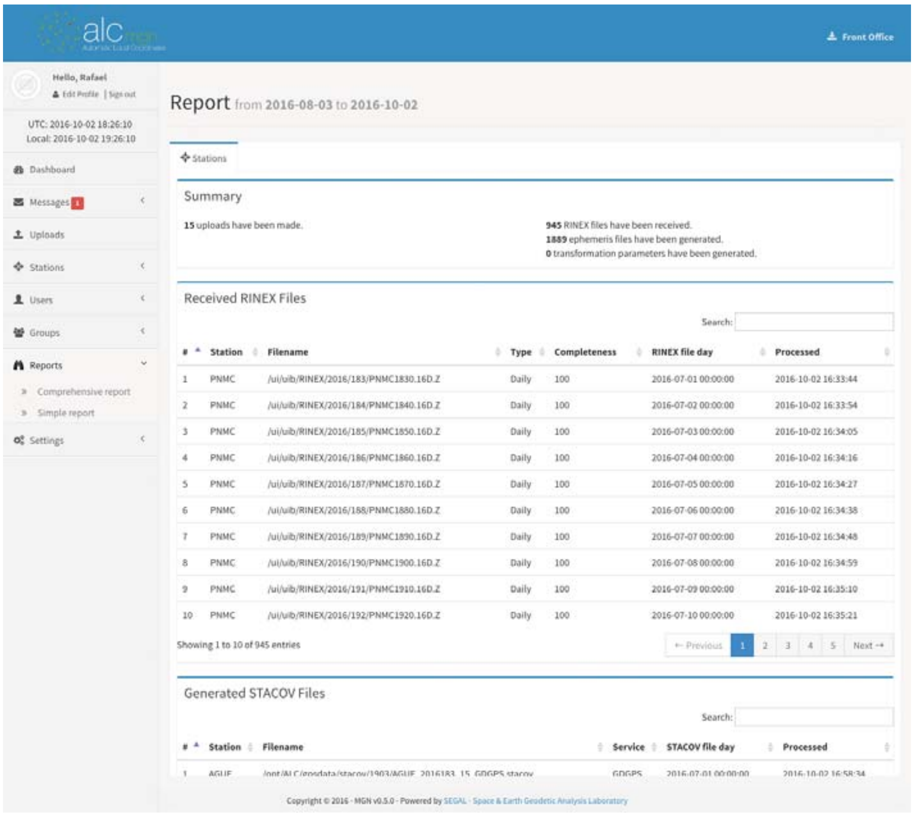
Figure 8.22: ALC administration panel - User groups list.

8.3.2.7 Reports

In the reports area it is possible to generate activity reports for the ALC software. Here it is possible to find data related to the availability of RINEX data, the generated STACOV files, user uploads and generation of transformation parameters.

The reports are divided in two kinds of reports:

- **Comprehensive report** Report with more complex data, which presents users activity, stations data, transformation parameters, etc. (illustrated in Figure 8.23);
- **RINEX report** Report with more concrete and simple data, which presents the availability of RINEX data from the configured stations (illustrated in Figure 8.24).



Report from 2016-08-03 to 2016-10-02

Summary

15 uploads have been made.

945 RINEX files have been received.
1889 ephemeris files have been generated.
0 transformation parameters have been generated.

Received RINEX Files

#	Station	Filename	Type	Completeness	RINEX file day	Processed
1	PNMC	/ui/uib/RINEX/2016/183/PNMC1830.16D.Z	Daily	100	2016-07-01 00:00:00	2016-10-02 16:33:44
2	PNMC	/ui/uib/RINEX/2016/184/PNMC1840.16D.Z	Daily	100	2016-07-02 00:00:00	2016-10-02 16:33:54
3	PNMC	/ui/uib/RINEX/2016/185/PNMC1850.16D.Z	Daily	100	2016-07-03 00:00:00	2016-10-02 16:34:05
4	PNMC	/ui/uib/RINEX/2016/186/PNMC1860.16D.Z	Daily	100	2016-07-04 00:00:00	2016-10-02 16:34:16
5	PNMC	/ui/uib/RINEX/2016/187/PNMC1870.16D.Z	Daily	100	2016-07-05 00:00:00	2016-10-02 16:34:27
6	PNMC	/ui/uib/RINEX/2016/188/PNMC1880.16D.Z	Daily	100	2016-07-06 00:00:00	2016-10-02 16:34:38
7	PNMC	/ui/uib/RINEX/2016/189/PNMC1890.16D.Z	Daily	100	2016-07-07 00:00:00	2016-10-02 16:34:48
8	PNMC	/ui/uib/RINEX/2016/190/PNMC1900.16D.Z	Daily	100	2016-07-08 00:00:00	2016-10-02 16:34:59
9	PNMC	/ui/uib/RINEX/2016/191/PNMC1910.16D.Z	Daily	100	2016-07-09 00:00:00	2016-10-02 16:35:10
10	PNMC	/ui/uib/RINEX/2016/192/PNMC1920.16D.Z	Daily	100	2016-07-10 00:00:00	2016-10-02 16:35:21

Showing 1 to 10 of 945 entries

Generated STACOV Files

#	Station	Filename	Service	STACOV file day	Processed

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Figure 8.23: ALC administration panel - Complex report.

Daily data 2016-08-01 00:00:00 - 2016-09-01 23:59:59

Date	AGUE	AMAR	AVIN	AVIS	BAIA	BEJA	BENA	BORB	BOTI	BRGA	BRGN	CASC	CBRA	CLDR	EDVD	ENTR	FAJA	FCOA	FVFI	GRIB	GUAR
2016-08-01	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-02	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	100%	100%	0%	100%	100%	100%
2016-08-03	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	100%	100%	0%	100%	100%	100%
2016-08-04	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-05	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-06	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-07	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-08	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-09	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	100%	100%	100%	0%	100%	100%	100%
2016-08-10	100%	100%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%	100%	100%	0%	100%	100%	100%

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Figure 8.24: ALC administration panel - Simple report.

8.3.2.8 Settings

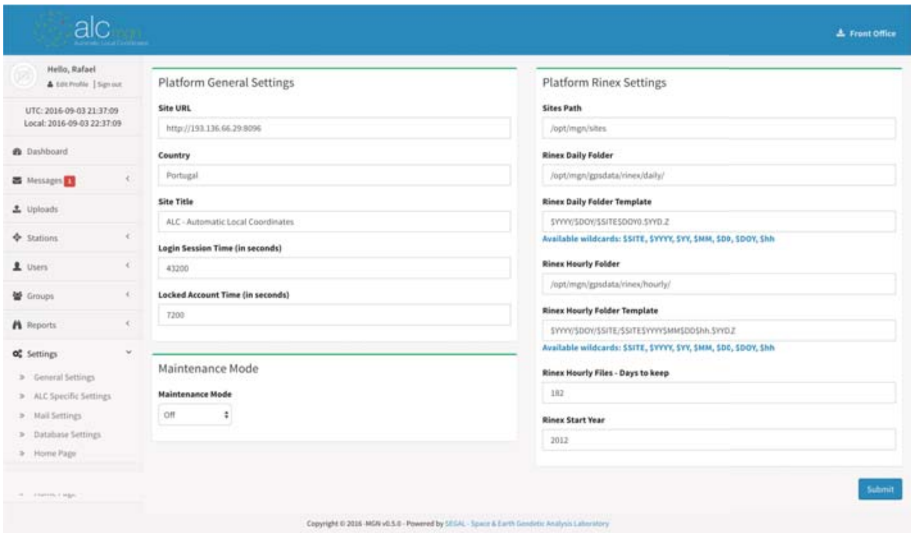
In this area it is possible to customize many of the software settings, from some simple aesthetic changes to more heavy changes that change the way the software behaves.

The settings area is divided in 5 sub-areas:

- **General settings** where it is possible to customize general settings and RINEX locations;
- **ALC specific settings** where it is possible to customize some of the main parameters used by the background processes;
- **Mail settings** where it is possible to customize the settings for the email account, which is responsible to notify and contact the registered users;
- **Database settings** where it is possible to customize the access to the database and, which feeds all the data that is presented to the users;
- **Home page** where it is possible to customize the home page presentation text.

General Settings

By clicking in the "General Settings" option from the "Settings" menu it is possible to access the general settings of the ALC software, as illustrated in Figure 8.25.



Platform General Settings

Site URL: http://193.136.66.29:8096

Country: Portugal

Site Title: ALC - Automatic Local Coordinates

Login Session Time (in seconds): 43200

Locked Account Time (in seconds): 7200

Maintenance Mode

Maintenance Mode: Off

Platform Rinex Settings

Sites Path: /opt/mgn/sites

Rinex Daily Folder: /opt/mgn/gpsdata/rinex/daily/

Rinex Daily Folder Template: $YYYY/$DOY/$SITE$DOY0.$YYD.Z

Available wildcards: $SITE, $YYYY, $YY, $MM, $DD, $DOY, $hh

Rinex Hourly Folder: /opt/mgn/gpsdata/rinex/hourly/

Rinex Hourly Folder Template: $YYYY/$DOY/$SITE/$SITE$YYYY$MMDDhh.$YYD.Z

Available wildcards: $SITE, $YYYY, $YY, $MM, $DD, $DOY, $hh

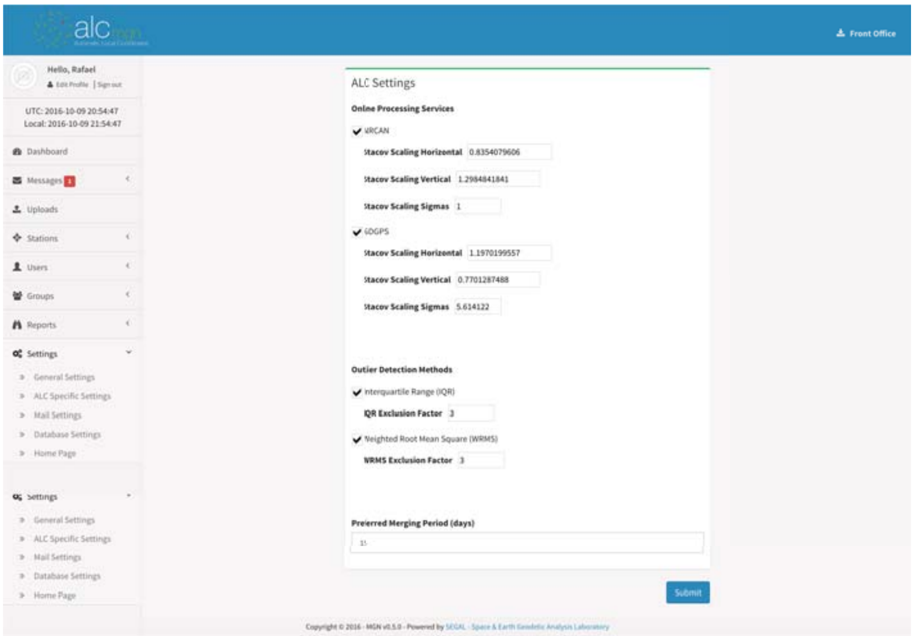
Rinex Hourly Files - Days to keep: 182

Rinex Start Year: 2012

Figure 8.25: ALC administration panel - General settings.

ALC specific settings

By clicking in the "ALC Specific Settings" option from the "Settings" menu it is possible to access the ALC specific settings of the ALC software, as illustrated in Figure 8.26.



ALC Settings

Online Processing Services

☑ NRCAN

Stacov Scaling Horizontal: 0.8354079606

Stacov Scaling Vertical: 1.2984841841

Stacov Scaling Sigmas: 1

☑ SDGPS

Stacov Scaling Horizontal: 1.1970199557

Stacov Scaling Vertical: 0.7701287488

Stacov Scaling Sigmas: 5.614122

Outlier Detection Methods

☑ Interquartile Range (IQR)

IQR Exclusion Factor: 3

☑ Weighted Root Mean Square (WRMS)

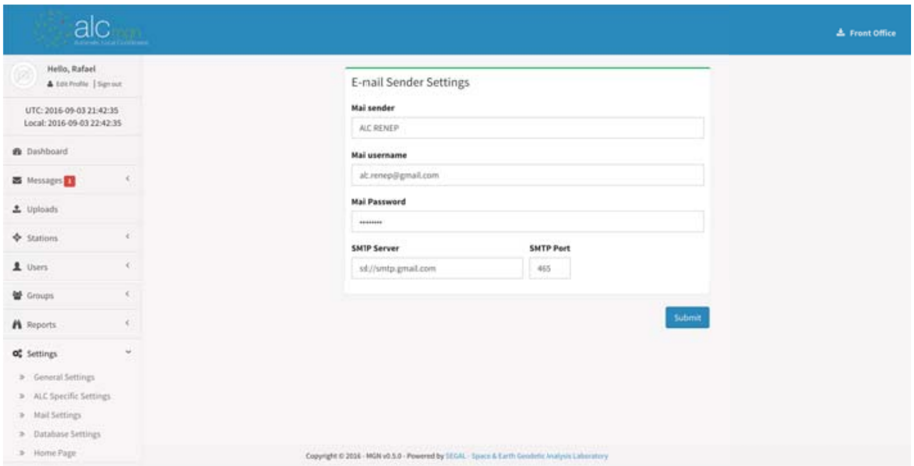
WRMS Exclusion Factor: 3

Preferred Merging Period (days): 15

Figure 8.26: ALC administration panel - ALC specific settings.

Mail settings

By clicking in the “Mail settings” option from the “Settings” menu it is possible to access the e-mail settings of the ALC software, as illustrated in Figure 8.27.



E-mail Sender Settings

Mail sender: ALC RENEP

Mail username: alc.renep@gmail.com

Mail Password: ••••••••

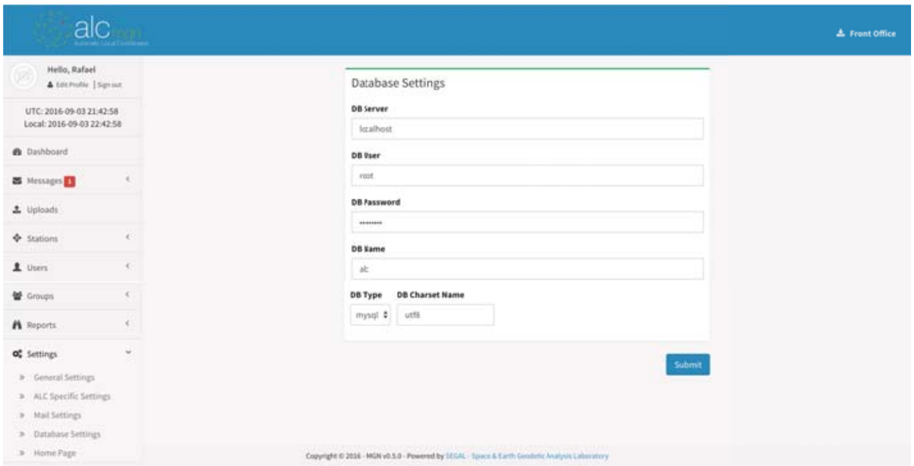
SMTP Server: ssl://smtp.gmail.com

SMTP Port: 465

Figure 8.27: ALC administration panel - Email settings.

Database settings

By clicking in the “Database settings” option from the “Settings” menu it is possible to access the database connection settings of the ALC software, as illustrated in Figure 8.28.



Database Settings

DB Server: localhost

DB User: root

DB Password: ********

DB Name: alc

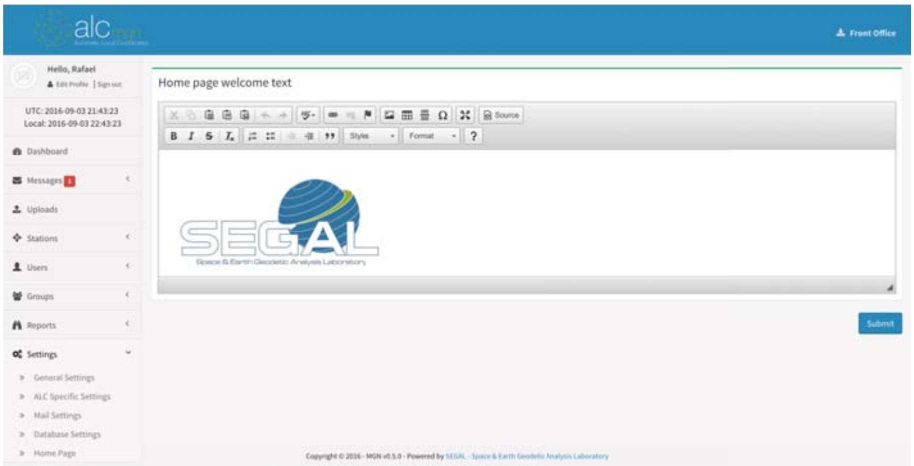
DB Type: mysql

DB Charset Name: utf8

Figure 8.28: ALC administration panel - Database settings.

Home page

By clicking in the “Home page” option from the “Settings” menu it is possible to access the home page presentation scheme of the ALC web platform, as illustrated in Figure 8.29.



Home page welcome text

Figure 8.29: ALC administration panel - Home page customization.

8.3.3 Background processes

This component called CheckUploadChanges is responsible for tracking the evolution of the user requests. It handles the incoming requests and the results of the processing of the user submitted observation files. This task is achieved by following flowchart 8.30.

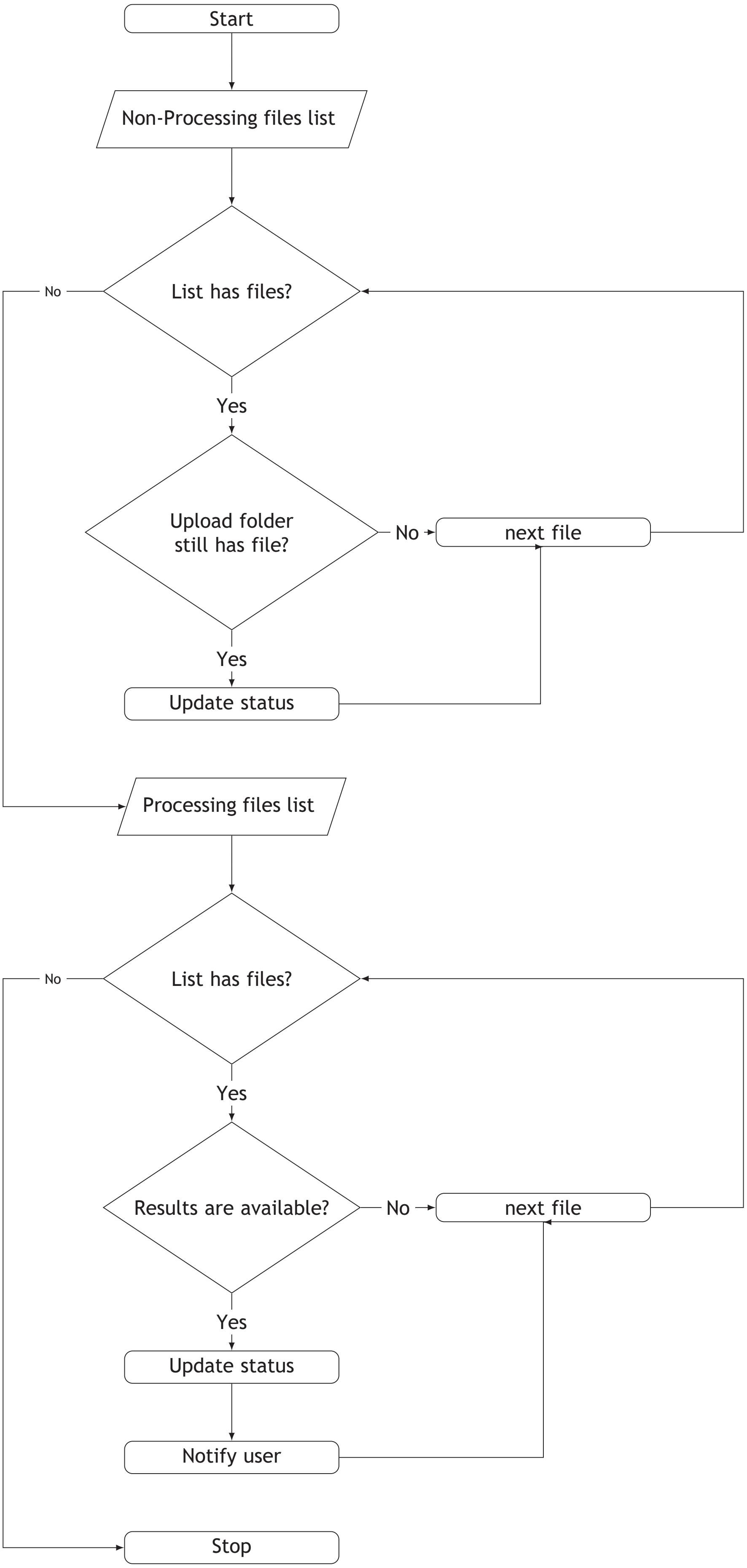


Figure 8.30: General flowchart of CheckUploadChanges component.

As illustrated in flowchart 8.30, using a list, provided by querying the database, of uploaded files that are in queue for being processed, the component will check if the file is still in the upload folder, and if not, it will update its status to being processing. The upload folder is the folder that was previously mentioned as being shared with the background processes, and if the file is not there anymore, it is because the `ProcessUserData` component has already put the uploaded observation file for processing. Then the component will also check if there are any results available, and if so, it will update the status to complete and notify the user that his results are ready to be downloaded.

This component has no command line options configured.

8.3.4 Integration with MGN

Since this platform is intended to be integrated with the MGN software, this section is dedicated to the description of what this integration means and how it supposed to work.

Management GNSS Network (MGN) is a web service that manages a network of GNSS stations. This solution allows its administrators to monitor the status of the GNSS stations of their network as well as to retrieve raw data and convert them into RINEX files, which can be later downloaded by registered users.

ALC and MGN are closely related as both services may be of interest of clients need RINEX data and precise positioning, thus this integration is highly pivotal for best experience on both platforms. Regarding the ALC architecture it is intended that ALC will, in the future, embed users and station data from MGN. This way it is possible that users already registered in MGN may use ALC without having to create a new single account for ALC. However users will also be able to register solely on ALC without having anything to do with MGN since stand-alone installations of ALC can be done.

8.4 Conclusion

In the present chapter the developed platform, ALC, was discussed. Taking into account all the detailed analysis of the different components of this work it is possible to have a better understanding of how it behaves and what it does. This chapter contains a very detailed analysis of the background processes where all the tools that were developed in order to estimate the final coordinates of the points were described. Also, an overview of all the functionalities and background processes of the web platform were described. Also the integration of ALC with the MGN was briefly introduced.

Chapter 9

Conclusions and Future Work

9.1 Implemented objectives

The main objective of this dissertation was the implementation of a platform and methods that made use of the currently available online services (able to compute precise positions with respect to a global reference frame at the epoch of observation) in order to automate the estimation of the coordinates of points with respect to a particular regional or national datum. The study of the reliability of the developed system was also successfully conducted.

Taking into account the initially proposed structure (see section 1.1), the following components were implemented to process the data:

- Process GNSS data using online processing services;
- Merge and detect outliers on a set of files for a specified time frame;
- Normalize formal errors between the solutions retrieved from the online processing services;
- Merge the already processed retrieved solutions from the various online processing services;
- Calculation and application of the transformation parameters using the Helmert transformation parameters method;
- Generation of reports that summarizes the operations performed on the user submitted data to compute the estimated positions;

The service is currently operational, available for users in Portuguese mainland at `http://segal.ubi.pt/ALC/`. It consists in a platform where the users can submit their own observation data (RINEX) and automatically process it. It also has capabilities for the management of the user activity and profile, the management of the network stations and also the management of the main ALC settings.

9.2 System assessment

In addition to the implementation of the system, assessment tests were conducted in order to establish the validity of the developed system. These assessment tests included the following tasks:

- **Outlier Detection**: Due to the possibility of having observations influenced by external factors, it is necessary to audit possible outliers in the estimated daily solutions provided by the online services. Their detection using the WRMS and IQR outlier detection methods were studied and implemented. The threshold values to be used as default by ALC were based on the analysis of the percentage of outliers detected in a global network of 51 IGS stations;

- **Formal Error Normalization**: After observation of some of the files processed by the online processing services it was possible to perceive that the formal errors attributed by the online services to the estimated coordinates was unbalanced and that it would bias the end results by showing a tendency to one of the solutions. Consequently, a tool to normalize the formal errors in order to obtain the best combined solution from individual independent solutions was also developed. Standard ratio values between the two analyzed online services were determined using the same IGS sub-network. The relative quality of both online services were also analyzed and corrective weight factors were computed in order to normalize the errors associated with the individual solutions;

- **Influence of time window in Transformation**: During the calculation of the transformation parameters it is better (due to outlier detection and reliability of the network) to use a solution based on several days instead of using just a single day. This implied the necessity to decide the best time window to be used in the merging process. To do this, a tool to merge data, detect its outliers, scale formal errors and lastly calculate the transformation parameters was developed and different time windows (1 day, 7 days, 15 days and 30 days) were tested in order to check for the best approach. The results of these tests showed no significant difference between the time windows, with a very slightly advantage of either 15 or 30 day windows. Therefore, the 15 days window was selected since it also permits to perform reliable outlier detection and minimizes the occasional absence of daily files for the reference stations;

- **Influence of Orbits in Transformation**: Another issue to take into consideration is the influence of using different orbits in the online processing service, as the end result of the positioning information changes accordingly. The same methodology as for the study of the influence of time windows was applied (but using different types of orbits, namely rapid and precise orbits). The outcome of these tests showed that there is practically no difference between using rapid or precise orbits, since the difference is less than 1mm when the RMS of the differences between the estimated coordinates are evaluated.

- **Performance on different networks in the estimation of the transformation**: The evaluation of the performance of the calculation and application of transformation parameters on different types of networks was also tested. Several sub-networks were extracted from the ReNEP network to simulate different kinds of networks, namely: networks with low density of stations; networks with stations with low reliability; and a worst case scenario where the six worst stations were used. The results of these tests showed that the lowest the number of stations the worse the results will be and that the quality of the transformation is also dependent of the spatial distribution of the reference network. Additionally, the impact of having an average-small network with inconsistent reliability (simulated by randomly change the number of stations was also analyzed. In this case, the results were approximate to the full network, however the fact that the Portuguese mainland is small, when compared with other countries, may have influenced the results and this fact may change in function of the region area and distance between stations.

- **Influence of the different network parameters** The last performed system assessment was related to the measurement of the robustness of the parameters using stations not used in the computation of the transformation parameters. In order to do this assessment, stations from the IGeoE were chosen and the different transformation parameters applied. In the end, the differences between the final coordinates calculated with respect to the national reference frame using the best set of ReNEP stations (30) and using the other networks were calculated. The results permitted to derive similar conclusion as when the transformation parameters were directly evaluated by looking at the deviations on the residuals of the reference stations: the number of stations, an uneven distribution, and the existence of outliers might influence the quality of the final positions. However, in a country as Portugal, with a dense network of reference stations, only extreme cases can cause real incorrect coordinates when ALC is applied.

9.3 Final notes

Although the system assessment validated the developed system, it would be important to test the solution using real data from other regional/national networks, namely networks that differ in density and reliability. These tests would imply the adaptation of ALC to other networks and filling in the data from that specific regional/national network.

This dissertation also provides good feedback regarding the performance of the studied online processing services (one error was detected in the GDGPS-APPS software that permitted to correct it), the difference between processing GNSS data using rapid and precise orbits and, lastly, the expected influence and performance of the calculation of transformation parameters on various types of networks.

As a personal note, the research and development of this project was extremely rewarding for me as it represented a huge challenge since the research area is very different from my current background. However, this experience certainly enriched my engineering background by improvement of my skills and definitely by literally showing me the world from another point of view, pun intended. Also the possibility to develop and make available a service that helps scientists and technicians to improve their work is also highly rewarding as it represents a very important public service.

9.4 Future work

As in any other kind of project, room for improvement is always present. For ALC there are two improvements that would increase its quality in a highly positive way:

1. Adding other online processing services would definitely improve the merging process and consequently the positioning. This addition would imply the development of a script to submit RINEX files to the new online service and to process the retrieved solution.

2. The addition of more configurable parameters in the ALC web platform would also be important so that the administrator can tweak in more detail some actions and parameters that are used in the ALC processing scripts. Examples of such configurable parameters are the permanent removal of stations in the calculation of the transformation parameters, manual (via web platform) execution of the re-calculation of transformation parameters, etc.

It would be also interesting the execution and analysis of more tests to validate even better the developed solution, mostly by testing the simulation of different kinds of networks and errors.

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Appendix A

Outlier Detection Result Graphs

In Figures A.1, A.2, A.3, A.4 , A.5, A.6 , A.7, A.8, A.9 and A.10 graphs with a more detailed view of the detected outliers is presented.

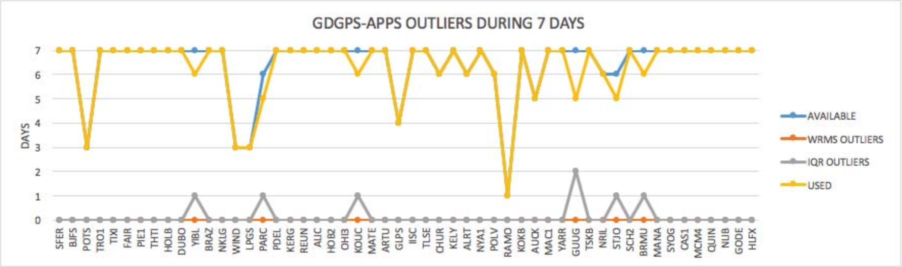

Figure A.1: GDGPS-APPS outliers during 7 days.

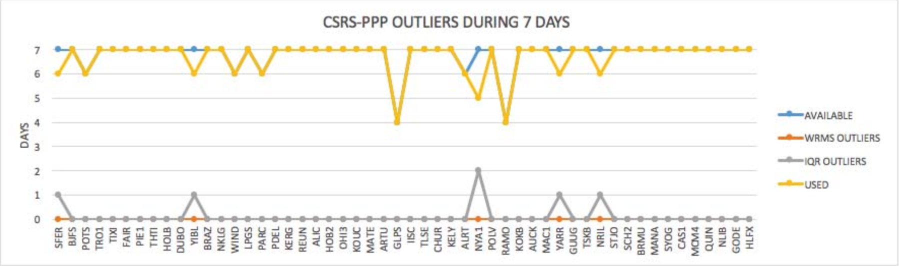

Figure A.2: CSRS-PPP outliers during 7 days.

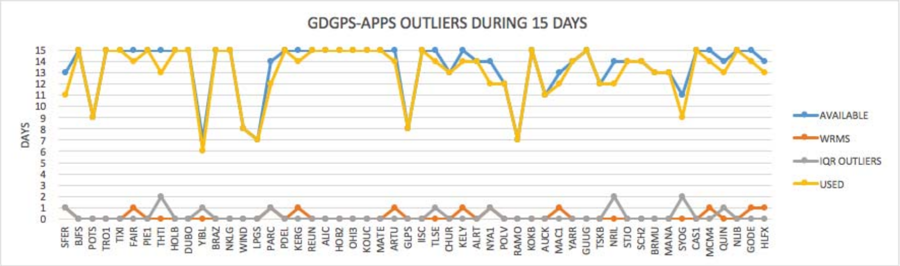

Figure A.3: GDGPS-APPS outliers during 15 days.

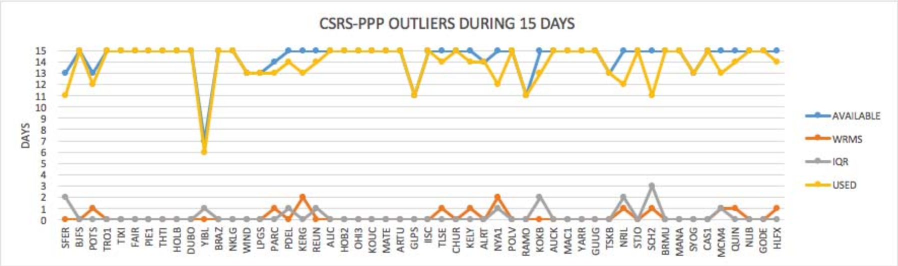

Figure A.4: CSRS-PPP outliers during 15 days.

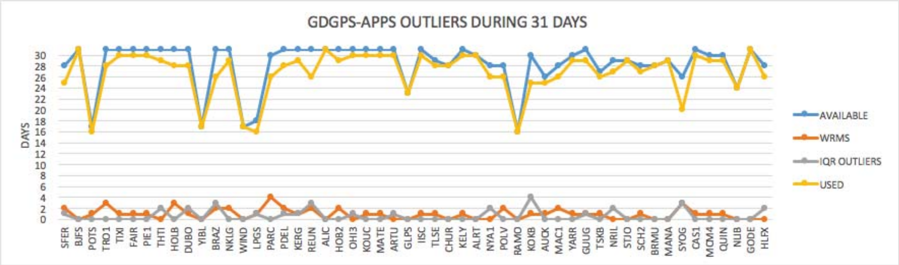

Figure A.5: GDGPS-APPS outliers during 31 days.

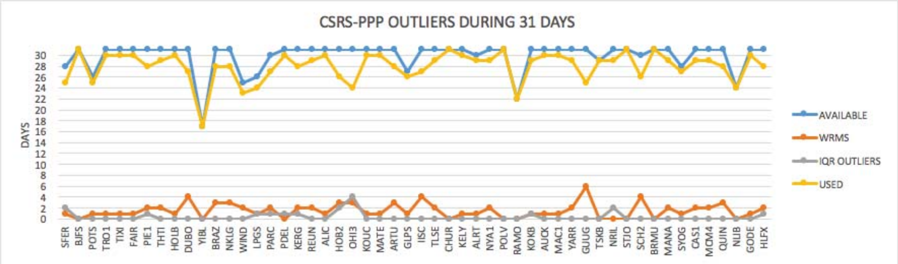

Figure A.6: CSRS-PPP outliers during 31 days.

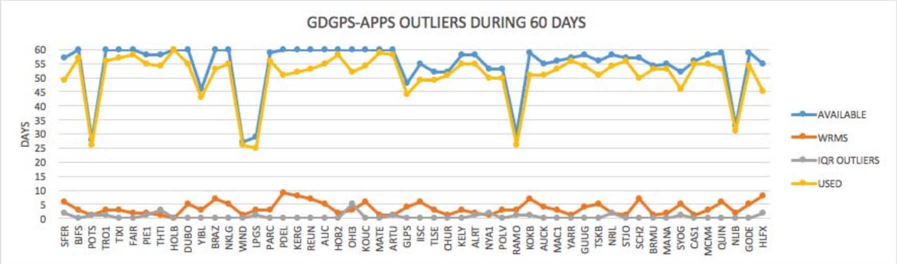

Figure A.7: GDGPS-APPS outliers during 60 days.

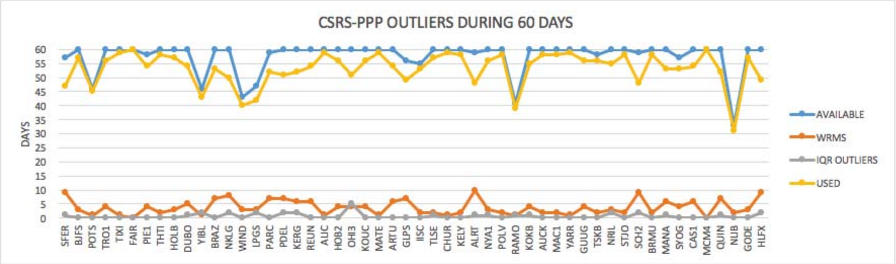

Figure A.8: CSRS-PPP outliers during 60 days.

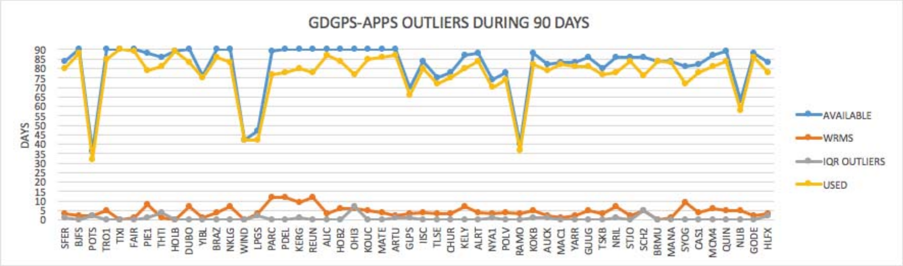

Figure A.9: GDGPS-APPS outliers during 90 days.

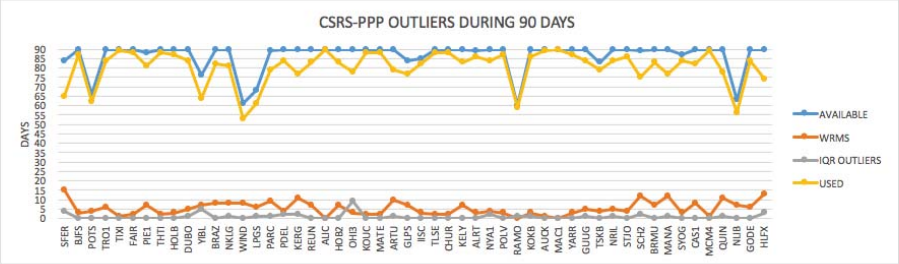

Figure A.10: CSRS-PPP outliers during 90 days.

Appendix B

Average Ratio Between Services

In Table B.1, a summary of the average ratio of the formal errors for each component X, Y, Z and 3D between the online services is presented.

Table B.1: Average ratio between services

Site	**Average Ratio X**	**Average Ratio Y**	**Average Ratio Z**	**Average Ratio 3D**
MATE	3.9221	5.3165	4.2363	4.2065
NYA1	6.3553	6.1899	4.0468	4.2411
CAS1	6.5830	5.2249	3.9597	4.3427
TIXI	6.4044	6.1708	4.0338	4.3473
BRAZ	4.4843	4.4607	3.8996	4.4100
LPGS	4.9389	4.3615	4.3321	4.4883
SYOG	5.5710	6.4445	4.2947	4.6080
TRO1	5.7251	6.8352	4.4085	4.7196
DUBO	8.3175	4.9258	4.4499	4.8978
NLIB	9.1342	4.5746	4.8256	4.9850
SFER	4.7230	7.2444	4.8812	5.0012
CHUR	8.2511	5.2389	4.6031	5.0366
OHI3	6.8003	5.7238	4.6616	5.0465
HLFX	6.1590	4.7673	4.9364	5.0589
SCH2	6.9700	5.1181	4.8147	5.1514
POTS	4.9947	8.1985	4.8800	5.2039
STJO	5.7578	5.2214	4.9688	5.2173
REUN	5.2913	5.2638	4.9325	5.2240
BJFS	6.1999	5.0351	5.0350	5.2408
THTI	5.1549	5.7446	4.9548	5.2863
MAC1	5.2665	7.6745	4.8842	5.2974
ALIC	5.3511	5.3247	5.1625	5.3063
BRMU	6.0733	5.1521	5.0699	5.3082
PDEL	5.0729	6.3057	5.1698	5.3134
WIND	5.1374	6.6198	4.9350	5.3267
AUCK	5.0418	7.9685	5.1741	5.3305
POLV	5.4760	6.1576	4.9884	5.3490
HOLB	6.1831	5.4654	5.0356	5.3767
TLSE	5.1143	8.7510	5.0846	5.3901
HOB2	5.4298	6.0711	5.1111	5.4344
YARR	6.3302	5.2726	5.0819	5.4364
PIE1	7.2790	5.2259	5.0543	5.4647
KOUC	5.2413	7.5301	4.8596	5.4772
MCM4	7.7862	8.1489	5.3775	5.5985
NKLG	5.3286	8.1318	3.5701	5.6233
GUUG	5.5973	6.0934	5.1798	5.7303
KERG	8.1590	5.5705	5.5553	5.8601
IISC	8.4246	5.5576	5.6479	5.9759
FAIR	6.6740	8.6734	5.5190	5.9907
GLPS	10.9605	6.1538	3.9861	6.5507
KELY	9.3148	8.3987	5.9458	6.5677
QUIN	8.5232	6.3665	6.1478	6.7099
KOKB	6.4954	9.0176	5.6202	6.7762
GODE	10.6364	6.3825	6.4393	6.9096
ARTU	9.5428	7.8237	6.1353	6.9489
MANA	12.4987	6.6186	5.3754	7.0778
TSKB	7.2440	7.6246	6.4518	7.1047
NRIL	13.0247	8.3492	6.5684	7.1350
ALRT	10.1632	9.3667	7.0256	7.1984
PARC	11.6023	7.3848	6.8357	7.5846
YIBL	8.8313	8.4533	7.8551	8.4540
Average	**6.9714**	**6.4646**	**5.1373**	**5.6141**

Appendix C

Assessment of Ratio Between Services

In Table C.1 a summary by station of the residuals RMS for vertical and horizontal components is presented. This Table contains the residuals RMS of vertical and horizontal components for the whole network that was used in the formal error normalization study. In accordance with what was previously stated in section 5.4, it is possible to observe that the horizontal component of the CSRS-PPP solutions have in average lower residuals than the solutions from GDGPS-APPS and the vertical component of the GDGPS-APPS solutions have in average lower residuals than the CSRS-PPP solutions.

Table C.1: Residuals RMS for vertical and horizontal components on online services.

SITE	CSRS-PPP		GDGPS-APPS	
	Ver. RMS	Hor. RMS	Ver. RMS	Hor. RMS
ALIC	3.91392	3.18284	4.30242	2.47685
ALRT	4.0271	2.5935	5.53009	2.27287
ARTU	6.10328	2.40082	5.46631	2.33494
AUCK	3.64098	2.87691	5.24214	2.7102
BJFS	4.54302	2.95894	4.6972	2.26331
BRAZ	6.11727	3.91672	5.88182	3.03166
BRMU	4.69068	3.38661	5.89268	2.45651
CAS1	4.45265	2.62723	5.62506	2.85185
CHUR	4.71503	3.2222	6.08304	2.91105
DUBO	6.05856	2.69708	6.35633	2.37348
FAIR	7.27502	2.79448	6.30103	2.38057
GLPS	6.66121	3.69176	6.1856	3.03038
GODE	4.65363	3.07224	5.71019	2.2456
GUUG	7.12383	4.83107	6.84131	3.06368
HLFX	6.04513	3.21259	6.00237	2.41166
HOB2	3.92984	3.21618	5.74254	3.02522
HOLB	4.10834	2.91308	5.36431	2.29028
IISC	6.24603	4.1096	5.47872	2.78443
KELY	3.55923	2.51974	4.93106	2.13397
KERG	5.95345	3.9319	7.16926	3.43983
KOKB	5.10563	3.08868	6.06251	2.78501
KOUC	4.85394	4.2738	6.35049	3.0975
LPGS	6.43847	3.47768	12.229	3.28462
MAC1	4.1472	2.83213	6.67111	3.09148
MANA	5.28278	3.92999	6.81201	2.6754
MATE	4.22954	2.82984	5.05215	2.3947
MCM4	4.0644	2.19653	6.12241	2.98846
NKLG	5.58058	4.37339	6.65308	3.4019
NLIB	5.52365	2.72075	7.26686	2.7475
NRIL	6.30923	2.72172	6.16106	2.30618
NYA1	6.48649	2.48846	6.45526	2.09181
OHI3	5.86451	3.78572	11.3432	3.32595
PARC	6.75391	4.07476	11.1102	4.03972
PDEL	4.9534	3.20014	6.82397	2.77259
PIE1	3.57037	2.7792	4.68978	2.36058
POLV	5.02282	3.04459	5.62048	2.29457
POTS	4.80564	2.80097	5.6256	2.10869
QUIN	3.8545	2.53357	4.67677	2.47919
REUN	5.98218	3.99723	7.28158	3.34959
SCH2	4.5846	3.47029	5.1989	2.99752
SFER	3.61667	2.80069	4.84655	2.47699
STJO	4.80553	3.01109	6.65256	2.56191
SYOG	3.67556	2.69458	4.4885	3.00957
THTI	7.57569	5.02928	8.95722	3.36543
TIXI	7.03725	3.60023	7.05105	2.65507
TLSE	3.78221	2.80122	4.85848	2.42698
TRO1	5.3032	2.79109	5.61745	2.37935
TSKB	5.2058	3.64598	5.04398	2.41127
WIND	3.76733	3.15944	29.1547	3.02943
YARR	3.73632	3.36769	4.5622	2.61568
YIBL	7.07465	4.76974	7.01496	3.0373
AVERAGE	**5.15**	**3.26**	**6.69**	**2.73**

Appendix D

Report Generated by ALC

```
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
Automatic Local Coordinates (ALC version 0.5.0)
Space & Earth Geodetic Analysis Laboratory - SEGAL
Universidade da Beira Interior
Rua Marques D'Avila e Bolama, 6200 - 001 - Covilha, Portugal
Site: http://segal.ubi.pt
Email: rafael.couto@segal.ubi.pt
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------


PROCESSING START  2016/09/01 23:41:03
PROCESSING END    2016/09/01 23:44:00
FOR USER          segal

-------------------------------------------------------------------------------
SECTION 1. File Summary
-------------------------------------------------------------------------------
1.1 Input Files
Filename           CAMI2350.16D.Z
Marker Name        CAMI
Reference Epoch    2016/08/22 00:00:00

1.2 Output Files
Processing summary CAMI2350.16D.sum
Output stacov      CAMI.stacov

-------------------------------------------------------------------------------
SECTION 2. Summary of Processing Parameters
-------------------------------------------------------------------------------
2.1 Reference Frame CORS
   pena brag ague amar avin avis baia beja bena borb boti brgn casc cbra crai edvd entr faja
```

```
   fcoa fvfi grib guar igp0 lago leir melr mert mess mira moga mvel odem palm pcou port scac
    sman tabu tavi torr vise

2.2 Transformation Parameters
    Data Period
      15 days

    CORS Used in Transformation Parameters
    AGUE AMAR AVIS BAIA BEJA BENA BORB BOTI BRGA BRGN CASC CBRA EDVD ENTR FAJA FVFI GRIB GUAR IGP0
    LAGO LEIA MELR MERT MESS MIRA MOGA ODEM PLMA PCOU PNMC PORT SCAC SMAN TABU TAVR TORA VISU

    Calculated Transformation Parameters
      CHI^2      =  0.1226E+05
      DOF        =         104
      CHI^2/DOF  =      117.92
      RX =  -.6549E-06  +-  0.1523E-07  rad
      RY =  0.7203E-07  +-  0.9347E-08  rad
      RZ =  0.7953E-06  +-  0.1912E-07  rad
      TX =  -.9606E+00  +-  0.4680E-01  m
      TY =  -.6051E+01  +-  0.1536E+00  m
      TZ =  0.4406E+00  +-  0.4305E-01  m
      S  =  -.2710E-07  +-  0.2168E-08  parts

2.3 Online PPP Services
    NRCan     Yes
    JPL/GDGPS Yes

--------------------------------------------------------------------------------
SECTION 3. Outcome of Processing
--------------------------------------------------------------------------------
3.1 Estimated Position at the Global Reference Frame at the Epoch of Observation
    CARTESIAN
      X   0.469960015465271E+07 +- 0.513987012061671E-02
      Y  -0.730704606705352E+06 +- 0.248683989960837E-02
      Z   0.423561528098669E+07 +- 0.450863614260094E-02

    ELLIPSOIDAL
      Latitude   (dec)   41.878544394
      Longitude  (dec)  351.162283966
```

```
      Elevation    (m)   69.3182772

3.2 Estimated Position in the Local Official Reference Frame
    CARTESIAN
      X   0.469960035639600E+07 +- 0.513987012061671E-02
      Y  -0.730705087004209E+06 +- 0.248683989960837E-02
      Z   0.423561481514964E+07 +- 0.450863614260094E-02

    ELLIPSOIDAL
      Latitude   (dec)   41.878539630
      Longitude  (dec)  351.162278622
      Elevation    (m)   69.2106750
```