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Justification File

for EGNOS Geodetic Coordinate Determination

22 May 2004

Determination of Geodetic Coordinates for

EGNOS RIMS and NLES Antennae

ET-NMA-RICO-DL5A

NORWEGIAN MAPPING AUTHORITY
GEODETIC INSTITUTE

GMV SISTEMAS

ONSALA RYMDOBSERVATORIUM
CHALMERS TEKNISKA HÖGSKOLA

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Contents

About this document

Scope/objective

This document has the intention to justify that the EGNOS RIMS/NLES geodetic coordinates expressed at central epoch of observation are:

- of globally homogeneous accuracy
- accurate enough for the specified need, 3cm/1sigma
- reliable, of good quality, and certifiable.

Furthermore, the document provides a velocity model with associate uncertainties, which describe the degradation of coordinates with time beyond the central epoch of observation. In particular, the velocity model is used to quantify the degradation until the *Operation Readines Review* (ORR) in mid2004.

Applicable Documents

AD1: E-SW-SYS-E21-0021-ESA: Statement of Work, Determination of geodetic coordinates for EGNOS RIMS and NLES antennas.

AD2: ITT/1-4186/2002/F/WE: Appendix 3: Special Conditions of Tender.

AD3: EGNOS AOC Design Document — Deployed baseline summary EGN-ASPI-SYST-DRD105/0002 rev 2D.

AD4: Determination of geodetic coordinates for EGNOS RIMS and NLES antennas. Technical proposal. ET-NMA-RICI-TEC.

AD5: Determination of geodetic coordinates for EGNOS RIMS and NLES antennas. Financial Management and Administrative proposal. ET-NMA-RICI-FMA.

AD6: Amendment — Determination of geodetic coordinates for EGNOS RIMS and NLES antennas. ET-NMA-RICI-AM1 (issue 1.3, 16 January 2003).

Reference Documents

RD1: NIMA Technical Report — TR 8350.2 Ed3 dated 01/00.

RD2: ”EGNOS Geodetic coordinates project: Software validation document”

RD3: DL1: ”Comparison of geodetic survey methods for EGNOS and recommendations”

RD4: DL2: ”Geodetic coordinates accuracy reliability and certifiability”

RD5: DL3: ”Characterisation of coordinate accuracy degradation”

RD6: DL5: ”EGNOS RIMS geodetic survey report”

Definitions

Accuracy of the estimated antenna position: estimate of the magnitude of the error with respect to the true antenna position in WGS84.

Reliability of the estimated antenna position and its accuracy: characterises the degree of confidence one can have in the estimated position and its associated accuracy.

Certifiability of the antenna position: the coordinates are considered certifiable if there is no obvious and immediate reason why they should not be accepted without signficant extra work by regulation authorities in Geodesy.

Station: for the purpose of this report, a station denotes one RIMS or NLES location. A station may have one or several antennas.

Site: for the purpose of this report, a site is either one RIMS mast or otherwise a geodetic marker (for eccentric points).

Acronyms and abreviations

AD	Applicable document
AOC	Advance Operation Capability
ARP	Antenna Reference Point
BIH	Bureau International del'Heure
CFI	Customer furnished Item
CGPS	Continuous GPS
CHTP	Center of Hole Top Plate
CME	Common mode error
CMGL	Center of Mast Ground Level
DGPS	Differential GPS
DoD	Department of Defence
DORIS	Doppler Orbitography and Radiopositioning integrated by Satellites
DRL	Deliverable
EGM	Earth Gravity Model
EGNOS **EOP**	European Geostationary Navigation Overlay Service Earth Orientation Parameters
ESA	European Space Agency
ESOC	European Space Operation Centre
ETRS	European Terrestrial Reference System
EUREF	European Reference Frame
GAMIT	GPS Analysis Software of MIT
GIPSY/OASIS-II	GPS Inferred Positioning SYstem/Orbit Analysis and Simulation Software
GLONASS	Global Navigation Satellite System
GNS	Global Network Solution
GPS	Global Positioning System
H.E.	Hosting Entity
IERS	International Earth Rotation Service
IGS	International GPS Service
ITRF	International Terrestrial Reference Frame
IVS	International VLBI Service
JPL	Jet Propulsion Laboratory
LGRP	Local Geodetic Reference Point
MARK	Geodetic Reference Marker
MIT	Massachusetts Institute of Technology
NIMA	National Imagery and Mapping Agency
NNSS	Navy Navigation satellite system
NLES	Navigation Land Earth Station
NMA	Norwegian Mapping Authority
OSO	Onsala Space Observatory
PM	Progress meeting
PPP	Precise Point Positioning
RE	Report
RIMS	Ranging and Integrity Monitoring Station
RINEX	Receiver independent exchange format
RNS	Regional Network Solution
SLR	Satellite Laser Ranging
SWEPOS	Swedish GPS Network
SATREF	Satellite based reference system
TN	Technical Note
WP	Work package
WGS84	World Geodetic System 1984
VLBI	Very Long Baseline Interferometry

1 Introduction

The task was to determine certifiable coordinates for the EGNOS RIMS and NLES sites (see Figure 1 for the station locations) with reliable accuracy estimates and an accuracy of 5 cm or better in ITRF/WGS84. The full description of the methodology is given in RD3 and detailed specifications are given in RD6. Here, material is provided to demonstrate the quality of the coordinates as well as to justify the reliability of the coordinates and the error estimates.

The basic tool for the determination of the geodetic coordinates has been the GPS system. Calibrated GPS receivers from the manufacturer Ashtech were used to collect GPS raw data. Classical measuring intruments like theodolite, measuring tape or rod, and magnetic compass were used for the on site 'local tie' measurements. Three different analysis strategies were used to analyse the GPS observations to determine the final geodetic coordinates.

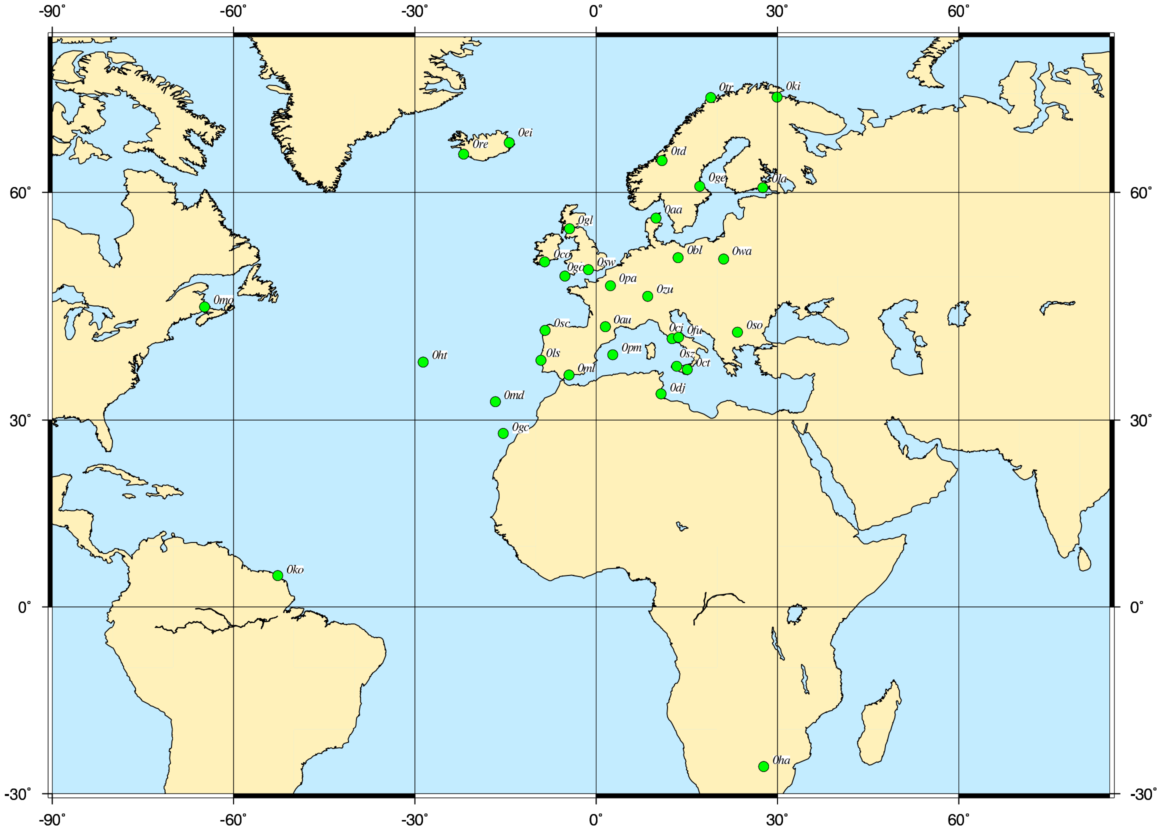

Figure 1: Location of the EGNOS RIMS and NLES stations.

The philosophy was to have as few basic information sources as possible, and to feed this information through a reliable production chain which produces for each station and each stie on the station the basic final coordinate file and the field survey reports with tables.

This is achieved by extensive use of computer scripts and programs, many of them specially designed for this project. The advantage of this approach is that the production procedures are self-documenting, traceable, and reliable. The scripts and programs have carefully been checked and validated (see RD2). In case of necessary changes or correction, it is relatively easy to rerun the process, and all relevant outputs are produced with minimal probability for typing errors.

To justify the reliability of the result including the error estimates, in this document the error budget and all elements of the processing are discussed in detail. In Section 2, the main conclusions are summarised. In Section 3, the different contributions to the error budget of the point coordinates are discussed individually. Focus is on the data analysis algorithms and instrument performance. Section 4 discusses the data flow during processing. The purpose of focusing on the data flow is to demonstrate the reliability of the coordinates by showing the extensive effort made to minimise the probability for typing errors and other blunders. Finally, in Section 5, the degradation of the coordinates with time is considered on the basis of the velocity model discussed in RD5.

Sections 3 to 5 give a complete picture of the the whole process used to arrive at the geodetic coordinates. These sections demonstrate the quality and reliability of the coordinates, both at the Central Epoch of Observation (CEO) and at a common reference epoch at a later time.

2 Conclusion

The final coordinates are the results of three different analysis methods based on three different softwares, namely GIPSY/OASIS-II, GAMIT/GLOBK, and BAHN. The given total error estimates are one 1-sigma level. The main contribution to this total error comes from the GPS analysis. This error contribution is estimated on the basis of a comparison of the three independent solutions. However, every individual solution shows a much better precision. The relatively big differences between the precision of the individual solutions and the accuracy estimates obtained from a comparison of the results from three different analysis strategies are mainly due to different approaches used to fix the reference frame to ITRF2000. Thus the stated error estimates give a realistic picture of the accuracy with which coordinates are given in ITRF2000. Moreover, the accuracy estimates turn out to be

The data flow is considered to be reliable due to extensive use of scripts and programs. Blunders are checked for by different means including manual checks, double checking, control plots, and proof reading.

In the total process, the local tie values are considered as the weakest part. It is important to notice that the total local tie from the GPS *Antenna Reference Point* (ARP) to the CMGL/MARK has two components for the RIMS sites, namely the component from ARP to CHTP and the component from CHTP to CMGL/MARK. For most sites, the local tie between ARP and CMGL is very well determined through the use of a fixed adopter. For the other sites, ARP is identical to CHTP. Thus, speaking of the local tie as the weakest part refers solely to the component CHTP to CMGL. Consequently, the coordinates of the CHTP are very reliable and not affected by the mentioned weakness of the local ties. Only for a small number of sites, no mast was avilable during the field survey or the GPS antenna could not be mounted on the mast. For these sites, the local tie between ARP and CHTP is more complex and introduce contribution to the total error budget of the CHTP.

In the very unlikely case of an error in the local ties component between CHTP to CMGL, this would result in the coordinates of the geodetic reference marker (either CMGL or MARK) being in error, while the CHTP coordinates are not affected. However, if changes in the antenna position are required and new local ties have to be determined, then such errors may surface if the CMGL/MARK coordinates are used. Therefore, it is recommend to carry out an independent check of the local ties between CMGL and CHTP before any old monument is dismounted. In the very unlikely case of discrepances between the new local ties and those inlude in the deliverable `egnos_local_ties_reference_to_chtp.dat` are found, then the coordinates for this CMGL/MARK given in the deliverable `egnos_geodetic_reference_marker.dat` would have to be corrected accordingly.

3 Error Budget/accuracy

Table 1 gives a quantitative overview of the total error budget for all sites. The individual contributions are discussed in detail in the subsequent subsection of this section.

Table 1: Error budget of the geodetic coordinates.

Site	Instr. calibr. (mm)	(Observ.) (mm)	Analysis (mm)	Local ties (mm)	Total (mm)
0AA1	5	2	10	2	12
0AA2	5	2	11	2	12
0AA3	5	2	12	2	13
0AU1	5	2	8	2	10
0AU2	5	2	9	11	15
0AU3	5	2	7	2	9
0AU4	5	2	9	4	11
0BL1	5	2	7	8	12
0BL2	5	2	7	5	10
0BL3	5	2	7	2	9
0CI1	5	2	9	2	11
0CI2	5	2	7	5	10
0CI3	5	2	9	1	10
0CO1	5	2	10	2	11
0CO2	5	2	7	2	9
0CO3	5	2	5	2	7
0CT1	5	2	10	4	12
0CT2	5	2	20	4	21
0CT3	5	2	14	2	15
0DJ1	5	2	9	3	11
0DJ2	5	2	9	3	11
0DJ3	5	2	8	2	10
0EI1	5	2	18	2	19
0EI2	5	2	19	2	20
0EI3	5	2	20	3	21
0FU1	5	2	13	5	15
0FU3	5	2	15	2	16
0GC1	5	2	14	4	15
0GC2	5	2	13	4	15
0GC3	5	2	12	2	13
0GE1	5	2	10	3	12
0GE2	5	2	10	3	11
0GL1	5	2	15	2	16
0GL2	5	2	8	2	10
0GL3	5	2	6	2	8
0GO1	5	2	10	16	20
0GO2	5	2	9	14	18
0GO3	5	2	6	2	8

Site	Instr. calibr.	(Observ.)	Analysis	Local ties	Total
0HA1	5	2	18	4	20
0HA2	5	2	19	8	21
0HA3	5	2	21	2	21
0HT1	5	2	9	6	12
0HT2	5	2	10	4	12
0HT3	5	2	9	2	10
0KI1	5	2	11	3	13
0KI2	5	2	13	3	14
0KI3	5	2	14	2	15
0KO1	5	2	12	4	14
0KO2	5	2	4	5	8
0KO3	5	2	4	1	7
0LA1	5	2	11	7	14
0LA2	5	2	8	7	12
0LA3	5	2	10	2	11
0LS1	5	2	7	3	9
0LS2	5	2	10	3	12
0LS3	5	2	10	2	11
0MD1	5	2	19	2	20
0MD2	5	2	26	3	27
0MD3	5	2	15	2	16
0ML1	5	2	10	3	11
0ML2	5	2	9	5	12
0ML3	5	2	10	2	12
0MO1	5	2	14	3	15
0MO2	5	2	16	3	17
0MO3	5	2	15	2	16
0PA1	5	2	19	7	21
0PA3	5	2	19	2	20
0PA4	5	2	49	2	50
0PM1	5	2	12	3	13
0PM2	5	2	12	3	14
0PM3	5	2	12	2	13
0RE1	5	2	11	3	12
0RE2	5	2	11	2	12
0RE3	5	2	15	2	16
0SC1	5	2	11	4	12
0SC2	5	2	12	3	14
0SC3	5	2	12	2	14
0SO1	5	2	10	3	12
0SO2	5	2	10	3	12
0SO3	5	2	12	2	13
0SW1	5	2	13	2	14
0SW2	5	2	18	2	18
0SW3	5	2	18	2	18
0SZ1	5	2	9	2	11

Site	Instr. calibr.	(Observ.)	Analysis	Local ties	Total
0SZ3	5	2	11	2	13
0TD1	5	2	10	5	13
0TD2	5	2	10	5	13
0TD3	5	2	10	0	11
0TR1	5	2	12	9	15
0TR2	5	2	12	8	15
0TR3	5	2	19	1	20
0WA1	5	2	10	2	11
0WA2	5	2	10	2	12
0WA3	5	2	15	2	16
0ZU1	5	2	13	5	15
0ZU2	5	2	13	3	14
0ZU3	5	2	13	2	15

3.1 GPS instrument calibration

Short description: Receiver and antenna calibration.

Main problems: Determination of vector from ARP to antenna phase center.

Quality assurance: Manufacturer reports and international antenna calibration files (IGS) are available. Receiver and antenna calibration have also been carried out at NMA headquarters in Hønefoss. A comparison of all receivers to one arbitrarily selected reference receiver using the same antenna and an antenna splitter was done after the batch 1 surveys. Antenna calibration was performed on the roof of the building, where a calibration site used for several years was utilised. Calibration was performed by carrying out small-baseline measurements between a reference antenna and the antenna to be calibrated. The vectors were computed with standard GPS analysis software (Ashtech Office Suite for Survey). For all the antennas, the differences in the baseline length are of the order of 1 mm (see RD6).

3.2 GPS observations

Short description: Here the accuracy is considered, with which the GPS receiver measures the carrier signal. That is normally 1% of the wavelength of the signal i.e. about 2 mm.

Main problems: Multipath.

Quality assurance: This contribution to the error budget is disregarded because the GPS analysis is based on a large number of individual observations. Thus, this error contribution is included in the GPS analysis error.

3.3 GPS analysis

Short description: The error for the analysis is based on a combination from three individual analysis centres, each using software and analysis strategies specific to that centre. The analysis errors include uncertainties in the analysis models, as well as the four-dimensional geometrical dispersion of all the observations.

The analysis approaches are in detail described and justified in RD3. Common to all three approches is the use of global products, namely the satellite orbits and clocks and Earth orientation parameters, which are determined on the basis of a global network of tracking stations. Using global products ensures a globally homogeneous accuracy of the resulting coordinates. In the analyses, different global products were used, namely the products provided by IGS and those provided by the Jet Propulsion Laboratory, Pasadena, USA. Moreover, different methods were used to fix the solutions to the ITRF. Consequently, the spreading of the three independent solutions give a reasonable estimate of the uncertainty of the reference frame fixing.

The resulting coordinates are referred to central epoch of observation (CEO). The degradation of coordinates with time depends on the velocity of the point with respect to ITRF. The velocities of the EGNOS RIMS stations relative to ITRF are discussed in RD5. The error due to transferring coordinates to other epochs without new surveys or processing of measurements depends on the accuracy of the velocity model used and the time span between CEO and the new reference epoch. This error is discussed in Section 5.

Main problems: In fixing the global products and station coordinates to the ITRF, typically a subset of 20 to 50 stations of the global IGS station network are used. For these stations, ITRF2000 coordinates are given together with their velocities. The solutions of each independent analysis are dependent on the selection of stations actually used to fix the frame to ITRF. The network of available station may vary in time due to drop-outs of individual stations.

Quality assurance: Three different analysis approaches are used by three different groups. The three approaches differ in software, processing strategies, global products, and subsets of the global tracking network. Error estimates provided by the individual programs are ignored in the computation of the error of the combined solution as these error estimates are considered to be very optimistic and more related to precision than accuracy. This means that each solution is treated with equal weight in the combination. The error estimates for each individual solution are however used to assess the quality of this solution. The individual solutions are also checked against ITRF2000 stations in the IGS netvork and the European Permanent Network EPN not used in the analysis.

3.4 Local ties

Short description: A local tie is the 3-dimensional vector between two reference points not too far away from each other. Here, two specific local ties are considered, namely the local tie from ARP to CHTP and the local tie from CHTP to CMGL/MARK. For eccentric points and RIMS where no mast was available at the time of the survey, the local tie is from ARP directly to MARK/CMGL. At RIMS sites where a mast was available at the time of the survey, the local tie ARP to CHTP is very reliable due to the use of a fixed adapter, ”Kolstad adapter”. At these sites, the local tie from CHTP to CMGL/MARK is measured manually by the surveyor. The horizontal components of the local tie vector (north and east) are measured by a theodolite, measuring tape or rod, and a magnetic compass. The vertical component is measured with a measuring tape or rod. At sites without mast, the local tie from ARP to CMGL/MARK is measured in the same way as the local tie from CHTP to CMGL/MARK.

Main problems: The main problem is that the process is manual and is done mostly by only one person but mostly two times. Another problem is the determination of geodetic azimuth which is required in order to be able to compute the north and east components from the vector length.

Quality assurance: Work is done after specifications given in Chapter 3 of RD6. The work was done carefully, but this step is considered to be the weakest point in the chain. However, as explained in Section 4 under ‘Product 5’, an error in the local ties does not effect the CHTP coordinates.

The length of the horizontal local tie vectors is in the range 0–16 cm. The determination of geodetic azimuth for the vector was done by a magnetic compass. At most sites, no adjustment for the deviation between magnetic north and geodetic north (magnetic declination) was required due to the horizontal component being very small. For example, a deviation of 20° would cause a maximum error of the horizontal components of a local tie vector with a length of 4 cm of 14 mm. In the few sites where the local tie vector length exceeds 4.4 cm the magnetic declination was checked by measuring magnetic azimuth in directions with known geodetic azimuth, and thus estimated the geodetic azimuth for the local tie vector and its accuracy. For most of the stations with horizontal local tie vector length less than 4.4 cm, the magnetic azimuth was used instead of the geodetic azimuth. This may introduce a possible error. Therefore a very pessimistic error on the magnetic azimuth of 18° is introduced, based on information from a US/UK World Magnetic Chart, taken from the web adress `http://www.ngdc.noaa.gov`. The local tie error estimates were adjusted based on this pessimistic azimuth error.

4 Coordinates reliability/quality

Figure 2 presents an overview of the data flow. The flowchart is organised in steps and products which are described in the following subsections. The version and validation status of all software referred to in this section are given in RD2.

4.1 Step 1: Field work

Short description: This is the process of collecting GPS observations (i.e. setting up the GPS antenna on the monument, connecting the GPS receiver to the antenna, initialising and running the GPS receiver for two full days, and down loading the GPS data to a computer), carrying out the local ties measurements, taking photos, preparing a log file for each site, and describing the station.

Main problems: Partly manual and partly automatic process. Collecting GPS observations is done automatically by the receiver and stored locally in it. Local tie measurements and documentation of the site are manual processes. Some results are stored in a traditional, hand-written log-book, and some are written on a laptop computer.

Quality assurance: Work is done after agreed specifications given in Chapter 3 of RD6. The log books are checked manually.

4.2 Product 1: Report text files, GPS observation files, and EGNOS site log files

Short description: The field observation are stored in 3 basic information sources. Moreover, *common report text files* contain text that is common to all field reports. *Field report text files* are specific for a station and include also station dependent sketches, and pictures. *GPS observation files* are the binary files containing the GPS receiver recordings of GPS observations. *EGNOS site log files* contain basic information needed in the coordinate processing. In these latter files, the critical information is ”antenna type” and ”local ties”.

Main problems: The main problem in the *EGNOS site log files* is the “antenna type” and “local ties” information. It is also a possibility to have in the *Field report text files* a type of errors we call blunders. An example could be in a sketch or picture saying that site $0{*}{*}1$ is $0{*}{*}2$ and vice versa.

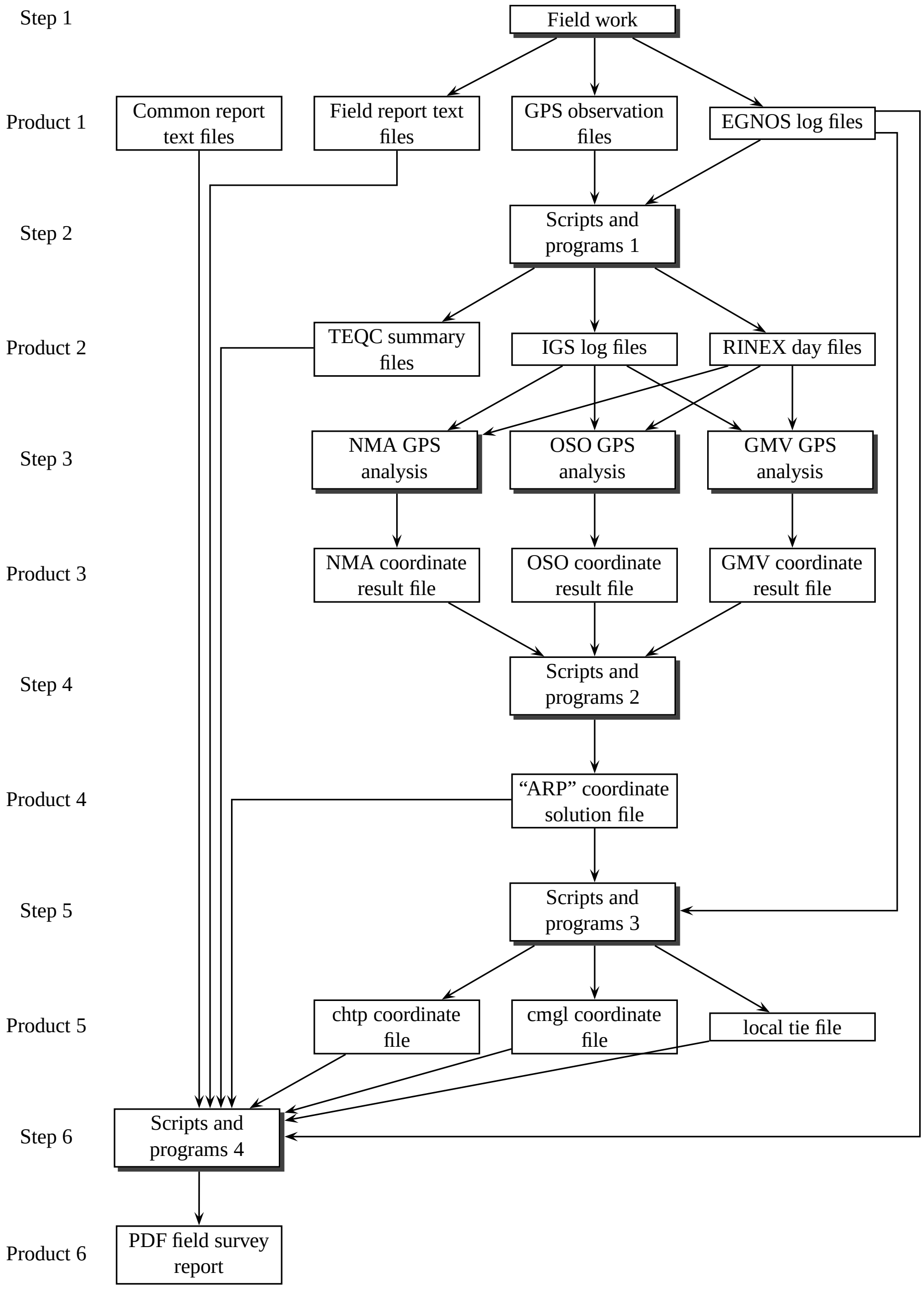

Figure 2: Data flowchart

Quality assurance: Blunders in *Field report text files*, *GPS observation files*, and *EGNOS site log files* are checked for by using plots of the sites produced from `egnos_geodetic_reference_markers.dat` (for an example, see Figure 3). These plots are manually checked by comparison with the content of the field report.

"Antenna type" errors in *EGNOS site log files* are minimised because all antennas have approximately the same characteristics i.e. the nominal distance from antenna phase centre to ARP is the same for all antennas. This is also verified by our instrument calibration, see Section 3.1. The nominal values are taken from IGS `antenna.gra` file.

"Local ties" errors in *EGNOS site log files* are checked for manually by another person who has not carried out the field work.

4.3 Step 2: Scripts and programs 1

Short description: Convert from Ashtech binary format to RINEX format and carry out a quality check of the GPS observations. The program TEQC is used for that purpose. Producing *IGS log files* from *EGNOS site log files*. Scripts and programs specially design at NMA for this project are used for that purpose. Scripts designed at NMA are used to tie the process together. Some manual interaction remains at this stage, namely typing of input file and output file names.

Main problems: Scripts and programs may contain bugs. Blunders may occur in manual command typing.

Quality assurance: TEQC is a well-known program used in the international GPS community for many years. No known bugs. Scripts and programs designed at NMA are manually checked. No known bugs. Possible blunders that may occur in manual command typing is taken care of both by doing some logical self-checking and by producing plots.

4.4 Product 2: TEQC summary files, IGS log files, RINEX day files

Short description: These files are intermediate products in the process. The TEQC summary file is a file that provides a quality information. Some information from the file is used for quality control, in particular approximate station coordinates, observation window, number of measurement, multipath condition. These are used only for information. The output has no consequence on the data processing. The validation of coordinate accuracy is taken from the 3 individual GPS analysis methods and the combination analysis of these 3 solutions. See step 3 and step 4.

Main problems: Files are moved manually between servers.

Quality assurance: Potential errors will be blunders and are checked for by plots.

4.5 Step 3: NMA/OSO/GMV GPS analysis

Short description: Three different institutions have performed independent GPS analysis (see RD3 for all details). NMA used the software package GIPSY/OASIS-II, OSO used the software package GAMIT/-GLOBK, and GMV used the software package BAHN. The packages were used with different analysis strategies. Common input files for all three software packages are the IGS site log files and the daily RINEX files. Each institution carried out the analysis with their specific software with a strategy giving best results for this particular software. This also means that program parameters and additional information like ocean loading, atmospheric mapping, elevation cut-off, and the choise of stations for reference frame fixing were not agreed or homogeneised. Each institution also interpreted the antenna type information in the IGS log file and found the vector from the antenna phase center to ARP individually. See also the comments concerning this point in 'Product 1' above. Each institution produces a coordinate output file.

A brief description of the three software packages is given here with focus on ephemeris used and the method of reference frame fixing applied.

OSO with GAMIT/GLOBK works in short as follows:

- Apriori orbits from SOPAC are used.
- Clock information is not important because of double differencing
- Orbits and station co-ordinates are computed while constraining the combined solution (Swedish network + SOPAC global networks) to roughly 30 globally distributed stations. The stabilisation includes corrections to orbits and stations and a 3D transformation (rotations and translations, (but usually no scale)) of the computed combined GPS network to the ITRF2000 frame.

NMA with GIPSY/OASIS-II works in short as follows:

- JPL precise no-fiducial orbits, clocks and epo's
- Seven parameter/Helmert transformation from the free GPS solution to ITRF2000 using quick transformation parameters from JPL global solution. No orbit relaxation.

GMV with BAHN works in short as follows:

- Apriori orbit information is GPS broadcast.
- Precise orbits, clocks and EOP's are computed internally. (only leap second information external).
- The analysis is based on a selection of IGS stations in ITRF2000. Coordinates and velocities are taken from `http://lareg.ensg.edu.fr/ITRF/ITRF2000/results/ITRF2000GPS.SSC`.

Main problems: Fixing the reference frame to ITRF2000 (see RD3 for a detailed discussion).

Quality assurance: Each institution performs their own internal quality checking of their own process. This includes the determination of coordinates of ITRF or EUREF sites with the same approach.

4.6 Product 3: NMA/OSO/GMV coordinate result files

Short description: NMA/OSO/GMV coordinate result files are the result of the individual computation at each institution. Files are sent by mail or uploaded to the egnos server. They are further transferred to a certain directory for each institution. These coordinates are referred to the ARP point of the antenna. Originally, it was intended to use the SINEX format for these files. However, since the combination is based on equal-weight averages (see Step 4, below), a more simple format containing only Station ID and the X, Y, Z coordinates and their errors was used for the exchange of the information.

Main problems: The three individual coordinate files are in slightly different formats. The Step 4 script and programs read each specific format.

Quality assurance: The test plots showing the discrepancies between each individual solution and the combined solution made from the 'ARP' coordinate solution file are checked manually (see Figure 4).

4.7 Step 4: Scripts and programs 2

Short description: Compute a combined solution file out of the three different solutions. Each solution is treated with equal weight. This simple method was considered to give a good estimate of the accuracy with respect to ITRF2000 of each individual solution as well as of the averaged final solution. The discrepancies between the individual solution are small compared to the accuracy requirement. There is always a problem to chose a right weight function based on the variance/covariance information from three different analysis strategies. The advantage of using an equal-weight approach is that this does not favour any approach to fixing the reference frame to ITRF2000. With a few exceptions (in particular Paris), the internal accuracy of the individual solutions was rather homogeneous. The discrepancy between the three individual solutions turns out to be the main contribution to the total error budget.

There are a two exceptions from the above specified production procedure:

- In site 0sw3, due to a power failure during the field survey, the observation interval was only a few hours. Therefore, a standard analysis with GIPSY/OASIS-II, GAMIT/GLOBK, or BAHN was not possible. The coordinates for 0sw3 were found by computing vectors (Ashtech AOS) from 0sw1 and 0sw2. The coordinates are therefore hard-coded in the script in step 4. The results are documented in the output of the program.
- For the sites 0ko2 and 0ko3, GMV could not provide a solution. The combined solutions are therefore combinations of the OSO and NMA solutions, only.

Main problems: We regard the fixing of the reference frame to ITRF2000 as the main problem. Internal accuracy within each software was usually very good.

Quality assurance: By comparing the three different analysis strategies, a good check on reference frame fixing is obtained. Plots showing the discrepancies between the combined (equal-weight average) solutions and the individual solutions are used for verification (see Figure 4 and Table 2)

4.8 Product 4: 'ARP' coordinate solution file

Short description: This is a coordinate file where the coordinates are referring to the ARP. This is an intermediate file, which is used to produce the files `egnos_CHTP_extended.dat` and `egnos_geodetic_reference_markers.dat`.

Main problems: The GPS observations are referring to the antenna phase centre. To be able to refer coordinates to the ARP, it is necessary to know the antenna characteristics.

Quality assurance: The information of the antenna characteristics is found independently by each analysing institution.

4.9 Step 5: Scripts and programs 3

Short description: Production of the *CHTP coordinate file, the CMGL coordinate file and local tie file.*

Main problems: Programming bugs.

Quality assurance: The scripts and programs are tested on different input, and the produced output is checked for consistency. No bugs are known to exist.

4.10 Product 5: CHTP coordinate file, local tie file, CMGL coordinate file

Short description: The *CHTP coordinate file* is named `egnos_chtp_extended.dat`. The *CMGL coordinate file* is named `egnos_geodetic_reference_markers.dat`. The *local tie file* is named `egnos_local_ties_reference_to_chtp.dat`. The coordinates are given as geocentric coordinates X,Y,Z expressed in reference frame ITRF2000 at the central epoch of observation.

Main problems: Coordinates of CMGL/MARK are influenced by local tie values which are originally from the field work and stored in the *EGNOS log file*.

Quality assurance: In the total process, we regard the local ties values as the weakest part (see Section 3.4 for more details). In a very unlikely case of an error in the local ties, this would result in geodetic marker coordinates being in error. However, such errors do not affect the CHTP coordinates included in `egnos_chtp_extended.dat`.

4.11 Step 6: Scripts and programs 4

Short description: Production of *PDF field survey report*.

Main problems: Programming bugs.

Quality assurance: The scripts and programs are tested on different input, and the produced output is checked for consistency. No bugs are known to exits.

4.12 Product 6: PDF field survey report

Short description: Field survey reports in Portable Document Format (PDF).

Main problems: None identified.

Quality assurance: The field survey reports are proof read.

Table 2: Difference table

DEVIATION FROM COMBINED SOLUTION(m)

		GMV			NMA			OSO		
Site	no	north	east	up	north	east	up	north	east	up
0AA1	1	-0.009	0.001	-0.007	0.005	0.001	0.004	0.005	-0.002	0.003
0AA2	2	-0.009	0.000	-0.007	0.004	0.002	0.005	0.005	-0.002	0.002
0AA3	3	-0.010	0.001	-0.008	0.005	0.001	0.008	0.005	-0.002	0.000
0AU1	4	-0.008	-0.001	0.002	0.006	-0.001	0.001	0.003	0.002	-0.003
0AU2	5	-0.008	-0.002	0.004	0.006	0.000	-0.001	0.002	0.002	-0.003
0AU3	6	-0.008	0.000	0.002	0.005	0.000	0.002	0.003	0.001	-0.004
0AU4	7	-0.005	-0.006	0.006	0.002	0.002	0.000	0.003	0.003	-0.006
0BL1	8	-0.002	-0.004	-0.004	-0.001	0.003	-0.001	0.003	0.001	0.005
0BL2	9	-0.002	-0.006	-0.004	0.000	0.005	0.002	0.003	0.001	0.003
0BL3	10	-0.002	-0.003	-0.006	-0.001	0.002	0.001	0.003	0.001	0.005
0CI1	11	-0.007	-0.002	-0.007	0.004	-0.001	0.005	0.003	0.003	0.002
0CI2	12	-0.008	-0.001	-0.002	0.005	-0.001	0.002	0.003	0.003	0.000
0CI3	13	-0.008	0.000	-0.006	0.005	-0.002	0.004	0.002	0.002	0.003
0CO1	14	-0.007	-0.002	-0.007	0.004	0.002	0.008	0.003	0.000	-0.001
0CO2	15	-0.007	-0.002	-0.001	0.005	0.001	0.005	0.002	0.001	-0.003
0CO3	16	-0.005	-0.001	0.002	0.002	0.000	-0.001	0.003	0.001	-0.001
0CT1	17	-0.001	0.002	0.007	0.003	0.001	0.004	-0.002	-0.003	-0.010
0CT2	18	0.003	-0.017	-0.014	-0.001	0.010	0.011	-0.003	0.007	0.003
0CT3	19	-0.003	0.009	0.011	0.003	-0.003	0.002	0.000	-0.006	-0.012
0DJ1	20	-0.005	-0.006	-0.003	0.002	0.002	0.006	0.003	0.004	-0.003
0DJ2	21	-0.004	-0.005	-0.006	0.001	0.001	0.007	0.003	0.005	-0.001
0DJ3	22	-0.005	-0.006	-0.005	0.002	0.002	0.004	0.003	0.005	0.001
0EI1	23	-0.010	-0.002	-0.018	0.008	0.002	0.009	0.002	0.000	0.009
0EI2	24	-0.011	-0.001	-0.019	0.008	0.001	0.009	0.003	0.000	0.010
0EI3	25	-0.010	-0.003	-0.020	0.008	0.001	0.012	0.003	0.001	0.009
0FU1	26	-0.013	-0.001	-0.007	0.007	0.002	0.006	0.006	-0.001	0.001
0FU3	27	-0.013	-0.001	-0.010	0.007	0.001	0.011	0.006	0.000	-0.001
0GC1	28	-0.012	0.002	0.005	0.006	-0.003	0.006	0.006	0.001	-0.010
0GC2	29	-0.013	0.001	0.005	0.007	-0.001	0.004	0.006	-0.001	-0.009
0GC3	30	-0.012	0.002	0.002	0.006	-0.002	0.003	0.006	0.000	-0.005
0GE1	31	-0.010	-0.003	-0.004	0.007	0.000	0.004	0.003	0.002	0.000
0GE2	32	-0.010	-0.001	-0.004	0.007	-0.001	0.001	0.003	0.002	0.003
0GL1	33	-0.004	0.000	-0.015	0.002	0.001	0.013	0.003	0.000	0.003
0GL2	34	-0.004	-0.001	0.009	0.001	0.000	-0.005	0.003	0.001	-0.003
0GL3	35	-0.004	0.001	-0.002	0.001	-0.001	0.005	0.003	-0.001	-0.004
0GO1	36	-0.007	-0.003	-0.007	0.004	0.003	0.008	0.003	0.000	-0.001
0GO2	37	-0.006	-0.001	-0.005	0.004	0.000	0.008	0.002	0.001	-0.003
0GO3	38	0.000	0.000	0.000	0.001	0.001	0.005	-0.001	-0.001	-0.005
0HA1	39	0.000	0.019	0.007	-0.002	-0.009	0.002	0.002	-0.010	-0.009
0HA2	40	0.001	0.019	0.006	-0.003	-0.008	0.003	0.002	-0.011	-0.009
0HA3	41	0.001	0.021	0.006	-0.003	-0.009	0.005	0.003	-0.012	-0.011
0HT1	42	-0.007	-0.003	0.007	0.003	0.000	-0.002	0.005	0.003	-0.005
0HT2	43	-0.007	-0.003	0.007	0.002	0.001	-0.001	0.005	0.002	-0.006
0HT3	44	-0.008	-0.003	0.003	0.002	0.002	0.002	0.005	0.001	-0.005
0KI1	45	-0.009	-0.005	-0.007	0.004	0.003	0.004	0.005	0.002	0.002
0KI2	46	-0.009	-0.006	-0.010	0.005	0.004	0.007	0.005	0.002	0.002
0KI3	47	-0.009	-0.005	-0.011	0.005	0.003	0.009	0.004	0.002	0.002
0KO1	48	-0.004	0.001	0.013	0.000	0.000	-0.007	0.004	-0.001	-0.005
0KO2	49	0.000	0.000	0.000	-0.003	0.000	-0.003	0.003	0.000	0.003
0KO3	50	0.000	0.000	0.000	-0.003	0.002	0.002	0.003	-0.002	-0.002
0LA1	51	-0.007	0.000	-0.006	0.004	0.001	0.011	0.003	0.000	-0.005
0LA2	52	-0.007	0.000	-0.002	0.004	0.000	0.006	0.003	0.000	-0.004
0LA3	53	-0.006	-0.002	-0.003	0.003	-0.001	0.008	0.003	0.003	-0.005
0LS1	54	-0.006	-0.002	-0.002	0.001	0.004	0.003	0.005	-0.002	-0.001
0LS2	55	-0.008	0.004	0.007	0.002	0.000	-0.002	0.005	-0.004	-0.006
0LS3	56	-0.006	-0.003	0.007	0.001	0.005	-0.004	0.005	-0.001	-0.003
0MD1	57	-0.012	-0.005	0.018	0.008	-0.001	-0.006	0.004	0.007	-0.011
0MD2	58	-0.012	-0.004	0.027	0.007	-0.002	-0.012	0.005	0.006	-0.016
0MD3	59	-0.012	-0.005	0.008	0.007	0.000	0.002	0.005	0.005	-0.010
0ML1	60	-0.010	-0.001	-0.003	0.004	0.000	0.000	0.006	0.001	0.004
0ML2	61	-0.011	-0.003	0.000	0.004	0.001	0.001	0.006	0.002	0.000
0ML3	62	-0.011	-0.001	-0.004	0.004	0.000	0.003	0.007	0.001	0.001
0MO1	63	-0.012	-0.002	0.009	0.006	0.000	-0.004	0.006	0.001	-0.005
0MO2	64	-0.012	0.000	0.014	0.006	-0.001	-0.004	0.006	0.001	-0.010
0MO3	65	-0.013	-0.003	0.009	0.007	0.000	-0.004	0.006	0.003	-0.006
0PA3	66	-0.013	-0.002	0.002	0.011	0.002	-0.016	0.001	0.000	0.014
0PA4	67	-0.017	0.001	0.041	0.019	0.012	-0.046	-0.002	-0.012	0.005
0PM1	68	-0.011	-0.001	0.003	0.006	-0.001	0.005	0.005	0.002	-0.008
0PM2	69	-0.011	-0.001	0.002	0.006	-0.001	0.006	0.005	0.002	-0.008
0PM3	70	-0.011	-0.001	0.007	0.006	-0.002	0.000	0.005	0.003	-0.007
0RE1	71	-0.007	-0.008	0.003	0.004	0.003	0.004	0.003	0.005	-0.006
0RE2	72	-0.006	-0.009	-0.003	0.004	0.004	0.006	0.002	0.005	-0.003
0RE3	73	-0.007	-0.009	-0.010	0.004	0.004	0.013	0.003	0.005	-0.003
0SC1	74	-0.009	-0.007	0.002	0.004	0.001	0.002	0.005	0.006	-0.004
0SC2	75	-0.011	-0.007	0.001	0.005	0.001	0.003	0.006	0.007	-0.004
0SC3	76	-0.010	-0.006	-0.003	0.003	0.000	0.007	0.006	0.006	-0.004
0SO1	77	-0.002	-0.005	-0.002	0.004	0.003	0.009	-0.001	0.002	-0.007
0SO2	78	-0.002	-0.006	-0.001	0.003	0.004	0.009	-0.001	0.002	-0.008
0SO3	79	-0.003	-0.006	-0.004	0.004	0.003	0.011	-0.001	0.003	-0.007
0SW1	80	-0.012	0.000	-0.007	0.006	0.002	0.008	0.005	-0.002	-0.001
0SW2	81	-0.012	-0.002	-0.014	0.005	0.002	0.014	0.007	0.000	0.000
0SZ1	82	-0.007	-0.005	0.005	0.007	0.005	-0.001	0.001	0.000	-0.003
0SZ3	83	-0.008	-0.005	-0.009	0.006	0.004	0.007	0.002	0.001	0.001
0TD1	84	-0.011	-0.001	0.001	0.007	0.003	-0.001	0.005	-0.002	0.001
0TD2	85	-0.011	-0.001	0.001	0.007	0.000	0.002	0.004	0.000	-0.003
0TD3	86	-0.010	-0.001	-0.003	0.005	0.003	0.005	0.004	-0.002	-0.002
0TR1	87	-0.009	0.000	-0.005	0.007	0.006	0.005	0.002	-0.006	0.000
0TR2	88	-0.008	-0.002	-0.007	0.007	0.006	0.007	0.002	-0.004	0.001
0TR3	89	-0.009	-0.002	-0.019	0.008	0.004	0.013	0.002	-0.001	0.006
0WA1	90	-0.010	0.000	0.005	0.005	0.000	0.001	0.005	0.000	-0.006
0WA2	91	-0.011	-0.001	0.001	0.005	0.001	0.004	0.006	0.000	-0.005
0WA3	92	-0.010	-0.001	-0.012	0.005	0.001	0.012	0.005	0.000	0.000
0ZU1	93	-0.013	0.000	-0.008	0.008	0.002	0.005	0.005	-0.002	0.003
0ZU2	94	-0.012	0.000	-0.007	0.007	0.002	0.006	0.005	-0.002	0.001
0ZU3	95	-0.012	0.000	-0.009	0.008	0.002	0.007	0.004	-0.001	0.002

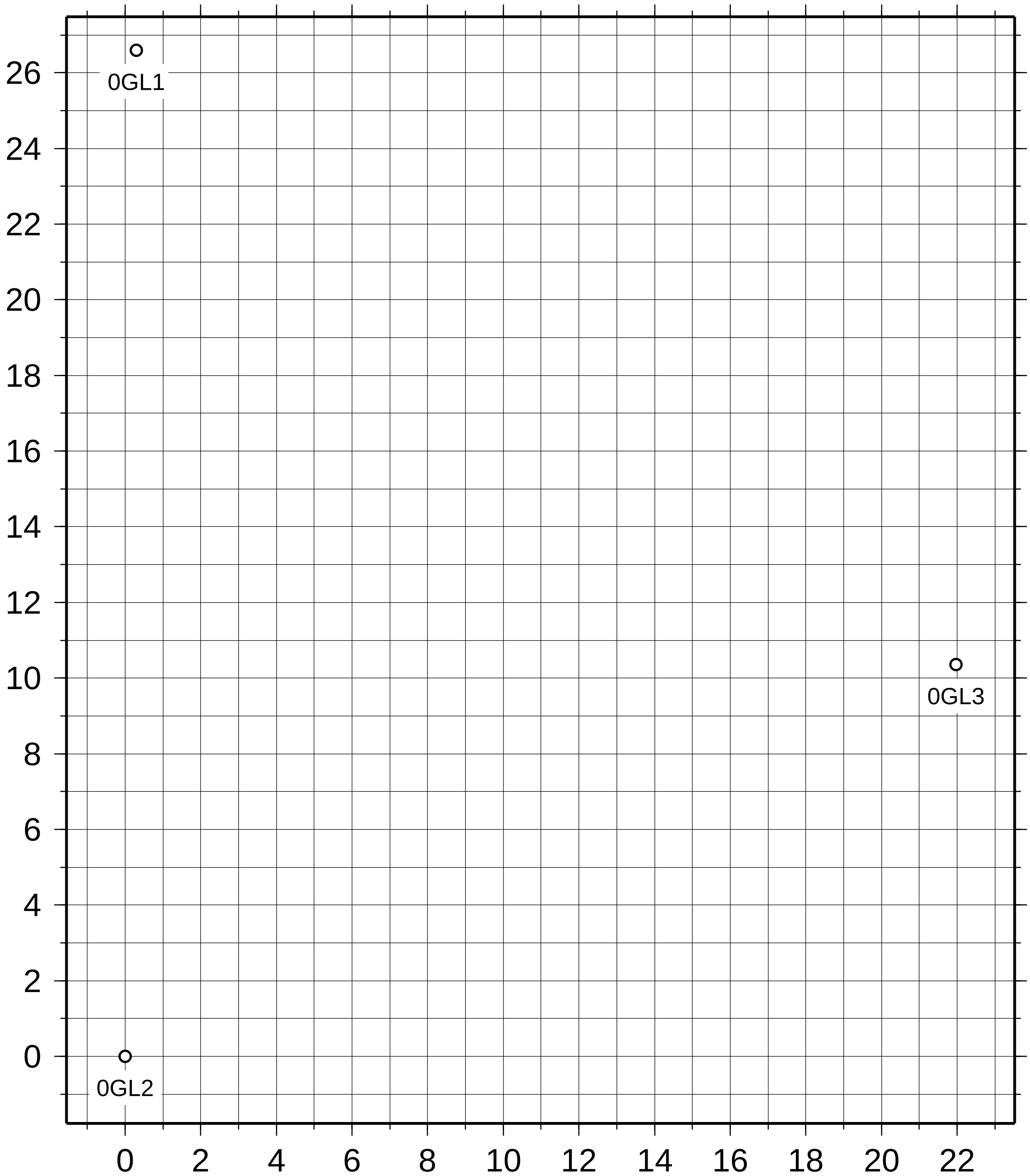

Figure 3: Local plot for station Glasgow. Units are m.

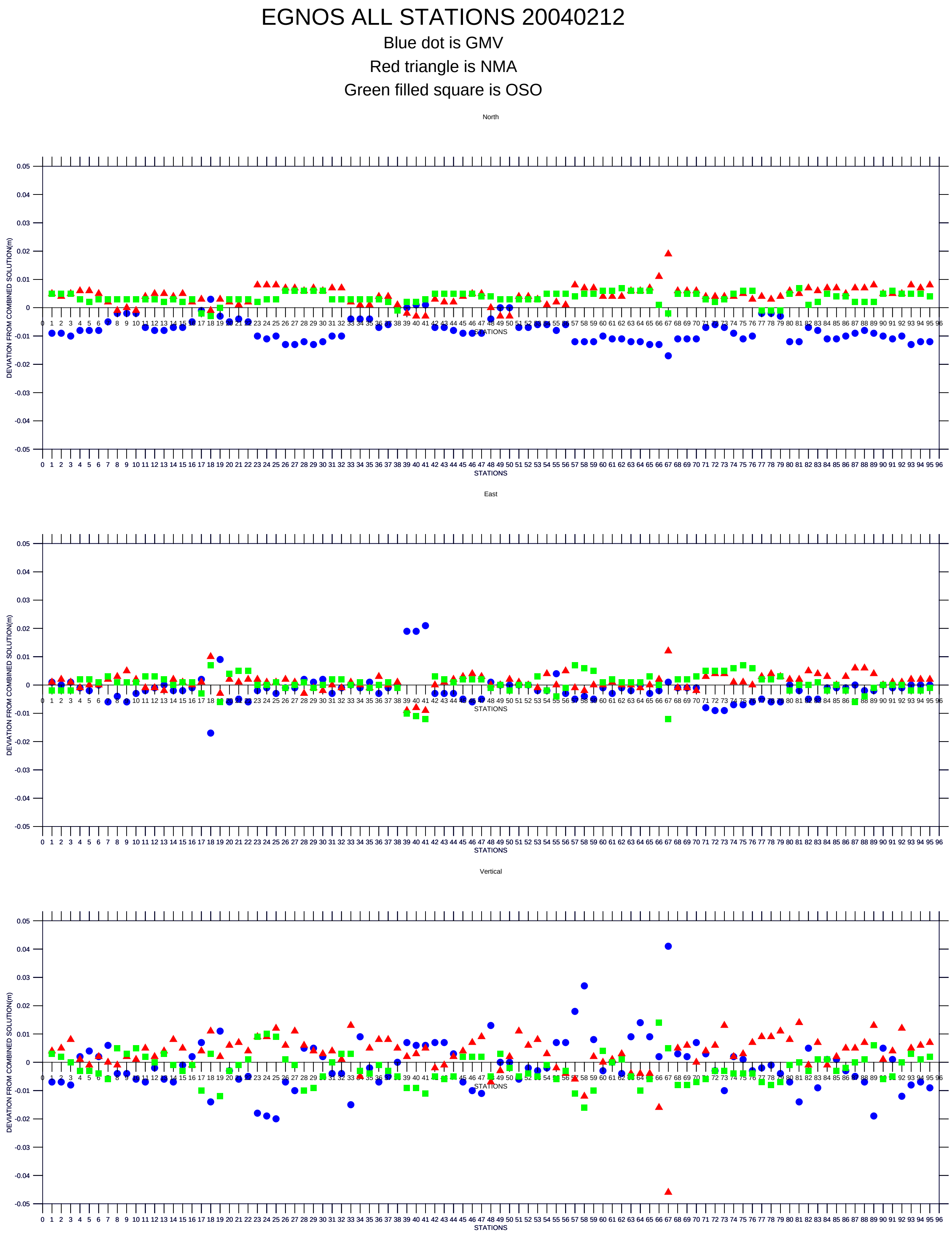

Figure 4: Difference plot

5 Coordinate degradation

The different processes causing point movements of the Earth surface with respect to a global geodetic reference frame are in detail discused in RD5. A major source of coordinate degradation is due to three-dimensional secular motion of all points on the Earth surface caused by geodynamic processes. The secular motion can be described by a velocity model with constant velocity. However, in large regions, knowledge of the secular velocity is still poor thus introducing considerable degradation of the accuracy of coordinates with time.

In tectonically active areas, non-linear motion can be expected. In such areas, degradation of coordinate accuracy may be considerable and, in the absence of permanent monitoring, is diffcult to assess.

In this section, a justification for the error estimates of the velocity model for the EGNOS sites provided in RD5 is given. These errors determine how much the accuracy of the coordinates degrade if the velocity model is used to update the coordinates from the central epoch of observation to another reference epoch. In Table 3, the error estimates for each RIMS station are given.

Without updating coordinates to a reference epoch close to presence, the degradation of the coordinates is rather rapid. The velocities given for the individual stations in RD5 reach more than 20 mm/yr and 10 mm/yr in the horizontal and vertical components, respectively. Therefore, it is assumed here that a frequent update of coordinates is performed, so that the degradation is solely due to the error in the velocity model.

The velocity model is mainly validated on the basis of the ITRF reference sites. IERS provides both coordinates and secular velocities for these sites. The coordinates of each site are determined through combination of several independent solutions taking into account the full variance-covariance matrix of the solutions. In this way, the reliability of these coordinates and velocities is high.

For the stable part of the European plate, a velocity model is available which, based on the comparison with all available ITRF stations, has an accuracy of ±1 mm/yr in each horizontal component and ±2 mm/yr in the vertical. At sites on the Iberian Penninsula, observations are rather sparse and indicate that the model errors are rather ±2 mm/yr in each horizontal component and ±3 mm/yr in the vertical.

Close to plate boundaries of the Eurasian plate, such as in Southern Italy, Iceland, the Azores, the velocity model has larger error. In these location, preference is given to actual, near-by observations, if available. Comparison between these observations and the velocity model gives an estimate of the maximum error. Based on the available information, the errors for these sites are estimated to be in the worst case ±4 mm/yr in each horizontal component and ±5 mm/yr in the vertical.

For the RIMS locations outside the Eurasian plate, it is noted that all these sites are in stable areas, where the tectonic plate model provides good estimates of the horizontal velocity. Again, the model is validated against the ITRF sites on the same plate. The velocity and error estimates are based on a combination of the available information.

Table 3: Accuracy of the EGNOS Velocity Model.

Station	East	North	Up
	mm/yr	mm/yr	mm/yr
0AA	1.0	1.0	2.0
0AU	1.0	1.0	2.0
0BL	1.0	1.0	2.0
0CO	1.0	1.0	2.0
0GE	1.0	1.0	2.0
0GL	1.0	1.0	2.0
0GO	1.0	1.0	2.0
0KI	1.0	1.0	2.0
0LA	1.0	1.0	2.0
0SW	1.0	1.0	2.0
0TD	1.0	1.0	2.0
0TR	1.0	1.0	2.0
0WA	1.0	1.0	2.0
0ZU	1.0	1.0	2.0
0PA	1.0	1.0	2.0
0LS	2.0	2.0	3.0
0ML	2.0	2.0	3.0
0SC	2.0	2.0	3.0
0PM	2.0	2.0	3.0
0SZ	3.0	3.0	4.0
0CT	3.0	3.0	4.0
0CI	3.0	4.0	4.0
0FU	3.0	4.0	4.0
0SO	3.0	3.0	4.0
ORE	2.0	2.0	3.0
OEI	3.0	3.0	4.0
0MO	2.0	2.0	2.0
0KO	2.0	2.0	3.0
0HA	2.0	2.0	3.0
0DJ	3.0	3.0	3.0
0GC	2.0	2.0	3.0
0MD	2.0	2.0	4.0
0HT	4.0	4.0	5.0