A ZERO ORDER NETWORK OF PERMANENT GNSS STATIONS FOR POSITIONING SERVICES IN ITALY: SOME HYPOTHESES AND TESTS

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Abstract

In these years, GNSS permanent networks finalized to real time and post processing positioning services are under development in Italy; for administrative reasons, they are designed, created and managed at a local scale, corresponding to Italian Regions. A permanent network materializes and distributes a reference frame to the user community; to guarantee that all the local networks distribute the same reference frame, they should be adjusted and monitored in a common zero order permanent network, following a common adjustment protocol.
From a theoretical point of view, the global IGS network and the IGS adjustment guidelines constitute the natural shared infrastructure. However, from a practical point of view, IGS permanent stations alone cannot constitute the Italian zero order network, because they are not homogeneously distributed in Italy; moreover IGS has not the scope of monitoring local subnetworks, whereas such a task could be performed by some kind of governing board taking care of the zero order network.
Actually, the natural choice is to establish a zero order permanent network at a national scale; this network should be adjusted and monitored in the global IGS network in order to provide the link between global and local networks. Moreover the zero order network also guarantees the consistency between local neighbouring networks. In order to fulfil these scopes, the zero order network should satisfy several scientific and technical requirements, from the design to the network monitoring choices.
The present paper focuses on these topics: the Italian situation is analysed and a numerical test is presented: a set of about 60 permanent stations has been chosen according to a good design criterion and their data for a three months period have been analyzed. Related results are discussed, with particular regard to the criteria for the automatic outlier rejection and results check.

1 Introduction

In the '80 and '90, zero order networks of GPS stations were established in almost all European countries, designed to disseminate the datum with an accuracy of some cm for cartographic purposes: dense enough, they were surveyed at the network setup and adjusted in the European Reference Frame (Adam et al, 1999) by constraining a subset of fundamental points to their published ETRF coordinates. In case they have not been periodically resurveyed, neither displacements in time nor velocities can be estimated: for these reasons they can be defined as static networks, that materialize static reference frames (RF's).
At that time, post-processed static (or fast static) was the typical surveying technique. Meanwhile, GPS data processing algorithms have greatly improved and new surveying techniques have been developed. Without considering historical details, at present Real Time (RT) static surveys represent the fastest way to achieve cartographic and cadastral accuracies; typically, post-processing is devoted to highly specialized applications, like for example kinematic trajectories estimation in aerial photogrammetry or high precision deformations monitoring. To fully exploit new GPS (or better, GNSS) techniques, particularly in RT, GPS Permanent Networks (PN's) have been set up in many European countries with the aim to provide positioning services to users: besides distributing RINEX files and estimated coordinates of the stations, typically they provide real time network products for RT surveys (see for example, Wübbena et al., 2001, Xiaoming et al., 2003). Several positioning services are already operating in Europe. Typically, they are supervised, or at least certified at the national scale, from a cartographic authority: from a technical point of view, small networks, like for example the Swiss (www.swisstopo.admin.ch) AGNES, are managed and adjusted in a single cluster; on the contrary, large networks like the German SAPOS (www.sapos.de) are typically clustered in several subnetworks, separately managed and adjusted.
To guarantee the maximum reliability and accuracy, a positioning service should monitor its stations coordinates by a continuous adjustment in the global IGS PN, by constraining IGS coordinates, ephemerides, EOP's, and according to the IGS adjustment guidelines. In this way, at its spatial scale, a positioning service materializes and distributes the current IGS realization of ITRS

(Kouba et al., 1998, Beutler et al., 1999, Mc Carthy et al., 2003, Ferland et al., 2004, Ray et al., 2004): particularly, at present, IGS05.

However, most of the users need to be connected to the national cartographic RF, that in the European countries, is typically a realization of ETRS89. For this reasons, to be effective for cartographic and cadastral applications, positioning services should also estimate and distribute the transformation between IGS05 and the national cartographic RF. All the details of these topics have been already discussed in Benciolini et al., (2008), Biagi et al., (2008).

By means of a continuous adjustment, a positioning service continuously monitors its stations coordinates and dynamically materializes the RF, considering not only the smooth long term trends but also the possible sharp discontinuities. This is not possible for the static networks, whose stations coordinates are not monitored. For this reason, PN's and related positioning services really represent the first chance to continuously and reliably monitor the distributed coordinates. This is important not only for high precision applications but also for cartographic purposes, so that fundamental networks are migrating from the static to the dynamic realization.

At last, note that from a technical point of view, the automation of the adjustment of a PN requires just a major initial effort; then, given a proper set up, the software maintenance should be minimal and the scientific analysis remains the main task.

In the following, the authors will discuss the Italian situation and the need of a national zero order PN as a framework to adjust and check the Italian positioning services; then, some proposals for the zero order PN are formulated; at the end, the results of a numerical experiment performed on a test network are presented.

2 The present situation in Italy

The official geodetic RF in Italy is ETRF89-IGM95, realized by a static network initially composed of 1250 benchmarks, surveyed by Istituto Geografico Militare Italiano (IGM, http://www.igmi.org/, Surace, 1997) in 1992-1994. In the adjustment, 9 benchmarks coincident with EUREF sites, were constrained to their ETRF89 (epoch $t = 1989.0$) coordinates: ETRF89-IGM95 (in the following, simply IGM95) is distributed by the benchmarks monographs. The 34% of the benchmarks have been surveyed by high precision levelling and 52% coincide with, or are linked to, benchmarks belonging to the historical first order trigonometric network: this has allowed the study of the local geoid and the connection between the old national RF's (Roma40 and IGM83) and the new one. In more recent years, new benchmarks and local subnetworks have been surveyed and officially added to IGM95, that now is composed of about 2000 benchmarks. Each update of IGM95 has been adjusted by maintaining both the original constraints and the original estimated baselines: neither time displacements or velocities have been estimated or inferred and officially published. Due to the intense and varied geodynamics of the Italian regions, IGM95 is strained at the national scale: in the elapsed time differential movements between North and South of several cm have been reported, but this is not the main problem for cartographic applications. IGM95 is characterized by locally correlated deformations and randomly sparse errors: standard deviations are 3 cm in planimetry and 5 cm in altimetry but localized errors larger than 10 cm are known; they are due to the '90 survey and adjustment techniques accuracy, as well as to the local relative movements of benchmarks during the last 20 years.

In the last years, GNSS positioning services are under development in Italy, both for RT and post processing applications (Biagi et al., 2006); for administrative reasons, and in lack of any national planning or coordination, they are designed, created and managed at a local scale, corresponding to Italian Regions. To give a more precise idea, Italy extension is 301388 km^2, including 20 Regions, whose extensions range within 3262 km^2 (Val D'Aosta) and 25708 km^2 (Sicilia). At present, less than 10 Regional Positioning Services are already operating and distributing data to the user community, but others are being implemented: the authors of the present work have been involved in the design, the creation and the monitoring of the first 3 ones, located in Piemonte (www.vercelli.polito.it/civili/topo0103.htm), Lombardia (www.gpslombardia.it) and Lazio Regions (w3.uniroma1.it/resnap-gps/index.asp).

To the authors knowledge, the permanent stations existing in Italy are at least 360 (Fig. 1), at least 200 of whom publish their data for free: 9 of them partecipate to IGS, 15 to EPN. At a national scale, the main PN's finalized to geodetic or geodynamic purposes are Geodaf, managed by Italian Space Agency (ASI, geodaf.mt.asi.it), RING, managed by Istituto Nazionale di Geofisica e Vulcanologia (INGV, ring.gm.ingv.it) and GAIN, managed by University of Trieste (http://www.alps-gps.units.it/gain-network.php); three private firms (Leica Italia, www.italpos.it, Geotop, www.geotop.it, Assogeo, www.assogeo.net) manage their own networks. Other stations are independently managed, either by privates or public administrations (note that in the above statistics, several stations belong to more than one PN). In national panorama the 57% of the stations is monumented on top of roofs, while the remaining 43% is monumented directly on ground.

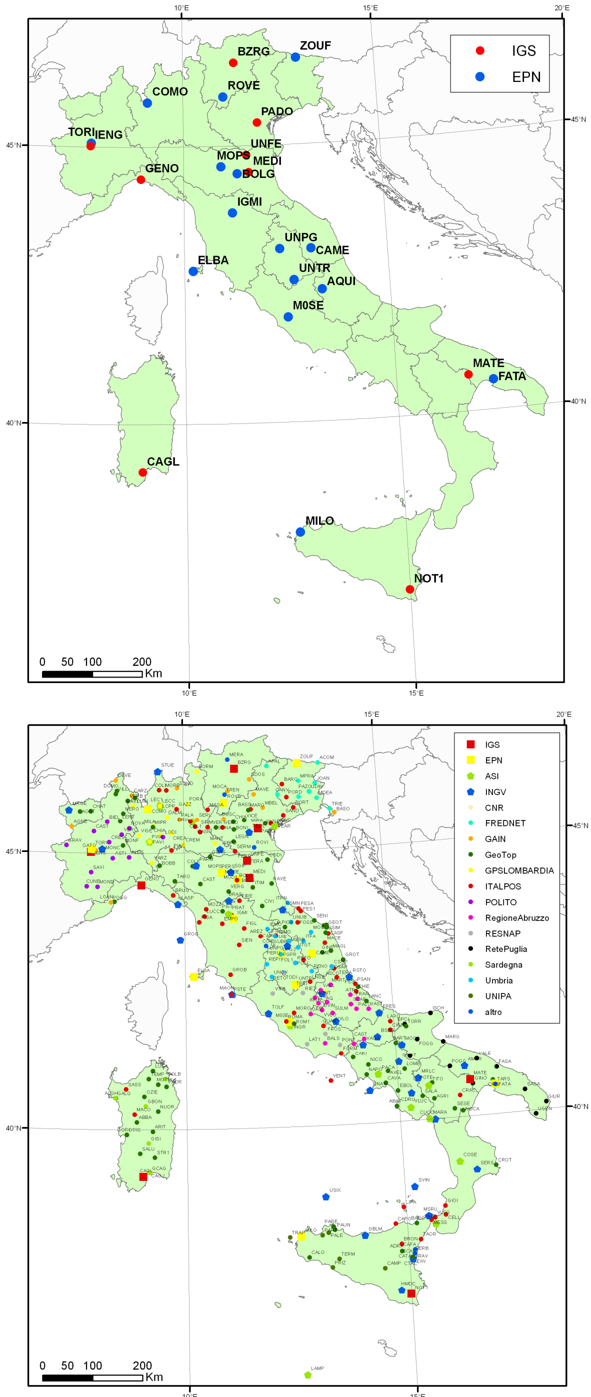

Figure 1 – Upper: IGS and EPN stations in Italy; lower: other public stations

3 The need of a zero order permanent network in Italy

The local organization of Italian positioning services may represent a weakness though it exhibits some advantages too: in principle it allows an easy management of each PN, a fast resolution of possible problems, a close interaction of each service with its users. Moreover, neighbouring PN's can exchange data streams of some stations, in order to increase their boundary redundancy.

On the other hand, local neighbouring positioning services should guarantee the distribution of consistent RF's, and this requires a national coordination. At a first level, they should be adjusted and monitored in a unique zero order PN, by following a common adjustment protocol, exactly as it happens for the analysis centres of IGS or EPN. Moreover, a national zero order PN could fulfil other aims. The first, and most important, is the Italian transition from the old, static IGM95 to a new RF, continuously monitored in the global ITRF, that could provide very accurate time series of coordinates. The application of the well known international transformation (Boucher, Altamimi, 2007) to the ITRF coordinates would provide their ETRF estimates too, by following the same approach applied for EPN stations (www.epncb.oma.be); moreover, the availability of long time series would allow the computation of the ITRF velocities, and their transformation to ETRF velocities. In this way a national cartographic realization of ETRS89 would be available, whit an accuracy comparable with the European PN, avoiding IGM95 deformations and errors. At last, the availability of ITRF and ETRF coordinates and velocities for a zero order PN would allow a national estimate of the transformations between the two RF's, at any reference epoch. The distribution of an official, unique national transformation to the user community would prevent local, independent choices, that typically lead to inconsistent results: on this regard, a recent experiment has been performed in Lombardia and Piemonte (Biagi et al., 2008) Regions, that are located in West-Northern Italy; the transformation parameters between ITRF-IGb00 and IGM95 have been independently estimated for these two neighbouring regions. The application of different transformation parameters at the common border produce unacceptable differences, characterized by biases and trend up to 5 cm horizontally and 15 cm in height.

The use of IGS stations alone to realize the zero order PN is unfeasible: at present, IGS stations (Fig. 1) are excessively sparse and not homogeneously distributed in Italy, particularly in southern regions. An IGS densification in Italy is possible but not explicitly foreseen: in any case, obviously, it would follow global geodynamics purposes and not national strategies. EPN has already a better distribution in Italy but, again, its development follows other priorities. In any case, and this is the ultimate problem, IGS and EPN have not the aim of monitoring local subnetworks. Instead, a national zero order PN should be designed by following national requirements and priorities, and its institution should be accompanied by a governing board that would guarantee both technical coordination between local PN's and a consistency check between the distributed coordinates.

In the present Italian situation, the authors have just tried the scientific exercise of writing the reasonable rules that should define a national zero order PN; then, as a technical experiment, a test network has been extracted from the existing stations in Italy and three month of data have been adjusted. The numerical experiment has not the aim to define the optimal, final, zero order PN: it is just a proof that the definition of a national zero order PN is already possible and practically does not require the monumentation of any new station; the only costs are related to the implementation and control of a system to continuously and automatically monitor the PN.

4 Hypotheses for a future zero order permanent network and test network

As minimal requirements, a zero order national PN should:

1. composed by stations homogeneously distributed over the whole nation, with a reasonable density;
2. include the main EPN and IGS stations;
3. include stations of the main national geodetic and geodynamic networks (ASI, INGV and GAIN);
4. include at least 2 stations for each local positioning service;
5. be composed only by stations whose data are freely available to the community by automated ftp;
6. be composed only by stations whose responsible agencies subscribe proper consistency and quality guidelines, like for IGS and EPN PS's.

Without entering into the other technical implications of the point 6, one is particularly important and relevant to the following quality analysis on the test network: the zero order PN should be composed only by PS's whose RINEX files are a posteriori downloaded from the memory of the receivers and not reconstructed from RTCM streams, in order to avoid data gaps due to transmission problems.

As mentioned, a zero order PN can be realized in Italy practically without any new installation; to asses this fact, a subset of the existing stations has been selected and adjusted. The test network is composed of 62 stations operating and distributing their data at the beginning of 2007, chosen by minimizing the compromises between above guidelines and the requirement of a mean interstation distance of the order of 100 km (Fig. 2).

IGS and EPN stations have been chosen taking all those available in the national territory and the most important around it, accordingly to a homogeneous distribution criterion; obviously, in case of twin stations (for example CAGL and CAGZ) only one of them has been used.

In the choice of the test network the following two compromises have been accepted with respect to the above minimal requirements: stations whose data are presently not freely available via ftp and stations whose RINEX are reconstructed from RTCM streams have been included. In any case, it should be pointed out that the responsible agencies of these stations are already available to overcome these problems in case of the inclusion in an official national zero order PN. The spatial configuration is very satisfactory in the north, while in central and southern Italy it presents some weak areas, due to the absence of operating stations at the experiment epoch; however (Chap. 2 and Fig. 1), the situation has already changed and is rapidly improving: a more complete design would now be possible.

5 The network adjustment

A near real time quality check, performed for example by a midnight inner adjustment, of a PN is always desiderable; however, this topic is not discussed here, and the focus will be posed on the final adjustment of the zero order PN. It should be performed according to the following minimal rules:

1. adjustment of the network in the global IGS and in the continental EPN PN's;
2. independent daily adjustments, with the latency of the IGS final products;
3. IGS PS's stochastically constrained to their published coordinates, with realistic covariances attributed to the constraints;
4. adoption, without any further parameters estimation, of the final IGS products: EOP, EPH and PCV;
5. adoption of the IGS and EPN guidelines to the adjustment of regional PN's;
6. accurate data consistency and quality check by automated analysis.

To perform the adjustment of the test network, three months of data, from the GPS week 1408 (2006, 31th December) to the GPS week 1420 (2007, 31th March), have been adjusted, according to the above processing strategies, by using the Bernese 5.0 software (BSW5.0). In the present analysis, no results redundancy is available because just one time series has been estimated; an optimal approach to the zero order PN monitoring requires that more (at least three) analysis centres perform independent daily adjustments; the following results comparison would provide a minimal consistency check.

The adjustment has been performed by the following procedure:

1. acquisition of final EOP, EPH, PCV from IGS,
2. orbit interpolation,
3. single station code processing (clock estimation),
4. single difference creation (network graph definition),
5. cycle slips identification and estimation,
6. float ionospheric free solution,
7. ambiguity fixing by QIF algorithm,
8. final ionospheric free fixed solution,
9. extraction of quality indicators from the BSW5.0 outputs,
10. outlier rejection and reprocessing of accepted data.

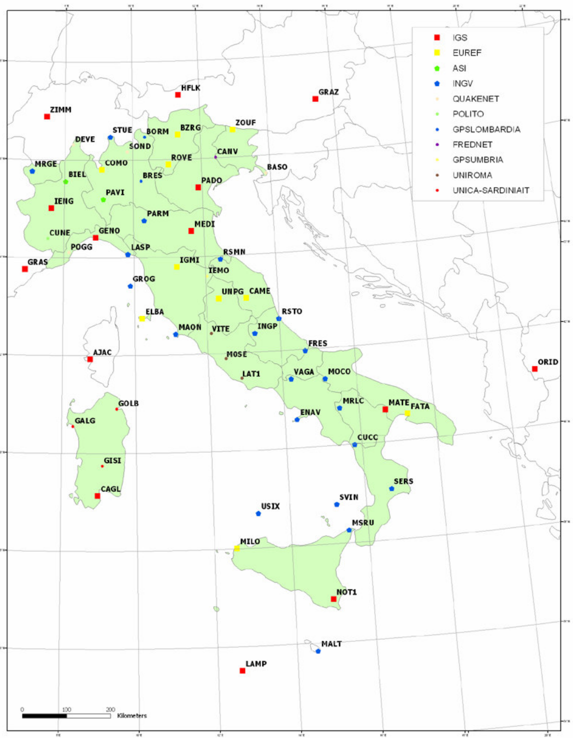

Figure 2 - The test network. The red squares represent IGS stations, constrained in the adjustment.

The data pre-processing has been done using NetDownload and RegNet programs, which allow to completely automate the elaboration and the results analysis. A detailed description of Netdownload is available at the software section of http://antartica60.spaces.live.com/; for a detailed description of the RegNet software, refer to (Biagi et al., 2007). In short, NetDownload manages the download of data, orbits and solutions from IGS FTP sites, propagates a priori coordinates for IGS stations, prepares BSW5.0 campaigns, put the data in the proper directories; it allows also to check some quality parameters and to create summary reports. The main functions of RegNet is to extract a series of quality indexes from BSW5.0 outputs, to create the relevant statistics at the end of the adjustment and to compare them with thresholds values. Among them, the indexes and statistics which are analyzed in the following are:

1. for each station, data presence and gaps (RXOBV3 output);
2. the receiver clocks modeling: for each station, the RMS's of single station ionospheric free code elaboration (CODSPP output);
3. the preliminary ionospheric free float solution, in single base approach: for each baseline, the number of initial ambiguities and the RMS of the solution (GPSEST, 1^{st} output);
4. the ambiguity fixing, by the QIF, in single base approach: for each baseline, the percentage of fixed ambiguities and the RMS (GPSEST, 2^{nd} output);
5. the final, multibase, daily RMS (GPSEST, 3^{rt} output); moreover, a comparison between the daily solutions and their linear interpolations, both for IGS and test network stations.

Different elaboration choices, principally related to the data quality control, have been tested; this allows to assess the relevant sensitivity of the final estimates. Particularly the following results will be here discussed:

1. a first adjustment approach, called *No outliers Rejection*: as the name suggest, the relevant results are those obtained by the adjustment of all downloaded data, without applying any data rejection based on the quality indexes: this approach was used to identify the significant quality indexes and the possible warning thresholds;
2. in the second approach, called *Outliers Rejection*, a first criterion of data rejection has been applied and evaluated, based on the results obtained in the first adjustment and previous studies;
3. both in the first and the second approach the IGS coordinates have been stochastically constrained with variances of 2 and 4 mm, respectively in horizontal and height: a third adjustment has been performed, to evaluate the effects introduced by a more restrictive constraining.

5.1 No outliers rejection approach

Data presence. The data availability (Tab. 1) has been the first indicator analyzed. Four stations (DEVE, FATA, POGG and VITE) initially candidates for the test network have never been available in the considered period, maybe due to temporary station hardware failures, or to data servers unavailability. In 80% of the days at least the 80% of stations are present; however, and this is not satisfying, in none of the days, at least 90% of available stations is present. Data absence is typically due to long data transmission problems: these problems can be easily overcome by adopting a posteriori data download instead of real time reconstruction.
CODSPP outputs. For ionospheric free codes positioning in modern receivers, typically RMS's of about 1 m with small deviations are expected; generally, worse values are due to problems with some satellite, local effects like multipath and incomplete sessions. Only 15 of about 4500 daily RINEX files present very anomalous code RMS's, of the order of dozens of meters (Tab. 2): these problems are discussed in Sect. 5.2, while all the other values are quite satisfactory.
GPSEST, 1^{st}. The success of the cycle slips estimation process can be directly evaluated by the final number of initial ambiguities (Tab. 3, Fig. 3); large values could indicate serious problems in the data: for the baselines of a network like this one, a reasonable threshold of 200 can be chosen. On this respect, in our case the worse baselines are those involving the MATE station: this is probably due to some station problem in the considered period. The smallest values after GPSW 1414 are due to incomplete files that in most cases regard the IEMO station.
GPSEST, 2^{nd}. The percentage of success of the ambiguities fixing process (QIF) is shown in Tab. 4 and Fig. 4. The mean percentage is near 85%, with a visible decrease after GPSW 1414; several days present 0% fix-

ing success: typically, these are consequences of incomplete sessions, in this case particularly related to the GOLB station. Also the ambiguities fixing RMS's series (Tab. 5, Fig. 5) presents two clearly different periods: the first one is quite good even for the worst baselines; in the second half the maxima reaches very bad values, denoting some fixing error, particularly related to AJAC-GOLB baseline.

GPSEST, 3rd. The daily final RMS's (Fig. 6) give an overall final quality index of the adjustment process. In general, the series assumes satisfying values; just two days show anomalous statistics, corresponding to high ambiguities fixing RMS's.

Final coordinate time series. To evaluate the dispersion of the daily time series, the coordinates have been linearly interpolated and their residuals have been analyzed: IGS and test network residuals have been separately handled. IGS residuals (in Fig. 7 their moduli, in Tab. 12 separated by horizontal and height components) are not uniform and, considering the stochastic constraints applied, show unsatisfactory statistics: on this regard, the worst residuals concern GRAS, with a maximum of about 7 cm. Test network residuals show the already mentioned worsening after GPSW 1414 (in Fig. 8 their moduli, in Tab. 13 separated by horizontal and height components), with standard deviations of about 5 cm, and 3 outliers greater than 1 m, involving IEMO and RSMN. As for previous problems, all the anomalous results are relevant to files with significant data gaps.

Presence	# of days	% of days
70%	91	100%
75%	90	99%
80%	75	82%
82%	52	57%
84%	29	32%
86%	16	18%
88%	8	9%
90%	0	0%

Table 1 – Data presence. Presence: percentage of present stations; # and % of days: number and percentage of days that fulfil the above presence percentage.

RMS iono-free code (m)	RINEX files		Daily maximum	
	#	%	#	%
RMS ≤ 1	1197	27%	0	0%
1 < RMS ≤ 2	3242	72%	65	71%
2 < RMS ≤ 3	14	0.3%	11	12%
3 < RMS ≤ 4	5	0.1%	1	1.1%
4 < RMS ≤ 10	0	0.0%	0	0.0%
10 < RMS ≤ 100	7	0.2%	7	7.7%
100 < RMS	8	0.2%	7	7.7%

Table 2 - Ionospheric free code RMS's distribution. RINEX files, # and %: number and percentage of files. Daily maximum, # and %: number and percentage of days whose maximum RMS is in the range.

Baseline	Med	E	Min	Max	σ	# days
BORM-SOND	90	89	78	96	3	91/91
COMO-SOND	92	91	80	102	3	91/91
MATE-ORID	110	156	44	544	118	64/91
MATE-MRLC	104	157	94	552	117	84/91
ALL (146 baselines)	108	110	10	566	36	91/91

Table 3 - Daily number of initial ambiguities of the 2 best and 2 worst baselines; general statistics on all the baselines. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation; # days: number of considered days.

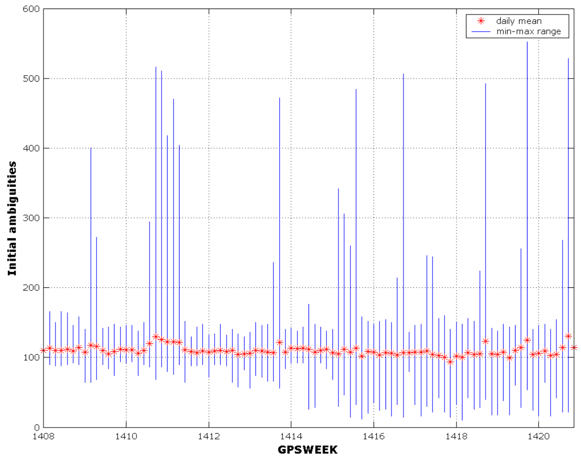

Figure 3 - Daily number of initial ambiguities. Dots: daily mean values; bars: daily minimum-maximum ranges.

Baseline	Med	E	Min	Max	σ	# days
BORM-SOND	98	97	89	100	2	91/91
COMO-SOND	97	96	91	100	2	91/91
FRES-VAGA	71	71	57	79	4	91/91
MILO-USIX	67	67	54	78	5	81/91
ALL (146 baselines)	87	85	0	100	10	91/91

Table 4 – Daily percentages of fixed ambiguities of the 2 best and 2 worst baselines; general statistics on all the baselines. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation; # days: number of considered days.

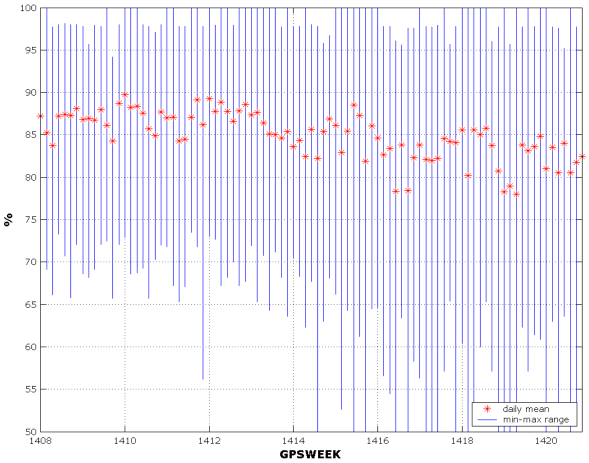

Figure 4 - Daily percentage of fixed ambiguities. Dots: daily mean values; bars: daily minimum-maximum ranges (values below 50% out of scale).

Baseline	Med	E	Min	Max	σ	# days
BZRG-HFLK	0.8	0.9	0.8	1.1	0.1	90/91
BRES-SOND	0.8	0.9	0.7	1.3	0.1	90/91
CUNE-IENG	1.8	2.2	1.7	24.9	2.9	64/91
AJAC-ELBA	2.0	2.4	0.9	5.9	1.5	69/91
ALL (146 baselines)	1.1	1.2	0.5	25.0	0.6	91/91

Table 5 – Daily ambiguities fixing RMS's of the 2 best and 2 worst baselines; general statistics on all the baselines. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation; # days: number of considered days. Values in mm.

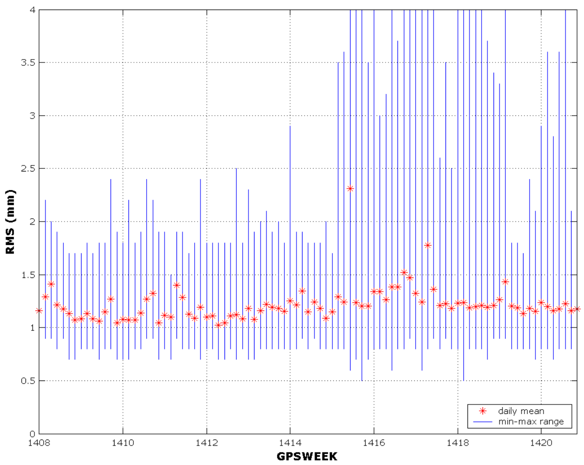

Figure 5 - Daily ambiguities fixing RMS's. Dots: daily mean values; bars: daily minimum-maximum ranges (values above 4 mm out of scale).

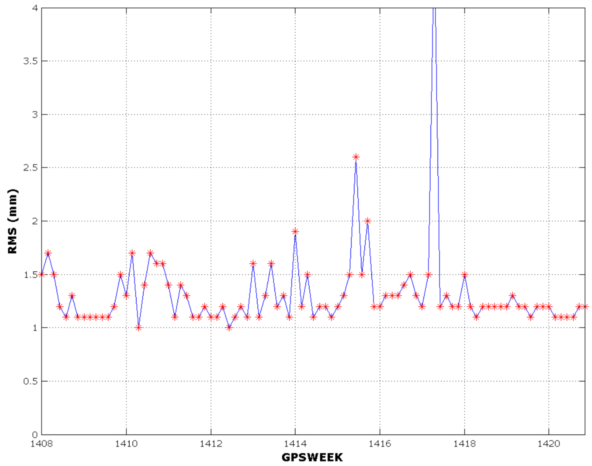

Figure 6 - Daily RMS's of the final multibase adjustment. Mean: 1.3 mm; minimum: 1.0 mm; maximum: 4.8 mm; standard deviation: 0.4 mm.

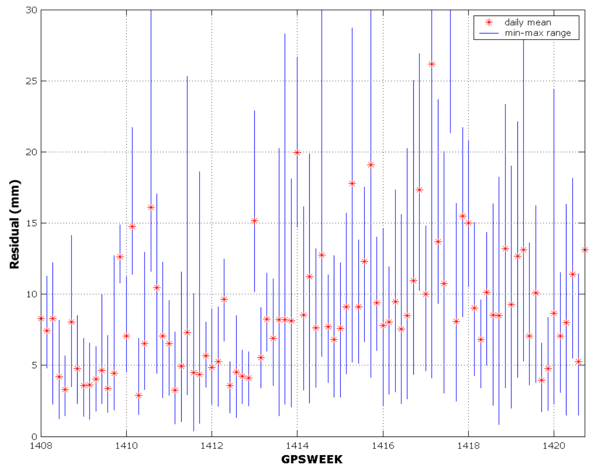

Figure 7 - Daily IGS residuals. Dots: mean values; bars: minimum-maximum ranges (values upon 30 mm out of scale). Mean: 9.1 mm; minimum: 0.4 mm; maximum: 68.6 mm; standard deviation: 6.6 mm.

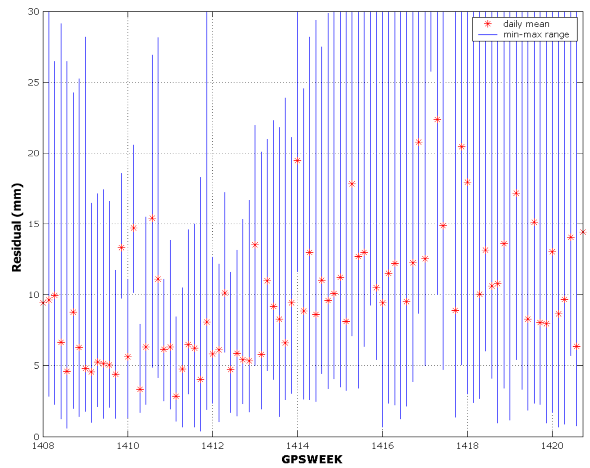

Figure 8 - Daily test network residuals. Dots: mean values; bars: minimum-maximum ranges (values upon 30 mm out of scale). Mean: 13 mm; minimum: 0.4 mm; maximum: 1.6 m; standard deviation: 50 mm.

5.2 Outliers rejection approach

By analyzing the previous results, data gaps typically cause problems in the final results; furthermore, also high code RMS's seems to anticipate bad results. To confirm this impression, a simple and in some way arbitrary, first outliers rejection criterion has been applied, by excluding RINEX files with:

- less than 23 hours of data (2760 over 2880 epochs/day);
- ionospheric free code RMS's greater than 4 meters.

Then, a complete network reprocessing has been carried out.

Data presence. The sessions screening result is shown in Tab. 6; IEMO is the worst station, with 83% of excluded sessions. Globally, the data presence check excludes 284 of 4469 files, i. e. the 6.3%.

Bad code RMS's. The exclusion involves 15 files of 3 stations: 2 of them are IGS (Tab. 7). The most interesting case is provided by IENG: its typical behavior in a problematic day is shown in Fig. 9: normally, the data do not show particular problems, with RMS's of about 1 m; however, at some epochs, the receiver residuals are of some km on all the satellites: probably the problem is due to a malfunction of the external clock connected to the receiver and obviously it could also influence phase data quality: to the authors knowledge, now IENG problems have been completely solved. MATE and CUNE problems are sporadic and not really significant.

GPSEST, 1st. After outliers rejection, the initial ambiguities number improves a little (Tab. 8, Fig. 10 vs. Fig 3): several peaks disappear as well as the smallest values, which were due to the incomplete sessions; the mean value obviously rises, but the standard deviation decreases.

GPSEST, 2st. The minimum percentages of success in ambiguities fixing improve; particularly, all the statistics change significantly after GPSW1414 (Tab. 9, Fig. 11 vs. Fig. 4); ambiguities fixing RMS's (Tab. 10, Fig. 12 vs. Fig. 5) are subject to great improvements: all the worst values disappear and the standard deviation lowers significantly.

GPSEST, 3st. Also RMS's of the final adjustment (Tab. 11, Fig. 13 vs. Fig. 6) improve, both in term of anomalous values and standard deviations of the time series. IGS PS's residuals improve, with particular regard to maximum residuals (Tab. 12, Fig. 14 vs. Fig. 7); test network coordinates improve with very good results: all the main outliers are eliminated and the standard deviation lowers of one order of magnitude (Tab. 13, Fig. 15 vs. Fig. 8). This outlier rejection approach has proved very effective to solve all the main problems: more investigations will be performed to automate the identification of smaller problems.

	Files			Files			Files	
PS	**#**	**%**	**PS**	**#**	**%**	**PS**	**#**	**%**
IEMO	38/46	83	M0SE	6/87	6.9	GOLB	1/45	2.2
ZOUF	48/89	54	ENAV	5/73	6.8	USIX	1/83	1.2
IGMI	23/70	33	MALT	6/89	6.7	MILO	1/90	1.1
CAME	22/82	27	BRES	4/91	4.4	MRGE	1/91	1.1
GISI	6/40	15	MSRU	3/86	3.5	BORM	1/91	1.1
CUNE	6/66	9.1	GALG	1/44	2.3			
UNPG	7/87	8.0	RSMN	2/91	2.2			

Table 6 – PS's, number and percentage of excluded files (note: % computed with respect to existing files).

	Files			Files			Files	
PS	**#**	**%**	**PS**	**#**	**%**	**PS**	**#**	**%**
IENG	9/73	12	MATE	5/81	6.2	CUNE	1/66	1.5

Table 7 – PS's, number and percentage of the bad code RMS files.

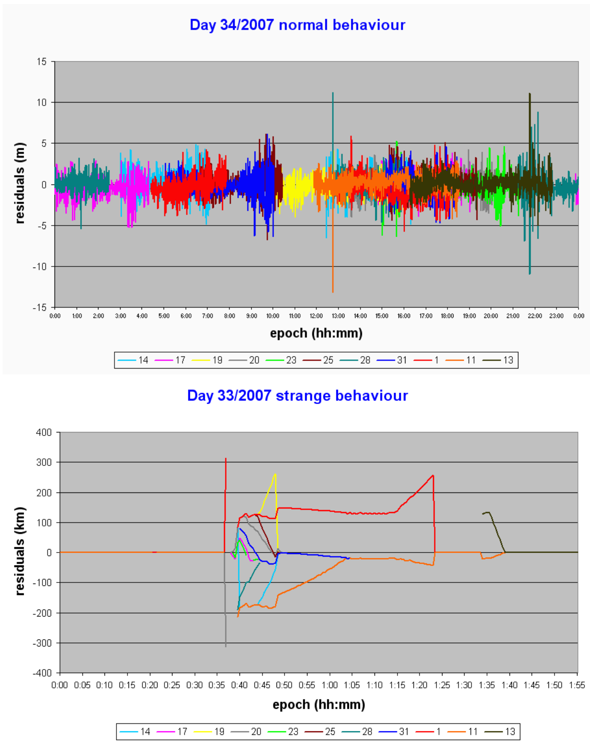

Figure 9 – Ionospheric free code RMS's of IENG. Upper: in normal conditions they are of the order of few meters. Lower: in some cases they present unexpected behaviour.

	No rejection	Rejection
Med	108	108
E	110	111
σ	36	28
Min	10	78
Max	566	552

Table 8 - Differences of the daily number of initial ambiguities. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation.

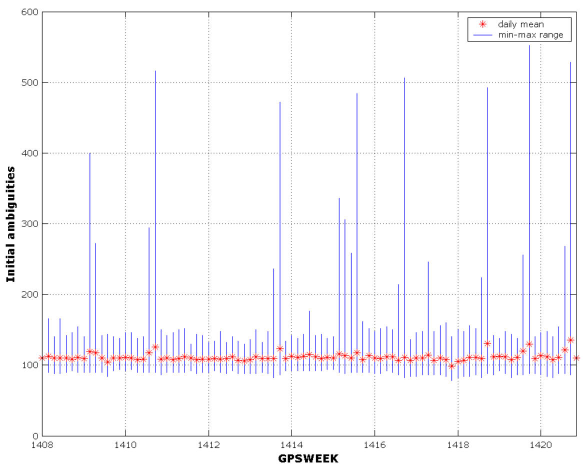

Figure 10 - Daily number of initial ambiguities after outliers rejection. Dots: mean values; bars: minimum-maximum ranges.

	No rejection	Rejection
Med	87	87
E	85	86
σ	10	8
Min	0	52
Max	100	100

Table 9 - Differences of the daily percentages of fixed ambiguities. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation.

Figure 11 - Daily percentage of fixed ambiguities after outliers rejection. Dots: mean values; bars: minimum-maximum ranges.

	No rejection	Rejection
Med	1.1	1.1
E	1.2	1.1
σ	0.6	0.2
Min	0.5	0.7
Max	25	3.2

Table 10 – Differences of the daily ambiguities fixing RMS's. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm.

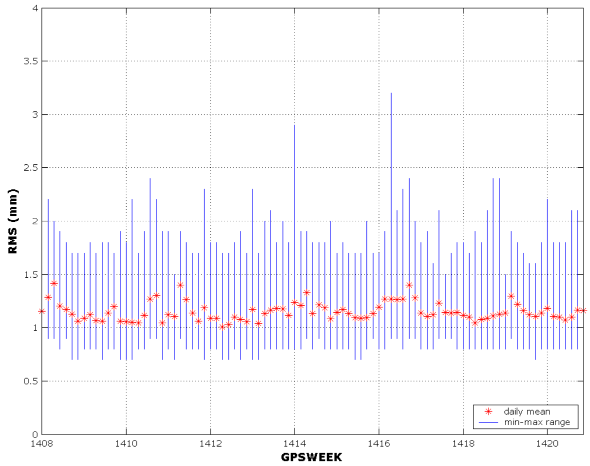

Figure 12 - Daily ambiguities fixing RMS's after outliers rejection. Dots: mean values; bars: minimum-maximum ranges.

	No rejection	Rejection
Med	1.2	1.2
E	1.3	1.3
σ	0.4	0.2
Min	1.0	1.0
Max	4.8	1.9

Tab. 11 - Differences of the daily final multibase RMS's. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm.

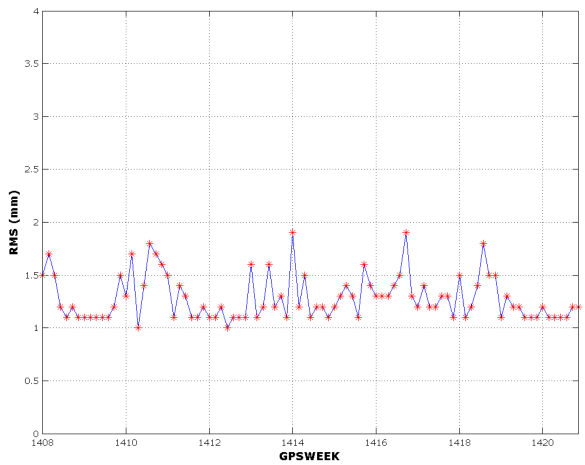

Figure 13 - Daily final multibase RMS's after outliers rejection.

	No rejection			Rejection		
Height	East	North	Height	East	North	Height
E	0.0	0.0	0.0	0.0	0.0	0.0
σ	5.3	3.7	9.2	3.7	3.2	6.2
Min	-67.4	-20.9	-36.4	-17.7	-20.4	-24.6
Max	15.8	40.7	68.6	16.2	44.6	45.1

Table 12 - Differences of the daily IGS residuals: East, North and height components. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm.

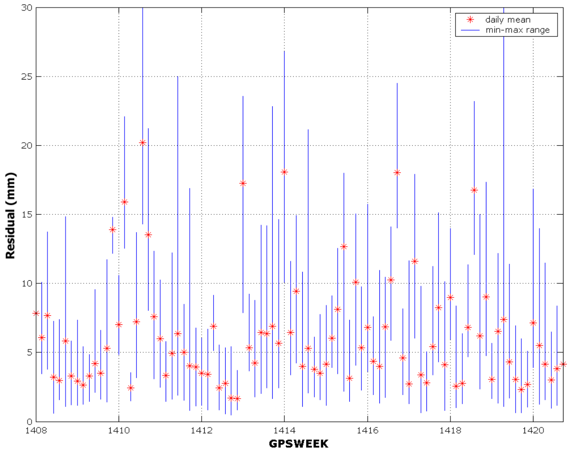

Figure 14 - Daily IGS residuals after outliers rejection. Red circles: mean values; blue bars: minimum-maximum ranges (values upon 30 mm out of scale).

	No rejection			**Rejection**		
Height	East	North	Height	East	North	Height
E	0.0	0.0	0.0	0.0	0.0	0.0
σ	26.4	23.5	37.8	3.5	3.2	6.1
Min	-364.7	-175.0	-1391.7	-18.6	-14.3	-62.1
Max	1210.7	1360.2	1649.3	15.6	26.7	63.0

Table 13 - Differences of the daily test network residuals: East, North and height components. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm.

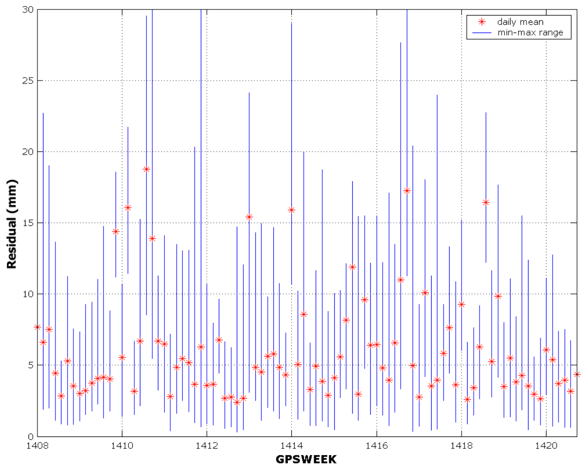

Figure 15 – Test network residuals after outliers rejection. Red circles: mean values; blue bars: minimum-maximum ranges (values upon 30 mm out of scale).

Hard constraints approach

The standard deviations attributed to IGS constraints in both the previous adjustments were chosen on the basis of common sense criteria: indeed it is well known that the formal variances published with the coordinates are typically unrealistic and underestimated. In this regard, one more adjustment has been performed in order to analyze the sensitivity of final results to the weights attributed to the constraints; particularly, a new final solution has been computed by assigning to the constraints very small standard deviations: 0.2 and 0.4 mm, respectively in horizontal and height. As expected, IGS residuals (Tab. 14, Figg. 16, 17) improve significantly; the test network horizontal residuals improvement (Tab. 15, Figg. 18, 19) is significant, while the effect on height is smaller. Starting from the time series, initial coordinates and velocities have been also estimated by linear regression (for example, Fig. 20), and then compared (Tab. 16): the initial coordinates differences involved by different constraining approaches are always smaller than 1 mm, and just one bias in height of 1 mm exist; velocities differences are always smaller than 0.03 mm/y. On the basis of these statistics, the final results are not very sensitive to the constraining choices.

	Rejection			**Hard constraints**		
Height	East	North	Height	East	North	Height
E	0.0	0.0	0.0	0.0	0.0	0.0
σ	3.7	3.2	6.2	1.6	1.2	2.6
Min	-17.7	-20.4	-24.6	-10.2	-10.3	-18.9
Max	16.2	44.6	45.1	5.3	22.3	22.8

Table 14 - Differences of the daily IGS residuals: East, North and height components. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm.

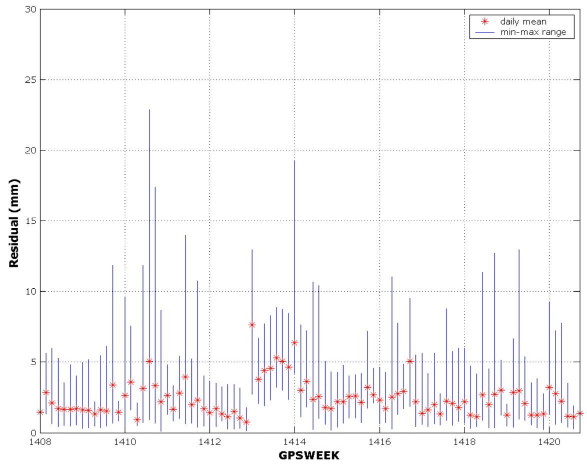

Figure 16 - Daily IGS residuals with hard constraints. Red circles: mean values; blue bars: minimum-maximum ranges (values upon 30 mm out of scale).

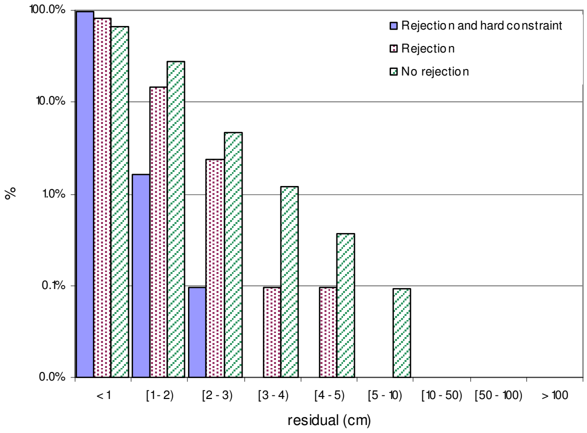

Figure 17 - IGS residuals distribution (y logarithmic scale).

	Rejection			Hard constraints		
	East	North	Height	East	North	Height
E	0.0	0.0	0.0	0.0	0.0	0.0
σ	3.5	3.2	6.1	1.6	1.7	4.9
Min	-18.6	-14.3	-62.1	-11.5	-8.8	-64.2
Max	15.6	26.7	63.0	11.2	27.6	65.0

Table 15 - Differences of the daily test network residuals: East, North and height components. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm.

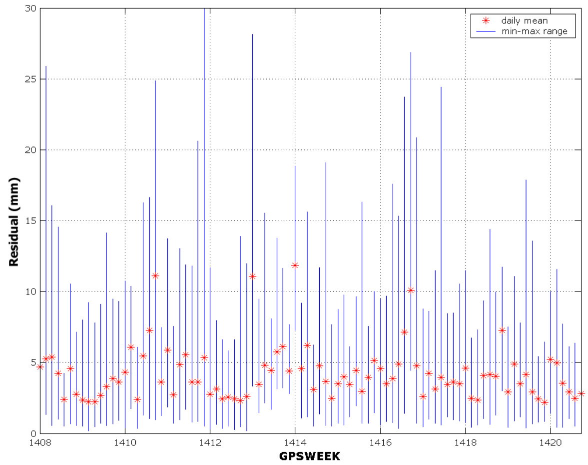

Figure 18 – Test network residuals with hard constraints. Red circles: mean values; blue bars: minimum-maximum ranges (values upon 30 mm out of scale).

		Rejection/Hard constraints		
		East	North	Height
C	E	0.3	0.2	-0.9
o	σ	0.2	0.2	0.1
o	Min	-0.3	-0.2	-1.2
	Max	1.0	0.5	-0.7
V	E	0.02	-0.02	0.02
e	σ	0.00	0.00	0.01
l	Min	0.00	-0.03	-0.00
	Max	0.02	-0.02	0.03

Table 16 – Differences in coordinates and velocities estimates. Med: median; E: mean; Min: minimum; Max: maximum; σ: standard deviation. Values in mm for coordinates, mm/y for velocities.

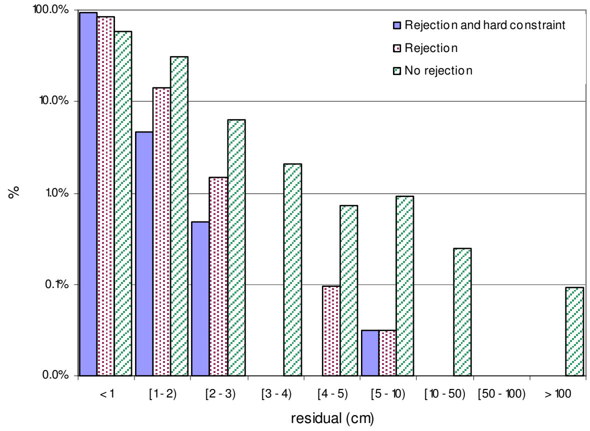

Figure 19 – Test network residuals distribution (y logarithmic scale).

Conclusions

In the Italian framework, the establishment of a zero order permanent network is considered as necessary to allow a common adjustment of local positioning services and the transition of the Italian cartographic reference frame from the static IGM95 to a continuously monitored ETRF. It implies minimal hardware costs, because enough and well distributed permanent stations already exist in Italy, whose data could be available to the users community for free.

In order to perform a numerical experiment, a test network has been selected and processed for the first three months of 2007. In the test, a complete package to automate all the data processing, based on BSW5.0, has been used; particularly important, the package allows the extraction of quality indexes from BSW5.0 outputs and the rejection of data not compliant with assigned thresholds.

As concerns the test network, its spatial distribution is not optimal and reflects the station presence in Italy at the experiment epoch: however, the aim was exactly to perform a test and not to define a final zero order PN; in the last months, new stations have been realized in areas once lacking and a better, optimal, configuration is already possible. Some problems exist in data integrity check: particularly, significant files losses and data gaps are experienced by some stations. Most of these

problems concern the stations whose RINEX files are reconstructed from RTCM streams: obviously this practice must be banned in a final configuration and this is the only major technical upgrade needed to guarantee data continuity and quality. A first file rejection criterion based on the presence of significant data gaps or high codes RMS's has been applied: this first, simple, approach has proved very effective to solve all the main problems present in the final results: more investigations will be performed to automate the identification of smaller problems.
The establishment and monitoring in IGS of a zero order PN should be accompanied by the definition of the transformation between IGS and national cartographic (ETRS89) RF's. In this respect, just some suggestion has been proposed: no test have been performed, because this topic has been preliminarily discussed in a quoted paper, and deeper analyses are in progress.
The test network results clearly prove the feasibility of the zero order PN, with sustainable costs at the national scale. Obviously, the establishment of the zero order PN implies also its continuous monitoring and this requires the employment of trained technicians; finally, it should be accompanied by the institution of a national geodetic authority, that controls the zero order PN results and checks the consistency of the coordinates distributed by the local positioning services.

Acknowledgements

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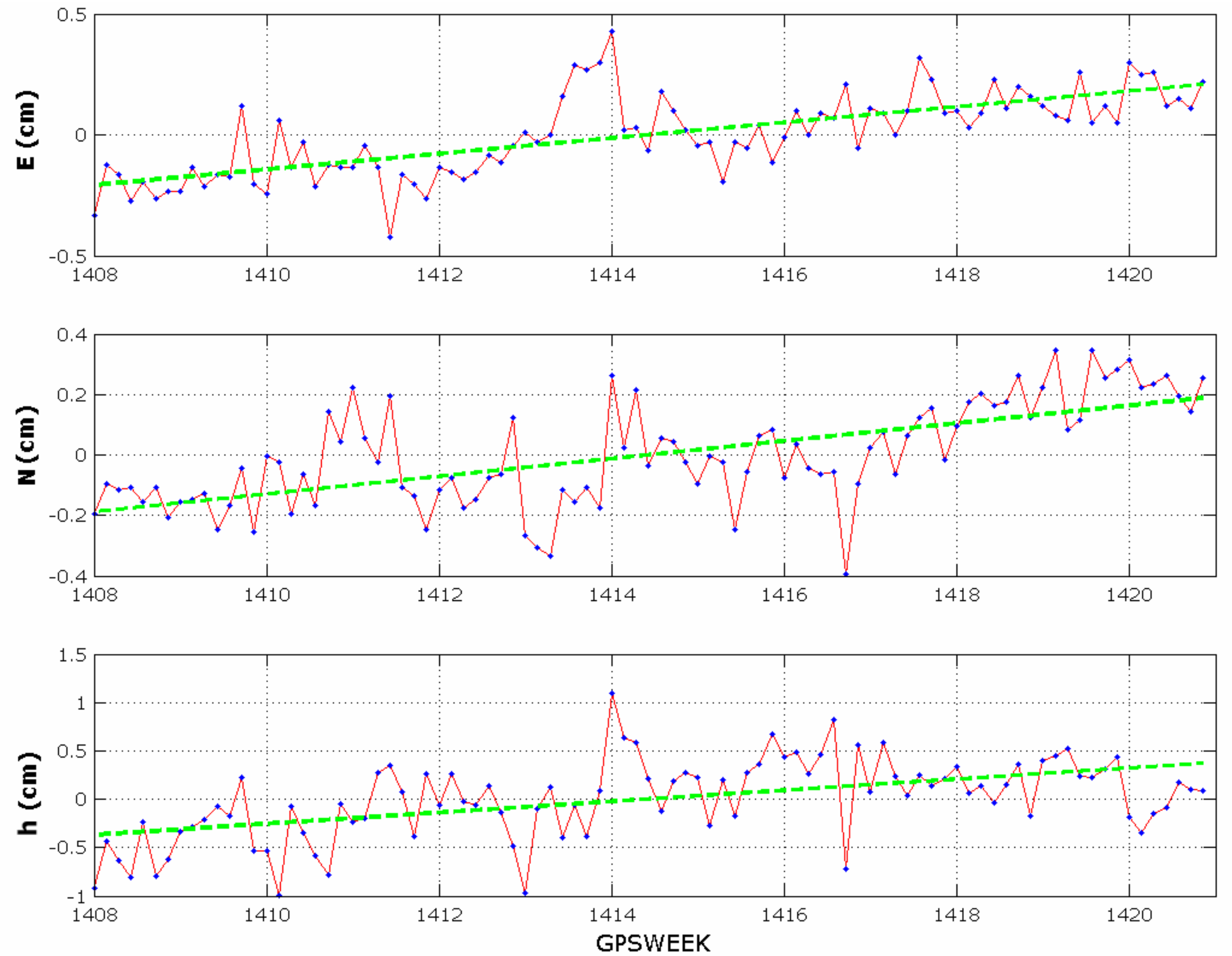

Figure 20 – Example of final coordinates time series: COMO.