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The new Italian geodetic reference network (RDN): a comparison of solutions using different software packages

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ABSTRACT

In 2009, the IGMI (Italian Geographic Military Institute) defined a new geodetic reference frame (ETRF2000) based on the new Italian geodetic reference frame RDN (Rete Dinamica Nazionale), a network consisting of about 100 permanent GNSS stations homogeneously distributed throughout the Italian peninsula. A key characteristic of the RDN network is its dynamic nature: the coordinates of the GNSS stations will be computed periodically to take into account the natural changes of the crustal surface. To date, a first computation of the RDN has been implemented during January 2009 by the IGMI using a dataset of 28 Julian Days and the Bernese scientific software. For the validation of the network, other Analysis Centers have been involved in the computation using the same software. One of these Analysis Centers is the Dept. DISTART (University of Bologna) that for this computation has used tree different software packages. This paper presents data-processing results for the same dataset (kindly provided by the IGMI) obtained using Gipsy-Oasis II, Bernese V.5.0 and Gamit-Globk software packages. In order to be aligned with the EUREF guidelines for network densifications an harmonization of the ancillary products and options has been necessary. For the results comparison, some statistical parameters derived by the solutions have been considered.
The first comparison has been performed between the Bernese solution of IGMI and the DISTART Dept. one: the differences are at millimeter level. Concerning the comparison of solutions derived by different software packages a very good agreement (at millimeter level) between Bernese and Gamit has been found. Gipsy solution, obtained in PPP and without any ambiguity resolution, presents an slightly higher scattering (but still at millimeter level) than others two.

Key words: GPS, network densification

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1. Introduction

In 2008, the IGMI (Istituto Geografico Militare Italiano), the authority for the definition and maintenance of the Italian Geodetic Reference Frame, decided to define a new national reference frame based on a network of permanent GPS stations. This network is called RDN (Rete Dinamica Nazionale).
RDN consists of 85 stations homogeneously distributed throughout the Italian peninsula and selected by IGMI (http://87.30.244.175/rdn/rdn.php) from among existing stations installed and maintained by public institutions (such as ASI, INGV, Universities and high schools) and many private companies (Figure 1).
To define the reference frame, a dataset of 28 days (from December 23, 2007 to January 19, 2008) was chosen. To frame this network into the EUREF reference frame, computations were performed considering 13 permanent stations of the European Permanent Network (EPN) and particularly (CAGL, GENO, GRAS, GRAZ, IENG, LAMP, MATE, MEDI, NOT1, PADO, SOFI, WTZR, ZIMM) that are located on the Italian peninsula or on the adjacent regions.
To officially define the RDN network as a densification of the EUREF reference frame, certain a priori procedures defined by the EUREF TWG (Technical Working Group) are mandatory. In particular, the network computation must be performed by different Analysis Centers and must satisfy certain data processing constraints published on the EUREF web page (http://www.euref-iag.net/).
The IGMI has performed the first official computation of the RDN using the Bernese Software Version 5.0 (BSW50; Dach et al., 2007). Two other Analysis Centers (the University of Padua and Polytechnic of Milan) have computed independent solutions of the network based on identical input data and the same scientific software.
A third analysis center (a research group of the Dept. DISTART of the University of Bologna) is responsible for processing the same data set using two different scientific software packages: Gamit/Globk Version 10.34 (Herring et al., 2006a, Herring et al., 2006b) and Gipsy-Oasis II Version 5.1 (Zumberge et al., 1997). This research group has also used the Bernese software, following an internal procedure designed to compute a network using additional software systems (Barbarella et al., 2009).
The choice to use multiple software pachages has previously been applied in geodetic infrastructures (e.g., Craymer, Piraszewski, 2001; Jivall et al., 2005) and for tectonic or geodynamic purposes (e.g., Dietrich et al., 2001; Even-Tzur et al., 2004; Geirsson et al., 2006; Kierulf et al., 2008, 2009; Simons et al., 1999; Teferle et al., 2008; Zakarevičius et al., 2008, Zanutta et al., 2008, Capra et al., 2008). Although it requires

much time and work, the use of multiple software systems is considered important for their ability to provide a quality check of the solutions, to identify any gross errors and to reduce, through averaging, any residual effect of software noise that may appear in the individual solutions.

The availability of different solutions for the same dataset derived from different software packages (in some cases using different approaches) also permits us to evaluate the performances and the peculiarities of each software system or strategy.

This study describes the database preparation procedures and the strategies for processing the whole dataset that have been adopted to evaluate the RDN coordinates. An assessment of the quality of each solution and a comparison of the results are presented.

2. Data set

The RDN observations were provided by the IGMI, whereas the IGS/EUREF stations used for datum definition were obtained from the IGS archives. The network, which consists of a total of 98 stations (85 belonging to the RDN network and 13 from IGS/EUREF) with a 30-second sampling rate across 28 days of observation, is characterized by a mean baseline length between 100 and 150 kilometers, excluding some reference stations located outside of Italy and the connection to Sardinia island.

The first step of this study was to implement an automatic procedure designed to prepare the dataset for analysis in multiple software packages, starting from the original format of the data files that was in RINEX format but not all the headers were correctly full filled.

The daily observations from each station were transformed into the standard RINEX format (Ver. 2.1). Starting from this data set, a global check of the RINEX file headers (station name, offset, antenna and receiver names and types) was performed. Statistics concerning the dataset consistency were produced.

In addition to ensure that only files with good consistency of data were processed, files with less than 12 hours of observations were excluded from the dataset. Thirty-eight RINEX files (about 1.4%) were discarded and not considered in further data processing.

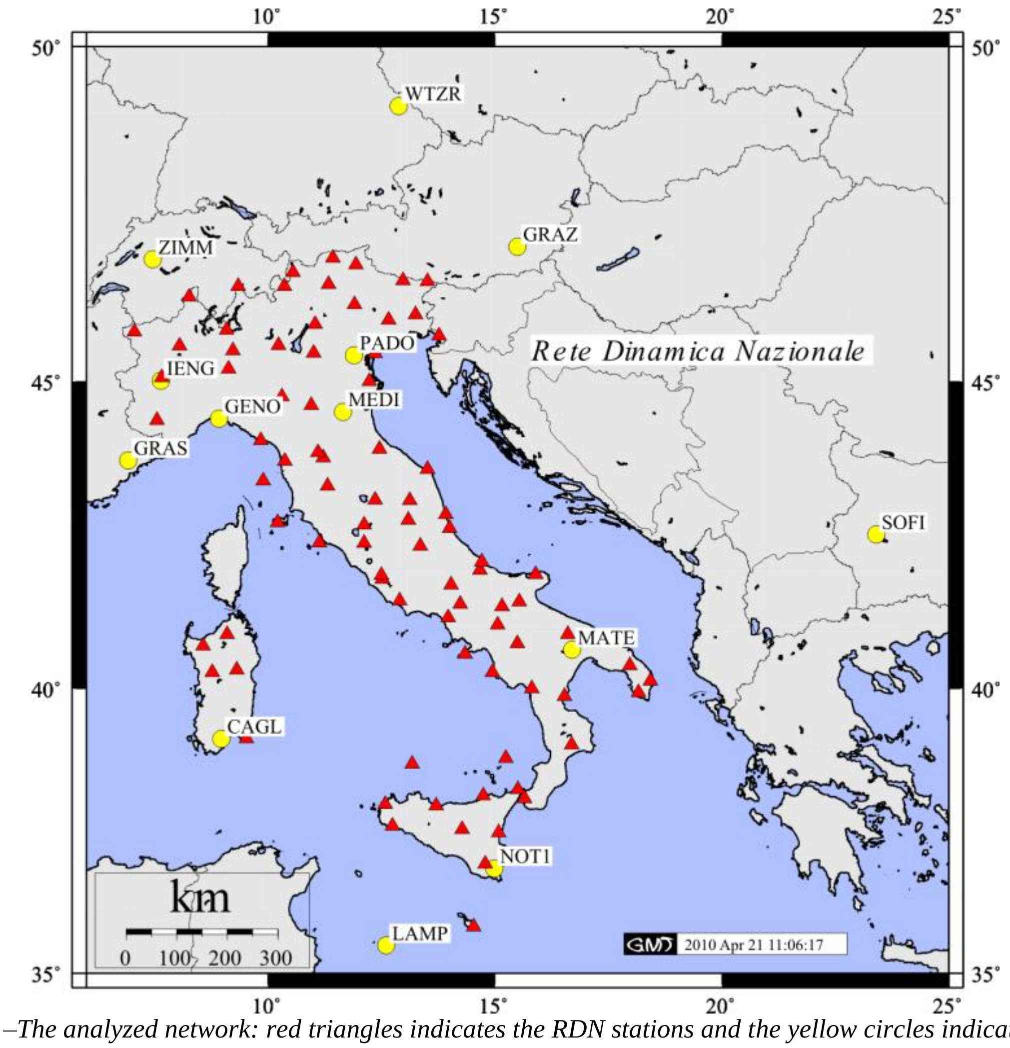


Figure 1 –The analyzed network: red triangles indicates the RDN stations and the yellow circles indicate the EPN EUREF stations used as reference stations

3. Data processing and software description strategy

As previously mentioned, three scientific software systems were adopted for the computation of the network: Bernese Version 5.0 (BSW50; Dach et al., 2007) and Gamit/Globk Version 10.34 (Herring et al., 2006a), both of which are based on a classical double-difference approach, and Gipsy-Oasis II Version 5.1 (Zumberge et al., 1997), which is based on an un-differenced approach. As the primary aim of this study was to define the new Italian reference frame and because the RDN constitutes a densification of the EPN network, the EUREF guidelines for densification networks (published on the EUREF web page ftp://epncb.oma.be/pub/general/Guidelines_for_EUREF_Densifications.pdf) were followed. These guidelines consist of a list of indications that cover all phases of data processing. In particular, the guidelines suggest using a data-processing strategy based on a differenced approach. Moreover, some constraints are considered mandatory while others are recommended which are reported in table 1 and 2. Some of the more important recommendations of the EUREF guidelines are to adopt the final IGS products, to introduce ocean-loading corrections for the stations, to use a 10° elevation cutoff angle and elevation-dependent weighting of observations, to adopt the Niell Mapping Function (NMF; Niell, 1996) and to map the tropospheric delay in the zenith direction. Furthermore, EUREF suggests that station-specific troposphere parameters should be estimated hourly and that the initial phase ambiguities should be fixed to integer values. Not all of the recommended indications were followed for the Precise Point Positioning (PPP) solution. In particular, the ambiguity has not yet been resolved but IGS products (orbits and antenna phase calibration) have been used. For the BSW50 and Gamit/Globk methods, after automated data processing, the phase observations were double-differenced (King & Bock 2000), and loosely constrained daily solutions were computed and then aligned into the ITRF2005 reference frame using a Helmert Transformation estimating the parameters using the EPN permanent stations indicated with circles in Figure 1 (Altamimi et al., 2007).

An important characteristic of BSW5.0 is its ability to perform multi-baseline daily solutions of a network without intrinsic limits on the number of points and with different approaches to the baseline definition.

For the Gamit/Globk solution, due to the limited number of stations that could be included in a single network (99 sites), a distributed procedure analysis (Dong et al., 1998) was applied for the network computation. The stations were subdivided into two regional sub-networks with thirteen common IGS/EUREF stations. The GLOBK software combined the solutions of each sub-network using the IGS coordinates and velocities of the 13 common sites. Afterward, loosely constrained daily solutions of the complete network were computed and then aligned into the ITRF2005 reference frame using the coordinates and velocities of the previous 13 sites.

Gipsy-Oasis II was used in the PPP mode (Kouba & Heroux, 2000). Implementation of a script in the Perl language permitted a completely automated process in which the entire dataset of RINEX files was split into four different threads. This script did not use yet any ambiguity resolution procedure (such as Ambigon or Ambizap) and could not permit a posteriori applications. However, an upgrade of the procedure is under construction for future tests and will consider the Ambiguity resolution using the Ambizap approach (Blewitt, 2008). The PPP approach (without ambiguity resolution) was adopted because of its great flexibility. Using this approach, it is possible to process one station separately from the others if necessary. This feature allowed us to reprocess a station affected by some gross mistake in the definition phase of some parameters, such as antenna height or antenna type. At the end of PPP processing, the resulting daily network coordinates were transformed using a seven-parameter transformation with the IGS stations as reference and the *stacov2x* Gipsy script.

Parameters or models	**Value**	**From GPS WEEK**	**To GPS WEEK**
Antenna Phase Center Corrections	Specification: Use elevation dependent phase center correction values adopted by IGS.	860	
Observation Cut Off Angle	10°	1130	
Observation Weighting	Apply elevation dependent weighting to the observations. AC's which cannot use an elevation dependent weighting scheme are advised to continue using a 15° el. cut off angle	1130	
GPS Satellite Orbits	Use IGS or CODE orbits	860	1129
GPS Satellite Orbits	IGS Final Orbits.	1130	
Orbits and Earth Orientation Parameter Consistency	GPS satellite orbits and earth orientation parameters have to be consistent.	860	
Tidal Displacements	Apply ocean loading corrections for the stations	1130	
Troposphere MF	Niell Mapping Function	1130	

Table 1 – Mandatory parameters and models adopted for densification specification of EUREF TWG.

Parameters or models	Value	From GPS WEEK	To GPS WEEK
Ambiguity fixing	Fix the ambiguities in the final solution.	860	
Observation Cut Off Angle	15°	860	1129
Observation Sampling Rate	Use an observation sampling rate of 180 sec for the final parameter estimation.	860	
RMS in SINEX files	Specification: If you use Bernese GPS Software include the RMS of unit weight, number of unknowns and number of observations in weekly SINEX file generation.	1130	
Number of Troposphere Parameters	Estimate one troposphere parameter for every 2 hours for each station.	860	1129
Number of Troposphere Parameters	Estimate hourly troposphere parameters for each station. This option is mandatory for ACs contributing to the Troposphere Special Project	1130	
Troposphere Parameter Reference	Specification: Save the estimated troposphere parameters in the daily normal equation files. Generate a weekly coordinate solution. Re-generate the daily troposphere parameter solutions with fixing the weekly coordinates (coordinate "re-substitution").	1130	
Global Troposphere Parameters	Specification: Introduce the troposphere parameter estimates of the global network solution as a-priori values.	1130	
Global Troposphere Parameters	No introduction of global troposphere parameter estimates (delete version A of this option).	1130	
A Priori Weight of Troposphere Parameters	Specification: Use 10 cm respect. 5 m a priori weight for the absolute respect. Relative parameters.	860	
A Priori Weight of Troposphere Parameters	Specification: Use 5 m a priori weight for the absolute and relative parameters.	860	

Table 2 - Recommended parameters and models adopted for densification specification of EUREF TWG

	Bernese	Gamit	Gipsy
Elevation mask	10°	10°	10°
Final Solution	Lc	Lc	Lc-Pc
Orbit Computation	No	No	No
Terrestrial parameter computation	No	No	No
RMS a priori for reference coordinates	10m	10m	not applicable
Orbits and terrestrial parameters	Final IGS	Final IGS	Final IGS
Antenna Phase center Variation	Igs05_wwww.atx	Igs05_wwww.atx	Igs05_wwww.atx
Tropospheric model	Saastamoinen (1972)	Saastamoinen (1972)	Saastamoinen (1972)
Troposphere Mapping function	Niell (1996)	Niell (1996)	Niell (1996)
Tidal Displacements	Apply ocean loading corrections for the stations	Apply ocean loading corrections for the stations	Apply ocean loading corrections for the stations
Ambiguity resolution	yes	yes	No
Criteria for Single difference creation	Minimum distance	Minimum distance	Not applicable
Framing strategy	7 parameter transformation	7 parameter transformation	7 parameter transformation

Table 3 – Common Parameters used for the network computation

4. Description of the automatic procedure for post-processing of data

Analyzing the solutions obtained by processing such large amounts of data with the three software packages required the creation of an automatic post-processing procedure. This procedure has been realized for the analysis of a network constituted by a large number of stations and for a long time span and applied in this contest where the time span is very short. The following operations were performed by this procedure:

a) transformation of the solutions expressed in geocentric coordinates to geographic coordinates (using a defined datum), in a local geodetic reference system with appropriate propagation of the original covariance matrix;
b) transformation of the ITRF solution into the EUREF reference frame ETRF2000.0 using the Altamimi procedure described in the memo v.6 (Boucher and Altamimi, 2007);
c) creation of a time series for each station;
d) calculation of a weighted linear regression of the time series for each site and for each component;
e) filtering of data affected by outliers (by rejecting any solution that differed by more than three times the standard error of the temporal series for any of the three geocentric components), this phase required multiple iterations until no more outliers were present;
f) plotting of the results;
g) calculation of the average position and standard deviation over time for each site (producing a file for each site containing the estimates obtained from the three software packages and the pairwise differences between them);
h) calculation of the position and standard deviation for each site at a defined point in time (on the basis of the linear regression parameters and reported site by site in a file containing the estimates obtained from the three software packages and the pairwise differences between them);
i) preparation of a complete statistical report containing for each site the number of solutions rejected for each software system, etc.

This procedure was implemented in the Linux C-shell using Fortran code and some Gipsy and Gamit scripts. Finally, Gnuplot was used to display the graphical results. Considering the particular contest the point c) and d) are probably unnecessary and should be substitute with a weighted average of solution, but the creation of a time series and the research of the weighted linear regression produce results very closed to the alternative approach.

4.1 Statistical results

The data processing procedure using the three software produced, for each one a final dataset of daily positions.

The post-processing procedure described in Section 4 was applied to the solutions. Step e) of this procedure filtered out solutions affected by outliers, assuming that the solutions followed a linear regression. At the end of this filtering procedure, a different percentage of solutions were rejected for each software package (Table 4).

	solutions rejected by the procedure
Bernese	11.0%
Gamit	2.7%
Gipsy	2.2%

Table 4 – Statistical summary of the post-processing procedure

To interpret the results, it is important to underline the relatively short time span of the dataset. Analyzing the rejected data is evident as two daily Bernese solutions are more scattered than the others. Considering the so short time span these two solutions induce a significant variation in the percentage of rejected data. Removing these two solutions from the sample the results are comparable to those previously obtained for other networks over a much longer time span (Barbarella et al., 2009).

5. Description of the solution comparison strategy

The pre-processing and post-processing procedures adopted here produced a set of results for each software package and for each site. These solutions differed between software packages, so it is important to consider how to compare the solutions and determine when two or more solutions give the same results or better when the solution are statistically in agree.

Considering a time series for each software and for each site, assume that $\underline{X}_{t,s}^{i}$ is the solution for site *s* obtained by software *i* at epoch *t*.

A variance/covariance matrix produced by the software can be associated to this solution, and the square root of the variance is the standard deviation associated with the given component. Thus, each software provides the standard deviation associated with the station coordinates, but this value may not be fully representative of the actual statistical variability of the station position. Moreover, generally the formal error associated to the Bernese solution is one order of magnitude smaller than the Gipsy and Gamit solutions. Nevertheless, the standard deviation computed by a particular software can be considered representative of the relative indeterminacy of such coordinates, so it is possible to define relative weights. From the time series for each site and for each coordinate (Figure 2), we can obtain a single value representative of the station position. The time span is sufficiently brief (not more than 28 days) than we could use the mean (simple or weighted), but we prefer to consider the trend of the series by estimating the weighted linear regression previously estimated in the post-processing procedure designed for general network.

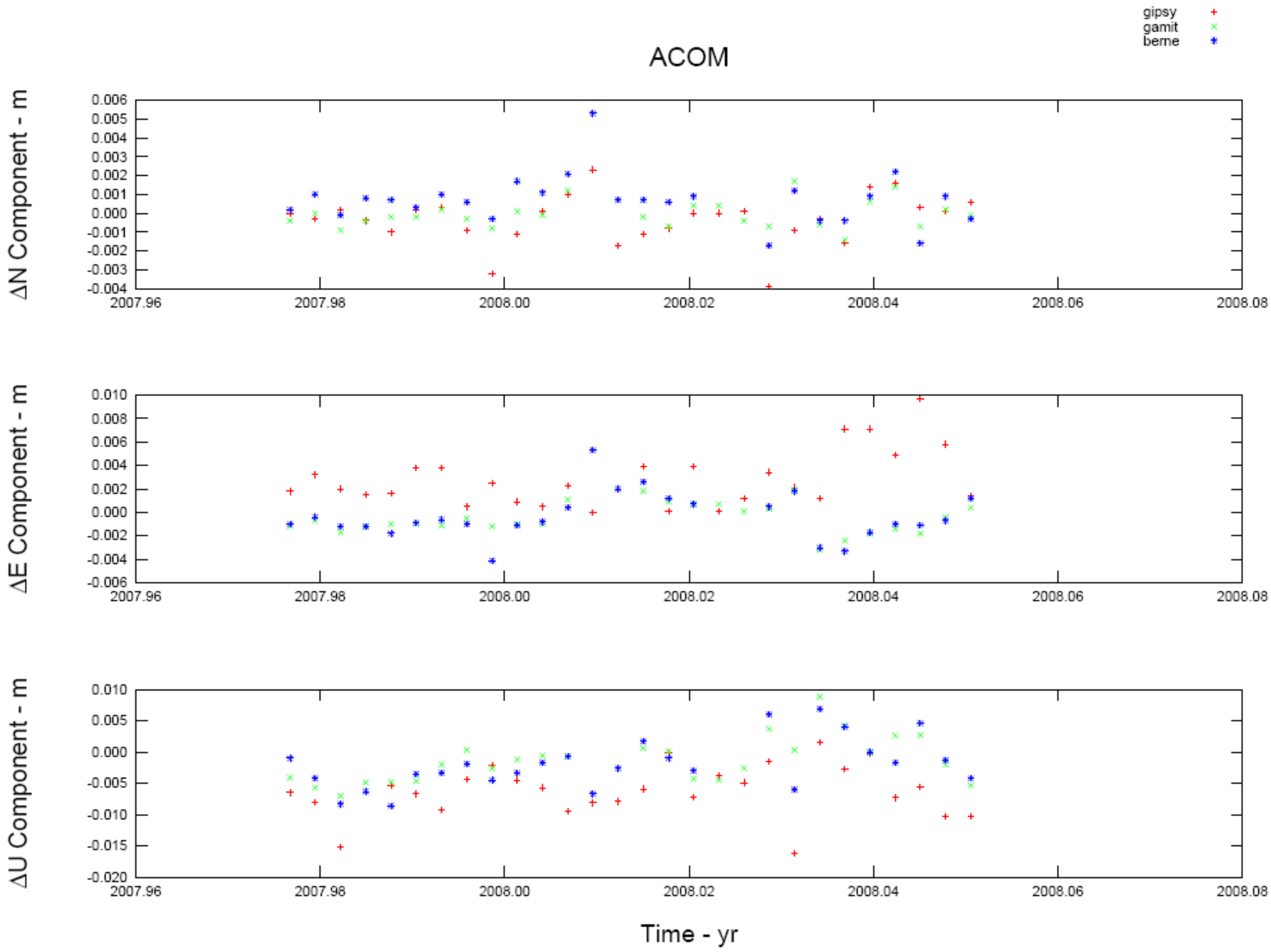


Figure 2 –Example of a time series obtained for the three software packages for one site (ACOM)

Moreover the IGMI data refer the position to a specific epoch, so from the least squares estimate of the regression parameters (slope $\hat{m}_s^i$ and intercept $\hat{q}_s^i$) it is possible to calculate the interpolated value of the corresponding coordinate at time t_o (1) and its standard deviation (2) as functions of the elements of the variance matrix of the estimated parameters.

$$\hat{x}_s^i(t_0) = \hat{m}_s^i\, t_0 + \hat{q}_s^i \qquad (1)$$

$$\left(\sigma_{\hat{X},s}^i\right)^2 = \sigma_{\hat{m}_s^i}^2\, t_0^2 + 2\,\sigma_{\hat{m}_s^i \hat{q}_s^i}\, t_0 + \sigma_{\hat{q}_s^i}^2 \qquad (2)$$

This process produces for each software system a single value for the point coordinates and their standard deviation. A value of t_o corresponding to January 1, 2008 (epoch 2008.0) is assumed. This representative value is used to evaluate the magnitudes of the differences among the results of the different software systems. The statistics considered for each site are the difference in the coordinates (3), the relative standard deviation (4) and the "normalized difference" (5) for each component of the site.

$$\Delta X_s^{i-j}(t_0) = \hat{x}_s^i(t_0) - \hat{x}_s^j(t_0) \qquad (3)$$

$$\sigma_s^{i-j} = \sqrt{\left(\sigma_{\hat{X},s}^i\right)^2 + \left(\sigma_{\hat{X},s}^j\right)^2} \qquad (4)$$

$$\Delta\tilde{X}_s^{i-j}(t_0) = \frac{\Delta X_s^{i-j}(t_0)}{\sigma_s^{i-j}} \qquad (5)$$

To compare the solutions, the use of these parameters is preferable because these are more representative of the solution variability respect to the formal errors associated to each solution.

6. Comparison of the available solutions

Several solutions were available from the different software packages and from different analysis centers, namely:

1) two different solutions obtained using the Gamit software (performed by DISTART Dept.), considering the possibility of splitting the network into different clusters or the possibility to compute the entire network in one block;
2) a DISTART solution obtained using the Bernese software;
3) a DISTART solution obtained using the GIPSY software;
4) a solution obtained by the IGMI using Bernese Software in accordance with the EUREF guidelines and published on the official IGMI web site

(http://87.30.244.175/rdn/rdn_download/allegato4.pdf); only one value for each site has been reported (no time series solutions are available), so only some comparisons can be performed.

To compare the available solutions, we use the parameters defined in Section 5.

6.1 A preliminary test comparing two different computation approaches

As a first step in comparing the different solutions, the differences between the results obtained by processing the network in two different modalities (both in accordance with the EUREF guidelines) are reported. The first set of results was obtained by performing a single run of the whole network, and the second was obtained through a posteriori adjustment of two or more clusters processed separately. This test was designed to take into account the intrinsic limit in the number of points (99) that can be included in a single run by the Gamit software. For Gamit users, if the number of stations exceeds this amount, the network must be split into several clusters, and processing must be performed separately and independently. The software also provides a procedure for the joint adjustment of the separate solutions (GLOBK module). Here, the number of the points in the network is only 98; however, possible future increases in the network size will exceed the limit.

In order to test the equivalence of the results obtained using a single processing step and those obtained by separation into clusters, computations were performed for both a single dataset (98 points) and two sub-blocks. Stations were partitioned from north to south (figure 3). Table 5 shows the difference between the solution obtained using a single block and that obtained by dividing the network into clusters and then joining the partial solutions. The differences between the solutions are at the 0.1-mm level not only for the mean value but also for individual points. The maximum range of the coordinates is 0.8 mm and no spatial correlation are evident.

These values demonstrate that the solutions are equivalent in terms of final accuracy. However, taking into account the difference in computation time depending on the size of the block to be calculated, the partitioned solution is preferable, because it can be computed faster and provides similar values. Given two available solutions, one must be chosen for subsequent comparisons (e.g., of scattering and accuracy) among software systems. In this case the single block solution is used in the following comparisons because generally the single block solution permit to dispose of a complete variance/covariance matrix of the solution.

Figure 3 – Partitioning of the network into two clusters, north (blue dots) and south (red dots). Yellow dots represent common stations used in processing both clusters and in joining the partial solutions.

Component	Parameters	Differences (mm)
ΔN	Mean	0.0
	St. dev.	0.1
	range	0.3
ΔE	Mean	0.0
	St. dev.	0.1
	Range	0.2
ΔU	Mean	-0.1
	St. dev.	0.3
	range	0.6

Table -5– Differences (in mm) between the single-block and partitioned solutions: means and variation.

6.2 Level of scattering (internal consistency) of each solution

Considering the final time series obtained for each site by each software system, the first comparison concerns the actual scattering of the various software solutions around the respective time series trends.
As described in Section 5, we compared the scattering of the solutions obtained from each software system based on the $\sigma^{i}_{\hat{X},s}$ values computed for each site and component at time t_0. As described, this parameter is not a function of the variance/covariance matrix derived from the adjustment but rather depends on the internal scattering of each solution around its regression lines. To show the scattering of the solutions obtained, three histograms (Figure 4) are shown.

		Mean (mm)	Standard Deviation (mm)	Maximum (mm)
Bernese	$\sigma_{\Delta N}$	0.2	0.1	1.0
	$\sigma_{\Delta E}$	0.3	0.1	1.1
	$\sigma_{\Delta U}$	0.8	0.2	1.8
Gamit	$\sigma_{\Delta N}$	0.2	0.1	0.6
	$\sigma_{\Delta E}$	0.2	0.1	1.1
	$\sigma_{\Delta U}$	0.7	0.2	1.8
Gipsy	$\sigma_{\Delta N}$	0.3	0.2	1.2
	$\sigma_{\Delta E}$	0.4	0.2	1.8
	$\sigma_{\Delta U}$	0.9	0.3	1.8

Table 6 – Summary of the primary statistical results for the scattering of the time series.

The values of the parameter $\sigma^{i}_{\hat{X},s}$ were usually less than one millimeter. Despite the differences in the formal errors associated with the solutions obtained from the various software, the adopted parameters of dispersion around the trend lines were similar for all the solutions, and these values can be considered the real values of the indeterminacy associated with each component.

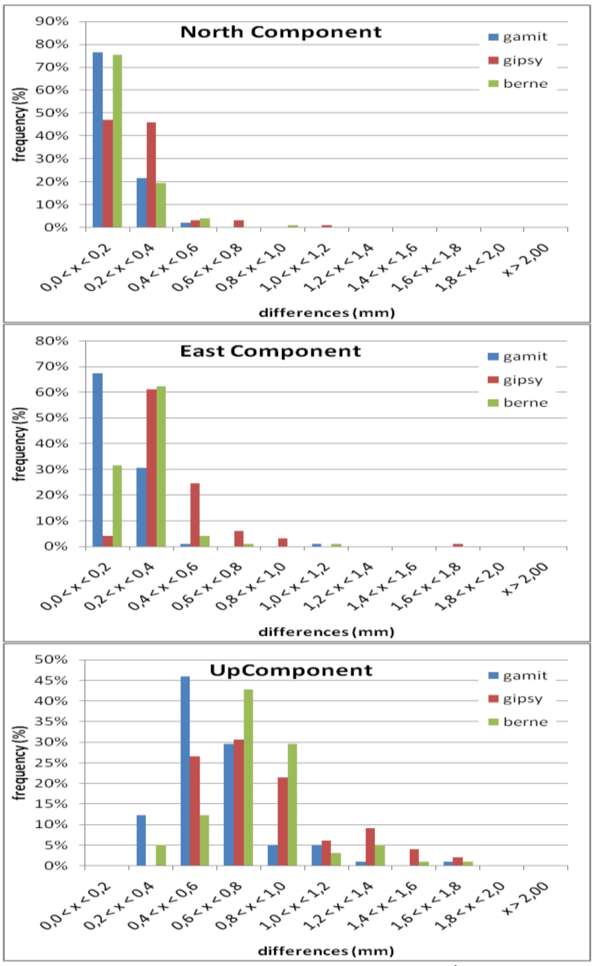
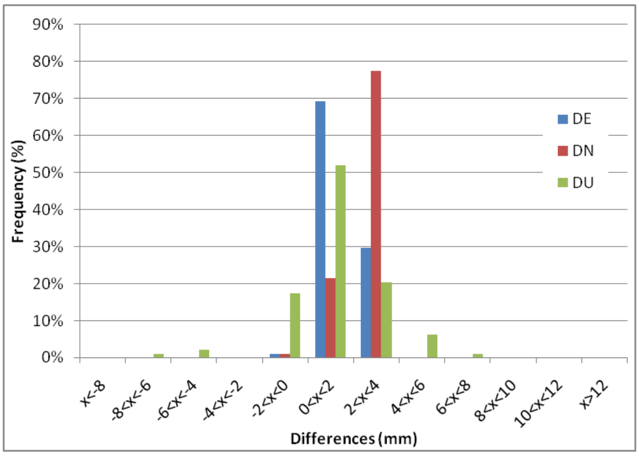


Figure 4 – Histograms of the dispersion $\sigma^{i}_{\hat{X},s}$ for the 98 sites for each component.

6.3 Comparison between IGMI and DISTART (Bernese) solutions

The solutions obtained by the DISTART research group and by the IGMI using the same software, starting from the same dataset, and using the same EUREF guidelines were compared. The differences reported in Figure 5 have several probable explanations.
First, the DISTART solution was produced by discarding files containing less than 12 hours of observations, so the processed dataset was not exactly the same as that used by the IGMI. Second, the post-processing procedure applied to the DISTART solutions was not exactly the same as the procedure adopted by the IGMI that is not published yet. Finally, secondary internal settings imposed during data processing (such as the number of MAUPRP or the Ambiguity resolution strategy) could have caused changes. The results obtained were comparable in terms of both the estimated coordinates and the scattering to those obtained by the other two research groups (Padua University and Milan Polytechnic) and to those published on the official IGMI web page (http://87.30.244.175/rdn/rdn_download/allegato8.pdf)



Difference	(mm)	IGMI
ΔN	Mean	0.2
	St. dev	0.4
	Max. abs.	2.0
ΔE	Mean	-0.1
	St. dev.	0.4
	Max. abs.	2.1
ΔU	Mean	-0.8
	St. dev.	2.0
	Max. abs.	9.1

Figure 5 – Histogram and primary statistical results relatively to the differences IGM - DISTART (Bernese) solution.

6.4 Comparison of the Bernese solution with the GAMIT and GIPSY solutions

The parameter $\Delta X_s^{i\text{-}j}(t_0)$, defined in (3) of Section 5, was used to compare the three solutions in terms of position. For this comparison, the Bernese solution performed by DISTART was used as a reference.
To analyze the distributional range of the differences found, the differences are represented in Figure 6 by circles with radii proportional to the square roots of the differences. In this way, the ratios of the areas of the circles are proportional to the ratios of the differences. Figure 6 displays the differences in the local geodetic reference frame (North, East and Up) of the sites. A summary of the differences obtained for the sites is also shown in Table 7. Figure 6 show the histogram of the "normalized differences" $\Delta\widetilde{X}_s^{i\text{-}j}(t_0)$ and in Figure 7 the differences are reported on the maps.

Difference	(mm)	Gamit	Gipsy
ΔN	Mean	0.1	0.0
	St. dev.	0.7	1.0
	Max. abs.	3.2	2.6
ΔE	Mean	0.2	-3.9
	St. dev.	0.5	4.4
	Max. abs.	2.1	16.6
ΔU	Mean	-0.2	2.2
	St. dev.	2.7	5.6
	Max. abs.	12.1	17.7

Table 7 – Statistical summary of the differences (in mm) among the three solutions with respect to the Bernese solutions.

From Figure 6, Figure 7 and Table 7, we can make the following observations.
The agreement between the Gamit and Bernese solutions is high (the means of the differences were close to zero and the standard deviations were less than 1 mm for the North and East component and less than 3 mm for the height).

The differences between the Gipsy and Bernese solutions were meaningful and indicated the presence of bias in the East component, confirmed in the literature (e.g., Jivall et al., 2005).

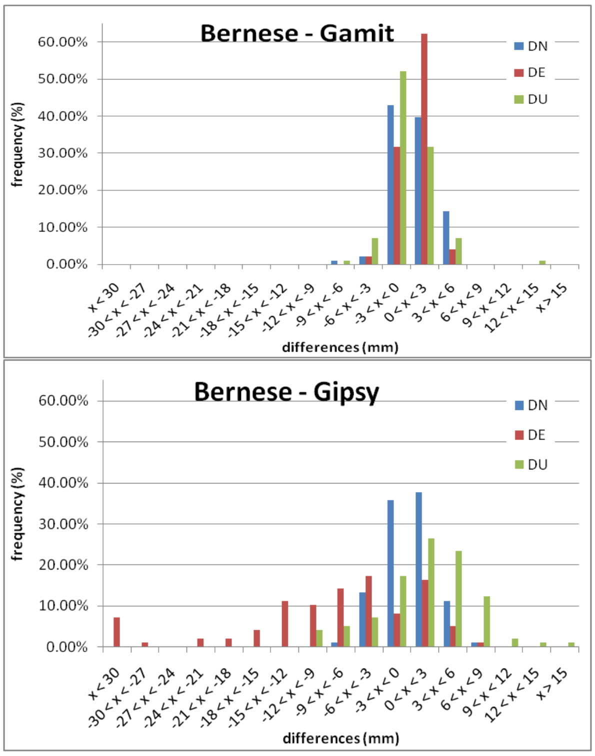


Figure 6 – Histograms of the normalized differences between the solutions obtained by the three software systems, using the Bernese (DISTART) solution as a reference for comparison to the other two software packages (Gamit and Gipsy).

Close analysis of the bias in the East component between the Bernese and Gipsy solutions shows that larger values of bias correspond to particular features of the antenna/radome. In particular, all stations that mounted a LEIAT504GG (LEIS) and a TRM29659.00 (UNAV) antenna presented a bias greater than 1 cm in the East component. Therefore, an additional solution, called "Gipsy trimmed," was obtained by excluding the above stations. The Bernese and "Gipsy trimmed" solutions are compared in Figure 8.

Although the major statistical parameters do not change significantly, Figure 8 shows the absence of values bigger than 22 mm in the East component seen in Figure 7. Although many tests have been performed to understand the nature of this bias, the reasons are still under investigation. Moreover, it is important to note that the bias occurs only at the 1.4-cm level and that no differences have been found in the velocity estimation (Barbarella et al., 2009).

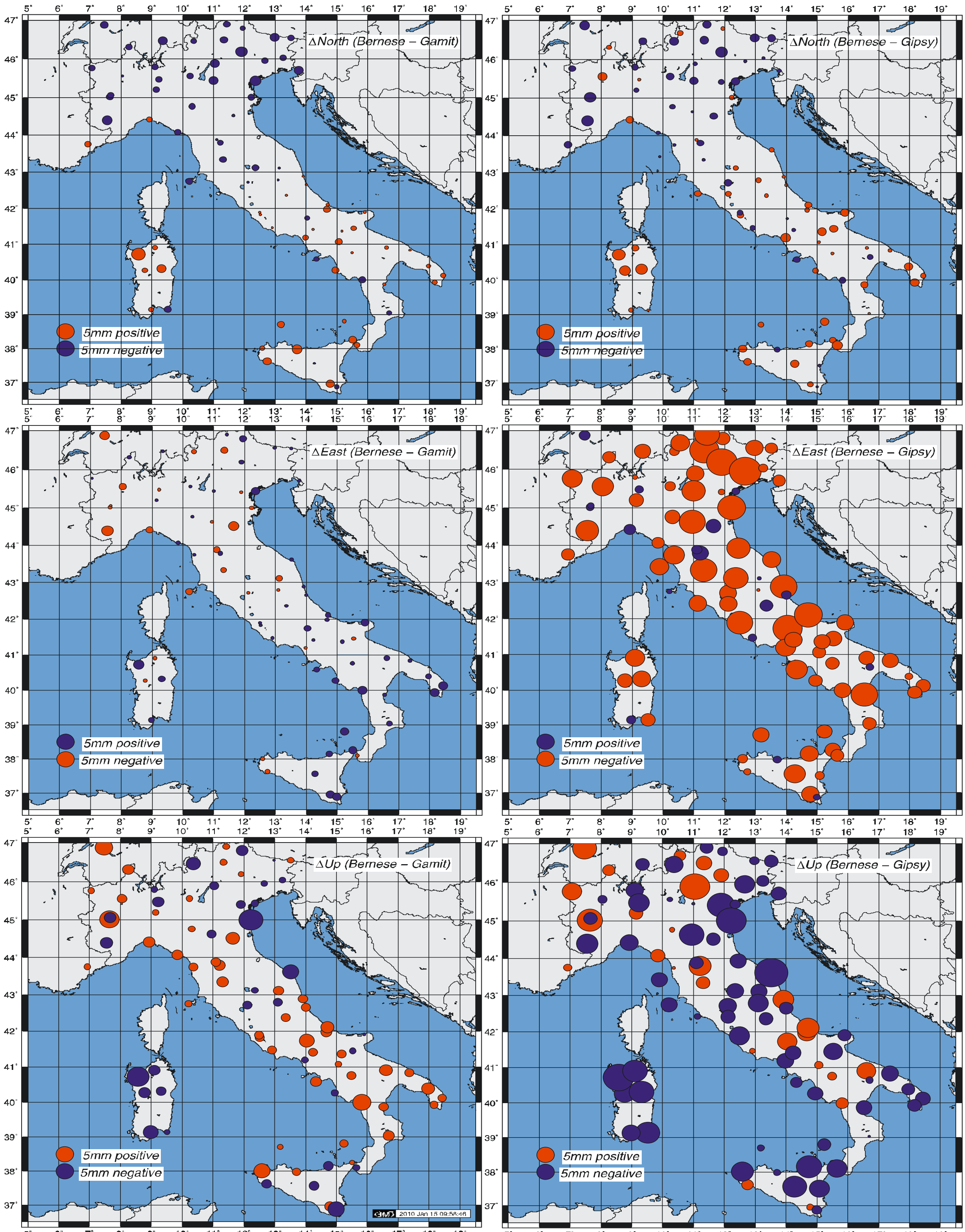
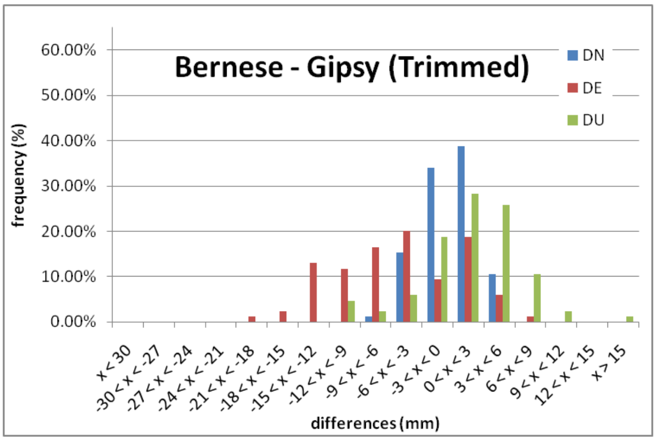


Figure 7 – Differences in the North East and Up components (local geodetic reference frame) between the Bernese solution and the Gamit (left) and Gipsy (right) solutions



Diff.	(mm)	Bernese - Gipsy (trimmed)
ΔN	Mean	0.0
	St. dev.	1.0
	Max. abs.	2.6
ΔE	Mean	-2.6
	St. dev.	2.9
	Max. abs.	8.6
ΔU	Mean	2.3
	St. dev.	5.3
	Max. abs.	17.7

Figure 8 – Histogram and major statistical results obtained when comparing the DISTART (Bernese) solution to the "Gipsy Trimmed" solution

7 Conclusion and considerations

The computation of the RDN (the Italian densification of the ETRF00 network) has been implemented by DISTART using three scientific software systems (Gipsy-Oasis II, Bernese V.5.0 and Gamit-Globk), starting with the same dataset and following the EUREF guidelines. The Bernese and Gamit/Globk software systems adopt the classical approach (based on double phase difference), while the Gipsy/Oasis II software implements the Precise Point Position approach.
The same processing setups and ancillary files (IGS orbits and clock model, physical bias models, etc.), datum and constraints were adopted to compute the solutions with minimum constraints. Furthermore, the coordinates obtained from different software systems were used to analyze possible differences among the results.
First, the solution we obtained with the Bernese software agreed at millimeter level with the IGMI solution (which was obtained using the same software). The formal errors coming from the Bernese software are confirmed to be lower than the dispersion of the sample respect to the regression line. To make the variation of the results obtained comparable to that of the other software systems, the accuracy of the solutions was evaluated from the regression data. The daily solutions of the network obtained from each computation were of good quality, with the standard deviation of the coordinate values estimated to be a few millimeters at epoch 2008.0. The values obtained from all software packages were nearly identical. This consistency also attests to the good quality of the permanent GPS stations that define the RDN network.
The network solution tests implemented using the Gamit-Globk software, processing the network either in a single block or in multiple clusters with common stations, indicated no significant differences among the solutions. The multi-cluster strategy is recommended to reduce computational time and simplify data management.
The differences between the Gamit and Bernese systems, which use the same differenced approach, were very small and did not exceed the differences between the solutions obtained by various computer centers using the same software. We conclude that for this dataset the two software packages are essentially equivalent.
The Gipsy-Oasis II solution showed greater differences from the others, especially in the East and Up components. This trend is probably due to the float solutions, which are in general noisier than fixed ones. Finally, a bias in the East components of the Gipsy solution was detected in GPS stations using particular geodetic antenna/dome combinations; this problem will require further investigation.

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IGMI Official Web Site:
http://87.30.244.175/rdn.php