Testing EGM2008 in the Central Mediterranean area

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Abstract

The last geopotential model EGM2008 has been compared with gravity and GPS/leveling data over the Central Mediterranean area. In this area, the gravity field has sharp variations due to strong topography/bathymetry signals and to relevant geophysical features. More than 300.000 gravity values covering the whole area have been considered in the comparisons. These data were used in the last Italian geoid computation and have been validated for datum consistency and for outliers. Further comparisons have been carried out using GPS/leveling data which are homogeneously distributed over the Italian Peninsula. About 1000 available values have been used in the comparison. The results show that, in this area, EGM2008 fits gravity and GPS/leveling data better than other existing global models. The geopotential model performances have been also compared with those of the last Italian geoid estimate, the ITALGEO05 geoid which has been computed in 2005. The statistics of the residuals with GPS/leveling data show that EGM2008 and ITALGEO05 have comparable accuracies, even though EGM2008 is slightly better.

1. Introduction

One feasible method for assessing the accuracy of the global geopotential models is through comparisons with point-wise measured values of functionals of the anomalous potential T(P). Usually, this is done using gravity anomalies at ground level and geoid undulations as derived by e.g. GPS and spirit leveling. Such comparisons are performed over areas with different features of the Earth gravity field in order to test for the global geopotential model performances under different conditions. There are regions where the geopotential field is strongly varying due to topography/bathymetry roughness and/or geophysical features. Tests carried out in these regions are particularly valuable since they prove how such strong variations can be recovered by the geopotential models.

One of these areas is the Central Mediterranean which, in our comparisons, will be considered as the region inside the boundaries: $35° \leq \varphi \leq 48°$, $5° \leq \lambda \leq 20°$. The Alps are on the northern edge of this region and the Apennines crosses it along one of its diagonals. There are shallow water areas in the Adriatic Sea and deep water seas such as the Ionian Sea. Moreover, hilly regions are close to deep waters as it is, e.g., in the southern part of Italy. This gives rise to a highly variable gravity field which is further perturbed by strong geophysical signals. Two examples of such signals are the Calabrian Arc structure along the eastern part of Calabria and the Ivrea body in the western Alps. Thus, over such a relatively small portion of the Earth, relevant changes in the gravity field can be found.

Furthermore, in this area, which has been widely surveyed, quite large ground gravity and GPS/leveling data sets are available. Also, a local geoid estimate has been recently computed in this region, the ITALGEO05 geoid.

These data sets and the ITALGEO05 geoid estimate have been used for checking the EGM2008 accuracy over this area where, as mentioned before, strong gravity field variations are present.

2. Gravity, GPS/leveling and DTM data over the Central Mediterranean area

The gravity data base used in this test has been compiled using different data sources. Most of the data have been supplied by *Servizio Geologico Nazionale* of Italy. Marine gravity comes from surveys which were performed by OGS (Morelli et al., 1975) while data outside the Italian borders are from BGI. In the whole, 310.660 point gravity values were collected in the window 35°≤ φ ≤48°, 5°≤ λ ≤20°. In Figure 1, this gravity data base is shown.

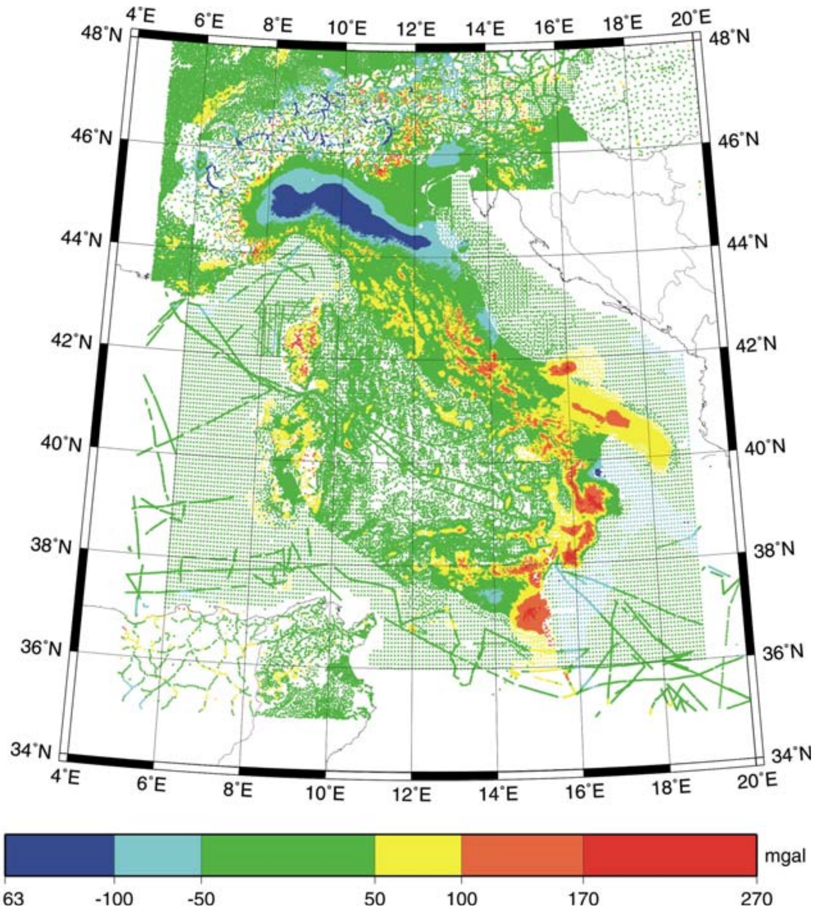

Figure 1. The gravity data base in the Central Mediterranean area.

The range of free-air anomalies is quite large, reflecting the complex structure of the gravity field of the area. As one can see, data are unevenly distributed. The Po plain is densely surveyed while the Alpine region is poorly covered. This reflects the fact that these data are basically ground gravity data which are easier to collect in flat topography areas. Marine gravity is known mostly in grid form even though some ship tack data have been included. Furthermore, it must be underlined that there are areas with no data available over the former Yugoslavia.

GPS/leveling data have been supplied by *Istituto Geografico Militare* (IGM) of Italy. The data base consists of 977 values distributed over the continental part of Italy. These are points belonging to the IGM95 GPS network which was measured in 2003-2004 by IGM (Surace, 1997). The ellipsoidal heights are framed to ETRF89. The leveling lines giving, on the same points, the orthometric heights have been surveyed by IGM over a large time

span. Thus, relevant discrepancies between GPS/leveling undulations and other geoid estimates can occur due to that.
In the context of Italian geoid estimate, both gravity and GPS/leveling data base have been carefully checked.
Gravity data co-ordinate have been referred to WGS84 and observed gravity has been reduced to IGSN71. These data were also checked for outliers following an approach based on a comparison between observed and collocation predicted values.
Check for outliers in GPS/leveling undulations has been performed via comparison with the last estimate of the Italian geoid.
The GPS/leveling data base used in the following comparisons is shown in Figure 2.

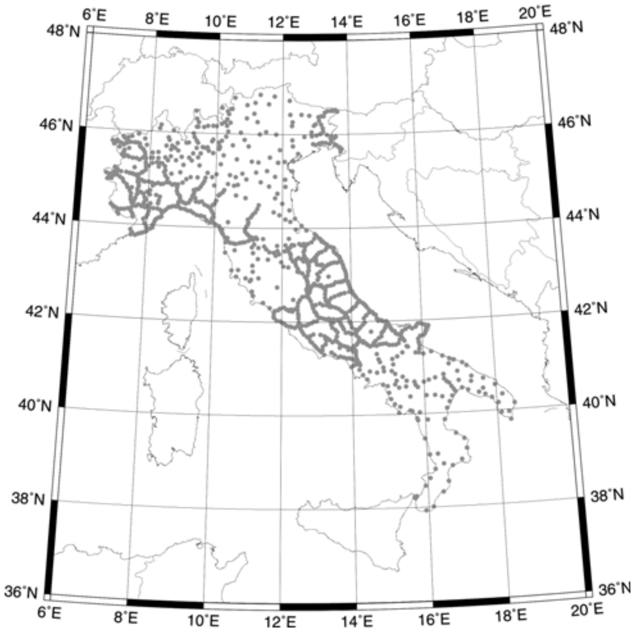

Figure 2. The GPS/leveling data base over the continental part of Italy

DTM has been also used in the computations. This DTM has been prepared for the Italian geoid computation merging different data bases:

- the SRTM3 DEM as a reference elevation model;
- the Italian DTM to fill the SRTM3 gaps over the Italian land region and for a strip of bathymetry near the coasts, where good resolution digitalised bathymetry is available;
- the new 1’ x 1’ NOAA bathymetry in deep seas (https://128.160.23.42/dbdbv/dbvquery.html);
- the GTOPO30 DTM where no other data were available (http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html).

The area on which this DTM has been assembled is 33°≤ φ ≤50°, 3°≤ λ ≤22°. The resulting grid has a regular geographical mesh of 3’’× 3’’ (Borghi et al., 2007).

3. Comparing EGM2008 and other existing geopotential models with gravity data

The EGM2008 geopotential model has been used to reduce gravity values belonging to the described data base. It has been firstly compared to GPM98CR (Wenzel, 1998) which is the model that better fits gravity over this test area (Barzaghi et al., 2008). As it is well known, this is a global geopotential model complete to degree and order 720. The statistics of the data and those of the residuals obtained using the two models are listed in Table 1.

	Δg_{fa} [mGal]	Δg_{fa} - $\Delta g_{M\_EGM2008}$ [mGal]	Δg_{fa} - $\Delta g_{M\_GPM98CR}$ [mGal]
#	310660	310660	310660
E	11.52	-5.22	-6.58
σ	63.93	18.38	23.99
Min	-162.55	-243.34	-228.65
Max	269.71	119.49	168.01

Table 1 – Gravity and residuals statistics (after model reduction)

The EGM2008 is remarkably better than GMP98CR model. There are still high residuals that are probably un-removed outliers. However, most of the residuals are contained in the [-50 mgal; 50 mgal] interval, as it can be seen in Figure 2.

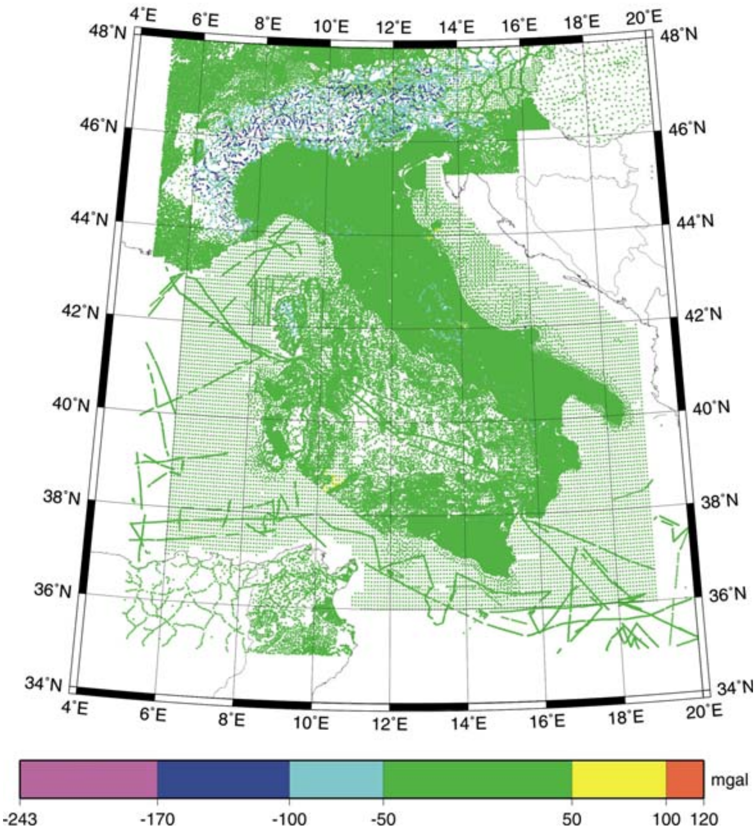

Figure 2. The gravity residuals after EGM2008 reduction

A further comparison has been carried out on the residuals after RTC reduction. RTC effect has been computed using the TC software of the GRAVSOFT package (Tscherning et al., 1994). The DTM described in the previous paragraph has been used as detailed terrain model. The mean DTM has been obtained from this detailed DTM by applying different moving averages. The cap size of the moving average used to get the mean DTM is 10' for the GPM98CR. The one used for the EGM2008 is 3'. They have been selected testing different cap amplitudes and looking for optimal residuals statistics (i.e. minimum mean and standard deviation). As expected, the EGM2008 is associated to a moving average operator that smooth less than the one related to GPM98CR.
The outcomes of this computation are presented in Table 2.

	Δg_{fa} [mGal]	Δg_{fa} - $\Delta g_{M\_EGM2008}$ - Δg_{rtc} [mGal]	Δg_{fa} - $\Delta g_{M\_GPM98CR}$ - Δg_{rtc} [mGal]
#	310660	310660	310660
E	11.52	-0.938	-1.14
σ	63.93	7.884	10.69
Min	-162.55	-287.745	-274.55
Max	269.71	117.257	106.64

Table 2 – Gravity and residuals statistics (after model and RTC reduction)

Apart from a small amount of anomalous values, the final residuals have a negligible mean and a standard deviation which is sharply reduced as compared to the initial value.
Also in this case, the EGM2008 improved the results obtained with GPM98CR. In Figure 3, the plot of the residuals after EGM2008 and RTC reduction is shown. Obviously, the RTC reduction has the strongest impact over the Alps (compare Figure 2 and Figure 3).

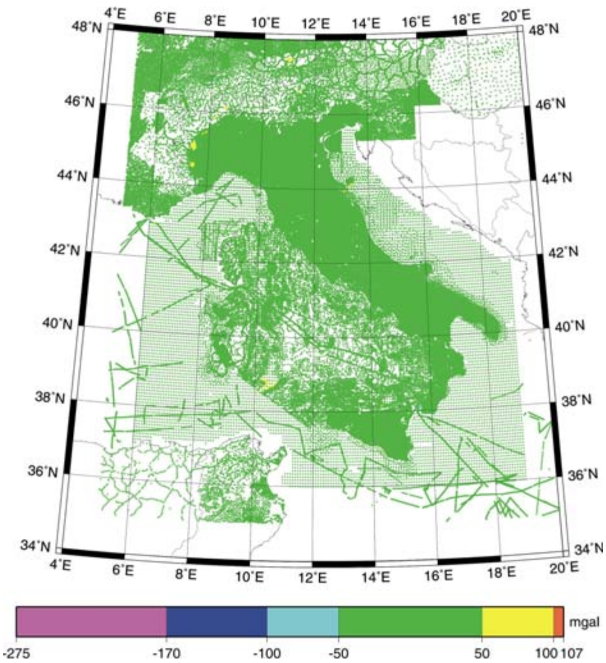

Figure 3. The gravity residuals after EGM2008 and RTC reduction

It is also interesting to compute the empirical covariance functions of the residuals which give an idea of their spatial correlation.
The empirical covariances of gravity after model reduction are plotted in Figure 4 while in Figure 5 those of the residuals after model and RTC reduction are plotted.

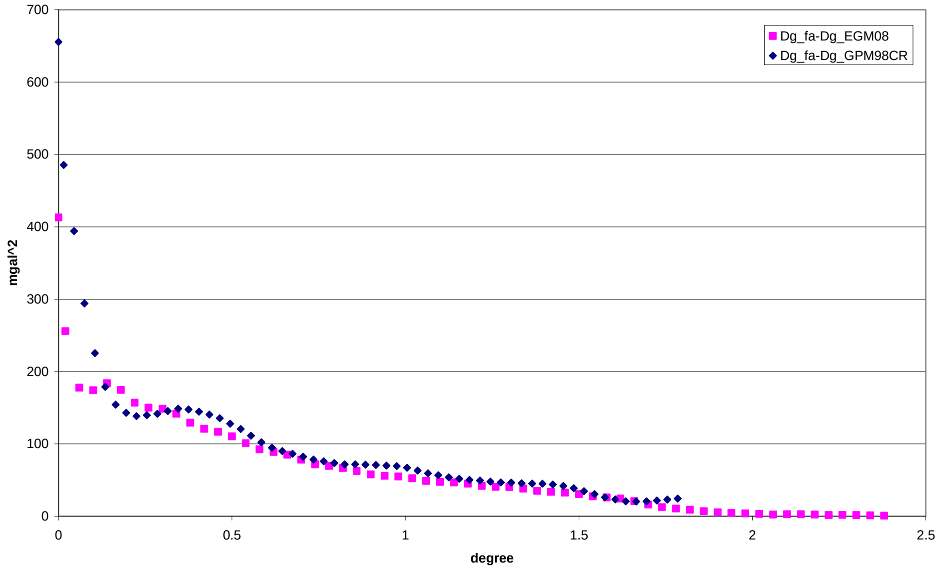

Figure 4. The empirical covariance function of gravity residuals after model reduction

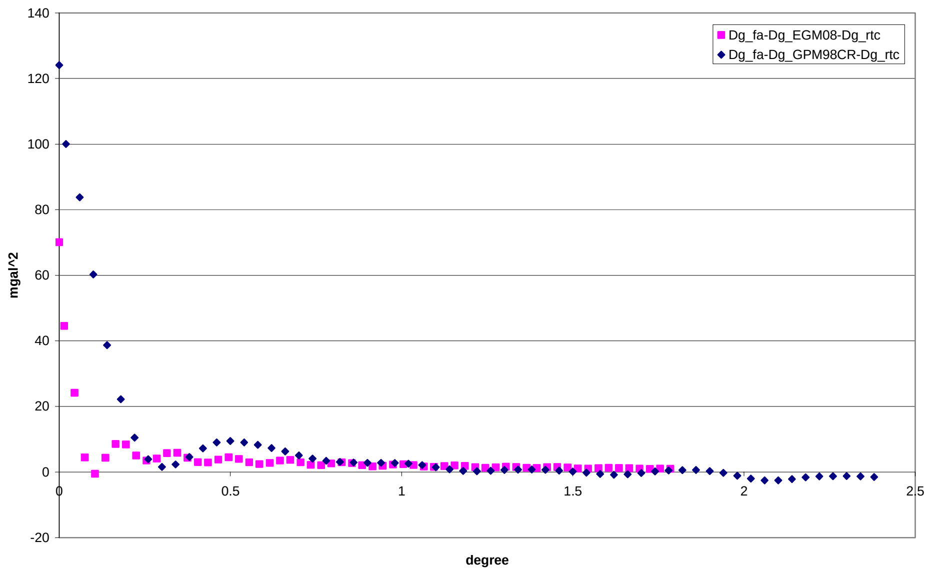

Figure 5. The empirical covariance function of gravity residuals after model and RTC reduction

Covariances after model reduction only are quite similar both for EGM2008 and GPM98CR, but for their values in the origin.
Covariances after model and RTC reduction seems to be more different in their behavior close to the origin. Particularly, the empirical covariance of the residuals obtained using the EGM2008 model displays a very short correlation length which can be hardly fitted using the standard model covariance functions.

Finally, we compared EGM2008 with other two global geopotential models, EIGEN-GL04C and EGM96 which are complete to degree and order 360. This test has been performed on a reduced gravity data set obtained by selecting the observed gravity points closer to the centers of a 1’×1’ grid. Again, one can see that the EGM2008 sharply improves the results obtained with previous global geopotential models (see Table 3).

	$\Delta g_{fa} - \Delta g_{M\_EGM2008\_2190}$ [mGal]	$\Delta g_{fa} - \Delta g_{M\_GL04C\_360}$ [mGal]	$\Delta g_{fa} - \Delta g_{M\_EGM96\_360}$ [mGal]
#	142196	142196	142196
E	-5.411	-7.334	-6.415
σ	20.321	32.244	31.135
Min	-241.556	-255.889	-253.978
Max	119.492	194.808	188.235

Table 3 – Residuals statistics using different global geopotential models

4. Fitting GPS/leveling data with EGM2008 and ITALGEO05

The ITALGEO05 is the last Italian geoid estimate (Barzaghi et al., 2008). It is based on a gravity data base which is closely related to the one used for checking the EGM2008 model.
The estimation procedure is the classical “remove-restore” technique (Tscherning, 1994) and the residual geoid component has been estimated using the Fast Collocation approach (Bottoni and Barzaghi, 1993).
The reference global geopotential model adopted in the computation is the GPM98CR, complete up to degree and order 720, while the RTC effect has been estimated using the DTM described in paragraph 2.
The final estimate is given on a regular grid in the area 35°≤ φ ≤48°, 5°≤ λ ≤20° with grid spacing 2’ × 2’. This geoid estimate is shown in Figure 6.

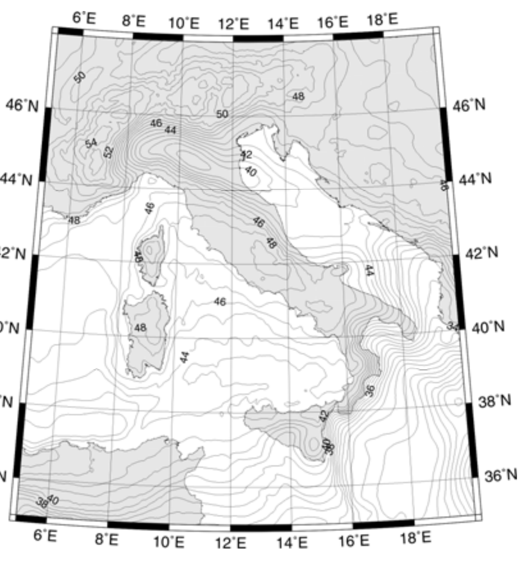

Figure 6 – The Italian geoid ITALGEO05 (equidistance =1m)

EGM2008 has been compared with this geoid estimate and with GPM98CR over the GPS/leveling data set previously described.
The results of this comparisons are summarized in Table 4.

	$N_{Italgeo05}$ - $N_{GPS/lev}$	$N_{GPM98CR}$ - $N_{GPS/lev}$	$N_{EGM2008}$ - $N_{GPS/lev}$
#	977	977	977
E(m)	0.00	0.00	0.00
σ(m)	0.12	0.35	0.10
Min(m)	-0.50	-1.30	-0.33
Max(m)	0.32	0.64	0.34

Table 4 – Residuals statistics on GPS/leveling data using different geoid estimates

Statistics refer to discrepancies after datum shift. The equation used to account for datum shift is the one described in Heiskanen and Moritz (1990):

$$
\begin{aligned}
N_{grav} &= N_{GPS/lev} + \Delta N(\theta, \lambda) = \\
&= N_{GPS/lev} + dx \sin\theta \cos\lambda + dy \sin\theta \sin\lambda + dz \cos\theta
\end{aligned}
$$

$$
\theta = 90° - \varphi \qquad (dx, dy, dz) = datum\ shift\ \ parameters
$$

EGM2008 fits GPS/leveling data much better than GPM98CR, as it is reasonable due to the higher degree information contained in EGM2008. Furthermore, it also gives results comparable with those of ITALGEO05 which is the most refined geoid estimate over the test area.
The discrepancies between GPS/leveling data and EGM2008 area shown in Figure 7, while the discrepancies between GPS/leveling data and ITALGEO05 are plotted in Figure 8.

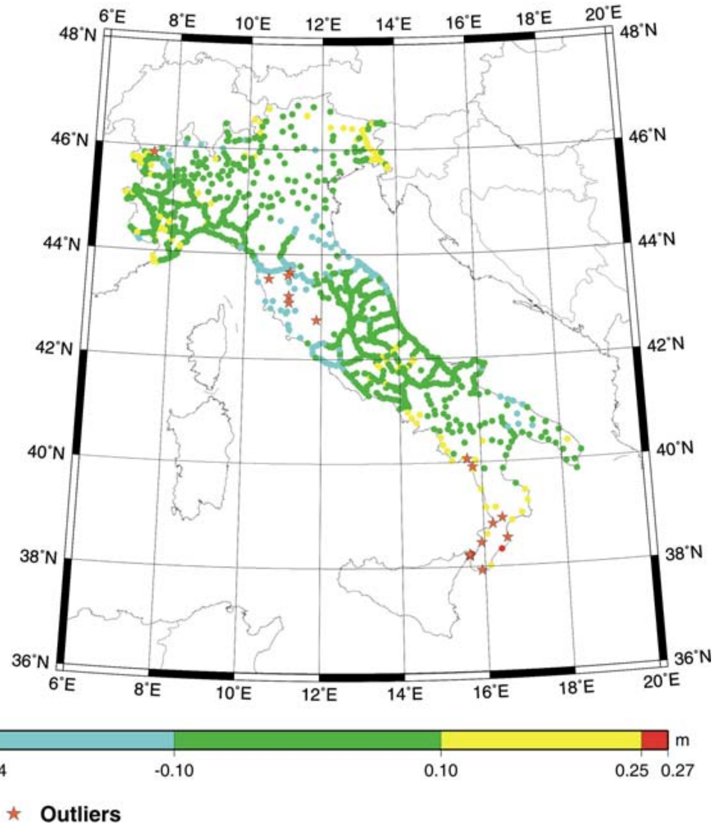

Figure 7. The residuals between GPS/leveling and EGM2008m after datum shift

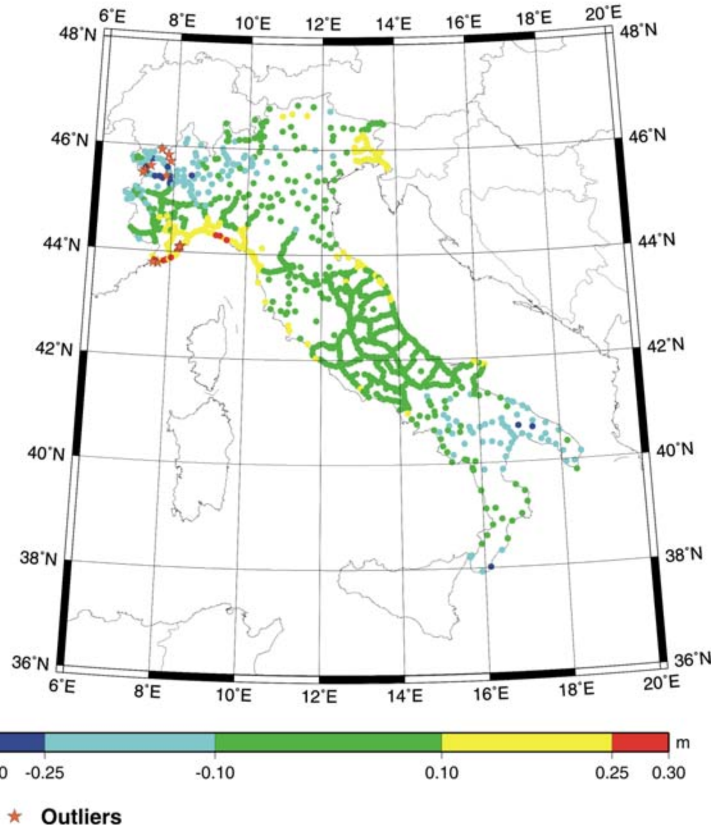

Figure 8. The residuals between GPS/leveling and ITALGEO05 after datum shift

By inspecting the two figures, one can see that these two geoid estimates have, in the whole, the same degree of accuracy. However, there are regions where ITALGEO05 fits GPS/leveling data better than EGM2008 and vice-versa. Also, possible outliers, that are marked during datum shift estimate, are in different regions for EGM2008 and ITALGEO05.

5. Conclusions

The EGM2008 global geopotential model proved to be very effective in fitting gravity and GPS/leveling in the Central Mediterranean area. This model is remarkably better than GPM98CR, previously the best model over the same area. Thus, the EGM2008 coefficients contain, even at high order, valuable information. Furthermore, its accuracy in fitting GPS/leveling data is equivalent (even slightly better) to the geoid estimate ITALGEO05. This regional geoid improves remarkably GPM98CR, which is used to model the low frequency component in the framework of the “remove-restore” technique. However, there are regions in which the EGM2008 fits better GPS/leveling than ITALGEO05, e.g. in the Northern part of the Alps and along the coast of Liguria. This is quite surprising since there the geopotential field is rough and a local geoid estimate should give better results. In fact, the “remove-restore” technique, which allows a detailed modeling of the terrain component, and the local data information should give a refined geoid estimate. This is not the case in the above mentioned regions; thus local geoid estimation procedure should be carefully checked to understand this behavior. Furthermore, an open question is the one related to the reference model to be used for reproducing the “low” frequency geopotential signal in local geoid estimation procedures. One could think to replace GPM98CR (in this test area) with EGM2008 and to apply the “remove-restore” method to get an improved geoid estimate. However, this is not so straightforward since the residuals obtained after EGM2008 and RTC reduction have a covariance structure that cannot be easily fitted with the standard covariance models. Hence, collocation cannot be efficiently applied. So, if collocation is to be used, new models must be studied and implemented. Thus, the results obtained in this test have shown the efficiency of the new geopotential model and have opened new interesting perspectives in geoid computation.

References

Barzaghi R., Borghi A., Carrion D., Sona G. (2008) - *Refining the estimate of the Italian quasi-geoid*, Bollettino di Geodesia e Scienze Affini, n°1.

Borghi A., Carrion D., Sona G. (2007) - *Validation and fusion of different databases in preparation of high resolution geoid determination* - Geophysical Journal International, 171 (2), pag. 539-549, ISSN 0956-540X.

Bottoni, G. and Barzaghi, R. (1993) - *Fast Collocation* - Bulletin Géodésique, Vol. 67, n° 2.

Heiskanen, W.A., Moritz, H. (1990) - *Physical Geodesy* - Institute of Physical Geodesy Technical University, Graz, Austria.

Morelli C., Pisani M., Gantar C. (1975) *Bathymetry, gravity and magnetism in the Strait of the Sicily and the Ionian Sea*, Bollettino di Geofisica teorica e applicata, XVII.

Surace, L. (1997) - *La nuova rete geodetica nazionale IGM95: risultati e prospettive di utilizzazione* - Bollettino di Geodesia e Scienze Affini, n° 3.

Tscherning, C.C., P. Knudsen and R. Forsberg (1994) - *Description of the GRAVSOFT package* - Geophysical Institute, University of Copenhagen, Technical Report.

Tscherning, C.C. (1994) - *Geoid determination by least-squares collocation using GRAVSOFT* - Lectures Notes of the International School for the Determination and Use of the Geoid. IGeS, DIIAR, Politecnico di Milano.

Wenzel, G. (1998) - *Ultra high degree geopotential models GPM98A, B and C to degree 1800* - Proceedings of the Joint Meeting of the International Gravity Commission and International Geoid Commission, September 7 -12, Trieste 1998. Bollettino di Geofisica Teorica ed Applicata.