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A Comparison Between Itagleo'95 and GPS/Leveling Data along the Coasts of Italy

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Abstract

In the last few years the number of GPS/Lev. data are increasing in order to investigate the geoidal undulations. In this paper the global model (OSU91A) and the Italian gravimetric quasigeoid (ITALGEO'95) are checked against two different kinds of GPS/Lev. data. Statistical and graphical results are reported.

1. Introduction

In the last few years the great amount of GPS/Lev. data has given rise to the problem of joining the gravity and GPS/Lev. observations.

In this paper two different kinds of GPS/Lev. data are used. The first GPS network (NET «A») is located along the coast of Italy. The geoidal undulation was obtained by the difference between ellipsoidal heights (using network adjustment of GPS data) and orthometric heights (extracted from description form of leveling benchmarks of the National Leveling network).

The second one, (NET «B») is in a small area located in the eastern part of the Po valley (North of Italy). The ellipsoidal and orthometric heights were obtained by simultaneous GPS survey and spirit leveling.

First of all both GPS/Lev. undulations are compared with OSU91A and ITALGEO'95. Undulation values of ITALGEO'95 have been computed by collocation method for each benchmark.

The presence of a trend between the theoretical geoidal undulations and the experimental ones has induced a reduction of data using different approaches.

The two different fitting models used are:

- regression plane (in the east part of the Po valley)
- S-transformations (along the coast of Italy).

After the trend has been removed a final comparison between the experimental global and national undulations are shown.

2. The Italian Quasigeoid ITALGEO95

In 1995 the new Italian quasigeoid has been estimated, based on gravity anomalies data in the area $36° \leq \varphi \leq 47°$, $6° \leq \lambda \leq 19°$, covering Italy and the surrounding seas (R. Barzaghi et al., 1996).

The estimation technique used is the well known remove-restore procedure (C.C. Tscherning, 1994), with the computation of ζ_r from Δg_r performed via Fast Collocation (G. Bottoni and R. Barzaghi, 1993), that allowed to get the gravimetric quasigeoid ITALGEO95, to be obtained on a $3' \times 3'$ grid, in a unique step.

The main improvements with respect to the previous Italian geoid (ITALGEO90, B. Benciolini et al., 1991) come from a set of updated gravity data, from the new detailed DTM (both data sets have been integrated with DTMs and gravity data available from the surrounding countries), from the use of Fast Collocation instead of simple Collocation (that made it necessary to break the computation of ITALGEO90 in eleven overlapping areas), from the use of the new global geopotential OSU91A (instead of IFE88), and from some minor refinements in the various steps of the remove restore procedure.

These improvements yield a much better agreement with GPS/levelling measurements in comparison with ITALGEO90.

In the estimation area three sets of gravity anomaly data have been merged together:

- the Italian gravity data base ;
- point gravity anomaly data coming from the BGI near the north-west Italian border, and on Corse Island;
- Morelli's gravity maps over Adriatic and Tyrrhenian seas (C. Morelli et al., 1975a, 1975b).

The Italian data set has been reduced and homogenised by selecting the gravity values closest to the centre of a regular $1' \times 1'$ grid and all the gravity data have been reduced to the same normal field (GRS80).

In order to compute the terrain effect on the whole prediction area, a DTM has been assembled in the area $34° \leq \varphi \leq 49°$, $4° \leq \lambda \leq 21°$, merging many different DTMs by bilinear interpolation to obtain a unique height data base with homogeneous grid mesh (7.5"x10").

The following DTMs have been considered:

- Italian DTM - data on land, on a regular geographical grid (7.5" × 10");
- Austrian DTM - (11.25" × 18.75");
- French DTM - Alps area and Corse (9" × 6");
- Swiss DTM - on a regular x,y grid (250m × 250m):
- German DTM - southern part (30" × 50");
- Morelli bathymetry - on sea surrounding Italy (5' × 7.5');
- ETOPO5U - on remaining parts (5' × 5').

Unfortunately, a large hole in gravity and height data occurs in the former Yugoslavian area and this could have affected the estimate in the north east corner of the prediction grid.

To avoid any interpolation problem in the comparisons between experimental and model undulation, quasigeoid point estimates have been computed i.e. the global geopotential model, the RTC effect and the residual component coming from collocation have been estimated directly on the GPS/levelling points.

3. GPS/Lev. networks

3.1 The coastal GPS/Lev. network (net "A")

A network spreading along nearly 4000 km of the Italian coast and which consist of about 1400 vertices was surveyed with the aim of constructing numerical cartography at a scale of 1:2000 along narrow State-owned bands of the Italian coast (nearly 100 m).

The GPS-surveyed cartography network consisted of new vertices established for this work as well as numerous trigonometric vertices and benchmarks belonging to the National trigonometric and levelling nets. Such vertices are necessary to transfer GPS data into National Italian Datum.

Measurement of the network baselines was carried out by collecting data on each vertex for at least 30 minutes with double-frequency P-code Trimble SSE receivers. The baseline lengths were generally 5 to 10 km long.

The whole area was subdivided into 79 coastal blocks, surveyed in succession and in an autonomous way. Each block was individually adjusted. Such a procedure was necessary because of the vastness of the area to be mapped and in order to simplify the project management.

Contiguous sub-networks have at least two common vertices so that a single network can be built.

All block measurements were joined together in a single network and an adjustment was performed; the global network includes 1432 vertices (which include more than 200 benchmarks) more than 83 off-centre trigonometric points and 2579 baselines.

The network is shown in Figure 1.

The «absolute» position of the network in WGS84 system was obtained by joining one of its vertices (V0) with the Matera IGS station, so that its WGS84 co-ordinates are estimated with a high level of precision.

3.2 GPS survey in the eastern part of the Po valley (net"B")

The GPS network was monumented using three dimensional self centring devices. A vertex located at Bologna University, was used as the reference station. Its absolute co-ordinates were obtained by a block adjustment with IGS permanent stations (Matera,Wettzell, Graz, Cagliari).

A large high precision levelling network was set up by local authorities, and connected to some benchmarks located in the stable zone of the Apennines (Castrocaro benchmark).

GPS static surveys were carried out during the same period as the spirit levelling survey using six Trimble dual frequency receivers 4000SST (Bitelli G. et al., 1994). The points were used as reference for a successive fast-static survey. Three-dimensional co-ordinates for about 90 points were obtained with a density of a point every 3 kilometres and quasi-homogeneous distribution (Figure 1). This density was chosen in order to obtain a reliable description of the high frequency components of the geoidal undulation in the successive surface interpolation due to local topographic effects.

The fast-static survey was conducted using Leica System200 and Trimble 4000SSE receivers over a period of a few days. The data obtained by Leica receivers was processed by software SKI and the Trimble dual-P code data by Gpssurvey and Geotracer software. The results obtained by network adjustment (95% confidence level) show an accuracy of about 2 cm. The practical application of this method requires a reduced baseline (<15km) between the points and the reference station and a session time ranging from 5 to 30 minutes. Moreover, it was necessary to measure the difference in height between the phase centre of the GPS antennas and the levelling benchmarks. The altimetric link was made by precise levelling set-ups using the classical high precision level Zeiss-Ni1 and the digital level Leica NA3000. All data are processed using the same reference system.

4. Comparison between experimental and theoretical values of geoid undulation

4.1 Network "A"

From the sequence of nearly 220 benchmarks included in the network it is possible to calculate an «experimental» value of geoid undulation. It must be stressed that the ellipsoidal heights are highly reliable due to a block adjustment and residual analysis error, while orthometric

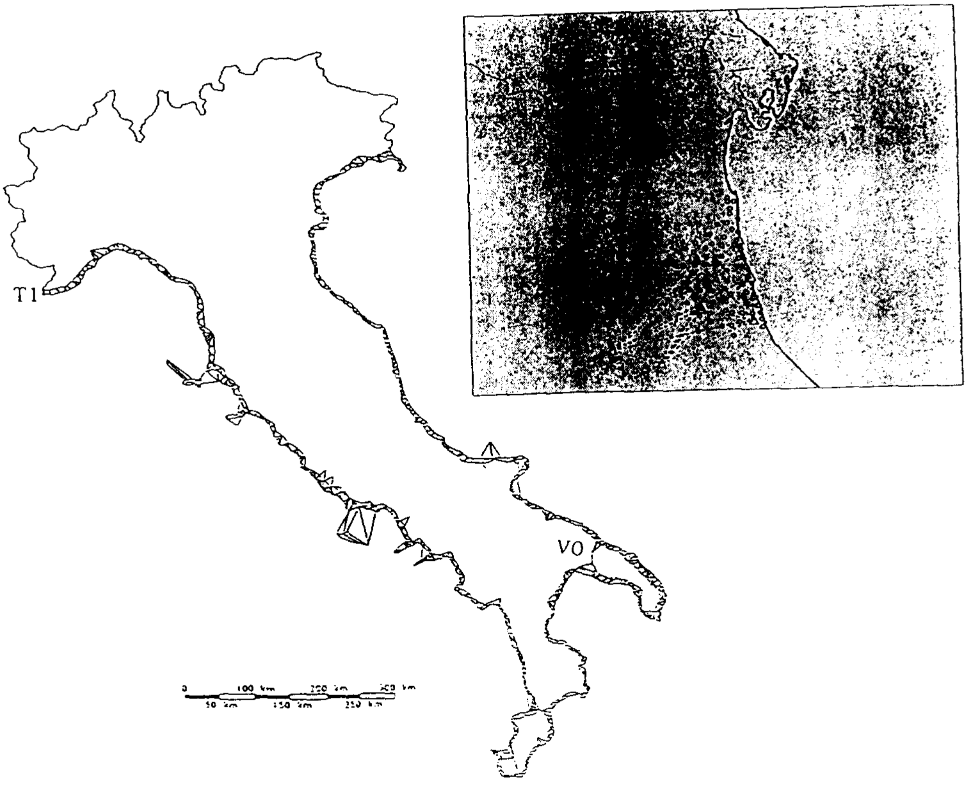


Figure 1 - Coastal network and the network established in the eastern part of the Po valley

heights of the benchmarks may be affected by outliers. Since the National Levelling-Net was surveyed many tens of years ago, some ground movement or damage to, and re-establishment of, benchmarks may have occurred.

The experimental value may be compared with mathematical model estimations, in particular that predicted by ITALGEO'95. Another available model is OSU91A, which is contained within the commercial software package used to process the raw GPS data.

The theoretical and the experimental undulations are reported in the graph of Figure 2, as a function of benchmark position along the sequence; this position is defined as the «distance» from the first benchmark, understood to be the progressive sum of the distances between subsequent benchmarks.

In Figure 3 the differences between experimental values and those forecast by theoretical models are reported. The experimental values seem to be in agreement with those of the Italian model.

The comparison between the experimental values of geoid undulation and those forecast by ITALGEO'95 model shows the presence of some systematic effects together with some variations distributed in a irregular way.

Such a difference increases in the north-south direction along both Tyrrhenian and Adriatic coasts.

The reason for the observed systematic effect in the differences might be related to datum problems.

In order to locate and then remove such a systematic effect, the undulations coming from the model were transformed on the experimental ones by means of a 7 parameters S-transformation performed according to Molodensky formulas:

$$
\begin{aligned}
a_1\, t_x + a_2\, t_y + a_3 t_z + a_4 s + a_5 e_x + a_6 e_y + a_7 e_z &= \phi^{exp} - \phi^{mod} \\
b_1\, t_x + b_2 t_y + b_3 t_z + b_4 s + b_5 e_x + b_6 e_y + b_7 e_z &= \lambda^{exp} - \lambda^{mod} \\
c_1\, t_x + c_2\, t_y + c_3 t_z + c_4 s + c_5 e_x + c_6 e_y + c_7 e_z &= N^{exp} - N^{mod}
\end{aligned}
$$

In Figure 4 the differences between the experimental undulation and the theoretical one are shown both before and after the S-transformation: the trend is removed although there are some zones in which high differences are still present. These last effects are probably due to the poor accuracy of the field form's height value.

The whole data set of the transformation residuals has been divided into three parts corresponding to the west, south and east coast. The frequency histogram (Fig.5) related to the east coast shows different behaviour from the other ones. The reason for high residual values in the east coast is more likely related to some errors present in the orthometric heights taken from monographs, rather than to some effects due to the model.

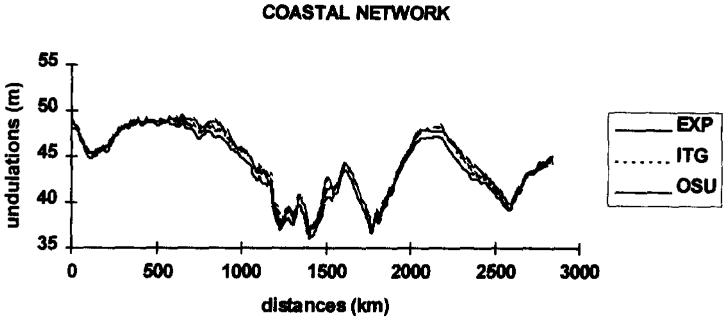


Figure 2 - Geoid undulation

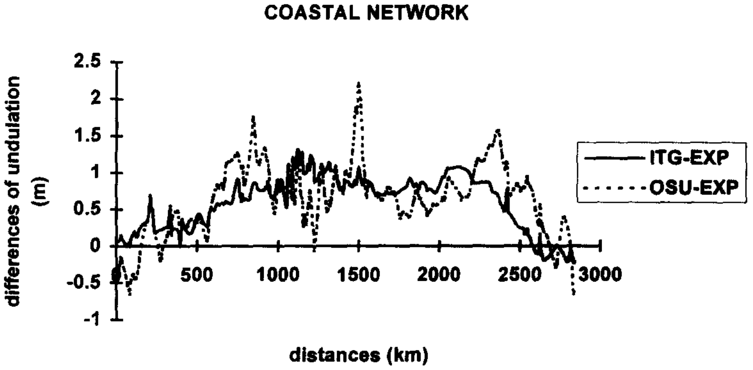


Figure 3 - Differences between experimental values and mathematical predictions of geoid undulation

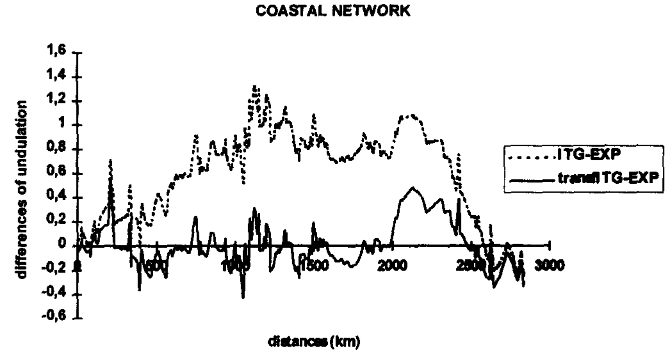


Figure 4 - Differences between experimental values and Italgeo '95 predictions of geoid undulation before and after the S-transformation

4.2 Network "B"

In the network «B», which has a higher density of points and a small dimension the observed differences are from 10 to 30 cm.

The point differences between the GPS and the Italian gravimetric geoid show systematic behaviour (Fig.6). To model this effect the network «B» was fit with a regression plane using «points» X, Y, N in order to estimate the three coefficients:

$aX + bY + c = N^{exp} - N^{mod}$

where GPS data are assumed as reference. This regression plane was then subtracted from the ITALGEO'95 geoidal undulation. The results of the comparison are shown graphically in Figure 7 and by statistics in Table 2.

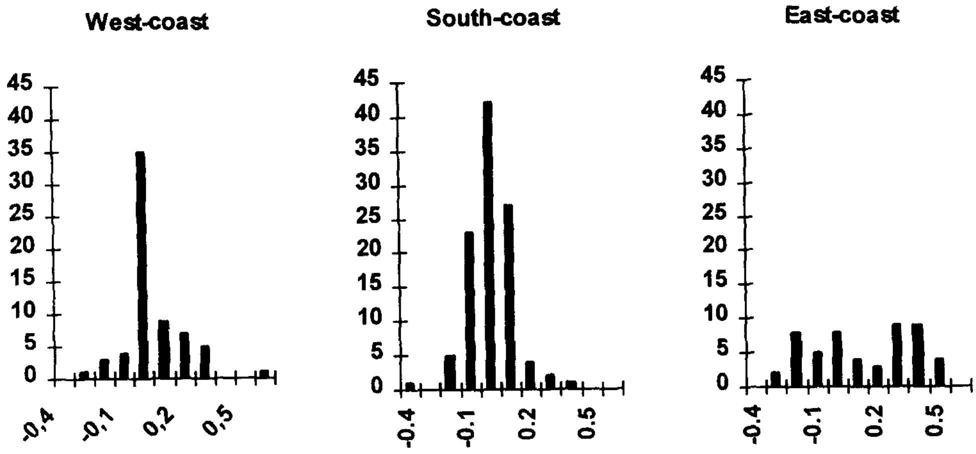


Figure 5 - Frequency histograms of the differences between experimental values and Italgeo'95 predictions after the S-transformation

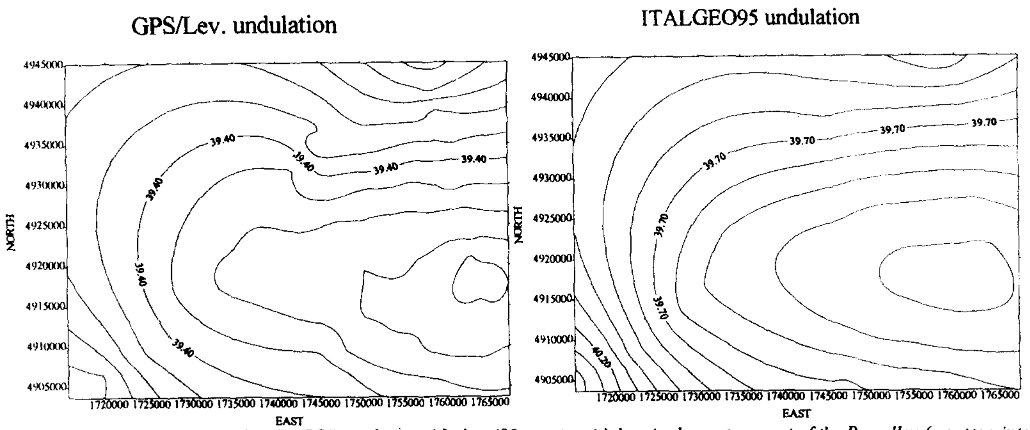
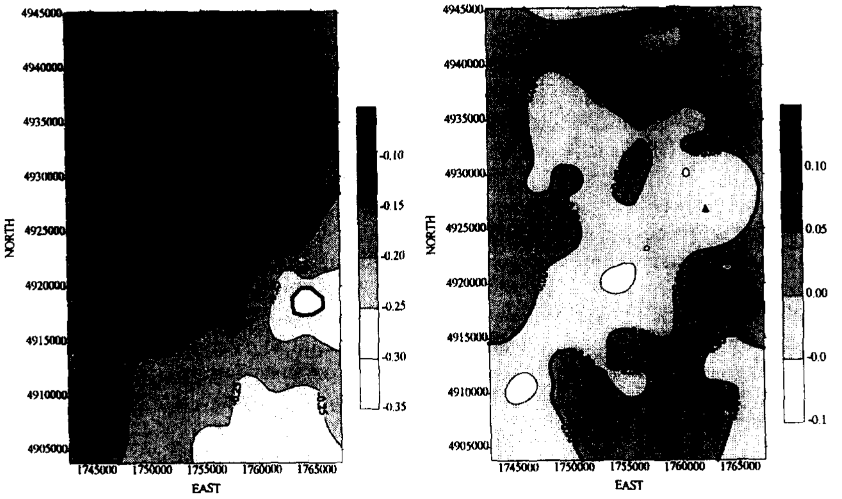


Figure 6 - Geoidal undulation calculated with GPS/Lev. data and Italgeo'95 quasigeoid data in the eastern part of the Po valley.(contour interval 0.1m)



a) b)

Figure 7 - Difference between the GPS/Lev. and Italgeo'95 undulation before (a) and after (b)the removal of the regression plane in the eastern part of the Po valley.

Point	Net	North	East	N^{ITG95}	N_A^{exp}	N_A^{TRA}	N_B^{exp}	N_A^{TRA}
1003C	B	4908663.	1767109.	39.339			39.131	39.130
ID28/6	A	4909935.	1767213.	39.329	39.320	39.121		
1001C	B	4910653.	1766708.	39.342			39.076	39.087
657	B	4920312.	1764277.	39.291			38.995	39.075
ID 1/7	A	4920323.	1764256.	39.269	39.272	39.073		
2122EDP	B	4921948.	1763750.	39.299			39.022	39.089
7C	B	4929269.	1761263.	39.452			39.295	39.270
ID22/4	A	4930458.	1761235.	39.475	39.550	39.291		
1/10D	B	4930392.	1770543.	39.486			39.360	39.308

Table 1- Comparison between undulation of close benchmarks belonging to the net «A» and net «B» (values in meters)

Eastern part of the Po valley		
	GPS/Lev.- Italgeo95	*GPS/Lev. - Italgeo95 (corr. by regression plane)*
Mean	-0.19	0
Min	-0.33	-0.08
Max	-0.07	0.10
St. Dev	0.05	0.03

Table. 2 - Statistical parameters for the difference between GPS/Lev and ITALGEO95 (corrected by a regression plane) undulation values. Values in meters.

5. Final considerations

The comparison between ITALGEO95 and the GPS/levelling data described in this paper is of particular interest to assess the precision of the quasigeoid estimation. Due to the structure of the two GPS/levelling networks, both global and local comparisons were carried out to identify possible low and high frequency distortions. High gradient quasigeoid areas are crossed by the GPS/levelling lines and the comparison can reveal possible high frequency problems in the ITALGEO95 estimate. On the other hand, the large area covered by the coastal network is suitable for datum shift and other low frequency distortions estimated in the residuals between GPS/levelling and the quasigeoid

The two considered networks don't have any common points even if they utilise the same coastal levelling line which was instituted by the local authorities in order to check subsidence.

Nevertheless, three benchmarks which are part of network «A» fall in the area covered by network «B» and therefore may be analysed in comparison with the nearest benchmarks in network «B». Some data are reported in Table 1. This table shows that the geoidal heights transformed by means of experimental data «A» (N-A^{TRA}) are very close to the results obtained in a similar way from the experimental data «B» (N-B^{TRA}).

References

Al-Bayari O., Bitelli G., Capra A., Donimici D., Ercolani E., Folloni G., Gandolfi S., Pellegrinelli A., Unguendoli M., Vittuari L., (1996): *A local geoid in the SOUTH-EAST of the Po Valley.* Proc. session G7 «Techniques for local geoid determination» EGS XXI Assembly, 96:2 Tziavos and Veermer eds.

Barbarella M., Bianco A., Carella P., Fiani M. (1996) - *Evaluation of geoid undulation using GPS measurements along the southern Italian coast.* Reports on Surveying and Geodesy - In memory of Prof. Alberto Gubellini and Prof. Giorgio Folloni. Editor M. Unguendoli, Ed. Nautilus, Bologna, pp. 94-104.

Barbarella M., Bianco A., Carella P., Fiani M. (1996) - *Confronto tra l'ondulazione geoidica sperimentale e prevista lungo la costa italiana.* Meeting of 15° Convegno GNGTS, Roma, November 6th-8th.

R. Barzaghi, M.A. Brovelli, A. Manzino, D. Sguerso, G. Sona (1996). *The new Italian quasigeoid ITALGEO95.* Bollettino di Geodesia e Scienze Affini, n. 1.

B. Benciolini, A. Manzino, D. Sguerso (1991). *ITALGEO90: risultati globali, validazioni e confronti.* Proceedings of the 10th annual Meeting of GNGTS, CNR, Rome, November 6th-8th.

Bitelli G., Capra A., Dominici D., Folloni G., Radicioni F., Unguendoli M., Vittuari L., (1994): *GPS measurements for ground subsidence monitoring and geoid computation in the Ravenna area,* Proceedings XX FIG Congress, Melbourne, pp 30-39,

G. P. Bottoni, R. Barzaghi (1993). *Fast Collocation.* Bulletin Geodesique, vol. 67.

C. Morelli, M. Pisani, C. Gantar (1975a). *Geophysical Anomalies and Tectonics in the Western Mediterranean.* Bollettino di Geofisica teorica ed applicata, vol. XVII.

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

C.C. Tscherning (1994). *Geoid determination by least-squares collocation using GRAVSOFT. Lecture notes of the* International School for the determination and use of the geoid, DIIAR - Politecnico di Milano, Milano.