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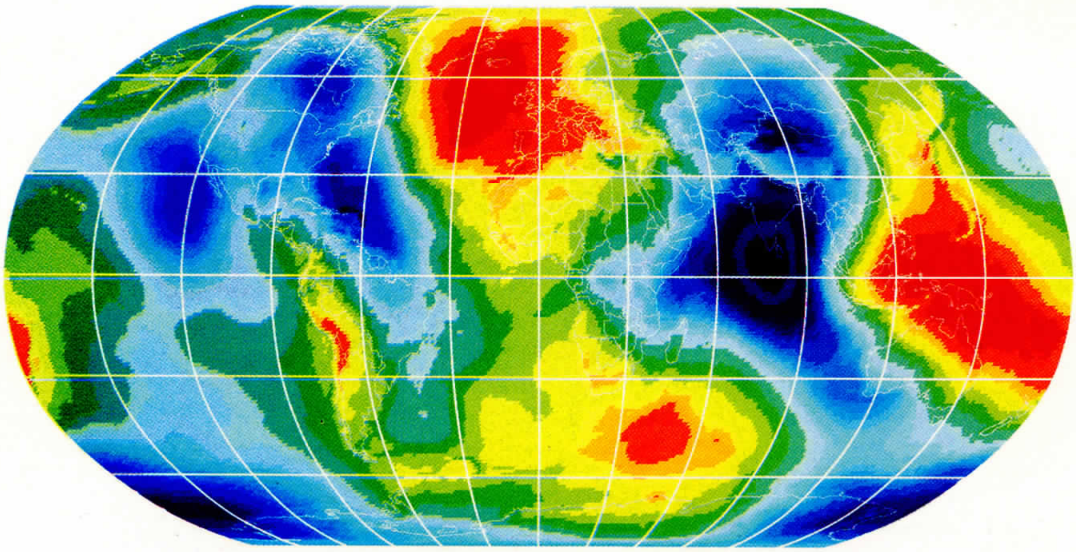
THE EARTH GRAVITY MODEL EGM96:
TESTING PROCEDURES AT IGeS



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THE EARTH GRAVITY MODEL EGM96: TESTING PROCEDURES AT IGES

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Summary

GEOPOTENTIAL MODELS VALIDATION AT IGES

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In the framework of the new DMA - NASA global gravity models validation, several tests were performed at IGES in Politecnico di Milano. Different data sets in the Mediterranean area were considered; they are listed in the following:

a) the Italian quasigeoid (ITALGEO95);

b) the GEOMED geoid;

c) the gravity data base used in the computation of the Italian quasigeoid;

d) the Italian data base of the deflection of the vertical;

e) GPS/leveling data in Italy;

f) absolute gravity measurements in Europe.

For each data set and for each model (also the OSU91A model was considered), usual statistics of the observations and of the differences between observed and model values were computed.
The model effects were derived using the f477 program by prof. R.H. Rapp (Rapp 1994).

THE ITALIAN QUASIGEOID

The Italian quasigeoid (Barzaghi et al. 1996) was computed on a regular grid of $3' \times 3'$ over the area

$$36 \leq \varphi \leq 47 \quad 6 \leq \lambda \leq 19 \ .$$

A slightly modified version of the usual remove-restore technique was applied, based on the OSU91A model, on a 250m × 250m DTM and on Fast Collocation. The main problem occurred in the computation was the one related to the reduction of the Corsica Island gravity data base. It was noticed that the OSU91A model did not take into account gravity and geoid signals on that island; this problem seems to be solved with the new models which improved a lot in that area. Furthermore, no data were present in the gravity data base used in the quasigeoid computation on the former Yugoslavia area, which was not taken into account in the comparisons.
The statistics of the original data and of the differences between the ITALGEO95 values and the corresponding values of the various geopotential models are collected in Table 1a and Table 1b. In Fig. 1 the contour plot of the differences between ITALGEO95 and the EGM96 model is presented.

	total values	mean (m)	st. dev. (m)	min (m)	max (m)
ITALGEO95	50231	44.01	5.31	25.37	54.96

Table 1a. - The Italian quasigeoid ($N_{ITALGEO95}$)

model	total values	mean (m)	st. dev. (m)	min (m)	max. (m)
osu91a	50231	0.17	0.73	-1.85	6.40
x01	50231	-0.11	0.45	-1.61	1.62
x02	50231	-0.12	0.41	-1.75	1.61
x03	50231	-0.13	0.48	-1.53	1.75
x04	50231	-0.13	0.47	-1.52	1.69
x05	50231	-0.14	0.46	-1.59	1.58
EGM96	50231	-0.09	0.43	-1.70	1.86

Table 1b. - The Italian residual quasigeoid ($N_{ITALGEO95}$-N_{MOD})

The maximum value of 6.4 m in OSU91A statistics occurs in the Corsica area, which is missing in the computation of OSU91A, and was introduced as local correction in ITALGEO95 computation.
The residual bias of 16 cm between ITALGEO95 and OSU91A is mostly accounted for by the residual terrain effect, here not included, and reduces to 0.08 m once RTC is taken into account.
Tab.1b shows a bias in residual geoid undulations in comparing OSU91A with the new models (ΔN_{OSU}-ΔN_{X0*}~25-30 cm), partly due to ITALGEO95 estimate based on OSU91A, and a clear improvement in standard deviation (from $\sigma_{\Delta N}$~73 cm to $\sigma_{\Delta N}$ ~ 40-47 cm).

THE GEOMED GEOID

The GEOMED project led to the determination of the geoid over the Mediterranean Sea (Barzaghi et al. 1992; Barzaghi et al. 1993; Arabelos et al. 1994; Barzaghi, Sona 1994). The computation was done in five overlapping areas merged together into a unique grid. The five original grids have regular spacing of 5' × 5' and the following bounds:

$35 \le \varphi \le 43$	$-5 \le \lambda \le 10$
$30 \le \varphi \le 47$	$8 \le \lambda \le 20$
$30 \le \varphi \le 41.5$	$17 \le \lambda \le 36$
$35 \le \varphi \le 45$	$5 \le \lambda \le 15$
$30 \le \varphi \le 40$	$15 \le \lambda \le 25$

In each estimate the remove-restore technique was used; the OSU91A model and the TUG87 DTM were considered in the westernmost area while the remaining estimates were computed using the OSU91A and the ETOPO5U DTM. The statistics of the original values and of the differences between GEOMED and model undulations are in Table 2a and Table2b. In Fig.2 are the contour lines of the differences between GEOMED and EGM96.

	total values	mean (m)	st. dev. (m)	min (m)	max. (m)
GEOMED	72144	35.99	11.86	1.29	55.65

Table 2a. - The GEOMED geoid (N_{GEOMED})

model	total values	mean (m)	st. dev. (m)	min (m)	max. (m)
osu91a	72144	-0.11	1.23	-4.73	6.59
x01	72144	-0.32	1.27	-4.62	8.18
x02	72144	-0.31	1.20	-4.60	7.77
x03	72144	-0.29	1.24	-4.47	7.34
x04	72144	-0.29	1.24	-4.46	7.42
x05	72144	-0.29	1.23	-4.59	7.34
EGM96	72144	-0.31	1.17	-4.89	7.26

Table 2b. - The GEOMED residual geoid (N_{GEOMED}-N_{MOD})

The final result of the merging procedure has to be considered a relative geoid, as the computation areas have been unified removing the biases between them, and considering the central area as the reference one; therefore the biases between global models and GEOMED are not significant.

THE ITALIAN GRAVITY DATA BASE

The Italian gravity anomaly data base was reduced to an average spacing of 5' among gravity values: gravity is in the IGSN71 system and the normal field is the GRS80 reference field. As pointed out before, the Corsica Island is now properly taken into account by the new models. Two different tests were performed: the former was on the residual values, i.e. observed anomalies minus contributions of the model and of the RTC; the latter was on the observed values minus the model contribution only.
The statistics of the original data and of the differences are in Table 3a, Table 3b, and Table 3c respectively. The map of the point positions and the contour plot of the observed values minus the geopotential model contributions are in Fig.3 - Fig.4.

	total values	mean (mgal)	st.dev.(mgal)	min (mgal)	max (mgal)
ITGRAV	16414	7.49	48.03	-162.36	249.35

Table 3a. - The Italian gravity anomaly data base (obs.)

model	total values	mean (mgal)	st.dev.(mgal)	min (mgal)	max (mgal)
osu91a	16414	0.48	16.61	-197.34	123.30
x01	16414	0.42	13.96	-181.46	109.53
x02	16414	0.48	14.03	-185.63	107.17
x03	16414	0.35	14.01	-181.22	110.12
x04	16414	0.33	14.26	-183.81	109.69
x05	16414	0.33	14.63	-185.53	111.40
EGM96	16414	0.51	14.47	-188.32	108.59

Table 3b. - Italian residual gravity anomaly (obs.- mod. - RTC)

model	total values	mean (mgal)	st.dev.(mgal)	min (mgal)	max (mgal)
osu91a	16414	-6.00	34.03	-242.84	224.43
x01	16414	-6.06	31.34	-236.32	178.48
x02	16414	-6.00	31.67	-242.86	177.32
x03	16414	-6.13	31.24	-235.74	177.82
x04	16414	-6.15	31.37	-240.98	175.91
x05	16414	-6.15	31.52	-247.00	173.89
EGM96	16414	-5.97	31.85	-249.24	176.87

Table 3c. - Italian residual gravity anomaly (obs.- mod.)

A general improvement can be observed in residual gravity anomalies statistics when considering the new geopotential models; the st.dev. improves from 34 mgal to 31.5 mgal (obs-models) and from 16.7 mgal to 14-14.7 mgal once RTC is taken into account.

In order to check the behaviour in regions with high variability in topography and in geoid undulation, local statistics have been computed in the area $44 \leq \varphi \leq 47$, $6 \leq \lambda \leq 13$ comprising Alps and Po Valley; the results are summarized in Table 3d and 3e.

model	total values	mean (mgal)	st.dev.(mgal)	min (mgal)	max (mgal)
osu91a	2774	-2.52	22.05	-197.34	114.14
x01	2774	0.79	18.26	-181.46	109.53
x02	2774	-0.10	18.06	-185.63	107.17
x03	2774	1.41	18.27	-181.22	110.12
x04	2774	1.33	18.13	-183.81	109.69
x05	2774	1.47	18.57	-185.53	111.40
EGM96	2774	-0.48	18.54	-188.32	108.59

Table 3d. - Residual gravity anomaly in Northern Italy (obs.- mod. - RTC)

model	total values	mean (mgal)	st.dev.(mgal)	min (mgal)	max (mgal)
osu91a	2774	-34.56	55.19	-242.84	138.55
x01	2774	-31.26	51.62	-236.32	139.99
x02	2774	-32.15	52.29	-242.86	136.14
x03	2774	-30.64	51.62	-235.74	140.76
x04	2774	-30.72	52.12	-240.98	137.94
x05	2774	-30.58	52.71	-247.00	135.59
EGM96	2774	-32.53	52.72	-249.24	133.63

Table 3e. - Residual gravity anomaly in Northern Italy (obs.- mod.)

As can be easily observed comparing Tab.3d, 3e with Tab.3b, 3c, the statistics in this restricted area are markedly worse with respect to the whole computation area, particularly before considering the terrain effect.
The set of new models, however, still shows an improvement in comparison with OSU91A.

THE DEFLECTIONS OF THE VERTICAL

The deflections of the vertical over Italy have been measured and collected from IGMI (Istituto Geografico Militare Italiano, the Italian national survey bureau) (Coticchia et al., 1995). They have been measured in the national datum and then transferred to the WGS84 geocentric datum. As for the gravity anomaly data base, two comparisons have been carried out: the former is on the differences between observed minus model and RTC contributions; the latter is on the differences between the observed and the model values. Statistics are in Table 4a, Table 4b and Table 4c: data distribution is in Fig. 5.

model	total values	mean (")	st. dev. (")	min (")	max.(")
ξ	264	-2.63	9.55	-31.60	17.00
η	232	3.71	9.03	-11.50	30.60

Table 4a. - Deflection of the vertical (obs.)

	component ξ (")					component η (")				
model	N.val	mean	st.dev	min	max	N.val	mean	st.dev	min	max
osu91a	264	0.05	3.40	-10.07	13.21	232	-0.17	3.01	-10.32	8.37
x01	264	-0.47	2.76	-10.40	10.31	232	0.22	2.59	-6.95	7.78
x02	264	-0.49	2.73	-10.37	10.25	232	0.11	2.61	-7.03	8.00
x03	264	-0.50	2.77	-10.52	10.39	232	0.26	2.61	-7.02	7.95
x04	264	-0.50	2.79	-10.80	10.40	232	0.21	2.63	-6.97	7.65
x05	264	-0.54	2.86	-11.38	10.59	232	0.25	2.72	-7.62	8.38
egm96	264	-0.48	2.78	-11.01	10.10	232	0.14	2.67	-7.50	8.50

Table 4b. - Deflection of the vertical (obs. - model - RTC)

	component ξ (")					component η (")				
model	N.val	mean	st.dev	min	max	N.val	mean	st.dev	min	max
osu91a	264	0.24	5.31	-17.74	16.85	232	-0.13	4.66	-16.55	17.68
x01	264	-0.29	5.02	-18.52	15.42	232	0.26	4.38	-13.65	16.69
x02	264	-0.30	4.93	-17.96	15.26	232	0.15	4.42	-14.19	16.74
x03	264	-0.32	5.03	-18.55	15.36	232	0.30	4.39	-13.59	17.00
x04	264	-0.32	4.99	-18.18	15.37	232	0.26	4.40	-13.85	16.81
x05	264	-0.36	4.91	-17.71	15.64	232	0.29	4.44	-13.91	17.01
egm96	264	-0.30	4.87	-17.64	15.57	232	0.18	4.44	-14.09	16.86

Table 4c. - Deflections of the vertical (obs. - model)

The main difference in the statistics of the components ξ , η derived by the new set of models is in the change of sign of the mean values, indicating that an average tilt between OSU91A and the new models is present; this can be explained with a difference in the reference system used for the new global models.

GPS/LEVELING IN ITALY

Several GPS/leveling campaigns have been performed in the Italian area (Surace, 1994; Asili et al. 1995; Achilli et al. 1994). The most relevant among them have been selected for the comparisons with the geopotential models: the Tyrrhenian geotraverse, the IGMI campaign in the southern part of Italy and measurements covering the Sardinia Island. (see Fig. 6). The statistics of the original values are in Table 5a, Table 6a and Table 7a. The statistic of the observed minus the model values are in Table 5b, Table 6b and Table 7b, and in Table 5c, Table 6c, Table 7c the residual terrain correction (RTC) is also subtracted.

total values	mean (m)	st. dev.(m)	min (m)	max. (m)
28	47.03	2.45	39.60	49.43

Table 5a. - Tyrrhenian Geotraverse (obs.)

model	total values	mean (m)	st. dev.(m)	min (m)	max. (m)
osu91a	28	0.02	0.36	-0.54	0.87
x01	28	0.07	0.22	-0.34	0.66
x02	28	0.10	0.22	-0.29	0.63
x03	28	-0.03	0.22	-0.45	0.54
x04	28	-0.08	0.21	-0.48	0.41
x05	28	-0.09	0.22	-0.56	0.36
EGM96	28	0.18	0.25	-0.29	0.79

Table 5b. - Tyrrhenian Geotraverse (obs. - mod.)

model	total values	mean (m)	st. dev.(m)	min (m)	max. (m)
osu91a	28	-0.49	0.24	-0.92	0.01
x01	28	-0.44	0.20	-0.80	-0.13
x02	28	-0.41	0.20	-0.79	0.02
x03	28	-0.54	0.25	-0.90	-0.13
x04	28	-0.59	0.30	-1.07	-0.11
x05	28	-0.60	0.32	-1.15	-0.10
EGM96	28	-0.33	0.20	-0.67	0.01

Table 5c. - Tyrrhenian Geotraverse (obs. - mod. - RTC)

total values	mean (m)	st. dev.(m)	min (m)	max. (m)
29	42.41	2.74	36.37	48.21

Table 6a. - IGMI campaign (obs.)

model	total values	mean (m)	st. dev. (m)	min (m)	max. (m)
osu91a	29	-0.65	0.50	-1.66	0.79
x01	29	-0.73	0.40	-1.43	0.35
x02	29	-0.67	0.31	-1.40	0.18
x03	29	-0.89	0.48	-1.53	0.43
x04	29	-0.96	0.46	-1.61	0.28
x05	29	-0.99	0.47	-1.67	0.29
EGM96	29	-0.64	0.40	-1.36	0.36

Table 6b. - IGMI campaign (obs. - mod.)

model	total values	mean (m)	st. dev. (m)	min (m)	max. (m)
osu91a	29	-1.29	0.48	-1.89	-0.10
x01	29	-1.38	0.39	-1.96	-0.54
x02	29	-1.31	0.36	-2.01	-0.71
x03	29	-1.54	0.43	-2.12	-0.46
x04	29	-1.60	0.42	-2.29	-0.61
x05	29	-1.64	0.44	-2.40	-0.60
EGM96	29	-1.29	0.32	-1.90	-0.53

Table 6c. - IGMI campaign (obs. - mod. - RTC)

total values	mean (m)	st. dev.(m)	min (m)	max. (m)
29	46.99	0.84	45.36	48.16

Table 7a. - Sardinia Island (obs.)

model	total values	mean (m)	st. dev.(m)	min (m)	max. (m)
osu91a	29	-0.74	0.30	-1.40	-0.26
x01	29	-1.38	0.29	-1.83	-0.80
x02	29	-1.22	0.29	-1.89	-0.74
x03	29	-1.45	0.30	-1.87	-0.84
x04	29	-1.50	0.30	-1.92	-0.87
x05	29	-1.49	0.29	-1.92	-0.89
EGM96	29	-1.11	0.28	-1.70	-0.59

Table 7b. - Sardinia Island (obs. - mod.)

model	total values	mean (m)	st. dev.(m)	min (m)	max. (m)
osu91a	29	-1.39	0.27	-1.88	-0.65
x01	29	-2.02	0.21	-2.64	-1.63
x02	29	-1.87	0.23	-2.37	-1.39
x03	29	-2.10	0.21	-2.70	-1.68
x04	29	-2.14	0.21	-2.76	-1.74
x05	29	-2.14	0.20	-2.75	-1.73
EGM96	29	-1.76	0.21	-2.27	-1.28

Table 7c. - Sardinia Island (obs. - mod. - RTC)

The differences among the average biases of Tab.5, Tab.6 and Tab.7 are not significant, as the GPS values come from different campaigns which were not jointly adjusted.
However, a general behaviour can be found through the GPS campaigns and also in the comparisons with ITALGEO95 and GEOMED geoid estimates (see Tab.1b and 2b): it is quite evident the grouping of X03, X04, X05 test models, as well as a similarity in the behaviour of the final EGM96 model with the X02 model.

THE ABSOLUTE GRAVITY DATA BASE

Absolute gravity measurements in the European area have also been taken into account in our tests. The normal GRS80 gravity field have been removed from the observed values and then the model contribution have been subtracted. The locations of the absolute gravity stations are plotted in Fig. 7 and the corresponding statistics are in Table 8a and Table 8b.

total values	mean (m)	st. dev.(m)	min (m)	max. (m)
43	31.13	61.54	-126.60	132.39

Table 8a. - Gravity anomaly derived from absolute gravity measurements (obs.)

model	total values	mean (mgal)	st.dev.(mgal)	min (mgal)	max. (mgal)
osu91a	43	5.59	37.02	-93.49	79.53
x01	43	5.94	38.79	-101.62	85.89
x02	43	5.05	39.02	-105.45	84.59
x03	43	5.91	39.00	-103.23	86.03
x04	43	5.26	38.94	-104.98	86.22
x05	43	5.01	38.72	-105.55	86.31
EGM96	43	4.77	38.58	-106.26	83.89

Table 8b. - Absolute gravity measurements (obs. -mod.)

For this kind of measurements it is not possible to take into account the residual terrain effect, as it is not available a suitable DTM on Europe.

CONCLUSIONS

A general improvement of the new set of geopotential models in comparison with OSU91A model is clearly shown by the statistics reported through the paper, in terms of mean and standard deviation of residual quantities.
The final model EGM96 proves to be the best among the new models in terms of geoid undulation, at least in global comparisons with ITALGEO95 and GEOMED (comparisons with geotraverses give a not so clear result), but the same conclusion cannot be stated if the different functional Δg is considered.

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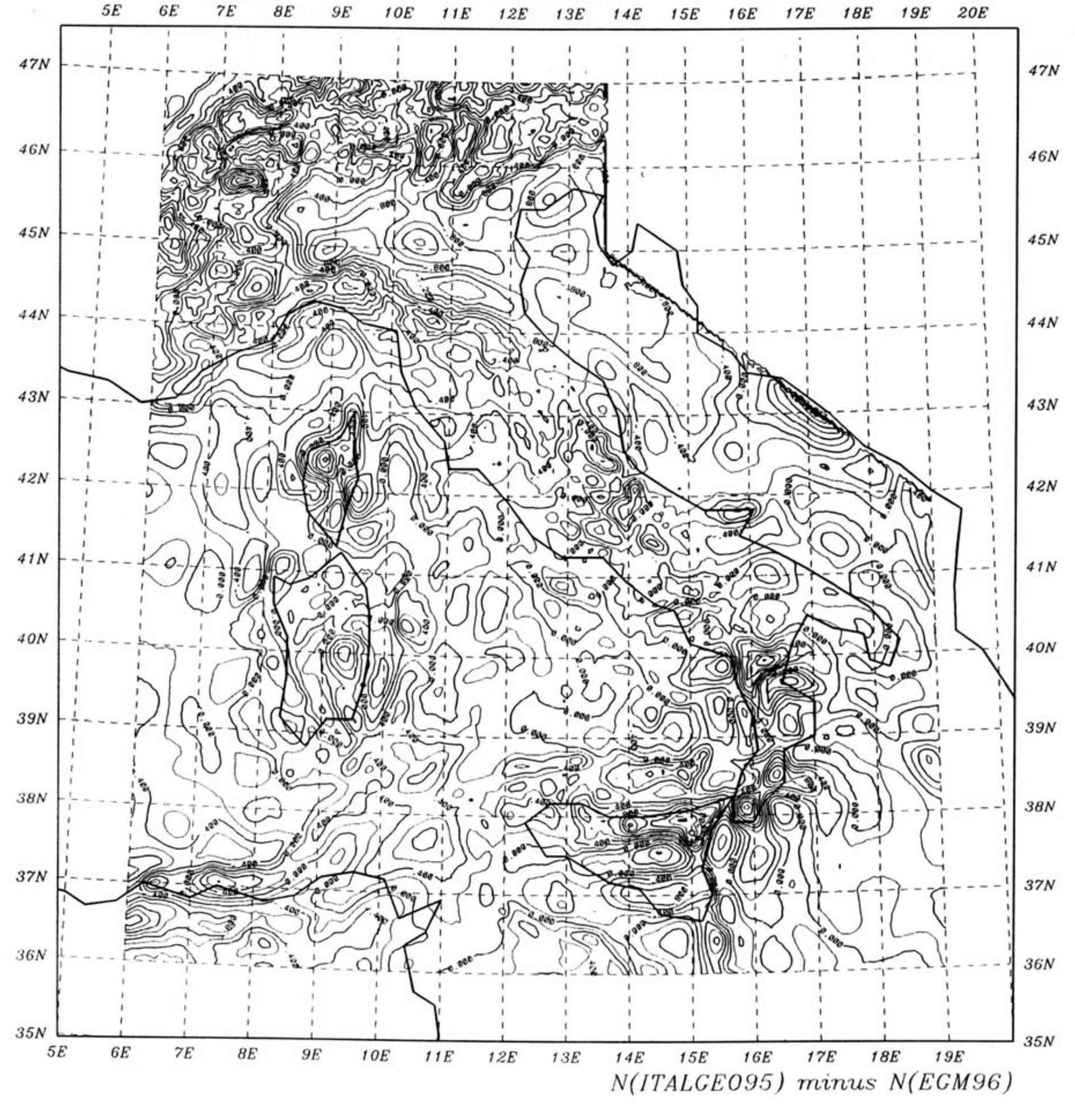

Fig. 1: N ITALGEO95 minus EGM96

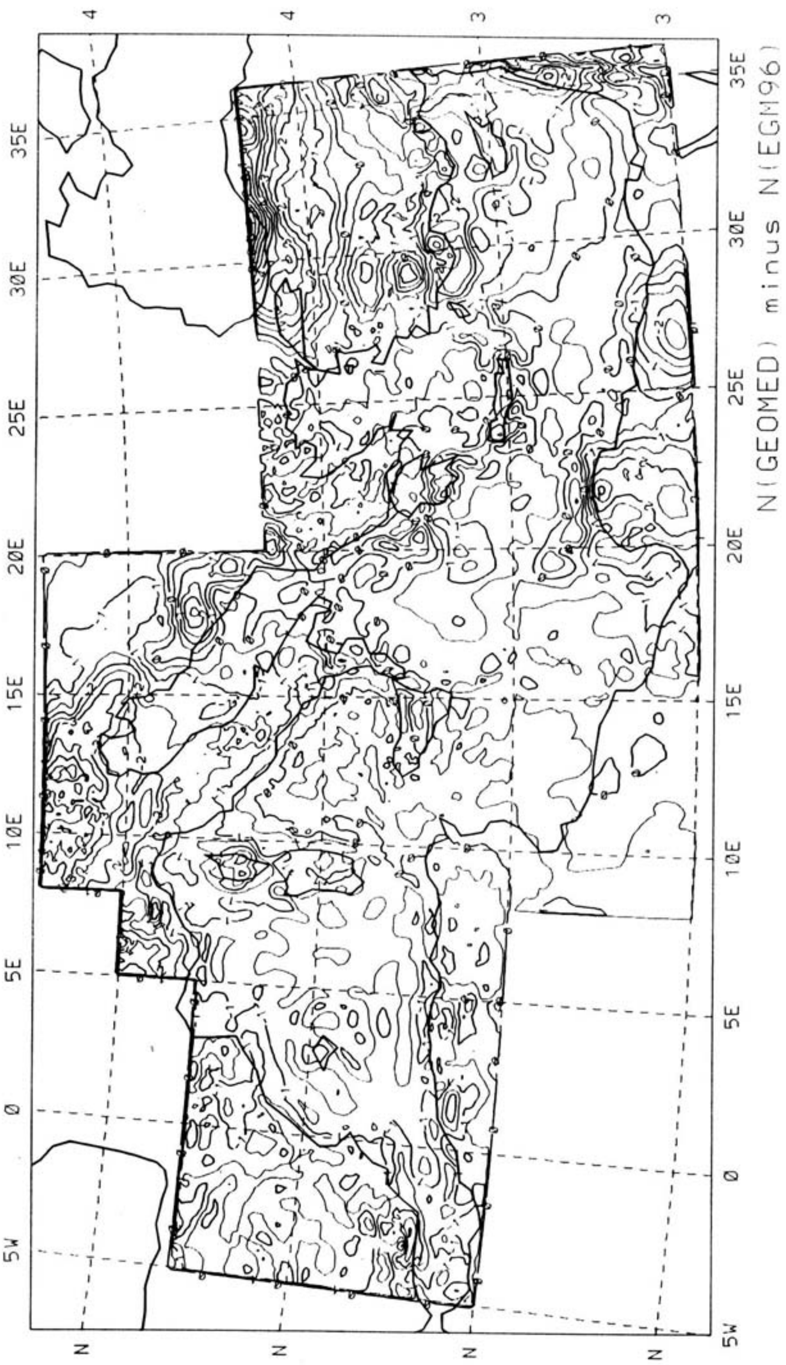

Fig. 2: N GEOMED minus EGM96

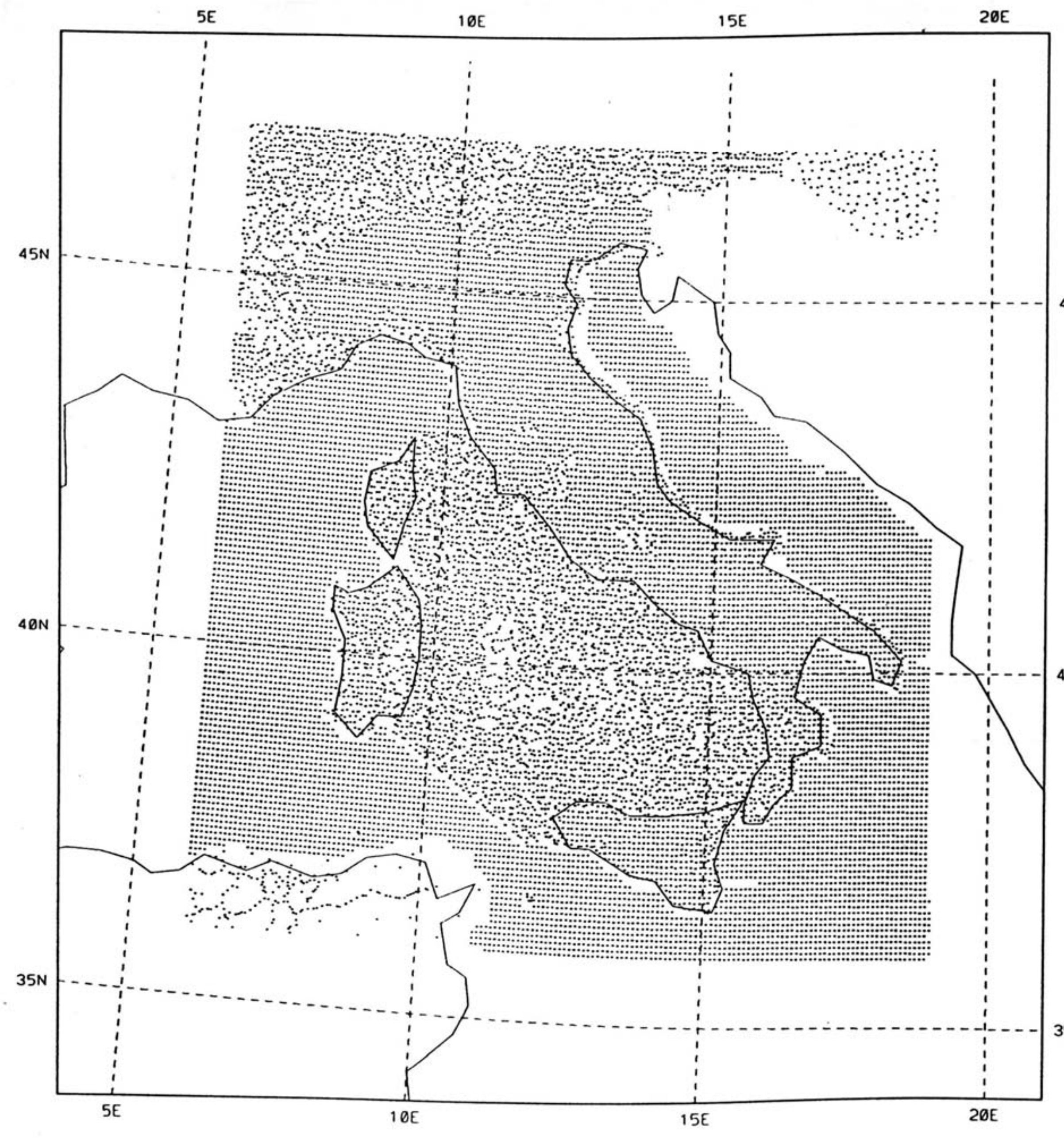

Fig. 3: gravity anomaly data base

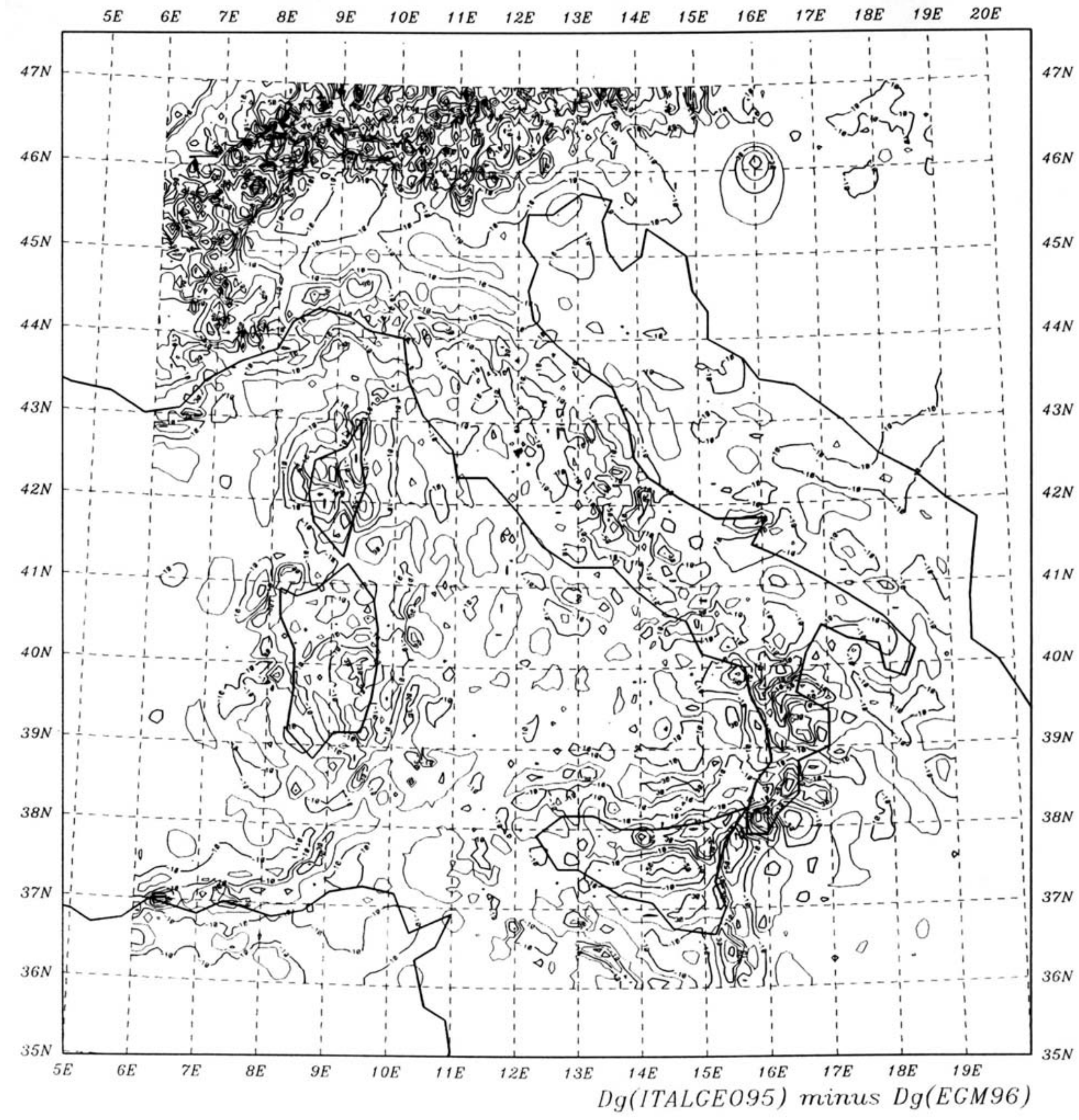

Fig. 4: Δg observed minus EGM96

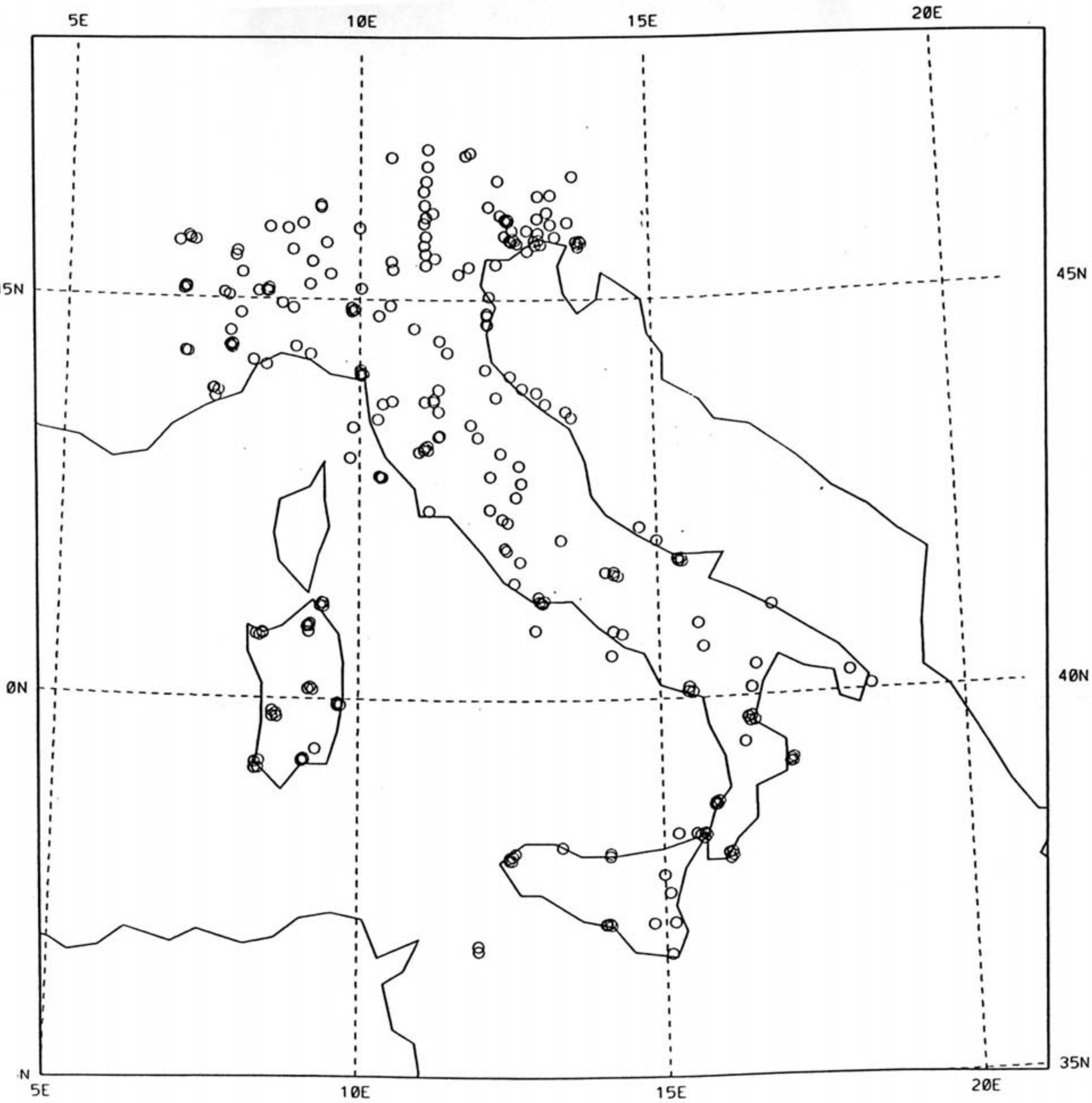

Fig. 5: vertical deflection data base

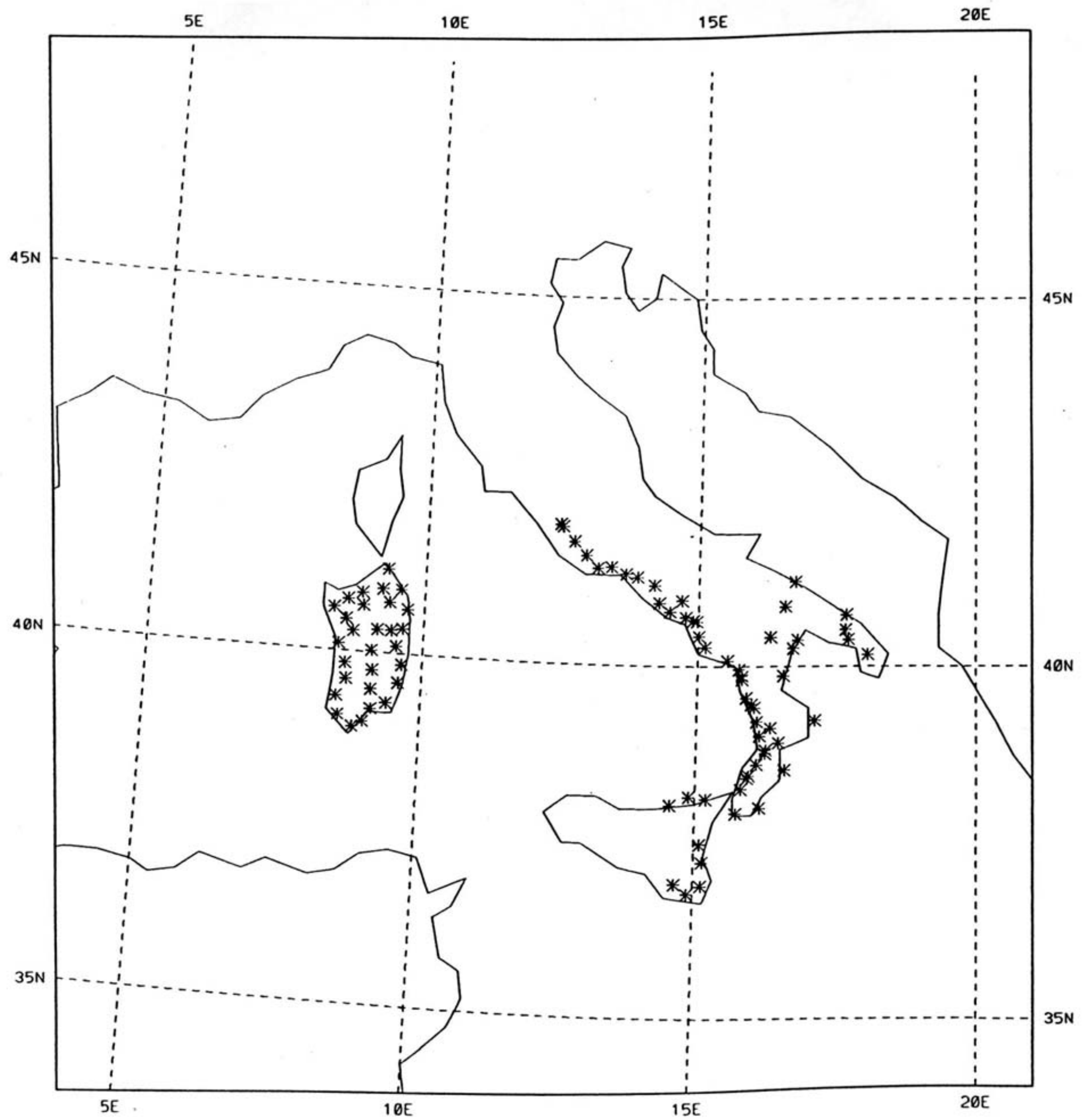

Fig. 6: GPS campaigns

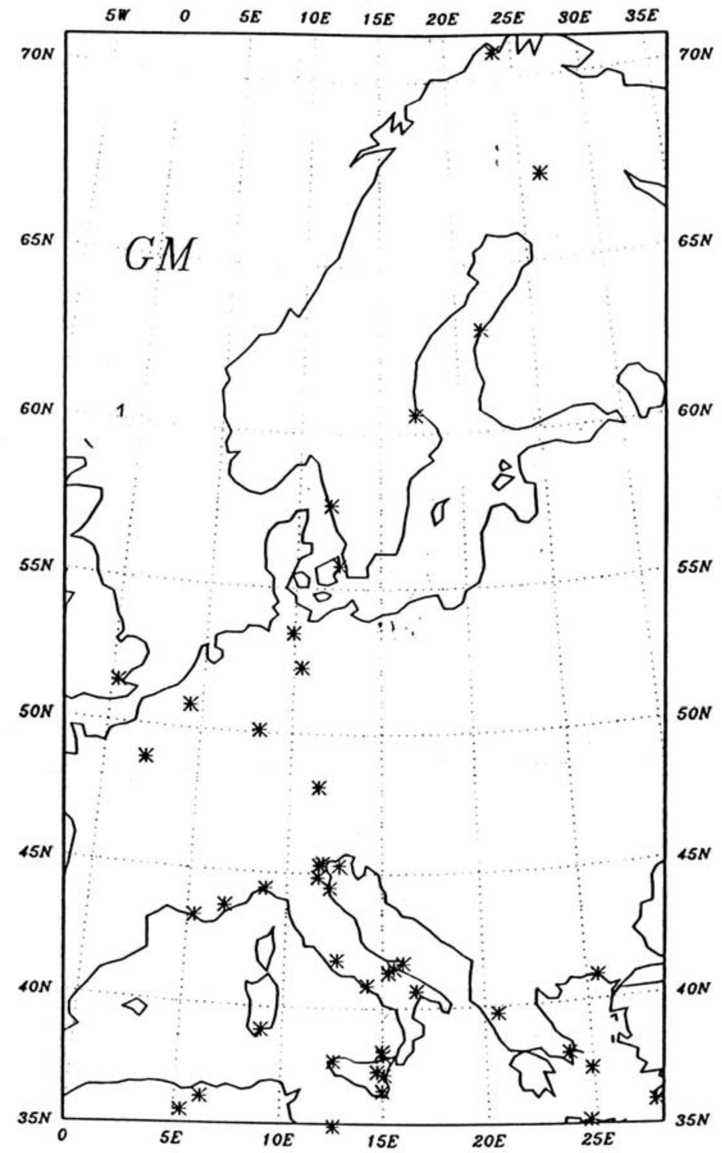

Fig. 7: absolute gravity data base