EDUCATION AND TRAINING ON GPS: DATA ANALYSIS

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Commission VI, Working Group 3

KEY WORDS: Staff selection and training, Numerical cartography, Photogrammetry survey, GPS network, Geoidal height.

ABSTRACT

In this paper we present a project which foresees the training of a neo-engaged staff and his employment in the realization of numerical cartography at a scale of 1:2000. The project is still in progress.
The results obtained by GPS operators in the period of training are analysed. A network having more then 1000 vertices along the Italian coast was calculated and finally the geoid behaviour was studied by means of nearly 200 benchmarks which are part of the network vertices.

KURZFASSUNG

In diesem Aufsatz wird eine Forschungsarbeit vorgestellt, die die Ausbildung einer neuen Arbeitsgruppe vorsieht. Die Taetigkeit der Gruppe ist auf die Verwirklichung einer numerischen Kartographie im Massstab 1: 2000 gericht. Das Forschungsprojekt ist noch im Gange.
Hier werden die Ergebnisse analysiert, die die GPS Operateure in der Ausbildungsperiode erzielt haben. Es wird ein Netz mit mehr als 1000 Punkten berechnet, das die Kueste Italiens durchlauft. Schliesslich wird das Profil des Geoids durch etwa 200 feste Punkte analysiert. Diese festen Punkte sind Teil des Netzes.

1. INTRODUCTION

In 1991 the Data Base constitution of the Italian maritime State Demesne was settled in order to manage the concessions to privates.
To work aim, the project foresaw the assumption of the required staff and his training in the different professional activity (on field, plotting and digitising operators, graphic station administrators, etc.).
First step of project is the realization of numerical cartography at a scale of 1:2000 by means of the institution of a frame network along a great part of the Italian coast.
The performed survey resulted very precise, so it was possible to carry out a quality analysis and to make use of the acquired data in order to calculate a single GPS network along the coast and experimentally evaluate the geoid behaviour.
First part of the paper presents the modality used in order to engage and train the GPS and the plotting operators. Afterwards, the survey results were analysed in order to test their precision and to calculate a single network which covers all the peninsular Italian coast.
The results which were obtained have also been used with the aim to evaluate the geoidal height, by means of a number of benchmarks of the National levelling net which are part of the network.

2. PROJECT

In 1991 began the fulfilment of a project aimed to carry out numerical cartography at a scale of 1:2000 of a narrow strip of nearly 100 m along the Italian coast, constituting the maritime State Demesne.
Project, survey, data elaboration, plotting and (geographical and administrative) Data Base have been performed by a neo-engaged staff. The project foresaw the selection and the training of a staff devoted to aforesaid activities.
Nearly 300 young people was selected among more than 2000 candidates and finally engaged. Among selected people nearly 20 were destined for the GPS operations and as much for the analytical plotter use.
Selection is based on standard procedures and it consists in the presentation of curriculum vitae and the execution of attitudinal, oral and practical tests; all that determined the final pass-list and then the assumption of the staff which was necessary for the whole activity to carry out.
In case of plotting operators, the attitudinal tests were protracted for about a week in order to evaluate the visual capability of candidates.

2.1 Staff training

The required time amount for theoretical-practical training was variable from 4 months for GPS operators to 6 months for plotting ones.
During the period of theoretical-practical training some lessons developed in room for two hours, followed by individual study (for two hours) of texts prepared by the teachers.
In the afternoon practical training takes place so that for the operators it was possible to become familiar with the instruments and the work methodologies. The course teachers are internal experts, university teachers and

experts from the companies which commercialises the instruments.

It follows the period of training on-the-job which consists in the real work execution that is cartography fulfilment. In that period the operators are guided by tutors and experts from companies.

Courses were organized with great care since a further selection was not foreseen. In the course of training the staff performance was monitored.

This fully productive stage lasts from 18 to 24 months.

An index of the achieved training results may be represented by the operators productivity.

As regards the GPS operators, the productivity may be defined by the GPS session numbers carried out by each one in a day. Figure 1 shows the graph obtained in 15 months of activity, during the years 1994-95 (continuous line) (Bianco et Al., 1996). By removing from real productivity the time loss due to some definite and not repeatable situations as the noise reception in some areas (overcome by the new receiver generation) or the logistical problems to access to islands and to some coastal sites, it is possible to obtain data relative to the potential productiveness achieving in normal condition (dashed line). The aforesaid curves concerned both GPS sessions carried out in order to measure the baselines and those ones to calculate the control points.

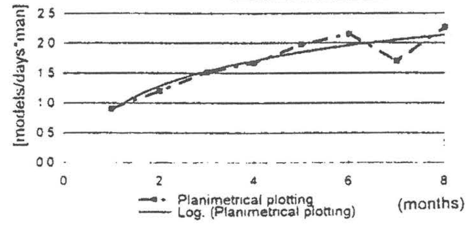
As regards analytical plotting, the productivity may be measured through the number of models worked by each operator in a day. In figure the obtained graph (in 8 months), relative in this case only to real productiveness, is shown. Note that the plotted area is very specific - a coastal band - usually little built.

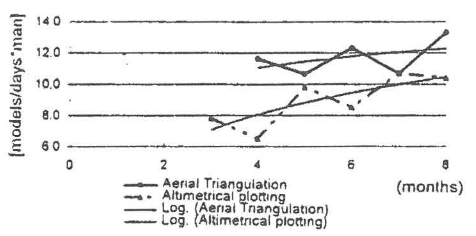
STEREOPLOTTING OPERATORS

Real Productivity

months	1	2	3	4	5	6	7	8
Planimetrical plotting	0.9	1.2	1.5	1.7	2.0	2.2	1.7	2.3
Altimetrical plotting	-	-	7.8	6.5	9.8	8.5	10.7	10.4
Aerial Triangulation	-	-	-	11.6	10.6	12.3	10.7	13.3

[models/days*man]



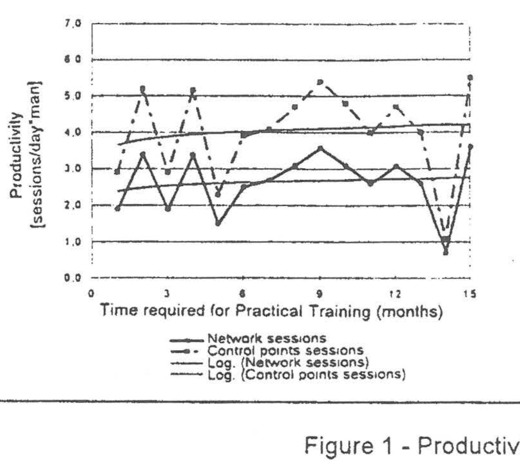


GPS OPERATORS

Real Productivity

Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
network ses.	1.9	3.4	1.9	3.4	1.5	2.5	2.7	3.1	3.6	3.1	2.6	3.1	2.6	0.7	3.6
Control p. ses.	2.9	5.2	2.9	5.2	2.3	3.9	4.1	4.7	5.4	4.8	4.0	4.7	4.0	1.1	5.5

[sessions/day*man]



Potential Productivity

Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
network ses.	2.8	3.0	2.9	3.4	2.2	2.8	3.0	3.4	3.6	3.5	3.3	3.1	3.5	3.7	4.0
Control p. ses.	4.3	4.6	4.3	5.2	4.8	4.3	4.6	5.2	6.0	5.3	6.0	5.2	6.1	5.7	6.0

[sessions/day*man]

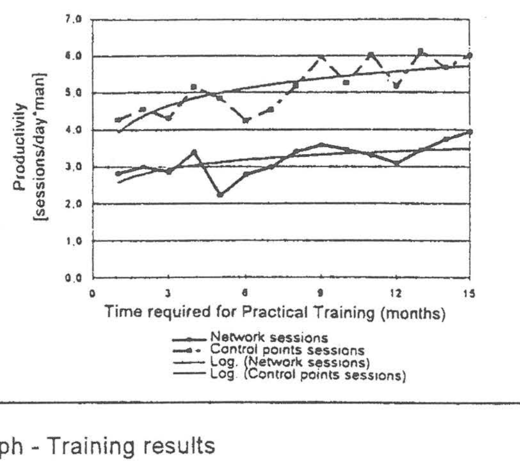


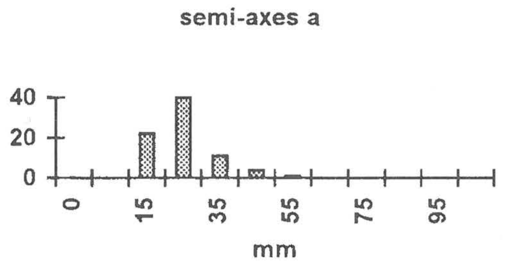
Figure 1 - Productivity graph - Training results

2.2 Survey of the network and control points

As said, the survey was performed with the aim to produce numerical cartography at a scale of 1:2000; data had finally to be inserted in a Data Base of State Demesne property in order to also permit the administrative management of concessions to privates.
Data elaboration were executed by a group of GPS operators specialised in such function and also devoted to network design.
In the period of two years of theoretical-practical and on-the-job training, a network developing on nearly 4000 km of the Italian coast and constituting by about 1400 vertices was surveyed and the network vertices and the control points co-ordinates (nearly 6500) were calculated; finally the co-ordinate transformation into National Italian system (Gauss-Boaga) was carried out through the estimate of 7 transformation parameters (Molodensky complete formulas).
The project is still outstanding. At the moment it was carried out the survey of the densification network and of the control points, while the plotting is in progress.
It is interesting to evaluate the quality that was obtained in the GPS surveys.
As said, the survey concerned on the whole nearly 4000 km of the Italian coast: the peninsula and the Sardinia island.
The densification network was carried out with GPS fast-static technique, standing on each point at least 30'; the average length of baselines was nearly 5 km.
The necessary control points for Aerial Triangulation were measured from the network vertices standing at least 15' on each point (fast-static survey).
The whole project held for a period of two years (included five months of training) in which vertices materialisation, survey, network and control points data elaboration were performed.
A team of ten Trimble SSE receivers (sometimes two teams of five receivers) and more than twenty operators worked at the same time on the survey.
All the phases of survey are submitted to strict specifications; this is very useful in order to permit a best organization of the next surveys, to guarantee product quality and reduce the possibility to commit errors.
The whole area was subdivided in 79 coastal blocks, which were surveyed in succession and in an autonomous way.
Each sub-network consists in nearly twenty-five vertices including those of new establishment, trigonometric points and benchmarks. Contiguous sub-networks have in common at least two vertices so as the building of a single network is therefore possible.
For each block the operations to carry out were subdivided in the following steps:

- network design and vertices materialisation
- measure and calculation of the GPS baselines both of the network and in order to connect the control points
- minimal constraints adjustment and data analysis
- transformation of the network into National Italian Datum
- calculation of the control points co-ordinates.

During the adjustment it was carried out a strict analysis of standardised residuals, separately for altimetrical, planimetrical and spatial components. The residuals which were calculated in the geocentric system have been transformed in a local geodetic system (north, east, up) as well as the variance matrix. The "up" component (1-D), the "north, east" vector (2-D) and "north, east, up" vector (3-D) are tested.
It was also carried out the estimate of transformation parameters through Molodensky formulas. The specifications requires that each block contains at least five trigonometric vertices of the National planimetrical network and five benchmarks of the National levelling net when this is possible. The strict analysis of the standardised residuals was performed in this occasion too.
It is possible to evaluate the reached precision in the calculation of vertices co-ordinates. In Figure 2 the frequency histograms of some error parameters for the network blocks are reported: the maximum values of the major semi-axis "a" of standard error ellipses on the point's tangential plane and the standard deviation of ellipsoidal height "σ_h" obtained for each block.



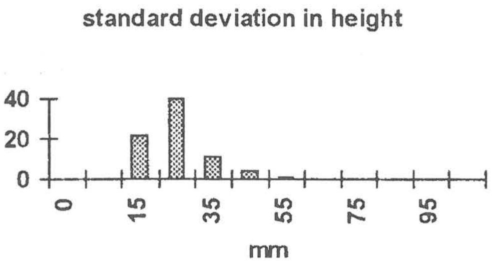


Figure 2 - Frequency histograms of error parameters

The range of values is from 1 to 5 cm for the maximum value of semi-axes "a" but the greater part of them are under 3 cm; for standard deviation in height it is about double (from 2 to 9 cm) and the greater part of values are under 5 cm. Each sub-network is therefore transformed in the National Italian Datum. The points amount which have to be known in local Datum so as to perform a S-transformation (by means of seven parameters) was included in each one. Molodensky formulas are utilised in order to consider separately the benchmarks heights (orthometric) and the planar trigonometric vertices co-ordinates. The transformation software allows to consider the geoid undulation; for this work the OSU91A model which is available in the receivers software was used. The residuals analysis was also performed in order to locate the trigonometric points and the benchmarks which are not reliable.

3. GLOBAL NETWORK

Considering the good quality obtained in the calculation of the sub-networks, all the measures were considered in block, in order to constitute a single network having 1432 vertices (among which more than 200 benchmarks) more 83 off-centre trigonometric points and 2579 baselines.
The network was adjusted at minimal constraints, by utilising a vertex connected with Matera fixed station as fixed (point V0 in Figure 3). This fixed point is not barycentric.
It was also performed an adjustment by utilising an extreme vertex at North West as fixed (point T1 in figure).
In order to calculate such a large network it was modified an adjustment FORTRAN code, using band recording. The shape of network makes the use of band-recording particularly efficient.
The amount of time necessary for a solution which includes the normal-matrix inversion, the calculation of portions of the inverse residuals-cofactors-matrix and of one, two and three dimensional error parameters both absolute and relative was from $1^h15'$ to $1^h30'$, depending on the band width, by utilising a Pentium 100 PC.

Figure 3 - Global network graph

In Table 4 the maximum values of the considered error parameters obtained by fixing once point V0 and once point T1 are reported; "a", "b" represent the semi-axes of the standard error ellipses, "s_h" ,the standard deviation in elevation and "a_3", "b_3", "c_3", the semi-axes of the standard error ellipsoids.

a	b	s_h	fixed	a_3	b_3	c_3
11	8	21	V0	23	11	7
14	10	28	T1	28	13	9

Table 4 - Minimal constraints adjustment precision

The maximum values of the errors by fixing point V0 is obviously in correspondence of the furthest points from fixed vertex.
The correspondent values by fixing point T1 are not much higher and the maximum values are now obviously in correspondence of the north-east vertices.
The adjusted ellipsoidal heights for the nearly 210 benchmarks inserted in the network along the Italian coasts were also obtained.
Owing to connection with Matera fixed station, the geocentric co-ordinates (and hence the ellipsoidal height of benchmarks) are in a "good" WGS84 system.
It is interesting to follow the progress of error parameters leaving the fixed point. Nearly 200 vertices (the benchmarks) were selected to represent the network so as to form a broken line (Figure 5).

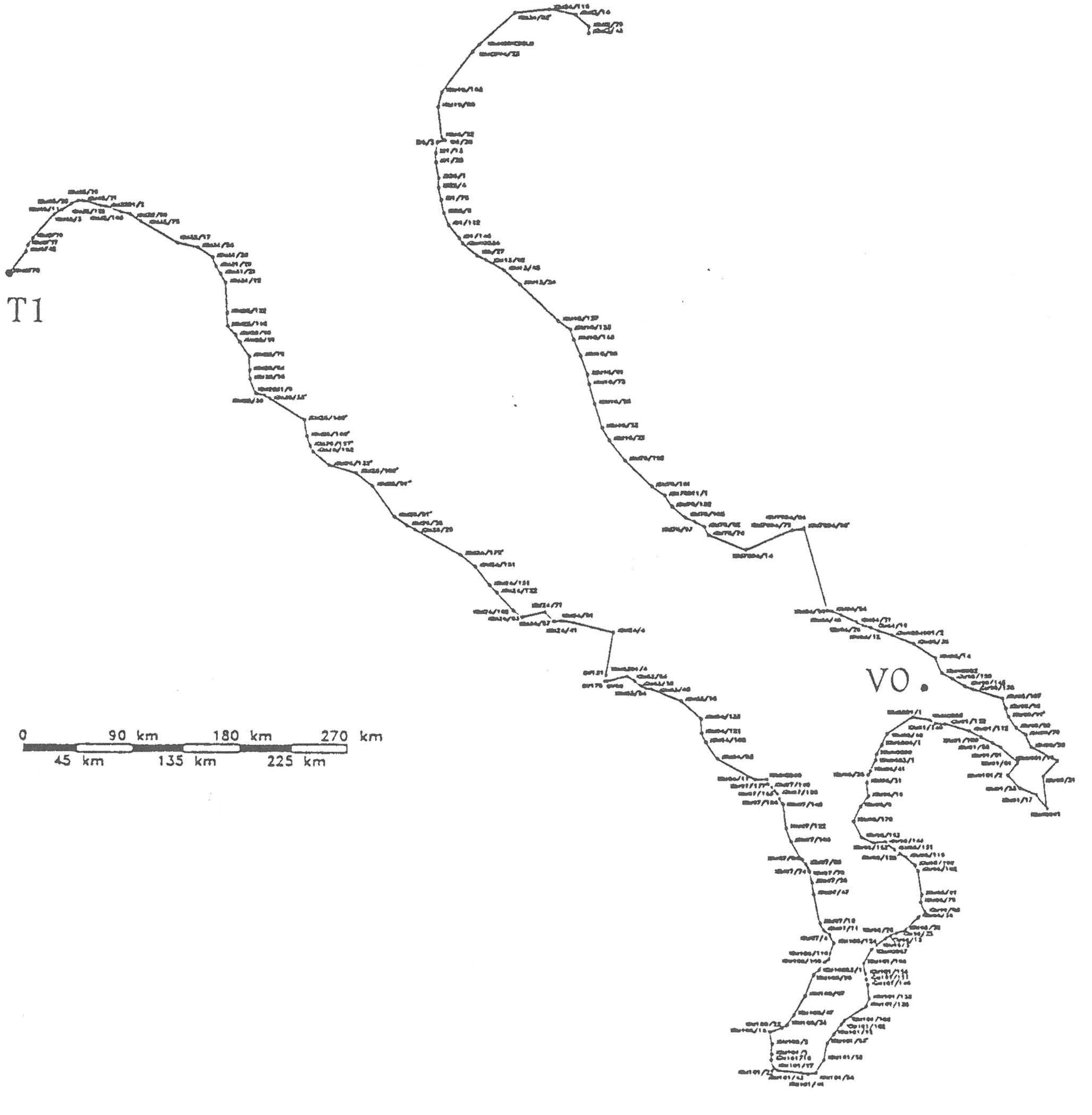


Figure 5 - Benchmarks sequence along Italian coast

The values of the error parameters obtained for the solution with V0 fixed are reported in the graph of Figure 6 as a function of benchmark position along the sequence; this position is defined as the "distance" from the first benchmark (at north-west), "distance" understood to be the progressive sum of the distances between subsequent benchmarks.

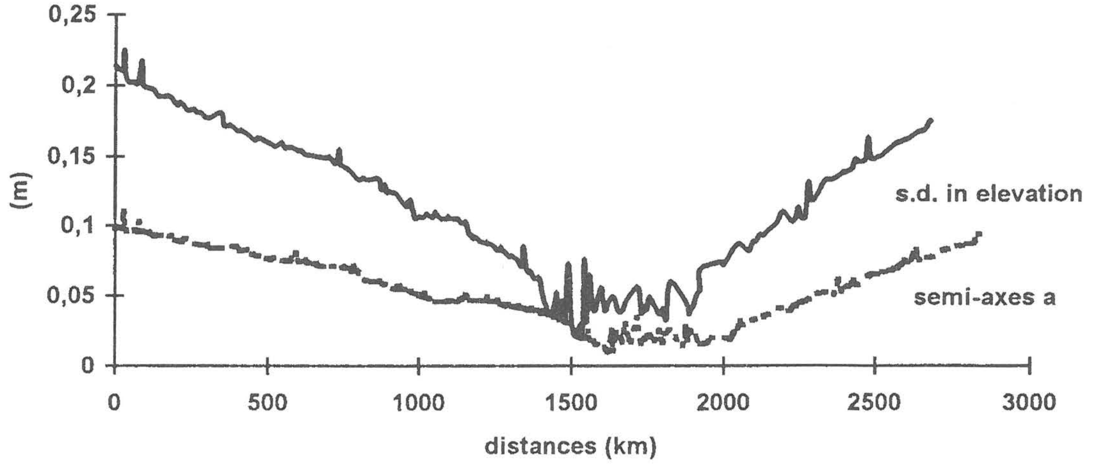


Figure 6 - Global network - Error parameters progress

The minimum values of error parameters are from 1500 to 2000 km far from the first point of the sequence, obviously near the fixed point V0.

All the values are smaller then nearly 20 cm for the standard deviation in elevation and then 10 cm for the semi-axes "a", values obviously obtained in correspondence of the farthest points at north-west and north-east.

4. EXPERIMENTAL GEOID UNDULATION

For the 210 benchmarks which are included in the network is obviously also known the height referred to geoid. It was therefore possible to obtain the experimental values of geoidal height N for the benchmarks sequence.

The obtained values are shown in Figure 7 in which they are reported again as a function of benchmark position along the sequence.

The experimental values may be compared with those estimated through a theoretical model; we utilize OSU91A in order to calculate undulation on the same points.

This model is also available within commercial software package and in the project it was adopted in order to correct heights for the transformation into National Italian Datum.

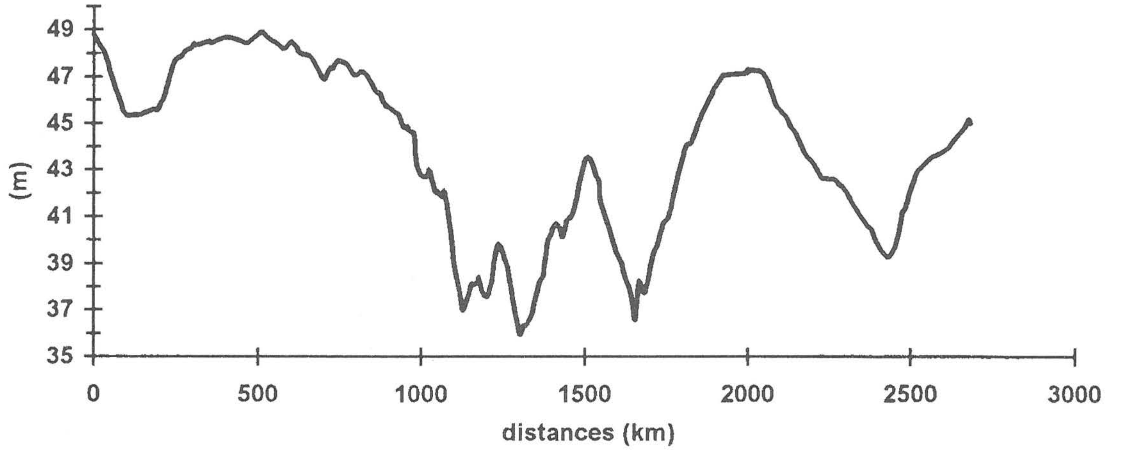


Figure 7 - Experimental geoid undulation

In Figure 8 the differences between experimental values and those forecast by OSU91A are reported separately for the west Italian coast (Tyrrhenian Sea), the south coast (Ionian Sea) and the east coast (Adriatic Sea).

Apart from errors eventually occurred in the experimental determination of undulation, such differences represent the amount of undulation component that is not forecast by the theoretical model. It is clearly visible a systematic component having a long wave-length in the direction north-south. This trend is present in both the coasts.

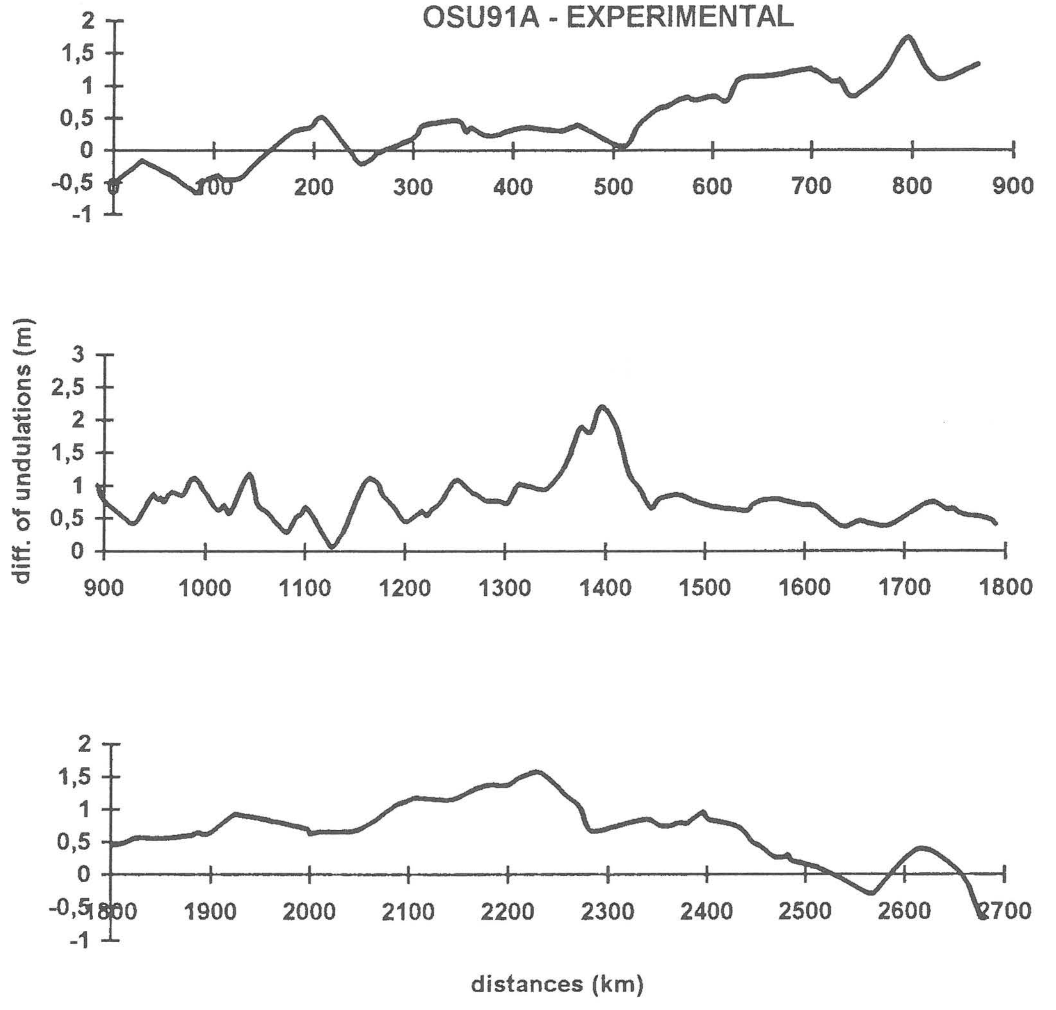


Figure 8 - Differences between experimental values and mathematical predictions of geoid undulation by OSU91A

In order to study the local undulation behaviour, the variations of undulation, defined as the differences between undulation values belonging to pairs of successive benchmarks along coastal line, were also calculated; they are expressed in p.p.m. (mm per km). Such variations are computed both for experimental and OSU91A model. In Figure 9 the differences of variations of undulation between experimental and OSU91A values are reported; this is the amount of variation that is not forecast by OSU91A model.

5. CONCLUSIONS

As regards the staff formation it is important to note that:

- the formation of a GPS field operator takes a time shorter than of a traditional one, since much less manuality is required;
- even for field operators a good theoretical preparation on GPS is nevertheless considered necessary;
- the presence of an expert charge-man is necessary in order to organize the team work;
- it is very important to define and observe precise operative specifications, useful to improve both the survey's productivity and the results' precision.

As for the results, it is to note that a careful analysis of the production's data set when they are subjected to quality control may supply some interesting informations on network's behaviour.
Calculation of big networks requires long but acceptable time even by utilising a PC, since it is sufficient to utilize a band algorithm in order to adjust a "chain" network.
The good quality of the produced data makes possible to utilize them for the analysis of geoid undulation.
In particular we note that:

- a "long wave" bias in direction North-South is present in OSU91A model;
- the local variation of undulation may assume values higher than 10 cm, which are not negligible for cartographic survey at a large scale.

Aknowledgement

The stated research has been financially supported by Agenzia Spaziale Italiana (ASI).
The authors wish to thank Rilter company which supplied the data set that has been used in the research work.

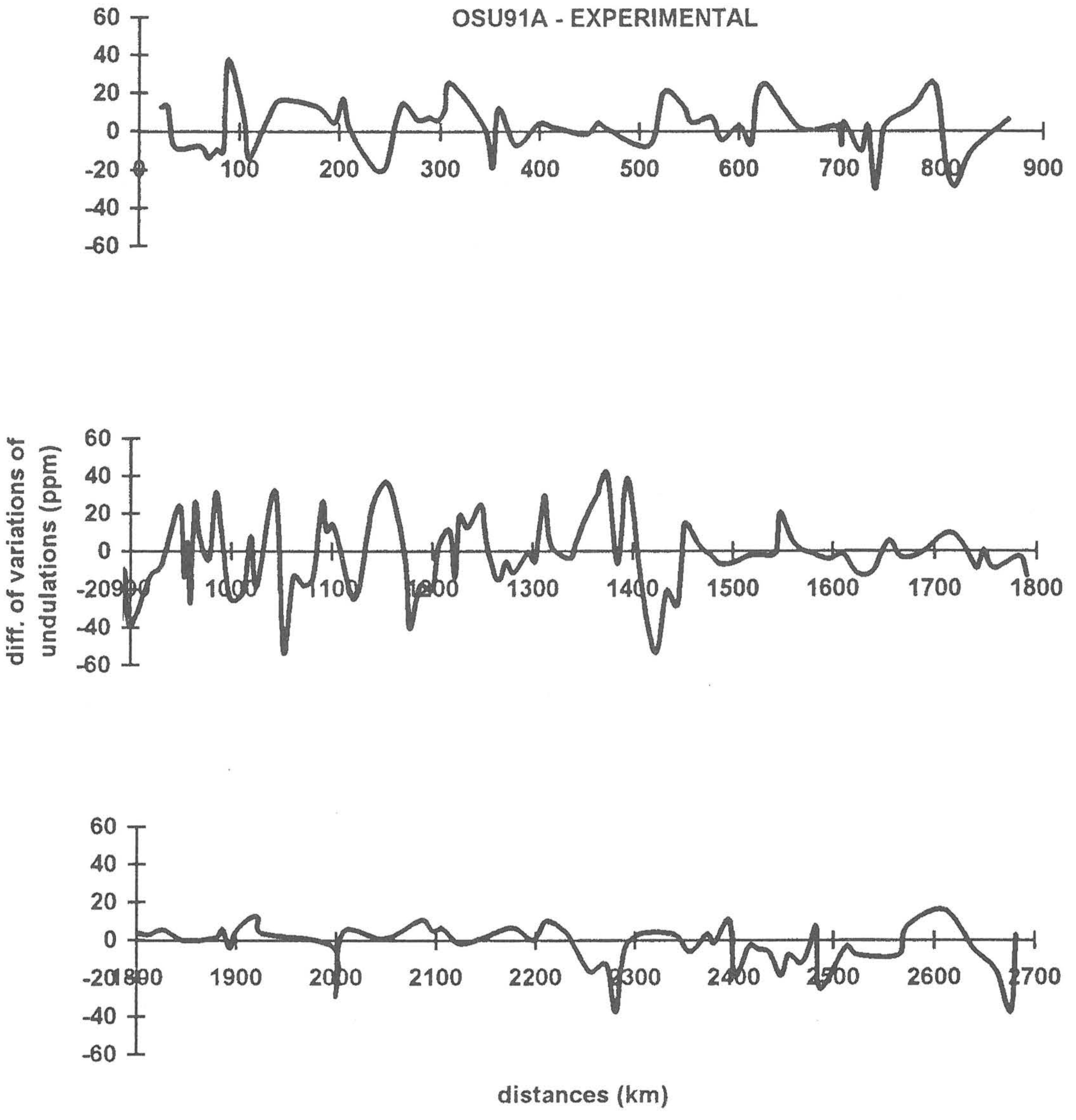


Figure 9 - Differences between variations of geoid undulation (OSU91A)

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