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Italian Magnetic Network at 1985.0

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Summary. – The new national geomagnetic network of repeat stations for total field *F*, horizontal component *H*, vertical component *Z* and declination *D*, has been repeated in the frame of a collaboration between Istituto Nazionale di Geofisica and Istituto Geografico Militare Italiano.

From the observed magnetic elements all repeat stations values were referred to 1985.0 and normal fields, in the form of a 2nd order polynomial in latitude and longitude, were computed.

All geomagnetic maps published previously have been updated at 1985.0 and are published here with the secular variation pattern. An overview of all work, including a brief history of the recent Italian geomagnetic measurements, new normal fields coefficients and secular variation normal fields, are presented here.

1. – INTRODUCTION

The first comprehensive survey to determine the elements of the Earth's magnetic field in Italy was carried out by IGMI (Istituto Geografico Militare Italiano) between 1932 and 1938. The network comprised 1496 measuring stations for *D*, *I* and *H* components, and 33 secondary stations for the *D* component alone in the anomalous region of Piedmont. The key points in the network consisted of 46 repeat stations, i.e. identifiable sites that could subsequently be reoccupied. The overall density of the measurements points was one every 208 km^2. The instruments at the time allowed a final accuracy of $\pm$ 1′ for *D* and $\pm$ 30 nT for *H*. The low precision affecting the inclination measurements made at the time prevented the vertical component from being calculated accurately. The Genova Castellaccio Observatory belonging to the Navy Hydrogreaphic Institute was used for the reduction of the measurements due to daily variations in the field. The work accomplished led to the determination of the normal field for Italy at 1935.0 and to the publication of the first magnetic maps at 1940.0 for the *D* and *H* components [9]. Subsequent repetitions of the measurements at the 46 repeat stations and other measurements led to the republication of the maps updated to 1948.0 and 1959.0.

During the International Geophysical Year 1957-58 (IGY), and as an extension of the latter, the World Magnetic Network (WMN) project was established, with the participation of Italy. This was of great importance at the Italian level since it marked the beginning of a collaboration between the Istituto Nazionale di Geofisica (ING), the University of Bari, IGMI and the Vesuviano Observatory. The Italian WMN network comprised 28 repeat stations, some of which of new construction, as well as the two new ING observatories of L'Aquila and Castel Tesino (Trento). The reduction of the measurements to 1965.0 and the calibration of the instruments were carried out using data from the L'Aquila observatory.

The WMN measurements led to an increase in the number of repeat stations available for component determination and the new instruments afforded greater accuracy in the observations. Measurements were made of the *D*, *H*, *Z* and *I* elements, as well as of the total field *F*. At international level the first planetary reference field was calculated and was given the name of IGRF (International Geomagnetic Reference Field) in 1965.0. Every five years since, the various IGRF versions have been recalculated. A concise treatment of the meaning of the various IGRFs and their generations can be found in [8]. All the IGRF grid values since 1965 are reported in [2].

On the basis of the previous magnetic maps for *H* and *D*, IGMI had meanwhile continued to publish updated magnetic maps of Italian territory using the secular variation measured at L'Aquila and the repetition of several stations. IGMI published the last *D* and *H* maps for 1973.0 using data from the original network composed by

1529 stations and 50 main stations: 46 belonging to the IGMI network, 3 to the WMN and a new one in Sardinia [11].

As part of the PFG project (Progetto Finalizzato Geodinamica), during the '70s it was deemed advisable to give a contribution to the thematic map of Italy provided for in the subproject relevant to a threedimensional model of the crust, by making a complete magnetic map. A special Geomagnetism working group was therefore set up for the purpose of enhancing the IGMI network by increasing the measurement dnsity in order to provide regular coverage of the irregular Italian profile, by adding the F and Z components, by constructing smaller regional fields and lastly by mapping the anomalies of the crustal residual field. It was immediatly perceived that the interpretation of residual field anomalies, in particular of F, would represent a scientific contribution of considerable importance for the construction of a geological model of the crust. The new measuraments and the re-occupation of several old repeat stations would also contribute to updating the IGRF fields.

Although the ways and means remained to be established, the Geomagnetism Group immediatly realized the advisability of repeating in future the new 1st order network being set up, if possible performing measurements every 5 years. Furthermore, the identification of any local anomalies in secular variation indicative of the existence of on-going tectonic activity in the crust, accompanied by possible stress accumulation or shifting of the Curie isotherm, could contribute to studies of seismic precursors [10].

The Vesuviano Observatory, and the Universities of Bari, Cagliari, Ferrara, Genoa, Padua, and Turin, collaborated on this very important project, which was coordinated by ING. The big amount of field work was divided into two stages: the first of these involved choosing the repeat stations and making measurements on the fundamental stations and the optimization of the distribution of the observatories for the reduction of the measurements; during the second stage the secondary network was set up. The latter, comprising some 2200 stations, was to be used to draw up the magnetic maps for the F, H and Z components, as well as to map total field anomalies.

2. – THE NEW ITALIAN MAGNETIC NETWORK IN THE PROGETTO FINALIZZATO GEODINAMICA (PFG)

The first stage of PFG work, i.e. between 1977 and 1979, was concerned with selecting and setting up the temporary observatories of Locorotondo (Bari) and Corongiu (Cagliari), and with comparing them with the permanent ING observatories of L'Aquila, Castello Tesino (Trento) and Gibilmanna (Palermo), and the Roburent Observatory (Cuneo) of the University of Genoa. These 6 photographic recording observatories were monitored and compared by means of absolute measurements carried out during a few consecutive days by a single team using the same instruments, thus creating a single standard. For all observatories the hourly, monthly and annual means were calculated for at least 6 months before and after the 1979.0 for the values of the magnetic components measured in the field. For the repeat station network the 34 repeat stations of the IGMI network were used (the others were unusable) plus 72 new ones. The latter ones had to be sited, a pillar constructed and the azimuth determined for the sights required to measure the declination. For each of the 106 repeat stations the components of the earth's magnetic field were measured. After reduction to the same period of 1979.0 the latter then enabled the reference fields to be determined which were valid for the whole national territory. During the second phase, which was completed in 1981, measurements were made on the secondary network of the same magnetic field components as for the primary network, except for *D*. Measurements were made on a total of 2252 stations with a mean density of one every 138 km^2. Also for this network all measurements were reduced to 1979.0 using the recordings of both the L'Aquila observatory and of that observatory among the other 6 which was geographically closer to the repeat or secondary station concerned.

ING has processed all the measurements and mapped the 1 : 500 000 scale maps for the three field components. The latter were used to compose the 3 1 : 1 500 000 maps for *F* and the *H* and *Z* components. After carefully comparing the normal fields computed from the Italian data with the international reference fields [6], the anomalies of the total field *F* were computed and mapped. These maps, originally distributed only to Italian users, will be attached to the final report on PFG sub-project 5 as part of the thematic maps still to be published by the CNR. The maps, together with raw and processed data, have been published in the form of monographs on the PFG project or in international reviews [1], [5], [6], [7]. At the conclusion of the PFG project, in order not to waste the experience acquired during the work, it was decided to continue in the direction of the regular repetition of the network so as to exploit the accumulated body of magnetic historical data from the main stations and to publish up-dated maps at scheduled intervals. The new organizational structure of ING and its expansion have made it independent of other institutions and enable it to make more rapid decisions. Since a wide experience on magnetic measurements and mapping was also in IGMI, that had not taken part in the PFG project, it was deemed of great importance to establish a lasting relationship between the two Institutes in view of the interest and experience both have, and will continue to have, in surveying, as well as to ensure the rapid publication of the update magnetic maps.

3. – REPETITION OF THE ITALIAN MAGNETIC NETWORK: IMPLEMENTATION OF THE NEW PROJECT

In 1985 a convention was signed between ING and IGMI providing for the division of the field work and the joint publication of the maps. ING retains control over the actual performance of the measurements and the coordination of both the field work and the subsequent processing of the data. IGMI's considerable experience and structure were to ensure the publication of final maps.

With regard to field measurements, territorial competence was provisionally subdivided as follows:

IGMI	ING
Puglie	Lombardy
Calabria	Trentino Alto Adige
Lucania	Friuli Venezia Giulia
Campania	Veneto
Emilia Romagna	Marches
Umbria	Abruzzi
Tuscany	Molise
Liguria	Lazio
Piedmont	Sardinia
Valle d'Aosta	Sicily

The geographic distribution of the main stations of the new magnetic network at 1985.0 is shown in fig. 1.

During the operational phase of the new project, which followed the initial planning phase, the rules governing the siting of any new main stations were the same as those established during the PFG project. The required characteristics were: considerable distance from present and possible future sources of magnetic contamination, both natural and artificial, and highly visible azimuth marks. Since during the reoccupation of repeat stations for the purpose of repeating measurements it often proved difficult to locate the pillar, particularly when insufficient information was contained in the relevant monographs, the monographs referring to the stations were updated after the phase of the work done by the PFG working groups. Special attention was paid to ensuring increased uniformity in the forms used.

Special care was taken in setting up both the field and observatory instruments needed to implement the repetition of the network. High level instrumental standards were worked out between IGMI and ING for magnetic measurement repetition. For 1985 the following field instruments were used: proton magnetometers for the F component, optical axial fluxgate magnetic theodolite (EDA DIM 100 type) for the I and D components, gyroscopic theodolite for determining geographic North. The instruments now used, which were the same for both Institutes, ensured greater accuracy than previously owing to the increased speed of execution of single field component measurements and to the reduction of the measurements.

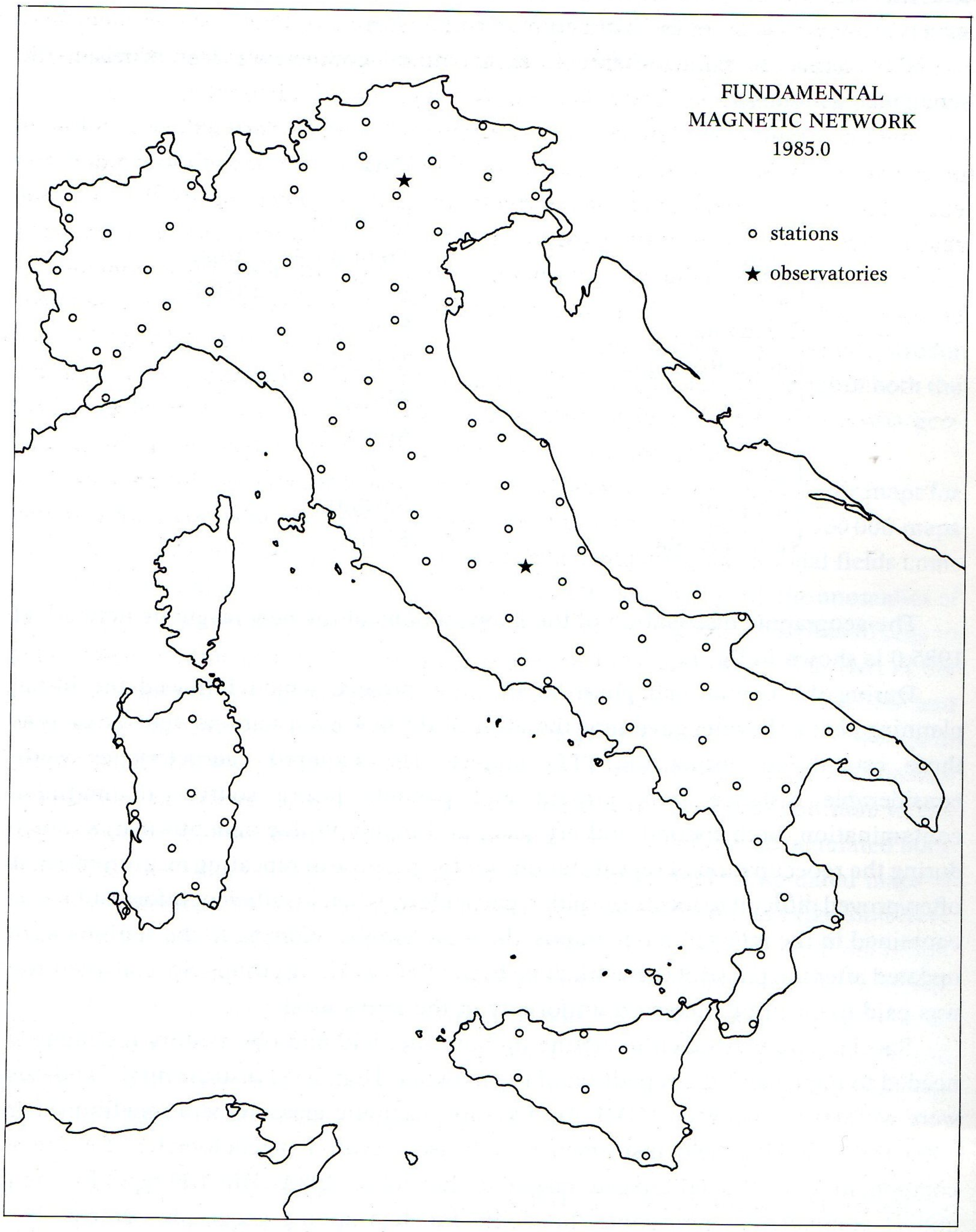

Fig. 1 – Italian Magnetic Network at 1985.0.

The field components F, D and I were measured in the field. For each primary network station in Italy 10 sets of measurements were performed, 5 in the morning at about 7.30-9.30 and 5 in the afternoon at about 1.30-5.30. Each measurement was carried out about 30 minutes after the preceding one. For the new stations the azimuth marks had previously been determined using the gyroscopic theodolite.

One important factor determining the accuracy of results during the repetition of the network was the rational procedure adopted to schedule movements from one repeat station to another during the field work. It was deemed necessary to concentrate measurements in as short a time span as possible compared with the total five year period in order to reduce the secular variation corrections to a minimum. In conclusion, the estimated error in the final values for the field components for the repetition stations, including measurements, time reductions and, in the case of D, the determination of the geographic meridian, were ± 8nT for F, H and Z and $\pm 1'$ for the declination. It should be kept in mind that in complex operations such as those related to the determination of a final value for the field (actual measurement, reduction, quality of the reference observatory, etc.) it is not possible to ascertain the statistical error rigorously. The error indicated is therefore merely to be considered as the maximum error affecting the final values.

4. – REDUCTION OF THE MAGNETIC MEASUREMENTS IN THE REPETITION AT 1985.0

In reducing the measurements to 1985.0 reference was made to the L'Aquila Observatory. The use of the automatic digital data recording system now in operation at the L'Aquila Observatory [4] has allowed all doubts to be resolved concerning the photographic type magnetometers used in the preceding network. The following expression was used for the reduction of measurements at the Observatory:

$$E\ (t, s) - E\ (85.0, s) = E\ (t, \text{Obs.}) - E\ (85.0, \text{Obs.})$$

where $E\ (t, s)$ = the value of the elements (D, F, H, Z) observed or computed at station s at time t, $E\ (t, \text{Obs.})$ = the value of the elements observed at the same time t at the observatory, $E\ (85.0, s)$ = the value of the elements of station s reduced to 1985.0. Using the same criteria as those adopted to choose the normal field for 1979.0 [1], also for 1985.0 an analytical expression in latitude and longitude T and L was used, specifically a second-order polynomial of the form:

$$E = a_0 + a_1\, T + a_2\, L + a_3\, T^2 + a_4\, L^2 + a_5\, T\, L$$

The coefficients were determined using the least squares method after application of

Chauvenet's exclusion criterion. Essentially the mean residual of each individual station was calculated using the expression $\sigma = \pm \sqrt{[vv]/(n-6)}$ where $[vv]$ was the sum of the square differences between observed and computed values, n is the number of stations used in the inversion and 6 is the number of coefficients [12]. Stations with residuals greater than 2σ were neglected and the calculation repeated for the remainder. This procedure was repeated until no residuals greater than 2σ were left.

Also this normal field, like that of 1979.0, was referred to sea level. In fact, as it is customary, all the main station values were previously reduced to sea level. This reduction was obtained by taking only the dipole terms of the magnetic field into consideration. The fraction $\Delta E = 3Eh/R$, where R is the mean earth's radius and h is the altitude of the point, was then subtracted from the element E. The normal field expression for the years 1979.0 and 1985.0 is given in table 1. Since the normal fields at 1979.0 and 1985.0 are fully comparable, being obtained using the same procedure, a reliable plot was obtained for secular variation between 1979.0 and 1985.0.

In order to obtain the set of coefficients of secular variation two different methods can be used: *a*) from the differences between 1985.0 and 1979.0 measured at the main stations, to determine the normal field directly by inversion; *b*) from the two normal fields set out in table 1, to obtain an expression valid for secular variation from the difference in the coefficients. The method definitively used to obtain the coefficients shown in table 2, and consequently the annual secular variations, was *a*). By this method it is, in fact, possible to obtain, from a single inversion, the set of coefficients needed to provide a network of values having minimum dispersion.

After the normal reference fields had been determined, the new maps were drawn up using the data from the secondary network for 1979.0, updated to 1985.0 using the secular variation computed as described above. The maps were produced using contour programs by means of a plotter on 6 1:500 000 scale sheets which were subsequently recomposed. This procedure was made necessary by the irregularity of the Italian peninsula and the consequent need to subdivide it into quasi-rectangular areas to allow mechanical plotting. The areas where measurements could not be made because they were too highly built-up or owing to strong natural anomalies are shown in yellow. The new maps for the total field and for the three elements are shown in the annexes 1, 2, 3 and 4.

Annual secular variation values obtained as the difference between values measured and reduced to 1985.0 and those measured and reduced to 1979.0 allow the 112 measurement points to be used to construct secular variation maps (or isoporic lines) for the various components. Also isoporic lines are shown in the annexes 1, 2, 3 and 4.

Secular variations for the Italian peninsula for Declination range from 5′/year in the Gulf of Otranto to about 7′/year at Oristano; over the same range, the values for F range from about 24 to 19 nT/year, and for H from 16 to 18 nT/year. These values do not

TAB. 1

COEFFICIENTS OF THE NORMAL GEOMAGNETIC FIELD IN ITALY FOR THE ELEMENTS F, H, Z AND D, REFERRED TO 1979.0 AND 1985.0

$D' = -0$	4.7	− 0.001T	+0.262L	−0.00008TT	−0.00007LL	+0.00009TL	1985.0
$D' = -0$	44.7		+0.289L	−0.00004TT	−0.00007LL	+0.00014TL	1979.0
F =	45506.8	+ 5.689T	+1.226L	−0.00158TT	+0.00048LL	−0.00014TL	1985.0
F =	45388.4	+ 5.709T	+1.111L	−0.00153TT	+0.00049LL	−0.00068TL	1979.0
H =	24162.0	− 9.156T	+0.052L	−0.00010TT	+0.00030LL	+0.00025TL	1985.0
H =	24104.2	− 9.043T	+0.110L	+0.00036TT	+0.00004LL	−0.00042TL	1979.0
Z =	38564.9	+12.518T	+1.427L	−0.00456TT	+0.00024LL	−0.00083TL	1985.0
Z =	38451.7	+12.467T	+1.259L	−0.00444TT	+0.00060LL	−0.00069TL	1979.0

T = (Lat. -42°) in min. L = (Long. -12°) in min.

TAB. 2

COEFFICIENTS OF THE SECULAR VARIATION NORMAL FIELD IN ITALY FOR THE ELEMENTS F, H, Z AND D COMPUTED FROM REPEAT STATION 1979.0 AND 1985.0 NETWORKS DIFFERENCES

D'	=	37.8	−0.002T	−0.023L		+0.00002LL	+0.00003TL
F	=	123.8	−0.002T	+0.044L	−0.00006TT	+0.00003LL	+0.00010TL
H	=	49.5	−0.095T	−0.082L	+0.00001TT	+0.00017LL	+0.00035TL
Z	=	115.3	+0.056T	+0.105L	−0.00009TT	−0.00011LL	−0.00015TL

T = (Lat. −42°) in min. L = (Long. −12°) in min.

correspond to those calculated on other occasions for the years preceding the period 1979-1985 and thus confirming the unpredictable nature of secular variation.

5. – DEVELOPMENTS OF THE ITALIAN MAGNETIC NETWORK AND CONCLUSIONS

The data from the initial secondary IGMI network, updated over the years and with the application of the secular variation measured at the repeat stations, have been used to produce an isogonic map at 1985.0. The most recent declination map, published as part of the PFG project, at 1979.0, was obtained using only primary network data [7]. It would thus seem advisable to plan a new secondary network also for the declination, as was done for the other elements at 1979.0, based for instance on regional programmes.

There remains, however, despite a few sporadic measurements, a gap in the maps compiled concerning the smaller islands. To complete also this programme the cooperation of the Istituto Idrografico della Marina would be useful, without considering the great importance for magnetic cartography of covering the sea areas around Italy and Corsica (For F this work has been carried out during oceanographic campaigns, see for instance [3]).

As mentioned above, in order to ensure that the network can be repeated rapidly every 5 years, it is necessary to keep the stations in working order. This can be achieved also by skilful plannning of the repetition, in which the repeat stations are divided into several categories: *a*) observatories with regular measurements, *b*) repeat stations of the primary network to be repeated every year, *c*) other important stations to be repeated every 2.5 years, *d*) all the other stations. The selection criteria for stations *b*) and *c*) could simply be their observed representativeness with regard to the normal field and the uniformity of their distribution over the territory.

The new magnetic maps of Italy give the trends of the various elements, and of the total field, at 1985.0. When compared with the corresponding maps of 1979.0, they provide a display of the process of the secular variation undergone by the geomagnetic field.

In conclusion, it may be stated briefly that: 1) the primary network, with its average spacing of 60 km, ensures the monitoring of the variation which, as shown by the isopors, has a regular but geographically non-uniform structure in Italy; 2) the repeat station network is suitable also for computing a normal field, the validity of which must however be thoroughly checked against planetary-scale reference fields (see for instance [6] for 1979); 3) the secondary network provides a solid basis for working out the medium-scale crustal anomalies of the Italian peninsula; 4) the structure of the crustal anomalies of the total field, although subject to small variations, does not change substantially except in the intensity of the anomalies themselves which, on the field map, contain a (vectorial) sum of the core field plus the crustal field.

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