MAGNETIC REPEAT STATION NETWORK IN ITALY AND MAGNETIC MEASUREMENTS AT HELIPORTS AND AIRPORTS

ANGELO DE SANTIS[20]
GUIDO DOMINICI
Istituto Nazionale di Geofisica e Vulcanologia

Abstract. The Italian Magnetic Network is composed of 114 repeat stations and its last complete measurement took place in the period 1999-2001, i.e. centred at epoch 2000. Mathematical models and maps were produced for declination, horizontal and vertical components, together with the total intensity of the geomagnetic field. By the end of 2005 the Magnetic Network measurement will be repeated again completely. To the Italian sites have been added also 11 other stations in Albania. Those were measured in 2004 with the collaboration of the Albanian Academy of Science and the University of Tirana. Together with this activity also another one dedicated to airports or heliports measurements has been undertaken. This kind of measurements has the objective to provide absolute magnetic knowledge of the magnetic declination in airports and heliport swinging roses where it is possible then to calibrate aircraft compasses.

Keywords: repeat stations; magnetic declination; swinging rose; navigation

1. Introduction

The geomagnetic field is an important property of our planet. It has allowed the life to progress in the evolution up to our times, screening most of the electric charges coming from the sun and the cosmic radiation that otherwise would have hit more dangerously the surface of the Earth, causing health damage and allowing the atmosphere to be blown away from the planet. The presence of a geomagnetic field has also allowed human

[20]Address for correspondence: Istituto Nazionale di Geofisica e Vulcanologia, V. Vigna Murata 605, 00143 Rome, Italy. Email: desantisag@ingv.it

J.L. Rasson and T. Delipetrov (eds.), Geomagnetics for Aeronautical Safety, 259–270.

beings to use it as orientation information. In this regard, observing the geomagnetic field, in particular its angular difference in orientation with respect to the geographic meridian, the so called Declination, provides together with the use of a compass one of the cheapest and simplest ways to know the orientation for navigation purposes at the Earth surface and above. The Istituto Nazionale di Geofisica e Vulcanologia (I.N.G.V.) is the Italian Institution that has the duty to make continuous observations of the geomagnetic field over the Italian territory. It runs two Observatories in Italy, L'Aquila (centre of Italy, working from 1960) and Castello Tesino (north of Italy, working form 1965) and two in Antartica, Zucchelli Base (along the coast) and Concordia (internal to the continent), the latter in conjunction with the French institute of IPGP. I.N.G.V. maintains also two continuous magnetic stations in Belluno (North East Italy) and Gibilmanna (South Italy - Sicily) where a series of absolute measurements is made at least once a year. Also a National Magnetic Network composed of around one hundred of repeat stations is measured every 5 years approximately. In this paper we will illustrate some information about the Magnetic Network and then will describe some notes on the measurements made at the swinging rose platforms of airports and heliports for allowing compass calibration of aircraft.

2. The Italian Magnetic Network

In Italy a long history of magnetic measurements and practice can be traced back in time to the XVII century (see Cafarella et al., 1992a, b) but the continuity in regularly repeated magnetic measurements started with the national unification at the end of the XIX century. Since the 1930's a modern Italian Magnetic Network composed of repeat stations regularly distributed over the Italian territory and integrated by Magnetic Observatories, has allowed the determination of the spatial structure and the time variation of the Earth's magnetic field over Italy (Cafarella et al., 1992a, b).

Table 27 shows a brief history of the magnetic surveys made in the Italian territory from 1640 to present, indicating the magnetic elements observed together with the number of repeat stations (# sites) and the corresponding observers. The magnetic survey of 1891-92 represents the first 3-component magnetic survey in the then re-united nation of Italy: we present here the chart of the horizontal component published at that time (Figure 130)

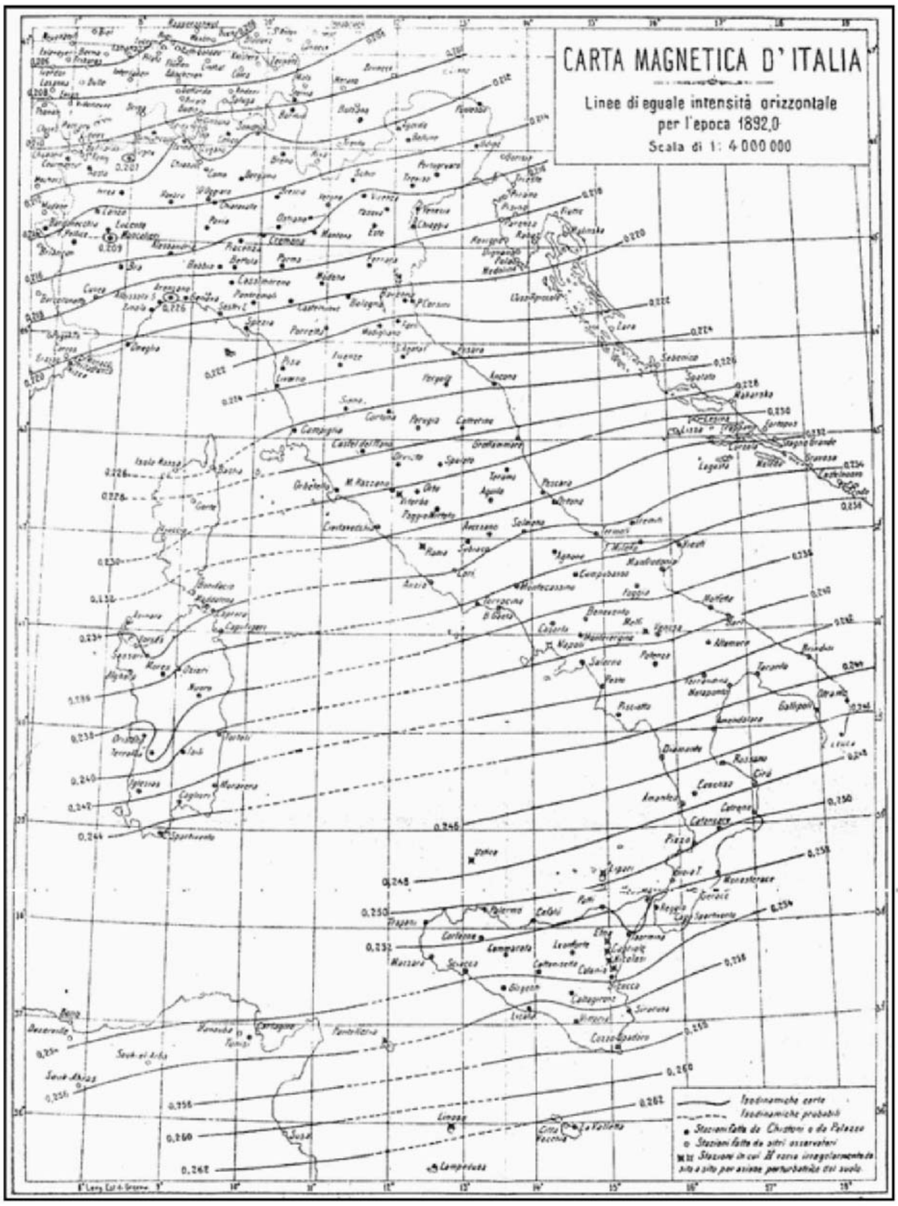

Figure 130. Chart of the horizontal magnetic component H for epoch 1892 as published by Chistoni and Palazzo after the 3-component magnetic survey of 1891-92 in Italy.

Table 27. History of Magnetic Surveys in Italy from 1640 to present. Acronyms are explained within the text. Additional acronym of UCMG stands for the Italian Central Office of Meteorology.

Epoch	Mag. Elements	#Sites	Observer
1640	D	21	Fathers Borri-Martini
1805-07	I,H	15	Humboldt
1845-56	D,I,H	24	Kreil – Fritsch
1875-78	D,I,H	77	Father Denza
1881-92	D,I,H	284	UCMG(Chistoni-Palazzo)¶
1932-38	D,I,H	46(1496)	IGMI
1948	D,I,H	46	IGMI
1959	D,I,H	46	IGMI
1965	D,I,H	28	ING+Universities
1973	D,I,H	50	IGMI
1979	D,I,F	106(2252)	ING+ Universities
1985	D,I,F	106	ING+IGMI
1990	D,I,F	116	ING
1995	D,I,F	116	ING
2000	D,I,F	114	INGV (Charts with IGMI)
2005	D,I,F	114	INGV (completed by end 2005)

Numbers in parenthesis: second order measurements, i.e. only F,H,Z. ¶ For this Survey we present a chart for H (see Figure 130).

Repeat Stations of the National Magnetic Network must satisfy the following requirements:

i) absence of significant artificial and natural disturbance;
ii) representative of a quite large area;
iii) availability of targets for azimuths with geographic meridian.

The "magnetic selection" of the repeat station locations then follows the many years of experience that has led to the identification of areas with low magnetic crustal anomaly level, primarily in relation to the knowledge of the geological and tectonic environment.

A magnetic repeat station is materially constituted of a mark on a concrete pillar or on a 1m^2 platform in the area of the location selected for the magnetic measurement procedures. The operators put the instrument tripod on top of this mark and, using several sightings on an azimuthally distributed landmark panorama, they can rely on a predefined geographical reference system for their measurements. Landmarks targets are generally materialized by churches bell towers, or crosses and recently also by antenna towers. Unfortunately the life time of a magnetic mark is not very long although a specific law protects these points of observation (Italian

Law n.1024, 3 June 1935): in fact the mark can be accidentally removed or a heavy magnetic interference can start with the edification of a new road or a building or other structures nearby. For this reason every repetition survey starts with an in depth inspection of the old marks and, if necessary, a new mark must be installed in the vicinity of the old unusable station.

Magnetic repeat stations are now well established and some of them show many years of "magnetic history" with measurements repeated on the same location for 80-90 years, thus providing information of great value about the secular variation of the geomagnetic field.

For each repeat station a monograph is prepared with the purpose not only to keep note of the magnetic measurements taken but also to allow a quick and correct finding of the place. For these requirements, the monograph consists of two parts: in the first we find indications about the relative area, e.g. field owner, and a brief description as to how reach the place with the help of a detailed map, coordinates and altitude of the site, together with the date of the first series of measurements. Also the Italian Institution that materialised the repeat station for the first time is indicated with the following acronyms:

- I.G.M.I. Istituto Geografico Militare Italiano, Florence;
- I.N.G.V. (I.N.G. before 2000) Istituto Nazionale di Geofisica e Vulcanologia, Rome;
- PADOVA Istituto di Fisica Terrestre, University of Padua;
- FERRARA Istituto di Mineralogia, University of Ferrara;
- GENOVA Ist. Geofisico e Geodetico, University of Genua;
- NAPOLI Osservatorio Vesuviano, Naples;
- BARI Ist. di Geodesia e Geofisica, University of Bari.

In the second part of the monograph, all targets with their azimuths are indicated. Finally all reduced magnetic field values are reported for all epochs of measurements.

In the repeat station survey of 2000, the number of repeat stations in Italy was in total 114, including two Observatories, L'Aquila (42°23'N, 13°19'E) and Castello Tesino (46°03'N, 11°39'E), corresponding to a density of about 1 station /3000 km^2 or about 58 km mean stations spacing.

For 2005, the survey included also the repetition of Albanian network: this sub-network consists of 10 repeat stations materialised and measured for the first time in 1994, in the framework of a joint project between the Center of Geochemistry and Geophysics of Tirana, the Physics Department of Tirana University and I.N.G.V. (I.N.G. at that time), and then repeated for the total intensity *F* alone in August 2003 (Duka et al., 2004) and for all magnetic components in September 2004 with the addition of 1 station (Berat). Figure 131 shows the progress in the measurements for the unfinished 2005 survey. During the period of survey also two magnetometers were deployed in the seafloor of the Tyrrhenian Sea in the framework of the European Project GEOSTAR. The completion of the whole magnetic survey is foreseen by the end of 2005.

Figure 131. Points of Repeat Magnetic Stations of Italy and Albania and their progress in time so far. Completion of the whole survey (to reach a total of 114 Italian sites + 11 Albanian sites) is foreseen by the end of 2005. During the period of survey also two sites in the seafloor were deployed for magnetic measurements in the framework of the European project GEOSTAR.

Magnetic repeat station network measurements now generally include measurements of inclination *I*, declination *D* and total intensity *F*. From these measurements also the horizontal and the vertical components, *H* and *Z*, can be determined. The measurements should be repeated in time over the same stations respecting a 5-year average periodicity as suggested by IAGA (International Association of Geomagnetism and Aeronomy). Instruments used at repeat stations are now Proton Precession Magnetometers and DI Flux magnetometers. A gyroscopic theodolite for the determination of geographic north is used when necessary. The field magnetic measurements need an independent local time variation monitoring: this is generally undertaken at a magnetic observatory. When necessary, time variations of the geomagnetic field were recorded also in the field by means of a portable tri-axial variometer.

Measurements at each repeat station are generally made as 10 sets of measurements: five in the morning at about 7.30-9.30 am LT, and five in the afternoon at about 3.30-5.30 pm LT.

As is known, the value of declination changes slowly with diurnal and secular variation but abruptly during a magnetic storm. For this reason it is important to check if the magnetic field is quiet enough at the day of the measurement. Nowadays it is easy to do it by means of an internet connection: in Italy, the magnetic activity at the two magnetic observatories can be seen in real time by connecting to the INGV web site (www.ingv.it).

3. Data analysis, normal reference fields and cartography

For what concerns the data reduction, the following procedure was used: the magnetic elements *D*, *I* and *F* observed at the repeat stations are reduced firstly to 02 UT for the diurnal variation correction, with reference to digital data from L'Aquila or Castello Tesino Observatory, or from the portable variometric station when the station was installed. Secondly, data will be reduced with the secular variation of L'Aquila Observatory for the fixed epoch, i.e. 2005.0. Prior to the computation of the normal field coefficients, all values will be reduced to sea level considering only the dipolar contribution (see Meloni et al., 1994). In formulae, the value of element 'E' (i.e., D, I or F) at station's', (Es) reduced i.e., to epoch 2005.0, will be calculated following the two steps:

$$\mathrm{Es(02\ UT) = Evar(02\ UT) + [Es(t) - Evar(t)]}$$

$$\mathrm{Es(2005.0) = Eobs(2005.0) + [Es(02\ UT) - Eobs(02\ UT)]}$$

where:

- Es(02 UT)= Value of E at station s reduced at time 02 UT of day of measure
- Evar(02 UT)= Value of E at variometer of station s at 02 UT of day of measure
- Es(t) = Value of element E observed at station s at time t
- Evar(t)= Value of element E at variometer of station s at time t
- Eobs(t) = Value of element E measured at the Observatory at the same time t
- Es(2005.0)= Value of element at station s reduced to epoch 2005.0
- Eobs(2005.0)= Mean value of element at the Observatory for epoch 2005.0

The data so reduced (at sea level and at the centred epoch, i.e. 2005.0) are analysed by means of a least squares regression, in order to provide a normal reference field for each magnetic element *D*, *I* and *F*. The other magnetic elements are deduced from these by means the known formulae relating all magnetic elements. Each normal field is usually expressed as a second order polynomial in latitude and longitude, referred to a central point with coordinates of 12^{o} E longitude and 42 ^{o} N latitude. Usually a rejection criterion is applied in order to reject the least significant coefficients. Normal reference fields so produced are compared with IGRF and another national reference field determined from IGRF and L'Aquila Observatory annual means (Molina and De Santis, 1987). Final significant coefficients are then published together with the corresponding cartography for all magnetic elements.

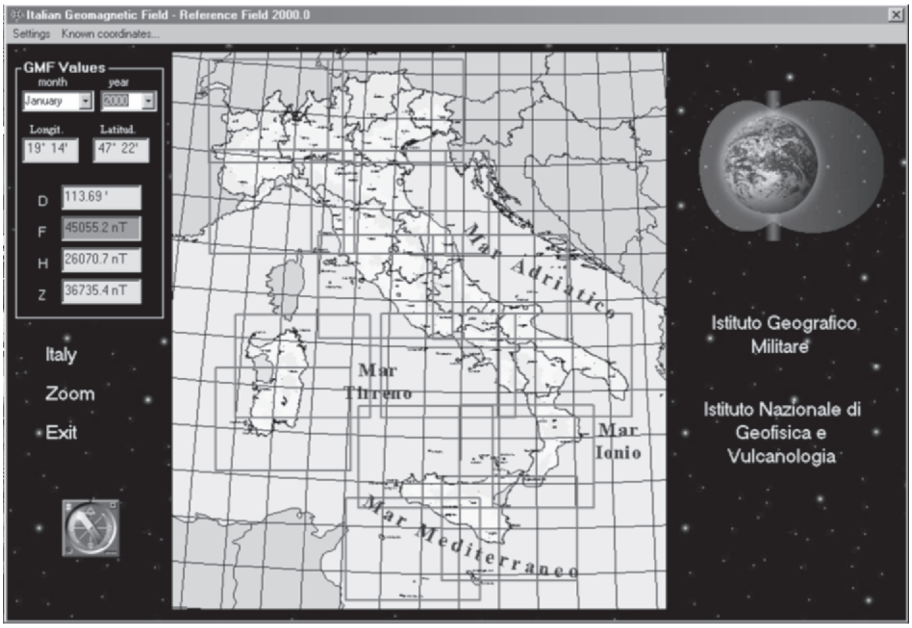

Figure 132. Snapshot of the interactive program that provides interactively the geomagnetic field values at any point of Italy in the epoch 2000.

The last complete survey made in Italy for magnetic maps production was undertaken in 1999-2001 and centred at 2000 (Coticchia et al. 2001). For that epoch in fact an edition of four magnetic maps to the scale 1/1,500,000, one for each element (D, H, Z and F), also with digital support (CD), was published in a joint collaboration between the Istituto Geografico Militare (I.G.M.) and the I.N.G.V.

The maps for F, H and Z were drawn with automatic graphic contouring programs after updating 2552 stations measured in the framework of the second order magnetic network undertaken in CNR Project of Research PFG at 1979.0, with the adopted secular variation model. For what concerns the map of declination the second order network was based on the old IGM 1529 stations data, updated with the usual method starting from the 1985 compilation.

A similar procedure will be followed for the new cartography of the magnetic survey of 2005.

An alternative analysis is also applied for providing a real Laplacian representation of the geomagnetic field over Italy: this is usually made by means of the Spherical Cap Harmonic Analysis (SCHA) (Haines, 1985; De Santis et al., 1990). In this case, no reduction in altitude nor in time (apart from the diurnal variation correction) is made, because this technique takes the proper altitude and time into account for any magnetic field observation. The corresponding references given at the end of this paper can be used to clarify all details of SCHA.

4. Declination measurements in heliports and airports

The regular condition of a periodic control of aircraft compasses is that the operator performs a procedure known as 'compass swing'. This operation consists in a rotation of the aircraft around a point (the centre of a platform also called the *swinging rose*) and compares the values of compass orientation with the horizontal direction of geomagnetic vector obtained by magnetic measurements.

In this section we report our experience in some activity specifically required by helicopter industries and aircraft companies for compass calibration (see Figure 133).

For a new pad dedicated to swinging rose, a visual inspection is important to check if the zone is:

- a level circular area,
- of sufficient strength to support the weight of aircraft,
- at least 180 m far from: buildings, railroad tracks, DC power lines, hangars causing possible big disturbances,
- at least 90 m far from other aircraft.

A total field survey with a proton magnetometer verifies that the area is magnetically quiet if the values measured do not scatter from the mean by more than 90 nT.

Particular attention is required for the construction of the platform so as not to use magnetic materials (e.g. reinforcing steel or ferrous aggregate), and to use non-magnetic material (e.g. PVC) if a drainage conduct is required within 90m.

Once the swinging rose is built, the azimuths of all possible geodetic target bearings must be measured with a gyro-theodolite having a precision not worse than 20 arc-seconds. Such a measurement is to be made only once. To avoid any possible confusion, it is suggested to paint the direction of the Geographic North with a different colour as the Magnetic North.

Magnetic angular measurements are made with a DI flux theodolite with precision of around 1-6’’ (depending on the instrument). Each measurement is reduced with the closest Observatory and then the mean value of declination is computed. This is the value officially given to the Authorities.

Figure 133. Swinging rose at Brindisi (South-East Italy) heliport of Agusta (Manufacturer of helicopters).

After the determination of the direction of Magnetic North, radial lines (usually 24, one every 15 degrees) are drawn with non-magnetic paint, with precision in direction of 1 minute, and some circles are drawn, usually with radii of around 5 m, 15m and 25m.

The Italian law regulations require the determination of magnetic Declination at least every 5 years, for civil use, and every 1 year for military use. Nevertheless, it is strongly suggested to update it annually for any use.

5. Conclusions

Maps and models deduced from the repeat station surveys and magnetic observatories do not only represent the geomagnetic field in all its aspects but can also improve our knowledge of the field dynamics, which is the field evolution in time. Improving the studies of the geomagnetic field, providing better present and predictive models will allow in the next future to improve also the quality of our measurements in the heliports and airports.

As the technology makes important progresses to improve our quality of life, such as in transportation and communications, it usually becomes more complex and sensitive to possible disruptions. It is in those emergencies that we should be able to rely on more natural information such as the orientation through the magnetic compass. Measuring the magnetic declination all over the national territory, with particular attention in some important places, such as heliports and airports, becomes fundamental for improving navigation, in particular for the safety in all operations related to landing and take-off in airports, and flying.

Acknowledgements

We would like to thank the organizers of the NATO ADVANCED RESEARCH WORKSHOP, held in Ohrid, Macedonia 18-20 May, 2005, in particular Dr. Jean Rasson, for inviting us to present this paper in the workshop. We also thank our colleagues of INGV, in particular Angelo Di Ponzio and Massimo Miconi, for their collaboration in many operations during the magnetic repeat station surveys of 2000 and 2005.

References

Coticchia A., Dominici G., De Santis A., Di Ponzio A., Meloni A., Pierozzi M., Sperti, M., 2001. Italian Magnetic Network and Geomagnetic field maps of Italy at year 2000.0, *Bollet. Geodes. Scie Aff.*, **IV**, 261-291. (with 4 maps 1/2.000.000 and CD-ROM).

Cafarella L., De Santis A., Meloni A., 1992. Secular variation from historical geomagnetic field measurements, *Phys. Earth Planet. Inter*., **73**, 206-221.

Cafarella L., De Santis A., Meloni A., 1992. *Il catalogo geomagnetico storico italiano*, *Publ. ING*, 160 pp..

De Santis A., O.Battelli, D.J. Kerridge, 1990. Spherical cap harmonic analysis applied to regional field modelling for Italy, *J. Geomag. & Geoelectr*, **42**, 1019-1036.

Duka B., Gaya-Piqué L.R., De Santis A., Bushati S., Chiappini M., Dominici G., 2004. A geomagnetic Reference Model for Albania, Southern Italy and Ionian Sea from 1990 to 2005, *Annals of Geophysics*, 47, 1609-1615

Haines, G.V., 1985. Spherical Cap Harmonic Analysis. *J. Geophys. Res.* **90** (B3): 2583-2591.

Meloni A., Battelli O., De Santis A., Dominici G., 1994. The 1990.0 magnetic repeat station survey and normal reference fields for Italy, *Annali di Geofisica*, Vol.XXXVII, **5**, 949-967.

Molina F., De Santis A., 1987.Considerations and proposal for a best utilization of IGRF over areas including a geomagnetic Observatory, *Physics Earth Plan. Inter*., **48**, 379-387.