Magnetic variation analysis for the June 1993 seismic events in Central Italy

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Abstract
A scientific collaboration between the Istituto Nazionale di Geofisica (Italy) and the Warsaw Academy of Science (Poland) gave rise to the installation of a few stations for the long-term measurement of magnetotelluric fields in Central Italy. The investigation sites were determined following the individual seismic interest of each location. For this project, the magnetic observatory in L'Aquila was also equipped with electric lines, for simultaneous measurements of the telluric field. After a few years of experience some of the installed stations had to be removed for their high noise level that made this study almost impossible. A first time interval was considered from January 1992 to February 1993 and showed the existence of significant changes in magnetotelluric parameters related to earthquake occurrence time, an extension of that analysis was made to include the event of June 1993 using the magnetic field time variation.

Key words *electromagnetic induction – induction vectors – seismicity*

1. Introduction

Measurements of variations in the Earth's magnetic and telluric electric fields are carried out, at times continuously, in various parts of the world with the intent to verify relations between these phenomena and seismic or volcanic activity. The terms «tectonomagnetism» or specifically in the case of seismic activity «seismomagnetism», are now widely used for the tectonic origin magnetic signals (Mueller and Johnston, 1990). Terms like «geoelectric signals» or «seismic electric-signals» are used to indicate the connection between telluric electric fields and seismicity (see for example Varotsos and Alexopoulos, 1984) when such signals are identified in the records and associated with earthquake occurrence. The study of the complex phenomena that take place in the preparation phase of earthquakes is undertaken also from the point of view of magnetotelluric analysis where both magnetic and electric time variations are used to reconstruct the so-called underground impedence. For a general review of all these studies see, for example, Park (1994).

A long-term data acquisition network for magnetotelluric investigation to study preseismic and coseismic effects, using a few stations, was installed in Central Italy in the year 1991 (see Meloni *et al.*, 1996). Each station is equipped with a telluric recording system

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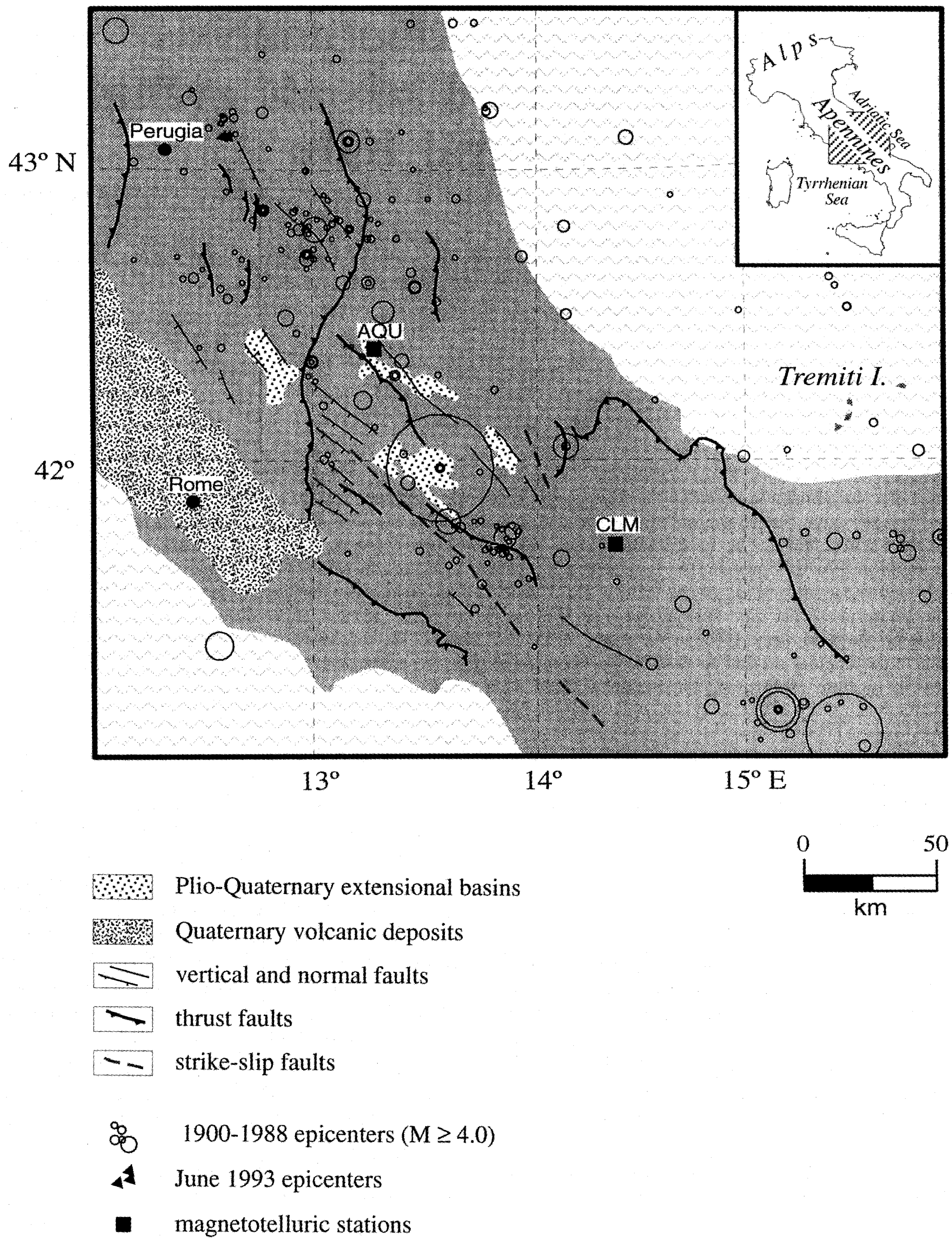

Fig. 1. Location of the magnetotelluric stations and L'Aquila magnetic observatory (AQU) in the Central Apennines and general information on geological structures.

(lines in N-S and E-W directions about 100 m long) and with Thorsion Photoelectric Magnetometers, for the magnetic field three component data acquisition (see Jankowski *et al.*, 1984); each channel operates with a 20 s sampling rate.

The area of study that is specifically referred to here is the Central Apennines in the Italian peninsula. This area is considered, from the seismic point of view, one of the most active regions in the Central Mediterranean. Epicenter distribution generally follows the Alpine-Apennine mountain belts with depths mostly ranging within the first 30 km. Central Italy is characterized by Meso-Cenozoic carbonatic sequences belonging to the Apennine domain and by wide sedimentary basins filled with Plio-Quaternary deposits. Along the Tyrrhenian side of the peninsula large amounts of volcanic deposits outcrop. Geological units are extensively fracturated at regional and local scale (*e.g.*, Bosi, 1975; Carraro *et al.*, 1981), tectonic structures predominantly trend NW-SE.

Significant changes in the magnetotelluric parameters related to the earthquake occurrence times were found analyzing the Central Italy network data showing, for example, an increase in the apparent resistivity at the time of earthquakes (see Ernst *et al.*, 1994). In this short paper an extension of that analysis is made to investigate more recent seismic activity, the June 4 and 5 1993 events, M_L 3.7 and 4.3, respectively, that took place in the area of the town of Perugia (ING, 1995). The 4.3 M_L event is the largest recorded since the magnetotelluric network installation, to include all 1995, in a 100 km circular area around L'Aquila city (see fig. 1 for details).

2. Data analysis

As well known horizontal magnetic field components H and D, are generally considered to be almost exclusively of external origin and they induce the telluric fields E_{ns} and E_{ew} respectively in the N-S E-W directions. There is a relation generally expressed in a frequency domain by the following formula ($\omega = 2\pi f$, f frequency):

$$\begin{vmatrix} \hat{E}_{ns}(\omega) \\ \hat{E}_{ew}(\omega) \end{vmatrix} = \begin{vmatrix} \hat{Z}_{11}(\omega) & \hat{Z}_{12}(\omega) \\ \hat{Z}_{21}(\omega) & \hat{Z}_{22}(\omega) \end{vmatrix} \cdot \begin{vmatrix} \hat{H}(\omega) \\ \hat{D}(\omega) \end{vmatrix} \quad (2.1)$$

where $\hat{E}(\omega)$ and $\hat{H}(\omega)$ indicate the Fourier transforms of electromagnetic components and $\hat{Z}_{ik}(\omega)$ are the Fourier transforms of the impulse response functions, called the impedence tensor as an ensemble. The apparent resistivity and impedence phase are generally defined as follows:

$$\rho_{ik} = 0.2\ T\,|\,\hat{Z}_{ik}(\omega)\,|^2,\quad i \neq k \qquad (2.2)$$

$$\text{phase} = \text{arctg}\left(\frac{\text{Im}\,(\hat{Z}_{ik}(\omega))}{\text{Re}\,(\hat{Z}_{ik}(\omega))}\right) \qquad (2.3)$$

if T is a period expressed in seconds, magnetic field elements are measured in nT and telluric field in mV/km, the resistivity is then expressed in $\Omega \cdot$ m (see, for example, Kaufmann and Keller, 1981).

As mentioned briefly in the introduction, this classical magnetotelluric data analysis was undertaken for a number of time sections of high quality data by means of apparent resistivity calculations performed in the time domain (see Ernst *et al.*, 1994; Meloni *et al.*, 1996).

In the case of the June 1993 events unfortunately recordings at the CLM station had a bad signal to noise ratio in the electric field telluric components (see fig. 1 for station location). In order to study the electromagnetic inductive component the vertical magnetic field element Z was then used. In situations generally met at mid latitudes, when the external magnetic field is represented only by the horizontal components, the inductive component Z follows in time domain the relation:

$$Z(t) = a(t) * H(t) + b(t) * D(t) \qquad (2.4)$$

while in frequency domain it is

$$\hat{Z}(\omega) = \hat{a}(\omega)\hat{H}(\omega) + \hat{b}(\omega)\hat{D}(\omega). \qquad (2.5)$$

A geomagnetic induction vector can be introduced to quantify the induction process starting

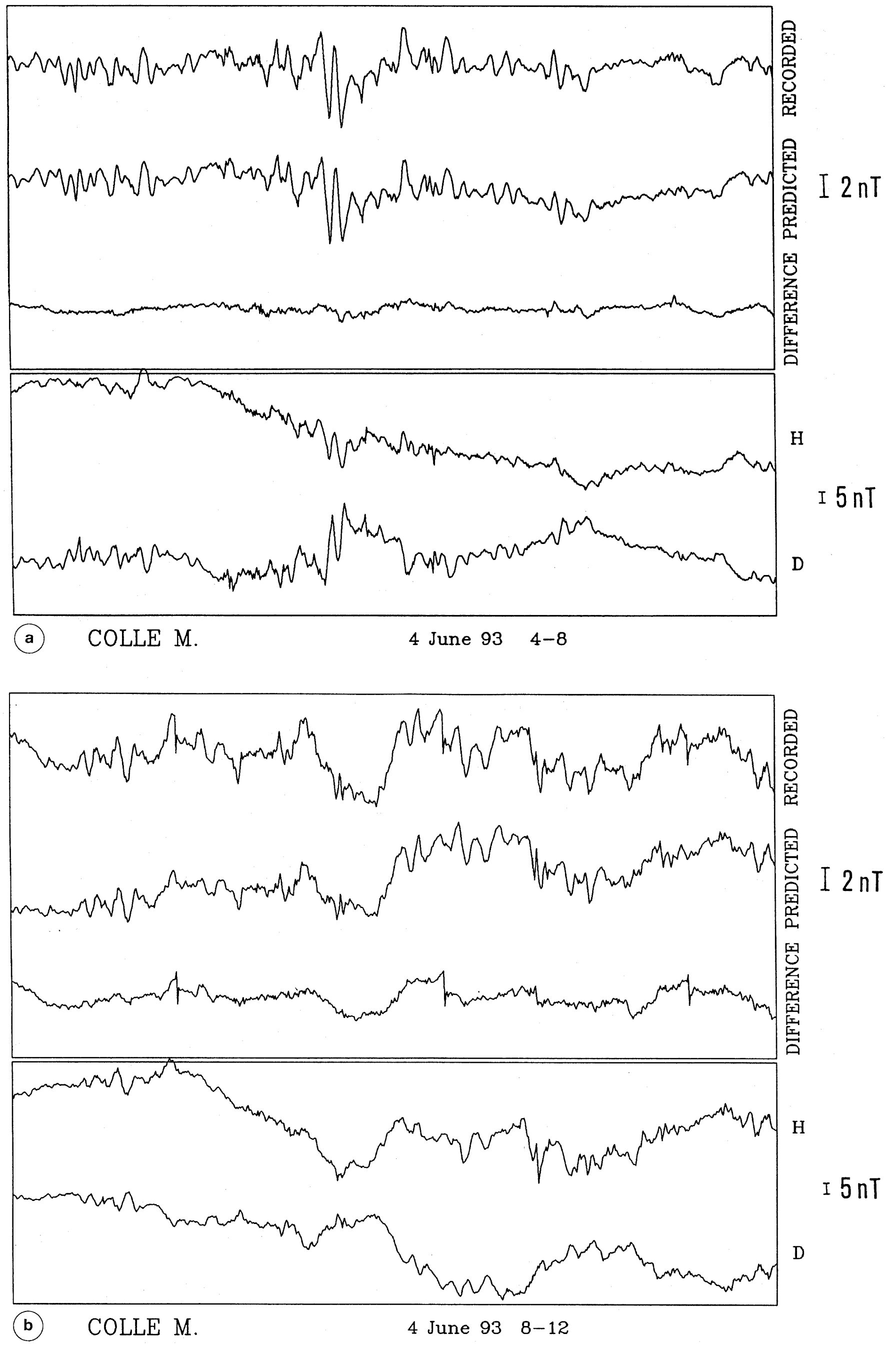

Fig. 2a,b. The recorded magnetic field elements *H* and *D* (lower diagram) and the recorded *Z* magnetic field component, its prediction and their difference (upper diagram) for the two four hour intervals (part a and b) of June 4th, 1993.

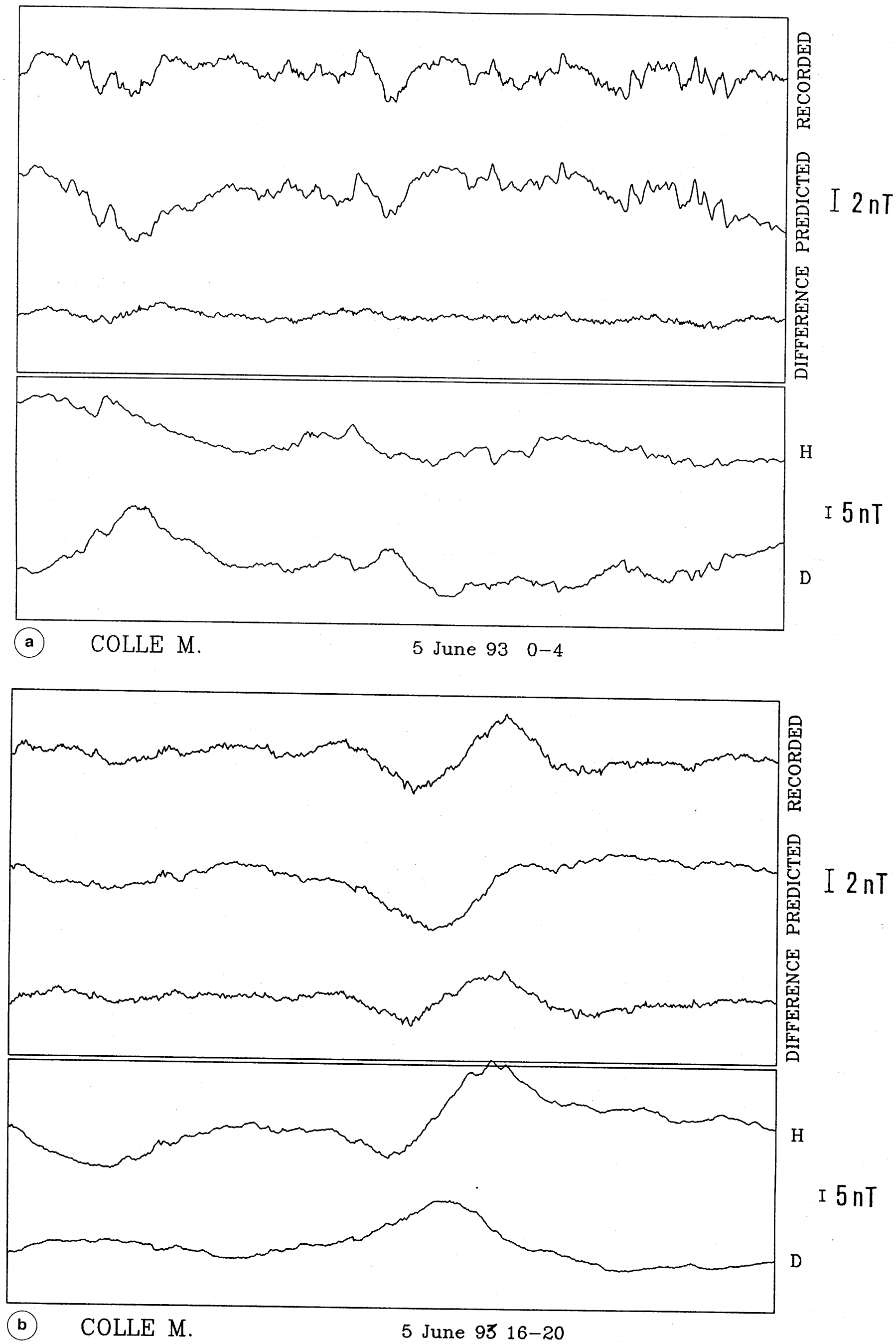

Fig. 3a,b. The recorded magnetic field elements *H* and *D* (lower diagram) and the recorded *Z* magnetic field component, its prediction and their difference (upper diagram) for the two four hour intervals (part a and b) of June 5th, 1993.

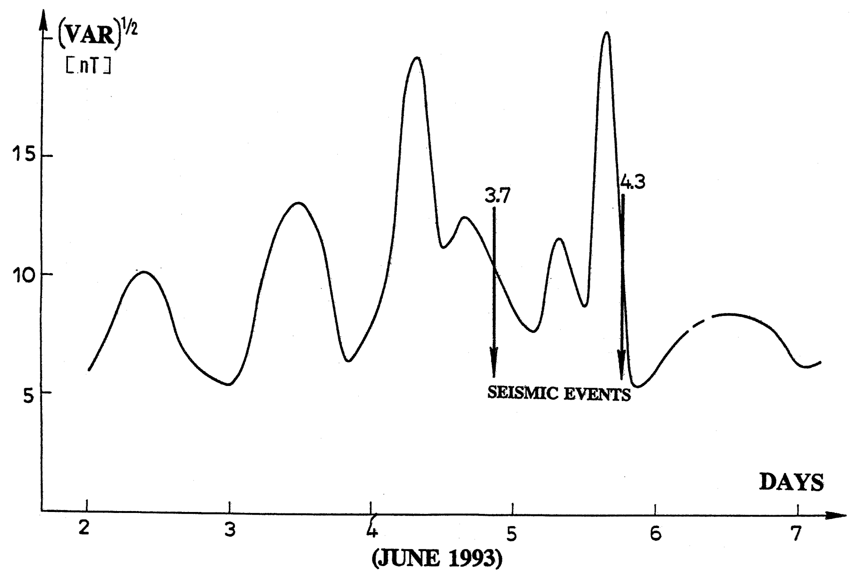

Fig. 4. Variance of the residual part of Z component and the seismic events in June, 1993; the corresponding seismic event times and magnitudes are indicated.

only from the magnetic field time variations. This vector is defined as the real part of the complex vector $[\hat{a}(\omega), \hat{b}(\omega)]$ (see for example Gough and Ingham, 1983). An example of the time sections of the magnetic field used for the computation of the predicted vertical field, according to (2.5), is given in figs. 2a,b and 3a,b for two 4 h sets. The predicted amplitude, computed on time sections around the seismic events and the variance of the residual part of the vertical component, as a measure of the non-inductive part of the Earth's electromagnetic response, were also computed. The applied procedure follows the Wieladek and Ernst algorithm (1977). The residual is reported in fig. 4 for days 2-7 June 1993; seismic event occurrence times are also shown in this figure as vertical lines with lengths proportional to their magnitudes.

3. Conclusions

After significant changes in magnetotelluric parameters related to earthquakes were found using data from an MT station network installed in the Central Apennines (see, Ernst *et al.*, 1994; Meloni *et al.*, 1996), more electromagnetic data were recorded in the area. In this paper the June 4 and 5 1993 seismic events (M_L 3.7 and 4.3 respectively) were investigated. The 4.3 M_L event is the largest recorded since the magnetotelluric network installation throughout 1995 in a 100 km circular area around L'Aquila city. In order to study the electromagnetic inductive component, the vertical magnetic field Z was used to compute 4 h sets of complex induction vector and then the residual part, as a measure of the non-inductive part of the Earth's electromagnetic response, was plotted for a time interval of a few days around the two seismic events (see fig. 4).

The time variance of the Z residual was then considered as an indication of a possible precursory active field. This variance can depend of course on many factors and processes that are difficult to separate, among others we will mention for example influences of deviation of underground conductivity structures from ideal assumptions in the induction process (as reported in formula (2.5)). We stress, however, that instrumental errors and errors introduced with the applied numerical procedure can be considered negligible. An interesting variation (*i.e.*, an increase in the variance a few hours before the earthquake occurrence) that seems promising to promote further studies in this direction, occurs as shown in fig. 4.

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