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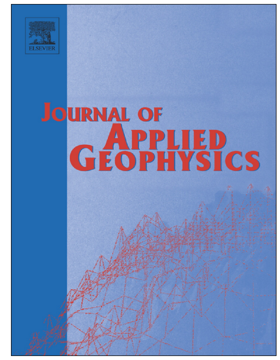

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C. Di Lorenzo, P. Palangio, A. Zirizzotti, C. Bianchi

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C. Di Lorenzo, P. Palangio, A. Zirizzotti and C. Bianchi

Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Geomagnetismo, Aeronomia e Geofisica Ambientale, via di Vigna Murata 605, 00143 Roma, Italy

Contact email: cinzia.dilorenzo@ingv.it, paolo.palangio@gmail.com, achille.zirizzotti@ingv.it, cesidio.bianchi@ingv.it

Abstract

Following the Mw 6.3 earthquake that hit the city of L'Aquila (Central Italy) on the 6th April 2009, a scientific project was proposed with the aim of investigating the Abruzzo area by means of different disciplinary approaches including geological, seismic, and physical studies. Electromagnetic field monitoring in the 0.01-500 mHz frequency band was implemented for the investigation of electromagnetic signals in the Earth's crust. Three measurement stations were installed in a tectonically active area with a radius of about ten kilometres. Each site was equipped with a fluxgate magnetometer with a 1 Hz sampling rate. This paper describes a long term geomagnetic deep sounding analysis for each site, aimed at investigating the dimensionality of the electrical structure of the subsoil in the area involved in the survey. According to a very simplified RL circuit model, some electrical properties of subsoil are also deduced.

Keywords: electromagnetic induction; conductivity; tipper arrow; geoelectric strike

Specifications Table

Subject area	*Geophysics*
More specific subject area	*Electromagnetic induction*
Type of data	*Image, binary file, text file, figure*
How data was acquired	*Lemi18 fluxgate magnetometer*
Data format	*Raw, filtered, analyzed*
Experimental factors	*Magnetic raw data with spikes, noise features or gaps were not used*
Experimental features	*1 Hz sampled data from three simultaneous working magnetic stations were used for the analysis*
Data source location	*CLB station: Lat. 42° 24' 32'' N, Lon. 13° 24' 15'' E* *PGN station: Lat. 42° 22' 51'' N, Lon. 13° 28' 20'' E* *PRT station: Lat. 42° 23' 1'' N, Lon. 13° 18' 58'' E*
Data accessibility	*Associated with this article*
Related research article	*In press*

Value of the Data

- The availability of simultaneous magnetic data from a two-dimensional magnetometer array is useful to spatially monitor the area investigated by the survey, to do inter station analysis and also to apply gradiometric methods.
- The array location is interesting because it covers an area with moderate/high seismic events. This could allow to study magnetic signals associated with tectonic activity.
- The existence of a permanent magnetic array guarantees a long term monitoring that is necessary to observe slow changes in the electrical characteristics of subsoil and also to characterize the 'normal' magnetic background necessary to define what 'anomalous' signal means.

Data

In this paper we describe a long term (about 4 years from 2013 to 2017) geomagnetic deep sounding analysis in the ULF frequency band using data from a two-dimensional magnetometer array located in Central Italy (Fig.1). The array is composed of three magnetic stations (CLB, PGN and PRT) disposed to form a triangle (Table 1). The mean distance between them is of about 10 Km. Each site is equipped with a Lemi18 fluxgate magnetometer.

Experimental Design, Materials, and Methods

The magnetic sensors were housed in fiberglass tanks buried at a depth of about 2 meters in order to achieve passive temperature stabilization, eliminate wind induced vibrations, and increase the mechanical stability of the sensors (Fig.2). Solar panels were used to power the system with a linear charge controller to charge the batteries supplying all the instrumentation.

All power devices were mounted on an aluminium trellis about 100 meters away from the instrumentation to prevent interference, with all power cables and signal transmissions being "twisted" and shielded for the same reason. The trellis also housed the power supply system and antennas of a GSM-UMTS router for data transmission, connecting the equipment to the Internet through the local telephone network. Fig.3 shows the CLB station.

Magnetic data are sampled at 1Hz. Binary files are produced by the acquisition system then they are converted as ASCII files using the Lemi018i program (Fig.4). Data files are organized as daily files. They are composed of 11 columns: year, month, day, hh, min, sec, Bx, By, Bz, Te, Tf. The two last columns represent the temperature of the electronic equipment and that of magnetic sensors, respectively. Raw data are previously selected leaving out data with spikes, noise features or gaps. The mean daily value was removed from the data, then they were filtered with a Butterworth filter (order 4) in the 1-450 mHz frequency band. To filter data we used the MATLAB Butterworth filter function.

Filtered data were used to calculate the magnetic transfer functions A and B in the frequency domain. This complex quantities relate the inductive vertical component Z to the horizontal inducing components X and Y.

$$Z(f) = A(f)X(f) + B(f)Y(f) + \varepsilon(f) \tag{1}$$

The last term represent the vertical non inductive component. A e B were evaluated minimizing the residual ε relative to A and B by means of the standard least-squares method. (Everett and Hyndman, 1967; Gough and Ingham, 1983). Cross spectral densities were used to this aim:

$$A(f) = \frac{<Z(f)X^*(f)><Y(f)Y^*(f)> - <Z(f)Y^*(f)><Y(f)X^*(f)>}{<X(f)X^*(f)><Y(f)Y^*(f)> - <X(f)Y^*(f)><Y(f)X^*(f)>}$$

$$B(f) = \frac{<Z(f)Y^*(f)><X(f)X^*(f)> - <Z(f)X^*(f)><X(f)Y^*(f)>}{<Y(f)Y^*(f)><X(f)X^*(f)> - <Y(f)X^*(f)><X(f)Y^*(f)>} \tag{2}$$

The symbol < > indicates the mean values of cross spectra calculated over temporal sub intervals of equal length. We applied a Hanning window of 512 seconds (frequency resolution is 2 mHz) covering the entire day without overlapping.

Real and imaginary parts of Tipper arrow (induction arrow) defined as [A,B] were taken into consideration. The mean daily value of these quantities was calculated in the 10-50 mHz frequency band (Figs.5a, b and c). The annual mean and standard deviation of both amplitude and phase are reported.

Also, magnetic transfer functions were used to calculate the Tipper skew (Jupp and Vozoff; Naidu, 2012), a rotationally invariant parameter that is indicative of geoelectrical dimensionality of subsoil. It is defined as:

$$S(f) = \frac{2\left[A_{re}(f)B_{im}(f) - A_{im}(f)B_{re}(f)\right]}{\sqrt{A_{re}^{2}(f) + A_{im}^{2}(f) + B_{re}^{2}(f) + B_{im}^{2}(f)}} \quad (3)$$

Its mean daily value in the 10-50 mHz frequency band for each station is shown in Figs.6a, b and c.

Finally, the phase of induced magnetic field Z, related to X and Y by eq. (1), was calculated for each site (Fig.7).

Fig.1: The two-dimensional magnetometer array located in Central Italy.

Table 1: Geographical parameters of magnetic stations.

CLB	PGN	PRT
Lat. 42° 24' 32'' N	Lat. 42° 22' 51'' N	Lat. 42° 23' 1'' N
Long. 13° 24' 15'' E	Long. 13° 28' 20'' E	Long. 13° 18' 58'' E
Alt. 1227.82 m	Alt. 932.4 m	Alt. 666.95 m

Fig.2: The sensors of Lemi18 fluxgate magnetometer.

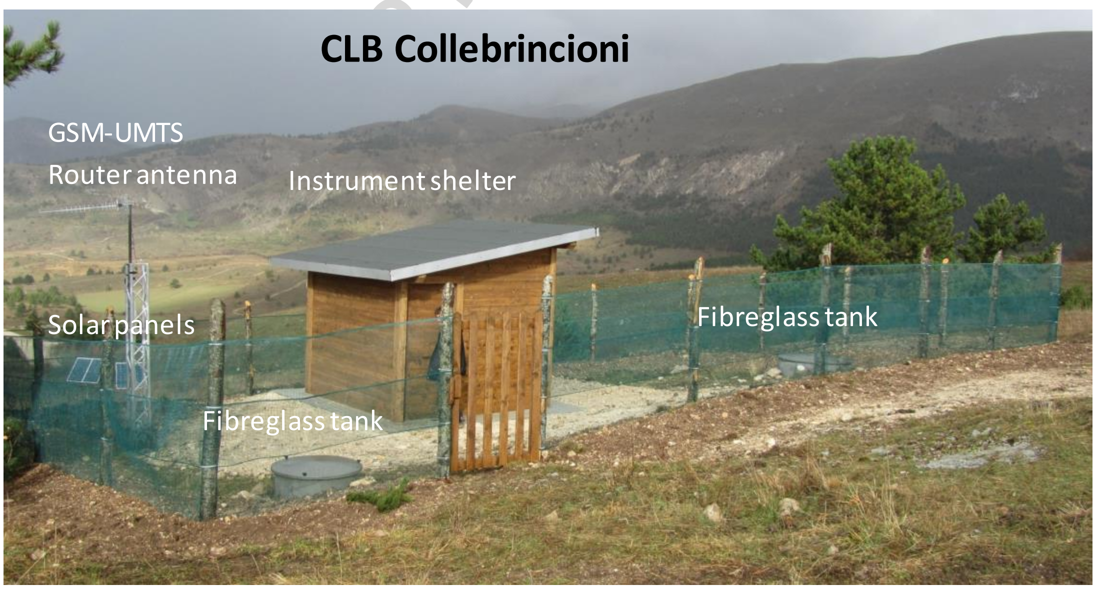

Fig.3: CLB magnetic station.

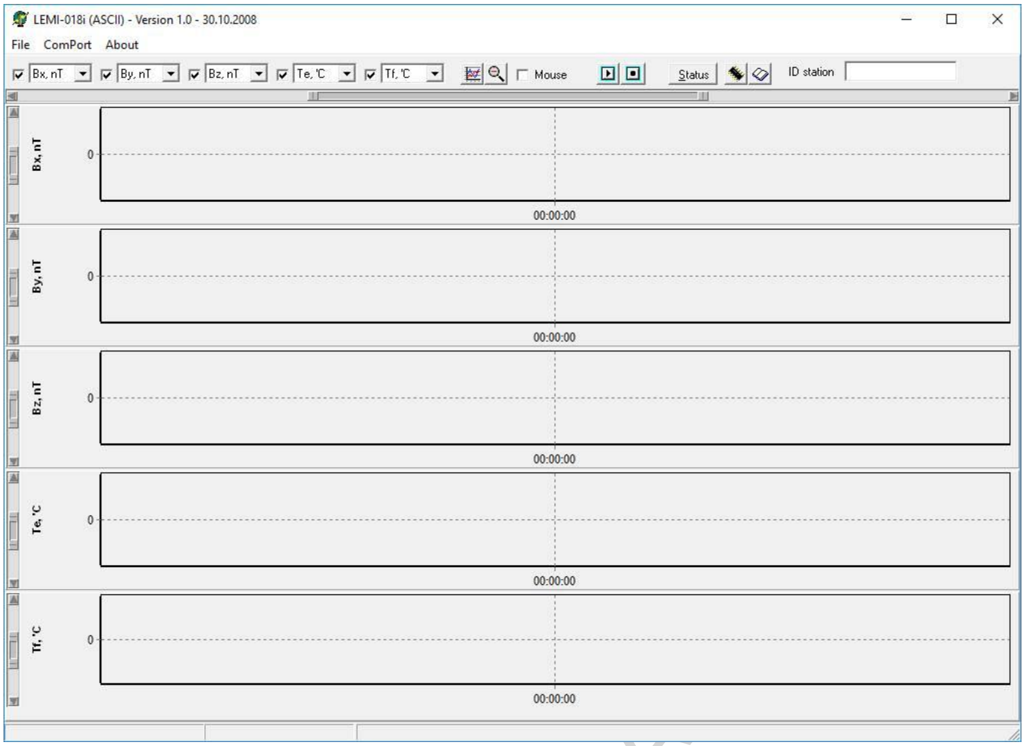

Fig.4: The graphical interface of Lemi018i program.

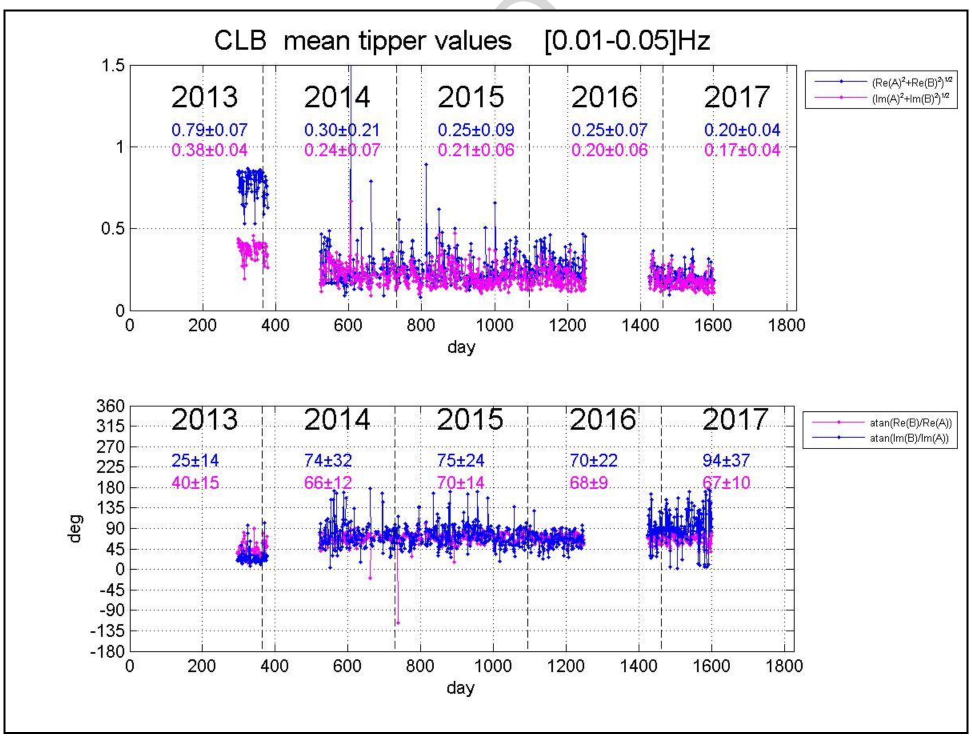

Fig.5a: The mean daily values of magnitude and phase of induction arrow at CLB, calculated in the [0.01 0.05] Hz frequency band.

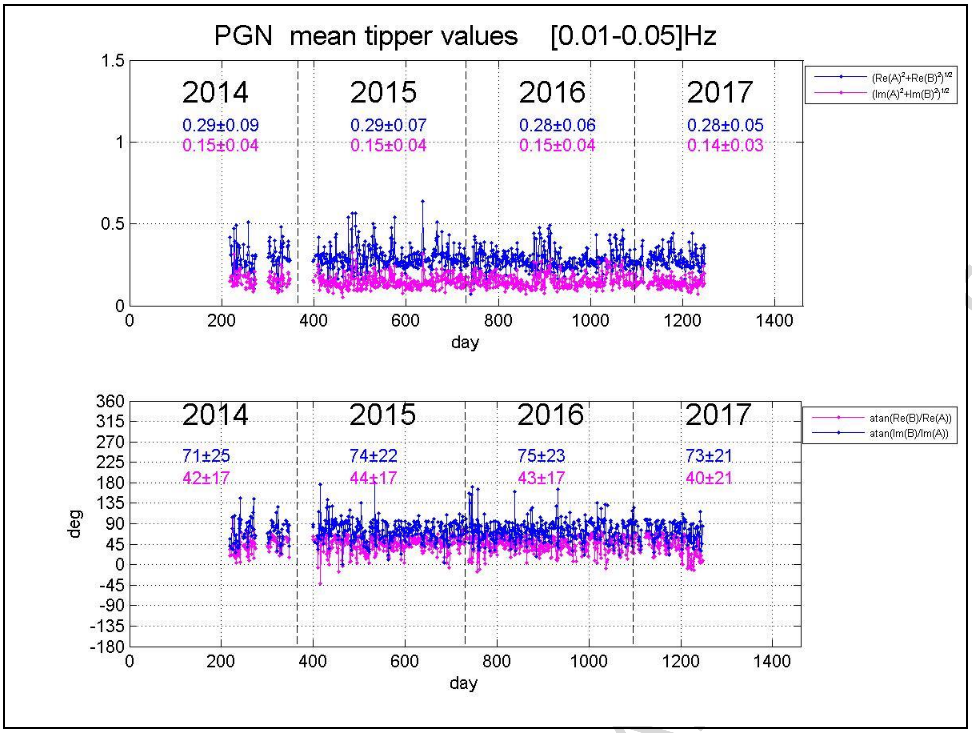

Fig.5b: The mean daily values of magnitude and phase of induction arrow at PGN, calculated in the [0.01 0.05] Hz frequency band.

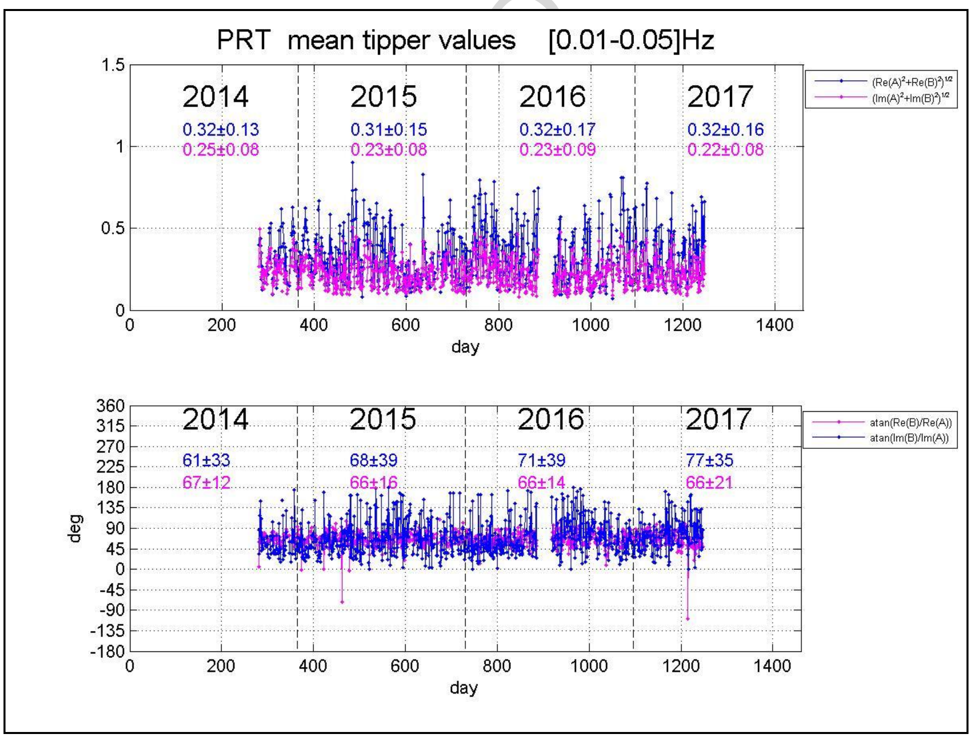

Fig.5c: The mean daily values of magnitude and phase of induction arrow at PRT, calculated in the [0.01 0.05] Hz frequency band.

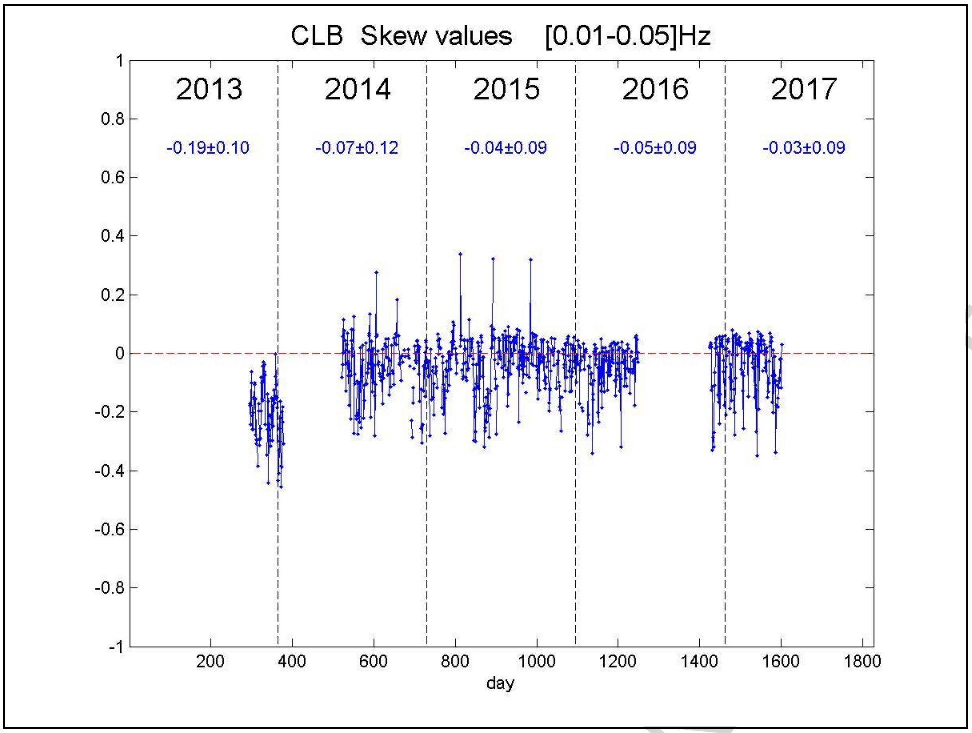

Fig.6a: The mean daily values of tipper skew at CLB in the [0.01 0.05] Hz frequency band.

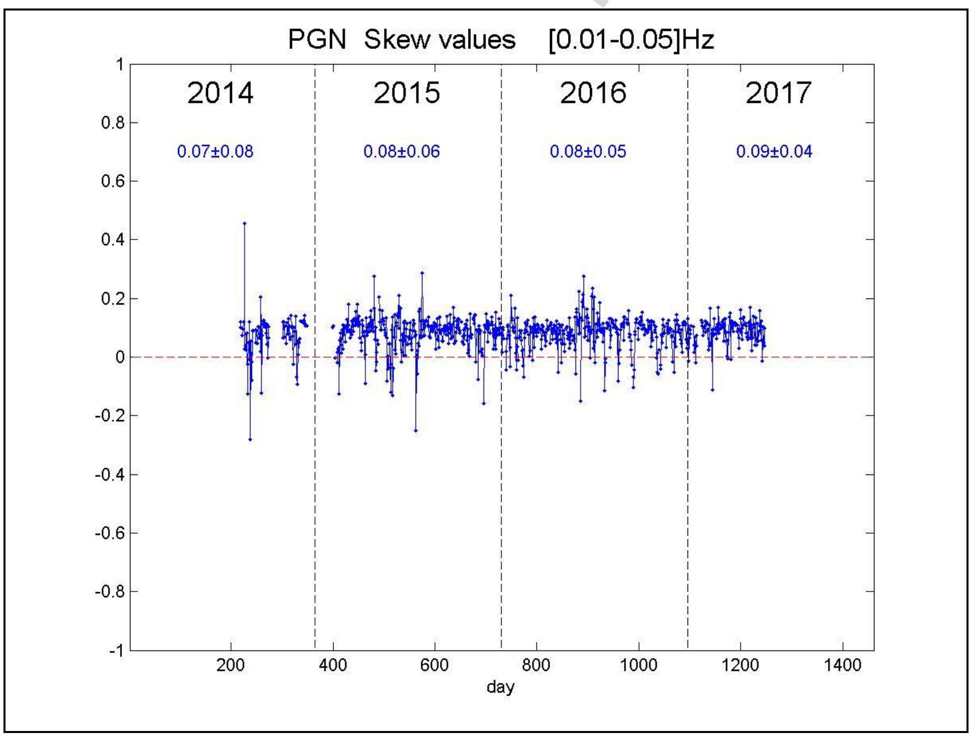

Fig.6b: The mean daily values of tipper skew at PGN in the [0.01 0.05] Hz frequency band.

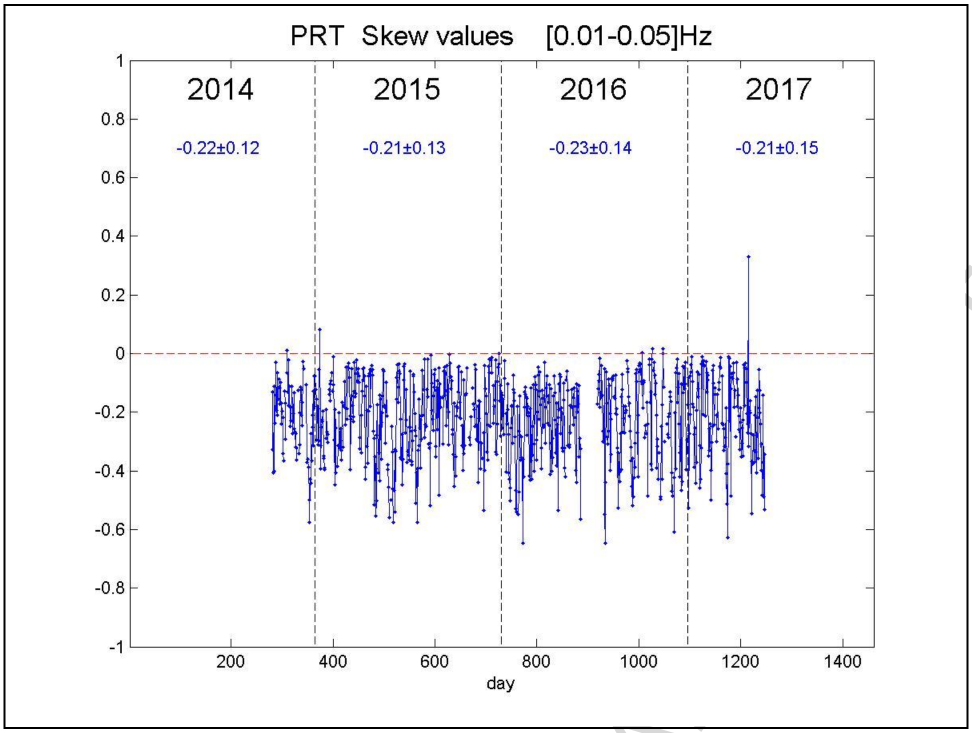

Fig.6a: The mean daily values of tipper skew at PRT in the [0.01 0.05] Hz frequency band.

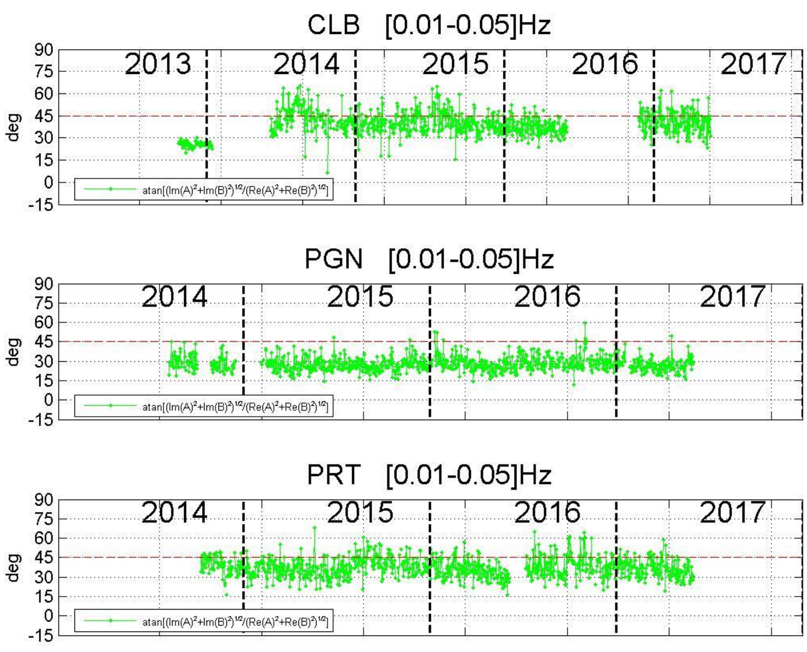

Fig.7: The main daily values of phase of the induced vertical component (Z) in the [0.01 0.05]Hz frequency band.

Acknowledgments

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Highlights

- A long term geomagnetic deep sounding analysis was made in Central Italy using magnetic data from a two-dimensional magnetometer array.
- The induction arrow (tipper) analysis shows a 2D electrical structure of subsoil in the area investigated by the magnetic survey.
- The geoelectric strike orientation is found to be located at ~160° from the North.
- Some electrical properties of subsoil are deduced by the analysis of magnetic transfer functions according to a very simplified RL electrical circuit model.