# A permanent array of magnetotelluric stations located at the South American subduction zone in Northern Chile.


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## Introduction

Monitoring the dynamic behavior of an active deep subduction system is focus of the Integrated Plate Boundary Observatory Chile (IPOC), a permanent array of combined geophysical and geodetic stations in Northern Chile which is operated since 2006 by the GFZ German Research Centre for Geosciences. Magnetotelluric (MT) data is gathered at seven out of a total of eleven observation sites.

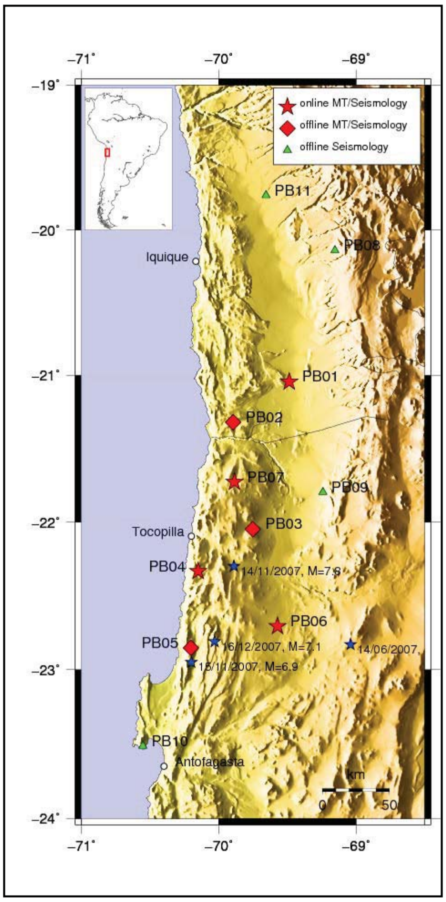


*Figure 1: The IPOC-MT array in Northern Chile showing sites PB01 to PB07 (red symbols). Blue stars indicate major earthquakes.*

The MT set up consists of three component long period fluxgate magnetometers (GeoMagnet) and non-polarizing Ag/AgCl electrodes to measure all three components of the magnetic field and both horizontal components of the electric field. The signals of the electromagnetic fields are continuously sampled at a rate of 20 Hz and at four sites transferred via satellite link to the GFZ in Germany. The objective of the project is to monitor and analyze electromagnetic data to decipher possible changes in the subsurface resistivity distribution, e.g. as a consequence of large scale fluid relocation.

Here, we present vertical magnetic transfer functions as time series over a time span of more than two years for the period range from $10^{-1}$ to $10^{4}$ seconds[1]. These vertical magnetic transfer functions are sensitive to lateral changes of electric conductivity in the subsurface. Some components of these transfer functions show frequency dependent variations with a periodicity of roughly one year. These effects are observed at all sites of the array.

Due to the extreme dry ground of the Atacama desert continuous monitoring the electric field is difficult. Contact resistances are on the order of MΩ and electrolyte is leaking. Different types of electrodes are currently being tested.

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[1] *Periods shorter than 10 seconds are not considered since this is the shortest period fluxgate magnetometers are able to resolve.*

## Periodic variations in the MT monitoring data

To identify changes in the subsurface we examine time series of vertical magnetic transfer functions Tx(ω) and Ty(ω):

$$Bz(\omega) = Tx(\omega)\, Bx(\omega) + Ty(\omega)\, By(\omega).$$

These quantities are sensitive to lateral changes of electric conductivity in the subsurface.

The value of each day and component of the transfer function time series is obtained by processing magnetic field time series of 3 days (using the day before and after). Subsequently the 3 day time window is forwarded by one day and the procedure is repeated until the entire time series is processed. The geomagnetic transfer functions were obtained using the robust processing described in Ritter el al. (1998), Weckmann et al. (2005), and Krings (2007).

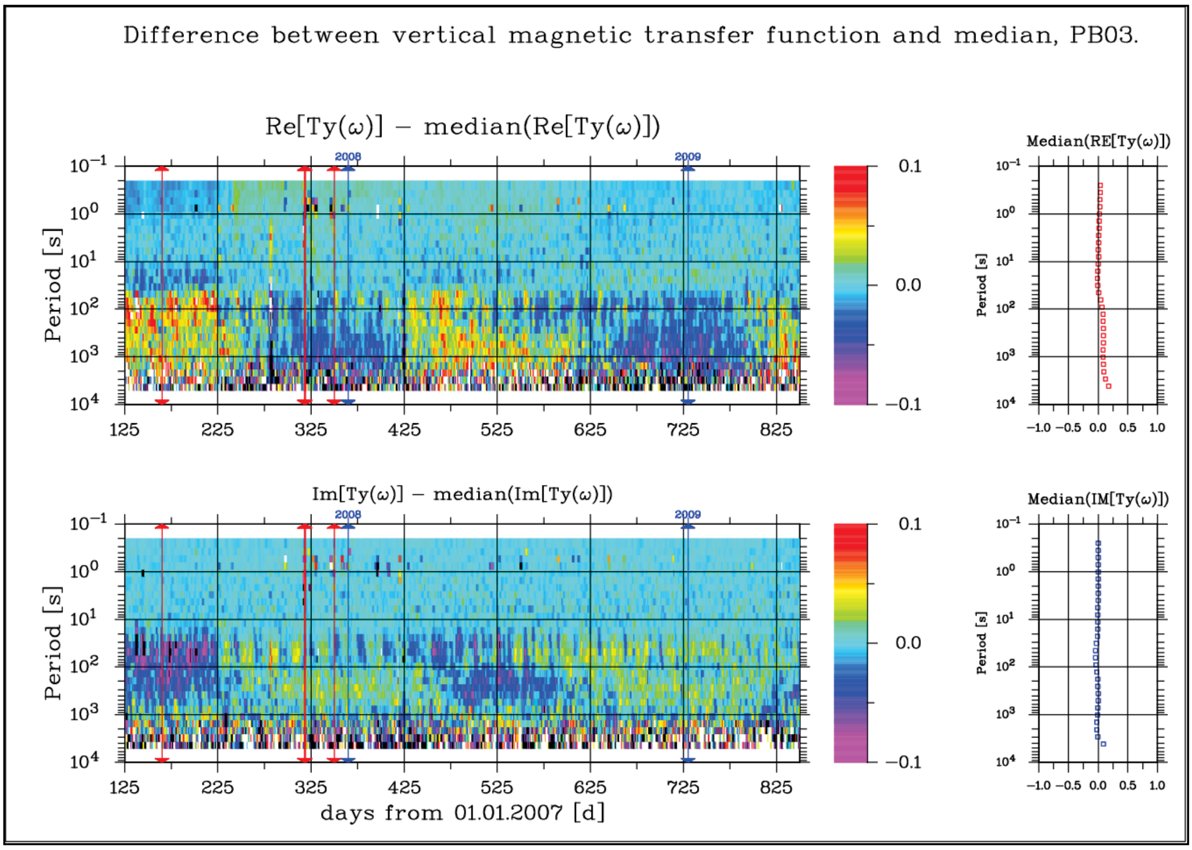


*Figure 2: Time series showing the differences between daily values of Ty and the median of the entire data section of 730 days at each period for site PB03. For monitoring purposes it is desirable to amplify variations in the vertical magnetic transfer function components. Therefore, the median is calculated for each period and component and subtracted from the value of each day. The median of each frequency band is plotted on the right hand side. The median is more robust against outliers than the arithmetic average. Vertical red lines indicate major earthquakes (see Fig. 1), vertical blue lines indicate turn of the year. Interestingly, the ocean effect, which would be indicated by a large positive value of the median of Re[Ty], is rather small at site PB03.*

The time series of the real and imaginary parts of the Ty (east-west) component at PB03 show a remarkable frequency dependent feature (Fig. 2). At periods between approximately 40 and 1000 s the observed Re[Ty] values show a continuous variation of the amplitudes with a periodicity of roughly one year. The amplitudes vary in the range ± 0.1 and reach maximum values in the austral winter before the winter solstice. In the austral summer, the minimum occurs before the summer solstice. Similar effects can be observed consistently at all sites of the array (Fig. 3).

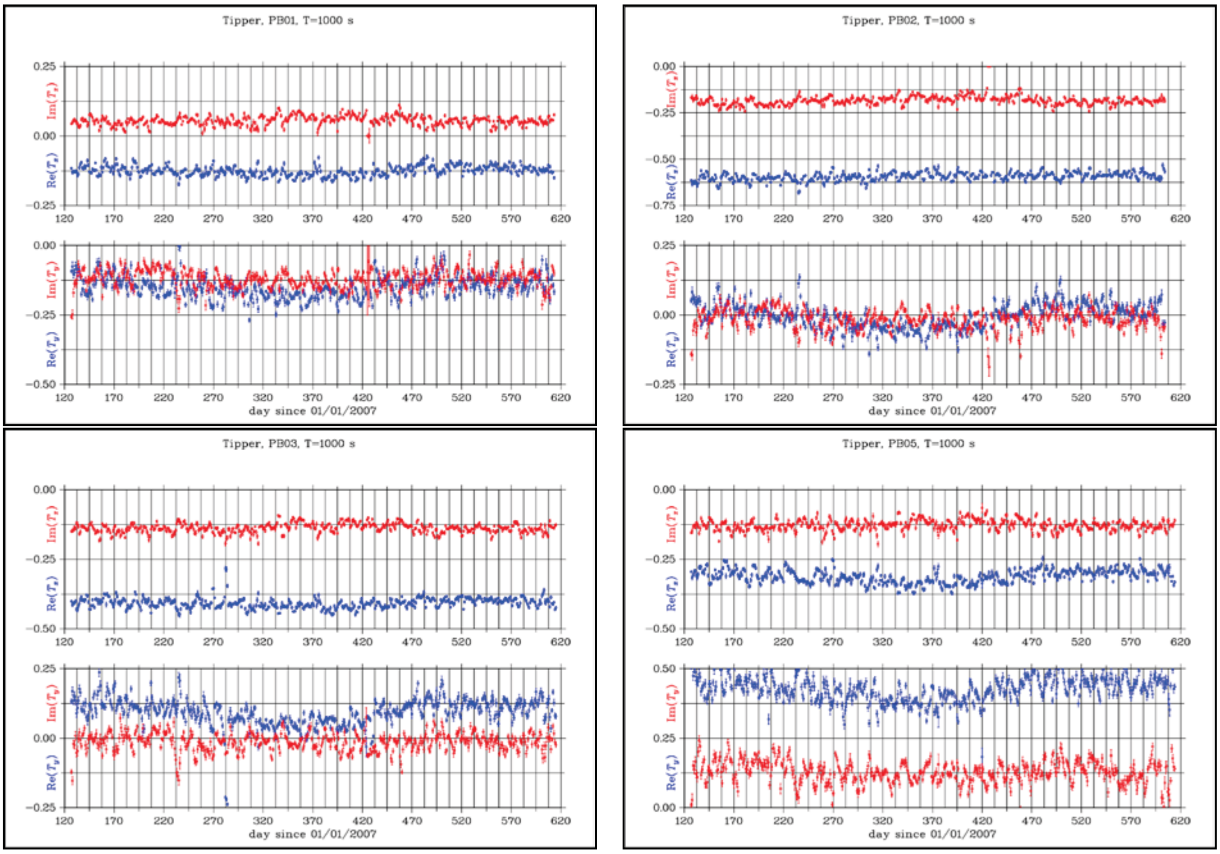


*Figure 3: Time series of real (blue) and imaginary (red) parts of vertical magnetic transfer functions Tx and Ty of around 600 days at a period of 1000 seconds of sites PB01, PB02, PB03 and PB05.*

## Possible causes for the periodic variations of Ty

Possible causes for this periodic variation of the Ty component could be source field inhomogeneities. The sources for the MT-method are the natural variations of the earth's magnetic field which are assumed to be far away from the observer so that electromagnetic waves penetrate

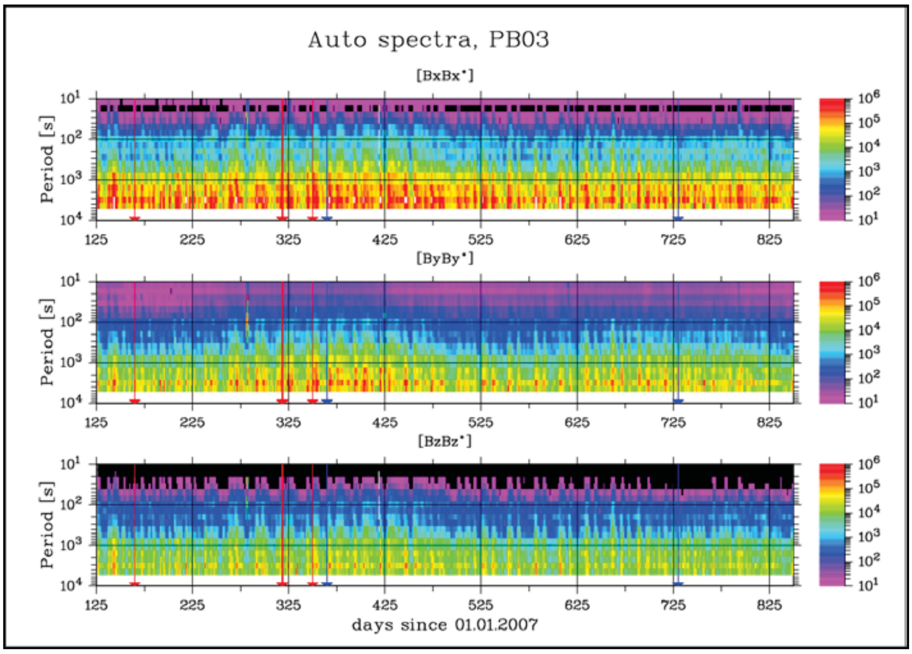


*Figure 4: Time series of the magnetic auto spectra of PB03, extracted from the 3-day-average processing described in section 2. The ByBy* spectra show the same variations with a periodicity of one year as Ty.*

the subsurface as plane waves.

To examine if the variations in the time series of vertical magnetic transfer functions are caused by seasonal alterations of source fields we plotted the time series of magnetic auto spectra of PB03 (Fig. 7) for the same time window as in Figure 2. These magnetic auto spectra show a clear correlation between the By-auto spectrum (east-west direction) and the Ty data (Fig. 8). This would support the idea that the results are influenced by source field effects.

## Sq variations and equatorial electrojet

There exist several effects on the geomagnetic field which have a wide spectrum of variations (*Onwumechili, 1997*). Annual variations of the geomagnetic solar quiet daily variation (Sq) show the same periodicity as the measured variations of the magnetic auto spectra at PB03. The geomagnetic Sq field has a variation with a dominant periodicity of 1 day. Solar radiation generates ionized molecules in parts of the ionosphere (around 80 to 300 km height) which produces variable charged particles and, consequently, conducting air. Additionally, the solar radiation causes thermo-tidal winds which move the conducting ionosphere through the geomagnetic field. The result is a system of electric currents depending on the position of the sun. Horizontal and vertical components of Sq tend to be predominantly semi-annual in the zone of Equatorial Electrojet (EEJ) but predominantly annual at other latitudes (*Onwumechili, 1997*).

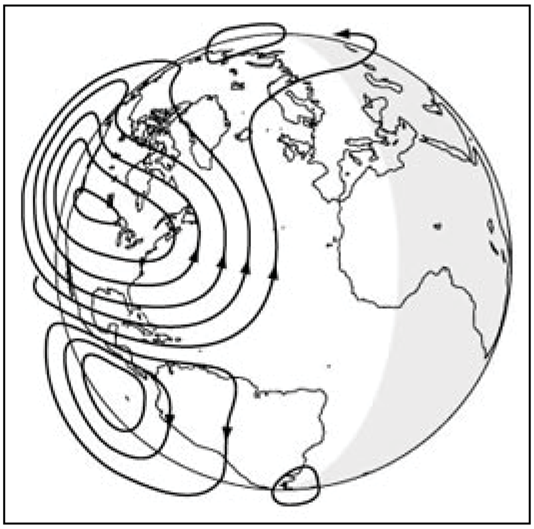

*Figure 5: Exemplary electric currents in the ionosphere cause Sq variations in the northern summer. http://geomag.usgs.gov/images/ionospheric_current.jpg (10.02.2010)*

The IPOC MT array (21 - 23° south) in Northern Chile is located near the tropic of Capricorn (23° 26' south). This means, it is influenced by the Equatorial Electrojet (EEJ), a varying electric current flowing eastward in the ionosphere at a height of 100 - 130 km. Over South America the EEJ is warped to the south because it follows the magnetic dip equator (Fig. 8). The amplitudes are aligned to the north and to the south by return currents (Lühr et al.,2004) with peak values at latitudes some 5° away from the magnetic dip equator.

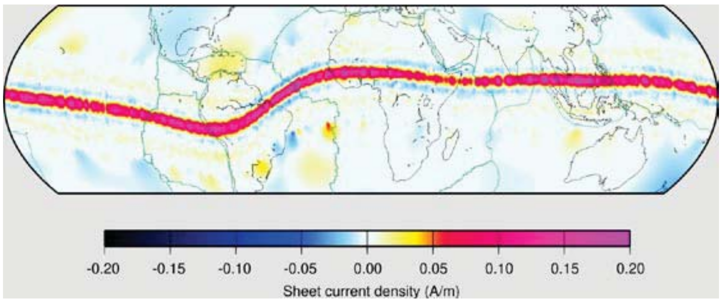


*Figure 6: Electrojet current densities inferred from 2600 passes of the CHAMP satellite over the magnetic equator between 11:00 and 13:00 local time. http://www.geomag.us/info/equatorial_electrojet.html (10.02.2010)*

Annual Sq variations are most likely the cause of the variations of the Y-component of the vertical magnetic transfer functions at the MT-array in Northern Chile.

## Non-periodic variations in the MT monitoring data

No periodic long term variations can be identified in the Tx component of the vertical magnetic transfer function time series (Fig. 7). A continuous variation at a period of approximately 20 s can be observed in the Re[Tx] component. It has a high amplitude variation between -0.2 and +0.2.

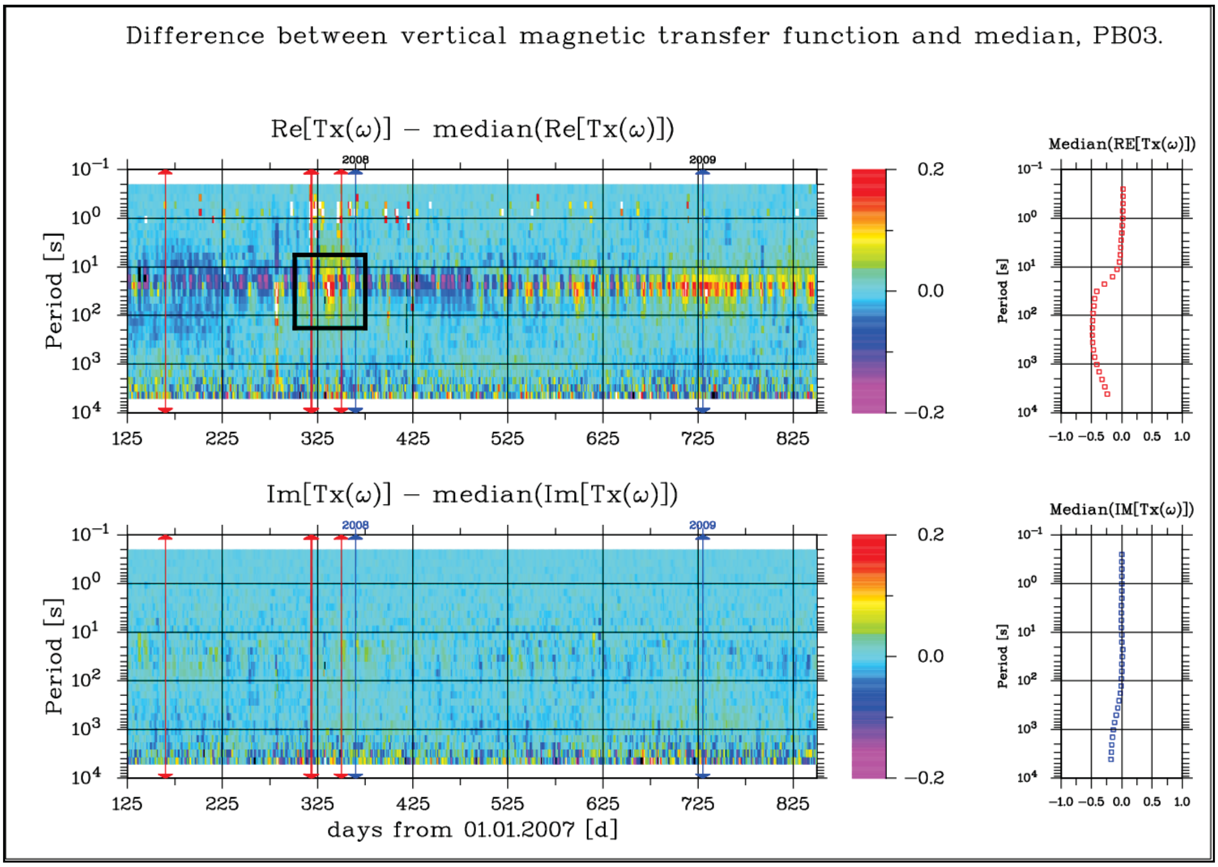


*Figure 7: Time series of differences between daily values of Tx and median of the entire data section at each period at site PB03. Vertical red lines indicate major earthquakes, vertical blue lines indicate turn of the year. Values of median versus period are plotted on the right hand side.*

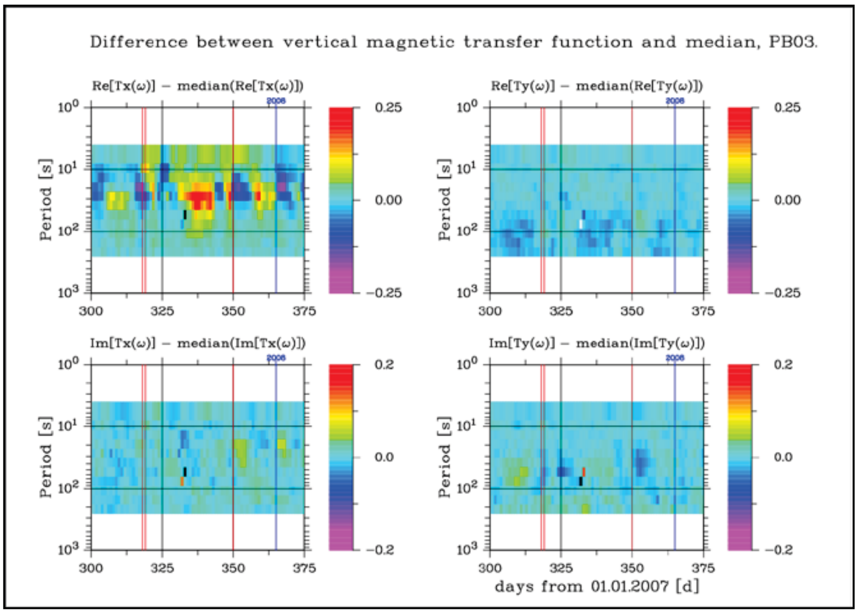


*Figure 8: Time series of differences between daily values of vertical magnetic transfer functions and median at site PB03 versus period. Length and period range correspond to the black box in figure 6. Vertical red lines indicate major earthquakes (Fig. 1), vertical blue lines indicate turn of the year.*

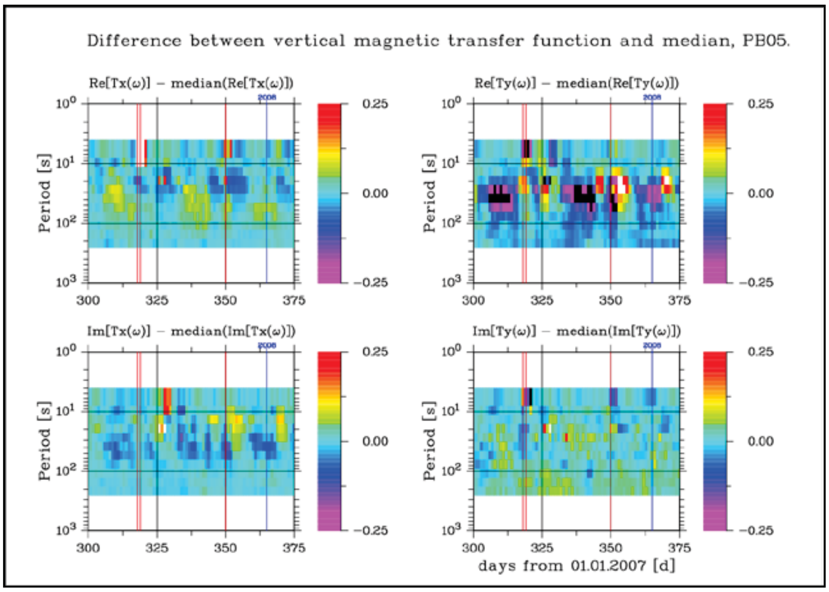


*Figure 9: Time series of differences between daily values of vertical magnetic transfer functions and median at site PB05 versus period. Length and period range correspond to the black box of Fig. 6. Vertical red lines indicate major earthquakes (Fig. 1), vertical blue lines indicate turn of the year.*

Note that the curve of the median, which represents the average transfer function, varies smoothly and consistently in this period range.

A remarkable feature can be observed between two major earthquakes in December 2007 (Fig. 7, black box). The area of interest shows a sudden rise in amplitudes up to ±0.25 (Fig. 8), which corresponds to 100% of the median value of Tx (Fig. 7, right hand side). A similar but less pronounced effect is observed at site PB05 (Fig. 9).

More modeling is necessary to quantify the scale and location of structural changes of the electrical conductivity in the subsurface which could explain these non-periodic variations in the vertical magnetic transfer function time series. Calculation and modeling of inter station transfer function time series should also give more detailed information about changes in the conductivity structure of the underground.

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