Long-term variations of magnetotelluric transfer functions in northern Chile

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Summary

For monitoring the deep electrical conductivity structure of the Nazca-South America subduction zone, long-period magnetotelluric (MT) data are continuously collected at an array of 9 stations in northern Chile. This study presents a characterization of the temporal variations observed in MT transfer functions (TFs) after 5 years of measurements (2007-2012). MT impedances exhibit temporal variations, with variability patterns that depend on the period band and the tensor component considered. Daily estimations of TFs show variability ranges that are mainly related to systematic seasonal variations (which were interpreted as a source field effect by Brändlein *et al.*, 2012), and cultural noise. Some of these effects can be removed by examination of differences between monthly TFs obtained at similar seasons and using a processing interval of 30 days to calculate each TF estimate. Following this approach, off-diagonal impedance components show long-term (over 4 years) variability $\leq \pm 10\%$ in apparent resistivity and $\leq \pm 5^\circ$ in phase, for periods between 100 and 1000s.

1 Introduction

Integrated Plate Boundary Observatory Chile (IPOC) is a permanent array of geophysical stations to monitor the dynamic behavior of the active subduction zone in northern Chile (18 and 24°Lat S). This segment of the Chilean margin is now considered in the terminal stage of a seismic cycle, because it exhibits an anomalous long gap of large earthquakes since 1877 (Figure 1). Magnetotelluric (MT) data are collected at nine IPOC sites, for identifying possible changes in the deep electrical resistivity structure. Temporal variations in electrical resistivity could be caused by large scale fluid relocation related to major tectonic processes. For instance, changes observed in the seismic velocity structure after the 1995 Mw 8 Antofagasta earthquake were explained by deep fluid flow into the South American Plate (Husen and Kissling, 2001).

Previous analysis of IPOC MT data revealed systematic seasonal variations in the vertical magnetic transfer functions, which were correlated with changes in the electromagnetic source field (Brändlein *et al.*, 2012). Here, we present a characterization of the temporal variations observed in MT transfer functions (impedance, apparent resistivity and phase). For any monitoring purposes it is necessary to define a base line of the transfer functions (TF) variability, which should be considered in order to interpret changes of the subsurface electrical resistivity.

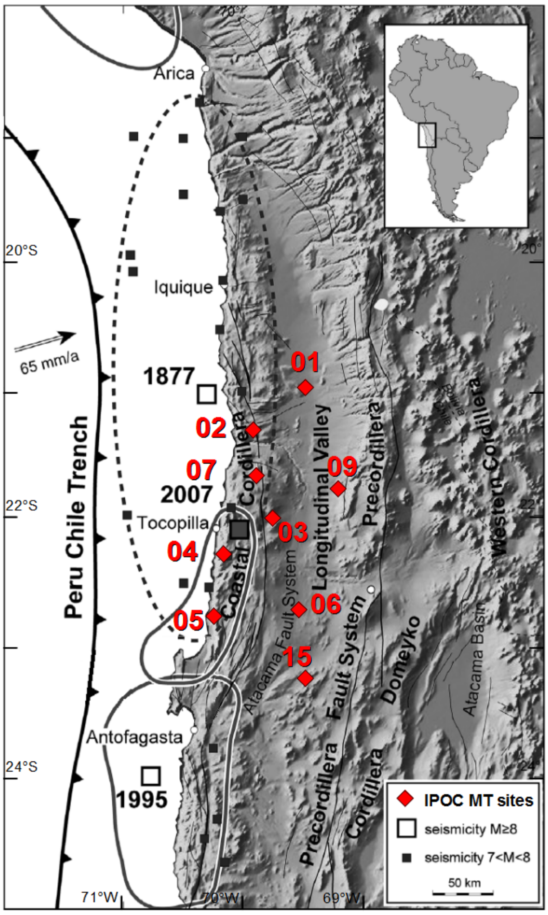

Figure 1: Map of northern Chile showing the IPOC MT array and the rupture areas of earthquakes with magnitude ≥ 8 since 1877 (modified from Victor *et al.*, 2011).

2 Data and Methodology

The MT IPOC array is distributed in an area of approx. 200 x 100 km, with an average separation of 50 km in between sites (Figure 1). At each site, the two orthogonal components of horizontal electric and magnetic fields and the vertical magnetic field are recorded. Magnetic field variations are measured using three component fluxgate magnetometers (Geomagnet), while electric fields are recorded with nonpolarizing Ag/AgCl electrodes (manufactured by the GFZ German Research Centre for Geosciences). The signals of all electromagnetic fields are continuously sampled at a rate of 20 Hz using Earth Data Logger system. The extremely dry conditions of northern Chile make electric field measurements very difficult, because usually electrolyte leaks and contact resistance are in the order of hundreds of kΩ. For this reason, electric field recordings are mostly unavailable between July 2007 and December 2010.

MT impedance (Z), apparent resistivity and impedance phase have been obtained using the EMERALD robust processing package (Ritter *et al.*, 1998; Weckmann *et al.*, 2005; Krings, 2007). We tried different processing intervals and data selection criteria, as well single-site and remote reference processing, for testing the influence of a range of processing schemes on the TFs variability. To obtain statistically robust MT responses for periods >1000s on a daily basis requires time series longer than 3 consecutive days.

3 Results

The daily MT responses exhibit temporal variations, with variability patterns that depend on the impedance component and the period of the signal considered. Figure 2a shows the median apparent resistivity and phases of all daily TFs calculated for a consecutive recording of 2 years at site 01. As can be seen, scatter around the 2-years median value (error bars) is larger for TFs derived from the Zxy impedance (the smaller off-diagonal component which also exhibits a worse signal-to-noise ratio). TFs appear most stable (small error bars) for periods between 80 and 1000s. Particularly at long periods (>1000 s) variances can exceed 100% of the median value (Figure 2a and b).

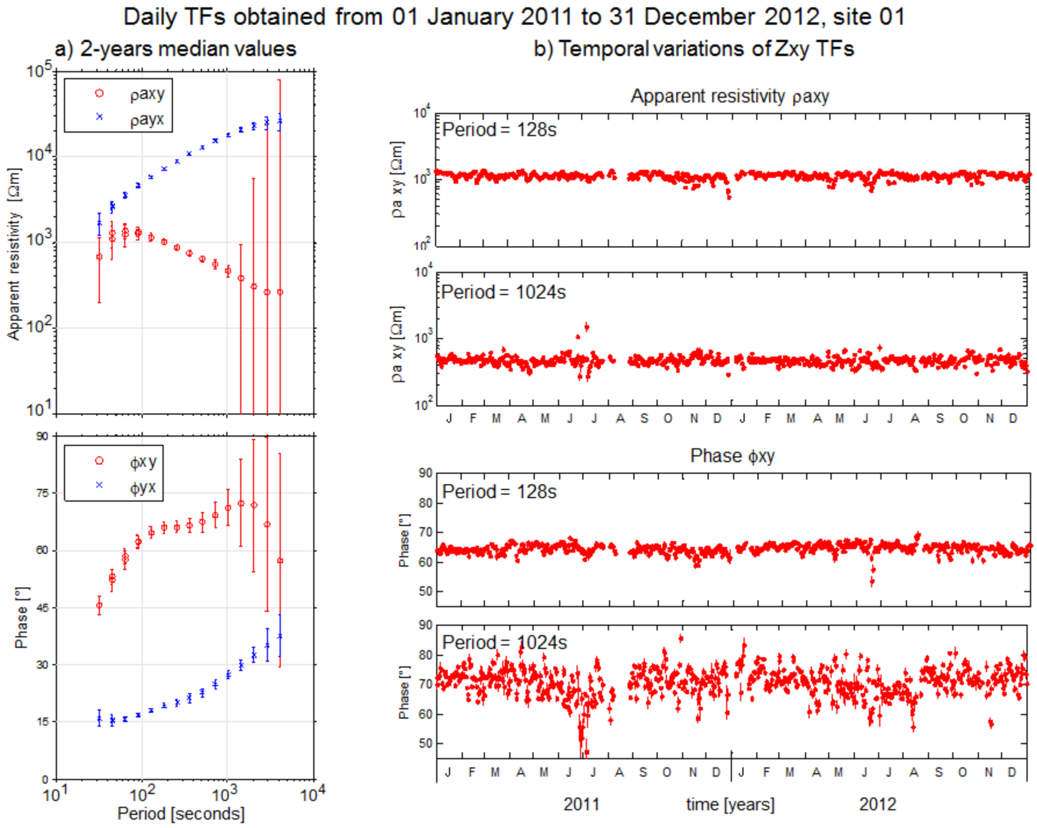

Figure 2: Daily apparent resistivity and phases from 01-January-2011 to 31-December-2012 for site 01: a) Median of all values (error bars represent one standard deviation of the population). b) Temporal variations of xy components, for periods 128 and 1024s (error bars represent the confidence interval of each daily TF). Note that the variability ranges in the Zxy components are larger than for the Zyx component, especially for periods > 1000s.

The observed TFs temporal variations show cyclic patterns with periodicities from 5 days to 1 year. The most obvious periodical signal are annual variations that peak around the June and December solstice, especially evident when the deviations of the daily estimates from the 2-year median is examined (for example, see daily temporal variations of phase in Figure 3). A similar pattern was observed for the vertical magnetic TFs, which was interpreted as a source field effect (Brändlein *et al.*, 2012). Other significant deviations from the median value appear to be randomly distributed, with durations of less than 10 days. As these patterns are not coherent across the array of stations, we suggest that most of these effects are caused by a combination of local noise sources and poor natural source activity.

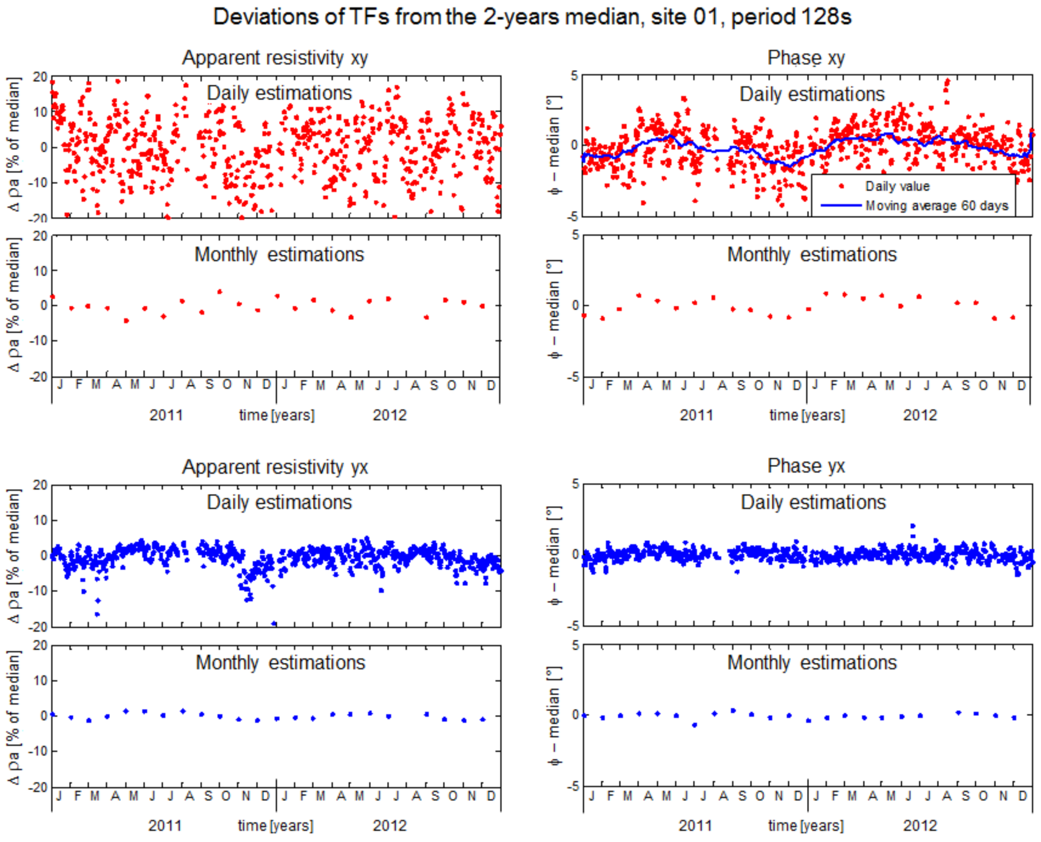

Figure 3: Comparison between daily and monthly TFs estimations presented as relative changes from the 2-years median, site 01, at a period of 128s. Deviations in apparent resistivity are expressed in terms of percentage of the 2-years median value. Note that daily temporal variations of phase show an annual periodical trend, with peaks around June and December.

To improve statistical properties of the TFs estimates, particularly for longer periods, we also calculated monthly averages. Figure 3 shows the TFs after processing 30-days intervals of the data in comparison with the daily values. As expected, this processing scheme results in more stable TFs. Now, we observe deviations from the median of less than ±5% in apparent resistivity and less than ±5° in phase (Figure 3). To examine long term trends and to reduce an influence of the seasonal variations, we compare TFs obtained at the same month (season).

Figure 4 shows that differences between May-2007 and May-2011 at sites 01 and 05, i.e. data recorded just prior to the November-2007 Mw7.7 Tocopilla earthquake and a long time afterwards. We generally observe differences $< \pm 10\%$ in apparent resistivity and $< \pm 5°$ in phase for the off-diagonal impedance components in a period band of 100-1000s, but without any clear trend. The Mw7.7 Tocopilla earthquake represents the largest seismic event registered since the MT array is working, and the epicenter was close to site 05. Unfortunately, the impedance estimates from months close to the Tocopilla seismic sequence could not be used, due to the bad quality of the electric fields measurements during that time (dried out electrodes).

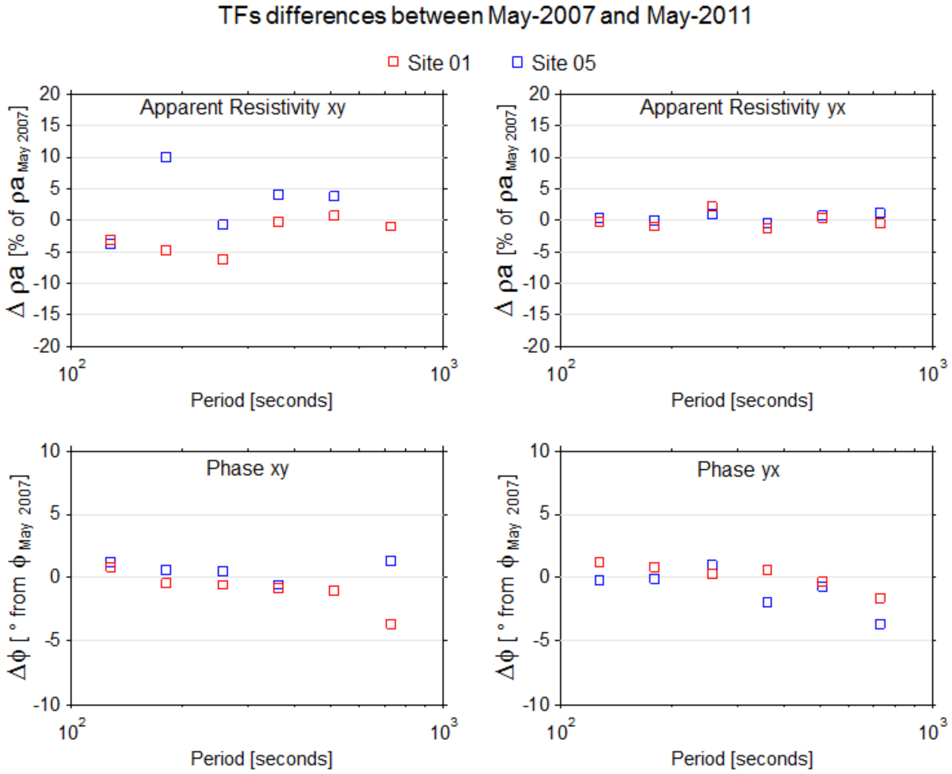

Figure 4: Comparison of deviations in the impedance estimates between May-2007 and May-2011 of sites 01 and 05. TFs were obtained using 1-month processing intervals. Site 05 is located close to the coast, inside the rupture area of the 14 November 2007 Mw7.7 Tocopilla earthquake, whereas site 01 is more than 100 km away from this region (see sites location and Tocopilla earthquake rupture area in Figure 1).

4 Conclusions

The IPOC MT data show that daily TFs exhibit temporal variations, with variability ranges that depend on the impedance component and period range considered. The variability is strongly influenced by seasonal variations which have been interpreted as a source effect (Brändlein *et al.*, 2012), and cultural noise in combination with varying natural activity. A more stable base line estimate of the impedance can be achieved with a processing interval of 30 days. Following this approach, off-diagonal impedance components show long-term (over 4 years) variability $< \pm 10\%$ in apparent resistivity and $< \pm 5^\circ$ in phase for periods between 100 and 1000s.

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