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Discussions

# Comment on “Non-inductive components of electromagnetic signals associated with L’Aquila earthquake sequences estimated by means of inter-station impulse response functions” by Di Lorenzo et al. (2011)

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## Abstract

Di Lorenzo et al. (2011) document the observation of magnetic signals in the frequency range [0.3–3] Hz from few minutes before to about one hour after the 6 April 2009 L'Aquila earthquake. This coincidence induced the authors to think that the observed magnetic disturbances were related to the main phase of the seismic event. Here, we will discuss some unclear points of Di Lorenzo et al. (2011) which cast serious doubts on the seismogenic origin of the magnetic disturbances observed by the authors.

## 1 Introduction

On 6 April 2009 at 01:32:39 UT a $M_\mathrm{w} = 6.3$ earthquake (Chiarabba et al., 2009) struck the town of L'Aquila. This event was preceded by a foreshock activity that lasted several months and culminated with the $M_\mathrm{w} = 4.1$ event of 30 March. Among thousands of aftershocks, two $M_\mathrm{w} > 5$ events occurred on 7 April ($M_\mathrm{w} = 5.5$) and on 9 April ($M_\mathrm{w} = 5.4$), respectively (see Pondrelli et al., 2010, and http://iside.rm.ingv.it/iside/standard/index.jsp). Figure 1 shows the locations of the epicentres of the seismic sequence up to the end of July 2009. Many papers have retrospectively documented the observation of pre-earthquake anomalies which the authors claim to be related to L'Aquila earthquakes. Among these anomalies there are electromagnetic disturbances. However, these studies do not show a strong correspondence between the documented electromagnetic signatures and the seismic activity, nor they document expected co-seismic effects which should occur at time of the rupture when the primary energy is released. Some of the presumed precursory electromagnetic signals are observed up to several hundred kilometres from the earthquake epicentre (see the references by Masci and Di Persio, 2012). Conversely, local observations from L'Aquila area do not show anomalous signals which can be described as signatures of the 6 April earthquake (see Masci, 2012; Masci and Di Persio, 2012; Villante et al., 2010).

Di Lorenzo et al. (2011) calculated the residual magnetic field at the time of the L'Aquila earthquake. The residual field was estimated by means of inter-station impulse response functions between the Italian observatories of L'Aquila and Duronia. The observatory of L'Aquila is located only 6 km from the epicentre of the 6 April main shock, whereas the observatory of Duronia is about 130 km from L'Aquila area. The sampling rate of magnetic data is 10 Hz.

## 2 Comments

Figure 2 shows the main findings of Di Lorenzo et al. (2011). Very feeble signals in the residual magnetic field (maximum amplitude about 200 pT) are seen to occur in the frequency band [0.3–3] Hz during the minutes before and about one hour after the $M_w = 6.3$ main shock. More precisely, leaving aside the evident co-seismic disturbance due to the shaking of the sensor in the Earth's magnetic field caused by the arrival of the seismic waves, Fig. 2 shows that one magnetic burst is present during about 10 min before the main shock, whereas other two bursts occur during [01:38–01:50] UT and [02:03–02:22] UT, respectively. Di Lorenzo et al. (2011) claim that these anomalous signatures should be related to the main phase of the L'Aquila earthquake. The authors conclude: "these emissions do not give enough warning because they are too short in time. However these results do not preclude the possibility that the electromagnetic monitoring of seismogenic areas may help to understand the physical processes associated with earthquakes, especially those preceding the seismic activity in the preparatory phase". Obviously, the study of the physical processes possibly associated with the preparatory phase of seismic events needs of trustworthy seismogenic signals. Any potential anomaly, before it can be considered to be generated by the seismic activity, should be excluded as a random anomaly or as an anomaly induced by alternative sources, both natural and artificial.

Here we would like to stress that in Di Lorenzo et al. (2011) there are some unclear points that do not support their claims. Our first observation concerns the unusual

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characteristics of the magnetic disturbances documented by the authors. Namely, Fig. 2 shows that the magnetic bursts occur synchronously in the geomagnetic field components $X$ and $Z$. On the contrary, the $Y$ component does not show corresponding disturbances. $X$, $Y$, and $Z$ represent the NS horizontal component, the EW horizontal component, and the vertical component, respectively. As emphasized by Di Lorenzo et al. (2011), seismogenic magnetic fields could be generated on the Earth's surface by electric currents flowing in Earth's crust mainly in the horizontal plane. These almost horizontal electric currents should induce disturbance signals mainly in the vertical component of the geomagnetic field. The findings of Di Lorenzo et al. (2011) partially support this assumption. We can see that the amplitude of the residual field of the $Z$ component is larger (about three times larger) than the amplitude of the residual field of the $X$ component. However, in our opinion, the lack of corresponding signals in the $Y$ component, which could suggest that the presumed seismogenic signals are polarized in the $X-Z$ plane, does not support the seismogenic origin of the documented magnetic bursts. If presumed magnetic seismogenic signals observed on the Earth's surface are generated by underground electric currents having a significant horizontal component, we should expect that the observed disturbances prevail in the vertical direction, but they should not have a preferred plane of polarization. Unfortunately, Di Lorenzo et al. (2011) have not investigated in deep the origin of the $Z-X$ polarization of the magnetic signatures.

Di Lorenzo et al. (2011) propose a simple model of source as support of their findings. According to the authors the model is based on the measured magnetic field and it includes the 1-D profile of the resistivity of the local Earth's crust which was calculated by a conventional magnetotelluric approach. However, the model does not consider any possible generation mechanism which could justify the $Z-X$ polarization of the observed magnetic signals. The authors assume a magnetic dipole as equivalent source of these signals. The orientation of the dipole is obtained taking into account the amplitude of the residual field in each of the geomagnetic field components. That is, the magnetic moment of the dipole results to be approximately vertical, with a small component in the NS direction, by imposing that the $Y$ component of the residual field is null. In summary, the simple model proposed by Di Lorenzo et al. (2011) does not support their claims as it should be, but, on the contrary, the model is mainly adjusted to the author's findings.

Another comment concerns the time length of the dataset reported by Di Lorenzo et al. (2011). They show only about one hour of data closely to the time of the earthquake. The authors exclude the existence of magnetic signals during the foreshock and the aftershock activity, but they did not investigate the possible occurrence of similar magnetic disturbances during a longer period of time in which no earthquake occurs. To exclude any possible occurrence of similar disturbances independently from the seismic activity, the 10 Hz datasets of L'Aquila and Duronia should be available for a long time period before and after the earthquake date. Unfortunately, Di Lorenzo et al. (2011) do not report any information on the temporal coverage of the 10 Hz data set of L'Aquila and Duronia observatories.

Regardless of the previous comments, now we would like to discuss some possible generation mechanisms of electromagnetic seismogenic signals which may justify the findings of Di Lorenzo et al. (2011). Many studies documented the observation of magnetic and electric signals shortly after the main shock. Such signals are observed in all the components of the electric and magnetic fields for some tens of seconds (see e.g. Karakelian et al., 2002; Matsushima et al., 2002). These signals are not generated in the focal region at the origin time of the earthquake, but they are related to the seismo-dinamo effect induced by the arrival of the seismic P-waves at the point of observation. In the case of magnetic disturbances observed by Di Lorenzo et al. (2011), we can undoubtedly exclude the seismo-dinamo effect both for the duration of the observed signals and for the period of time in which they were observed.

At the time of fault rupture, direct electromagnetic signals may be generated in the earthquake focal region. These signals propagate in the Earth's crust with electromagnetic wave speed. Therefore, they should be observed before the arrival of the seismic waves, few moments later the origin time of the earthquake. Mechanisms which may induce direct electromagnetic signals as piezoelectric and triboelectric phenomena have been excluded by Di Lorenzo et al. (2011). The piezomagnetic effect can be excluded as well. According to Cicerone et al. (2009), piezomagnetic phenomena can generate signals having a maximum magnitude of $10^{-2}$ nT. The amplitude of these signals is one order of magnitude less than the signals observed by Di Lorenzo et al. (2011). In our opinion, the electrokinetic effect, resulting from fluids diffusion through rocks, could be also excluded. Lucente et al. (2009) and Di Luccio et al. (2010) suggest a scenario by which deep fluids may have a fundamental role in the seismotectogenesis of L'Aquila area. The change in pore pressure along the fault planes could have controlled the space-time distribution of the events of the L'Aquila seismic sequence with reactivation of pre-existing structures. According to these researchers the rupture which generated the 6 April 2009 main shock was driven by fluids migration induced by the $M_w = 4.1$ event of 30 March 2009. In addition to that, the NW–SE distribution of aftershocks should be compatible with a fluids migration in that direction (see Di Luccio et al., 2010). If the magnetic signals documented by Di Lorenzo et al. (2011) were generated by electrokinetic phenomena, the large amount of fluids that migrated in NW–SE direction should have generated similar magnetic disturbances for longer periods before and after the main shock. On the contrary, as Di Lorenzo et al. (2011) emphasize, no anomalous signal was observed the days before and after the earthquake main phase.

Freund et al. (2006) have recently proposed a new theory for the generation of electric currents in the Earth's crust, the so called P-hole mechanism. According to Freund and his colleagues, when igneous rock is subjected to stress, electronic charge carriers are activated (as in a semiconductor) and the rock behaves as if it was a battery from which current can flow out. When the stress is removed, the "battery" returns in the inactivate state. The P-hole theory, that may explain possible pre-earthquake electromagnetic signals in case of crustal stress loading, does not support the observation of electromagnetic disturbances after the main phase of the earthquake when the stress is removed. However, at the hypocentral depth, the level of the local stress does not significantly change during the days to minutes before the earthquake (see Lay and Wallace, 1995). High-resolution borehole strain and pore pressure measurements in active fault areas do not indicate significant precursory crustal stress increase in the hours to minutes before seismic events (see Johnston et al., 2006). Thus, if stress increase occurred during the months to weeks before the 6 April, the precursory magnetic signatures should have been observed for a long period of time, and not only for a few minutes before the main shock. Kopytenko et al. (1993) document the observation of ULF magnetic precursory signals at the time of the 7 December 1998 $M_\mathrm{s} = 6.9$ Spitak earthquake. These signals appeared many hours before the main shock and before some aftershocks and had duration up to several hours.

Now, let us consider seismic and geodetic data just before and after the 6 April main shock. Figure 3 shows position time series at the three-component (North, East, and Vertical) Global Position System (GPS) site of CADO. The GPS station of CADO is located about 10 km from the epicentre of the 6 April earthquake (see Avallone et al., 2011). Co-seismic displacements at 01:32:39 UT are clearly evident in all the components. The figure also shows that no evident surface displacement (horizontal shift or subsidence) occurred just before and shortly after the main shock. Figure 4 shows the continuous recording of seismic data at the AQU station which is located in the basement of the Spanish Castle, in the centre of L'Aquila. We can see that during the minutes before the 6 April main shock no significant seismic event occurred. In summary, seismic and geodetic data do not support the idea that during the minutes before the 6 April main shock the stress at the hypocentral depth is increased so as to generate magnetic disturbances documented by Di Lorenzo et al. (2011).

## 3 Conclusions

The study by Di Lorenzo et al. (2011) shows some unclear points that do not fully support the possibility that the magnetic signals documented at the time of the 6 April L'Aquila earthquake had a seismogenic origin. The first point concerns the unusual

$X-Z$ polarization of the observed magnetic disturbances. Secondly, no possible generation mechanism of electromagnetic seismogenic signals can undoubtedly explain the authors' finding. In addition, local geodetic and seismic data do not support the possibility that the magnetic disturbances documented by Di Lorenzo et al. (2011) may have been generated by crustal stress increase. The only argument which might support the claims of Di Lorenzo et al. (2011) is that the magnetic signals were observed very close to the time of the 6 April main shock. However, this does not mean that these signals undoubtedly come from seismogenic sources. In summary, we cannot exclude that these signals could be just chance events or that they may have been generated by other sources or by instrumental malfunction.

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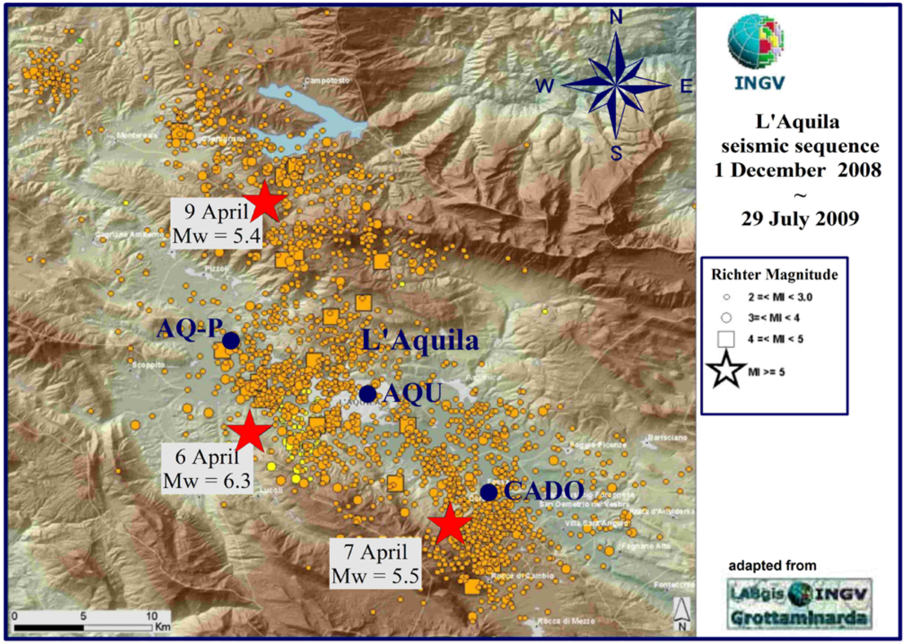

**Fig. 1.** L'Aquila seismic sequence from 1 December 2008 to 29 July 2009. Red stars refer to the main shock of 6 April and to the two $M_w > 5$ aftershocks. AQ-P, AQU and CADO refer to the Geomagnetic Observatory of L'Aquila, to the seismic station located in the basement of the Spanish Castle of L'Aquila, and to the GPS site of Fossa, respectively.

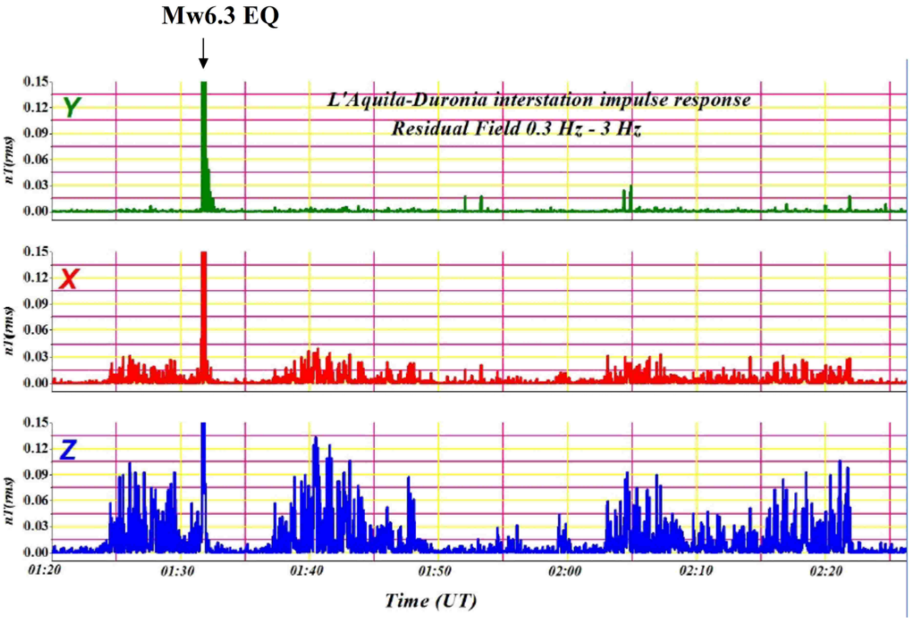

**Fig. 2.** A reproduction of Fig. 7 by Di Lorenzo et al. (2011). Root Mean Square (RMS) representation of the residual magnetic field at L'Aquila Geomagnetic Observatory close to the time of the 6 April 2009 earthquake. See Di Lorenzo et al. (2011) for details.

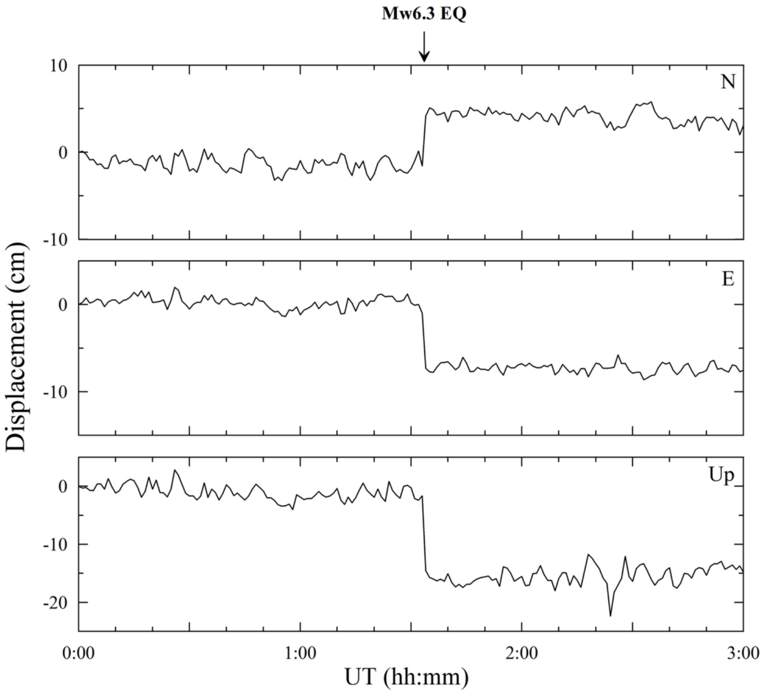

**Fig. 3.** Position time series at the three-component GPS site of CADO from 00:00 UT to 03:00 UT of the 6 April 2009. Each panel show GPS raw data (sampling 60 s).

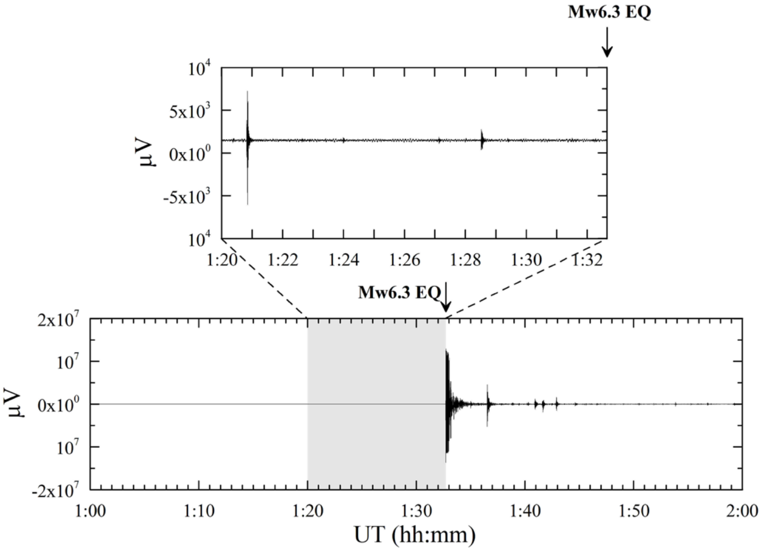

**Fig. 4.** Continuous seismic data recording (vertical component) at the AQU seismic station from 01:00 to 02:00 UT of the 6 April 2009. The upper panel shows 12 min of data before the main shock. The local magnitude ($M_l$) of the seismic event that occurred at 01:20:46 UT is 1.1.