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Retrospective investigation of geomagnetic field time-series during the 2009 L'Aquila seismic sequence

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ABSTRACT

This paper reports the analyses of ULF (Ultra-Low-Frequency) geomagnetic field observations coming from the Geomagnetic Observatory of L'Aquila during the period 2008–2009. This period includes the L'Aquila 2009 seismic sequence, where the main shock of 6 April heavily damaged the medieval centre of the town and its surrounding area, causing 308 deaths, more than 1000 injuries and about 60,000 displaced people. Recently, several publications have documented the observation of precursory signals which occurred before the 6 April earthquake (e.g. Eftaxias et al., 2009, 2010), while others do not find any pre-earthquake anomaly (e.g. Villante et al., 2010; Di Lorenzo et al., 2011). In light of this, the goal of this study is to carry out further retrospective investigations. ULF magnetic field data are investigated by means of conventional analyses of magnetic polarization ratio, improved magnetic polarization ratio, and fractal analysis. In addition, total geomagnetic field data coming from the INGV Central Italy tectonomagnetic network have also been investigated, using the simple inter-station differentiation method. Within the limits of these methods, no magnetic anomalous signal which may be reasonably characterized as a precursor of the L'Aquila earthquakes has been found.

1. Introduction

About fifty years ago pioneering studies (Breiner, 1964; Moore, 1964; Stacey, 1963) reported electromagnetic anomalous signals associated with the occurrence of earthquakes. During the following years, many publications claimed the observation of pre-earthquake electromagnetic anomalies over a wide range of frequencies maintaining that the preparation process of strong earthquakes includes both seismic events and electromagnetic emissions. In addition, even if the anomalous signals have been retrospectively related to seismic events, several researchers consider these signatures a new way towards the possibility of developing earthquakes prediction capabilities (e.g. Hayakawa and Hobara, 2010).

Several papers (e.g. Johnston, 1997; Johnston et al., 2006) report the observation of co-seismic electromagnetic phenomena within a few tens of kilometres of earthquake epicentres which are clearly related to earthquake rupture. However, no indication of precursive behaviour is apparent in the days or months before any of these events in electromagnetic or other datasets (Johnston et al., 2006). On the other hand, many other publications (e.g. Eftaxias et al., 2001, 2009; Molchanov and Hayakawa, 2008; Pulinets and Boyarchuk, 2004; Varotsos, 2005) claim the observation of electromagnetic earthquake precursors but with no clear co-seismic effects. As a consequence, many in the scientific community doubt the reliability of electromagnetic signals claimed to be precursors of pending earthquakes. The principal criticisms of these researchers are: the lack of validation and reproducibility of the precursory signals; claimed pre-seismic signals are chance events; the retrospective validation of earthquake precursors; the observation of precursors without expected co-seismic related larger signals (see e.g. Geller, 1997; Johnston et al., 2006; Pham and Geller, 2002). In addition, even if both electric and magnetic anomalies are expected to occur in relation to the seismic activity, simultaneous measurements of both electric and magnetic fields are uncommon. Recently, some researchers have cast doubts on well-known magnetic anomalies which previous papers have related to the earthquake occurrence. These authors maintain that the claimed seismogenic signatures could be reasonably related to instrumentation malfunction (Thomas et al., 2009a) or are generated by normal geomagnetic activity (Campbell, 2009; Masci, 2010, 2011a, 2011b, 2012; Thomas et al., 2009b). Masci (2010, 2011a) also criticizes the methodology used in previous papers, asserting that it is rather inaccurate to relate a magnetic ULF anomaly with the preparation process of the incoming earthquake without properly taking into account the global geomagnetic activity level.

On 6 April 2009 at 01:32:39 UT an earthquake of magnitude Ml = 5.8 (Mw = 6.3) hit the Abruzzo region, Central Italy, very close to the town of L'Aquila. The foreshock activity began at the end of 2008 and it increased during March 2009 culminating on 30 March with the strongest foreshock (Ml = 4.1). Two Ml > 5 aftershocks struck the L'Aquila area on 7 April (Ml = 5.3; Mw = 5.6) and on 9

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April (Ml = 5.1; Mw = 5.4), respectively. Fig. 1 shows the locations of the epicentres up to the end of July 2009. In the figure, AQU refers to the INGV (Italian Istituto Nazionale di Geofisica e Vulcanologia) Geomagnetic Observatory of L'Aquila. The area covered by seismic events is about 40 × 15 km, trending in the NW–SE direction parallel to the Apennine mountain chain and to the main fault structures known in the area. The seismic events were shallow and very close to the Geomagnetic Observatory of L'Aquila, considering that the epicentres of the three Ml > 5 events were further from the observatory at distances of about 6, 17 and 11 km, respectively (refer to the INGV earthquakes catalogue database at http://iside.rm.ingv.it). These characteristics could justify the observation of seismogenic electromagnetic emissions, providing an opportunity for a careful investigation of the reliability of the methodologies adopted in previous studies.

After April 2009, several researchers claimed to observe pre-seismic anomalies which they maintain to be related to the L'Aquila earthquakes (Akhoondzadeh et al., 2010; Boudjada et al., 2010; Eftaxias et al., 2009, 2010; Genzano et al., 2009; Perrone et al., 2010; Prattes et al., 2011; Rozhnoi et al., 2009; Tsolis and Xenos, 2010). The pre-seismic signatures include electromagnetic anomalies in a wide range of frequencies (ULF-VLF-LF), anomalous Total Electron Content (TEC) variations, perturbations of the ionosphere over the earthquake preparation area, and anomalies in the Earth's emitted Thermal Infrared Radiation (TIR). In any case, the anomalies occur during different time periods, from the middle of March 2009 until a few days before the main shock. In some cases the anomalous signatures were observed several hundred kilometres from the L'Aquila area. For example, Eftaxias et al. (2009, 2010), investigating electromagnetic data coming from the Greek station of Zante (located 800 km away from L'Aquila), report the observation of electromagnetic anomalies at different frequencies which they claim to be related to L'Aquila earthquakes. These include ULF (<1 Hz) electric field anomalies continuously recorded in the period 29 March–2 April 2009, electric field anomalies at 41 MHz and 54 MHz which occurred in the period 26 March–2 April, and magnetic field anomalies at 3 kHz and 10 kHz which emerged on 4 April 2009. The authors point out that the precursory signals are asynchronous; they justify the time lags between the different anomalies maintaining that each type of precursor refers to a different state of the earthquake preparation process, which also implies a different generation mechanism of the electromagnetic emissions. They also exclude the presence of any co-seismic electromagnetic signal. However, other researchers (e.g. Di Lorenzo et al., 2011; Villante et al., 2010) based on the investigation of magnetic observations coming from the L'Aquila area maintain that no magnetic precursory signal was observed in the days or months before the 6 April earthquake. Villante et al. (2010) report the analysis of the ULF geomagnetic field observations of the L'Aquila University magnetic station which is located very close to the INGV Geomagnetic Observatory of L'Aquila. They conclude that no clear magnetic precursory signal, which could be reasonably related to the L'Aquila seismic activity, was found by means of conventional techniques of ULF data processing. In contrast, Prattes et al. (2011), using the same geomagnetic data of Villante et al. (2010), report new analyses claiming that possible seismogenic signals emerged about two weeks before the L'Aquila earthquake. In fact, Masci (2012) shows that the precursor reported by Prattes et al. (2011) is part of the normal geomagnetic activity. Di Lorenzo et al. (2011), by means of inter-station impulse response functions calculated between the two observatories of L'Aquila and Duronia (located 130 km from L'Aquila), claim that co-seismic magnetic signals in the AQU geomagnetic field time-series are present. These weak signals (maximum amplitude about 200 pT) occur in the frequency band 0.3–3 Hz beginning a few minutes before the main shock and lasting for about 1 h. The authors also did not find any magnetic signals associated with the foreshock activity.

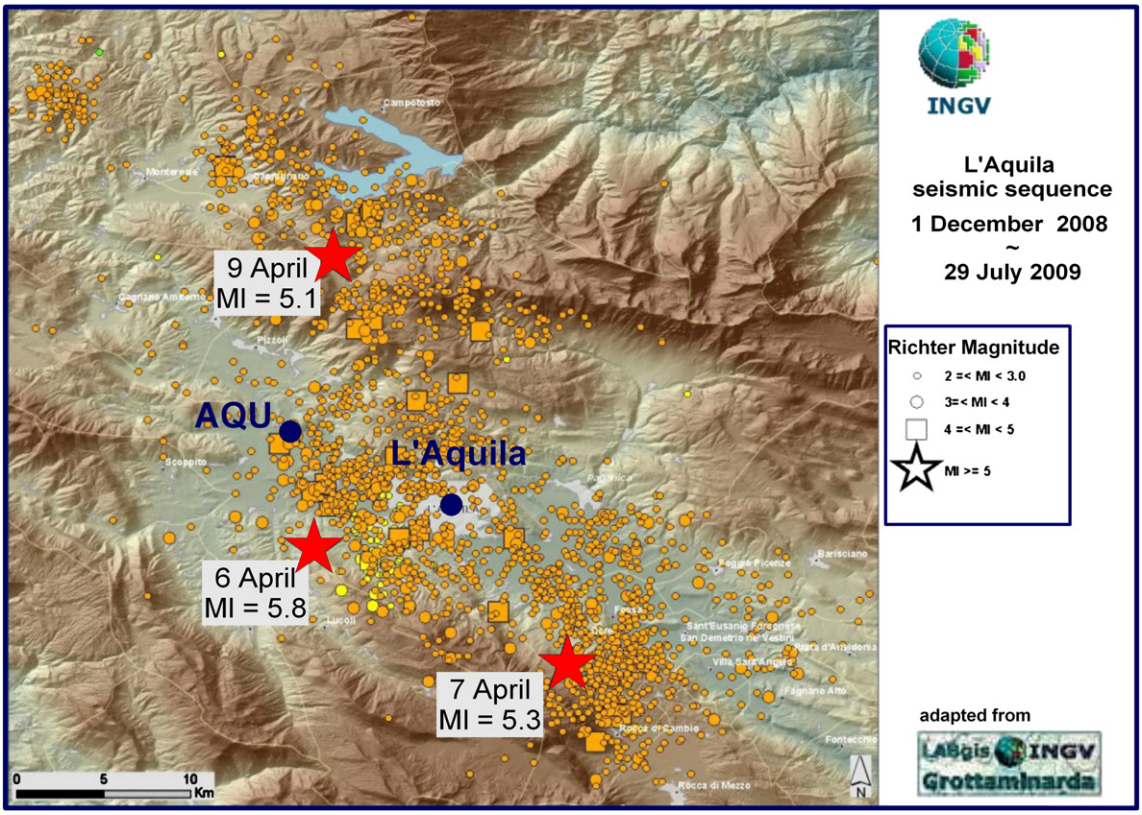

Fig. 1. L'Aquila seismic sequence from 1 December, 2008 to 29 July, 2009. AQU refers to the INGV Geomagnetic Observatory of L'Aquila. Red stars refer to the main shock of 6 April and to the two Ml > 5 aftershocks.