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Ionospheric activity and possible connection with seismicity: Contribution from the analysis of long time series of GNSS signals

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ABSTRACT

The modifications of some atmospheric physical properties prior to a high magnitude earthquake were debated in the frame of the Lithosphere Atmosphere Ionosphere Coupling (LAIC) model. In this work, among the variety of involved phenomena, the ionisation of air at the ionospheric levels triggered by the leaking of gases from the Earth's crust was investigated through the analysis of GNSS (Global Navigation Satellite System) signals. In particular, the authors analysed a 5 year (2008–2012) long series of GNSS based ionospheric TEC to produce maps over an area surrounding the epicentre of the L'Aquila (Italy, $M_w = 6.3$) earthquake of April 6th, 2009. The series was used to detect and quantify amplitude and duration of episodes of ionospheric disturbances by a statistical approach and to discriminate local and global effects on the ionosphere comparing these series with TEC values provided by the analysis of GNSS data from international permanent trackers distributed over a wider region. The study found that during this time interval only three statistically meaningful episodes of ionospheric disturbances were observed. One of them, occurring during the night of 16th of March 2009, anticipated the main shock by 3 weeks and could be connected with the strong earthquake of 6th of April. The other two significant episodes were detected within periods that were not close to the main seismic events and are more likely due to various and global reasons.

1. Introduction

As reported by several authors (Kouris et al., 2001; Liperovsky et al., 2000; Molchanov et al., 2004; Namgaladze et al., 2009; Ouzounov and Freund, 2001; Pulinets, 2006, 2004; Pulinets and Boyarchuk, 2004; Pulinets et al., 1997) modification of atmospheric physical properties prior to a high magnitude earthquake can occur over a wide area near the epicentre after the ionisation of air caused by possible gases leak from the Earth's crust. These processes are summarised in the Lithosphere Atmosphere Ionosphere Coupling (LAIC) model (Hayakawa et al., 2004; Hayakawa and Molchanov, 2002; Pulinets and Boyarchuk, 2004; Pulinets et al., 2000). In the LAIC model, the processes involved, produce different physical evidences that are considered as possible precursors of seismic activity. Among these, thermal anomalies and modification of the ionospheric activity constitutes some of the perturbing phenomena at atmospheric levels. Due to the dispersive properties of the ionospheric plasma, the electric activity on such strata can be investigated by the inspection and analysis of data provided by Global Navigation Satellite System (GNSS) services. In this field, the possibilities offered by the DEMETER satellite also have to be highlighted. DEMETER operated at an altitude of 710 km along a nearly sun-synchronous orbit and it was able to screen the top part of ionosphere and detect anomalous variations of electromagnetic waves, particle fluxes and thermal plasma parameters (Akhoondzadeh et al., 2010; Pulinets et al., 2006a, 2006b).

In the GNSS sciences, ionospheric activity can be investigated through the analysis of refractive phenomena occurring on the dual frequency signal along the path from the satellite to the receiver. Therefore, maps representing the ionospheric activity as Total Electron Content (TEC) could be routinely produced (1 TEC unit = 10^{16} electrons m^{-2}).

By using global and regional ionospheric maps based on data provided by GNSS network, several authors recently exploited

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the dispersive properties of the ionosphere to detect possible anomalies over areas affected by earthquakes (Akhoondzadeh et al., 2010; Hasbi et al., 2011; Hayakawa et al., 2004; He et al., 2014; Liu et al., 2001, 2004, 2009; Namgaladze et al., 2009; Plotkin, 2003; Pulinets et al., 2003, 2006a; Pulinets, 2006; Stangl et al., 2011). As also reported by Namgaladze et al. (2009), regardless of the specific approach, the amplitude of plasma modification would reach the noticeable value of 30–90% in comparison with the undisturbed level. In these papers, some evidence was encountered. However, the spatial scale and temporal domains over which such disturbances would come into evidence remains a controversial topic. The moderate number of papers produced on such an aspect relies on investigations focused on confined periods around the time of a seismic event and quiet periods are generally neglected by the analyses.

Reducing the analysis over a short (days to weeks) time period increases the possibility of achieving a potential temporal correspondence by chance between ionospheric disturbances and relevant seismic activity. An investigation focused on short periods might see problems in the absolute quantification of an anomalous ionospheric activity. The identification of significant ionospheric anomalies on a regional or local scale could be also compromised by the influence of global effects, such as solar activity or other perturbing geomagnetic phenomena. All the mentioned factors could limit the reliability of results introduced by papers focused on the search of possible connections between ionospheric activity and seismicity. With the aim to provide a contribution to the study of supposed chronological relationships between seismic phenomena and ionospheric effects, a long time series of GNSS derived hourly TEC maps were analysed and possible connection with seismic event investigated over a study area.

2. Methodology

In this work a 5 year (2008–2012) long series of GNSS based ionospheric maps were produced over an area around the city of L'Aquila (Abruzzo, Italy) struck by a $M_w = 6.3$ earthquake on April 6, 2009. Such earthquake produced devastating effects that left more than 300 people dead and around 60000 homeless. In particular, the proposed methodology is supposed to be able to assess the temporal behaviour of the ionospheric activity over the study area by the production and analysis of long time series of TEC (Total Electron Content) values from GNSS data collected by 13 stations distributed within an extent around the epicentre (approximately at latitude 42°.34 N and longitude 13°.38 E). In order to distinguish between ionospheric effects generated by local or global phenomena, an additional TEC series at larger spatial scale was produced by the analysis of GNSS data of 45 international permanent stations (EUREF GNSS Permanent Network) and 4 more stations introduced to cover large gaps in central Italy. For a better definition of the geographical GNSS sites distribution see the location map of Fig. 1.

The need for a dual analysis was also motivated by the deficiency of official GNSS stations belonging to international organisations (EUREF and International GNSS Service) around the study area and, therefore, by the need to strengthen the station's density and reinforce the ability of the GNSS stations to intercept ionospheric anomalies encountered over restricted areas. In the attempt to investigate possible ionospheric disturbances with respect to quiet conditions, free from the effect of diurnal solar activity, the above mentioned comparison was performed on an hourly basis and exclusively referred to night-time periods ranging from 00 to 05 UT. Moreover, as introduced by Grimalsky et al. (2003), the ability by an electrostatic field to penetrate from the lithosphere into the ionosphere is much better at night than during the diurnal hours. Thus, the dual approach to the estimation of the ionospheric activity establishes the ionospheric activity on a large spatial scale, as representative of global/regional trends, and allows the separation between regional/global and local phenomena through the comparison of solutions. Moreover, whenever anomalies are detected on a local scale, the dual approach allows for the investigation of possible external sources of ionospheric disturbances introduced by signals received from low lying satellites.

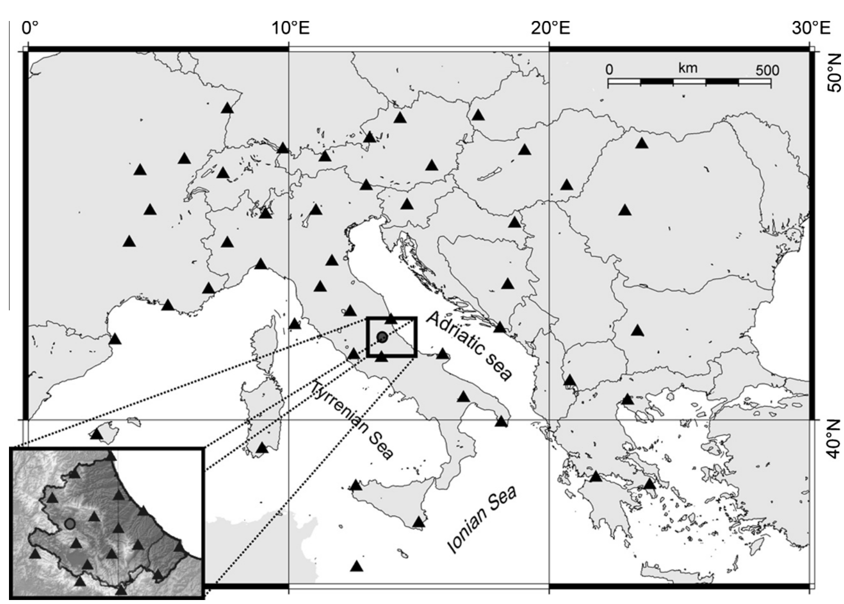

Fig. 1. Geographical extension of GNSS clusters used to model the ionospheric activity at regional and local scales through the TEC values assessment. The whole extent represented in the figure is used to model the ionospheric activity at regional scale. The area within the rectangle encloses GNSS sites distributed over an area around the epicentre of the main seismic shock and is used to model the ionospheric activity on a local scale. Black triangles: location of the 49 stations used at regional extent; black dot: epicentre of the main seismic shock.