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Anomalies in VLF radio signals related to the seismicity during November–December 2004: A comparison of ground and satellite results

P.F. Biagi [a,b,*], L. Castellana [a], T. Maggipinto [a], G. Maggipinto [a], A. Minafra [a], A. Ermini [c], O. Molchanov [d], A. Rozhnoi [d], M. Solovieva [d], M. Hayakawa [e]

[a] Department of Physics, University of Bari, Via Amendola, 173, 70126 Bari, Italy
[b] Inter-Department Centre for the Evaluation and Mitigation of the Volcanic and Seismic Risk, University of Bari, Italy
[c] Department of Engineering of Enterprise, University of Roma Tor Vergata, Italy
[d] United Institute of the Earth's Physics, Russian Academy of Science, Russia
[e] Department of Electronic Engineering, The University of Electro-Communications, Japan

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ABSTRACT

A previous study of the intensity of VLF signals radiated by two ground transmitters located in Germany (f = 16.6 kHz) and France (f = 18.3 kHz) and received on board the French satellite DEMETER, revealed an intensity drop in the time interval November 23–December 12, 2004, probably connected with the occurrence of earthquakes (M = 5.4–5.5) in central Europe. From 2002 a receiver has been operating at Bari (Italy) and the intensity and the phase of the VLF/LF radio signals radiated by GB (f = 16 kHz, United Kingdom), FR (f = 20.9 kHz, France), GE (f = 23.4 kHz, Germany), IC (f = 37.5 kHz, Island) and IT (f = 54 kHz, Sicily, Italy) are being monitored with a 5 s sampling rate. In order to confirm the results obtained by the satellite measurements, both the intensity and the phase data collected by the Bari receiver from October 2004 to January 2005 have been analysed. As concerns the intensity, drops of the GB, FR, GE and IC signals were revealed before the middle of November and a drop of the IT signal appeared before December 10. The geomagnetic activity gives satisfactory justification of the November drops; on the contrary no correspondence stood up with the drop in December and seismic effects can be claimed. As concerns the phase data, at first the wavelet analysis was applied and clear anomalies were revealed on the FR and IC signals at the end of November. These anomalies appear as precursors with respect to all the mentioned seismic activity. Then, the standard deviation of the phase data sets was investigated and a clear drop was revealed on the GE signal on 23–24 November, that is just before one of the previous large earthquakes. So, not only an agreement of the ground results with those obtained by the satellite appears, but also a more precise definition of the connection between the radio anomalies and the earthquakes stands up using the ground data.

1. Introduction

The satellite DEMETER is a micro-satellite built by the French CNES (Centre National d'Etudies Spatiales) that was launched on June, 29, 2004 on a nearly circular ~710 km altitude quasi-heliosynchronous orbit at 98° inclination. Measurements of the electric and magnetic components of the electromagnetic waves are performed respectively by the ICE (Instrument Champ Electrique) equipment (Berthelier et al., 2006) and by the IMSC (instrument magnetic search coil) equipment (Parrot et al., 2006). These instruments provide the power spectra of electric and magnetic components averaged over 2 s in the ELF and VLF ranges between 20 Hz and 20 kHz with a frequency resolution of 19.5 Hz.

Generally, VLF–LF (low band) radio signals radiated by powerful transmitters located on the ground can be received not only by ground receivers but also on board satellites. Practically, the signals from several VLF ground transmitters are recorded by the mentioned instruments on any orbit of the satellite DEMETER. In a previous study (Molchanov et al., 2006), some of the authors analyzed the electric data related to two transmitters located in Germany (f = 16.6 kHz) and in France (f = 18.3 kHz), that are clearly recorded on board of the satellite. The analysis was conducted examining the data collected for long time intervals (20–35 days). One drop of the radio signals intensity in the time interval November 23–December 12, 2004 was found, if comparing the situation with the one in the time interval before (October 25–November 22, 2004) and in the time interval after (December 26, 2004–January 31, 2005); it must be noted the lacking of data from December 13 to December 24. The possibility that this drop was related to some earthquakes occurred in central Europe, very close in

* Corresponding author. Address: Department of Physics, University of Bari, Via Amendola, 173, 70126 Bari, Italy. Tel.: +39 0805442343; fax: +39 0805442434.
E-mail address: biagi@fisica.uniba.it (P.F. Biagi).

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magnitude (M = 5.4–5.5), was proposed. The location of such earthquakes is indicated by stars in Fig. 1 and their time occurrence is indicated, too. It was not possible to better specify the connection of the radio anomaly with these earthquakes.

Since 2002, in the framework of a scientific cooperation among Japanese, Russian and Italian teams, a VLF–LF (low band) receiver has been operating at Bari (South Italy). The receiver is the Japanese OMNIPAL connected to a computer by a digital card and it is located in the Department of Physics of Bari University. The electric antenna and the GPS sensor are installed on the roof of the building. The measurement system is detailed in Dowden and Adams (1989). The intensity and the phase of the electric field radiated by the transmitters GB (f = 16 kHz, United Kingdom), FR (f = 20.9 kHz, France), GE (f = 23.4 kHz, Germany), IC (f = 37.5 kHz, Iceland) and IT (f = 45.9 kHz, Sicily, Italy) have been sampling with a 5 s sampling rate. The geographic and geomagnetic coordinates of the receiver and transmitters are reported in Table 1 together with the different distances receiver-transmitter. Fig. 1 shows the location of the receiver and of the transmitters; the relative paths are indicated, too. Previously, some data collected by the Bari receiver have been studied and possible seismic effects have been revealed (Biagi et al., 2004, 2007). Here the data collected by the receiver from October 2004 to January 2005 have been analyzed in order to compare ground results with those obtained on board a satellite.

Table 1
Geographic (λ and ϕ) and geomagnetic (Λ and Φ) coordinates of the Bari receiver (Ba) and of the five VLF–LF transmitters (GE, IC, GB, FR and IT) shown in Fig. 1

Label	λ°	ϕ °	Λ °	Φ °	Path (km)
Ba	41.11	16.88	40.32	98.80	
GE	53.08	7.67	53.54	94.80	1500
IC	63.95	−22.47	69.26	72.20	3580
GB	52.37	−1.18	54.52	85.80	1850
FR	46.62	1.08	48.60	85.10	1400
IT	37.10	14.10	36.95	94.90	500

In the geographic longitude – means West. The length of the different transmitters-receiver paths is reported, too.

2. Data analysis and results

At first, in order to manage the huge amount of data (at 5 s sampling rate), the radio intensity and the phase time series were obtained considering one datum for each minute, by averaging 12 raw data per minute. It must be noted that the averaging procedure does not affect the main features of the signal. The VLF–LF signal are strongly related to the ionosphere conditions which are very different at day time and at night time. So, at first the intensity of the radio signals is strongly asymmetric from day (low values) to night (high values); then, at day time it is strongly affected by sudden and different ionosphere disturbances. Therefore, in the analysis of the signals often only the night data have been considered (Rozhnoi et al., 2004, 2006a). This procedure seems efficient for the singling out of small variations in the data. In this study, variations in data stood up clearly without the use of the mentioned procedure.

In a first qualitative analysis, the trends of the five radio signals intensity from October 1, 2004 to January 31, 2005 were examined. These trends are shown in Fig. 2 where the dashed lines indicate the period (November 23–December 12) when the satellite analysis pointed out drops of the VLF (16.6 kHz and 18.3 kHz) radio signals intensity. From Fig. 2, two different cases can be noted: (a) drops in the IC, FR, GE and GB signals (particularly evident in the last two trends) during some days before November 15, i.e. before the mentioned period; (b) a drop in the IT signal in the first days of December, i.e. inside this period.

Besides, the standard deviation σ of the intensity and phase 1-min averaged data sets was investigated in the period from October 2004 to January 2005. The most evident result is the appearance of a clear short drop in the phase data of the GE radio signal on 23–24 November 2004 as it is shown at the bottom of Fig. 4. For safe of the best graphic resolution, $1/\sigma$ is reported in Fig. 4. This anomaly is a further result to be inserted in the case (b).

Afterwards, since the statistical characteristics of the signals under analysis change in time, the wavelet transform on the data was applied (Torrence and Compo, 1998). In this way it has been possible to highlight the spectral components of the signal by using

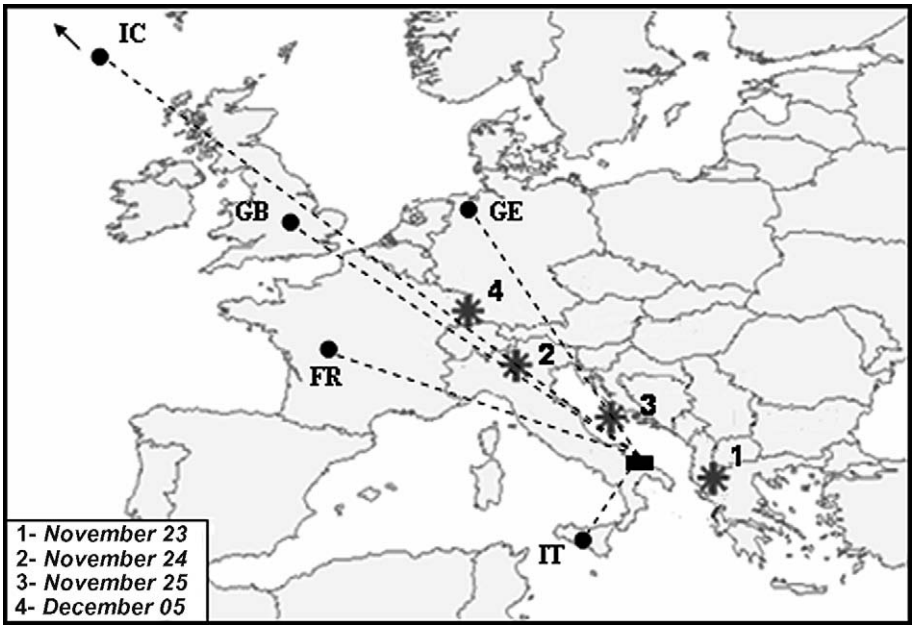

Fig. 1. Map showing the location (stars) of the earthquakes (M = 5.4–5.5) occurred in central Europe in the period November–December 2004. The time occurrence of such earthquakes is also indicated. The black rectangle represents the VLF–LF receiver (Bari, southern Italy) and the black circles the five VLF–LF transmitters. The different radio-paths are indicated by dashed lines.