RADIO WAVE ANOMALIES, ULF GEOMAGNETIC CHANGES AND VARIATIONS IN THE INTERPLANETARY MAGNETIC FIELD PRECEDING THE JAPANESE M9.0 EARTHQUAKE

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Abstract: From the results of monitoring carried out in Italy, analyses were made of radio wave anomaly data in frequencies lower than 10 Hz and peaks between 55 microGauss and 0.3milliGauss which had preceded the M9.0 Japanese earthquake on 11 March 2011. From the 1 March onwards, the "trains" of interferences had already markedly increased –a good 179 radio wave anomalies were measured, in comparison to 109 during the previous month, February 2011. This series of data remained on the high side until plummeting to only 66 on the day of the earthquake, then rising sharply again to 246 on the following day (12th March 2011). The magnetic field observed by satellite, both before and during the earthquake, showed a pattern analogous to the number of radio wave anomalies measured on the ground. Here too there was a dramatic fall when the earthquake occurred, followed by an abrupt rise. In Italy, just a few minutes after the mainshock, the gravimeter registered a substantial reduction in the gravitational field, which has been interpreted as a temporary swelling of the Earth's crust due to the energy released by the seismic shock.

Keywords: *short-range earthquake prediction, ULF geomagnetic change, changes in IMF, variations in gravity due to strong earthquakes, radio wave anomalies*

INTRODUCTION

The violent seism which occurred in Japan on the 11th March 2011 is only the latest in a series of disastrous earthquakes that have devastated the terrestrial globe over the last few decades. The dramatic consequences of the Japanese seism which led to the loss of tens of thousands of human lives and caused vast damage to the economy and infrastructure, is a salient reminder, in view of what is at stake, that no stone should be left unturned when it comes to finding methods to analyze seismic precursors.

This study will present and discuss data measured both on the ground (anomalies in the frequencies of the radio wave band and variations in terrestrial gravity) and by satellite (variations in the interplanetary magnetic field - IMF), both prior to and during the disastrous earthquake.

Examining the electromagnetic anomalies of pre-seismic phenomena has proved equally useful on the occasion of other seismic events (Fenoglio et al., 1993; Fraser-Smith, 1990; Straser, 2010) in view of the fact that certain electromagnetic signals almost always precede shocks reported by seismographs. At the same time, satellite data too has been analyzed as well as the perturbations found in these on the occasion of Japan's seismic sequence, which were analogous to those recorded in other seisms of magnitude 6 or over (Bhattacharya et al., 2009; Zhang et al., 2009).

Indeed, it is thanks to techniques based on GPS satellite information that ionospheric anomalies have been observed just prior to or during strong seisms above regions later struck by an earthquake, as Pulinets and Boyarcuk (2004) and Fidani et al. (2010) have reported. Measurements taken during earthquakes with a magnitude of 6+ have frequently shown that in the epicentre areas significant perturbations may occur in the air due to ionization processes in the atmosphere, causing clouds of condensation created by the energy released by crust stress.

In fact, in the lithosphere/atmosphere interface, perturbations in the electromagnetic fields in many cases are generated in connection with high magnitude seismic events, which can extend as far as the magnetosphere. Electromagnetic interference can also influence the stability of the Van Allen belts and trigger the release of protons and electrons generating further anomalies measurable by satellites, since the latter have a privileged observation point in space outside the Earth. It is on account of satellite data that we have been able to measure in real time the speed of the solar wind, the flow of matter, and the interplanetary magnetic field, which show quite evident alterations during the run-up to earthquakes.

Significant electrical and magnetic perturbations associated with strong earthquakes are also observable on the ground, including interference in the radio wave band, which represent the Earth's "background noise" during the run-up to a major seismic event (Villante et al., 2001; Molchanov et al., 1992; Hayakawa et al., 2007; Karakelian et al., 2002).

Radio wave interference measured in Italy and caused by a superimposition of electromagnetic waves in the ELF and SLF bands (Schumann's resonance) generated by endogenous phenomena, have been recorded anywhere from a few minutes to some hours before the occurrence of destructive seisms on a global scale.

Findings from 2009 onwards have shown in many cases, but not all, that it is possible to observe radio wave anomalies in the ELF band in concomitance with seismicities with magnitude 6+, and in some cases even as low as 4, right across the globe. From experience gained in the field and analysis of data in the laboratory it appears that the greater the magnitude of earthquakes, the greater the number of radio wave anomalies.

In this present case, the electromagnetic data recorded were compared with variations in gravity measured at a second monitoring station (Rovigo – Italy 45°.05' N; 11°.48' E), as shown in **Fig. 1**, situated around 500 km from the principal one (Rome – Italy 41°41'4.27"N; 12°38'33.60"E). Measurements of variations in the gravitational field following the seismic shock led to certain hypotheses regarding the behaviour of the terrestrial crust prompted by the seismic stress.

Fig. 1. Index map. 1 – Gravimetric monitoring station (Rovigo); 2 – radio wave anomaly monitoring station.

The sequence of radio wave anomalies during the first 10 days of March 2011

Interpretation of the radio wave anomalies during the first 10 days of March 2011, which had increased markedly with respect to the previous months, turned out to be a pivotal element in identifying the run-up phenomena of the Japanese seismic sequence (**Fig. 2**).

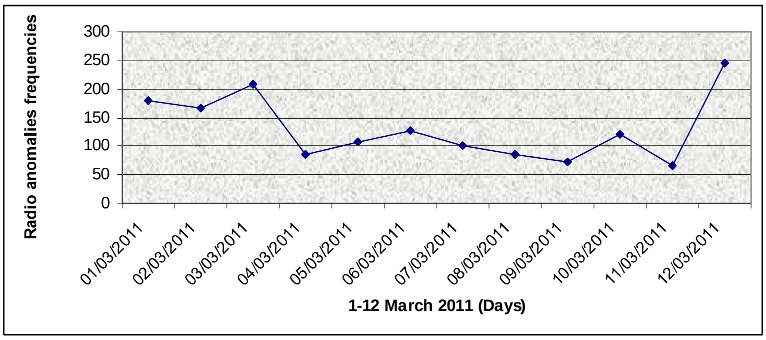

Fig. 2. In abscissa the first twelve days of March 2011, and in ordinate the pattern of radio wave anomalies recorded at the Cecchina station, Rome, Italy.

In 2010, in the month of October, the spectrograms showing anomalies numbered 542, 657 in November, and 304 in December. In 2011, the anomalies recorded during the month of January 2011 were 472, and 109 in February. In contrast, the first three days of March showed an abrupt rise in radio wave anomalies to as many as 552, while in the following days the figure remained high. In detail, the radio wave anomalies were: 1^{st} March 2011 = 179, 2^{nd} March = 166 (where an increase in the intensity of certain individual emissions was noted with respect to the previous day), and 3^{rd} March = 207 (the increase in duration of some emissions was some 2 to 10 times greater).

From previous instrumental observations carried out starting from 2009, it had been observed that, as a rule, the greater the number of interferences in the radio band, the stronger the earthquake was. An increase in the number of radio interferences measured with frequencies <10 Hz, has been interpreted as a premonitory phenomenon of energy accumulating underground. The appearance of these frequencies, by now well known in scientific literature, has also been recorded on the occasion of strong earthquakes over the last few decades (Hayakawa et al., 1996; Hattori, 2004).

In the case of the monitoring results under discussion, the single signals or groups of signals observed were of intensity between 55 microGauss and 0.3 milliGauss, but generally had a lower frequency. This fact too represented a significant symptom of energy accumulating underground.

In parallel with the instrumental results on the ground, also the data from a GOES magnetometer – while remaining within the normal range of IMF activity – showed a gradual increase over the first days of March 2011 (**Fig. 3**), as can be construed from the peaks relating to the magnetic field, which displayed a slightly greater intensity with respect to previous ones.

Before the impressive seismic sequence in Japan, which included around 100 shocks with a magnitude of 5+ in just three days, culminating in the violent earthquake with a magnitude of M9.0 (near the East Coast of Honshu, Japan; see: www.usgs.gov/), the anomalies recorded previously had also preceded the occurrence of strong earthquakes with a magnitude of M6+:

Date/ Time	Latitude	Longitude	Depth	Magnitude	Seismic Area
2011/03/06 12:31:58	-18.115	-69.391	101.3	**6.2**	**Tarapaca, Chile**
2011/03/06 14:32:36	-56.387	-27.019	84.2	**6.5**	**South Sandwich Islands Region**
2011/03/07	-10.334	160.739	37.9	**6.6**	**Solomon Islands**

00:09:39					
2011/03/09 02:45:20	38.424	142.836	32.0	**7.2**	**Near the East Coast of Honshu, Japan**

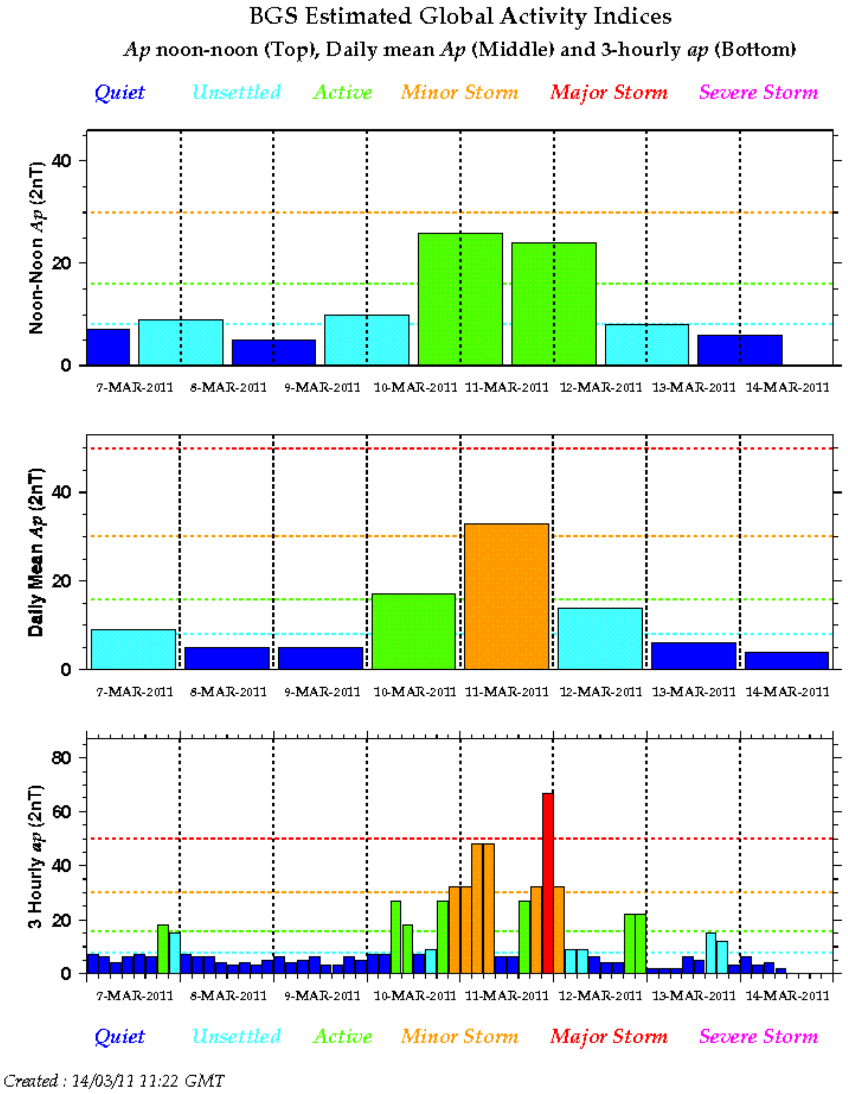

Fig. 3. Variations in the magnetic field observed by BGS' Space Weather Monitoring centre from 7 to 11 March 2011. (www.geomag.bgs.ac.uk/research/)

Instruments used

Spectrograms

The spectrograms obtained by the station were recorded every 10 minutes; i.e. 1 horizontal line every 1,600 milliseconds. The data of the Spectrum Lab setting are as follows:

Effect of FFT settings with fs = 44.1000 kHz:
Width of one FFT-bin: 21.0285 mHz
Equiv. noise bandwidth: 28.5988 mHz
Max freq range: 0.00000 Hz to1.37813 kHz
FFT window time: 47.554s
Overlap from scroll interval: 96.6%

Spectrograms

Colorimetric Scale

Using a colorimetric scale created by Gabriele Cataldi (**Fig. 4**), the spectrogram colours represent specific values in relation to the type of signal produced. Normally, the so-called electromagnetic seismic precursors (ESP or ESS) reach on average 60 nT at 10 MHz (*Fraser-Smith et al., 1990)*, however it is possible to study ESP at frequencies as low as 15 Hz (ELF and SLF bands), even if in practical terms, it is easier to study these signals at 30 Hz, without looking for "MHz". The colorimetric scale shows signals that reach 30 nT in red and in white those that reach 100 nT. In this way, all signals lower than 20 nT appear BLUE and can be easily distinguished from the others. Between 20 to 30 nT the blue changes to red. A deviation of only 10 nT between blue and red efficiently displays all those values of any significance on the one spectrogram. To make a comparison, it is worthwhile recalling that 30nT is equal to three times the magnetic field produced by an electric toaster measured from one metre away, which means that the value is undeniably significant in studying ESPs. Radio wave anomalies in spectrograms are shown in yellow (all the shades of yellow until becoming white), and surrounded by red. In this way we can be certain that we have before us a signal of intensity no lower than 65 nT (the first shade of yellow, which corresponds to intensity greater than that produced by a fluorescent tube 1 metre away).

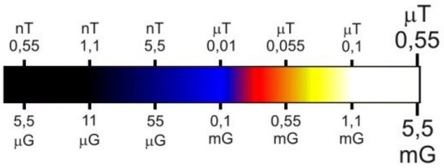

Fig. 4. Colorimetric scale (courtesy of Gabriele Cataldi)

Satellites

Data from satellite tracking system (Orbitron) are as follows: (http://www.swpc.noaa.gov/Data/goes.html)

GOES 13 (Primary): orbiting at 35,809km; Long 74.5403° O; Lat 0.3317° S; Ht (km) 35 809.730; Azim 272.3°; Elev -10.7°; RA 12h 26m 24s; Decl. -7° 07' 04".

GOES 15 (Secondary): orbiting at 35,782km; Long 88.9147° O; Lat 0.0344° N, Azim 284.2; Elev -18.6°; RA 11h 29m 43s; Decl. -6° 37' 18".

Gravimeter

Gravimetric measurements

The gravimeter has a device which is independent from barometric pressure variations and a pendulum with low expansion rod to limit errors due to thermal dilatation. The oscillator with a position finder able to produce a very precise synchronism signal suffers no electromagnetic interference and is connected to an electronic clock which is precise to the eighth-ninth significant figure.

This system is controlled by a calculator. In one day, about 52 values of the Earth’s gravitational field are obtained and data continue to be collected between one measurement and the next thanks to being recorded on a disk. The relative error over 1,000 measurements is 0.000000089.

DISCUSSION

Analysis of satellite data has shown generalized shifts in the magnetic field on the approach of seisms with a magnitude of M6+, characterized by a dramatic fall in values. This pattern is in line with the data observed in the M7 earthquake which occurred in 1989 at Loma Prieta (USA), where a variation (upsurge) in the natural low was observed a good 2 weeks before the seismic event, which then fell rapidly just a few hours before (Molchanov et al., 1992).

The satellite graphs show considerable perturbations in the magnetic field corresponding to the seismic outbreak between 6 to 14 March, i.e. coinciding with the increase in radio wave anomalies measured by the monitoring station at Cecchina (Rome). The magnetic field observed by GOES 13 and GOES 15 on the occasion of the violent M9.0 earthquake near the East Coast of Honshu, Japan (see: www.usgs.gov/), shows a dramatic decrease, which coincided with the sharp fall in the rate of radio wave interferences (**Fig. 5**). A similar pattern also prevailed during the M6.0 seism of the 14th of March 2011 again near the East Coast of Honshu, Japan (see: www.usgs.gov/). Analogous perturbations were also observed for those seisms which occurred on 6, 7 and 9 March 2011 in **Tarapaca, Chile, South Sandwich Islands Region, Solomon Islands, near the East Coast of Honshu, Japan, the New Britain Region, and Papua New Guinea.(**http://www.swpc.noaa.gov/Data/goes.html)

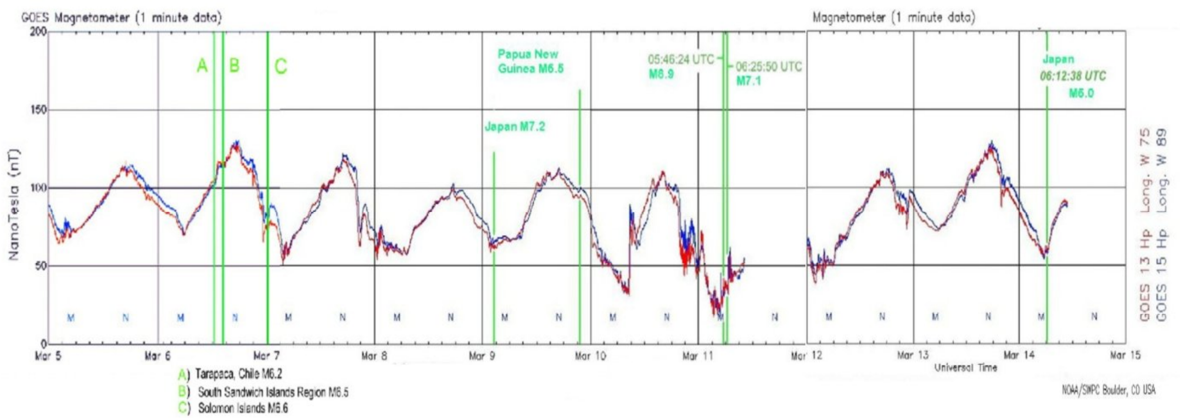

Fig. 5. Electromagnetic fields observed by GOES satellites 13 and 15, in relation to the seismic sequence in Japan from 8 to 14 March 2011.

The pattern of values measured by satellite and on the ground was compared with those from the HAARP station (**Fig. 6**) on the occasion of the seismic sequence in Japan, which also confirmed a notable anomaly during the main shock and the subsequent M7.1 seismicity. (http://137.229.36.30/cgi-bin/magnetometer/gak-mag.cgi).

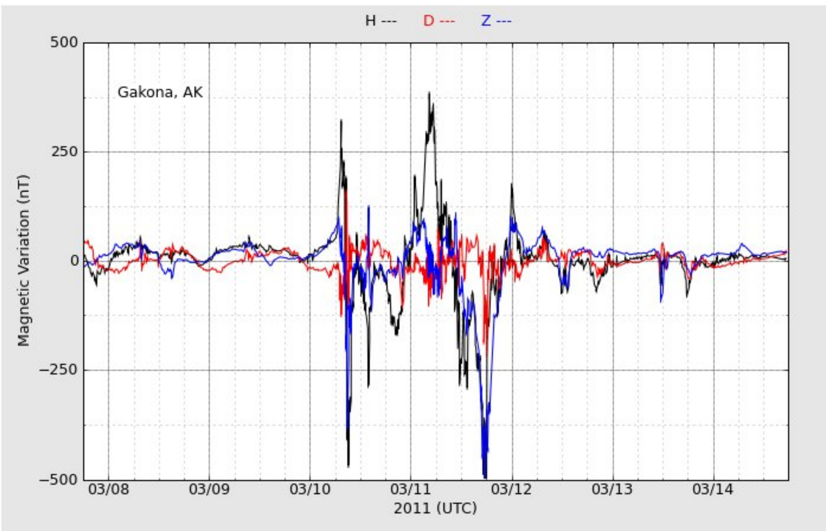

Fig. 6. Magnetic field as observed by HAARP, from 3 to 14 March 2011 (http://137.229.36.30/cgi-bin/magnetometer/gak-mag.cgi).

Further data relating to variations in the magnetic field were confirmed by BGS' Space Weather Monitoring centre (www.geomag.bgs.ac.uk/research/). These data too (**Fig. 3**) correspond to the frequency and pattern of the radio wave anomalies which preceded the seismic event of 11th March 2011.

Summing up, therefore, it has been observed that during strong earthquakes:
1) Solar activity is greater
2) IMF activity is subject to variations (increases or abrupt reductions in intensity),
3) Seismicities are generally preceded by a reduction in the natural magnetic background. Clearly, this too is subject to fluctuation.

Measurements made with a gravimeter, on the other hand, have allowed a comparison of the data with anomalies of an electromagnetic type and the number of radio wave interferences in the low frequency range.

This is not a datum recorded by seismograph, the result of a complex variation in an oscillating mass, but a phenomenon which developed uniformly in a body lasting around 9 minutes; in practice, a semi-wave in reduction in gravity, with subsequent settling (**Fig. 7**).

This is evidenced by the fact that the semi-wave was plotted and later defined by three measurements 135 seconds apart, which design a symmetrical cusp. This figure is significant, since it shows as an instrumental datum, a measurement of the phenomenon with a regular pattern which reached its maximum at 07:05a.m, Italian time.

The perturbations may therefore have given rise to a swelling towards the outside of the terrestrial crust, which subsequently shrank during the relaxation phase. The data strongly suggest this interpretation, however the phenomenon would have been more complex, provoking also modest accelerations in addition to the lifting.

What remains striking about the gravimeter findings is the symmetry of the perturbation. From the values found, and taking the time zones into account, the perturbation took 2 hours and 16 minutes to cover the distance between Japan and Italy.

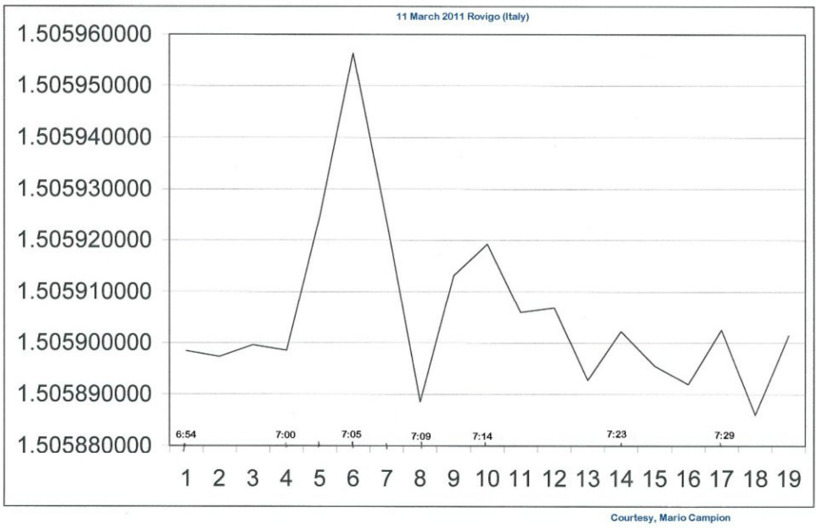

Fig. 7. Graph of variations in the gravitational field (see: www.astrofilipolesani.it), which followed the M9.0 seism of 11 March 2011 (6:50 a.m. Italian time; courtesy of Mario Campion). In abscissa the 19 measurements made at intervals of 135 seconds for a total of 42.75 minutes, centred on the perturbation found, while the ordinate indicates the value of the sensor period in seconds. The peak on the graph corresponds to a fall in the gravitational field which occurred at 07.05 a.m. Italian time (06:05 UTC).

CONCLUDING REMARKS

At least two types of conclusion may be drawn: The first concerns the pre-seismic signals manifested by the radio wave anomalies and the interference in the interplanetary magnetic field which occurred in correspondence with the earthquake (**Fig. 8**). The second concerns the effects provoked by the violent earthquake on the crustal dynamic.

In the first case, "trains of interference" have always been found to precede the occurrence of earthquakes, and the greater these anomalies, the greater the energy of the seism, with single or groups of signals of intensity from 55 microGauss to 0.3 milliGauss and frequencies lower than 10Hz. The earthquakes discussed in this work always occurred after a fall in IMF and sudden interferences recorded by satellite.

The second conclusion made use of the gravimeter to interpret the dynamic of the propagation of seismic energy during the phase immediately following the main event which, in this case, showed a time lag between the seismic event and the appearance of an anomaly (decrease) in the gravitational field, which may be interpretable as a temporary swelling of the terrestrial crust.

Thus, observation of the electromagnetic anomalies which manifest before an earthquake could prove useful in an interdisciplinary work aimed at monitoring seismic precursors, since radio wave anomalies and sharp falls in the magnetic field have always preceded the mechanical effects of an earthquake reported by seismographs.

Radio wave anomalies, in combination with satellite data concerning the magnetic field, have proved useful in making short-range forecasts of strong earthquakes with magnitude 6.0 or greater.

Acknowledgements: I wish to express heartfelt thanks to Gabriele Cataldi and his team for their support and for providing me with real time data on radio wave anomalies from the monitoring station at Cecchina (Rome), as well as the GOES satellite data. Further thanks must go to Mario Campion and Jerry Ercolini for their constructive discussions and for sending me the graph of variations in gravity relating to the earthquake in Japan on the 11 March 2011, as well as to the anonymous reviewers for stimulating me to improve the paper with additional reflections and a correct scientific dialogue. Lastly, my thanks and gratitude must go to Dong Choi for accepting this report, written just a few days after the occurrence of the seism.

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Postscript: Earthquake prediction

Precursory signals (whether physical, chemical or of another kind) typically manifest in the areas where the seism is about to occur; what I wanted to suggest in this study, on the other hand, concerns a new class of precursory phenomena that I prefer to define as “global seismic precursors”. This type of pre-seismic signal indicates that “very soon” a strong seism on a global scale is going to occur, however, without specifying the future epicentre. To obtain real efficiency in forecasting an earthquake and localizing the epicentre, it is necessary to combine these indicators with other forecast methods, already tried and proven by the scientific community.

Let’s take the seismic sequence in Japan that culminated in the earthquake of 11 March 2011 as an example.

1 – In the recent *NCGT Newsletter*, no. 58, on p.78, there is a photo taken from a satellite, sent by Zhonghao SHOU, which shows “earthquake clouds” or a “geo-eruption” near the future epicentre; this appeared 16 days before the violent Japanese seism of 11 March 2011.

2 – Instead, in this study, an abnormal increase in radio anomalies was pointed out which began 11 days before the M9.0 Earthquake mainshock.

The first precursory datum concerns the site of the future epicentre, but not the actual day when the earthquake will occur, while the second provides a generic indication that a strong earthquake is about to occur on a global scale, without, however, specifying the location of the epicenter.

By combining the two data it is possible to say that: “*in the offshore area of northern Japan a violent earthquake is about to occur*”, while it is highly likely, according to experiments carried out by Shou (2007), “*that the magnitude of the seism will be fairly high and that the earthquake’s epicenter will be found near the site of the geo-eruption*.”

When exactly?

3 – The graphs of the satellite (GOES) data (**Fig. 5**) show that M6.0+ seisms occur when the line forms a “ripple” characterized by an “S”, and the latter is associated with a radio anomaly. Instead, the various magnetometers showed a significant variation in the magnetic field in the run-up to the strong M9.0 seism and coinciding with it.

If we combine the three methods we can then hypothesize that: “*within a few days, in the seismic zone near Japan, close to the site of the geo-eruption, as shown by Shou (2011), a violent earthquake will occur, and that it may conceivably happen in association with a significant variation in the magnetic field, especially where this coincides with one or more radio anomalies*.”

This is merely one example of integrating the three working methods, which could be supplemented by variations in radon gas, temperature, or the concentration of gases in the atmosphere, as well as other phenomena, in order to formulate more accurate hypotheses.

Only the existence of a truly international network or organization can provide proper integration and comparison of findings in order to accurately forecast strong seisms, while what has been proposed in this study might well constitute, within this complex working scenario, "the framework" of precursory signs.

Encouraging results, in this sense, have already emerged from experiments carried out over the last few years, such as those of the Global Network for Forecasting Earthquakes (www.seismonet.org). This project, which boasts international scientific cooperation, has shown a real application of the Method based on instrument data, but also specific new technologies (Khalilov, 2007), in combination with a fresh approach, at a global level, to the whole problem of forecasting earthquakes (Khalilov, 2008).

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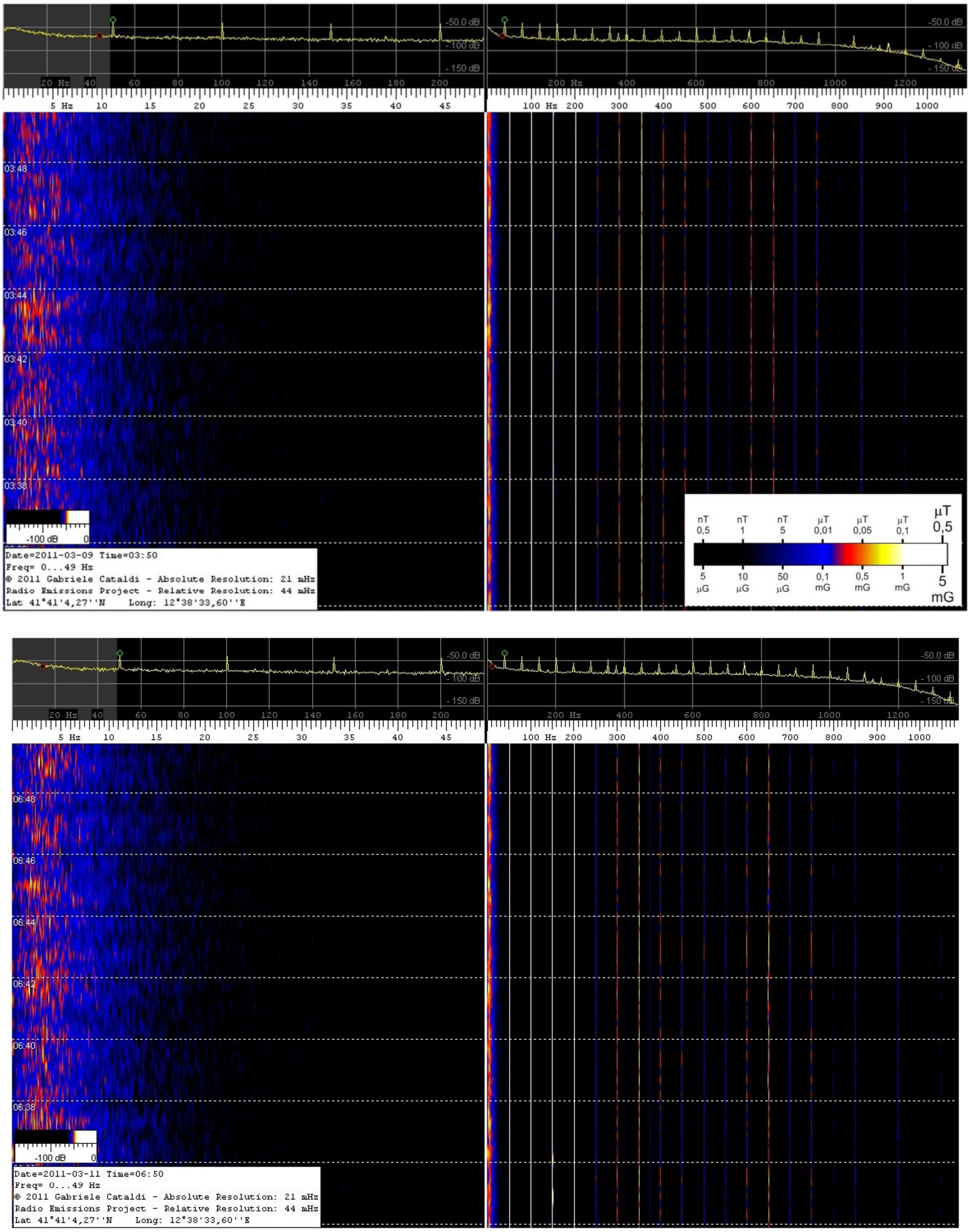

Fig. 8. Plotting of the radio wave anomalies made by the Cecchina monitoring station (Rome, Italy), which preceded the seisms of 9 March (M7.2, 03:45 hh:mm Italian time) and 11 March 2011 (M9.0, 06:50 hh:mm Italian time) both occurring near the East Coast of Honshu, Japan, see: www.usgs.gov/.