VARIATIONS IN GRAVITATIONAL FIELD, TIDAL FORCE, ELECTROMAGNETIC WAVES AND EARTHQUAKES

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ABSTRACT: This paper is the report on an experiment carried out between the month of December 2009 and the month of April 2010 between the Venetian Lagoon and the Northern Apennines in Italy, to check on a potential relationship between earthquakes and variations in the local gravitational field, the effect on the tide exercised by the interaction between the moon and the Sun, the appearance of anomalous light effects in the atmosphere ("Earth lights"), and the emission of radio waves caused by stresses in the Earth's crust. The cases studied show that there is indeed some concomitance between the periodic rising and falling of the sea level and the terrestrial tide effect, due to the gravitational attraction of the moon and sun on the Earth. In fact, changes in the local force of gravity coincided with the cycle of high and low tides and, in certain cases, with a variation in the electromagnetic field that preceded the occurrence of a seismic event by just a few hours. The observations in the article are limited to the magnitude range discussed in the paper.

Keywords: seismicity, tidal force, variations in gravity, magnetic field, earthquake triggering.

Introduction

The recent disastrous earthquakes that have struck various zones of the Earth, producing victims and provoking huge damage to buildings and the economy, call for urgent experimentation with methods that might help to mitigate seismic risk.

Even though the mechanisms that trigger earthquakes provoked by lunar/solar gravitational interaction are not yet clear, various authors have already investigated the relationship between lunar cycles and terrestrial earthquakes. According to Bagby (1973) "*Earthquakes occur more often when the sun and moon are in opposition (opposite sides of the Earth) or in conjunction (aligned on one side of the Earth)*"; Kolvankar et al. (2010) have shown a relationship between lunar cycles and earthquakes, Kokus (2006) has drawn attention to the movements of the moon in the occurrence of earthquakes along the San Andreas fault, while (Omori, 1908), over a century ago, found a correspondence between the rhythmic movement of the tides and earthquakes.

The tides represent the macroscopic effect of the influence exercised by the moon and the Sun on the Earth. The perturbations caused by the moon on our planet mainly involve liquid masses, since these are subject to major deformations with respect to the solid portions of the terrestrial crust.

In many places around the world, in response to the stresses produced, peaks of anomalous light phenomena in the atmosphere so-called "earth lights" have been recorded, as well as earthquakes when the moon is at its perigee, i.e. at its closest point to the Earth (Kolvankar et al., 2010). At its perigee, the intensity of the tidal forces is at a maximum and, for this reason, it cannot be excluded that perturbation from the moon is able to exert an effect on rocks, by placing them in a state of mutual compression, with the possibility of triggering both earthquakes and Earth lights.

Vice versa, just as the moon influences our planet's equilibrium, the Earth also produces perturbations on the moon, inducing tide effects and "moonquakes" (Zhao et al., 2008).

Lunar seismicity, recorded starting from 19 November 1969 until 30 September 1977, revealed the various seismic sources on the moon: from those due to the impact of meteorites to those caused by artificial impacts, from variations in daily temperature to deep seisms (Nakamura, 2003) more commonly called "lunar earthquakes" or "moonquakes", around 1,000 kilometres below the surface and caused by lunar tides (Goulty, 1979).

In most cases, moonquakes occur with a periodicity of around 14 days, i.e. approximately half of the lunar or synodic month (Lammlein, 1974). Since the moon's orbit round the Earth is elliptical, at the shortest distance from our planet (perigee) the tidal force tends to create stress in the mass of the moon, creating internal tensions which can provoke seisms. In contrast, at the furthest point (apogee), which is reached after approximately 14 days, the lunar surface is subject to contrary shifts, i.e. distension, provoking new tensions in the crust, and potentially triggering seismic aftershocks.

The effects exercised by the variation in the lunar/solar tidal force on the Earth, as well as playing an active role in the mechanism of terrestrial tides, also have repercussions on the sea bed inducing surface micro-seisms, as has been observed with volcanic eruptions from the Axial volcano on Juan de Fuca Ridge off the coast of the north-western United States (Tolstoy et al., 2002), and in other areas of the Earth, as a response to the effect of the variation in the local force of gravity (Tanaka et al., 2004; Zhao et al., 2002), conceivably caused by variations in pressure exercised by the water in the pores of the rocks (Tanaka et al, 2006; Contadakis and Asteriadis, 2001).

Changes in local gravity values measured during seismic events (Woollard, 1959; Kokus, 2002), appear to be related to variations in density underground and vertical movements of the terrestrial crust (Imanishi et al., 2004; Hayakawa et al., 2009), as confirmed by data from satellites (Han et al., 2006).

Interestingly, much research has been done in this regard on the moon (Kawamura et al., 2009), using the Apollo 17 lunar surface gravimeter (LSG), data from which has been used to analyse the sources of deep moonquakes far below the surface.

The object of our own survey was to examine those perturbations influencing the momentary conditions of the dynamic equilibrium of the Earth's crust. For instance, whether interactions between celestial bodies and the Earth can induce a seismic event in a rock mass already near breaking point: i.e. when an outer perturbation adds enough energy to exceed the elastic limit or shear strength of the rock (Straser, 2008a & 2008b).

In this particular context, tidal forces would seem to play an important role in triggering earthquakes.

Area of the Investigation

The choice of the area for investigation (**Fig. 1**), already studied by the seismologist and astronomer Raffaele Bendandi in 1931, comprised a zone between the Venetian lagoon and the Northern Apennines of Italy, since earthquakes in these areas are relatively frequent (see: www.ingv.it) and they are therefore suitable for ascertaining potential links between tidal perturbations, precursory signs and seisms. In fact, in these zones the recurrence of seismic phenomena, the appearance of earth lights, the production of radio waves and the effect provoked by lunar cyclicity on the Adriatic Sea, all function as a proper laboratory platform which allows a systematic study of the phenomena and possible relationships between them.

The first zone monitored, lying fairly close to the Adriatic coast near the Venetian Lagoon, was chosen to assess tidal effects in relationship to the local gravitational value. The second, in the Northern Apennines, was picked to measure electromagnetic fields in response to tectonic stress, and also because in that area there is a recurrence of Earth lights, also interpretable as precursory signal (Straser, 2007). The values measured at the two stations, lying around 80 km apart, were correlated to a timescale with the epicentres of earthquakes occurring near the monitoring stations.

Monitoring Station no. 1

For the gravimetric measurement, the zone near Venice was particularly suitable since the Adriatic Sea has a basin of an ideal shape to assess tidal forces. In fact, its oblong form lying along the meridian means that rises in sea level follow a movement in tune with the passage along the meridian of both the moon and the sun (**Fig. 2**).

Monitoring Station no. 2

The second area, chosen to measure electromagnetic fields in the radio frequency, is well-known for the frequent appearance of earth lights; in addition, it has already been studied for concomitance between electric and magnetic static field variations and the occurrence of earthquakes (Straser, 2009a). This area can be surveyed precisely since there are no telephones or electric lines within 300 metres. This allows environmental mapping of long waves (VLF), plus the possibility of removing any interference disturbing the signal.

Figure 1. Index map showing the study area in a red circle.

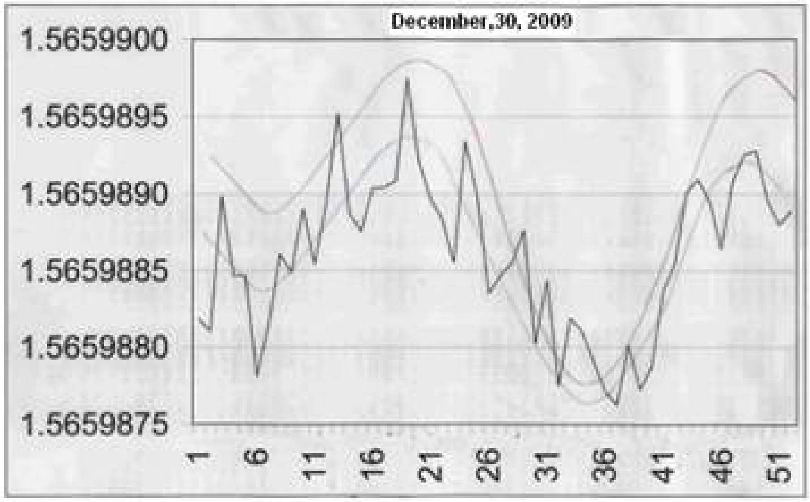

Figure 2. The graph shows the monitoring of gravity on 30 December 2009. In the frame the oscillator time is shown (ordinate), not the gravity expressed in mGal with the result of reversing the graph curve, as the water levels follow this progression and appear increased in concomitance of a lower level of gravity, while, in abscissa we find the sequence of measurements taken from midnight, with gaps of about 28 minutes in which the oscillator made 1000 swings. The line underneath indicates the average course of these data points, while the line above indicates the expected tidal course again on 30 December, for the detector at Canal Porto of Venice Lido. The analogy is clear between the two courses. On 30 December 2009 the measured progression of the Earth's gravitational field induced by the same forces which cause the tides, are in phase.
(www.45gru.it; www.astrofilipolesani.it).

Instrument

Measurements of electromagnetic waves and survey of earth lights

The receiver set for continuous bandwidth reception (VLF 00.Hz – 30 kHz), was connected to a 1.5 metre antenna and the acquisition system ARGO. For the photographic support a Canon Eos 30D with Tokina telezoom 24-200mm F2 lens ED with an IR Hoya screen, a Canon Eos 30D with Nikon Catadioptric lens. A Sony Full HD 1024 lines/mm video camera and an Intel Centrino Duo PC were also used.

Software

"Spectrum Lab" set as follows:

Effect of FFT settings with FS= 22.0500kHz:
Width of one FFT-bin: 21.0285MHz
Equiv. noise bandwidth: 28.5988MHz
Max freq range: 0000.00Hz - 1378.13Hz
Data collection for one new FFT: 47.554s
Overlap from scroll interval: 97.9 %
Resolution: 0.02Hz
Registration field: 1 line/s (500ms)
Antenna pointing towards the nadir

Gravimetric measurements

The gravimeter has a device which is independent from barometric pressure variations and a pendulum with low expansion rods to limit errors due to thermal dilatation. The oscillator with a position finder able to produce a very precise synchronism signal has 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 1000 measurements is 0.000000089.

Data

The data on gravity tides and electromagnetism were measured during the first months of 2010. In particular, data from the 26, 27 and 28 February (**Fig. 3**) and the 28 February 2010 (**Fig. 4**) were compared between the two monitoring stations, since those dates corresponded to the Full Moon. In the same period, the two zones under investigation were monitored to verify the seismic events reported by the Web site of the *Istituto Nazionale di Geofisica e Vulcanologia* (Italian National Institute of Geophysics and Volcanology (www.ingv.it/).

Monitoring Station 1 (Rovigo – Italy) 45°.05' N; 11°.48' E
Monitoring Station 2 (Rosano – Italy) 44°.27' N; 10°.20' E

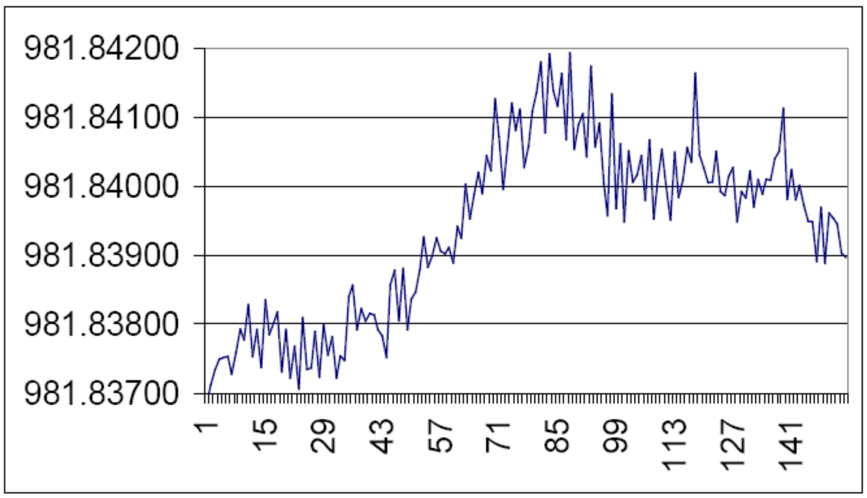

Figure 3. The graph shows gravity behaviour on 26, 27, 28 February 2010. Between the first two days there is an increase of about 4mGals (ordinate) with a maximum on 27 February 2010. In abscissa are indicated the measurements, with gaps of about 28 minutes. This gravity behaviour happens with a uniform progression where some peaks, which recur and have the same uniform progression either upwards or downwards can be seen. On the 28 February 2010 the following graph was produced to show more clearly the behaviour of gravity during the Full Moon.

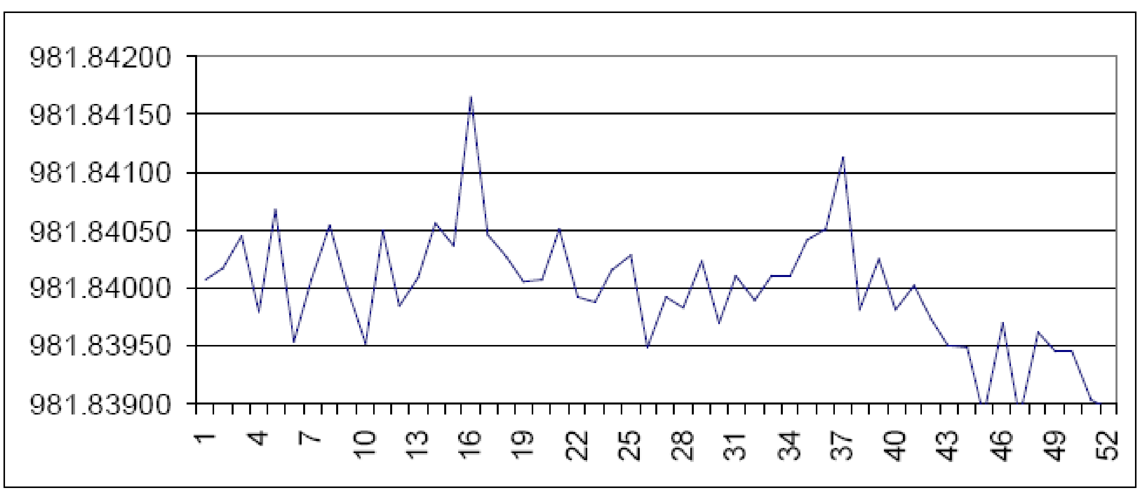

Figure 4. Graph of 28 February 2010, where in concomitance with two tidal minimums, the presence of two peaks which point to a significant increase in gravity (mGal), can be seen. The horizontal axis shows the time intervals approximately every 28 minutes.

Earthquake .1A

Day	Time (UTC)	Lat.	Long.	Depth	Magnitude	Seismic District
02/03/2010	12:46:34	44.121°N	12.286°E	37.7km	Ml: 2.5	Rimini

Earthquake .2A

Day	Time (UTC)	Lat.	Long.	Depth	Magnitude	Seismic District
03/03/2010	22:00:24	44.322°N	11.41°E	35.7km	Ml: 2.8	Bolognese Apennines

Earthquake.1B

Day	Time (UTC)	Lat.	Long.	Depth	Magnitude	Seismic District
31/03/2010	18:38:37	44.255°N	12.087°E	10km	Ml: 2	Area of Forli

Eearthquake.2B

Day	Time (UTC)	Lat.	Long.	Depth	Magnitude	Seismic District
28/03/2010	21:48:47	44.259°N	10.9°E	6.7km	Ml: 2.2	Modenese Apennines

Report and discussion

Before performing measurements in the field, a preliminary investigation was carried out in the area near the Venetian Lagoon to verify possible links between the appearance of earth lights (http://www.astrofilipolesani.it) and lunar phases (syzygies and quadratures), since Earth lights have been interpreted as a response to regional crust stress (Straser, 2009b; Teodorani, 2004 & 2008). These lights can occasionally be observed at some considerable distance from the epicentre area, however they usually appear at a distance of 10 to 60 kilometres from it.

The time that elapses between the appearance of earth lights and seisms in the North-western Apennines is approximately 52 days (Straser, 2007): which corresponds roughly to two lunar months, while in the plain between the Venetian lagoon and the North-western Apennines, the recurrence is more discontinuous and the time intervals are around 60 days.

The distribution of the events, as reported in (**Fig. 5**) seems far from accidental, since the earth lights become concentrated during the quadrature, on the days of the syzygies and quadratures.
This preliminary experiment led to the hypothesis of a relationship between the “cyclicity” of the lunar movement – and therefore with the tide cycle, and the stresses produced in the rocks below.

The earthquakes took place in the days near the Full Moon, i.e. when the tidal sinusoidal oscillations are greatest. The seisms considered in this paper happened after a few hours or up to three days from the variations in gravity and electromagnetic waves (ULF and VLF). It seems that the crust stresses caused by tidal variations bring about micro-fractures in the rocks; the water then enters and reduces cohesion until it causes a seismic event (Shou, 2006) some hours or up to three days later, while the occurrence of earthquakes seems to be related to a sudden variation in the gravitational field and not a gradual one, which is true also of the tidal forces, for example as happened during the earthquakes of 2 and 3 March 2010 (**Fig. 6**).

Values measured at Station 1:
The daily graphs of the gravity values show notable dispersion.

The measurements taken with the gravimeter, examined daily, showed uneven gravitational variations in the order of 0.3 –0.5 mGal, modulated by a wave-like trace in the order of 1.0-1.5 mGal (**Figs. 2, 3 & 4**).

The graph for the month of March (**Fig. 6**), shows a clear accentuation in the depth of the traces, corresponding to the tidal maximums during the New Moon and the Full Moon, while normally (rising) variations in gravity level can be observed that are fairly marked and correspond to the quarters of the Moon (quadrature) which later tend to re-enter the norm.

Starting from the quarters of the Moon, as the solar and lunar tidal forces very gradually become closer and closer to end up overlapping, the depth of the sinusoids tends to increase. There was however at least one day, the 30 December 2009, where the gravimeter graph shows obvious analogies with what was reported by the tidal graphs from the nearby Adriatic Sea (**Fig. 2**).

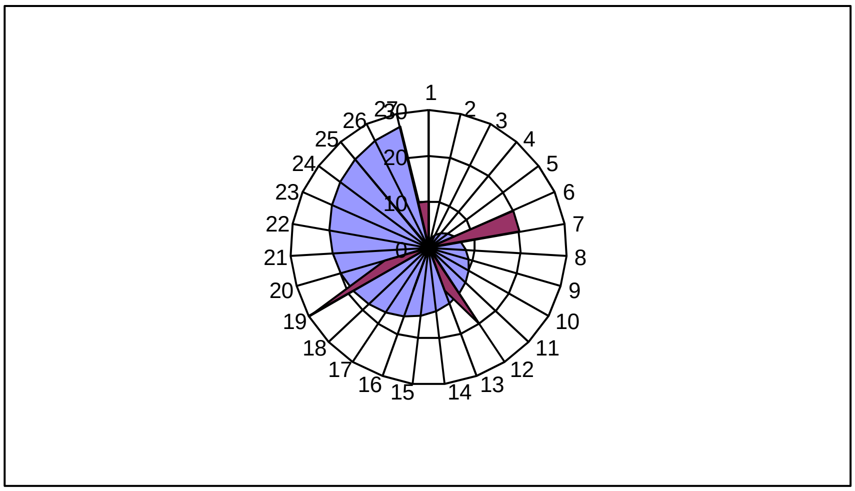

Figure 5. Distribution of the Earth lights photographed in the Rovigo area in Italy (www.astrofilipolesani.it), over a period of 7 years. The graph values were multiplied by 10 to observe the progress of the earth lights more clearly over the lunar month. The figure "1" corresponds to the day of the New Moon, "7" to the first quarter, "14" to the Full Moon, the "21" to the last quarter.

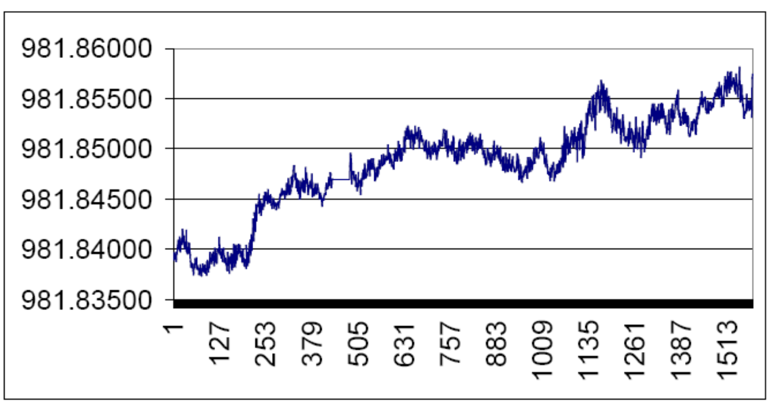

Figure 6. The graph refers to March 2010, where the short straight line of measurements, near the 451st refers to a power blackout. The graph shows the link between the value of gravity (mGal) and the gaps of about 28 minutes (abscissa).

In the graph showing the findings on 6 April 2010 (**Fig. 7**), there is a shortening of the average oscillation period, corresponding to an increase in gravity, which frequently occurs close to the first and second quarter of the moon.

This increase in gravity occurs with a uniform progression, during which can be observed certain peaks that repeat and have the same behaviour, both upwards and downwards; they appear to be the result of an action that lasts up to about fifteen hours, during which a stretching (or compression) of the ground occurs, again uniformly.

On the 28 February 2010, in correspondence with the two tidal minimums (Full Moon), two peaks can be observed that signal a marked increase in gravity. These and other behaviours are contained in the traces of the daily graphs, whose interpretations raise many questions, such as the coincidence with the strong seismic activity that was occurring on the opposite part of the globe in Chile. This concomitance, however, can be excluded from the interpretations, in view of the recordings made on the 28/03/10 where the same frequency occurs with the same "modular" behaviour. The increase in the local gravitational field, in correspondence with the low tide, correlated with the forces exercised by the lunar/solar interaction, is open to several interpretations: from a variation in density caused by a migration (resurfacing?) of materials underground, or by a change in the value of water pressure in the pores of the rocks, to a stretching of the terrestrial crust.

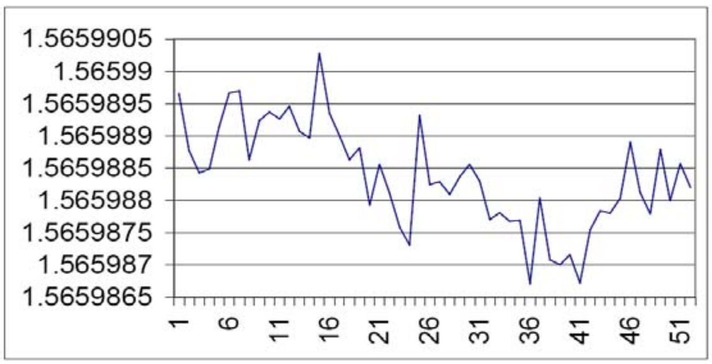

Figure 7. Graph of 6 April 2010, in which a decrease in the length of the average time of oscillation corresponding to a gravity rise can be noticed, which often takes place near the first and second quarters of the moon. This gravity rise happens with a regular progression, in which some peaks, which recur and have the same progression, both towards the top and the bottom, can be noticed, and these seem to be due to an action lasting about 15 hours during which time a uniform stretching (or compression) of the ground took place.

Values measured at Station 2:

From the photographic evidence nothing of particular interest emerged, even if the area is often the scene of earth lights appearing and passing, while from the instrument recordings from the VLF receiver, various frequencies were measured in the 110Hz and 100Hz range, with a total absence of disturbance frequencies such as the 50Hz of the public mains supply.

The environmental monitoring, after the measurements of 27 February 2010 (**Fig. 8**), was repeated on the 28 March 2010 (**Fig. 9**) with the same instrument setup, taking the same environmental and meteorological conditions as operating principle. Monitoring was started by taking images using an IR filter and recorded with a VLF 0-30Khz continuous bandwidth receiver. Following the data recorded previously, environmental measurements were again carried out increasing the efficacy via some supplementary calibration tests to eliminate any interference or instrument malfunctioning.

The VLF receiver recorded, in addition to the normal disturbance frequencies, the usual modular frequency and other continuous frequencies of 5Hz and 95Hz. The first discordance that can be observed by comparing the tabulations of the two environmental readings is rather singular, in fact in those of the 27/02 the 50Hz frequency is absent, not even appearing as a redundancy at 100Hz, while there is only one frequency with modular behaviour ranging between 10-100Hz. This frequency is also found in the tabulations of the 28/03 where, as usual, the 50Hz frequency (public mains line) also appears with its redundancy.

In **Figs. 8 and 9** below, the spectrograms of the frequencies on 27 February 2010 and 28 March 2010 are shown with the same "modular" progression of the frequencies. The low frequency was measured the same day as the gravity variation at Monitoring Station no.1 (Figs. 3-4). Data comparison shows that there is a link between the two events, but it remains to be verified whether the production of low frequencies corresponds to a stretching or compression of the crust.

On 27 February the modular frequency appeared, while on 28 March other frequencies appeared in addition to this. Continuous frequencies of 5Hz (Schumann's resonance) and 95Hz were also observed along with the 50/100Hz frequencies. The datum from 27 February 2010 measured at the Rosano station, was compared with the datum measured between 03:27:57 a.m. and 03:28:47 a.m. by the electromagnetic monitoring station at Cecchina (latitude 41°41'4.27"N; longitude 12°38'33.60"E) near Albano Laziale (Rome – Italy) (http://ltpaobserverproject.weebly.com).

Concluding remarks

This work sought to answer a question, i.e.: whether there is an interaction mechanism between the tidal force exercised by the lunar/solar system and that local gravitational field, and whether there is any relationship between these, electromagnetic signals, and earthquakes.

The data collected in the field during the experiment showed that the various elements, both physical and geophysical, may be linked, and that the periodic rising and falling of sea level and terrestrial tides are concomitant.

The earthquakes happened on the days of the Full Moon, i.e. when the sinusoidal oscillations of the tides are greatest, and the latter corresponded both with increases in the force of gravity and the production of electromagnetic waves in the radio bandwidth, in the ULF-VLF frequency band.

In the two seismic events, the epicentre areas were very close to one another but decentred by several kilometres with respect to the monitoring stations, and highlighted a singular coincidence: namely, that the epicentres, the magnitude, and the hypocentres, were comparable with one another.

As the research stands, however, it is not possible to confirm with any certainty the model proposed in this work; the intention is to open up new questions that could and must stimulate researchers not to ignore any new avenues of investigation that might mitigate seismic risk.

Lastly, reasoning long term, it may be claimed that the persistence of earthquakes in a determined seismic zone, such as for example, one affected by the cyclic movements of the Moon, may also affect the evolutionary factors of the terrestrial crust (Tanaka et al., 2004) ending up producing, over time, areas of fragility (Maslov and Anokhin, 2007), as is probably happening in the zone considered by this study.

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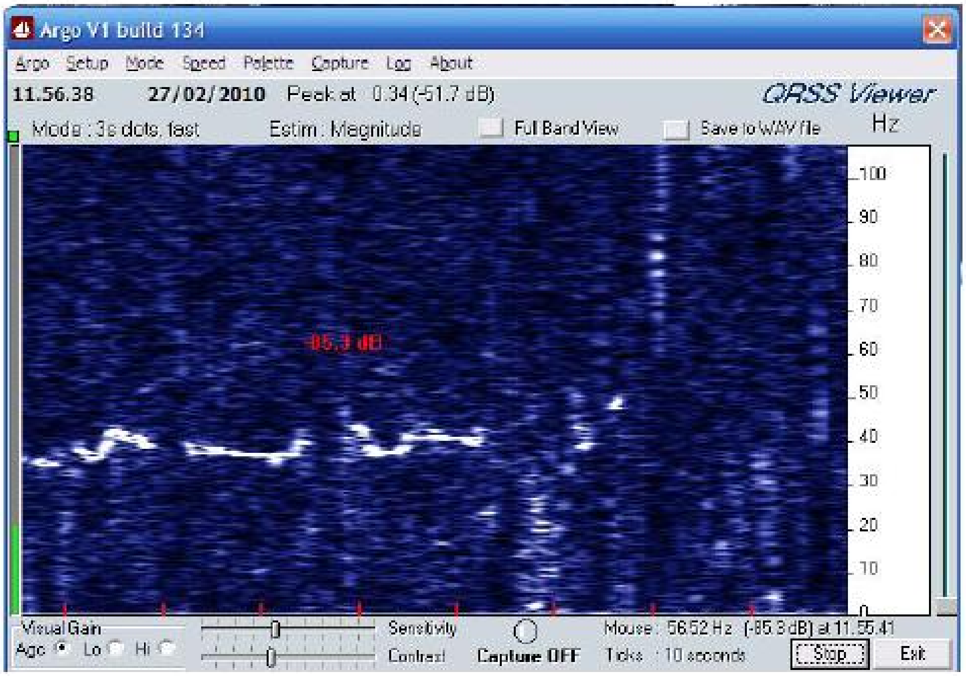

Figure 8. Spectrogram of frequencies from 0-40Hz registered on 27 February 2010.

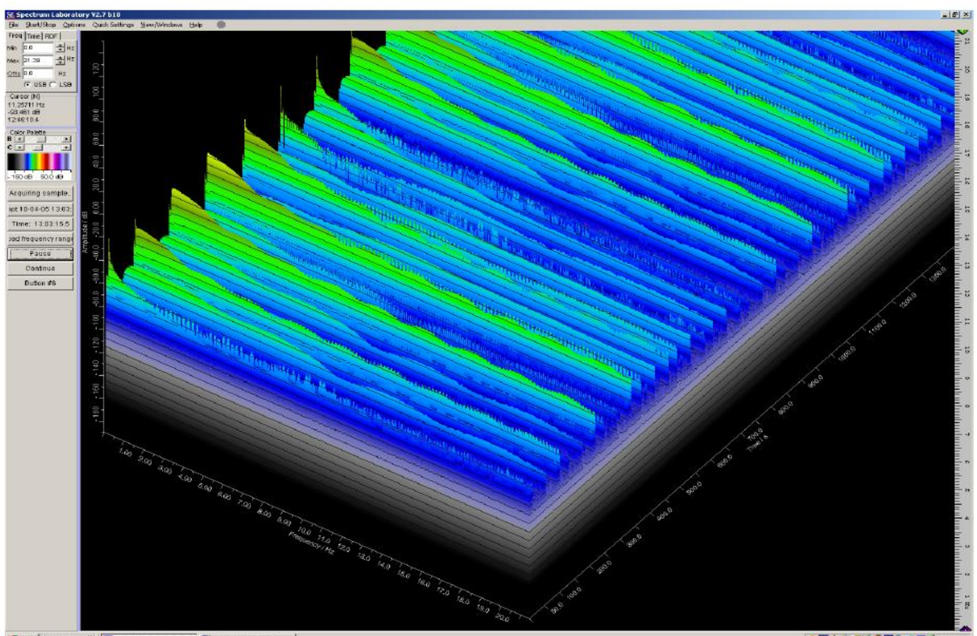

Figure 9. Representation in 3D of the 0-20Hz frequencies registered at Rosano on 28 March 2010.

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