SOLAR WIND IONIC AND GEOMAGNETIC VARIATIONS PRECEDING THE Md8.3 CHILE EARTHQUAKE

Valentino STRASER[1], Gabriele CATALDI[2] and Daniele CATALDI[3]
[1] valentino.straser@alice.it; [2] ltpaobserverproject@gmail.com; [3] ltpaobserverproject@gmail.com

ABSTRACT: The recent disastrous earthquake with a magnitude of 8.3, and the ensuing earthquake swarm that struck Chile, recalls the urgent need to step up the study of seismic precursors both for a greater understanding of the mechanisms that govern earthquakes and to protect people. Among the signals that preceded this strong earthquake, from a few days up to a few hours before the mainshock, both proton variations in the Solar Wind and geomagnetic changes were considered. The Chilean earthquakes occurred in correspondence with a clear peak in geomagnetic activity and an impulsive proton activity event that preceded the mainshock by some hours. The increase in ions in the Solar Wind, noted during the Chilean earthquakes of 16 and 17 September 2015 and observed also during all earthquakes with a magnitude greater than M6 that occurred on a global scale between 2012 and 2014, strengthens the hypothesis of a potential relationship between solar activity and seismic activity on the Earth.

Keywords*: geomagnetic background, earthquake forecasting, solar wind ionic variation, Chilean earthquakes*

INTRODUCTION

Background

The Sun constantly emits a flow of electrically charged particles into the interplanetary medium: The Solar Wind, an extremely subtle plasma consisting mainly of electrons and protons (95%) which have variable temperature, density and velocity (200-900 km/s close to the Earth), with motion patterns linked to the cycles of solar activity. When the Solar Wind reaches the Earth, it interacts with the terrestrial magnetosphere generating perturbations in the geomagnetic field that can be monitored using magnetometers located on the Earth's surface. Data on ion flows are recorded by artificial satellites, such as the Advanced Composition Explorer (ACE) Satellite and the Solar and Heliospheric Observatory (SOHO) Satellite, both in orbit near Lagrange point L1.

From the 1970s onwards, possible relationships between solar activity and seismic activity on the Earth began to be hypothesized (Anagnostopoulos et al., 2010; Simpson, 1968; Kalinin, 1974; Machado, 1973), based on analyses of solar physics data such as:

- flow of protons emitted by the Sun (SPE and SEP) (Velinov, 1975);
- High Speed Solar Wind (HSSW) (Sytinsky, 1989) expelled by coronal holes (Odintsov, 2006);
- Coronal Mass Ejections (CME) (Odintsov, 2006)
- magnetopause oscillations caused by an increase in the dynamic pressure of the Solar Wind (Makarova and Shirochkov, 1999).

Coronal Mass Ejections (CMEs) have been correlated with strong intensity seismic events during the solar maximum; while the High Velocity Solar Wind (HSSW) has been correlated with strong intensity seismic events during the solar minimum (Odintsov, 2006; Jusoh and Yumoto, 2011).

Volcanic manifestations correlated statistically to solar activity have also been presented in many scientific studies from 1962 to 2002 (Abdurakhmanov et al., 1976; Guschenko 1979-85; Stoyuko et al., 1969).
G. Y. Vasilyeva and V. I. Kojanchikov carried out a study on 2,000 earthquake samples that occurred in different parts of the Earth from 1962 to 1973. The results of this confirmed that the number of earthquakes occurring on the Earth's surface rises when solar activity increases (Khain and Khalilov, 2008).

Analogous results have been obtained by analysing:

A. M6+ seismic activity in China (116 events) that took place from 1875 to 1975 (100 years),
B. seismic activity of Vesuvius from magnitude 1.8 to 3.4 (1,402 seismic events) recorded in 1986,
C. seismic activity in Tokyo recorded in two different periods:
    1. 347 M6+ seismic events that occurred from 1895 to 1995 (100 years),
    2. 214 M5+ seismic events that occurred from 1991 to 1993.

In 2014 the Team Radio Emission Project in collaboration with the National Research Institute of Astronomy and Geophysics (NRIAG) of Cairo, Egypt, presented to the international scientific community the results of three studies carried out on a total sample of 41,459 M5+ seismic events that took place in Misallat and Amtasia in three different periods: 1960-2000, 1986-2000 and 1995-2010 (Straser et al., 2015). These results confirmed that the number of earthquakes recorded and terrestrial geomagnetic activity follow the same modulation, confirming that solar activity is correlated to seismic activity. In 2015, a study was carried out on a sample of 428 M6+ earthquakes that occurred on a global scale from 2012 to 2014 (Straser, 2015) confirming that all of these earthquakes were preceded by an increase in ions in the Solar Wind, bearing out the strict relationship between solar activity and global seismic activity.

Chilean earthquakes

The recent disastrous earthquakes in Chile on 16 and 17 September, and the signals of an electrical and electromagnetic nature that preceded them, constituted a further occasion to verify the potential relationship between ionic variations in the Solar Wind, which manifest from six days to a few hours before earthquakes with a magnitude greater than M6.

DATA

The data on the solar activity concern the variation in the ionic density of the solar wind detected by the ACE (Advanced Composition Explorer) satellite orbiting the L1 point (Lagrange point) at 1.5 million kilometers from Earth; Solar Wind Density (ENLIL Heliosphere Ecliptic Plane), variations in interplanetary magnetic field or IMF (GOES); X-ray flux (GOES), temporal monitoring of CMEs events or Solar Coronal Mass Ejections (ISWA); monitoring of the coronal holes position on the Sun's surface (NSO/SOLIS-VSM Coronal Hole); Solar Wind Velocity (ENLIL Helisphere Ecliptic Plane); Electron flux (NOAA/SWPC).

The data on geomagnetic activity were retrieved from: AL-Index (WINDMI and Kyoto WDC); DST-Index (WINDMI and Kyoto WDC); Hemispheric Power (NOAA/POES); Total Electron Content (TEC SWACI map); Electron Density (Electron Density map JRO); variations in the geomagnetic field (provided by geomagnetic observatories: Tromso, Sodankyla, Pushkov Institute, Kiruna, USGS, Canberra, Scoresbysund, Denmark, Narsarsuaq, Kullorsuaq); Estimated Kp-Index (NOAA/SWPC) A-Index (Tromso Geomagnetic Observatory); variations in polar electromagnetic emission (GOES/METP).

The data on the global seismic activity on the M6+ scale were real-time retrieved from USGS (United States Geological Survey).

DISCUSSION

Analysis of the data was performed considering the geomagnetic patterns and the proton variation in the interplanetary medium that preceded the mainshock (M8.3) and the ensuing seismic swarm.

To realize the analysis of the Earth's geomagnetic field we used the data on H, Z and D geomagnetic component variation released by the Tromsø Observatory Geomagnetic (TGO), Norway (**Fig. 1**). The variation of Earth’s geomagnetic field in relation to the time data of M6+ earthquakes occurred in Chile between 16 September 2015 and 17 September 2015 (USGS Data) follows the classic daytime Sq modulation observed at a latitude of 69°N but are added, however, perturbations of intensity above normal which have submitted the following features. The Chilean M8.3 earthquake recorded at 22:54 UTC on 16 September 2015 occurred two hours and 54 minutes after the start of the first geomagnetic perturbation observed by the Tromsø Observatory Geomagnetic on H and Z geomagnetic components. The H and Z components have presented a deviations of +90nT and -160nT respect to their basal level, which they have been; 10780nT for the H component and 52390nT for the component Z. The Z geomagnetic component, at 22:46 UTC on September 16, 2015 showed a further increase reaching, at approximately 23:35 UTC, the value of +305nT respect basal level. During this increase, in Chile were recorded five earthquakes: M8.3 (22:45:33 UTC), M6.4 (22:59:13 UTC), M6.1 (23:03:56 UTC), M6.2 (23:16:05 UTC), M7.0 (23:18:42 UTC).

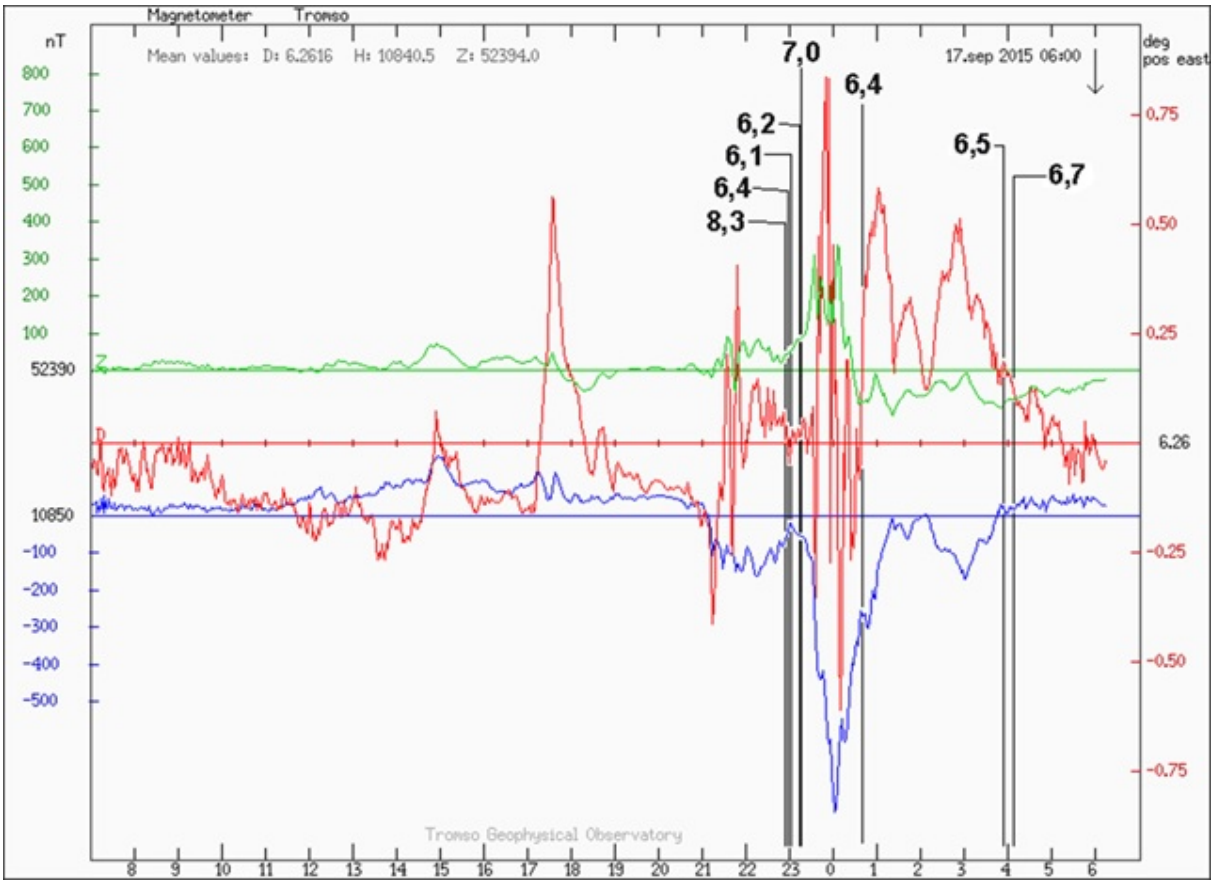

Fig. 1. Magnetogram containing the variation of the Earth's geomagnetic field, relative to Z (green line), H (blue line) and D (red line) component, registered by the Tromsø Geomagnetic Observatory (TGO), Norway, between 16 and 17 September 2015. The Z component is a vertical component, assumed positive when it's directed towards the inside of the Earth. The H component is the horizontal component, namely the component aligned in the direction of the magnetic North. The D component is magnetic declination angle between the direction of H and the geographic meridian passing through the point in question (Tromsø Geomagnetic Observatory), taken as positive when H is directed to the East of the geographic North. The vertical black lines represent the temporal markers of M6+ earthquakes occurred in Chile between 16 and 17 September 2015; while the numbers represent the magnitude (Mw) of earthquakes

Taking the H geomagnetic component as a reference at the same time, we note that at 23:05 UTC on 16 September 2015, this has been a rapid descent, reaching at 00:05 UTC on 17 September 2015, the value of -850nT respect to its baseline level: during this period, in Chile occurred three strong earthquakes: M6.1 (23:03:56 UTC), M6.2 (23:16:05 UTC), M7.0 (23:18:42 UTC). Also the Z geomagnetic component at 12:05 UTC on September 17, 2015 reaches its maximum variation respect to basal level: +325nT. This maximum deviation, considering also that of the H geomagnetic component, will be the maximum recorded at least for the next 36 hours.

After the maximum variation of H and Z geomagnetic component recorded at 12:05 UTC on 17 September 2015, the two values being slowly to return to normalize level, to achieve their basal level at 05:00 UTC on 17 September 2015. During this period, in Chile three seismic events of strong intensity were recorded: M6.4 (01:41:09 UTC), M6.5 (03:55:06 UTC) e M6.7 (04:10:30 UTC).

Also the D geomagnetic component has undergone remarkable variations during the Chilean seismic train observed between 16 and 17 September 2015. The first important variation of D geomagnetic component occurred between 17:00 UTC and 19:00 UTC on 16 September 2015, reaching a value of +0.56° (respect to baseline considered: 6.26 °) at 17:35 UTC. Between 21:15 UTC and 21:45 UTC on September 16, 2015, the D component has undergone another major oscillation: from -0.35° to + 0.31° in respect to basal level. After this variation the D component has stabilized oscillating rapidly between +6.38° and +6.30° and in the same amount of time have occurred five earthquakes: M8.3 (22:45:33 UTC), M6.4 (22:59:13 UTC), M6.1

(23:03:56 UTC), M6.2 (23:16:05 UTC), M7.0 (23:18:42 UTC). At 23.30 UTC on September 16, 2015, the D component undergoes a strong third and final variation that will last until at 05:00 UTC on 17 September 2015. During this time have registered two intense peaks of variation: the first at 23:50 UTC on 16 September 2015 and the second at 00:12 UTC on 17 September 2015. After these two strong peaks, in Chile was recorded an M6.4 earthquake (22:59:13 UTC) after which, during the "settling" of D geomagnetic component that is returned at its basal level at 05: 00 UTC on 17 September 2015, have been recorded other two major earthquakes: M6.5 (03:55:06 UTC) and M6.7 (04:10:30 UTC).

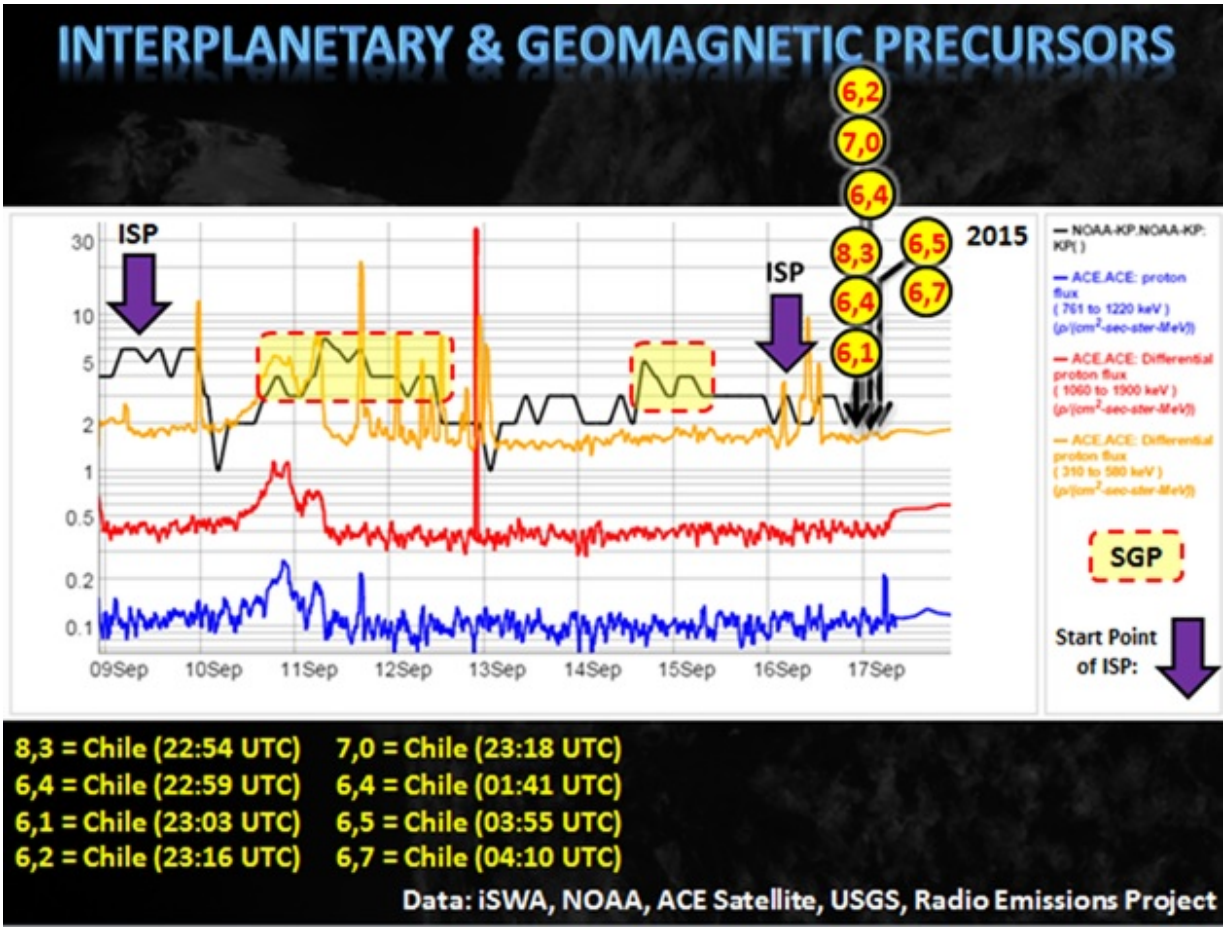

Fig. 2. Graph contains the data on the variation of solar wind proton density occurred between 9 and 17 September 2015 at the L1 Lagrange point by Advanced Composition Explorer Satellite; the variation of Kp-Index between 9 and 17 September 2015, and the temporal markers (black vertical arrows) of M6+ earthquakes registered in Chile between 16 and 17 September 2015. The vertical purple arrow represents the beginning of the “gradual” proton density increase. The yellow areas surrounded by the red dashed line indicates increases of Kp-Index that preceded the Chilean earthquake, up to six days before.

Comparing the time data of the Chilean earthquakes that occurred between 16 and 17 September 2015 with the interplanetary medium proton "near Earth" has been observed that these were preceded by a series of increases of “impulsive” type (**Fig. 2**), of the proton fraction with energy comprised between 310 and 580 keV who also represented the beginning of a gradual increase of proton density which is shown more clearly only between 18 and 19 September 2015.

The impulsive increases were three (**Fig. 3**): the first occurred at 04:35 UTC on 16 September 2015, reaching a density of 3.69 p/cm^2; the second occurred at 10:20 UTC on 16 September 2015 and reached a density of 9.79 p/cm^2, while the last one occurred at 13:05 UTC on 16 September 2015 and reached a density of 4.83 p/cm$^{2.}$ The basal level of proton density of this energy fraction is equivalent to 1.79 p/cm^2.

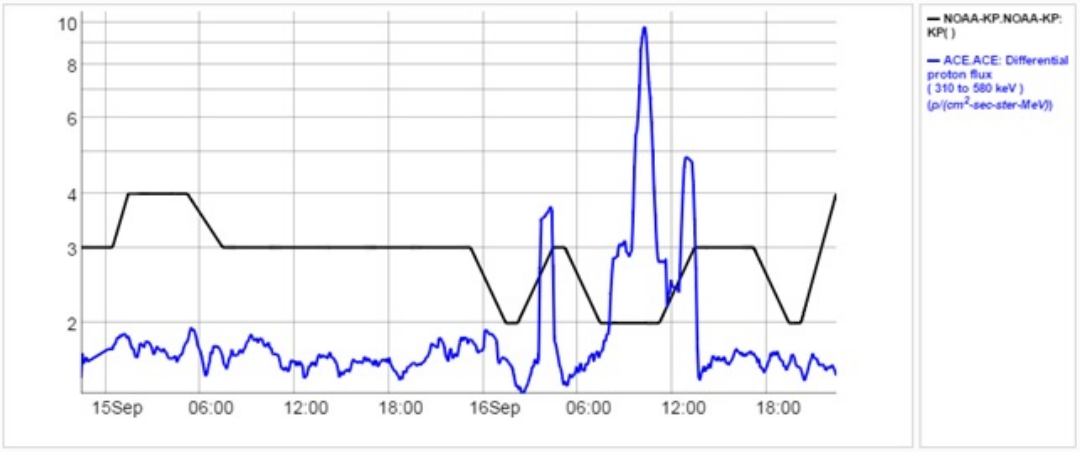

Fig. 3. Graph contains the data on the variation of solar wind proton density, relative to the fraction of proton with energy comprised between 310 and 580 keV, occurred between 9 and 17 September 2015 at the L1 Lagrange point by Advanced Composition Explorer (ACE) Satellite.

Also the magnetogram produced by "Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN)", Russian Academy of Sciences (**Fig. 4**), confirms that the Chilean earthquakes were preceded by an increase of solar activity which produced a disturbance of the Earth; also confirming of geomagnetic field data provided by the Tromsø Geomagnetic Observatory (TGO).

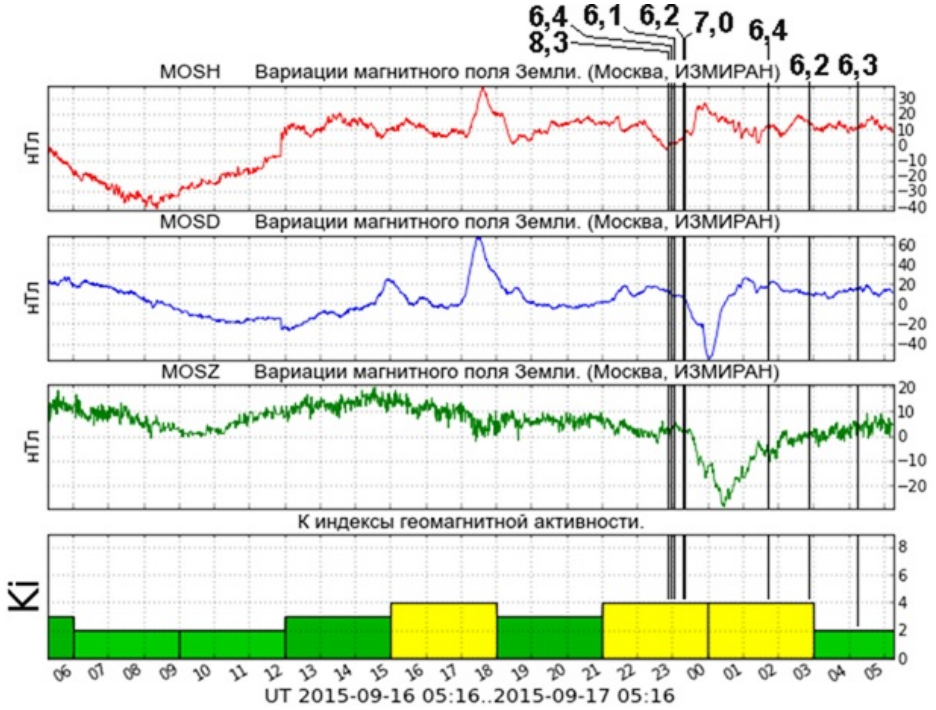

Fig. 4. Graph containing the variation of the Earth's geomagnetic field recorded on H (red line), Z (green line) and D (blue line) component provided by the Space Weather Prediction Center of Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN), Troitsk, Moscow Region. The black vertical lines represent the temporal markers of M6+ earthquakes occurred in Chile between 16 and 17 September 2015, and the numbers represent the magnitude (Mw) of earthquakes. The lower portion of the graph (Ki) is the K-Index.

CONCLUSION

The Chilean earthquakes have born out the link that exists between proton variation in the Solar Wind, the geomagnetic field, and earthquakes with a magnitude greater than M6. The seisms occurred during an increase in proton density from "A" to "B" (Straser et al., 2015), in a hypothesis formulated by Straser, Cataldi and Cataldi (2015), and in correspondence with a peak in geomagnetic activity. Nonetheless, it must be underlined that the proton increase, unlike the increases analysed between 2012 and 2014 (Straser et al., 2015), was not of the gradual type in the energy fraction from 310 to 580 keV, but followed a gentler

progression, succeeded by an impulsive event.

In the case of Chilean seisms, the gradual proton increase was not complete and the impulsive increase that followed it and preceded the mainshock by some hours was confirmed by the magnetometers of both the Pushkov and Tromsø Institutes.

REFERENCES CITED

Abdurakhmanov, A.I., Firstov, L.P. and Shirokov, V.A., 1976. Possible connection of volcanic eruptions with 11-year cyclicality of solar activity. In the book Bulletin of volcanic stations. *Science*, no. 52, p. 3-10.

Anagnostopoulos, G., Papandreou, A. and Antoniou, P., 2010. Solar wind triggering of geomagnetic disturbances and strong (M>6.8) earthquakes during the November – December 2004 period. *Demokritos University of Thrace, Space Research Laboratory*, 67100 Xanthi, Greece. Cornell University Library.

Guschenko, N.I., 1979. World volcanoes eruptions. Catalogue. *Science*, p. 475.

Guschenko, N.I., 1985. Cyclicality of eruptions. *Volcanology and seismology*, vol. 2, p. 27-48.

Jusoh, M. H. and Yumoto, K., 2011. Possible correlation between solar activity and global seismicity. *Space Environment Research Center of Kyushu University*, ISW/MAGDAS School, Lagos, Nigeria.

Kalinin, Y.D., 1974. Solar conditionality of days duration change and seismic activity. *Krasnoyarsk, Institute of Physics of Siberian Department of USSR Academy of Science*, p. 23.

Khain, V. E. and Khalilov, E. N., 2008. About possible influence of solar activity upon seismic and volcanic activities: long-term forecast. *Transactions of the International Academy of Science* H &E. vol.3. 2007/2008, ISSN 2070-0334.

Makarova, L.N. and Shirochkov, A.V., 1999. On the connection between the Earth's magnetosphere magnetopause position and the earthquakes occurrence, In: Abstracts of XXVI *General Assembly LJRSI*, Toronto, Canada, August 13-21, 1999, p.755.

Machado, F.A., 1973. A hipotese de uma pulsacso de gravitacao com periodo de il anos. *Gareia Orta. Ser, Geol.*, vol. 1, no. 2, p. 27-35.

Odintsov, S., Boyarchuk, K., Georgieva, K., Kirov, B. and Atanasov, D., 2006. Long-period trends in global seismic and geomagnetic activity and their relation to solar activity. *Physics and Chemistry of the Earth*, vol. 31, p. 88–93.

Simpson, I.F., 1968. Solar activity as a triggering mechanism for earthquakes. *Earth and Planet, Sci. Letter*, vol. 3, no. 5, p. 417-425.

Stoyuko, A., Stoyko, N., 1969. Rotation de la terra, phenomenes geophysiques et activite du soleil. – *Bull. Cl. Sci. Acad. Roy.Belg.*, vol. 55, p. 279-285.

Straser, V., Cataldi, G. and Cataldi, D., 2015. Solar wind ionic variation associated with earthquakes greater than magnitude 6.0. *New Concepts in Global Tectonics Journal*, vol. 3, no. 2, p. 140-154.

Velinov, P., 1975. The effect of solar activity on geophysical processes, *Bu/g Geofiz. Spis.*, vol. 1, p. 51-77.