ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2521-0890 (Print)
ISSN: 2521-0491 (Online)
CODEN: GBEEB6

Geological Behavior (GBR)

DOI: http://doi.org/10.26480/gbr.01.2020.42.46

CrossMark

RESEARCH ARTICLE

IONOSPHERIC PLASMA VARIATIONS AFORE THE EAST OF KURIL ISLANDS EARTHQUAKE OF 13th JANUARY, 2007

Thomas, J. E.[a], George, N. J.[a*], Ekanem, A. M.[a], Akpan, A. E.[b]

[a]Geophysics Research Group, Department of Physics, Akwa Ibom State University, Nigeria
[b]Department of Physics, Geophysics Programme, University of Calabar, Cross River State, Nigeria
***Corresponding Author Email:** anny4mart@yahoo.com; jewelemem@gmail.com; nyaknnojimmyg@gmail.com*

ARTICLE DETAILS

Article History:

Received 02 May 2020
Accepted 05 June 2020
Available online 04 August 2020

ABSTRACT

Plasma Analyzer (IAP) and Langmuir Probe (ISL) experiments of the DEMETER microsatellite were used to check the state of the ionosphere in the region of the M8.1 East of Kuril Islands earthquake of 13th January, 2007,30 days afore and 10 days after the event using statistical approach. The study strongly revealed that all three investigated ionospheric parameters of electron density, total ion density and electron temperature displayed unfamiliar ionospheric variations eight days before the earthquake in the daytime time half orbit measurement. To this, the electron density, total ion density and electron temperature recorded a variation of 4.09, 5.73 and -2.03 respectively. These irregularities were vetted for untrue signals using the geomagnetic indices of Kp and Dst. It was however realized that the state of the ionosphere was geomagnetically quiet during this day, hence the observed variations were seismogenic.

KEYWORDS

DEMETER, earthquakes, geomagnetic and variations.

1. INTRODUCTION

The physics of earthquake has proven to be very complex and vast. The incident is connected to the dynamics of earth crust. Due to acoustic driven mechanisms in the atmosphere, the foundation of the waves created at the Earth's surface circulates to the ionosphere, thereby triggering the redistribution of the neutral gases in the ionosphere afore the earthquakes (Pulinets and Boyarchuk, 2004; Pulinent and Davidenko, 2014; Ryu et al., 2014; Cöısson et al., 2015). The disturbances as well as the underlying mechanisms responsible for the seismio-ionospheric coupling activities have been widely reported (Ondo, 2003; Oyama et al., 2008; Hayakawa et al., 2009; Namgaladze et al., 2009; Freund, 2010; Zhang et al., 2011; Kuo et al., 2011; Ibanga, et al., 2017; Akpan et al. 2019). Nevertheless, the electromagnetic fields, neutral winds, diffusion mechanisms, and the acoustic gravity wave originated from the lower altitude of the atmosphere, are the chief drivers of low- and mid-latitude ionospheric dynamics throughout and after the earthquake preparation (Heelis, 2004).

Diverse procedures and dimensions have been earlier used to study ionospheric precursors of earthquakes. These precursors are related to various mechanisms of the formation of the ionosphere and the atmosphere, which are binding on different ionospheric disturbances (Surkov, 2015; Parrot *et al.,* 2016). Parrot et al. (2016) reported that the onset of the abnormalities in the morphology of the ionosphere is near to the future epicenter (7-15 days). These irregularities were brought about by gravity waves emanating from the activation of the fault where the permeability changes and where aerosols and gas including radon can appear (Surkov, 2015). This results in the ionization of air molecules, which accounts for the re-modification of the ionosphere. Thus, various effects can happen: growth of air temperature, formation of temperature and pressure anomalies, anomalies in Outgoing Long wave infrared Radiation (OLR), redistribution of electric charges in the Earth's atmospheric system and then in the ionosphere due to the global electric circuit (Harrison et al., 2010), and electric field irregularities are all in connection with the above actions.

Extensive reports on earthquake forecasting in past decades have given rise to the recognition of numerous earthquake precursors in the lithosphere, atmosphere and ionosphere. The lithosphere-atmosphere-ionosphere coupling is a very multifaceted subject comprising a lot of somatic effects and interactions at all levels commencing from underground to the Earth's magnetosphere. (Pulinets and Boyarchuk, 2004; Pulinets and Davidenko, 2014) expounded unequivocally the early stage of development of seismo-ionospheric effects and ionospheric anomalies that may be detected over the earthquake preparation area for over five decades. The impacts of the pre-seismic activity on the ionosphere can be scrutinized using the ionospheric electron temperature, electron and ion densities. Perturbations of the ionospheric plasma in the absence of substantial solar and geomagnetic disturbances may be ascribed to earthquakes. These anomalies usually happen in the E-layer and F-layer and may be observed 1–10 days prior to the earthquake and continue a few days after it (Akhoondzadeh et al., 2010). These variations could be depicted by a low Earth Orbit satellite such as the DEMETER.

The 2007 Kuril Islands earthquake happened in the eastern part of Kuril Islands on January 13, 2007 at about 1:23pm local time. The seismic event had a moment magnitude of 8.1 and a Mercalli intensity of VI (strong). This earthquake had generated a non-destructive tsunami, which had a

Quick Response Code	Access this article online	
	Website: www. geologicalbehavior.com	**DOI:** 10.26480/gbr.01.2020.42.46

Cite the Article: Thomas, J. E., George, N. J., Ekanem, A. M., Akpan, A. E. (2020). Ionospheric Plasma Variations Afore The East Of Kuril Islands Earthquake Of 13th January, 2007. *Geological Behavior, 4(1): 42-46.*

maximum displacement of 32m. The earthquake occurred due to normal faulting. This present paper seeks to investigate ionospheric plasma parameter pre and post the earthquake with the aim of identifying possible short-term precursors to this event using DEMETER data. The **Kuril Islands** form part of the ring of tectonic instability. Information from DEMETER, which is used in assessing the said earthquake is capable of identifying what happens before and after earthquake occurrence.

1.1. The DEMETER satellite data

Detection of Electromagnetic Emissions Transmitted from Earthquake Regions (DEMETER)was a microsatellite launched by the French Space Agency: Centre National D'etudes Spatiales (CNES) at about 06:30 UTC from Baikonour (Kazakhstan) on June 29, 2004 onboard a Dnepr rocket launcher. The transmission of this satellite into space was with a very high accuracy and it landed the expected orbit with the following parameters: elevation of 709 km, inclination of 98^0, orbit period (100 min), orbits per day (14) (data available in half orbit) (Cussac et al., 2006). The DEMETER was fashioned like a rectangular box having dimensions of 60 x 85 x 11 cm and an overall massof 129 kg. The orbit of DEMETER was polar, spherical and almost sun-synchronous. Measurements were carried out almost at two different local times 10:30 and 22:30 UTC (Kintner et al., 2013; Ibanga, et al., 2017). However, the height of this satellite was dropped to 660 km in December 2005, it was situated a Low Earth Orbit (500 to 2000 km in altitude) and seen for 10–20 min at a time (Sonakia, 2014).

DEMETER functioned in dual modes (i) a survey mode which documented low bit rate data throughout the Earth at invariant latitudes not more than ~ 65^0. and (ii) a burst mode that documented high bit rate data of 1.7 mb/s above seismic active areas. Recording in the burst mode was spontaneously activated each time satellites traversed a seismic zone. In general, the time and space locations of either of the two modes were determined as function of the ground volcanic and seismic targets (Parrot et al., 2014) The primary scientific objectives of DEMETER experiments were to investigate the disturbances of the ionosphere from seismo-electromagnetic effects and from anthropogenic activities which cover Power Line Harmonic Radiation, Very Low Frequency (VLF) Transmitters, and High Frequency broadcasting stations). This involved detection and characterization of ionospheric electrical and magnetic perturbations in connection with seismic activity. This scientific payload was made up of a three-axis magnetic search-coil instrument (IMSC), four electrical sensors (ICE), two Langmuir probes (ISL), a plasma analyzer (IAP), energetic particle detector (IDP) and electronic units (BANT) (Cussac et al., 2006 Berthelier et al., 2006, Ibanga, et al., 2017). However, this present study utilized data from IAP and ISL experiments in the burst mode.

The IAP unit created an unceasing record of the key parameters of the thermal ion population with two objectives: (a) detection of turbulences in the ionosphere that could result from the coupling between seismic event on the ground and upper atmosphere and ionosphere, and (b) provision of ample time resolution for ionospheric parameters such as plasma density and ion composition required for the analyzes of plasma wave data obtained from ICE and IMSC experiments. The IAP was wellplanned to record the parameters of the thermal population, which are the densities of the major ionospheric ions: hydrogen (H+), helium (He+) and oxygen(O+) (within a range of 10^2–5.10^5 ions/cm^3), their temperatures (from 500–5000 K) and the ion flow velocity in the earth's frame of reference (Berthelier et al., 2006).

The ISL, was designed for in-situ measurements of the bulk ionospheric thermal plasma parameters. This instrument had two sensors: a classical cylindrical sensor and a spherical sensor whose surface was divided into seven segments (six electrically isolated spherical caps and other part of the sphere used as a guard electrode). The ISL sensor recorded the electron density of plasma (10^8-5.10^{11} m^{-3}, electron temperature (600–10,000 K) and satellite potential (~±3 V) in the ionosphere out of which the relative ion and electron density along orbits of the DEMETER satellite were obtained. Variations of these parameters were given with a time resolution of 1s (Berthelier et al., 2006, Brien and Cornely 2015). Nevertheless, DEMETER satellite mission came to an end on 9th December, 2010but its data are stored at Centre de Données de la Physique des Plasmas (CDPP) and can be accessed through the web server(http://demeter.cnrs-orleans.fr//). The data are arranged and plotted in half orbits. CDPP offers a vast array of data to explore variations in electromagnetic emissions; creation of plasma inhomogeneities and other ionospheric phenomena linked with seismic events. Its high sensitivity upholds the reliability of its data. Figures 1a and 1b show example of some DEMETER orbits that were within the expanse of this seismic event.

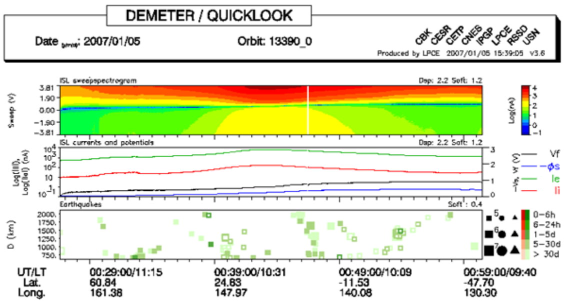


Figure 1a: DEMETER orbit that recorded the anomalous variations eight days afore the seismic event.

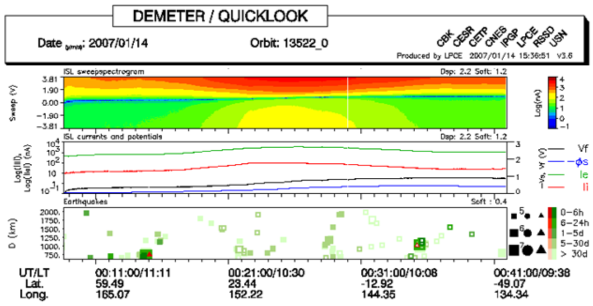


Figure 1b: some other DEMETER orbit that was within the earthquake preparation zone during our period of investigation.

DEMETER recorded many events as given in Figures 1a and 1b. This corresponds to the seismic event of January 13, 2007 at 04:23 UT with a magnitude of 8.1 and a focal depth of 10 km. Its geographic coordinates are 46.27^0 and 154.45^0. From the top to the bottom panels, the top panel gives the header frame that includes date, orbit number, involved institutes, date and version of quick look creation. The second panel gives the ISL sweep spectrograph with the version of the onboard and ground processing frame. The spectrogram of the Langmuir probe measures the sweep voltage in volt and collected current in log (nA). Parameters deduced from ISL measurements (ISL current and potentials) are displayed in the third panel. To this, the version of onboard and ground processing software are given at the top right side of the panel, as well as currents and potentials (Vf – floating potentials in V, ϕs – potential in V(-ϕs is displayed) and Ie- electron current in nA (log (Ie) is displayed). The bottom panel indicates the satellite closest approach of past and future EQ epicenters that are within 2000 km from the DEMETER orbit. The *Y* -axis represents the distances *D* between the epicenters and the satellite, from 750 up to 2000 km. The symbols are filled square for post-seismic events, filled triangle for pre-seismic events. The scale on the right represents the time interval between the EQs and the DEMETER orbit with a graduation from >30 days up to a [0–6 h] interval. The empty symbols have similar significations except that they are related to the magnetically conjugated points of the epicenters (the distance *D* is then the distance between these magnetically conjugated points of the epicenters and the satellite). The symbol sizes correspond to EQs of magnitude [5–6], [6–7], and [>7]. At 03:40:45 UT the red triangle indicates the closest approach to the epicenter of this EQ and the other smaller red triangle indicates an aftershock.

1.2. Geomagnetic data

Ionospheric parameters are well-defined by means of solar geophysical conditions and geomagnetic storms typically in the equatorial and polar zones. Auroral activity has vital part in the mid-latitude ionospheric disturbances. The ionosphere current and equatorial storm- time ring current in periods of solar- terrestrial conditions yield major geomagnetic field instabilities. Subsequently, in studying solar-terrestrial relationship, there is a dire need to know the level of energy released into the magnetosphere at a time. Several mechanisms available for this assessment have spatial as well as temporal variations that create alarms of different kinds, going from X-rays to Ultra Low Frequency (Rostoker, 1972). Observing any of these disturbances gives a gross estimate of the level of magnetospheric activity. to this, Planetary index (Kp), Planetary Amplitude (Ap), Auroral Electrojet (AE) and Disturbance storm time (Dst), are usually used for rating magnetospheric activity.

The Kp index is a planetary 3-hour range index of magnetic activity derived by averaging the standardized K-index from the 13 geomagnetic observatories located between 44^o and 60^o in the northern or southern geomagnetic latitude. Kp index computes disturbances in the horizontal component of the Earth's magnetic field with an integer in the range 0-9expressed in thirds of a unit such that 5- is 4⅔, 5 is 5 and 5+ is 5⅓ (a minus after a number means reduction of the numerical value by one-third while a positive sign increases the magnitude by one- third). With 1 being quiet and 5 and above showing a geomagnetic storm (Bartels *et al.,* 1939). The Kp index is a quasi-logarithmic number. The purpose of this index is to calculate solar particle radiation by its magnetic effects and give the total activity during the day. The content of Kp comes from at least two main sources: the auroral electrojet and the ring current (Rostoker, 1972).

The disturbance storm time (Dst) index measures the geomagnetic activity which is used to assess the severity of magnetic storms. Dst expressed in nanoteslsa (nT) is the average value of the horizontal component of the Earth's magnetic field derived hourly from four near-equatorial geomagnetic observatories. The possibility of using Dst as index of storm strength lies in the fact that the strength of the surface magnetic field at low latitudes varies inversely with the energy content of the ring current, which increases during geomagnetic storm (Mayaud, 1980). Ionospheric activities are affected mainly by solar and geomagnetic activities (Fuying and Yun 2009). With reference to the magnitude of the geomagnetic disturbance, magnetic storms are classified into weak (-50 nT<Dst ≤ - 30 nT), moderate (-100 nT<Dst ≤ -50 nT), strong (when – 200 nT<Dst ≤ -100 nT) and extra strong (Dst ≤ - 200 nT) (Xinzhi*et al.,* 2014, Xu et al., 2009). Dst index had been used by Hayakawa (2014), to isolate seismo-ionospheric irregularities from solar and geomagnetic activities in the Japan 2011 quake. He studied the solar and magnetic activities during related periods and detected minor geomagnetic activities, stating that days of anomalous ionospheric disturbances were relatively geomagnetically undisturbed. Hence, he attributed the anomalies to be seismo-induced. Akhoondzadeh *et al.* (2010) used the geomagnetic indices of Dst and Kp to distinguish geomagnetic disturbances from seismo-ionospheric disturbances. Ibanga, et al., 2017 also employed Dst and Kp in isolating geomagnetic induced variations from seismo-induced variations in the M6. Auckland earthquake of September 30, 2007. The Kp index monitors the planetary activity on a global scale while the Dst index records the equatorial ring current variations (Mayaud, 1980). The ionospheric influence of a geomagnetic storm has a global effect being observed all over the world while, the seismogenic impact is observed only by places with distance less than 2000 km from the potential epicenter. In this research, a day was assumed geomagnetically quiet when kp was less than three and Dst was less than -30nT.

2. Methodology

The seismic event employed in this research, had necessary statistics which included time of incidence, geographic location, earthquake magnitude, orbits nearest to the epicenter (at a resolution of 20^0 for longitude and 10^0 for latitude) were chosen 30 days afore and 10 days after the earthquake. Figure 1 present some selected orbits closest to the epicenter (Pulinets et al., 2003). This large time frame allowed enough room for monitoring of the ionospheric plasma parameter from its normal to abnormal state; thus, enhancing detection of seismic anomalies from the background of natural variations, supposing the former to appear at the end. Various time frames from five days to two months have been employed to screen the ionosphere but chiefly, reports on seismo-electromagnetic variations are observed three weeks or less to the earthquake day (Rong et al., 2008; Píšaet al., 2011; Ibanga, et al., 2017). The total ion density (sum of the Oxygen, Hydrogen and Helium ions) were obtained by downloading data files from the DEMETER website. Data from each orbit were confined to both the survey and burst modes but only the burst mode data were used in this investigation. The median and the inter-quartile range of the data were used to find their upper and lower bounds in order to discriminate seismic variances from the background of regular variations. A reference value k was selected to be 2.1. Any alarm outside these bounds were anomalous. These involved computation of upper and lower boundaries, median value and inter-quartile range using Eqs. (1)–(3) below:

$$x_{high} = M + k \bullet IQR \quad (1)$$

$$x_{low} = M - k \bullet IQR \quad (2)$$

$$x_{low} < x < x_{high} \Rightarrow -k < \frac{x - M}{IQR} < k ; Dx = \frac{x - M}{IQR} \quad (3)$$

where x,x_{high} , x_{low}, M, IQR and D_x are parameter values, upper bound, lower bound, median of the data, inter-quartile range and differential of x respectively. From Eq. (3), if the absolute value of Dx is greater than k, (i.e., |Dx| > k), (|Dx| > k), then the behaviour of x is considered to be anomalous. K values must be selected to be proportional to earthquake magnitude and therefore, for large events with M > 7.0, values greater than 2 may be used. A k value of 2.1 was used for this seismic event.

However, the irregularities in the ionospheric factors are not from earthquakes only since there are likelihoods of ionospheric distresses that can emanate from other sources (solar activity, acoustic gravity waves, traveling ionospheric disturbances, plasma dynamics, and large meteorological phenomena). Thus, the observed parameters may present variations even when seismic activity is nonexistence; making it challenging to segregate pre-seismic ionospheric phenomena from the ionospheric instabilities due to the solar-terrestrial activities (Ondoh, 2008, Ibanga, et al., 2017). Thus, to discern the seismo-ionospheric alarms from geomagnetic alarms, the geomagnetic indices Dst and Kp were also screened within this time frame.

3. Results

In this section, we present results of our findings as shown in Table 1 and Figs 2 to 3 from both sets of data (DEMETER and geomagnetic) 30 days prior and 10 days post the January 13th, 2007 quake of East of Kuril Island. The discussion of the results is also undertaken to ascertain the ionospheric Plasma variations before the East of Kuril Islands earthquake of 13th January 2007.

Table 1: List of detected anomaly in the studied seismic event as obtained from the statistical anaysis of DEMETER (IAP and ISL) data correlating with the geomagnetic indices (kp and Dst). Days are relative to earthquake day (13th January, 2007).

			DEMETER				Geomagnetic indices		
Name	Date	Time	Day	Value	Sensor	Parameter	Time	Kp	Dst
East of the Kuril islands, Russia	13/01/07	4:23	-29	6.15	IAP	Total ion density	10:30	-30	-30
			-29	4.27	ISL	Electron density	10:30	-29	-29
			-27	5.46	ISL	Electron density	10:30	-28	-28
			-27	6.74	IAP	Total ion density	10:30	-25	-27
			-27	-2.56	ISL	Electron temperature	10:30	-24	-26
			-24	2.25	IAP	Total ion density	10:30	-23	-25
			-14	3.26	IAP	Total ion density	10:30	-21	-24
			-12	2.72	IAP	Total ion density	10:30	-20	-23
			-11	3.49	ISL	Electron density	10:30	-11	-22
			-11	5.01	IAP	Total ion density	10:30	-10	-21
			-11	-2.15	ISL	Electron temperature	10:30	-9	-20
			-8	4.09	ISL	Electron density	10:30	2	-19
			-8	5.73	IAP	Total ion density	10:30	3	-18
			-8	-2.03	ISL	Electron temperature	10:30	4	-17
			2	2.68	IAP	Total ion density	10:30	5	-11
			5	2.51	ISL	Electron density	10:30	6	-10
			5	3.89	IAP	Total ion density	10:30		-9
			8	2.23	IAP	Total ion density	10:30		-1
									4
									5
									6
									6

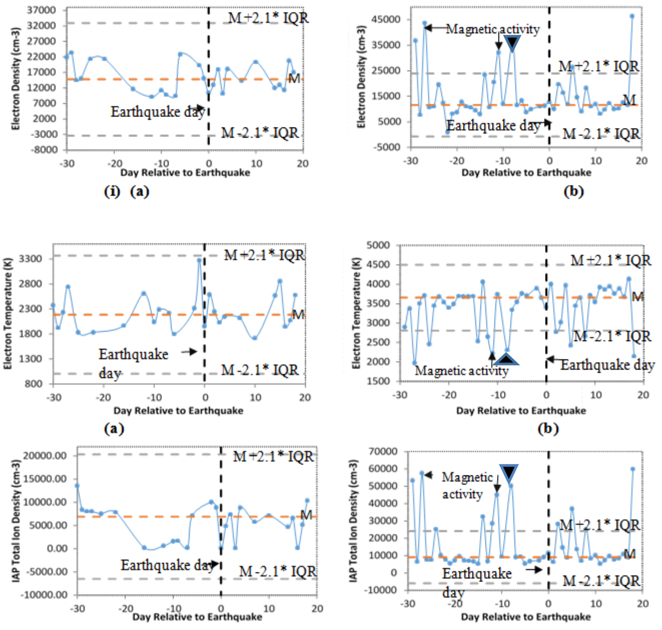
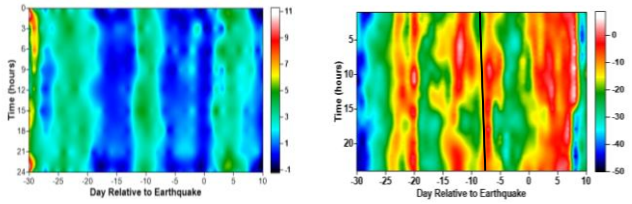


Figure 2: Line plots from statistical analysis of DEMETER data for the East of Kuril Island Earthquake (13th January, 2007). Ionospheric plasma parameters of electron density, electron temperature and total ion density respectively are plotted against day relative to the earthquake (a) nighttime measurment and (b) daytime measurement.The small red triangles show depicted anomaly eight days before the event in quiet geomagnetic conditions.



(a) (b)

Figure 3: Results from analysis of geomagnetic indices (a) kp index and (b) Dst index. The y-axis represents universal time (UTC) while the x-axis shows the day relative to earthquake (13th January, 2007). The black lines within the contour plot show the condition of the indices eight days prior to the event while the colour bar shows the ranges for different colours used.

With the duration (at a resolution of 20^0 for longitude and 10^0 for latitude) within the window frame of 30 days afore and 10 days after the seismic event, it is possible to evacuate lives and properties. This period was carefully chosen to enable ample time for monitoring of the ionospheric plasma parameter from its natural to perturbed state enhancing separation of seismic anomalies from the background of natural variations, expecting the former to appear at the end of the period.

Different durations ranging from five days to two months have been employed to screen the ionosphere but primarily, reports on seismo-electromagnetic variations are detected three weeks or less to the earthquake day (Rong et al., 2008; Píšaet al., 2011; Ibanga, et al., 2017). The total ion density (sum of Oxygen, Hydrogen and Helium ions from the IAP Sensor) were acquired by taking data files from the DEMETER website. Data from each orbit were confined to the two modes but only the burst mode data were used in this research.The median and the inter-quartile range of the data were used to obtain their upper and lower limits in order to distinguish seismic perturbations from the natural variation backgrounds as opined (Akhoondzadeh et al. 2010; Liu et al. 2004).

4. Discussion

Plasma parameters in the ionosphere obtained from DEMETER data have been succinctly investigated for unusual variations within the radius of the earthquake preparation zone before, during and after East of Kuril Islands earthquake of 13th January 2007. Anall-inclusive report on our findings in the two sets of data is shown in Table 1. Days are comparative to the earthquake day (0) with minus and plus signsdepicting pre and post days. An array of anomalous variations were observed during the study. As visibly displayed in our line plots (Figure 2), where the plasma parameters of electron density, electron temperature and total ion density are plotted against day relative to earthquake. From equations 1-3, as reported by Liu et al., 2004, Akhoondzadeh et al., 2010 and Ibanga, et al., 2017, perturbations beyond the bounds are viewed as being unusual. A summary of the perturbed days is given in Table 1. Our investigations revealed that all three parameters were disturbed on -27, -11 and -8days; nevertheless, other days showed distortion in one or two parameters (Table 1 and Figure 2). However, it is worthy to note that phenomena beside seismic activity can perturb the ionosphere, hence, to discriminate these perturbations from geomagnetic activities, the geomagnetic indices of kp and Dst were checked (Fig. 3a and 3b) on these days. Days -27 and -11 showed remarkable geomagnetic activities; thus the observed unusual plasma variations was not seismo-induced but geomagnetically induced. On the 8th day preceding the seismic event,a very salient revelation presented itself on orbit no13390_0 (figure 1a), above the vicinity of the impending seismic event. On this day, all three plasma parameters of electron density (4.09), electron temperature (-2.03) and total ion density (5.73) displayed unusual ionospheric variations (red triangles in the line plots) in quiet geomagnetic conditions (black straight lines in Figures 3a and 3b). The unusual variations observed in the investigated parameters from the DEMETER data had both positive and negative values.

5. Conclusion

In this study, we have clearly shown the proficiency of DEMETER IAP and ISL devices to detect striking anomalies in electron temperature, electron density and total ion density parameter variations, in the region of strong earthquake epicenters eight days before its occurrence. Both IAP and ISL sensors of DEMETER satellite reliably detected unusual ionospheric variations eight days in its daytime half orbit measurements before the occurrence of the earthquakes. The discussion of the results has ascertained the ionospheric Plasma variations before the East of Kuril Islands earthquake of 13th January 2007, which could have helped in evacuation of lives and properties in the earthquake zones before it occurred. It is worth mentioning that the pre-seismic ionospheric anomalies, which appeared 8 days prior to the earthquake had both positive and negative signs. Due to the fact that geomagnetic activity was undisturbed on this day, the detected anomalies is regarded as the pre-seismic ionospheric variations. Nevertheless, it is pertinent to bear in mind that the ionosphere has complex behavior even in quiet geomagnetic conditions and the obtained parameters sometimes display variations in quiet seismic conditions, which can be associated to other unidentified factors. The seismo-ionospheric anomalies represented in this paper are encouraging for the short-term forecasting. However, additional investigation is needed to achieve a very precise regional model of quiet time ionosphere to differentiate seismic precursors from the background of daily variations.

6. Acknowledgements

The authors acknowledge NOAA for the geomagnetic data and CNRS/LPC2E for the DEMETER data.

References

Akpan, A. E., Ibanga, J. I., George, N. J., Ekanem, A. M. 2019, Assessing seismo-ionospheric disturbances using Vanuatu and Honshu earthquakes of March 25, 2007, employing DEMETER and GPS data, International Journal of Environmental Science and Technology 16(11), 7187-7196, Doi 10.1007/s13762-019-02339-x.

Akhoondzadeh, M., Parrot, M. and Saradjian, M. R. 2010, Electron and ion density variations before strong earthquakes (M>6.0) using DEMETER and GPS data. Natural Hazards and Earth System Sciences, 10,7-18.

Berthelier, J. J., Godefroy, M., Leblanc, F., Seran, E., Peschard, D.,Gilbert, P. and Artru, J. 2006, IAP, the thermal plasma analyzer on DEMETER. Planetary and Space Science, 54, 487-501.

Brien, M. O. and Cornely, P. R. 2015, Analyzing Anomalies in the Ionosphere above Haiti Surrounding the 2010 Earthquake. Journal of Young Investigators, 29(5), 36 - 40.

Cöısson, P., P. Lognonne, D. Walwer, and L. M. Rolland 2015, First tsunami gravity wave detection in ionospheric radio occultation data, Earth and Space Science, 2, 125–133, doi:10.1002/2014EA000054 36

Cussac, T., Clair,M., Ultre´-Guerard, P., Buisson, F., Lassalle-Balier, G., Ledu, M., Elisabelar, C., Passot, X. and Rey, N. 2006, The Demeter microsatellite and ground segment. Planetary and Space Science, 54, 413-427.

Freund, F. 2010, Toward a unified Solid-State theory for pre-earthquake signals, ActaGeophysica 58(5), 719- 766 doi 10.2478/s 11600-009-0066

Fuying, W. Z. and Yun, L. J. 2009, Study on method of Detecting Ionospheric TEC anomaly before Earthquake. Journal of Geodesy and Geodynamics, 29(3), 50- 54.

Harrison, R. G., NAplin, K. L. and Rycroft M.J. 2010, Atmospheric electricity coupling between earthquakes regions and the ionosphere, J. Atmos. Sol. Terr. Phys., 72, 376 – 381.

Hayakawa M, Y. Sue, and T. Nakamura 2009, The effect of earth tides as observed in seismo-electromagnetic precursory signals, Natural Hazards and Earth System Sciences, 9, 1733–1741

Hayakawa, M. 2014, Seismo-Ionospheric Perturbations, and the Precursors to the 2011 Japan Earthquake. Electromagnetic Compatibility. International Symposium on Electromagnetic Compatibility, Tokyo.155-158.

Heelis, R. A. 2004, Electrodynamics in the low and middle latitude ionosphere: A tutorial, J. Atmos. Sol. Terr. Phys., 66, 825–838, doi: 10.1016/j.jastp.2004.01.034.

Ibanga, J. I., Akpan, A.E., George, N.J. Ekanem, A.M. and George A.M. 2017, Unusual Ionospheric Variations before the strong Auckland Islands, New Zealand earthquake of 30th September 2007. NRIAG Journal of Astronomy and Geophysics

Kintner, P. M., Coster, A. J., and Rowell, T. F., Mannucci, A.J., Mendillo, M. and Heelis, R. 2013, Mid latitude Ionospheric Dynamics and Disturbances. America: American Geophysical Union.

Kuo, C. L., Huba, J. D., Joyce G. and Lee, L. C. 2011, Ionosphere Plasma bubbles and density variations induced by pre-earthquake rock currents and the associated surface charges. Journal of Geophysical Research: Space Physics 116 (A10)

Liu, J. Y., Chuo, Y. J., Shan, S. J., Tsai, Y. B., Chen, Y. I., Pulinets, S.A., and Yu, S.B 2004, Pre-earthquake ionospheric anomalies registered by continuous GPS TEC measurements, Ann. Geophys.,22, 1585–1593, http://www.ann geophys.net/22/1585/2004

Mayaud, P. N. 1980, Derivation, Meaning and use of geomagnetic indices, Geophysical Monograph 22, American Geological Union, Washington DC.

Namgaladze A. A., Klimenko M.V., Klimenko V.V. and Zakharenkova I.E. 2009, Physical mechanism and mathematical simulation of ionosphere earthquake precursors observed in total electron content, Geomagnetism and Aeronomy, 49, 252–262

Ondoh, T. 2003, Anomalous sporadic E-layers observed before M7.2 Hyogo-ken Nanbu earthquake; Terrestrial gas emanation model, Advance Polar Upper Atmosphere Research 17, 96-108

Ondoh, T. 2008, Investigation of precursory phenomena in the ionosphere, atmosphere and groundwater before large earthquakes of M >6.5. Advance Space Research, 43, 214-223.

Oyama, K.-I., Kakinami, Y., Liu, J.-Y., Kamogawa, M., Kodama, T., 2008,Reduction of electron temperature in low latitude ionosphere at 600 km before and after large earthquakes.Journal of Geophysical Research 113, A11317.http:// dx.doi.org/10.1029/2008JA013367.

Parrot M. Tramutoli V, Tiger J, Liu Y, Pulinets, S, Ouzounov D, . Genzano N, Lisi M, Hattori K, Namgaladze ,A 2016, Atmospheric and ionospheric coupling phenomena 1 related to large earthquakes, doi:10.5194/nhess-2016-172.

Parrot, M., Nemec, F. and Santolik, O. 2014, Statistical Analysis of VLF radio emissions triggered by power line harmonic radiation and observed by the low- altitude satellite DEMETER. Journal of Geophysical Research: Space Physics, 119 (7), 5744 - 5754.

Píša, D., M. Parrot, and O. Santolík 2011, Ionospheric density variations recorded before the 2010 Mw 8.8 earthquake in Chile. Journal of Geophysical Research, 116, A08309; doi: 10.1029/2011JA016611

Pulinets, S. A., Legen, A. D., Gaivoronskaya, T. V., and Depuev, V.K. 2003, Main phenomenological features of ionospheric precursors of strong earthquakes, Journal of Atmospheric Solar and Terrestrial Physics, 65, 1337-1347.

Pulinets, S. A. and Boyarchuk, K. A. 2004, Ionospheric Precursors of Earthquakes. Berlin: Springer, Verlag Publishers. Germany.

Pulinets, S. and Davidenko, D., 2014, Ionospheric precursors of earthquakes and Global Electric Circuit, Advances in Space Research doi: http://dx.doi.org/10.1016/j.asr.2013.12.035

Rong, Z., Feng, J. and Xin-yan, O. 2008, Ionosphericpertursbations before Pu'er earthquake observed on DEMETER. Acta Seismologica Sinica, 21(1), 77 -81.

Rostoker, G. 1972, Geomagnetic Indices. Reviews of Geophysics and Space Physics, 104, 935-950.

Ryu, K., E. Lee, J. S. Chae, M. Parrot, and S. Pulinets 2014, Seismo-ionospheric coupling appearing as equatorial electron density enhancements observed via DEMETER electron density measurements, J. Geophys. Res. Space Physics, 119, 8524–8542, doi:10.1002/2014JA020284

Sonakia, A. 2014, Investigation of lonospheric perturbation due to Seismic activity using satellite and ground-based observations. International Journal of Research and Engineering, 1(2), 15 -19.

Surkov, V. V. 2015, Pre-seismic variations of atmospheric radon activity as a possible reason for abnormal atmospheric effects, Ann. Geophysics, 58(5), A0554.

Xinzshi, W., Junhui, J., Dongjie, Y. and Fuyang, K. 2014, Analysis of Ionospheric VTEC disturbances before and after the YutianMs 7.3 earthquake in Xinjiang Uygur Autonomous Region. Geodesy and Geodynamics, 5(3), 8 - 15.

Xu, D., Chen T., Zhang, X.X. and Liu, Z. 2009, Statistical relationship between solar wind conditions and geomagnetic storm. Planetary and Space Science, 57 (12) 1500 -1513.

Zhang, X., Zeren, Z., Parrot, M., Battiston, R., Qian, J. and Shen, X. 2011, ULF/ELF ionospheric electric field and plasma perturdations related to Chile earthquakes. Advance Space Research 47(6), 991- 1000.

Cite the Article: Thomas, J. E., George, N. J., Ekanem, A. M., Akpan, A. E. (2020). Ionospheric Plasma Variations Afore The East Of Kuril Islands Earthquake Of 13th January, 2007. *Geological Behavior, 4(1): 42-46.*