# Detection of ionospheric perturbations associated with earthquake using data of IAP and ISL instruments of DEMETER satellite.

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**Abstract-** Ionospheric variations were observed by DEMETER (Detection of Electro-Magnetic Emission Transmitted from Earthquake Regions) satellite, during strong earthquake. The main aim of the DEMETER satellite mission is to study the ionospheric variations associated with seismic activity. In present paper, we have studied ionospheric irregularities for strong earthquake by using ion and electron density data. These data recorded by the IAP and ISL instruments of DEMETER satellite, respectively. Perturbations in plasma parameter were observed near the epicenter of the earthquake few days before the main shock. Observed variation in ionosphere was examined by checking geomagnetic (Dst and Kp indices) data.

**Key Words-** Ionospheric perturbations, Ion density, Electron density, Seismo-electromagnetic emissions, DEMETER satellite.

## 1. Introduction-

Earthquake precursory signature is recently known to appear not only in the lithosphere, but also in the atmosphere and ionosphere [1, 2]. These effects of the seismic activity on the atmosphere and ionosphere, which occur several hours to several days before or during the pre seismic phase[3], this means that earthquakes can create atmospheric and ionospheric perturbations by direct coupling. This is called Lithosphere-Atmosphere-Ionosphere (LAI) coupling phenomenon. Theoretical and experimental studies show that Lithosphere-Atmosphere-Ionosphere coupling phenomenon is a promising method for earthquake prediction [4].

Many reports have also been published on in-situ observations of electromagnetic emissions (EM) and ionospheric perturbations associated with seismicity. First report in the satellite measurements of ionospheric precursors of earthquakes could be attributed to the beginning of the 1980s [5, 6], where ionospheric precursors were registered by number of satellites. Results were obtained from Intercosmos-19 satellite on the large scale of anomalies within the ionosphere associated with the earthquake preparation [7]. Onboard AE-C and ISIS-2 satellites data analysis show results for local plasma density and temperature variations [8, 9] as well as results obtained from GPS-TEC [10], ionosonde [11], Radio probing measurements have shown the significant relation between the ionospheric perturbations and earthquakes. Therefore, consequently, DEMETER satellite was designed to detect anomalous variations of electromagnetic waves which could be related to seismic activity. The aim of this paper is to show ionospheric perturbations which have been recorded by various experiments onboard DEMETER when it was passing over active seismic regions.

## 2. Data

DEMETER satellite (weight 130kg) was launched on June 29, 2004.It is in a synchronous solar quasi-circle orbit at a low-altitude of 710 km (changed into 660 km since December 2005). There are several payloads on DEMETER to survey the ionospheric activity. The Langmuir Probe Instrument (ISL) is designed to measure the electron density of plasma, electron temperature (in the range 500 K - 3000 K) and the potential of the satellite (in the range +/- 5 V). The Plasma Analyzer Instrument (IAP) measures the ion density, composition and temperature (range 1000 K - 5000 K) and velocity of dominant ions $H^+$, $He^+$, $O^+$ (less than 2km/s). Details of these experiments can be found in article by Parrot [12, 13]. There are two modes of operation of instruments- (1) survey mode to record low bit rate data all around the Earth and (2) burst mode to record high bit rate data above seismic regions. There are three types of data for each instrument. We have used level N1 and N2 data of ISL and IAP instruments. Data and plots are available in a web server (http://demeter.cnrs-orleans.fr).

## 3. Results

We have observed ionospheric perturbations for strong earthquake, which occurred at (Geog. Lat. = $46.58^0$ N Geog. Long. = $153.25^0$ E) on November 15, 2006 at 11:14:16 UT. The magnitude and depth of this earthquake were 8.3 and 26.7 km, respectively. The DEMETER's orbit path is shown in Fig. 1 along with the epicenter of the earthquake (asterisk). Fig. 1 shows the ground track of path on 2 November, 2006 (orbit 12450_0) thirteen days before and on 8 November, 2006 (orbit 12544_1) seven days before the main shock. The maximum ionospheric perturbation observed in $2^0$ zones around the epicenter for level N2 data and the earthquake preparation zone is 3706.80 km.

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On 2 November 2006, DEMETER recorded the data, when it passed over the earthquake region and it is shown in Fig. 2. The change in plasma parameter has been shown in parenthesis. The Y-axis represents the distances (D) between the epicenters and the satellite. The symbols are green square, red triangle and blue circle for post-seismic events, pre-seismic events and earthquakes occurring during the half-orbit, respectively. The color scale on the right represents the time interval between the earthquakes and the DEMETER orbit with a color gradation from >30 days up to a [0–6 h] interval. The symbol sizes correspond to earthquakes of magnitude [5– 6], [6–7] and [>7]. In the bottom panel group of red triangles indicates closest approach to the epicenter of an earthquake, which occurred at 00:33:00 UT.

In first panel IAP ion density started to increase from ($50.08^0$ N, $155.82^0$ E) at 00:31:56 UT and the gradually returns to normal ($43.98^0$ N, $153.50^0$ E) at 00:33:38 UT. The change in plasma parameter has been shown in parenthesis. Maximum enhancement in ion density was observed near ($47.01^0$ N, $154.61^0$ E) at 00:32:47 UT than the undisturbed state of ion density for $He^+$ and $H^+$ ion constituents. Fluctuation (increases) in $He^+$ ion constituent was observed in between $1.85 \times 10^3$ to $3 \times 10^3$ ion cm$^{-3}$ and for $H^+$ ion fluctuation it was observed between $1.8 \times 10^3$ to $3.5 \times 10^3$ ion cm$^{-3}$. Enhancement in $He^+$ and $H^+$ ion densities was observed ~38% and ~48% greater than that of their undisturbed state, respectively. Similarly, ISL electron density increased during satellites journey between ($49.26^0$ N, $155.49^0$ E) at 00:32:10 UT to ($43.96^0$ N, $153.51^0$ E) at 00:33:38 UT. The value of electron density reached to its maximum near ($46.52^0$ N, $154.46^0$ E) at 00:32:54 UT at the centre of parenthesis and gradually returned to normal. The maximum electron density ($1.8 \times 10^4$ electron cm$^{-3}$) observed about ~33% greater than that of the undisturbed ($1.2 \times 10^4$ electron cm$^{-3}$).

DEMETER passed again seven days before the same earthquake, above the seismic region (orbit 12544_1) (Fig. 1) and corresponding level N2 data is shown in Fig. 3. In the bottom panel the group of red triangles indicates closest approach to the epicenter of an earthquake, which occurred at 11:24:00 UT. Fluctuation in IAP ion density observed between positions ($44.74^0$ N, $155.22^0$ E) at 11:23:12 UT & ($49.64^0$ N, $153.36^0$ E) at 11:24:33 UT. Enhancement in $O^+$ and $H^+$ ions constituents values reached to maximum of 25% and 37% of their undisturbed states and it was observed near ($48.52^0$ N, $153.81^0$ E) at 11:24:15 UT. Electron density maximum increased up to $1.1 \times 10^4$ electron cm$^{-3}$ than that of undisturbed state ($0.9\times 10^4$ electron cm$^{-3}$). Enhancement in electron density (~18% greater than the undisturbed state) was observed in the orbit from ($46.42^0$ N, $154.61^0$ E) at 11:23:40 UT to ($48.52^0$ N, $153.81^0$ E) at 11:24:15 UT.

We have analyzed level N1 data for one month before and five days after the main shock. The data have been studied of latitude and longitude range between $37^0$N - $54^0$N and $140^0$E -$162^0$E, respectively. This latitude and longitude range has been selected in order to have at least one orbit per day over the seismic region. Each orbit track is more or less close to the epicenter. The DEMETER satellite parameters are studied of the area around the epicentre (asterisk) which is shown in Fig. 4. Figs. 5 (a) and (b) show day to day and latitudinal variations of the $O^+$ ion density, respectively. The red line represents the average value of the density during the complete time interval and the dotted line corresponds to the variation in density. Fig. 5 (a) shows enhancement in $O^+$ ion density. Maximum enhancement of $O^+$ ion density was observed during 9$^{th}$ to 12$^{th}$ November, as compared to average value. Large enhancement was observed 6 days before the main shock. On earthquake day $O^+$ ion density value was near to average value. Fig. 5 (b) shows that maximum enhancement in $O^+$ ion density observed in latitudinal interval of $42^0$–$52^0$ N between 9$^{th}$ and 10$^{th}$ November (in the plot, 22$^{nd}$ and 23$^{rd}$ days). Anomalous enhancement in $O^+$ ion density was observed within $\pm 5^0$ around the epicentral latitude.

We have examined the possibility of ionospheric perturbation due to geomagnetic activity by examining Dst and Kp indices. Fig. 6 shows the Dst and Σ Kp indices for the period of 1 October, 2006 to 15 December, 2006 and vertical arrows indicate the day of the earthquake. Dst and Σ Kp values, during observation period, were less than -50 nT and 30, respectively. It means that the geomagnetic activity was quiet. Hence, we can conclude that, the observed ionospheric perturbation was due to the electromagnetic emissions associated with the earthquake. The ionospheric perturbation appeared few days before due to the seismoelectromagnetic emissions [11, 14].

**4. Conclusions**

Strong earthquake having magnitude greater than eight has been studied for ionospheric perturbations in terms of different plasma parameter. These perturbations were recorded by ISL and IAP instruments of DEMETER satellite. The observed ionospheric perturbations near the earthquake epicenter were, most probably, due to electromagnetic emissions associated with earthquake. Geomagnetic disturbances (shown by Dst and Kp indices) during these ionospheric perturbations were absent. Real time study of plasma parameters can give good hints for the earthquake predications.

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**References**


1. M. Hayakawa, (Ed.), "Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes," *Terra Scientific Publishing Co., Tokyo*, 1999, pp. 996.
2. T. Yamauchi, M. Yoshida and M. Hayakawa, "The wave-like structures of ionospheric perturbation associated with Sumatra earthquake of 26 December 2004, as revealed from VLF observation in Japan of NWC signals Takumi Horie," *Journal of Atmospheric and Solar-Terrestrial Physics,* **69**, 2007, pp. 1021–1028.
3. A. Rozhnoi, O. Molchanov, M. Solovieva, V. Gladyshev, O. Akentieva, J. J. Berthelier, M. Parrot, F. Lefeuvre, M. Hayakawa, L. Castellana, and P. F. Biagi, "Possible seismo-ionosphere perturbations revealed by VLF signals collected on ground and on a satellite," *Natural Hazards Earth System Science*, **7**, 2007, pp. 617–624.
4. Z. Rong, Y. Dong-mei, J. Feng, Y. Jun-ying and O. Xin-yan, "Ionospheric perturbations before Pu'er earthquake observed on DEMETER," *Acta Seismologica Sinica,* **21**, 2008, pp. 77-81.
5. V. V. Migulin, V. I. Larkina and O. A. Molchanov, (et al.), "Detection of the earthquake effects on the VLF-ELF noises in the upper ionosphere," *Preprint IZMIRAN Moscow,* **25(390),** 1982**,** pp. 28.
6. M. B. Gokhberg, V.A. Pilipenko and O.A. Pokhotelov, "Satellite observations of electromagnetic radiation above the epicentral region of an imminent earthquake," *Doklady of the Academy of Sciences of the USSR,* **268(1),** 1983a, pp. 53-55.
7. V.V. Afonin, O.A. Akentieva, O.A. Molchanov and M. Hayakawa, "Statistical study of equatorial anomaly from high apogee satellite APEX and low apogee satellite COSMOS-900," *International Workshop on Seismo-Electromagnetics, Programme and Abstracts, NASDA*, 19-22 Sep 2000.
8. M.B. Gokhberg, V.A. Pilipenko and O.A. Pokhotelov, "On seismic precursors in the ionosphere," *Izvestiya USSR Academy of Sciences, Physics of the Earth Series,* **10**, 1983, pp. 17–21.
9. J. Boskova, J. Smilauer, F. Jiricek and P. Triska, "Is the ion composition of outer ionosphere related to seismic activity?," *Journal of Atmospheric and Terrestrial Physics,* **55(13)**,1993, pp. 1689–1695.
10. P. Lognonne, J. Artru, R. Garcia, F. Crespon, V. Ducic, E. Jeansou, G. Occhipinti, J. Helbert, G. Moreaux and P.E. Godet, "Ground-based GPS imaging of ionospheric postseismic signal," Planetary *Space Science,* **54**, 2006, pp. 528–540.
11. S. A. Pulinets, A. D. Legenk, T. V. Gaivoronskaya and V. K. Depuev, "Main Phenomenological features of ionospheric precursors of strong earthquakes," *journal of atmospheric and solar-terrestrial physics,* **65**, 2003, pp. 1337-1347.
12. J.P. Lebreton, S. Stverak, P.Travnicek, M. Maksimovic, D. Klinge, S. Merikallio, D.Lagoutte, B. Poirier, Z. Kozacek, M. Salaquarda, "The ISL Langmuir Probe experiment and its data processing onboard DEMETER: Scientific objectives, description and first results," Planetary *and Space Science*, **54**, 2006, pp. 472-486.
13. M. Parrot, D. Benoist, J. J. Berthelier, J. Blecki, Y. Chapuis, F. Colin, F. Elie, P. Fergeau, D. Lagoutte, F. Lefeuvre, C. Legendre, M. Leveque, J. L. Pincon, B. Poirier, H. C. Seran and P. Zamora, " The magnetic field experiment IMSC and its data processing onboard DEMETER: Scientific objectives, description and first results," *Planetary and Space Science*, **54**, 2006, pp. 441-455.
14. S. A. Silina, E. V. Liperovskaya, V. A. Liperovsky, and C. V. Meister, "Ionospheric phenomenon before strong earthquakes," *Natural Hazards Earth System Science*, **1**, 2001, pp. 113-118.

# Figures

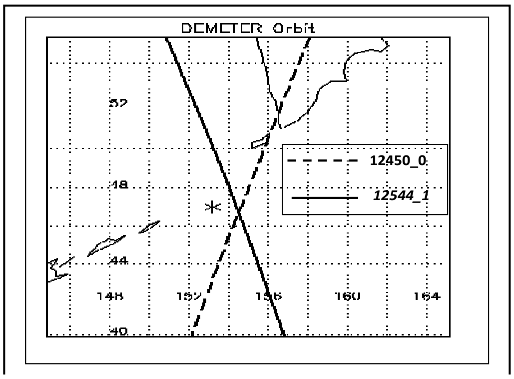



Fig. 1 Track of DEMETER above the Kuril Islands on 2 and 8 November, 2006. The asterisk indicates the position of an epicenter for 15 Nov., 2006 earthquake.

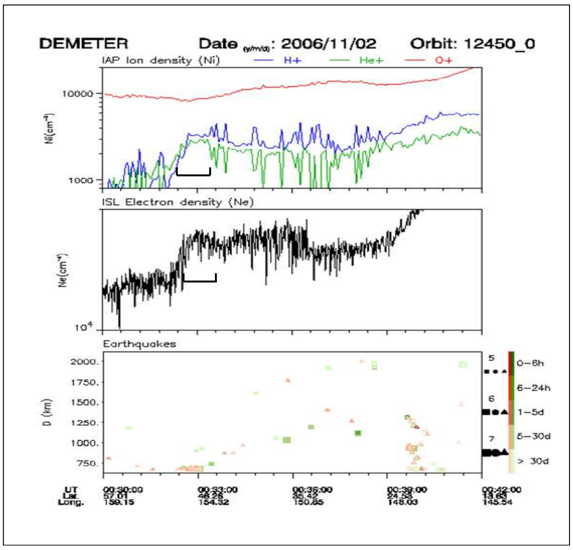



Fig.2 Data recorded by DEMETER along its orbit 12450_0

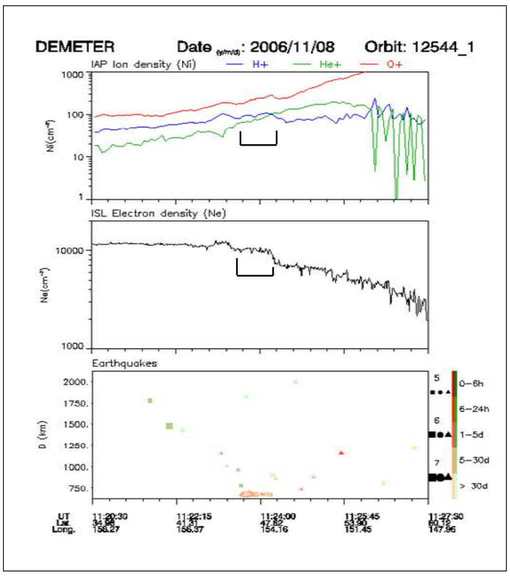



Fig.3 Data recorded by DEMETER along its orbit 12544_1 is shown in Fig. 1.

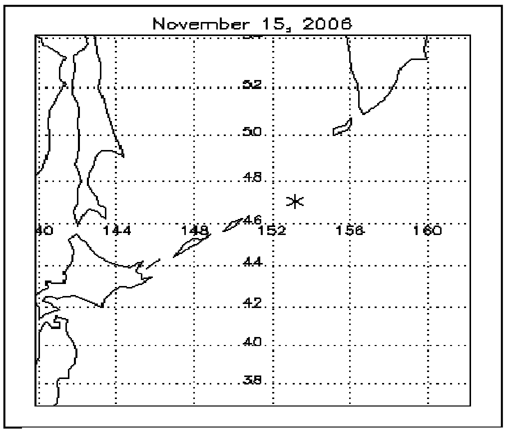
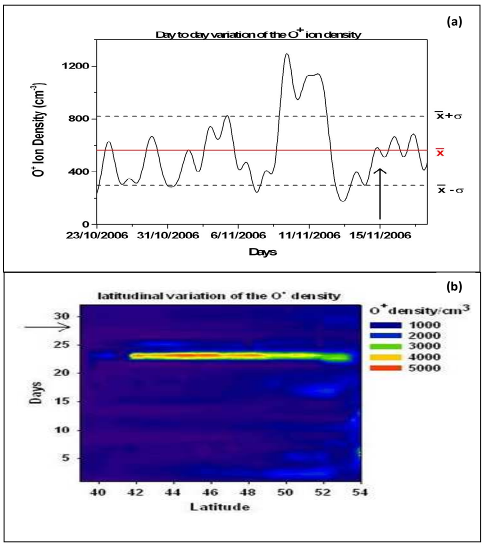



Fig.4 Area around the epicentre (asterisk) where the DEMETER parameters are studied for 15 November. 2006 earthquake.




Figs.5 (a) Day to day variation of the $O^+$ ion density as function of days. (b) Latitudinal variation of the $O^+$ ion Density as function of latitude and days from 23 October to 20 November 2006.

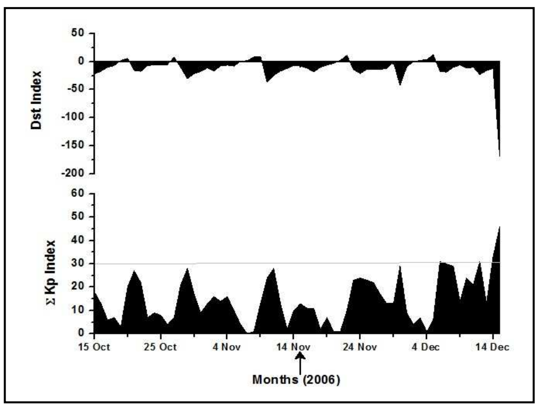



Fig.6 Dst and Σ Kp values plotted during 15 October, 2006 to 15 December, 2006. Dst and Kp index data .