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Correlation Possibility Between Earthquakes and Demeter Satellite Ionospheric Electron Density Perturbations

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Abstract: Many authors have reported ionospheric perturbations observed from a few days to a few hours prior to the strong coastal or land earthquakes. They suggest that an ocean-atmosphere-ionosphere and Earth-atmosphere-ionosphere coupling, respectively, is originally from these perturbations. We are interested in the investigation of a possible correlation between the variations of ionospheric electron density and the seismic activity while an event is preparing. For this purpose; DEMETER (Detection of Electro Magnetic Emissions Transmitted from Earthquake Regions) satellite electron density (Ne) data are examined when the satellite is over the seismic region while an event is preparing. According to that; we have selected the earthquake of magnitude 6.9 occurred on September 5th, 2004 in the region of Kii-peninsula (33.05°N, 136.78°E) at 10:07:07UT. DEMETER has recorded this event 7 days before the quake. The wavelet analysis of the DEMETER satellite ionospheric electron density data (Ne) is used for detecting singularities in Ne. After that, a correlation between the temporal localisation of singularities with the seismic activity, given by DEMETER satellite, when the satellite is on the target region, is realized.

Key words: Ionospheric perturbation · Seismic precursors · DEMETER satellite · Wavelets analysis

INTRODUCTION

Further to the Earth-atmosphere-ionosphere and land-ocean-atmosphere coupling, the ionosphere is disturbed before, during and after the main earthquake event. Several papers discussed these precursor signals, atmospheric and ionospheric anomalies during earthquake occurrences [1-3]. Indeed; ionospheric anomalies given by the variation of critical plasma frequency foF2 measured by satellites or ionosondes [4, 5] are observed few days prior to the strong earthquakes. A statistical correlation between ionospheric anomalies and 184 Taiwan strong earthquakes during the period 1994-1999 was enhanced for earthquakes with high magnitudes ($M \geq 5.4$) and epicentral distance from the ionosonde instrument less than 140 km [5]. In the other hand; an increase of the Column Water Vapour (CWV) and the Surface Latent Heat Flux (SLHF) over coastal zones is noticed within few days prior to the large coastal earthquakes ($M \geq 5.4$) [6-9]. In fact, an analysis of SLHF and CWV throughout the globe with 40 coastal earthquakes happened from 1998 to 2003 has shown similar characteristics about 1 - 14 days prior to the earthquakes [8]. Singh and al., 2007a have also shown that the variations in Relative Humidity consistent with CWV and SLHF variations prior to the Denali (Alaska) earthquake occurred on November 3, 2002 with Mw=7.9. However, this behaviour is not observed over seismic regions far away from the coast prior to the strong earthquakes ($M \geq 5.4$) [8, 6].

This work aims to show the possible correlation between earthquakes and ionospheric perturbations observed in electronic density data measured by the Langmuir Probe Instrument (ISL) onboard DEMETER (Detection of Electro Magnetic Emissions Transmitted from Earthquake Regions) satellite [10]. Therefore; we do not discuss the physical process originally of ionospheric disturbance further to seismic activity. In this paper, a preliminary investigation in detection of the ionospheric electronic density variations leaded by the strong earthquake occurred in Japan on September 5, 2004 ($M \geq 6.9$) using wavelet analysis is given.

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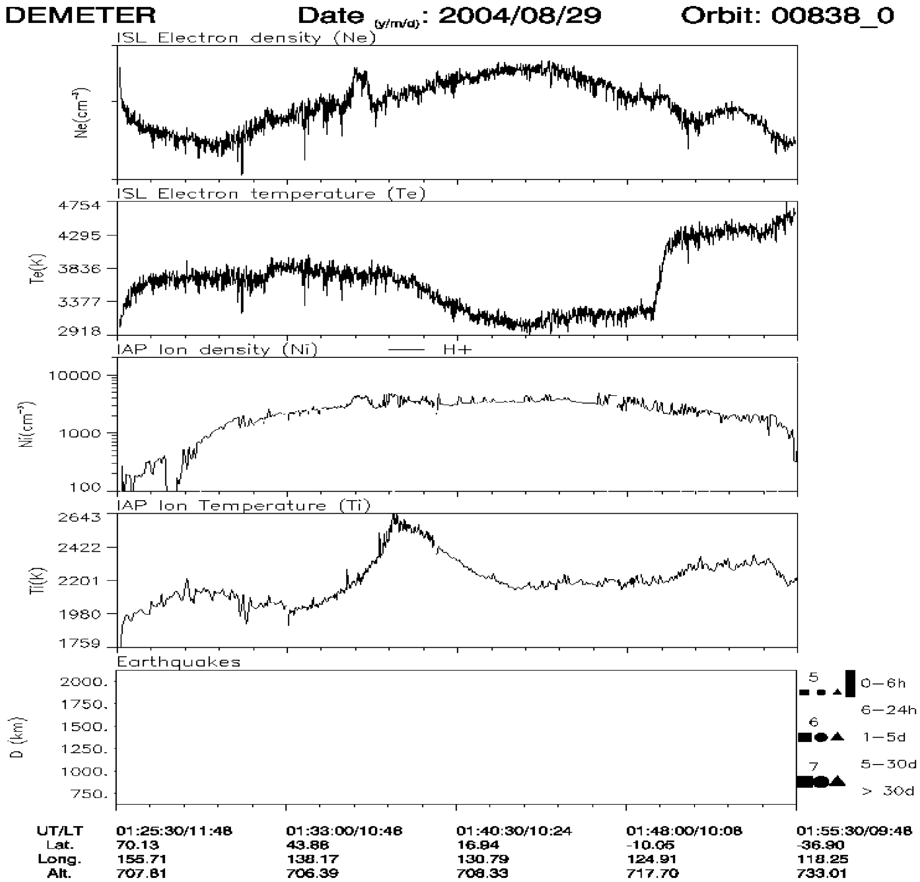

Fig. 1: Ionospheric signals recorded by DEMETER over Japan (33.05°N, 136.78°E) 7 days before the earthquake (5/09/2004 at 10:07:07TU, M= 6.9) (http://demeter.cnrs-orleans.fr). From the top to the bottom the panels successively show the electron density (Ne) and temperature (Te), the ion density (Ni) and temperature (Ti). The last panel displays the distribution of earthquakes seen by DEMETER along the orbit. The Y-axis represents the distances D between the epicentre and the satellite, from 750km up to 2000km. The colour scale on the right represents the time interval between the earthquakes and DEMETER orbits with a colour gradation from >30 days up to [0-6h] interval, the size of symbols (square, circle and triangle) is according to the earthquake's magnitude [12]. Filled green square, filled red triangle and filled blue circle correspond, respectively, to post-seismic, pre-seismic and earthquakes occurring during the half orbit. The empty symbols represent the same events corresponding to the conjugate point of the epicentre [13].

The wavelet analysis is already used in order to search a possible connection between electromagnetic disturbances and Sumatra earthquakes (December 26, 2004 M=9.3 and March 28, 2005 M=8.7) by analyzing CHAMP magnetic data [11]. Indeed a gradual enhancement of short period fluctuations in both earthquakes occurring some 70-80 minutes after their respective events is found and a high power signal developed over 700 km and accompanied by a bend in the electron density diagram with a period of about 16s, when CHAMP was closely over the epicentre zone of the first Sumatra earthquake, is discovered [11].

Data Analysis: The ionospheric electron density (Ne) data recorded by the Langmuir probe onboard DEMETER, with a time resolution of about 1s and collected in the burst mode with a high rate acquisition (1.6 Mbits/s) are used. The data have been downloaded from http://demeter.cnrs-orleans.fr and analyzed with the continuous wavelet transforms. The selected event (M=6.9) is recorded by DEMETER satellite 7 days before the quake (orbit 838_0) (Figure 1) and coincide with the first seism of a series of two strong earthquakes occurred on September 5, 2004 in the region of Kii-peninsula (33.05°N, 136.78°E) at 10.07.07UT and

Table 1: Orbits selection criteria

Date - Number Orbit	Seismic Activity	Time	Geomagnetic Activity (ΣKp)
2004/08/29 – 838	Earthquake (M=6.9) occurred on September 5th, 2004 Kii-peninsula (33.05°N, 136.78°E) at 10:07:07UT	Daytime	11
2005/02/14 – 3296	No Earthquakes	Daytime	11

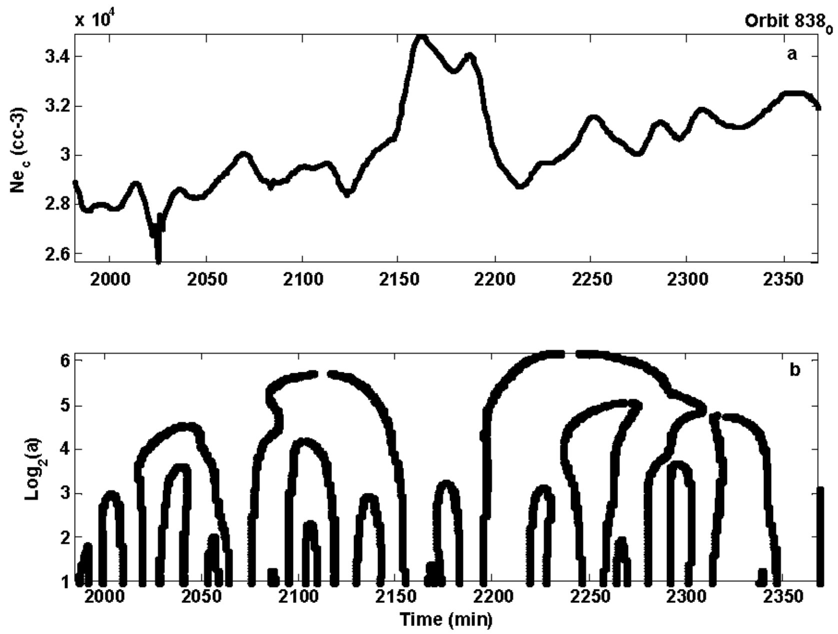

Fig. 2: (a) Ne_c along the daytime orbit 838_0 (over Japan) and (b) lines of maxima associated with singularities in Ne_c. The lines of maxima converge towards the times at which the singularity occurs (dilation $a \to 0$).

14.57.18UT, respectively [12]. Nevertheless, only the first event will be considered in order to do not confuse between aftershocks of the first earthquake and the precursor signals of the second one. The ionosphere is directly influenced by the solar activity; therefore, to dissociate the solar activity from pre-seismic signals we have chosen another DEMETER orbit (3296_0) over the region of Kii-peninsula in the absence of any seismic activity, whereas we keep the same conditions of time period (daytime) and geomagnetic activity (Table 1). Notice that the geomagnetic activity, which is quite in our case (ΣKp=11), is described by the sum of daily Kp index provided by the website (http://www.cetp.ipsl.fr/~isgi).

Analysis Method:

Introduction: Our interest in this work lies in detecting singularities resulting from a discontinuity of the α^{th} derivative of the signal, α being eventually a non-integer positive number. While real data are often imperfect, it is necessary to dissociate the useful signal from noise which creates singularities in turn. Thus, the continuous wavelet transforms is very well adapted for singularity detection. Indeed, all abrupt changes in a signal will be precisely localised for dilations sufficiently small [14, 15].

The wavelet transform is given by the convolution product of the signal f with the wavelet ψ.

$$Wf(t,a) \equiv f\,\psi_a(t)$$

Where $\psi_a(t) = a^{-1}\,\iota(t/a)$, t is the time and a>0 is the dilation parameter.

Data Processing and Results: Two recording data periods over the Kii-peninsula region (Japan) are selected. The first time coincides with a seismic activity; DEMETER passes (orbit 838_0) over 5 days before the main earthquake event of magnitude 6.9 occurred on September 5th, 2004 in the region of Kii-peninsula (33.05°N, 136.78°E). The second one (orbit 3296_0) is chosen in the absence of any seismic activity (Table 1). Although the geomagnetic activity was quiet over the time of recording for both orbits (ΣKp=11) (Table 1), we will check whether the singularities in the analyzed signals are due to the seismic activity or an external one.

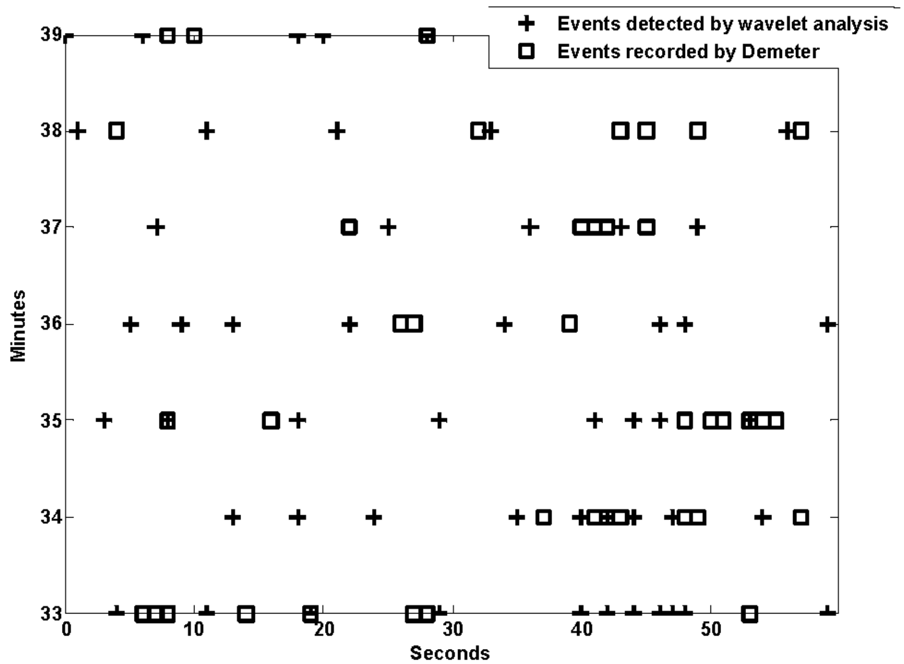

Fig. 3: Temporal distribution of singularities detected in the Ne_c wavelet analysis and the pre-seismic events of the earthquake occurred on September 5th, 2004 in the region of Kii-peninsula (33.05°N, 136.78°E) at 10:07:07UT recorded by the satellite along the orbit 838_0.

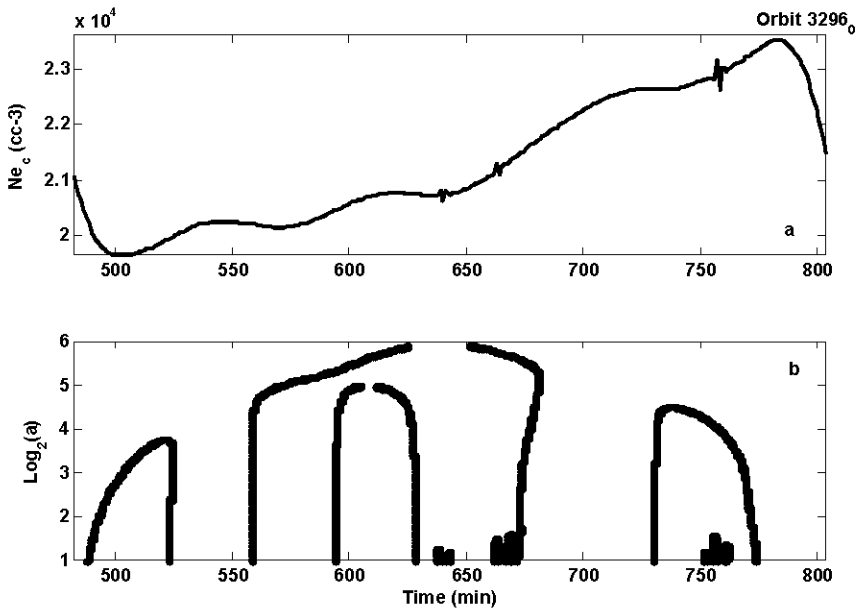

Fig. 4: (a) Ne_c along the daytime orbit 3296_0 (over Japan) and (b) lines of maxima associated with singularities in Ne_c. The lines of maxima converge towards the times at which the singularity occurs (dilation $a \to 0$).

Before starting the data processing, the ionospheric electron density (Ne) is corrected from noise for each orbit (Figure 2a and Figure 4a) in order to exclude the singularities generated by the noise. The denoised signal is naming Ne_c for both orbits. Then Ne_c is analyzing using the Ricker wavelet. The wavelet analysis reveals lines of maxima associated with the singularities existing in Ne_c. Note that the lines of maxima are giving by the variation of the logarithm of the dilation a to the base 2 ($Log_2(a)$) according to the time. It can be seen that each line of maxima converges towards the time at which the singularity occurs (Figure 2b and Figure 4b).

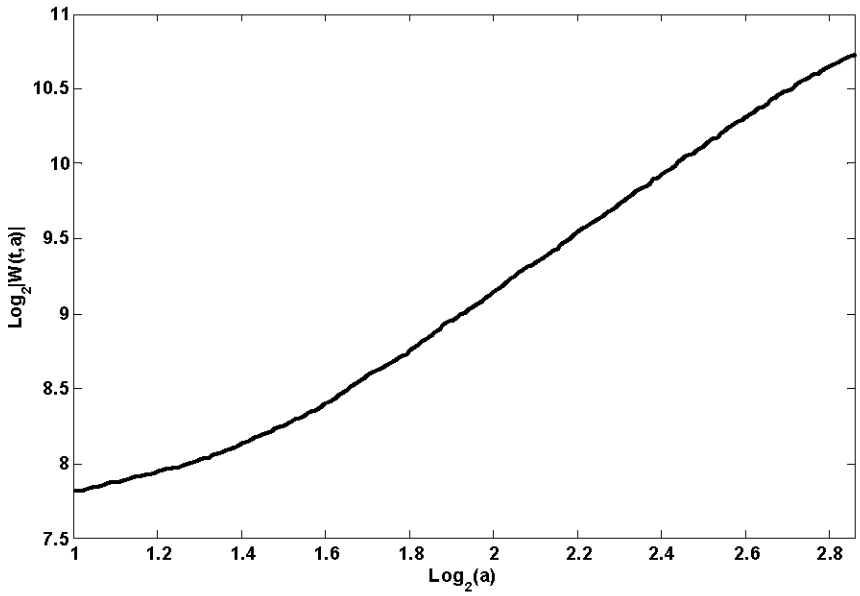

Fig. 5: Log-Log plot of the ridge function associated with a line of maxima. The regularity is given by the slope of the straight line of the ridge function

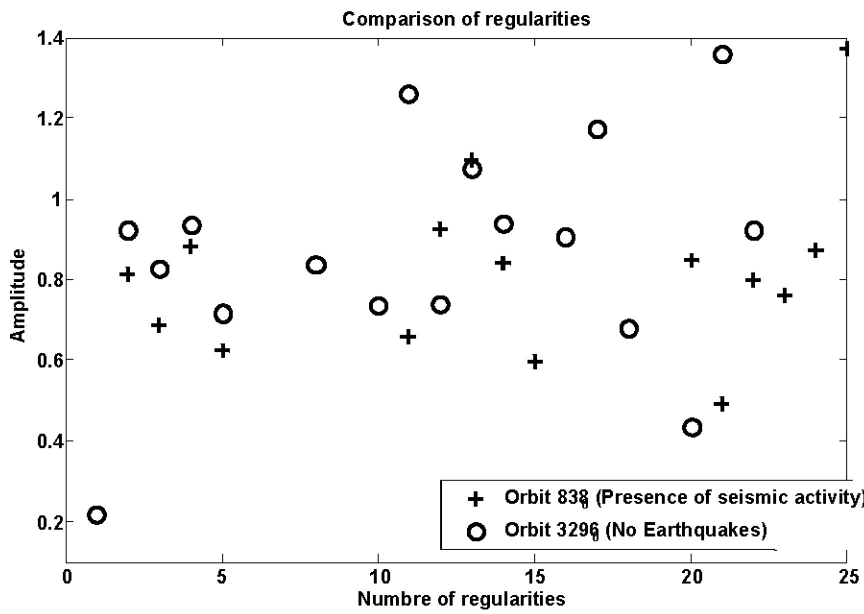

Fig. 6: Distribution of singularity regularities of the Ne_c wavelet analysis in both cases (presence and absence of seismic activity)

In order to check whether the singularities detected in Ne_c for the orbit (838_0) are generated by the earthquake; the localisation of each singularity in Ne_c (cross symbol) and the pre-seismic events detected by DEMETER (square symbol) are plotted in Figure 3. The pre-seismic events are given by the "seismic events" file available in DEMETER website (http://demeter.cnrs-orleans.fr). Now, we can say that we have overcome our objective to point out some events detected by DEMETER satellite. Consequently, an extension of this study can be done with other orbits which coincide with earthquakes throughout the Earth.

Singularities Characterisation: Note that Ne_c is processed for two cases: existence and absence of the seismic activity (orbit 838_0) and (orbit 3296_0), respectively. In both cases the wavelet analysis reveals the singularities in Ne_c (Figure 2 and Figure 4).

However, it is necessary to characterise these singularities in order to distinguish those generated by the seismic activity from those generated by other activities such as solar activity. Thus, we determine the regularity α for each singularity. The regularity α is the slope of the ridge function that is defined by the variation of $Log_2|Wf(t,a)|$ according to $Log_2 a$ along a given line of maxima and plotted on a ratio scale (Figure 5) [16].

Figure 6 shows the distribution of singularity regularities of the Ne_c wavelet transform for both orbits. In both cases of presence and absence of the seismic activity with a quiet geomagnetic activity, the regularities are ranged in the interval [0.2, 1.4]. That means that we cannot, at this step, differentiate between singularities generated by the seismic activity and the external activities. However, it can be seen that the variation of regularities, in each case, is regular and looks like a sinusoid. This behaviour suggests a variation under a mathematical law. The modelling of such mathematical law will allow us to predict precursor events.

CONCLUSION AND DISCUSSION

In this preliminary work, Ne data recorded by DEMETER satellite along the daytime orbits (838_0) and (3296_0) while an earthquake is in preparation and in the absence of seismic activity, respectively, are used. We have detected singularities in the denoised ionospheric electron density (Ne_c). Thus, the wavelet analysis has pointed out some events detected by DEMETER as shown in Figure 6. The characterisation of singularities suggests behaviour under a mathematical law. The determination of the mathematical law of the variations of singularity regularities in Ne_c leads us to predict earthquakes some days/hours before the main shock.

However, regularities in both cases (presence and absence of the seismic activity) vary in the same range [0.2, 1.4]. In order to distinguish between the various contributions such as the solar and geomagnetic activities it becomes necessary to study them.

We would like to mention here, that these results concern only the analysis of one event. Thus, it will be well recommended to extend this study with other DEMETER orbits over regions which are seismically active and coincide with strong earthquakes. We can also establish the same analysis on the ionospheric ionic density (Ni) recorded by DEMETER as well as a statistic study for results.

REFERENCES

1. Fujiwara, H., M. Kamogawa, M. Ikeda, J.Y. Liu, H. Sakata, Y.I. Chen, H. Ofuruton, S. Muramatsu, Y.J. Chuo and Y.H. Ohtsuki, 2004. Atmospheric anomalies observed during earthquake occurrences. Geophysical Research Letters, 31(17): L17110.1-L17110.4.
2. Liu, J.Y., Y.J. Chuo, S.J. Shan, Y.B. Tsai, Y.I. Chen, S.A. Pulinets and S.B. Yu, 2004. Pre-earthquake ionospheric anomalies registered by continuous GPS TEC measurements. Annales Geophysicae, 22: 1585-1593.
3. Di Mauro, D., S. Lepidi, A. Meloni and P. Palangio, 2005. Magnetic and Electromagnetic signals related to tectonic activity: updates and new analyses on measurements in Central Italy. Natural Hazards and Earth System Sci., 5: 925-930.
4. Chmyrev, V.M., N.V. Isaev, O.N. Serebryakova, V.M. Sorokin and Y.P. Sobolev, 1997. Small-scale plasma inhomogeneities and correlated ELF emissions in the ionosphere over an earthquake region. J. Atmospheric and Solar-Terrestrial Physics, 59(9): 967-974.
5. Kamogawa, M., 2006. Preseismic Lithosphere-Atmosphere-Ionosphere Coupling. Eos, 87(40): 417-424.
6. Dey, S. and R.P. Singh, 2003. Surface latent heat flux as an earthquake precursor. Natural Hazards and Earth System Sci., 3: 749-755.
7. Dey, S., S. Sarkar and R.P. Singh, 2004. Anomalous changes in column water vapor after Gujarat earthquake. Advances in Space Res., 33(3): 274-278.
8. Singh, R.P., G. Cervone, V.P. Singh and M. Kafatos, 2007. Generic precursors to coastal earthquakes: Inferences from Denali fault earthquake. Tectonophysics, 431: 231-240.
9. Singh, R.P., G. Cervone, M. Kafatos, A.K. Prasad, A.K. Sahoo, D. Sun, D.L. Tang and R. Yang, 2007. Multi-sensor studies of the Sumatra earthquake and tsunami of 26 December 2004. International J. Remote Sensing, 28(13-14): 2885-2896.
10. Lebreton, J.P., S. Stverak, P. Travnicek, M. Maksimovic, D. Klinge, S. Merikallio, D. Lagoutte, B. Poirier, P.L. Blelly, Z. Kozacek and M. Salaquarda, 2006. The ISL Langmuir probe experiment processing onboard DEMETER: Scientific objectives, description and first results. Planetary and Space Sci., 54: 472-486.

11. Balasis, G. and M. Mandea, 2007. Can electromagnetic disturbances related to the recent great earthquakes be detected by satellite magnetometers?. Tectonophysics, 431: 173-195.
12. Parrot, M., J.J. Berthelier, J.P. Lebreton, J.A. Sauvaud, O. Santolik and J. Blecki, 2006. Examples of unusual ionospheric observations made by the DEMETER satellite over seismic regions. Physics and Chemistry of the Earth, 31: 486-495.
13. Lagoutte, D., J.Y. Brochot, D. De Carvalho, L. Madrias and M. Parrot, 2006. Demeter Microsatellite, Scientific Mission Center, Data Product Description. Lpce, Cnrs.
14. Gibert, D., 1996. Éléments de traitement du signal. Université de Rennes 1. UMR Géosciences Rennes. France.
15. Mallat, S. and W.L. Hwang, 1992. Singularity detection and processing with wavelets. IEEE Transactions on Information Theory, 38(2): 617-643.
16. Alexandrescu, M., D. Gibert, G. Hulot, J.L. Le Mouël and G. Saracco, 1995. Detection of geomagnetic jerks using wavelet analysis. J. Geophysical Res., 100(B7): 12,557-12,572.