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# Unusual ionospheric variations before the strong Auckland Islands, New Zealand earthquake of 30th September, 2007

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ABSTRACT

Using the IAP experiment on board, the DEMETER and TEC from GPS data, unusual ionospheric variations have been observed some days before the 7.4 magnitude New Zealand earthquake. Both sets of data recorded perturbations 10 days before the earthquake at about the same time. The total ion density per centimeter cube ($cm^{-3}$), recorded a variation of 6.94 while the differential total electron content (DTEC) in total electron content unit $10^{16}$ electron per metre square gave a value of 2.93TECU. The observed anomalies were screened for false alarm using the geomagnetic indices of Kernnifzer digit (*Kp*) and disturbance storm time (Dst.) It was however seen that the state of the ionosphere was geomagnetically quiet during this period; hence the observed variations were seismogenic.



## 1. Introduction

The damaging nature of earthquakes and their frequent occurrences characterize the natural disasters that continue to challenge the existence of life on planet earth as thousands of lives and properties valued at billions of US dollars are destroyed every year. Their challenges are particularly more damaging in some third world countries like India, New Zealand, Pakistan, Haiti, China, Japan and Indonesia, where a large chunk of the world's population resides (Meli and Alcocer, 2000). The location of some of these countries in the Circum-Pacific Ring of Fire, characterized mainly by subduction tectonics, have increased their occurrence rate, thus causing over eighty percent of the more damaging earthquakes to be concentrated there. Comparatively, other regions like the East Atlantic, where the West Africa is located, their impacts are generally low though not completely free (Murty et al., 2005). The pains and challenges posed by this repetitive natural disaster have prompted scientists to conduct broad-based researches on various phenomena relating to this disastrous event with a view to predicting them. Thus, for many decades, understanding earthquake corollaries and ways of mitigating them have continued to dominate discussions at many scientific and social fora.

Earthquakes of varying types and magnitudes occur every year. Generally, earthquakes refer to any seismic event originating from either natural or human activities, which generate seismic waves that propagate through the earth's interior. Thus, excepting earthquakes from natural causes, whose occurrences are sometimes more catastrophic, earthquakes can also be induced by human activities like mining (Francesco and Bizzarri, 2014; Bommer et al., 2015), oil exploration and exploitation activities (McGarr, 2014; Davies et al., 2013), groundwater over exploitation (Klose, 2013; Gupta, 1983), dam construction (Verdugo and Gonzalez, 2015) etc. However, earthquakes originating from human activities are usually of low magnitudes (tremors/microseisms). In all cases, particularly those of natural origin, the amount of elastic strain energy released during earthquake and their effects have continued to desperately, confer on man dire need to find reliable precursors for it. Thus, common questions of research interest provoked from the resulting scenario are: "what happened in the weeks, days and even hours before this terrifying event occurred? And were there indicators that such a disaster was on the way? Scientists have, however, acknowledged that all seismic electromagnetic anomalies are hallmark of processes, which started days prior to the main event and persisted few days after it (Akhoondzadeh et al., 2010). This seismic event by itself rarely kills people or

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animals, but the secondary events triggered by it like collapse of buildings, fires, tsunamis (seismic sea waves) and volcanoes, are actually the main cause of human disaster. Better designs and constructions of dwelling places, safety systems, early warnings and planning, are some ways that could help in mitigating their risk (Celebi et al., 2012).

Earthquakes are very complicated physical processes being neither regular nor linear. This has conferred on it a high degree of sophistication such that predicting it from its dynamic relation between its parameters always results in a high degree of uncertainty. Hence, it has become absolutely imperative that we find more reliable approaches of studying, monitoring and understanding the underlying physical and chemical processes that usually precede them. Preparatory to an earthquake activity, a vast amount of energy is usually transferred due to crustal movement and at the instant of the shock, a break down occurs between the source of the energy and the environment. Studies have shown that these alterations before, during and after such events do have different physical and chemical effects on the lithosphere, atmosphere and ionosphere (Chmyrev et al., 2013; Rozhnoi et al., 2009, Kamogawa, 2006; Hayakawa and Molchanov, 2002; Rapoport et al., 2004) thus making their detection possible. Consequently, perturbations in threshold state of lithospheric, atmospheric and ionospheric parameters can serve as earthquake indicators (precursor). If these ionospheric perturbations are real and systematic, then they could serve as short-term precursor, happening before, between and after the seismic events. All precursors are not expected for all events, hence a single precursor cannot be used alone in forecasting earthquake but an integrated approach employing different precursors from different experiments is the best.

### 1.1. The DEMETER satellite data

DEMETER is an acronym that stands for Detection of Electromagnetic Emissions Transmitted from Earthquake Regions. It is a microsatellite that was launched by the French Space Agency: *Centre National D'etudes Spatiales* (CNES) at about 06:30 UTC from Baikonour (Kazakhstan) on 29th June, 2004 aboard a Dnepr rocket launcher. Its transmission into space was done with a very high precision and it reached the required orbit with the following parameters: altitude of 709 km, inclination of $98^0$, orbit period (100 min), orbits per day (14) (data available in half orbit) (Cussac et al., 2006). DEMETER was designed like a rectangular shaped box with dimensions of $60 \times 85 \times 11$ cm and a total mass of 129 kg. DEMETER's orbit was polar, circular and nearly sun-synchronous and measurements were made at approximately two different local times 10:30 and 22:30 UTC (Kintner et al., 2013).

However, the altitude of this satellite was reduced to about 660 km in December 2005 and it was located onboard a Low Earth Orbit (500 to 2000 km in altitude) and visible for 10–20 min at a time. Medium Earth Orbit (2000 km to a little below 35,786 km) and Geostationary satellites (orbiting the earth above the Equator at a constant distance of 35,786 km and covering about $^1/_3$ of the earth's surface per time) also exist (Parrot, 2012; Sonakia, 2014). DEMETER was operated in two modes (i) a survey mode that recorded low bit rate data all around the Earth at invariant latitudes less than $\sim 65°$. This mode was equipped with an onboard processing facilities used in reducing telemetry flow rate to 25 kb/s, and (ii) a burst mode that recorded high bit rate data of 1.7 mb/s above seismic active regions. Burst mode recording was automatically triggered whenever satellites crossed 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. The scientific payload of the DEMETER is 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). The IMSC captor was set at the end of a 1.9 m long boom while the ICE captors were kept at the extremes of four booms each 4 m long, to avoid electromagnetic disturbances to the sensors from the satellite (Hayakawa, 2016).

IMSC unit had three orthogonal magnetic antennae joined to a pre-amplifier unit with a shielded wire of 80 cm. This magnetometer is made up of a core in perm alloy on which the main coil of several thousand turns (12,000) of copper wire were wound and a secondary coil with just a few turns. The flat frequency response of the VLF went from 100 Hz up to 17.4 kHz. The IMSC measured the three components of the magnetic field in a frequency range from a few Hz to 20 kHz (Parrot et al., 2006; Kintner et al., 2013)

*Instrument champ Electrique* (ICE) experiments were on the DEMETER mission with the aim of providing a near continuous survey of the electromagnetic and or electrostatic waves which may arise from coupling the seismic activity with the upper atmosphere and ionosphere. It used four spherical electrodes with embedded pre-amplifiers to measure the three components of the electric field in a frequency range from DC to 3.5 MHz.

The solid state energetic particle detector (IDP) with a wide geometrical factor was designed to measure trapped electron fluxes in the range of 70 keV–0.8 MeV. It also provided information on the electron fluxed between 0.8 and 2.5 MeV. The ultimate aim of this experiment was to measure high energy electrons and protons (Buzzi, 2007, Akhoondzadeh et al., 2010).

The RNF experiments were used for continuous recording of other electromagnetic phenomena like whistler. It consisted of a neural network system, which was utilized to automatically identify and classify electromagnetic waves from the extremely low frequency to very high frequency signals usually encountered by the satellite, hence identification of whistlers on board the DEMETER.

The *instrument d' Analyse du plasma* (IAP) unit generated a continuous record of the main parameters of the thermal ion population with two goals: (a) detection of disturbances in the ionosphere that may result from the coupling between seismic event on the ground and upper atmosphere and ionosphere, and (b) provision of sufficient 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 plasma analyzer instrument was carefully designed to record the parameters of the thermal population, which are the densities of the main 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 Langmuir probe experiment, technically called *instrument Sonde de Langmuir* (ISL), was designed for in-situ measurements of the bulk ionospheric thermal plasma parameters. This instrument has two sensors: a classical cylindrical sensor and a spherical sensor whose surface was segmented into seven sections (six electrically isolated spherical caps and other part of the sphere used as a guard electrode). The ISL experiment measured the electron density of plasma ($10^8$–$5{\cdot}10^{11}$ m$^{-3}$), electron temperature

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