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Statistical correlation analysis of strong earthquakes and ionospheric electron density anomalies as observed by CSES-01

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Summary. — In this work, we preliminary analyse ionospheric electron density as observed by the first China Seismo-Electromagnetic Satellite (CSES-01) from April 2018 to July 2019, defining an anomaly along each track objectively. We then apply a worldwide statistical correlation in space and time of these anomalies with respect to M5.5+ shallow earthquakes (USGS source) occurred in the same period. Although the data are short and cover discontinuously the period of concern, in general, the preliminary results seem to confirm those obtained with an analogous analysis on the Swarm satellite data recently published in DE SANTIS A. *et al.*, *Sci. Rep.*, **9**, (2019) 20287.

1. – Introduction

Earthquakes represent one of the most energetic phenomena in our planet. Although the earthquake prediction has been considered for many years an almost impossible mission [1], more recently the scientific community made significant steps forward [2]. In laboratory, rocks under stress show peculiar electric and thermal properties before break, while in nature, during the preparation of earthquakes some precursors could appear due to a Lithosphere-Atmosphere-Ionosphere Coupling (LAIC). There are different LAIC models: dynamo from stressed rocks [3, 4] or from release of radon and charged aerosols [5, 6]. In this paper we analyse some preliminary data coming from the Chinese

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Seismo-Electromagnetic Satellite (CSES-01). This satellite is part of a satellite mission specifically dedicated to find any possible signal in the ionosphere that could anticipate the occurrence of strong earthquakes. The main objective of our analysis is to establish (or refute) a significant statistical correlation between these ionospheric signals and the major earthquakes in the globe.

2. – Sensors and data

A global network of satellites, together with ground observations, could detect earthquake precursors. CSES-01 was launched on 2 February 2018 in a fixed (almost) polar Sun-synchronous orbit at around 500 km altitude. The satellite payload consists of several instruments: magnetometers, Langmuir Probes, Plasma Analyser Package, Electric Field Detectors, high-energy particle detectors, a GNSS Occultation Receiver and a Tri-Band Beacon. In this work we analyse the electron density (Ne) as measured by the Langmuir Probes in order to verify any correlation with strong earthquakes. CSES-01 Ne data availability was in the following periods: April, August, September 2018 and from 1 January to 30 July 2019, that is about 10 non-contiguous months. Differently from [7], we did not consider magnetic field data, because they have not been completely validated yet.

3. – Data analysis

We checked all Ne track data in the above periods in order to remove potential samples classified as outliers. Then, we analysed all Ne data in terms of their first time derivative (first differences divided by the corresponding sampling time) removing a cubic

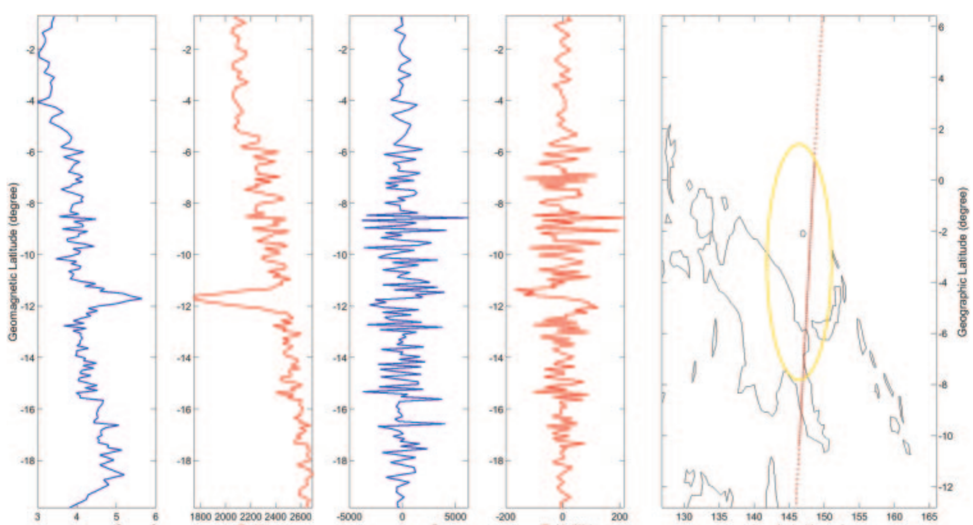

Fig. 1. – Case study on 2019-01-17 M6.3 Papua New Guinea earthquake. From left, the CSES-01 data corresponding to a track of 10 days before the earthquake: electron density Ne, electron temperature Te, their derivative along the orbit, and geographical map showing the CSES-01 orbit projected at the Earth's surface (dashed red line) and Dobrovolsky region (yellow circle; oval in this projection; its centre is the earthquake epicentre).

spline for each track. The residuals are investigated by a moving window computing the corresponding root mean square (rms) and comparing it with the root mean square of the whole track (RMS) between 50°S and 50°N magnetic latitudes. We define an Ne anomaly when the rms of the small moving window overcomes the RMS by 2.5 times [7]. An example is shown in fig. 1 where we applied this criterion to a case study. In particular, we identify an anomaly along a particular track passing over the epicentral region of an impending earthquake. This anomaly occurred about 10 days before the M6.3 (17 January 2019) Papua New Guinea earthquake: it is characterized by a clear increase of Ne and decrease of Te almost over the epicentre.

4. – Worldwide statistical correlation in time and space

We extracted and declustered from the USGS catalog all shallow (depth $\leq$ 50 km) M5.5+ earthquakes occurred in the periods of CSES-01 data availability. In this way we obtained 237 earthquakes. We then applied a Superposed Epoch and Space Approach (SESA) to the data, constructing a space-time diagram where we put the origin (0, 0) as the location and the temporal occurrence of each earthquake. Then we placed each Ne anomaly occurred in the Dobrovolsky area [8] and from 3 months before to one after the earthquake origin time in the diagram with its position and time with respect to the origin. Figure 2 shows that 160 earthquakes out of the 237 present some anomalies in the analysed space and time domain associated with about the 8.5% of the CSES-01 Ne anomalies (defined as above). We notice several concentrations at around 10 and 20 days

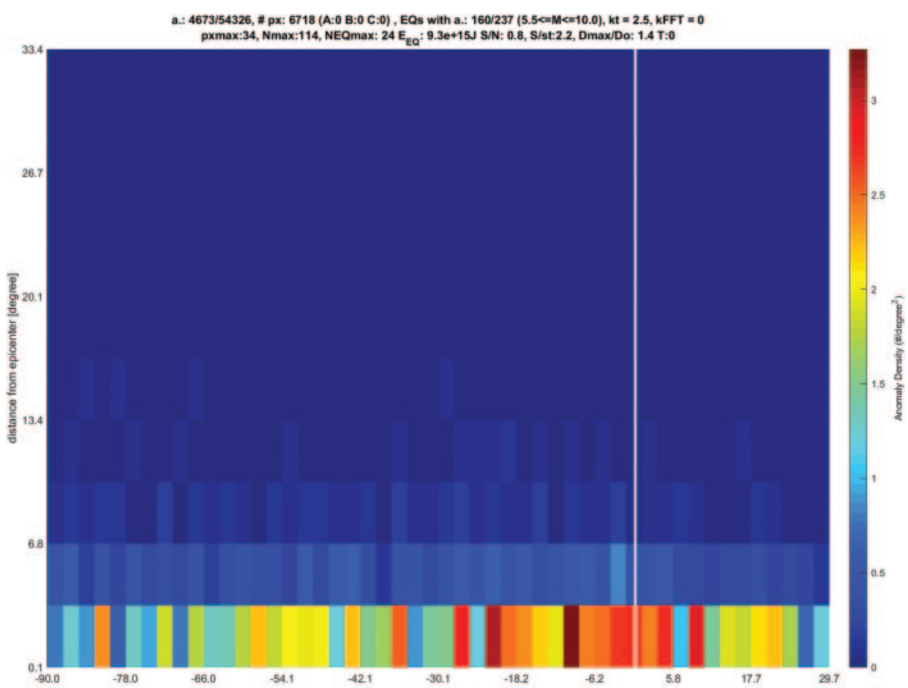

Fig. 2. – Space-time diagram as resulting from the Superposed Epoch and Space Approach applied to Ne CSES-01 data and shallow M5.5+ earthquakes.

before the earthquake occurrences. In addition, these concentrations are confined in the closest band of the first 3.4 degrees from each epicentre, *i.e.*, within 380 km.

To evaluate the significance of the obtained results we made 20 simulations of homogeneous random distributions with the same number of anomalies all over the globe. We then define two statistical parameters, d and n, as follows:

$$d = \frac{[D_{MAX}/D_0]_{real}}{[D_{MAX}/D_0]_{random}}; \quad n = \frac{[D_{MAX}/D_0]_{real} - [D_{MAX}/D_0]_{random}}{\sigma_{random}},$$

where D_{MAX} is the density of anomalies in the largest concentration and D_0 is the theoretical mean concentration of an homogeneous distribution. The ratio of the two quantities is computed for the real analysis and compared with that calculated for the simulations; σ is the standard deviation of the ratios between D_{MAX} and D_0 for the 20 random simulations. For a random distribution we expect $d = 1$ and $n = 0$. We consider a significant result when $d \geq 1.5$ and $n \geq 4$ (see [7] for more details). For the results of fig. 2 we find $d = 1.8$ and $n = 15$, so the results are robust and significantly different from a random distribution.

5. – Conclusions

We analysed about one (sparse) year of Ne CSES-01 data between 50°S and 50°N magnetic latitudes and selected a dataset of anomalies. Then we compared them with all occurred M5.5+ shallow earthquakes by means of SESA. The results seem encouraging, confirming that there is a LAIC phenomenon preceding most earthquakes, as already found for the same kind of data but a different satellite missions, for instance, Swarm satellites by the European Space Agency [7], still in orbit, and DEMETER, a French small satellite flown in the period 2004–2010 [9]. However, given the short span of CSES-01 data here analysed, it will be fundamental to extend the present analysis also to a longer dataset of CSES-01 Ne data, as soon as the data will be available.

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