The great potentiality of low earth orbiting satellite missions such as Swarm for detecting pre-earthquake ionospheric anomalies

Poster #106

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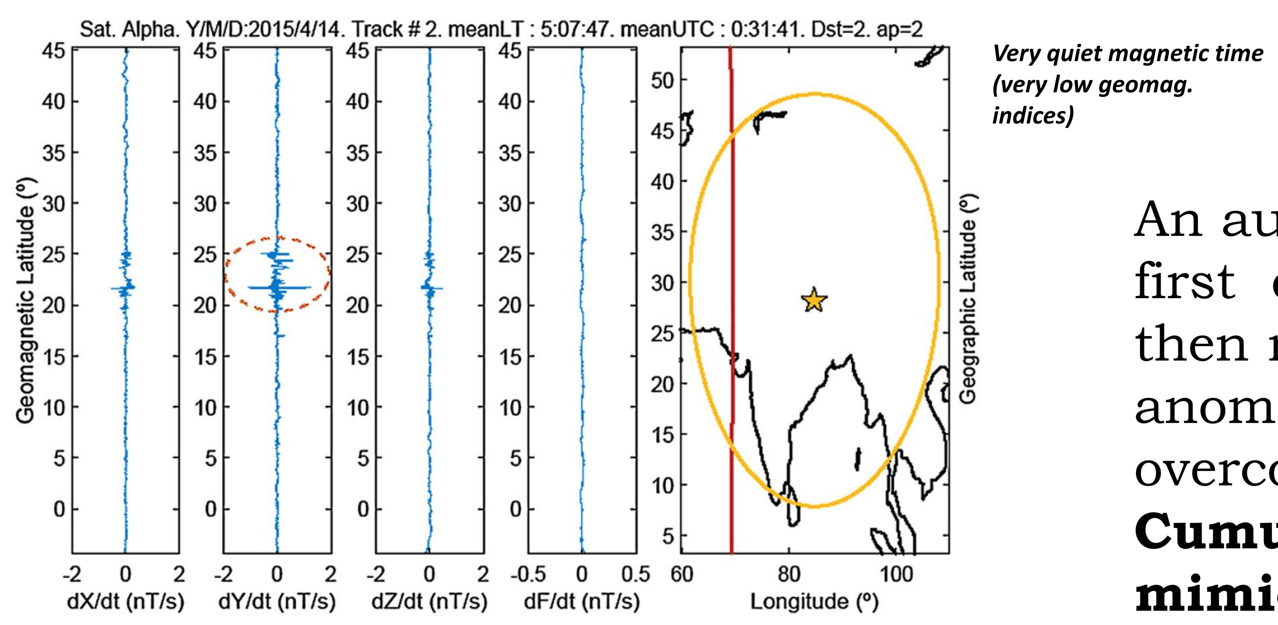
Abstract

Sometimes, satellites designed for specific objectives, therefore equipped with appropriate payloads, extend their field of application to scientific areas very distant from the original ones. This is the case of the Low Earth Orbiting ESA Swarm mission: initially designed with its original configuration (three identical satellites equipped with magnetometers, Langmuir probes, high-energy particle detectors, GPS, etc.) to monitor and study the geomagnetic field and the state of the ionosphere and magnetosphere, the same data could be analysed to investigate pre-earthquake (EQ) ionospheric anomalies. For the first time, in 2017, a study (De Santis et al., 2017) showed **some pre- and post-EQ magnetic field anomalies detected by the Swarm satellites** on occasion of the **2015 Nepal M7.8 earthquake**. Interestingly, **the cumulative number of satellite anomalies and the cumulative number of EQs behaved similarly** with the so-called **S-shape**, providing an empirical proof on the lithospheric origin of the satellite anomalies and supporting a lithosphere-atmosphere-ionosphere coupling (LAIC; Pulinets Ouzonov 2011). Following the same approach, other promising results were obtained for **12 case studies in the range of 6.1-8.3 EQ magnitude**, in the framework of the **SAFE (SwArm For Earthquake study) project funded by ESA** (De Santis et al., 2019a). In 2019, almost five years of Swarm magnetic field and electron density data were analysed with a **Superposed Epoch and Space approach** and correlated with major worldwide M5.5+ earthquakes (De Santis et al., 2019b). The analysis verified **a significant correlation between satellite anomalies and earthquakes above any reasonable doubt**, after a statistical comparison with random simulations of anomalies. The work also confirmed **the empirical Rikitake law** (1987), initially proposed for ground data: **the larger the magnitude of the impending earthquake, the longer the precursor time of anomaly occurrence in the ionosphere from satellite**. A more recent investigation (Marchetti et al., 2022) over a longer time series of Swarm data, i.e. 8 years, confirmed the same results. Furthermore, we demonstrated through several case studies (e.g. De Santis et al., 2020; De Santis et al., 2022; Akhoondzadeh et al., 2022) that **the integration with other kinds of measurements from ground, atmosphere and space** (e.g. CSES data) **reveals a chain of processes before mainshocks** of many seismic sequences. We finally propose **a two-way model** including a diffusion process in the lithosphere with almost direct (likely electromagnetic) coupling with the above atmosphere and ionosphere and another with a delayed LAIC to explain most of the found anomalies preceding large earthquakes.

1 – First application: the case of 2105 M7.8 Nepal earthquake



An anomaly was detected 11 days before the EQ

An automatic algorithm (**MASS***) calculates the first differences of the magnetic field signal then removes a cubic spline and finally detects anomalies when rms of a small window overcomes by 2.5 RMS of the whole track. **Cumulative number of anomalous tracks mimics the same of foreshocks.**

* De Santis et al. EPSL; 2017

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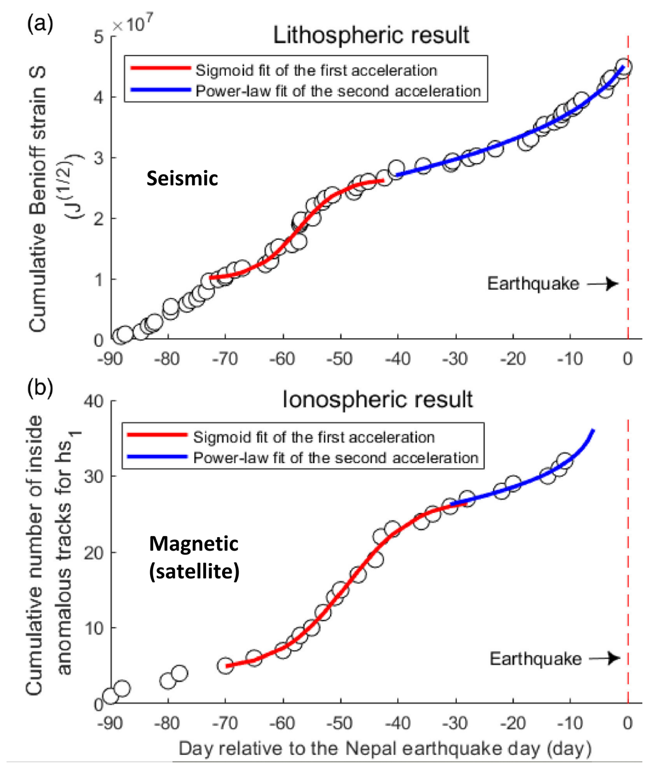
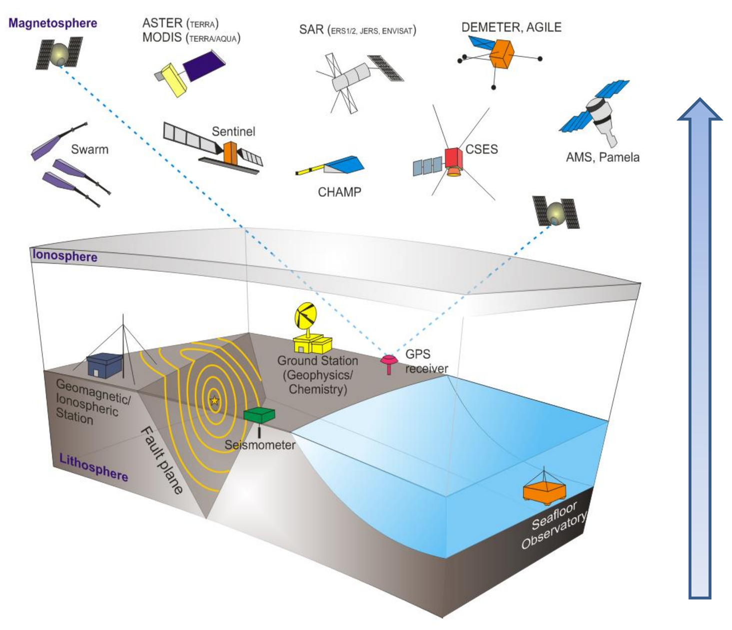
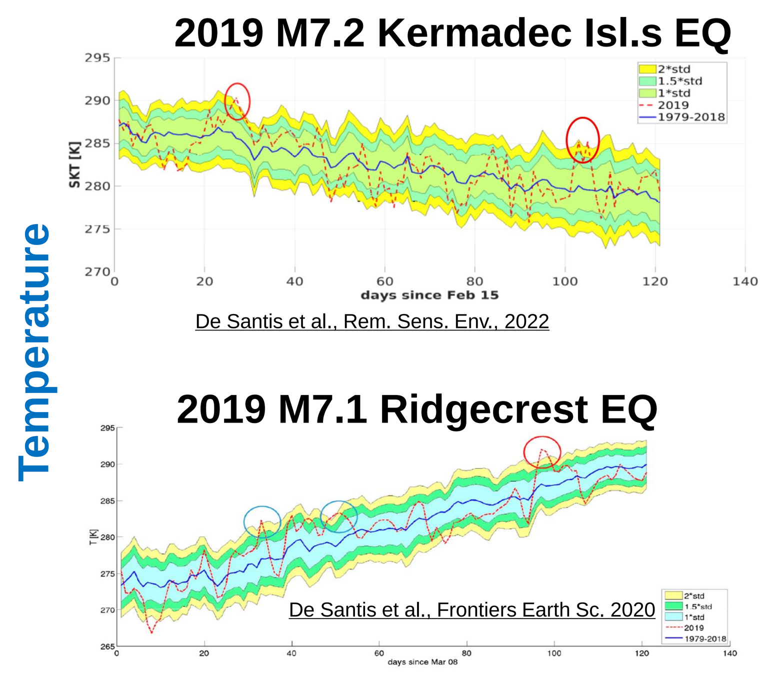


2 – An integrated multilayer-multilevel approach: some other case studies



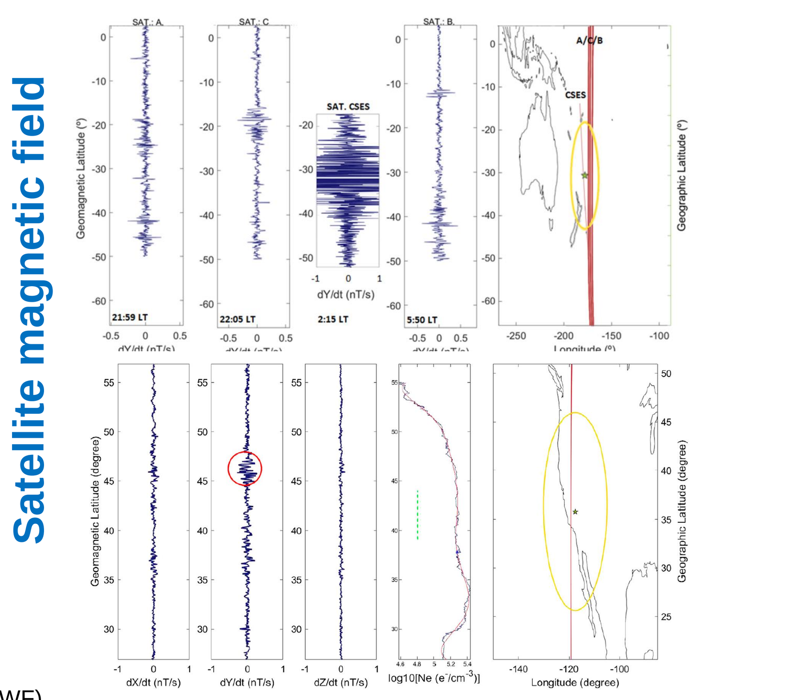
Data from different geolayers are analysed

Atmosphere investigation

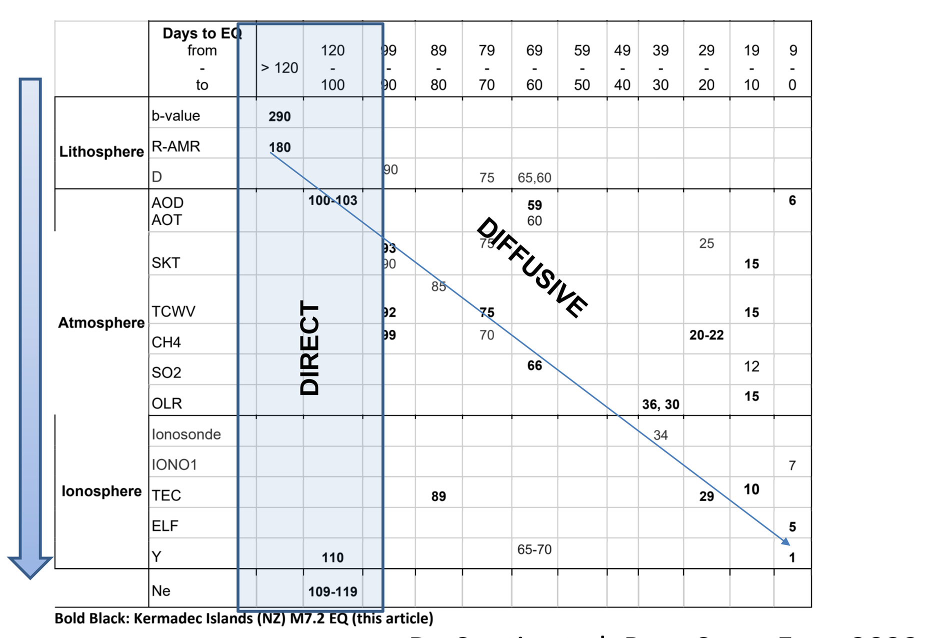


Data from the European Centre for Medium-range Weather Forecasts (ECMWF)

Ionosphere investigation



Overall behavior of anomalies



De Santis et al. Rem.Sens. Env.; 2022

3 – Worldwide statistical correlations

World Statistical Correlation (WSC) on **8 years of Swarm data** by **Superposed Epoch and Space Approach** (De Santis et al. 2019b; Marchetti et al. 2022)

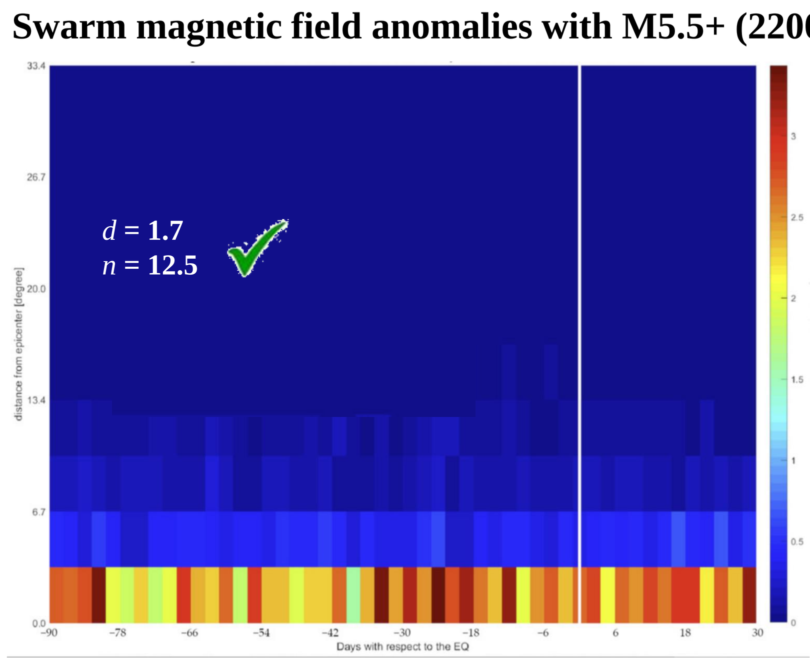
Largest concentrations of anomalies are close to epicentres and occur **10-30 and 80 days before EQs**

d= real max / random max

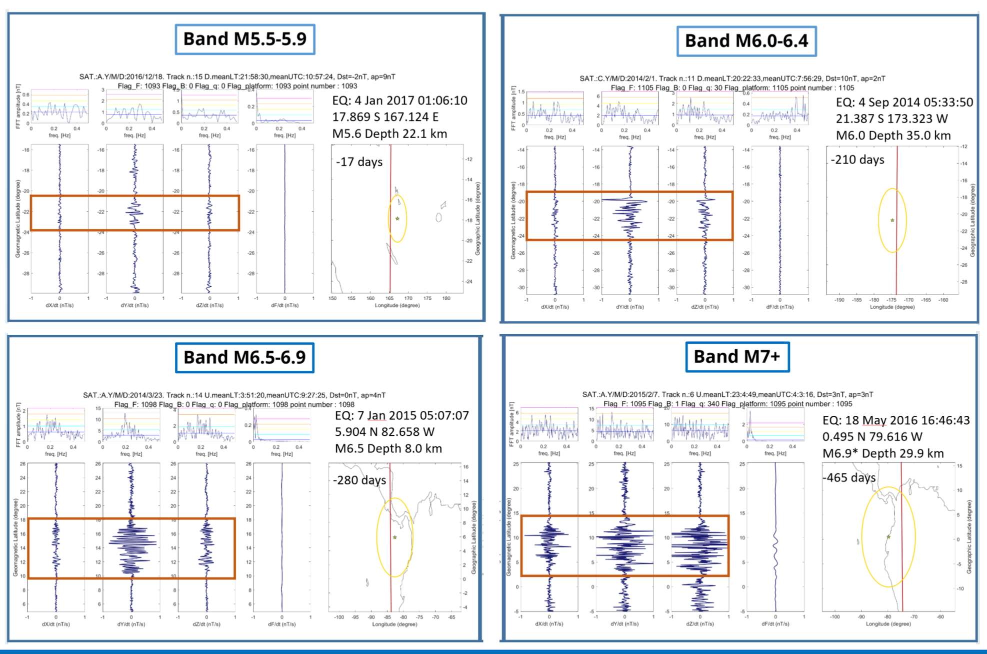
n= real st. deviation vs. random st. deviation

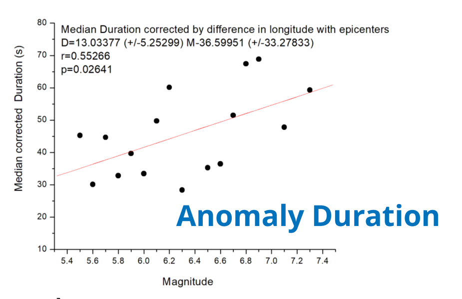
Significant results if $d \geq 1.5$ & $n \geq 4$

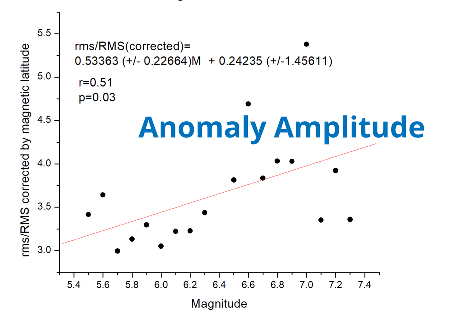
Swarm magnetic field anomalies with M5.5+ (2200) EQs



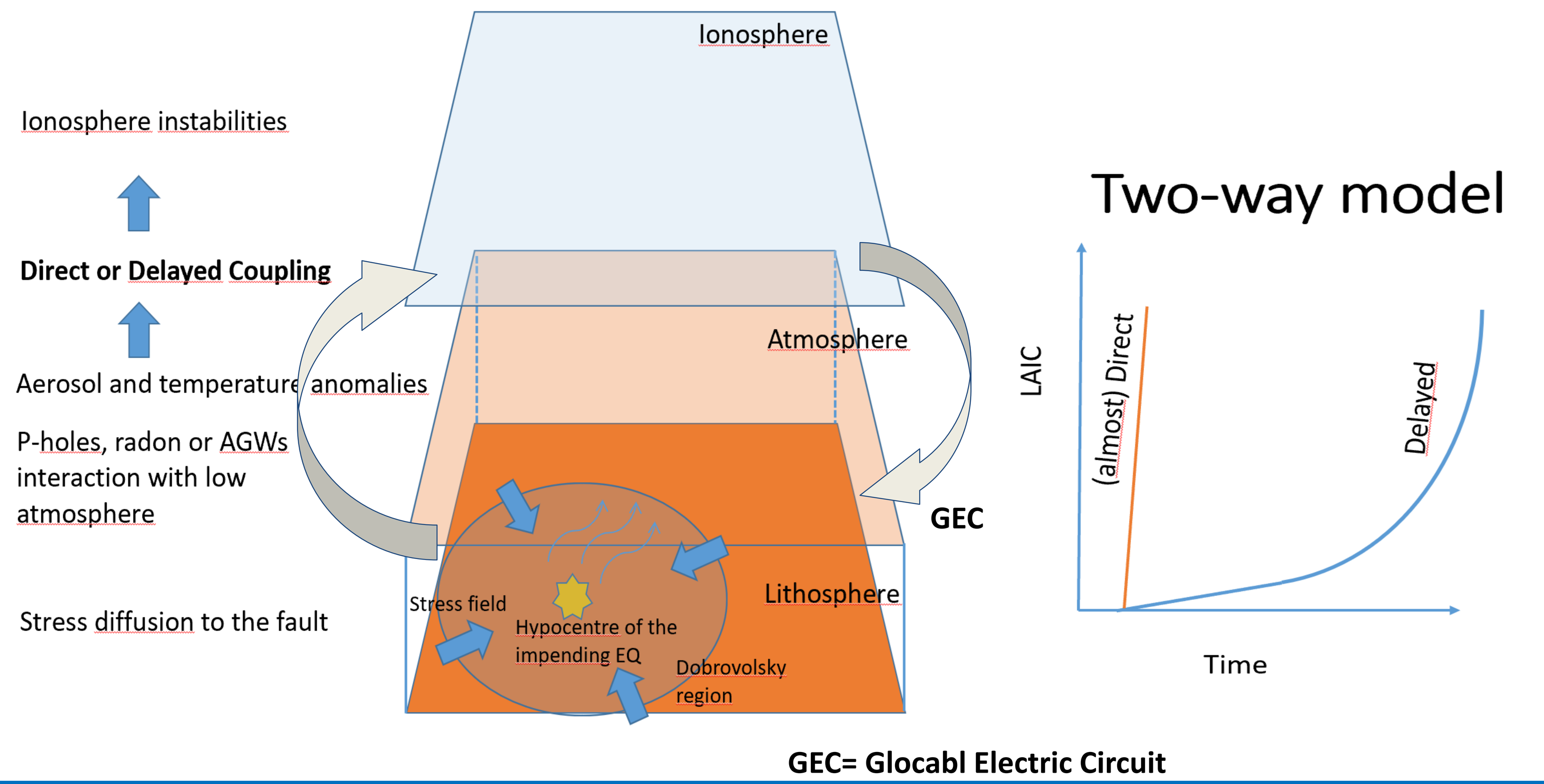
Duration and amplitude of the anomalies in the largest concentrations depend on the EQ magnitude







4 – A two-way model of LAIC



GEC= Glocabl Electric Circuit

5. Conclusions

1. **A multiparameter-multilayer approach** is important to detect the preparatory phase of a strong earthquake, in which **satellite data analyses** are fundamental.
2. Earthquake case studies show **peculiar patterns in the lithospheric, atmospheric and ionospheric anomalies**, accelerating toward the moment of the mainshock.
3. **Worldwide statistical analyses** on 8 years of Swarm electron density and magnetic field show **significant correlations with earthquakes**.
4. **A two-way model** is proposed that takes into account of the overall progression of anomalies from different geolayers.

6. References

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