Pre-earthquake signals from space

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Data from low earth orbiting satellites with detectors usually designed for specific objectives (e.g. magnetometers, Langmuir probes, high energy particle detectors, GPS, etc.), could be adapted to study pre-earthquake ionospheric anomalies. For instance, the Swarm three-satellite mission by ESA was initially designed with its original configuration to monitor and study the geomagnetic field and the state of the ionosphere and magnetosphere. For the first time, in 2017, the Swarm satellites detected some pre- and post-earthquake magnetic field anomalies on occasion of the 2015 Nepal M7.8 earthquake. Interestingly, the cumulative number of satellite anomalies and the cumulative number of earthquakes behaved similarly with the so-called S-shape, providing an empirical proof on the lithospheric origin of the satellite anomalies [1]. Following the same approach, other promising results were obtained for 12 case studies in the range of 6.1-8.3 earthquake magnitude, in the framework of the SAFE (SwArm For Earthquake study) project funded by ESA [2]. 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 [3]. 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 Rikitake (1987) law [4], 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 [5] over a longer time series of data, i.e. 8 years, confirmed the same results. Furthermore, we demonstrated in several case studies [6-7] 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 propose a diffusion process to explain most of the found anomalies.

References

[1] A. De Santis et al., "Potential earthquake precursory pattern from space: The 2015 Nepal event as seen by magnetic Swarm satellites", *Earth and Planetary Science Letters*, 461, 119-126, 2017. https://doi.org/10.1016/j.epsl.2016.12.037.

[2] A. De Santis et al., "Magnetic Field and Electron Density Data Analysis from Swarm Satellites Searching for Ionospheric Effects by Great Earthquakes: 12 Case Studies from 2014 to 2016", *Atmosphere*, 10(7), 371, 2019 https://doi.org/10.3390/atmos10070371.

[3] A. De Santis, A.; et al. "Precursory worldwide signatures of earthquake occurrences on Swarm satellite data*". Sci. Rep.,* 9, 20287, 2019b. https://doi.org/10.1038/s41598-019-56599-1

[4] T., Rikitake, "Earthquake precursors in Japan: Precursor time and detectability". *Tectonophysics,* **136**, 265–282, 1987.

[5] D. Marchetti, et al. "Worldwide Statistical Correlation of Eight Years of Swarm Satellite Data with M5.5+ Earthquakes: New Hints about the Preseismic Phenomena from Space". *Remote Sens.,* 14, 2649, 2022. https://doi.org/10.3390/rs1411264)

[6] M. Akhoondzadeh et al., "Anomalous seismo-LAI variations potentially associated with the 2017 Mw = 7.3 Sarpol-e Zahab (Iran) earthquake from Swarm satellites, GPS-TEC and climatological data", *Adv. Space Res.,* 64, 1, 143-158, 2019; https://doi.org/10.1016/j.asr.2019.03.020

[7] A. De Santis et al., "A Multiparametric Approach to Study the Preparation Phase of the 2019 M7.1 Ridgecrest (California, United States) Earthquake", *Frontiers in Earth Science*, Sec. Solid Earth Geophysics, vol. 8, 2020; https://doi.org/10.3389/feart.2020.540398