Seismic Anomaly Detection in Time Series Electromagnetic Data by the SWARM Satellites

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Abstract

It has been hypothesized that electromagnetic (EM) anomalies act as precursors to seismic activities. More recently, there have been a lot of studies regarding seismic events and their possible link with EM sequential anomalies from different sources. A lot of work has been done such as in [1], where statistical methods have been used to prove this connection. Machine learning (ML) methods were used in [2] . Here, to analyze the data we use simple and computationally efficient methods. The two proposed methods, a novel variant of Cumulative Sum (CUSUM) with Exponentially Weighted Moving Average (EWMA) and a Fuzzy Inspired Approach are evaluated under new EM observations by the SWARM satellites. Specifically we are investigating two seismic events occurred on the 6^{th} of December at 02:43 and 18:20 respectively and their possible causal links with EM anomalies.

Objectives

- Study and analyze characteristics of anomalies that are thought to act as precursors to seismic events.
- Develop, evaluate and compare new methods from different fields in detecting anomalies in time series EM sequential data.
- Identify any possible correlations between EM anomalies and seismic events.
- Investigate possible models for predicting seismic events by the analysis of the anomalies in time series data.

Methods

The CUSUM-EWMA variant:

$$C_n^+ = max[0, x_n^+ - (z_n + K) + C_{n-1}^+] \qquad (1)$$

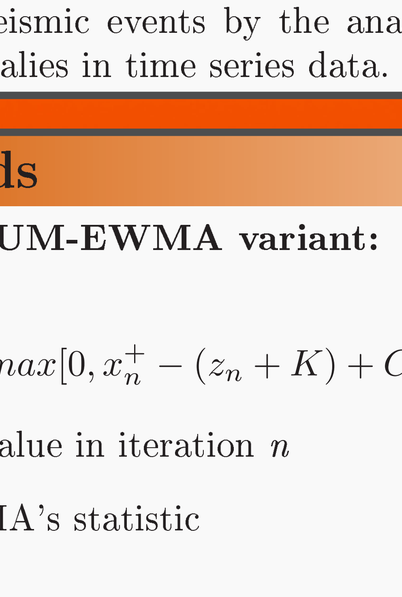
- x_n^+, value in iteration n
- EWMA's statistic

$$z_n = \lambda x_n + (1 - \lambda) z_{n-1} \qquad (2)$$

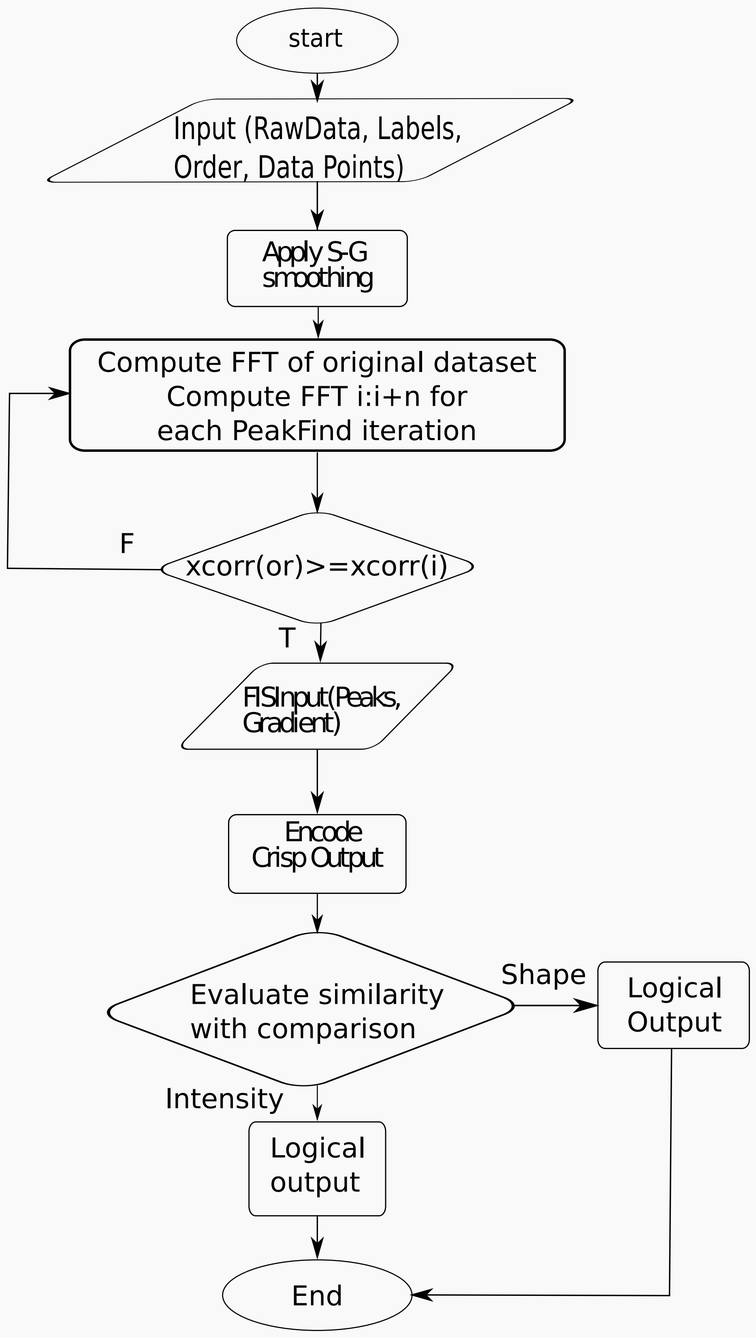
- K, slack value allowed by the CUSUM

Fuzzy Inspired Approach:
Different serialized components work towards the anomaly detection.

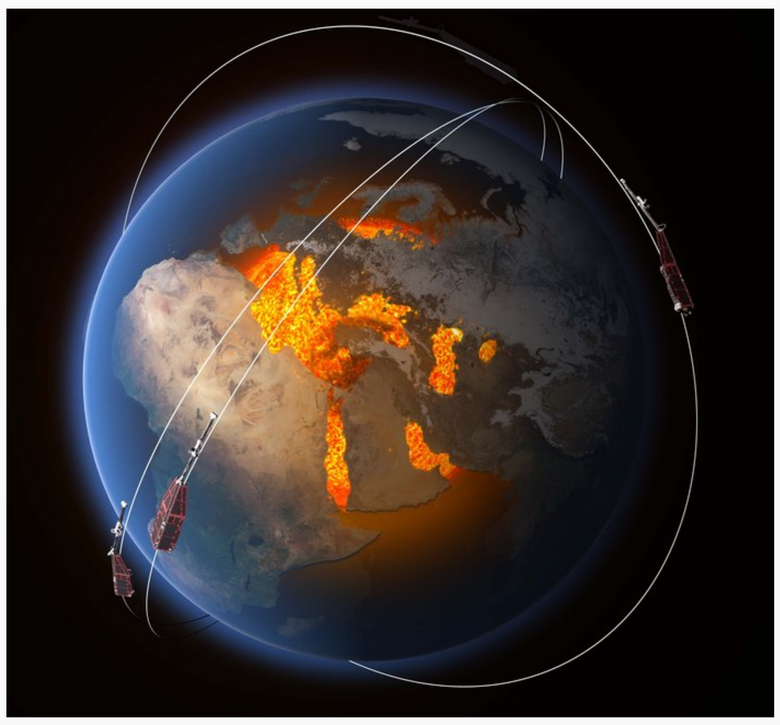
Method I: CUSUM-EWMA



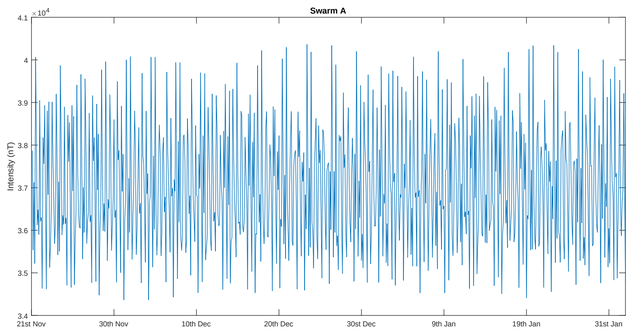
Method II: Fuzzy Inspired



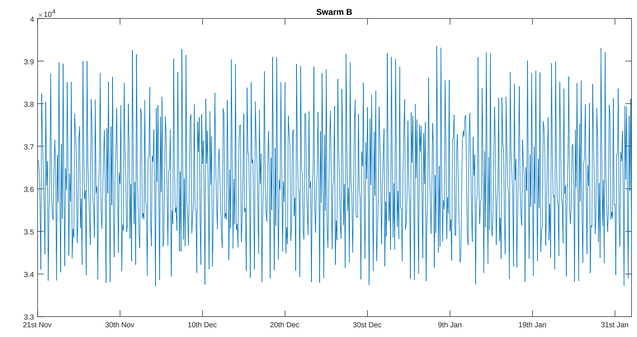
Data



The SWARM constellation of satellites, launched in 2013 to help us understand the earth's interior and its effects, consists of three identical satellites. SWARM A and SWARM B that orbit at an altitude of 450km and SWARM C at an altitude of 530km [3]. The earth's magnetic field is measured by the satellites' Vector Field Magnetometer (VFM) at a continuous per second rate. After the preprocessing the data from a total of 86400x72 were transformed to a 720x1 vector.

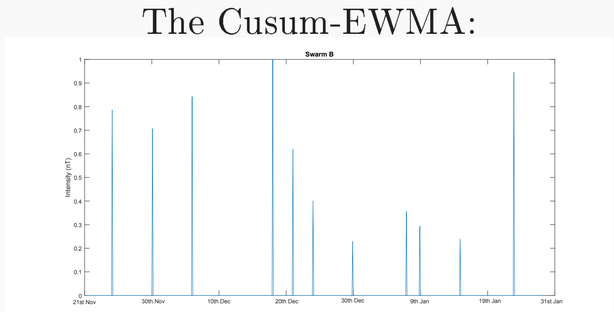


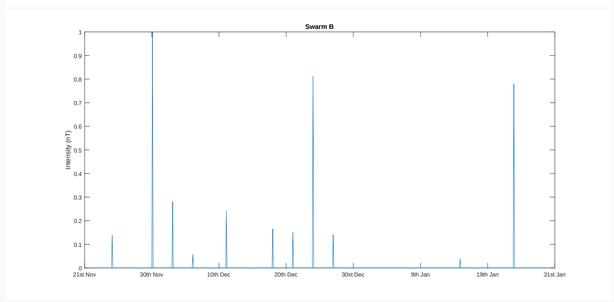
Data (Cont'd)



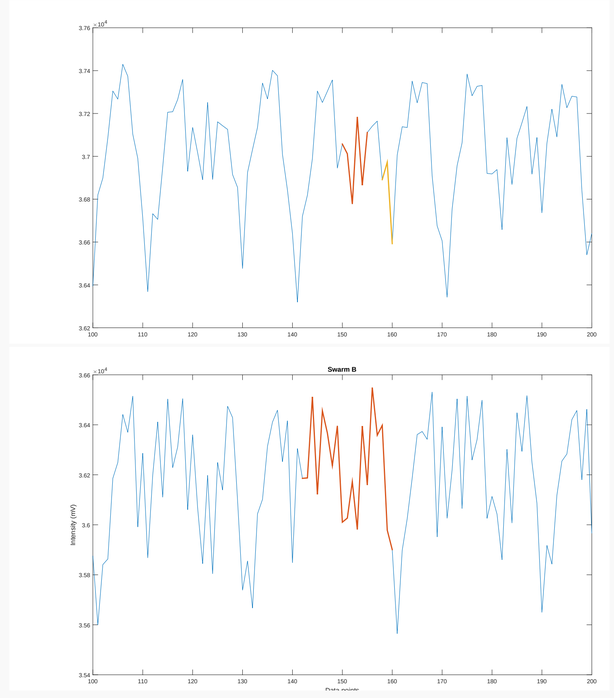
Results

The Cusum-EWMA:





The Fuzzy Inspired:



Summary

The methods can detect anomalous sequences in the dates prior and post seismic event that occur less frequently afterwards. Anomalies appear even a month after the seismic events. Although the results are promising, further work needs to be carried out in order to produce more accurate and confident results. These methods call for a deep understanding of the nature of the anomalies and investigation of any seasonality or patterns in the data. To achieve a higher order of understanding, knowledge from a range of fields has to be drawn such as Statistics, Geology, ML and Physics.

References

[1] Bi, Y. et al. *A comparative analysis for detecting seismic anomalies in data sequences of outgoing longwave radiation*, Springer, Berlin Heidelberg, (2009)

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[3] Friis-Christensen, E. et al. *Swarm: A constellation to study the Earth's magnetic field*, Earth, planets and space, (2006)