

A Statistical Study on Satellite VLF Observations during Cascading Earthquakes

Ashanthi Maxworth⁽¹⁾, Jackson Elwell⁽¹⁾, James Higgins⁽¹⁾, Jon Dyer⁽¹⁾, Jeremy Qualls⁽¹⁾, Gareth Perry⁽²⁾

Mark Golkowski⁽³⁾, and Andrew Yau⁽⁴⁾

(1) University of Southern Maine, Portland, ME, USA

(2) New Jersey Institute of Technology, Newark, NJ, USA

(3) University of Colorado - Denver, CO, USA

(4) University of Calgary, Calgary, AB, Canada

Abstract

This work presents a statistical study between satellite observed very low frequency (VLF) events and earthquakes. We have observed strong VLF turbulences under geomagnetic quiet conditions, but during cascading earthquakes, implying the possibility of a seismic – ionospheric connection, although the exact connection mechanism is yet to be identified.

1 Introduction

Earthquakes cause thousands of casualties and many millions of dollars worth of property damage every year. Therefore, there has been long interest in methods of predicting earthquakes. The first step in predicting earthquakes is finding the correct precursor signal. The scientific community has been working on identifying these seismic precursor signals in multiple frequency ranges including very low frequencies (3 kHz– 30 kHz)[1,2] Despite years' worth of studies, the topic of predicting earthquakes using VLF signals is still under debate.

In this paper, we present statistical observations of VLF emissions (especially VLF turbulences and lower hybrid resonance) during cascading earthquakes. The VLF observations were observed by the radio receiver instrument (RRI) on the enhanced polar outflow probe (e-POP)[3,4]. The earthquake data were extracted from the USGS Earthquake database [5].

2 Data

The steps involved in the data collection and data analysis process were as follows;

Step 1: extract VLF events from the satellite database.

Step 2: identify the earthquakes in the vicinity within 24

hours, corresponding to each satellite event.

Step 3: analyze spatial relationships.

Step 4: analyze temporal relationships.

The VLF signals were observed by the radio receiver instrument (RRI) on the enhanced polar outflow (e-POP) satellite. The RRI contains four 3m monopole antennas which can be configured in the monopole or dipole mode. While it is in the dipole mode, collects in-phase and quadrature data. All the observations used in this study were collected while RRI was operating in the dipole mode. From the satellite database hosted by University of Calgary [4], we extracted the VLF events which contains, VLF turbulences and lower hybrid resonance (LHR). Table 1 below records the number of VLF observations analyzed for seven years.

Table 1: Number of VLF events extracted from the e-POP database from 2014 through 2020.

Year	Number of ELF/ VLF events
2014	79
2015	85
2016	63
2017	136
2018	237
2019	340
2020	211

Once the VLF data were extracted, we queried the USGS earthquake database, for earthquakes occurring within the same day (24 hours) as the VLF observation, in a circular region with a 1000km radius centered on the geographic location of the VLF observation, and with a minimum magnitude of 2.5 [5].

3 Results

Following figures summarize the results obtained for 2014.



Figure 1: A map showing the geographical locations of satellite observations of strong VLF signals in 2014. The map shows the locations of 61 events (blue) with no associated earthquakes and 18 events with earthquakes occurred on the same day (24 hours).



Figure 2: Temporal relationship between strong VLF events and earthquakes for 2014. Red asterisk indicates the time of the strong VLF event from satellite observations. Blue vertical lines show the time-span between the first and last earthquake within 24 hours. Number of earthquakes are indicated for each day in Black.



Figure 3: Geomagnetic conditions corresponding to the 18 days of interest. The results are a mix of quiet days and disturbed geomagnetic conditions.

6 Conclusions

Our results suggest a connection between VLF turbulences and lower hybrid resonance during cascading earthquakes. One factor considered here was the planetary Kp index, which gives a measure of geomagnetic conditions. On the majority of days VLF turbulences were observed under geomagnetic quiet conditions, indicating an aftereffect from the strong cascading earthquakes. Currently, we are in the process of identifying the connective plasma mechanism between seismic and VLF events.

7 Acknowledgements

We acknowledge NASA CubeSat Core grant to University of Southern Maine.

8 References

- 1. D.I. Vavilov, D.R. Shklyar, E.E. Titova, Michel Parrot. Study of the lower hybrid resonance frequency over the regions of gathering earthquakes using DEMETER data. Journal of Atmospheric and SolarTerrestrial Physics, Elsevier, 2013, 100-101, ff10.1016/j.jastp.2013.03.019ff. ffinsu-01291266f.
- Alexander Rozhnoi, Maria Solovieva, Michel Parrot, Hayakawa Masashi, Pier Francesco Biagi, et al.. Ionospheric turbulence from ground-based and satellite VLF/LF transmitter signal observations for the Simushir earthquake (November 15, 2006). Annals of Geophysics, Istituto Nazionale di Geofisica e Vulcanologia (INGV), 2012, 55 (1), pp.187-192. ff10.4401/ag-5190ff. ffinsu-01295678tJ. Doe, "Title of paper if known," unpublished.
- Maxworth, A.; Hussey, G.; Gołkowski, M. Coexistence of Lightning Generated Whistlers, Hiss and Lower Hybrid Noise Observed by e-POP (SWARM-E)–RRI. Atmosphere 2020, 11, 177.
- James, H.G., King, E.P., White, A. et al. The e-POP Radio Receiver Instrument on CASSIOPE. Space Sci Rev 189, 79–105 (2015). <u>https://doi.org/10.1007/s11214-014-0130-y.</u>
- 5. US Database for Earthquakes <u>https://earthquake.usgs.gov/</u>, accessed on September 18, 2020.