IDENTIFYING LARGE TRANSIENTS WITHIN ARTEMIS SOLAR WIND DATA FOR NIGHTSIDE TIME DOMAIN ELECTROMAGNETIC SOUNDING

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Abstract

Mysteries regarding the Moon's internal composition persist. By studying the induced magnetic fields produced by the Moon in response to changes in the magnetic field of the surrounding solar wind, inferences can be made regarding the associated eddy currents and thus regarding the electrical conductivities of the lunar regions hosting these currents. In this manner, a greater understanding of the Moon's inner geophysical properties can be garnered. This investigative strategy, known as electromagnetic sounding, can be employed using magnetic field data from the ARTEMIS satellites, in particular, data taken from time intervals in which one satellite is within the lunar wake and 500 km of the surface while the other is immersed within the pristine solar wind and relatively far from the surface. Per Faraday's Law, the steeper the magnetic transient from the solar wind, the greater the current induced within the Moon, and per Ampère's Law, the greater this induced current, the larger the magnetic field it produces. Larger signals generally feature higher signal-to-noise ratios (SNRs). Thus, larger transients tend to produce more valuable data in terms of sounding. The enhanced separation between reaction signal and source signal via the aforementioned positioning of the probes during time intervals of interest augments the SNRs as well.

Here we discuss a tool developed in Python (making use of the PySPEDAS package [1]) that expedites the task of identifying large magnetic transients within these time frames of interest. These exceptional changes in magnetic field are then evaluated for use in electromagnetic sounding as described above. We have identified 51 major transient events (during times of interest) from 8/1/2011 to 7/31/2021. One key hurdle we overcame was identifying and navigating data gaps. These data gaps would occasionally interfere with our time intervals of interest, necessitating an algorithm to avoid them.

Background & Motivation

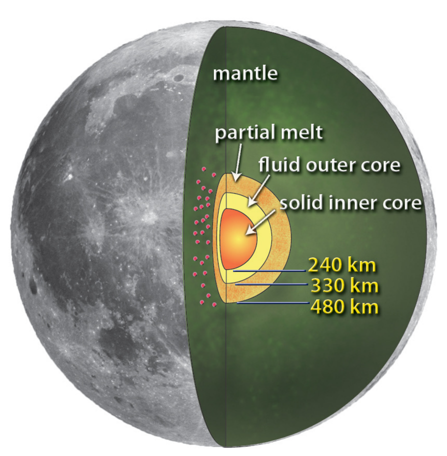

Figure 1. A summary of the lunar interior based on Apollo seismic analyses. [2]

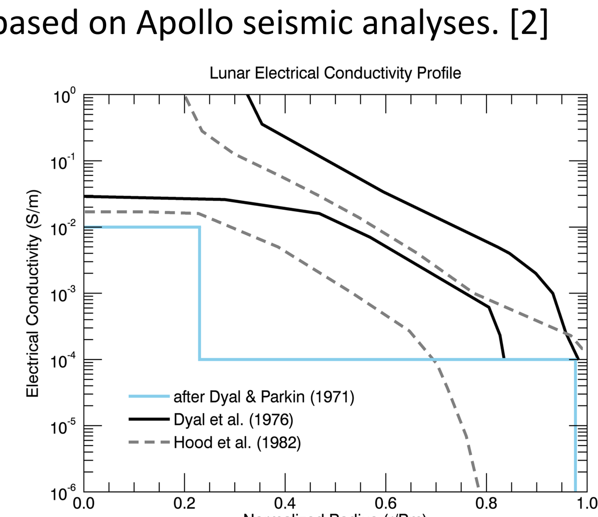

Figure 2. Summary of observed lunar conductivity profiles from Apollo magnetometer. Blue profile indicates 3-layer model. [3]

- By studying the induced magnetic fields produced by the Moon in response to changes in the magnetic field of the surrounding solar wind, inferences can be made of the electrical conductivities of the lunar regions hosting these currents. This is known as **Electromagnetic Sounding**.
- Per Faraday's Law, the steeper the magnetic transient from the solar wind, the greater the current induced within the Moon, and per Ampère's Law, the greater this induced current, the larger the magnetic field it produces. Larger signals generally feature higher signal-to-noise ratios (SNRs). Thus, larger transients tend to produce more valuable sounding data.
- Unfortunately, locating promising magnetic transients in the data can be a painstaking process, with the current state of the art being identification by eye. It is desirable to develop an automated system by which potentially beneficial transients can be detected in the data given time intervals of interest.

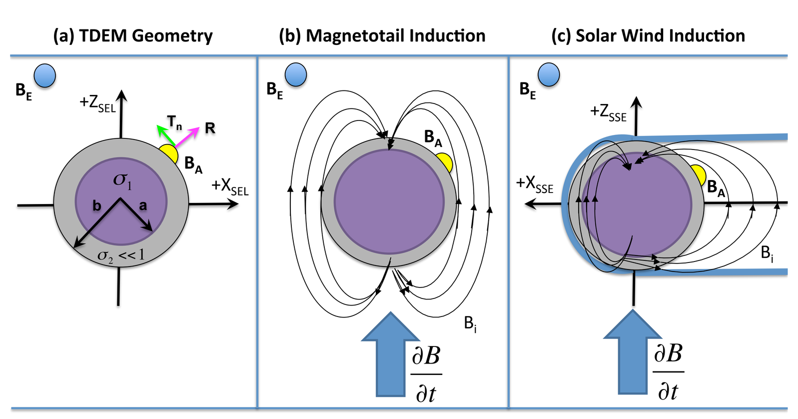

Figure 3. (a) Time Domain Electromagnetic (TDEM) Sounding requires an observer at or near the lunar surface (B_A) and a reference well outside of lunar effects (B_E). The induced magnetic field, B_i , opposes the external field, B_E. Boundary conditions vary: (b) vacuum, (c) Solar wind varies day and night-side confinement. [3]

Methods

- Data from the ARTEMIS satellites are used (Figure 4).
- Of primary interest are data taken from time intervals in which one satellite is within the lunar wake and 500 km of the surface while the other is immersed within the pristine solar wind and relatively far from the surface (Figures 3c & 5).
- Our code was written in Python. It utilizes the PySPEDAS package (contains tools designed for ARTEMIS data) [1].
- One key hurdle we overcame was identifying and navigating data gaps (Figure 6). These data gaps would occasionally interfere with the time intervals of interest, necessitating an algorithm to avoid them.

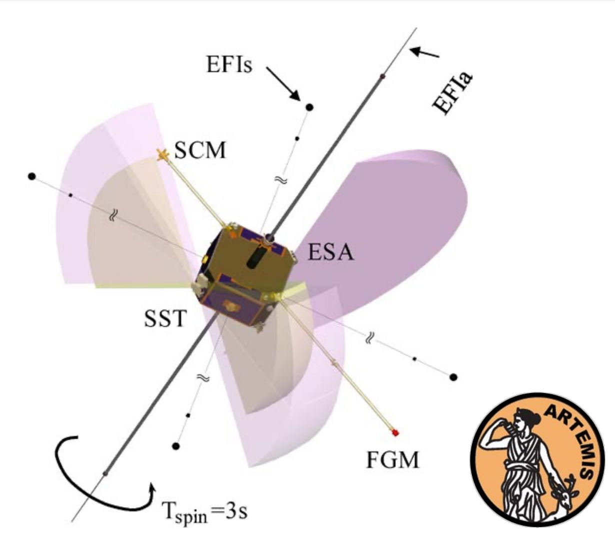

Figure 4. We use data from ARTEMIS's fluxgate magnetometer, or FGM. [4]

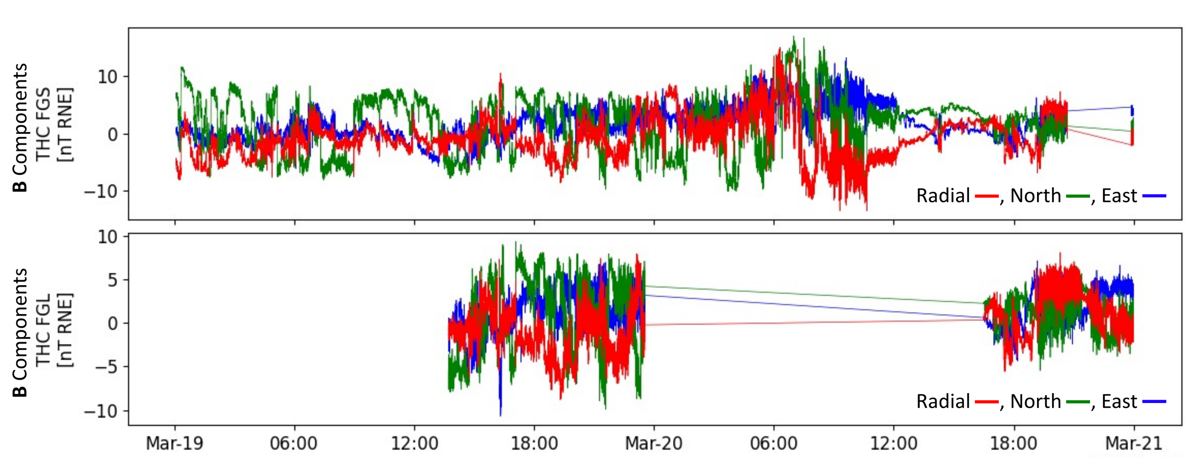

Figure 6. Fortunately, when there was a gap in FGS magnetic field data (favored data type), FGL data usually did not have a gap.

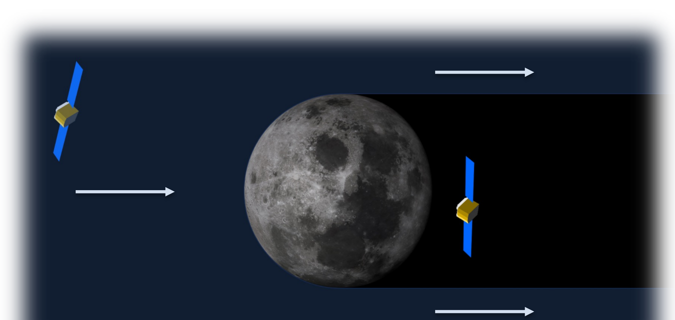

Figure 5. These probes are well-positioned for sounding (arrows show direction of the solar wind) [5].

Results

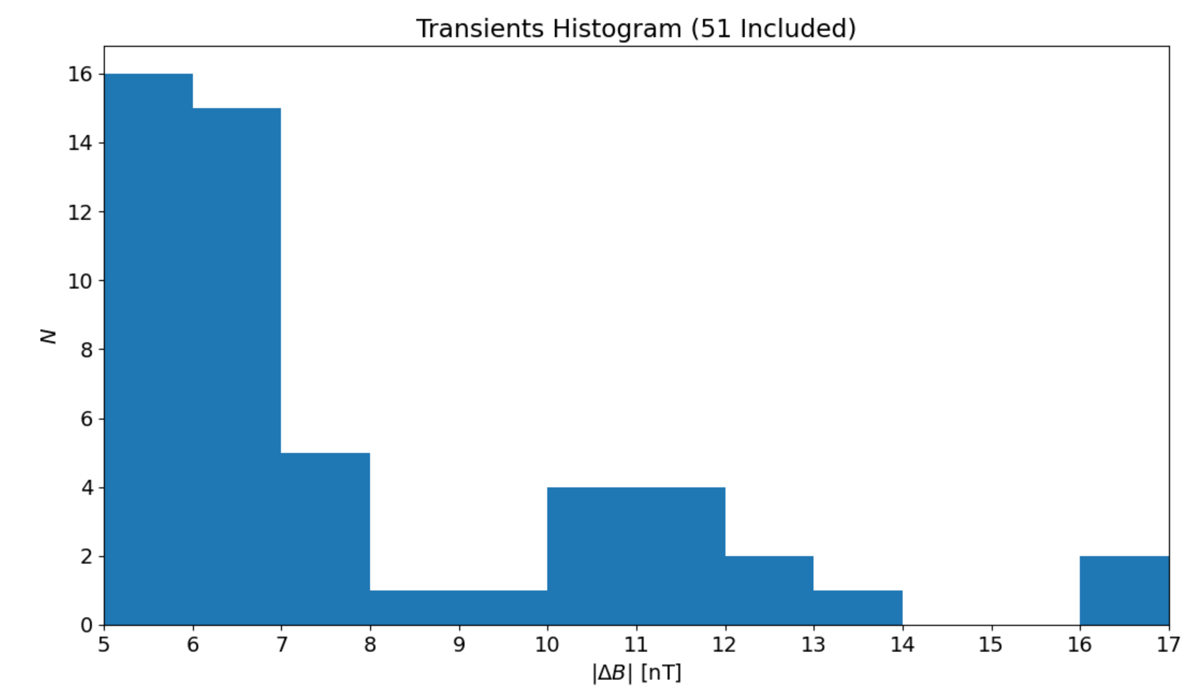

Figure 7. We found 51 magnetic transients within time intervals of interest with magnitudes of at least 5 nT.

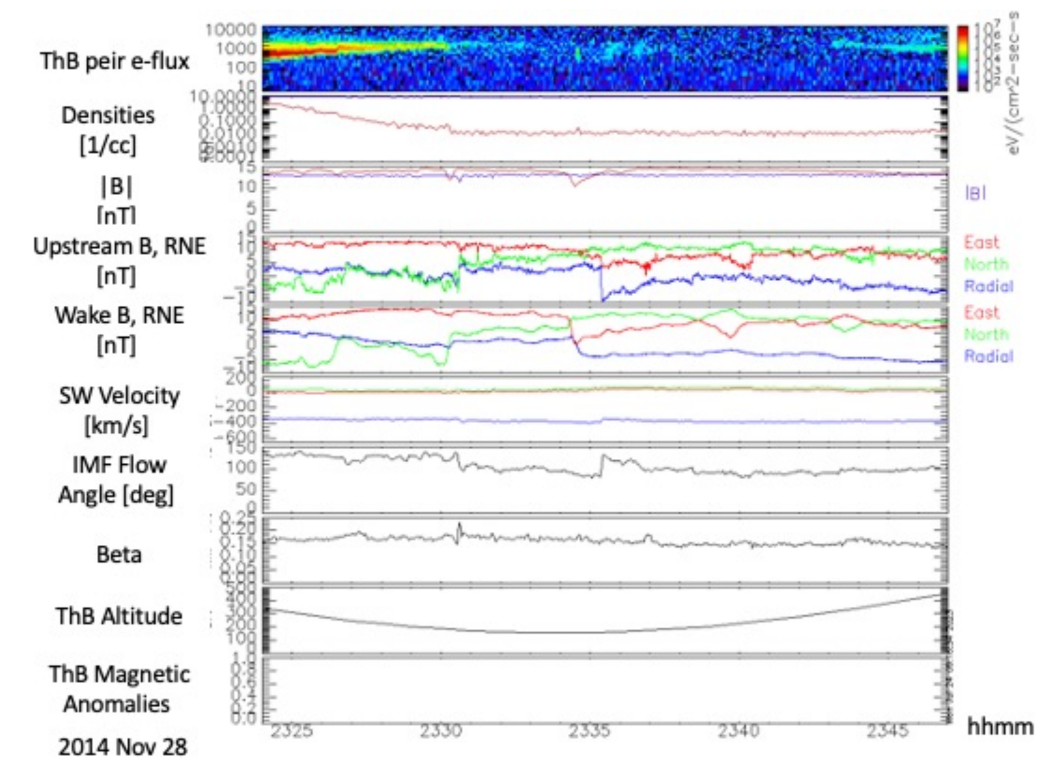

Figure 9. Wake summary fields showing the plasma and fields for context for the event depicted at the top of Figure 8.

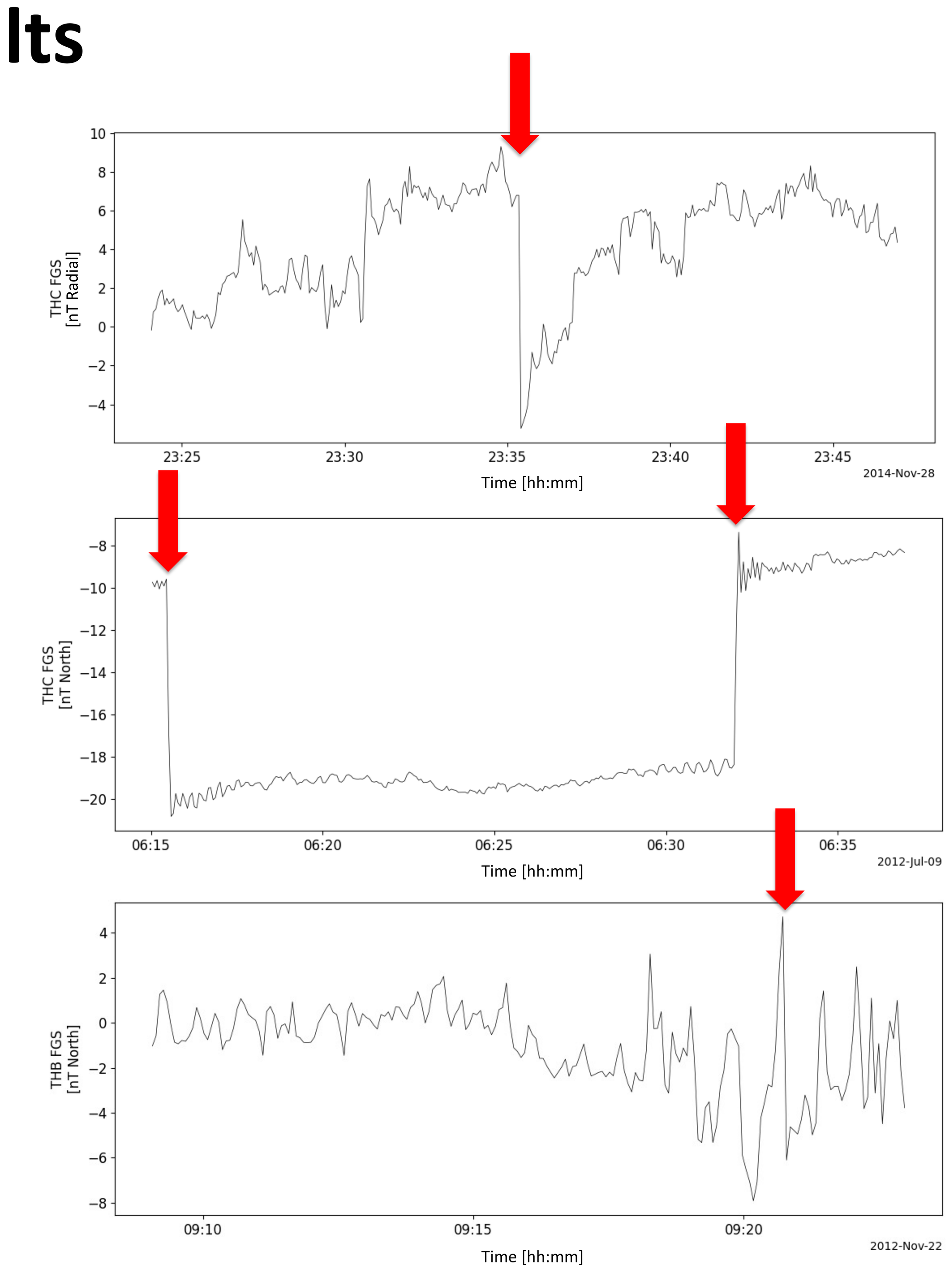

Figure 8. Bottom: The main transient showcased here is not particularly useful for sounding. Indeed, the smaller magnetic field changes surrounding the main ~11 nT transient are of comparable size. Middle: The two clean, ~11 nT transients found here, within the same time interval of interest, are especially promising for sounding. The surrounding magnetic field remains relatively calm (changes are mostly small relative to the main two transients). Top: The main ~12 nT transient displayed in this plot also carries notable sounding potential. The magnetic field changes around the main transient are larger than in the previous case; however, they do not threaten to eclipse said transient. Additional context is provided for this transient in Figure 8.

Future Work

- Some of the more promising signals we have identified will be analyzed for sounding (modeling work) [3,6].
- ARTEMIS is active (satellites have longevity), providing new data every day; thus, our tool can be reapplied frequently.
- Our codes (transient-finding tool and modeling codes) can be applied to other time periods of interest (e.g., probes and Moon within Earth's magnetotail [Figure 3(b)]).

Summary

- The interior of the Moon can be probed via Lenz's Law (which is the geophysical technique of Electromagnetic Sounding).
- Larger, isolated changes in the solar wind's magnetic field are more promising for sounding.
- Our code serves to help identify these large (|slope| ≥ 5 nT / 4 s over ~4 s or ~8 s) changes more expediently.

References and Acknowledgements

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