The ISS Magnetometer Interferences: A Simple Idea that Might Just Work

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Abstract

"Can storms interfere with a magnetometer in space? A strange idea, but not so absurd."

When we think of storms, we imagine lightning, strong winds, and atmospheric turbulence, but we rarely consider their potential impact on the magnetic field detected from space. Yet, our research stems from this unusual question: can storm clouds beneath the International Space Station (ISS) generate magnetic interferences detectable by onboard sensors?

To investigate this hypothesis, we analyzed ISS magnetometer data and compared it with the presence of large cloud systems below, including storms with and without lightning, intense atmospheric disturbances, and clouds with a high charge content. The goal was to identify anomalies in the magnetic field that might correlate with these phenomena. Through data analysis and noise filtering techniques, we observed intriguing correlations, including a magnetic anomaly recorded as the ISS passed over an extensive storm system. Coincidence or a real signal?

This study does not claim to provide a definitive answer but opens the door to a little-explored phenomenon. If storms can disrupt the Earth's atmosphere, could they also leave a magnetic footprint detectable from space? Sometimes, exploring the improbable leads to unexpected discoveries.

1 Introduction

1.1 The context and the scientific question

The instruments onboard the International Space Station (ISS) are designed to operate in a relatively stable environment, far from the magnetic interferences typically found on Earth's surface. However, the ISS constantly flies over vast atmospheric regions, including large storm systems. This led us to an unusual question: can storms on Earth generate magnetic interferences detectable from space?

1.2 Why suspect a correlation?

Storm clouds are not just visible meteorological formations; they contain intense electric fields, moving charges, and, in some cases, large-scale electrification phenomena. Some studies suggest that atmospheric processes, such as charged convective currents or interactions with the ionosphere, may have effects at the magnetic level. But do these influences extend as far as the ISS's orbit? And if so, can we measure them?

1.3 From idea to the ISS: selection in the AstroPi program

This question found a concrete opportunity for testing through AstroPi, a competition organized by the European Space Agency (ESA) that allows young students to develop scientific experiments executable directly onboard the ISS. Our proposal was recognized as innovative and scientifically relevant enough to be selected among the projects to be developed, uploaded, and executed in orbit. This allowed us to transform a theoretical idea into a real space experiment— a rare and prestigious opportunity to test our hypothesis in the unique environment of Earth's orbit.

2 Software design

When designing the software for our experiment, our primary goal was to collect, process, and store magnetometer data from the ISS while simultaneously capturing images of the Earth's surface. Instead of performing complex data processing onboard, we prioritized efficient data acquisition and storage, ensuring that all measurements could be analyzed later in correlation with atmospheric conditions.

2.1 Data sources and instrumentation

The software was designed to interface with multiple data sources onboard the ISS:

- Magnetometer (Sense HAT sensor): Measures raw magnetic field components (X, Y, Z).
- Pi Camera: Captures images of the Earth's surface to analyze cloud coverage.

- ISS orbital position (from orbit library): Retrieves real-time latitude and longitude of the ISS to georeference each data point.

2.2 Data collection workflow

The program followed a structured loop to ensure continuous and synchronized data logging over a period of nearly three hours:

- Retrieve magnetometer data: The magnetometer's raw X, Y, and Z values were recorded.

- Determine the ISS position: The real-time latitude and longitude of the ISS were retrieved to associate each measurement with a precise location.

- Capture and process ground images: The Pi Camera captured images of the Earth's surface. A cloud mask processing algorithm was applied to detect the percentage of cloud coverage in the frame.

The magnetometer readings, ISS coordinates, and cloud coverage percentage were stored in a CSV file for post-mission analysis.

3 Running the experiment on the ISS

After the software was fully developed and tested, it was submitted to the European Space Agency (ESA) for pre-flight validation. This step ensured that the experiment complied with all safety and operational requirements necessary for execution onboard the International Space Station (ISS).

Once ESA approved the software, it was uploaded to the ISS and executed as planned. The program successfully ran its mission, collecting magnetometer data and capturing images of the Earth's surface according to the designed data acquisition workflow. Here are some of the most captivating images taken from space during the experiment:

Figure 1: Image of Australian coast line captured during the mission.

Figure 2: Image of Turkey captured during the mission.

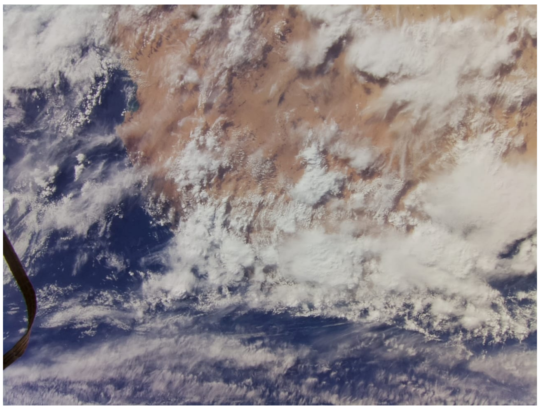

Figure 3: Image of northern Africa captured during the mission.

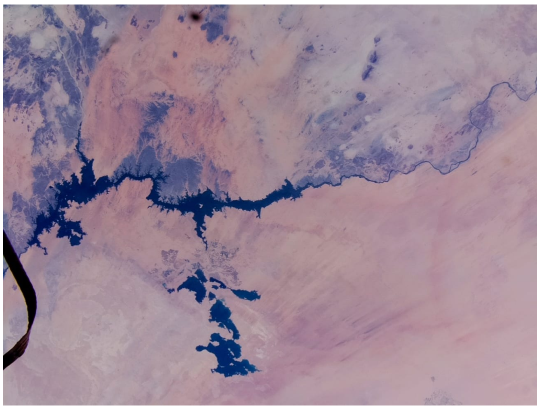

Figure 4: Image of the Nile river captured during the mission.

4 Data analysis approach

The data analysis focused on two main objectives: identifying magnetic field anomalies that could not be explained by the normal orbital behaviour of the ISS and verifying whether these anomalies could be correlated with storm systems below.

4.1 Processing the magnetometer data

Ideally, the magnetic field measured by the ISS should follow a smooth and continuous curve, without sudden directional changes or abrupt variations. This is because the ISS orbits Earth with a stable and constant motion, free from rapid accelerations or attitude shifts that could cause sharp fluctuations in the recorded magnetic field. Any significant deviation from this expected pattern could therefore indicate external interferences.

To model this expected trend, a Savitzky-Golay filter was applied, generating a polynomial fit to the recorded data. This method was chosen for its ability to smooth out noise while preserving the underlying structure of the signal, which, in this case, should reflect the regular and predictable variations of the magnetic field along the orbit. The resulting model provided a reference for the expected behaviour of the magnetic field, free from unexpected fluctuations or distortions.

The recorded signal was then compared to this theoretical model by calculating the difference between the actual data and the polynomial fit. This process allowed us to isolate anomalous variations, appearing as deviations from the expected baseline. To further highlight these fluctuations, the residual signal was amplified and plotted separately, making it easier to identify significant anomalies.

4.2 Analysis of atmospheric conditions

To better understand the possible causes of the detected magnetic anomalies, the images captured during the flight were analyzed, focusing on the presence of large and dense cloud formations. The goal was to determine whether the variations in the magnetic field recorded by the ISS could be associated with specific atmospheric structures below.

This analysis was supported by the data processed in real-time onboard, where the software applied a mask to quantify the cloud coverage in the captured images. This processing step helped refine the visual interpretation, making it possible to precisely identify areas dominated by large-scale storm systems and distinguish them from regions with fragmented or minimal cloud cover.

5 Discussion of results

Using the techniques described in the data analysis approach, we identified multiple instances of magnetic interference throughout the dataset. After highlighting the most evident anomalies, we examined the corresponding images and cloud masks taken at the same timestamps.

From the very beginning, a clear pattern emerged: the intensity of the magnetic disturbances tended to increase or decrease in sync with the density and extent of large-scale cloud systems below the ISS. This correlation became particularly striking when analyzing the most prominent interference event recorded. At the corresponding timestamps, the images revealed a massive, circular cloud system covering an extensive region. At first glance, its structure and scale strongly resembled that of a hurricane.

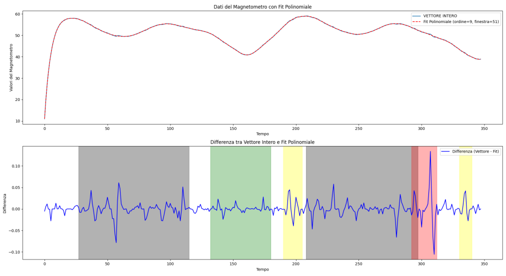

Figure 5: Visualization of the extracted magnetic interferences from the ISS magnetometer data. Significant anomalies are highlighted in color: green for weak, yellow for moderate, and red for strong interferences. Black areas indicate nighttime periods during the mission, where visual confirmation of cloud systems was not possible.

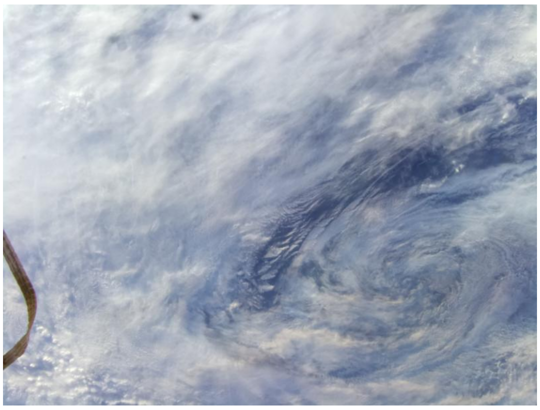

Figure 6: Image captured from the ISS showing a large circular cloud system.

5.1 Analysis of the circular cloud system

To better understand the characteristics of this cloud system, we first estimated its dimensions. By analyzing subsequent frames, we identified a fixed land reference in France, visible both in the images and confirmed by GPS data. Using this as a scale, we determined that the central region of the cloud system spanned approximately 250 km in diameter, confirming its substantial size.

Following this, we examined historical hurricane archives to check if one had been recorded in the same location on the date of our observation. However, no official records indicated the presence of a hurricane in that area at that time. Given its structure and remarkable size, we classified it as a mesoscale convective system (MCS) with a circular shape, a large storm system capable of generating significant atmospheric disturbances.

5.2 Investigating other possible causes of the magnetic interference

To rule out external factors unrelated to the MCS, we conducted an extensive search for alternative sources that could explain the detected magnetic anomaly. One of the primary aspects investigated was space weather activity, as geomagnetic storms or solar activity could potentially influence onboard instruments.

We reviewed multiple datasets related to space weather conditions, including solar wind data, geomagnetic indices (such as Kp and Dst), and recorded solar flares during the mission period. None of these indicators showed anomalies or disturbances that could correlate with the observed interference. Additionally, no sudden variations in the ISS's onboard systems or its orbital parameters were detected at the time of the event.

Given the absence of any known external disturbances, the magnetic interference recorded during the experiment appears to be directly associated with the presence of the MCS rather than being caused by broader space weather phenomena or instrumental malfunctions.

5.3 Additional Cases of Magnetic Interference

Even at lower intensity levels, the detected magnetic interferences still appeared to be linked to large-scale convective systems below the ISS. The following images correspond to moderate (yellow) and weak (green) interference events, further illustrating this recurring pattern.

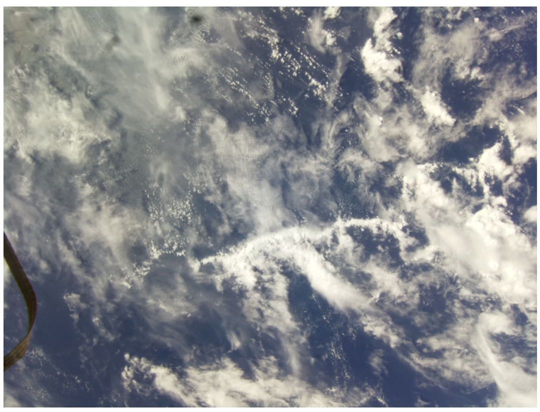

Figure 7: Image captured during a weak (green-band) magnetic interference period. No significant cloud systems detected.

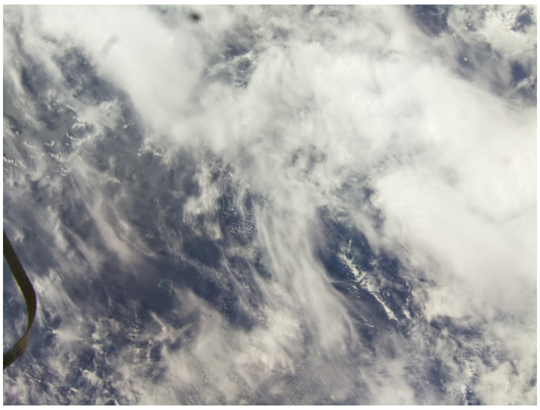

Figure 8: Image captured during a weak (green-band) magnetic interference period. A small cloud system is visible.

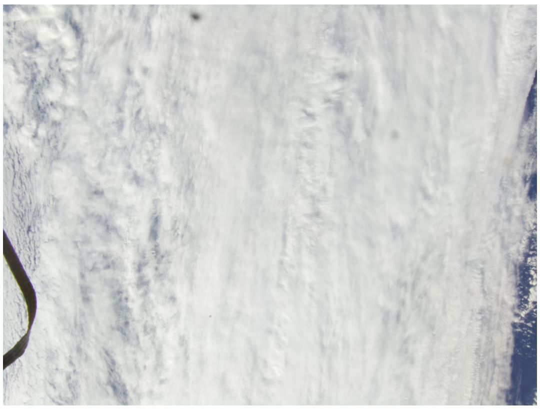

Figure 9: Image captured during a medium (yellow-band) magnetic interference period. A large, elongated mesoscale convective system (MCS) is visible, suggesting the presence of strong winds.

5.4 What science says about MCSs and magnetic disturbances

Many studies have explored how mesoscale convective systems (MCSs) interact with the ionosphere, and while we won't pretend to be pioneers in space-atmosphere coupling, some of these findings align surprisingly well with what we observed.

Research has shown that MCSs can generate gravity waves and pressure disturbances due to their intense convective activity, strong winds, and rapid pressure variations. These disturbances propagate upward, altering the Total Electron Content (TEC) of the ionosphere. A study published in Atmospheric Chemistry and Physics (Bock, Nuret, 2019) examined how MCSs in West Africa influenced GPS tropospheric estimates, revealing that these systems can introduce measurable atmospheric perturbations that extend well beyond the lower atmosphere.

Further research has demonstrated that MCSs can generate electromagnetic effects that propagate into the ionosphere. Füllekrug and Fraser-Smith (1998) analyzed how electric fields produced by MCSs contribute to mesoscale electrodynamics, reinforcing the idea that these convective systems might impact the ionospheric environment. Similarly, a study in Advances in Atmospheric Sciences (Su et al., 2017) investigated an MCS that produced a sprite (a transient luminous event in the upper atmosphere), demonstrating how convective systems can excite electrical activity extending into higher layers of the atmosphere.

Another key study published in Earth, Planets and Space (Nishioka et al., 2013) explored how acoustic-gravity waves generated by convective storms influence the ionosphere, showing that the disturbances created by large thunderstorms—including MCSs—can significantly impact TEC values and ionospheric conditions.

Now, we're not claiming to revolutionize space weather science here—we're just connecting a few dots. We don't yet have the expertise (or the prestige) to make grand declarations, but existing research suggests that what we detected might not be a coincidence. Given that MCSs have already been shown to interfere with GPS signals and electromagnetic wave propagation, their potential role in influencing magnetometer readings aboard the ISS is at least worth further investigation.

6 Resources

- *Bock, O., Nuret, M. (2019). Sensitivity of GPS tropospheric estimates to mesoscale convective systems in West Africa. Atmospheric Chemistry and Physics.*: link to research

- *Füllekrug, M., Fraser-Smith, A. C. (1998). On the calculation of electric fields and currents of mesoscale convective systems.*: link to research

- *Su, H., Liu, X., Chen, L. (2017). Analysis of a mesoscale convective system that produced a single sprite over Northeast China. Advances in Atmospheric Sciences.*: link to research

- *Nishioka, M., Saito, A., Tsugawa, T. (2013). Observations of acoustic-gravity waves in the ionosphere generated by convective storms. Earth, Planets and Space.*: link to research

Acknowledgment on AI assistance

This document was written with the assistance of ChatGPT, used as a tool to enhance clarity and fluidity in presenting a complex topic.

However, the research, data analysis, interpretations, and scientific conclusions presented here are entirely the result of our own work. The role of AI was limited to refining the writing style and improving readability, while all technical content, ideas, and findings are original and derived from our research efforts.