NASA Space Apps Challenge 2023

São José do Campos - Brazil

Challenge:

"MAGNETIC RECONNECTION"

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HELYZE
Spectrographic Analysis of the Magnetic Reconnection

INTRODUCTION

The most important goal of the Magnetic Reconnection (MR) Challenge is to develop a computer program for the public that performs statistical and/or spectral analysis of the vector components of the Interplanetary Magnetic Field (IMF) measured by the ACE, WIND, and DSCOVR missions to discover how often MR occurs on our planet and also how frequently it affects society technology as, for example, Satellites and the Power Grid of the word.

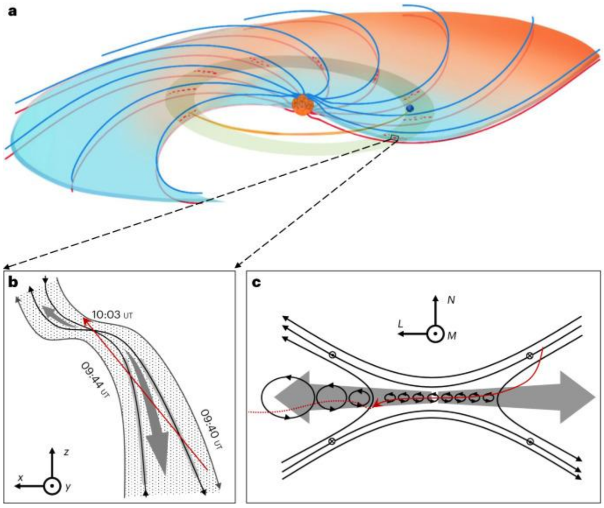
We chose this challenge because it represents a problem that has grown a lot over time: magnetic reconnection interference in satellites orbiting the earth, which we use in countless ways. The occurrence of reconnection in the earth's atmosphere mainly affects power grids and satellites mostly related to geolocation and telecommunications systems.

For Solving the problem we have searched for the data of the missions and seek to understand how the coordinates of the geocentric coordinate system work and which vetorial component was the most important to analyze: Bz. When the values are negative, it indicates the occurrence of the event. Finally we compared all the data relative to those years the three missions were working together, 2016, 2017, 2018, 2019, 2020, 2021.

The theoretical base for this work was to understand what were the missions that we will work on so we could have a solid understanding about what the data is about. All those missions are located in or near Lagrange points, which are positions in space where the gravitational force between two massive bodies are stable and the centripetal force is precisely the value for a small object to move along with those massive bodies, there is five Lagrange points, three unstable (L1, L2 and L3) and two stable (L4 and L5). ACE is in L1, approximately 1.5 million kilometers, as well as WIND and DSCOVR.

When we knew where those missions were in space we could start to understand what kind of data was received. Interplanetary magnetic field (IMF) is not a stable event in relation to the position because of the solar rotational and its harmonics, as described in illustration below.

Figure 1. Effect of the solar rotational over magnetic field.



Source: WANG, R. WANG, S. et al.

The IMF is the critical factor that determines major space disturbances around Earth, it is developed from the coronal mass ejections (CMEs) from the Sun, which carry a magnetics component with a large southward component, it causes magnetic storms through magnetic reconnection with Earth's magnetic field. It can happen even in scenarios with no major CMEs occurrence; the southward IMF's component can be supplied in other ways.

It was expected to be non-deterministic behavior of the IMF components because of the nature of the solar surface. This variational way of being affects beyond the heliosphere and it affects the IMF polarity near the Earth. The Bx and By components should reflect the distribution of the coronal source and they can be seen in both GSE and GSM coordinate systems. The coronal source also affects the Bz IMF periodicity; which is the one in which most of the ionized particles from the Sun interact with Earth's atmosphere. To analyze this event we should pay attention to the Russel McPherron effect.

So understanding these effects and how they work we focus to isolate the data from possible noise and see the results in the Bz component in a GSM system.

THE EFFECTS OF THE SOLAR STORMS

Solar Storms are important events to analyze while our focus is to understand the dynamics and the interactions between the Sun and the solar system and to study the heliodynamics and how it works and affects our lives here on earth. During the periods of greater activity the effects the solar storms cause on earth are evident for example: the increasing on the occurrence of The Northern Lights, blackouts in the radio communication systems, the increased flicker effect in GPS signals, the increased drag force on Satellites reducing their speeds and, consequently, the altitude of their orbits.

Besides these effects, as we saw, there are a lot of problems related to the Solar Storms and, as we searched, by knowing and understanding it and how it works and happens, we can understand how often these phenomena happen

THE DATA

The dataset cut used was downloaded from the Goddard Space Flight Facility's OMNIWeb, and is specifically obtained through "interfaces for comparing multi-source data", where there is the merged magnetic field and plasma dataset.

In this dataset there are the measurements of the Bz component of the IMF vector, on the GSM coordinates, throughout the years made by the spacecrafts ACE, WIND and DSCOVR.

Table 1. Datasets applied.

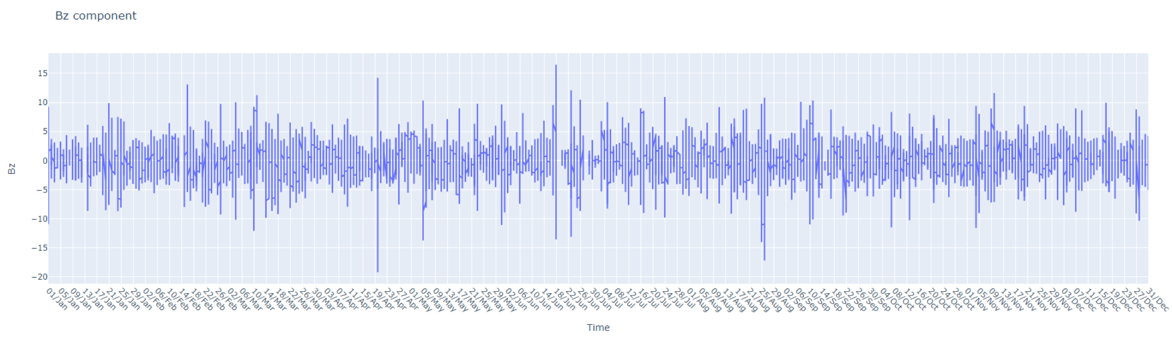
Year	Coordinates System	Mission	Star	Stop
2016	GSM	ACE	06/08	12/08
2016	GSM	DSCOVR	06/08	12/08
2016	GSM	WIND	06/08	12/08
2017	GSM	ACE	01/01	12/31
2017	GSM	DSCOVR	01/01	12/31
2017	GSM	WIND	01/01	12/31
2018	GSM	ACE	01/01	12/31
2018	GSM	DSCOVR	01/01	12/31
2018	GSM	WIND	01/01	12/31
2019	GSM	ACE	01/01	12/31
2019	GSM	WIND	01/01	12/31
2020	GSM	ACE	01/01	12/31
2020	GSM	WIND	01/01	12/31
2021	GSM	ACE	01/01	12/31
2021	GSM	WIND	01/01	12/31

THE DATA ANALYSIS

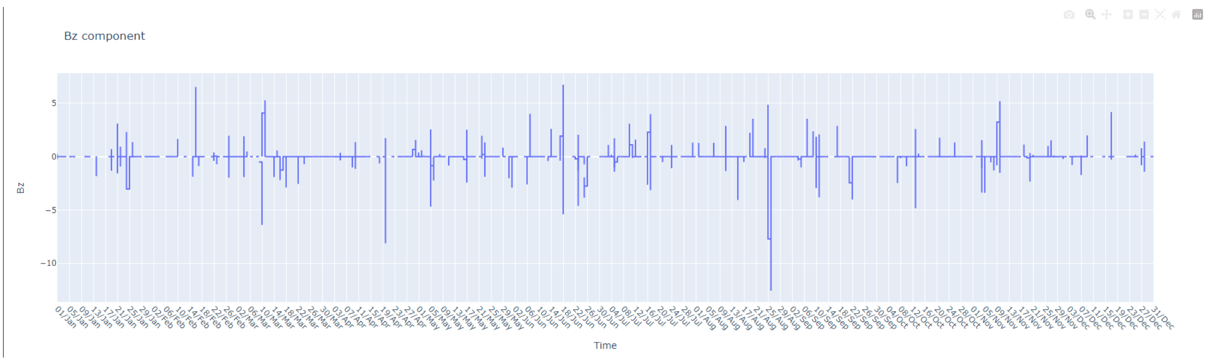
On the OMNIWeb site's scatter plots our team had already observed that the Bz vector measurements had a lot of noise, which made a deeper effective data analysis harder to accomplish, so this dataset required some kind of transformation to better identify the negative peak values of the measurements, which could possibly indicate the occurrence of MR.

In the first place, we strongly considered applying a usual Fourier Transform using Python to identify the peaks, but, doing a deeper research on the subject of spectroscopic analysis, we found that another transformation is commonly better suited for our data: the wavelet transform.

Applying the wavelet transform to our data set, using the PyWavelets library, our team could easily identify the negative peaks of the Bz vector component. In the images below we see the effect of the wavelet transform on the data set:

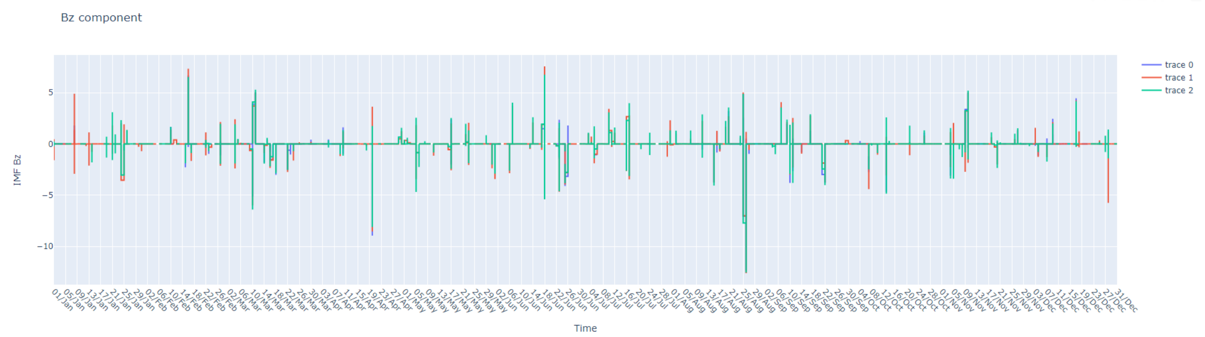


Rough Bz vector component measured by the DSCOVR spacecraft through the year of 2018



Denoised Bz vector component measured by the DSCOVR spacecraft through the year of 2018

After applying the wavelet transform in the data sets, we combined the data of the 3 denoised versions of the datasets of the measurements of Bz made by ACE, Wind and DSCOVR, in the same time span, in a single graph to compare the data they presented. The graph below represents this superposition made:



Combined denoised versions of the measurements made by the 3 spacecrafts through 2018

Analyzing the graph above, we can see that most of the measurement negative peaks of the 3 spacecrafts overlap, which can wield our analysis with some degree of reliability.

WHAT BENEFITS DOES IT HAVE?

Our model is very interesting to use because it makes it possible to compare information from several years of data collected by the DSCOVR, ACE and WIND missions and to analyze all this data together without noise. This makes it possible for someone looking for magnetic activity data from the missions' years of activity

THE USAGE OF ARTIFICIAL INTELLIGENCE

Either at the code workflow and at the presentation the use of artificial intelligence played an important role. At the code, chat OpenAI GPT provided us with resources to solve intermediate steps. At the presentation, it helped us at the brainstorming and at providing the project an unique look to some images. One of the main points of this usage was to manage how to make the requests in an “AI-friendly” language.