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Predictive Space Environment Forecast with Deep Learning

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ABSTRACT

Exploring the state, change and future of the space environment is critical for planet Earth, astronauts and spacecrafts. It is essential to watch solar flares, solar winds moving rapidly towards the earth, and examine Earth magnetic fields that protect us from these harmful solar activity. The ThemisB spacecraft, which examines the close earth orbit, and the Wind spacecraft, which studies solar activity, were selected. In this study, data such as magnetic field and its components, solar wind speed, ion density and ion temperature were obtained for two spacecraft from SSWEB-NASA and statistical analyzes were made. Data has been manipulated. Time series charts were examined and correct future predictions were made using the Long Short Term Memory (LSTM) algorithm. It was learned from this research that information about future solar activities and the fate of changing magnetic regions can be obtained by using historical data. It is obvious that this combination can take precautions against possible disasters.

Key words. Bow shocks, Solar activity, LSTM algorithms, Artificial Neural Network, Forecast Estimation,Deep Learning,

1. Introduction

The space weather conditions datas for this research have been taken from NASA's Space Physics Data Facility (SPDF). Space weather conditions data is essential to prevent many catastrophes.
There are many negativities in space, but the earth is absorbed from these negativities as it is protected by the atmosphere.Atmosphere eliminates the danger from space thanks to its magnetic field. One of these events is the solar wind.
The solar wind is the stream of charged particles released from the Sun's Corona (upper atmosphere of the Sun). This plasma consists of mostly electrons, protons and alpha particles with densities; embedded in the solar wind plasma is the interplanetary magnetic field.

In section 3 ,the orbits of magnetopause were simulated, magnetosheath and bow shock zones and compared with the data of NASA.
In this work, the effects of solar wind activity and near-earth space events with bow shock were investigated by adapting the datas from Wind and Themis Spacecraft to the time series.Section 5
Moreover, the current state of the bow shock event has been designed, created by the solar wind when it enters the magnetosphere of the Earth, using magnetic field data from Themis spacecraft in time series graphics. We have worked on predicting the forecast of such an event in the future by using forecast LSTM algorithms. Section 6

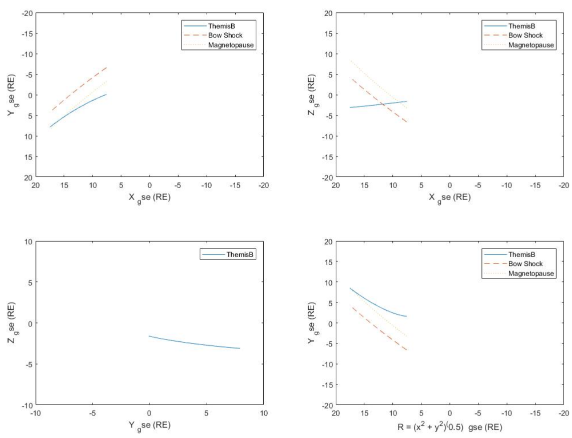
Then, the response of these spacecraft to the solar conditions was compared using the correlation matrix. (Section 7)

2. Magnetospheric Regions

Magnetosphere is a region surrounds Earth created by the Earth's magnetic field. It has constantly changing comet-shaped bubble, which has playing a critical role in our planet's habitability. Magnetopause is the outer wall of magnetosphere. It is a region in Earth ionosphere where magnetosphere first interacts with the solar wind. Magnetosheat is the region between magnetopause between and magnetosphere. A bowshock is a shock wave formed by the collision of a stellar wind such as solar wind with the magnetosphere of a planet.

3. Orbit Plotting

The aim at the chosen specific dates was that the themis spacecraft in near-earth orbit would pass through all the magnetic regions just mentioned. Themis B spacecraft to travel through solar wind, bow shock, magnetosheath, magnetopause and magnetosphere chosen according to orbit plotting. The same time interval was preferred for Wind Spacecraft in order to compare the space environment condition. An orbit modeling was created in MATLAB according to the coordinate data obtained from NASA. In order to make orbits clear is added orbit plots from SSWEB-NASA with plot option since bowshock and magnetopause regions are more discernible and time interval was correct.



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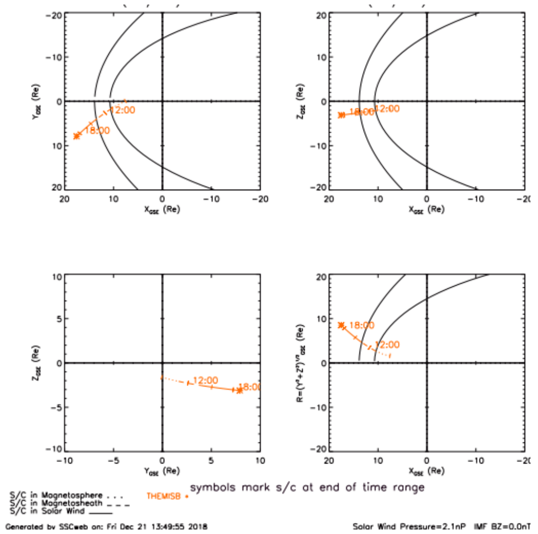
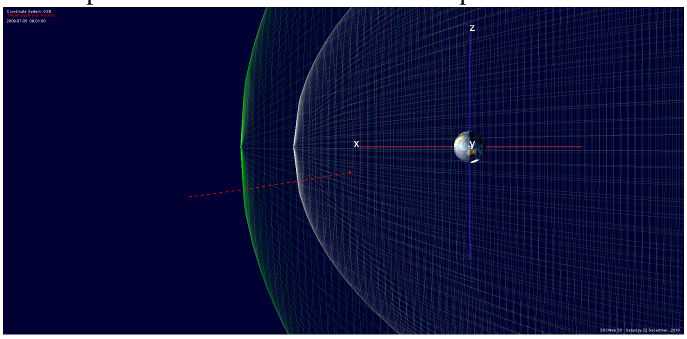


3.1. 4D Orbit Plotting

SSWEB-NASA 4D orbital plotting-modelling option was used to better see the magnetosphere, magnetopause and spacecraft's passage through these regions. The green area represents the magnetosphere and the red dashed line represents the motion of the spacecraft ThemisB.



4. Statistical Analyses

Themis and Wind spacecrafts, which have specialized data collection instruments, provide information on space weather conditions on the same or different conditions.Themis' specialized data collection instruments are Instrument Data Processing Unit (DPU), Electric Field Instruments (EFI), Flux Gate Magnetometer (FGM), Search Coil Magnetometers (SCM), Electrostatic Analyzer (ESA) and Solid State Telescope (SST).The instruments of the Wind spacecraft that collect data in different parameters are Wind Magnetic Field Investigation (MFI), Wind Solar Wind Experiment (SWE), Wind 3D Plasma Analyzer, Wind SMS Suprathermal Particle Data, Wind EPACT High Energy Particle Data, Wind WAVES Radio and Plasma Waves Data, Wind KONUS and TGRS Data.

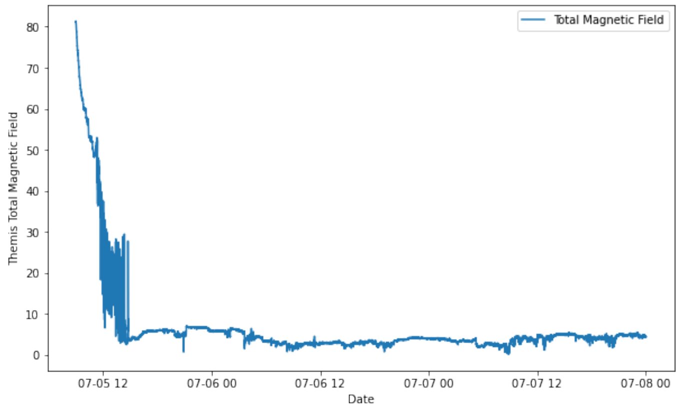
The 3-day magnetic field data of Themis and Wind spacecraft can be examined and commented on the magnetic field region in which they are located. One of these spacecraft's specialized instruments that collect data, Themis's Fluxgate Magnetometer(FGM) collects much more data than Wind Magnetic Field Investigation(MFI). When the data was examined, Themis collected 87337 data in 3 days while Wind collected 4295 data in the same period.....

5. Time series Analysis

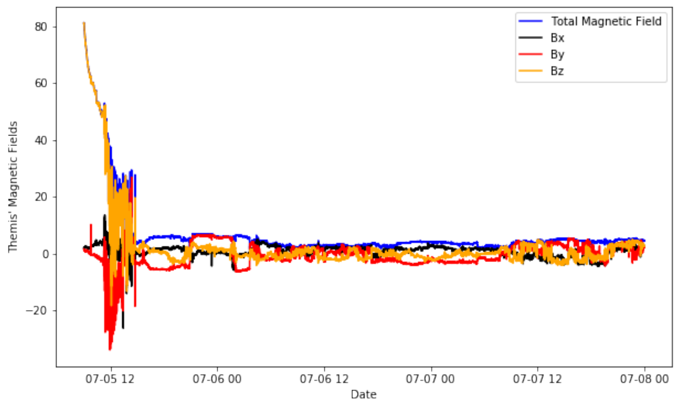
Using time series, we had the opportunity to interpret the changes of parameters such as magnetic field, solar wind speed, proton density, proton temperature over time and use historical data for future prediction. How the data moved in a specific time period was examined with time series graphics. In addition, LSTM has been studied and studied how time series graphs can be used to predict future space conditions.It is important to make predictions for the future with the data to take precautions against possible changes in space conditions.

5.1. Themis Magnetic Field's Time Series

The graphics show the changing environment based on the data ThemisB collects as it goes from the magnetosphere to the interplanetary medium. As seen in the graph, there is a sharp change between the two environments.The 80nT magnetic field, which decreases as it goes through magnetopause and A sharp drop to 20nT is observed in magnetopause and It fluctuates around 10nT in Magnetosheet. After this,the spacecraft in the outside of the magnetosphere where all conditions are dominated by solar winds, corona.

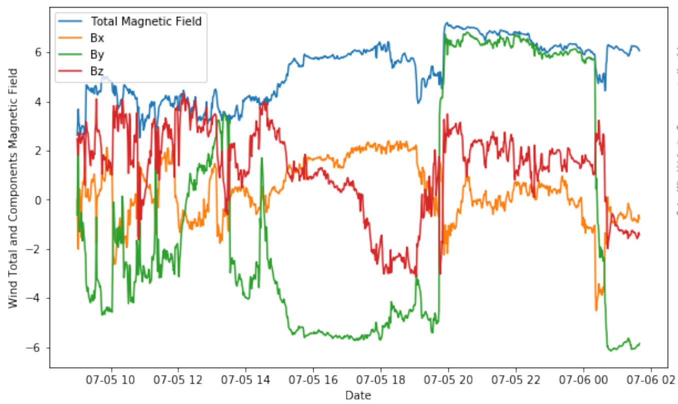


When examining the earth's magnetic field as it consists of 3 components, it is seen that the dominant component is Bz. Bx and By is weak for the effect of the magnetospheric region and changes in Bz determine the magnetospheric region.



5.2. Wind's Magnetic Field Time Series

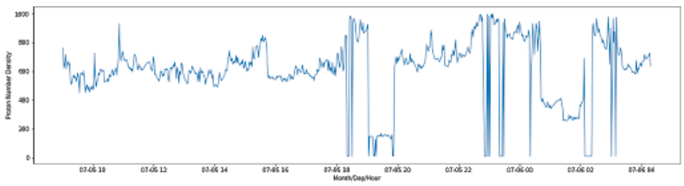
The graphs for Wind Spacecraft show how space weather changes with sun activity. The sun surface is a surface where continuous explosions occur. It has electrically charged gases that generate areas of powerful magnetic forces. These areas are called magnetic fields. The Sun's gases are constantly moving, which tangles, stretches and twists the magnetic fields. This motion creates a lot of activity on the Sun's surface, called solar activity.A fluctuation between about 6nT and -6nT is therefore considered nominal.

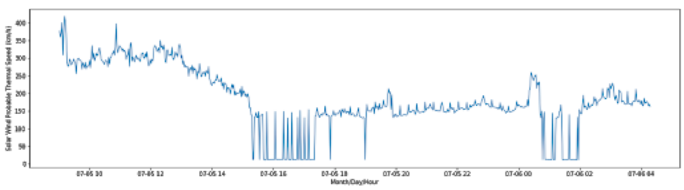


in a single coordinate at a certain time, these graphs fluctuate.

5.3. Solar Wind's Time Series

These results are created by adapting the speed of solar wind to time series over wind space craft data. As far as solar wind speed is concerned, it is an important parameter that determines the dynamics of the Heliosphere, namely the distribution of flows, energy transfer and interaction of particles and their evolution by distance. The high energies of the particles formed in the sun can escape from the sun's gravity due to the high temperature of the corona and the magnetic, electrical and electromagnetic phenomena in it. Total Solar Wind Speed does not change much and is around 350 km/s, this is normal for solar activity. Figure x is the km-h speed graph of wind versus time. In this graph, the velocity parameter starts to decrease with the bow shock, and a decrease in proton density was observed in the later hours. The graph below explains the proton density. Ion density indicates that space weather conditions are normal and there is no unexpected solar activity. It fluctuates between 1000-400 (x0,01).





5.4. Solar Wind Velocity In GSM coordinates(km/s)

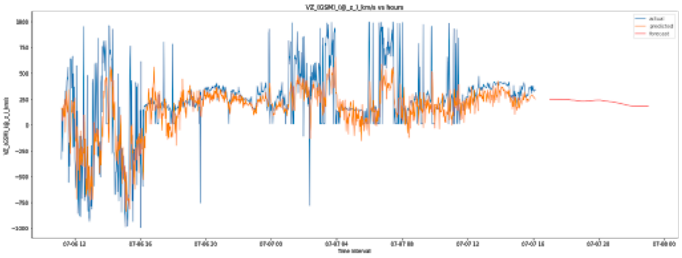
These graphs are the velocity data of the solar wind in x y z coordinates. In the graph on the left, I have combined all the positions on a single axis. The data on the right is X, Y, Z respectively. This data is compatible with the data from the WIND spacecraft, which shows the solar wind speed around 350 km/s. In watches with bow shock, there is a decrease in the By parameter, then the bz parameter follows it. Since bow shock occurs

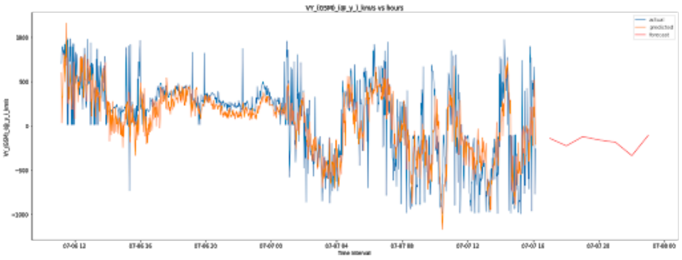
6. Forecasts Using Time Series with LSTM algorithms

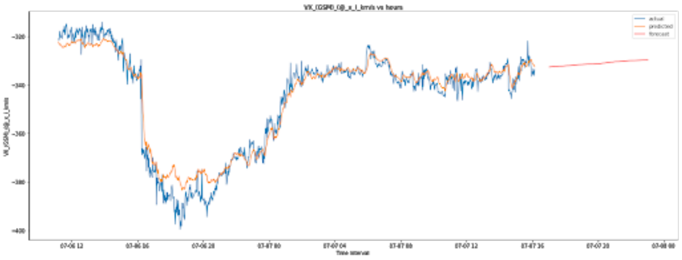
In this study, forecast is made from past events by using LSTM algorithm. LSTM algorithm is a type of artificial neural network. Artificial neural networks are structures designed to provide solutions to supervise learning problems. LSTM algorithm created after setting the data to time series.
Time series is considered as a linear model: A (i)… A (i + t) B (i + t + 1). In the format, B (i + t + 1) shows how to use time series entered t-steps to predict the next step. B represents hidden functions produced by the algorithm, which were not actually found in experiments. General events are calculated from the data we have in the form of hidden function.
There are three common types of artificial neural networks. These are: DeepNeuralNetwork, RecursiveNeuralNetwork and Long Term Short Memory. The LSTM algorithm is RNN's customized tool. LSTM (Long short term memory) is a deep learning algorithm widely used in forecast estimates. Recursive Neural Network is an improved version of the DNN algorithm. Unlike DNN, it can also perform a test operation on the hidden layer. Deep neural network (DNN) is an artificial neural network with multiple layers between input and output layers.
The reason the LSTM algorithm is used is because it actually makes a better prediction compared to the DNN or RNN model. It was provided to predict the bow shock effect, which is one of the solar activities.

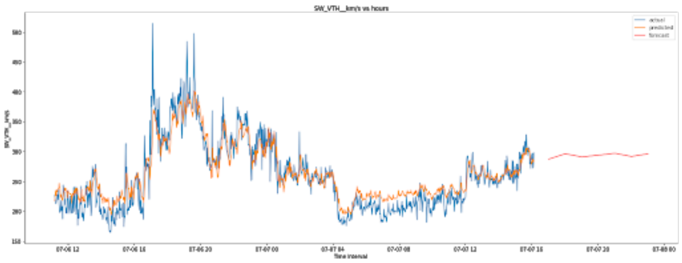
6.1. Solar Wind's Magnetic Fields Forecast

This graphic includes the adaptation of the changes in the total X, Y, Z coordinates of the magnetic field of WIND to the LSTM algorithm. Here, WIND magnetic field charts were launched on the 9th of the month. Because LSTM requires a certain sample density, such a method was used to see the 12-hour difference. The graphics and forecast turned out to be quite compatible. Process was made over 10000 lines, from here, tests were made on 4000 samples and regression analysis was compatible.

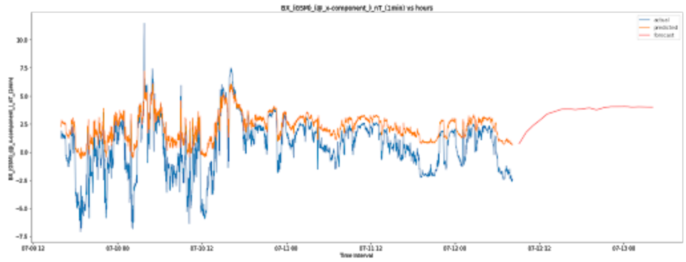


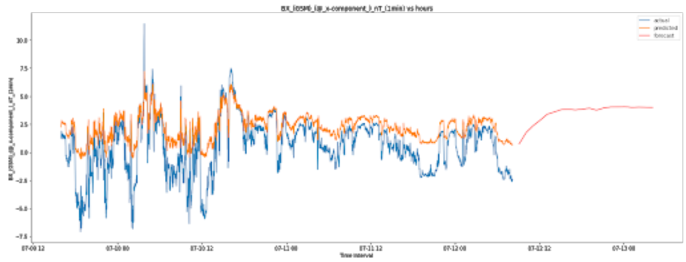


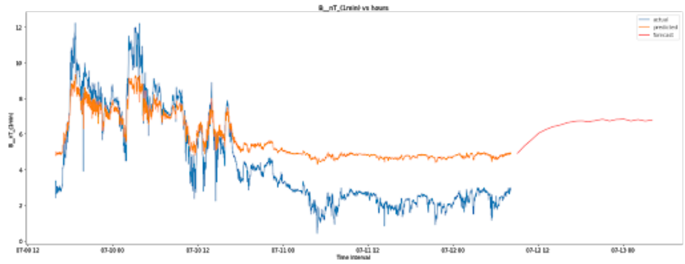




the bow shock occurring in the X coordinate. The speed estimates were run on 2000 data with a very high regression analysis. Forecasts turned out to be very compatible.

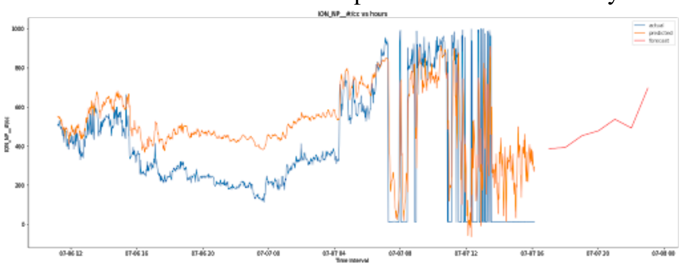






6.2. Solar Wind's Proton Number Density Forecast

In this graph, ion intensity is between 200 and 800 and fluctuation is observed at frequencies in the area where bow shock will occur. Since there is a relationship between proton density and velocity, the proton density was examined and a structure was displayed in accordance with space conditions. The main goal was to determine its magnetic structure. As the wind moves towards the Earth, it carries with it the Sun's magnetic field. This magnetic field contains very high velocity and dense particles. Here a graph of proton densities at 4-hour intervals from the 7th day of the month was found. Regression analysis of 0.95 was found on 2000 data and forecast prediction came out very well.

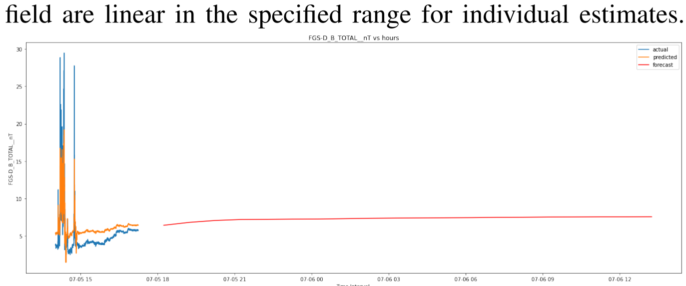


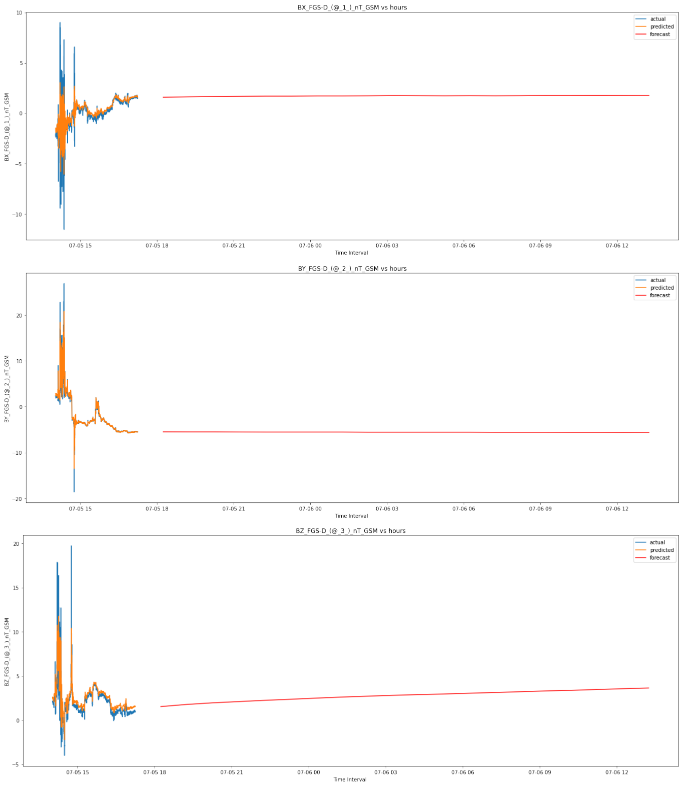
6.3. Solar Wind's Most Probable Thermal Speed Forecast

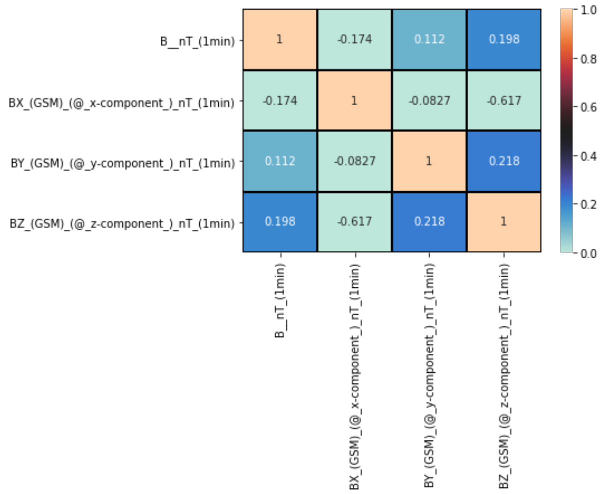
In this graph, the forecast was made on the wind data. The reason for the decrease in the graph on the upper right is

6.4. Themis's Magnetic Fields Forecast Using Time Series

The time interval taken for this graph is the time interval before exiting the magnetosphere in Themis's Time Series, which was plotted earlier.With LSTM, it is seen that the magnetic field, which is expected to be zero when Themis leaves the magnetosphere, is correctly predicted.It is obvious that the 3 components of the magnetic field and the total magnetic field are linear in the specified range for individual estimates.

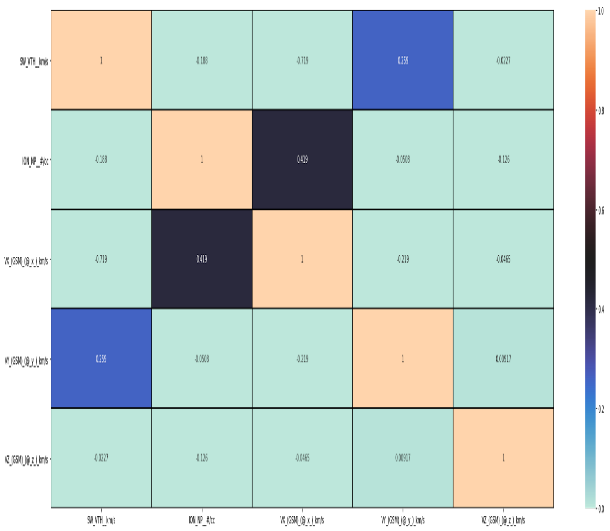






7. Comparing With Correlation Matrix

The correlation matrix is an important data analysis metric tool calculated to summarize data to understand the relationship between various variables and make decisions accordingly. The correlation coefficient is a statistical measure of the strength of the relationship between the relative movements of two variables. Values range from -1.0 to 1.0. Proximity to 1 means that the parameters are compatible. The left-hand table is the correlation matrix of wind. He concludes that there is a strong relationship between ionic density and speed values due to solar flares. The right-hand side is the correlation matrix of themis. This graph states that the total magnetic one of B is a harmonious relationship between By and Bz.



8. Conclusions

In this project, it was understood how to distinguish magnetic regions and how some physical parameters change in these regions. First, a spacecraft was selected to study these magnetic regions. A time interval was detected during which the spacecraft passed through solar wind, bow shock, magnetosheat, magnetopause and magnetosphere. Then another spacecraft was chosen to examine the solar winds hitting these magnetic fields. data were normalized and statistical analysis was done. Time series of selected physical parameters were extracted and interpreted. Results were as expected. Future predictions were made at certain time intervals by using time series graphics and LSTM algorithm. No extraordinary situations were encountered. To conclude, this reliable study has shown that the data we collect can protect people, spacecraft, and astronauts from unexpected disasters.

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