PROJECT SYNOPSIS

On

SCRUTINIZING SPACE WEATHER PREDICTION SYSTEM

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1. INTRODUCTION

As we are becoming more and more dependent on electricity to carry on with our day-to-day activities, it has become an important task for us to predict the abrupt and calamitous changes in our space weather that can directly or in-directly hamper with our electricity grids and our satellite systems. The Sun is the major celestial body responsible for changes in the space weather. The Sun, though responsible for life on earth, can also create disastrous impacts on our satellite systems responsible for major communications on earth.

Solar flares, eruptions, CMEs and other storms arising due to changes in the surface temperature and magnetic field of the Sun, can have catastrophic impacts to technological systems around or on the earth. They have been responsible for various failures to our satellites, power supplies, communications and navigation systems in the past. Damage caused to these systems have secondary effects that can easily damage and disrupt indirectly every other system and major infrastructure dependent on them, including telecommunication industry, climatic weather forecasting stations, transport sectors, defence sectors, various emergency response systems and other wireless networks and electronic devices which can lead to significant economic losses.

Hence, it has become an important task for us to predict the occurrence of various solar storms and coronal mass ejections as they disrupt our Earth’s magnetic field resulting in sudden and alarming changes in the magnetosphere (the region of space surrounding Earth where the dominant magnetic field is the magnetic field of Earth) that results in generation of powerful waves and currents in the Earth’s ionosphere (Part of Earth's upper atmosphere, from about 80 to 600 km where ionization of atoms is caused by Extreme Ultraviolet (EUV) and x-ray solar radiation, thus creating a layer of electrons). These currents are replicated in the Earth’s conducting surface as geomagnetic induced currents. Since the critical electrical infrastructure is grounded the induced currents can hamper power grids and communication networks.

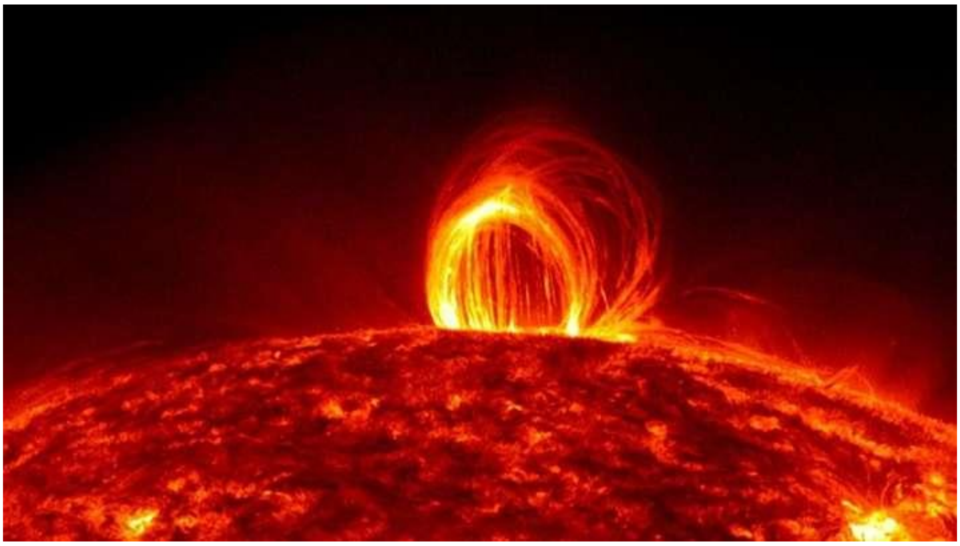
Solar storms are harmful for various communication systems like radio communications, satellite communications, radars and navigation systems. When the frequencies are below 30MHz, the ionosphere generally acts as a good reflector, allowing communications to distance effectively. Solar extreme ultraviolet and soft x-ray emissions from solar flares and other solar activities change the density of electrons and causes variations in the functioning of ionosphere responsible for effective communication. An abrupt increase of x-ray radiation from a solar flare causes an increase in ionization of the lower region of the ionosphere producing disturbances of radio signals, sudden phase changes, unnoticed enhancement of signals and fading of short waves. Polar cap absorption (PCA), aurora absorption etc are the effects that are associated with coronal mass ejections (CMEs), can also disrupt radio communications. The prediction will help us take active measures and save the various satellites from damage.

1.1 What are Solar storms?

There are mainly three major components responsible for the emergence of solar storms. They are: -

1.1.1 Solar Flares

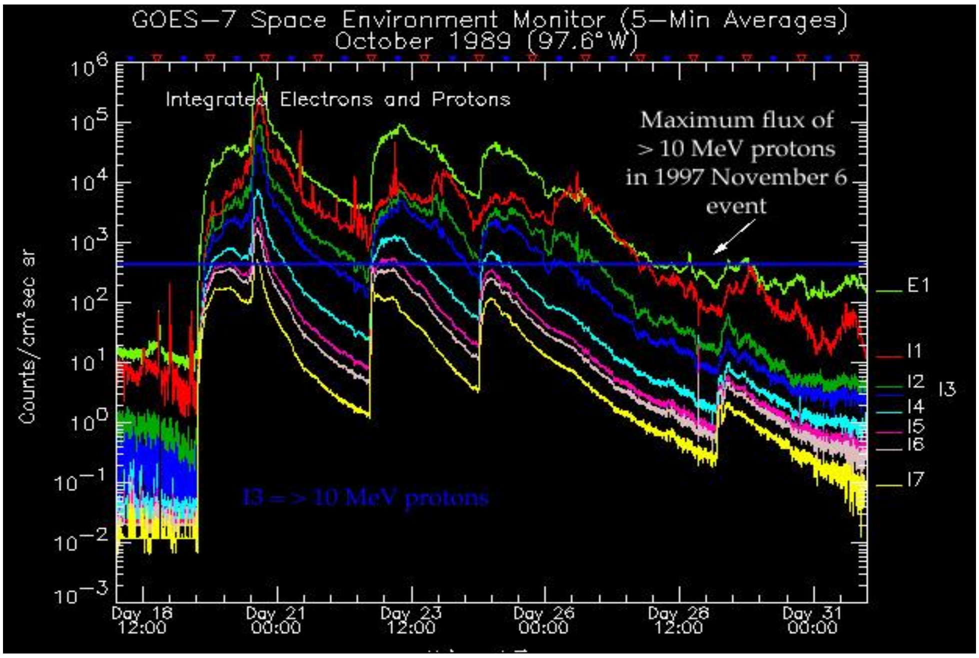
Solar flares are the most violent events occurring on the surface of the sun. They occur due to sudden release of tremendous amount of energy stored up in the sun's magnetic field, as magnetic energy or gets converted into heat energy and motion. Approximately about, 7 to 8 minutes after they occur, a powerful burst of electromagnetic radiation in the form of various electromagnetic radiation like x-ray, extreme ultraviolent rays, gamma ray radiation and radio burst reach the earth. The UV rays heat up the upper atmosphere which causes the outer atmospheric shell to expand. The electron density in the ionosphere is suddenly increased as the x rays strip electrons from the atom.



(fig 1: solar flare)

1.1.2 Solar Proton Events (SPE)

Solar proton events abbreviated as SPE are cosmic rays mainly comprising of protons and ions having energies in between the range of 100MeV to 10MeV. They are even capable of producing nearly relativistic protons. They produce satellite disorientations, damage to electronic equipment installed in the spacecrafts and the International Space Station. Solar Panel installed to fulfill the electricity requirements in various satellites and spacecraft begin to degrade because of SPEs. They are also hazardous to astronauts as they contain extreme radiation which is also responsible for ozone layer depletion causing cardiac arrest, dementia and cancer.



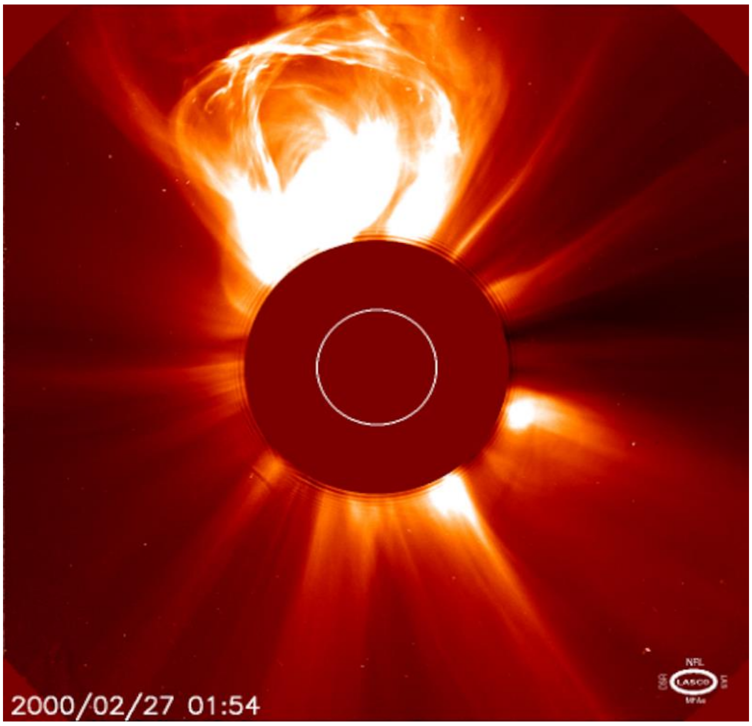
(fig: 2 Graph depicting energies of protons and electrons released during Solar Proton Events in 1976)

1.1.3 <u>Coronal Mass Ejection (CME)</u>

Coronal Mass Ejections are phenomenon when the plasma from the corona (core) of the sun is ejected into space releasing tremendous amount of energy and are accompanied by magnetic flux. This activity results in creation of a solar storm of a high magnitude containing various electromagnetic waves (SUVI, X rays) and magnetic flux. The debris is responsible for damage to communication satellites and degradation to solar panels resulting in decrease in efficiency in telecommunication and broadcasting. Whereas, the magnetic flux induces an emf in the earth due to change in field in the magnetosphere of the earth. This induced emf results in induced currents in the earth. Since all our electrical grids, electronics are grounded to the earth, they get damaged.

CMEs are often released from the area experiencing prolonged solar flares due to unstable temperature gradient on the surface of the sun. They are often detected by ultraviolet, magnetic imaging equipment present on the space weather observatory satellites.

CMEs are responsible for the most of the prominent solar storms causing most of the damage caused to the communication infrastructure.



(fig: 3 CME ejection recorded by SDO (Space Dynamics Observatory) On 27th February 2000)

2. LITERATURE REVIEW

2.1 Previous Recorded Events

It has been seen before that solar activity can prompt space weather changes that could impact technological systems. There were many such events in the history, some of them are listed below: -

- **August 28th to September 2nd, 1859,** a massive coronal mass ejection reached earth in eighteen hours. Many sunspots and solar flares were also seen.

- The geomagnetic storm caused by the combination of the solar flare and coronal mass ejection, created strong induced currents in some of the long telegraph wires, in both America and Europe, shocking telegraph operators and causing fires.

- **March 13th, 1989,** the Hydro-Quebec power grid was collapsed as many protection equipment relays tripped in a continuous sequence of events caused by a severe geomagnetic storm.
  About 6 million people were left in blackout for 9 hours, resulting in enormous economic loss.

- **November, 2003,** due to GIS activated storm, an unknown problem was encountered at five major stations, 11 transformers, which eventually collapsed.

- **February, 2011,** 3 solar flares erupted on the sun which created the strongest electromagnetic shocks that can be felt after even 3 days by spacecrafts and a satellite used to measure radiation, bursts few minutes before they reached the earth.

- Various other damages were reported in the past caused by various solar flares, CMEs, and other solar activities, that resulted in economic losses in various parts of the world like Great Britain, United States of America, France etc.

Hence, it has been of extreme importance to predict these solar activities, before they could reach the earth and cause damages that can disrupt the normal working of the essential equipment responsible for smooth functioning of the economic infrastructure.

3. PROBLEM DEFINITION

Coronal Mass Ejection (CMEs) from the sun can cause Geomagnetic Storms, because of there influence extra current gets induced in the ground, that can prove devastating for our power grids and there smooth working. Geomagnetic storms can also hinder radio communication as they increase the ion density in the ionosphere due to extra ionization of atoms and molecules, resulting in in-efficient reflection of radio and micro waves. Hence, signals utilized in radio communication and navigation systems (GPS and GNSS), gets modified and this results in degradation of accuracy. Because of this, aviation and air traffic control, weather reports, and other departments that rely on these technologies gets affected the most.

3.1 Project Objective

Hence, as we are becoming more and more dependent on electricity to carry on with our day-to-day activities, it has become an important task for us to predict the abrupt and calamitous changes in our space weather that can directly or in-directly hamper with our electricity grids and our satellite systems. It has been of extreme importance to predict these solar activities, before they could reach the earth and cause damages that can disrupt the normal working of the essential equipment responsible for smooth functioning of the economic infrastructure.

3.2 Proposed Methodology

The following indices are used to predict the occurrence of solar storms:

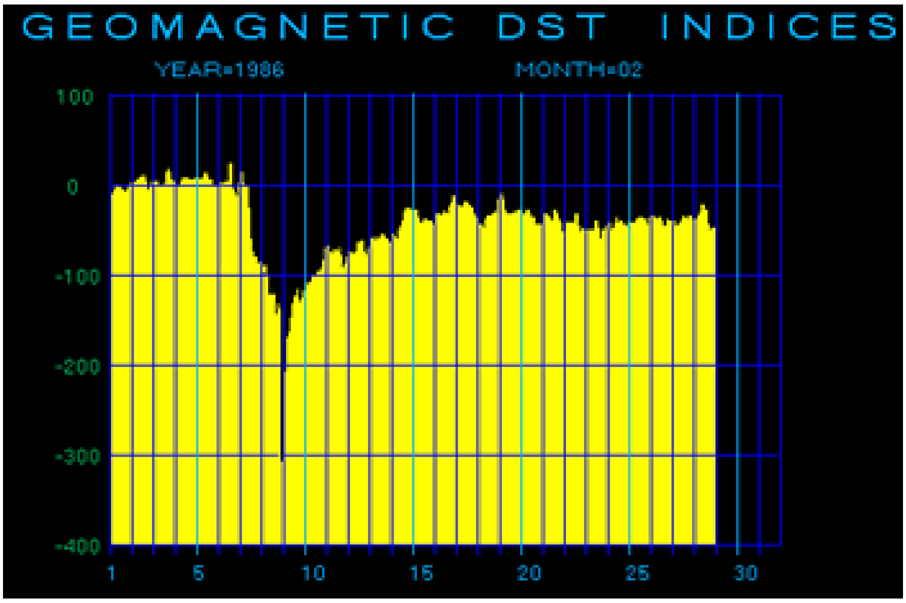
1. **Auroral Electrojet Index (AE Index):**
   Magnetic activities in the auroral zones are produced due to enhancements in ionospheric currents flowing through the auroral ovals of the earth. These enhancements are due to occurrence of solar activities causing variations in the space weather. To obtain a quantitative measure of these activities globally, AE index is designed.

2. **Ap Index:**
   A daily average levels of geomagnetic activities occurring can be predicted using Ap Index. It is obtained by taking an average of 8 values taking in the interval of 3 hours for each day. Thus, using this, it has been seen that the days with high geomagnetic activity has higher values of Ap-value.

3. Kp Index:

The severity or calamity power of the global-magnetic or geomagnetic storms around the earth in space can be indicated precisely using the Kp index.
The value ranges from 0 to 9 where o being quiet and 9 being most disturbed.
There are 12 to 13 magnetic field observatories who calculate their K values. The average of these values gives the Kp value.

4. Disturbance Storm-Time (Dst) Index:



(fig: 4 Hourly values of index from 1 Jan 1957 to
30 Sep 1992 at Kyoto Japan)

The equatorial ring currents or electrojet causes variation in magnetic field. This variation is measured by this index. The four near-equatorial observatories record these variations and help in calculation of dst.

4. SPACE WEATHER PREDICTION SYSTEM

- Theses indices work in a set and clearly defines ranges. Our work in to use this character in order to predict the solar storm.

- For missing data, we will use an average of 5 days in order to make our dataset consistent.

- We will also use image processing to identify the occurrence of CME through the satellite imagery data from SDO.

- For this we will be using python and OpenCV or Keras.

4.1 Levenberg-Marquardt Algorithm

The Levenberg-Marquardt Algorithm is used to solve non-linear least squares problems. It is also known as damped least-squares (DLS) method. Many software applications use this algorithm to solve generic curve-fitting problems. However, this only find the local minimum as compared to all other algorithms.

This was Published by Kenneth Levenberg, while working at the Frankford Army Arsenal in 1944.

4.2 Bayesian Regularization

Bayesian Regularization uses the concept of bayes theorem to train artificial neural networks. This concept is also known as Bayesian Regularization Artificial Neural Network (BRANN).

4.3 Scaled Conjugated Gradient

The Conjugated Gradient Method is an approach for finding solutions based on numerical analysis of particular combinations of non-linear equations, mostly matrices whose definite is positive. It is implemented as an iterative algorithm, used on sparse systems.

4.4 Technologies

4.4.1 Python

Python is an interpreted, object oriented, and a reliable language that is very simple. It has a variety of libraries containing modules to support integration of complex solutions from pre-built components. Python is an open-source project. It is a scripted language, platform-independent, with complete access to operating system APIs. This allows users to build and integrate applications seamlessly to create high-powered, highly-focused applications.

4.4.2 Deep Learning

Deep learning is a variant of artificial intelligence (AI) and Machine Learning that tries to replicate the way in which human brain perceive things and gain knowledge from it. It includes predictive modelling and uses statistics, is an important part of data science and extremely beneficial for data scientists. It makes the process of interpreting large amounts of data faster.

4.4.3 Tensor Flow and Keras

TensorFlow an open-source software library for machine learning (ML) and artificial intelligence (AI). It can be used across a range of tasks but has a particular focus on training and creating of deep neural networks. Tensor flow is a symbolic math library based on dataflow and differentiable programming. Keras is an open-source library that provides a python interface for ANN (artificial neural network). Keras acts as an interface for the TensorFlow library.

5. SOFTWARE / HARDWARE REQUIREMENTS

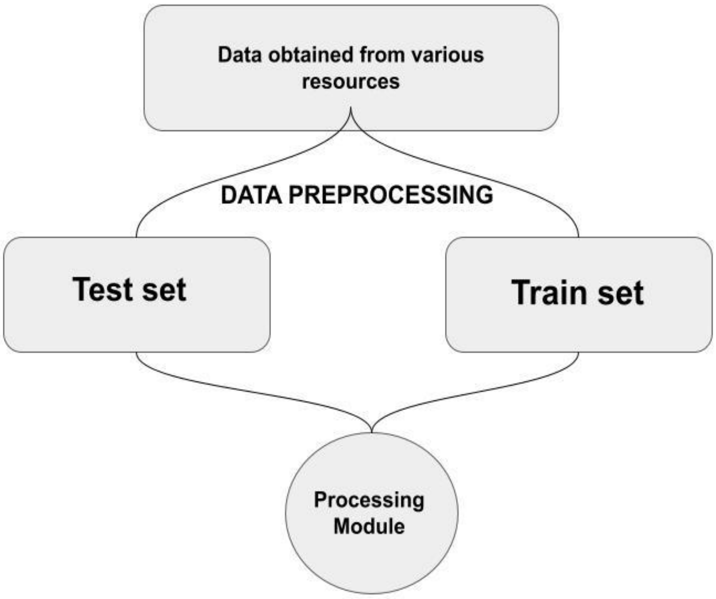
5.1 Software

- PyCharm Python IDE by Jet Brains
- VS Code by Microsoft
- Postman API
- Operating System – Microsoft Windows 10
- Spyder

5.2 Hardware

- Processor – Intel i5 8th generation
- Ram – 4 GB
- Graphics – Intel integrated graphics
- Disk Space – 100 GB

6. MODULE DESCRIPTION



Various training algorithms will be used for prediction:

- Levenberg-Marquardt Algorithm
- Bayesian Regularization
- Scaled Conjugated Gradient etc.

The data set will be divided into three parts for each comprising of:

- 70% Training Set
- 15% Validation Set
- 15% Test Set

To Preprocess the data and fill the missing values, we are required to take and average of 3 to 4 days dst index readings.

7. APPLICATIONS AND LIMITATIONS.

7.1Applications

As we are becoming more and more dependent on electricity to carry on with our day-to-day activities, it has become an important task for us to predict the abrupt and calamitous changes in our space weather that can directly or in-directly hamper with our electricity grids and our satellite systems.

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7.2 Limitations

Hence, it has been of extreme importance to predict these solar activities, before they could reach the earth and cause damages that can disrupt the normal working of the essential equipment responsible for smooth functioning of the economic infrastructure. But since there is no means of placing a satellite near to the surface of the sun due to the extreme high temperature. Hence, there is a limit to which we can predict the storms coming.

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APPENDIX

LIST OF FIGURES