Development Of An Onboard Space Weather Module For Satellite Operation

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We propose a satellite-based space weather prediction module that will provide 24/7 live updates, information, prediction, and alerts on space weather. The objectives of the system are to produce predictions of geomagnetic storms and substorms, spacecraft charging (overall and differential), other radiation predictions, alerts, updates to astronauts, provide data for research, etc.

The capabilities of the system are to effectively communicate with other spacecraft systems and ground systems for inputs, to produce accurate results, it must run 24/7 with live feed, provide data from machine learning, manage existing and incoming data, would have an easy to use user interface, etc.

Machine learning software is a key component of the SWPS. It is used to improve the accuracy rates of the predictions. The output data each time would be fed into the machine learning software which would have an external input (at first) from an astronaut or researcher confirming the predictions and their levels. This would be done based on observing the values of the various parameters during a geomagnetic event.

The first factor tested was substorm onset time by taking various indices like SML, AL, AE, AU, AO, Dst, and Kp OMNI. After an initial phase of testing, the values would be given ranges and set into the software. So each time the output is passed through the machine learning software, the software compares the data with the set parameter ranges and if it matches and based on how much it matches, an accuracy level is given.

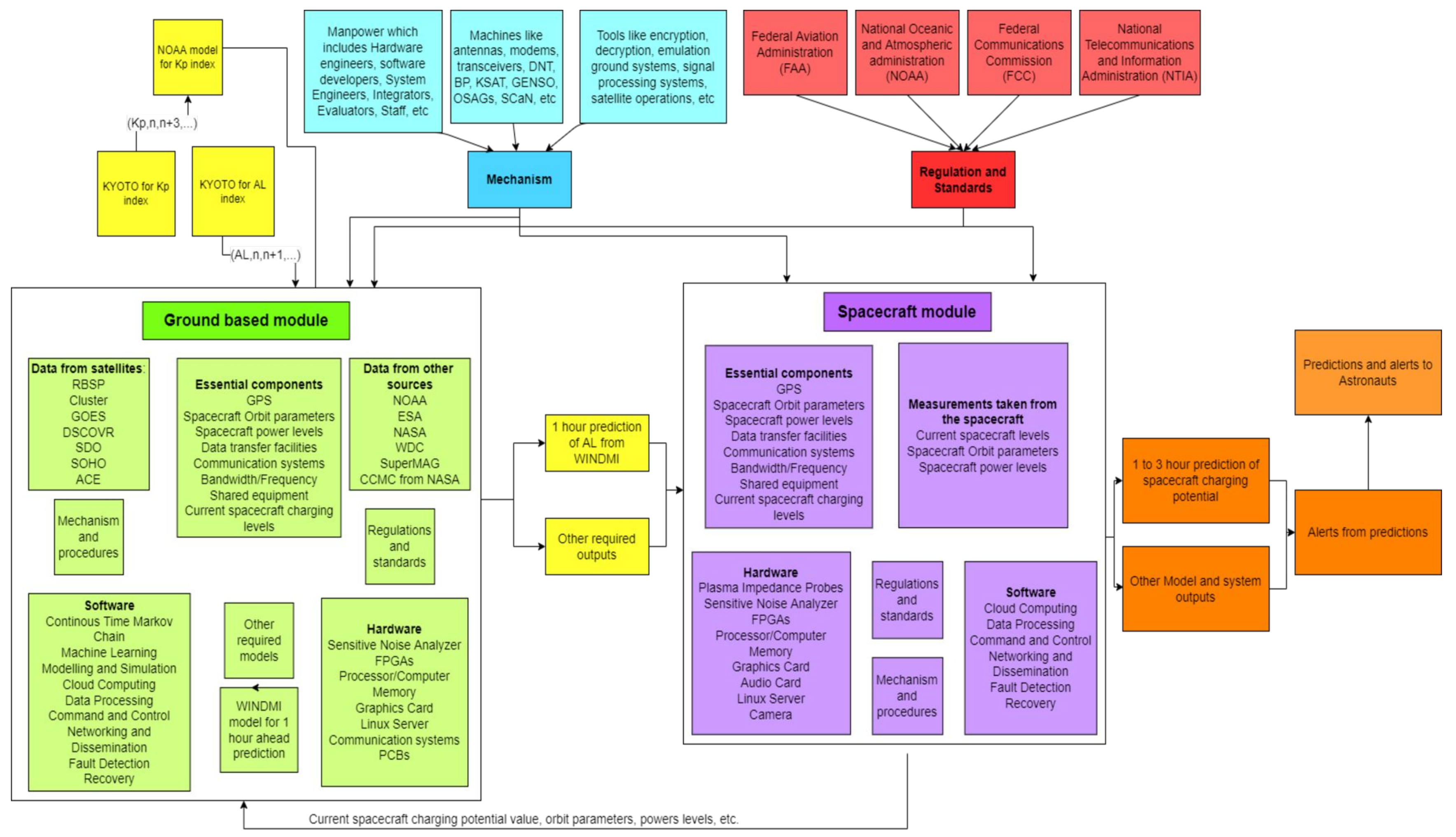
INTRODUCTION

The idea is to design and develop an onboard space weather prediction system which could be part of any satellite/spacecraft. This would have various components as shown in figure 1. We are splitting each component into separate units to design, train, test and verify. And then intend to combine all successful components. Figure 1 is a basic IDEF diagram with the major components being the ground based module and space based module. The system model will have two-way communications between the ground-based module and the spacecraft module. Both these modules have essential components, hardware, software, and required information to produce predictions. A specialized ground-based module, consisting of a suite of instruments, a local software prediction model, run other supporting models, and software such as machine learning, data processing, CTMC, dissemination, etc. Using local plasma and particle measurements, together with orbit, attitude, and schedule information, and a low dimensional model of the earth's magnetosphere called WINDMI, the system will output local indices to alert the satellite's main control system of space weather events. Additionally, the spacecraft module will monitor the spacecraft power system for noise, spacecraft charging values, and other indicators in real-time to provide situational awareness status to the satellite control system. The expected outputs of the module would be various predictions like spacecraft charging, one to three hour ahead geomagnetic indices, recognition of geomagnetic activity such as substorm and substorm onsets, etc. This system will focus on how to use the measurements by understanding what the measurements may be at a particular location based on current space weather conditions. The component researched here is substorm onsets predictions.

CURRENT WORK

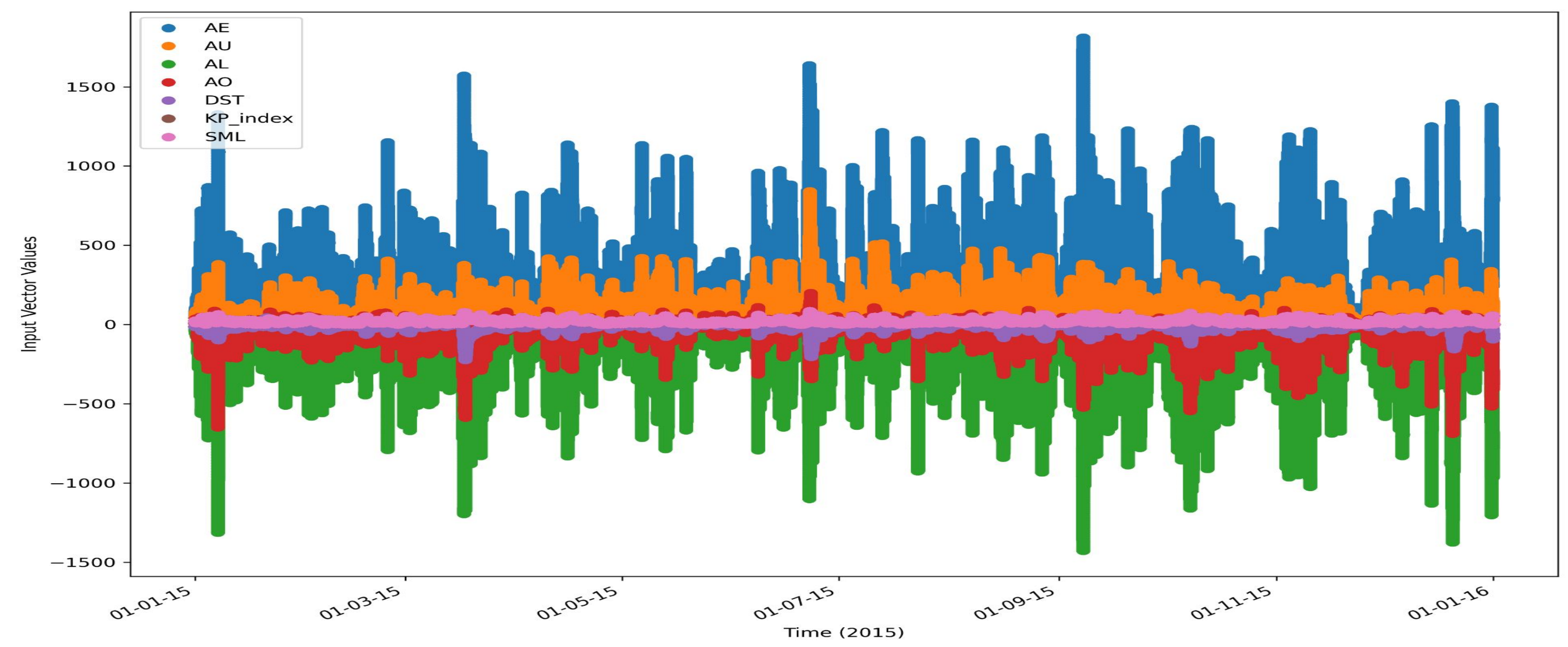
- For the preliminary round of tests one year (2015) of AE, AL, AU, AO, Dst, and Kp OMNI indices data was obtained from World Data Center for Geomagnetism, Kyoto and SML index was obtained from SuperMAG and were used as inputs to the machine learning model.
- The SML data was obtained for every minute and other parameters were obtained every hour so the data was fit to every minute and was overfitting. The missing data was filled and was cleaned.
- The substorm onset time predictions by Newell, Forsyth, and Othani was obtained from SuperMAG website and combined for the year 2015 to determine if there is a substorm/substorm onset time (output vector) and for training and testing the model.
- The model used for this particular study was a sequential neural network using the TensorFlow using the tf.keras.sequential model.

MODULE IDEA

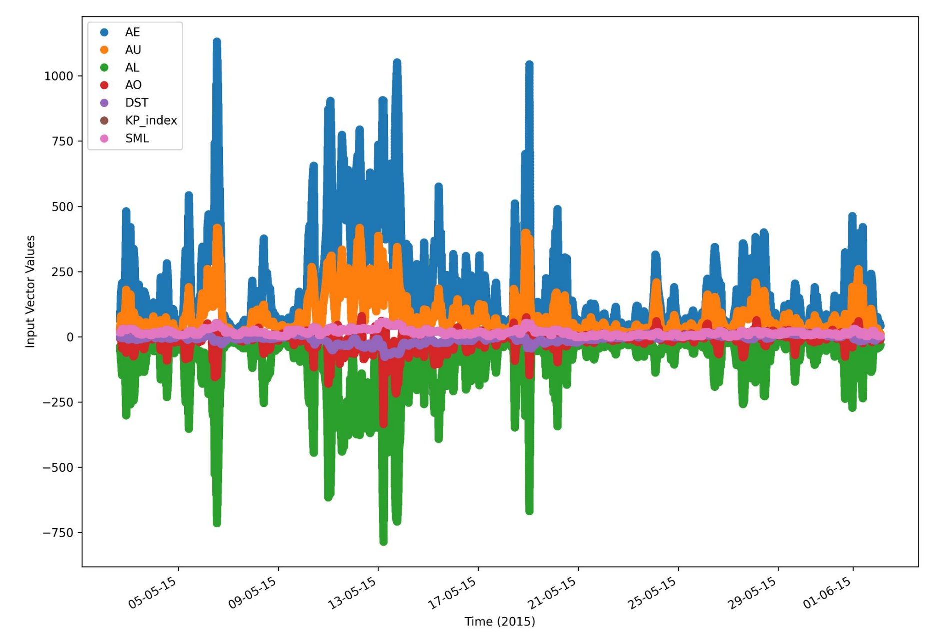


RESULTS

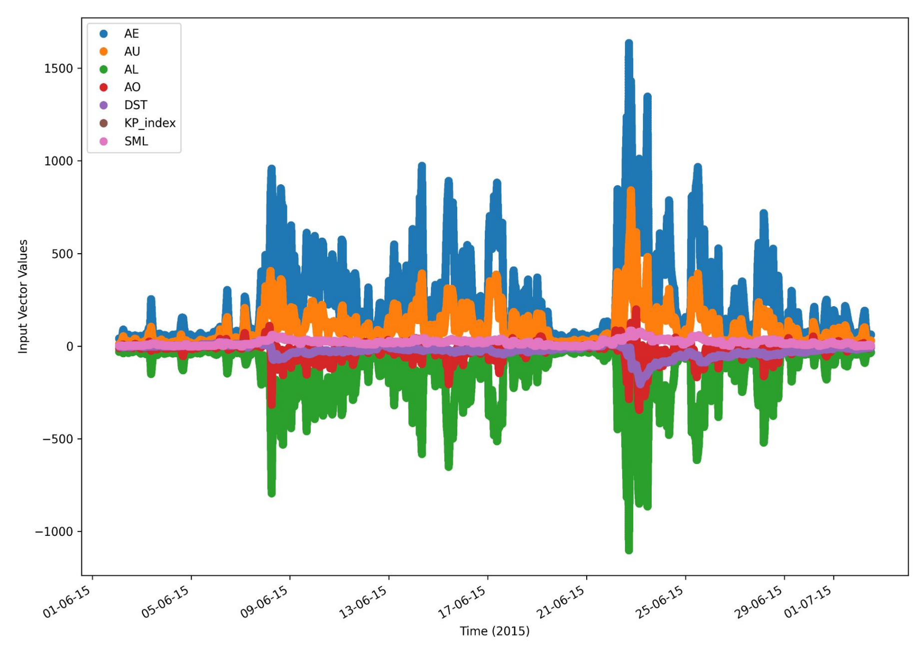
Input data for the whole year 2015



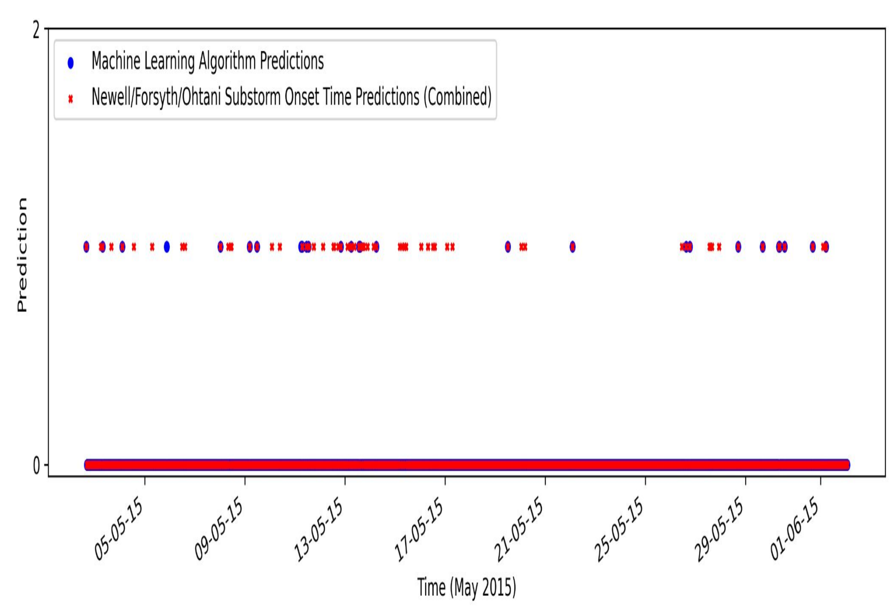
Input data for May 2015



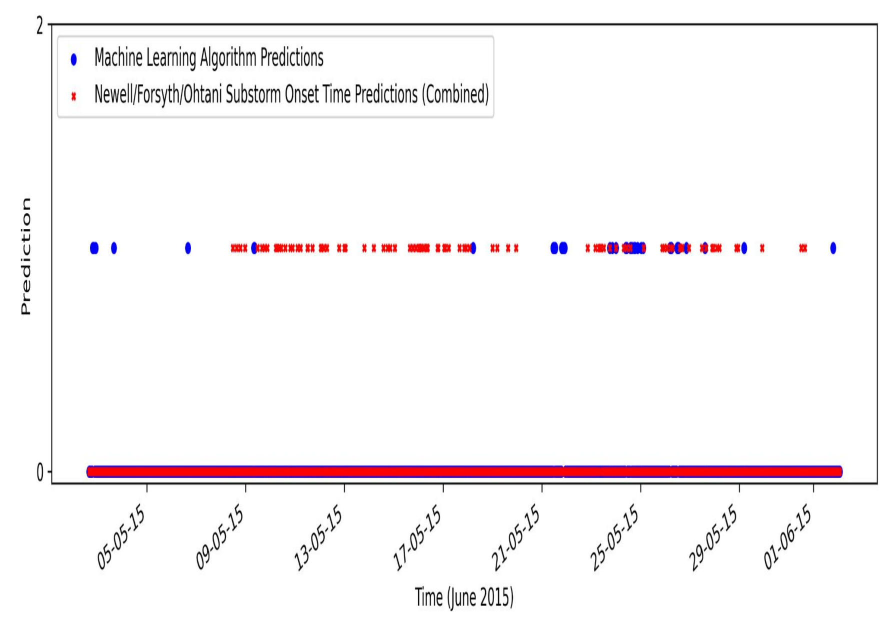
Input data for June 2015



Output data for May 2015



Output data for June 2015



DISCUSSION AND CONCLUSION

- The machine learning algorithm showed promising results with an accuracy of 90 - 95 % depending on which randomized test set was used.
- The number of data points used was 525600. Due to the abundance of zeros in the output training data, we believe the algorithm is slightly overfit and the data on which it is trained could be adjusted to get better results.
- By experimenting with the algorithm such as adding more classes and better fitting the data we hope to expand the study to the duration of substorms and storms.

FUTURE WORK

We will address the following questions going forward:

- How can the WINDMI model be improved so that it can effectively combine with other models to process the various inputs (like the magnetic field of the solar corona, solar coronal temperature, density, plasma pressure, magnetic fields, velocity, electric currents, and other MHD/plasma parameters [14] [15]) from varied data sources?
- What kind of software or algorithm needs to be used to process the data (inputs or processed data) from various sources (NASA satellites, GBOs, NOAA, etc)?
- How accurately can a machine learning algorithm be programmed to predict space weather events (Sunspots variance, CME occurrences, solar flare strength, Size and magnitude of geomagnetic storms and substorms, ionospheric scintillation, etc)?
- What is the correct input vector, of the existing data (NASA satellites, GBOs, NOAA, etc), to supply the machine learning algorithm?
- What all models can be combined effectively to run the data from various satellites and ground stations?
- How can the machine learning algorithm be programmed to work with previously recorded SWPS data, user observations (astronaut observations in space), and data from other sources (data from GBOs and data from other forecasting systems) to improve predictions?

ACKNOWLEDGEMENTS

1. One year AE, AL, AU, AO, Dst, and Kp OMNI indices data was obtained from World Data Center for Geomagnetism, Kyoto.
2. SML index, SML predicted substorms by Newell, Forsyth, and Ohtani was obtained from SuperMAG.
3. This work was partially supported by the NSF EPSCoR RII Track-1 Cooperative Agreement OIA-1655280, the Alabama EPSCOR Graduate Research Scholars Program, and NSF Grant 2134451.
4. Data was run on TensorFlow using the tf.keras API sequential.

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