Forecasting Solar Energetic Particle Events

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Space Weather and the Significance of Solar Energetic Particle Events

The term Space Weather collectively refers to a plethora of naturally occurring phenomena which occur as a result of the Sun's influence on the Earth, near-Earth space, and throughout the Solar System. Like terrestrial weather, space weather is highly variable over a wide range of spatial and temporal scales and has the potential to disrupt many aspects of our technology and critical infrastructures. NOAA's Space Weather Prediction Center (SWPC), here in Boulder, serves as the nation's official source for advance warning of such disturbances. Forecasters at SWPC issue space weather warnings and alerts to customers who use these forecasts to safeguard their assets.

Space weather disturbances may be logically separated into three main categories: Geomagnetic storms, ionospheric disturbances, and energetic particles. Solar energetic particle (SEP) events, falling within the latter, are showers of energetic particles, mainly protons, which are generated in solar flares (FL) and by shocks driven through interplanetary space by solar coronal mass ejections (CMEs). When these particles traverse the near-Earth environment, they can have a number of impacts: Radiation hazards in near-Earth space for astronauts and manned space flights; Malfunction of spacecraft electronics; and High-frequency (HF) radio blackouts.

Project Objective

Current physics based models of SEPs are unable to execute sufficiently fast in order to provide actionable information towards forecasting such disturbances, which can impact Earth within tens of minutes of the onset of an eruptive event. This is compounded by the intrinsic latency of certain key observations, which are used to define the initial conditions of these models. Instead, there is a reliance on statistical models to provide forecast probabilities of Earth-bound SEPs using real-time data. Since the largest, most impactful events occur infrequently, some regions of the feature space are sparse and simple discrete binning procedures have limitations. The goal of this project is to improve upon the empirical SEP proton prediction forecast model (PROTONS) currently in operational use at SWPC, through the application of modern machine learning techniques.

Data

- An initial dataset comprised of all SEP events from 1986-2004, along with a list of control events comprised of periods with similar observables that did not result in an SEP at Earth, is available at SWPC (Balch 2008 investigation http://onlinelibrary.wiley.com/doi/10.1029/2007SW000337/full).
- Supplemental data is publically available under open data policies (e.g.NOAA, NASA, ESA spacecraft data and ground based US Air Force radio data), affording the potential for expanding the initial dataset or feature list.

Approach

- Generate features from observables which are known to provide some predictive capabilities for the forecasting of SEPs (e.g., FL size, FL location, radio burst occurrence, etc.).
- Investigate potential features which have been identified in the literature but are not considered in the current PROTONS model (e.g. CME speed, CME width).
- A requirement of the model should be a probabilistic SEP forecast. Therefore, the project will begin by investigating results of a Logistic Regression. However some consideration will be give to SVM and KNN models to assess the feasibility of classifying events through different techniques, regardless of a probabilistic output.
- Investigation of feature importance within classification model and removal of features exhibiting minimal predictive capabilities. Lasso regularization may help identify redundant features that are correlated and provide no additional predictability.
- Some new features, which prove to hold predictive capabilities, may not have observables which are currently available in real-time (research vs operational spacecraft data). However, proof of feature importance could inform future mission/instrument requirements.
- Performance will be assessed in terms of the true skill statistic (TSS), to account for a likely imbalance between class sample sizes (less SEP events). False positives and false negatives are also important but are application specific. For example, a conservative alert system might be appropriate to ensure safety of astronauts. However, the financial concerns of users with spacecraft assets likely result in a, relatively, less conservative forecast with minimal false negatives.