Classification of Forbush decrease events utilizing machine learning

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Introduction

The dynamic activity of the Sun's coronal magnetic field can give rise to complex space weather events, which may include solar flares, coronal mass ejections, their interplanetary counterparts known as interplanetary coronal mass ejections, the emission of solar energetic particles, and similar phenomena.

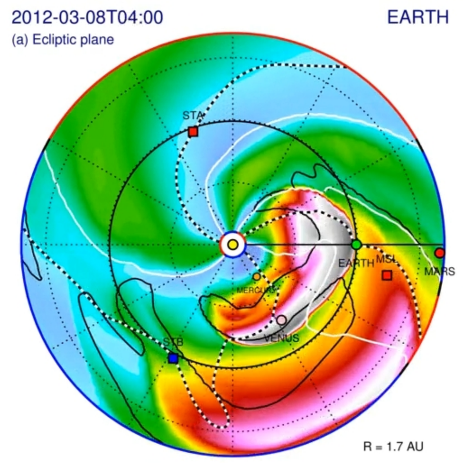

Figure 1: Development of an CME by ENLIL Solar Wind Prediction [1]

A coronal mass ejection (CME) is a large eruption of plasma and accompanying magnetic field from Sun's corona. Upon entering the interplanetary space it is referred to as an interplanetary coronal mass ejection (ICME). CMEs/ICMEs often follow intense solar flare (SF) events.

These complex events can result in a number of effects in the heliosphere, one of which is the acceleration of solar energetic particles (SEPs). There is a distinction between particles accelerated by a SF in the lower Sun's atmosphere and those accelerated locally by the CME shock. The later are often referred to as energetic storm particles (ESPs) [2].

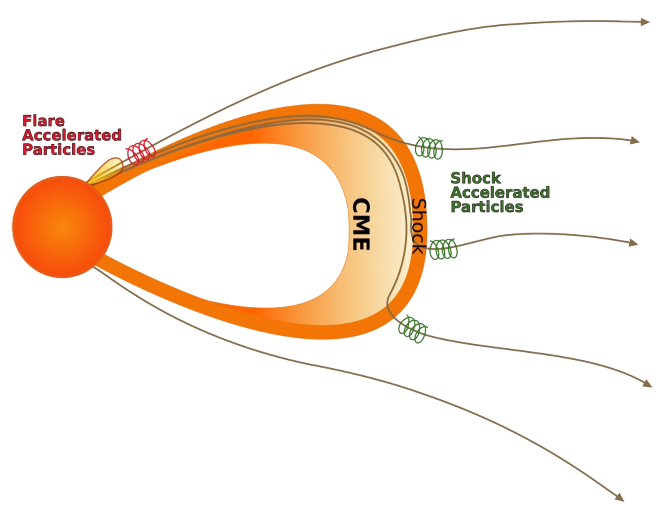

Figure 2: Acceleration mechanisms of energetic particles by SFs and CMEs in the heliosphere.

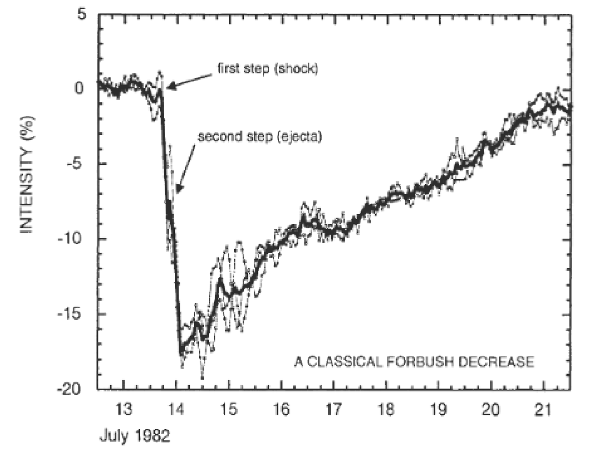

Figure 3: A typical two-step Forbush decrease event (Cane, 2000 [3])

Additionally, the passage of a CME can affect the primary cosmic rays (CRs) and lead to a sudden drop of the observed CR flux, followed by a recovery phase that takes place over the several following days. This effect is known as a Forbush decrease (FD) and can be observed by Earth-based CR detectors.

Motivation

Since both ESP and FD events are induced by CMEs, some relationship was assumed [4]. To establish this possible connection, correlation of characteristics of proton fluence spectra and FD parameters was investigated.

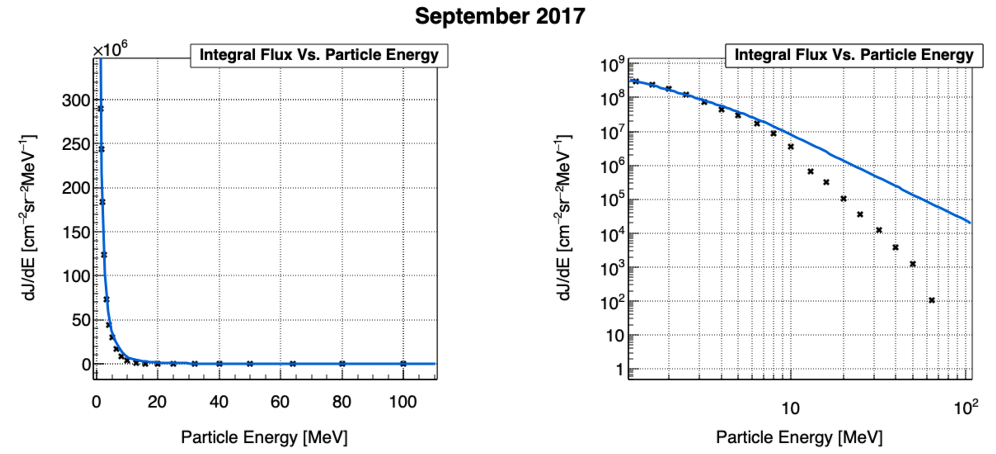

Figure 4: Proton fluence spectra measured by SOHO/ERNE at L1 [5] for a selected event in September 2017..

The proton fluence spectra were fitted by a double-power law, and obtained exponents were used to parameterize the spectra shape.
Correlation between these exponents and FD magnitudes was established. However, this analysis also indicated a possible existence of two classes of FD events.

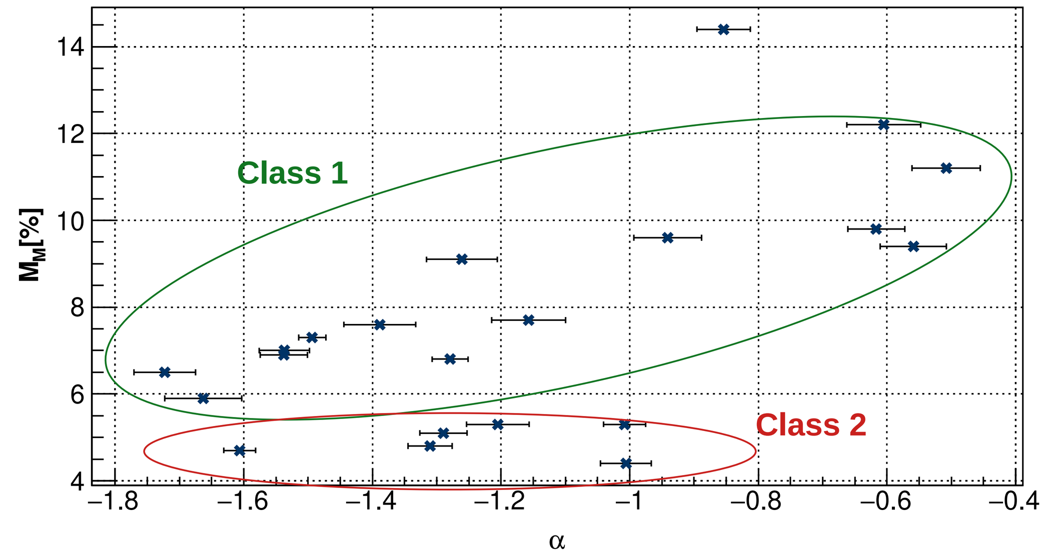

Figure 5: The dependence of the FD magnitude corrected for the magnetospheric effect on one of the proton fluence spectra exponents. The green line indicates a class of events that exhibit stronger correlation, while the red line indicates a class of weekly correlated events. The boundary between classes appears to be determined by the intensity of the event.

Due to relatively low statistics of events where proton fluence can be reliably determined, one idea for extending this analysis is to try and utilize other space weather (SW) parameters in order to increase statistics and establish more strongly the assumed existence of two classes of FD events.

Methods and Results

The IZMIRAN catalogue of Forbush-effects [6] contains an extensive list of FD events and associated SW parameters. The parameters selected for this analysis fall into several cathegories: parameters describing the source (Otype, Stype) or the characteristics of the CME (Vmean, CMEwidth); solar wind parameters (Vmax, KTmax, Ktmin); parameters describing interplanetary of geomagnetic field (Bzmin, Kpmax, Apmax, Dstmin); and parameters related to the associated solar flare (Xmagn, Sdur, SSN).
Several methods implemented in the TMVA analysis network were tested in order to establish the optimal FD magnitude for the separation of two classes, as well as the optimal algorithm.

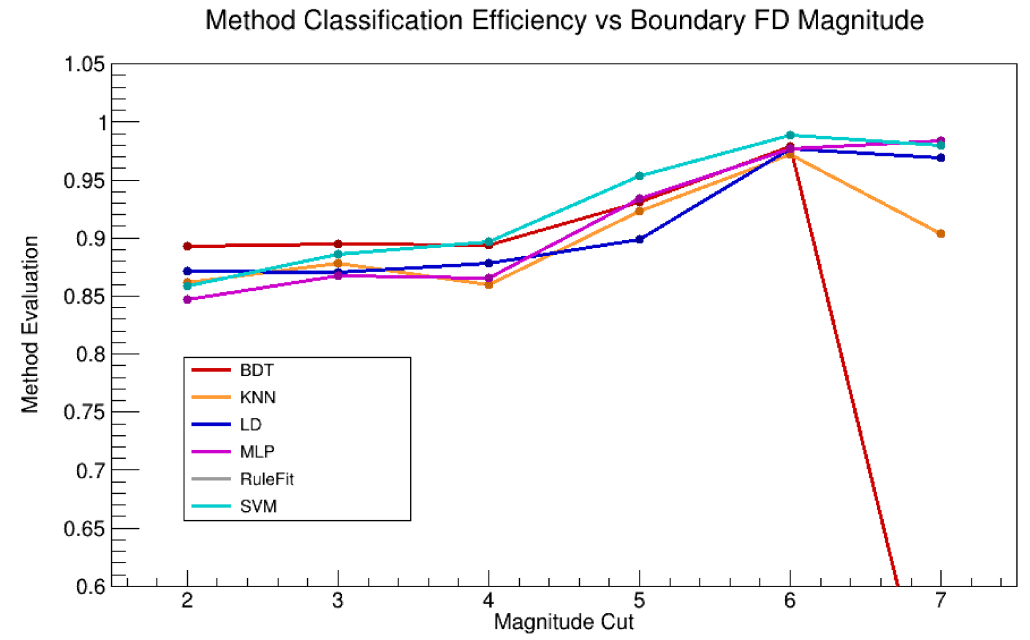

Figure 6: Comparing the classification efficiency of various TMVA methods, it was found that the optimal separation between two classes is achieved with an FD magnitude cut set at 6%. SVM was identified as the overall best-performing algorithm.

The Support Vector Machine method (SVM) was selected for further classification analysis. SVM implementation in the scikit-learn package was utilized to identify which of the SW parameters could reliably classify FD events. It was found that a third-degree polynomial kernel was the most flexible and efficient algorithm.

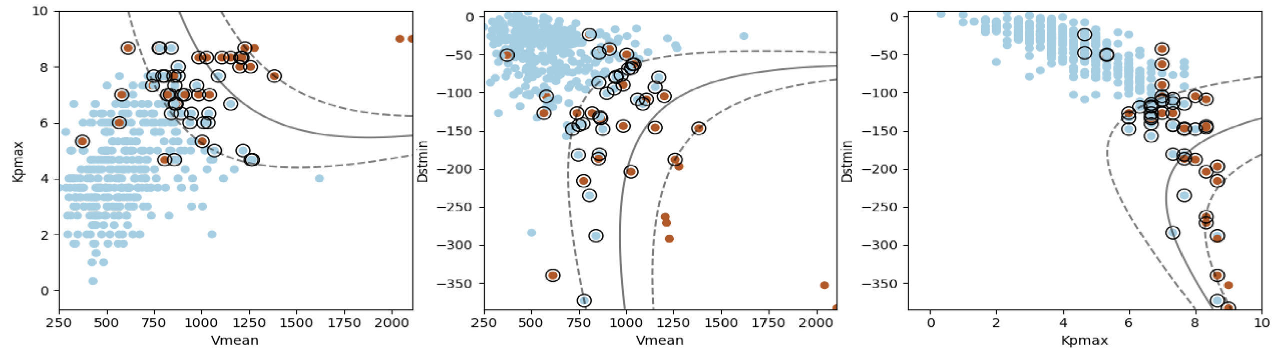

Figure 7: Space weather parameters, such as the mean CME velocity (Vmean), and geomagnetic parameters, such as the maximum Kp index over the event's duration or the minimal Dst index over the event's duration proved to be efficient parameters in classification.

The presented analysis appears to confirm the assumption regarding the existence of two classes of FD events. Furthermore, a subset of SW parameters that are more reliable in classification of FD events was determined. The selected parameters include: mean CME velocity (Vmean), geomagnetic indices (Kpmax, Apmax, Dstmin), with possible inclusion of the solar wind speed (Vmax) and minimal hourly component of the interplanetary magnetic field (Bzmin).

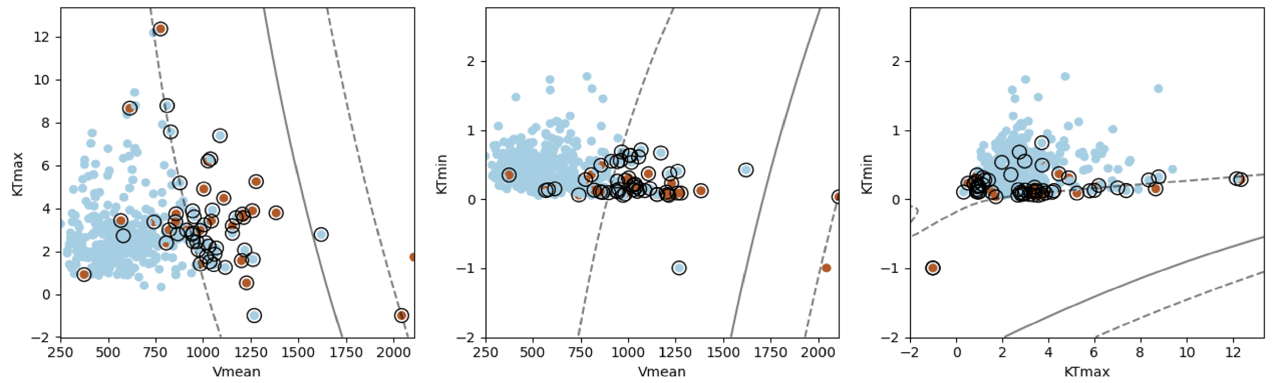

Figure 8: Space weather parameters such as some solar wind parameters (Ktmax, KTmin), or solar flare related parameters proved to have low usability for classification.

Conclusions

The potential existence of two classes of FD events was investigated. To increase statistical robustness and reduce uncertainties, the analysis was expanded to include a wider set of various space weather parameters, that are more reliably determined. Machine learning techniques were employed in an attempt to separate FD events into two assumed classes, using a number of selected SW parameters as input variables. We compared the efficiency of different machine learning algorithms, and established the optimal boundary value of FD intensity to be used for class separation. The SVM algorithm was selected for the analysis based on its overall performance, efficiency and flexibility, and used to select a subset of space weather variables to be used for reliable classification of FD events and further analysis.

References

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