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Space Weather Prediction System providing forecasts and alerts on solar flares and SEP events

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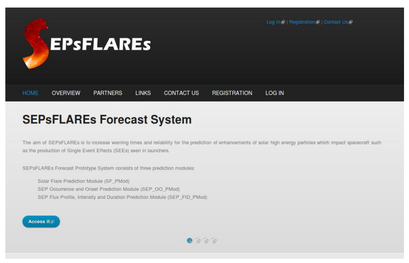
Abstract

A web-based prototype system for predicting Solar Energetic Particle (SEP) events and Solar Flares (SF) to be used by space launch operators is presented. The system has been developed as a result of the European Space Agency (ESA) project named SEPsFLAREs, which stands for Solar Events Prediction system For space LAunch Risk Estimation. A web-based prototype system for predicting Solar Flares and Solar Energetic Particle (SEP) events for its use by space launcher operators or any interested user has been implemented. The main goal of this system, called SEPsFLAREs, is to provide warnings/predictions with forecast horizons from 48 hours before to a few hours before to the SEP peak flux, and duration predictions.

SEPsFLAREs Overview

SEPsFLAREs main objective has been the development of a **web-based prototype system** (see right figure) with capability to provide **improved forecasts on solar flares and SEP events and provide warning alerts on safe/unsafe conditions** for launch operators or any other interested Space Weather user.

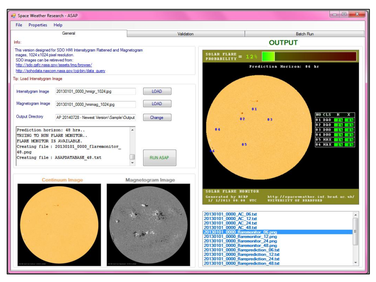


For this purpose, the system consists of several modules covering from pre-flare to intra-SEP scenarios:

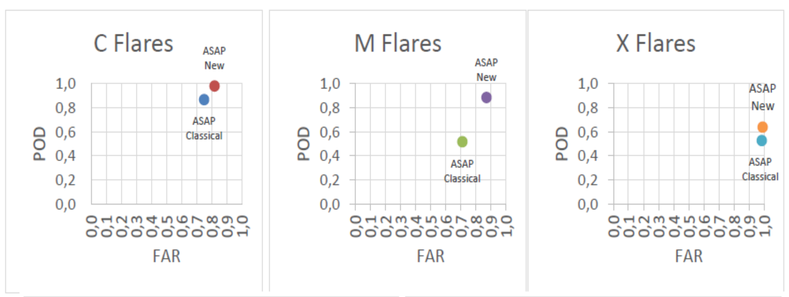
(1) The prediction of solar flares by means of an updated Automated Solar Activity Prediction (SEPsFLAREs **ASAP**; see http://spaceweather.inf.brad.ac.uk; [2])
(2) An early SEP occurrence Warning tool based on SEPsFLAREs ASAP.
(3) The prediction of SEP occurrence and onset by means of UMA Solar energetic proton Event Predictor SEP prediction (**UMASEP**; http://spaceweather.uma.es; [7])
(4) The prediction of SEP characteristics, such as SEP peak and duration.
(5) The near real time monitorization of solar flares occurrence by means of GNSS-based techniques (GSFLAD and SISTED; [5] and [4], respectively).

Solar Flare Prediction module

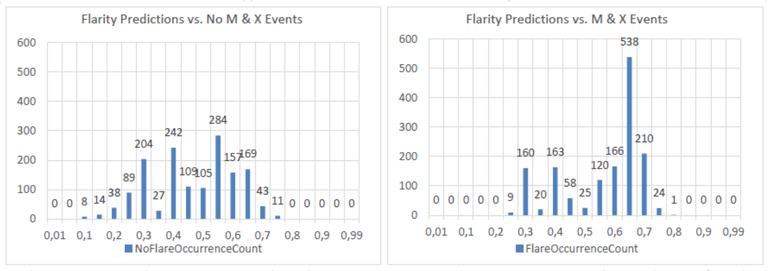
The module responsible for predicting solar flares is based on the well-known ASAP flare predictor [2], which learns rules by using machine learning techniques on SDO/SOHO solar images to automatically detect sunspots, classifies them based on the McIntosh classification system, and predicts C-, M-, and X-class flares.



The SF_PMod has been trained on data from 1st January, 1982 till 31st December, 2013 and the performance has been evaluated on new data from 1st January, 2014 till 31st May, 2014 for forecast horizons of 6, 12, 24 and 48 hours. In this period, 98 M- and X-class flares and 2,318 pairs of SDO/HMI intensitygram-magnetogram images were given.
The 24-hour window was found to provide the best performance: the Probability of Detection (POD), False Alarm Ratio (FAR) and True Skill Statistic (TSS) estimations were 63.8% 99.0% and 0.5 respectively for predicting X-class flares; and 88.7%, 87.0% and 0.59 respectively, for predicting M-class flares.



POD and FAR obtained from the classical and the upgraded SEPsFLAREs ASAP. Prediction horizon: 24 h.



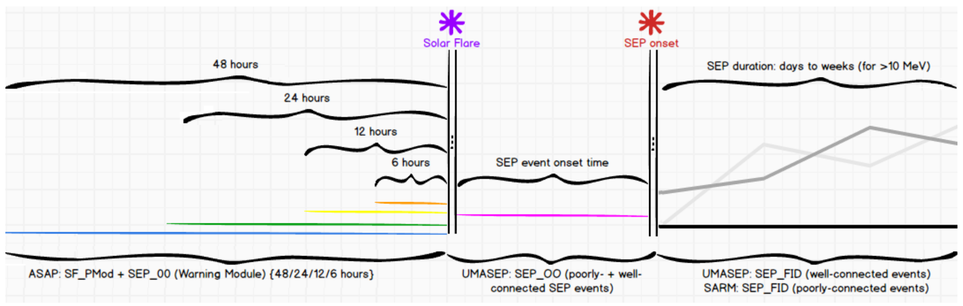
ASAP's flarity prediction probabilities against the number of no M and X flare occurrences (left diagram) and the number of M and X flare occurrences. Forecast horizon: 24 h.

Note that, since the prediction cadence was high, many predictions can be classified as unsuccessful repeatedly if they indicate a flare occurrence within a particular prediction horizon and a flare occurs just after the prediction horizon. This kind of scenario contributes highly to the increase of FAR.

Introduction

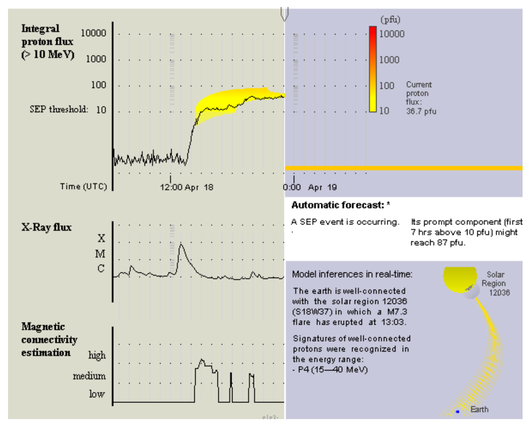
The occurrence SEP events poses a serious health risk to humans in space and can result in increased radiation doses for high-latitude aircraft flights and constitutes a serious hazard for hardware elements of satellites, aircraft and launchers. A SEP predictor needs to indicate early and reliably that the energetic particle flux will reach a hazardous level. The prediction system should neither miss relevant events that exceed the hazard level nor issue false warnings at an unacceptably high rate such that it might be disruptive for space activities. Moreover, it should continuously warn of radiation storm until the particle environment allows for continuation of routine or launch operation.

A solar radiation storm almost always has an associated flare. The figure below presents the two main events associated to a radiation storm (i.e. the flare and the SEP onset), and the three scenarios that space weather users shall take into account for effective decision making: the pre-flare, post-flare/pre-SEP, and intra-SEP scenario. The SEPsFLAREs system has been designed to provide real-time tools for each of these scenarios.



SEP Occurrence and Onset Prediction module / Warning module

On the one hand, the post-flare/pre-SEP scenario is handled by the SEP Occurrence and Onset prediction module, in which a solar flare has already taken place and there is evidence that a SEP onset could take place. In this case, the predictions are directly derived from the well-known UMASEP predictor [6], which performs X-ray and proton flux correlations to find the first symptoms of future well- and poorly-connected SEP events. UMASEP is working since 2010, making real time predictions.



In SEPsFLAREs, UMASEP has been tested against data from January 1994 to June 2014. The obtained results have implied a POD of 86.82%, a FAR of 25.83% and an Average Warning Time (AWT) of 3.93 hours (2.47 hours for well-connected events and 6.36 hours for poorly-connected events, with a maximum of 24 hours for the case of very gradual SEP events).

On the other hand, the so-called Warning Tool has been developed for issuing warnings on potential SEP occurrences in the pre-flare operational scenario. It is based on analyzing flare predictions from SEPsFLAREs ASAP to provide warnings proton enhancements with forecast horizons of 6, 12, 24 and 48 hours. In this context, the warning confidence has been derived from a statistical study of past events on the probability of a SEP occurrence given a flare class and location, and a minimum SEPsFLAREs ASAP probability of flare occurrence.

Confidence table

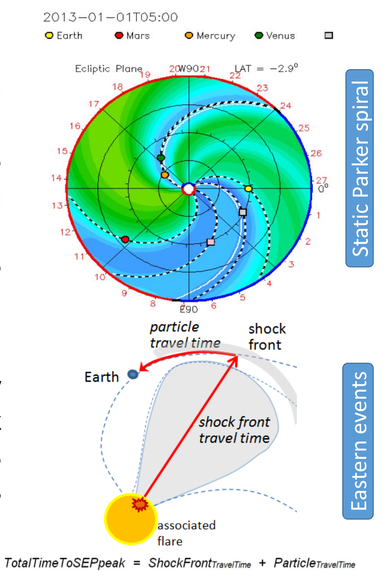
Bin	X-class	M-class	C-class
E90-E15	HIGH	LOW	no warning
E15-W15	HIGH	LOW	no warning
W15-W45	HIGH	MEDIUM	no warning
W45-W75	HIGH	MEDIUM	no warning
W75-W90	MEDIUM	MEDIUM	no warning

The performance of the Warning Tool with the adopted configuration (see [3] for the details) may be summarized as follows: Probability of Warning Detection (POWD) is 58.3%, False Warning Ratio (FWR) is 90.1% and Average Warning Time (AWT) is 23.1 hours.

SEP Peak & Duration Prediction module

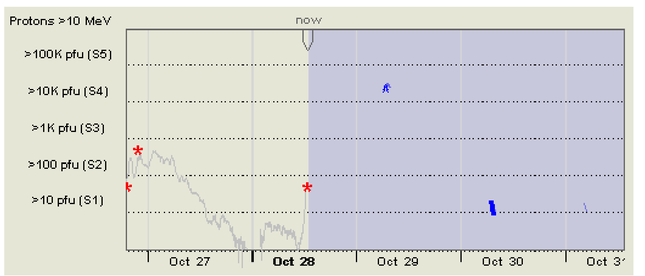
The intra-SEP scenario is handled by the SEP Flux, Intensity and Duration prediction module though predictions can be issued before the SEP onset. It has two main components: the model for predicting the SEP event Peak (intensity and timing) and Duration of >10 MeV SEP events (abbreviated as SEPPD; [3]) and the Shock ARrival Model (SARM; [7]).

On the one hand, the prediction of SEP peak and duration is based on:
(1) The identification of the parent solar flare heliolongitude associated to an observed/predicted SEP
(2) The simulation of the radial propagation of the predicted shock on a representative Interplanetary Magnetic Field (IMF) structure (in this work, a static Parker Spiral from a representative day in quiet conditions).
Then, the prediction of the particle peak arrival time and intensity, as well as the expected SEP end time, can be derived.



On the other hand, SARM has been used to predict arrival times with flare data only (peak, duration and location). It is based on a 1-D differential equation to predict shock arrival times from 0.7 AU to 8.7 AU (for the details please refer to [7]). In those cases where the shock propagation model cannot be used (i.e. either well-connected events or SEP events whose associated flare has not been identified), statistical/regression models have been constructed.

This prediction module has been validated taking into account the 129 SEP events from January, 1994 to June, 2014, obtaining a Mean Absolute Error (MAE) of SEP peak time predictions of 11.3 h, a MAE of peak intensity predictions of 0.53 in log10 units of pfu, and a MAE of SEP end time predictions of 28.8 h (for the details please refer to [3]).



Conclusions

SEPsFLAREs is a newly developed web-based prototype system close to be operational at http://sepsflares.esa.int. Its main purpose is the provision of forecasts on solar flares and SEP events. In this regard, ASAP has been improved with new functions, also enabling 6, 12, 24, and 48 hours forecast horizons. Also, the latest version of UMASEP has been included and a new Warning Module was developed for processing SEPsFLAREs ASAP flare predictions and providing warnings on potential proton flux enhancements. Also, a new SEP Peak and End/duration prediction model was developed that uses a new Shock ARrival time prediction Model (SARM; [6]) and a static Parker Spiral. Finally, the system provides nowcasts of solar flares facing the Earth from GNSS-based GSFLAD and SISTED ([4],[5]).

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Acknowledgements

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