



Foretelling Flares and Solar Energetic Particle Events: the FORSPEF tool

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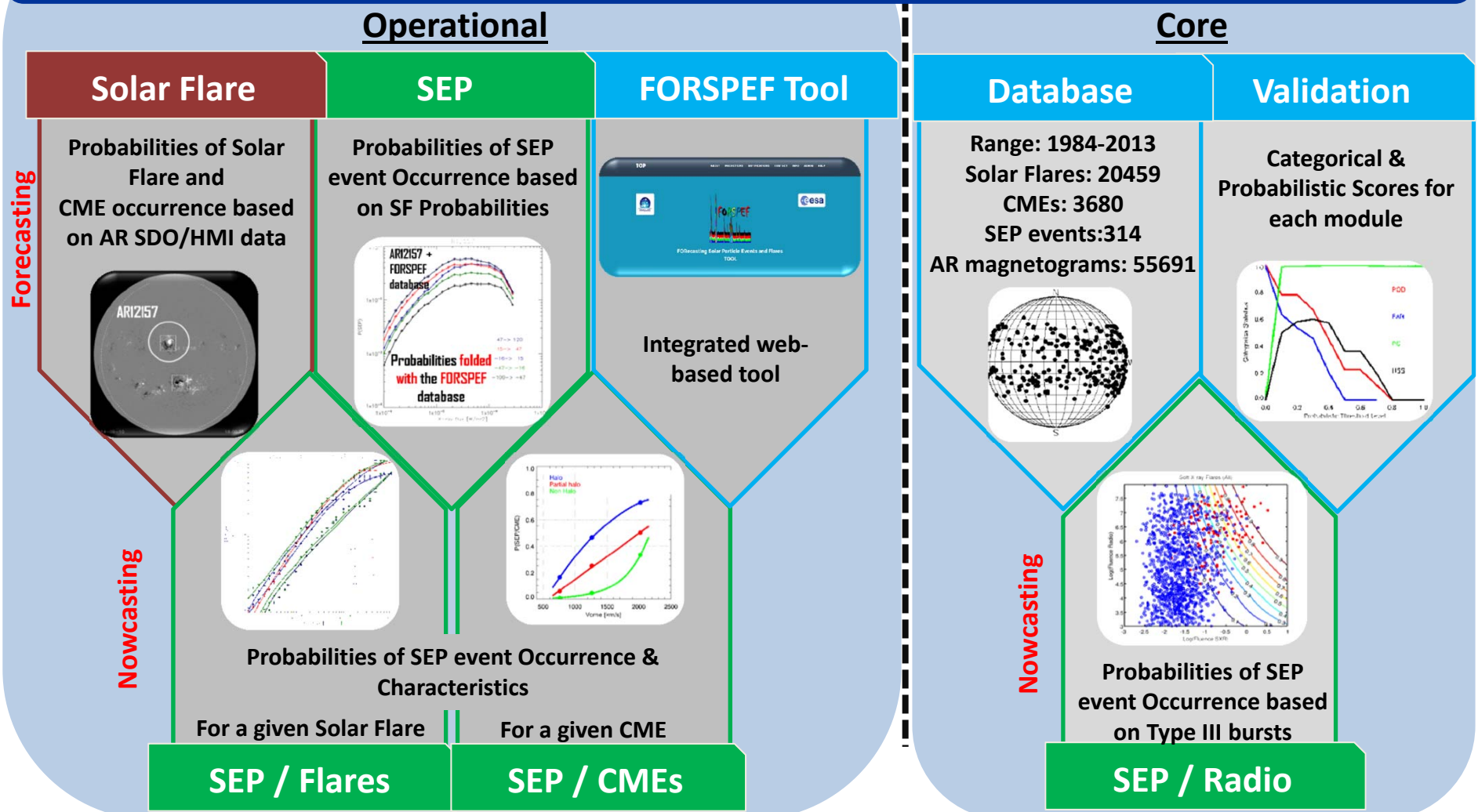
⁴ESTEC/ESA, Space Environment and Effects Section Keperlaan 1, Noordwijk, The Netherlands

Hellenic Astronomical Society

13th Conference

2017

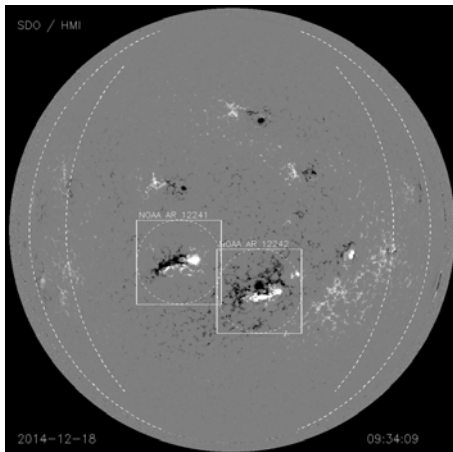
The *operational* system: FORSPEF Tool



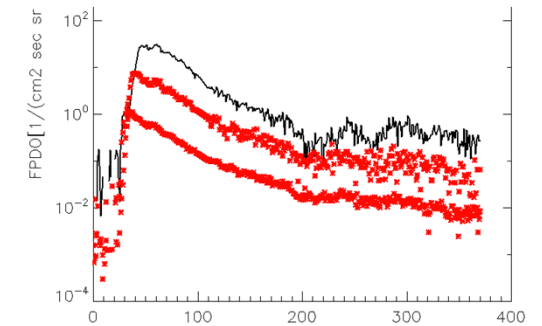
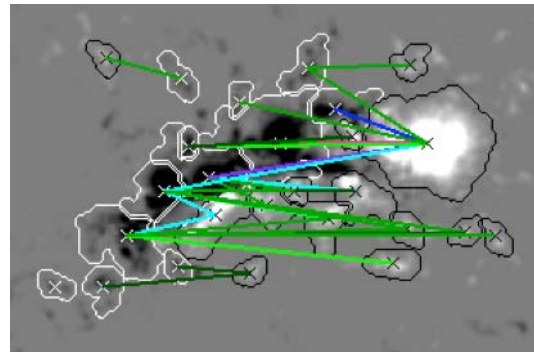
<http://tromos.space.noa.gr/forspef>

Background

SEP Forecasting (*pre-event* mode)



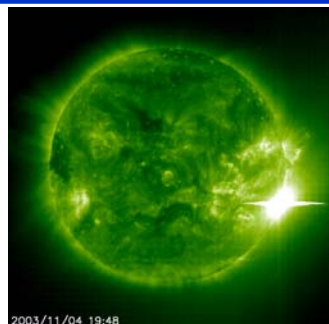
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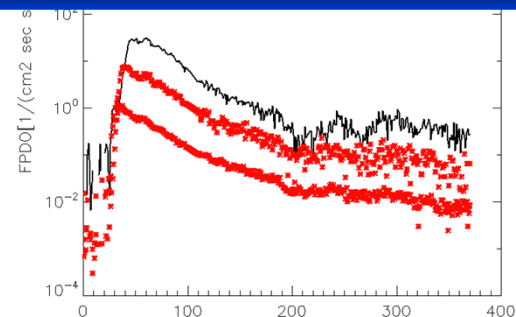
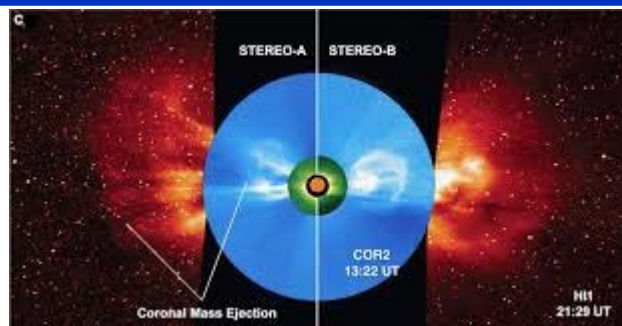
> Given a suitable proxy (e.g. **total magnetic flux, B_{eff}**) identify the probability that an **SEP event** will **occur**

Background

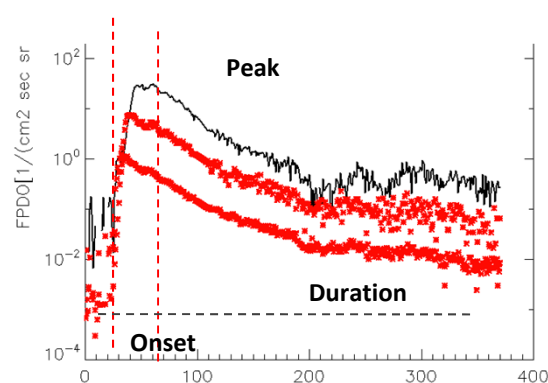
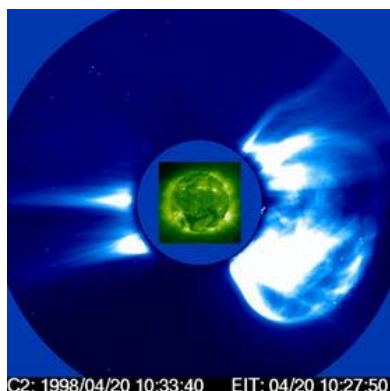
SEP Nowcasting (*post-event* mode)



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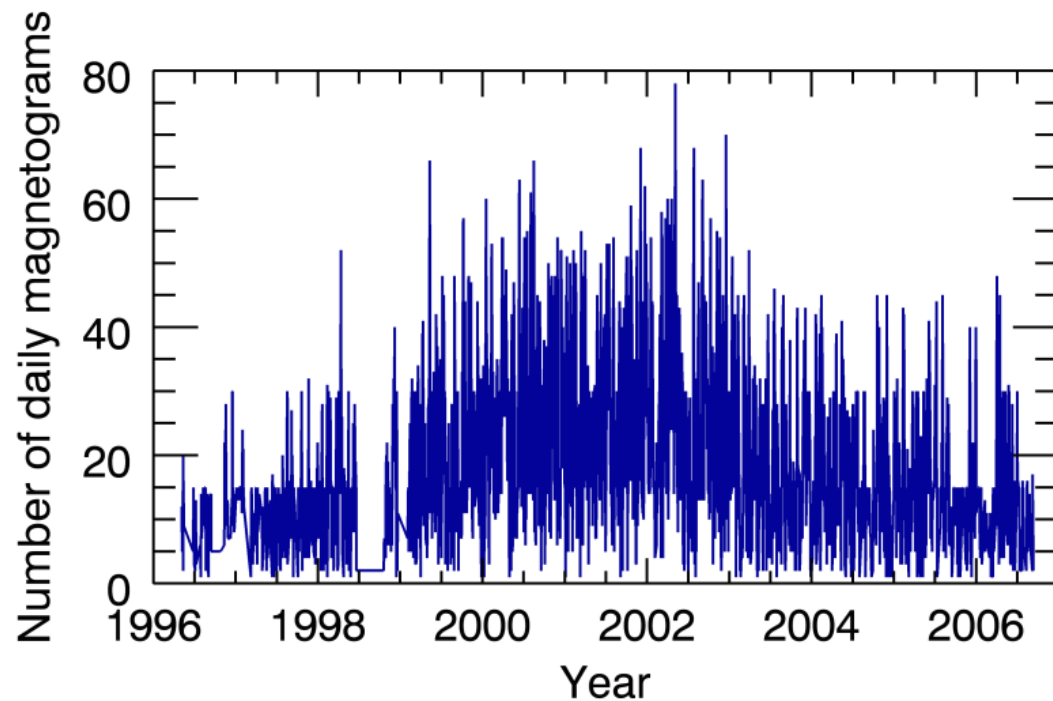
> Given **specific solar parameters** (flare mag, cl, CME width, velocity) identify the probability that an **SEP event** will **occur**



> Given **a subset of flares and CMEs that do produce SEP events**, how do the characteristics of the SEP event relate to those of the parent solar event?

The database

1 : Database of magnetograms

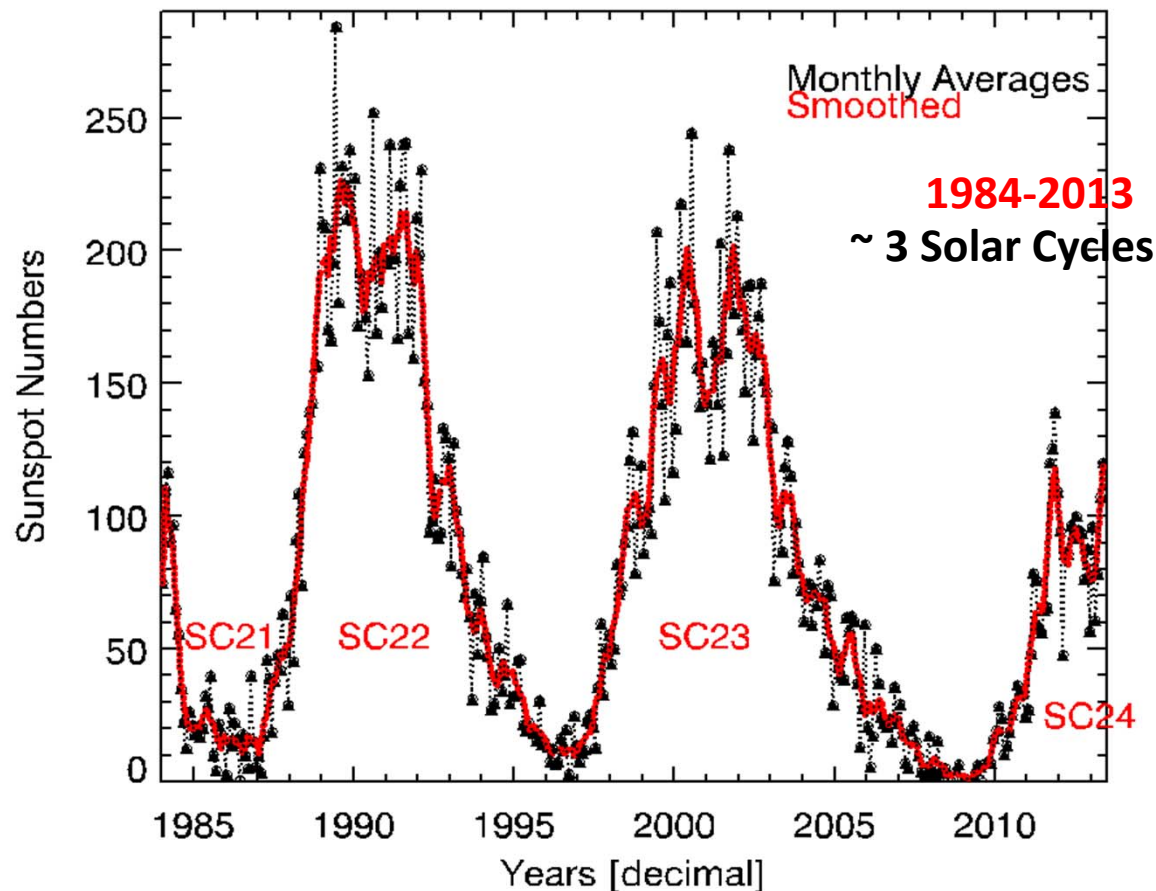


Data at a glance:

- **2,736** data-filled calendar days
- **1,416** different **ARs**
- **55,691** magnetograms

The database

#2: Database of SFs, CMEs, radio & SEP events



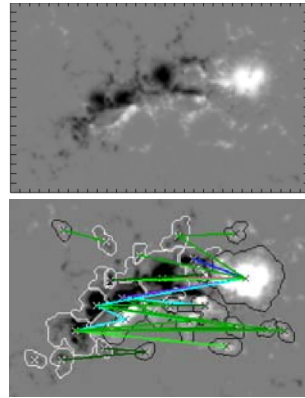
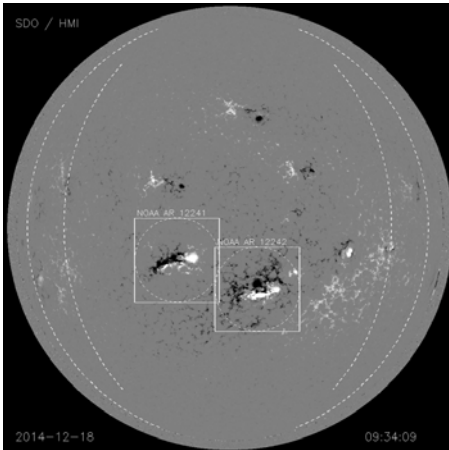
Data at a glance:

- 35,306 Soft X-ray solar flares (\geq C1.0)
- 22,143 Coronal Mass Ejections (CMEs)
- Cleaned GOES differential Proton Fluxes (courtesy of the SEP-EM team)

Papaioannou et al., J. Space Weather Space Clim., 6, A42, 2016

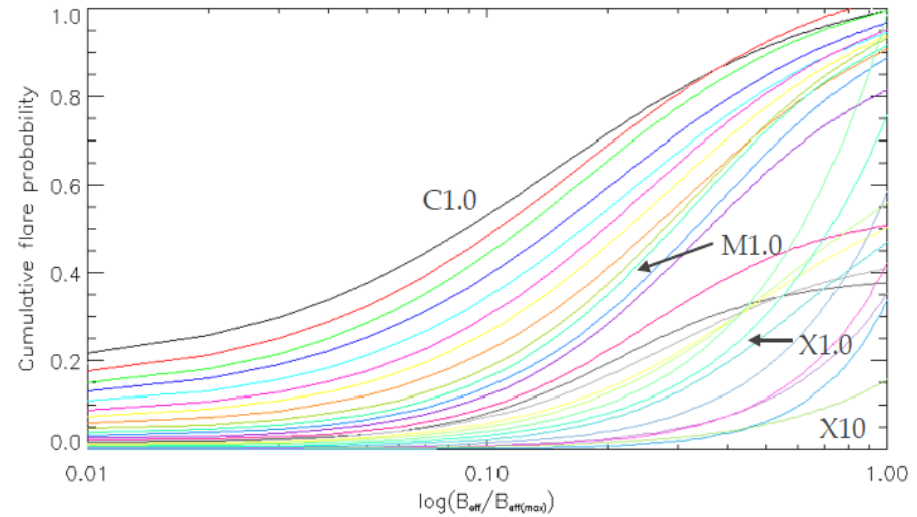
The system

Forecasting mode (Solar Flares)



B_{eff} prediction metric:

$$B_{\text{eff}} = \sum_{i=1}^{N_+} \sum_{j=1}^{N_-} \frac{\Phi_{ij}}{L_{ij}^2}$$



$$P(\geq \text{thres_class}) = A_2 + \frac{A_1 - A_2}{1 + \exp\left(\frac{\log(B_{\text{eff}}(\text{norm})) - X_0}{W}\right)}$$

> Step 1 ARIA cutouts

- Identifies ARs from up to $\pm 70^\circ$ EW in central meridian distance
- Provides the AR cutouts for further analysis

> **Step 2:** The **Solar Flare Prediction** relies primarily on the “**effective connected magnetic field strength**” (B_{eff}) prediction metric

> Step 3: Probabilities of SF occurrence based on B_{eff}

All **fitting curves** for all B_{eff} -values and **flare classes** are pre-calculated

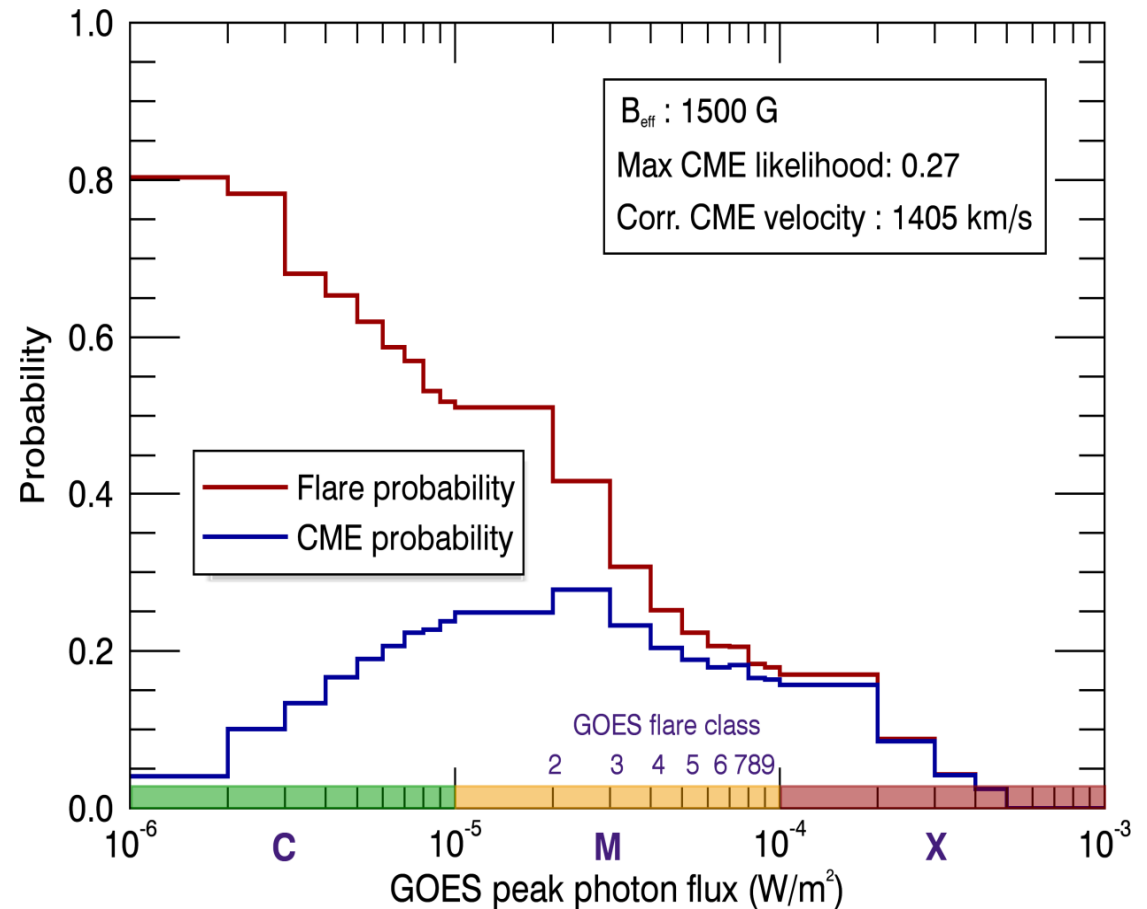
The system

Forecasting mode (Solar Flares)

> Final Output:

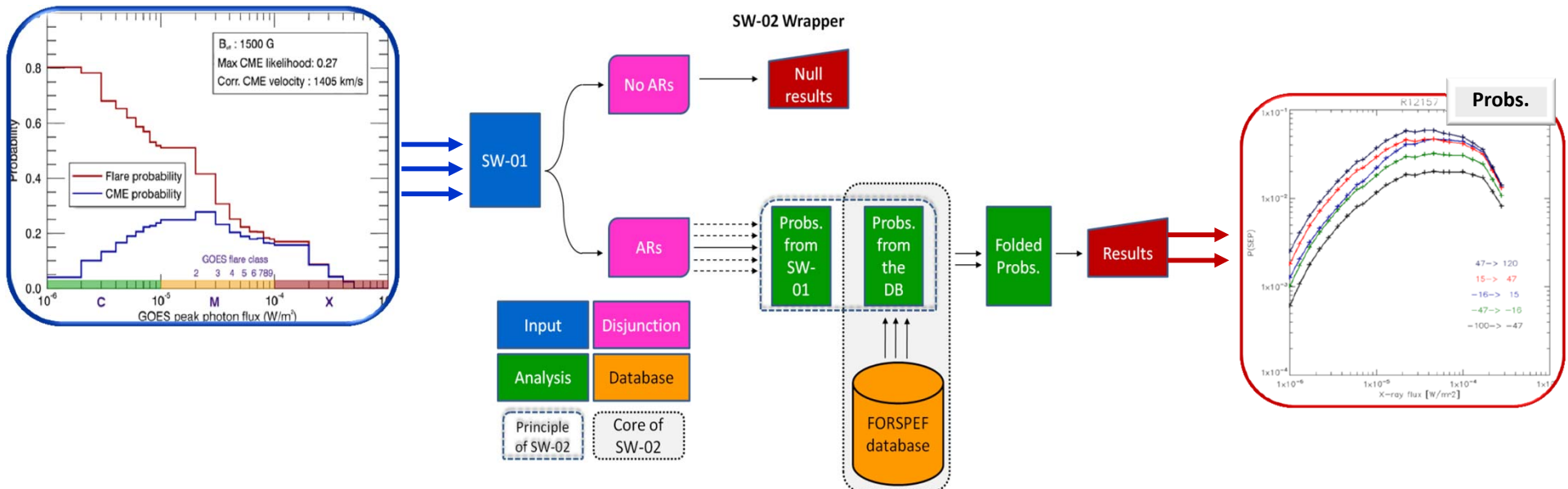
Flare & (Projected) CME prob.

A pictorial output of the range of probabilities for different flare classes (**red histogram**). Also shown is the respective CME likelihood curve (**blue histogram**).

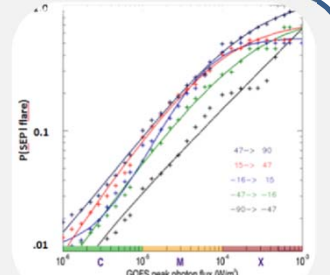
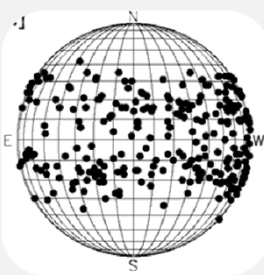
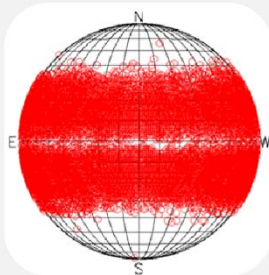


The system

Forecasting mode (SEP events)



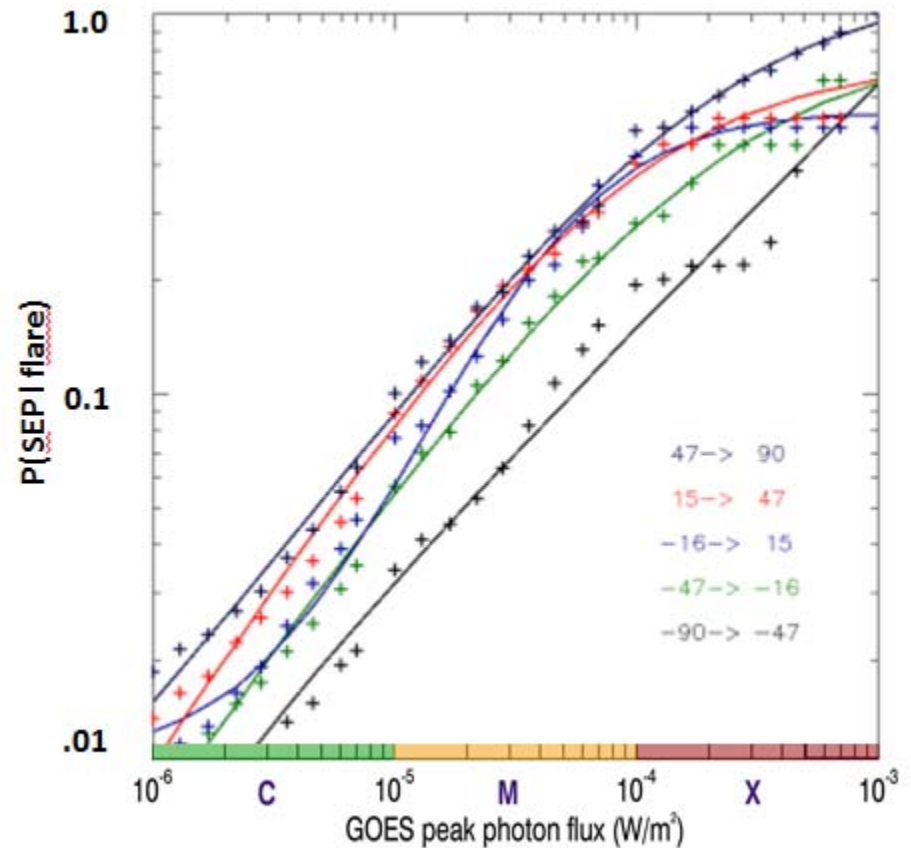
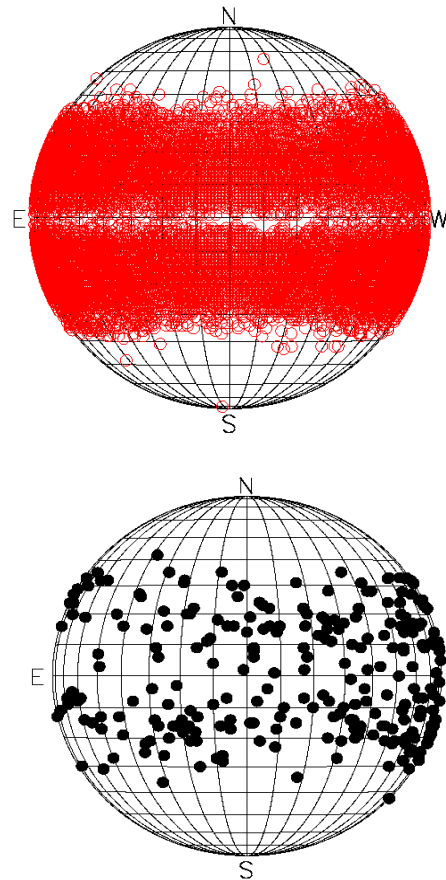
Core of the
Forecasting
Mode (SEPs)



The system

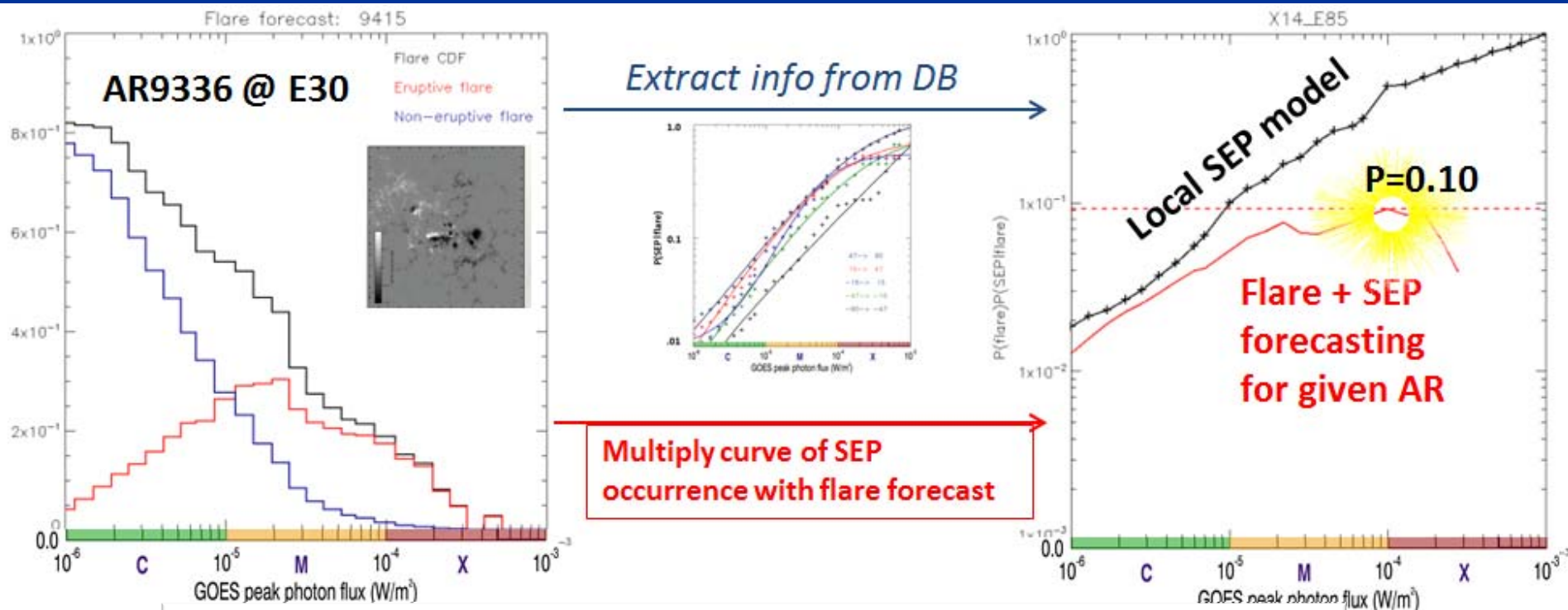
Forecasting mode (SEP events)

> **Step 1:** The **#2 database** is used for the construction of the **Probability Function (sigma-fits)**.



The system

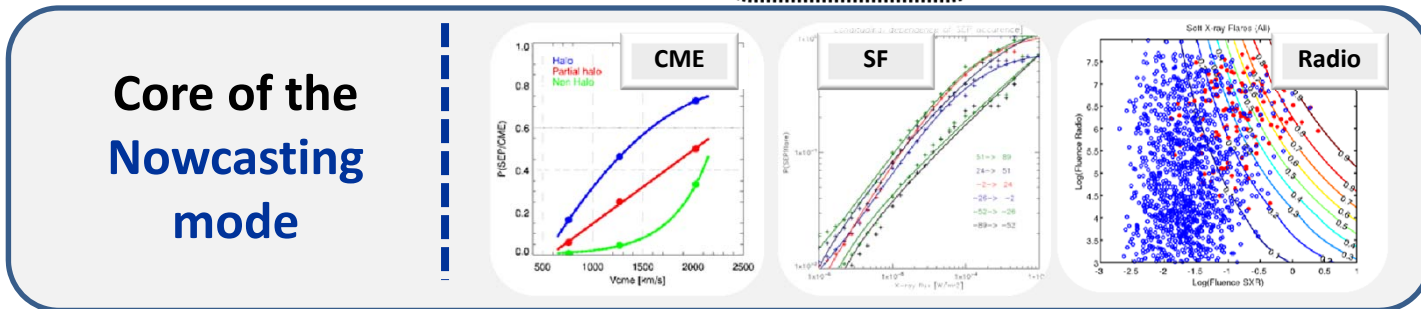
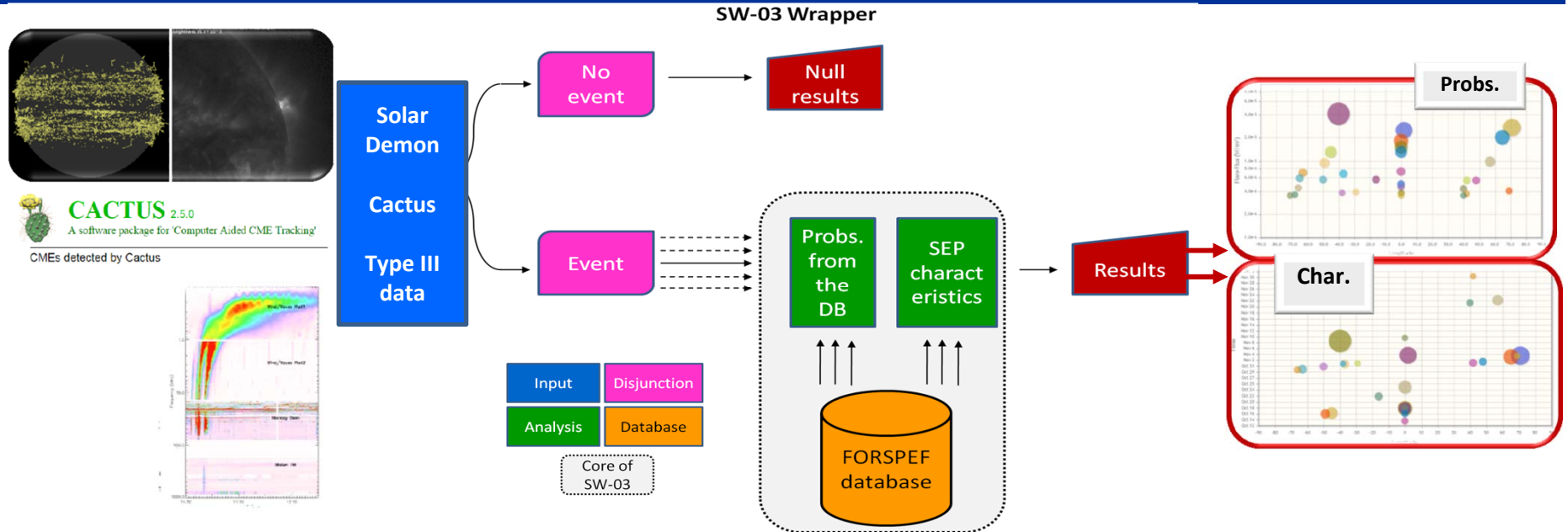
Forecasting mode (SEP events)



- > **Step 2:** For any given AR, extract **4000 flares** from the #2 db, around the longitude of the AR.
- > **Step 3:** Build a **Local SEP model**
- > **Step 4:** Fold the **Local SEP model** with the **Output** of the **Flare Forecasting**

The system

Nowcasting mode



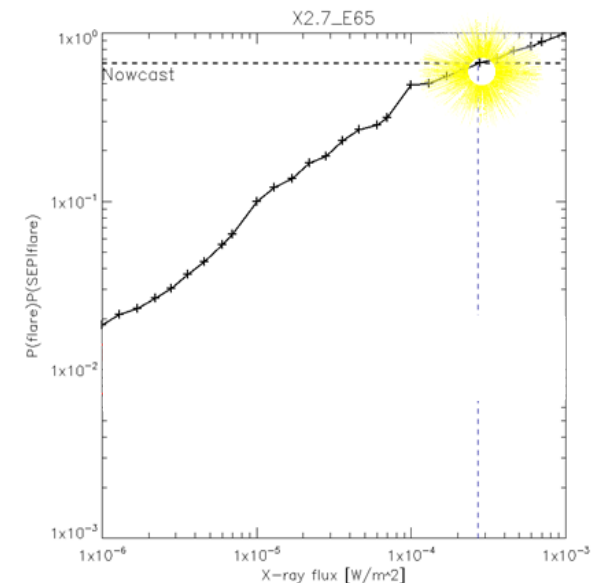
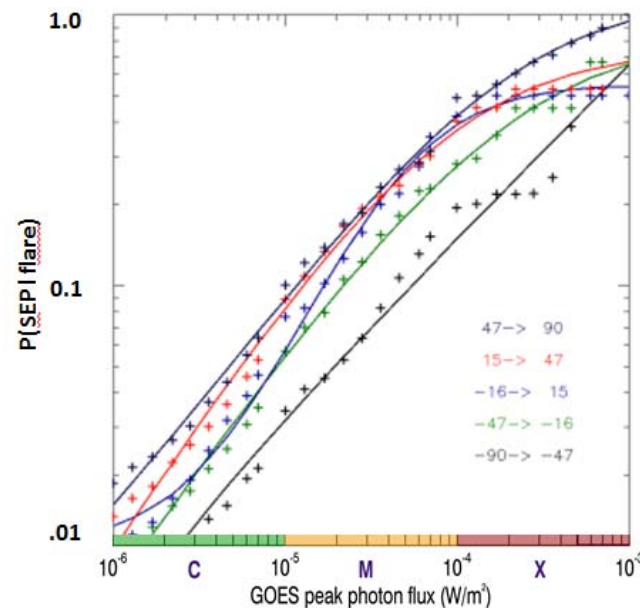
The system

Nowcasting mode (based on *Solar flares*)

> **Step 1:** Locate **4000 flares** around the longitude of the given SF, in the **#2 db**

> **Step 2:** Build a **Local Probabilistic Model (CDF)**

> **Step 3:** **Interpolate CDF** at the given **SF magnitude**

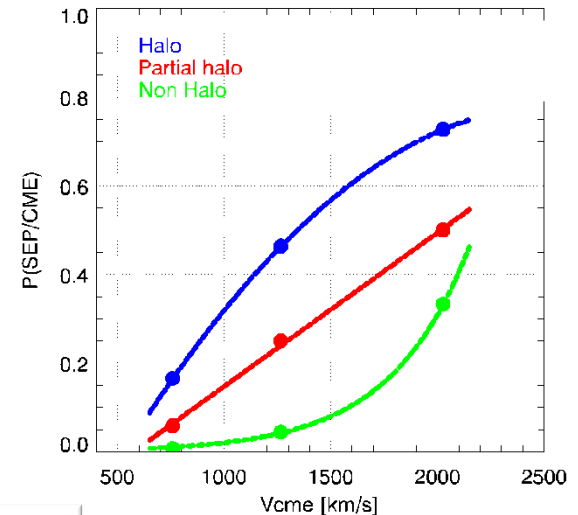


The system

Nowcasting mode (based on CMEs)

Table 1: SEP Occurrence Probabilities Depending on three CME speeds and three CME angular widths

	Slow	Moderate	Fast	Total
Partial Halo	5.8%	25%	50%	12.4%
	(14/208)	(10/40)	(9/18)	(33/266)
Halo	16.5%	46.3%	72.7%	39.4%
	(20/121)	(38/82)	(48/66)	(106/269)
Non Halo	0.7%	4.4%	33.3%	0.9%
	(9/1258)	(3/68)	(1/3)	(13/1329)
Total	2.7%	26.8%	66.6%	8.1%
	(43/1587)	(51/190)	(58/87)	(152/1864)



Park et al., J. Geophys. Res., 2012

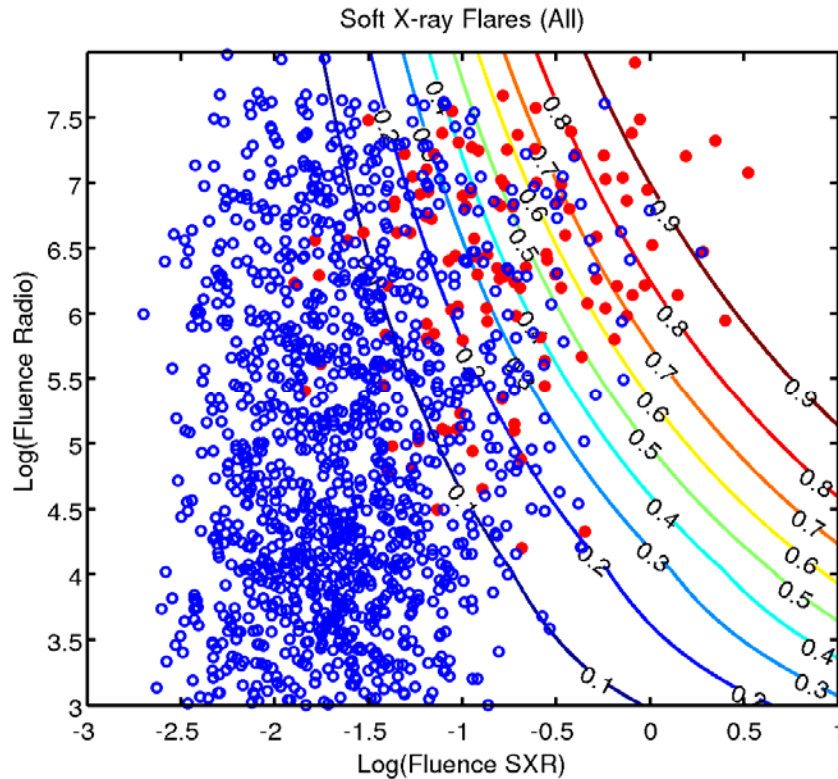
- > **Step 1:** Use **the #2 database** to extract 2D probabilities for **nine sub-groups**, in accordance to the **CME characteristics (width, velocity)**
- > **Step 2:** Find **proper fits** per width
- > **Step 3:** Use the **width** of a given CME to identify the fit to be used in the nowcasting
- > **Step 4:** Use the **velocity** of a given CME to spot the expected probability of SEP occurrence



The system

Nowcasting mode (based on *ESPERTA*)

Laurenza et al., Space Weather, 2009



- flares ass. to SEPs
- flares

> **SEP Nowcasting, offers:**

- Probability of SEP occurrence for a given solar flare and type III radio burst

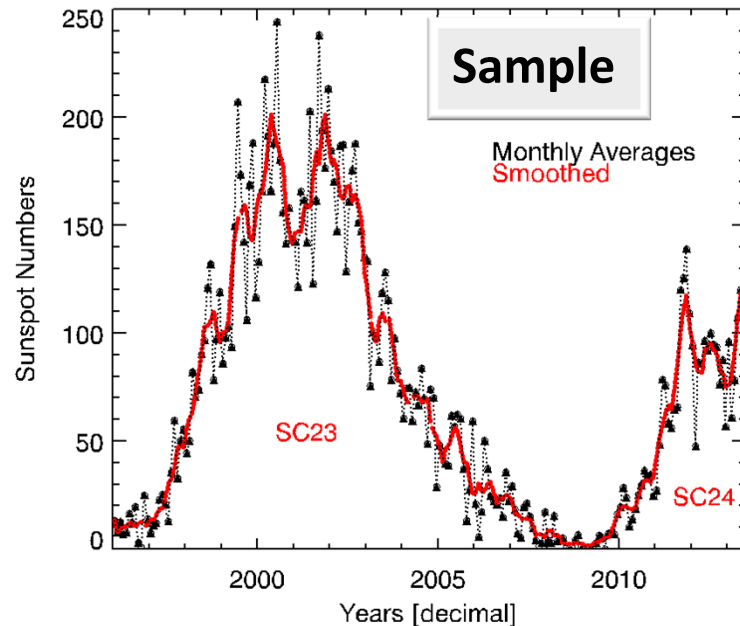
$$P(\log X, \log R) = \frac{e^n}{1 + e^n}$$

$$n = b_0 + b_1x_1 + b_2x_2 + b_3x_1x_2$$

- > **Step 1:** Calculate the *fluence* of the **SXR** and **radio flux** of the parent solar flare
- > **Step 2:** Apply the **logistic regression model** to identify the expected probability of SEP occurrence

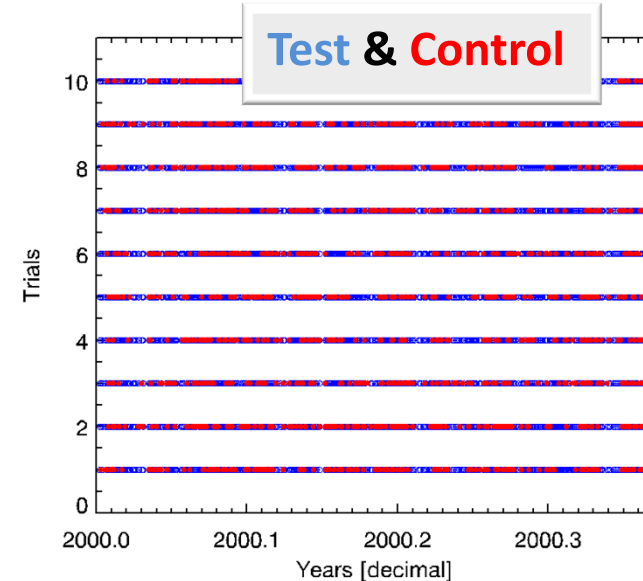
Validation

SEP events Nowcasting



Data at a glance:

- 10,026 solar flares
- 3,680 different CMEs
- 174 SEP events
- 150 Type III bursts

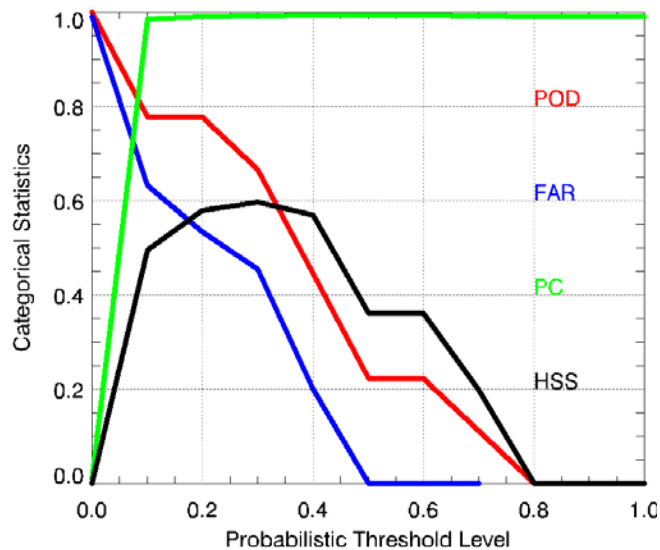


- We take **~90%** of the solar flares as **training period** (9,026 solar flares)
- The remaining **1000 flares** (~10% are **test flares**)
- The selection is **completely random**

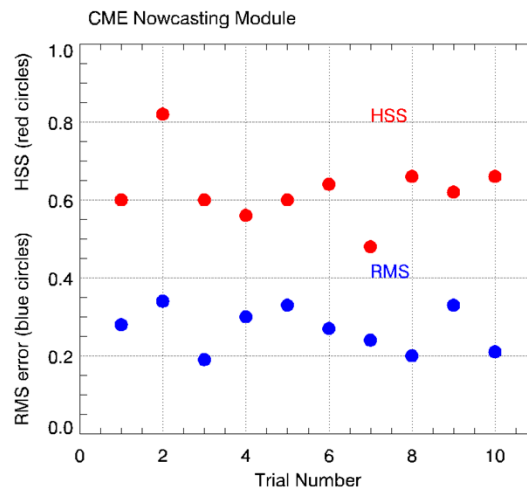
Validation

Nowcasting based on *CMEs*

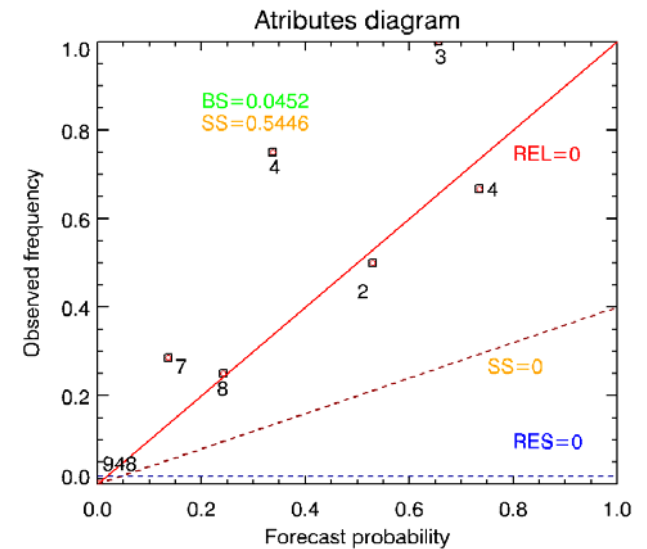
> Solar Energetic Particles Nowcasting
- Coronal Mass Ejections sub-module



> Mean POD: 0.70
> Mean FAR: 0.41

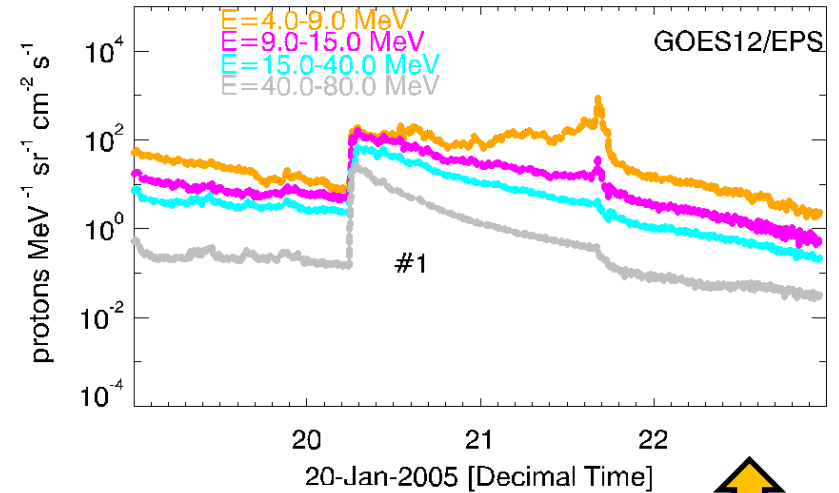
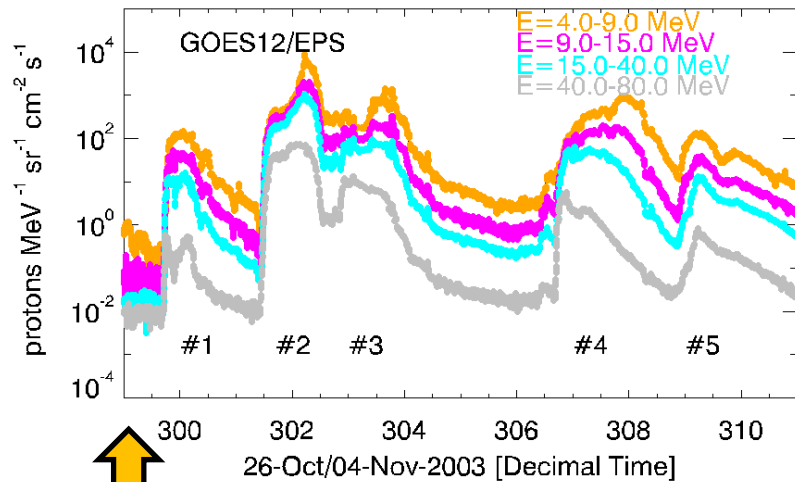


> Mean HSS: 0.67 ± 0.007
> Mean RMS: 0.269 ± 0.003



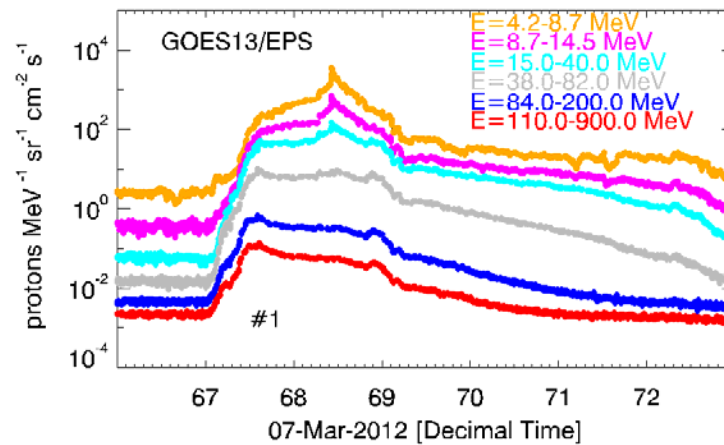
Validation

Case studies



> Halloween SEP events

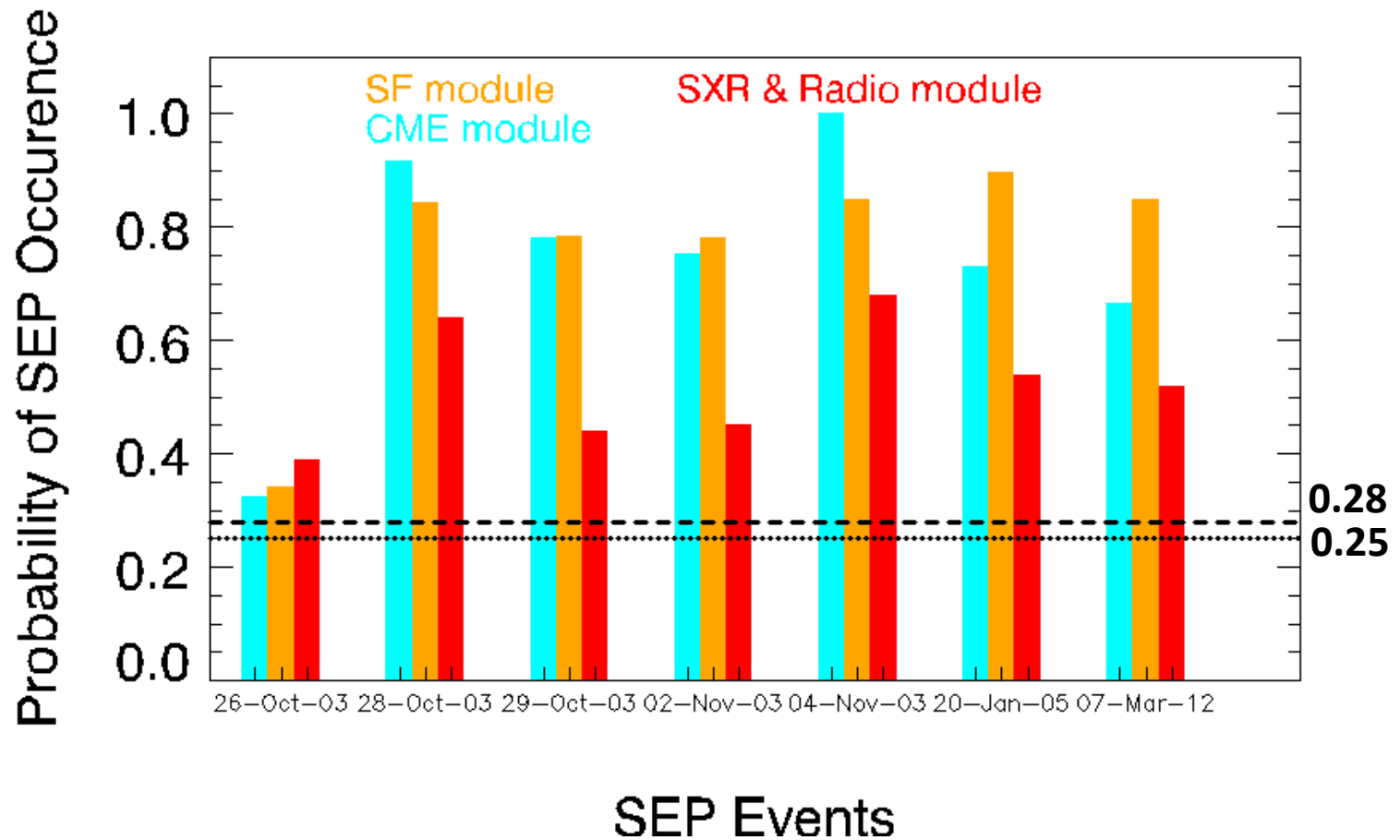
- > 26-Oct-2003
- > 28-Oct-2003
- > 29-Oct-2003
- > 02-Nov-2003
- > 04-Nov-2003



- > 20-Jan-2005
- > 07-Mar-2012

Validation

Case studies: summary (per sub-module)



Conclusions

> **Data driven statistical methods** for SEP forecasting / nowcasting are in need of *comprehensive databases*. In this work two databases have been compiled

- A new database, **covering a large time-span** from 1984-2013, consisting of **20459 solar flares**, **3680 CMEs** and

314 SEP events was developed as part of the *SEP Nowcasting and Forecasting modules*.

- A large database of **SOHO/MDI ~55,000 magnetograms** **spanning SC23** was incorporated in the *Solar flare Forecasting module*

> The application of the *Data driven statistical methods* led to the implementation of forecasting/nowcasting modules for the:

- **Forecasting** of **solar flares** with a projection to *coronal mass ejections* (CMEs) (*occurrence* and *velocity*).

- **Forecasting** of the likelihood of occurrence of a **solar energetic proton (SEP) event**.

- **Nowcasting** of the *SEP events probability of occurrence* based on actual **solar flare** and **CME** near real-time data.

- **Nowcasting** of the **SEP event characteristics** (peak flux, fluence, rise time, duration) per parent solar event.

- **Nowcasting** of the *SEP event probability of occurrence* based on **solar flare** and **type III radio burst data**.

Acknowledgement

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