Solar flare forecasting using photospheric active region properties

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Abstract

Daily observations of the photosphere are performed by the Equatorial Spar of INAF- Catania Astrophysical Observatory. In this poster we describe the results obtained by a tool developed for solar flare forecasting on the base of photospheric active region properties. We measured five parameters describing the morphology of the active regions appeared on the solar disc from January 2002 up today: area, Zurich class, number of pores and sunspots, relative importance between leading spot and density of the sunspot population and type of penumbra of the main sunspot. By means of a linear combination of these parameters we determined the probability that a flare of C-, M- and X- class occurs in such active regions. Comparing our forecasting with the number of flares registered by GOES satellites in the 1 - 8 Å X-ray band during the subsequent 24 hrs we evaluate the accuracy of our method using different skill scores.

INAF-OACT flare forecasting service

Using sunspot data collected by the Equatorial Spar of INAF-Catania Astrophysical Observatory (INAF-OACT) from January 2002 up today, we provide an indication of the probabilities that each active region, visible on the solar disc, may host solar flares of C-, M- and X- class.

The method used to obtain the flare probability is described by the scheme on the right. Every day each active region visible on the disk is cataloged on the base of its photospheric configuration, providing a numerical code (ursigram) named **USSPS** which contains the main characteristics of the sunspot groups. Integrating the USSPS file with the information of the **Solar Region Summary** provided by NOAA, we get the **complete dataset** useful to apply our forecasting method. Every day between 6:30 UT and 10:30 UT, when the weather conditions permit, we publish our flare forecasting in terms of probability that a flare of C-, M- and X- class occurs in each active region visible on the solar disc. The INAF-OACT flare forecasting service is available at the following URL: **http://ssa.oact.inaf.it/oact/Flare_forecasting.php**

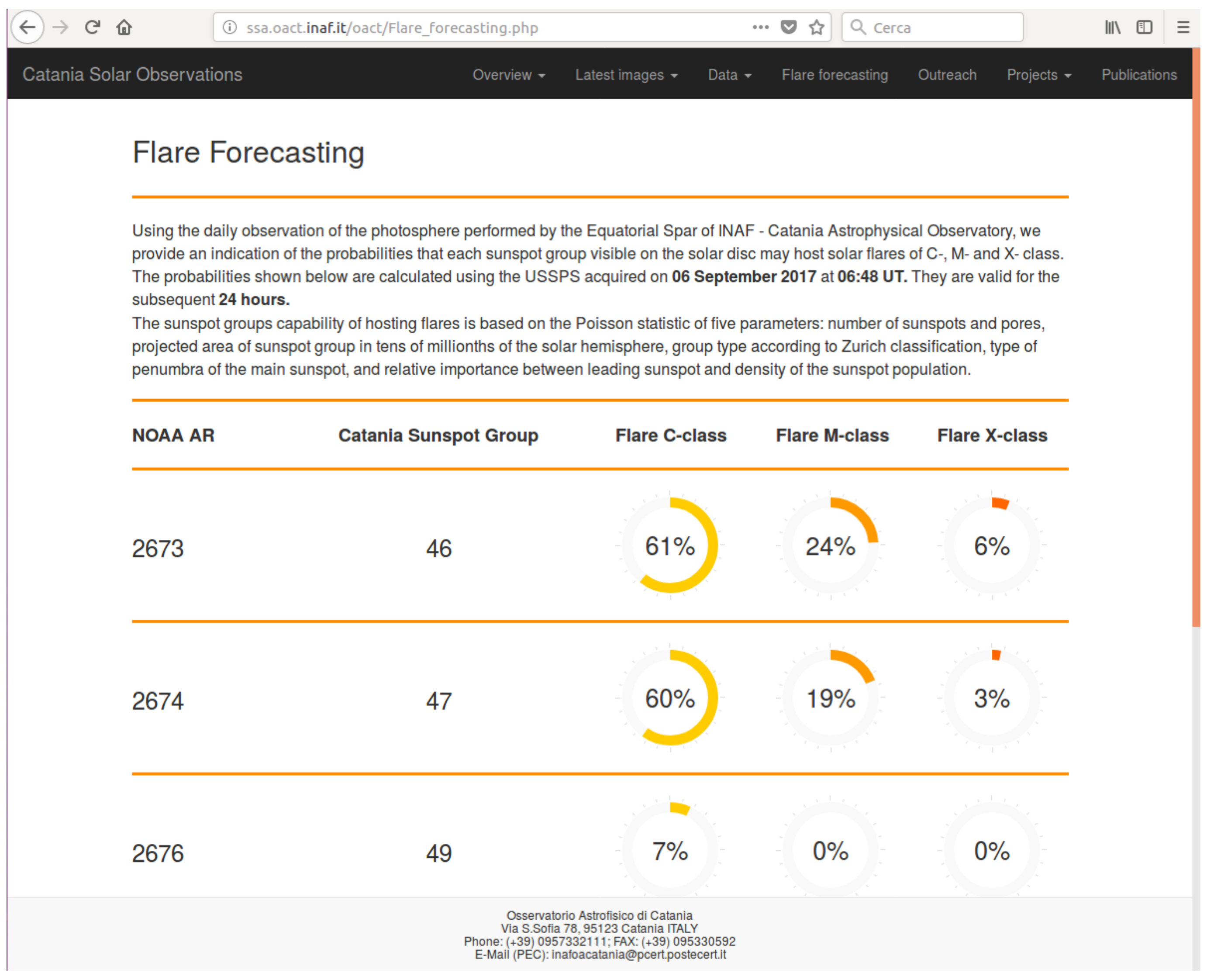
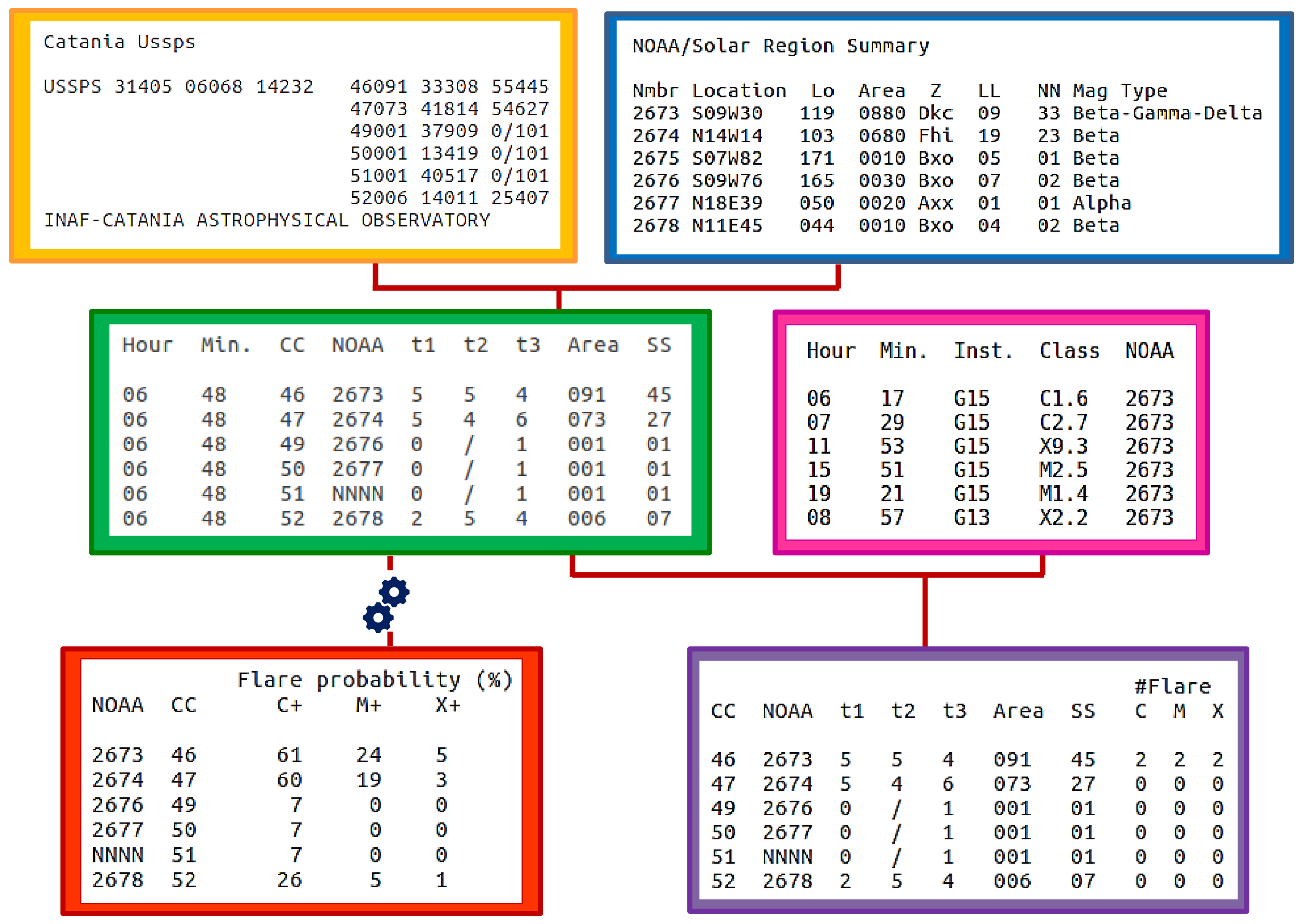


Fig. 1 *Snapshot of the INAF-OACt webpage dedicated to the flare forecasting.*

Our method uses a **database** containing the descriptions of the sunspot group characteristics observed by INAF-OACT from January 2002 up today and the flare records obtained by the GOES satellites and saved in the **Space Weather Prediction Center reports**.



Forecasting method

We condider five sunspot group parameters: number of sunspots and pores (SS), projected area (AA), group type according to Zurich classification (t1), type of penumbra of the main sunspot (t2) and relative importance between leading spot and density of the sunspot population (t3). For each parameter, k, we compute the flare rate, FR, by the ratio between the number of sunspot groups which hosted at least a flare and characterized by a specific value of that parameter, $N_f(x_k)$, and the total number of sunspot groups characterized by the same value of that parameter $N(x_k)$:

$$FR_k(x_k) = \frac{N_f(x_k)}{N(x_k)}$$

The average among the flare rates for all parameters:

$$FR = \frac{FR_{SS}(x_{ss}) + FR_{AA}(x_{AA}) + FR_{t1}(x_{t1}) + FR_{t2}(x_{t2}) + FR_{t3}(x_{t3})}{5}$$

provides an estimation of the capability of hosting flares for sunspot groups characterized by a particular configuration, size and fragmentation.

Assuming that the flare event frequency follows the Poisson statistic, for each flare class the event probability is given by:

$$p_f = 1 - \exp(-FR)$$

Forecasting performance measures

We measured the accuracy of our probabilistic forecasts by a variety of skill scores (see Barnes et al., 2016 for details): the **Appleman's Skill Score (ApSS),** the **Hanssen & Kuipers' Discriminant (H&KSS)** and the **Barier Skill Score (BSS).** We determined a **threshold probability** to build a contingency table and generate the binary categorical classification to maximize ApSS and H&KSS. Any forecast probability over the threshold was considered to be a forecast for an event, and anything less was considered to be a forecast for non-event. The main statistic parameters are summarized in Tab. 1, while the performance results and the probability thresholds are reported in Tab. 2.

The Receiver Operating Characteristics curves (left column of Fig. 2) show the H&KSS, plotting the probability of detection as a function of the false alarme rate. We computed for each flare class the threshold probability which maximizes the H&KSS. Instead, the reliability plots (right column of Fig. 2) show a slight tendency to overprediction (points lying below x=y) for the smaller probability bins of all flare classes.

Almost all scores shows values corresponding to performance better than the considered reference forecasts, although our present method seems more accurate at predicting stronger events (M1.0+ and X1.0+ class flares), which are more important for their Space Weather effects.

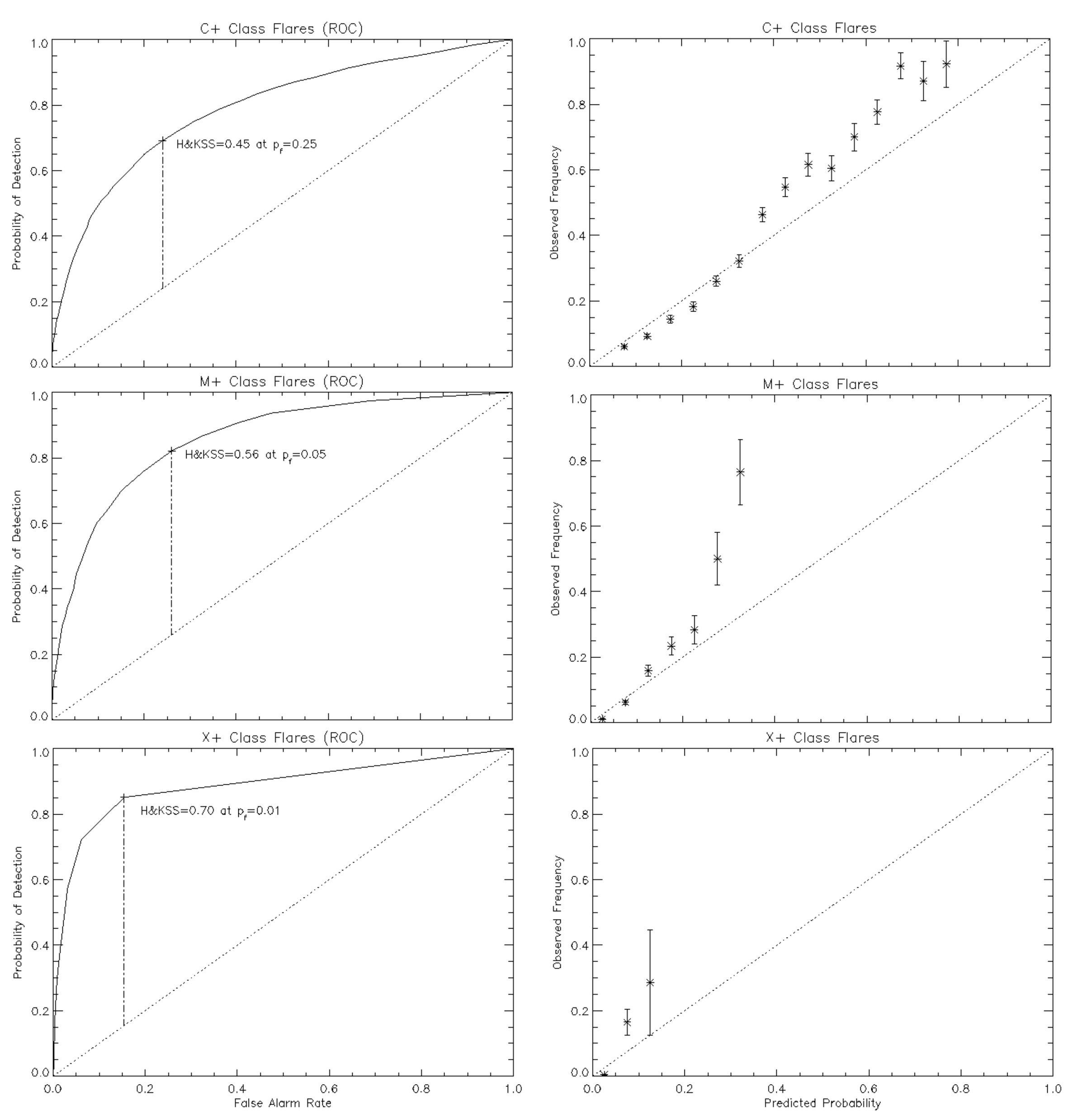


Fig. 2 *Receiver Operating Characteristic (ROC) curves (left column) and Reliability plots (right column) for C1.0+ (top panels), M1.0+ (middle panels) and X1.0+ (bottom pannels).*

Tab. 1 *Verification statistics for our predictions.*

Parameters	C+ class flares	M+ class flares	X+ class flares
Active region	8598.00	8598.00	8598.00
Active region with flares	1841.00	347	47
$\langle p_f \rangle$	0.214	0.040	0.005
$\langle o \rangle$	0.214	0.040	0.005
Median p_f	0.160	0.020	0.002
σ_{p_f}	0.144	0.049	0.010
σ_o	0.410	0.197	0.074
$\langle p_f \vert o = 1 \rangle$	0.337	0.127	0.036
$\langle p_f \vert o = 0 \rangle$	0.136	0.037	0.005
Median $p_f \vert o = 1$	0.337	0.107	0.035
Median $p_f \vert o = 0$	0.136	0.018	0.002
SD $p_f \vert o = 1$	0.170	0.085	0.023
SD $p_f \vert o = 0$	0.112	0.043	0.009
MAE(p_f, o)	0.281	0.070	0.010
MSE(p_f, o)	0.134	0.034	0.005
Linear association	0.469	0.364	0.232
SS(p_f, o)	0.206	0.119	0.044

Tab. 1 *Performance results and probability thresholds.*

Flare class	H&KSS	ApSS	BSS
C 1.0 +	0.45 (0.25)	0.16 (0.40)	0.20
M 1.0 +	0.56 (0.05)	0.04 (0.27)	0.12
X 1.0 +	0.70 (0.01)	-	0.04