

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 URL: forecasting service available the following İS at http://ssa.oact.inaf.it/oact/Flare_forecasting.php

Catania Ussps USSPS 31405 06068 14232 46091 33308 55445 47073 41814 54627 49001 37909 0/101 50001 13419 0/101 51001 40517 0/101 52006 14011 25407 INAF-CATANIA ASTROPHYSICAL OBSERVATORY	NOAA/Solar Region Summary Nmbr Location Lo Area Z LL NN Mag Type 2673 S09W30 119 0880 Dkc 09 33 Beta-Gamma-Delta 2674 N14W14 103 0680 Fhi 19 23 Beta 2675 S07W82 171 0010 Bxo 05 01 Beta 2676 S09W76 165 0030 Bxo 07 02 Beta 2677 N18E39 050 0020 Axx 01 01 Alpha 2678 N11E45 044 0010 Bxo 04 02 Beta
06 48 46 2673 5 5 4 06 48 47 2674 5 4 6 06 48 49 2676 0 / 1 06 48 50 2677 0 / 1 06 48 51 NNNN 0 / 1	Area SS 091 45 073 27 001 01 001 01 001 01 001 01 001 01 001 01 001 01 001 01 006 77 29 G15 C2.7 2673 11 53 G15 X9.3 2673 15 51 G15 M2.5 2673 19 21 G15 M1.4 2673 08 57 G13 X2.2 2673
Flare probability (%) NOAA CC C+ M+ X+ 2673 46 61 24 5 2674 47 60 19 3 2676 49 7 0 0 2677 50 7 0 0 NNNN 51 7 0 0 2678 52 26 5 1	CC NOAA t1 t2 t3 Area SS #Flare C M X 46 2673 5 5 4 091 45 2 2 2 47 2674 5 4 6 073 27 0 0 0 49 2676 0 / 1 001 01 0 0 0 50 2677 0 / 1 001 01 0 0 0 51 NNNN 0 / 1 001 01 0 0 0 52 2678 2 5 4 006 07 0 0 0

Flare Fore	casting				
provide an indication The probabilities sh subsequent 24 hou The sunspot groups projected area of su	ervation of the photosphere performed by th n of the probabilities that each sunspot grou own below are calculated using the USSPS rs. capability of hosting flares is based on the nspot group in tens of millionths of the solar in sunspot, and relative importance betwee	up visible on the solar dis S acquired on 06 Septem Poisson statistic of five p r hemisphere, group type	c may host solar flares ber 2017 at 06:48 UT. arameters: number of s according to Zurich cla	of C-, M- and X- class. They are valid for the unspots and pores, ssification, type of	
NOAA AR					
2673	46	61%	24%	6%	
2674	47	60%	19%	3%	
2676	49	7%	0%	0%	

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 $N(x_{k})$:

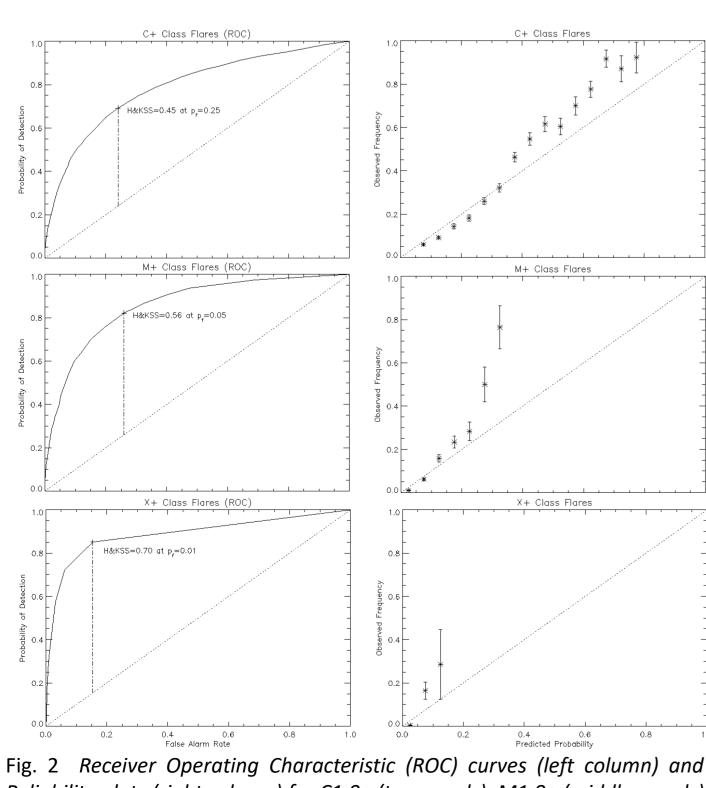
$$FR_k(x_k) = \frac{N_f(x_k)}{N(x_k)}$$

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. Tab. 1 Verification statistics for our predictions.

Reliability plots (right column) for C1.0+ (top panels), M1.0+ (middle panels) and X1.0+ (bottom pannels).

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 Tab. 1 Performance results and probability thresholds. accurate at predicting stronger events (M1.0+ and X1.0+ class flares), which are more important for their Space Weather effects.

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
$\langle p_f o = 1 \rangle$	0.337	0.127	0.036
$\langle p_f o = 0 \rangle$	0.136	0.037	0.005
Median $p_f o = 1$	0.337	0.107	0.035
Median $p_f o = 0$	0.136	0.018	0.002
$\operatorname{SD} p_f o = 1$	0.170	0.085	0.023
$\operatorname{SD} p_f o = 0$	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

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