A short-term solar eruption events forecasting model

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- Background & Motivation
- Present situation of solar flare forecasting
- Difficulties of CMEs forecasting
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Background & Motivation

- The sun is the main source of space weather, so it is important to forecast the solar eruptions.
- There are some practical flare forecasting models
- We do not have any practical forecasting model for CMEs
- Flares and CMEs are two different manifestations of the same energy release process
- We need a solar eruption events forecasting model which considers flares and CMEs together
  - ➢ Quiet
  - ➢ Confined flare: flare without CME
  - ➢ Eruptive flare: flare associated with CME
- Solar eruption events forecasting model
  - ➢ Improved flare forecasting model
  - ➢ Simplified CMEs forecasting model

G. P. Zhou et al., A&A 2006

Associations	CME number	percent
related to ARs	231	80%
related to long eruptive filaments	109	38%
Total earth-directed CMEs	288	100%

Present situation of solar flare forecasting

- Probabilistic yes/no forecasts based on the Non-potentiality of an active region

- McIntosh classifications
- Magnetic field gradient
- Length of neutral line
- Number of singular points
- Tilt angle
- Magnetic shear angle
- Current density
- Free magnetic energy
- Twist parameter
- Spectral index
- Fractal dimension
- Flow field

Difficulties of CMEs forecasting

- Uncertainty of frontside or backside CMEs
- Uncertainty of source region for CMEs

☐ CMEs are inherently large-scale events

L. van Driel-Gesztelyi et. al. Ann. Geophys., 2008

☐ CMEs start small-scale and then evolve to become large-scale events

- In short:

  Closed magnetic field structure + Non-potentiality

☐ Appearance of closed magnetic field structure on the Sun

☐ Magnetic source region has to build-up free energy

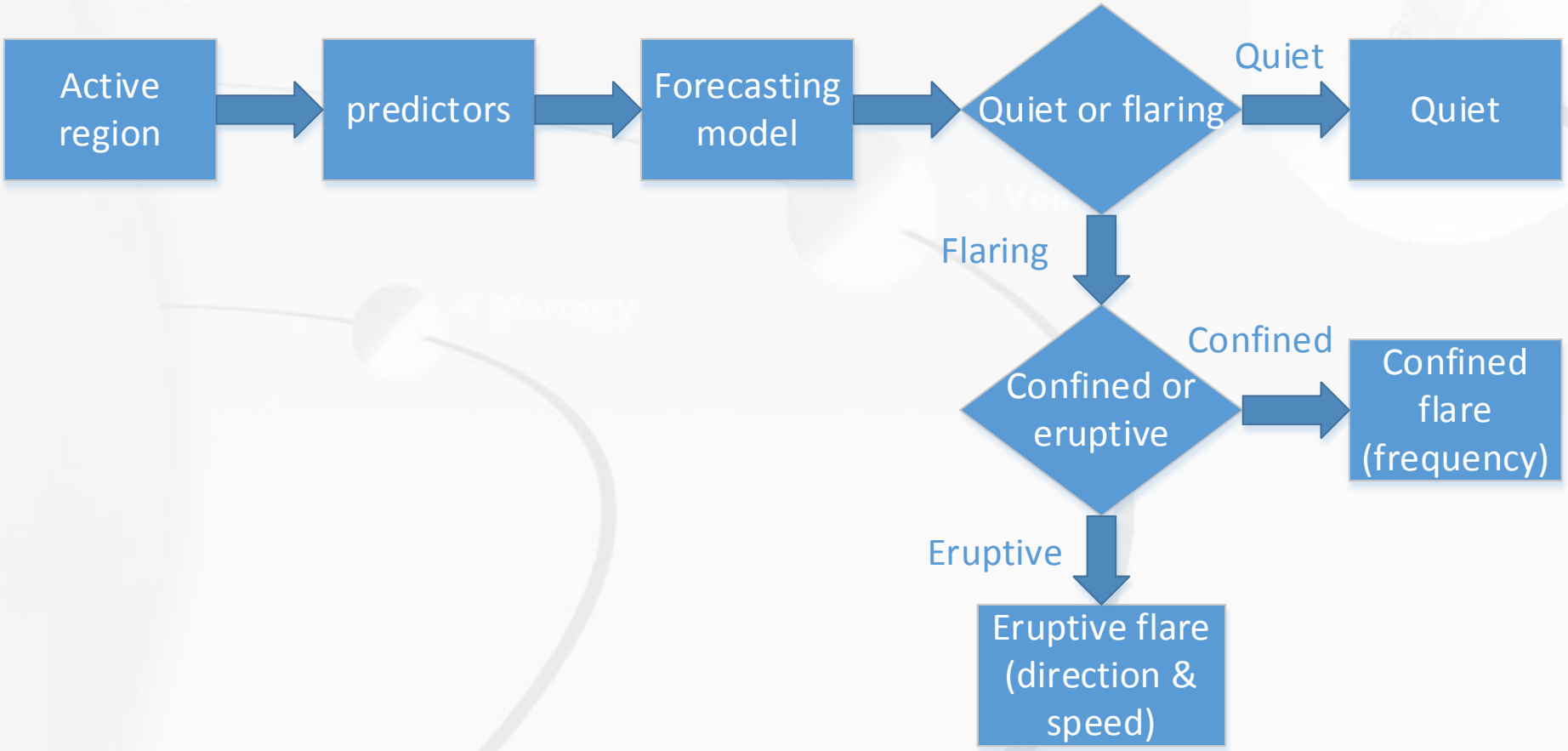
Relationship between flares and CMEs

- Flare VS CMEs
  - ➢ Larger solar flare is easier to associate with CME
  - ➢ C 16%-25%, M 42%-55%, X 90%-92% (Yashiro et al 2005)
- Confined flare VS Eruptive flare
  - ➢ Non-potentiality (Sun et al 2015)
  - ➢ Displacement of the location of the energy release (Wang & Zhang 2007)
  - ➢ Background field (Cheng et al 2011)
- All parameter is only used to analysis relationships after flare has happened, can not be used to forecast

Solar eruption events forecasting model

- Displacement parameter between center of active region and the center of the free magnetic energy and the overlying magnetic parameter are extracted to distinguish confined flares from eruptive flares
- Combined with the classical flare forecasting model (based on non-potential parameters), we get the solar eruption events forecasting model

Solar eruption events forecasting model



Active region data

- 12 month data (2011.8—2012.7)

Data Tar-Ball	Data Listing	Event Lists:	
		C1.0 + , Latency: 0hr, Validity: 24hr	M1.0 + , Latency: 0hr, Valid
201108.tgz (7.0Gb)	hmi 201108 contents	events C10min Z00max lat0hr val24hr 201108.txt	events M10min Z00max lat0hr val24h
201109.tgz (11Gb)	hmi 201109 contents	events C10min Z00max lat0hr val24hr 201109.txt	events M10min Z00max lat0hr val24h
201110.tgz (15Gb)	hmi 201110 contents	events C10min Z00max lat0hr val24hr 201110.txt	events M10min Z00max lat0hr val24h
201111.tgz (18Gb)	hmi 201111 contents	events C10min Z00max lat0hr val24hr 201111.txt	events M10min Z00max lat0hr val24h
201112.tgz (17Gb)	hmi 201112 contents	events C10min Z00max lat0hr val24hr 201112.txt	events M10min Z00max lat0hr val24h
201201.tgz (13Gb)	hmi 201201 contents	events C10min Z00max lat0hr val24hr 201201.txt	events M10min Z00max lat0hr val24h
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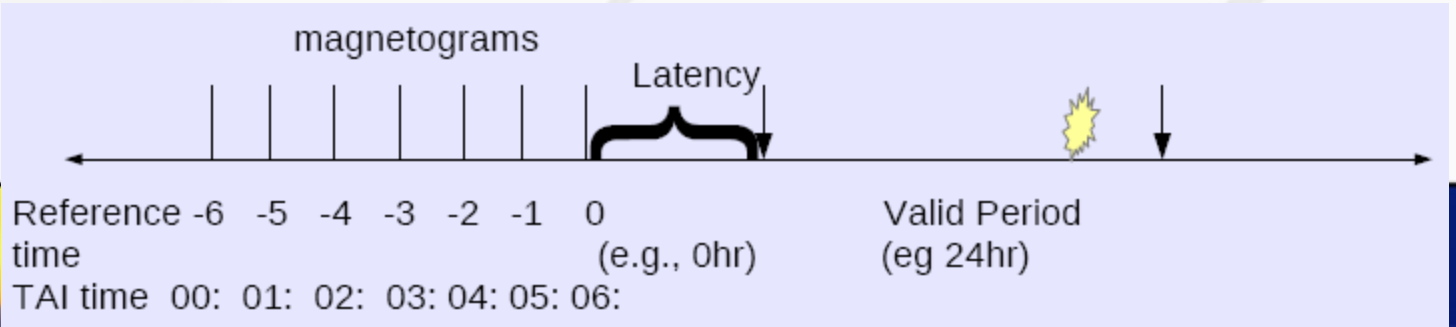
201203.tgz (8.8Gb)	hmi 201203 contents	events C10min Z00max lat0hr val24hr 201203.txt	events M10min Z00max lat0hr val24h
201204.tgz (9.4Gb)	hmi 201204 contents	events C10min Z00max lat0hr val24hr 201204.txt	events M10min Z00max lat0hr val24h
201205.tgz (10Gb)	hmi 201205 contents	events C10min Z00max lat0hr val24hr 201205.txt	events M10min Z00max lat0hr val24h
201206.tgz (8Gb)	hmi 201206 contents	events C10min Z00max lat0hr val24hr 201206.txt	events M10min Z00max lat0hr val24h
201207.tgz (15Gb)	hmi 201207 contents	events C10min Z00max lat0hr val24hr 201207.txt	events M10min Z00max lat0hr val24h

Second NWRA Flare Forecasting Workshop hosted by Drs. Leka and Barnes

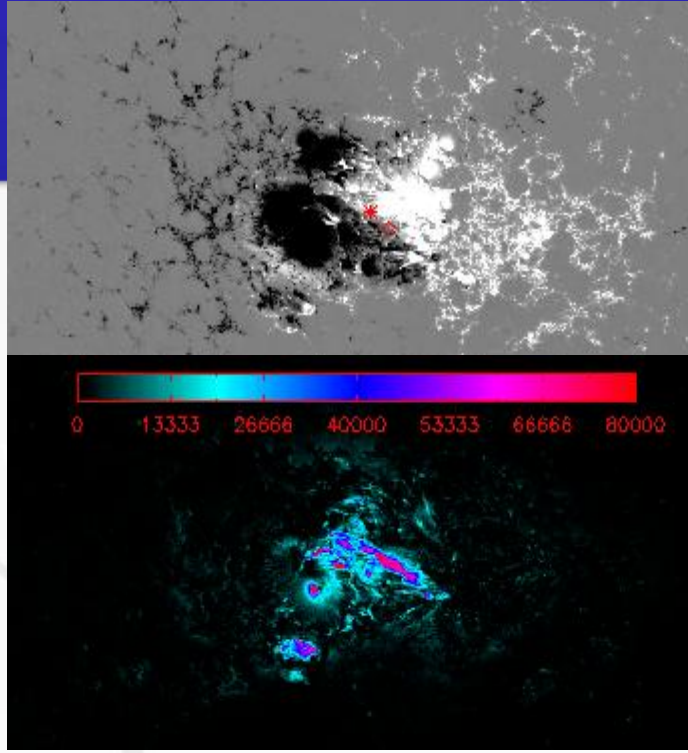


Event data

- 12 month data (2011.8—2012.7)

Flare Mag,	Time Start,	Time Stop,	Time of Max,	Flux,	AR Association,	SPE,	CME,	C2AppearanceTime,	CentralPA,	Ar
M1.40,	2011-08-02 05:19:00,	2011-08-02 06:48:00,	2011-08-02 06:19:00,	1.40000e-05,	11261,	no ,	1,	2011-08-02		
M1.10,	2011-08-03 03:08:00,	2011-08-03 03:51:00,	2011-08-03 03:37:00,	1.10000e-05,	11261,	no ,	0			
M1.70,	2011-08-03 04:29:00,	2011-08-03 04:35:00,	2011-08-03 04:32:00,	1.70000e-05,	11263,	no ,	0			
C8.70,	2011-08-03 07:38:00,	2011-08-03 08:06:00,	2011-08-03 07:58:00,	8.70000e-06,	11261,	no ,	0			
M6.00,	2011-08-03 13:17:00,	2011-08-03 14:10:00,	2011-08-03 13:48:00,	6.00000e-05,	11261,	no ,	1,	2011-08-03		
C8.50,	2011-08-03 19:23:00,	2011-08-03 19:42:00,	2011-08-03 19:30:00,	8.50000e-06,	11261,	no ,	0			
M9.30,	2011-08-04 03:41:00,	2011-08-04 04:04:00,	2011-08-04 03:57:00,	9.30000e-05,	11261,	yes,	1,	2011-08-04		
M3.50,	2011-08-08 18:00:00,	2011-08-08 18:18:00,	2011-08-08 18:10:00,	3.50000e-05,	11263,	no ,	1,	2011-08-08		
C7.70,	2011-08-08 22:00:00,	2011-08-08 22:20:00,	2011-08-08 22:09:00,	7.70000e-06,	11263,	no ,	0			
C5.30,	2011-08-08 23:02:00,	2011-08-08 23:59:00,	2011-08-08 23:22:00,	5.30000e-06,	11263,	no ,	1,	2011-08-08		
M2.50,	2011-08-09 03:19:00,	2011-08-09 04:08:00,	2011-08-09 03:54:00,	2.50000e-05,	11263,	no ,	1,	2011-08-09		
X6.90,	2011-08-09 07:48:00,	2011-08-09 08:08:00,	2011-08-09 08:05:00,	0.000690000,	11263,	yes,	1,	2011-08-09		
C6.10,	2011-08-10 10:21:00,	2011-08-10 10:55:00,	2011-08-10 10:44:00,	6.10000e-06,	11263,	no ,	1,	2011-08-10		
C6.20,	2011-08-11 09:34:00,	2011-08-11 10:36:00,	2011-08-11 10:23:00,	6.20000e-06,	11263,	no ,	1,	2011-08-11		
C5.50,	2011-08-30 22:02:00,	2011-08-30 22:53:00,	2011-08-30 22:46:00,	5.50000e-06,	11281,	no ,	0			
C8.30,	2011-09-04 01:01:00,	2011-09-04 01:13:00,	2011-09-04 01:07:00,	8.30000e-06,	11286,	no ,	0			
C9.00,	2011-09-04 04:36:00,	2011-09-04 05:03:00,	2011-09-04 04:53:00,	9.00000e-06,	11286,	no ,	1,	2011-09-04		
M3.20,	2011-09-04 11:21:00,	2011-09-04 11:50:00,	2011-09-04 11:45:00,	3.20000e-05,	11286,	no ,	1,	2011-09-04		
C5.80,	2011-09-04 15:21:00,	2011-09-04 15:53:00,	2011-09-04 15:34:00,	5.80000e-06,	11286,	no ,	1,	2011-09-04		
M1.60,	2011-09-05 04:08:00,	2011-09-05 04:32:00,	2011-09-05 04:28:00,	1.60000e-05,	11286,	no ,	0			
M1.20,	2011-09-05 07:27:00,	2011-09-05 08:06:00,	2011-09-05 07:58:00,	1.20000e-05,	11286,	no ,	0			
M5.30,	2011-09-06 01:35:00,	2011-09-06 02:05:00,	2011-09-06 01:50:00,	5.30000e-05,	11283,	no ,	1,	2011-09-06		
X2.10,	2011-09-06 22:12:00,	2011-09-06 22:24:00,	2011-09-06 22:20:00,	0.000210000,	11283,	no ,	1,	2011-09-06		
X1.80,	2011-09-07 22:32:00,	2011-09-07 22:44:00,	2011-09-07 22:38:00,	0.000180000,	11283,	no ,	1,	2011-09-07		
M6.70,	2011-09-08 15:32:00,	2011-09-08 15:52:00,	2011-09-08 15:46:00,	6.70000e-05,	11283,	no ,	0			
M2.70,	2011-09-09 06:01:00,	2011-09-09 06:17:00,	2011-09-09 06:11:00,	2.70000e-05,	11283,	no ,	1,	2011-09-09		
M1.20,	2011-09-09 12:39:00,	2011-09-09 12:56:00,	2011-09-09 12:49:00,	1.20000e-05,	11283,	no ,	0			
M1.10,	2011-09-10 07:18:00,	2011-09-10 07:56:00,	2011-09-10 07:40:00,	1.10000e-05,	11283,	no ,	1,	2011-09-10		
C6.60,	2011-09-11 08:41:00,	2011-09-11 09:27:00,	2011-09-11 08:51:00,	6.60000e-06,	11283,	no ,	1,	2011-09-11		

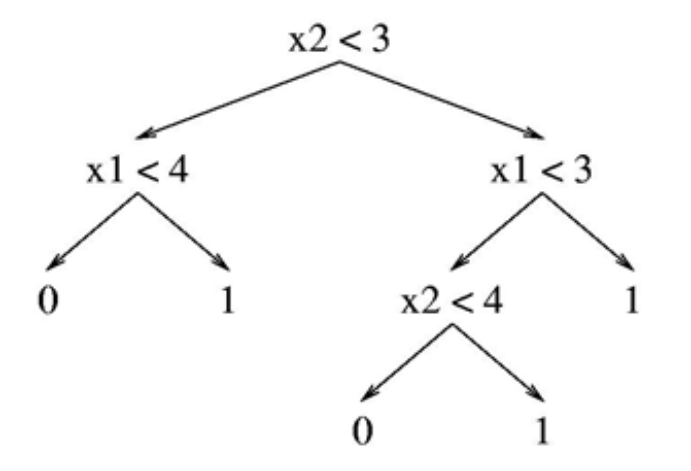
Predictors

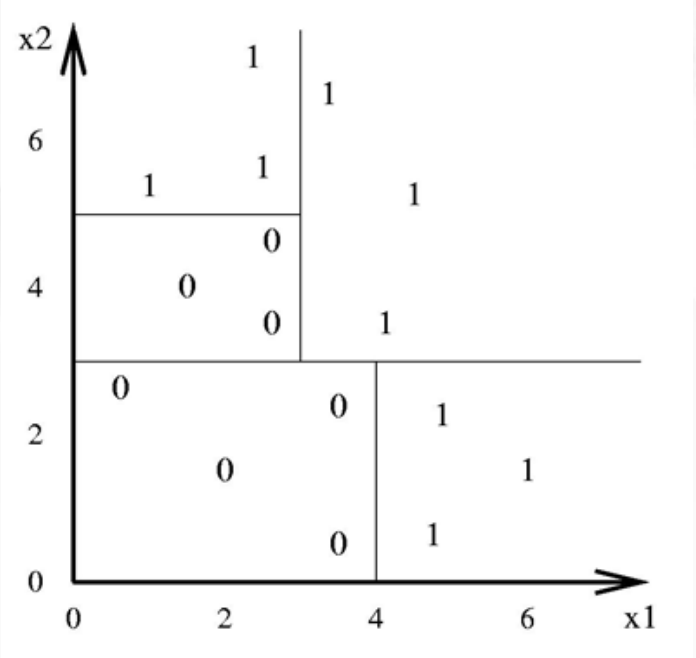


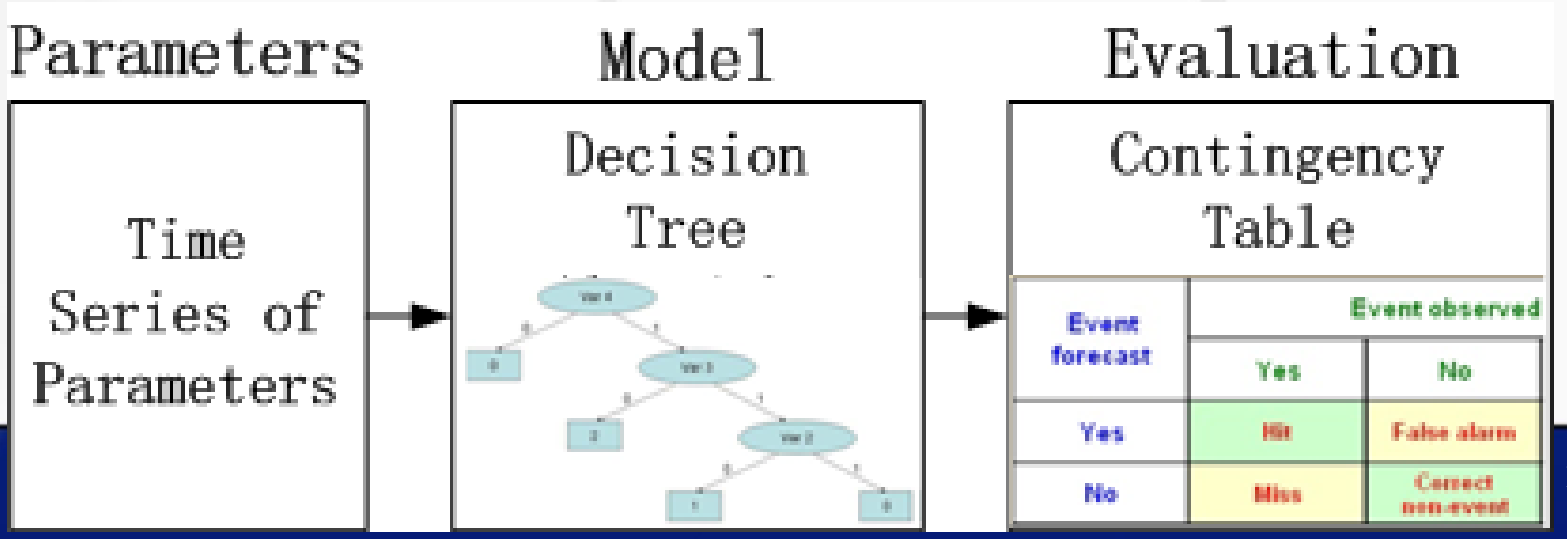
- Quiet or flaring
  - Magnetic field gradient
  - Length of neutral line
  - Number of singular points
  - Total photospheric magnetic free energy
- Confined or eruptive
  - Displacement parameters
    - Distance between the center of longitudinal magnetogram and the center of photospheric magnetic free energy density (Dmf)
    - Distance Ratio between Dmf and Dpn (Dpn is the distance between positive magnetic field and negative magnetic field)
  - Coronal parameters
    - Decay Index at the height of 10 Mm
    - Transverse magnetic flux ratio between the summation from 0Mm to 10Mm and the summation from 10Mm to 20Mm

Modeling method

- Decision tree







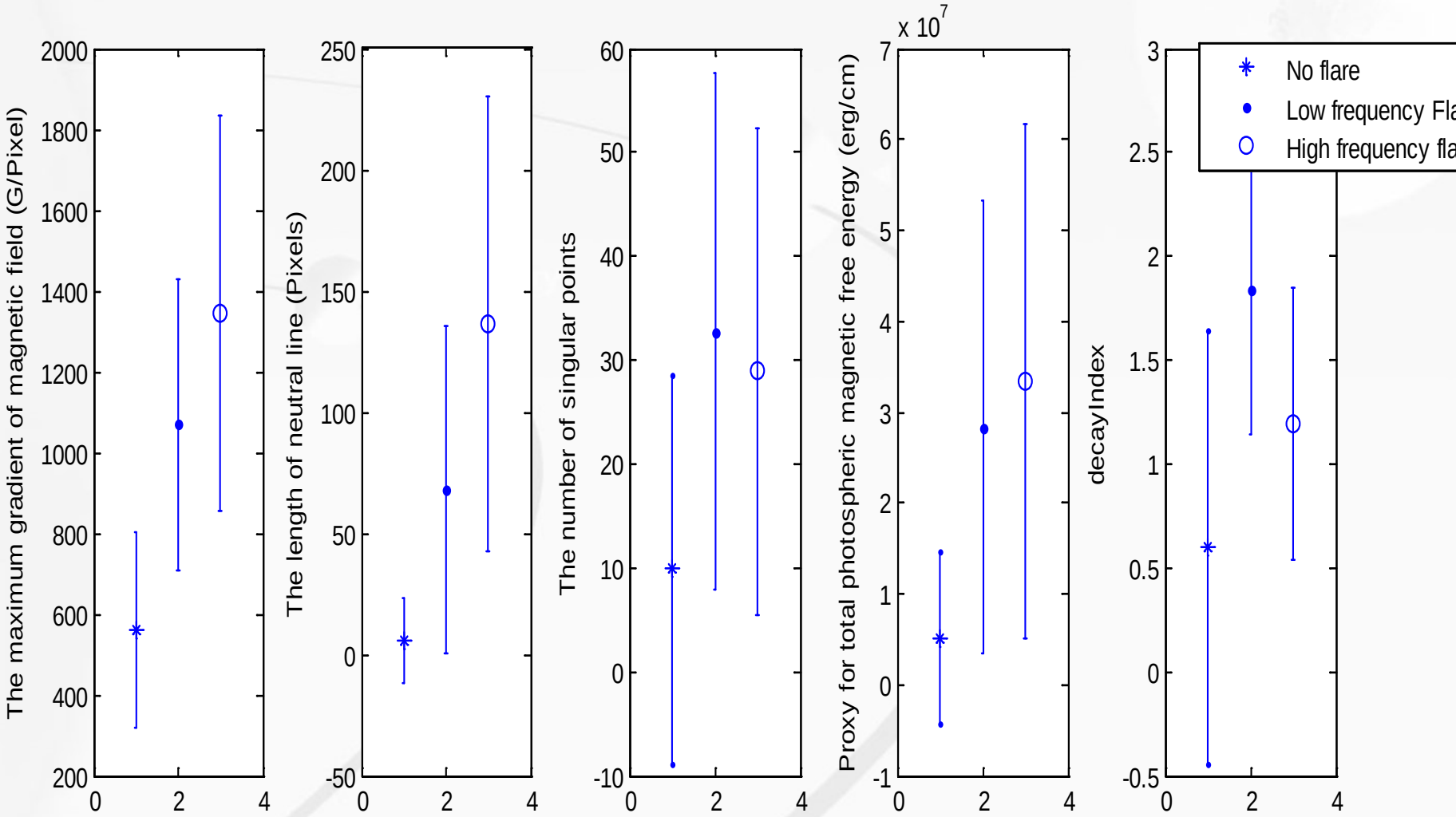
Performance

TP Rate	FP Rate	
0.783	0.122	→ 0
0.613	0.089	→ 1
0.605	0.136	→ 2

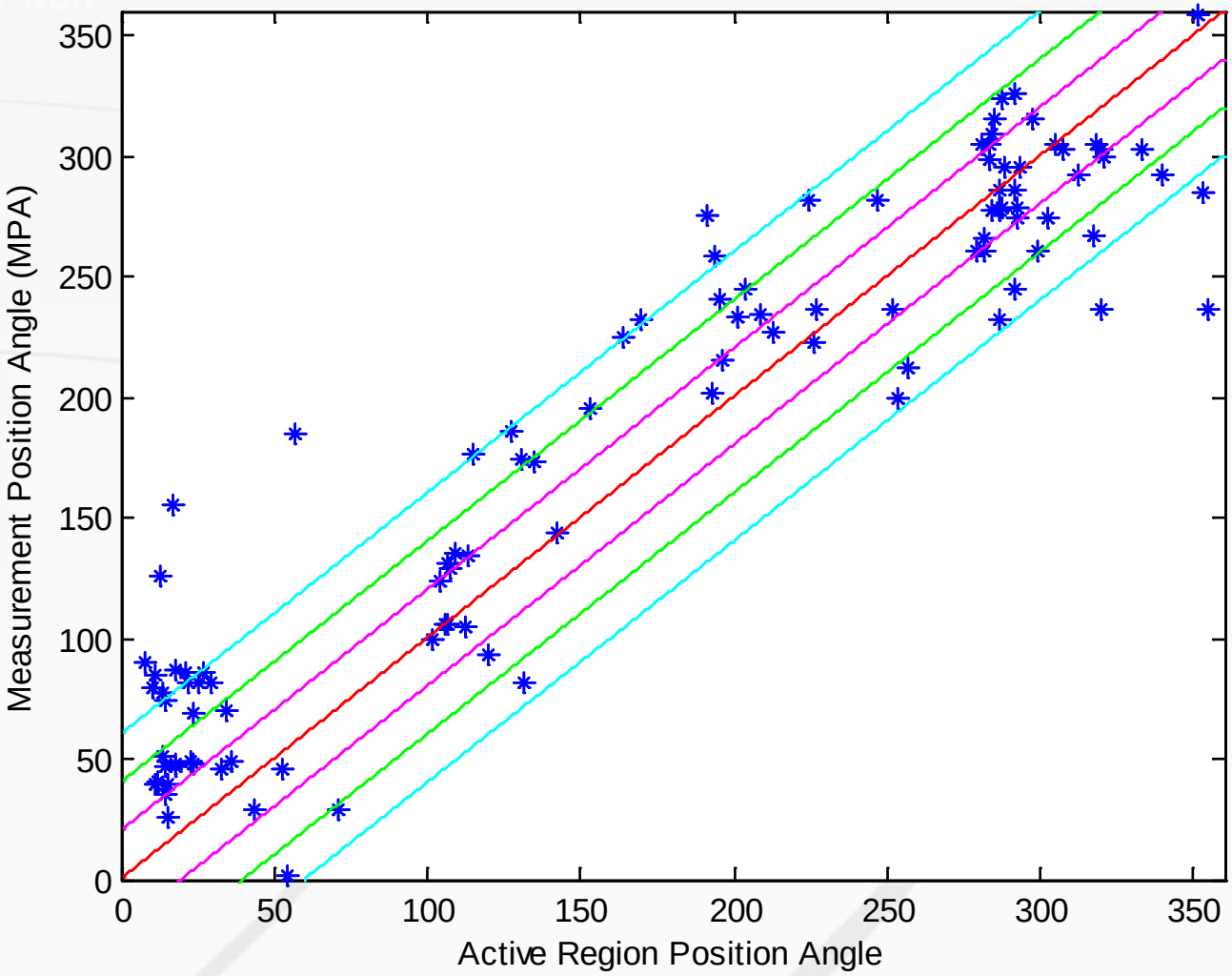
=== Confusion Matrix ===

a	b	c	← classified as
1139	122	193	a = 0
3	19	9	b = 1
6	11	26	c = 2

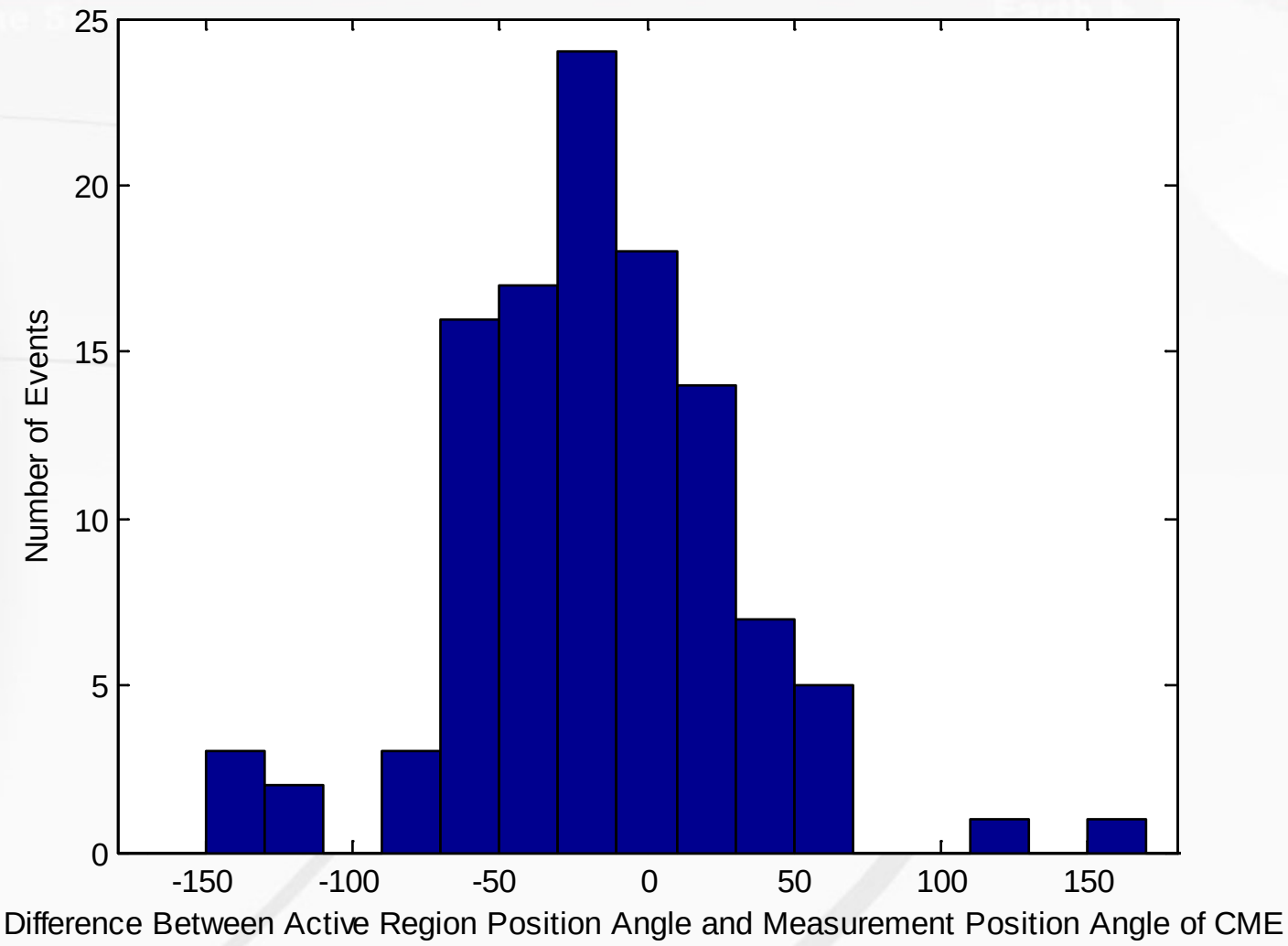
Statistical characteristics of events: flare frequency



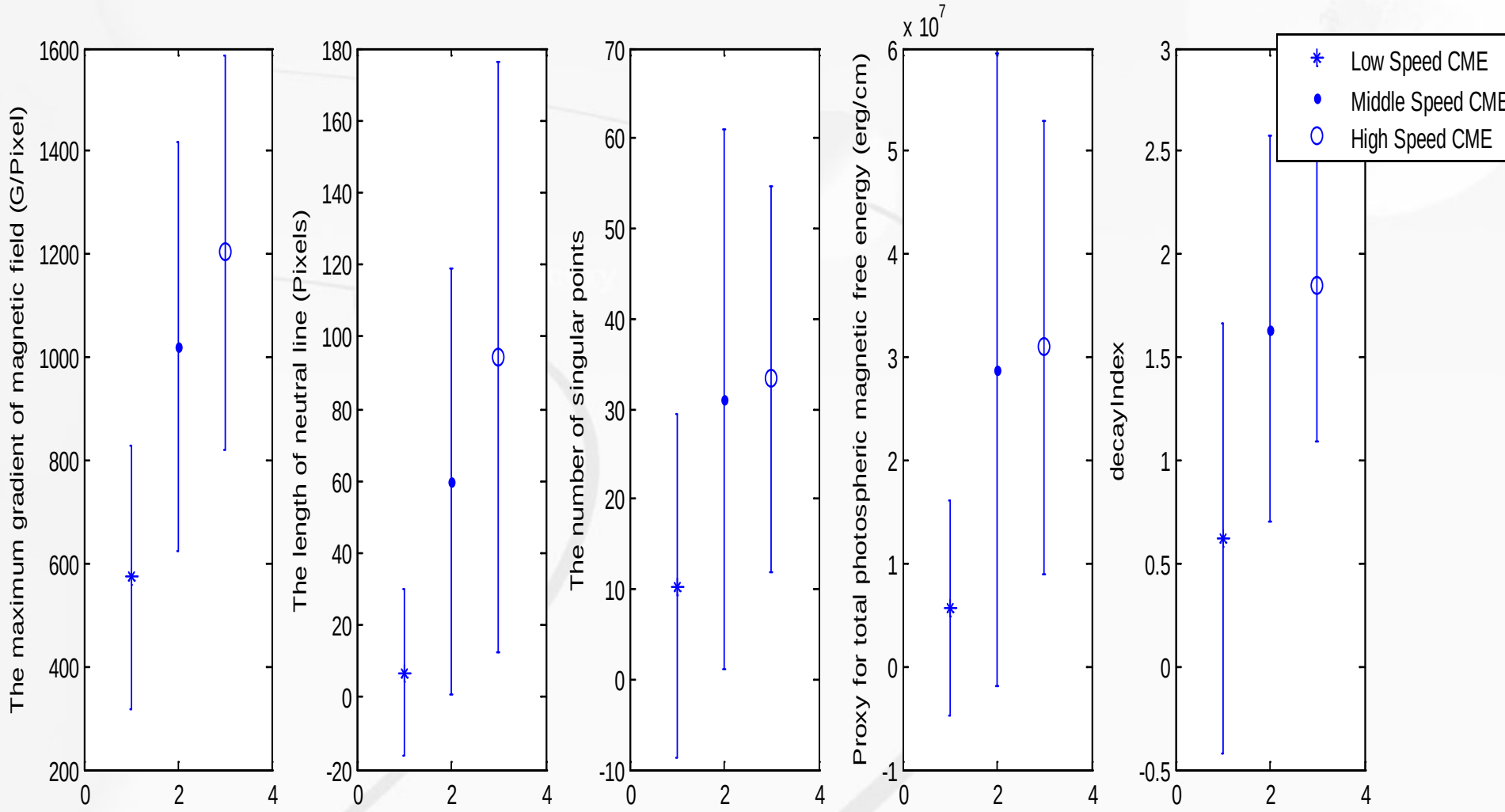
Statistical characteristics of events: attacking direction



Statistical characteristics of events: attacking direction



Statistical characteristics of events: speed

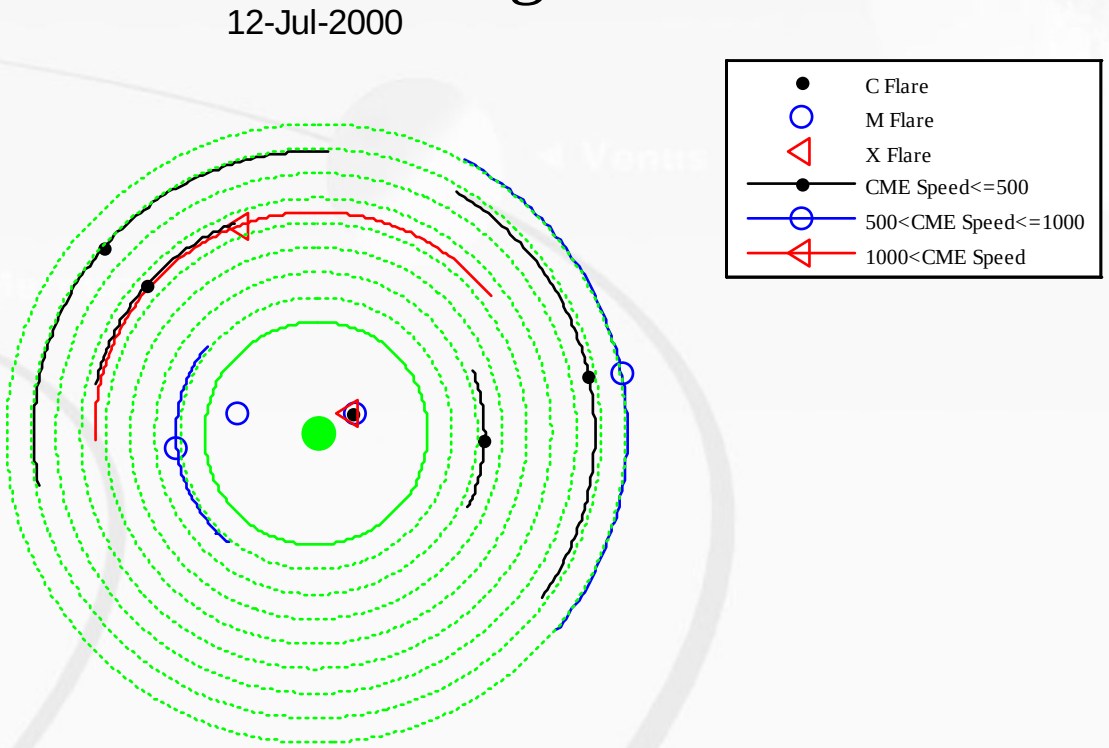


Summary

- From the flare forecasting point of view:
  - Extended flare forecasting model, flares and CMEs are considered as different manifestation of the magnetic releasing process
- From the CMEs forecasting point of view:
  - The associated flares reduce following uncertainties of CMEs:
  - Uncertainty of frontside and backside
  - Uncertainty of source region

Summary

- Solar eruption events forecasting model



- Further work

➢ Study on the relationships between quiet filaments and CMEs,

➢ Build the forecasting model for quiet filament related CMEs

Thanks !