LYRA

the **L**arge-**Y**ield **Ra**diometer onboard PROBA2

Space climate and space weather observations with PROBA2/LYRA

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XIIIth Hvar Astrophysical Colloquium
Hvar, Croatia, 22-26 Sep 2014

Contents

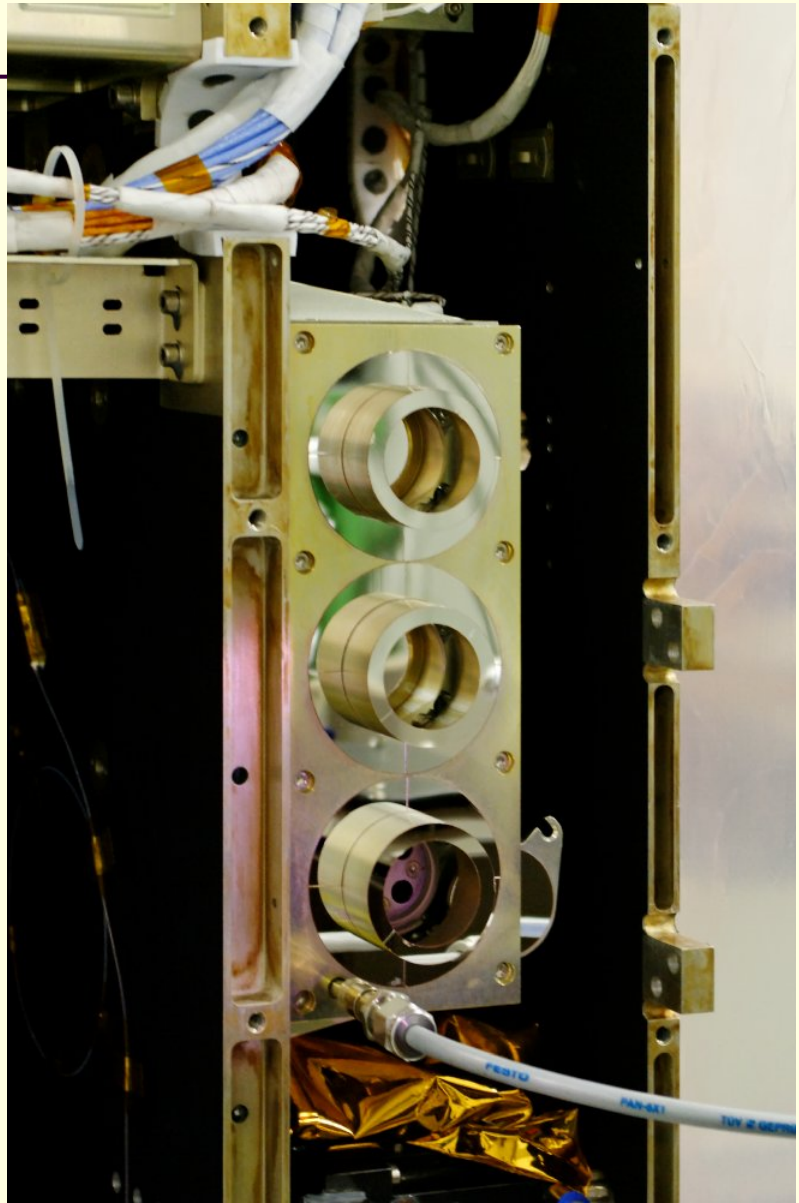
- LYRA: description, spectral response, data
- Long-term development, short-term forecast
- Results, future perspectives

PROBA2: PRoject for On-Board Autonomy

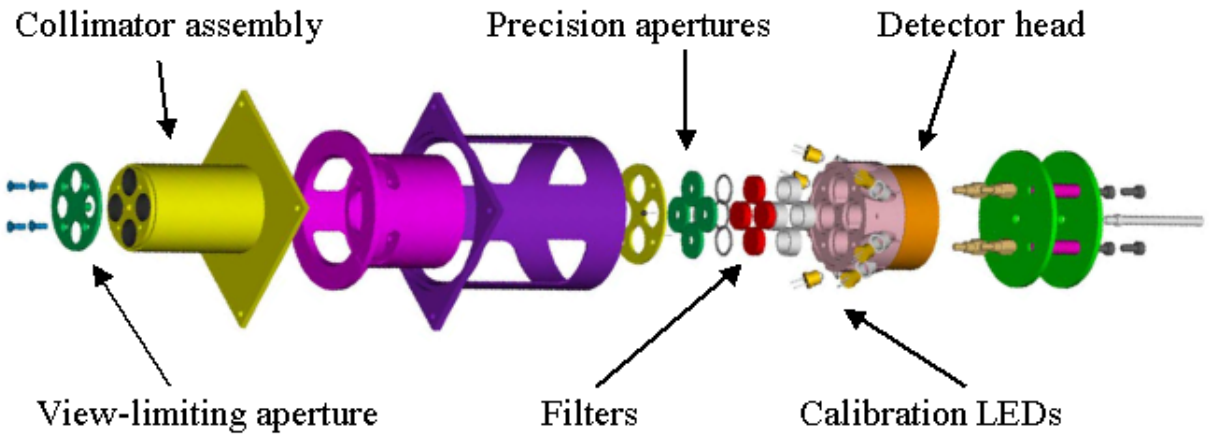
- ESA microsatellite in Sun-synchronous orbit, 725 km altitude
- Built in Belgium, commanded from ROB, launched 02 Nov 2009
- 17 technological experiments, 4 innovative instruments, for in-orbit demonstration (combined technology and science mission)
- LYRA and SWAP have been observing the Sun in EUV, continuously since Jan 2010

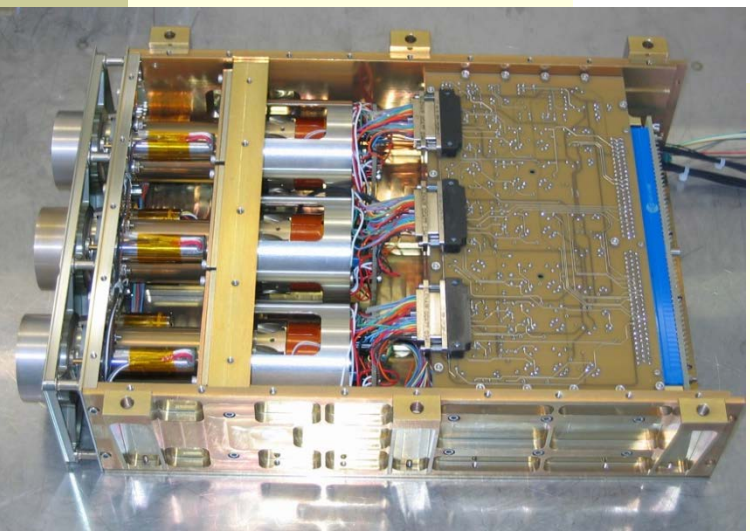
LYRA: the Large-Yield RAdiometer

- 3 instrument units (redundancy)
- 4 spectral channels per head
- 3 types of detectors,
  Silicon + 2 types of
  diamond detectors (MSM, PIN):
  - radiation resistant
  - insensitive to visible light
    compared to Si detectors
- High cadence up to 100 Hz



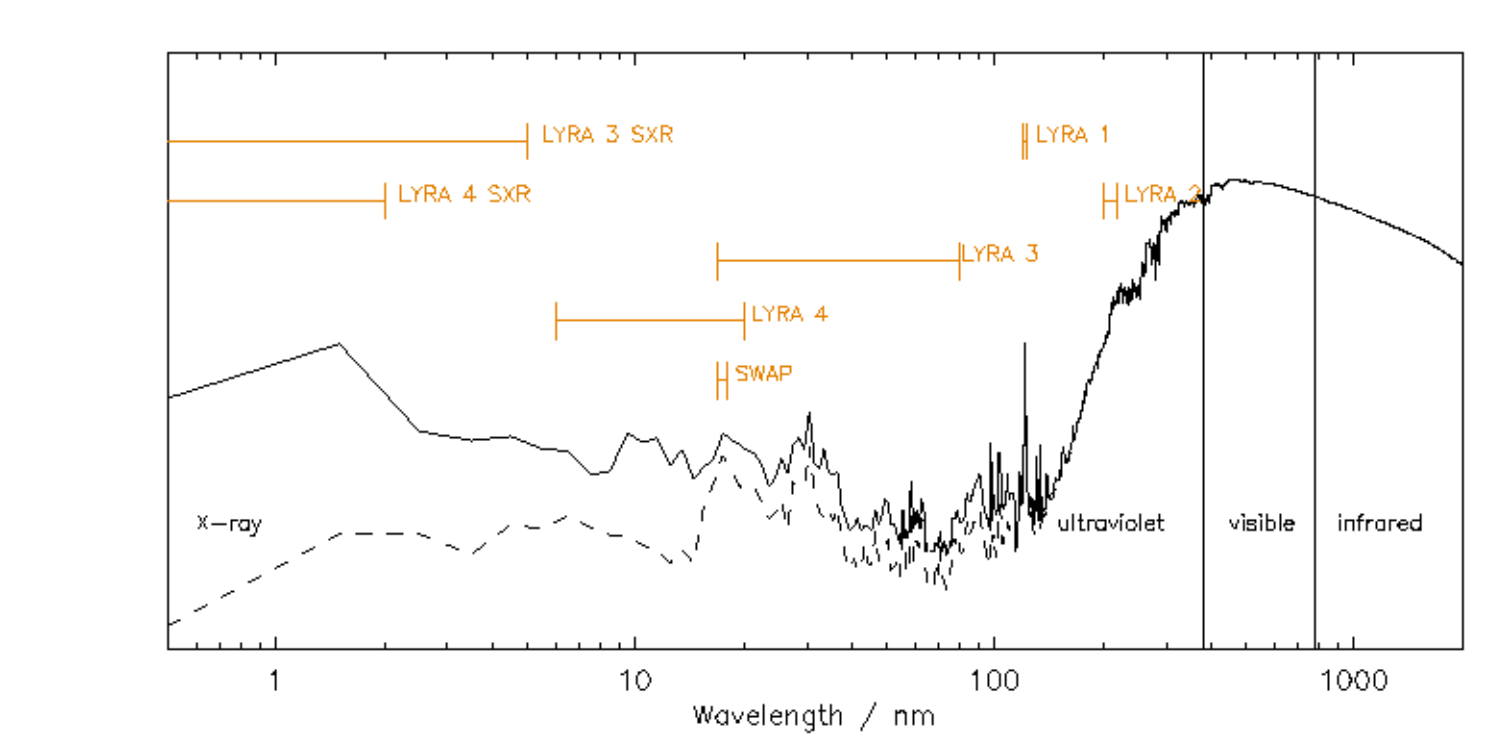
LYRA design





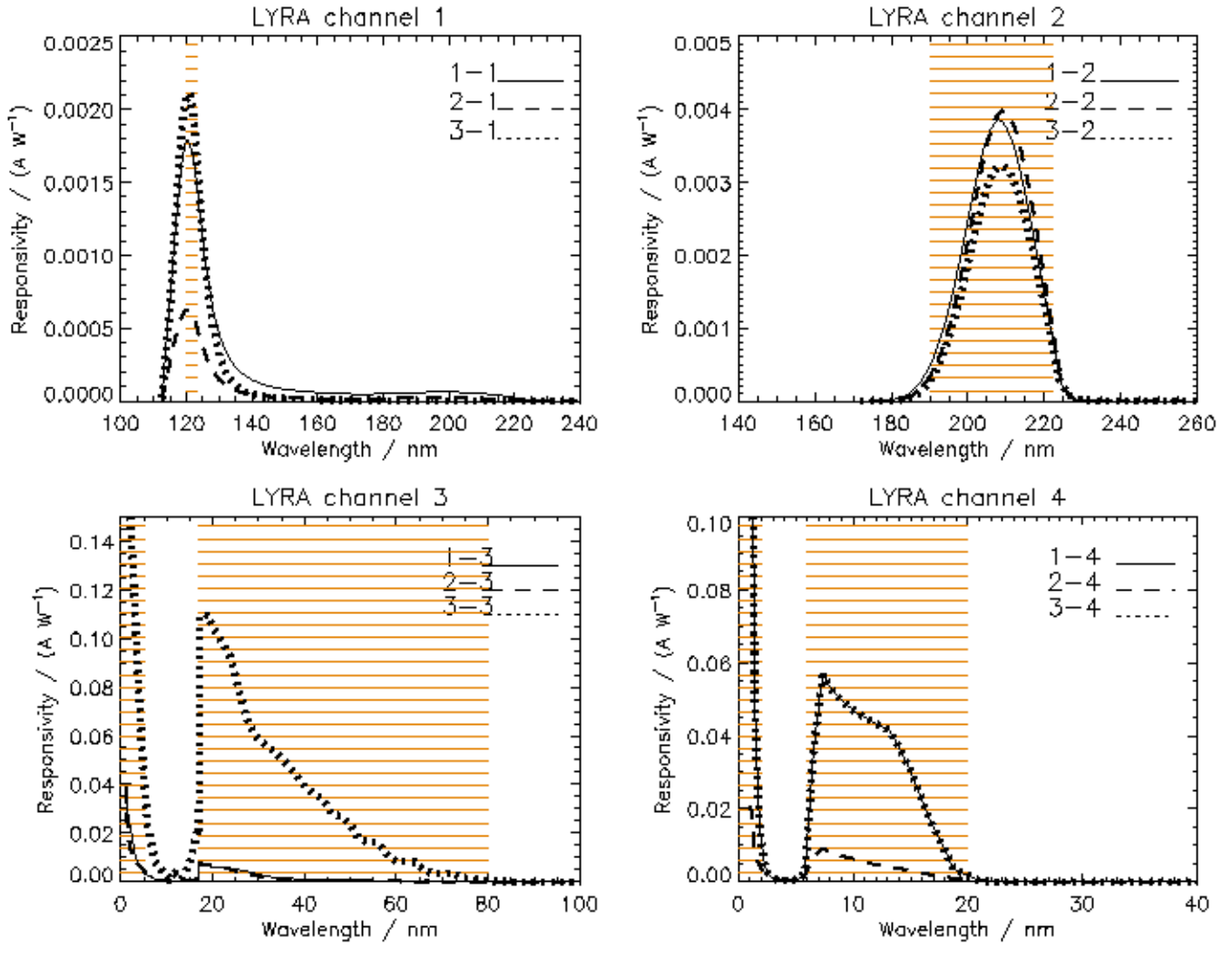
- Royal Observatory of Belgium (Brussels, B)
  Principal Investigator, overall design, onboard software specification, science operations
- PMOD/WRC (Davos, CH)
  Lead Co-Investigator, overall design and manufacturing
- Centre Spatial de Liège (B)
  Lead institute, project management, filters
- IMOMEC (Hasselt, B)
  Diamond detectors
- Max-Planck-Institut für Sonnensystemforschung (Lindau, D)
  calibration
- science Co-Is: BISA (Brussels, B), LPC2E (Orléans, F)…

SWAP and LYRA spectral intervals for solar flares, space weather, and aeronomy

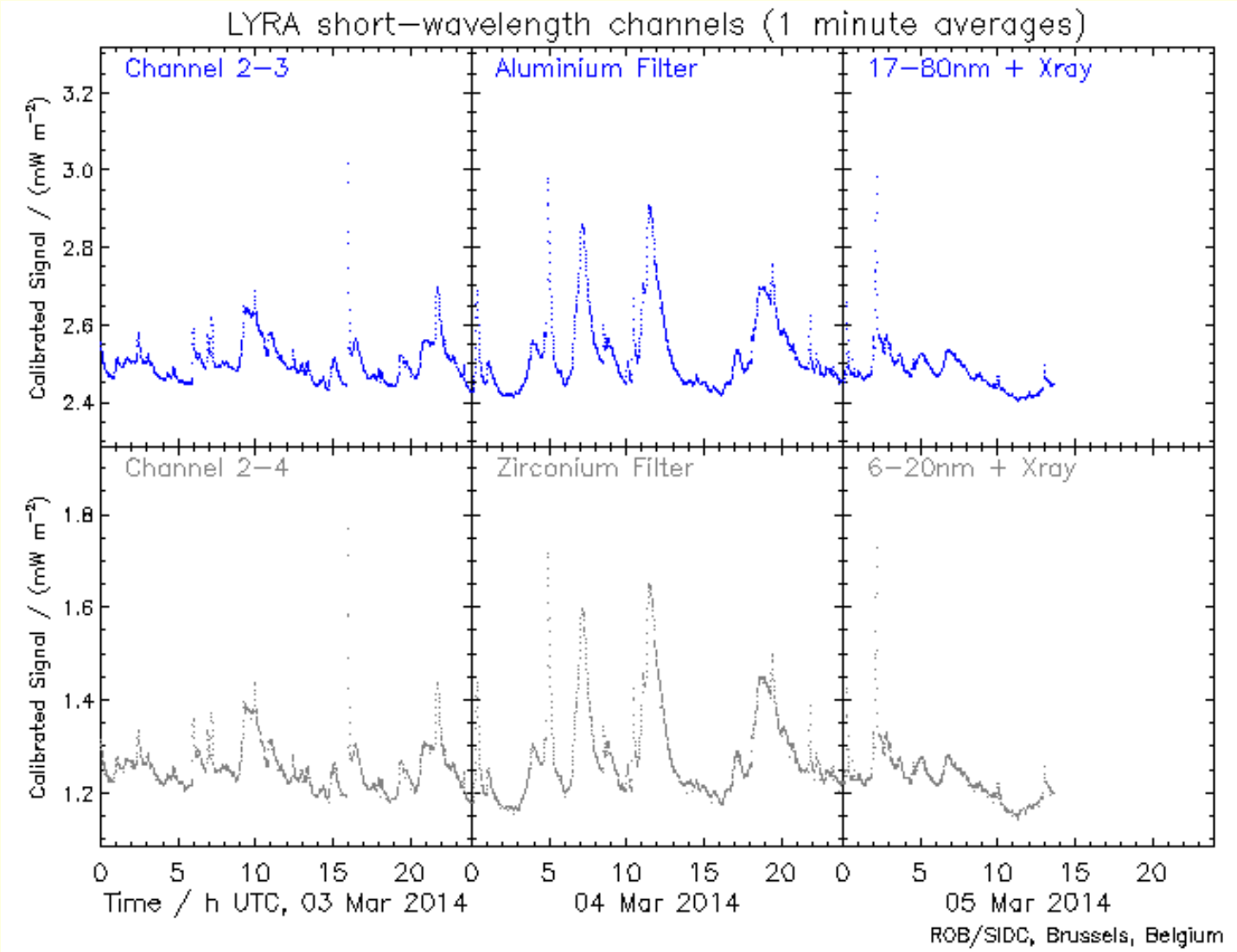


LYRA channel 1: the H I 121.6 nm Lyman-alpha line (120-123 nm)
LYRA channel 2: the 200-220 nm Herzberg continuum range (now 190-222 nm)
LYRA channel 3: the 17-80 nm Aluminium filter range incl the He II 30.4 nm line (+ <5nm X-ray)
LYRA channel 4: the 6-20 nm Zirconium filter range with highest solar variablility (+ <2nm X-ray)
SWAP: the range around 17.4 nm including coronal lines like Fe IX and Fe X

LYRA spectral response



LYRA data product: 3day quicklook



LYRA data product: flare list

2014 LYRA Flare List - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://proba2.oma.be/lyra/data/Flarelist/Flarelist.html

Most Visited Getting Started Latest Headlines

2014 LYRA Flare List

Please note:

- This list uses the "G14" and "G15" X-ray entries from the "Edited Events" lists of the NOAA Space Weather Predict
- The purpose of the list is to get an overview of the flares that LYRA observes and relate them to class, begin, max
- In the daily images (follow links below), the flares are marked at the top of the LYRA Zr-channel curve, with event corresponding to their temporal "begin".
- Images of intervals around each flare (1h before, 2h after) are linked to a list below this curve (follow event links), observing during this interval.
- In the flare images, event number and class are again marked at the top, corresponding to their "begin", while the GOES maximum is marked with a short vertical line. These images contain all four LYR
- From November to January, PROBA2 experiences "eclipse se it, the solar disk is occulted by the Earth, and the observed irradiances decrease to dark-curre y) hidden.
- Additional information can be found at the PROBA2 website LYRA 3day quicklook page.

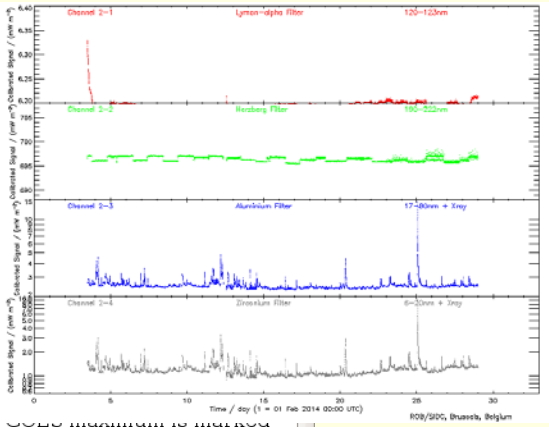
IDL program to read and display LYRA FITS files

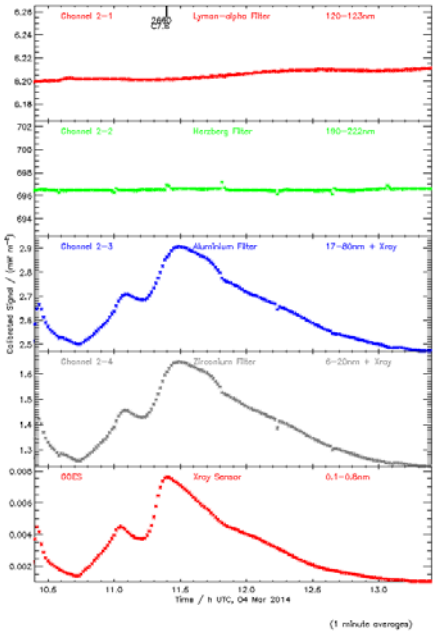
List of GOES flares since LYRA First Light 06 Jan 2010
new: List of daily flare statistics

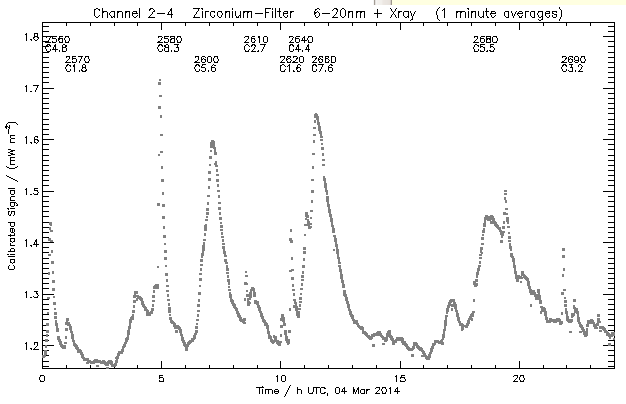
2010 page
2011 page
2012 page
2013 page

March 2014

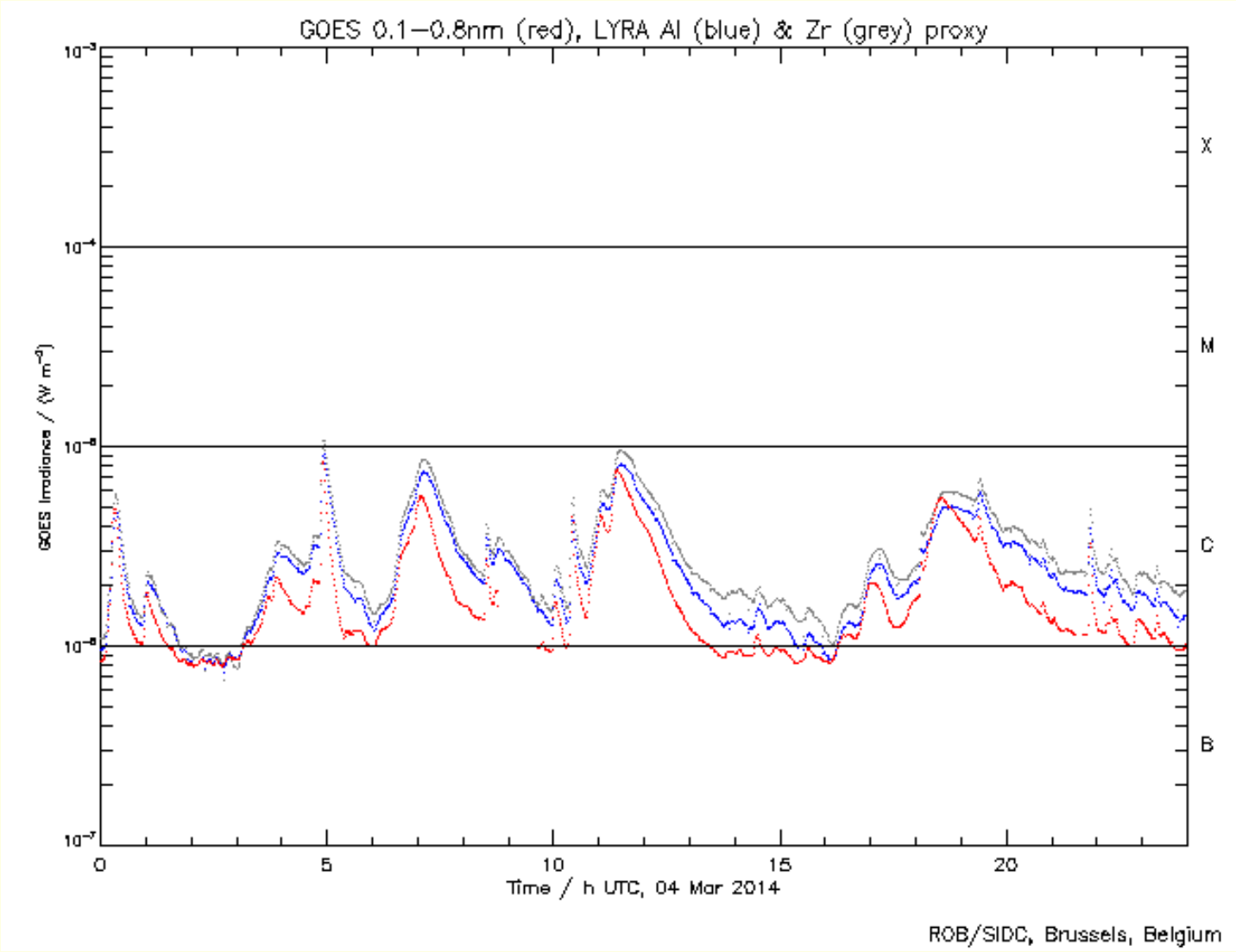
					Sat 01	Sun 02
Mon 03	Tue 04	Wed 05	Thu 06	Fri 07	Sat 08	Sun 09
Mon 10	Tue 11	Wed 12	Thu 13	Fri 14	Sat 15	Sun 16
Mon 17	Tue 18	Wed 19	Thu 20	Fri 21	Sat 22	Sun 23
Mon 24	Tue 25	Wed 26	Thu 27	Fri 28	Sat 29	Sun 30
Mon 31						







LYRA data product: GOES vs. LYRA proxies



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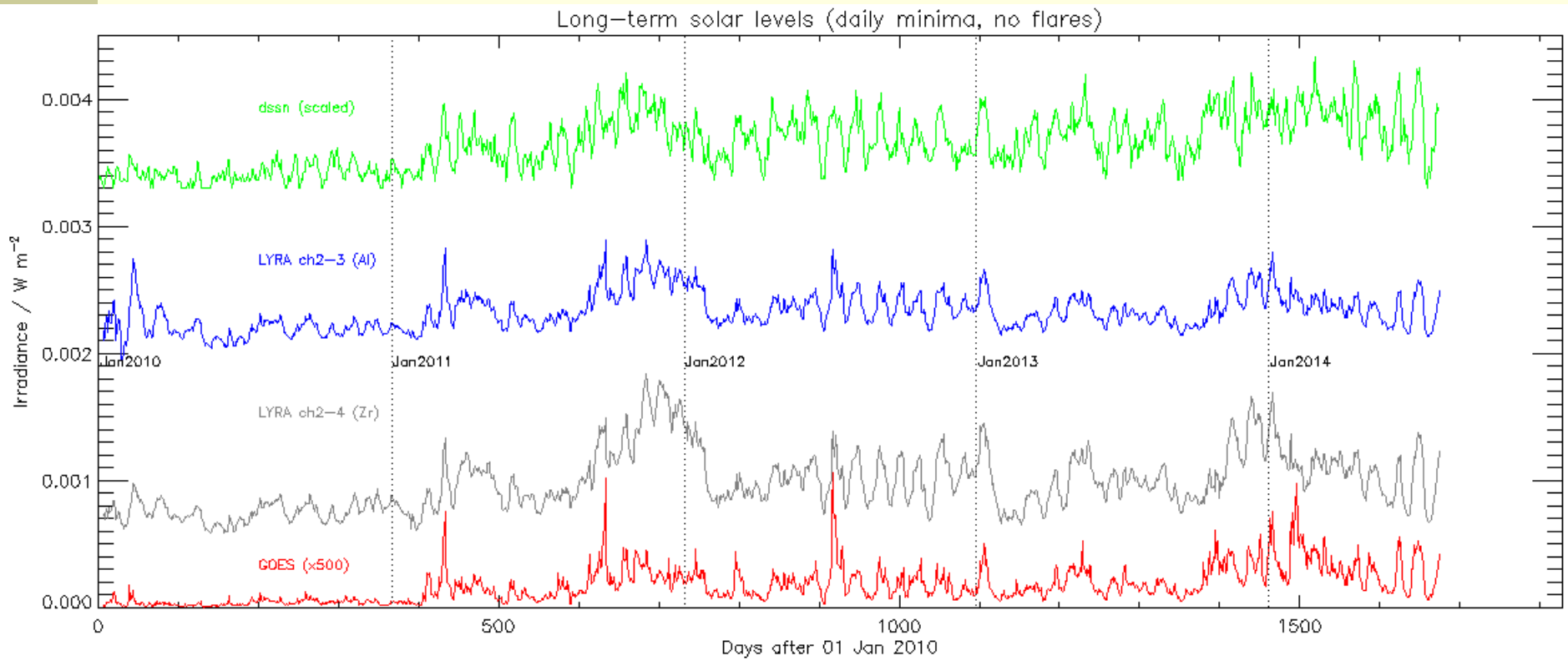
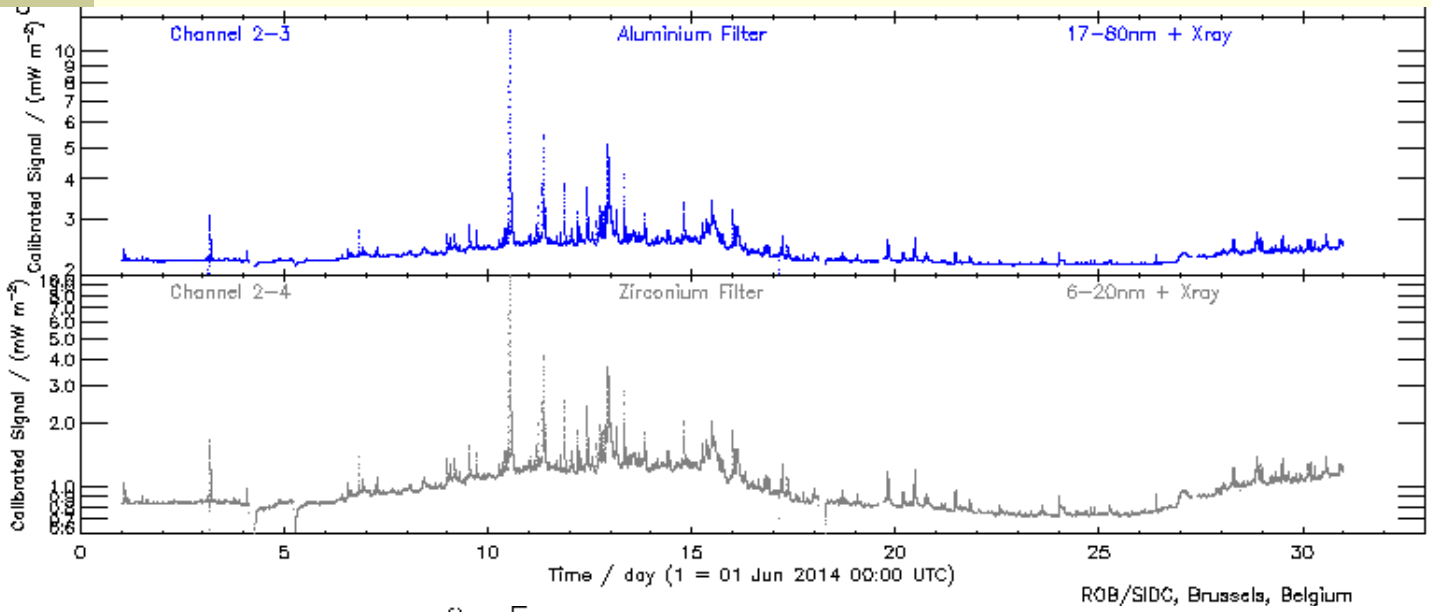
LYRA data product: Long-term solar levels

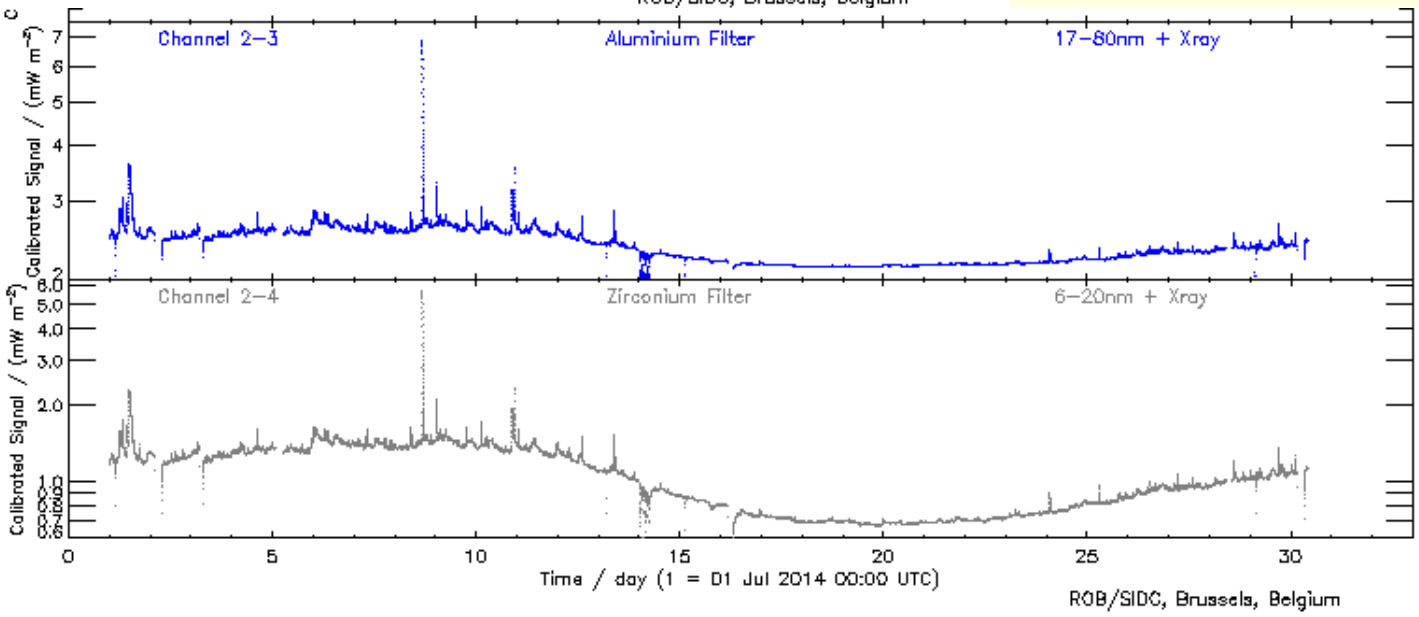


Keywords: spectral range (vis., EUV, SXR), temp. range (photosphere, quiet corona: 1-2 MK, AR: ~4 MK, flares: higher), cycle max vs. 27-day var.

Daily level, variance, flare size



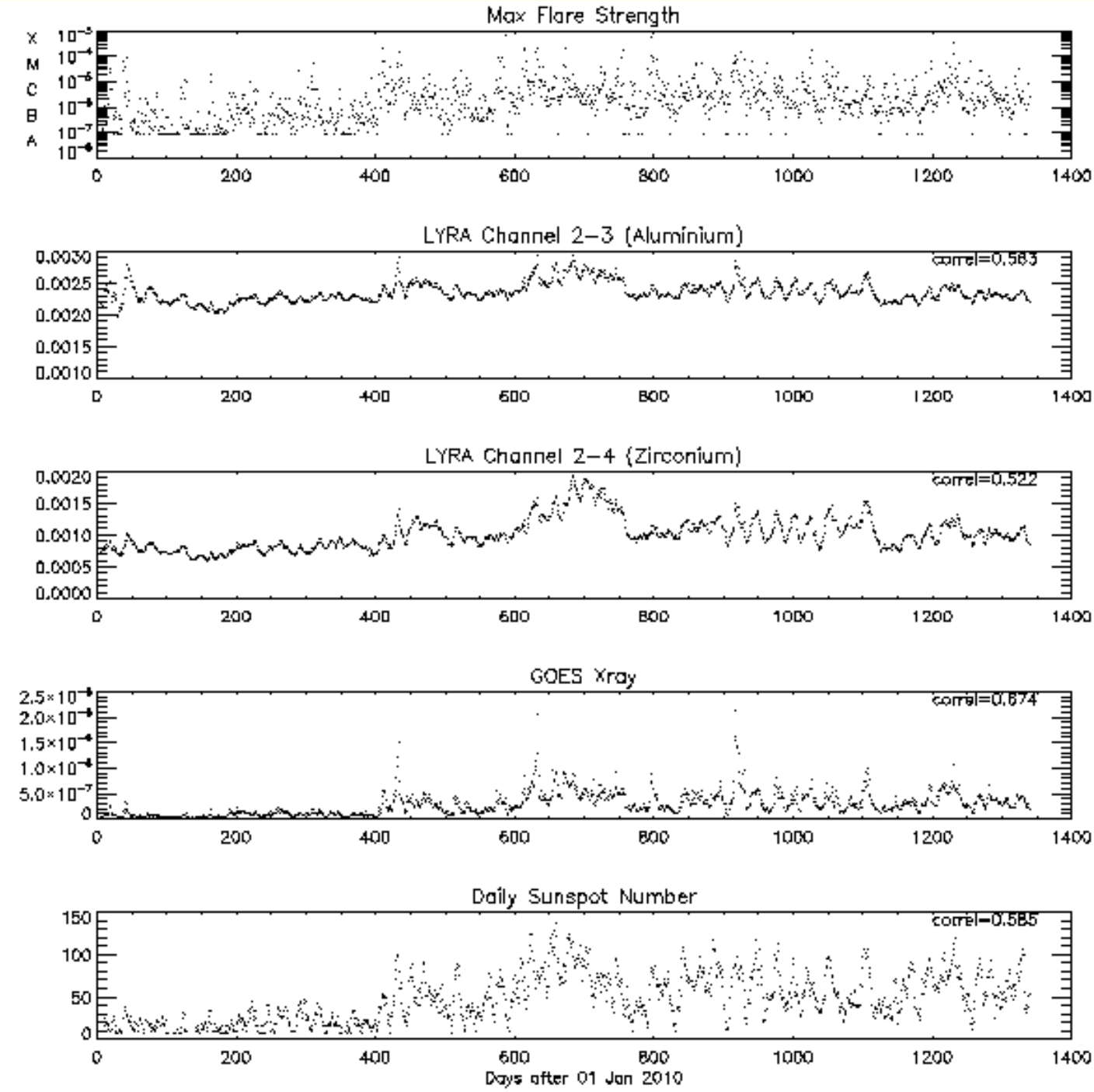
June 2014



July 2014

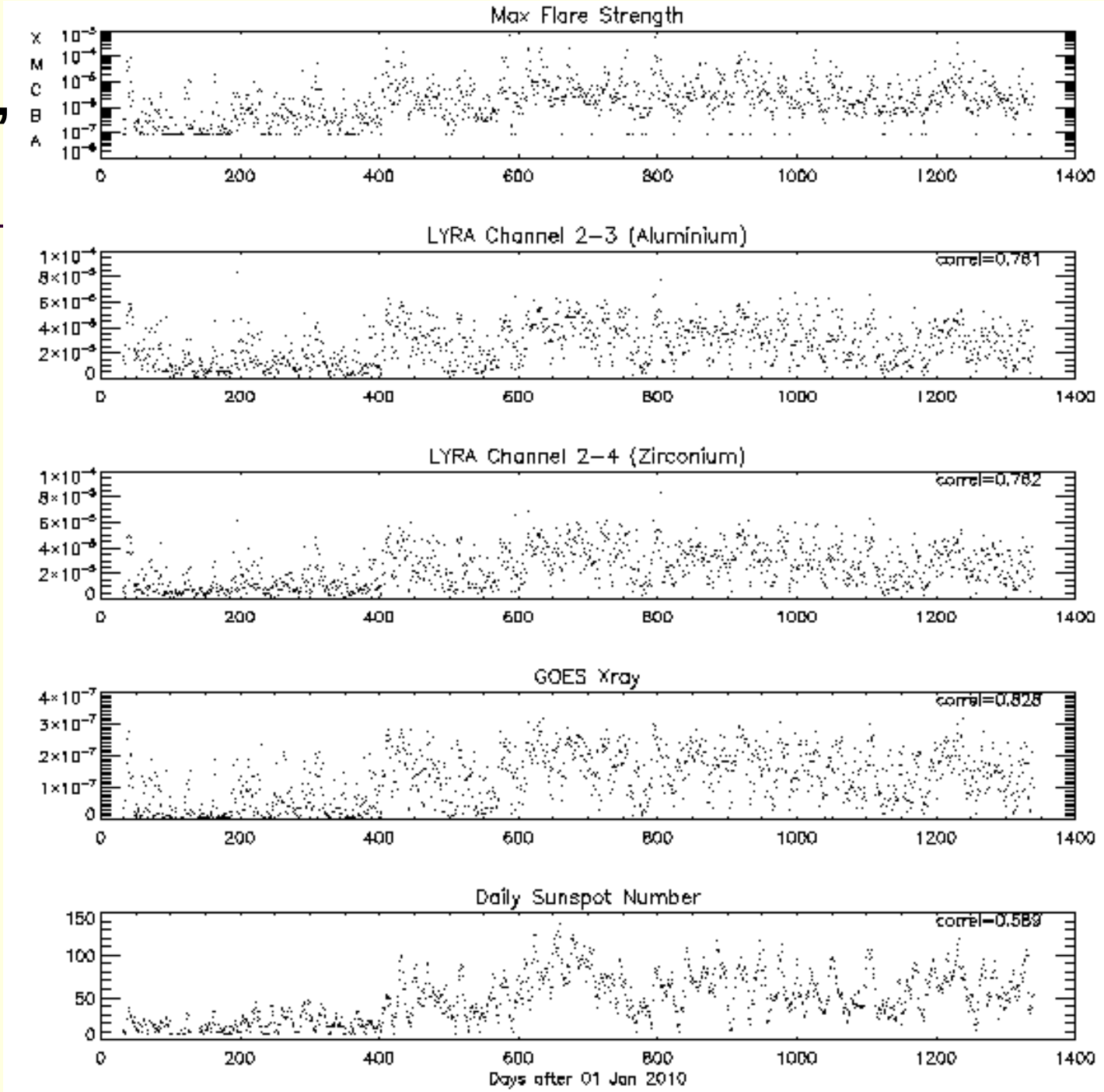
“Level”

Significant daily minimum, without flares or instrumental artefacts



“Variance”

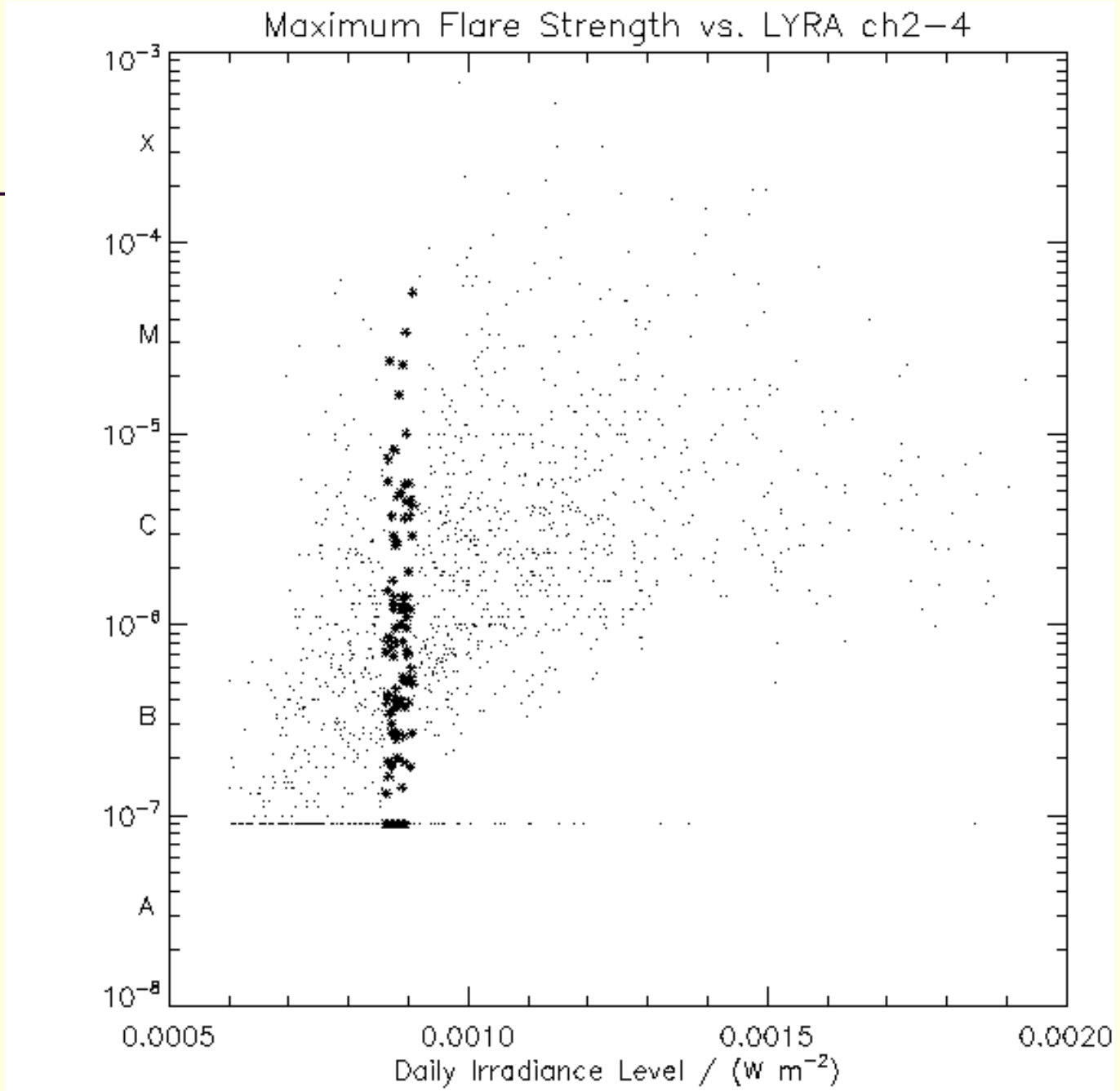
Daily minor-flaring activity, standard deviation in small corridor



“Level”

100 values (*) closest around LYRA ch2-4 selected from 1300 observations
=>
estimated distribution of flare strengths

Same for LYRA ch2-3, GOES, DSSN
=>
forecast based on 400 values



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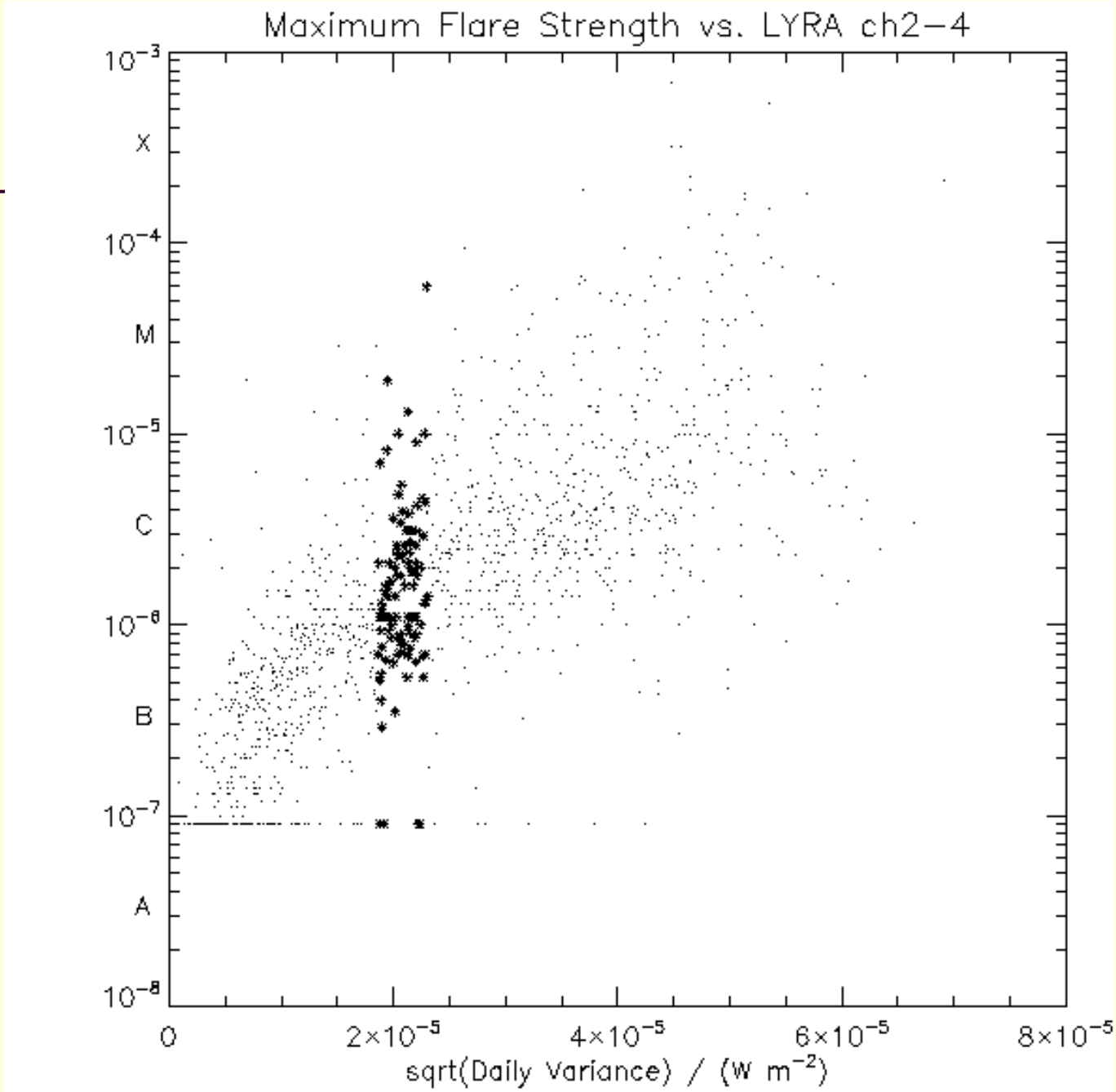
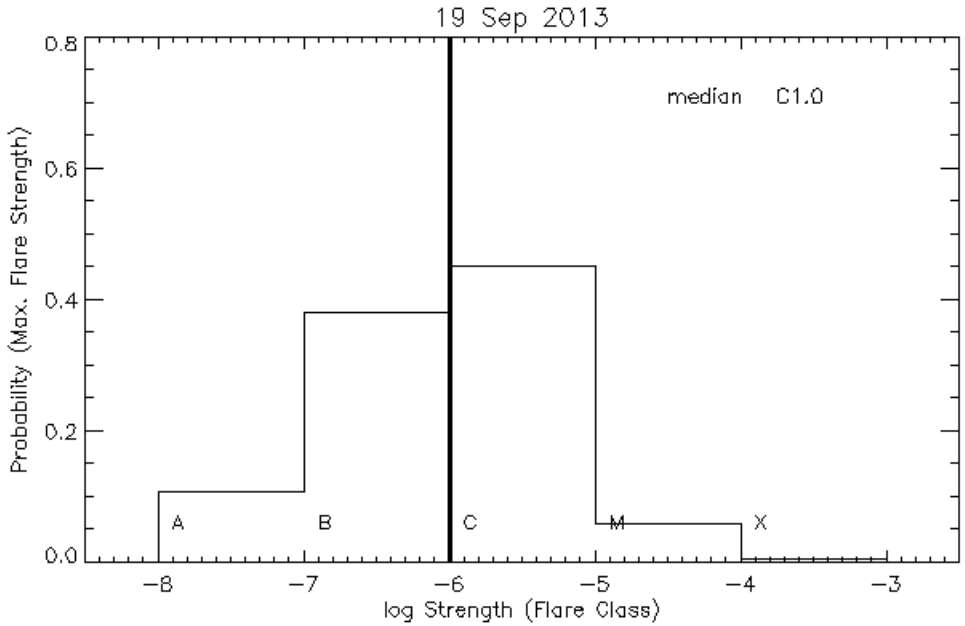


“Level” – daily forecast

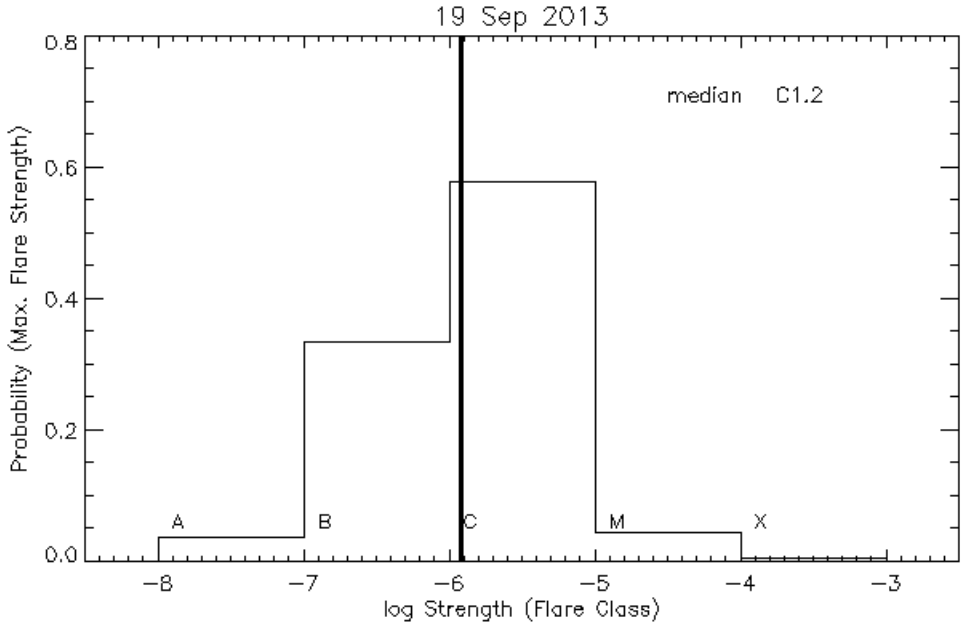
Estimated Flare Probability



based on		A[%]	B[%]	C[%]	M[%]	X[%]	median
LYRA ch2-3 =	0.00223394	24	49	23	4	0	B3.7
LYRA ch2-4 =	0.000884117	11	48	35	6	0	B7.3
GOES Xray =	2.95000e-07	3	22	67	8	0	C1.8
est. ISN =	44.0000	5	33	55	5	2	C1.2
together		10.75	38.00	45.00	5.75	0.50	C1.0
realized							C1.8

“Variance” – daily forecast

Estimated Flare Probability



based on		A[%]	B[%]	C[%]	M[%]	X[%]	median
LYRA ch2-3 =	2.07391e-05	4	41	50	5	0	C1.1
LYRA ch2-4 =	2.07291e-05	4	30	61	5	0	C1.4
GOES Xray =	1.04609e-07	2	30	65	3	0	C1.4
est. ISN =	44.0000	5	33	55	5	2	C1.2
together		3.75	33.50	57.75	4.50	0.50	C1.2
realized							C1.8

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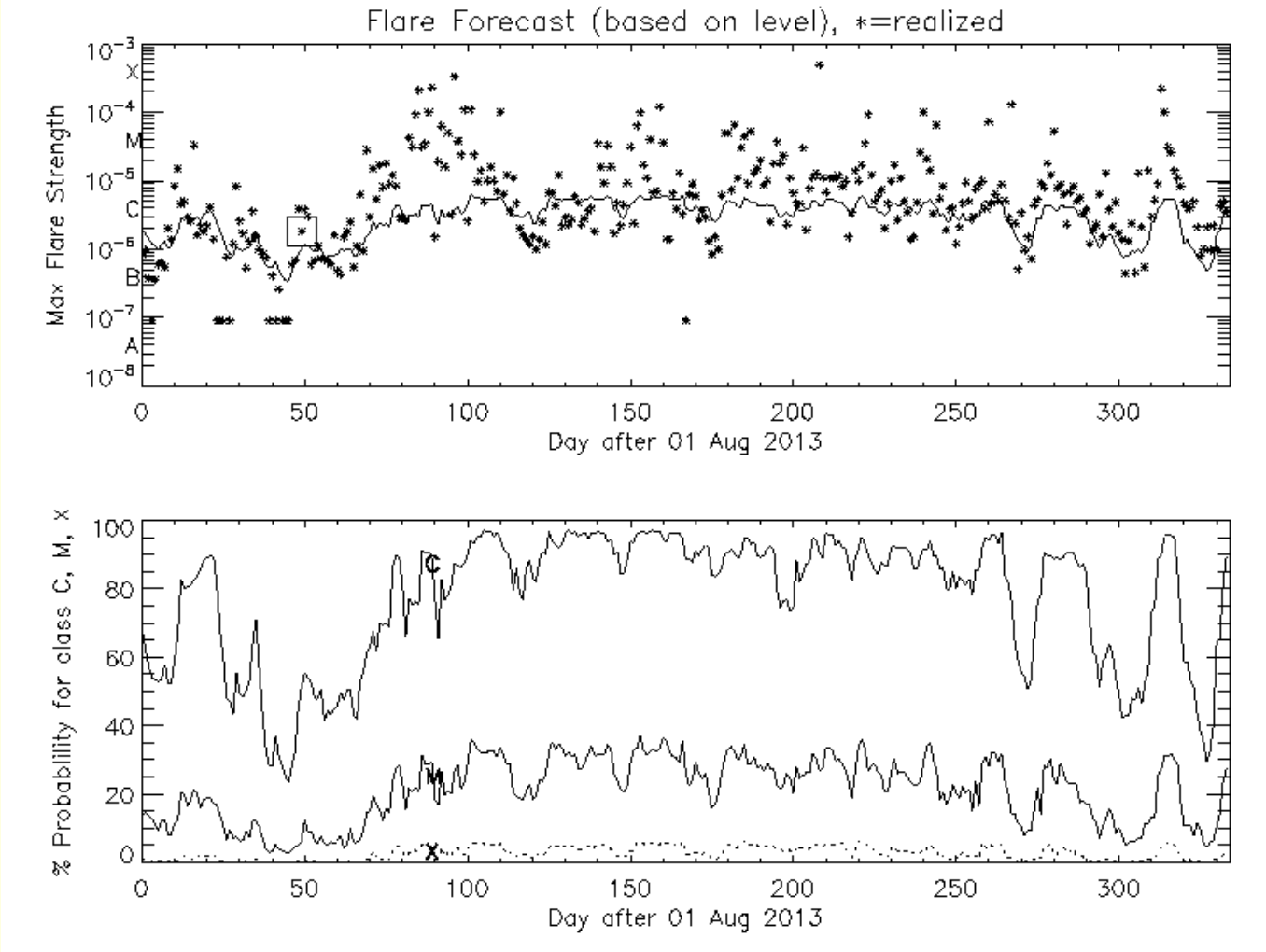
Forecast method “Level”

Test Aug 2013 – Jun 2014

Method changes slower than “Var”

Median leads to underestimation during high activity

Probabilities reflect situation better than simply median



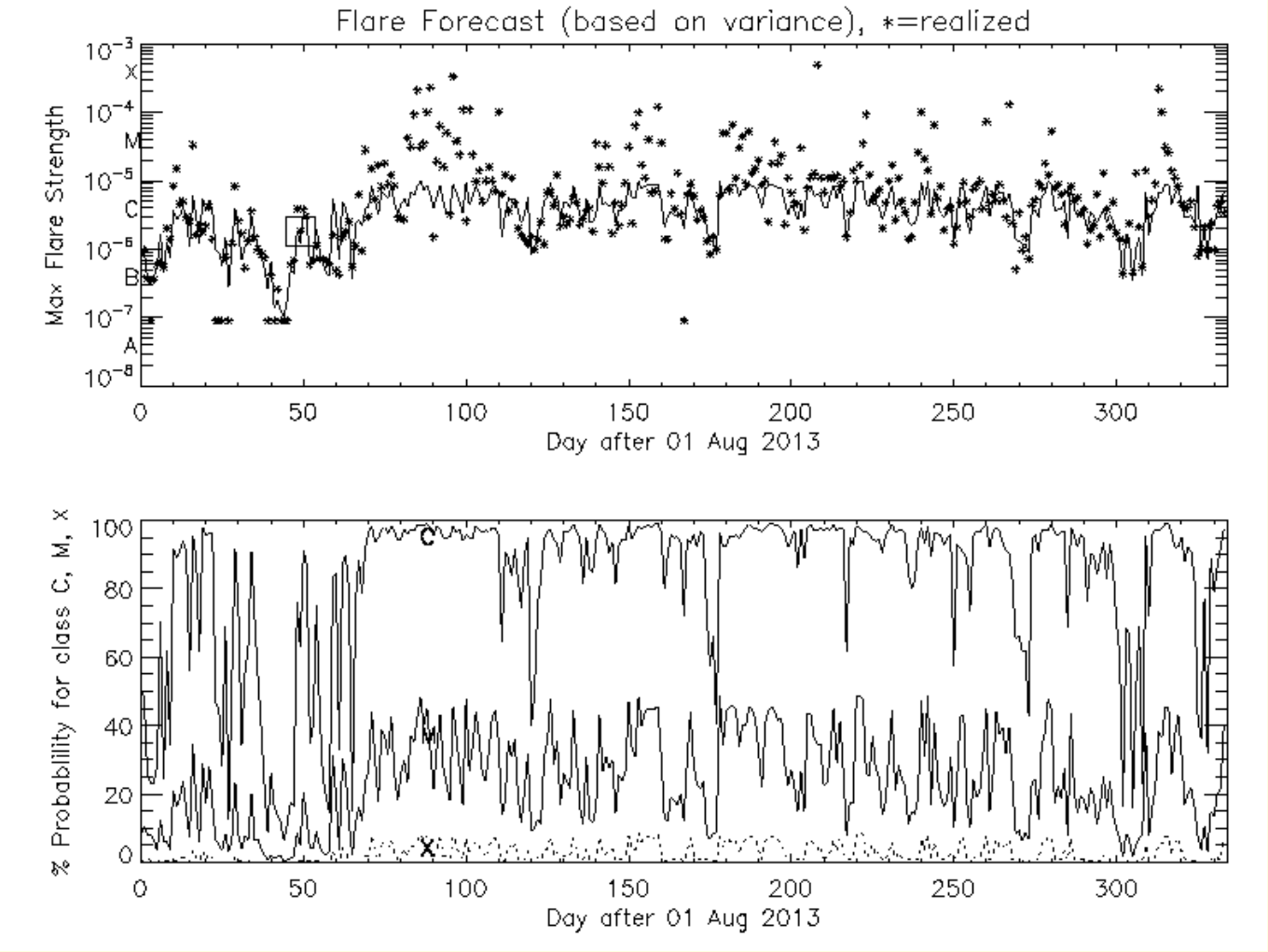
Forecast method “Variance”

Test Aug 2013 - Jun 2014

Method follows closer than “Lev”

Median leads to underestimation during high activity

Probabilities reflect situation better than simply median



Forecast verification measures (I)

- Root mean squared error (RMSE) — Skill score
  - Level = 0.60 [orders of magnitude] — 0.03
  - Level Day-1 = 0.62 — -0.03
  - Variance = 0.48 — 0.38
  - Variance Day-1 = 0.57 — 0.13
  - Persistence = 0.61 — 0.00
  - constant C1.5 = 0.84 — -0.90
- Skill score definition
  - 1 – MSE / MSE(ref)
  - ref = Persistence model
  - 0: as useful as reference model
  - <0: worse than reference model
  - 1: perfect forecast

Forecast verification measures (II)

- Contingency table (for binary events: either – or)

		Observation	
		Y	N
Forecast	Y	a (hit)	b (false alarm)
	N	c (miss)	d (correct rejection)
Example: Persistence		268	19
forecasting flare > C1.0		20	27

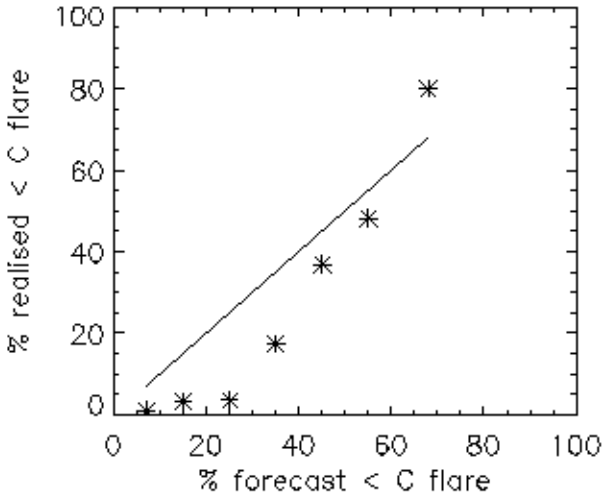
- Skill score definition
  - Example: True Skill Statistic
  - TSS = (ad - bc) / ((a+c)*(b+d))
  - 0: no skill; useless like constant or random forecast
  - <0: even worse
  - 1: perfect forecast

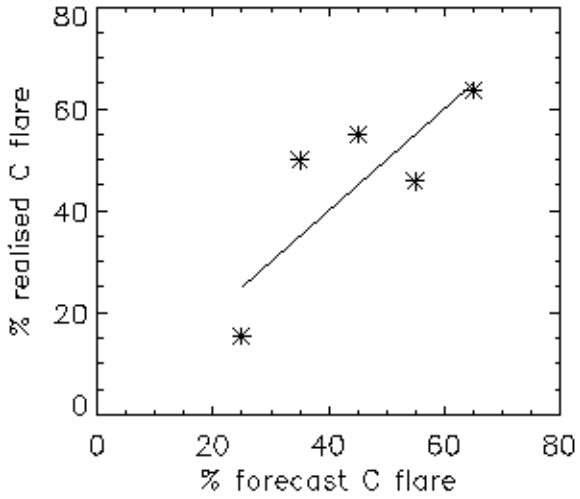
Forecast verification measures (III)

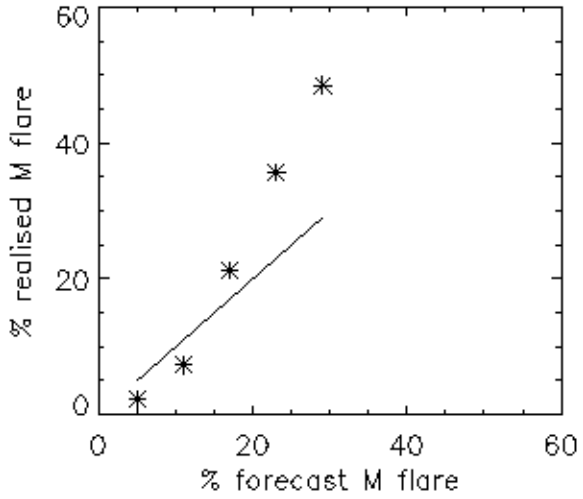
- Forecasting flare > C1.0 Skill score
  - TSS(Level) = 0.44
  - TSS(Variance) = 0.72
  - TSS(Persistence) = 0.52
- Forecasting flare > M1.0 Skill score
  - TSS(Level) = 0.00
  - TSS(Variance) = 0.00
  - TSS(Persistence) = 0.34

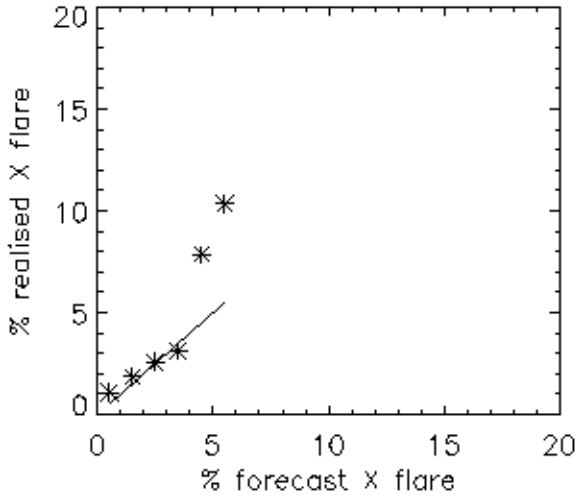
Forecast verification measures (IV)

- Reliability function ("Lev")



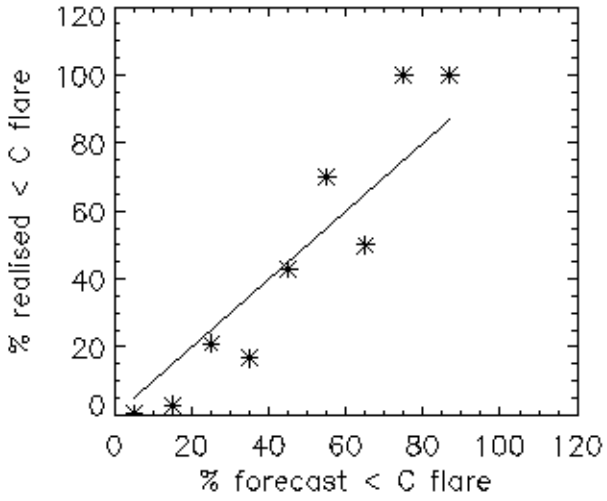


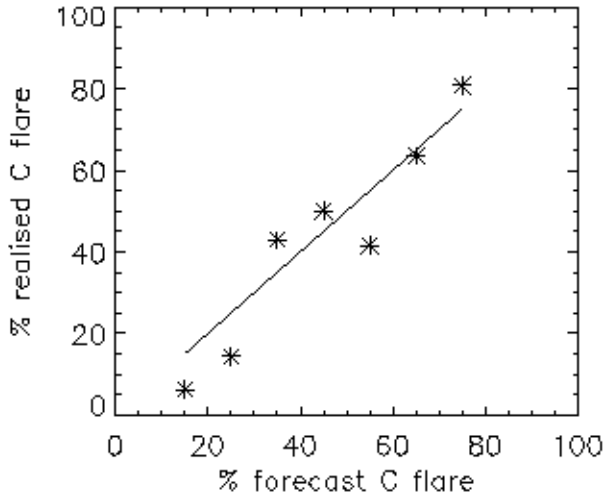


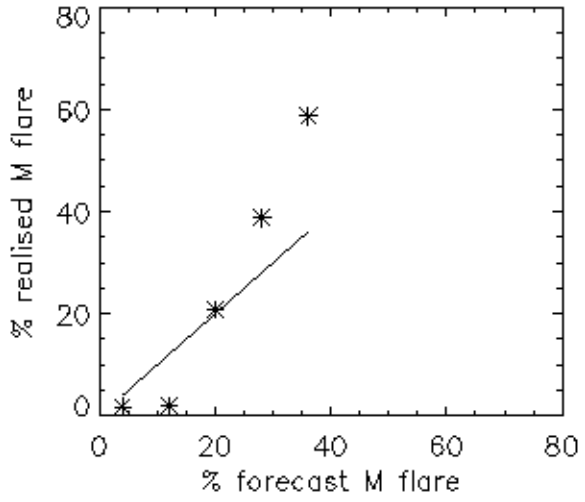


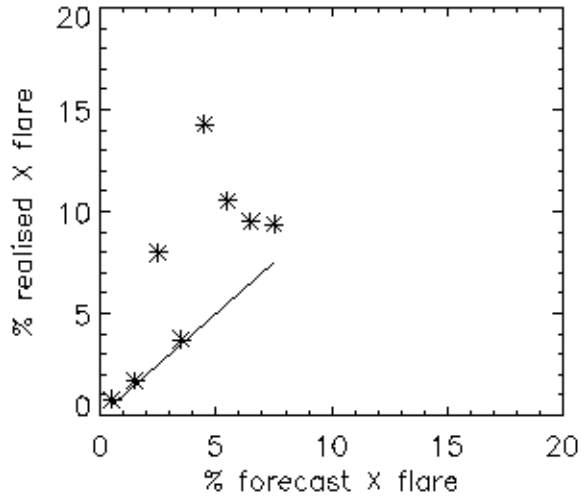
Forecast verification measures (V)

- Reliability function (“Var”)









Questions for the future

- Second activity peak of cycle 24 – does it change the statistics? YES ! (see below)
- How can the methods be improved?
- Can the two methods be integrated?
- Which forecasting parameter is the most reliable?
- Can the parameters be weighted accordingly?
- Are space weather forecasters interested?
- [I heard that most methods have difficulties with rare events like M- and X-flares]

- First improvement: Take all days into account, because the second peak does make a difference.

Forecast verification measures (I), updated

- Root mean squared error (RMSE) Skill score

	RMSE			Skill score		
Level	= 0.60	0.55	**0.55**	0.03	0.19	**0.19**
Level Day-1	= 0.62	0.58	**0.57**	-0.03	0.10	**0.13**
Variance	= 0.48	0.45	**0.42**	0.38	0.46	**0.53**
Variance Day-1	= 0.57	0.55	**0.55**	0.13	0.19	**0.19**
Persistence	= 0.61	0.61	**0.61**	0.00	0.00	**0.00**
constant C1.5	= 0.84	0.84	**0.77**	-0.90	-0.90	**-0.60**
	old	new	**all**	old	new	**all**

- “old” = test period (Aug 2013 – Jun 2014) with part of days
- “new” = test period (Aug 2013 – Jun 2014) with all days
- **“all” = full period (Feb 2010 – Jun 2014) with all days**

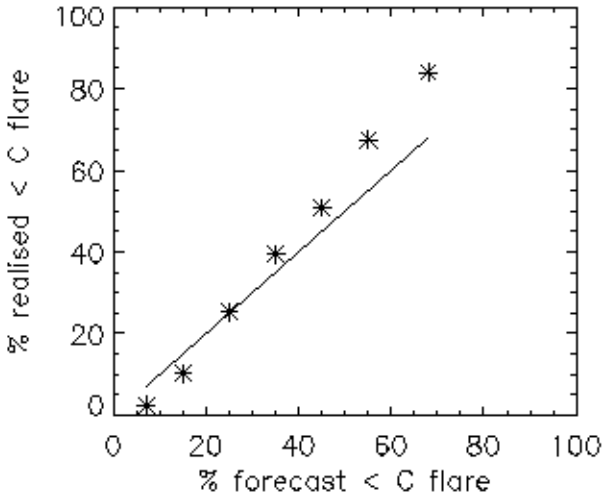
Forecast verification measures (III), updated

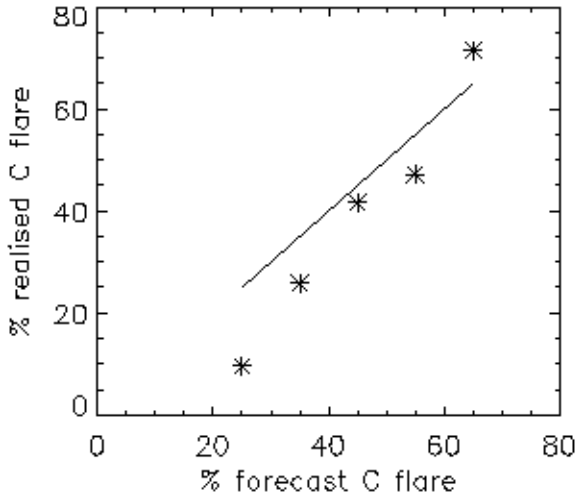
Forecasting flare > C1.0	Skill score		
TSS(Level)	= 0.44	0.31	**0.52**
TSS(Variance)	= 0.72	0.77	**0.80**
TSS(Persistence)	= 0.52	0.52	**0.58**
Forecasting flare > M1.0	Skill score		
TSS(Level)	= 0.00	0.00	**0.00**
TSS(Variance)	= 0.00	0.24	**0.16**
TSS(Persistence)	= 0.34	0.34	**0.39**
	old	new	**all**

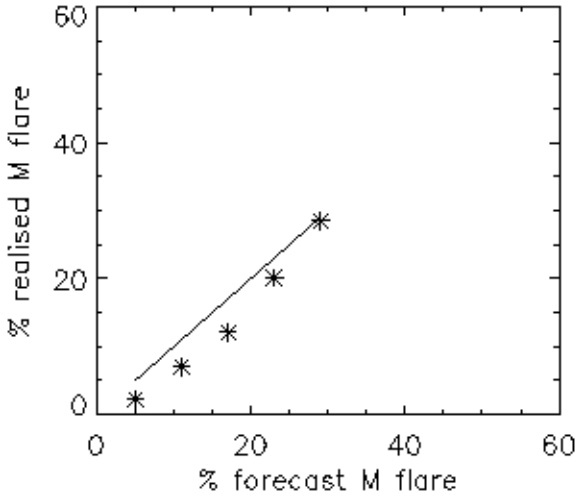
Forecast verification measures (IV), updated

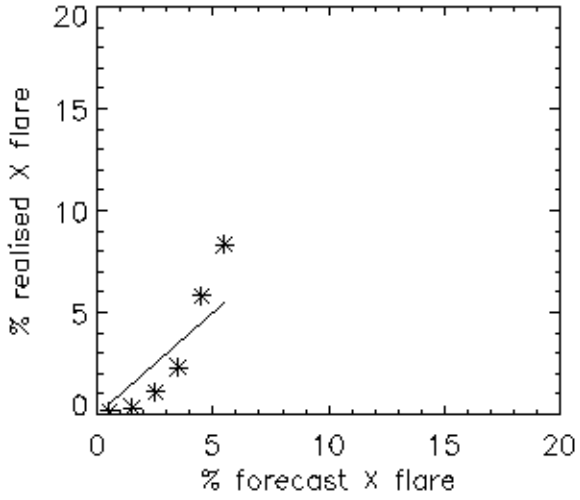
- Reliability function ("Lev")

for **all** days





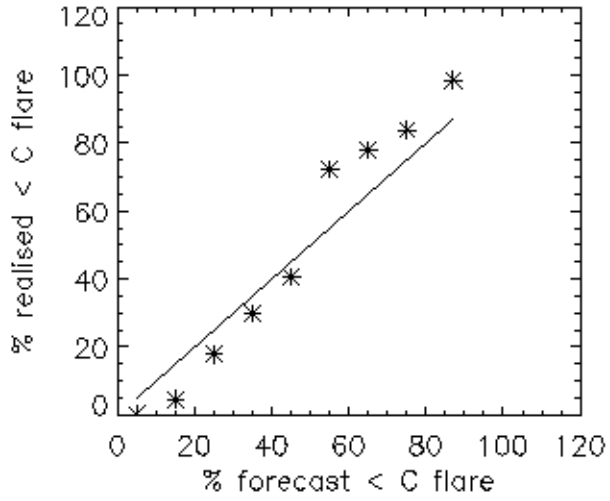


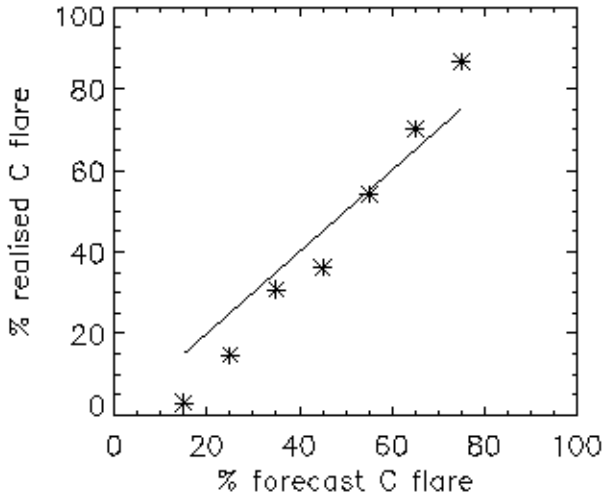


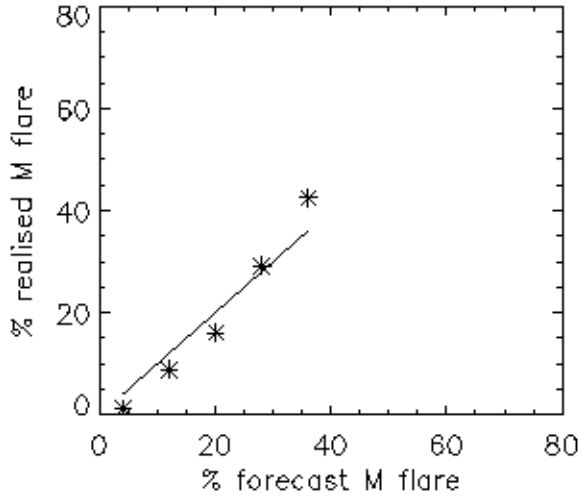
Forecast verification measures (V), updated

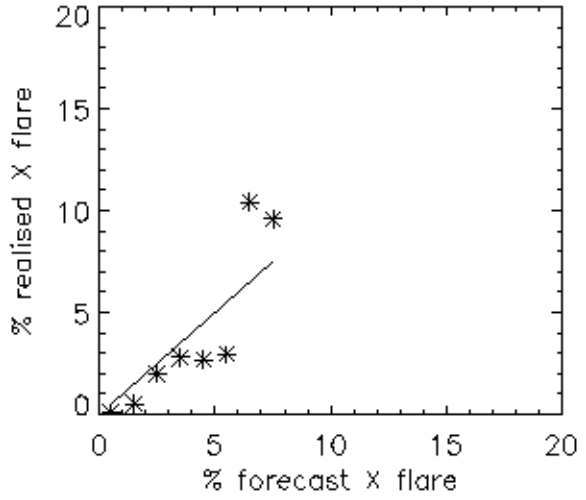
- Reliability function ("Var")

for **all** days









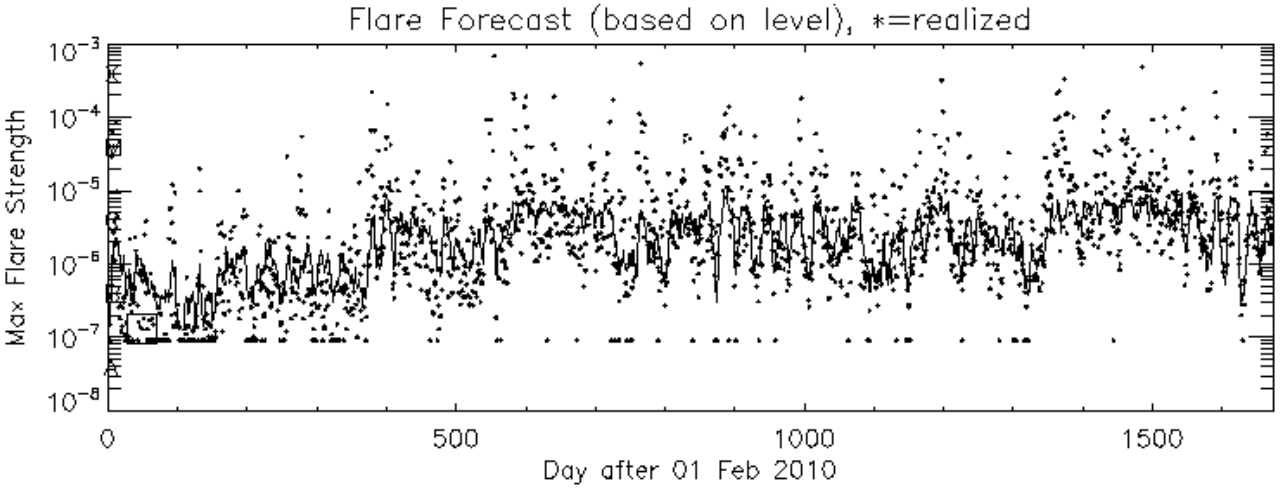
Forecast method “Level”, updated

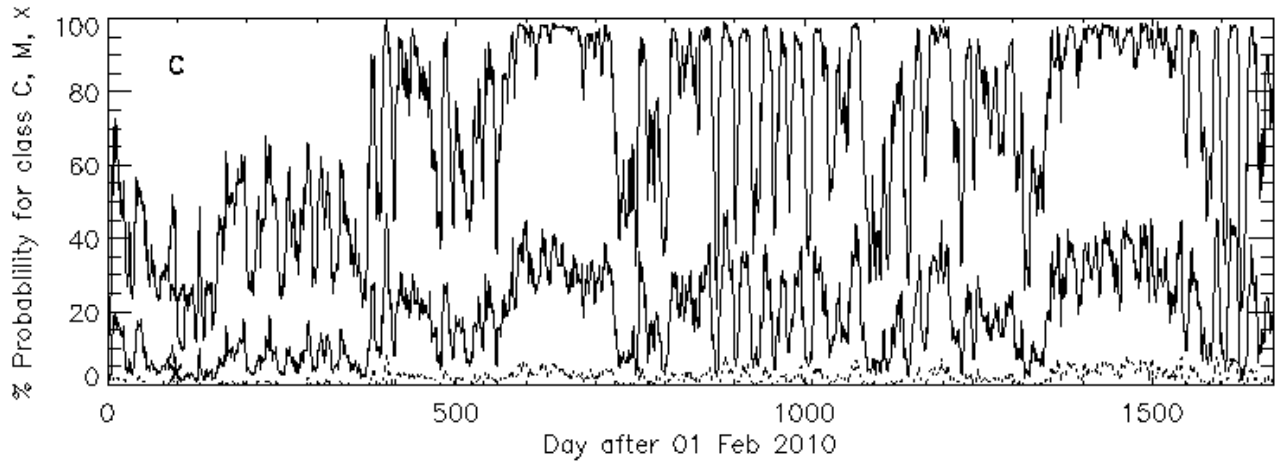
Test Feb 2010 – Jun 2014 **(“all”)**

Method changes slower than “Var”

Median leads to underestimation during high activity

Probabilities reflect situation better than simply median





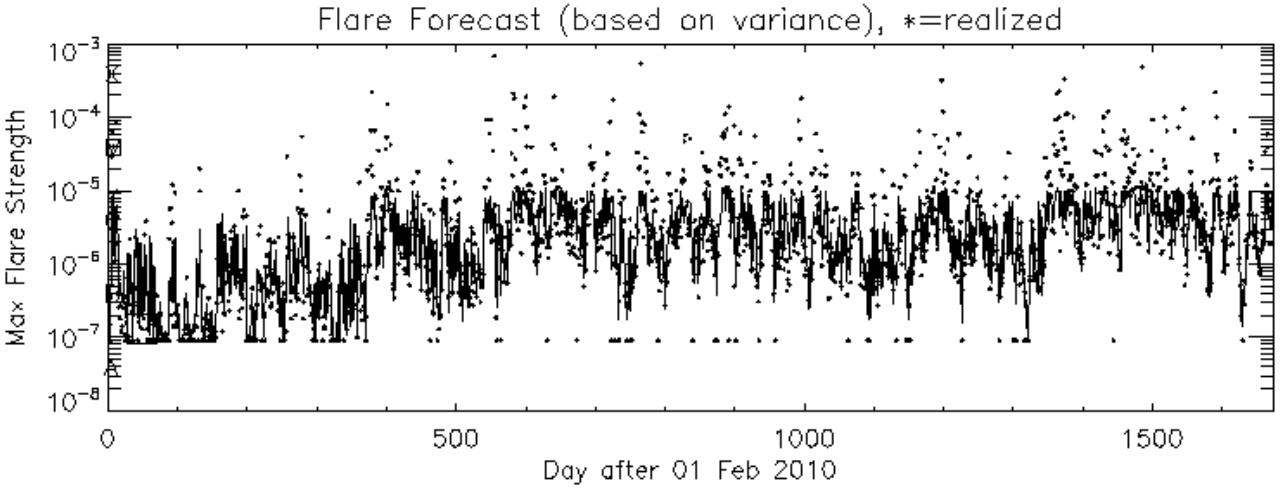
Forecast method “Variance”, updated

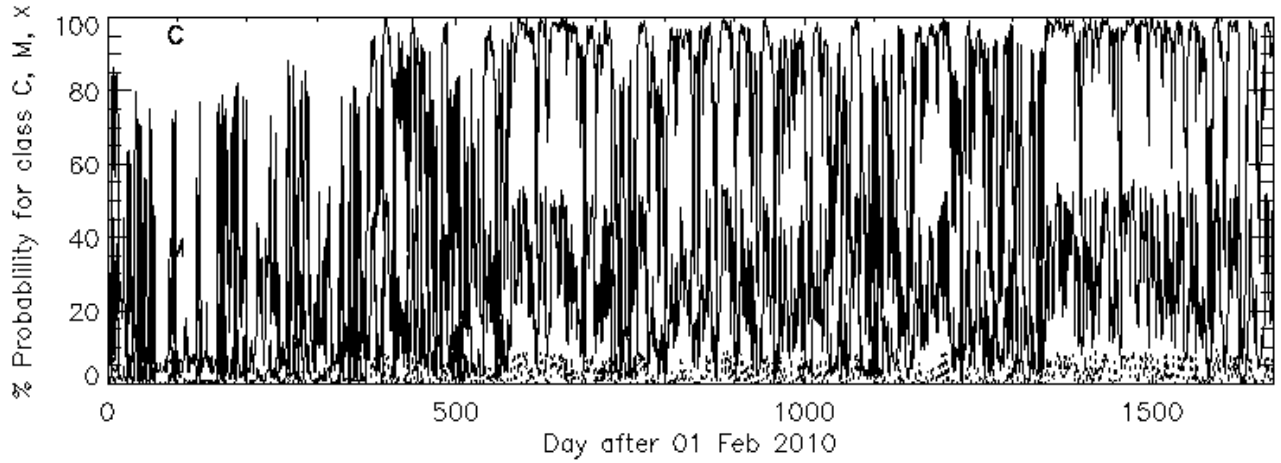
Test Feb 2010 - Jun 2014 **(“all”)**

Method follows closer than “Lev”

Median leads to underestimation during high activity

Probabilities reflect situation better than simply median





Remark

- Methods: Variance > Persistence, Level. Why?
- Role of active regions?
- Magnetic complexity (~ microflaring ~ Variance) maybe more important than brightness or size (~ irradiance, ~ Level)

Please visit

- http://solwww.oma.be/users/dammasch/flares/FlareProbability.html
- http://solwww.oma.be/users/dammasch/flares/FlareProbabilityVar.html
- and of course the official PROBA2 website
- http://proba2.oma.be/

- ***Thank you for your interest !***