



*X-ray flare characteristics and
probability of solar proton events*

A. Belov



IZMIRAN, Russia

abelov@izmiran.ru

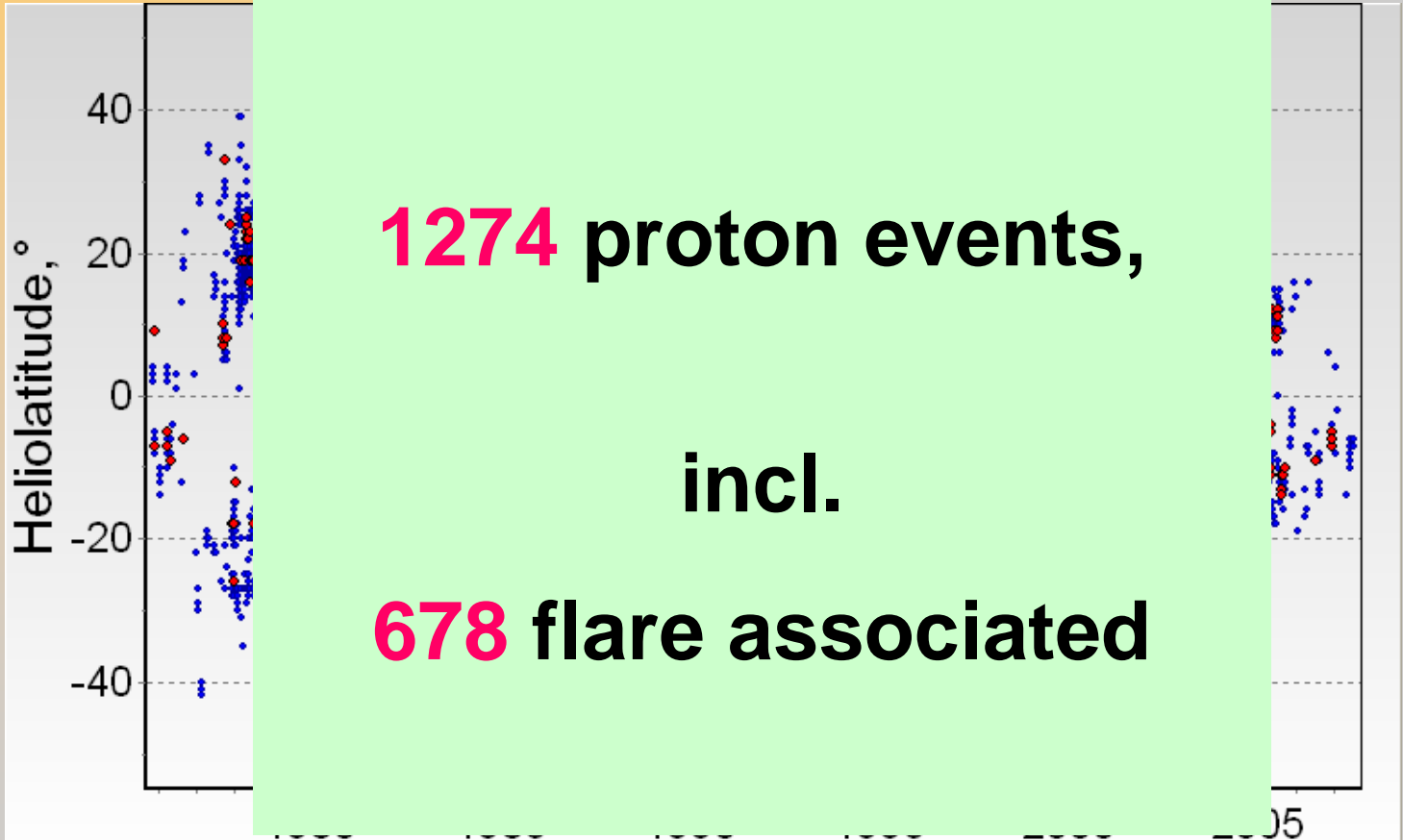


Athens, September 2007



X-ray flare and proton event database

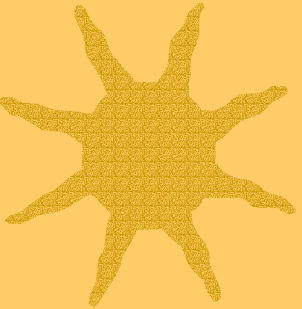
~ 63 000 flares



All X-ray flares and proton associated flares (red dots).

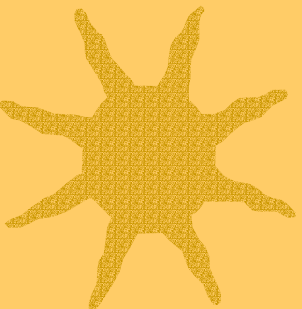


Coauthors



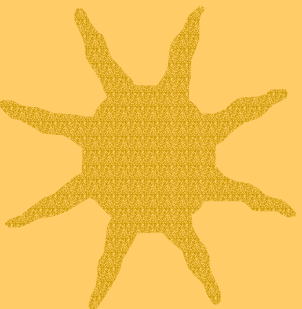
- ★ Belov A., **Garcia H., Kurt V., Mavromichalaki H.** and **Gerontidou M.**

Proton enhancements and their relation to x-ray flares during the three last solar cycles
Solar Phys., 229, 1, 135-159, 2005



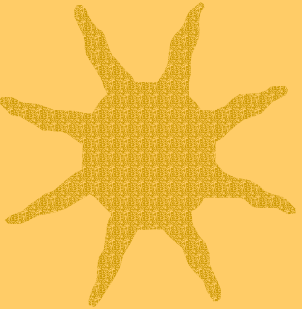
- ★ A.V. Belov, **E.A. Eroshenko, O.N. Kryakunova, V.G. Kurt, V.G. Yanke**

X-ray flare characteristics and probability of solar proton events
30th ICRC 30, Merida, 2007

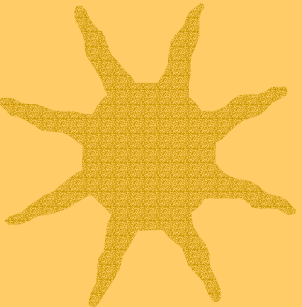




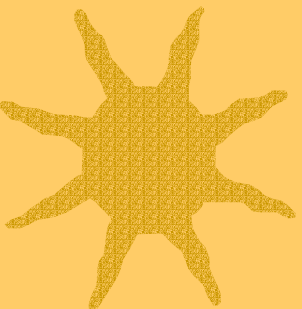
Two requests to everybody



✓ Hear me



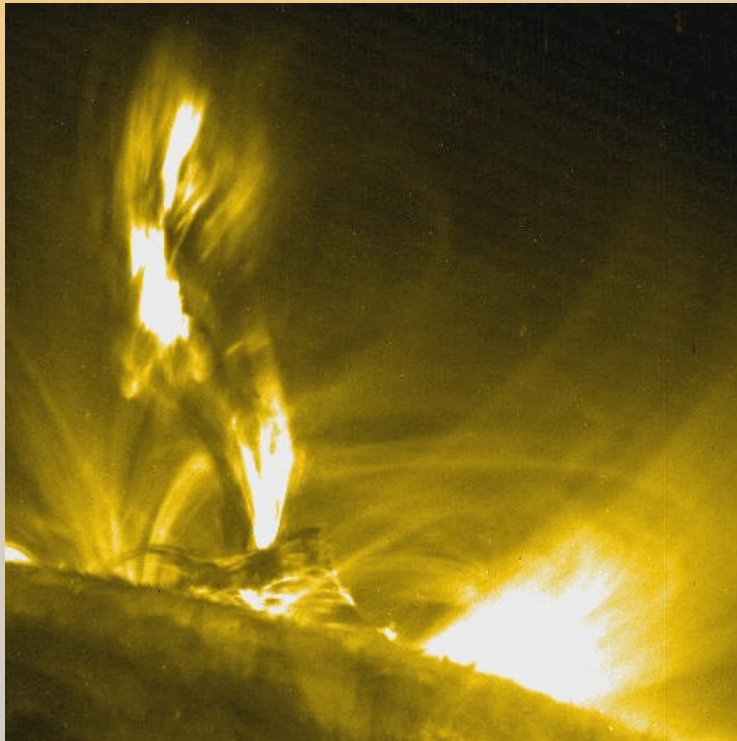
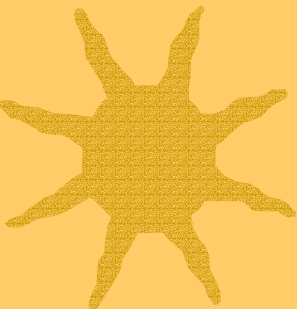
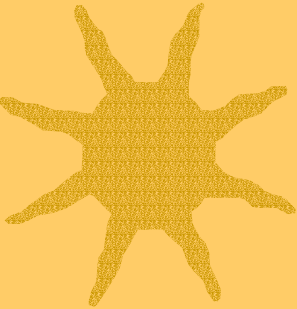
✓ Don't believe me



✓ Please



Why is it here???



solar X-ray flares

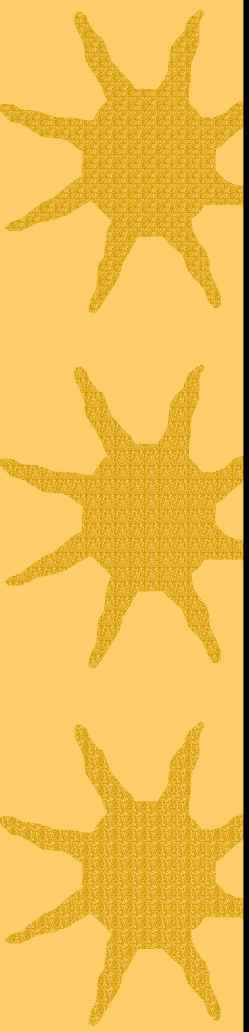
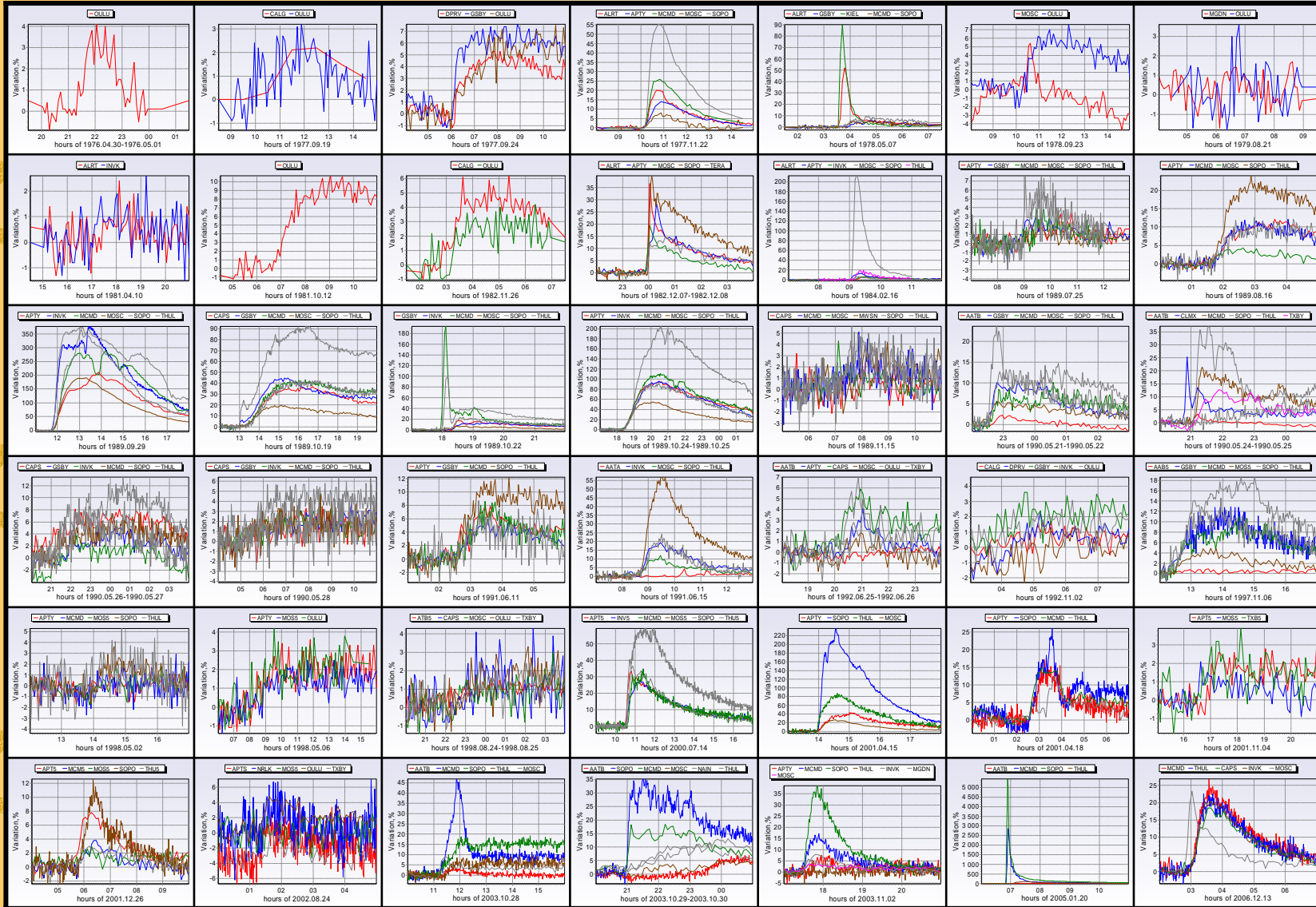
File View Tools Sort Relation Plot Window

1991.01.11 Start 1991.01.21 End dt X Y 62958

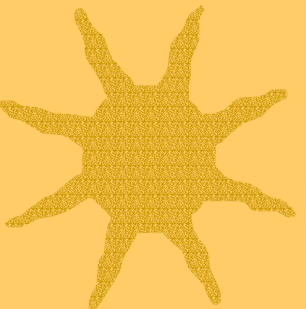
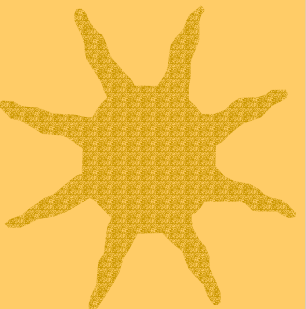
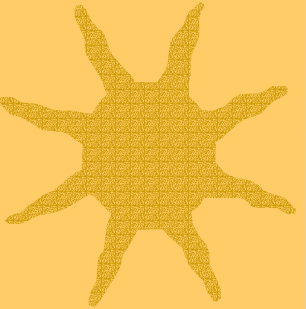
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1991.01.07	22:50:00	-23	69	0.00036	8	2	C 2.8	SF		2.9E-6	181	0.00025	1.45	0.323	0	6426	
1991.01.07	23:34:00	-09	399	0.00064	12	2	C 2.4			2.4E-6	399	0.00029	1.2	0.2	0	0	
1991.01.08	2:11:00	89	999	0.003717	21	10	C 5.9			5.9E-6	999	0.00284	0.99	0.909	0	0	
1991.01.08	4:09:00	11	48	0.07236	134	23	M 1.9	1N		1.0E-5	157	0.02484	0.79	0.207	0	6442	
1991.01.08	6:23:00	12	50	0.01617	49	35	M 1.1	SF		1.1E-5	150	0.0231	0.31	2.5	0	6442	
1991.01.08	11:24:00	-13	51	0.0126	35	0	M 1.2	1N		1.2E-5	156	-1	-1	-1	0	6442	
1991.01.08	18:15:00	99	999	0.0162	72	33	C 7.5			7.5E-6	999	0.01495	0.23	0.846	0	0	
1991.01.09	4:45:00	17	49	0.00513	30	2	C 4.5	1F		4.5E-6	46	0.00054	2.25	0.056	0	6444	
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1991.01.10	0:37:00	15	64	0.008656	63	8	C 6.2	SF		6.2E-6	30	0.00289	0.77	0.179	0	6444	
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1991.01.10	7:00:00	99	999	0.00292	19	4	C 2.6			3.0E-6	999	0.00086	0.9	0.267	0	0	
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1991.01.10	9:30:00	12	57	0.009629	38	2	C 5.2	SF		5.2E-6	22	0.00062	2.6	0.056	0	6444	
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1991.01.10	16:34:00	12	56	0.001606	8	1	C 6.8	SF		6.8E-6	21	0.00041	6.8	0.126	0	6444	
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1991.01.10	18:05:00	16	72	0.00081	5	0	C 3.0	SF		3E-6	3	-1	-1	-1	0	6447	
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1991.01.12	8:27:00	99	999	0.00126	5	3	C 3.0			3E-6	999	0.00162	3	1.5	0	0	
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1991.01.12	16:02:00	-8	45	0.00072	16	10	C 1.9	SF		1.9E-6	4	0.0009	0.15	0.167	0	6447	
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1991.01.12	19:06:00	-9	47	0.0033	44	8	C 2.5	1F		2.5E-6	1	0.00012	0.31	0.222	0	6447	
1991.01.12	21:00:00	-6	56	0.000936	37	5	C 4.6	1F		4.6E-6	349	0.00138	0.92	0.196	0	6447	
1991.01.12	22:07:00	-6	43	0.00064	20	6	C 5.4	1N		5.4E-6	3	0.00089	1.57	0.429	0	6447	



SEE and databases



Databases and SEE



X-ray flares



SPEs



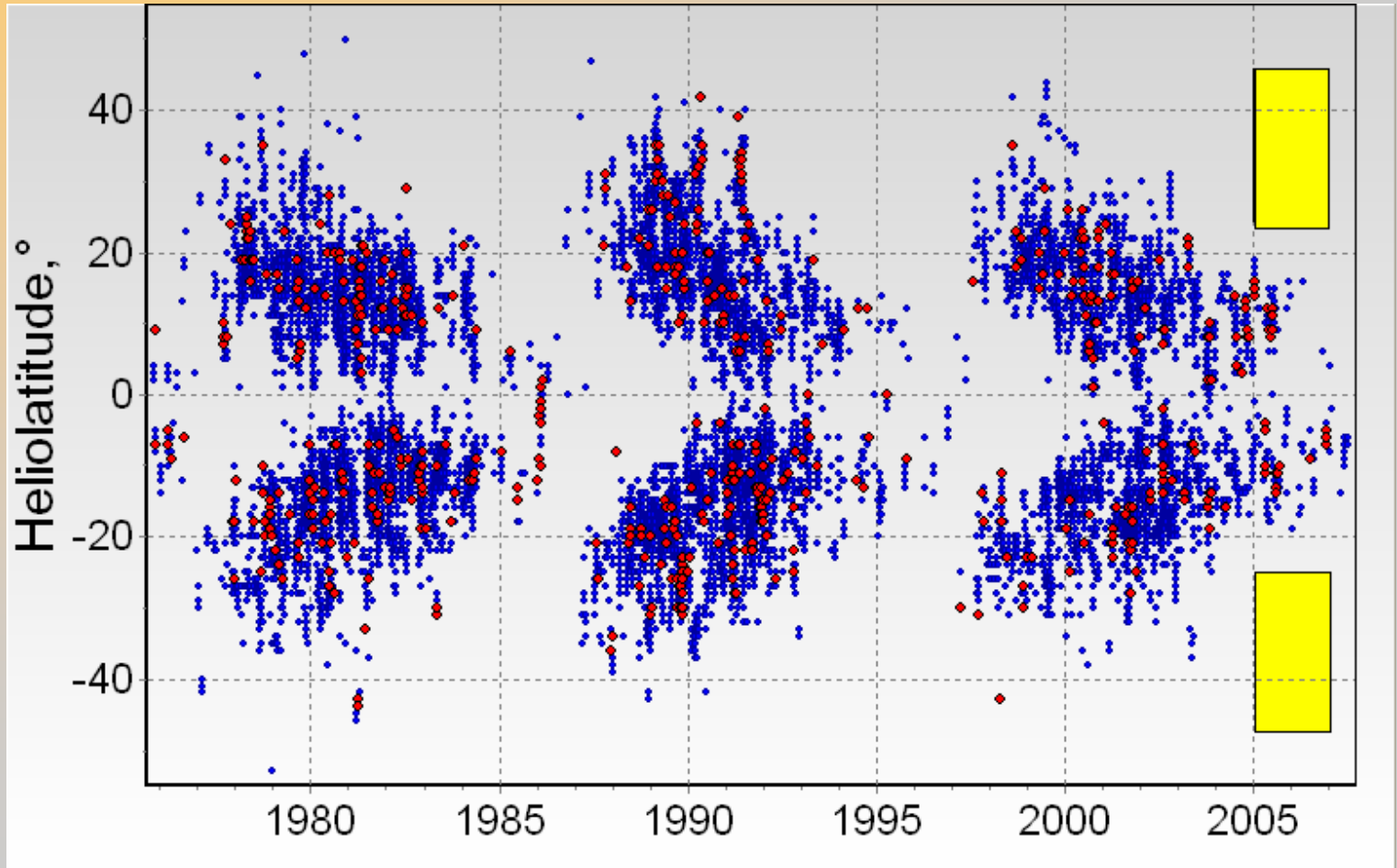
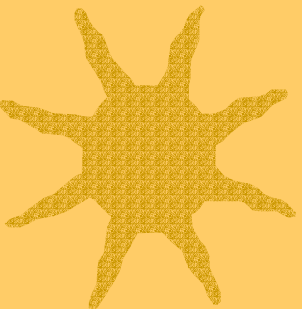
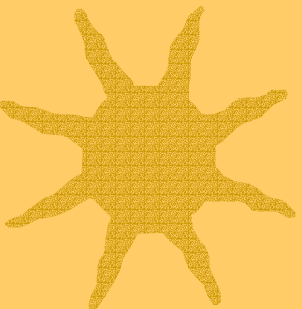
GLEs



Our databases are concise history of extreme events

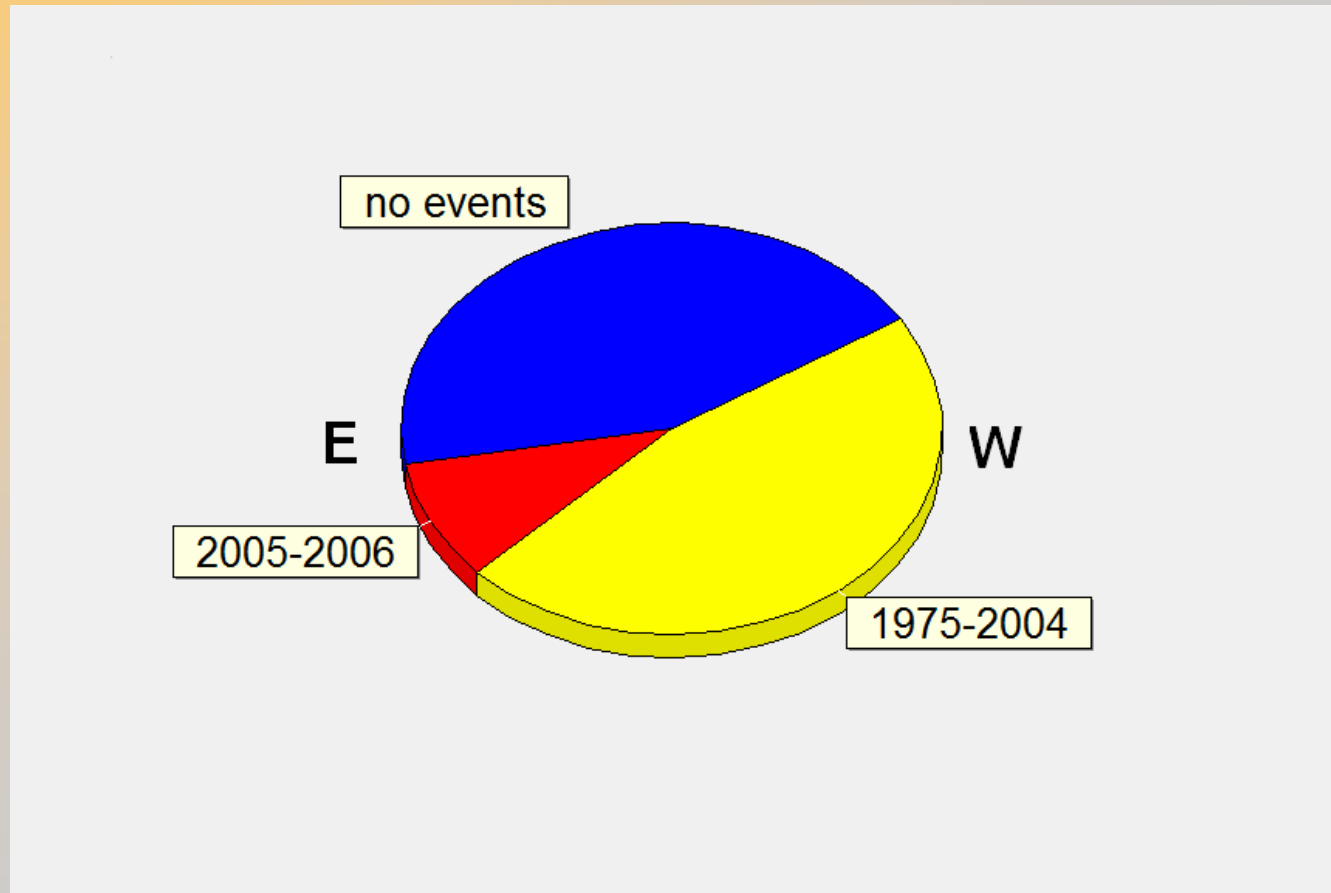
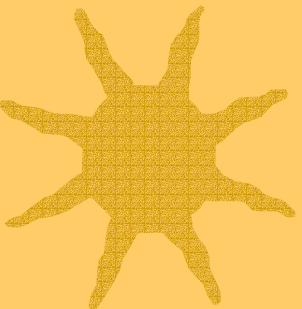
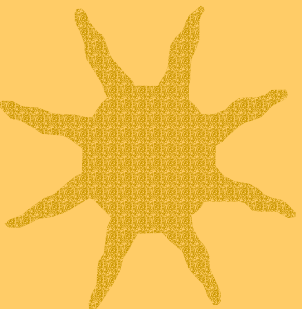
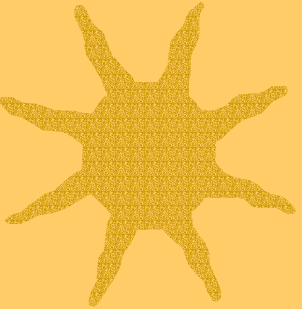


Is it the old history?





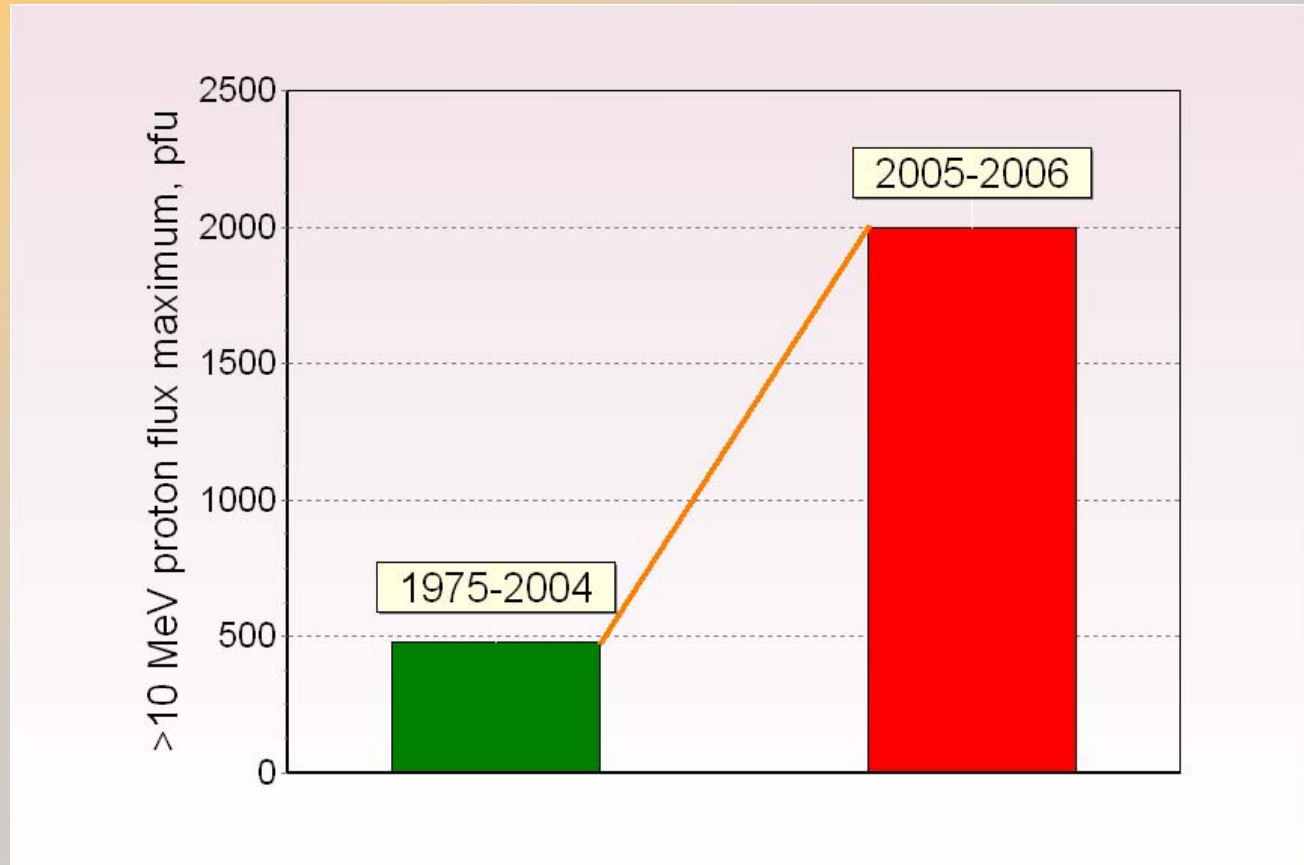
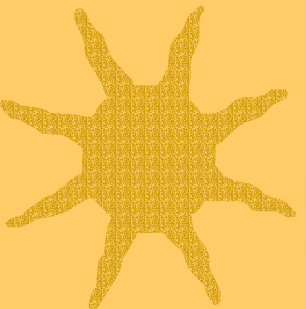
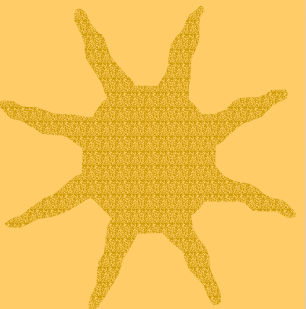
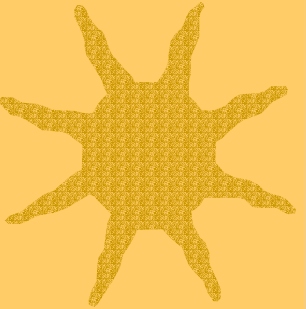
Flares, associated with >5 pfu flux for >100 MeV protons



Extremal east longitude moved from E43 to E77 (34°)



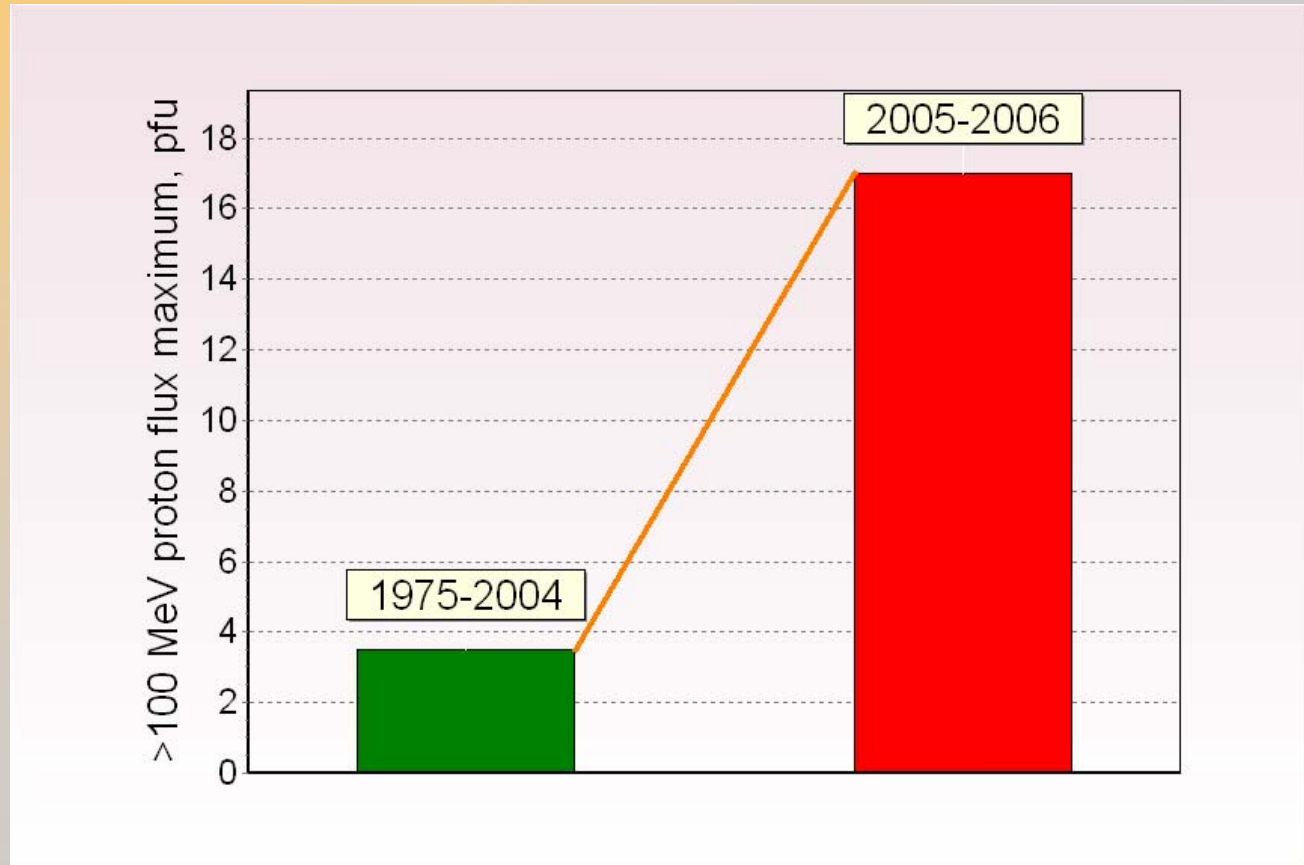
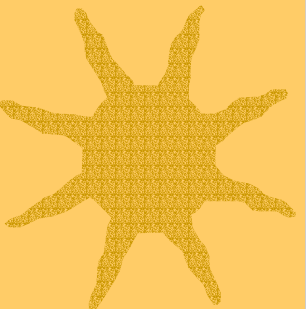
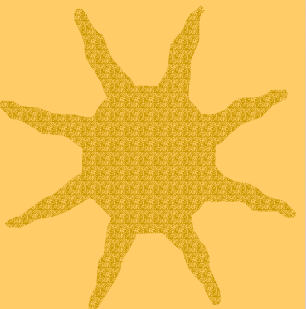
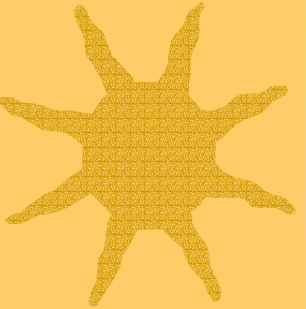
Maximum >10 MeV proton flux from far east (<60E) sources



Maximum flux increased from ~480 up to ~2000 pfu (4+ fold)



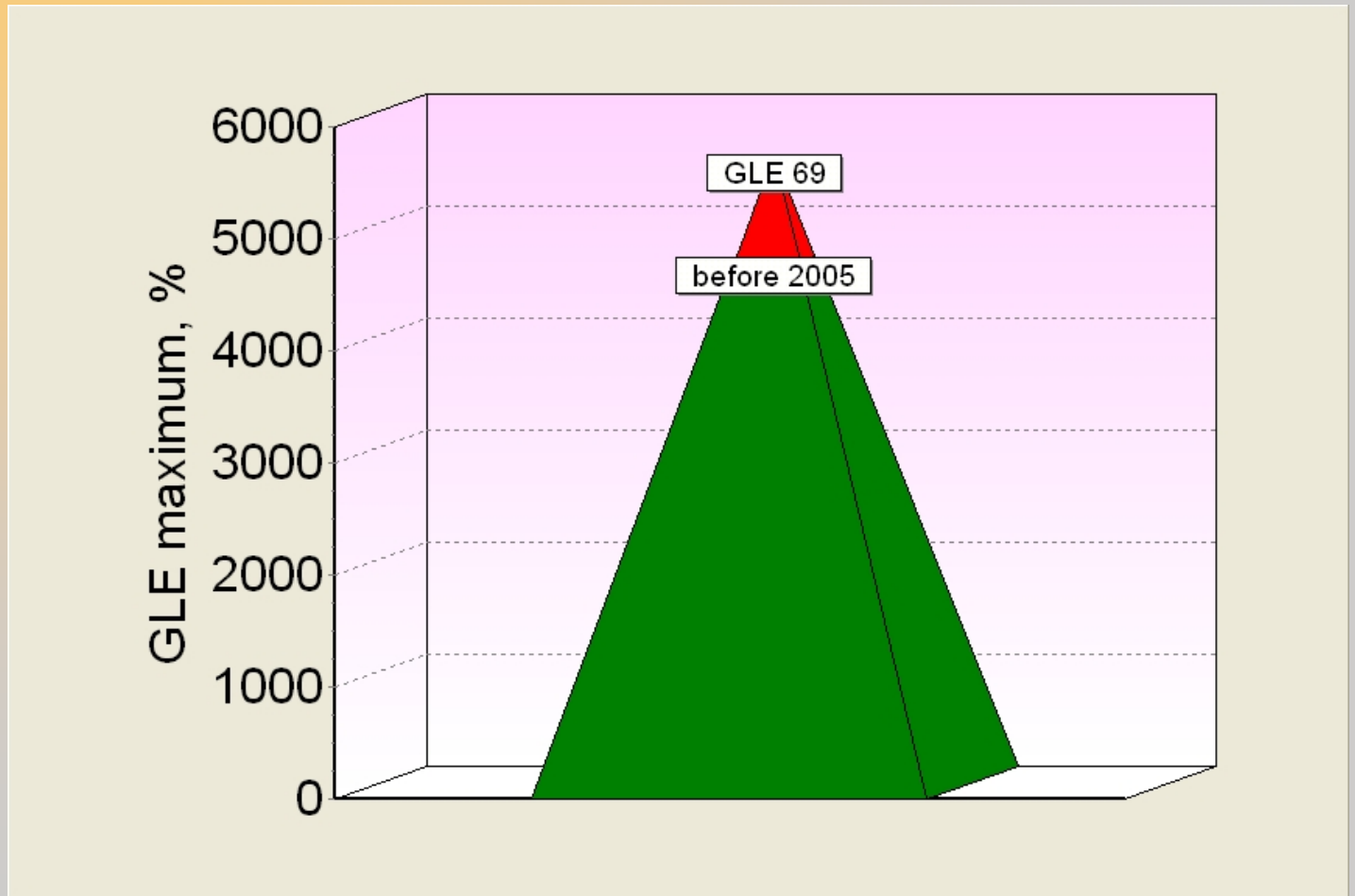
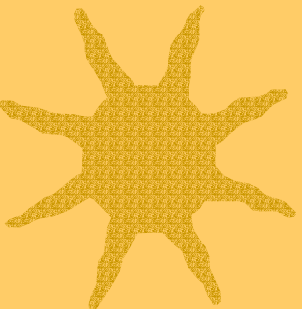
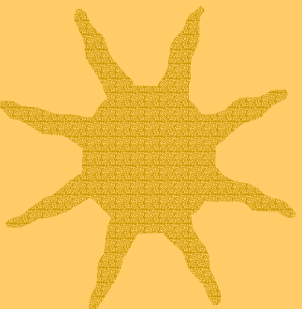
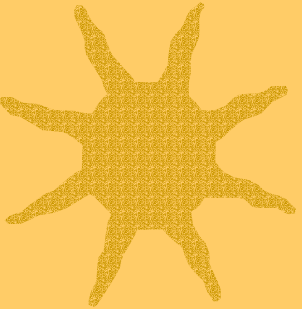
Maximum >100 MeV proton flux from far east ($<60E$) sources



Maximum flux increased from 3.5 up to 17 pfu (~5 fold)

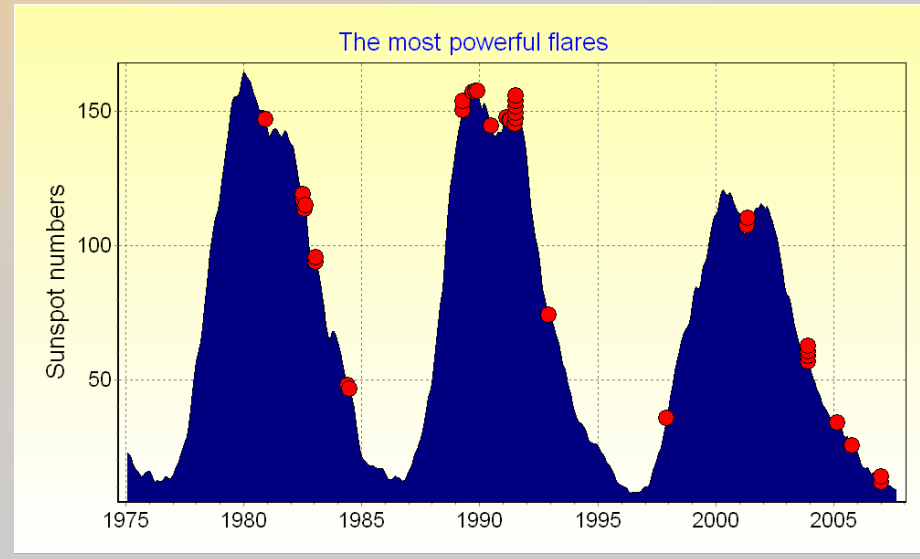
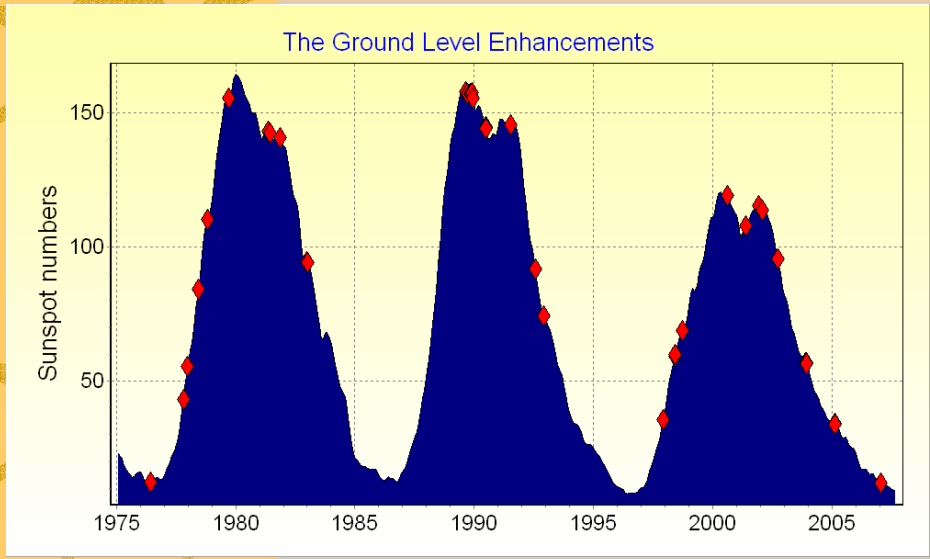
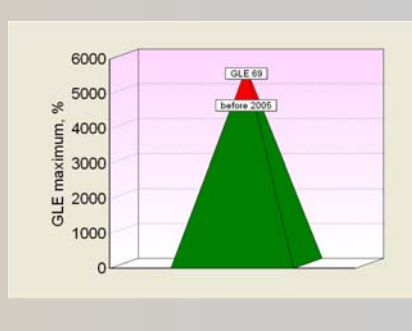
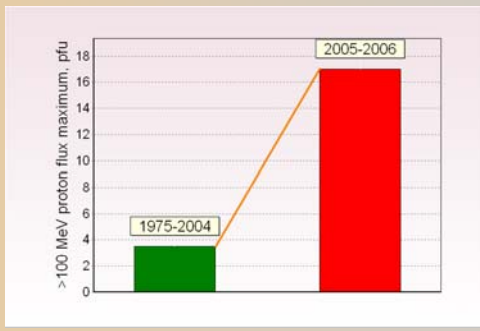
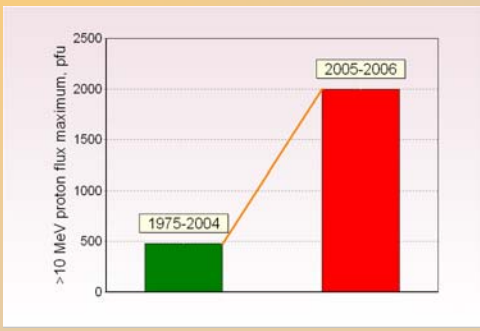
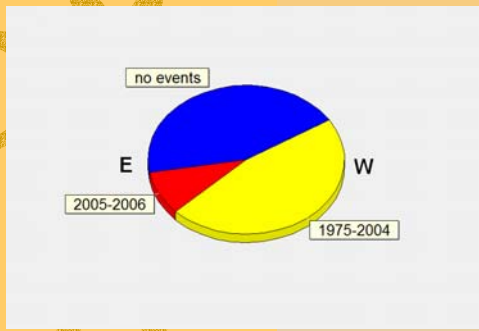


Maximum of GLE



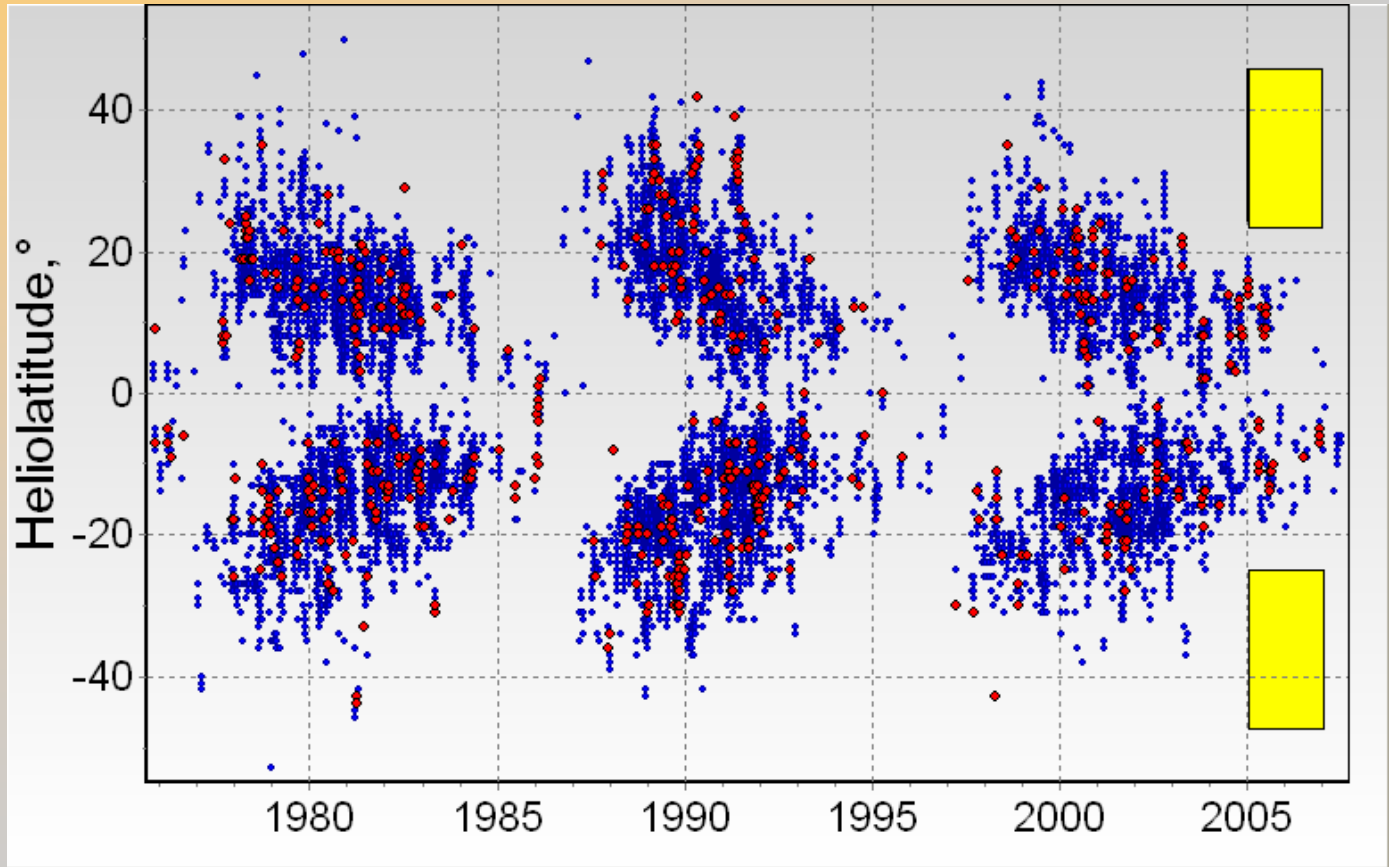
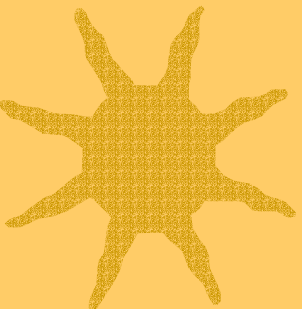
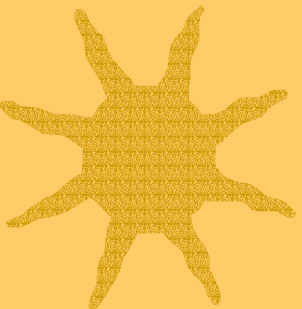
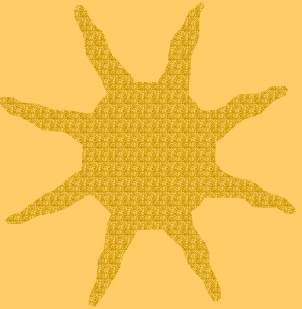


Records of 2005-2006



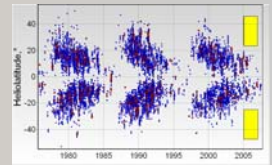


Outstanding years?

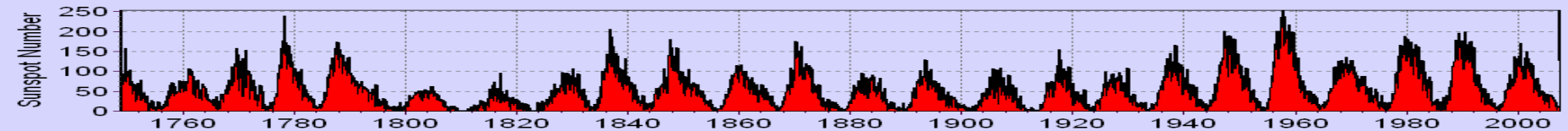


*Very short period –
very small sample*

~30 years



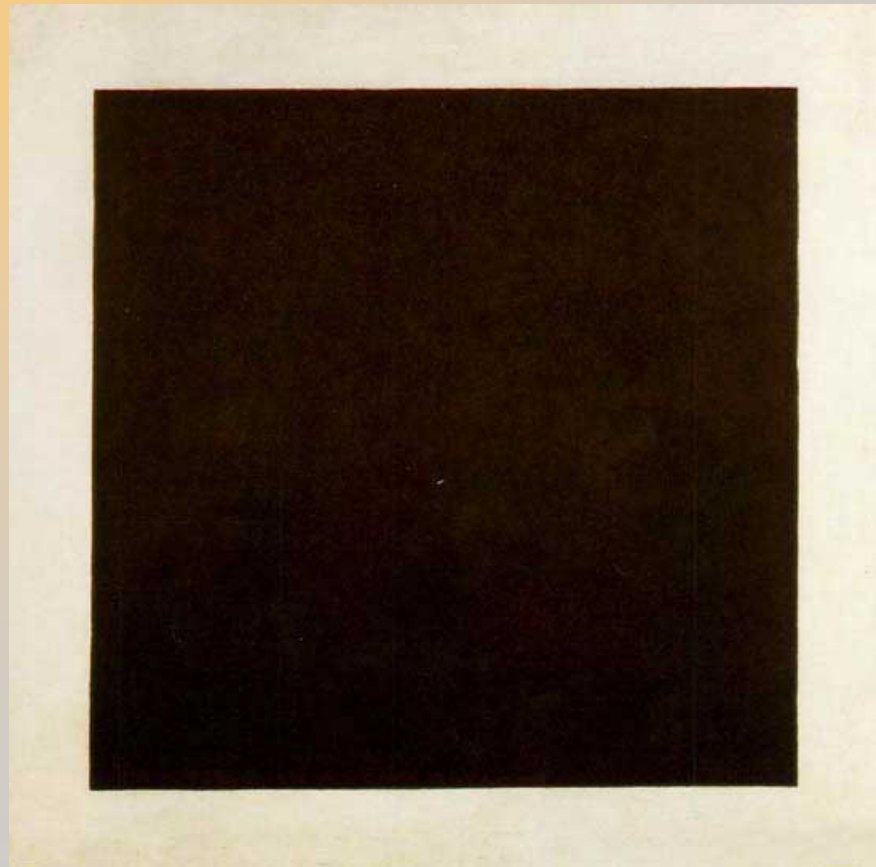
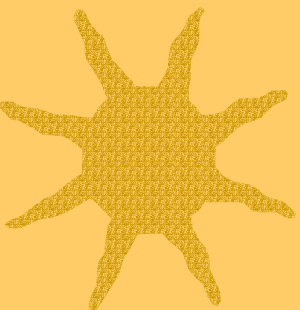
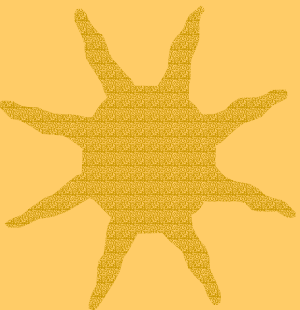
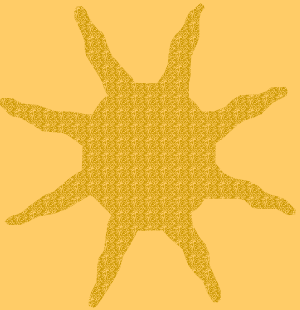
~300 years



>3 000 000 000 years



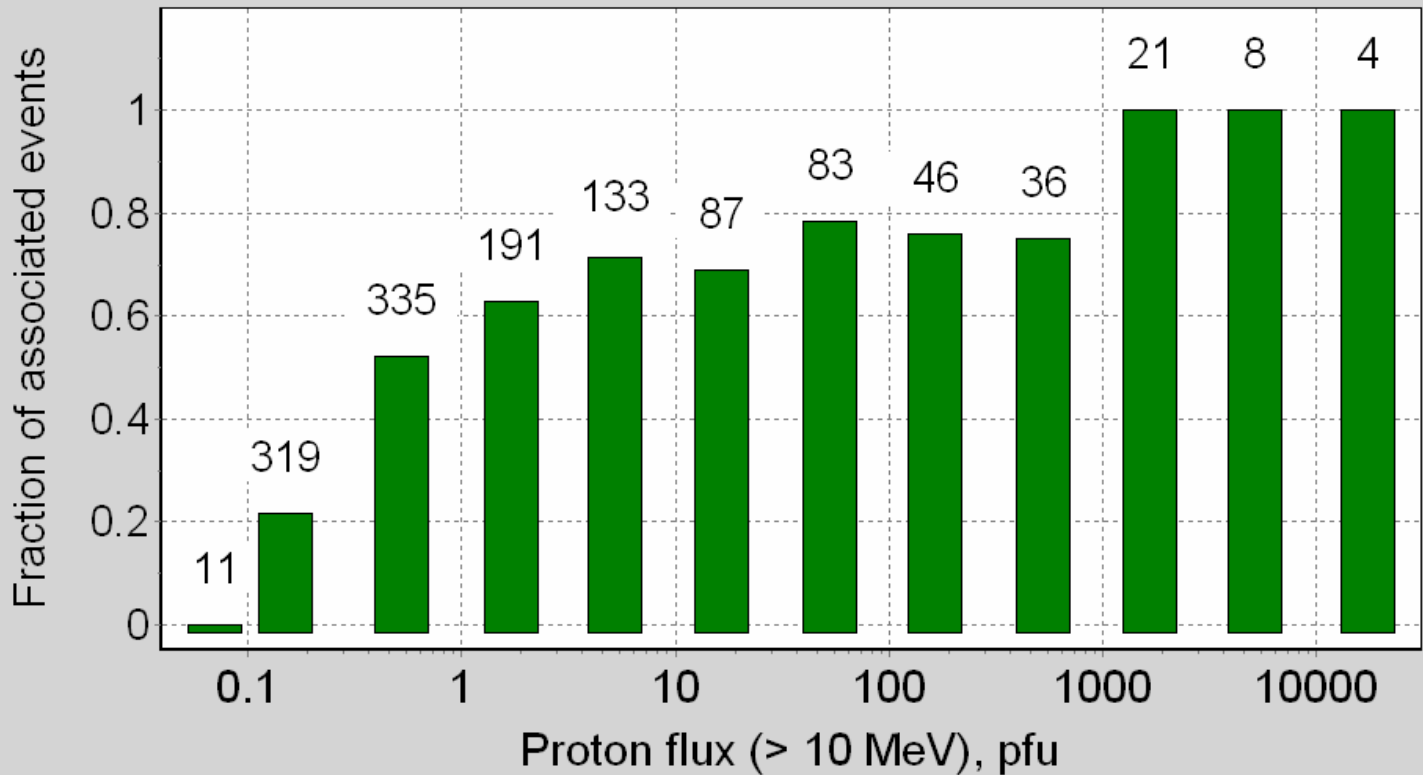
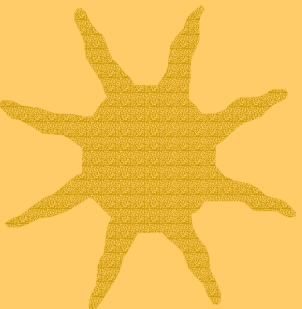
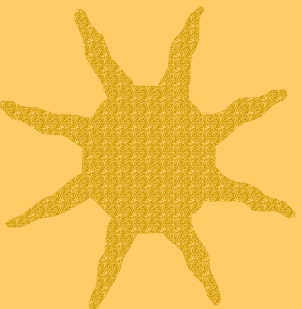
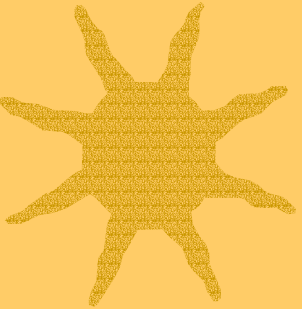
What we know about SEE?



Nothing

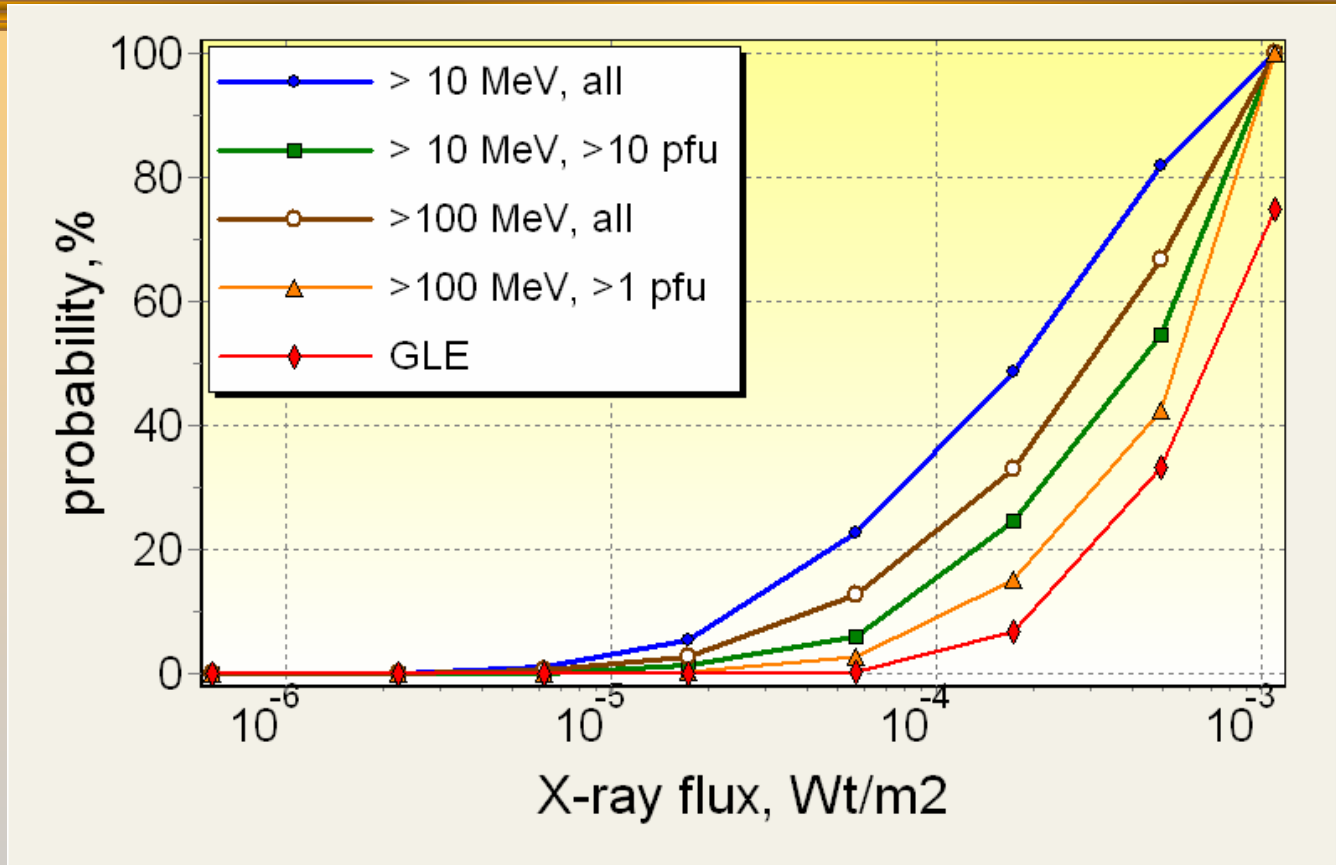
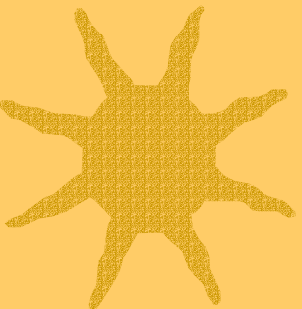
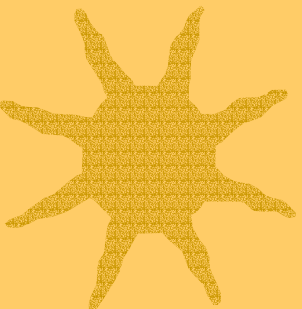
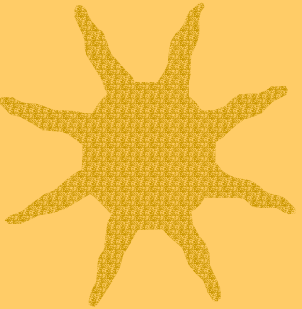


Fraction of SPEs, associated with flares





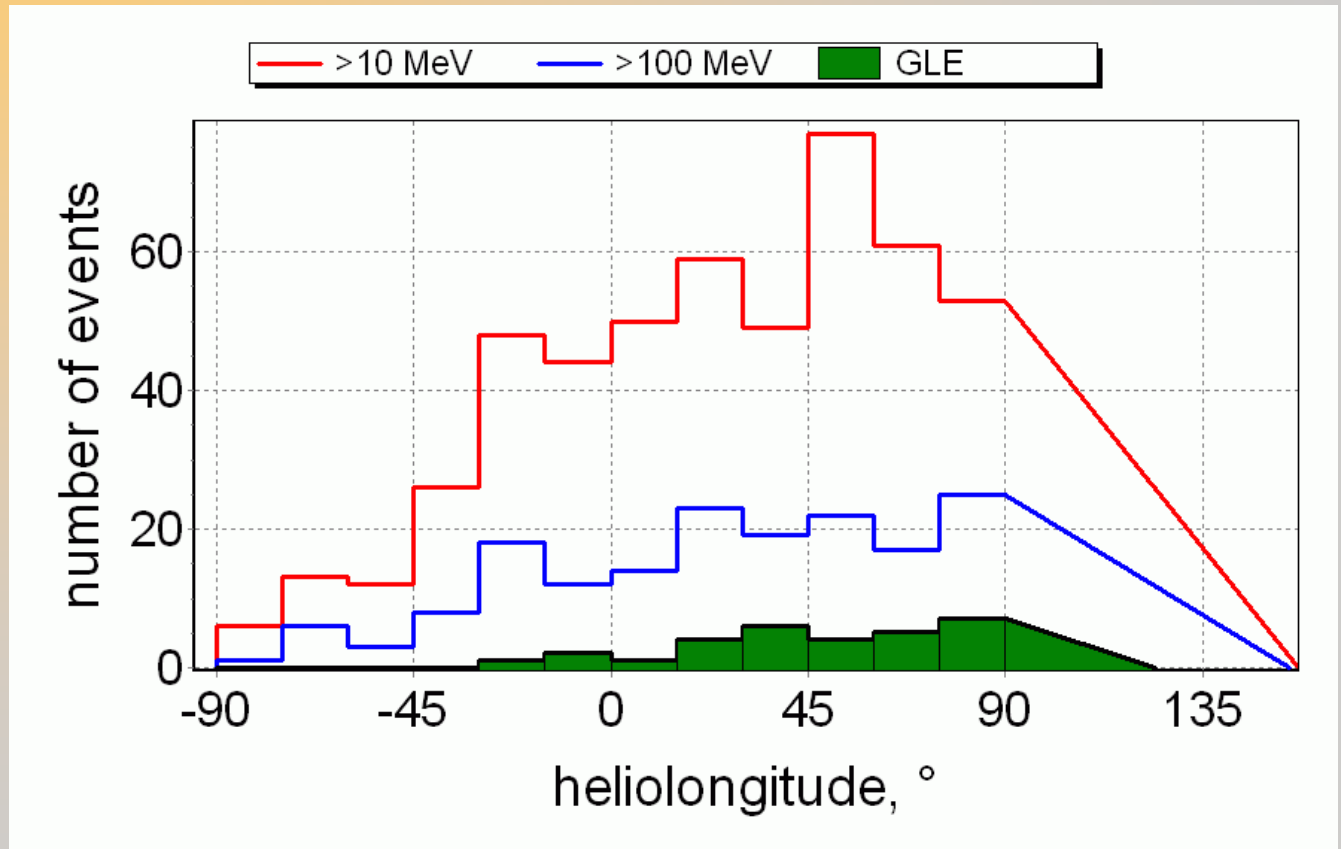
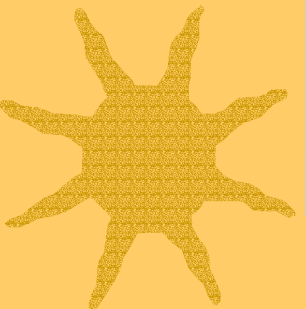
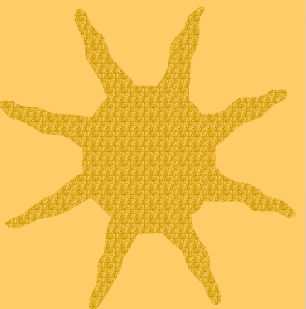
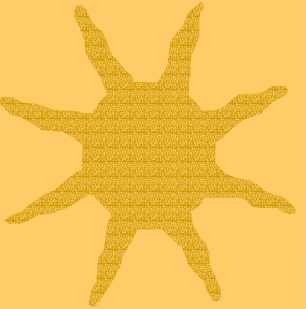
Flare importance and SPE probability



SPE probability versus X-ray flare peak fluxes
of western flares (W15-W75).



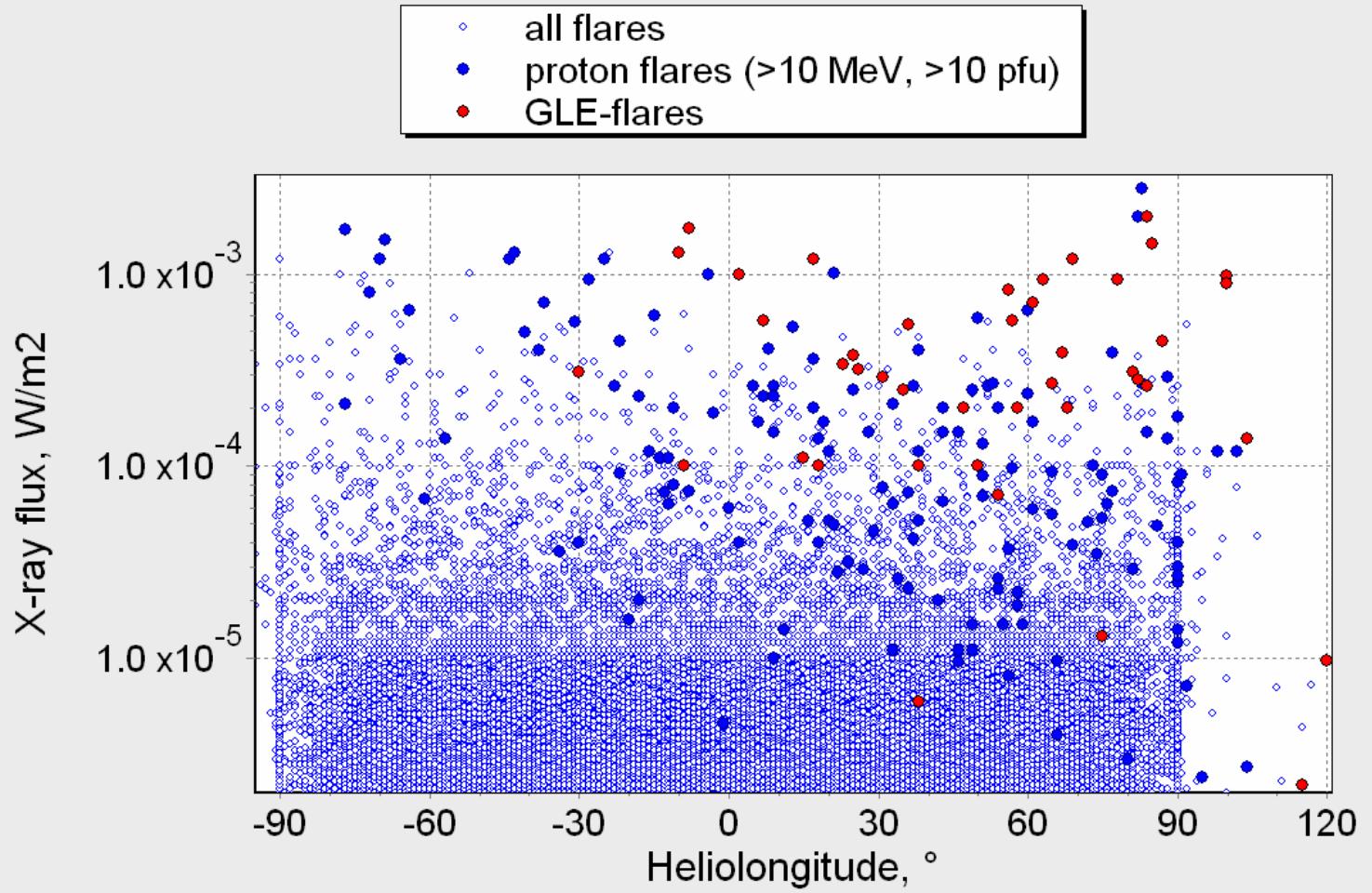
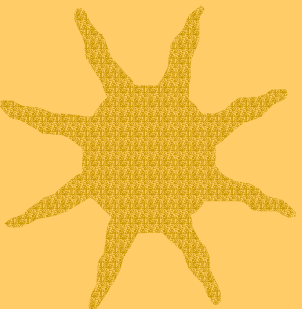
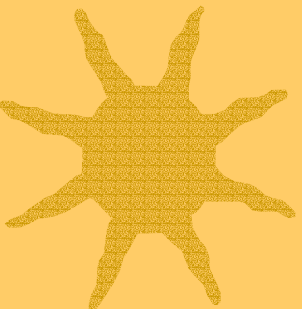
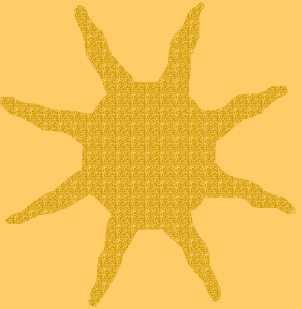
Heliolongitude distribution



Longitudinal distributions of the SPE associated flares. Distributions are given for >10 MeV, >100 MeV SPEs and GLEs.

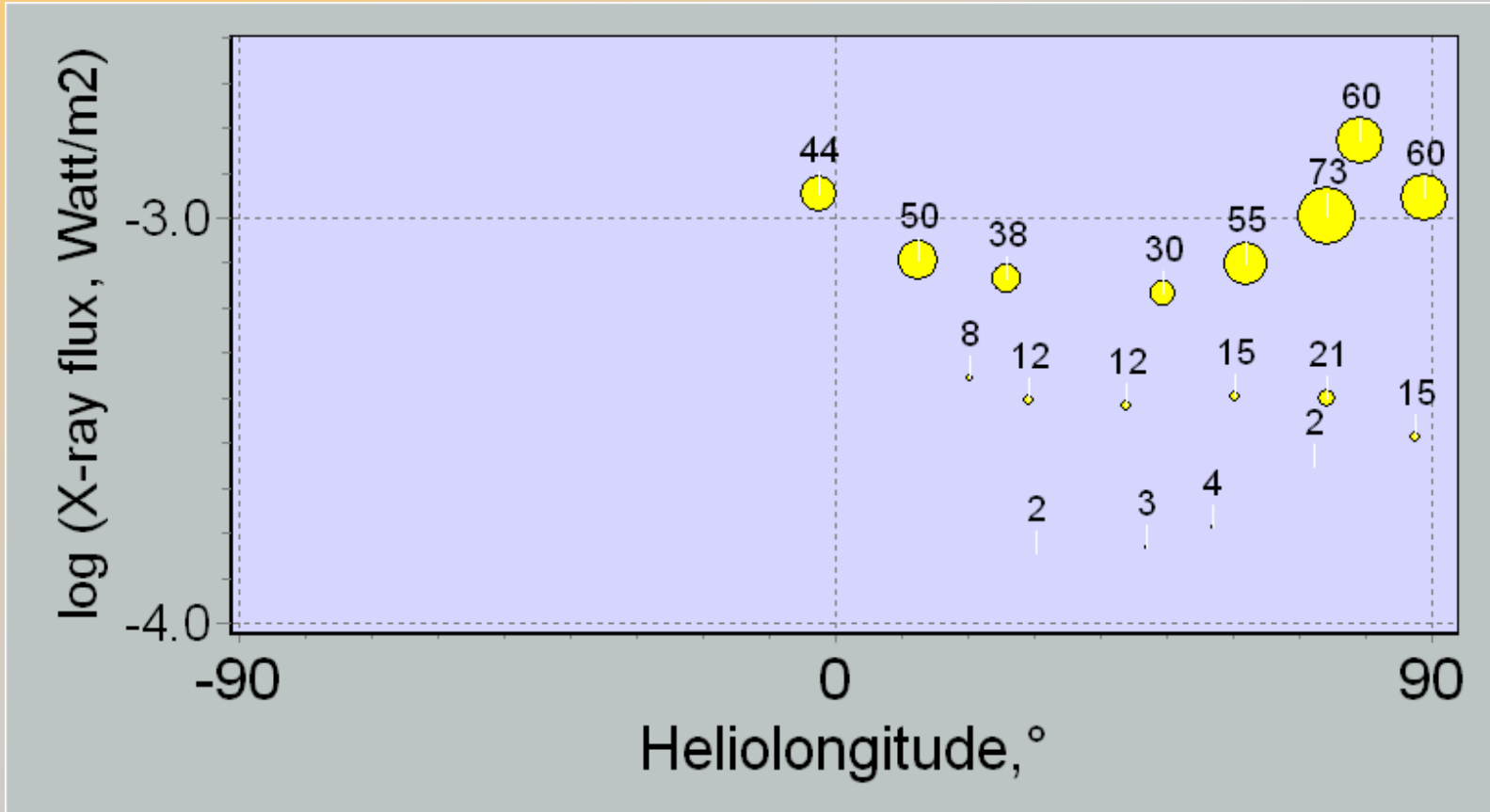
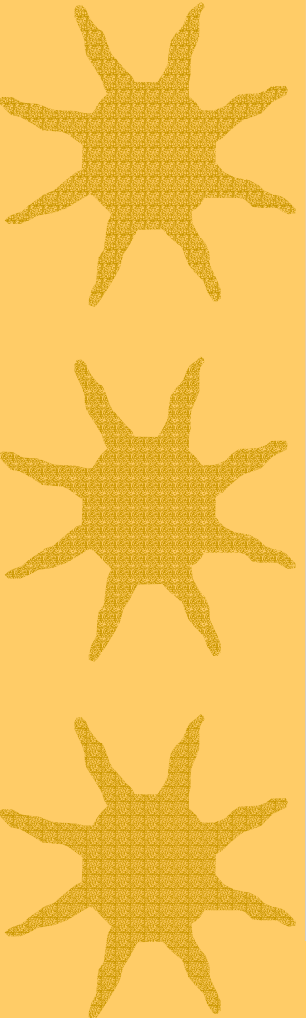


Distribution of X-ray flares





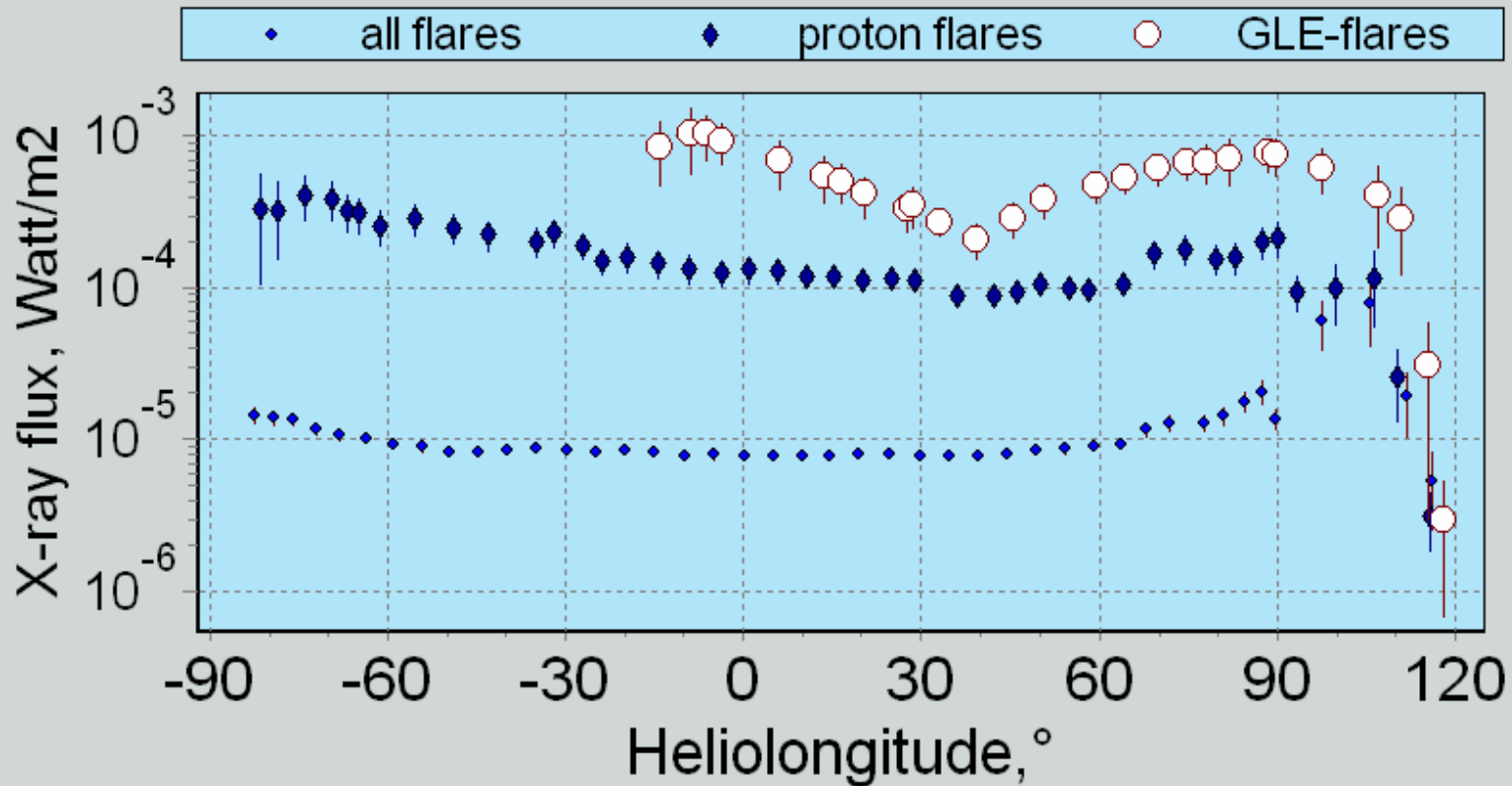
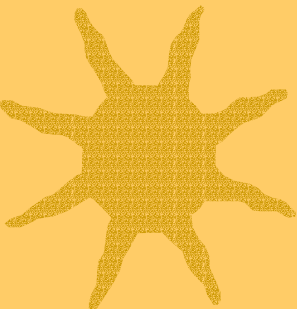
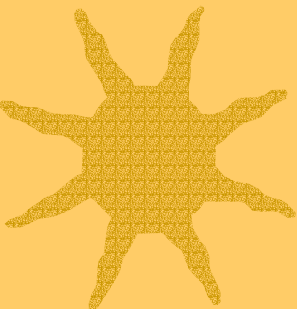
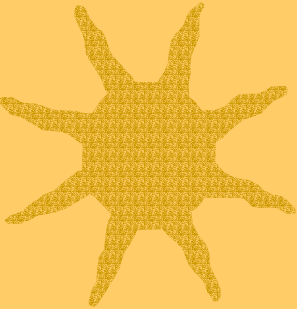
GLE probability



Dependence of GLE probability on X-ray flare importance and longitude.



X-ray flare power and longitude



Characteristics of proton enhancements and associated solar flares.

E_p , MeV	I_{PC} , pfu	N	N_I	I_{XM}	$\varphi_m, ^\circ$	γ	I_0	φ_0	$\sigma_{\varphi}, ^\circ$	$P_s > 0.5$	$P_s < 0.01$	$P_s, X1 45^\circ W$
>10	0.05	1274	678	X1.5	36	0.91±0.10	2.4±0.7	35±12	82±12	72.3	0.24	45.93
>10	1	595	430	X2.1	37	0.93±0.10	5.3±1.0	30±12	97±13	72.4	0.11	21.19
>10	10	275	215	X3.3	42	1.06±0.12	8.0±1.3	34±12	101±13	75.6	0.05	11.03
>10	100	100	94	X4.7	46	1.41±0.18	7.8±0.9	42±8	87±8	71.9	0.04	5.52
>100	0.01	637	399	X2.2	43	0.88±0.10	6.4±1.3	35±14	103±14	72.2	0.15	19.52
>100	1	120	107	X4.8	52	1.30±0.16	9.3±1.3	43±14	99±12	78.6	0.03	5.51
>100	10	46	45	X5.6	51	2.00±0.33	8.8±0.7	54±5	63±5	72.2	0.02	1.29
GLE	-	44	44	X5.4	55	2.02±0.30	8.8±0.6	54±5	63±5	72.2	0.02	1.24

E_p - kinetic proton energy; I_{PC} - minimum threshold of the proton flux;

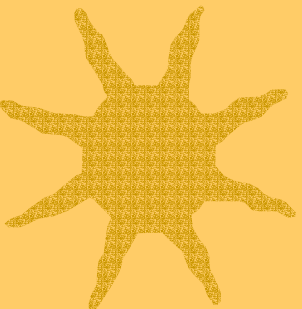
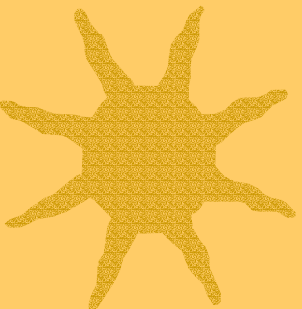
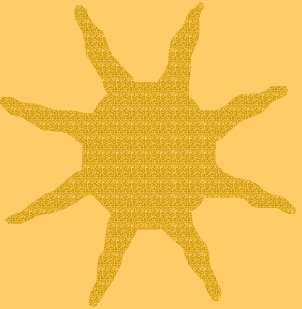
N and N_I – number of all and flare associated proton events;

I_{XM} – mean importance of the X-ray flares, estimated for the events within E85-W85 longitude range;

φ_m – mean longitude of the flares, associated with GLE and large SPEs, and it is median longitude for all other cases.



Model of a proton event probability

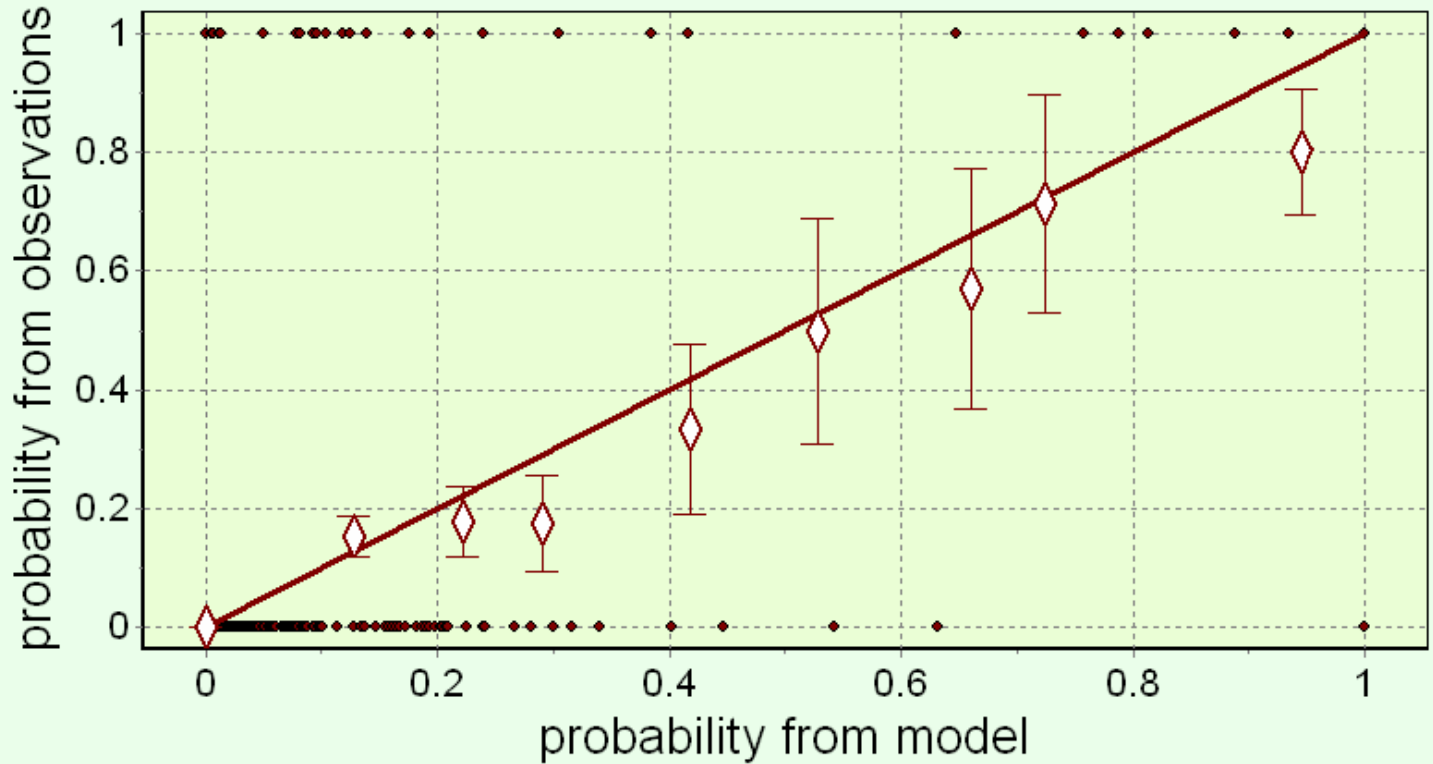
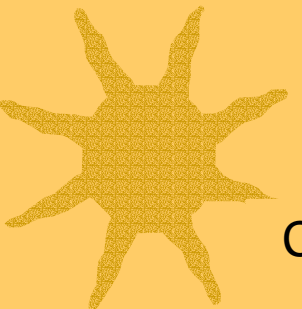
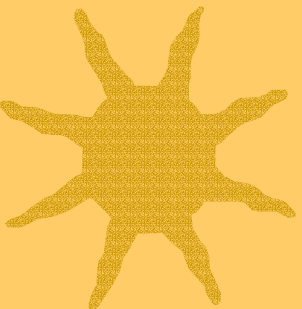
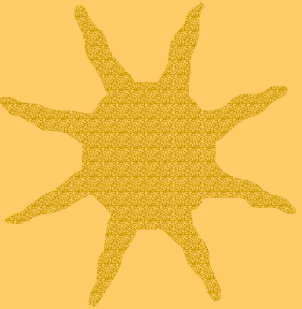


$$P_S(I_X, \varphi) = \begin{cases} \left(\frac{I_X}{I_0} \right)^\gamma \exp \left[- \left(\frac{(\varphi - \varphi_0)}{\sigma_\varphi} \right)^4 \right] & (I_X < I_0) \\ \exp \left[- \left(\frac{(\varphi - \varphi_0)}{\sigma_\varphi} \right)^4 \right] & (I_X \geq I_0) \end{cases}$$

$I_0, \gamma, \varphi_0, \sigma_\varphi$ were derived using all the flares with importance >B5



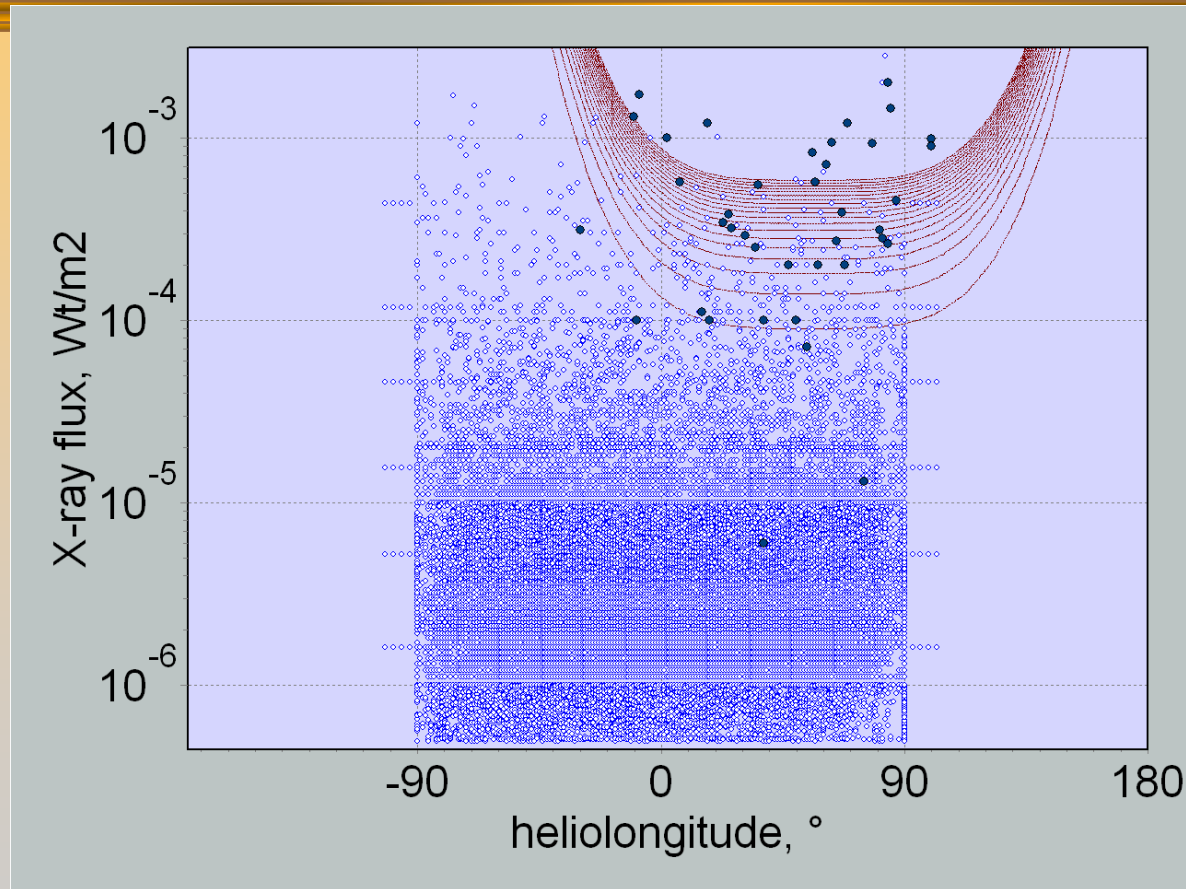
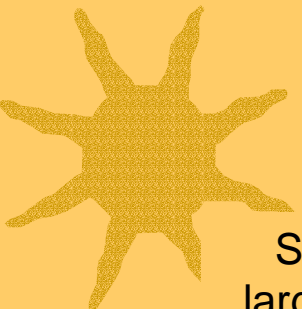
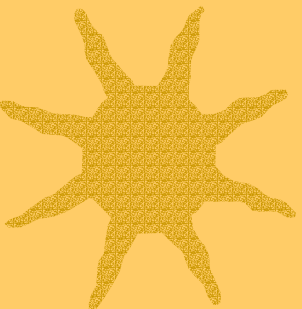
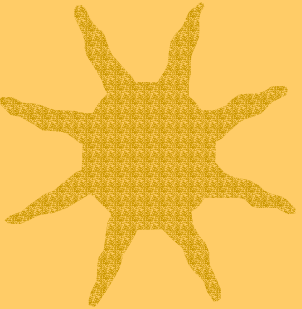
Model of GLE probability



Correlation between simulated and observed GLE probabilities. Points mark flares associated and not associated with GLE. Diamonds are averaged experimental probabilities corresponded to different ranges of P_s .



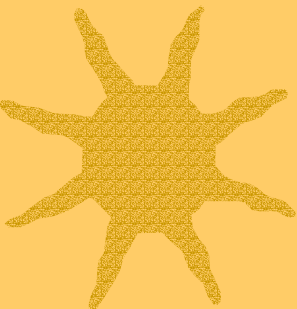
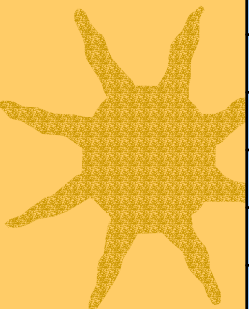
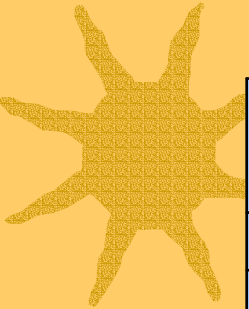
Model of GLE probability



SXR flare distribution (light points) by importance and heliolongitude. Dark points of larger size represent the flares, associated with GLEs. Contour curves are depicted for equal P_S ; inside contour corresponds to probability of 50%, outside one – to 1%.



Model parameters for different SPE types

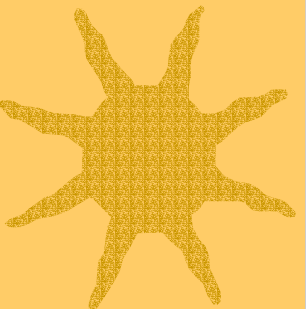
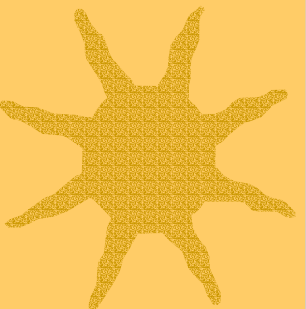
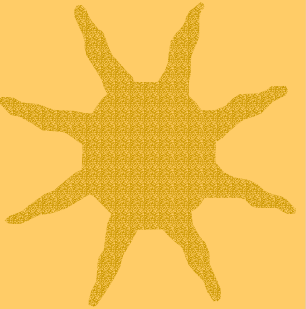


Ep, MeV	I _{pc} , pfu	N	N _I	I _{XM}	φ _m , °	γ	I ₀	φ ₀	σ _φ , °	X1 W45		
>10	0.05	1274	679	X1.5	36	0.91±0.10	2.4±0.7	35±12	82±12	72.3	46 %	
>10	1	595	430	X2.1	37	0.93±0.10	5.3±1.0	30±12	97±13	72.4		
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>10	100	100	94	X4.7	46	1.41±0.18	7.8±0.9	42±8	87±8	71.9	0.04	5.52
>100	0.01	637	399	X2.2	43	0.88±0.10	6.4±1.3	35±14	103±14	72.2	0.15	19.52
>100	1	120	107	X4.8	52	1.30±0.16	9.3±1.3	43±14	99±12	78.6	0.03	5.51
>100	10	46	45	X5.6	51	2.00±0.33	8.8±0.7	54±5	63±5	72.2	0.02	1.29
GLE	-	44	44	X5.4	55	2.02±0.30	8.8±0.6	54±5	63±5	72.2	0.0	1 %

$$\left(\frac{I_X}{I_0} \right)^\gamma \exp \left[- \left(\frac{(\varphi - \varphi_0)}{\sigma_\varphi} \right)^4 \right]$$



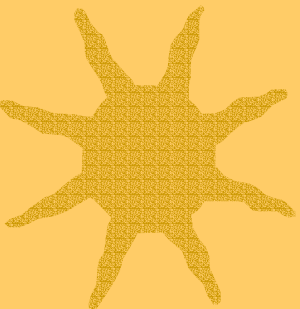
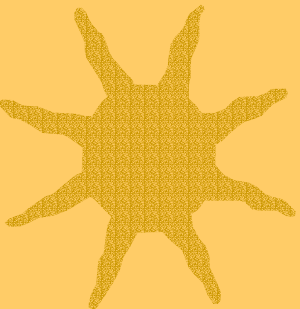
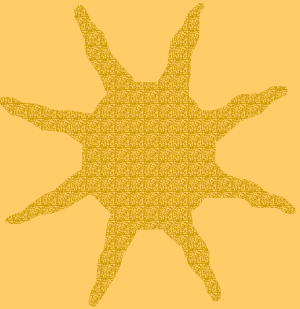
Conclusion



- **The proposed model is suitable both for a short time forecasting from X-ray observations, and for a more long time forecasting in combination with flare forecast.**
- **We see a lot of possibilities to improve the model**



The End





The show continues

