SOLAR EXTREME EVENTS: QUESTIONS OF DEFINITION OF THE PHENOMENA AND THEIR FORECAST.

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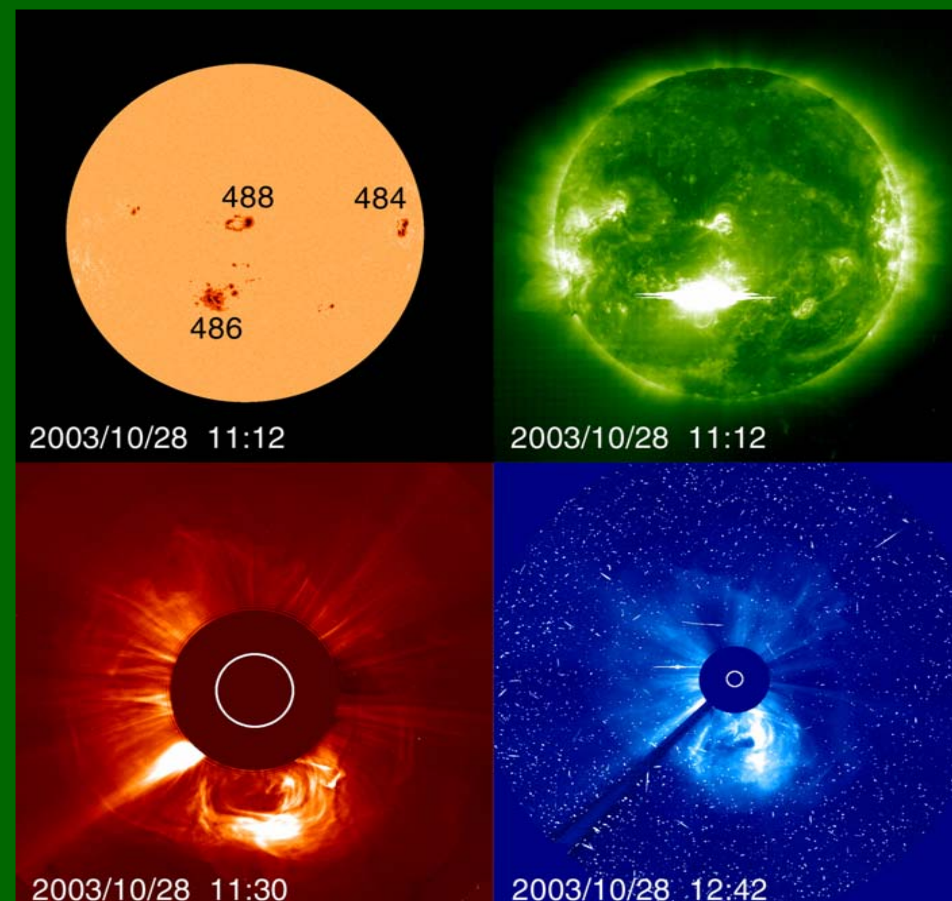


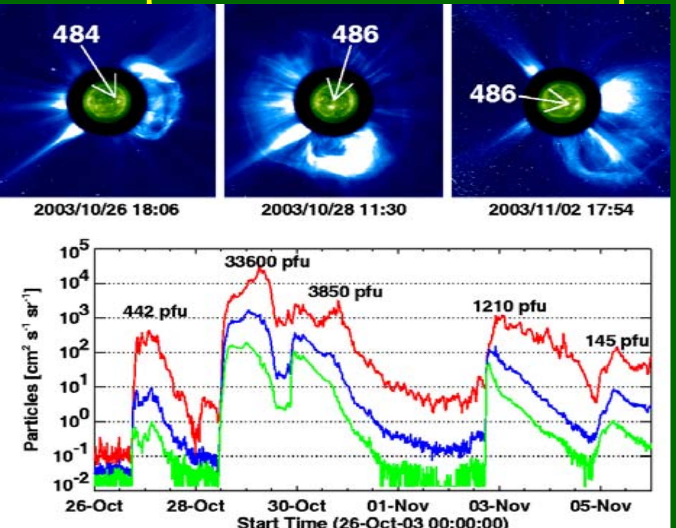
Gopalswamy, 2006

In the light of sharp splash in interest to solar extreme events (SEE) there is a question on definition of the investigated phenomenon. In opinion one definition SEE completely and entirely depends on those disturbances (significant deviations from background values) in a Earth's environment space or in any point of a heliosphere which make the solar active phenomena. Now influences of the solar active phenomena on environment can be estimated in a five-point scale on three positions:

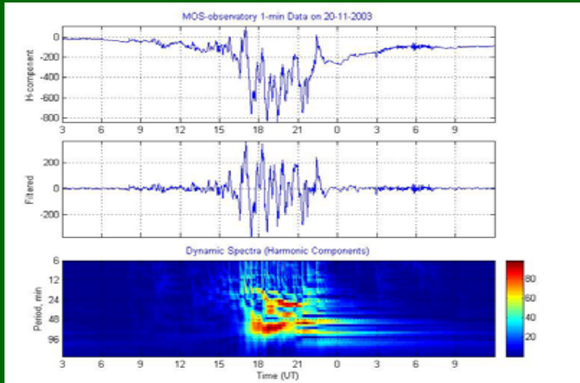
–Electromagnetic impact - influence of electromagnetic radiation during development of powerful solar flares basically on an ionosphere (SIDs), breaking a radio communication on a time interval till several hours **(R1 - 5)**.

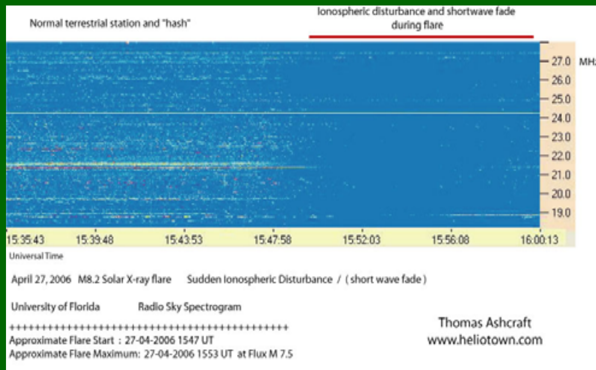
– Solar proton events - arrival to a environment of the solar charged particles, influence basically radiating conditions in a vicinity of the Earth, cause growth of electronic concentration above polar caps absorption, breaking radio communication on polar lines **(S1 - 5).**

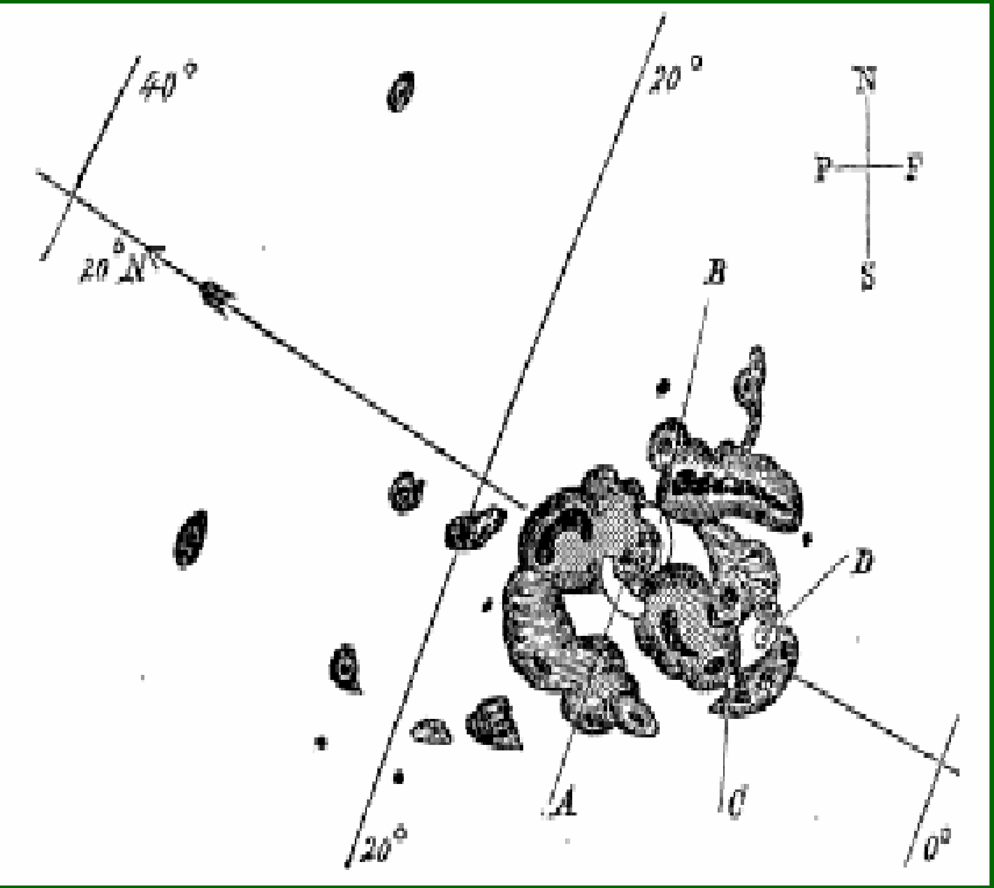
– Disturbances of a geomagnetic field – magnetic storms – consequence of arrival to environment of solar plasma streams with the raised density, speed of particles, temperatures, and with the strengthened magnetic field **(G1 - 5).**



Gopalswamy, 2006





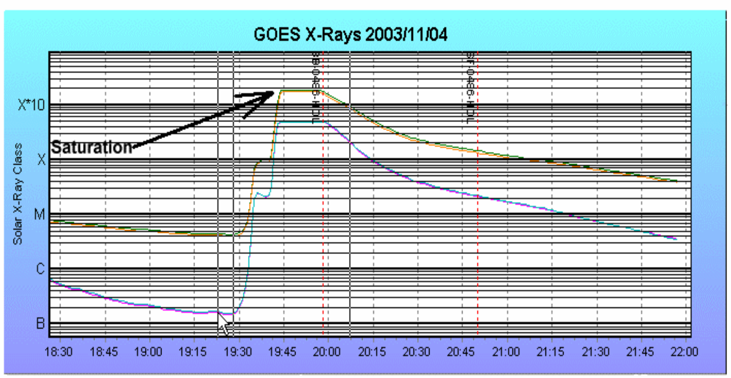


For the first time solar extreme event R.Carrington 1.09.1859, as observed flare in "white light“ after which through **17h 40m** (V=2342 km/s) in America and the Europe within hours gross infringements of wire cable communication have noted been. Polar lights were observed in Rome, in Havana and on Hawaii.

Flare had A ~ 2500 mvh
Estimated GOES flare size: X6
log X = -8.34 + 1.50log A

Estimated speed of CME~1850 km/s,
log V = 2.54 + 0.22log A
Gopalswamy et al., 2004

In table 1 the most intensive flares in a range (12.5-1 keV=1-8Å) are collected. Here the situation even more gets confused, as the X-ray detectors established on various US GOES satellites for measurement of a fluxes of soft X-ray radiation in the range (1– 8 Å), had a different threshold of saturation.



Till 1976 the threshold of saturation corresponded to X ≥ 5.4 and consequently the well-known flares on August 4 and 7 1972 had a formal point X≥ 5.4, then up to 1996 – X≥12.5. After 1996 the threshold of saturation has grown up to X ≥ 17.5. In this case the X-ray importance is defined for flares proportionally time of saturation of X-ray detectors. Therefore would be to characterize an X-ray importance of such flares with saturation not only threshold value of the X-ray detectors, but also duration of a time interval of saturation of X-ray detectors more objectively. Unfortunately, in the literature not for each powerful flare it is possible to find these data, and in most cases for such flares the estimated soft X-ray importance is underlined. Extrapolation of an X-ray importance for very large flares with long saturation is hardly justified.

McIntosh has suggested to count a flare index of active regions on all flares registered in given AR. The X-ray flare index was calculated from all flares of class X and M carried out in given AR, appropriating flares of class M1 value 0.1, M2 - 0.2, etc., and to flares of class X1 value 1, X2 - 2, X10 - 10, etc.

In opinion of the author it is necessary to distinguish the extreme solar phenomena from extreme events in Earth's environment. The last can be caused by power (not extreme) flare events, since capacity of influence flare events on Earth' environment in a greater measure depends on geometrical factors of the sources (flare) localization on a visible disk of the Sun, conditions of disturbance propagation on interplanetary space and plurality of the phenomena influencing on environment at present. For example, even flares of a X-ray class M with strong halo CME in the central area of the Sun, occurrence in AR near which the coronal hole or sector boundary of the general solar magnetic field are located, can lead to sharp strengthening of geomagnetic disturbances and provide arrival to environment of solar protons strong fluxes.

Table 1. The most powerful solar flares on X-ray (1986 – 2006)

Y/ M/ D	IMP	τ		Φ(J/m2)		Coordinats	AR	CME
1991/06/01	X>12.5	26m		4.44		N25E90L248	6659	
1991/06/06	X>12.5	26m		2.55		N33E44L248	6659	
2003/11/04	X>17.5	11m	(X28)	2.30		S19W83L286	10486	2657/ H
1991/06/15	X>12.5	22m		2.85	GLE	N33W66L248	6659	
1991/06/04	X>12.5	19m		3.53		N30E70L248	6659	
1991/06/11	X>12.5	17m		1.81	GLE	N32W15L248	6659	
2001/04/02	X>17.5	?	(X22)	1.50		N19W90L152	9393	2505/pH
1989/08/16	X>12.5	?	(X20)	6.70	GLE	S15W85L076	5629	
2003/10/28	X 17.2			1.80	GLE	S16E08L286	10486	2459/H
2005/09/07	X 17.1			2.60		S06E89L229	10808	g
1989/03/06	X>12.5	?	(X20)	----		N33E71L257	5395	
1989/10/19	X>12.5	?	(X15)	4.79	GLE	S25E09L211	5747	
2001/04/15	X 14.4			0.61	GLE	S20W85L001	9415	1199/
1991/01/25	X 10.7			1.07		S12E90L142	6471	
2003/10/29	X 10.0			0.87	GLE	S15W02L286	10486	2029/ H
1991/06/09	X 10.0			0.63		N32E13L248	6659	
1989/09/29	X 9.8			2.23	GLE	S24W98L220	5698	1828/
1991/03/22	X 9.4			0.53		S26E28L188	6555	
1997/11/06	X 9.4			0.04	GLE	S18W63L352	8100	1556/ H
1990/05/24	X 9.3			0.46	GLE	N33W78L321	6063	
1992/11/02	X 9.0			2.88		S22W102L071	7321	
2006/12/05	X 9.0			0.71		S06E79L009	10930	g

THE MOST POWERFUL SOLAR FLARES ON IMPORTANCE IN THE SOFT X-RAY RANGE (1 – 12.5 KeV)

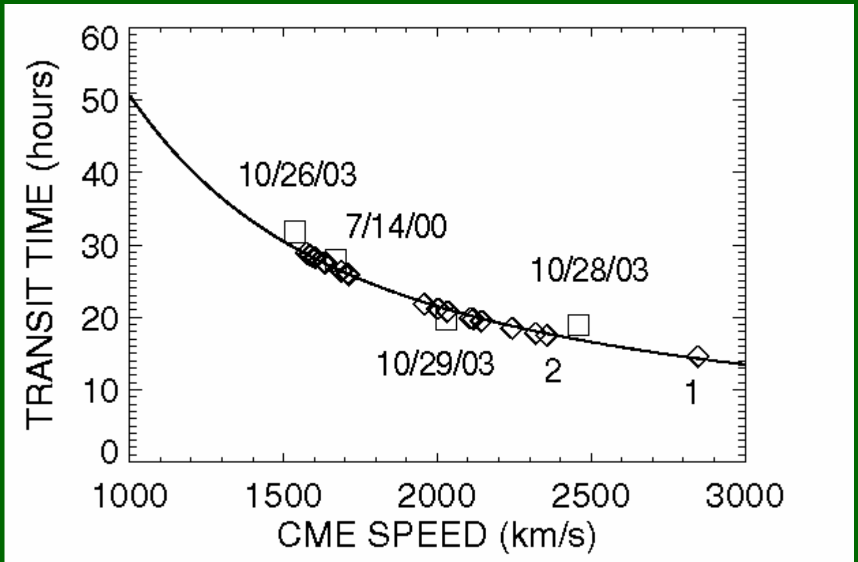
R	Y/M/D	X Class	τ	∑Φ (J/m2)	Position	AR	
1	**1991/06/01**	**X>12.5**	**26m**	4.44	**N25E90L248**	**6659**	
1	**1991/06/06**	**X>12.5**	**26m**	2.55	**N33E44L248**	**6659**	
1	***2003/11/04***	***X>17.5***	***11m***	2.30	***S19W83L286***	***10486***	2657/ H
2	**1991/06/15**	**X>12.5**	**22m**	**2.85**	**N33W66L248**	**6659**	
3	**1991/06/04**	**X>12.5**	**19m**	**3.53**	**N30E70L248**	**6659**	
4	**1991/06/11**	**X>12.5**	**17m**	1.81	**N32W15L248**	**6659**	
4	2001/04/02	X>17.5	? (X20)	1.50	N19W90L152	9393	2657/ H
4	1989/08/16	X>12.5	? (X20)	**6.70**	S15W84L076	5629	
5	***2003/10/28***	***X17.2***		1.80	***S16E08L286***	***10486***	2459/pH
6	***2005/09/07***	***X17.1***		2.60	***S06E89L229***	***10808***	g
6	1989/03/06	X>12.5	? (X15)		N33E71L257	5395	
6	1978/07/11	X>12.5	? (X15)		N18E45L170	1203	
6	***2001/04/15***	***X14.4***			***S20W85L001***	***9415***	1199/
7	1984/04/24	X>12.5	? (X13)		S11E45L334	4474	
7	1989/10/19	X>12.5	? (X13)	**4.79**	S25E09L211	5747	
7	1982/12/15	X>12.5	? (X12.9)		S09E24L077	4026	
8	1982/06/06	X12.0			S10E25L086	3763	
9	1991/01/25	X10.7			S12E90L142	6471	
10	1982/12/17	X10.1			S08W20L089	4025	
10	1984/05/20	X10.1			S07E53L357	4492	
11	***2003/10/29***	***X10.0***			***S15W02L286***	***10486***	2029/ H
12	**1991/06/09**	**X10.0**			**N32E13L248**	**6659**	
13	1982/07/09	X 9.8			N18E76L322	3804	
13	1989/09/29	X 9.8		2.23	S24W98L220	5698	1828/
14	1991/03/22	X 9.4			S26E28L188	6555	
14	1997/11/06	X 9.4			S18W63L352	8100	1556/ H
15	1990/05/24	X 9.3			N33W78L321	6063	
16	1980/11/06	X 9.0			S12E74L098	2779	
16	1992/11/02	X 9.0		**2.88**	S22W102L071	7321	
16	2006/12/05	X 9.0			S06E79L009	10930	g

Table: Most rapid CME (SOHO data)

Date	CME time	v, km/s	GoesFlare location	AR	X-ray class
04.11.2003	19:54	2657	S19W83L286	10486	X>17.5(28)
12.05.2000	23:26	2604	S18E63		C6.6
02.11.2003	17:30	2598	S14W56L286	10486	X8.3/2B
24.11.2000	01:31	2519	N20W05	9236	X2/3B
02.04.2001	22:06	2505	N19W90L152	9393	X20
18.04.2001	02:30	2465	S20E87	9415	C2
28.10.2003	11:30	2459	S16E08L286	10486	X17.2/4B
10.04.2001	05:30	2411	S23W09	9415	X2/3B
21.04.2002	01:27	2409	S14W84	9906	X1/F1
24.09.2001	10:30	2402	S16E23	9632	X2/2B

(Yakovchuk, 2007)

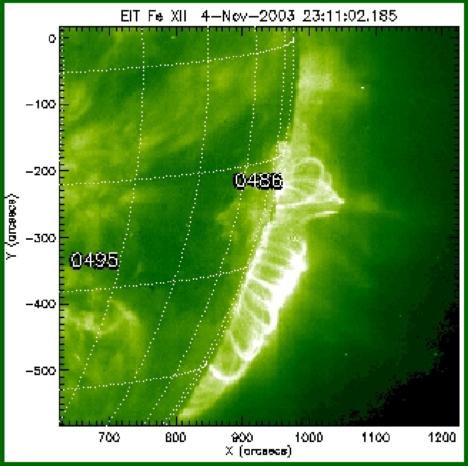
t = a.bV+ c with a=151.002 b=0.998625; c=11.598 Empirical Shock Arrival model

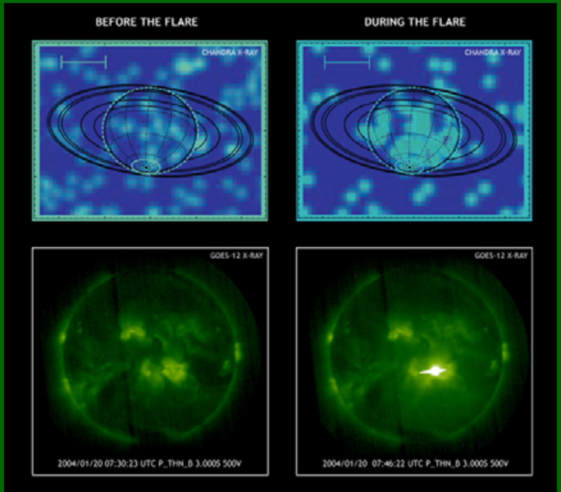


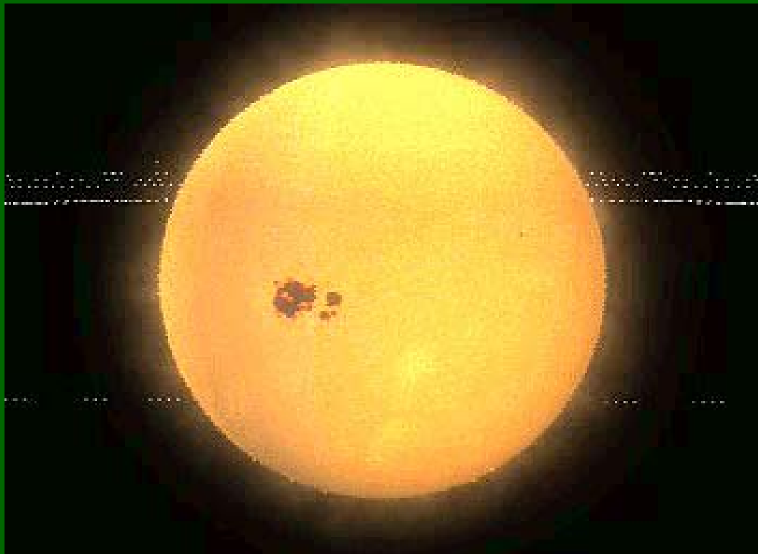
Data from
Hale 1931
Newton, 1943
Cliver & Svalgaard 2004
Gopalswamy et al 2005
(once in 30 yr)
1- Aug 4, 1972
2- Sep 1, 1859 Carrington

Gopalswamy, 2006

Therefore for solar extreme flare events it is possible to try to distract from a space environment and to consider them in conditions of a heliosphere. Then key parameters will be (R5) electromagnetic impact, an integrated fluxes of radiation in a range of radiation 1 - 8 Å, a fluxes of solar protons ($S \geq 4$) and, probably, density and speed of a stream of plasma (G *). We shall to definition solar extreme event (SEE) as solar flare superevents with a x-ray class not less X10, accompanied powerful coronal mass ejection with $V \geq 1500$ km/s, with an integrated flux of radiation in a range of radiation 1-8 Å not less 1.5 J/m^2, and a flux of protons in an interplanetary space not less than 10^4 p.f.u. Such flares are accompanied by intensive dynamic radio splashes II and IV type, and frequent ejection of solar filaments. Similar events undoubtedly affect all heliosphere, and Earth's environment space is simply a special case only.







Mostly flare productive active regions 1970 – 2003

№	CMP	AR	Φo	Lo	Sp max	R, S, G	XRI	M±y
1	09 06 1991	6659	N31;	248	2300	R5/S4/G4	>86.5	+2
2	*29 10 2003*	*10486*	*S17;*	*354*	*2610*	*R5/S4/G5*	*>62.56 (73.06)*	*+3.5*
3	12 03 1989	5395	N34;	257	3600	R5/S4/G5	>57.0	-0.5
4	*14 09 2005;*	*10808*	*S09;*	*229*	*1430*	*R5/S3/G3*	*49.21*	*+5.5*
5	08 06 1982;	3763	S08;	086	1270	R4/S2/G2	42.4	+2.5
6	04 07 1974;	0433	S14;	156	1334	R4/S3/G5	≥41.4	+5.5
7	16 12 1982;	4025	S06;	089	500	R4/S2/G3	36.7	+3
8	23 03 1991;	6555	S23;	188	2530	R4/S5/G4	32.6	+1.5
9	15 07 1982;	3804	N14;	322	2960	R4/S4/G5	31.6	+2.5
10	14 07 1978;	1203	N18;	170	1600	R5/S2/G2	29.7	-1
11	*10 04 2001;*	*9415*	*S22;*	*359*	*880*	*R4/S3/G4*	*28.73*	*+1*
12	08 08 1989;	5629	S17;	076	1320	R5/S4/G4	≥26.8	-0.5
13	04 08 1972;	0331	N12;	010	1330	R5?/S4/G5	≥26.0	+3.5
14	11 11 1980;	2779	S11;	098	2000	R3/S1/G4	25.9	+1
15	*28 03 2001;*	*9393*	*N20;*	*152*	*2440*	*R5/S2/G5*	*>25.74 (28.24)*	*+1*
16	18 05 1990;	6063	N34;	321	940	R3/S3/G2	23.1	+1
17	12 01 1989;	5312;	S31;	308	1800	R3/S1/G2	22.4	-0.5
18	*15 01 2005;*	*10720;*	*N13;*	*179*	*1630*	*R4/S3/G4*	*21.5*	*+4.7*
19	*11 12 2006;*	*10930;*	*S06;*	*009*	*680*	*R4/S3/G4*	*21.44*	*+6.6*
20	28 04 1984;	4474;	S13;	334	2160	R5/S3/G3	21.2	+5
21	18 06 1982;	3776;	N13;	312	3300	R4/S1/G1	18.8	+3

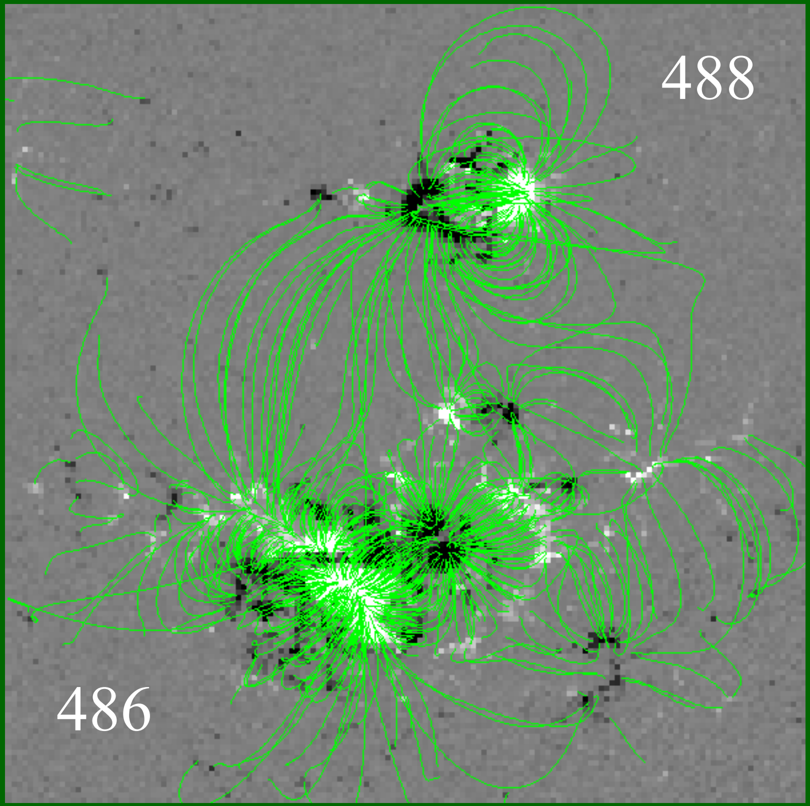
AR Potential Energy & CME Kinetic Energy

Gopalswamy, 2006

- AR 486: Volume ~ 10^{31} cm^3 (300 x 300 x 300 $arcsec^3$)
- Potential Energy ~ 4.6 x10^{33} erg
- Total Magnetic Energy ~ 2 x PE ~ 9.2 x10^{33} erg
- Free energy ~ 4.6 x10^{33} erg
- CME Kinetic Energy ~ 1.2 x 10^{33} erg
- ~1/4 of free energy goes into CME KE

All other forms of energy an order of magnitude lower for large CMEs (Emslie et al.2004 JGR)

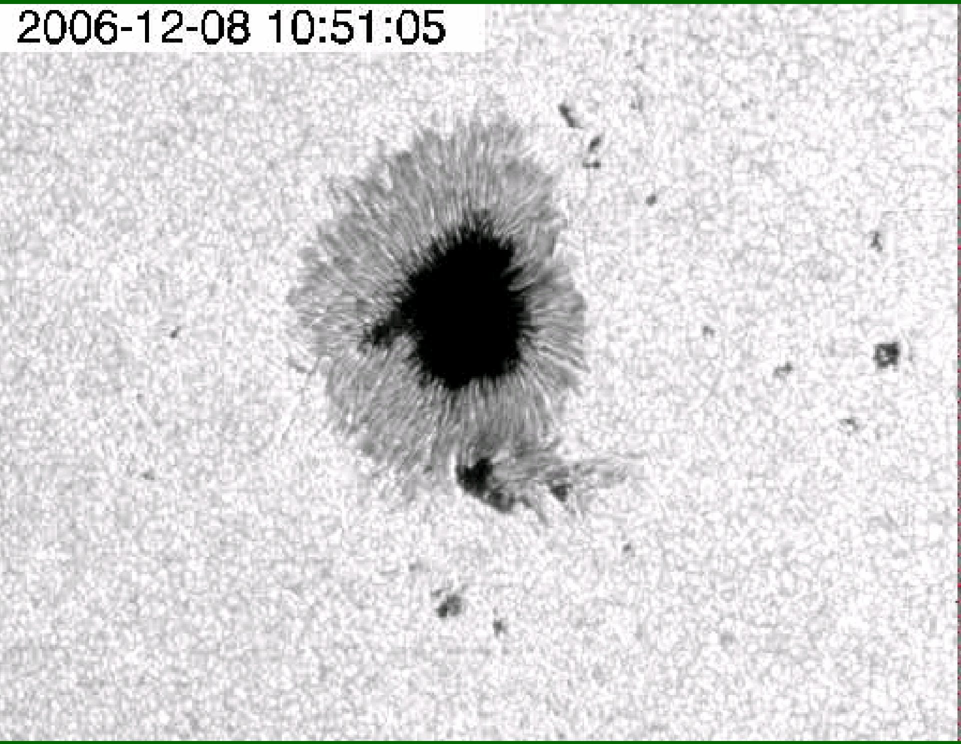
Potential Field Extrapolation From MDI Magnetogram

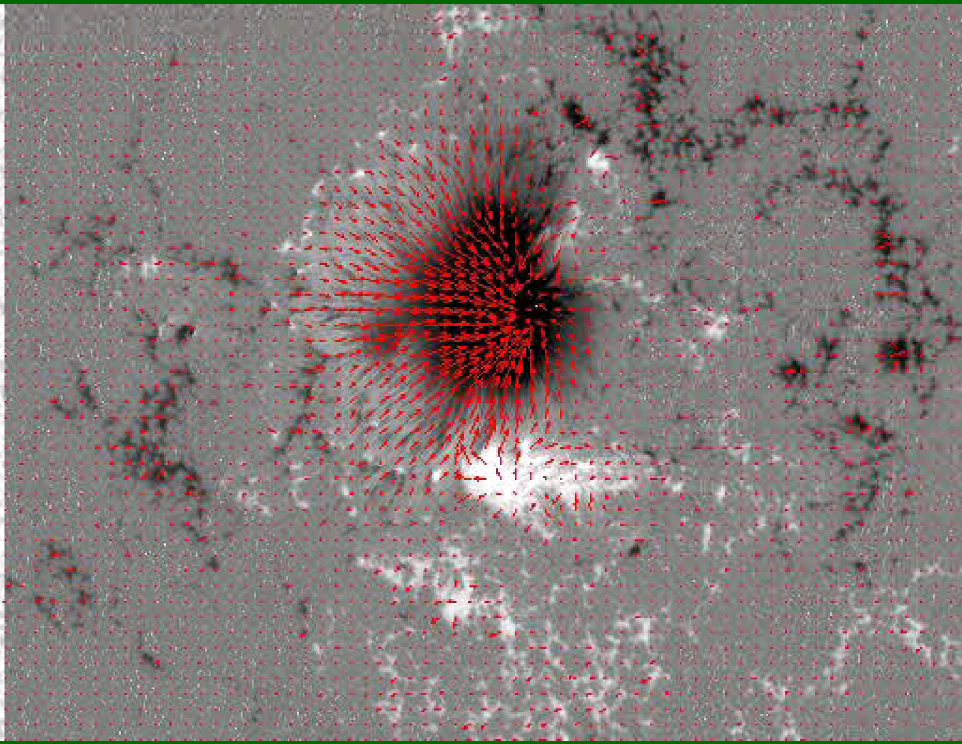


Courtesy: Yang Liu

This report provide sufficient reasons to consider the process of solar flare occurrence as an ORIGINAL PROCESS within common evolution of active region. This physical process has the concrete beginning – the emergence of a new magnetic flux and reaching the stage of interaction between new and old magnetic structures (1.5 - 3 days); maximum – the time interval when middle and large flares occur, that caused by interaction between these magnetic structures (2 – 3 days), and the end – when the energy of EFR is realized fully. The consequences of large new magnetic flux emergence are:

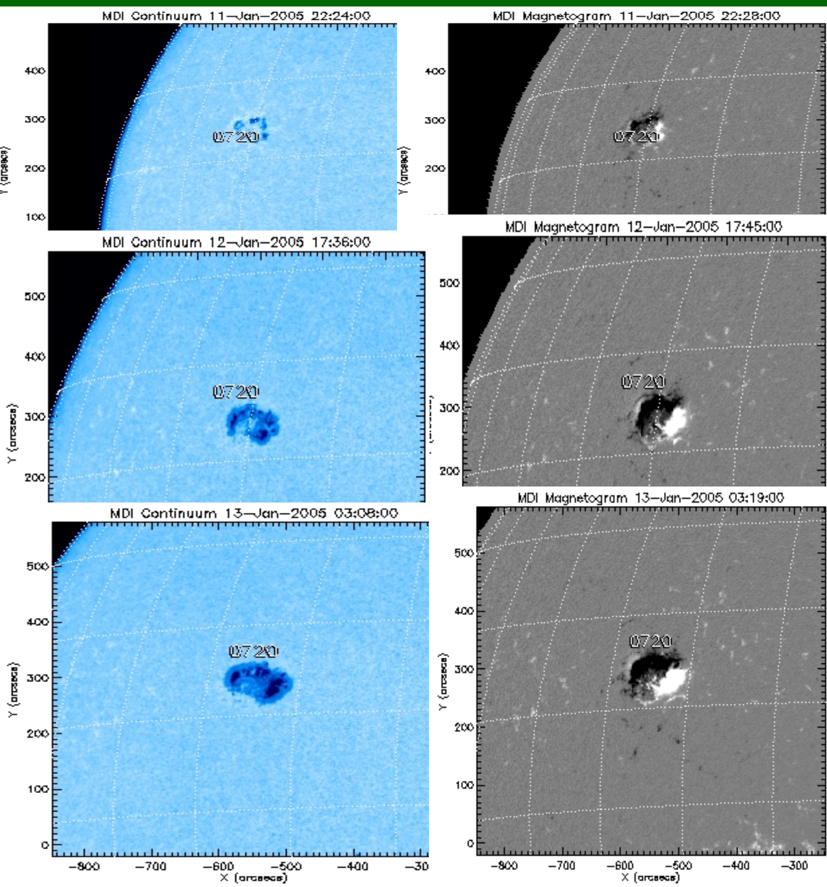
- rapid proper motions of one or more spots, umbrae or pores;
-appearance of sheared magnetic configuration ("shear") in regions immediately adjacent to the line of polarity reversal in the active region.





HINODE-2006

The large flare events forecasting is presently based on observations of:
- the process of new magnetic flux emergencies,- their evolution: the magnitude growth and rate of emergence, - their localization and interaction with already existing magnetic fields of the AR or outside of them.



AR10720 (N09L177; CMP 15.01.2005
Sp max = 1630, EKI, δ
$X_5^{7.1}$+M_{19}+$C_{65;}$ XRI=21.5),

I FERI 14-15.01 (17^h): (X_2+M_9) [4],
II FERI 16-17.01 (9^h): (X_1+M_3) – [1],
III FERI 18-20.01 (39^h): (X_2+M_4) – [3]

The emergencies of new magnetic fluxes may occur in all phases of active region evolution. Their interactions with overlying magnetic fields will always cause the flare activity increasing. For normal active region: the magnitude is $\Phi \geq 10^{12}$ Wb , and the rate of emergence is $V = 10^7$ Wb/s. For flare EFR the magnitude is $\Phi \geq 10^{13}$ Wb and the rate of emergence is $V \geq 10^9$ Wb/s. The temporal interval during which the bulk of large and moderate solar flares occur we will call as "*FLARE ENERGY RELEASE INTERVAL*" (FERI);
- PFER occurs on 1 - 3 day after the first evidences of the emergence of a new sufficiently powerful magnetic flux;
- PFER may last from 16 to 80 hours (the average duration is about 55 +/- 30 hours or 5-25% of whole the time of AR passage across the solar disk) depending on the degree of AR evolution, parameters of its magnetic field and characteristics of a new emerging flux.

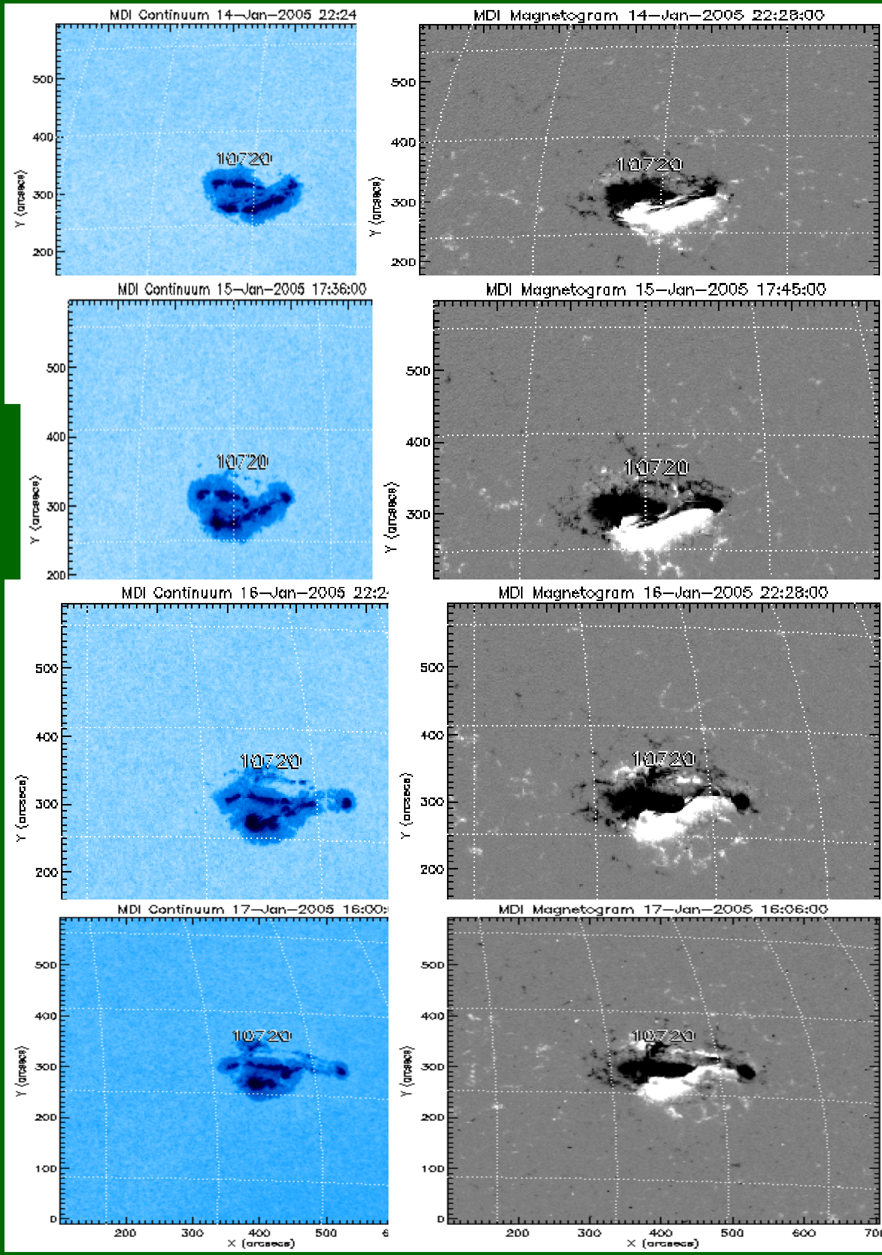
It is the most important to notice that ALL large flares and the most of moderate flares of given active region occur in this temporal interval;

All large flares are necessarily accompanied by middle importance flares;

Solar flares of large and middle importance are distributed not at random in time, but they form the successions; Obashev et al., (1973), Ishkov, (1989);

in most cases they occur within a certain limited temporal interval, Ishkov, (1998, 1999).

To occur other large solar flares in given active region a new large magnetic flux emergence must take place.



AR10720; 1 ПВЭ 14-15.01(17^h):(X_2+M_9) [4],
I ПВЭ16-17.01 (9^h): (X_1+M_3) – [1], IIIПВЭ18-20.01 (39^h): (X_2+M_4) – [3]

The scope for large flare forecast:

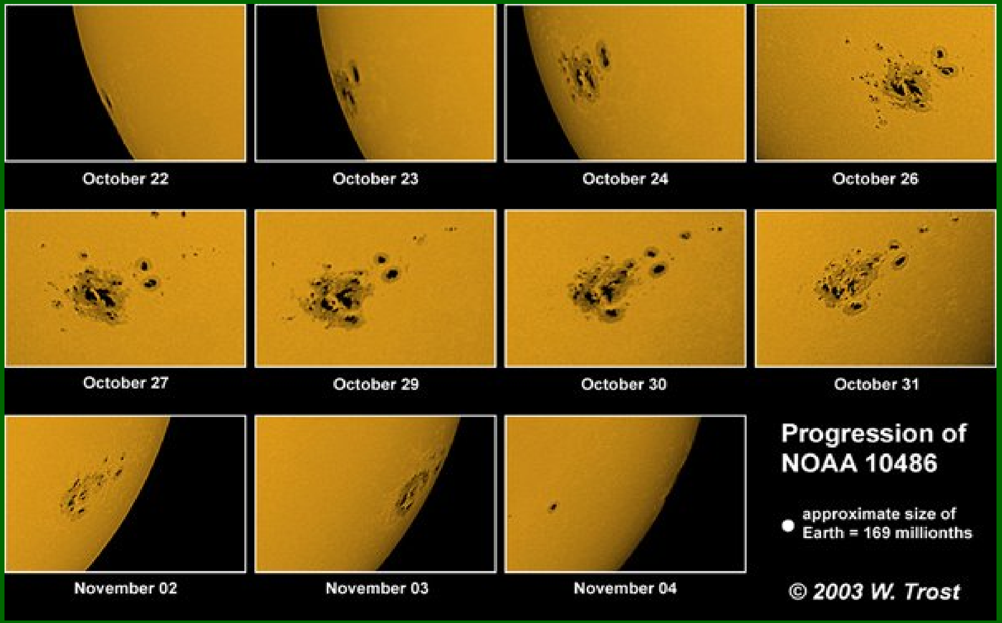
At observations of a new significant emerging magnetic fluxes in AR

- forecast PFER for 24-48 h;
- the tentative estimation of geoefficiency flare events (R, S, G) on localization and surrounding structures of AR;

At observations flare events

- On a x-ray class - R;
- On a radio emission, localization of the flare events and to characteristics of CME - S, G;

http://www.



- Impossibility of the forecast of time and point of separate event during PFER;
- Real difficulties of allocation of a new emerging magnetic fluxes in complex, compact AR with areas Sp> 1500 m.v.h.;
- Difficulties of an estimation flare potential in AR near limb;

- The method of the solar flare events prediction has been put to succesfful test on Russian scientific sattelits such as GRANAT, GAMMA, CORONAS-I and F. Computer version this forecast techniques has been developed on the base of real-timt solar data.
- http://titan.wdcb.ru/virbo_rus/viewlast.do?section=RBBulletin – English version;
- http://izmiran.ru/space/solar/forecast - Russian version