Statistical analysis of recurrent and sporadic Forbush decreases at different phases of solar ativity

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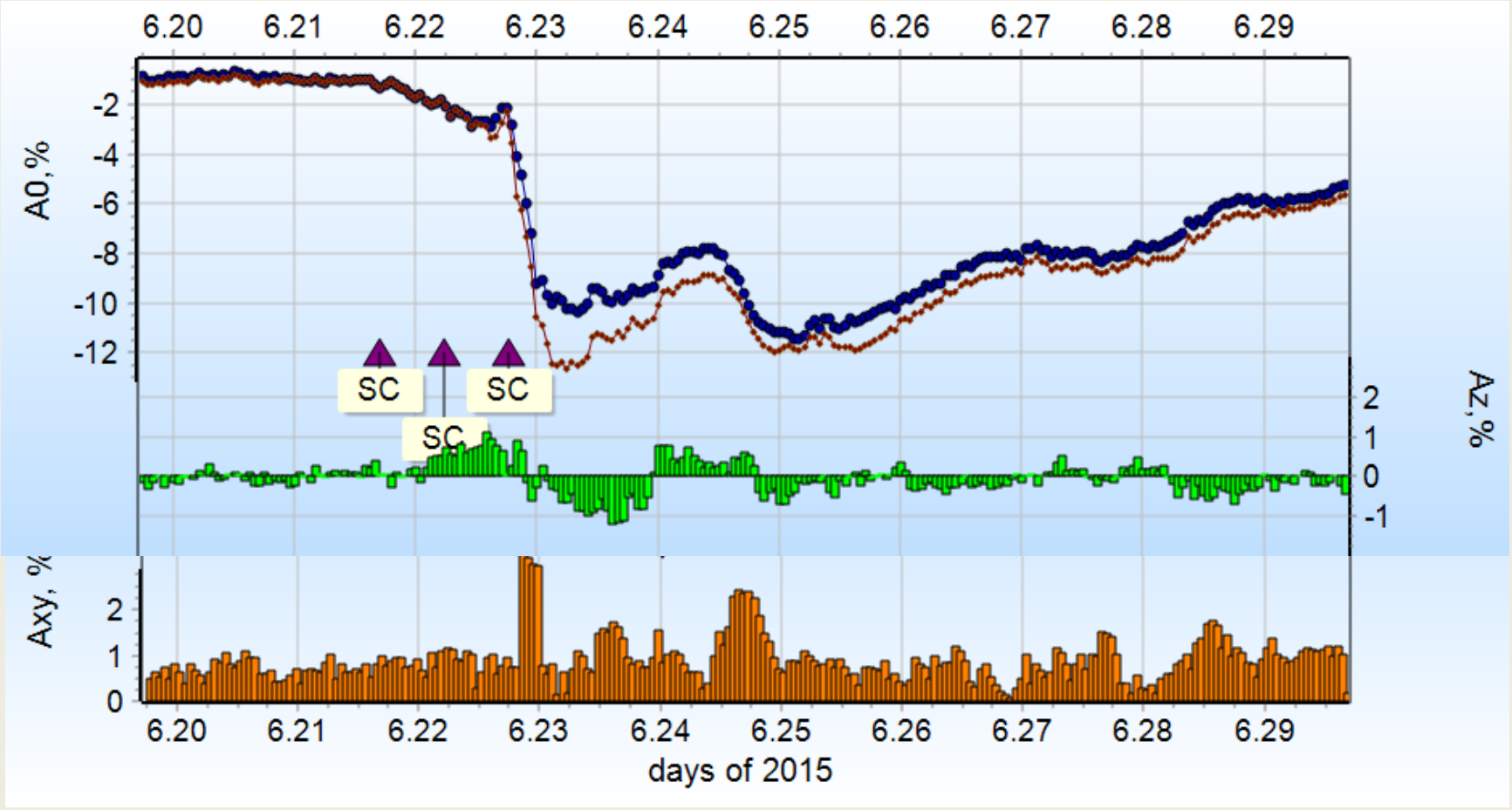
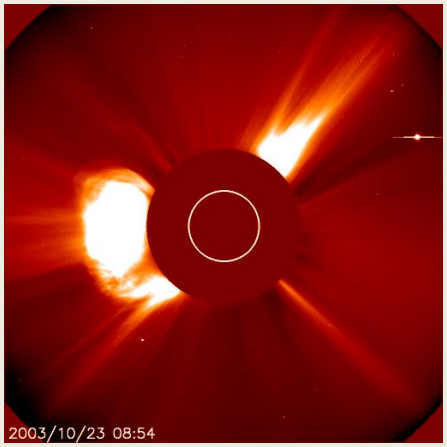
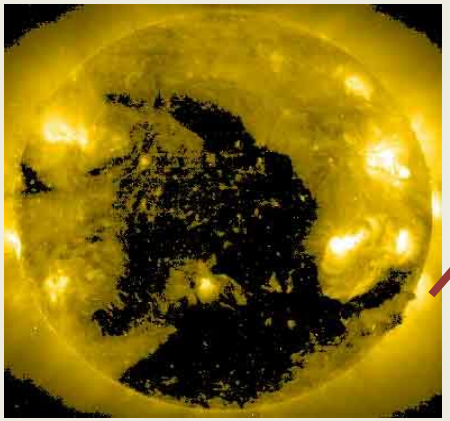
Forbush Decreases – Cosmic Ray variations

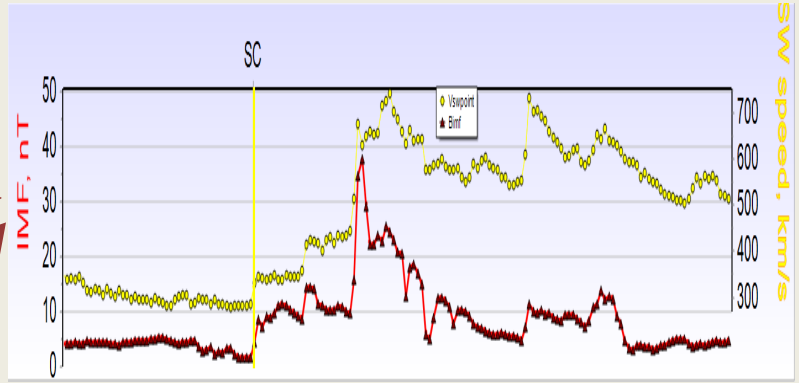


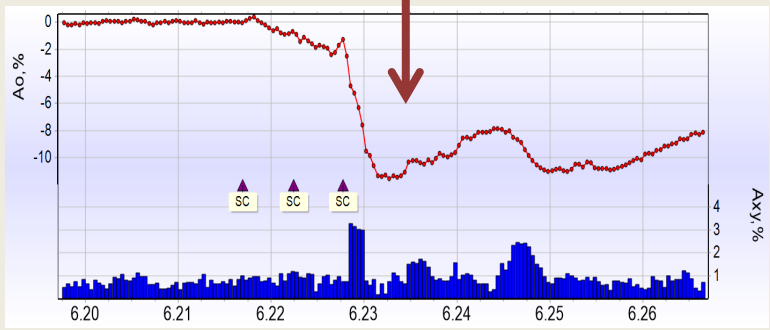
FD as a rule demonstrate relatively fast CR density decrease followed by a slower recovery on a time scale of several days. CR anisotropy is extremely variable and large during FD.

Forbush Decreases are created by Solar Wind disturbances



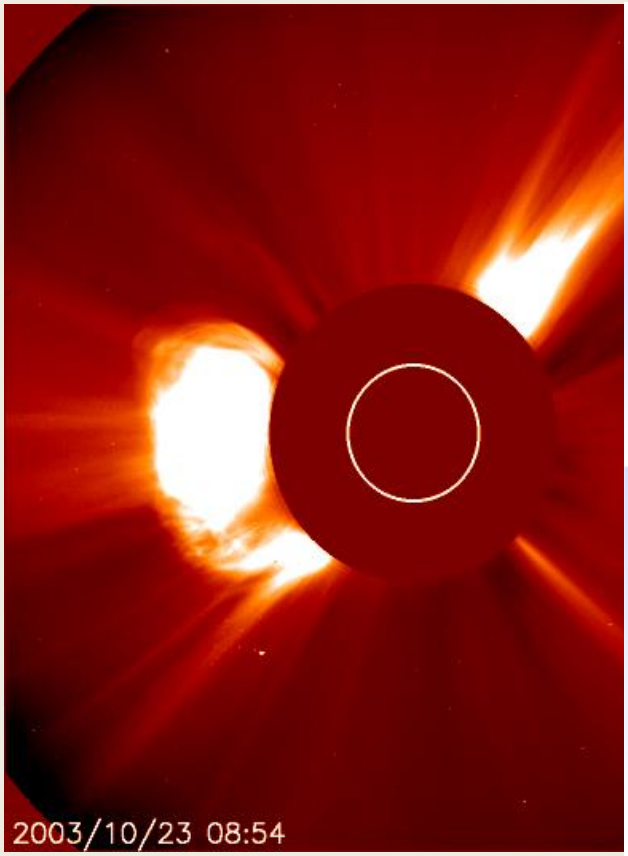


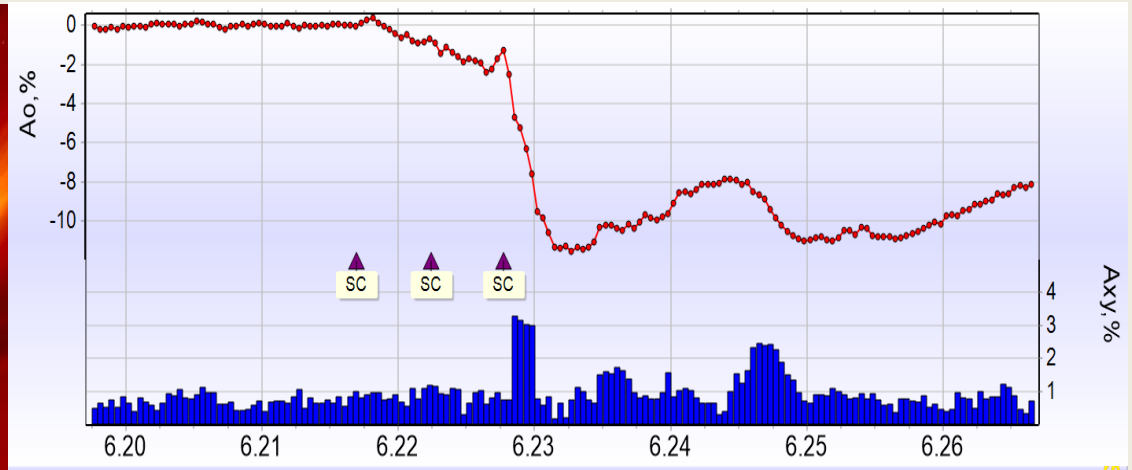


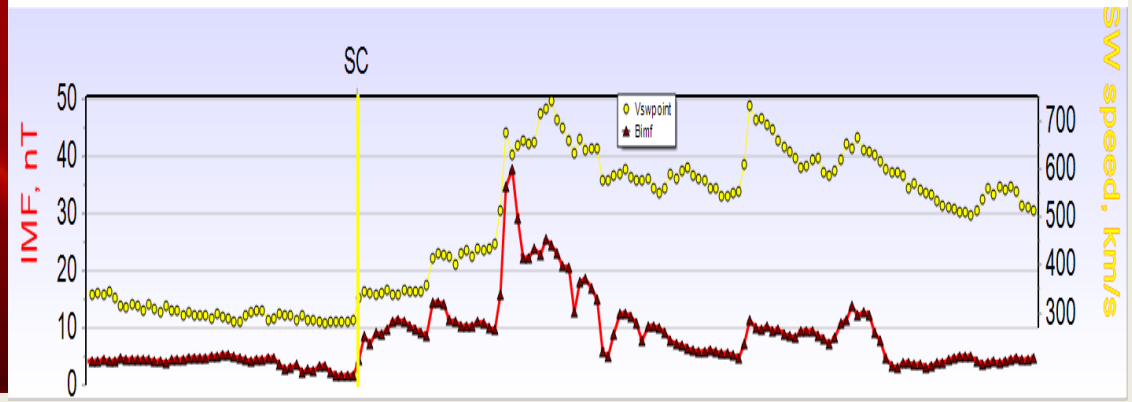


FDs are results of the influence of SW disturbances on background CR. SW disturbances are created by interaction of factors both sporadic (CME) and recurrent (HSS from CH) origin with ambient SW.

Sporadic Forbush Decreases

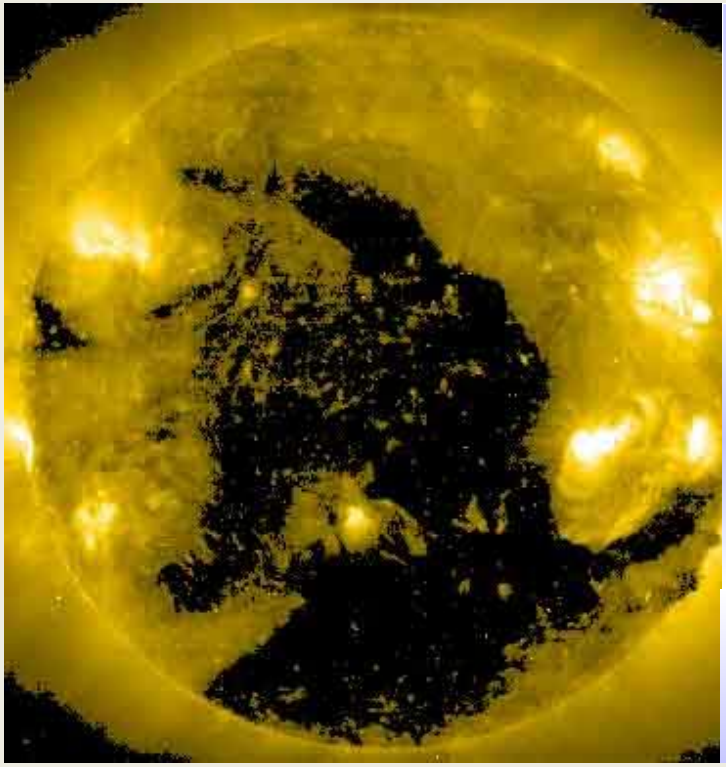


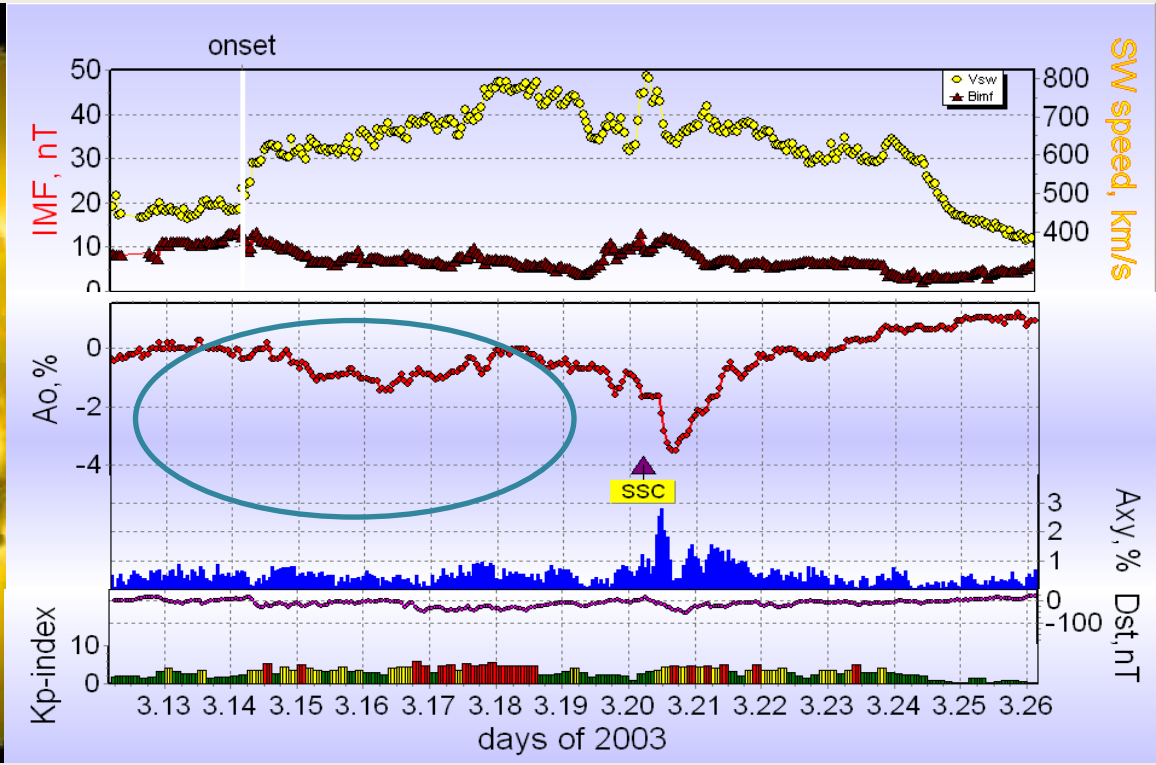




All giant FDs (>12%) as well as most middle and small FDs are the sporadic events. They demonstrate fast CR density decrease with relatively large magnitude. During sporadic FDs, the most modulated GCR are observed (magnitude up to 28%, October 2003).

Recurrent Forbush Decreases





Recurrent FDs have more smoothed and shallow time profile and relatively small magnitude (≤ 5%). They dominate in the minimums of solar activity and in the recent solar cycle 24.

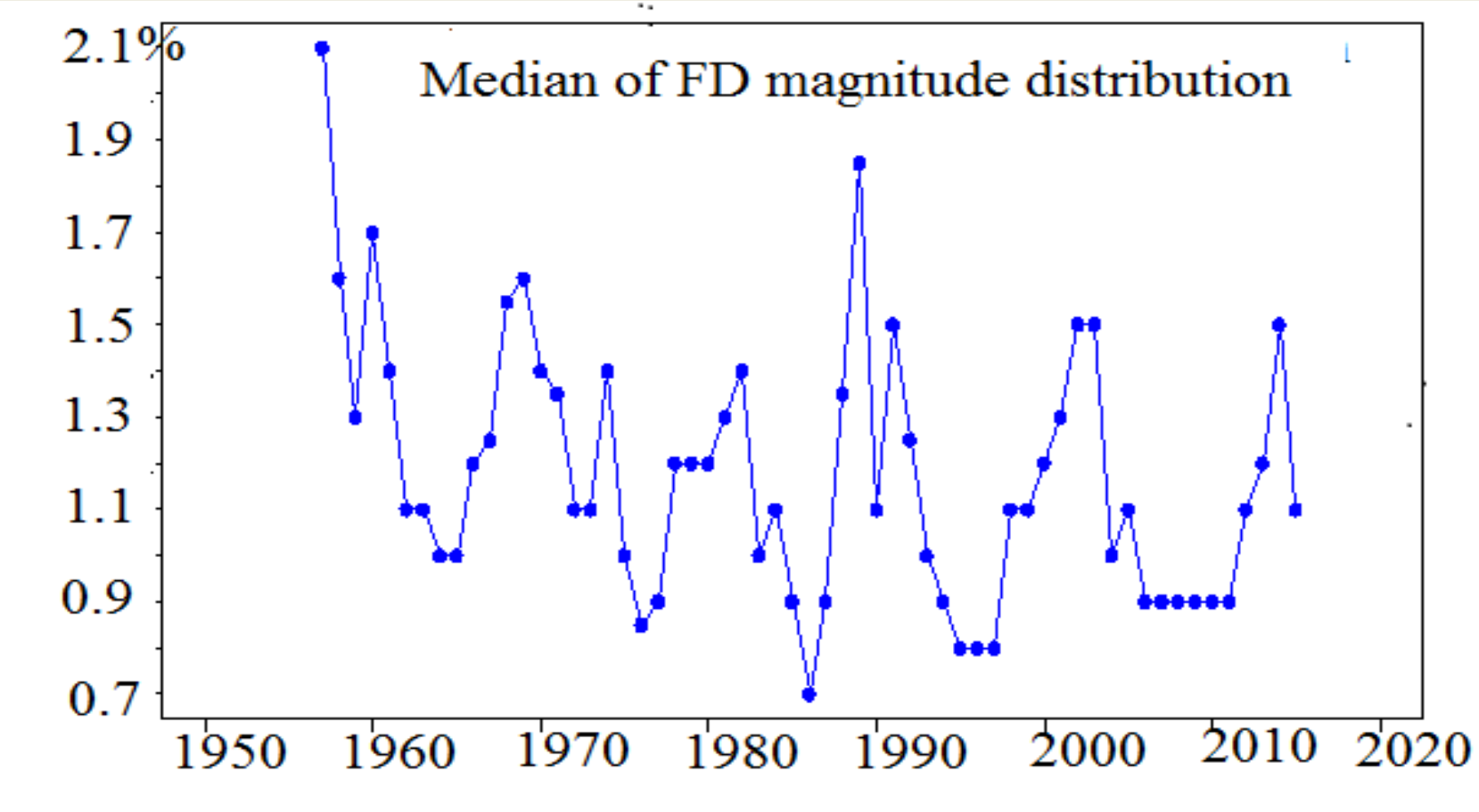
Forbush Effects and Interplanetary Disturbances Database

http://spaceweather.izmiran.ru/eng/dbs.html

FD parameters are obtained by GSM using data of about 40 NMs for particles with rigidity 10 GV

Years	Solar cycles	Type of events	Number of FDs
1957-2015	19-24	All FDs	7021
1957-2015	19-24	Isolated FDs	4692
1997-2015	23-24	Isolated FDs	1662
1997-2015	23-24	Recurrent FDs	350
1997-2015	23-24	Sporadic FDs	207

Yearly value of FD magnitude median

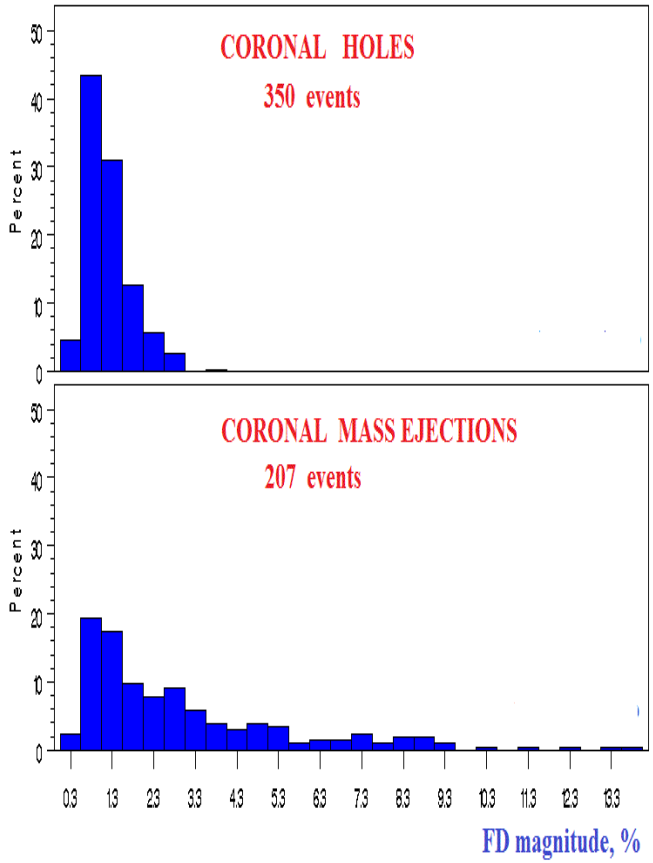


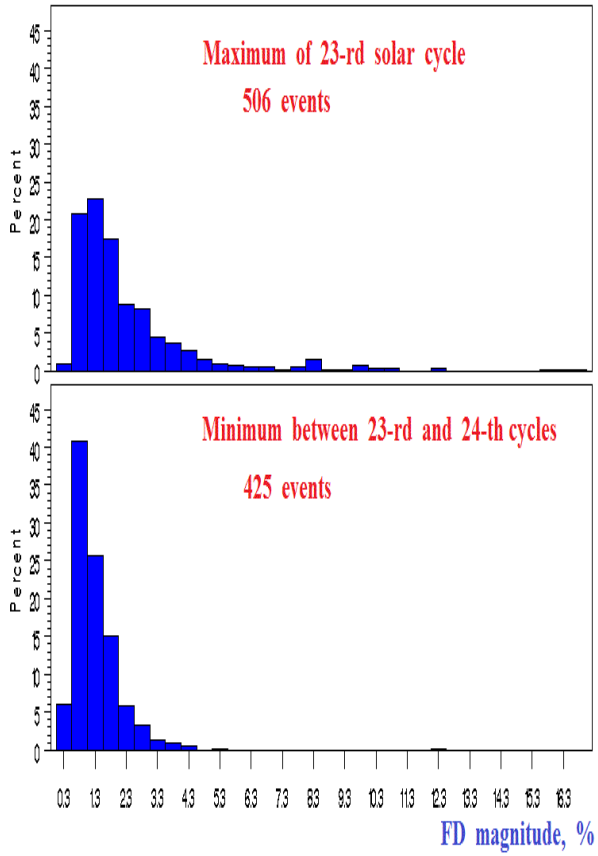
Maximum values of medians: 2.1% SC 19; 1.8% SC 22; 1.6% SC 20; 1.5% for SCs 23 and 24; 1.4% for SC 21. A plateau with constant small median values 0.9% - from 2006 to 2011.

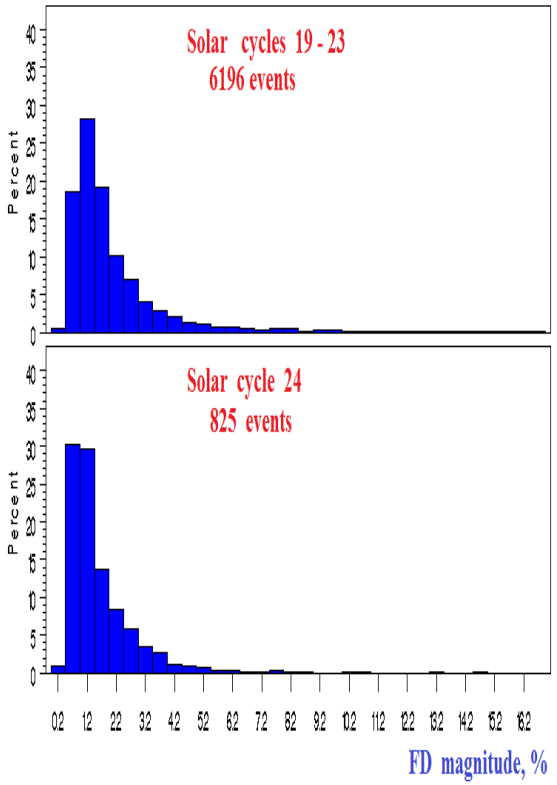
Medians and means of FD magnitudes

Solar activity phase or solar source	Years	FD number	FD magnitude (%)		
			Median	95% Confidence interval of mean	
19 – 23 cycles	1957 – 2008	6196	1.5	1.99	2.19
24 cycle	2009 – 2015	825	1.2	1.47	1.87
Max 23	1999 – 2002	506	1.7	2.02	2.82
Min 23-24	2006 – 2010	425	1.1	1.16	1.48
Max 24	2012 – 2015	511	1.4	1.60	2.10
CH	1997 – 2014	350	1.1	1.10	1.34
CME	1997 – 2014	207	2.1	2.30	3.76

FD magnitude distributions

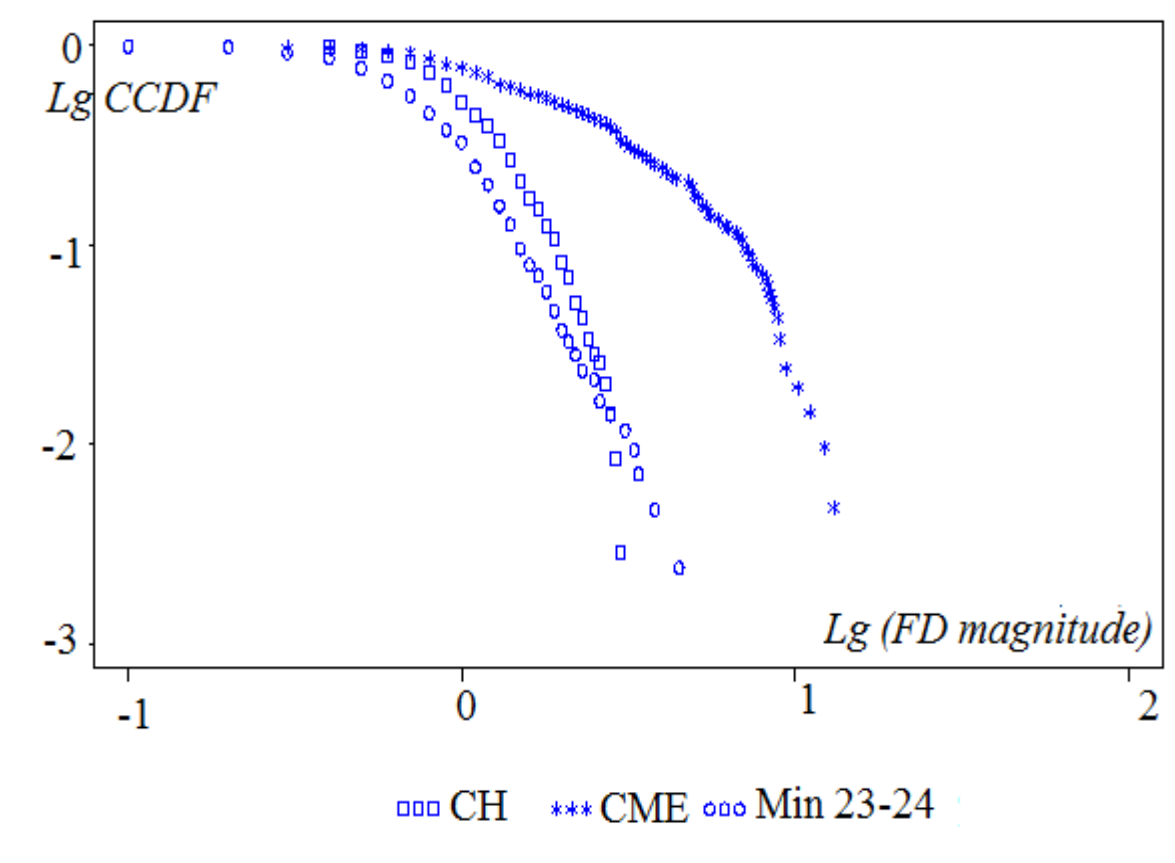






Distributions for the minimum between SCs 23-24 and recurrent FDs are peaked and compact; for the maximum of SC 23 and sporadic FDs – more flat-topped with long tails of large values

CCDF of FD magnitude for the deep minimum between solar cycles 23 and 24



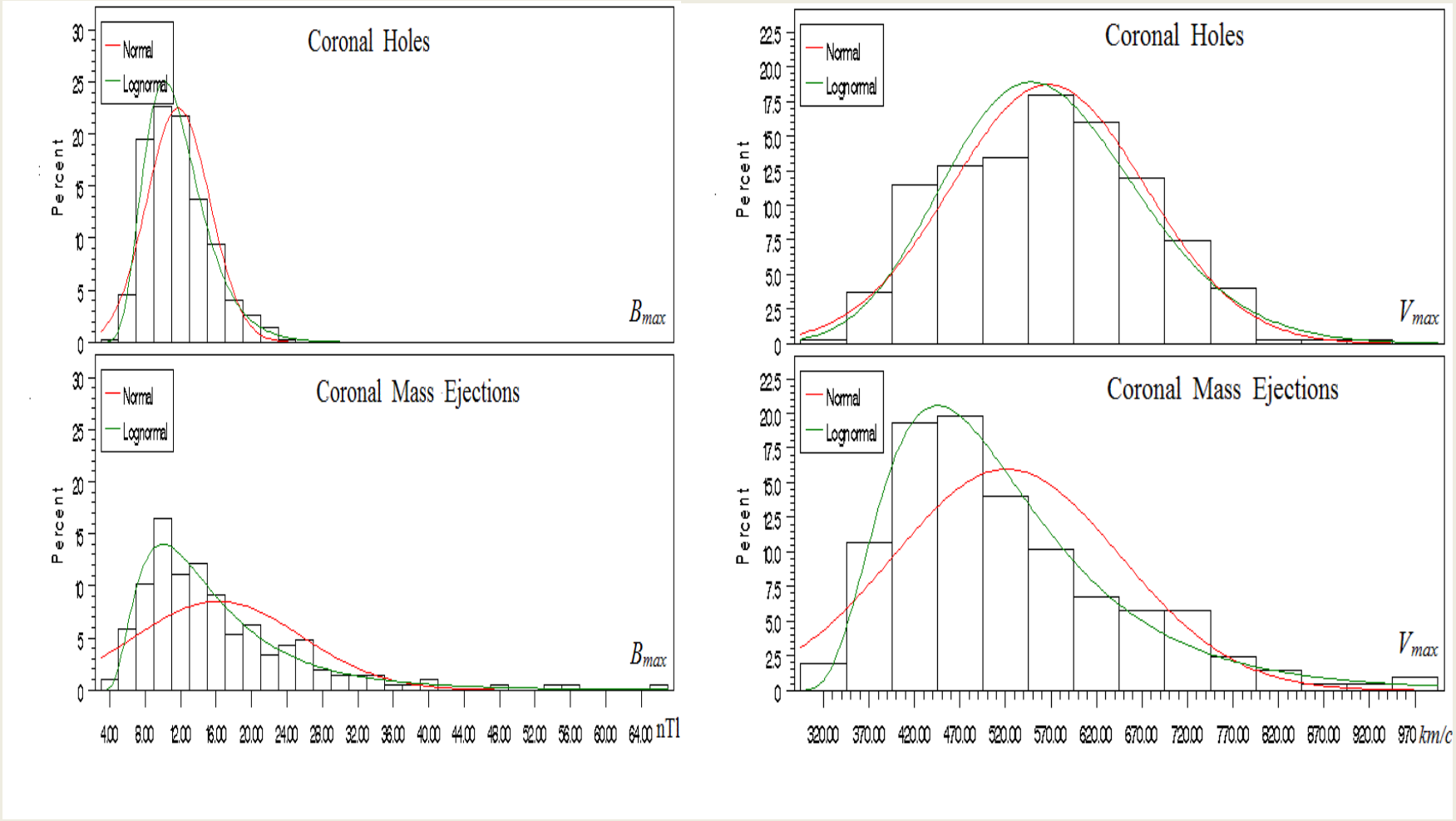
CCDFs of FD magnitude are much steeper for the recurrent FDs and FDs in the minimum between SCs 23-24 than for the sporadic FDs

Mean values of FD magnitude, Vmax, Bmax

Solar activity	FD numbers		FD magnitude, %		Vmax, km/s		Bmax, nT	
	CH	CME	CH	CME	CH	CME	CH	CME
Max 23	**34**	**70**	1.4	**3.2**	560	**524**	12.7	**17.0**
Min 23-24	**165**	**25**	1.2	**1.9**	559	**459**	11.2	**10.5**
Max 24	47	39	1.3	3.3	549	510	11.0	15.2
SC 23	212	136	1.3	3.2	593	539	12.5	17.6
SC 24	138	71	1.1	2.7	537	488	10.6	13.9
Total	350	207	1.2	3.0	568	523	11.7	16.3

During the Min 23-24 not only the number and magnitude of sporadic FDs fallen off but corresponding SW velocity and IMF intensity significantly decreased.

Distribution of SW velocity and IMF intensity in the CH and CME groups



K-S test: lognormal distribution of IMF intensity in the CH and CME groups and SW velocity in the CME group. For SW velocity distribution in the CH group: -0.09≤Skewness≤ 0.43 (α=0.95)

Multiple linear regression (Model 1).

Group		Standardized regression coefficients			
		CH	CME		
Dependent variable		FD magnitude	FD magnitude	FD decrease rate	CR equatorial anisotropy
Predictors	IMF intensity	0.38	0.46	0.38	-
	SW velocity	-	0.37	0.41	0.38
Determination coefficient		0.23	0.65	0.61	0.41
Multiple correlation coefficient		0.48	0.81	0.78	0.64

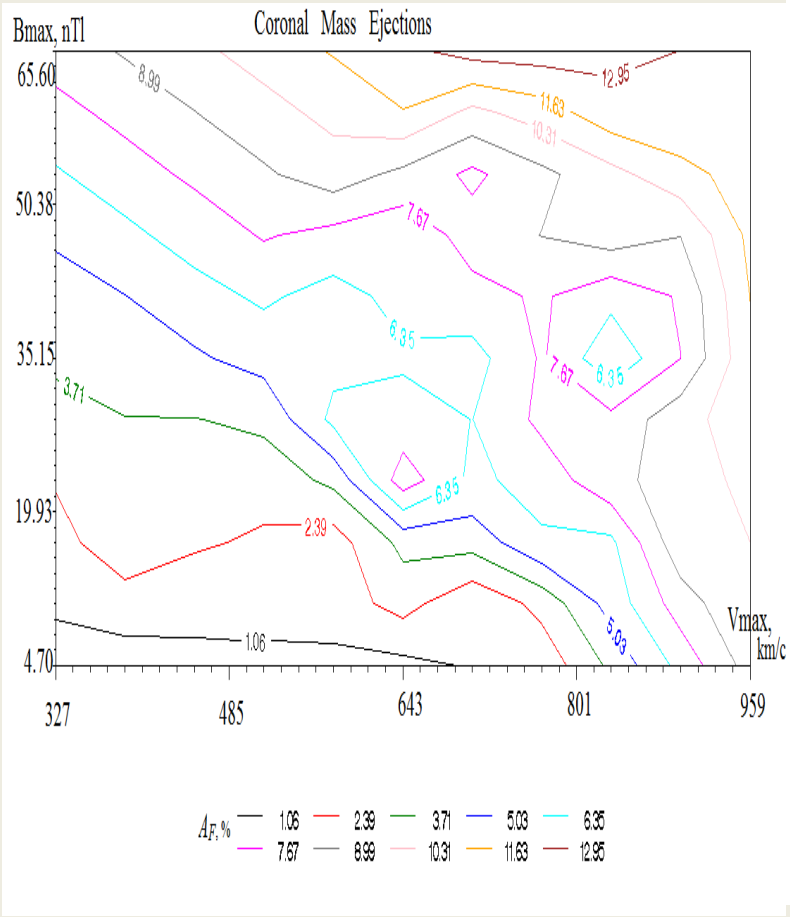
Model 1. **Dependent variables: FD magnitude and decrease rate, CR equatorial and north-south anisotropy. Set of predictors: SW velocity, IMF intensity, geomagnetic *Ap* and *Dst* indices.**

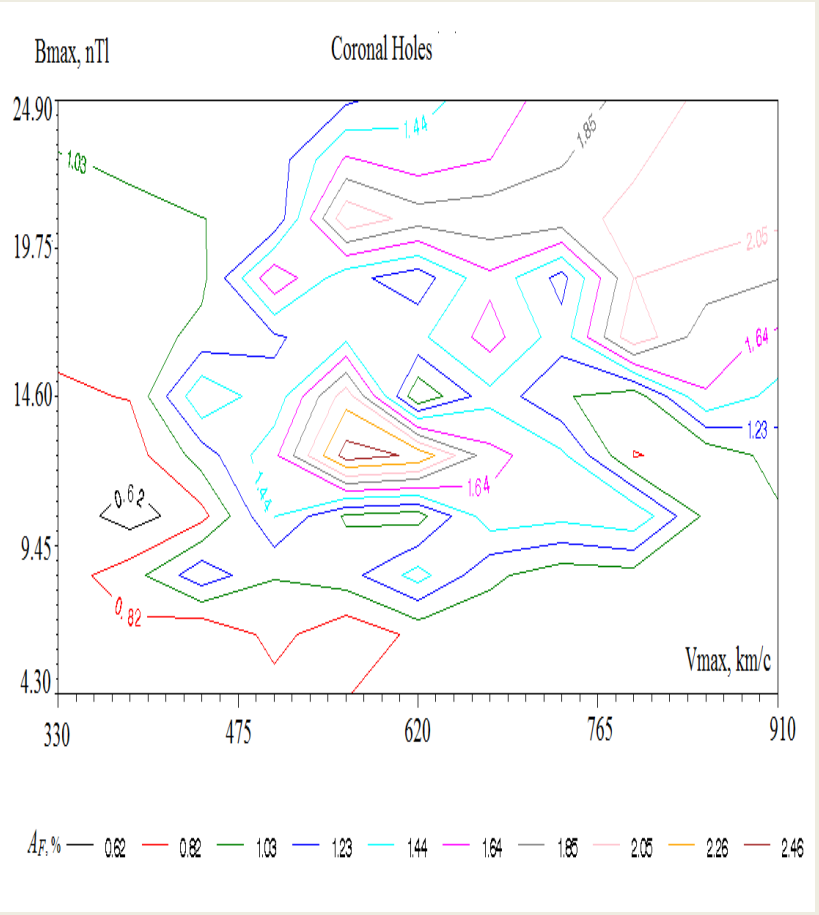
Multiple linear regression (Model 2)

Group		Standardized regression coefficient			
		CH	CME		
Dependent variable		*Apmax*	*/Dstmin/*	*Apmax*	*/Dstmin/*
Predictors	IMF intensity	0.36	0.30	0.64	0.73
	SW velocity	0.41	0.32	0.28	-
Determination coefficient		0.46	0.30	0.67	0.64
Multiple correlation coefficient		0.68	0.55	0.82	0.80

Model 2. **Dependent variables: geomagnetic *Ap* and |*Dst*| indices. Set of predictors: SW velocity and IMF intensity.**

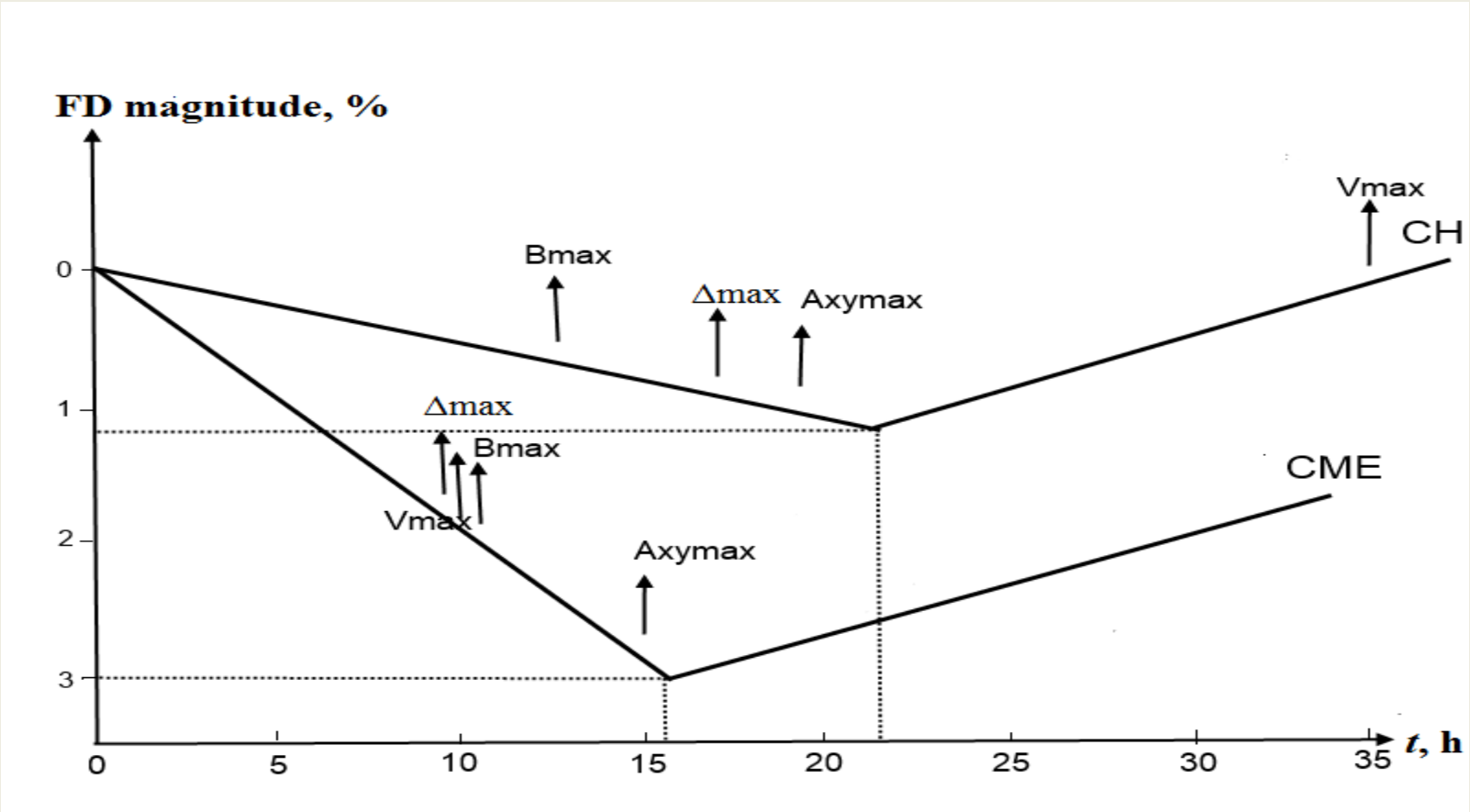
Dependence of FD magnitude on SW velocity and IMF Intensity





The dependence of FD magnitude on SW parameters is much closer to the linear model for the CME group of events

Time delays in the CH and CME groups



Time delays	Max 23		Min 23–24		Max 24	
	CH	CME	CH	CME	CH	CME
T_{min}, h	20.5	14.9	25.5	23.2	15.4	16.0
T_{dmin}, h	16.8	8.3	16.4	15.6	19.4	7.2
T_{axymax}, h	25.9	16.0	19.1	20.2	15.6	10.2

- **Medians of FD magnitude are greater at high solar activity. Distributions of FD and SW parameters differ for recurrent and sporadic FDs.**
- **FDs in solar cycle 24 and in the minimum between cycles 23 and 24 are mainly caused by HSS from CHs, in the maximum of cycle 23 - by ICMEs.**
- **FD parameters are greater for sporadic FDs. This difference is larger in the maxima of cycles 23 and 24 than in the minimum between the cycles.**
- **IMF is greater for sporadic FDs in the maxima of cycles 23 and 24 and is practically the same for the two groups of events in the minimum. IMF for sporadic events is much smaller in cycle 24 than in cycle 23.**
- **SW velocity is in average larger for recurrent FDs. This velocity is greater for sporadic FDs at the maxima of cycles 23 and 24 and for recurrent FDs in the minimum between the cycles. The velocity is lower for both groups of FDs in recent cycle than in previous one.**
- **In the maximum of cycle 23, sporadic FDs develop much faster than recurrent ones; in the maximum of cycle 24 and in the minimum between the cycles, the duration of main phase is approximately the same for recurrent and sporadic FDs; this duration is shorter during the maxima of cycles 23 and 24 than during the minimum between the cycles for both groups of events.**

Acknowledgement

We are grateful to all,

- who provided CME, CH, SW and CR data,
- who gathered these data in databases,
- who explained these data
- who create the useful models and software.

We are grateful to the personnel of the world network of cosmic ray stations providing data from the continuous record of the neutron component.