Properties of interplanetary drivers of magnetospheric disturbances

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Several results have been published and may be found in
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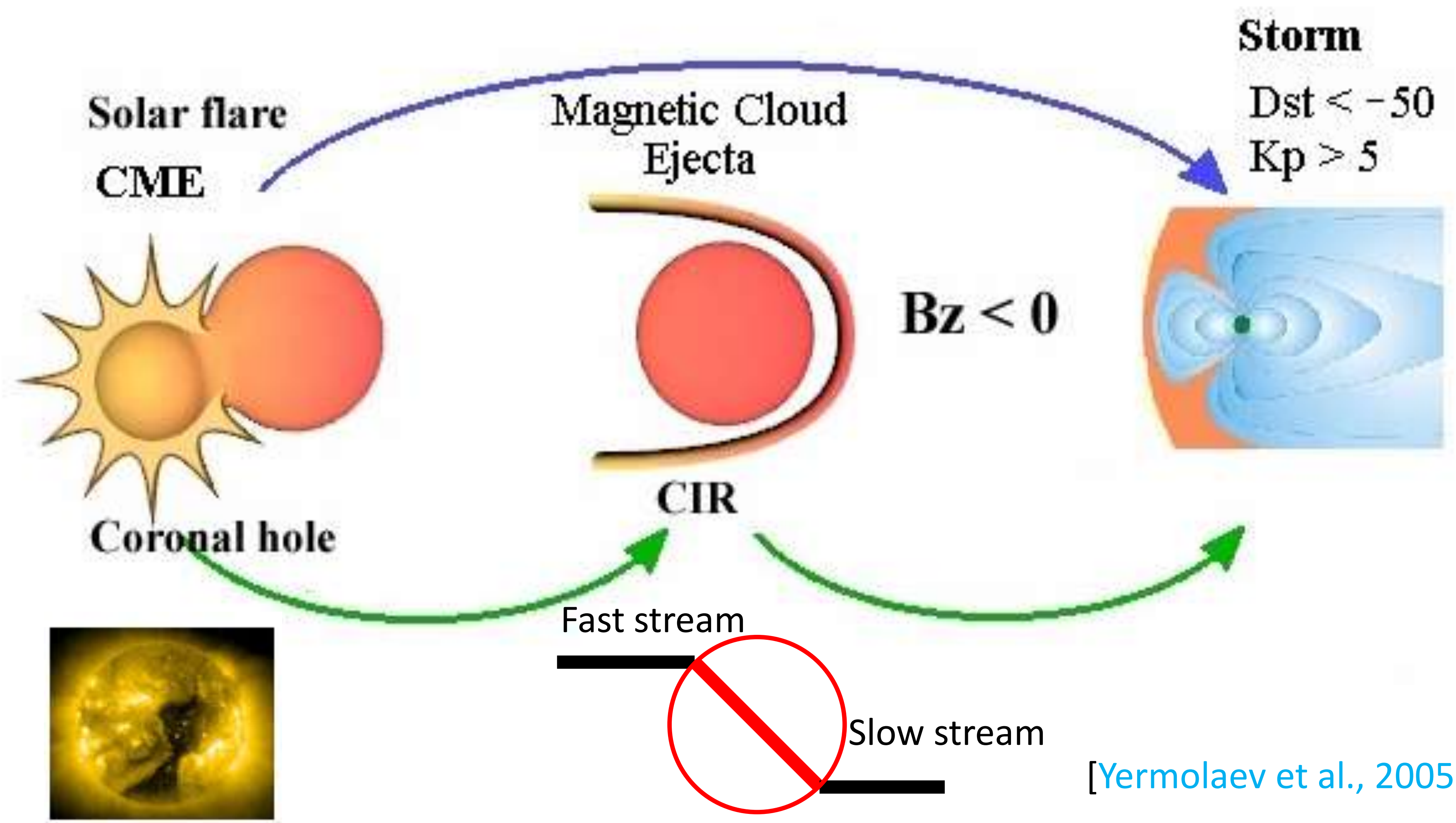
Introduction

- Interplanetary source of magnetic storms is southward IMF (Bz <0) component (*Russell et al., 1974, Burton et al., 1975; Akasofu, 1981*)
- Non-disturbed solar wind contains IMF which lies in ecliptic plane => Bz =0 !
- Only disturbed types of solar wind may be geoeffective.
- 2 scenarios of generation of Bz <0 component:

1) CME => MC/Ejecta + Sheath => Bz<0 => Storm

2) Coronal hole => CIR => Bz <0 => Storm

General concept of storm effectiveness of solar and interplanetary events

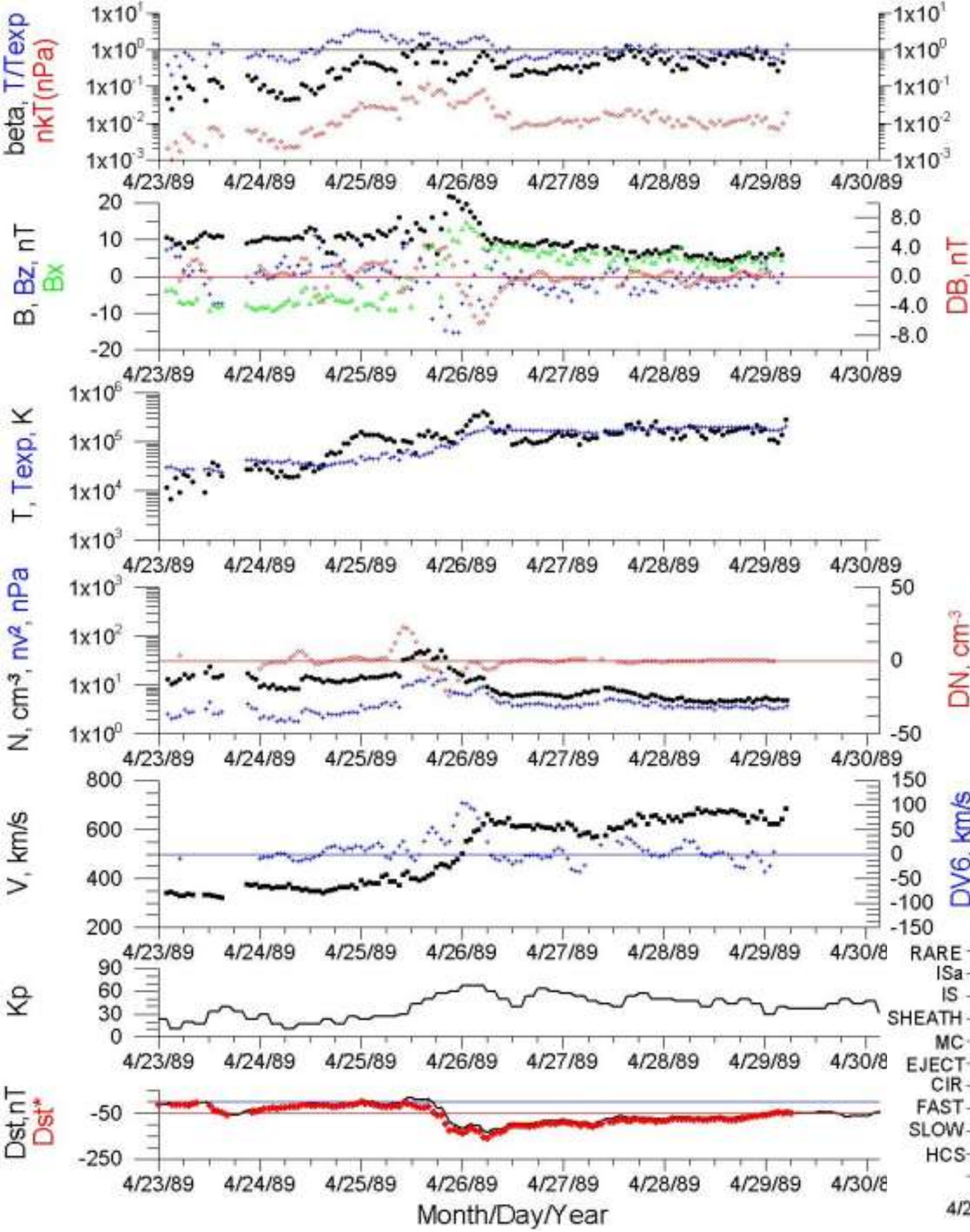


[Yermolaev et al., 2005]

DATA

Catalog of solar wind phenomena 1976-2017

(Yermolaev et al., 2009)



Example of OMNI data and calculated parameters in our database

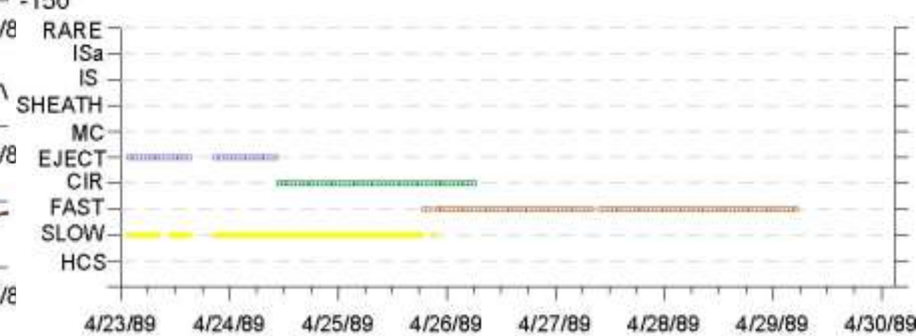
ftp://ftp.iki.rssi.ru/pub/omni

(← left)

and identification of solar wind types

ftp://ftp.iki.rssi.ru/pub/omni/catalog/

(↓ bottom)

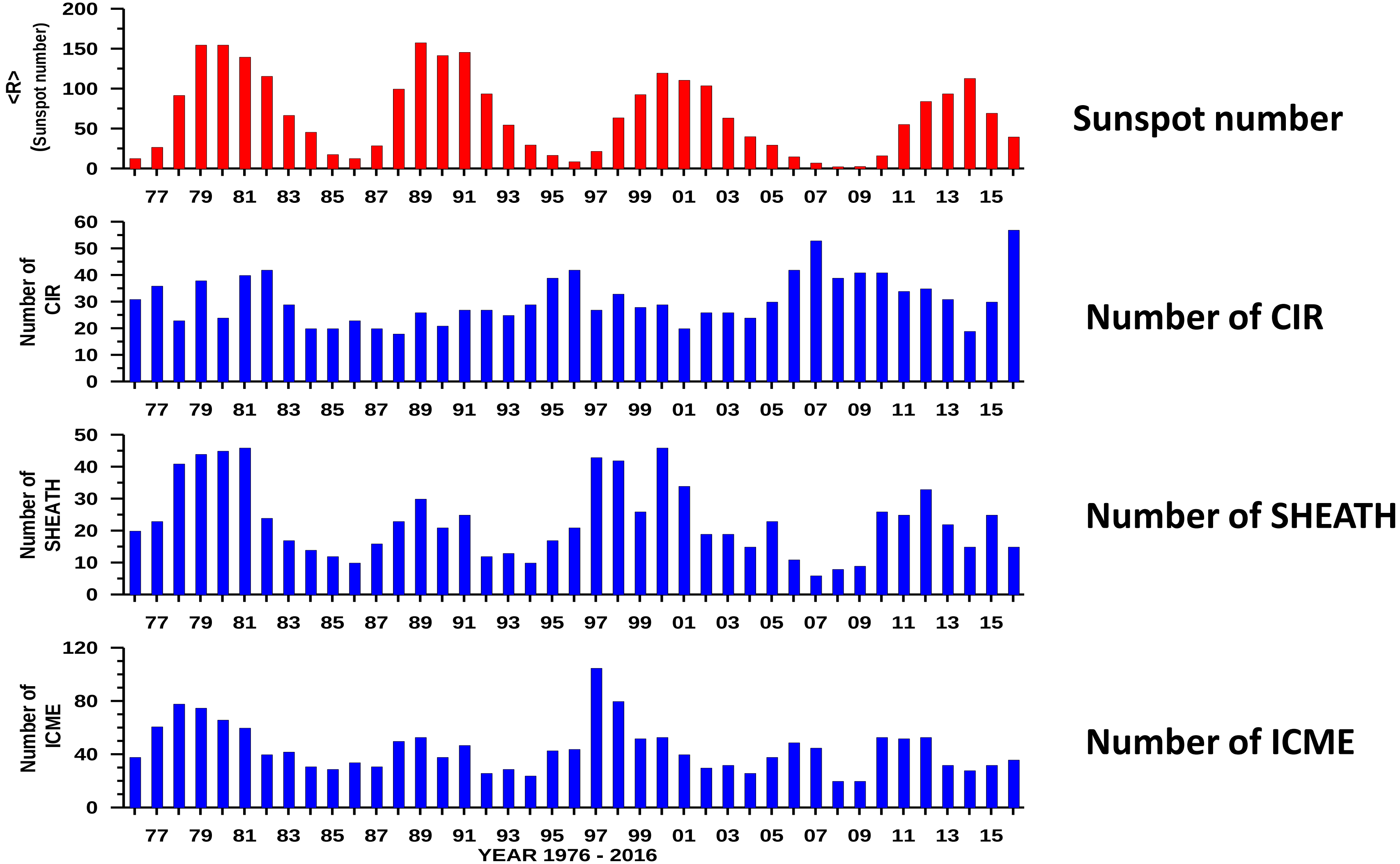


List of solar wind events

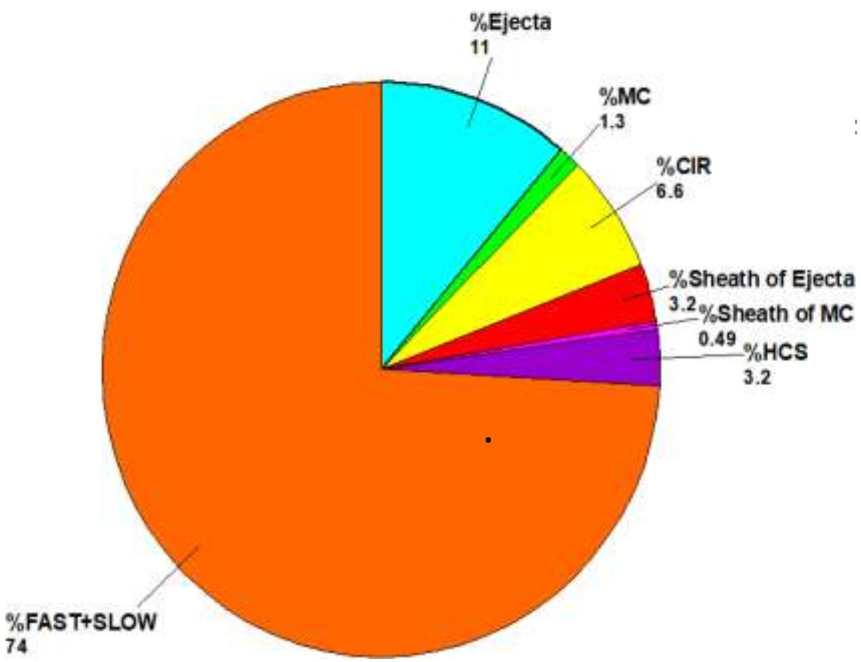
ftp://ftp.iki.rssi.ru/pub/omni/catalog/1988/1988int.txt

noData	1988	1	1	1	0	1	1988	1	1	1	2	3	3
SWslow	1988	1	1	1	3	4	1988	1	1	1	7	8	5
IS	1988	1	1	1	8	9	1988	1	1	1	8	9	1
SWslow	1988	1	1	1	9	10	1988	1	1	1	19	20	11
noData	1988	1	1	1	20	21	1988	2	1	2	4	29	9
SWslow	1988	2	1	2	5	30	1988	2	1	2	5	30	1
SHE	1988	2	1	2	6	31	1988	2	1	2	15	40	10
EJE	1988	2	1	2	16	41	1988	3	1	3	8	57	17
SWslow	1988	3	1	3	9	58	1988	4	1	4	1	74	17
noData	1988	4	1	4	2	75	1988	4	1	4	10	83	9
SWslow	1988	4	1	4	11	84	1988	4	1	4	16	89	6
IS	1988	4	1	4	17	90	1988	4	1	4	17	90	1
CIR	1988	4	1	4	18	91	1988	5	1	5	1	98	8
noData	1988	5	1	5	2	99	1988	5	1	5	13	110	12
SWfast	1988	5	1	5	14	111	1988	5	1	5	15	112	2
noData	1988	5	1	5	16	113	1988	5	1	5	23	120	8
SWslow	1988	6	1	6	0	121	1988	6	1	6	3	124	4
noData	1988	6	1	6	4	125	1988	11	1	11	14	255	131
SWslow	1988	11	1	11	15	256	1988	11	1	11	22	263	8
SHE	1988	11	1	11	23	264	1988	12	1	12	21	286	23
EJE	1988	12	1	12	22	287	1988	13	1	13	22	311	25
SHE	1988	13	1	13	23	312	1988	14	1	14	5	318	7
MC	1988	14	1	14	6	319	1988	15	1	15	9	346	28
SWfast	1988	15	1	15	10	347	1988	16	1	16	2	363	17
noData	1988	16	1	16	3	364	1988	17	1	17	13	398	35
SWslow	1988	17	1	17	14	399	1988	18	1	18	4	413	15
noData	1988	18	1	18	5	414	1988	24	1	24	9	562	149
SWslow	1988	24	1	24	10	563	1988	24	1	24	11	564	2
noData	1988	24	1	24	12	565	1988	24	1	24	23	576	12
EJE	1988	25	1	25	0	577	1988	25	1	25	23	600	24
SWslow	1988	26	1	26	0	601	1988	26	1	26	18	619	19
HCS	1988	26	1	26	19	620	1988	26	1	26	21	622	3
SWslow	1988	26	1	26	22	623	1988	27	1	27	12	637	15
ISa	1988	27	1	27	13	638	1988	27	1	27	13	638	1
SWslow	1988	27	1	27	14	639	1988	27	1	27	23	648	10
HCS	1988	28	1	28	0	649	1988	28	1	28	2	651	3
SWslow	1988	28	1	28	3	652	1988	28	1	28	9	658	7
ISa	1988	28	1	28	10	659	1988	28	1	28	10	659	1

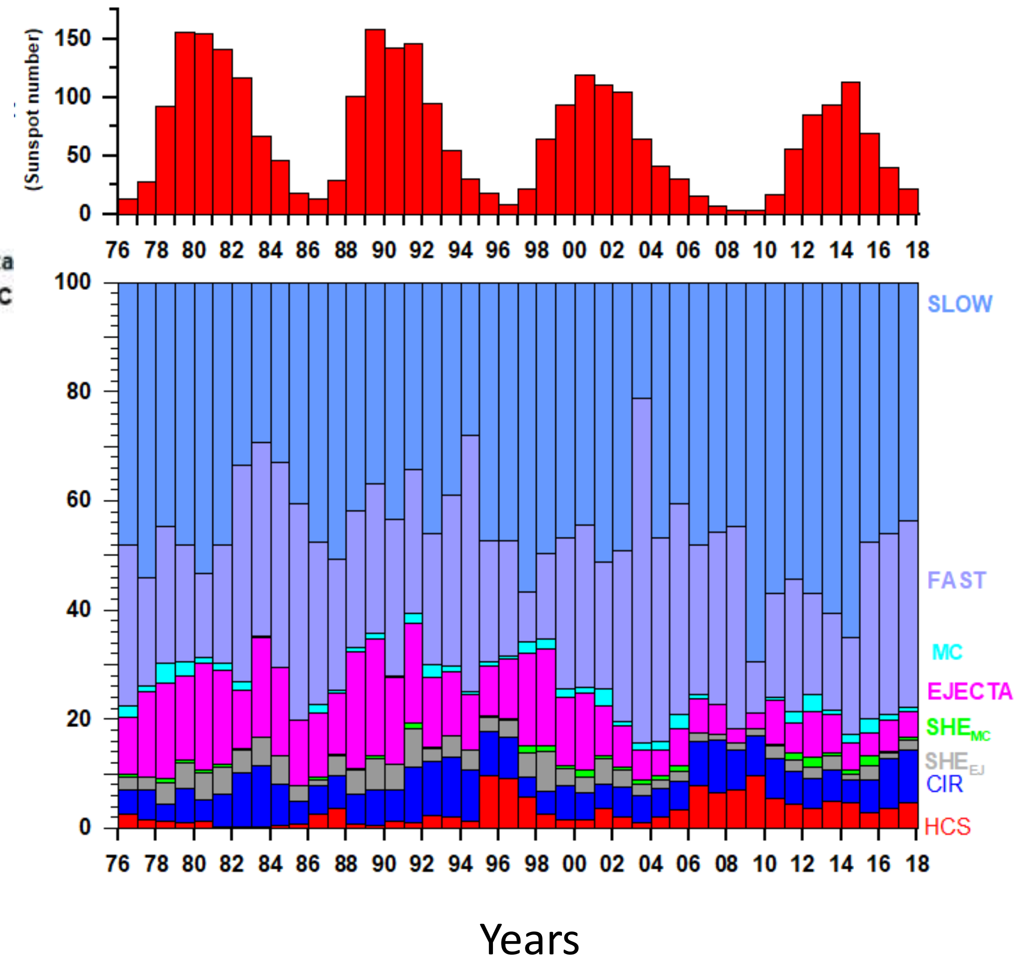
Yearly number of different types of solar wind phenomena (1976-2016)



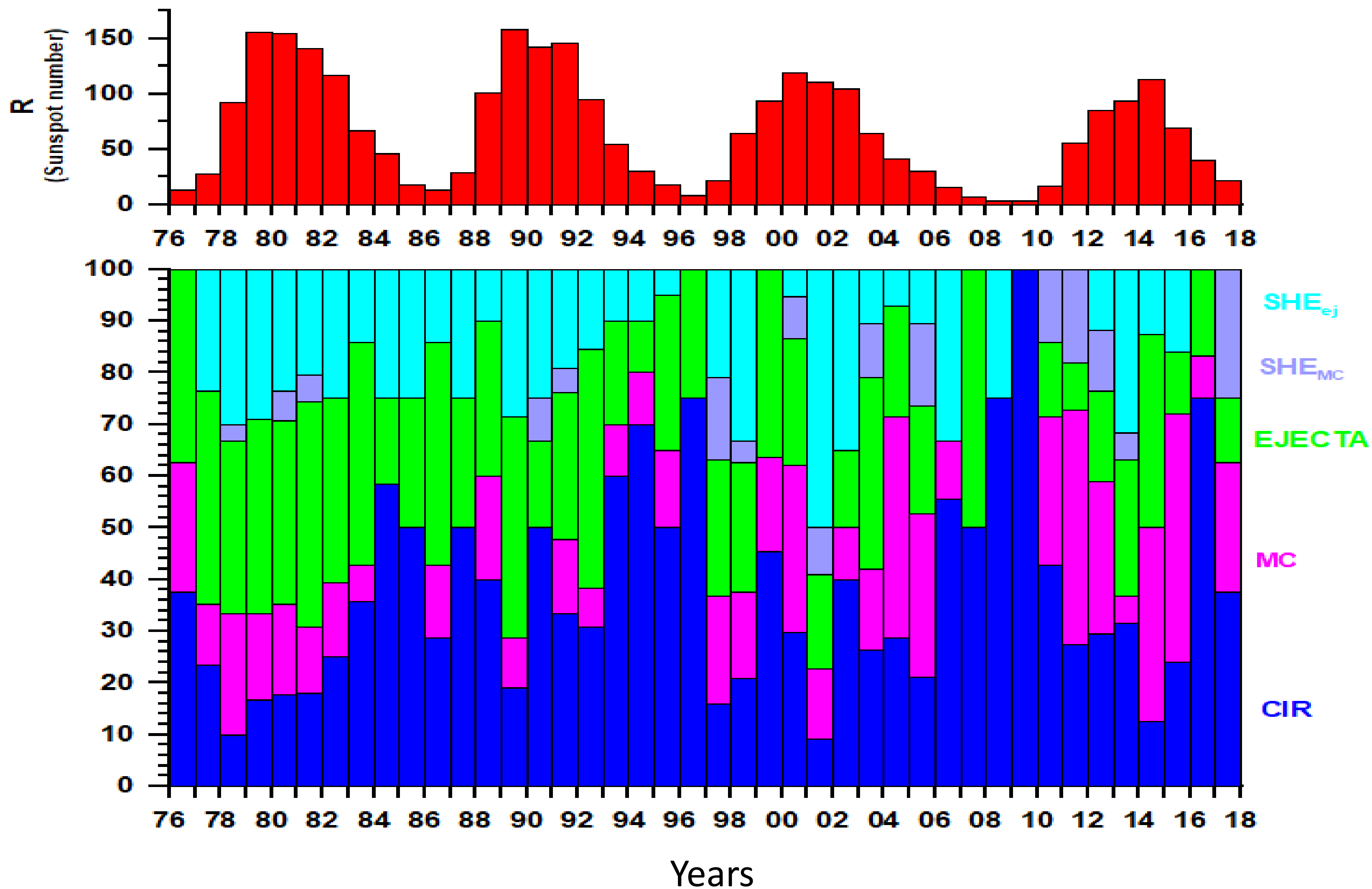
Distribution of durations of different types of solar wind during 1976-2017



Solar wind contains ~30% of disturbed phenomena during 21-23 solar cycles and only ~20% during 24 solar cycle.



Distributions of interplanetary sources of magnetic storms (Dst<-50 nT)



Methods

Sequences of SW types and interaction between them

We separately analyze the following sequences of the phenomena (Yermolaev et al., JGR, 2015):

(1) SW/CIR/SW,

(2) SW/IS/CIR/SW,

(3) SW/Ejecta/SW,

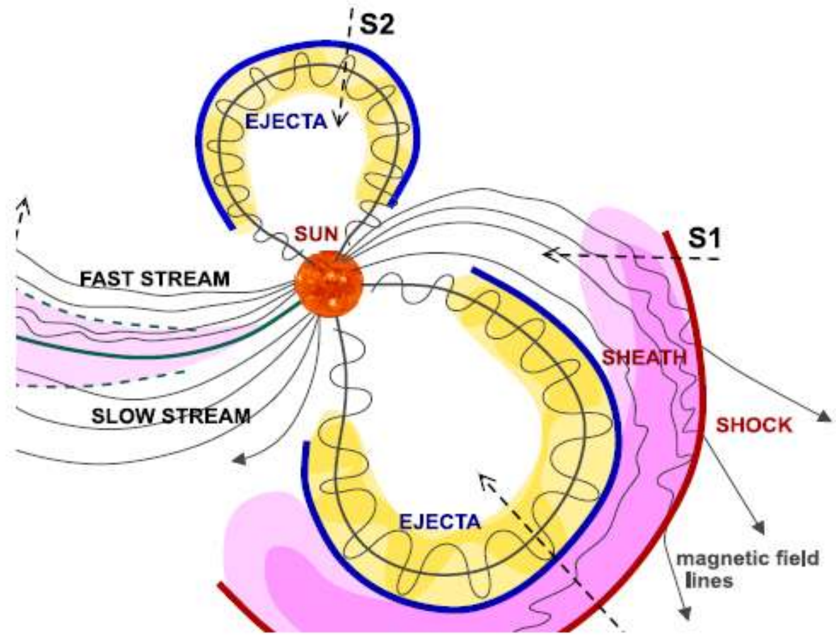
(4) SW/Sheath/Ejecta/SW,

(5) SW/IS/Sheath/Ejecta/SW,

(6) SW/MC/SW,

(7) SW/Sheath/MC/SW, and

(8) SW/IS/Sheath/MC/SW



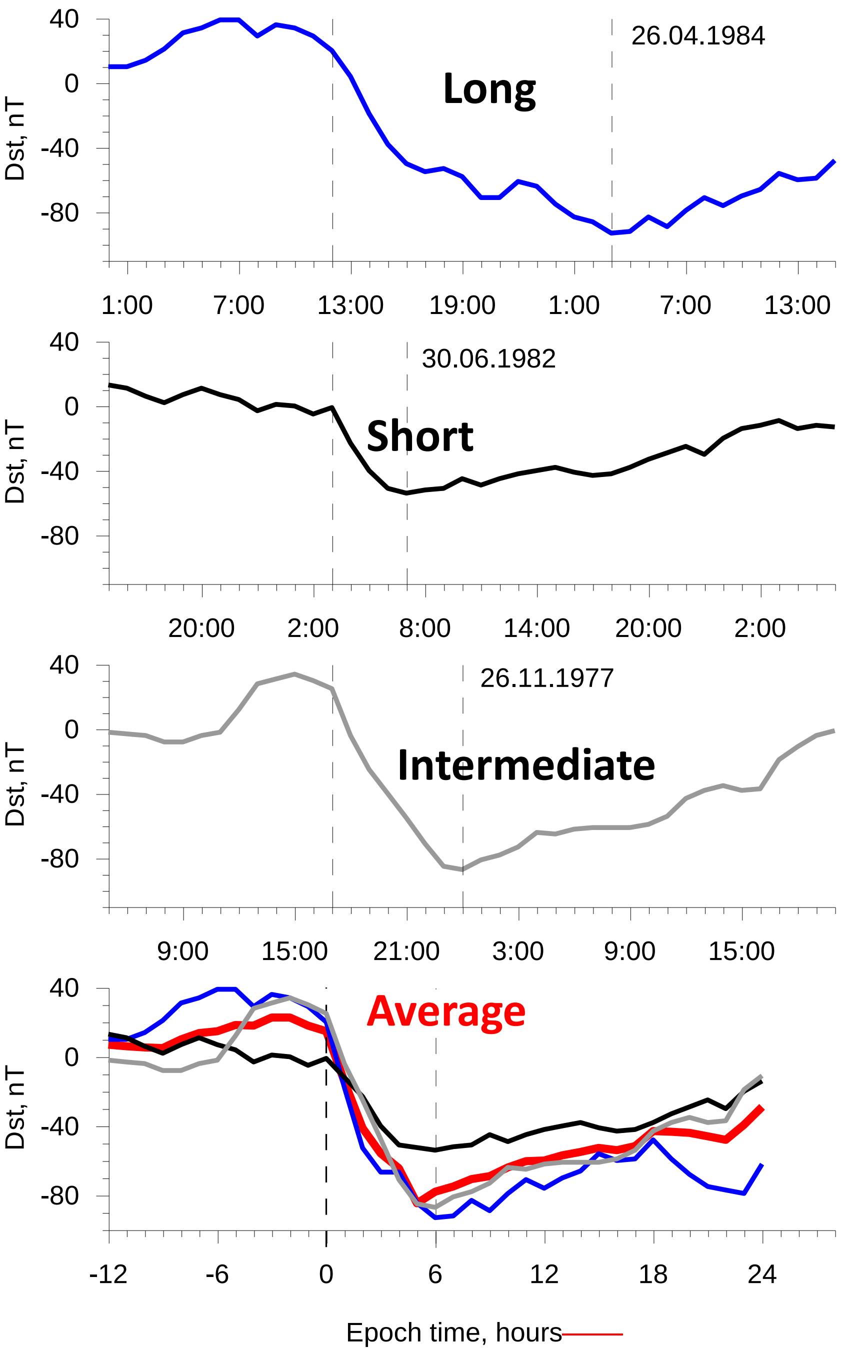
Several cases are shown in Figure from Kilpua et al., 2015

Sequences #4 and #6 contain **Sheath** but do not contain **IS**

Method of double superposed epoch analysis

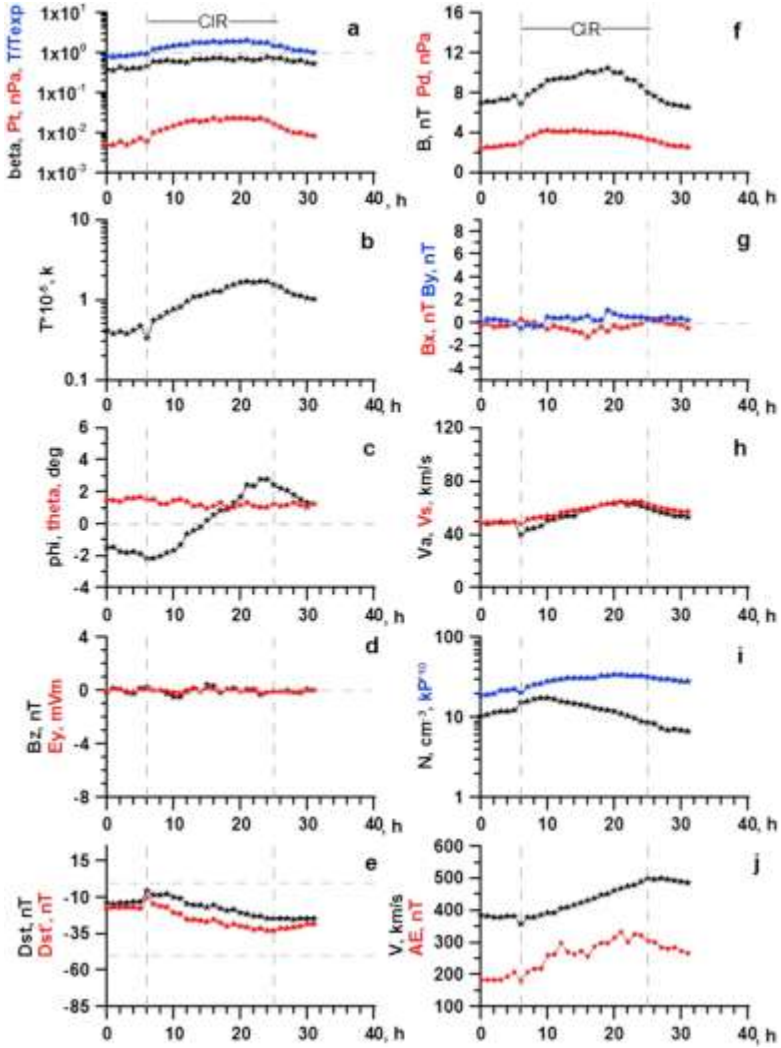
- To take into account the different durations of SW types, we use the double superposed epoch analysis (DSEA) method: rescaling the duration of the interval for all types in such a manner that, respectively, beginning and end for all intervals of selected type coincide.

Yermolaev et al., AnnGeoPhys. 2010

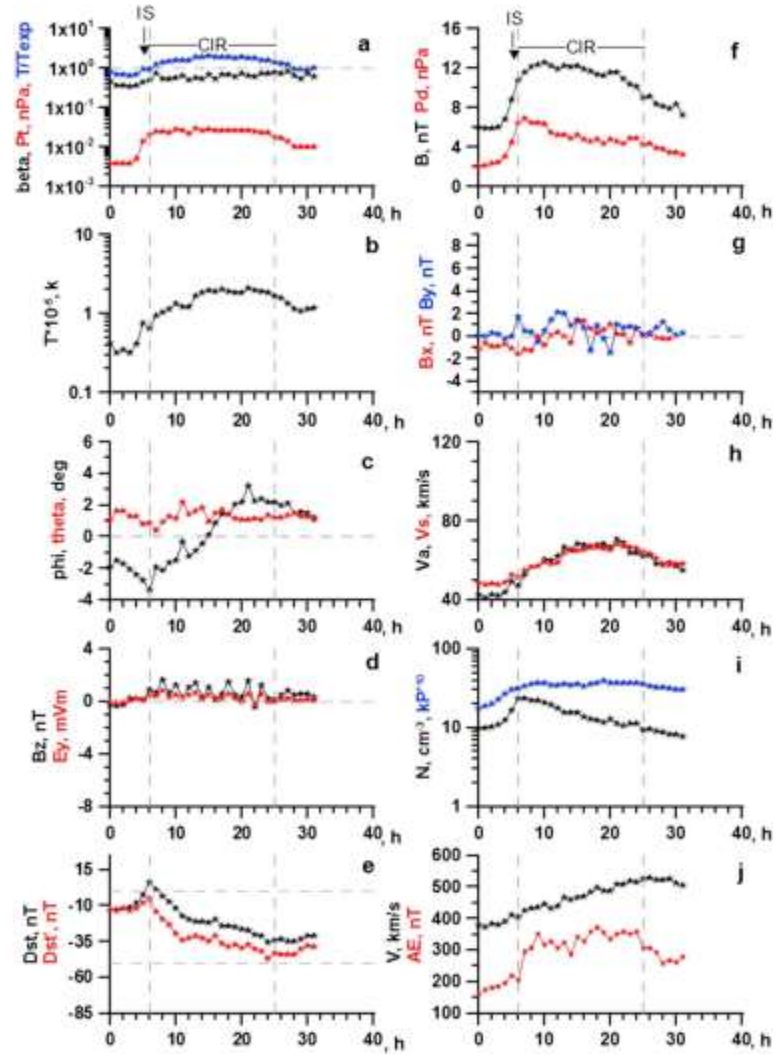


CIR

Without Shock

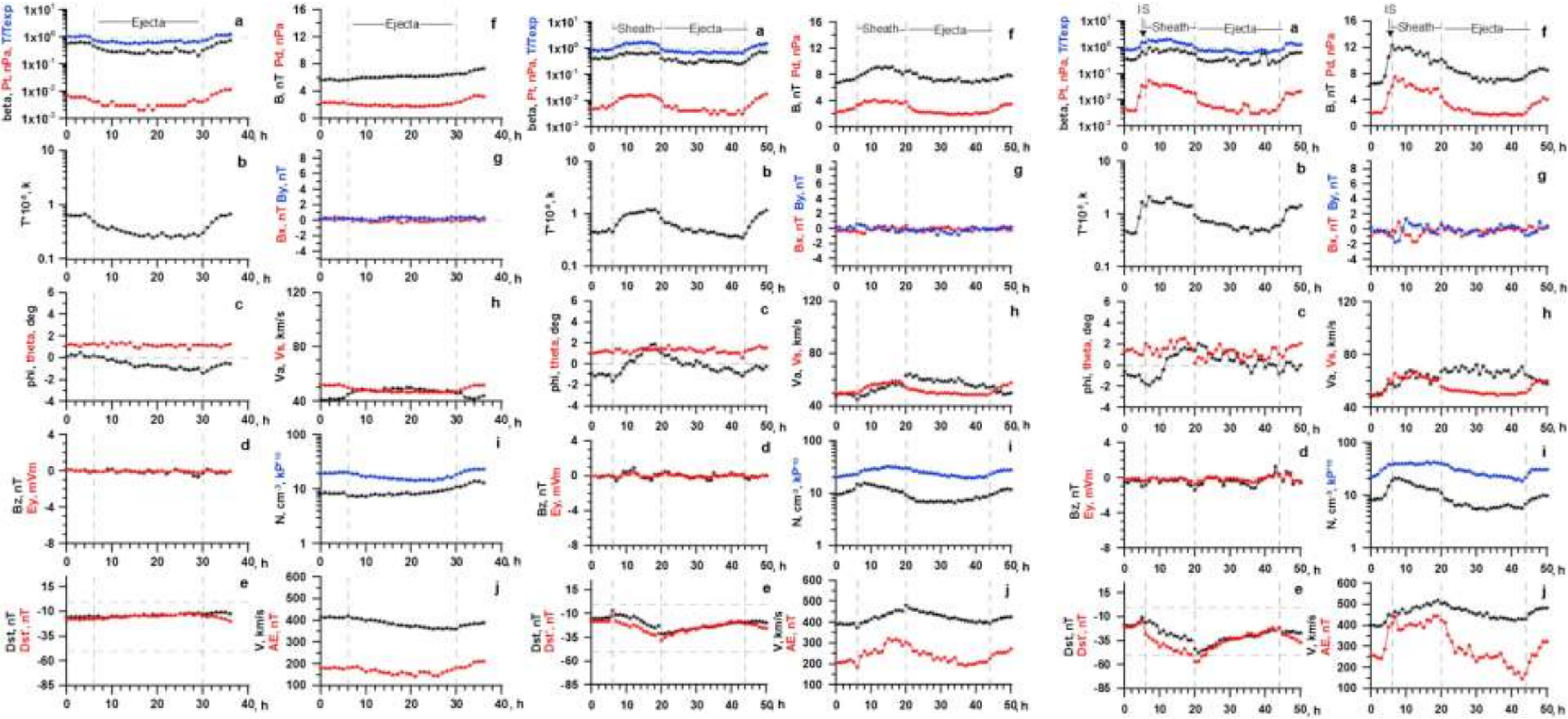


With shock



Yermolaev et al., JGR, 2015

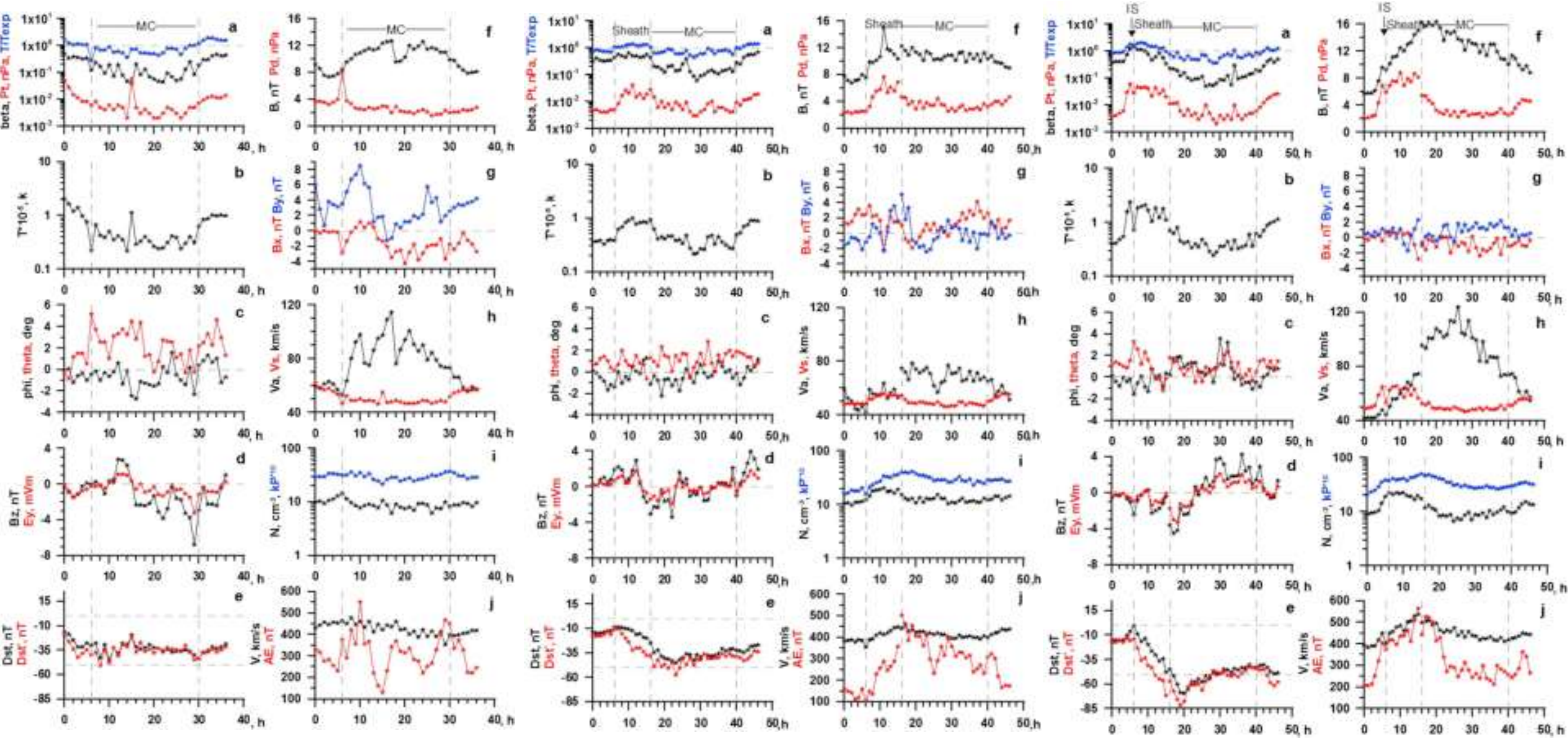
Ejecta



Ejecta | Sheath + Ejecta | IS + Sheath + Ejecta

Yermolaev et al., JGR, 2015

Magnetic Cloud



MC

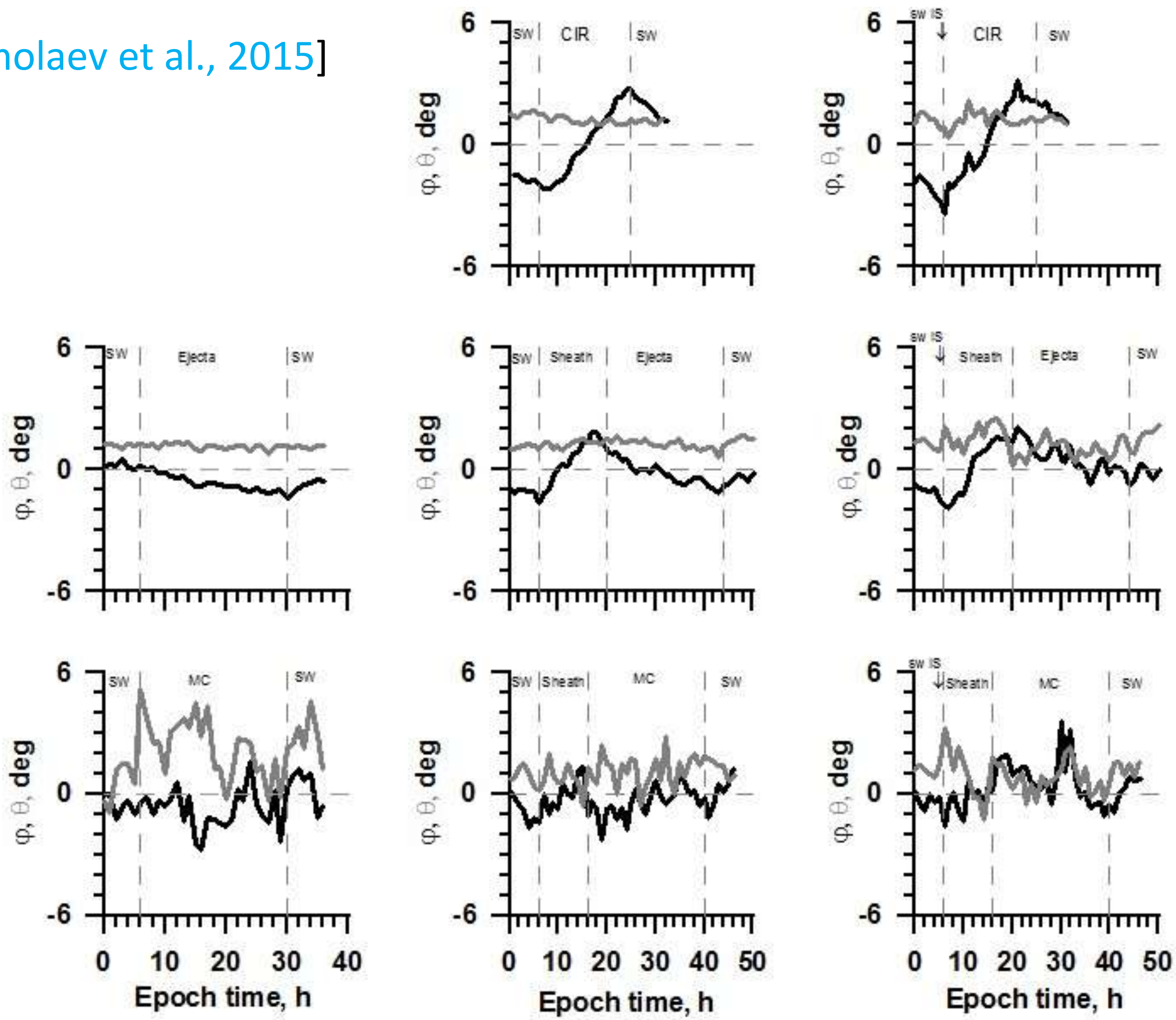
Sheath + MC

IS + Sheath + MC

Yermolaev et al., JGR, 2015

Average behavior of longitude ϕ (black) and latitude ϑ (gray) bulk velocity angles

[Yermolaev et al., 2015]



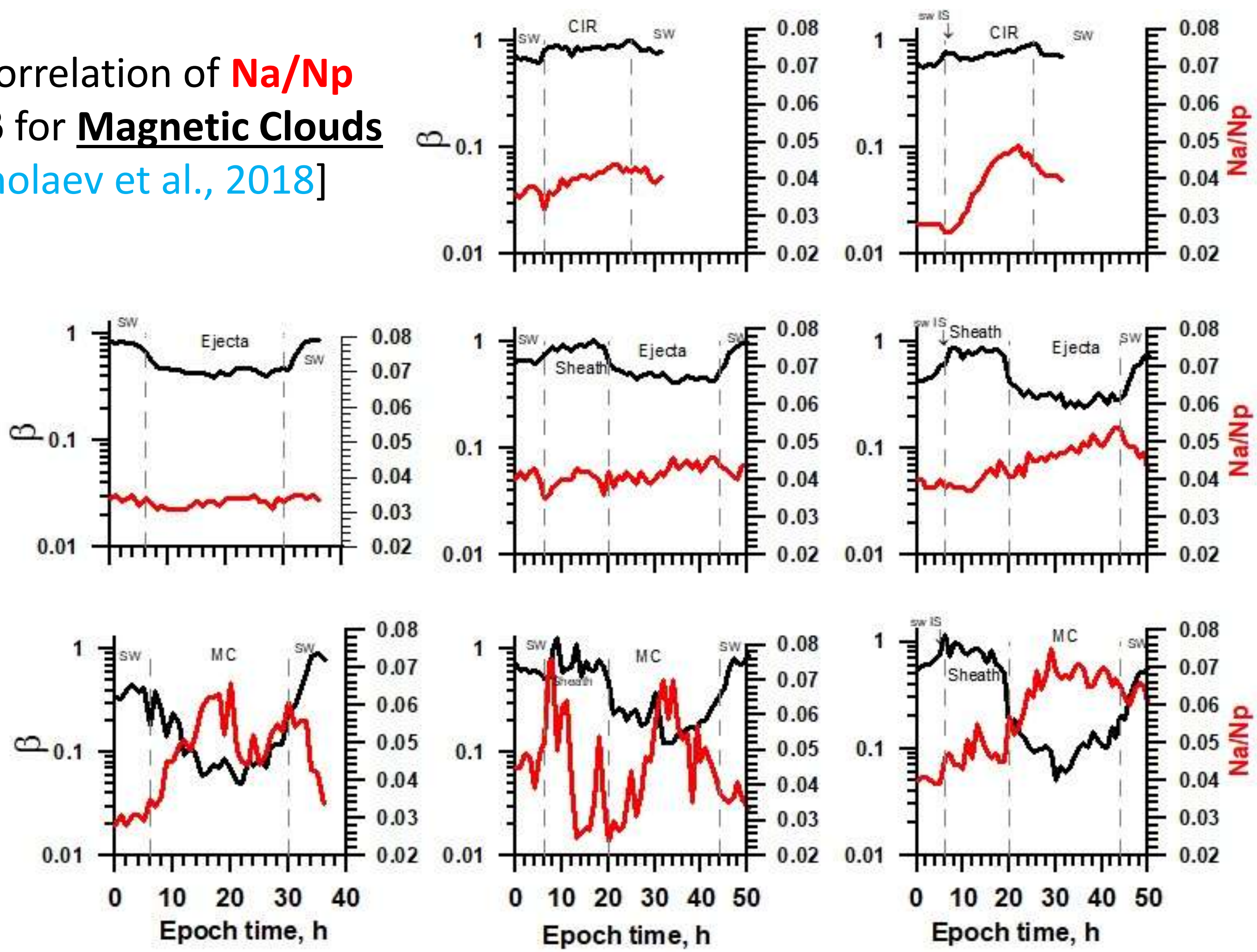
CIR

Ejecta

MC

Average behavior of β-parameter (black) and helium abundance Na/Np (red)

Anticorrelation of **Na/Np** and **β** for **Magnetic Clouds** [Yermolaev et al., 2018]

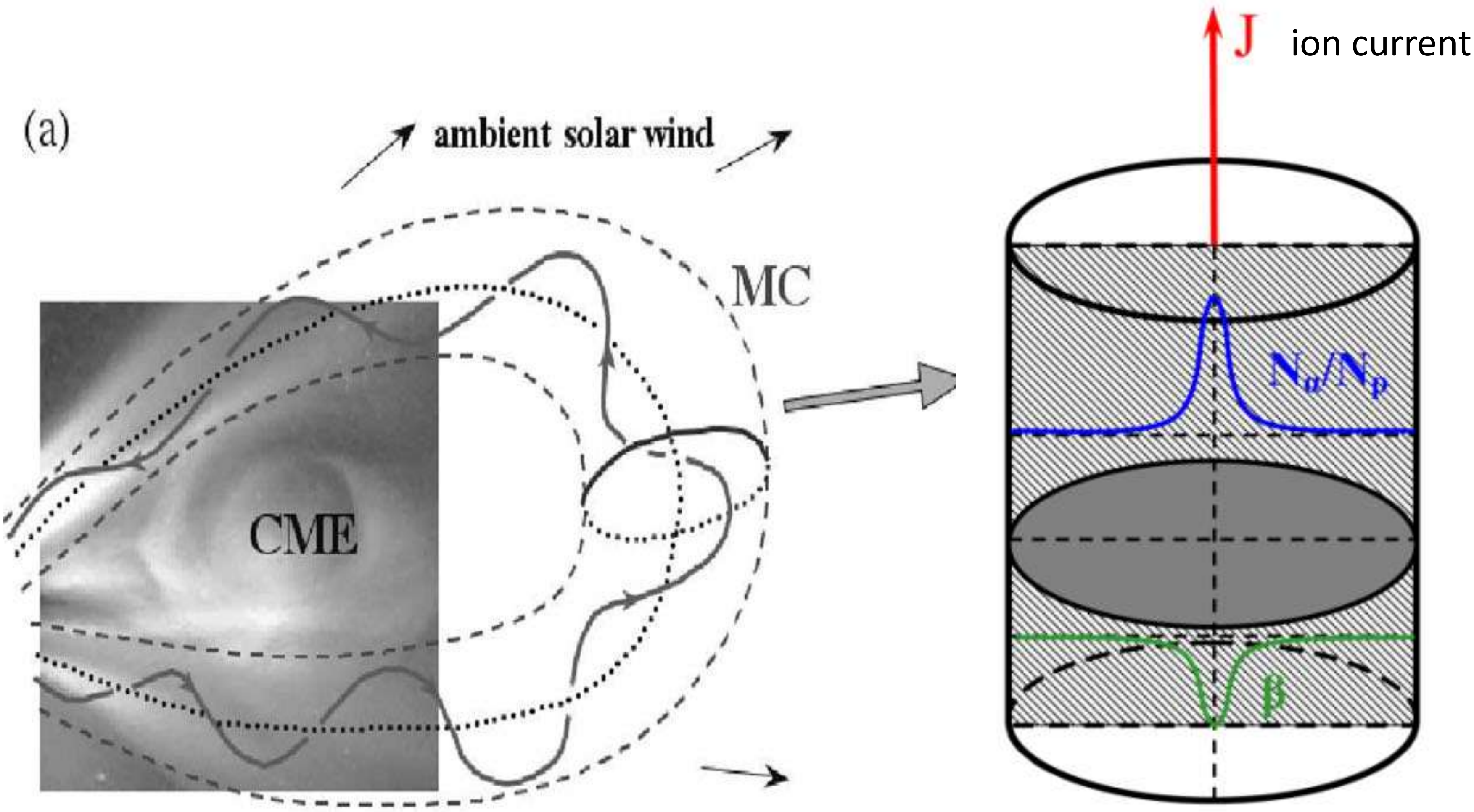


CIR

Ejecta

MC

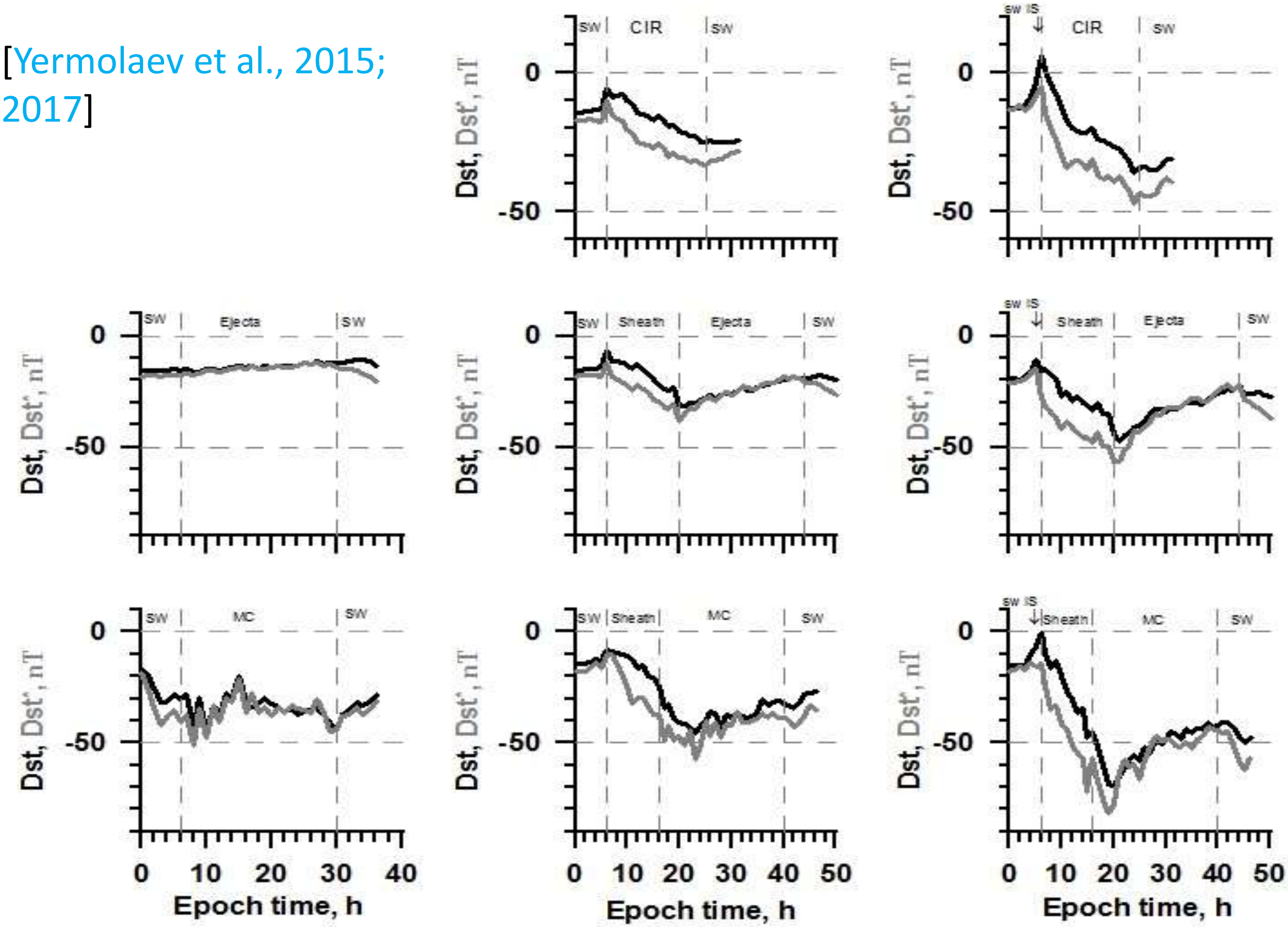
Nα/Np and β spatial distributions in the MC section



High helium contribution in ion current in MC [Yermolaev et al., 2018]

Average behavior of Dst (black) and Dst*(gray) indices

[Yermolaev et al., 2015; 2017]

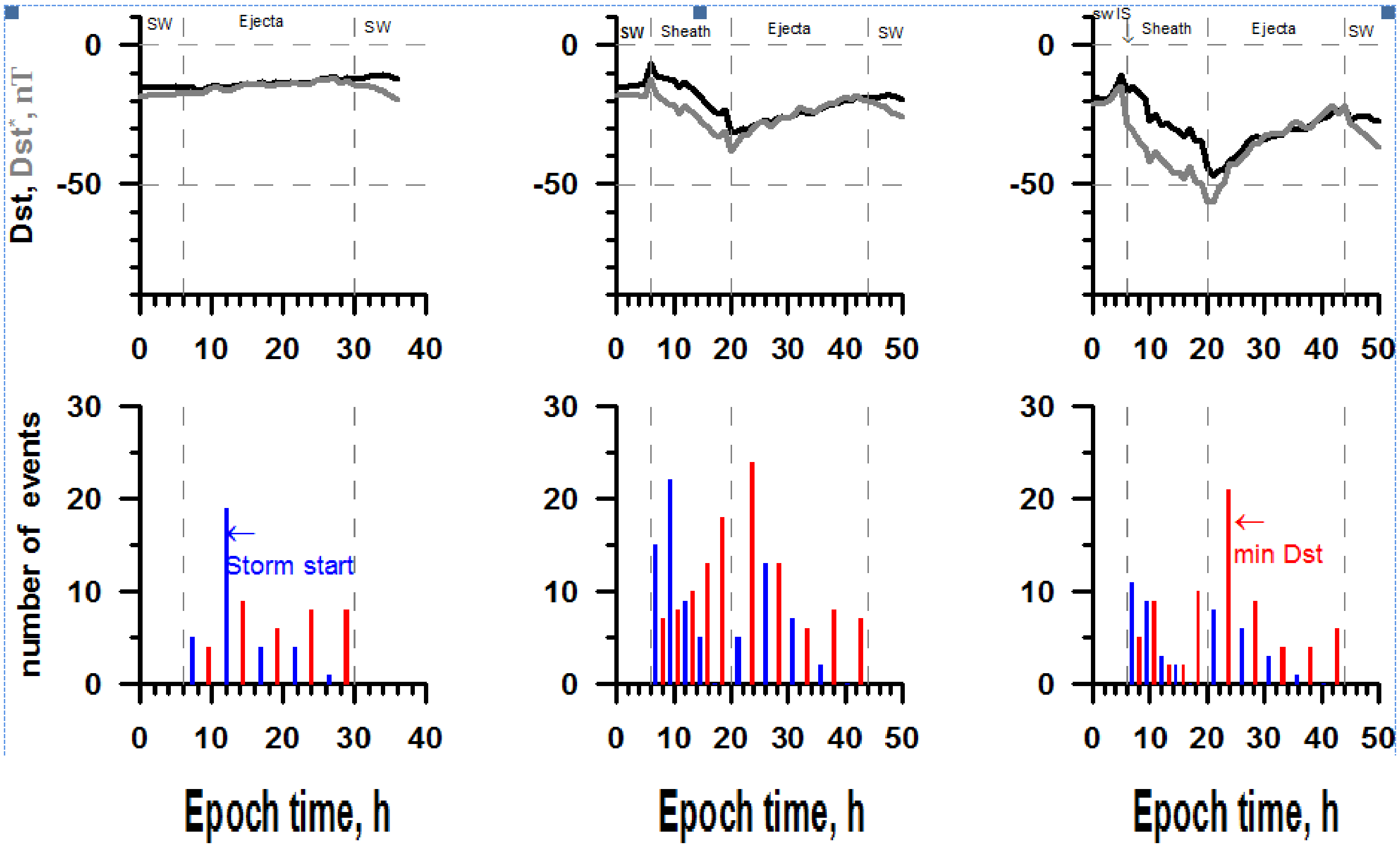


CIR

Ejecta

MC

Average behavior of Dst and Dst* indices and time distributions of storm start and min Dst



Ejecta

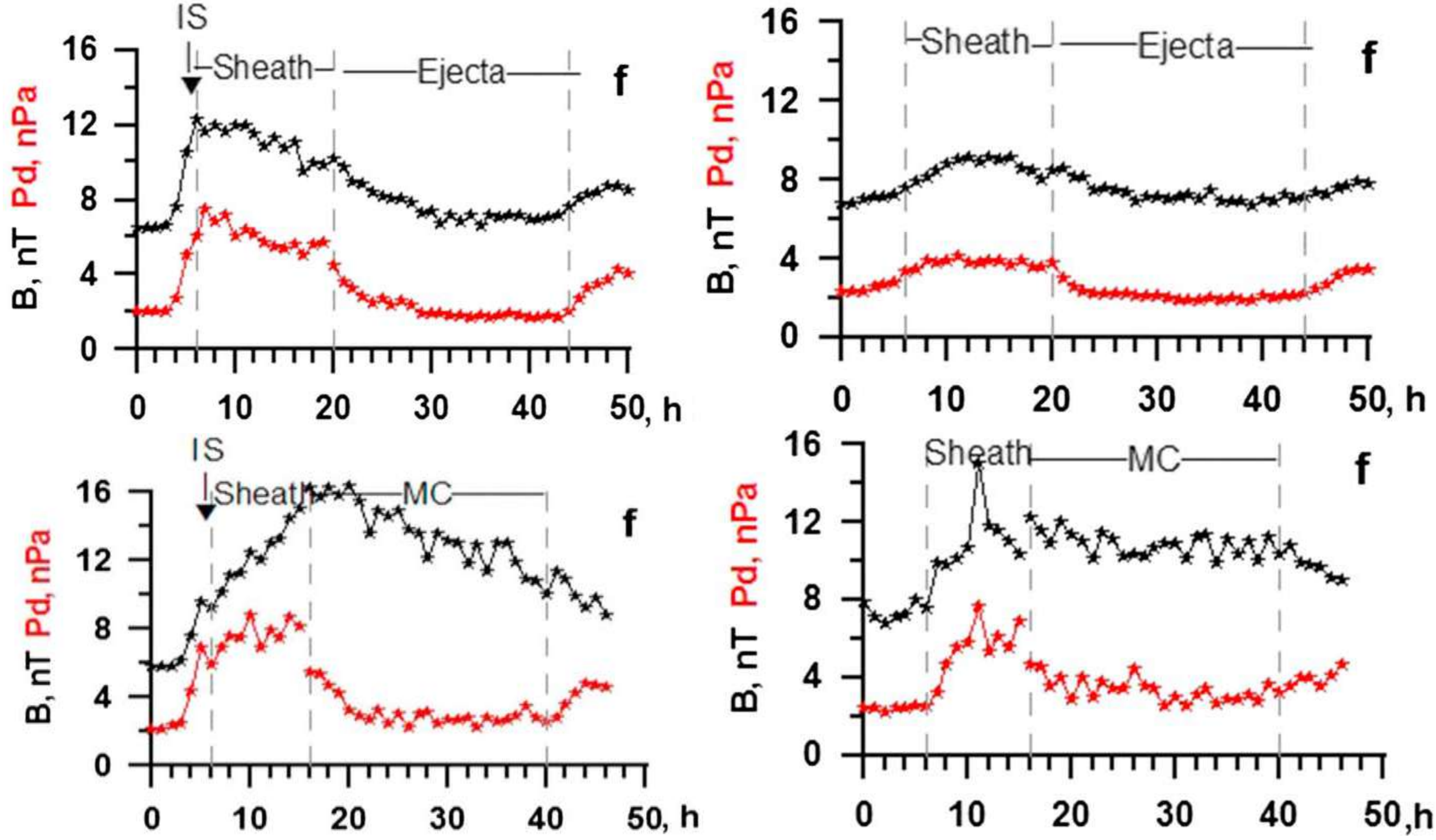
Sheath + Ejecta

IS + Sheath +Ejecta

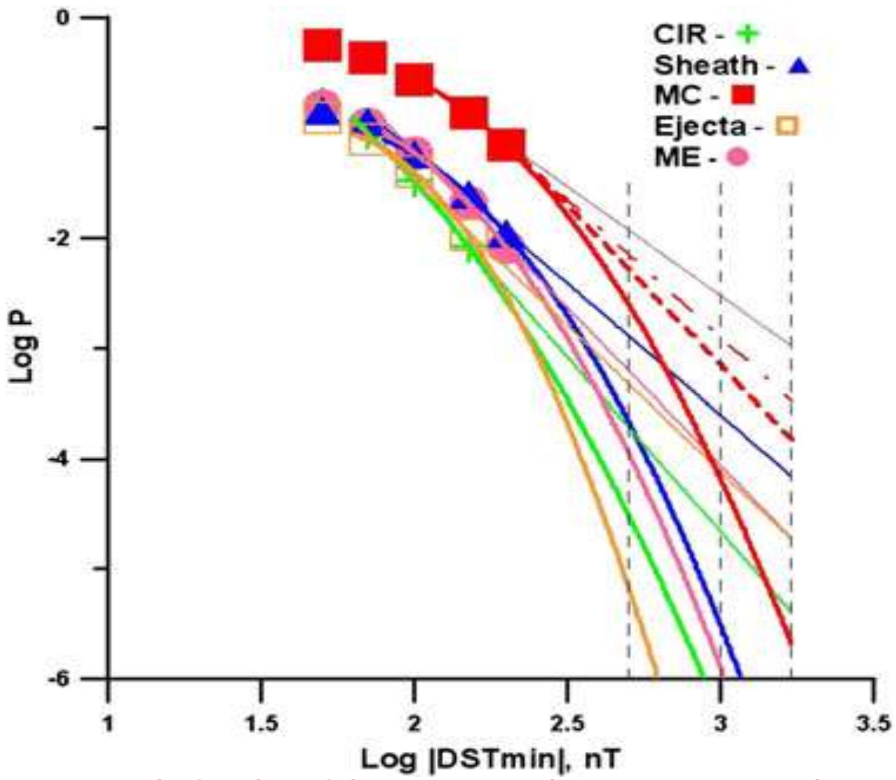
(Yermolaev et al., 2015; 2017)

Average magnetic field in Sheath is higher than in Ejecta and close to MC

(Yermolaev et al., 2015)



Approximations of the integral probability *P*(|*Dst*| > *Dst*0) dependence of storm occurrence with Dst<Dstmin for different types of solar wind.



Vertical dashed lines mark storms with Dst< -500 nT, -1000 nT, and -1700 nT.

The lowest limits of waiting times for extreme magnetic storms T_{MC}(Dst_min< –500 nT) ~ 20 years, T_{MC} (–1000 nT) ~ 120 years, and T_{MC} (–1700 nT) ~ 500 years (with accuracy of factors ~ 1.5, ~ 2, and ~ 3), respectively. [Yermolaev et al., 2013; 2017]

Conclusions

Statistic study of solar and interplanetary data allow us to conclude:

- Main interplanetary sources of storms are CIRs, Sheaths and ICMEs (MC and Ejecta).
- Part of disturbed SW phenomena changed from ~30% in 21-23 solar cycles to ~20% in 24 cycle.
- The longitude speed angle ϕ in ICME changes from *2 to −2*$^\circ$ while in CIR and Sheath it changes from −2 to 2°, i.e., the streams in CIR/Sheath and ICME deflect in the opposite side.
- MCs have maximal Nα/Np and minimal β-parameter (maximal IMF magnitude, B) in the center of them (Yermolaev et al.,2018). This supports theoretical and experimental findings that heavy ions can play important role in the development of current structures in various space plasmas (Kistler et al.,2005; Zelenyi et al.,2006; Grigorenko et al.,2017)
- So-called strong "CME-induced" storms are results of complex phenomena including two geoeffective parts: Sheath and ICME [Yermolaev et al., 2015; 2017].
- Majority of extreme storms are generated by interacting Sheath/ICME structures [Eselevich & Fainshtein, 1993; Wang et al., 2003; Veselovsky et al., 2004; Farrugia et al., 2006; Yermolaev & Yermolaev, 2008; Benacquista et al., 2016 …].
- Extreme storms with Dst < -1700 nT (Carrington-like storms) can be generated on the Earth with frequency not higher than one event during ~ 500 years with accuracy of this factor ~ 3. [Yermolaev et al., 2013; 2017].