Dynamics of large-scale solar wind streams obtained by the double superposed epoch analysis

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Abstract Using the OMNI data for period 1976–2000, we investigate the temporal profiles of 20 plasma and field parameters in the disturbed large-scale types of solar wind (SW): corotating interaction regions (CIR), interplanetary coronal mass ejections (ICME) (both magnetic cloud (MC) and Ejecta), and Sheath as well as the interplanetary shock (IS). 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. As the analyzed SW types can interact with each other and change parameters as a result of such interaction, we investigate separately eight sequences of SW types: (1) CIR, (2) IS/CIR, (3) Ejecta, (4) Sheath/Ejecta, (5) IS/Sheath/Ejecta, (6) MC, (7) Sheath/MC, and (8) IS/Sheath/MC. The main conclusion is that the behavior of parameters in Sheath and in CIR are very similar both qualitatively and quantitatively. Both the high-speed stream (HSS) and the fast ICME play a role of pistons which push the plasma located ahead them. The increase of speed in HSS and ICME leads at first to formation of compression regions (CIR and Sheath, respectively) and then to IS. The occurrence of compression regions and IS increases the probability of growth of magnetospheric activity.

1. Introduction

Studying the large-scale structure of the solar wind (SW) plays the key role in the space weather investigations. As well known the main source of magnetospheric disturbances including the magnetic storms is the southward component $B_z$ of interplanetary magnetic field (IMF) [Dungey, 1961; Fairfield and Cahill Jr, 1966; Rostoker and Falhammar, 1967; Russell et al., 1974; Burton et al., 1975; Akasofu, 1981]. In the steady types of the SW streams the IMF lies near the ecliptic plane, and these types are not geoeffective. Only disturbed types of SW streams can contain the IMF component perpendicular to the ecliptic plane and in particular the southward IMF component. Such disturbed types are the following SW streams: interplanetary manifestation of coronal mass ejection (ICME) including magnetic cloud (MC) and Ejecta, Sheath — compression region before ICME and corotating interaction region (CIR) — compression region before high-speed stream (HSS) of solar wind (see reviews and recent papers by Gonzalez et al. [1999], Huttunen and Koskinen [2004], Yermolaev and Yermolaev [2006, 2010], Zhang et al. [2007], Yermolaev et al. [2012], Hietala et al. [2014], Cid et al. [2014], Katus et al. [2015], and references therein). In the mentioned above works the SW types are considered as sources of magnetospheric disturbance, i.e., the selection of SW events is carried out in connection with magnetospheric activity. There is only a small number of articles in which authors investigate the disturbed types of SW streams without their relation with the magnetospheric activity (see, e.g., papers by Zuruchen and Richardson [2006], Yermolaev et al. [2009], Borovsky and Denton [2010]; Thather and Muller [2011], Richardson and Cane [2012], Mitsakou and Moussas [2014], and Wu and Lepping [2015]). To understand geoeffectiveness of various types of SW streams, it is necessary to compare the characteristics of the streams inducing magnetic storm with the characteristics of all events of this type independently of possibility to storm generation. In the present work we analyze full sets of various solar wind types for interval 1976–2000.

As showed by numerous researches, for the majority of tasks it is not enough to analyze separate values of parameters, and it is necessary to study their dynamics. The analysis of time evolution in the interplanetary parameters using the superposed epoch analysis (SEA) method is more informative. The choice of zero (reference) time for SEA is important and substantially influences the results [Yermolaev et al., 2007; Ilie et al., 2008]. In the most part of the previous papers, the authors use the beginning or end of intervals as zero time for SEA, but this choice is convenient only for studying the beginning or the end of the interval, respectively,
because various SW types have different durations (see, e.g., papers by Yermolaev et al. [2007], Gupta and Badruddin [2009], and references therein). For the analysis of dynamics of parameters in the intervals with different durations the methods are used in which there are two reference times and the initial and final points of intervals are combined with these times, and points between the ends of intervals are transformed by some procedure. For example, in the work of Simms et al. [2010] the measured points only near two reference times are processed by the SEA method, and points between them are not processed and ignored. In other works (see, e.g., papers by Yermolaev and Yermolaev [2010], Kilpua et al. [2013, 2015], Hietala et al. [2014]) the durations of all intervals are made equal by artificial change of distance between points. We use the “double” (with two reference times) SEA method (Yermolaev and Yermolaev, 2010), that is, we rescale the duration of the interval of all SW types in such a manner that, respectively, beginning and end for all intervals of selected SW type coincide.

In the present paper we analyze the full set of disturbed SW types using one method. In addition to average values of parameters we analyze the dynamics of streams by the double superposed epoch analysis. As CIR, Sheath, and interplanetary shock (IS) before them are the result of interaction of different types of streams, we analyze following consequences of streams: (1) CIR, (2) IS/CIR, (3) Ejecta, (4) Sheath/Ejecta, (5) IS/Sheath/Ejecta, (6) MC, (7) Sheath/MC, and (8) IS/Sheath/MC. We analyzed ~50 plasma and IMF parameters for these consequences of streams and obtained very large set of data and figures. Therefore, in this paper we limited the results to 20 parameters, 8 figures, table, and a qualitative discussion of the results. Detailed quantitative discussion of these data will be a subject of the subsequent papers. The organization of the paper is as follows: section 2 describes data and method. In section 3, we present results on dynamics of parameters in various SW types. Section 4 summarizes the results.

2. Methods

We use the 1 h interplanetary plasma and magnetic field data of OMNI database [King and Papitashvili, 2004] as a basis for our investigations. We made our own data archive including OMNI data and calculated (using OMNI data) additional parameters. In order to classify different SW types, we use method similar to ones which are based on comparison of relations of kinetic, thermal, and magnetic field energies in the studied SW streams and the corresponding relations in average solar wind and described in many papers (see reviews by Zurbuchen and Richardson [2006], Wimmer-Schweingruber et al. [2006], Tsurutani et al. [2006], and references therein). For this purpose we determine the following parameters: velocity $V$, density $N$, proton temperature $T$, module and components of IMF, proton thermal pressure $NkT$, proton plasma $β$ parameters (ratio of thermal and magnetic field pressures), ratio of measured temperature, and temperature estimated on the basis of average velocity-temperature relation $T/T_{\text{exp}}$, derivatives of them and compare them with standard threshold criteria which are present in Table 1 of paper by Yermolaev et al. [2009]. Identification procedure which includes (1) automatic comparison of parameters with the corresponding thresholds in each point, (2) calculation of reliability of identification (taking into account weight of various parameters), and (3) direct vision, is described in details in paper by Yermolaev et al. [2009]. This method allows us to identify reliably three types of quasi-stationary streams of the solar wind (heliospheric current sheet, fast streams from the coronal holes, and slow streams from the coronal streamers), five disturbed types (compression regions before fast streams (CIR) and interplanetary manifestations of coronal mass ejections (ICME) that can include magnetic clouds (MC) and Ejecta with the compression region Sheath (SHEMC and SHEEj) preceding them). In contrast with Ejecta, MCs have lower temperature, lower ratio of thermal to magnetic pressure ($β$ parameter), and higher, smooth and rotating magnetic field [Burlaga, 1991]. In addition, we have included into our catalog forward and reverse shocks and the rarefaction region (region with low density) [Yermolaev et al., 2009], but these types of events are not analyzed in this paper. Obtained results of SW identification presented in our website ftp://ftp.iki.rssi.ru/pub/omni/ basically agree with the results of other authors (see, for instance, paper by Thatcher and Müller [2011]), but in contrast with other similar studies, we used a general set of threshold criteria for all SW types and made the identification for each 1 h point.

As we noted in section 1, the purpose of our work is the analysis of dynamics of parameters in the nonstationary disturbed types of the solar wind. Therefore, here we analyze only four types of the solar wind: CIR, Sheath, MC, and Ejecta. We selected only such events for which the SW type and the edges of an interval of the type could be defined on the basis of measurements (measurements of some parameters on this interval could be absent). Such events were 695 for Ejecta, 451 for CIR, 402 for Sheath, and 60 for MC. Because of further selection on adjacent SW types, the subsets of events have lower statistics, the smallest statistics...
Table 1. Average Values of Several Parameters in Figures 1–8

| SW Type | V (km/s) | T (10^5 K) | N (cm⁻³) | B (nT) | 𝛽 | T/Texp | Va (km/s) |
|---------|---------|------------|---------|-------|---|--------|----------|
| SWa     | 383     | 0.48       | 12.2    | 7.7   | 0.40 | 0.96   | 49.9     |
| CIR     | 432 ± 84| 1.21 ± 1.05| 13.5 ± 9.2| 9.2 ± 3.7| 0.66 ± 0.67| 1.69 ± 2.38| 56.4 ± 33.7|
| SWb     | 495     | 1.43       | 8.3     | 7.6   | 0.71 | 1.43   | 57.5     |

*Figure 1: SW/CIR/SW*

| SWa     | 412     | 0.75       | 16.5    | 8.8   | 0.45 | 0.97   | 49.3     |
| CIR     | 474 ± 101| 1.63 ± 1.62| 15.4 ± 11.8| 11.5 ± 4.9| 0.65 ± 0.65| 1.69 ± 1.12| 63.4 ± 24.2|
| SWb     | 528     | 1.58       | 9.7     | 9.2   | 0.74 | 1.36   | 62.7     |

*Figure 2: SW/IS/CIR/SW*

| SWa     | 495     | 1.43       | 8.3     | 7.6   | 0.71 | 1.43   | 57.5     |

*Figure 3: SW/Ejecta/SW*

| SWa     | 412     | 0.59       | 8.6     | 5.6   | 0.58 | 0.98   | 42.4     |
| CIR     | 474 ± 101| 1.63 ± 1.62| 15.4 ± 11.8| 11.5 ± 4.9| 0.65 ± 0.65| 1.69 ± 1.12| 63.4 ± 24.2|
| SWb     | 528     | 1.58       | 9.7     | 9.2   | 0.74 | 1.36   | 62.7     |

*Figure 4: SW/IS/Ejecta/SW*

| SWa     | 392     | 0.50       | 11.5    | 7.2   | 0.40 | 0.89   | 47.8     |
| Sheath  | 427 ± 90| 0.99 ± 0.98| 12.8 ± 8.8| 8.6 ± 3.7 | 0.61 ± 0.64| 1.45 ± 1.13| 53.2 ± 25.6|
| Ejecta  | 425 ± 85| 0.48 ± 0.49| 7.45 ± 5.1| 7.3 ± 3.2 | 0.30 ± 0.36| 0.71 ± 0.58| 59.3 ± 30.9|
| SWb     | 374     | 0.38       | 10.9    | 6.5   | 0.37 | 0.78   | 46.3     |

*Figure 5: SW/IS/Sheath/Ejecta/SW*

| SWa     | 450     | 1.66       | 14.9    | 10.5  | 0.66 | 1.51   | 58.1     |
| Sheath  | 483 ± 105| 1.66 ± 1.87| 16.0 ± 12.9| 11.1 ± 4.7| 0.73 ± 0.80| 1.6 ± 1.19| 63.0 ± 30.3|
| Ejecta  | 455 ± 83| 0.60 ± 0.64| 6.5 ± 5.1 | 7.7 ± 3.0 | 0.33 ± 0.65| 0.73 ± 0.90| 70.3 ± 38.8|
| SWb     | 454     | 0.77       | 7.7     | 8.1   | 0.37 | 0.88   | 63.6     |

*Figure 6: SW/MC/SW*

| SWa     | 452     | 0.77       | 13.0    | 7.8   | 0.35 | 1.01   | 56.7     |
| MC      | 426 ± 117| 0.37 ± 0.38| 8.6 ± 7.7 | 11.1 ± 4.2 | 0.12 ± 0.20| 0.92 ± 3.74| 92.1 ± 56.1|
| SWb     | 393     | 0.83       | 8.9     | 9.7   | 0.30 | 1.55   | 66.3     |

*Figure 7: SW/IS/MC/SW*

| SWa     | 385     | 0.39       | 11.5    | 7.9   | 0.34 | 0.69   | 46.5     |
| Sheath  | 416 ± 96| 0.77 ± 0.77| 17.2 ± 9.9| 10.7 ± 7.1 | 0.49 ± 0.49| 1.22 ± 0.75| 57.4 ± 36.0|
| MC      | 412 ± 81| 0.39 ± 0.49| 12.2 ± 7.4| 10.8 ± 3.6 | 0.17 ± 0.28| 0.71 ± 0.67| 69.7 ± 30.5|
| SWb     | 414     | 0.52       | 12.7    | 10.8  | 0.24 | 0.94   | 66.4     |

*Figure 8: SW/IS/MC/SW*

| SWa     | 448     | 2.40       | 19.3    | 9.5   | 1.18 | 1.82   | 47.6     |
| Sheath  | 486 ± 140| 1.39 ± 1.72| 19.9 ± 12.7| 12.5 ± 6.3 | 0.75 ± 0.98| 1.49 ± 1.05| 64.7 ± 36.4|
| MC      | 449 ± 96| 0.43 ± 0.57| 9.3 ± 8.5 | 13.5 ± 5.5 | 0.12 ± 0.20| 0.59 ± 0.65| 112.7 ± 70.3|
| SWb     | 426     | 0.54       | 9.6     | 11.4  | 0.18 | 0.77   | 74.1     |

*Last SW point before corresponding sequence of disturbed SW types.*

*First SW point after corresponding sequence of disturbed SW types.*

(nine events) was for MC without Sheath and IS (see Figure 6), and in other cases the subsets included from 18 to 372 events. As each type has characteristic (average) duration (see, e.g., Jian et al. [2008], Yermolaev et al. [2009], Mitsakou and Moussas [2014], and references therein), and duration of separate events can differ from average, the most effective way of studying of dynamics of parameters is the method of double superposed epoch analysis (DSEA) [Yermolaev et al., 2010]. We used various fixed durations for various types of streams which are close to average durations of corresponding SW types: 20 h for CIR, 25 h for Ejecta and MC, 14 h for Sheath before Ejecta, and 10 h for Sheath before MC. The time between beginning and end of interval for each event was rescaled (proportionally increased/decreased) such a way that after this transformation all events of separated type of streams have equal durations in the new time reference frame.
Figure 1. The temporal profile of solar wind and IMF parameters for CIR obtained by the double superposed epoch analysis.

To consider influence of both the surrounding undisturbed solar wind, and the interaction of the disturbed types of the solar wind on the parameters, we separately analyze the following sequences of the phenomena: (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 (see Figures 1–8).

Parameters for undisturbed SW intervals (before and after disturbed types) are calculated using the standard (without rescaling duration) SEA method on six points with reference points on the edges of corresponding disturbed types of stream. Thus, though the method used by us is similar to the former DSEA (double superposed epoch analysis) method [Yermolaev et al., 2010], this method is more developed and can be called as multiple superposed epoch analysis (MSEA) method.

To characterize the value of parameters, we use the terms “low”, “high,” and so forth. These terms are qualitative and are defined by comparison with the average value of the corresponding parameter in the undisturbed solar wind. In order to estimate the existence of temporary change of parameter in selected SW type, we
defined the statistical significance of temporal trend as a linear dependence of parameter on time [Bendat and Piersol, 1971]. In all cases, when we write about the temporal change, there are linear dependences with probability not less than 90%.

3. Results

Results are presented in Figures 1–8 which have similar structure and show the following parameters: (a) the ratio of thermal and magnetic pressures ($\beta$), the thermal pressure $P_t$, the ratio of measured and expected temperatures $T/T_{exp}$; (b) the proton temperature $T_p$; (c) the solar wind velocity angles: longitude $\phi$ and latitude $\theta$; (d) the z component of IMF $B_z$ and y component of interplanetary electric field $E_y$; (e) the measured and density-corrected $Dst$ and $Dst^*$ indexes; (f) the magnitude of IMF $B$ and the dynamic pressure $P_d$;
(g) the y and x components of IMF ($B_y$ and $B_x$); (h) the sound and Alfvénic velocities $V_s$ and $V_a$; (i) the ion density $N$ and the $Kp$ index increased by coefficient 10; and (j) the solar wind bulk velocity $V$, the $AE$ index.

For convenience of the reader the basic lines are presented on some panels of figures:

1. In Figures 1a, 2a, 3a, 4a, 5a, 6a, 7a, and 8a the line corresponds to values $\beta = 1$ and $T/T_{exp} = 1$ which are important at identification of SW types.

2. In Figures 1c, 2c, 3c, 4c, 5c, 6c, 7c, and 8c the line shows velocity angles equal to zero.

3. In Figures 1d and 1g, 2d and 2g, 3d and 3g, 4d and 4g, 5d and 5g, 6d and 6g, 7d and 7g, and 8d and 8g the lines show IMF components equal to zero.

4. In Figures 1e, 2e, 3e, 4e, 5e, 6e, 7e, and 8e the lines correspond to values $Dst$ and $Dst^*$ equal to 0 and $-50$ nT, respectively.

Below we discuss the dynamics of these parameters for various consequences of solar wind types.
3.1. CIR and IS/CIR Phenomena

Figures 1 and 2 present the average temporal profiles for sequences of events SW/CIR/SW and SW/IS/CIR/SW, i.e., the distinction between drawings consists in existence of the interplanetary shock (IS) in Figure 2. Vertical dashed lines in the figures show the first (point no. 6) and last (point no. 25) points of CIR interval.

Both figures contain the dynamics of characteristic parameters for CIR type: (1) the high values of the $\beta$ parameter, thermal pressure $P_t$, and ratio of temperatures $T/T_{exp}$ (in comparison with undisturbed solar wind) throughout all interval; (2) the increase of bulk, sound, and Alfvénic speeds throughout all interval; (3) the increase of density; dynamic pressure, and magnitude of magnetic field at the beginning of the interval with the subsequent their reduction by the end of the interval; (4) the gradual increase of temperature and thermal pressure; (5) the turn of the direction of stream from $-2$ to $+2^\circ$ of $\phi$ angle; (6) the Alfvén speed close to sound one; (7) the small average values of components of magnetic and electric fields; (8) the small increase

![Figure 4. The same as in Figure 1 for Sheath + Ejecta.](image-url)
in magnetospheric activity ($D_{st}$, $D_{st}^*$, $K_p$, and $AE$ indexes); and (9) the value of measured $D_{st}$ index higher than the value of density-corrected $D_{st}^*$.

Distinctions between figures generally consist in more abrupt change of a number of parameters when crossing an interplanetary shock. The reason of generation of the shock can be connected with higher speed of the solar wind (changing from 380 to 495 and from 410 to 530 km/s) and higher Alfvénic Mach number (9.1 and 9.5). Main differences are the following:

1. The density, the thermal and dynamic pressures, and the magnitude of magnetic field are higher for CIR with IS.
2. The magnetospheric activity on basis of all indexes is higher for CIR with IS.

It should be noted that the higher variability of several parameters for CIR with IS may be connected with lower statistics of events relative to CIR without IS.

**Figure 5.** The same as in Figure 1 for IS + Sheath + Ejecta.
3.2. Ejecta, Sheath/Ejecta, and IS/Sheath/Ejecta Phenomena

Figures 3–5 present the average temporal profiles for sequences of events SW/Ejecta/SW, SW/Sheath/Ejecta/SW, and SW/IS/Sheath/Ejecta/SW. Three figures have characteristic features of Ejecta: (1) the low values of the $\beta$ parameter, thermal pressure $P_t$, and the ratio of temperatures $T/T_{exp}$ (in comparison with undisturbed solar wind) throughout all interval; (2) the decrease of bulk speed throughout interval; (3) the moderate and low value of density and temperature; and (4) the moderate and high magnitude of magnetic field.

It is possible to note several features of Ejecta dynamics: (1) the decrease of temperature throughout interval; (2) the increase of density throughout interval; (3) the decrease of $\phi$ angle throughout interval; and (4) the Alfven speed is higher than sound one,

Figures 3–5 have the following differences for Ejecta:

1. The bulk and Alfven speeds and the temperature are highest for IS/Sheath/Ejecta and lowest for Ejecta without Sheath.
2. The magnitude of magnetic field for Ejecta without Sheath is lower and slightly increases throughout interval, while it for Ejecta with Sheath is higher and decreases.

3. The Alfvén and sound speeds for Ejecta without Sheath are lower and do not change throughout interval, while they for Ejecta with Sheath are higher and slightly decrease.

4. The \( Dst \) and \( Dst^* \) indexes are close to each other for all subtypes of Ejecta.

5. The \( Dst \) and \( Dst^* \) indexes for Ejecta without Sheath are \( \sim -10 \) nT and do not change throughout interval, while they for Ejecta with Sheath are more negative and increase throughout interval from \( \sim -20 \) nT for Sheath/Ejecta and from \( \sim -50 \) up to \( \sim -30 \) nT for IS/Sheath/Ejecta case.

Main features of Sheath in Figures 4 and 5 are the following:

1. The high values of the \( \beta \) parameter, thermal pressure \( P_t \), and the ratio of temperatures \( T/T_{exp} \) (in comparison with undisturbed solar wind) throughout all interval.

2. The increase of bulk, sound, and Alfvénic speeds throughout all interval.
3. The increase of density, dynamic pressure, and magnitude of magnetic field at the beginning of the interval with the subsequent their reduction by the end of the interval.
4. The gradual increase of temperature and thermal pressure.
5. The turn of the direction of stream from $-2^\circ$ to $+2^\circ$ of $\phi$ angle.
6. The Alfvén speed is close to sound one.
7. The small average values of components of magnetic and electric fields.
8. The small increase in magnetospheric activity ($Dst$, $Dst^*$, $Kp$, and $AE$ indexes).
9. The value of measured $Dst$ index is higher than the value of density-corrected $Dst^*$.

3.3. MC, Sheath/MC, and IS/Sheath/MC Phenomena

Figures 6–8 present the average temporal profiles for sequences of events SW/MC/SW, SW/Sheath/MC/SW, and SW/IS/Sheath/MC/SW. A number of lines have not smooth form because of small statistics. Nevertheless, it is possible to make several conclusions.
Dynamics of MC in Figures 6–8 is close to dynamics of Ejecta in Figures 3–5. These are the following differences between MC and Ejecta.

1. MC has higher magnitude of magnetic field and Alfven speed than Ejecta (in agreement with criterion selection of these types on IMF magnitude).
2. During MC the magnetospheric activity is higher than during Ejecta.

Dynamics of Sheath before MC is close to dynamics of Sheath before Ejecta.

1. Sheath before MC has higher magnitude of magnetic field than before Ejecta.
2. The magnitude of magnetic field is lower in Sheath before MC than in MC, while the magnitude of magnetic field is higher in Sheath before Ejecta than in Ejecta.

4. Discussion and Conclusions

First of all, it should be noted that in most cases the components of the magnetic and electric fields are close to zero while the magnetospheric activity is noticeable. It can be explained by two facts. First, the components in each point can be random, and their averaging results in values close to zero. Second, the magnetospheric activity is not linear function of the components (for example, as showed in our recent empirical works [Nikolaeva et al., 2013, 2015], Dst and Dst* indexes are well approximated by linear function of integral of electric field) and therefore averaging of indexes lead to nonzero result.

In general, our results on temporal profile of parameters in CIR are close to results previously obtained by various authors [e.g., Borovsky and Denton, 2010, and references therein]; however, unlike the previous authors, we made the analysis separately for CIR without IS and with IS. Our results confirm the natural dependence: the formation of IS before CIR is connected with higher bulk speed and Alfven Mach number. Generation of IS before CIR results in the increase of magnitude and components of IMF and therefore in the increase of the magnetospheric activity as illustrated by the variation of all indexes.

Obtained results on average values and temporal profiles of parameters in ICME (both Ejecta and MC) are in good agreement with earlier published results [Zurbuchen and Richardson, 2006; Richardson and Cane, 2012; Mitsakou and Moussas, 2014]. In addition to previous data we consider separately ICME with Sheath and IS and ICME without them. Our results show that the formations of Sheath and then IS before ICME are connected with increasing bulk speed and Alfven Mach number. Occurrences of Sheath and then IS before ICME increase the magnitude and components of IMF and therefore increase the magnetospheric activity.

In contrast with the CIR and ICME types, the Sheath type is investigated rather poorly, and our analysis, apparently, is the first analysis of this sort. The main conclusion is that the convincing evidence is obtained that the behavior of parameters in Sheath and in CIR is very similar not only qualitatively (on the temporary profiles) but also quantitatively.

The indication in favor of a hypothesis is obtained that the speed angle $\phi$ in ICME changes from $2$ to $-2^\circ$ while in CIR and Sheath it changes from $-2$ to $2^\circ$, i.e., the streams in CIR/Sheath and ICME deviate in the opposite side. It can be explained by the interaction of fast ICME with slow plasma in Sheath.

We consider that the results presented here are only the initial stage of researches: in the subsequent works we plan to describe in detail some interesting facts which are described only briefly here and also to compare the full set of events to events which were geoeffective.

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