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POSSIBLE PREDICTORS OF TYPICAL MAGNETIC STORMS DURING SOLAR CYCLE 24

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Abstract: *Based on five strong gemagnetic storms with Dst ≤ -100 nT and five weak geomagnetic storms with Dst > -100nT we studied the behavior of the basic parameters of the solar plasma: the speed, density and temperature of the solar wind, and the four components of the interplanetary magnetic field: Bx, By, Bz and Bt. The behavior has been studied for ten days before geomagnetic storms. Morphological analysis shows that before the onset of geomagnetic storms there is a change of 2 to 3 days in the field of temperature, which during strong geomagnetic storm is a sharply delineated large and sudden decline. After it the temperature remains approximately constant two to three days before the start of the storm itself. During weak geomagnetic storms such change is absent and there is a gradual decrease in temperature. So it is more difficult to determine a starting point for the stationing of temperature, which leads to more difficult determination of the onset of geomagnetic storm.*

The reduction in speed may also be used as a predictor for 2 to 3 days, but there the form of the drop is even more complicated due to the exponential form of the distribution of the values of velocity in time.

These are initial studies which can not readily predict whether or not there will be a geomagnetic storm. But the fact that there is a change in the basic parameters of solar plasma before geomagnetic storms, could serve as a precursor in forecast space weather.This requires the continuation of this kind of research.

ВЪЗМОЖНИ ПРЕДВЕСТНИЦИ НА ХАРАКТЕРНИ МАГНИТНИ БУРИ ПРЕЗ 24-ТИ СЛЪНЧЕВ ЦИКЪЛ

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Ключови думи: *Космическо време, Геомагнитни бури, Магнитни облаци.*

Резюме: *На базата на пет силни геомагнитни бури с Dst ≤ -100nT и пет слаби геомагнитни бури с Dst > -100nT е изследвано поведението на основните параметри на слънчевата плазма: скорост, плътност и температура на слъневия вятър, и четирите компоненти на междупланетното магнитно поле: Bx, By, Bz и Bt. Това поведение е изследвано за десет дни преди геомагнитните бури. Морфологичният анализ показва, че 2-3 дена преди настъпване на геомагнитните бури има изменение в полето на температурата, което при силни геомагнитни бури е рязко очертано със скок спад, след който температурата стационира от 2 до 3 дни преди започване на самата буря. При слаби геомагнитни бури липсва такъв рязък скок, а има постепенно понижение на температурата и по-трудно може да бъде определен началния момент на стациониране на температурата, което води до по-трудно определяне на появата на геомагнитна буря.*

Понижението на скоростта също може да бъде използвано като предвестник с 2 до 3 дена, но там формата на спада е още по-усложнена поради експоненциалната форма на разпределение на стойностите на скоростта във времето.

Това са начални изследвания, от които не може еднозначно да се предскаже дали ще има или няма да има геомагнитна буря. Но фактът, че се наблюдава изменение в основните параметри на слънчевата плазма преди геомагнитни бури, би могъл да послужи като предвестник в прогнозата на космическото време. Това изисква продължаването на този вид изследвания.

Introduction

In the contemporary conditions of the space weather study special attention is made on the sources of the Sun, the parameters of space plasma (mainly solar wind) and the magnetosphere. The sources on the Sun, such as Coronal Mass Ejections (CME), Coronal Holes (CH), Solar Flares (SF), Corotating Interaction Regions (CIR), etc. [1, 2, 3] are the main disturbances in the interplanetary medium. The interplanetary medium is characterized by the speed of the solar wind (SW) [4], the density and temperature of the space plasma, and the components of interplanetary magnetic field, respectively [5].

When studying and forecasting of the space weather a basic information is obtained from the spacecrafts SOHO and ACE, which are located in the Lagrange point L1 [6], one of the equilibrium points between the Sun and Earth, which is located at a distance of 1.5 million kilometers from Earth. In fact, the data from both satellites are the only information for prediction of the interplanetary medium, which is used in real time, in particular of the plasma flow before it interacts with the Earth's magnetosphere and forms the magnetopause. The solar plasma travels the distance between Lagrange point and magnetopause for about 1 - 1,5 hours, depending on its velocity [7]. It is too soon to predict the response of the magnetosphere and the effects in Earth's magnetic field, i.e. the geomagnetic storms.

But even in the short-term prognosis, such as one-hour forecast of geomagnetic activity, the accuracy is not always enough, and we can say it is unsatisfactory in most cases, especially during geomagnetic storms. As for the short-term forecast (of the order of three to eight days) the accuracy is more related (in most cases) with the appearance of geomagnetic storms, than to the magnitude of geomagnetic disturbances. Therefore, the monitoring of overall state of the above mentioned parameters of interplanetary medium appears an important element of its forecasting.

The task, that at first step we set ourselves, is to follow these interplanetary parameters known to us before a geomagnetic storm and to determine how they relate to each other, i.e. before geomagnetic storm, what was the behavior in SW speed, density and temperature and in the magnetic field components at the point of Lagrange L1. For this purpose we used some geomagnetic storms observed by us in the 24-th solar cycle. We made a conditional separation of geomagnetic storms into two main categories: strong geomagnetic storms with Dst index (which has a reasonable physical assessment) ≤ -100 nT and weak geomagnetic storms with Dst > -100 nT.

Here the storms that are examined are the following:

(1) strong geomagnetic storms on:

7-8 October 2015, 17 March 2015, 17 March 2013, 9 March 2012 and 24 October 2011;

(2) weak geomagnetic storms on:

27 August 2015, 16 August 2015, 04 July 2015, 10 and 15 July 2013.

Analysis

What does morphological analysis of graphs describe at least ten days before geomagnetic storms? First we must emphasize that all the hourly values of the interplanetary medium have been taken. Smoothing was not done because our aim is to register every change in every hour, not to track averaged behavior of the parameters.

1. Strong geomagnetic storms Dst ≤ -100 nT

<u>7-8 October 2015</u>: Ap = 65/44, v = 936 km/s, Dst = -100 / 110 nT, Bz = -14 nT, By = + 14 nT. The most important parameter with a special behavior is ion temperature. The behavior of the temperature is characterized by sharp decrease of T from $3x10^5$ to $1x10^5$ K°. Then for 2.5 days the value of T oscillates around $1x10^5$ K°. Such behavior has the SW velocity: from 480 km/sec it drops below 400 km/sec. This behavior change is more gradual. In our opinion, two parameters, ion temperature and velocity of SW, are connected to a common physical process. The proton flux density has a significant decrease 3 days before the geomagnetic storms - on 4 October, according the storms on October 7-8. The source which provoked the geomagnetic storm is a co-rotating interaction region with coronal holes. It causes the solar wind (SW) acceleration. A gradual decrease of the SW velocity from 500 to 390 km/s two days before the geomagnetic storm is measured. After that a jumping increase of the SW velocity appears (Fig.1).

17 March 2015: This storm is preceded by calm values of Dst, which are around 0. Bz component of 17.03. has a characteristic oscillating behavior and reaches -22 nT. The behavior of the other two components is not remarkable. The speed of the solar plasma starts to fall from 420 km/s (March 13) and reaches its minimum at 15.03. evening - about 300 km/s. This behavior of the SW flow is smooth for 2.5 days. After the minimum the velocity starts incrementally to increase. The new maximum is reached on March 17 at the beginning of the geomagnetic storm - 600 km/s. The temperature behavior of protons is interesting. On March 13 there is a sudden drop in temperature, not as in the previous days, when there are sinus-oscillations. Then for 3 days, 14-16 and at the beginning of 17 March, the temperature was kept constant low, such as it has been decreased on 13 March. Only after the onset of geomagnetic storm the temperature jumps sharply from 0.5 to $5x10^5$ K°. The characteristic values are the following: Dst = -223 nT, Ap = 10^8. The storm was triggered by CME on 15.03.2015 as a consequence of magnetic thread breaking. There are two coronal holes in the northern and southern solar hemispheres. The time interval where a temperature and velocity decrease appears, correspond probably to magnetic cloud transport [8] (Fig.2). In dependence on the magnetic cloud structure there is different behavior of the solar plasma parameters.

17 March 2013: Values of Dst = -130 nT and Ap = 72. It is caused by CME of 15 March and by coronal hole in the southern hemisphere. Solar wind speed is in the range 300-700 km / s. Before the geomagnetic storm Dst values oscillate around 0 over 6 days. Bz has a typical decrease to more than -10 nT. By has a particular behavior three days before the geomagnetic storm - there is an increase of oscillating values around 0 to 5 nT, and then there are oscillations around zero at the rate of 10 nT and even more. The change of the speed of solar wind with this storm is radically different from that in previous cases. Two days before the geomagnetic storms the speed increases stepwise, and during the storm itself increases significantly from 400 to 720 km/s. The temperature Tp of protons despite of many data gaps, emerged the following picture: from March 10 to March 14 Tp oscillates around the absolute zero. On March 14, it leaps and reaches $1x10^5$K and again on March 15 it increases to $2x10^5$K. Tp then falls back to $1x10^5$K and lasts almost two days. Despite the changed behavior of Tp with the initial jump 1.5 days before the geomagnetic storm, the scenario remains and the temperature keeps a similar behaviour as that during the previous geomagnetic storms, i.e. there is still a relative decrease in T before the geomagnetic storm. Regarding the the proton flux density, we could not comment it because of lack of data and the fragmentation of their plotting.(Fig. 3).

9 March 2012: We look at the geomagnetic storm which has two stages: the first is on March 7, 2012 with Dst = -70 nT and the second geomagnetic storm is on March 9 with Dst = -130 nT. At the maximum of the storm Ap = 87. On 6.03. a frontally directed CME to Earth is observed. Bz component during the first geomagnetic storm from 7.03. jumped with +5 nT and with +10 nT and oscillated with -4 nT around 0. During the second geomagnetic storm from 9.03. there is an even greater increase in Bz from +5 nT to +25 nT. Ultimately Bz behavior is not typical but it is a problem for another study. Tp behavior of protons is similar to that, during previous geomagnetic storms, with a sharp drop of 1.5 days before the first geomagnetic storm of 7.03. For the second geomagnetic storm there are missing data. The same applies to the flux density of protons. The storm is caused by a great sunspot (Fig. 4).

24 October 2011: The minimum value of Dst is Dst = -150 nT. 7 days before the geomagnetic storm Dst values oscillate around 0 and a little below it. Bz has typical behavior with a fall during the geomagnetic storm with values -10 nT. Unfortunately, the speed and temperature of the proton flow are not full prior to and during the geomagnetic storm, so we can not do any interpretations.(Fig. 5).

Minor geomagnetic storms: Dst > -100 nT

23 and 26 August 2015: Two small geomagnetic storms are considered: weaker from 23.08.2015 with Dst = -50 nT and from 26.08.2015 with Dst = -90 nT. Bz component has standard behavior. At the first storm the decrease is 10 nT, at the second it is 11 nT. The solar plasma speed behavior shows a decrease from 450 to 350 km/s. It is continuous like by the strong geomagnetic storms. Now the duration is smaller, it is 1.5 days. After that the speed increases up to 590-600 km/s as during the first weaker storm.

The behavior of the other parameter, the ion temperature, shows a decrease, which continues 2 days but this decrease is not sharp, it is gradual. That is different from the case of strong geomagnetic storms. For the second geomagnetic storm on 26.08.15 we cannot make conclusions because the solar wind parameters – speed and temperature – are influenced by the previous storm. It is caused by coronal hole in the Southern hemisphere (Fig. 6).

16 August 2015. The next geomagnetic storm begins on 15.08.2015 and reaches maximum of development on 16.08.2015 with values Dst = -84 nT, Ap=31. It is a result of transequatorial coronal hole. The Dst values before the geomagnetic storm oscillate between 0 and -20 nT. The Bz

component behavior of the interplanetary magnetic field is standard and the decrease reaches -18 nT. It is interesting that 1 day before the storm the Bx component decreases gradually during 1 day from -2 to -8 nT.

The temperature rapidly decreases 3 days before the geomagnetic storm and oscillates near the value of $5x10^4$K. The other parameter which characterizes the interplanetary environment is the solar wind speed. It decreases gradually 2 days before the geomagnetic storm. This decrease has small gradient but it is with stable trend almost without oscillations (Fig. 7).

4 July 2015. The next relatively weak geomagnetic storm begins on 4.07.2015 and reaches its maximum on 5.07.2015. The second geomagnetic storm in relatively short time interval is on 11.07.2015 and continues with second deeper minimum on 13.07.2015. The value of Dst=-60 nT. Bz component of interplanetary geomagnetic field shows classical behavior with decrease of -10 nT for the first geomagnetic storm and -7 nT for the second. Bx and By have respectively increase and decrease and mark both geomagnetic storms.

The solar wind speed behavior is clearly expressed with decrease and stable trend without oscillations in an interval longer than 2 days before the geomagnetic storm. Before and during the first geomagnetic storm there is rapid increase of speed from 300 to 550 km/s. Similar behavior is observed also by the second geomagnetic storm in the solar wind speed. Concerning the ion temperature by the first and by the second storm there is 2-3 days decrease. But it is with smaller gradient in comparison with the strong geomagnetic storms (Fig. 8). The geomagnetic storm is generated by co-rotating interaction region coronal hole.

We consider the last two geomagnetic storms from July 2013.

10 July 2013. The first geomagnetic storm is from 10.07.2013 with minimal value of Dst = -45 nT. This geomagnetic storm is caused by slowly moving coronal mass ejection from 6.07.2013 which reaches the terrestrial magnetosphere on 10 July. The Bz behavior is not standard. There is an increase with 10 nT before the storm. The other geomagnetic field components have stochastic character and it is difficult to make concrete conclusions. Some conclusions for solar wind temperature and speed cannot be made because of lack of data (Fig.9).

15 July 2013. The second geomagnetic storm appears on 13.07. and reaches minimal values of Dst = -75 nT on 15.07.13. This storm is a result from CME shock wave periphery which passes on 13.07 near the Earth. By that storm also Bz component has not standard behavior as its values increase with more than 10 nT. The solar wind speed increases rapidly from 400 to 500 km/s 1 day before the storm.

After that the velocity decreases gradually in the period of geomagnetic storm development. One day before the geomagnetic storm begin the proton temperature decreases rapidly from $2x10^5$ K to $2x10^4$K. After that the temperature remains almost constant until the geomagnetic storm maximum. The proton flux density cannot be analyzed because of lack of data during investigated period.(Fig 9).

Analysis and conclusions

In the analyzes made of the two types of magnetic storms we can make some conclusions about the three main parameters of the solar wind - speed, temperature and density. Each of them has a similar, yet differing behavior depending on whether it is strong or weak geomagnetic storm.

By strong geomagnetic storms it is clearly seen that the temperature decreased by a sharp rise by 2 to 3 days before the beginning of the storm. While the weak geomagnetic storms have again lower temperatures, but it becomes a smooth transition and the time before the storm is reduced by 1 to 1.5 days.

As regards the velocity of the solar wind - also a decrease in speed is obseved, which, however, is expressed in a continuous steady trend of decrease, which may last 1-2 days before the geomagnetic storm. There are also cases of elevated speed, which has the same kind of trend, but with a rise up. Following our opinion, it depends on the magnetic cloud field whether an increase or a decrease of the velocity appears. The kind of the source of the disturbance is not so important for it. The time interval where the temperature and the velocity are decreased probably corresponds to magnetic cloud transfer. In dependence on the structure of the magnetic cloud there is different behavior of the solar plasma parameters [8].

Such temperature decreases in the solar plasma have been investigated yet in the 90s of the previous century [9]. Usually they are related to CME and the duration of these regions is 1 to 80 hours. Approximately one third of the cases present a meeting with the heliospheric plasma sheet

(HPS). Such events are observed more often at solar activity increases when HPS lies near the ecliptic. The irregular low temperatures could be related to HPS.

With respect to the SW density, it also has a similar course as the temperature, but with much internal oscillations and it can be hardly defined the start and the end of density variation of the interplanetary environment compared to the beginning of the geomagnetic storm.

The morphological analysis showed that before the onset of geomagnetic storm there is a change of 2 to 3 days in the field of temperature, which by strong geomagnetic storm is sharply outlined jump-shaped drop, after which the temperature stationed two to three days before the start of the storm itself.

In weak geomagnetic storm the surge is absent and there is a gradual decrease in temperature and it is more difficult to define a starting point for the stationing of temperature, which leads to more difficult determination of the onset of geomagnetic storm.

The reduction in velocity may also be used as a predictor of 2 to 3 days, but there the form of a drop is even more complicated due to the exponential form of the distribution of the values of velocity in time.

So established before geomagnetic storms histories of SW temperature and velocity indicate the presence of certain space-time structures that are crucial for the impact on the Earth's magnetosphere and on the Earth in general.

These structures are important also for the impact of such cosmological factors as galactic cosmic rays and solar energetic particles on the Earth environment. They can play the role of a lens for focus and defocus of the above mentioned factors [10, 11].

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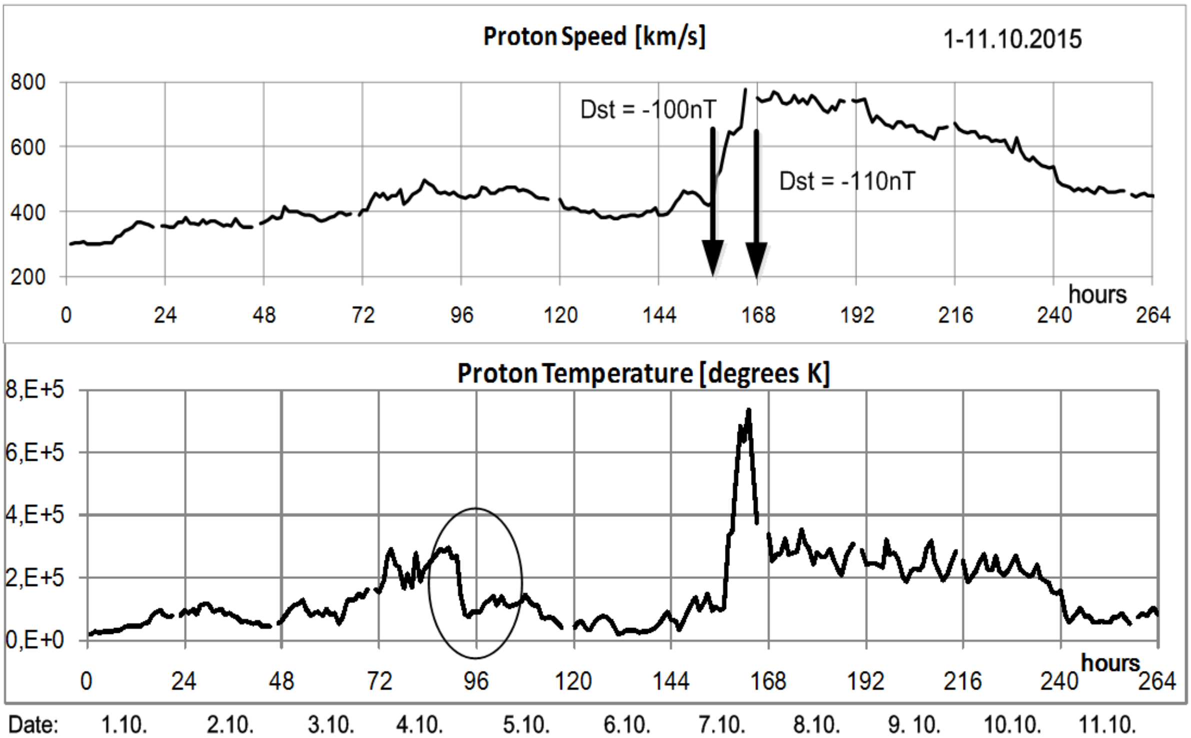

Fig. 1. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 7 and 8 October 2015 with minimal Dst = -110 nT. Most evident is the sudden decrease of temperature, for hours (it is shown with ellipse over the temperature course), and after that almost permanent keeping of low T values. All values are measured every one hour.

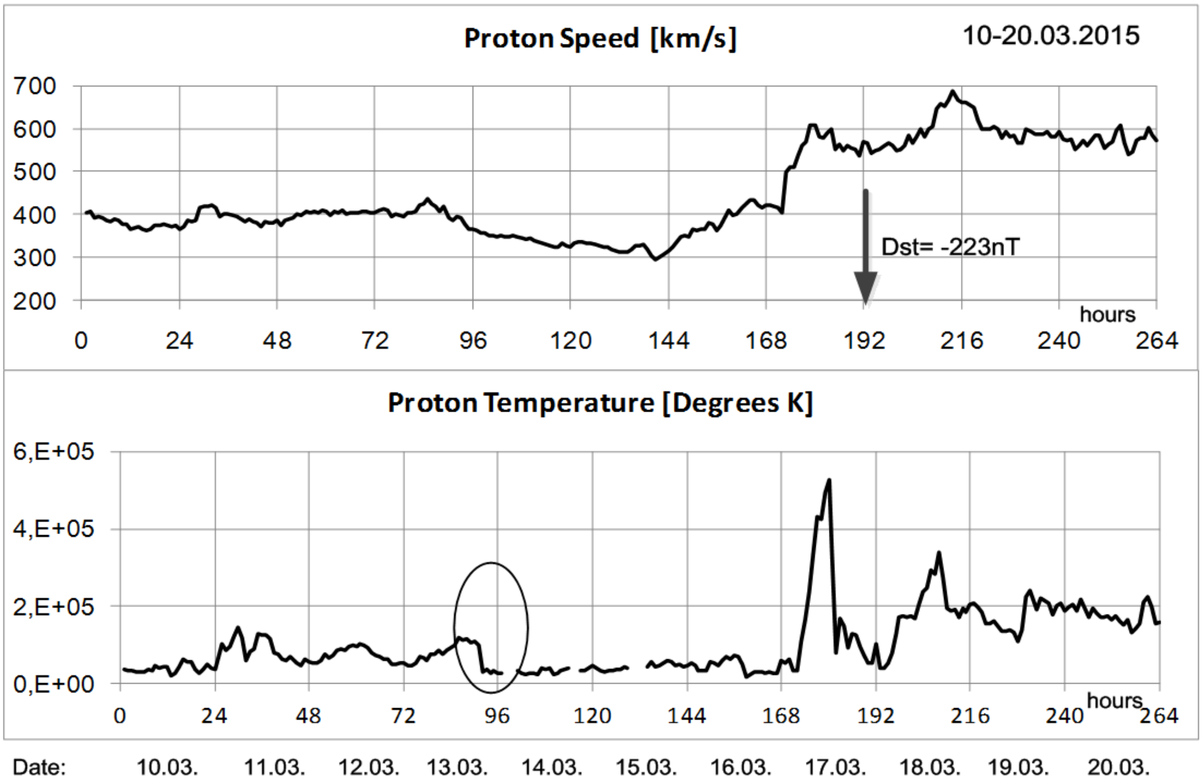

Fig. 2. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 17 March 2015 with minimal Dst = -223 nT. Most evident is the sudden decrease of temperature, for hours (it is shown with ellipse over the temperature course), and after that almost permanent keeping of low T values. All values are measured every one hour.

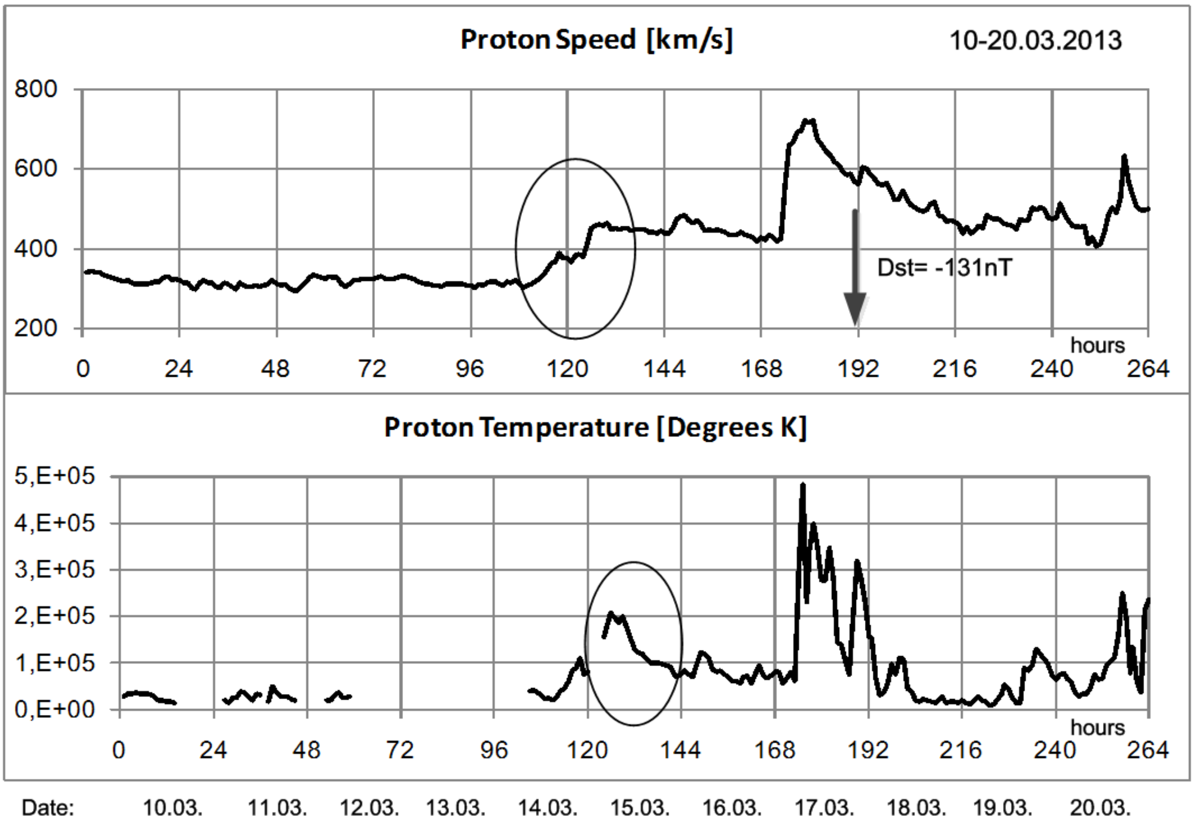

Fig. 3. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 17 March 2013 with minimal Dst = -131 nT. Most evident is the sudden decrease of temperature, for hours (it is shown with ellipse over the temperature course), and after that almost permanent keeping of low T values. All values are measured every one hour.

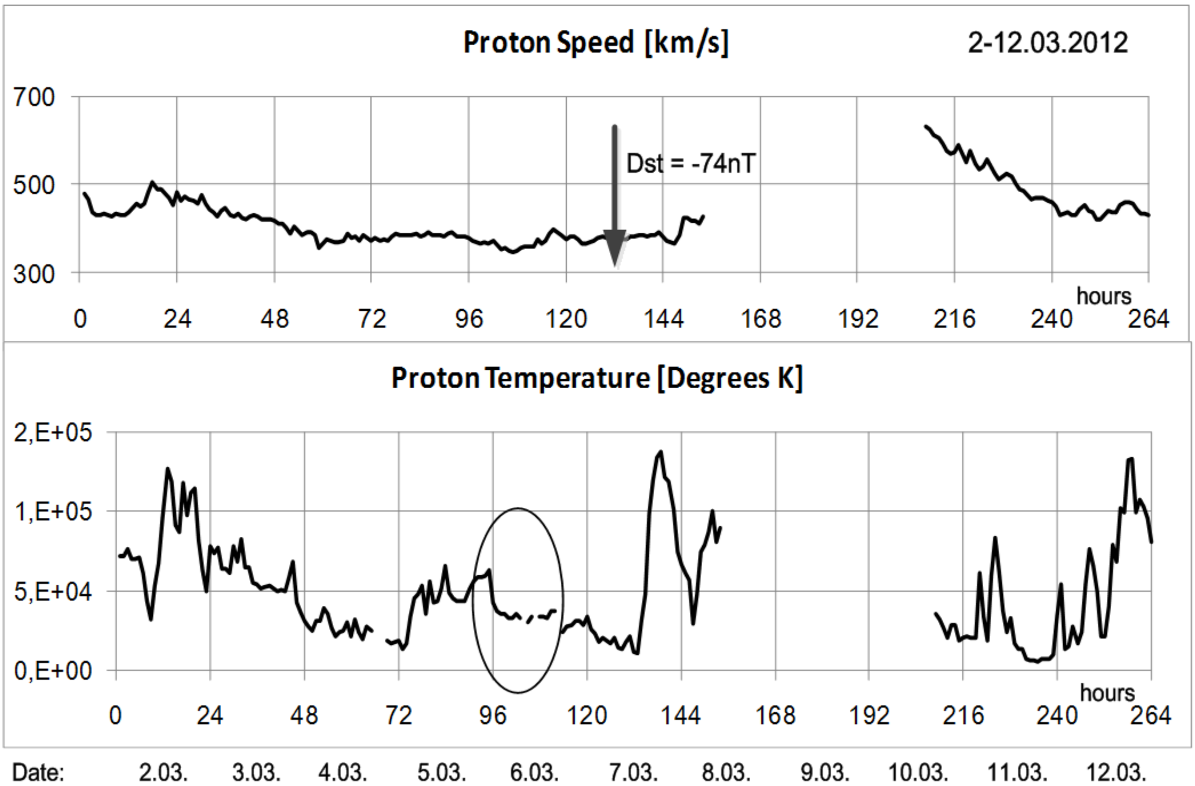

Fig. 4. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 7 March 2012 with minimal Dst = -74 nT. In the temperature course the decrease is observable (it is drawn with ellipse).

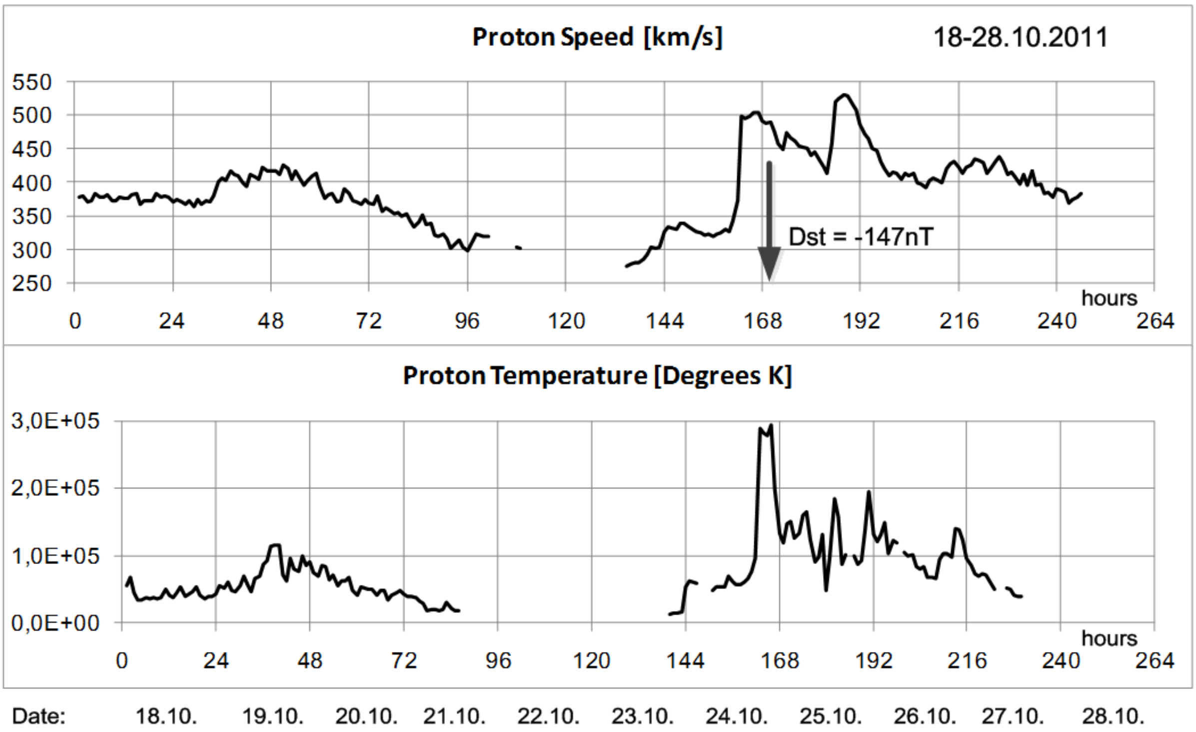

Fig. 5. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 24 October 2011 with minimal Dst = -147 nT. In both parameters some decreased values before the storm are observed. Because of lack of data it can not be affirmed categorically.

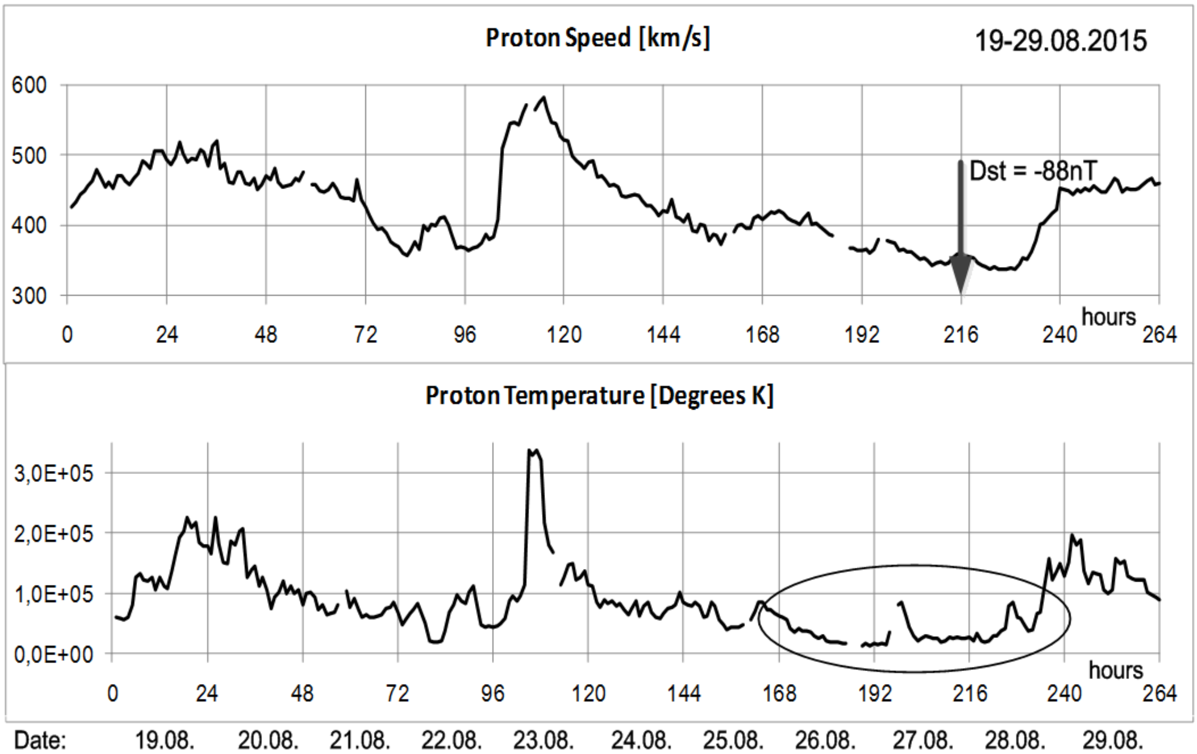

Fig. 6. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 27 August 2015 with minimal Dst=-88 nT. This is an weak geomagnetic storm, but before the storm some low temperature values are also observed (drawn with ellipse).

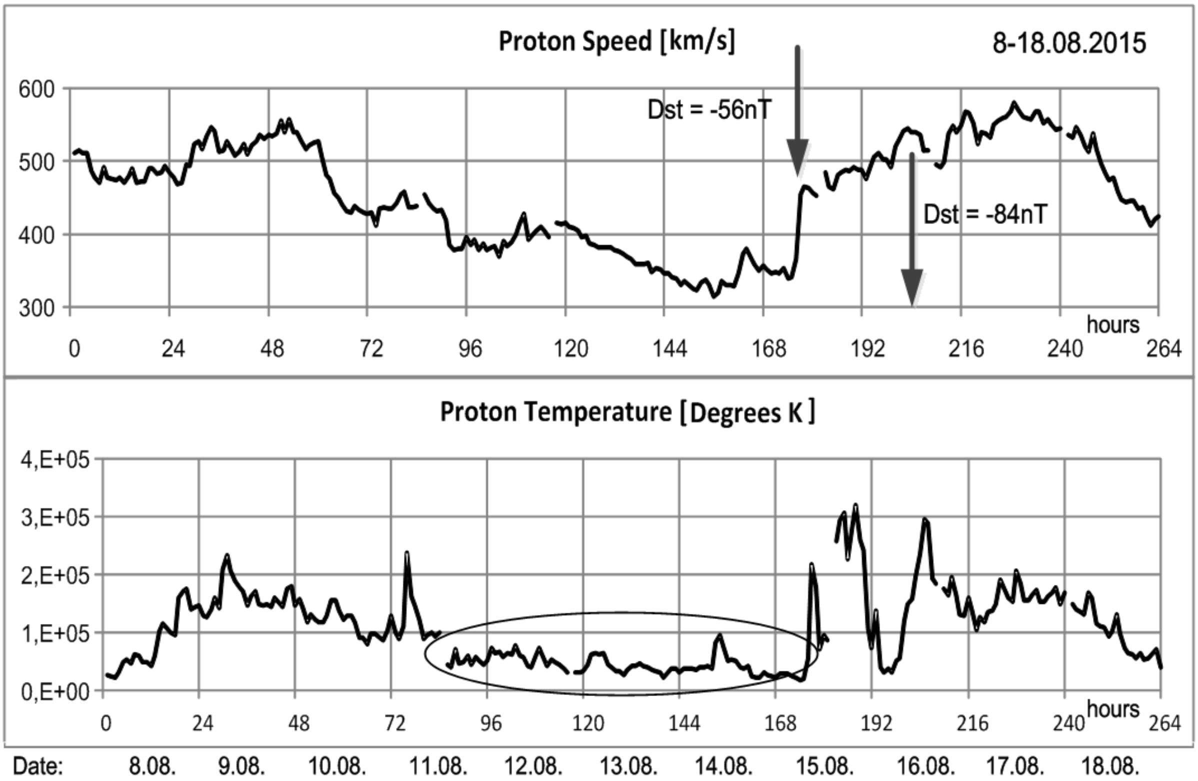

Fig. 7. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 15 August 2015 with first minimum Dst = -50 nT and second minimum on 16.08. with Dst = - 84 nT. The low temperature values are clearly seen three days before the geomagnetic storm (drawn with ellipse).

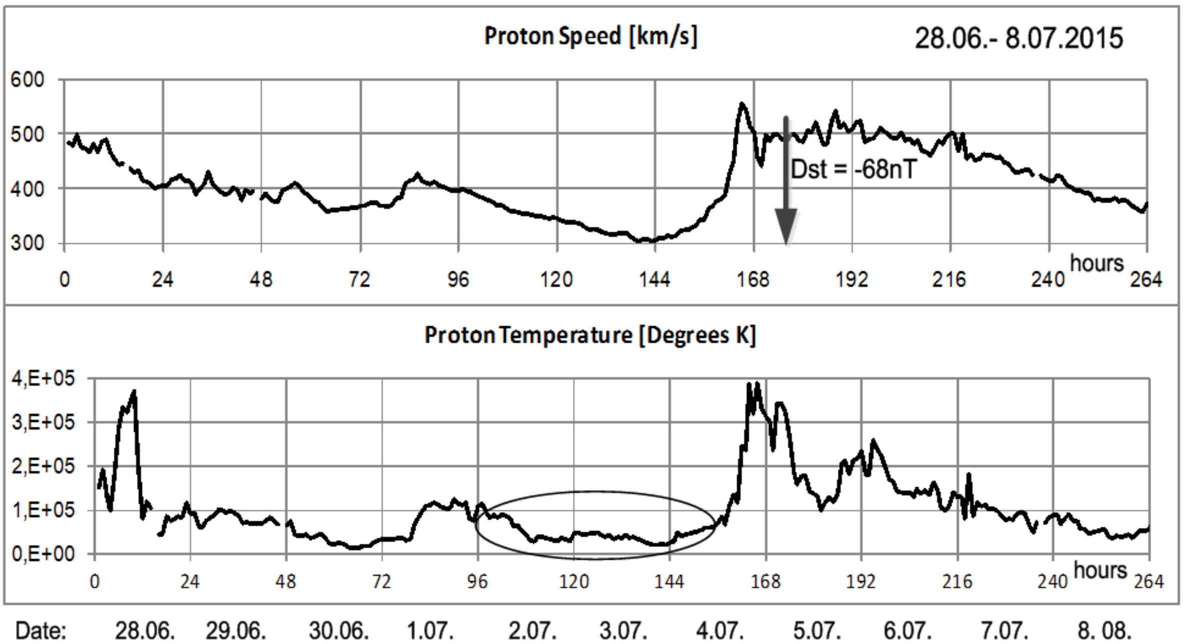

Fig. 8. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 04 July 2015 with minimum of Dst = -68 nT. The low temperature values are clearly seen two and a half days before the geomagnetic storm (drawn with ellipse).

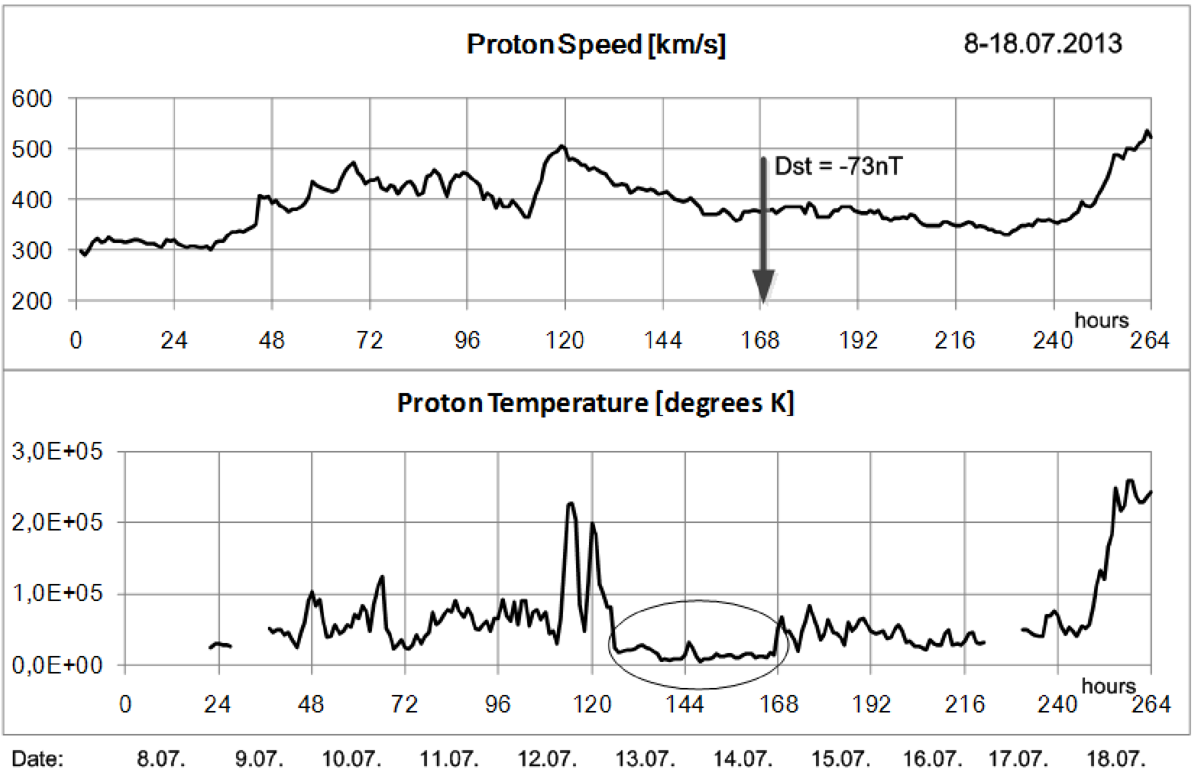

Fig. 9. Behavior of both basic solar wind characteristics, velocity and temperature, before and during the geomagnetic storm from 15 July 2013. A more complex behavior is shown because before that there is also one weak geomagnetic storm on 10. July. However there is a temperature decrease and stationing two days before the geomagnetic storm from 15.07. (drawn with ellipse).