"BEHIND HORIZON" DETECTION OF A POWERFUL SOURCE OF ACTIVITY ON THE SUN BY EFFECT "HALO" IN COSMIC RAYS

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ABSTRACT

Non-locality of cosmic rays, due to the fractal nature of magnetic field in the vicinity of the shock wave, is manifested in the correlation of fluctuations or focusing particles with the formation “beams” of particles: the effect "halo" in cosmic rays. Such particle beams are, in fact – predictors of a shock wave. The “halo" effect in cosmic rays is most pronounced when an activity source is detected in time for emerging or going of activity source the edge of Sun disk. Problem of detecting in real-time powerful source of activity behind edge of Sun disk we solve by distance method of diagnosing near-Earth space with use created robotic expert system Cyber-FORSHOCK (http://www.forshock.ru/pred.html) on the base of the existing world network of high-latitude cosmic ray stations: http://www.nmdb.eu.

INTRODUCTION

The first experiments on the early diagnosis of interplanetary shock waves from ground-based cosmic ray monitoring were conducted at the Tixie Polar Observatory. Even then, the possibility of detecting a powerful source of activity at the stage of its exit on the visible part of the solar disk was noted. First of all, we mean such unique events as August 3-5, 1972 and July 13-15, 1982, as well as the event in April 1984. Given the importance of the results obtained, the task of verification has been set in recent years not only methods for analyzing fluctuations of cosmic rays, but also the general methodology for their study. It is known that the effectiveness of any physical research is achieved when the method of study is adequate to the physics of the phenomenon.

The ever-increasing dependence of modern civilization on high-tech life support systems in space, in air and on Earth makes us, in fact, hostages of scientific and technological progress, based, in particular, on satellite technologies, primarily exposed to the destructive effects of extreme manifestations of Space Weather. First of all, “storm” particles preceding the arrival of a flare shock wave into the Earth’s orbit. Below, an approach is proposed that to some extent solves the problem of early detection of a powerful source of activity before it reaches the visible part of the solar disk, or when such a source has already disappeared behind the “horizon line”.

PROBABILITIE IDENTIFICATION OF CRITICAL REGIME IN THE VICINITY OF THE SHOCK FRONT

Recently, there have been indications that the unpredictable, "catastrophic" nature of extreme manifestations of solar activity is due to the possible realization of a state of "self-organized criticality" on the Sun, see, for example, [1]. On the other hand, it is known from the probabilistic theory of continuous medium fracture (and reliability theory) that the generalized Weibull-Gnedenko distribution function describes the system's output to the limit critical regime [2], before the conditional "catastrophe". In our case, this can be considered as a transition regime in the vicinity of the front of a large-scale perturbation of the solar wind - the shock wave.

In the language of this probabilistic theory, the problem boils down to the task of determining the function of the failure rate of a system that has exhausted its resources. The maximum of the failure rate function, or the maximum of the Risk function, is, in fact, the probability of reaching a critical value of the analyzed variable, in this case, the intensity of cosmic rays [3-4]. The ratio of the density of the Weibull-Gnedenko distribution function to the "reliability function" is the desired probability (Risk function) or the GKL fluctuation parameter [5].

Further, it remains only to isolate the harbinger-signal from the Gaussian noise: the Gaussian noise is contained, more simply, in the "before the critical" linear region of the Risk function, and the desired harbinger-signal in the "behind the critical" nonlinear region. The desired nonlinear component of the harbinger-signal is formed when the degree (probability) of the process of the critical value is exceeded, i.e. at $P > P_{cr}$. TESTING of the proposed method on a control series, which is a random series of numbers, showed that the probability values (hereinafter, the fluctuation parameter) lying below the level of $P \leq 0.65$ can be reliably (at a significance level of 90%) attributed to Gaussian noise.

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Obviously, the identification of the source of activity by cosmic rays is desirable for a single and powerful active region. As this, for example, we observed at the Tixie Polar Observatory in July 1982. Then it was the first case that a harbinger was detected for a single and powerful source of activity, which *emerges* on July 7 on the eastern edge of the solar disk as the halo-effect in cosmic rays. In view of the importance of the obtained result, then, in 1982, a control calculation was performed for 2 high-latitude cosmic-ray stations Tixie and

Apatity spaced in longitude. The results of mutual spectral analysis confirmed the conclusion that the cosmic rays detected in advance a powerful source of activity on the Sun, i.e. at the stage of its release on July 7, 1982 to the visible part of the solar disk. Obviously, such favorable conditions for identifying a powerful source of activity should be fulfilled at the geoeffective phase of the beginning of the decline branch of the 11-year cycle. At this time, the number of spots is already much smaller than in the maximum of the 11-year cycle, and the probability of dominance of a powerful and only active area is still quite large.

Simply *ideal conditions* for reliable identification of the source of activity developed from August to September 2005, when the maximum of the 11-year cycle (2000-2001) was already passed. Moreover, the evolution of active region No. 798 could be traced from its inception on August 19 (on the practically clean disk of the Sun) with its subsequent manifestation in the form of Forbush-decrease in GCR intensity on August 24–25 and its departure on August 25 to the invisible part of the solar disk. It is noteworthy that (http://spaceweather.com/archive.php?day=03&month=09&year=2005&view=view) before the next exit on the visible part of the Sun's disk, the activity of the indicated source (http://spaceweather.com/archive.php?day=06&month=09&year=2005&view=view) only *increased*. In early September, large flares were observed, accompanied by CME. On September **3**, the *harbinger* in cosmic rays was registered (Fig. 1). Moreover, it is important: other potential sources of activity in the form of active groups of spots and coronal holes were *not observed* at this time. The source's exit to the eastern limb (http://spaceweather.com/archive.php?day=08&month=09&year=2005&view=view) of the Sun on September 7 was accompanied by a giant flash of class **X17**. A systematic *decrease* in the fluctuation parameter up to recording low, i.e. of *diagnostic* values on September 7–9 (against the background of the started *decrease* in the GCR intensity), was ended with a precursor on September 10, with the subsequent registration of a large Forbush-effect on September 11–12.

Similar a favorable situation developed also in the first half of December 2006. Indeed, starting from the third decade of November 2006, the large but inactive region No. 923 is left on the invisible part of the solar disk. The surface of the Sun during the week remained practically without any stains. Only in the last week of November two inactive groups of spots appeared (926 and 927). The activity in the third decade of November was determined only by the coronal holes, giving only a minor contribution to the modulation of the GCR intensity at this time (Fig. 2).

The return (inactive on the previous solar rotation) of area No. 923, but already under the new number No. 930, was marked by *increased* activity even before its release from 4 to 5 December on the visible eastern part of the solar disk, when a powerful **X9** class X-ray flash was detected. Indeed, from December 2, a series of X-ray flashes of amplified power (up to class C) began, which ended on December 5-7 with large and very large class M and X. The monotonous nature of the increase in flare activity from December 2-7, and also the very seriality of events allow us to say that the source was one. In this case, it is AO No. 930: http://spaceweather.com/archive.php?day=05&month=12&year=2006&view=view. In the same time, the inactive nature of the region 926, according to solar observations, is noted on the same Internet-site for space weather. The inactive nature of the other two regions (AO 927 and 928) was discussed above.

Thus, this event sufficiently satisfies the conditions for identifying the source of activity. A significant precursor was registered on December **2**, 2006, i.e. for ≈ 2 days before the powerful active area 930 reaches the visible part of the solar disk from 4 to 5 December (Fig. 9). The active area 930, at the time of its release on the visible eastern part of the solar disk from December 4 to 5, was already extremely active: from December 2-7, registered a series of X-ray flashes of class C, M and X growing in power, accompanied by storm particles in a fairly wide range of energies (from 100 KeV to 100 MeV).

Further developments took place as follows: from December 7-12, began a long Forbush-decrease in the GCR intensity and geomagnetic storms. On December 10-12 and December 13, harbingers were recorded with a subsequent Forbush effect on December 14-17 with an amplitude of ≈7%, accompanied by a powerful geomagnetic storm (Kp= 8). This (http://spaceweather.com/archive.php?day=14&month=12&year=2006&view=view) increased activity is associated with large class X flares, the increase of storm particles on December 13-15, as well as the ground increase of SCR on December 13, i.e. particles with an energy of the order of ~ 1 GeV (the shaded region in Fig. 2).

Obviously, the most favorable conditions for identifying of the source "behind limb" of Sun by cosmic rays are formed during the period of the deep minimum of the 11-year cycle, i.e. with the practical absence of sunspots on the visible part disk of Sun. For example, in 2008 - it was the “whitest” year when the maximum number of days in a year without spots was recorded. It is important to note that the character of “Cosmic Noise” during this period is clearly chaotic. Obviously, this is due to the chaotic nature of the increased background radiation of galactic cosmic rays, due to a lower level of solar activity during the minimum of the 11-year cycle: dependence of correlation (fractal) dimension for the dimension of the enclosed phase space during the minimum of the 11-year cycle is typical for a random process with monotonic dependence **d(n)~n** [6-7].

The only harbinger was recorded on January 1, 2008 (Fig. 3), in the complete absence of sunspots on the solar disk. On the previous day, December 31, on the side of the Sun invisible from the Earth, according to the data of the Stereo-A spacecraft, two large C8 class X-ray flares were observed, accompanied by coronal mass emissions. A possible source (https://spaceweather.com/archive.php?view=1&day=31&month=12&year=2007) of these X-ray flares could be the giant active region No. 978 — the only active region observed in the previous rotation of Sun. The low values of the GCR fluctuation parameter recorded on November 4 indicate the registration of disturbances in cosmic rays from CME.

For reliable identification of the source of activity, it would be desirable to exclude recurrent high-speed currents or “jets” of the solar wind. As it was, for example, in early September 2005. Similar rare case also appeared in September 2011, when the activation of a powerful source of activity (AO 1302) on the side of the Sun invisible from the Earth took place (http://spaceweather.com/archive.php?day=22&month=09&year=2011&view=view) in the absence of coronal holes. The active region 1302 was noticeably manifested in the registration of large flares of class M and X, accompanied by a series of CMEs, starting from September 19 and on, as they reached the visible part of the solar disk on September 22. With its further advance to the central meridian, in cosmic rays the from September 25 to 26 was detected Forbush effect (Fig. 4).

The harbinger in cosmic rays was registered September 19, i.e. 2-3 days before the specified active region reaches the eastern edge of the solar disk. And in this case, low, i.e. the diagnostic value of parameter GCR September 26 is a marker of the Forbush effect in GCR intensity. This is confirmed by the results of a simulation conducted by the Goddard Space Weather Lab from measurements made on US spacecraft, Stereo-A and Stereo-B (Appendix 1): powerful shock wave from the ejection of coronal mass (CME) is registered on the Earth’s orbit also on September 26 (Earth shown to the right of the Sun's disk in the center, by yellow circle on the horizontal axis). Variations in the GCR fluctuation parameter at the end of September and at the beginning of October reflect the manifestation of “aftershock” activity of the same source.

No less favorable conditions for identifying the source of activity were formed in early March 2012. The only and inactive sunspot near the central meridian, the mean values of the solar wind velocity and the geomagnetic index Kp=4 indicated weakly disturbed conditions in the solar wind. On the other hand, AR 1429, already was active, when on March 3 (http://spaceweather.com/archive.php?day=03&month=03&year=2012&view=view) she appeared on the eastern edge of the sun disk. From March 1-2, the activation of the source began: March 2, 2012, a large M3 class flash limb was recorded, accompanied by a coronal mass ejection — CME. In cosmic rays, all this was manifested in the registration of the harbinger on March 1-2, 2012 (Fig. 5), and from March 3–8 were recorded low, i.e. diagnostic values of the GCR fluctuations parameter with a pronounced Forbush effect on March 7-10. The alternation of high and low values of the parameter of fluctuations from March 3–8 reflects variations in the degree of inhomogeneity of the IMF http://spaceweather.com/archive.php?day=07&month=03&year=2012&view=view. At this time, large flashes were registered (class M2 and X5) and a series of CME.

The ongoing activity of the same source March 9-10, 2012 was of the cause (http://spaceweather.com/archive.php?day=09&month=03&year=2012&view=view) a small (repeated) decrease in GCR intensity from 11 to 12 March, 2012, which is consistent with a low diagnostic value of the GCR fluctuation parameter (Fig. 5). It is confirmed by the results of a simulation conducted at the Goddard Space Weather Lab by data of measurements on the Stereo-A and Stereo-B spacecrafts USA (Appendix 2). The shock wave from the CME is recorded on the Earth's orbit, which is indicated by a yellow circle on the horizontal axis, also from 11 to 12 March 2012, i.e. the low diagnostic value of the GCR fluctuation parameter is indeed a marker of the shock wave from March 11-12. The forerunner of this re-decrease in GCR intensity from March 11 to March 12 was registered on March 10-11 (Fig. 5).

Region 1429 remained active at the time of its March 15 exiting on the western edge of the Sun's disk. The harbinger was registered on March 14 (Fig. 5). And only the location of the active region at the (western) edge of the solar disk did not allow it to properly manifest itself in the GCR intensity. The harbinger of March 14, in this case, played the role of a marker of a slight decrease in the GCR intensity on March 15, which was accompanied by a sharp decrease in the fluctuation parameter from March 14 to March 15 (Fig. 5). This decrease is due to the arrival of the shock wave into the Earth's orbit from the CME from AO 1429, which has already gone beyond the western limb of the Sun: the image of AO "in front" (http://spaceweather.com/archive.php?day=15&month=03&year=2012&view=view) has changed on image of AO "in profile". Despite the fact that the impact from the strong shock wave was tangent, the registration of the shock wave on Earth was accompanied by a geomagnetic storm with a magnitude of Kp=6. The presence of such a harbinger-marker from March 22 to 23 (Fig. 5) allows us to confirm the conservation of activity on the "reverse" side of the Sun. Indeed, only from March 23 to 26 at least 4 powerful ones were registered (http://spaceweather.com/archive.php?day=24&month=03&year=2012&view=view) CME.

Repeated detection of the same powerful source of activity from AR 1429 in cosmic rays beyond the eastern edge of the solar disk (Appendix 3) manifested itself in the registration of the harbinger from time interval equal one rotation of the Sun on March 27 (Fig. 4). During the period from March 24-27, neither active groups of spots, nor large solar flares, nor active coronal holes were registered on the visible part of the solar disk. Before the exit http://spaceweather.com/archive.php?day=27&month=03&year=2012&view=view of AR 1429: to the visible part of the solar disk on March 26, the next powerful, 11th in a row CME. In this case, the role of a marker of the same activity source from AR 1429 (before its exit to the visible part of the solar disk) was played by high significant values of the GCR fluctuation parameter in the form of a forerunner of March 27.

Many more interesting case of detecting source of activity behind (western) of edge of solar disk, took place in the third decade of July of the same 2012. The background to the development of this kind of unique event is as follows: starting from the second decade of July 2012, a powerful active region of 1520 dominated on the visible part of the solar disk. Coronal holes were also absent as potential sources of solar activity. True, the first decrease in GCR intensity with its harbinger of July 3, 2012 (Fig. 6), was due (https://spaceweather.com/archive.php?day=02&month=07&year=2012&view=view) to the passing of the central meridian of the active area 1515. The second decrease of GCR intensity from July 7 to July 8, whose precursor was recorded from July 5–7 (Fig. 6), was the result of flare activity of the same region 1515, accompanied by a series of coronal mass (https://spaceweather.com/archive.php?day=05&month=07&year=2012&view=view) ejections from July 4–7, 2012. And in this case, the low diagnostic values of the fluctuation parameter on July 4 and 7–8, respectively, are markers of registration the arrival of shock waves into the Earth's orbit (Appendix 4).

The exit of the new active region 1520 and its subsequent advance to the central meridian was accompanied by powerful flares of class M and X: https://spaceweather.com/archive.php?day=12&month=07&year=2012&view=view. The precursor in cosmic rays was registered 12.07.2012 (Fig. 6). The Forbush effect in GCR intensity began on July 14. What is indicated by the low, i.e. the diagnostic value of the GCR fluctuation parameter on July 14, which plays the role of a marker of the arrival of a shock wave to the Earth's orbit (Fig. 6). This is confirmed by the results of a simulation conducted at the Goddard Space Weather Lab by data to measurements on the Stereo-A and Stereo-B spacecraft (Appendix 5): indeed, the shock wave from the CME near the central meridian is recorded in the Earth's orbit as well on July 14, 2012.

Low values of the fluctuation parameter on July 18-20 reflect the fact of (prolonged) decrease in the GCR intensity due to the passage on the Earth's orbit of several ejections (http://spaceweather.com/archive.php?day=18&month=07&year=2012&view=view) coronal mass of the Sun ("slow explosions") was recorded. But even in this case, the low diagnostic value of the parameter of fluctuations on July 19-20 played the role of a marker of a small decrease in the GCR intensity on July 19-20 (Fig. 6). This is once again confirmed by the simulation results make by the data measurements on the Stereo-A and Stereo-B spacecrafts: the shock wave from the "delayed" CME in the Earth's orbit is recorded on July 20 (Appendix 6). A small amount of decrease in GCR intensity is due to the fact that the source of activity was already far from the central meridian. More precisely, near the western edge of the solar disk, with the result that the Earth was in the zone of only the tangential impact of the shock wave (from a series of "delayed" CME).

It so happened that the most extreme manifestations of solar activity were observed at the beginning of the third decade of July 2012. At this time, the active region No. 1520 was already was hidden behind the western edge of the solar disk. However, in cosmic rays, it nevertheless manifested itself in the form of a precursor in the parameter of fluctuations of the GCR of July 20 and 22 (Fig. 5). There were no active groups of spots with large flares and geoeffective coronal holes on the visible part of the solar disk on July 21-22. And in this case, we are dealing with the manifestation of the non-local properties of cosmic rays from (http://spaceweather.com/archive.php?view=1&day=19&month=07&year=2012) the most (http://spaceweather.com/archive.php?day=23&month=07&year=2012&view=view) powerful behind-limb, in this case - western source of activity, see Appendix 7. So, in parameter of the GCR fluctuations was recorded the precursor of the most powerful shock wave, and not only in the current 24 cycle! According to the known chart of the registered of velocities in the solar wind, such extreme shock waves with velocities of ≈3000 km/s and above are a very rare event (Extremely Rare events). The registration of two harbingers on July 20 and 22 means that during this period at least a pair of powerful CMEs were recorded with an interval of 1-2 days, followed by "merging" of a pair of shock waves into one powerful shock wave: unique in its characteristics, event July 23-24, 2012 (Appendix 8).

According to a number of authors, the unique event on July 23-24, 2012 is related to the SUPERSTORM level, like the famous Carrington event of 1859 [8]. Thus, in the 21st century, our civilization was lucky at least twice. In early November 2003, when a giant flare of the **X28** class X-ray occurred at the moment the active region already was on the most edge of western limb of the solar disk and at the beginning of the third decade of July 2012, the next activation of the source from the active region 1520 occurred already on the invisible from the Earth side of the Sun. But since it is naive to hope for such “luck”, the very possibility of forecasting, more precisely, the early detection of extreme events of Space weather, including events which be behind of edge of solar disk (which we register by effect "halo" in cosmic rays), must be quite timely.

It is clear, that the probability of the occurrence of “zalimb” events should be greater at the maximum of the solar cycle. This and was observed in February and August-September 2014. On February 25, 2014, the exit of active region No. 1990 was accompanied (https://spaceweather.com/archive.php?day=25&month=02&year=2014&view=view) by a powerful flare of **X5** class and a series of CME coronal mass ejections. Moreover, AR 1990 (https://spaceweather.com/archive.php?day=25&month=02&year=2014&view=view) was quite active 3 days before it reached the visible part of the solar disk. Coronal holes, as potential sources of solar wind disturbances, were absent during this period. Activity of the "zalimba” source was manifested in the registration of harbinger on February 22, 2014 (Fig. 7), followed by the Forbush effect with an amplitude of ≈**5**% and Dst-variation up to **-100** nT, February 27-28. Low diagnostic values of the fluctuation parameter from February 27 to 28 are a marker of the registration of a shock wave in the Earth’s orbit at this time.

No less interesting events were observed in August 2014. On August 15, the effect of “disappearance of solar fiber” was recorded, followed by coronal mass ejection of CME (https://spaceweather.com/archive.php?day=16&month=08&year=2014&view=view), arrival of which into orbit of the Earth was expected in the late hours of August 18. Indeed, the sharp and low diagnostic value of the GCR fluctuation parameter on August 18-19 confirms this. Coronal holes and active sunspots, as potential sources of solar wind disturbances, were not observed during this period. On August 21, the harbinger in cosmic rays was registered (Fig. 8). The source of large M-class flares was the active region No. 2149, located on August 21 (https://spaceweather.com/archive.php?day=22&month=08&year=2014&view=view) beyond the eastern edge of Sun's disk. AR 2149 reached the visible part of the solar disk the next day on August 22. The passage of the active region to the central meridian of the Sun was accompanied by large flares of class M3 and M5. The moment of intersection of the AR of the central meridian was manifested in the registration of a low diagnostic value of the GCR fluctuation parameter, which is a marker of the arrival of a shock wave into the Earth's orbit.

At the same time, it is important to get an answer to the question about the time magnitude of the advance early detection of the source of activity on the Sun. The answer to it is obviously connected with the potential power an invisible from the Earth, source of activity. But sorry, the Stereo-A and Stereo-B spacecraft do not have X-ray sensors. In this regard, it is interesting to present the monitoring results in late August - early September 2014. In late August, there were no potentially significant active areas on the Sun. At the time of registration of the harbinger on August 30 (Fig. 9), no active sources were detected on the visible part of the solar disk. However, on according to the data of the Stereo-B spacecraft, September 1 a powerful flash (presumably of X-class) was detected beyond the northeastern https://spaceweather.com/archive.php?day=02&month=09&year=2014&view=view part of the Sun's limb in the extreme ultraviolet spectral range. Unfortunately, it was not possible to determine the class of this flash due to the lack of X-ray sensors on the Stereo-A and Stereo-B spacecraft. Nevertheless, on the site of this outburst, a powerful ejection of CME coronal plasma was recorded, with an extremely high speed of ≈2000 km/s. Active regions under numbers No. 2155-2156 and No. 2157-2158 reached the visible part of the solar disk in 3-4 days: September 4-5. And just because the impact on the Earth was tangent, a decrease in the intensity of GCR September 4-5, as one would expect, was small. Subsequent harbingers of September 7–10 preceded the Forbush effect of September 11–13 (Fig. 9), which was caused by a series of CMEs from powerful flares of class M and X recorded on September 9–10.

Obviously, by analogy with the events in the third decade of July 2012, the cumulative effect, of at least, a couple of interacting CMEs may turn out to be the source of most extreme events. The most powerful magnetic storm in the current 24 cycle, March 17-18, 2015 (http://wdc.kugi.kyoto-u.ac.jp/dst_provisional/201503/index.html) can also serve as confirmation. Its source was the only one - this is the active area http://spaceweather.com/archive.php?day=05&month=03&year=2015&view=view No. 2297. She was the source of large outbreaks and the CME series. By the way, before its exit March 7 (http://spaceweather.com/archive.php?day=06&month=03&year=2015&view=view) to the visible part of the solar disk: March 5 - a class M1 flares, March 6 - M3 and 7 March - M9. The increased activity of the source remained, both at the time of release and further (http://spaceweather.com/archive.php?day=11&month=03&year=2015&view=view), as it passed through the solar disk from March 9-16. The precursors in parameter of cosmic ray fluctuation were recorded on March 2–3 (Fig. 10), i.e. for the same 3-4 days before the powerful active region 2297 reaches the visible part of the solar disk on March 7th. As a result, it can be concluded that the lead time τ of the “beyond-horizon” detection of a powerful source of activity is **τ=3**(±1) days. Over the next week, from March 9-16, class M1-M5 flares accompanied by a series of CME were recorded almost daily, and class X2 flare was registered on March 11. The precursors in cosmic rays on March 12 and 14–15 were registered more before giant Forbush-effect and SUPER-storm March 16–18, 2015 (Fig. 10).

Quite unexpected cases of over-horizon detection of the source of activity appeared relatively recently, in the July and September events of 2017. The peculiarity of this period is that this period refers to the beginning of the phase of a minimum of cycle 24. 11-14 July, the central meridian of the Sun was crossed by the giant and only active region No. 2665. On July 13-15, large X-ray flares of the C5, C6 and M2 class were registered (https://spaceweather.com/archive.php?day=14&month=07&year=2017&view=view), by accompanied CME. From July 14 to July 15, a harbinger in cosmic rays was registered, followed by the Forbush effect on July 16 (Fig. 11). From July 18 to July 19, AO 2665 disappeared behind the limb of the Sun. When the indicated active region was already on the side of the Sun invisible from the Earth, a series of CME emissions was observed on July 20 and 23. On July 21, a harbinger was recorded in cosmic rays (Fig. 11). Since the source of activity was already beyond the edge of the solar disk, no pronounced decrease in the GCR intensity was observed. In contrast, in the GCR fluctuation parameter, the trailing front of the shock wave of July 20 manifested itself as a rather sharp decrease in the fluctuation parameter of July 22–25.

The end of August ended with the passage of a recurrent “jet” of the solar wind, which is (http://spaceweather.com/archive.php?day=31&month=08&year=2017&view=view) a complex region interaction flows with different velocities. This is indicated by the registration of the harbinger from August 30 to August 31. A significant precursor was registered on September 2-3, 2017 (Fig. 12), which is obviously associated with a literally “explosive” (within 24 hours) increase in the activity of source No. 2673. Subsequently, this active region was the source of two powerful X9 class X-ray flashes from 09/06/2017 and X8 from 09/10/2017. Moreover, the second powerful X-ray flare occurred on the part of the solar disk that is invisible from the Earth, which been already beyond “horizon line” September 10, 2017 (http://spaceweather.com/archive.php?day=10&month=09&year=2017&view=view). A significant harbinger of the manifestation of this event in cosmic rays was recorded on September 9-10 (Fig. 12). Moreover, a significant decrease in the fluctuation parameter from September 13 to 14 corresponds to the transit time of the Earth’s orbit of the trailing edge of the shock wave from the coronal mass ejection (CME). This is confirmed by the results presented in [9], by data of measurements on the Stereo-B spacecraft (Appendix 9).

CONCLUSION

In conclusion, it is important to note the following circumstance: to detect an invisible (from Earth) source at the Sun, the United States had to launch into a special orbit two very expensive Stereo-A and Stereo-B spacecraft. The same problem of advance detecting a powerful source of activity on the Sun, which is behind edge solar disk we solve by remote method of diagnosing near-Earth space through the Cyber-FORSHOCK robotic expert system created by us based on the already existing global network of the (high-latitude) cosmic ray stations [1]. In our case, the planet Earth, together with the high-latitude stations (of the order of ~ **10**) operating on the reception of space radiation, is the unique single "DEVICE"!

RESULTS

1. The nonlocality of cosmic rays in the vicinity of an interplanetary shock wave manifests itself in clustering of the phase volume of cosmic rays, i.e. in the registration of correlated fluctuations in the form of *particle beams*: the "**halo**" effect in cosmic rays on a shock wave. The "halo" effect is most pronounced in case of *over-horizon* detection of a powerful source of activity behind the limb of the Sun.

2. A method is proposed for the *early detection* of interplanetary shock waves with advance time of the order of **~ 1** day, based on cosmic ray super-monitoring by data of the world network of (high-latitude) stations: http://www.nmdb.eu. The method is implemented in the form of a Cyber-FORSHOCK robotic expert system (http://www.forshock.ru/pred.html), with a probability of *forecasting* geoeffective Cosmic Weather events ≈**80**%.

BIBLIOGRAPHY

1. Kozlov V.I., Kozlov V.V. ARRYTHMIA OF THE SUN. In cosmic rays. Yakutsk: publishing house FGBUN IMZ SB RAS. IKFIA SB RAS. 2019. P. 214.

2. Ayvazyan S.A., Enukov I.S., Meshalkin I.D. APPLICATION STATISTIC . Basics of modeling and primary data processing. M .: Publishing House Finance and Statistics. 1983. P. 313.

3. Kozlov V.I., Krymsky P.F. The physical basis for the prediction of catastrophic geophysical events. Yakutsk. YSC SB RAS - IKFIA. 1993. 164 p.

4. Kozlov V.I., Kozlov V.V. "Abnormal" activity of the Sun in "weak" cycles 20 and 23 as a manifestation of the invariant of the 11-year cycle // Solar-terrestrial physics. 2008. Issue. 12. T. 1. P. 32-33.

5. Kozlov V.I., Kozlov V.V. The parameter of fluctuations of galactic cosmic rays — an indicator of the degree of inhomogeneity of the magnetic field. Geomagnetism and Aeronomy. 2011. V. 51. No. 2. P. 191-201.

6. Kozlov V.I. Scale invariance of the dynamics of cosmic-ray fluctuations on the geoeffective phases of the solar cycle // Geomagnetism and Aeronomy. P. 39. № 1. P. 95-99. 1999a.

7. Kozlov V.I. Estimation of the scaling properties of the dynamics of cosmic-ray fluctuations in the solar activity cycle // Geomagnetism and Aeronomy. P. 39. № 1. P. 100-104. 1999b.

8. Baker D.N. et al. A major solar eruptive event in July 2012: defining extreme space weather scenarios // Space Weather. Vol. 11, P. 585-591 (https://doi:10.1002/swe.20097). 2013.

9. Schwadron N.A., Rahmanifard F., Wilson J. et al. Update on the Worsening Particle Radiation Environment Observed by CRaTER and Implication for Future Human Deep – Space Exploration. Published: 22 February 2018. https://doi.org/10.1002/2017SW001803).

In conclusion, the authors is deeply grateful to Vyacheslav Kozlov for the development, creation, and software support of a robotic expert system for forecasting and diagnosing geoeffective events of the Space Weather in real-time Cyber-FORSHOCK.

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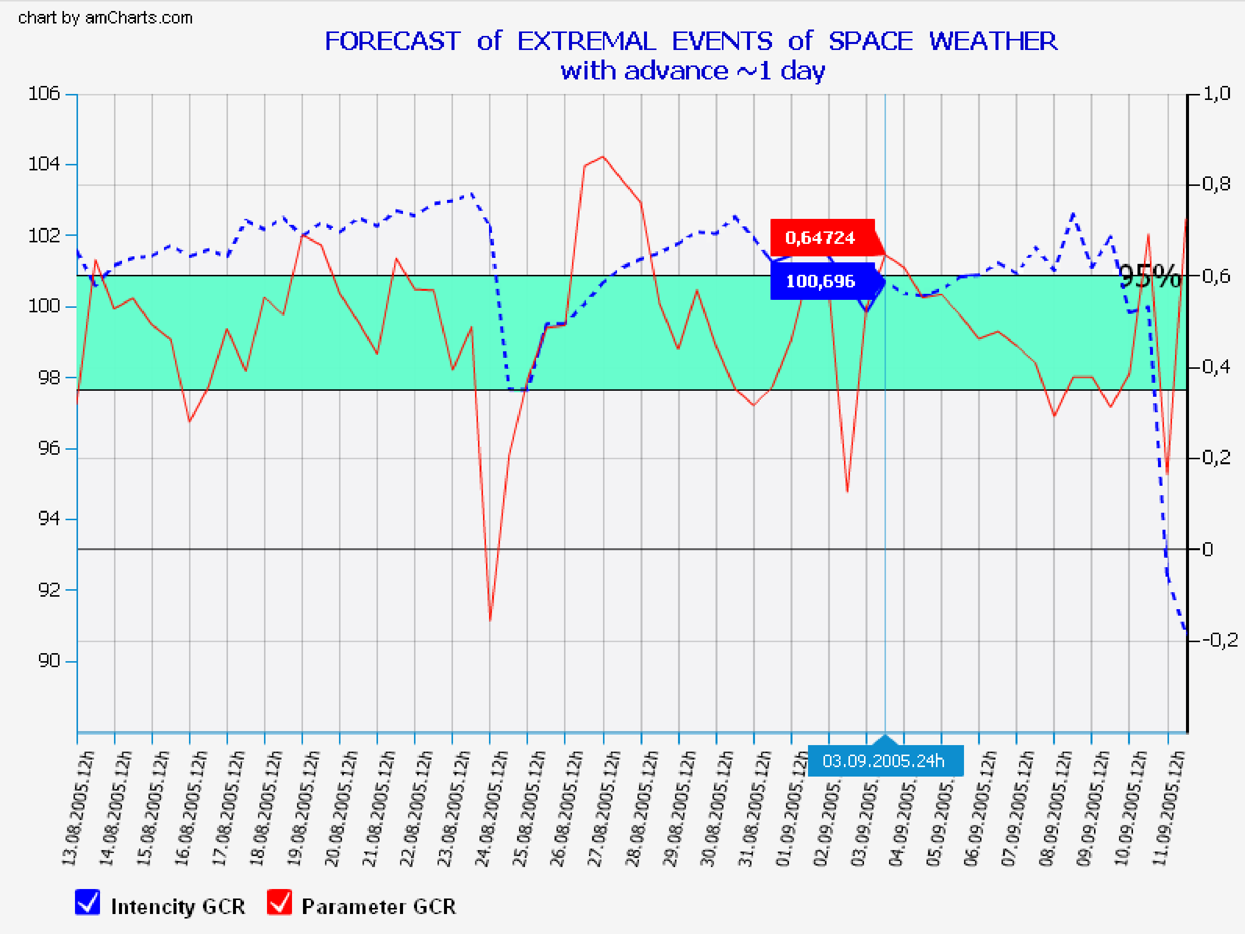


Fig. 1. Results of fluctuation parameter calculating in **August-September 2005**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

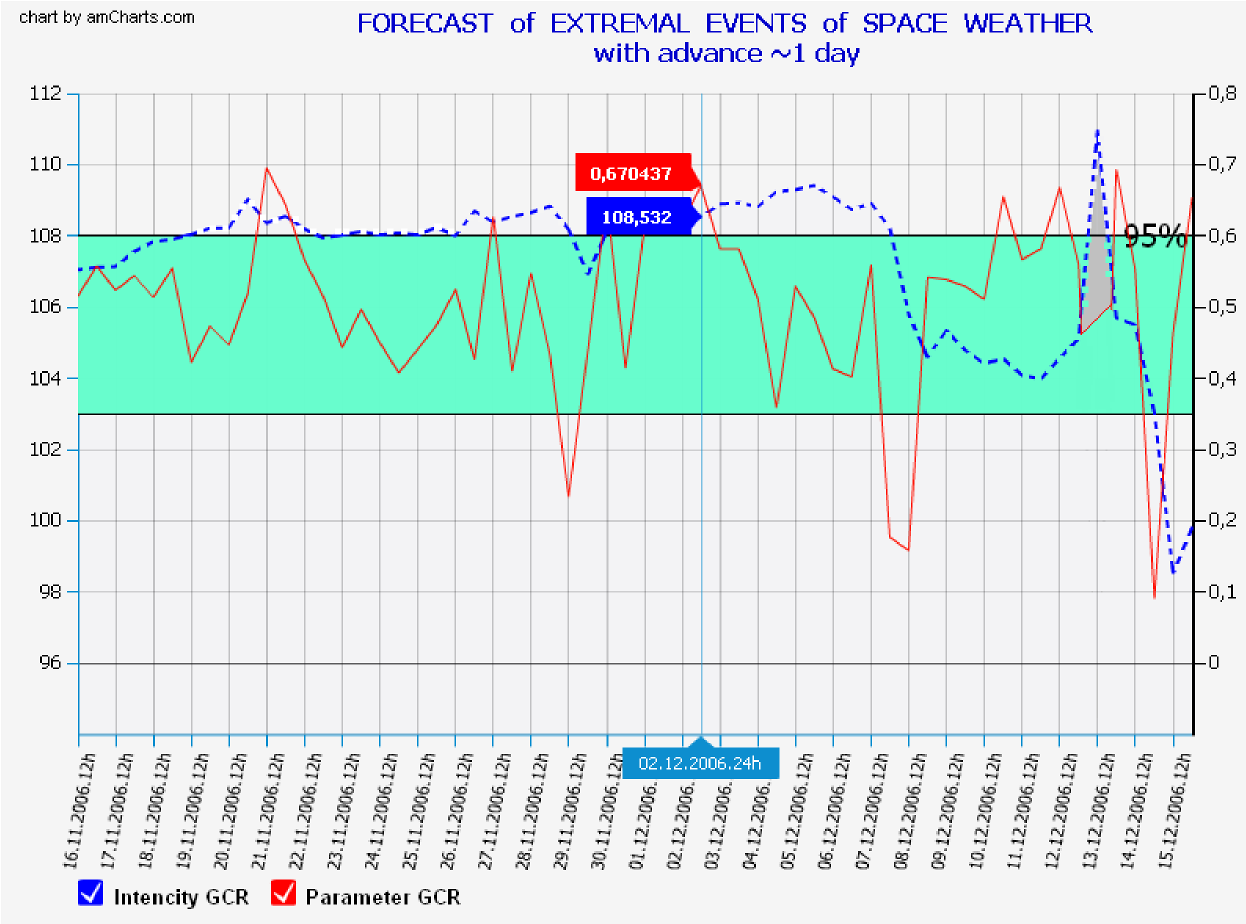


Fig. 2. Results of fluctuation parameter calculating in **November-December 2006**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

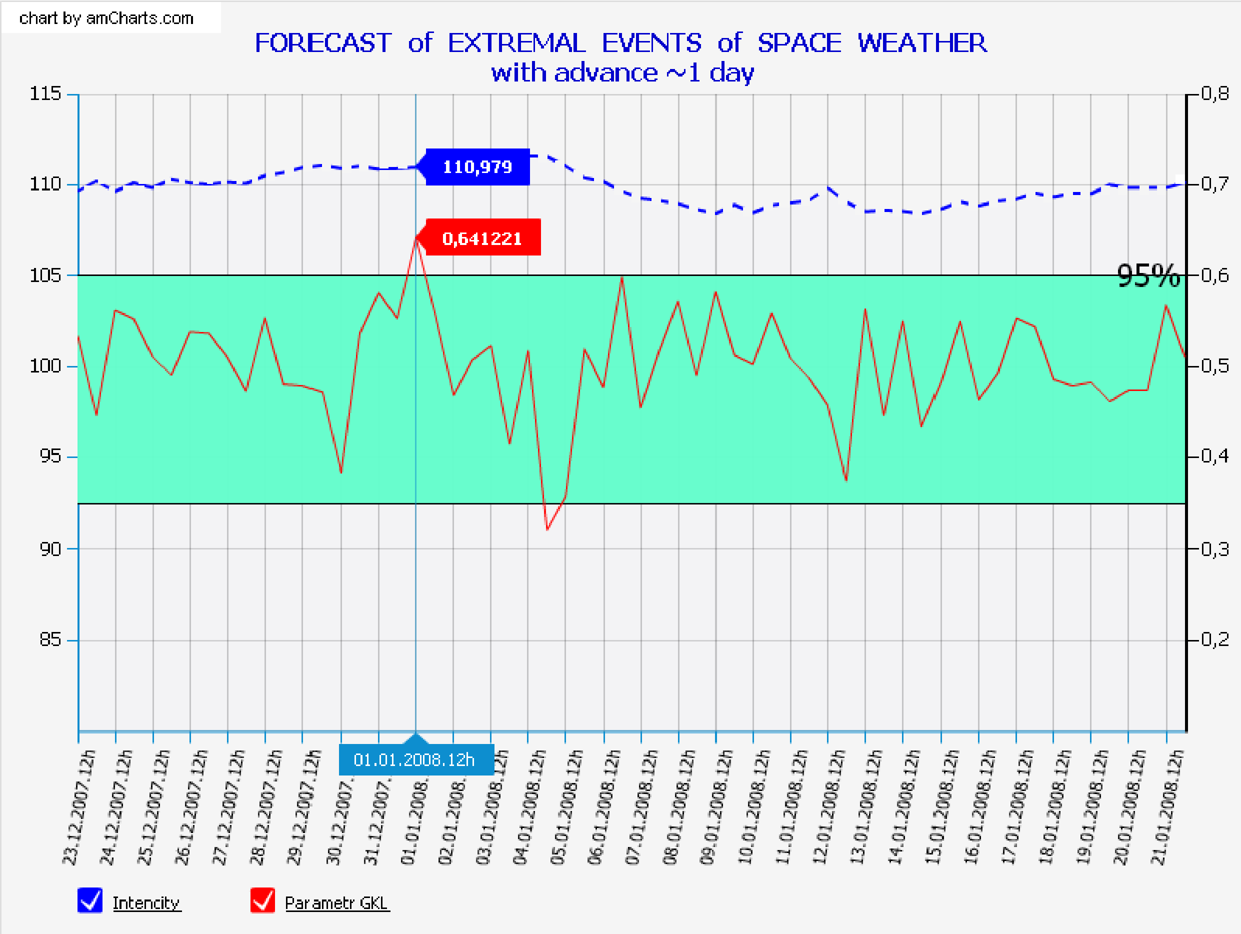


Fig. 3. Results of fluctuation parameter calculating in **December 2007-January 2008**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

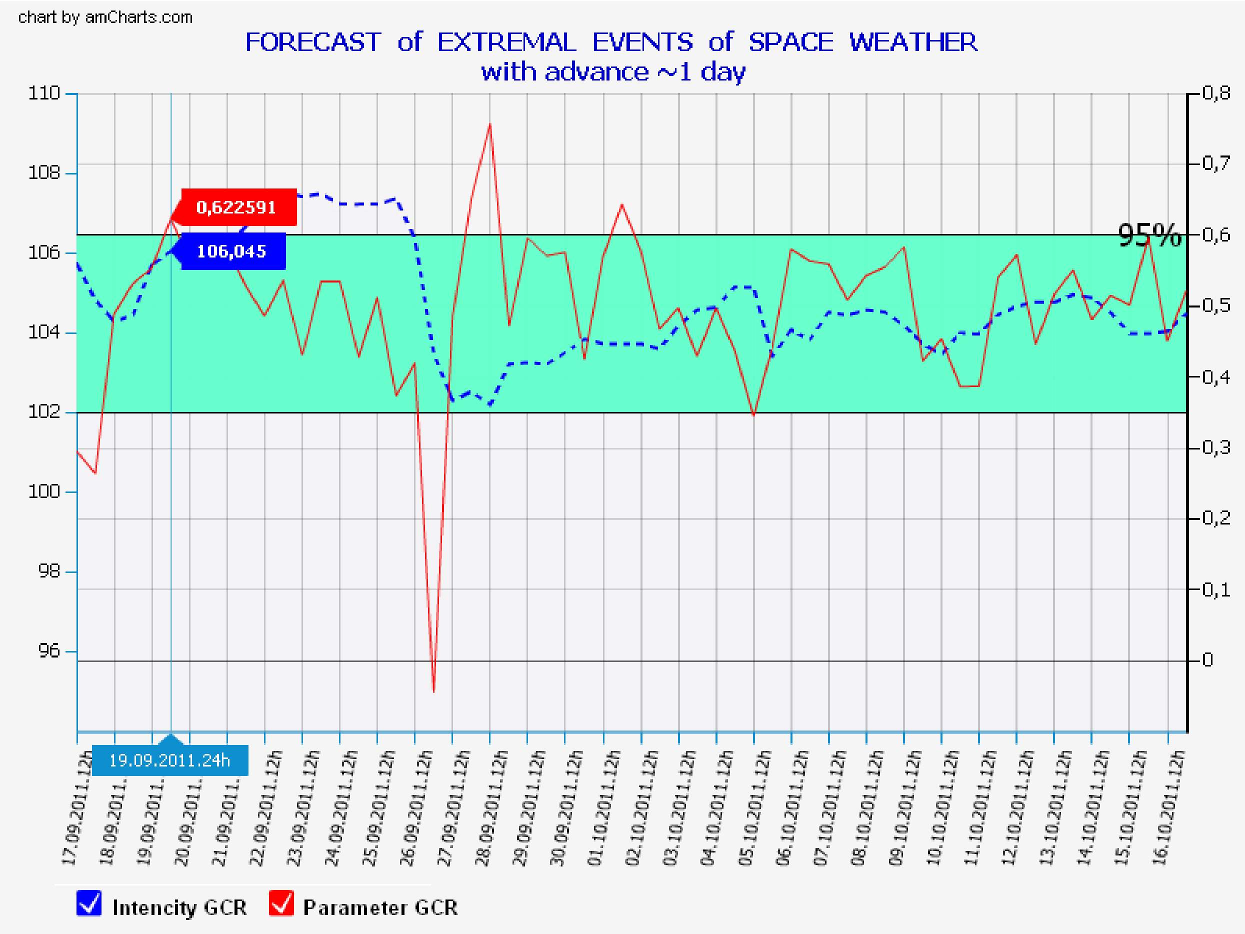


Fig. 4. Results of fluctuation parameter calculating in **September-October 2011**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

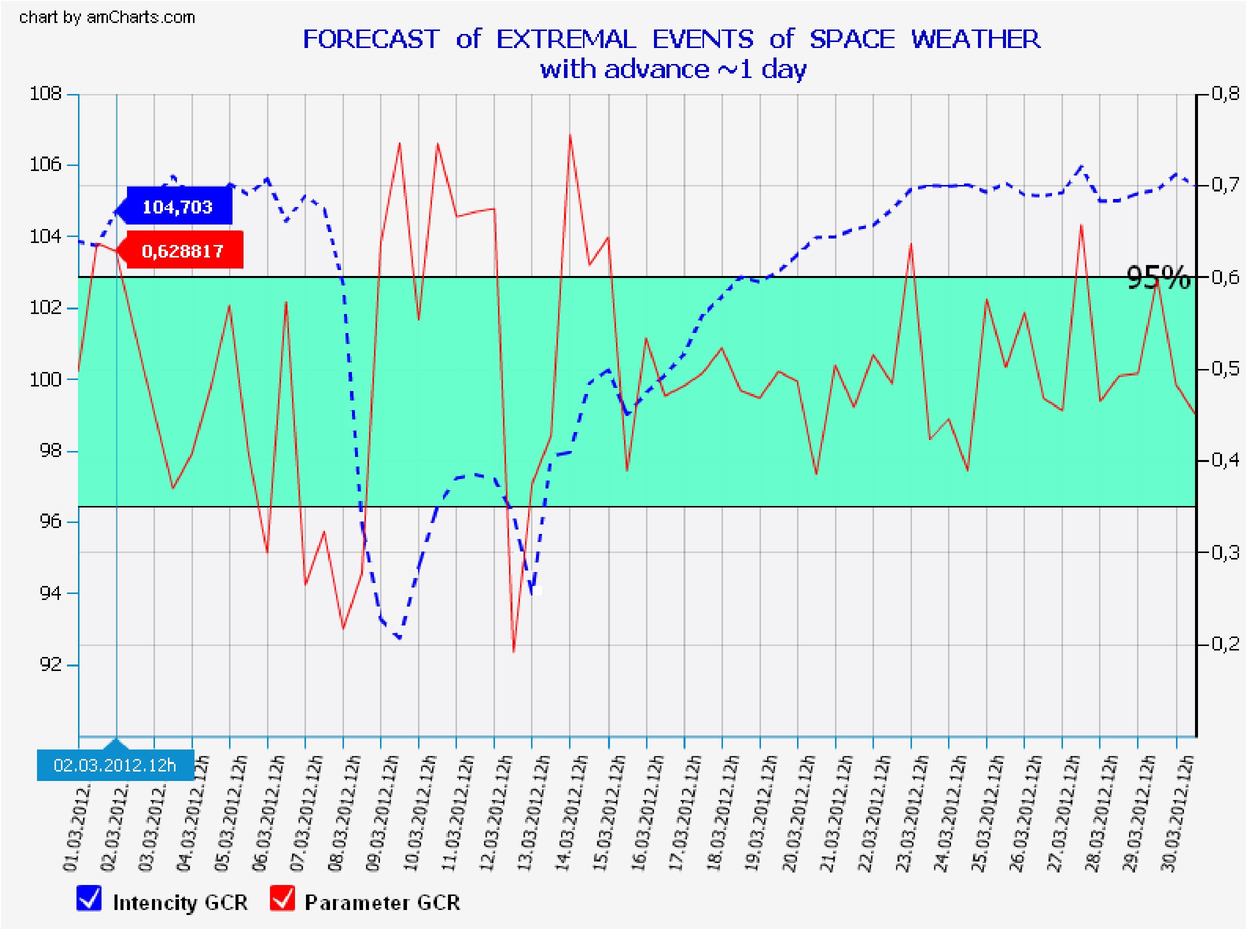


Fig. 5. Results of fluctuation parameter calculating in **March 2012**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

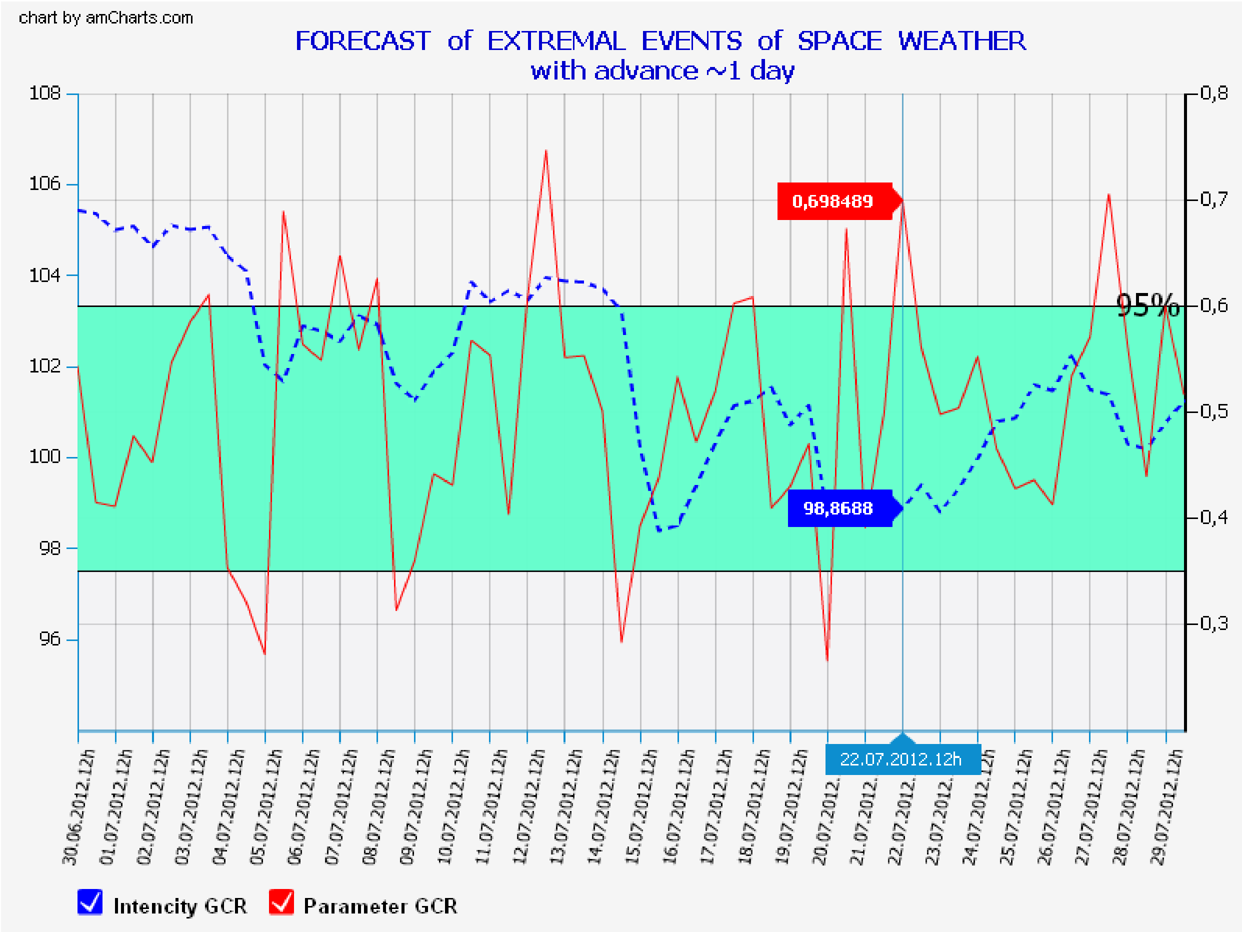


Fig. 6. Results of fluctuation parameter calculating in **June-July 2012**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

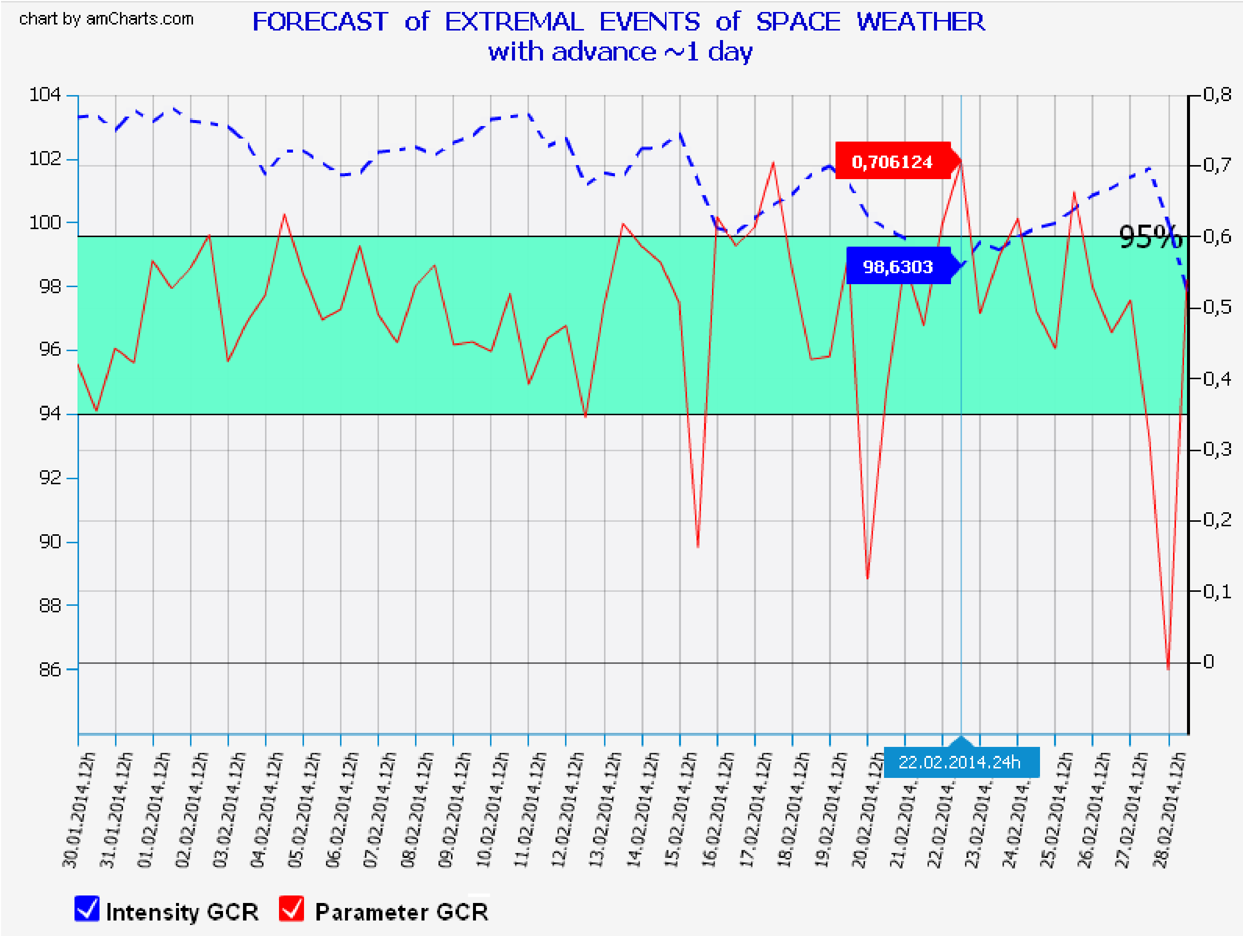


Fig. 7. Results of fluctuation parameter calculating in **January-February 2014**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

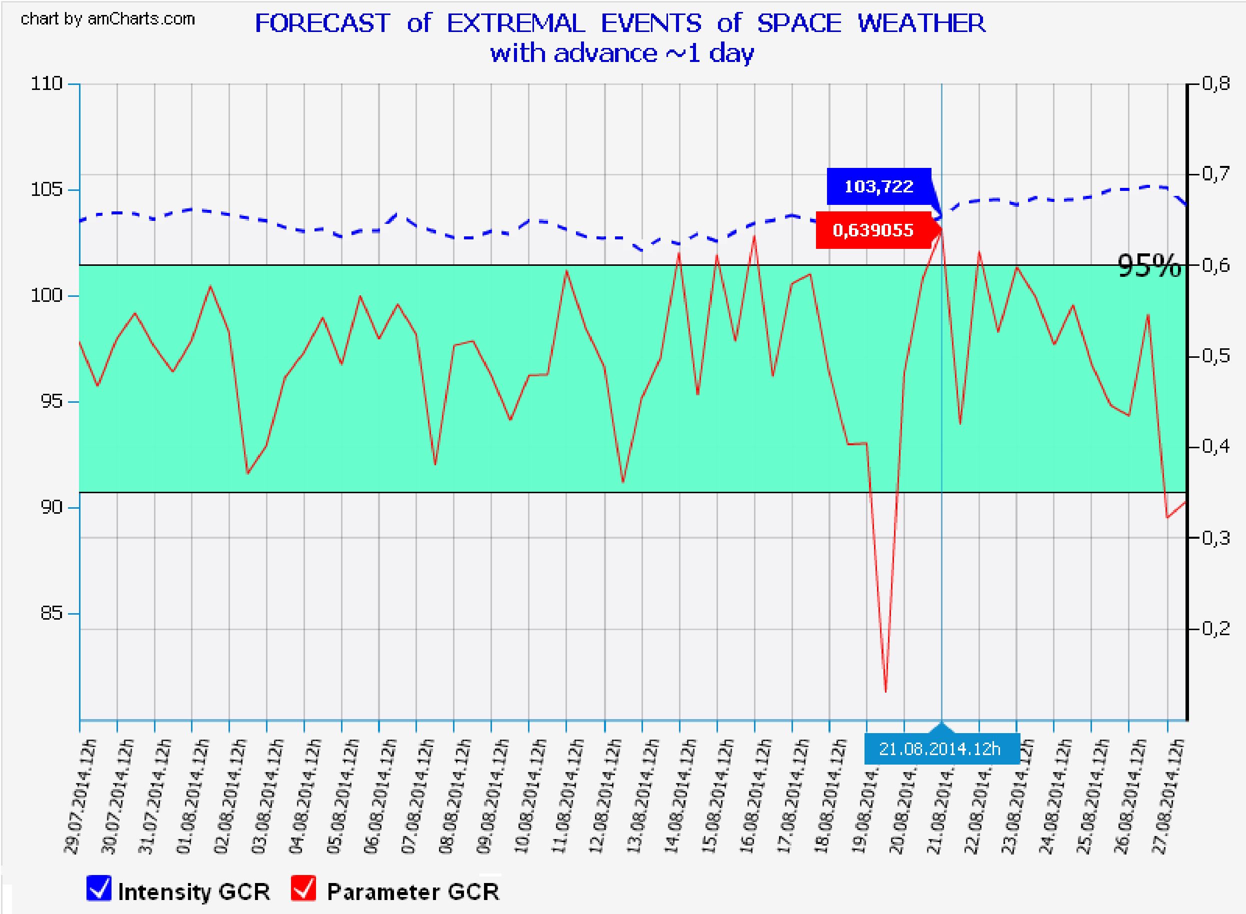


Fig. 8. Results of fluctuation parameter calculating in **July-August 2014**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

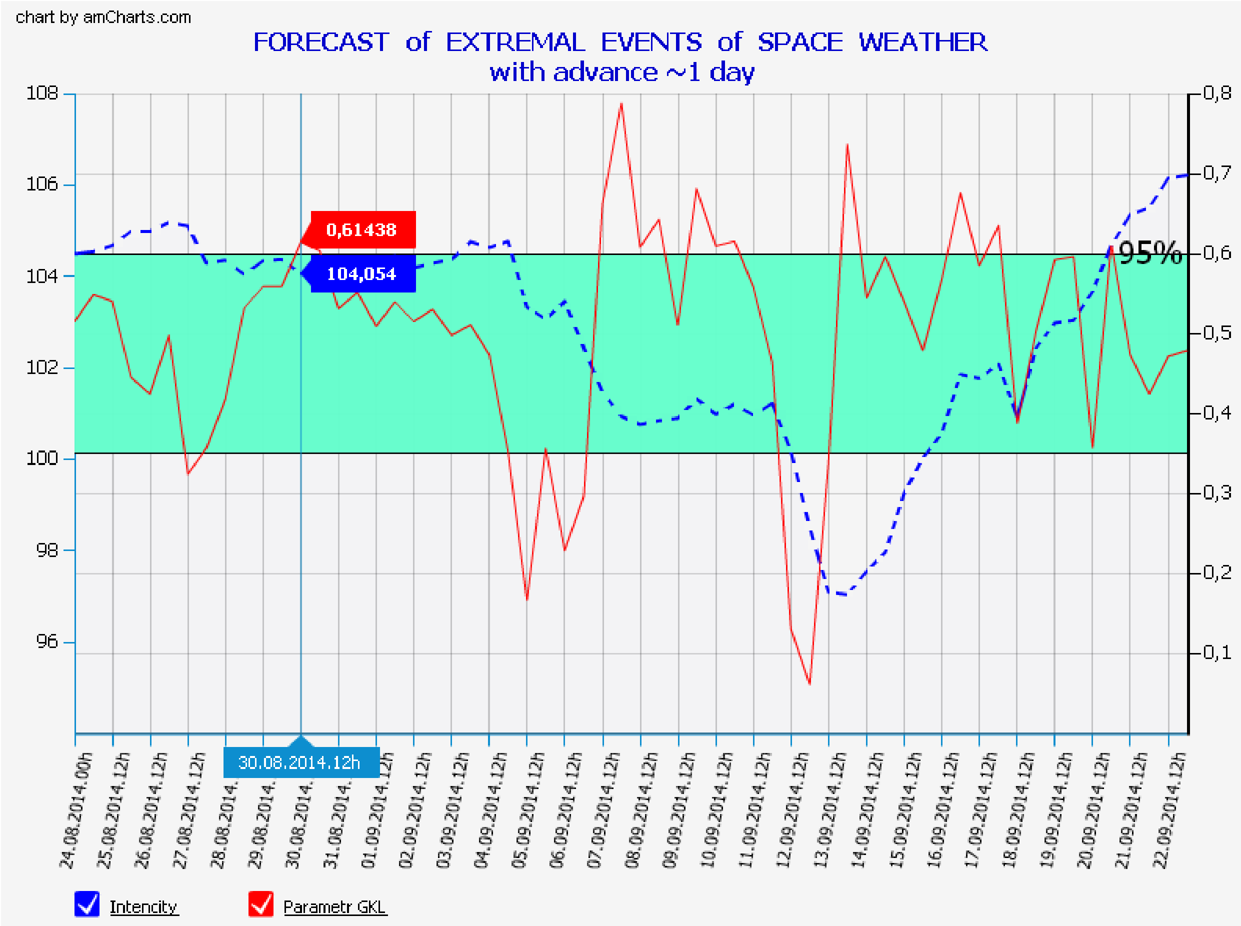


Fig. 9. Results of fluctuation parameter calculating in **August-September 2014**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

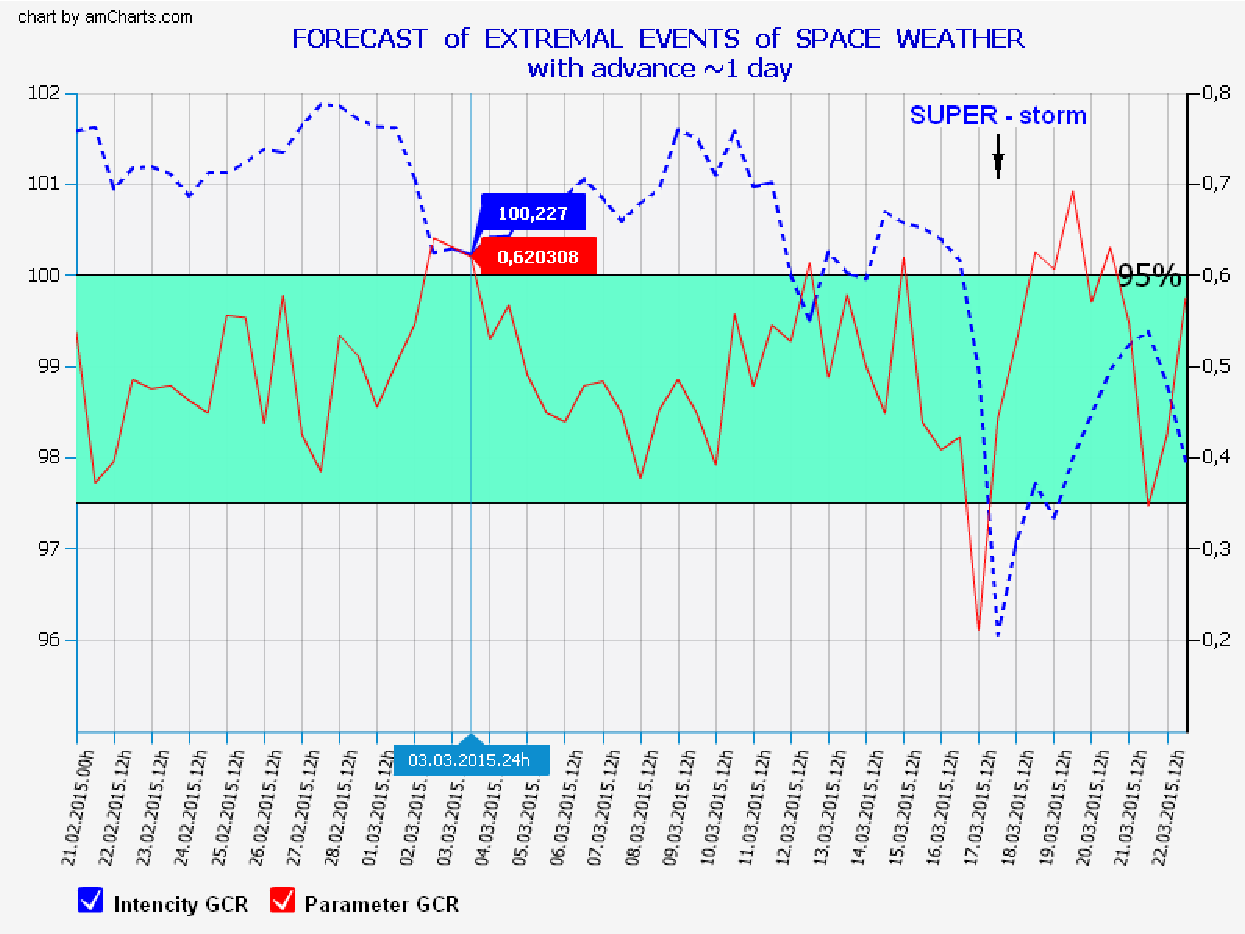


Fig. 10. Results of fluctuation parameter calculating in **February-March 2015**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

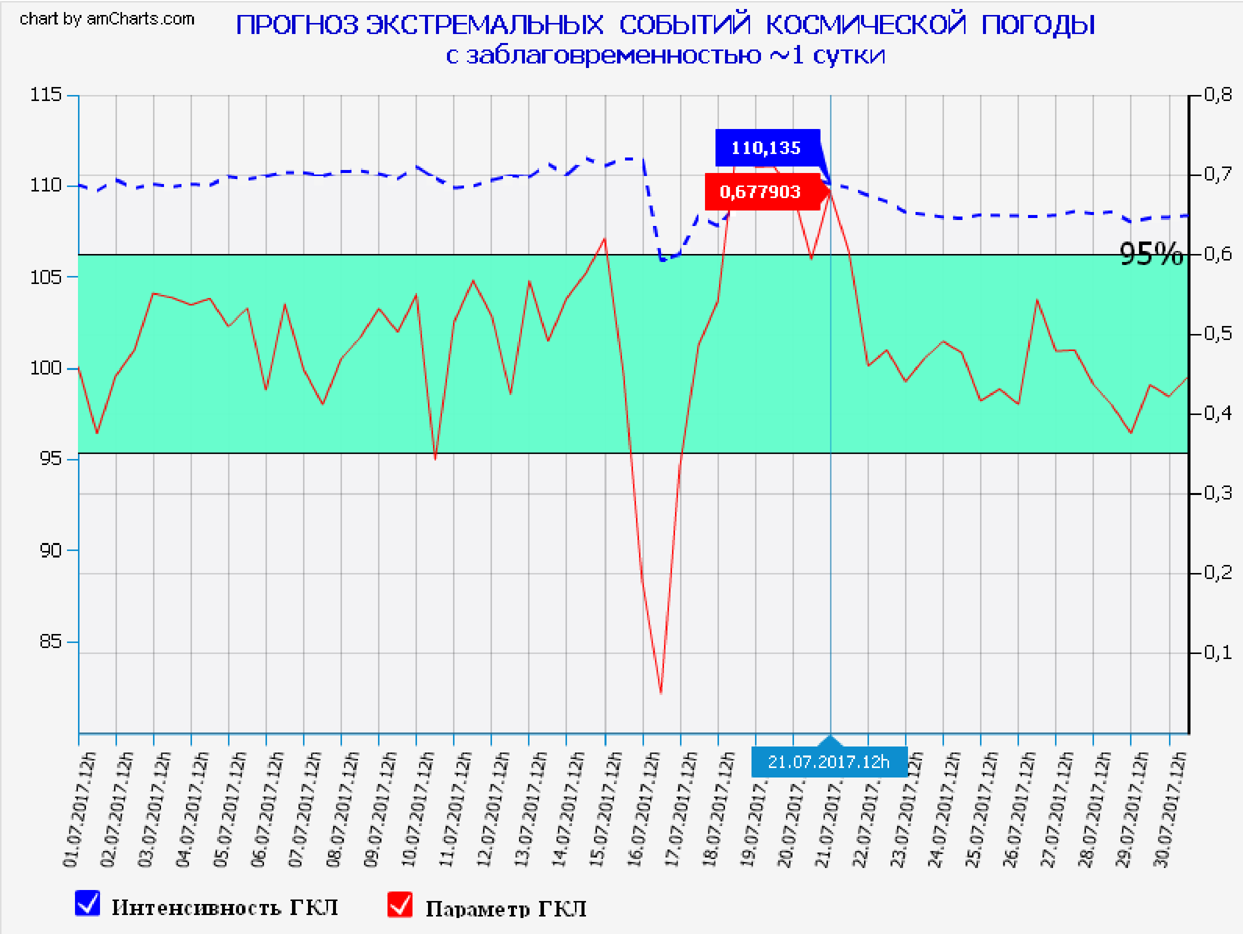


Рис. 11. Results of fluctuation parameter calculating in **July 2017**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.

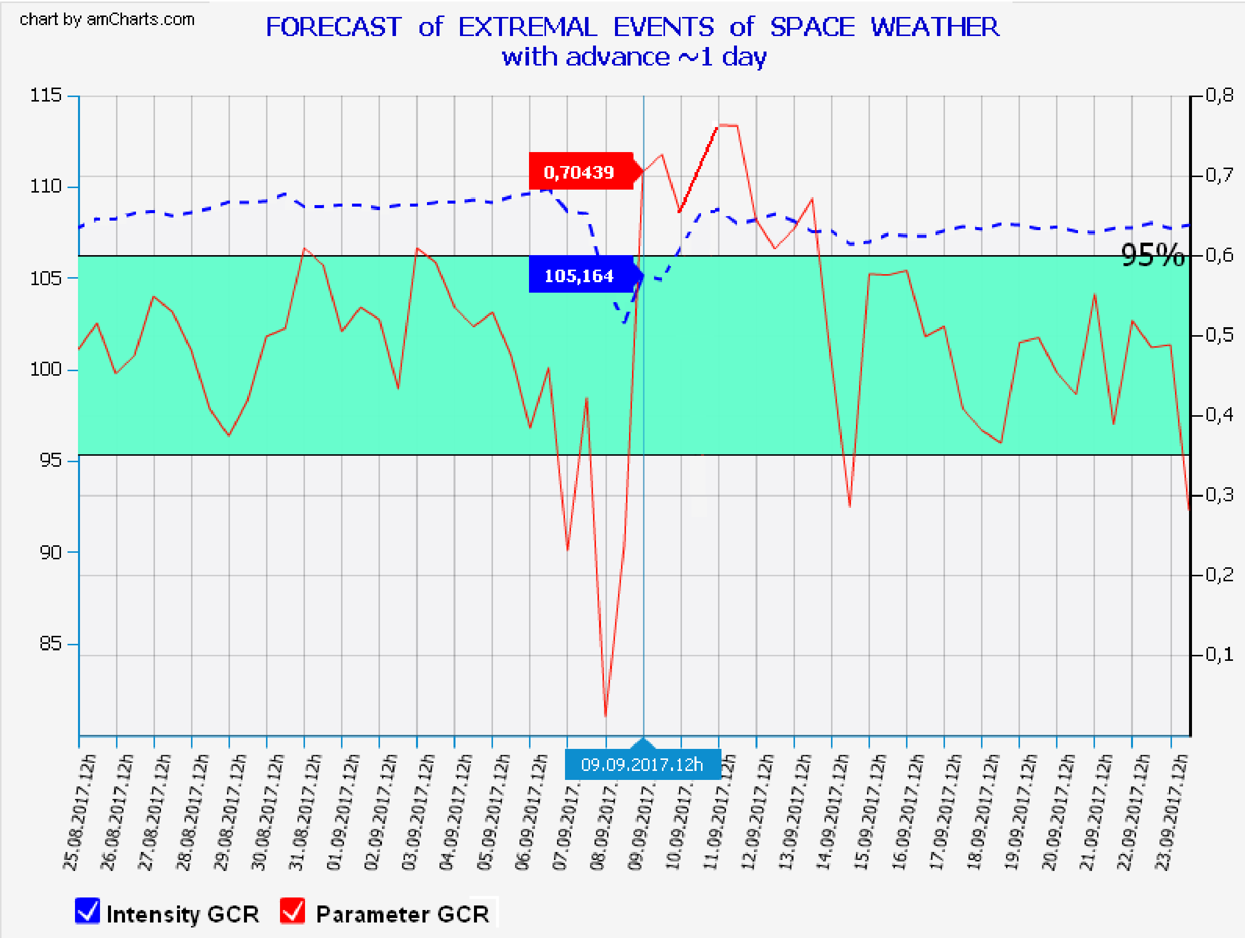
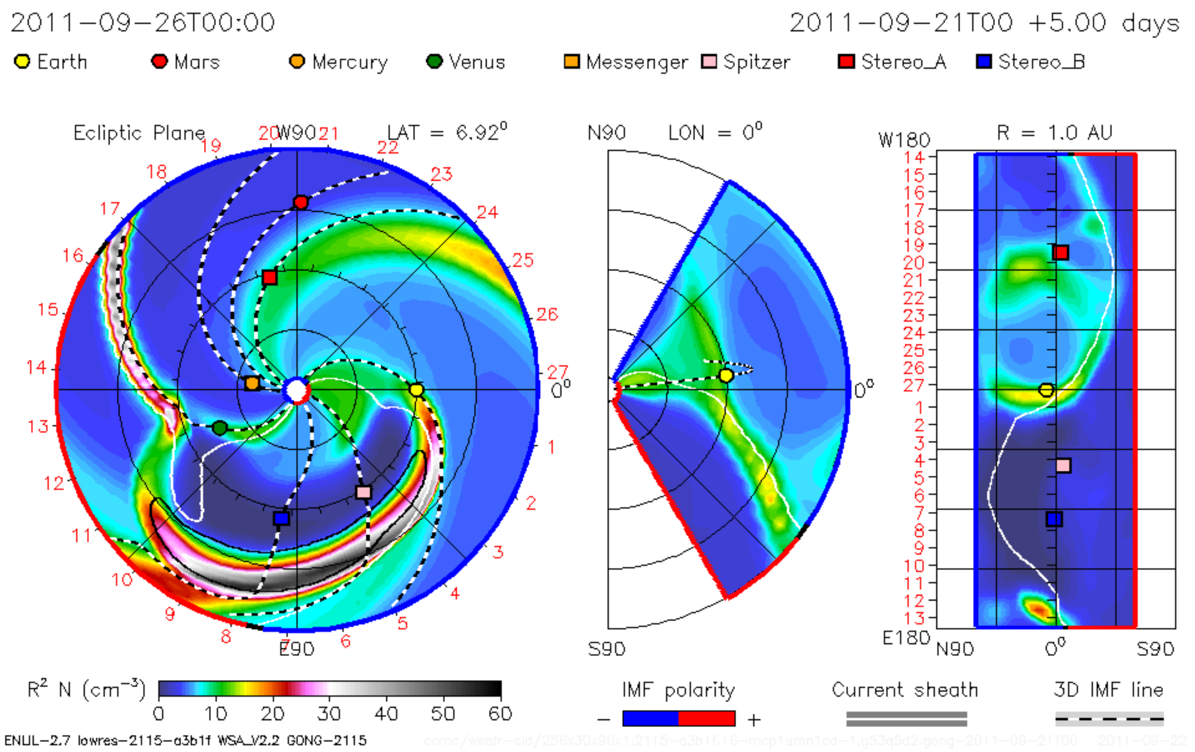
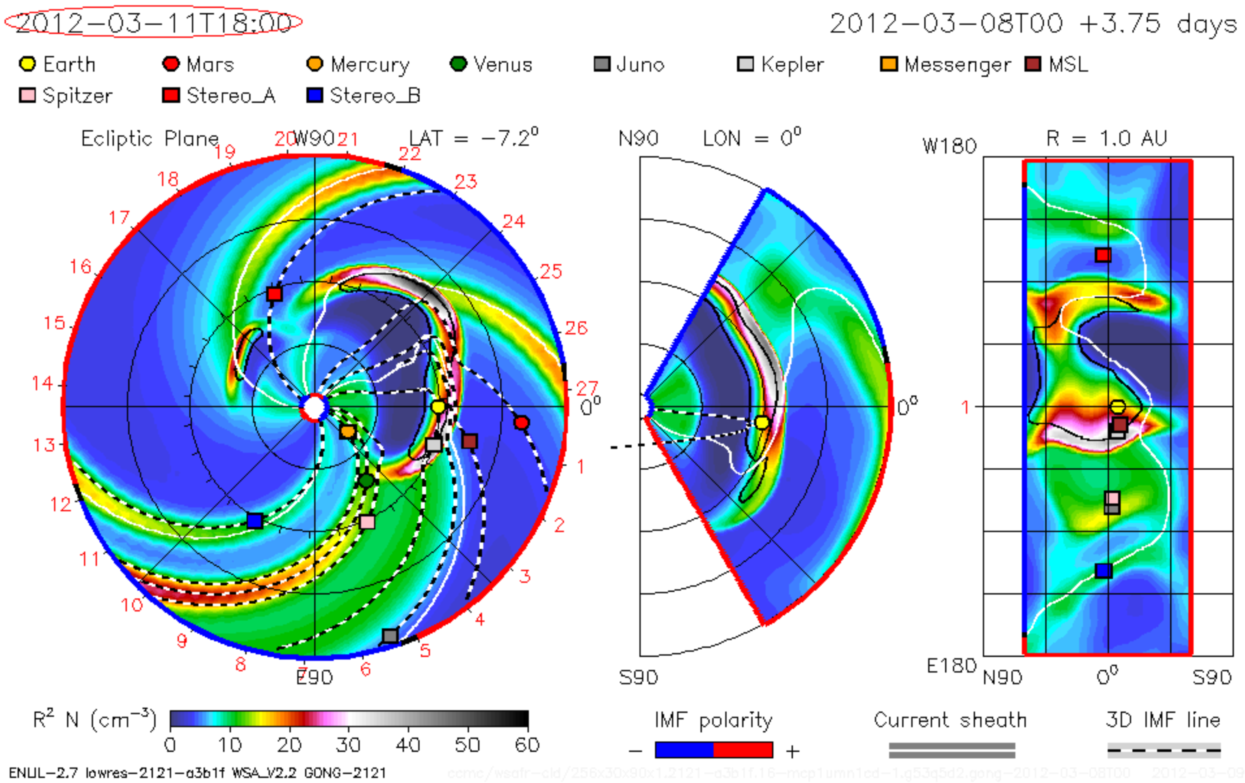


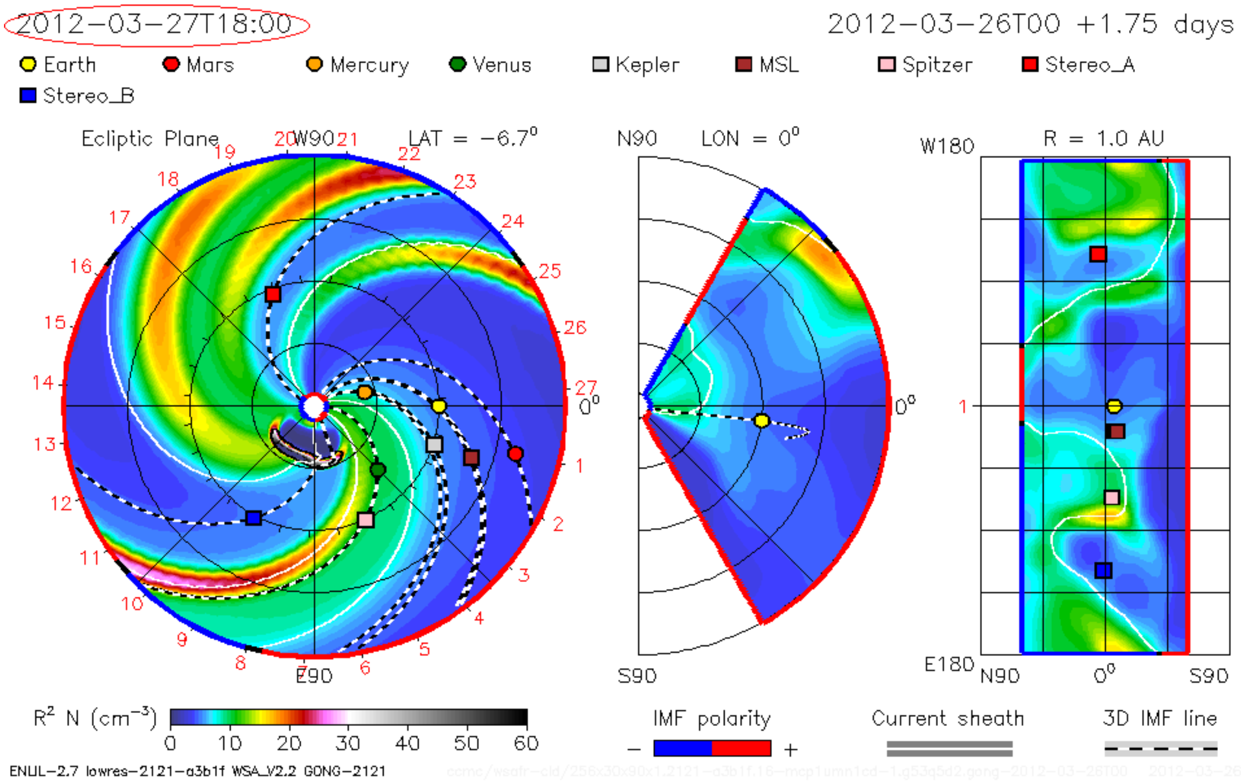
Fig. 12. Results of fluctuation parameter calculating in **August-September 2017**, according to actual data from high-latitude cosmic ray stations from the European database (http://www.nmdb.eu) by means of a robotic expert system: http://www.forshock.ru/pred.html Cyber-FORSHOCK. On the ordinate axis: the scale on the right (solid curve) - values of probability or fluctuation parameter; scale on the left (dashed curve) - the count speed in pulses for 5 minutes (averaged over 12 hours) by data of the neutron monitor of the Oulu station (Finland). The parameter values are enclosed in the interval: 0.35 <P <0.60 - the "Space noise" area. The abscissa is the date: year - month - day - hour.



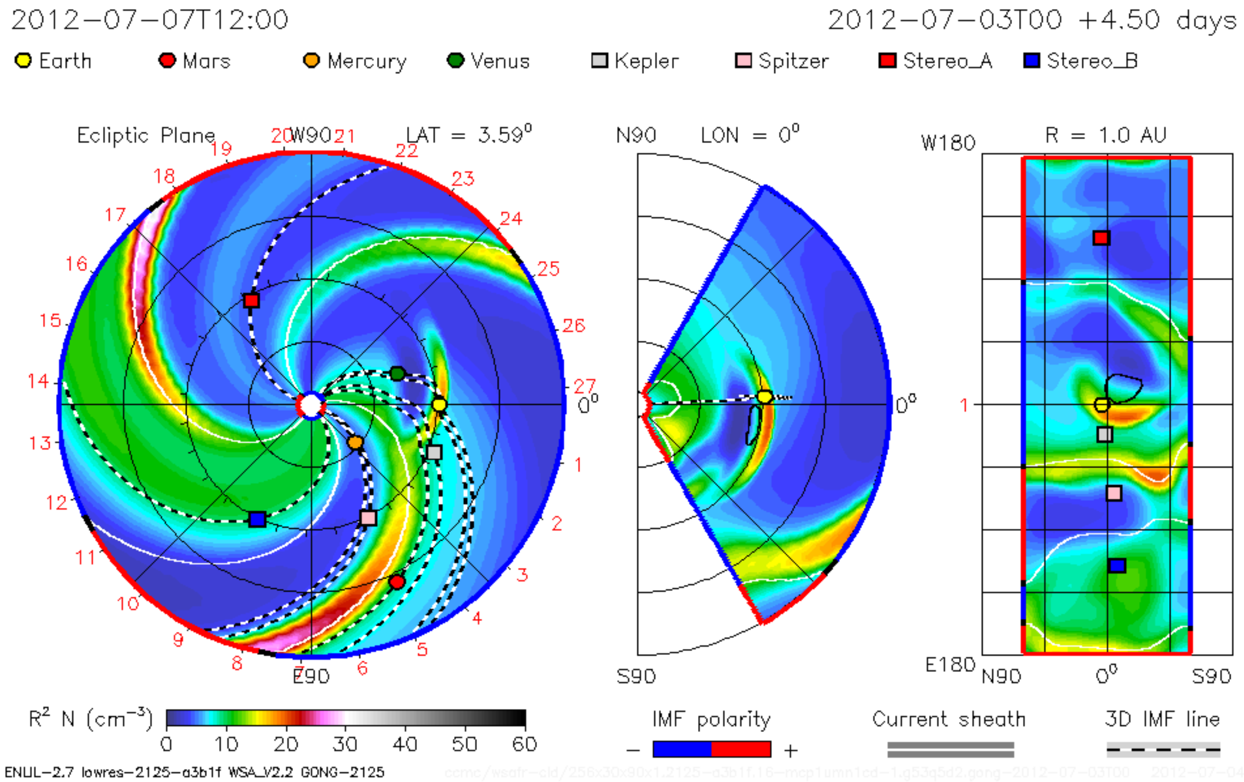
Appendix 1. Animation scheme of the dynamics of the extreme event on **September 25-26, 2011**, registered behind the eastern edge of the solar disk on the basis of model calculations Goddard Space Weather Lab from measurements on space vehicles Stereo-**A** and Stereo-**B** (https://spaceweather.com/archive.php?day=22&month=09&year=2011&view=view). Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.



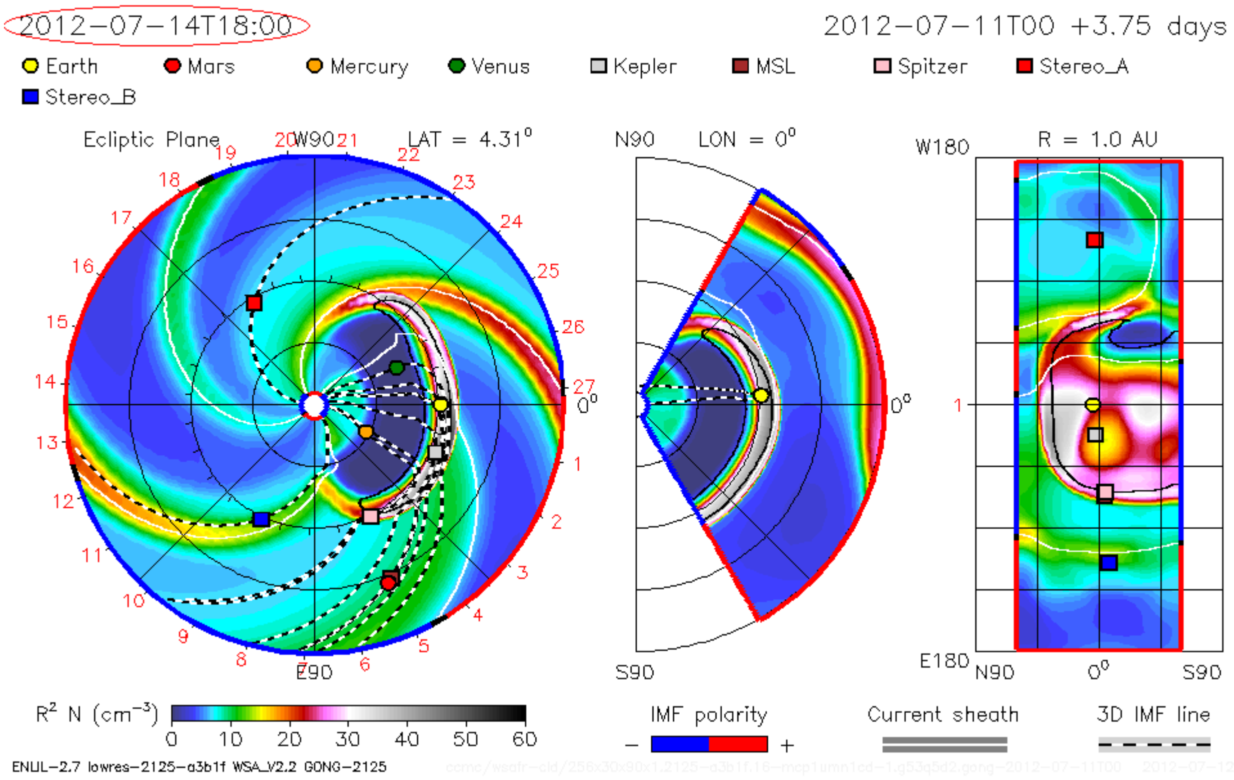
Appendix 2. Animation scheme of the dynamics of the extreme event on **March 12, 2012**, registered behind the eastern edge of the solar disk on the basis of model calculations Goddard Space Weather Lab from measurements on space vehicles Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.



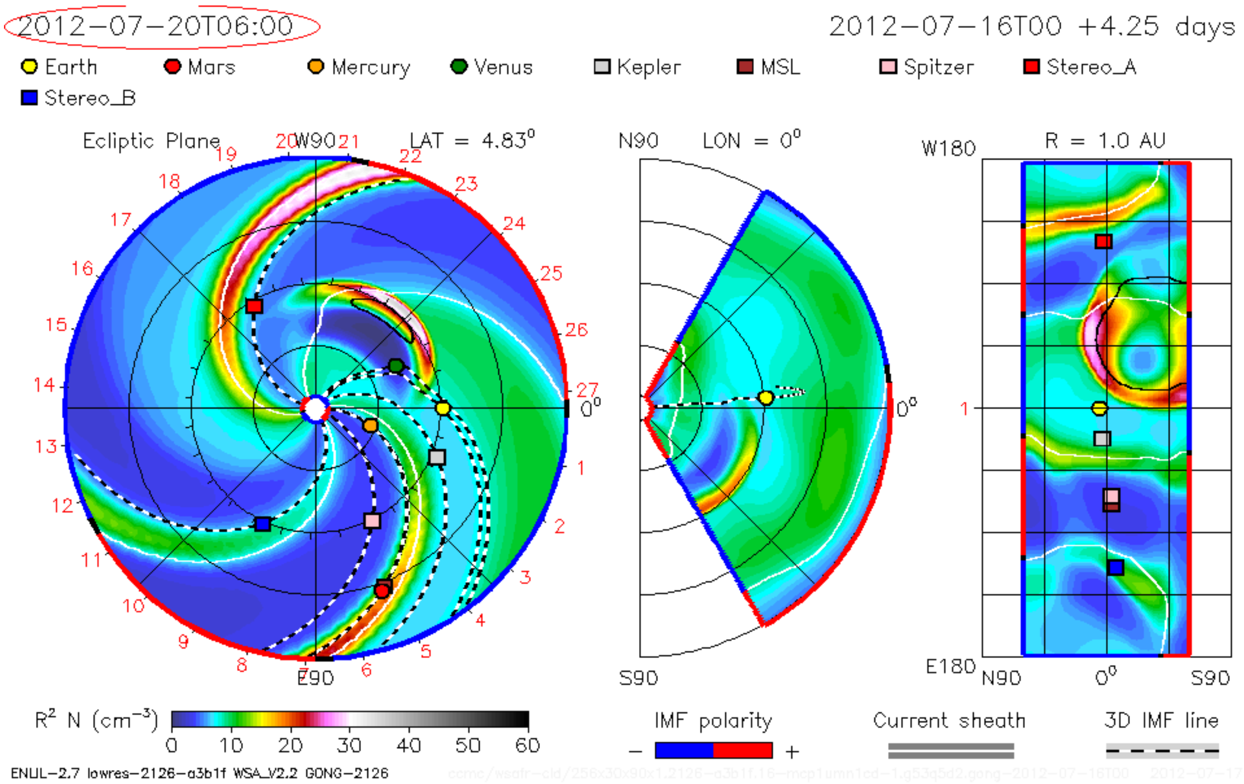
Appendix 3. Animation scheme of the dynamics of the extreme event on **March 27**, **2012**, registered behind the eastern edge of the solar disk on the basis of model calculations Goddard Space Weather Lab from measurements on space vehicles Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.



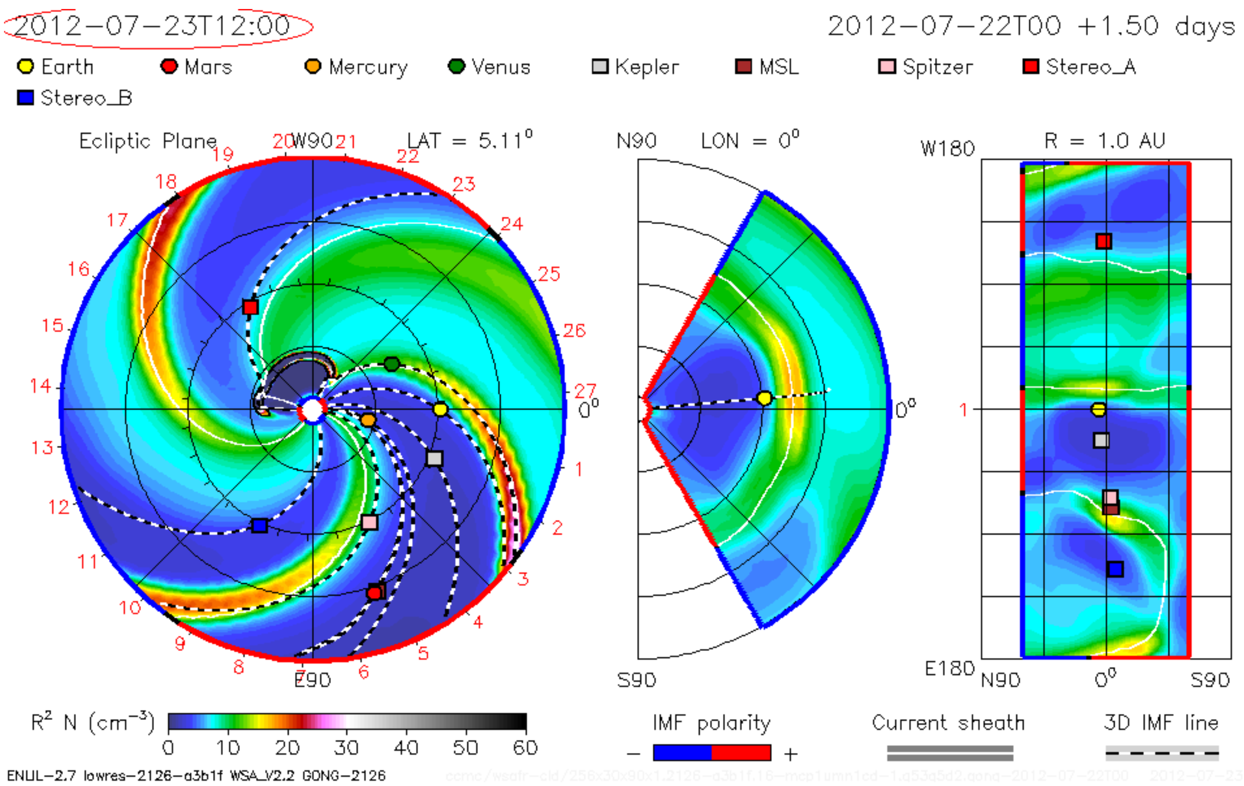
Appendix 4. Animation scheme for the dynamics of the extreme event on **July 7**, **2012** from the active region from the central meridian of the Sun, based on the model calculations of the Goddard Space Weather Lab from measurements on spacecraft Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.



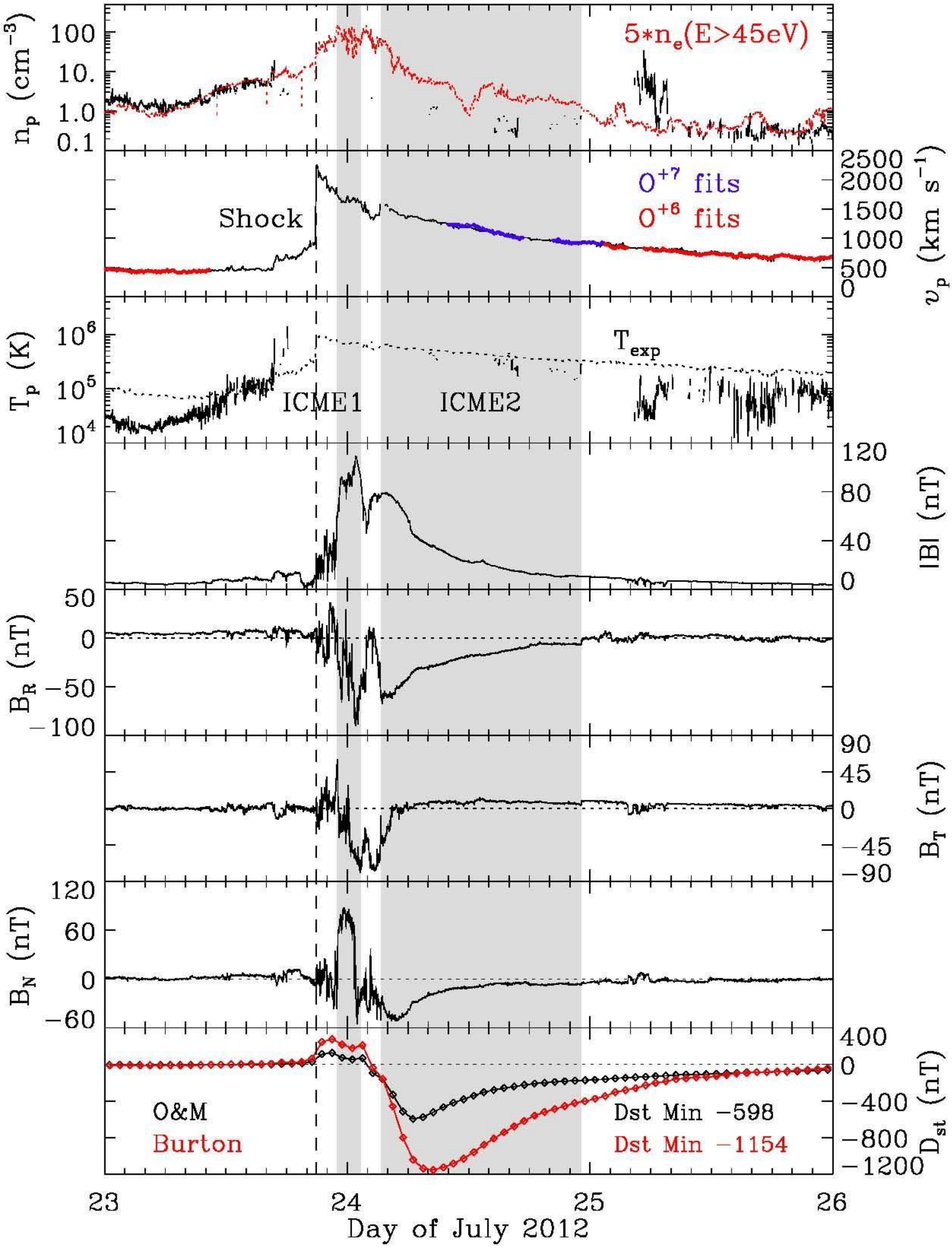
Appendix 5. Animation scheme for the dynamics of the extreme event on **July 14**, **2012** from the active region from the central meridian of the Sun, based on the model calculations of the Goddard Space Weather Lab from measurements on spacecraft Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.



Appendix 6. Animation scheme of the dynamics of the event on **July 19-20**, **2012** from the active region, which came to the western edge of the solar disk of the Sun on the basis of model calculations of the Goddard Space Weather Lab from measurements on space vehicles Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.

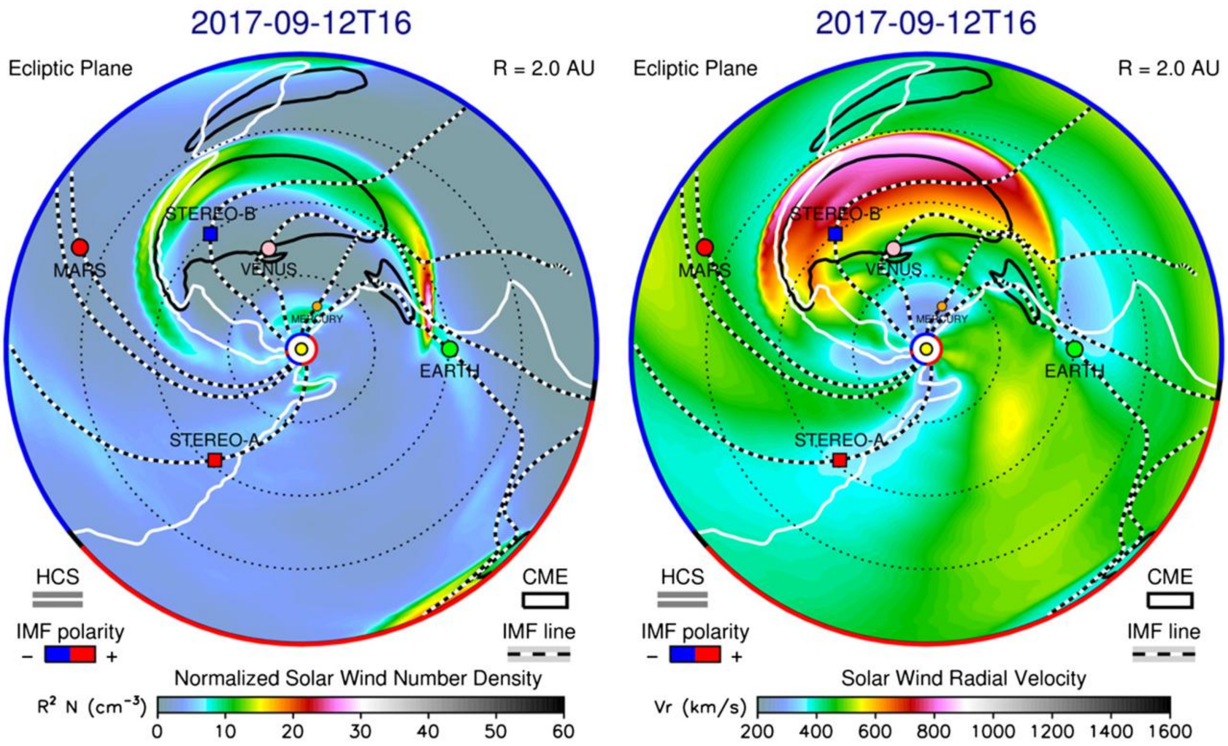


Appendix 7. Animation scheme of the dynamics of the giant event **July 22-23**, **2012**, registered behind the western edge of the solar disk based on model calculations Goddard Space Weather Lab from measurements on spacecraft Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **yellow circle** on the horizontal axis to the right of the disk of the Sun.



http://www.srl.caltech.edu/ACE/ASC/level2/

Appendix 8. Data of direct measurements of the solar wind parameters for the SUPER-event on **July 23-25, 2012**, registered **behind** the western edge of the solar disk in the most extreme event of the new 24 cycle.



Appendix 9. Animation scheme of the dynamics of the extremely event **10-14 September 2017**, registered behind the western edge of the solar disk based on model calculations Goddard Space Weather Lab from measurements on spacecraft Stereo-**A** and Stereo-**B**. Earth's orbit is indicated by a **green circle** on the horizontal axis to the right of the disk of the Sun.