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Similarity and diversity of solar extreme events

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Abstract. Solar extreme events (SEEs) are rare dissipative phenomena. Enormously weak or strong activity periods look as similar or different manifestations in the solar atmosphere depending on the situations controlled by many independent MHD and kinetic dimensionless parameters. We consider here extremely strong solar flares and coronal mass ejections (CMEs) driven by subphotospheric energy sources in different ways - through the heat flows, bulk mass motions, electric currents.

Key words. solar activity; eruptive flares; coronal mass ejection; scaling

1. Introduction

New observational material obtained about different phenomena on the Sun and in the heliosphere during the period of extremely strong solar activity in October-November, 2003 suggests several questions about their physical origins (Veselovsky et al. 2004, 2005). Possible cause-sequence relations between observed processes are now reevaluated based on this information and on the comparison with other similar situations, as well as on the available theoretical arguments. The results demonstrate that physical causes of solar and heliospheric phenomena in October-November, 2003 are not localized only in the active regions and above them on the Sun. The energy reservoirs and driving forces of these processes are distributed more globally. Their essential parts are hidden in the interiors of the Sun remaining invisible for observers. Driving subphotospheric processes could proceed quickly and in a rather unexpected manner which difficult to predict. As usually, sunspots and other tracers (e.g. magnetic fields, motions and different kinds of radiation) can be used as diagnostic tools to follow these smooth or abrupt transformations on the Sun. Direct and inverse energy cascades and transformations of scales permanently happen on the Sun and represent the immanent feature of the solar activity and its cyclic as well as irregular variations. The most intense geomagnetic storm in recorded history was the 1-2 September 1859 event with estimated Dst 1760 nT using the magnetic field measurements at the Colaba observatory in India. The storm was produced by the eruptive event on the Sun described by Carrington (1859) and Hodgson (1859). The brightness of the parent white light flare was dazzling for the protected eyes. It was the first documented solar flare in the new history. It was a white light flare. The magnetic storm started 17 hours 40 min after the flare, which allows the estimate of the average velocity of the ejecta. It was not faster than in August 4, 1972 event. Vaisberg and Zastenker (1976) reported about 14,6 hour delay and the average speed 2850 km/s in this

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case. More detailed descriptions and chronological lists of large magnetic storms and parent solar extreme events (SEEs) can be found in the literature (see e.g. Tsurutani et al., 2003). Just looking at the magnetic field records during geomagnetic storms some similarity and broad diversity can be established for isolated and multiple events. It is also true for SEEs of 2003 (Veselovsky et al. 2004, Kozyra, 2004). Rare statistics and scarce knowledge of driving processes on the Sun and in its interiors preclude any reliable estimates of the allowable assumptions regarding uppermost energy releases on the Sun and their heliospheric and magnetospheric responses. The purpose of this paper is to discuss physical causes of SEEs and approaches to the possible unambiguous classification of similar and different solar events.

2. Similarity and diversity criteria

The only one known to us reasonable and reliable way for constructing scientific classification schemes not biased by personal preferences is based on the evaluation of dimensionless scaling parameters. The set of these parameters is rather broad (see e.g.Veselovsky 2001). Such an approach is a warranty of a sound and systematic classification.Similarity and diversity can be quantified in this manner, which allows to avoid any ambiguity with criteria in hands. First of all, statistical distributions and their parameters should be considered. For example, it is easy to establish conventions about 'normal' and 'abnormal', 'common' and 'rare', 'big' and 'small', if the occurrence frequency demonstrates the normal or some other well established distribution regarding the corresponding parameter like the number of events, their size or the scale under consideration like power, energy, volume, time duration etc. For normal distributions, the 'middle' class population with parameters close to the mean, most probable or average values (which is nearly the same in such situations) can be unequivocally considered and termed as common, usual, typical and ubiquitous. The problem consists in the firm knowledge of statistics, which is poor for extreme events by their definition. The situation is much more difficult when statistical distributions appreciably deviate from normal laws and real laws are not known a priori as a rule. Even the terminology is arbitrary in this case. For example, small and/or big elements can appear to be the most abundant. In this case they represent two typical classes, but the middle class is rare, non-typical. The demarcation is conventional and the middle class can be considered as non-existing. (For the clarity of explanation we can use an analogy: in several parameters such a situation is observed in the society and economics of contemporary Russia.) In some models of the coronal heating and acceleration prevail global elements and direct energy cascades from larger to smaller scales and from the solar core through interiors to observed activity. The alternative hypotheses about inverse cascades from small-scale phenomena and structures like tubes, waves, micro-nano-pico-flares etc. to the larger (but not global!) scales are currently fashionable. The intermediate point of view consists in the classical thinking about the role of active regions and complexes, i.e. the mesoscales in space and time are assumed to be important components of the energy distribution systems on the Sun. Direct and inverse cascades on the Sun obviously coexist and interact in a complicated manner with partially regular and dynamically predictable character, but current predictability horizons are absolutely not clear as a rule. The remaining 'chaotic component' prevails in many instances. Arbitrary guesses are often substitute scientific forecasts in this situation.

3. About forecasts

Predictability limits of solar extreme events (SEEs) are not established. At present, with no diagnostics of subphotospheric processes and very poor knowledge of the solar interior dynamics, one can say that SEEs are practically not predictable. 'Helioseismology' in the broad sense of this word indicates the way to this aim, but the situation could appear similar to earthquakes: well developed seismic diagnostics and continuos monitoring exists, but predictability is also low and its limits remain unclear. It is because of very complicated multi-scale internal organization and non-linear dynamics of interiors in both cases, which is principally unpredictable and demonstrates "chaotic" and non-regular behavior in a practically interesting space and time scales. As we know, weather (or market) forecasts using some dynamical models trying to produce "time tables" for cyclones (or economic trends and oscillations) are a kind of art and speculations, not mention more global problems in nature and society. The situation in the space weather area is not much more different. Reliable predictions are not possible without deep understanding of the processes. If no good science is available - no good forecasts will be expected. Good science per se does not warranty the success, but it gives the only hope to extend reliable predictability limits in all mentioned cases, 'space weather' is not exclusion.

4. Diversity of solar extreme events

The ample diversity of SEEs and of more usual solar events is understandable if we take into account very broad ranges of thinkable and really observed combinations of the large number of the governing dimensionless parameters making some regimes negligible or dominant depending on the situation on the Sun. Recent good examples of this diversity can be found in SEEs of October-November 2003 (Veselovsky et al. 2004). We are not discussing in the present communication the opposite extremity in the solar activity - its lowest attainable values (no spots, no aurora, grand minima etc.). This topic is also very interesting and important for the better understanding of the nature of the solar variability. It deserves special considerations beyond the scope of this paper.

5. Discussion

Solar and heliospheric variability is termed as activity in a broad sense. Attainable limits of this variability are not known. Many different manifestations of solar and heliospheric activity are well documented, but a deep physical understanding of their origins and relations to each other and to primary subphotospheric drivers is still not available. It is due to several serious difficulties. First, the information about solar interiors is not sufficient and many models remain speculative. Second, the observed processes in the solar atmosphere and in the heliosphere are regulated by connection to subphotospheric energy, momentum and mass transports which are poorly known. Third, the empirical data about the solar atmosphere and the heliosphere are limited. As a result, we have no firm grounds to discuss cause-sequence relations in detail and construct convincing dynamical models based on the first principles. Because of this, predictability limits are not clear. Flare-like and CME-like phenomena on the Sun are delimited by the dimensionless parameter Ve, so called "velocity/emission ratio" with its nominator and denominator being emitted powers in two physically different shapes: solar wind plasma kinetic energy motion (nominator) and electromagnetic radiation (denominator). Asymptotically small values of this parameter could correspond to flares without appreciable CMEs (confined and impulsive flares at low altitudes). Large values correspond to the opposite situation - CMEs without appreciable flares (long duration events and large altitudes). In reality, however, this parameter is never zero or infinity, which means that both phenomena accompany each other in different measure given by Ve. Processes at low/high altitudes or impulsive/long-duration events can be quantitatively evaluated in this way. Additional investigations are needed, but currently it is clear that solar flares and CMEs are not related by any cause-sequence dependence against each other. Both opposite paradigms considered in the past should be abandoned as "flare myths" or "CME myths".

Eruptive flares (impulsive, long-duration and super-long-duration events) are nonlinear manifestations of much more energetic global processes on the Sun. This conclusion is not new, but very often neglected in the current studies guided by the ideas of instabilities of an equilibrium in closed physical systems in the upper atmosphere instead of considering non-steady states of open physical systems with large energy, momentum and mass flows. The recuperation and storage processes in the solar atmosphere play their role, but it is secondary: strong flares and CMEs were never observed above the 'quiet' Sun with no strong evolution. Flares and CMEs should be considered merely as 'powerful crests on the tops of large ocean waves', which drive them.

6. Conclusions

Similarity of SEEs is due to the existence of the main general causes residing in the interiors of the Sun and the solar atmosphere for the free energy, momentum and mass transports. Diversity is related to the different dimensionless parameter scaling in a broad range of values from smallest and practically negligible through intermediate to largest and dominant. This diversity precludes hypothetical universal scenario, which pretended to be valid for all flares and all CMEs. Such scenario does not exist and can be not constructed. In the best case, a 'quasi-universal scenario' is thinkable for the statistically most frequent situations. SEEs does not fall in this category.

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