Cosmic Rays and Space Weather Prediction

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Abstract: Galactic and solar cosmic rays registered by neutron monitors can play a useful key-role in space weather storms forecasting and in the specification of magnetic properties of coronal mass ejections, shocks and ground level enhancements. In order to produce a real-time prediction of space weather phenomena, only real-time data from a neutron monitor network should be employed. Interplanetary perturbations, initiated in the solar atmosphere, affect galactic cosmic rays. In some cases their influence on the cosmic ray intensity results in data signatures that can possibly be used to predict geomagnetic storm onsets. The concept of Space Weather was launched before a decade to describe the short-term variations in the different form of solar activity and their effect in the near Earth environment. Space weather affects the Earth’s atmosphere in many ways and through various phenomena. Among them, geomagnetic storms and the variability of the galactic cosmic ray flux belong to the most important ones as for the lower atmosphere. We have performed superposed epoch analysis using hourly neutron monitor data for three different ground-based neutron-monitoring stations of different cut off rigidity as a measure of cosmic ray intensity. In the present work the superposed epoch analysis has been done for the time of occurrence of CMEs are defined as key time (zero or epoch hour/day). It is noteworthy that the use of cosmic ray data in space weather research plays a key role for its prediction. We have studied the cosmic ray, geomagnetic and interplanetary plasma/field data to understand the physical mechanism responsible for Forbush decrease and geomagnetic storm that can be used as a signature to forecast space weather.

Keywords: Space weather, cosmic ray, geomagnetic storm, forbush decrease.

1 Introduction

Huge magnetized plasma clouds and shocks initiated by coronal mass ejections (CME) travel in the interplanetary space with mean velocities up to 2500 km/s. These so-called interplanetary coronal mass ejections (ICMEs) are known as major drivers of severe space weather conditions when arriving at the Earth. On their way to Earth, ICMEs also “modulate” the flux of galactic cosmic rays (GCRs) introducing anisotropy and changing the energy (rigidity) spectra [Dvornikov et al., 1988] of the previously isotropic population of protons and stripped nuclei accelerated in the numerous galactic sources. Changes in the rather stable flux of GCRs are detected by space-borne spectrometers (rigidities up to 1 GV) and by world-wide networks of particle detectors (rigidities up to 100 GV) located at different latitudes, longitudes, and altitudes. The magnetic field found in some ICMEs, known as magnetic clouds, usually has a well-formed flux rope structure [see Koskinen and Huttunen, 2006, and references therein]. The cross section of the magnetic “rope,” a twisted bundle of magnetic fields connecting the Earth’s magnetosphere directly to the Sun, was observed by the Time History of Events and Macroscale Interactions during Substorms satellites on 20 May 2007 (see http://science.nasa.gov/headlines/y2007/11dec_themis.htm). This structure can explain the “collisionless” transport of solar cosmic rays via “highways” inside the magnetic system connecting the Sun with ICMEs [see Valtonen, 2007, and references therein]. Space weather is now a popular scientific term and concept. Space weather refers to conditions on the Sun and in the heliosphere, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space based and ground based technological systems and can endanger human life or health [1]. On the ground the effects of space weather perturbations are due to magnetic field effects [2-3]. Thus, space weather predictions and forecasts are essential for the protection of both the ground based and space based technological systems and other hazardous effects.
Earlier studies indicate a strong association between interplanetary coronal mass ejections and in-terplanetary shocks [4]; interplanetary shocks and cosmic ray intensity variations [5-6]; interplanetary shocks and resulting geomagnetic disturbances [7]. Kane [8] noticed that during very severe geomagnetic storms; ionospheric storm behaviour was erratic, violent and highly localized, reminding one of meteorological storms which can be devastating and yet confined to small geographical locations. Solar flares are often followed by geomagnetic distur-bances has been known since long [9]. However, even at a stage when no interplanetary data were available, Gold [10] indicated the missing link between the Sun and the Earth.

A number of investigations showed a significant correlation between the incidence of clinically im-portant pathologies and strong geomagnetic field variations. The most significant results have been those on cardiovascular and nervous system diseases, showing some association with geomagnetic activity; a number of laboratory results on the correlation between human blood system, and solar and geomagnetic activity supported these findings.

There are numerous indications that natural, solar variabil-ity driven time variations of the Earth’s mag-netic field can be hazardous to human health and safety. There are two lines of possible influence: ef-fects on physical systems and on human beings as biological systems. High frequency radio commu-nications are disrupted, electric power distribution grids are blacked out when geomagnetic-induced currents cause safety devices to trip, and atmospheric warming causes increased drag on satellites. An ex-ample of a major disruption on high technology op-erations by magnetic variations of a large extent oc-curred in March 1989, when an intense geo-magnetic storm upset communication systems, orbiting satel-lites, and electric power systems around the world. The most remarkable and statistically significant effects have been observed during days of geomag-netic pertur-bations, defined by the days of the declining phase of FD in CR intensity.

2 Data Analysis

We used the hourly averaged cosmic ray counts observed with different neutron monitor. We have performed superposed epoch analysis using hourly neutron monitor data as a measure of cosmic ray in-tensity. In the present analysis the time of occurrence of corona mass ejections are defined as epoch day. The data of cosmic ray is used sometimes before and after the key day or epoch day. We also use the geo-magnetic activity index Ap, equatorial ring current index Dst to observe adverse space weather impact arise due to geomagnetic storms. It is well known that big geomagnetic storms have an adverse influence on technological devices and radio wave propa-gation. Major geomagnetic storms, associated with Forbush decreases (FDs) in cosmic ray (CR) intensity, have also been found to increase the incidence of some diseases (in particular, the frequency of myocardial infarction increases by 13 ± 1.4%).

3 Results and Discussion

It is obviously now that according to data for the past on large variations of planetary surface temperature in scales of many millions and thousands years the Earth’s global climate change is determined mostly by space factors: moving of the Solar system around the center of our Galaxy with crossing galactic arms and dust-molecular clouds, nearby supernova and supernova remnants. Important space factor is also the cyclic variations of solar activity and solar wind (mostly in scales of hundreds years and decades). The action of space factors on the Earth’s climate is realized mostly through cosmic rays (CR) and space dust influenced on formation of clouds controlled the total energy input from the Sun into the Earth’s atmosphere. The propagation and modulation of galactic CR (generated mostly during Supernova explo-sions and in Supernova remnants in our Galaxy), in the Heliosphere are determined by their interactions with magnetic fields frozen in solar wind and in coronal mass ejections (CME) with accompanied interplanetary shock waves (produced big magnetic storms during their inte-ractions with the Earth’s magnetosphere). The most diffi-cult problem of monitoring and forecasting the modula-tion of galactic CR in the Heliosphere is that the CR intensity in some 4D space-time point is determined not by the level of solar activity at this time of observations and electro-magnetic conditions in this 4D-point but by electromagnetic conditions in total Heliosphere. These conditions in total Heliosphere are determined by develop-ment of solar activity during many months before the time-point of observations. Cosmic rays represent one of the most fascinating research themes in modern astrono-my and physics. Significant progress is being made to-ward an understanding of the astrophysics of the sources of cosmic rays and the physics of interactions in the ultrahigh-energy range. This is possible because several new experiments in these areas have been initiated. Cosmic rays may hold answers to a great number of funda-mental questions, but they also shape our natural habi-tat and influence the radiation environment of our planet Earth. The importance of the study of cosmic rays has been acknowledged in many fields, including space weather science.

We have plotted (not shown here) the cosmic ray neutron monitor data for three different neutron monitoring stations viz. Oulu, Inuvik and Kiel as a superpose epoch results before and after the onset of Forbush decreases. We observed from these plots an intensity deficit some days prior to the onset of de-crease. The geomagnetic activity parameters Ap and Dst shows enhancement on the onset of these forbush type decreases. As we know that the physical process responsible for these two phenomena i.e. forbush de-crease and geomagnetic storm is different, the com-mon cause for these two may be interplanetary shocks or coronal mass ejections.
It is observed that the use of cosmic ray intensity data in space weather research has practical applica-tion for its prediction. Cosmic rays in the loss cone, i.e. along a narrow range of pitch angle originate in the cosmic ray depletion region, downstream of the approaching shock when the interplanetary events are stronger.

We have also performed the superposed epoch analysis for the interplanetary magnetic field strength (B) its components (Bx, By, Bz) and solar wind plasma speed (V)during these epoch period. We observe significant variations in all these pa-rameters during these epoch periods. Cosmic ray observations till now are used out of complete vol-ume in the space weather tasks. The main reason of such inefficiency is inaccessibility of many kinds of the cosmic ray data for an operative analysis. Fortu-nately, this situation is now changing fast to the bet-ter. In particularly, data from ~25 ground level cos-mic ray stations now are available in real time. It gives a hope that in the nearest years we shall see more wide and effective use of the cosmic ray char-acteristics for space weather forecasting.

When we speak on Space Weather we are com-monly meaning the radiation and electro magnetic conditions in the near Earth space. Cosmic ray varia-tions define di-rectly a radiation situation. Besides of this they are closely related to the second component of the space weather – to the variations of electro-magnetic conditions in the interplanetary space and Earth’s magnetosphere. This makes cosmic ray variation as one of the important re-source for diag-nosting of the space weather state and forecasting of its changes.

4 Conclusion
When considering CR variations as one of the possible causes of long-term global climate change we need to take into account not only CR modulation by solar wind but also the change of geomagnetic cutoff rigidities. We observed that two phenomena forbush decrease and geomagnetic storms can be used to predict the space weather forecast. The use of cosmic ray inten-sity records has practical application for space weather pre-dictions.

5 References