Space weather near Earth and energetic particles: selected results

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Space weather near Earth and energetic particles: selected results

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Abstract. Space weather effects have two links to research of energetic particles in space. First, the direct one, connected with the interaction of high energy cosmic particles including galactic, solar cosmic rays, as well as magnetospheric particles, with various materials as satellite systems, atmosphere, ionosphere, airplane systems, human body at high altitudes and in space. Second one, the indirect relations, is checking the relevance of possible forecasts of space weather phenomena according to the data of energetic particles both on the ground and on the satellites and space probes. We review few selected aspects of the second type of relations with references mainly to recent studies, namely (i) progress in description of selected quasi-periodicities in cosmic ray time series which are of potential use for space weather studies, (ii) status in the forecast of geoeffective and radiation storm alerts using signatures of ground-based observations, (iii) problem of relativistic electrons in the vicinity of Earth.

1. Introduction.

Several books, review articles and presentations in electronic form on relations between Space Weather research and energetic particles in space are available, e.g. [1-7] on relations to cosmic ray (CR) studies; [8,9] on relations to magnetospheric populations; [10] on radiation hazard in space; [11,12] on space weather effects and physics behind. There exist several models of galactic cosmic rays (GCR) useful for radiation hazard estimates. Paper [12] compares several GCR models and test their applicability for exposure assessment of astronauts, with references to earlier models. Probabilistic models of solar energetic particle (SEP) flux can be found e.g. in [13,14] or at site [15]. Recent review on CR and health is e.g. in [16,17]. Only few *selected* results relevant to relations between energetic particles in space and space weather effects, especially those obtained in past years, are mentioned. This selection is far from being complete. Impact of CR on atmosphere and health issue is not listed here.

2. Selected quasi-periodic variations observed in cosmic rays.

For Space Weather studies the comparison of occurrence of quasi-periodic (q-per) variations of CR with those of various geomagnetic, interplanetary and solar characteristics, is relevant. Distinction in the occurrence in q-per variations of CR time series with those of other potential drivers of space weather phenomena can help in identification the causality of some space weather effects. For example the discrimination between solar and cosmic ray forcing on the terrestrial climate was

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discussed e.g. in [18]. We mention here only some recent results on selected quasi-periodicities in CR time series as observed on the ground or near the Earth's orbit.

2.1. Quasi-periodicity (q-per) ~ 1. 7 years.

Recurrence in CR intensity at ~ 1.7 years was reported first in [19], analyzed by wavelet methods in [20], found also in outer heliosphere in data of Voyager [21]. Using neutron monitor (NM) data Calgary and Deep River the authors of [22] indicated at ~ 20 months power spctrum shape is changing. Author of [23] reports that length of the quasi - 2 year periodicity in the even and odd numbered cycles differs by ~2 months. In cycles 20 and 22, T = 22–23.5 months, while in the 21st and 23rd T = 20.2–20.8 m. Paper [24] analyzing solar magnetic flux in 1971–1998 found that ~ 1.7 year is the dominant fluctuation for all the types of fluxes analyzed (total, closed, open, low and high latitude open fluxes) and has a strong tendency to appear during the descending phase of solar activity. Rouillard and Lockwood [25] relate a strong 1.68-year oscillation in GCR fluxes to a corresponding oscillation in the open solar magnetic flux and infer CR propagation paths confirming the predictions of theories in which drift is important in modulating CR flux.

Power spectrum analysis of surface atmospheric electricity data (42 years of potential gradient, PG at Nagycenk, Hungary) showed also ~1.7 year q-per [26]. The ~ 1.7 year periodicity in the PG data is present in 1978 – 1990, but absent in 1963 – 1977. Using the monthly data of modulation parameter of CR available since 1936 from paper [27], we computed the wavelet spectrum. In the epoch without the ~1.7 year wave in atmospheric electricity (PG) the corresponding wavelet spectrum density (WSD) of CR is at lower level than that for the 1978-1990. It would be of interest to perform wavelet analysis of both time series (CR, PG) over long time interval including also epoch after 1990 not covered in [26]. We found the variable WSD of ~1.7 year wave over the period 1953 – 2006 when Climax data are available. The time evolution of the ~ 1.3 year wave in CR to the signal was obtained too (reported earlier in interplanetary parameters and in geomagnetic activity e.g. by Mursula and Zieger [28] as well as by Obridko and Shelting [29] in solar magnetic fields since 1915 inferred from H-alpha filament observations). The ~1.3 year wave density profile is different from that of ~ 1.7 year. That analysis allowed us to identify also the 2.2-2.3 yr enhancement indicated earlier by Mavromichalaki et al [30] where the authors used coronal index from coronal stations [31]. That q-per has been found in CR as enhancement of density especially in the 22nd solar cycle. It may be the edge of QBO discussed recently by Laurenza et al [32]. More about comparison can be found in paper [33]. Mid-term q-pers (1-2 years) are observed also in other solar activity characteristics. In sunspot groups and flare index the periodicities in that range have shown differences in the solar hemispheres [34]. Recently Vecchio et al [35] performed the detail analysis of different components of heliomagnetic field for 1976-2003. The authors found that quasi-biennal oscillations (QBO) are also identified as a fundamental timescale of variability of the magnetic field and associated with poleward magnetic flux migration from low latitude around the maximum and descending phase of solar activity cycle.

2.2. Three solar activity cycle quasi-periodicity?

The q-pers in CR shorter than ~11 years have been reported by using different methods from data 1953-1996 e.g. by Mavromichalaki et al [30]. Periodicities ~11 yr and ~22 yr along with their origin are discussed e.g. by Venkatesan and Badruddin [36]. Lomb-Scargle Periodogram of Climax NM data (1953 – 2006) we computed, indicates several q-pers at very low frequencies (~5.5, ~6.4, ~ 8.2 yr) [33]. Its significance, however, requires more detail testing.

Since nowadays there exist rather long time series of CR measured *directly* both on the ground [27] as well as in stratosphere at various depths [37,38], it is worth to check the trend of three-solar cycle recurrency reported for the first time by Ahluwalia [39] from the ground based CR measurements. The analysis done by Pérez-Peraza et al.[40] using the cosmogenic ^{10}Be nuclide as an indirect proxy of CR over the long time period, has shown common frequency of 30± 2 years which appears also in the time series of Atlantic Hurricanes. Longer time series of CR, solar activity and IMF were examined recently [41]. Here we use the direct stratospheric measurements of CR provided routinely over long time period [37,38] as well as data [27]. The periodograms in Figure 1 indicate the tendency that the three-cycle trend is present in both data sets.

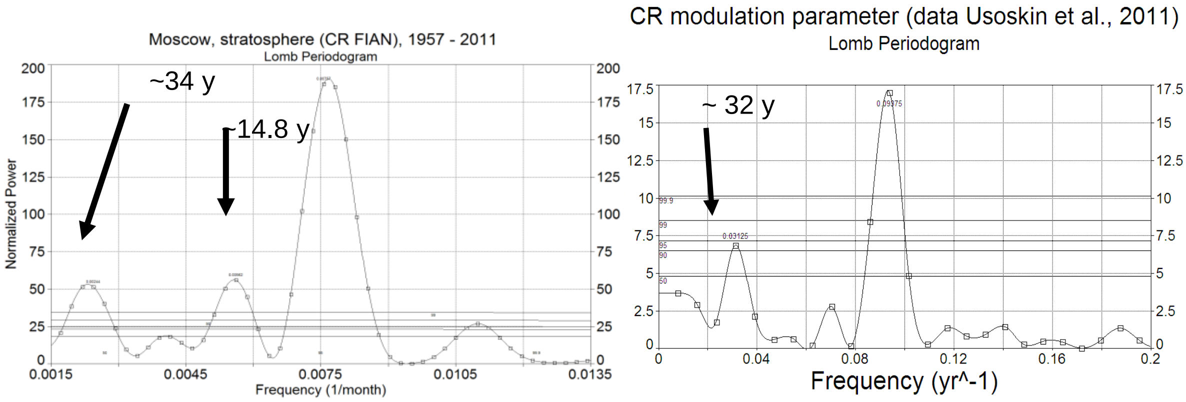

Fig. 1. Left panel: Periodogram of the monthly means of stratospheric CR measurements near Moscow [37,38] taken at the highest altitude. Along with the highest peak at ~ 11 yr, the ~ 3 solar cycle peak and ~ 14.8 year peak are exceeding significance level 0.99. Right panel: periodogram of ground based CR data according to table in paper [27]. The levels of significance correspond to only white noise.

2.3. Quasi-periodicity at ~ 27 days.

Discussion about ~ 27 d periodicity in ground based CR recordings continues in accordance with obtaining longer time series of NMs and muon telescope (MT) data. Recently this has been discussed in detail e.g. in papers [42,43]. Agarwal [44] indicates that ~27 d CR variation correlates with B, Bz, v, and B(v x B). Wavelet method provides fine structure of appearing q-pers in the signal as inspected over long time. For example the profile of WSD using Climax NM data over 1953-2006 indicates the double structure during year 1986, with two peaks, one around ~27 days and another ~30-31 days. The two peak structure is similar to that reported by Dunzlaff et al [45] for GCR from measurements at lower energies, EPHIN on SOHO. Gil and Alania [46] reported the 3–4 cycling structure of ~ 27 day q-per amplitude in NM data with cut-off rigidities below 8 GV. Analysis of data from Nagoya MT (Sabbah, personnal communication) were checked by periodogram technique and we found that the ~3 Carrington rotation q-per is significant even at higher energies of primaries [27]. Modzelewska and Alania [47] discussed the 3D model of ~ 27 d CR variations. By checking linear correlation of amplitude of 27 d wave of Climax NM [48] with various interplanetary parameters, we found rather high correlation with magnitude of IMF B, with sunspot numbers, with tilt angle of heliospheric current sheet and with coronal hole area as deduced from the green coronal line [49]. Yearly averages of 27 d amplitude give correlation coefficient 0.93 for the fit in period 1977 – 2003 (Figure 2 [48]).

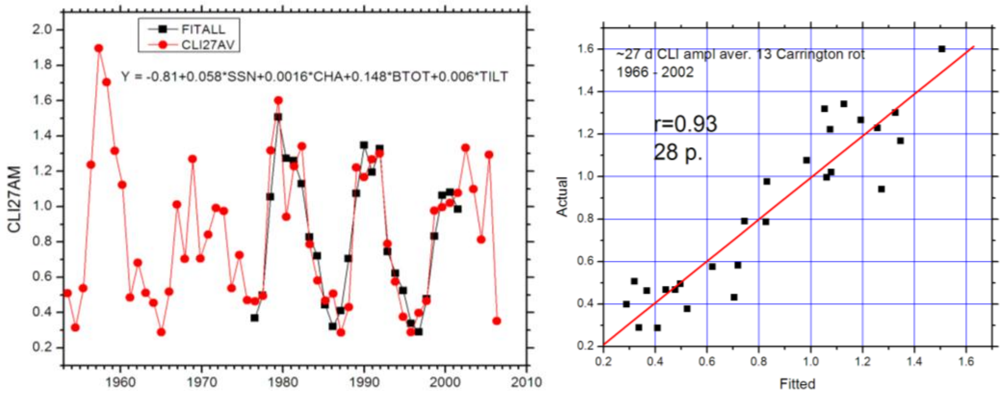

Fig. 2. The amplitude of 27 day variation at Climax NM (data from Sabbah, personnal communication) averaged over 13 rotation periods (CLI27AV) and the best multiple linear regression with sunspot numbers, coronal hole area, magnitude of IMF and tilt angle of current sheet. Fitting was done when all solar activity parameters were available. Right panel illustrates the quality of the fit.

Wavelet analysis in the vicinity of ~13.5 q-per indicates also “non-monochromatic” structure during the long time using Climax NM data. Position of maximum is varying during the time period examined and also double structure is apparaent (not shown here). In general our result is consistent with the result reported earlier [50] indicating that the power spectrum of 13.5- and 27-day variations repeats the power spectrum change of the number of sunspots and tilt angle of the current sheet. Checking the dependence on solar magnetic field polarity requires more detailed study. Recently Vieira et al [51] found a double structure in power spectrum density near ~ 13.5 days for muon detector data. Chowdhury and Dwivedi [52] reported results from wavelet analysis of GOES high energy electron data during solar cycle 23 and a part of cycle 24 and found a number of quasi-periodic oscillations in both data sets. We made a spectral analysis of the daily fluence of relativistic electrons (>2 MeV) and high energy protons (>100 MeV) measured by GOES. A clear difference of ~ 27 day wave is found: while for electrons the increase around that q-per is very clear (with some fine structure), there is no indication about 27 day recurrency in the proton data (Figure 3). The ~27 q-per in daily energetic electron fluence is probably related to the Jovian electrons studied e.g. in [53]. CIR modulation effect provides an explanation for the ~ 27-day variation in the Jovian electron flux intensity near Earth [54].

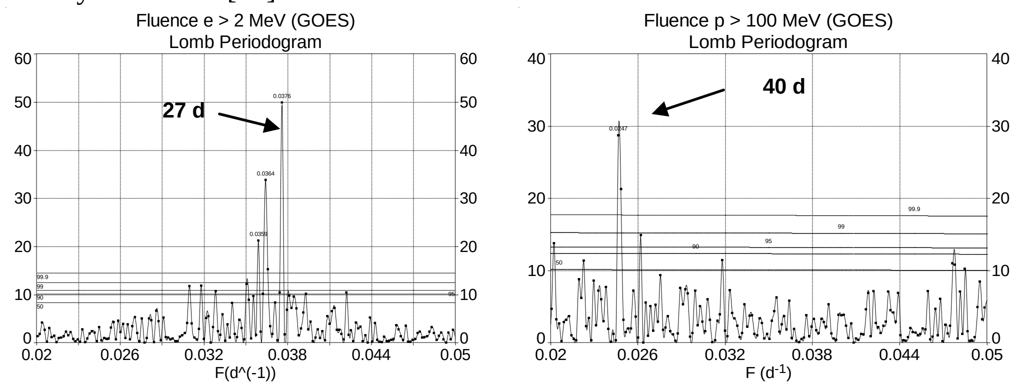

Fig.3. Selection (per. 20 – 50 days) of the periodogram of the daily fluences of relativistic electrons (left) and high energy protons (right) measured by GOES. Data from 1996 until June 2012 are used (from site prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center).

Solar, geomagnetic and IMF parameters recently analyzed by Katsavrias et al [55] by wavelet and the Lomb-Scargle periodogram identified the ~27 d periodicity (with ~13.5 days being its harmonic) in solar wind parameters, in Bx, By, and in the geomagnetic indices. Detailed analysis of various q-pers in solar wind and in CR during the 23rd solar cycle is performed in paper [56]. Such type of analysis with the wavelet transform is important to survey various solar cycles with available data.

2.4. Rieger's quasi-periodicity.

Rieger et al [57] reported the existence of q-per in occurrence of of gamma ray flares at ~ 154 days. Several papers deal with this range of periods in solar activity parameters. Since solar flares with consecutive CMEs and plasma discontinuities in interpalnetary space modulate CR flux near Earth, and from another side the flares themselves contribute to SEP and ground level events (GLE, recently summarized and analyzed for solar cycle 23 e.g. in [58,59]), the temporal behaviour of CR time series is of interest around that periodicity too. Chowdhury et al [60] found several intermediate-term q-pers in solar activity characteristics and in CR. Period 150-160 days was found prominent during ascending phase of cycle 23 in both GCR and in solar indices. Detailed studies of ~156 d q-per in various time series of solar activity parameters was published recently [61]. Figure 4 indicates that there may be a more complicated structure in the time series of CR measured by NM and wavelet analysis is needed for more detailed analysis of the periodicities and their occurrence in the vicinity of Rieger's quasi-perodicity.

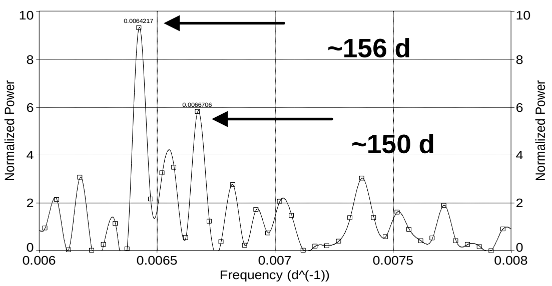

Fig. 4. Periodogram of daily means of Climax NM count rates 1953 – 2006 in the range 125 - 167 days. The only two peaks above significance level 0.95 are those at periodicities marked with the arrows. We acknowledge the University of New Hampshire, "National Science Foundation Grant ATM-0339527" for data of Climax NM used throughout this paper.

3. Alerts of Space Weather effects: networks of CR measurements on ground and satellite data.

3.1. Radiation storms.

For radiation hazard effects during solar storms with consequences on element failures on satellites, on communications, on health of the astronauts etc., high fluxes of ions with energy of several tens to hundreds MeV are important. Before their massive arrival to the Earth, NMs having good time resolution and high count rate, if they are in real-time bound in the network, can provide useful short-term alerts (several minutes to tens of minutes) in advance of the alerts prepared on basis of satellite particle measurements [62]. During last few years it was shown that CR ground based measurements along with the satellite ones are useful tools for improvement short-term forecasts of radiation storms. NM at a single site (high latitude, high statistics) allows to obtain real time energy spectrum of SEP. South Pole combination of NM64 and that lacking usual lead shielding was illustrating that probably for the first time for the GLE 69 on January 20, 2005 [63]. Paper [64] reported the potential of South Pole NM data for prediction of radiation storm intensity measured by GOES. The energy spectrum was estimated in [65]. 31 SEPs have been associated with GLEs. Fluences and peak intensities of SPEs have good correlation with % increases in GLEs, best at channels > 350 MeV). For > 350 MeV the threshold values for GOES fluence and peak intensity are found: most SEPs above threshold are associated with GLEs, almost none below the threshold. GLE enhancement real-time alarm based on 8 high latitude NMs including those at high mountain is described by Kuwabara et al [66]. Three level alarm system is used. Out of 10 GLEs in 2001-2005 archived data, the system produced 9 correct alarms. GLE system gives earlier warning than satellite (SEC/NOAA) alert in the range of 9-34 min. Including NM at various cut-offs improves in few cases the timing of the alert. Several steps of GLE alert algorithm using NM network is described in [67]. Paper [68] describes the development of alert signal for GLEs. The tool is available at http://cr0.izmiran.ru/GLE-AlertAndProfilesPrognosing. The first GLE in the 24^{th} solar activity cycle has been observed on May 17, 2004, GLE 71 [69]. The highest signal was observed at South Pole. It was not seen at NMs with vertical geomagnetic cut-off > 3 GV. Report from the Athens group distributed [70] informs the operational real-time Alert Code of the Athens NM via NMDB issued an Alert signal at 17.05.2012 at 02:13 UT, i.e. 39 min in advance from GOES. The alert was based on measurements on the three high-latitude NMs, namely Apatity, Oulu and FSMT. NOAA issued an Alert based on the recordings of the proton channel at 100 MeV when exceeding 1 pfu. This Alert was issued for the event under investigation at 17.05.2012 at 02:52 UT. Figure 5 illustrates the increase of particle flux as observed on the satellites.

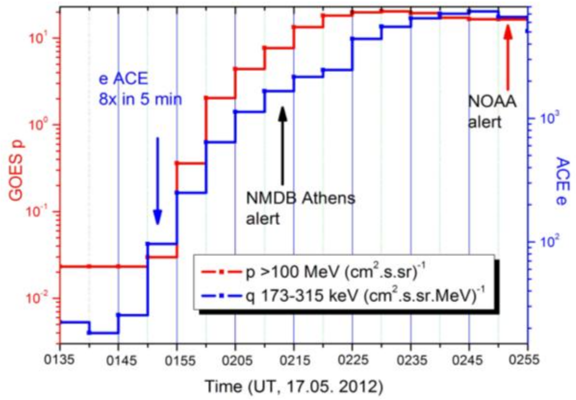

Fig. 5. GOES proton and ACE electron data during the GLE71. The NMDB alert by Athens Center preceeds by almost 40 min the NOAA alert. Still before the NMDB alert there is relatively fast increase of energetic electrons on ACE. PIs of the respective measurements, namely R. Gold (ACE) and D. Reeves (GOES) are acknowledged for providing their data.

Posner [71] showed the important possibility of short-term forecasting of appearance and of intensity the solar ion events by means of relativistic electrons measured on satellites. Even for fastest-rising major proton event on record (January 20, 2005), the electron precursor signal was detected 20-25 minutes in advance. Relativistic Electron Alert System for Exploration (REleASE) provides the real time forecast of proton flux in the range of several MeV to ~ 50 MeV and its comparison with the SOHO energetic particle measurements (available at http://costep2.nascom.nasa.gov/). As a part of integrated Space Weather Analysis System at the site http://iswa.gsfc.nasa.gov, under Heliosphere and UMA proton flux forecast, can be found in real time the prediction of onset and intensity of first hours of well magnetically connected SEP events and the onset of poorly connected SEP events. Nuňez [72], using X rays and higher energy protons, describes the forecast scheme of SEP protons with E > 10 MeV. During some of the solar flares the protons accelerated to very high energies can produce by nuclear interactions with the material of solar residual atmosphere the neutrons as well as high energy photons from decay of neutral pions. At the site http://cr0.izmiran.ru/SolarNeutronMonitoring a tool for real time monitoring of solar neutron events can be found. Very high energy photons observed from several solar flares e.g. by CORONAS-F satellite can serve as a tool for identification of onset time of proton acceleration to high energies and they are in some cases seen as a precursor to GLE from few tens to several hundreds of seconds [73,74]. Laurenza et al [75] developed a technique to provide short-term warnings of SEP events that meet or exceed the Space Weather Prediction Center threshold of J (>10 MeV) = 10 # $cm^{-2}s^{-1}sr^{-1}$. The method is based on flare location, size, and evidence of particle acceleration/escape as parameterized by flare longitude, time-integrated soft X-ray intensity, and of type III radio emission 1 MHz, respectively. By this technique, the warnings are issued 10 min after the maximum of ≥M2 soft X-ray flares. Valach et al [76] used the ANN method to forecast SEP using data on X ray flares (class, position), on radio emissions (type II or IV radio bursts) and on CME (position angle, width of the CME, linear speed). The output is the forecasted flux of energetic protons (> 10MeV). There are limits on SEP forecast when only GLE are used as a signature. Paper [77] reports that 2001–2006 observations indicate more than 50% of SEP are omitted if only NM warning is used for forecast. Higher reliability requires using additional data on the state of solar and heliospheric activity. For the eventual forecast of GLEs and/or SEP events the change of the power spectrum density of time series not only of GCR but also in solar activity characteristics are important to check. Such analysis is done e.g. in [78].

3.2. Geoeffective events.
Almost half a century ago there were reported cases with precursors in neutron monitor time series (pre - decreases, pre - increases) before the arrival of interplanetary (IP) shock to the Earth's orbit and before the onset of Forbush decrease (FD), e.g. in [60]. FDs and geoeffectiveness is not "one to one" and the relation depends on geometry and motion of CME in interplanetary space with respect to the Earth's position, as well as on interplanetary magnetic field (IMF) when CME starts to interact with the magnetosphere of Earth. The evolution of geomagnetic storms as measured by Dst and of the FD as measured by the depression of CR intensity observed by NMs and muon detectors (MD) on the ground, are differing from case to case (e.g. [79,80]). During the increased geomagnetic activity both the magnetospheric transmissivity change as well as the CR anisotropy evolving in interplanetary space have to be assumed simultaneously. Strong changes in geomagnetic cut-offs during strong storms have been reported [81]. Different geomagnetic field models forecast the different changes of geomagnetic cut-offs and the shifts of the asymptotic directions (e.g. [82]). The cut-off changes can be parametrized by the IMF, solar wind and geomagnetic activity [83]. Assuming both IP anisotropy and change of cut-offs leads to estimate of rather high anisotropy for an event decribed in detail in [84]. High velocity of CR particles in comparison with the speed of large-scale IMF inhomogeneity (moving CME "obstacle") and large parallel mean free path of CR particles (λ_{par}), are causing that the information about precursory CR anisotropy originated in IP space, is transmitted quickly to distant sites. The deficit in CR intensity is observed down to $0.1 \, . \, \lambda_{par} \, . \, \cos(\Phi)$, Φ – IMF cone angle [85]. If CR flux is observed at Earth from various asymptotic directions simultaneously, the IP anisotropy is appearing several hours before the geomagnetic storm onset. Precursors to FDs are proposed in the frame of pitch-angle transport near oblique, plane-parallel shock. Numerical simulations of CR interactions with a CME shock performed in [86] for various shock-field angles and various values of the power-law index of magnetic turbulence of IMF provided estimates that loss-cone precursors (deficit of low pitch-angle particles) to FD should typically be detectable by NMs ~4 hr prior to shock arrival and by MD ~ 15 hr prior to shock arrival.

Recently several case as well as statistical studies indicating the potential possibilities and limitations of using ground based CR measurements for alerting geoeffective events were published. Paper [87] using GMDN (Global Muon Detector Network) data, analyzed in detail the anisotropy before the FD on December 14, 2006. A signature of loss-cone distribution appearing almost one day before the onset of FD and related to geomagnetic storm, just ~ 7 hours after CME release from the Sun, when the shock was at the distance only ~0.4 AU, is reported. By virtue of recently completed the European project NMDB (Neutron monitor data base, http://nmdb.eu), which continues by updating and archiving the data from many NMs, various studies of CR variations can be done. By using many NM records paper [88] illustrated the anisotropy evolution of CR before the SSC and geomagnetic storm on Sep. 5, 2005. For that case a clear onset of anisotropy almost a day before the storm is shown.

The question what is the fruitfulness of the anisotropy alerts by CR before the geomagnetic storms is gradually clarified. Precursory appearance probability by GMDN before the geomagnetic storms (2001-2007) is analyzed in paper [89]. For precursors the authors differentiate two types, namely loss-

cone and enhanced variance one. While for the superstorms (Dst < -250 nT) the probability to observe the precursor is about 0.9 (relatively low statistics), with the decreasing "strength" of geomagnetic storms measured by minimum Dst, the percentage of the events accompanied by the precursors prior to SSC decreases with decrease of |Dst|. Although GMDN precursors before the weaker geomagnetic storms are not appearing frequently, in some cases its signature is reported (e.g. [90]).
Using NM network, the authors of [91] analyzed FDs in 1967 – 2006 with anisotropy *Axy* > 1.2% (93 events). 27 different FDs, out of 93, were chosen based on their common behaviour in asymptotic longitudinal CR distribution diagrams. Three groups are recognized, namely (1) pre-decrease in the zone 90° – 180° noticed almost 24 h before the shock arrival; (2) pre-increase in the longitudes around and above 180° and lasting almost 12 hours until the FD and (3) pre-decrease in different longitudes and of different duration. The increase in the first harmonic of CR anisotropy before the shock arrival is a good tool in searching predictors of FDs and magnetic storms and can also serve as one of the indices characterizing occurrence of precursors. Group 1 is analyzed in detail in paper [92]. Enhanced diurnal anisotropy and intensity deficit of CR have been identified as precursors to FDs [93]. Paper [94] critically analyzes the differences in geoeffectiveness due to different features, with distinct plasma/field characteristics in IP space. SEP flux can be used also for prediction of geoeffective events as indicated e.g. in [95]. Recently collected data set [96] is useful base for extensive studies of precursors before the geoeffective events.

Another approach to eventual forecast of geoeffective events is related to the search of changes in time series characteristics of CR flux records with higher temporal resolution. Short term fluctuations (T <1 h) have been probably first studied in [97]. Significant changes in the spectra of rapid fluctuations are often observed about a day before and during large-scale IMF disturbances (e.g. [98-102]). Different distribution of the CR indices for 24 h before the sharp Dst decreases in comparison with that for geomagnetically quiet periods, as well as better relation of Dst to "prehistory" of CR fluctuations than to the actual fluctuations was reported in paper [103]. CR fluctuation parameter - indicator of the IMF inhomogeneity degree in the vicinity of shocks was introduced in paper [104]. This parameter is important for a medium-term prediction of geoeffective 11-year cycle periods with a lead time of ~1 solar rotation and for an online prediction of shocks with lead time of ~1 day. The parameter was shown to exceed clearly the significance interval already on October 23, 2003, well before the strong disturbances appeared in late October - early November 2003. CR fluctuations have been studied in recent years also with higher statistics. In addition to ground NM and MT, the measurements of high energy particles from satellite detectors with large geometrical factors are important for checking the fine structure of CR fluctuations before, during and after geomagnetic storms (and/or FD). Such possibility gives e.g. INTEGRAL measurements [105]. Due to high statistics (more than 1 order higher than NMs at mountains, direct measurements) the authors revealed fine structure of CR within a 3-day interval from 19.8. to 21.8. 2006 with many intensity variations in the GCR on a variety of time scales and amplitudes. Another potential possibility for CR fluctuations analysis provides the Pierre Auger project – its part Scaler. The full array was completed in 2008, with a collecting area of > 16 000 m^2 and a Scaler counting rate is 2×10^8 min^{-1} [106]. The data are now available with 15 min resolution. If 1 min data are available, its statistical accurracy is by 2 orders higher than that by NMs.

In recent decade there are put into the operation several new detectors/systems with their high potential to contribute to space weather studies, in particular to the forecasts of geoeffective events. Only few of them are mentioned. SEVAN detector network developed in Armenia [107] is now installed in several laboratories. The muon hodoscope Uragan described in [108] and references therein provides the detailed informations about the flux, energy and angular distribution of CR primaries at energies above those to which NMs are sensitive [109]. Muon detector system named MUSTANG [110], another one at high altitude of Mussala [111,112], CARPET in Andes [113], KACST [114] are providing continuous informations about the secondary CR and its variations on the ground. Recently a new NM started to work in Spain [115]. Network of NMs requires intercalibrations. Plans for a network of mini neutron monitors, as well as progress of calibration effort of NMs are shortly presented in [116].

4. Relativistic electrons.

Electrons due to their penetration ability into materials (cables, inner spacecraft system) are dangerous for the satellites. They have a very deletrious influence on spacecraft systems due to the deep dielectric charging affecting also the inner parts of satellite systems (e.g. [117]). Relativistic electrons on satellites can cause the variations in crystallinity, defects and dangling bonds at the interface, which eventually results in variation of electrical properties (e.g. [118,119]). At low altitude satellites the SEU have been reported with increased probability at South Atlantic Anomaly and at high latitudes. Also the nighttime injection of electrons to magnetosphere during the geomagnetic storms correlate with the satellite errors. The extensive statistical studies of satellite anomalies (220 satellites) found characteristics for quiet and dangerous days anomalies, indicating difference in energetic electron fluence [120-122]. The effect is reported at geosynchronous orbits and at low altitudes.

Strong redistributions of high energy electrons in the magnetosphere including low altitude orbits are observed. Large changes of the electron flux in connection with the geomagnetic storms in July – September 2004 have been recently reported in papers [123,124]. The observations by low altitude polar orbiting satellites CORONAS-F at 500 km and SERVIS-1 at 1000 km at L = 3.5 over South Atlantic Anomaly have shown variations in the intensity up to 2 orders and different behavior for different energies. Essential part of the radiation belt dynamics during magnetic storms may be explained by the change of the magnetic field configuration and by the adiabatic effects. Along with non-adiabatic radial diffusion it results in the radial displacement of the outer radiation belt rather than the large losses or total disappearance of the outer trapped zone. The detailed studies of such type, even with using the older data sets available, can contribute both as an input for electron flux models useful for space weather, but also to understanding the reconfiguration of the magnetosphere. Current status of the diagnostics of magnetosphere using the energetic electron measurements as a tool is summarized e.g. in the detailed review [125]. Recently paper [126] using *CORONAS-F* data, during 22 strong storms reported that a maximum of new belt of relativistic electrons (0.6–1.5 MeV) at low altitudes (~500 km) is located on average at lower L values as compared to similar measurements near the geomagnetic equator plane. Simultaneous measurements of the fluxes of relativistic electrons at low and high altitudes, can serve as a check of real shape of magnetic field lines at $L < 4$ during geomagnetic disturbances. It should be mentioned that also solar CR boundary of penetration can be used for testing the geomagnetic field model validity (e.g. in paper [127]). The injection of relativistic electrons to the inner magnetosphere is described in terms of shock and storm injection. The first one, observed rather rare, has a very short duration. It was explained originally by Tverskoy due to the drift in E and B fields in the situation when sudden short time bipolar pulses are originated [128]. More frequently the storm injection electron events are observed with longer duration.

There are observed increases of relativistic electrons on geosynchronous orbit with some delay after the increased solar wind speed at the Earth's orbit. One such case, without any clear geomagnetic storm, is shown in Figure 6.

Reeves et al [129] by extensive analysis confirmed that the geosynchronous relativistic e flux (1.8-3.5 MeV) is best correlated with the solar wind velocity measured 2 days earlier. The dependence is not linear, high fluxes are observed for various solar wind velocities (triangle distribution). Balikhin et al [130] stressed importance of high speed, low density solar wind for electron flux. Data from low altitude polar orbiting satellites provide the opportunity to check the relation between the solar wind parameters "prehistory" and energetic electron flux at various L values. This can be useful not only for progress in forecast of high electron fluxes in the inner magnetosphere, but also for understanding the processes of transport and acceleration of electrons. Preliminary analysis of data from Themis during the solar minimum period in the outer magnetosphere, namely during 2007-2009, indicate that the maximum correlation coefficient of the electron flux versus solar wind speed and density occurs with the delay depending both on energy and L value.

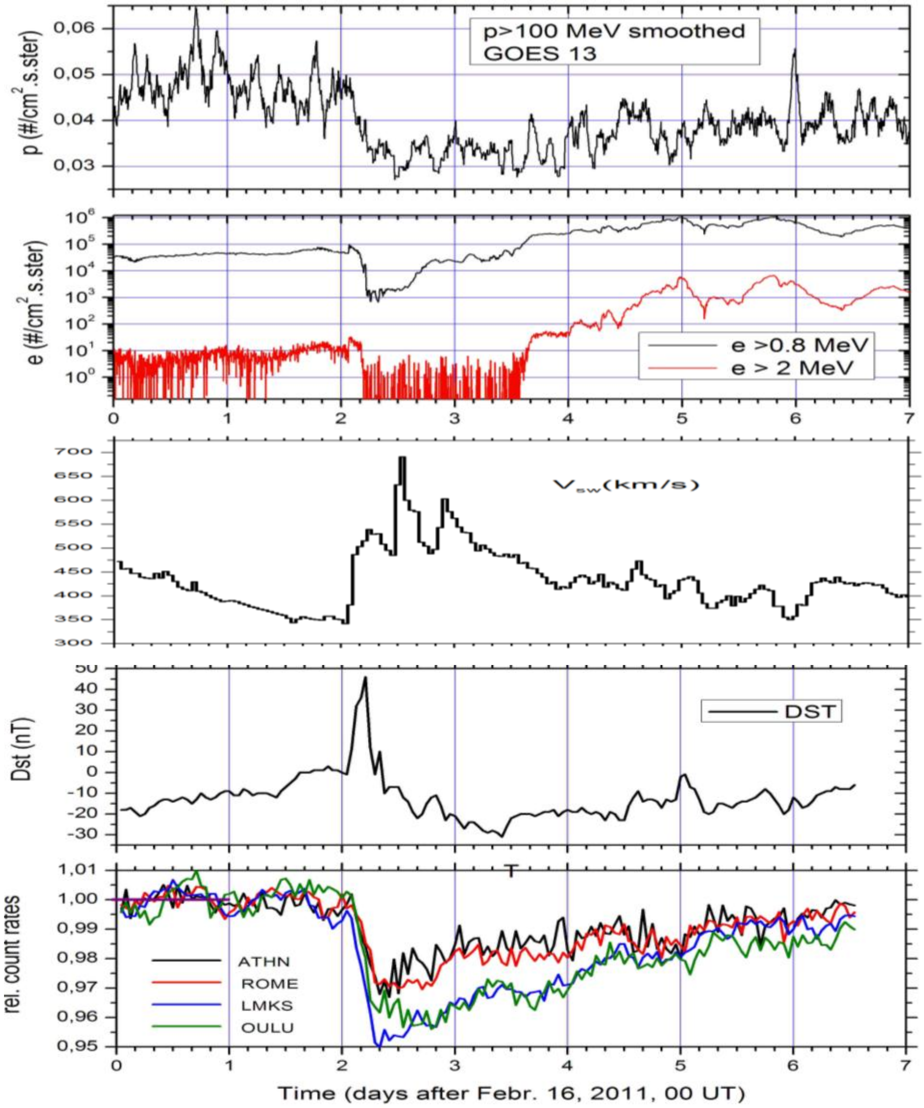

Fig.6. After the strong multiple sudden increases of solar wind speed on February 18, 2011 (observations on ACE, we acknowledge the PI of the experiment) - third panel, the electron flux >2 MeV observed on GOES, reached the level of flux by > 2 orders higher than before. At the same time rather strong Forbush decrease was observed at neutron monitors with various nominal vertical geomagnetic cut-offs (Athens, Rome, Lomnický štít and Oulu). The event was not accompanied by any clear sharp Dst decrease.

Papers [131,132] indicate that also the auroral oval can be considered as a region of intense acceleration of energetic electrons which is important for the analysis of processes leading to the filling of the outer radiation belt and appearance of “killer-electrons”. At high latitudes there are regions with trapping-like structure of magnetic field. Rather high fluxes of electrons have been observed on three subsequent passes of CORONAS-photon satellite over L > 20 in the south. The electrons were observed during geomagnetically quiet periods and when no significant flux of electrons has been observed in interplanetary space. This is also worth to be included in the updated models of electron flux.

4. Concluding remarks.

Description of quasi-periodic variations of CR along with interplanetary, solar and geomagnetic activity physical characteristics, examined by the same methods, can contribute to discriminating of CR from other "outer-space drivers" of Space Weather and Space Climate effects. In partial, this study shows the ~1.7 variability in CR should be studied in comparison with long term data of atmospheric electricity; 3 solar cycle periodicity reported earlier from indirect indications (cosmogenic nuclides) is confirmed by the analysis of stratospheric CR and by modulation parameter since 1936; empirical dependence of (averaged) ~27 day q-per on solar and IP activity was found for 1977 - 2003; ~3 cycle periodicity (~27 d wave) is present in CR to high energies as measured by muon detectors; difference in q-per in daily fluences of relativistic *e* and high energy *p* near 27 day period is found. Fine structure checking various q-pers in CR requires wavelet analysis technique.

Relativistic *e* variability near Earth, its relation to solar wind characteristics "prehistory", is important for the forecasts of high flux of relativistic *e* having impact on satellite systems. Both low and high apogee satellite measurements of *e*, especially during and after geomagnetic and IP enhanced activity intervals, are one of important tools for checking geomagnetic field models, better understanding the transport and acceleration mechanisms in magnetosphere as well as providing inputs for update of radiation models. Magnetospheric transmissivity, especially during active periods along with the IP anisotropy requires to be assumed simultaneously in analysis of geoeffective Space Weather events.

Past decade brought a progress in development of alerts of the geoeffective events using NM and GMDN network (both case and statistical studies). Along with new networks as NMDB is, the new masurement devices with potential to study geoeffective events have been installed. One of the important point for the future is to estimate efficiency of alerts based on anisotropy of CR measured at Earth, for the geofffective events, based on long term existing data. Fluctuations of CR are also one of important tools for checking IMF inhomogenities in IP space and for alerting the geoeffective events. Progress can be expected if the analysis of fluctuations observed by NMs is done jointly with satellite measurements by instruments having large geometrical factor (e.g. INTEGRAL) and with high statistical acurracy of other ground based measurements (e.g. Scaler in the project Pierre Auger and others, if better time resolution is available). There is need of joint study of CR dynamics with the solar physicists as well as with the specialists running the satellite energetic particle measurements.
SEP alerts progressed in recent years. Along with systems based on network of NMs and produced on-line, there are now on-line systems based on satellite energetic particle measurements as well as on other characteristics of flares including the magnetic connectivity to Earth. Important (also for the geoeffective alerts) is intercalibration of various NMs running in different conditions, and need towards joint effort of networking of NMs with other high temporal resolution and high statistics measurements, both on the ground as well as on the satellites and on space probes.

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