Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo,
Gustavo Medina-Tanco, José F. Valdés-Galicia (eds.)
Universidad Nacional Autonóma de México,
Mexico City, Mexico, 2009
Vol. 6, pages 239-253

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Mérida, México

Ground Level Events and Terrestrial Effects (Cutoffs, Cosmic Rays in the Atmosphere, Cosmogenic Nuclides)

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Abstract. This report summarizes the contributions to sessions SH1.8 and SH3.6. Topics include first results on the new Ground Level Enhancement (GLE) of 13 December 2006 and advancements in the analysis of the 20 January 2005 GLE. Steady progress both in complexity and evaluation speed can be reported on the modelling of geomagnetic effects as well as of the interaction of cosmic rays with the Earth's atmosphere. Cosmic-ray induced ionization in the atmosphere has gained increased interest for the assessment of radiation dosage at aircraft altitude and possible climatic effects. New results on cosmogenic isotopes and nitrates in polar ice allow a reconstruction of cosmic ray intensity and solar activity in time scales that today range from decades up to the order of 10'000 years. Finally, first results and perspectives were also presented on new analysis techniques of ground based cosmic ray observations aiming for near-real time diagnostics of the Earth's atmosphere, near-terrestrial space, and heliosphere.

Introduction

In session SH 1.8 a total of 28 papers were presented, 13 of them in oral form. Session SH 3.6 consisted of 42 contributions (15 oral). Topics of the two sessions included

- the 13 December 2006 and the 20 January 2005 GLEs,
- Geomagnetic Effects,
- Effects in the Atmosphere,
- Cosmogenic Nuclides, Nitrates, Cosmic Rays and the Sun, and
- New Techniques.

Ground Level Events

Ground Level Events (or Ground Level Enhancements, GLEs), i.e. the sporadic short-time increases in the GeV cosmic ray intensity as observed by ground-based detectors, are the signatures of high-energy processes at and near the Sun. On an average, GLEs occur statistically at a rate of about one event per year. Shea and Smart [1] investigated the occurrence of GLEs during the last five solar cycles (1954-2007). While the majority of GLEs occurred during years 2-8 of the solar cycle, GLEs have also occurred during solar minimum (e.g. 1976 and 2006). The distribution of GLEs over the solar cycles 19-23 is shown in Fig. 1. Shea and Smart also found that the number of GLEs can be associated with a relatively small number of solar active regions, with each region producing several large events in a sequence. Of the 70 GLEs recorded between 1942 and 2006, 36 of these events were associated with only 15 active solar regions.

Together with particle data at energies up to a few hundred MeV obtained by detectors on board space platforms, and with observations of electromagnetic radiation, GLE measurements provide key information for the investigation of the physical processes responsible for the acceleration of particles (stochastic and shock acceleration) and of the transport of solar particles through interplanetary space from Sun to Earth. As only part of these aspects is covered here, the reader is referred to complementing reports in these proceedings, e.g. on sessions SH 1.2 to SH 1.7.

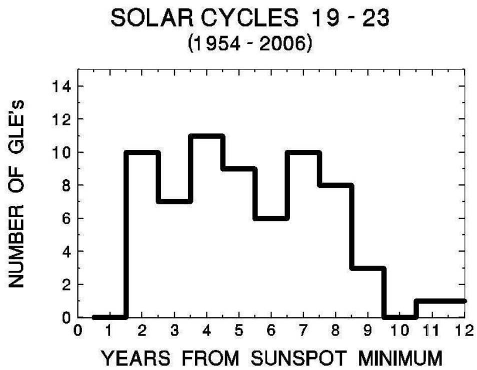

Fig. 1. Distribution of GLEs over the last five solar cycles [1].

Analysis of GLEs

From the recordings of the worldwide network of ground-based cosmic ray detectors, the characteristics of the solar particle flux near Earth (spectral shape, amplitude, pitch angle distribution, and apparent source direction) can be evaluated as a function of time. Several techniques for the analysis of neutron monitor data have been developed over many years, e.g. by Smart et al. [2], Debrunner and Lockwood [3], Belov et al. [4], Cramp et al. [5], and Plainaki et al. [6]. By adjusting the input parameters in an iterative process one calculates the best fit of the theoretical response to what the detectors actually measured. Hereby, detailed information is required about detector yield and particle propagation in the Earth's magnetic field. This topic was addressed in several papers. Standard yield functions generally used for neutron monitors are e.g. Clem and Dorman [7], Debrunner [8], and Nagashima [9]. At this conference Flückiger et al. [10] presented a new parametrized yield function for the IGY and NM64 neutron monitors especially suited for near-real time GLE analysis within space weather applications. Geomagnetic effects are usually described by the concept of cutoff rigidities, asymptotic cones of acceptance, and transmission functions. The standard method to quantitatively evaluate the respective information is based on the calculation of particle trajectories in the Earth's magnetic field represented by an advanced mathematical model [11]. Recent progress was mainly aimed at the speed at which such results can be obtained. Characteristics of near real-time cutoff calculations on a local and global scale were discussed by Bütikofer et al. [12].

At this conference an alternative GLE analysis method was presented by Bieber et al. [13]. This new approach consists of three steps. In step 1 individual station data are fitted to an angular distribution of the form $f(\mu) = c_0 + c_1 \exp(b\mu)$, with μ being the cosine of pitch angle, and c_0, c_1, and b free parameters. The symmetry axis from which pitch angles are measured is also a free parameter. In the second step the first three Legendre coefficients, f_0, f_1, f_2, are computed from the derived distributions $f(\mu)$. They are representing "Density", "Weighted Anisotropy", and "2nd Legendre". Event modelling is finally performed in step 3: the Legendre coefficients as functions of time are fitted to numerical solutions of the Boltzmann equation describing the particle transport in the IMF. Free parameters are the scattering mean free path and the profile of particle injection at the Sun. Results obtained with this procedure for the 13 December 2006 GLE will be discussed later in this report.

Another analysis method based on registrations of two detectors with different sensitivities at Sanae (a 6NM64, and a 4NMD, i.e. a neutron monitor with four $^{10}BF_3$ counter tubes in paraffin wax cylinders but without lead) was presented by Stoker et al. [14].

The GLE of 13 December 2006 (GLE70)

On 13 December 2006, almost at solar minimum, an unusually large GLE was observed after a 4B solar flare at 02:20 UT, in NOAA/USAF active region 10930 at S06 W24, accompanied by an X3.4 X-ray event and type II and IV radio bursts. The GLE with onset at ~02:48 UT and a peak increase around 03:00-03:10 UT exceeding 70% at some stations (Fig. 2) was registered by more than 30 neutron monitors (NMs) of the global network. The time history of major flare activity from AR10930 in December 2006 was summarized by Storini et al. [15].

Several papers were presented with observations and first modelling results [16, 13, 10, 17, 18, 19, 6, 1, 14, 15, 20, 21, 22, 23].

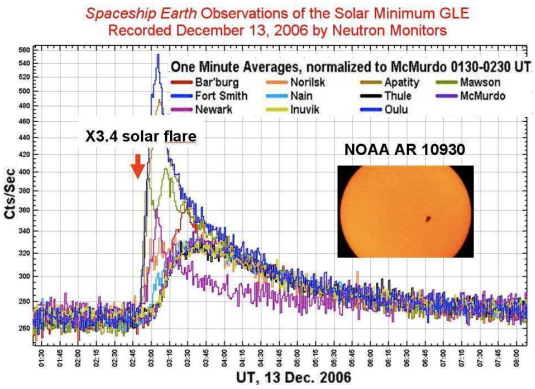

Fig. 2. The GLE of 13 December 2006 (adapted from [13]).

Beside neutron monitor data, ground-based observations of this GLE include recordings e.g. of the URAGAN muon hodoscope reported by Timashkov et al. [21]. Vashenyuk et al. [23] also used balloon data from Apatity and Mirny (Antarctica). Heber et al. [18] presented observations of the December 2006 event made above 70°S and at a heliospheric distance of 2.8 AU by the Ulysses spacecraft.

The apparent source direction (symmetry axis) for GLE70 near Earth was determined to be around 25°S and 95°E in geographic coordinates [10], corresponding to about 0° latitude and -45° longitude in GSE coordinates [23]. Analysis results on the pitch angle distribution are illustrated in Fig. 3 [23]. From onset to ∼03:05 UT the solar particle flux was a highly collimated beam with a characteristic half-width of ∼30°. The spectrum can be described by a power law in rigidity with exponent γ. Slightly different values for the spectral exponent were obtained by different groups. During the initial phase of the event (02:45-02:50 UT) Plainaki et al. [6] report γ=-2.9. Vashenyuk et al. [23] find values of about -4 to about -7 from 02:57 to 04:00 UT, whereas in [10] γ ∼-6 at 03:05-03:10 UT. All results, however, show a consistent tendency of spectral softening with time. Fig. 4 shows the solar particle spectrum as evaluated in [23] from neutron monitor and balloon observations, together with satellite data.

In several papers results of event modelling were presented. Bieber et al. [13], by using the analysis technique described above, found that a

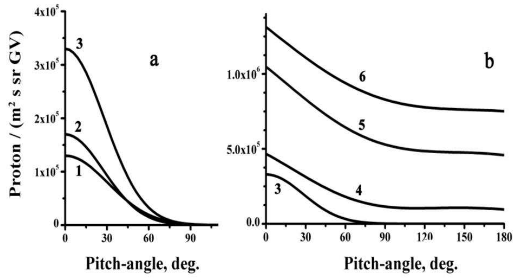

Fig. 3. The solar particle pitch angle distribution during the GLE of 13 December 2006 at 1: 02:57 UT, 2: 03:00 UT, 3: 03:05 UT, 4: 03:20 UT, 5: 03:30 UT, and 6: 04:00 UT [23].

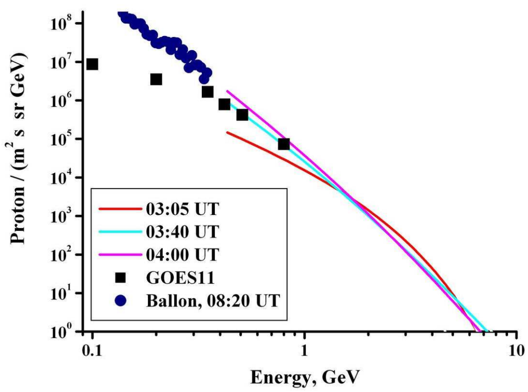

Fig. 4. The solar particle spectrum during the GLE of 13 December 2006 [23].

standard Parker IMF did not yield a satisfactory fit. They suspected that a downstream magnetic mirror may have been affecting transport. Fig. 5 shows that a bottleneck fit works quite well. For this fit, the optimal mean free path is 1.08 AU, and the optimal bottleneck location is at 1.52 AU. This is consistent with a "Fearless Forecast" that suggests that at event onset the Earth was connected to a downstream compression region at ∼1.6 AU. This is reminiscent of the Bastille event, in which transport was affected by a downstream magnetic bottleneck [24].

The GLE of 20 January 2005 (GLE69) and GLE Modelling

The GLE of 20 January 2005 (Fig. 6) is considered to be the second largest in the last 50 years. A large number of first analysis results were already presented at the 29th ICRC. Reports at this conference

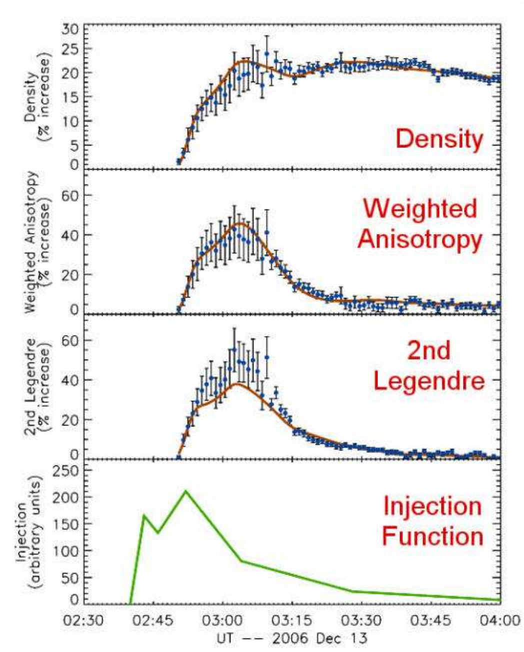

Fig. 5. Spaceship Earth modelling of GLE70 assuming a bottleneck at 1.52 AU [13].

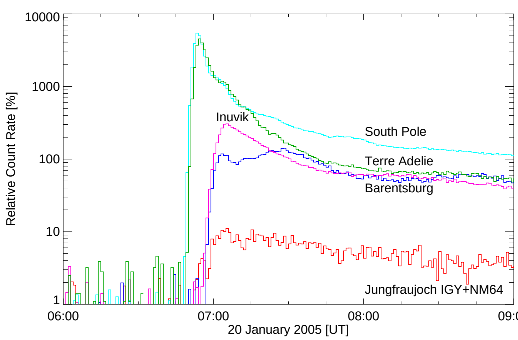

Fig. 6. The GLE of 20 January 2005.

concentrated on refined analysis of the near-Earth characteristics of the solar particle flux [25, 19, 26] and on a comprehensive interpretation of the modelling results [27, 28, 22, 29].

On behalf of the Milagro collaboration, Morgan et al. [26] presented ongoing work combining neutron monitor and Milagro data to construct a time-dependent spectrum for GLE events. Results for the 20 January 2005 GLE are illustrated in Fig. 7.

Vashenyuk et al. [29] presented results of a comparative analysis of the characteristics of the

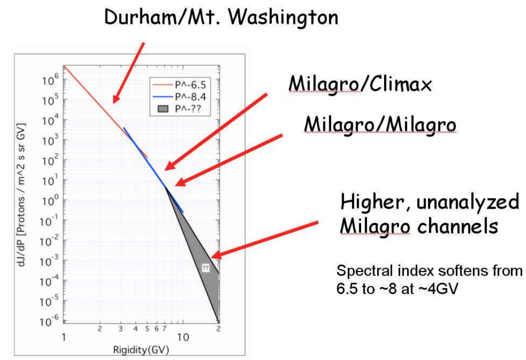

Fig. 7. Solar proton spectrum during the GLE of 20 January 2005 as obtained from Durham / Mt. Washington neutron monitors, and Milagro data [26].

solar particles in the two largest GLEs: the 23 February 1956 event and 20 January 2005 GLE. In both events they identified two particle populations, a highly anisotropic prompt component with an exponential energy spectrum, and a delayed component with moderate anisotropy and a power-law spectrum. The prompt component is considered as the cause of the giant pulse-like increase in only a distinct number of NM stations, and the delayed component as the cause of a gradual increase on a global scale. In an extension of this study [22], the authors find the same features in 14 large GLEs in the time period 1956-2006. They hypothesize that the exponential spectrum may be evidence of the acceleration by electric fields arising in the reconnecting current sheets in the corona, and that the possible source of the delayed component particles may be stochastic acceleration at the MHD turbulence in the expanding flare plasma.

During the 20 January 2005 GLE the Sanae NM recorded three distinct intensity peaks (Fig. 8), with the first two being of special interest. Using these observations, together with those of 10 other NMs, Moraal et al. [28] and McCracken and Moraal [27] showed that Pulse P1, commencing at 06:49:45$\pm$15$''$ was short-lived, field-aligned, highly anisotropic, and had a hard spectrum. Pulse P2 was longer-lived, much less anisotropic but still field-aligned. It had a softer spectrum, and started $\sim$8 minutes after P1, at 06:57:30$\pm$30$''$. P1 had little radiation with pitch angles $>$120°, while P2 contained a significant number of cosmic rays with much larger pitch angles from its onset. In ad-

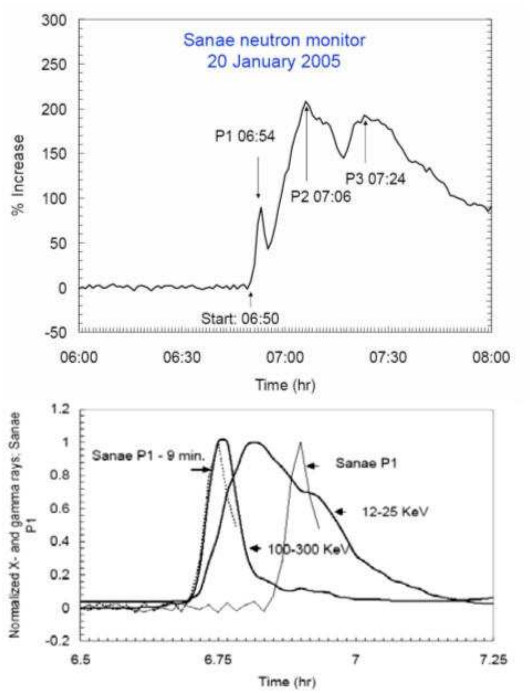

Fig. 8. 20 January 2005 GLE as seen by the Sanae NM (top), and Sanae P1 pulse compared with RHESSI 12-25 keV and 100-300 keV X- and gamma ray profiles (bottom) [27, 28].

dition, P1 was primarily due to particles of up to 5 GV, and essentially free of velocity dispersion. The 12-25 keV and 100-300 keV X- and gamma ray data obtained by RHESSI provide evidence for the acceleration of the first, highly anisotropic pulse low in the corona. McCracken and Moraal conclude that there were two distinct cosmic ray populations in GLE69, and that these were accelerated in two different regions. They also argue that such initial ephemeral enhancements have been observed in at least 9, and perhaps 11 previous GLEs associated with western flares. This leads them to propose that the 20 January 2005 event is a defining example of the GLE, namely that there are two separate acceleration episodes: (a) acceleration directly associated with the flare itself in the lower corona, and (b) acceleration by a supercritical shock driven by the associated CME, at about 2.5 solar radii. This concept is illustrated in Fig. 9 and summarized in Fig. 10.

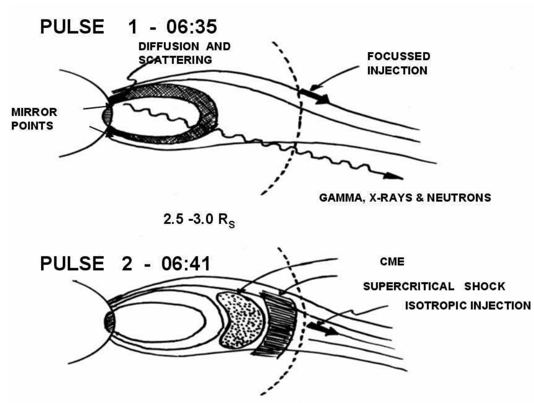

Fig. 9. Two-step GLE particle acceleration model proposed in [27].

THE GENERIC SOLAR ENERGETIC PARTICLE EVENT
(GLE and Lower Energies)

THE IMPULSIVE PHASE
- A highly anisotropic pulse of cosmic rays at Earth
- Coincident release of high energy gamma and neutron pulses
- Hard cosmic ray spectrum
- Acceleration low in corona
- Scatter free propagation due to focusing close to the Sun.
- High He/He ratio; high ionisation state.
- From western third of solar disk

THE GRADUAL PHASE
- Mildly anisotropic pulse of cosmic radiation at Earth.
- Soft cosmic ray spectrum
- Acceleration high in the corona, >2.5-3.0 R_s
- Diffusive propagation to Earth
- From central regions of solar disk

Fig. 10. Characteristics of the generic GLE model proposed in [27].

Geomagnetic Effects and Effects in the Atmosphere

As mentioned above, the standard procedures for the evaluation of the geomagnetic effects of cosmic rays are well established [11], and they are continuously being adapted e.g. to progress in the mathematical modelling of the dynamical magnetic field in the Earth's magnetosphere [30, 31, 32, 33, 34].

The International Geomagnetic Reference Field (IGRF) used to model the Earth's main field and its annual rate of change (secular variation) is updated every five years. The latest updates are the IGRF 10th generation (revised 2005) and 9th generation (revised 2003) (http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html). Using the 9th generation of the IGRF, Shea and

Smart [35] presented a new world grid of calculated cosmic ray vertical cutoff rigidities for Epoch 2000.0, specifically computed for updating aircraft radiation dose.

Bütikofer et al. [12] at this conference presented a procedure to compute in near real-time the effective vertical cutoff rigidity at specified locations and for a world grid with a mesh size of 5° x 5° in geographic longitude and latitude. An example of a possible output is given in Fig. 11. Although such near-real time calculations have a considerable potential for space weather applications (e.g. assessment of aircraft radiation dose), limitations persist, in particular during times with a strongly disturbed geomagnetosphere.

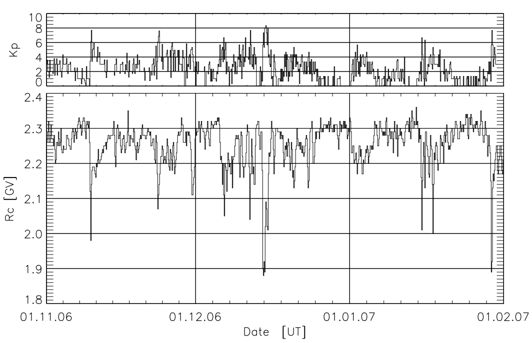

Fig. 11. Calculated vertical cutoff rigidity for the NM station Kiel (bottom panel) and Kp index (top panel) for the time interval November 2006 - February 2007 [12].

Shea and Smart [35] and Bütikofer et al. [12] also investigated the change in the cutoff rigidities between 1950-2000 and 1955-2005 respectively due to secular changes in the Earth's magnetic field. The results confirm that average cutoff values continue to decrease especially in the South Atlantic and South American areas. However, in the North Atlantic and the east coast of the North American continent, the cutoff values are increasing.

Recent in situ measurements for the validation of geomagnetic transmission models were reported by Casolino on behalf of the PAMELA collaboration [36]. The characteristics of the magnet spectrometer and the orbit of the satellite (high inclination: ~70°, low altitude: 350-600 km) allow PAMELA to perform a detailed measurement of

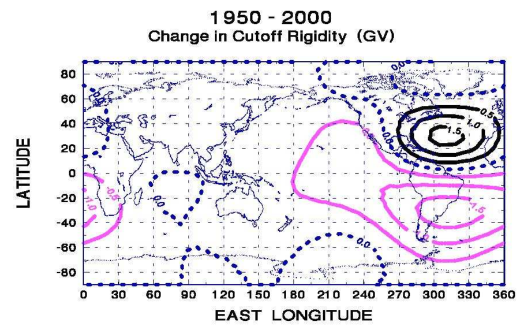

Fig. 12. Global map of the change in vertical cutoff rigidity (in units of GV) between 1950 and 2000 (black indicates increase, red indicates decrease) [35].

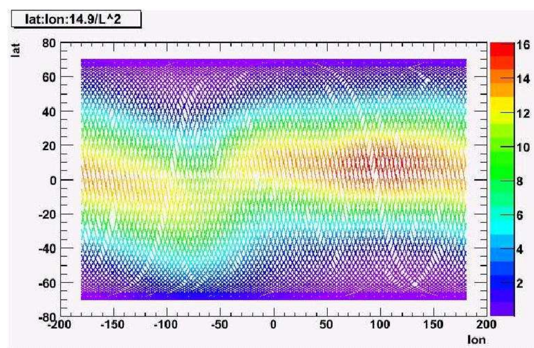

Fig. 13. Vertical Stoermer cutoff evaluated along the orbit of PAMELA [36].

the nature and the spectra of primary (above cutoff) and secondary particles (sub-cutoff: trapped, reentrant albedo, etc.). Fig. 13 illustrates the vertical Stoermer cutoff evaluated along the orbit of PAMELA. In Fig. 14 the differential proton flux measured at different cutoff regions is shown. Similar results based on AMS observations were published for the first time in [37]. As in the AMS results, the PAMELA data also allow a clear identification of the two components.

Effects in the Atmosphere

A large variety of cosmic ray effects in the atmosphere were addressed in more than 30 papers, as summarized in Table 1.

In recent years it has been suggested that cosmic rays might play a key role in physical and chemical processes in the Earth's atmosphere that are relevant to weather and climate. Therefore,

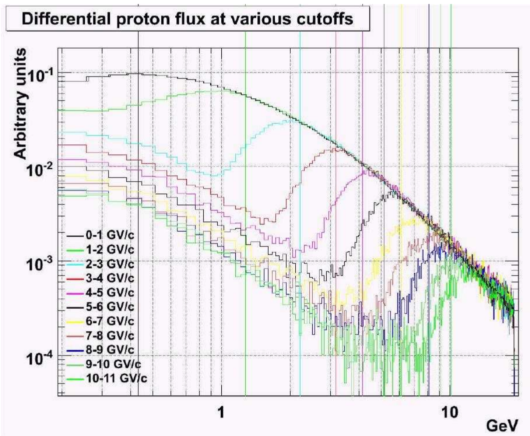

Fig. 14. Differential proton energy spectrum of PAMELA at different cutoff regions [36]. It is possible to see the primary spectrum at high rigidities and the reentrant albedo (secondary) flux at low rigidities. The transition between primary and secondary spectra is lower at lower cutoffs.

Topic	Paper/Reference No.
Particle fluxes, Spectra	276 [38], 315 [39], 932(n) [40], 966(n) [41], 541(Temperature profile) [42]
Ionisation	433 [43], 472 [44], 916 [45], 1083 [46], 1222(Ozone hole) [47]
Radiation Dose	376 [13], 798 [48]
Cosmic Rays and Clouds/Climate	1303 [49]
Cosmogenic Nuclides	221 [50], 224 [51], 240 [52], 529 [53], 556 [54], 559 [55], 1004 [56]
Nitrates	718 [57], 725 [58]
E-Fields, Lightning, Thunderclouds	265 [59], 439 [60], 447 [61], 867 [62], 1099 [63]
Hurricanes	321 [64], 323 [65], 1165 [66]
Space Weather	260 [67], 296 [68]
Technical (Detectors, Calibration, Applications)	58 [69], 849 [70], 1000 [71], 1093 [72]

Table 1. Contributions addressing effects in the atmosphere.

this hypothesis is presently the object of intense research. Various correlations and effects have been proposed, e.g. cosmic rays and ionization in the atmosphere, cosmic rays and cloud cover, cosmic rays and aerosols as “condensation nuclei” for cloud formation, cosmic rays and lightning.

Only a few selected contributions to these topics are summarized here. The interested reader is referred to the original papers for more information.

Ionization / Radiation Doses

There has been an increasing demand by atmospheric chemists and physicists for comprehensive information about particle radiation in the Earth’s atmosphere and, in particular, about the cosmic-ray induced ionization in function of position, time, solar and geomagnetic activity, and in dependence of the characteristics of solar particle events. Due to the lack of coordinated continuous worldwide in situ measurements, the development and validation of computer models simulating the atmospheric ionization under various conditions has been emphasized during the last years.

Within the European COST724 project “Developing the scientific basis for monitoring, modelling and predicting Space Weather” (http://cost724.obs.ujf-grenoble.fr/) several European research teams concentrated efforts for a quantitative modelling of the cosmic-ray induced ionization in the atmosphere, with the aim to provide the scientific community with a tool that allows computing the atmospheric ionization induced by solar and galactic cosmic rays. At this conference results of this work were presented in papers [45] and [43]. The work of the third group is described elsewhere, e.g. in [73]. A comprehensive report summarizing the topic of cosmic-ray induced ion production in the atmosphere will be available in [74].

The Velinov and Mishev model [45] as well as the Usoskin and Kovaltsov model [43] are based on Monte Carlo simulations of the electromagnetic-muon-nucleonic cascade in the atmosphere using the CORSIKA tool with the FLUKA package, whereas the “PLANETOCOSMICS” model developed by Desorgher (http://cosray.unibe.ch/∼laurent/planetocosmics) is based on the GEANT4 toolkit [75]. All three models are applicable to the entire atmosphere, from the ground up to the stratosphere, as illustrated in Fig. 15 for the Oulu model [43]. And with each one the contribution of the different secondary radiation components to total ionization can be individually evaluated. Together with

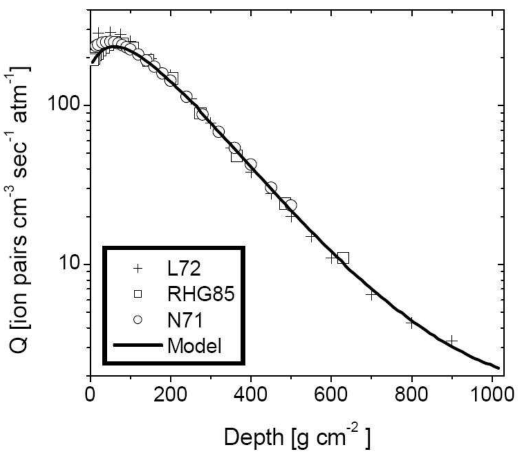

Fig. 15. Model calculations of the cosmic-ray induced ionization in the Earth's atmosphere (solid curve) compared to direct measurements. For details see [43].

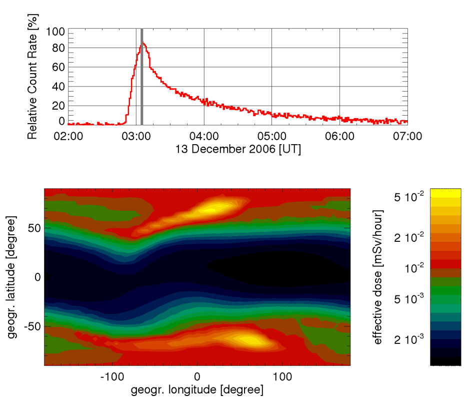

Fig. 16. Global map of computed effective dose rate at aircraft altitude during the main phase of the 13 December 2006 GLE [76] (bottom), and Apatity neutron monitor data (top).

program modules that take into account the geomagnetic effects (e.g. in PLANETOCOSMICS) and the variable primary cosmic ray spectrum (e.g. during GLEs), world grids of time dependent cosmic-ray induced ionization profiles can be evaluated. In the workshop "The Role of Ground-Based Cosmic Ray Detectors in Solar Particle Studies", held during the 30th ICRC, Flückiger [76] presented results on the ionization and radiation exposure at aircraft altitude during the 20 January 2005 and the 13 December 2006 and the solar particle events (Fig. 16).

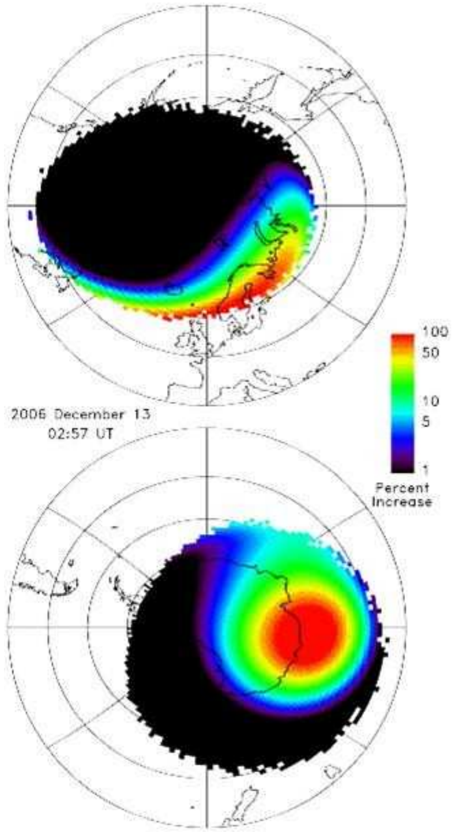

Fig. 17. Increase in radiation intensity in polar regions during the main phase of the 13 December 2006 GLE [13].

Bieber et al. [13] showed corresponding maps of the radiation intensity changes in polar regions as obtained from NM data during selected GLEs (Fig. 17).

The possible relationship between cosmic rays and the size of the Antarctic ozone hole was investigated in a new study by Alvarez-Madrigal et al. [47]. Based on a Morlet wavelet analysis they found that the changes in the size of the ozone hole and in the cosmic ray intensity have similar periodicities, with a frequency of ∼3.5 years. A preliminary inference seems to indicate that there is a non-linear relationship between the ozone hole size and galactic cosmic ray intensity. However, further research is needed.

Cosmic Rays and Clouds/Climate

In recent years it has been suggested that cosmic rays might provide the missing link between solar activity and climate and weather on Earth. If confirmed, this would have important consequences for our understanding of climate processes. Since the famous publication by Svensmark and Friis-Christensen in 1997 [77] where they found that the global cloud cover changed in phase with the cosmic ray flux, the hypothesis of a causal relation between the near-Earth cosmic ray intensity and cloud cover has been the subject of intense and controversial discussions. Later analysis indicated that the correlation holds only for low clouds (below 3.2km altitude) at low latitudes [78, 79, 80]. One of the most often postulated mechanisms that might be responsible for this correlation involves cosmic-ray induced ionization followed by the formation of cloud condensation nuclei (e.g. [81]). Another mechanism based on solar wind induced changes of air-earth current density has been suggested by Tinsley [82]. At the present time, an interdisciplinary team of scientists from Europe, Russia, and USA operates a novel experiment, known as CLOUD (Cosmics Leaving OUtdoor Droplets), with a prototype detector in a particle beam at CERN to explore the microphysical interactions between cosmic rays and clouds [83].

Sloan and Wolfendale [49] refer to the controversial cosmic ray - cloud hypothesis [80]. In order to check the possible role of ions as condensation nuclei for clouds and possible related cosmic ray effects on global warming, they compare the average cosmic-ray induced ionization in the Earth's atmosphere with the additional ionization generated in two extreme "radioactive events": i) the Chernobyl nuclear accident and ii) nuclear bomb tests as e.g. the BRAVO test on 01 March 1954. Based on the fact that no increase in cloud cover was observed in association with these events, their tentative conclusions regarding cosmic ray contribution to global warming are that i) the cosmic ray contribution to the 11-year cycle variability of the mean global temperature is less than 15%, and ii) the cosmic ray contribution to the slow increase of the mean global temperature over the last 35 years is $<$1%. Therefore, the hypothesis of a connection between cosmic rays and global warming does not seem supported by these still preliminary results.

Cosmogenic Nuclides

At this conference "cosmogenic nuclides" had a special platform with the highlight talk by McCracken [84]. The reader is referred to the written version of the McCracken paper as well as to [85, 86] for a review of the present state of the art in this research topic. At the dedicated ICRC sessions contributed papers concentrated on ^{7}Be and ^{14}C.

In [55], Kikuchi et al. report about the relationship between the aerosol sizes and the ^{7}Be concentrations and the possibility to investigate the altitude distribution of ^{7}Be from the size distribution of aerosols with attached ^{7}Be. In their results, the diameters of almost all particles with attached ^{7}Be are smaller than 5.0 μm.

In a series of papers, Yoshimori discusses long-term and seasonal variations in ^{7}Be concentration and the role of air mass exchange in the transport of ^{7}Be from the production site in the stratosphere to the Earth's surface [51, 50, 53]. The study is based on continuous concentration measurements of cosmogenic and terrestrial radionuclides in Tokyo since 2002. The present results indicate that the surface ^{7}Be concentrations are anticorrelated with the 11-year solar cycle and that possible air mass motions do not essentially affect the ^{7}Be long-term variations. However, in each year from 2002-2006 the data indicate clear enhancements in the ^{7}Be concentration in the spring and autumn. The authors claim that these seasonal variations are not associated with scavenging by precipitation because the surface ^{7}Be concentrations do not correlate with rainfall. They suggest the possibility that the stratospheric ^{7}Be is transported to the upper troposphere through a large-scale air mass exchange between the stratosphere and troposphere. The postulated air mass exchange is inferred to occur in association with a periodic passage of a high pressure and an extratropical low pressure system over Japan in the spring and autumn.

In [54], Kikuchi et al. investigate the relationship between the variation of the ^{7}Be concentration and solar activity, using a 7-year data set obtained in Yamagata, Japan, and a 3-year dataset in Iceland (64.7°N, 21.2°W). In the Yamagata data the variation in the ^{7}Be concentration was 38% during the

7 years whereas the sunspot numbers changed by 75%.

Takahashi et al. [52] presented new results of ^{14}C concentrations in old tree rings. Using single-year tree ring measurements from the Choukai Jindai cedar they find that the ^{14}C concentrations in the period from 2650 to 2600 years BP showed a rapid decrease with a rate of 1.1% in 7 years.

In a comprehensive report Beer and McCracken [56] address the subject of cosmic ray intensity in the past. Direct measurements with ionization chambers and neutron monitors provide continuous records only for the past 50-70 years. In order to investigate cosmic rays on centennial to millennial time scales one has to rely on cosmogenic radionuclides. Based on [87] Beer and McCracken show that production rates evaluated from ^{10}Be data from ice cores and from ^{14}C in tree rings are well correlated with cosmic ray intensity represented by high-latitude neutron monitor data. Using advance analysis procedures they now combined ^{10}Be with ^{14}C and thus constructed a cosmic ray record going back almost 10'000 years (Fig. 18). Based on their results the authors conclude that i) cosmogenic nuclides can be considered as a new type of cosmic ray monitor, ii) the temporal resolution is >1 year, iii) the signal to noise ratio (on a 100 year time scale) is 9:1, and iv) the time range today is about 10'000 years, but may reach 40'000 years (^{14}C in trees) and 100'000 years (^{10}Be in ice) in the future.

Nitrates

By interacting with the terrestrial atmosphere, cosmic rays can initiate catalytic cycles for the ozone depletion, involving NO_x (N, NO, NO_2) and HO_x (H, OH, HO_2) components. Storini and Damiani [88] looked for effects of the January 2005 GLE/SEP events on the OH and HNO_3 species in the atmosphere. HNO_3 is considered a good proxy for "odd nitrogen" (complex of nitrate radicals designated by the symbol NO_y). The results obtained by Storini and Damiani show that there is a response in the minor atmospheric components, which is different in the winter and summer terrestrial hemispheres. Fig. 19 shows contours of averaged HNO_3 (volume mixing ratio) values during the second part of January 2005 at $\sim$75°–82°N. They interpret the HNO_3 increase as being the result of the OH and NO_2 rise during SEP events and/or through the reaction of water cluster ions with NO_3.

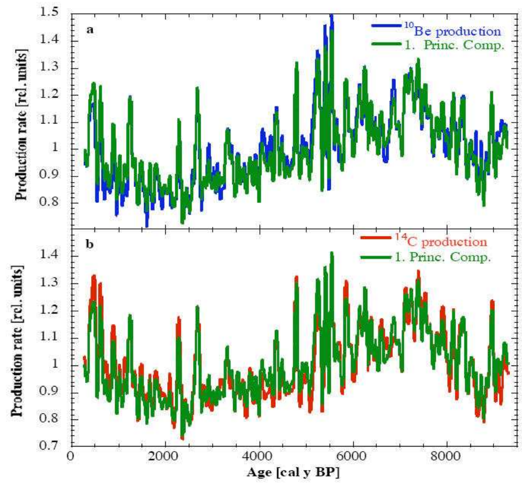

Fig. 18. Comparison of the first component of the principal component analysis (in green) with the measured relative ^{10}Be (panel a) and ^{14}C (panel b) production changes. The first or production component explains about 90% of the total variance of the low-pass (1/100y) filtered data [56].

As stated in [58], "contemporary state-of-the-art measurements of the denitrification of the polar atmosphere find significant nitric acid trihydrate particles (called NAT rocks) in the polar stratospheric clouds". Some of the HNO_3 is transported to the troposphere, where it is precipitated downward to the surface. Nitrate depositions in polar ice are therefore markers of the HNO_3 precipitation. The potential and significance of nitrate concentration in ice cores as an identifier of large GLEs have been demonstrated previously [89, 90].

At this conference Kepko et al. [58] presented a comparison of the impulsive nitrate deposition events found in high resolution measurements from polar ice cores obtained from the northern polar cap (Summit, Greenland) and the southern polar cap (Windless Bight, Antarctica) with the first four GLEs recorded by ionization chambers between 1942-1949 (Fig. 20). They show that large and sudden enhancements in the nitrate records from both hemispheres were observed within weeks after the dates of the GLEs. The observation of impulsive nitrate enhancements simultaneously in

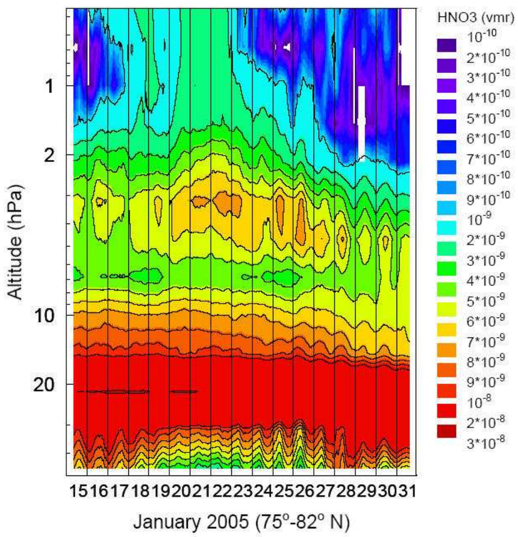

Fig. 19. Contours of averaged HNO_3 (volume mixing ratio) values at $\sim$75°–82°N during the second part of January 2005 [88].

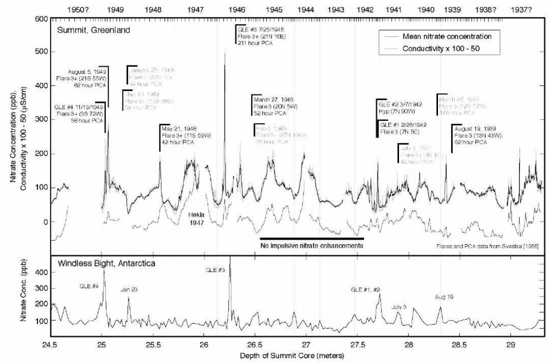

Fig. 20. Observations of impulsive nitrate enhancements associated with ground-level cosmic ray events 1-4 and strong polar cap absorption events (1942-1949) [58]. Top: Nitrate data from the 2004 Greenland core with annotated solar events (high resolution). Bottom: Nitrate deposition data from 1988-1989 Antarctica ice cores (1.5 cm resolution).

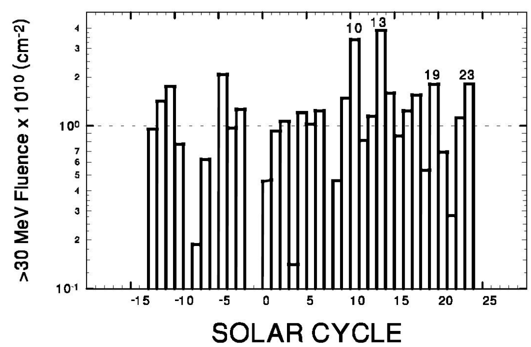

Fig. 21. The >30 MeV omnidirectional proton fluence for 36 solar cycles [57].

both hemispheres shortly after a large solar proton event is strong evidence in support of a causal connection and argues convincingly for rapid gravitational sedimentation of atmospheric nitrates.

Using nitrate enhancements in the polar ice as a proxy for solar proton events, Smart et al. [57] determined the proton fluence above 30 MeV for 31 solar cycles between 1610 and 1954 (cycle -12 through cycle 18). They find, as illustrated in Fig. 21, a wide range of solar proton fluences over these 31 solar cycles, from three cycles with no significant proton events above 10^9 cm^{-2} to a high of 38 x 10^9 cm^{-2}. In a comparison of the two cycles with the highest solar proton fluence, cycle 10 was dominated by one major event (the Carrington event in 1859), while cycle 13 had 7 major events contributing to the total fluence. The total fluence for most cycles is within a factor of 2 of the maximum fluence per cycle measured by spacecraft since 1965. Smart et al. state that until new deep ice cores are available for both calibration with known fluences and for verification of the original results, these derived solar proton fluences over a number of solar cycles represent the only available values as upper limits for space exploration experiments.

New and Emerging Techniques

Munakata et al. [91] demonstrated that muon diagnostics is a potential technique for remote monitoring of dynamic processes in the heliosphere. The new technique based on the analysis of spatial and temporal variations of muon flux simultaneously detected from various directions (see Figs. 22 and 23 for an illustration of the concept) has been explored extensively since then. In view of additional applications to magnetospheric and atmospheric phenomena, new detector concepts and dedicated global networks are investigated. Space weather prediction with cosmic rays, e.g. the identification of “loss cone precursors”, is presently

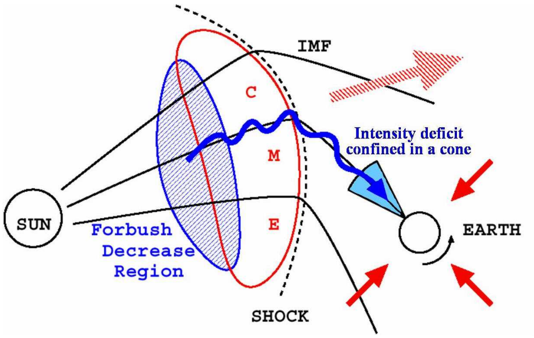

Fig. 22. The concept of loss-cone anisotropies as a warning tool of approaching disturbances.

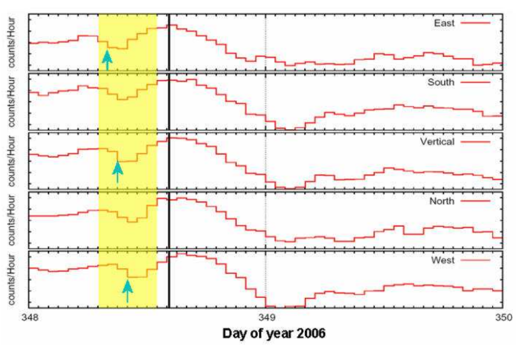

Fig. 23. Loss cones appear as a "predecrease" when viewed by a single detector. Event on 14 December 2006 observed by muon detector in São Martinho, Brazil. As detector viewing directions rotate through loss cone, a predecrease is seen first from the East, then from Vertical, and finally from West.

one of the major anticipated applications (see e.g. http://neutronm.bartol.udel.edu//spaceweather/).

At this conference Timashkov et al. [68] presented the multi directional muon telescope developed at the Moscow Engineering Physics Institute and animated first results obtained with the URAGAN muon hodoscope. Observations included the 13 December 2006 GLE and a time period of disturbed interplanetary conditions on 07 July 2006.

Having given first experimental evidence of neutron production in lightning discharges [92], Shah et al. [60] presented a new study on this still controversial subject. Using a sophisticated new hardware and software system, their detector records the time profiles of the neutron bursts following the initiation of lightning discharges. The new study confirms production of neutrons in atmospheric lightning discharges, and the observed time profiles could be important in determining details of neutron production in lightning.

Summary and Conclusions

In this rapporteur's opinion the main messages from sessions SH1.8 and SH3.6 are:

- New large GLE on 13 December 2006.
- Ongoing discussion about two mechanisms for particle acceleration at the Sun (on the basis of the 20 January 2005 GLE).
- Cosmogenic radionuclides (^{7}Be,^{10}Be,^{14}C) can serve as a new type of neutron monitor with time range of up to 100'000 years.
- Nitrate technique for GLE archive in polar ice established.
- A multitude of atmospheric effects are under investigation.
- New promising probing techniques for space weather applications emerging (e.g. muon diagnostics).

Many papers could unfortunately not explicitly be discussed in this review. This should by no means be considered as a quality judgement. It may simply be due to page limitations, to the fact that the respective topic does not quite fit into the main outline of the report, or (most likely) that the rapporteur is incompetent. In this sense my apologies for all omissions and mistakes.

Acknowledgements

I would like to thank the organizers of the 30th ICRC for their warm hospitality, for the invitation to be a rapporteur, and for their patience. I am also very grateful to all the authors of Sessions SH 1.8 and SH 3.6 for stimulating discussions and for liberally providing material. Rolf Bütikofer, Benoît Pirard, and Louise Wilson gave me most valuable assistance in preparing this report. Finally, the support of the Swiss National Science Foundation (grant 200020-113704) is gratefully acknowledged.

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