LONG-TERM VARIATIONS OF COSMIC RAYS
AND TERRESTRIAL ENVIRONMENT

rapporteur talk on SH3.4, SH3.5, SH3.6
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*Illya G. Usoskin*
Sodankylä Geophysical Observatory / University of Oulu, Finland

e-mail: Ilya.Usoskin@oulu.fi
http://spaceweb.oulu.fi/~usoskin/
Statistics

Total number: 69 contributions (31 talks + 38 posters)

- Long-term CR modulation (13 = baker's dozen)
- Cosmogenic data (baker's dozen)
- Terrestrial effects (baker's dozen)
- CR transport in the Earth magnetosphere (baker's dozen)
- Details of CR measurements (4 contributions)
- Miscellaneous (baker's dozen):
Cosmogenic isotopes

Natural archival (indirect) data on CR measured *nowadays* (off-line measurements)

- **$^{10}$Be in polar ice**: (highlight talk by J. Beer) $CR + N,O \rightarrow ^{10}$Be ($\tau_{1/2} \sim 1.5 \times 10^6$ y)
  
  *Effective CR energy 1.3 GeV/n* (local polar Alanko et al., SH3.3-4) to *2 GeV/n* (global McCracken, SH3.5-2);

- $^{7}$Be ($\tau_{1/2} = 53.3$ days) in the air (similar process, Yoshimori et al. SH3.6-12; 2P-212; Sakurai et al., SH3.6-13)

- **Radiocarbon $^{14}$C**: new measurements (H. Sakurai et al., SH3.5-4; Miyahara et al., SH3.5-5, 2P-222; Masuda et al., SH3.5-6)

  $n + N \rightarrow ^{14}$C ($\tau_{1/2} \sim 5730$ y) $\rightarrow CO_2 \rightarrow \text{carbon cycle} \rightarrow \text{tree rings}$

  *Effective CR energy is about 2.8 GeV/n* (Alanko, Usoskin, Mursula, Kovaltsov, SH3.3-4);

  *mean altitude 10-15 km* (Aoki et al., 2P-195);

  *Suess effect* (fossil fuel burning) and nuclear tests make the *direct calibration difficult*.

Radiocarbon $\Delta^{14}$C for the last millennium (Stuiver & Braziunas, 1993)

- **$^{44}$Ti in meteorites** ($\tau_{1/2} \sim 59$ y) $p + Fe,Ni \rightarrow ^{44}$Ti (Cini Castagnoli et al., SH3.4-6, 2P-195)

  *Effective CR energy > 70 MeV/n*

- **Nitrates in polar ice** (ionisation by strongest SEP events $> 10^9$ cm$^{-2}$ (> 30 MeV), Zeller & Parker, 1981; Gladysheva & Dreschhoff, 1997; McCracken et al., 2001) - Shea, Smart, Dreschhoff, McCracken, SH3.6-14
Models of \(^{10}\text{Be}\) production (McCracken, SH3.5-2; Beer et al., 2P-194)

The results of \(^{10}\text{Be}\) suggest that (McCracken et al., SH3.5-1, SH3.5-2):

» The GCR intensity (1–2 GeV/n) has varied by a factor of 2.5;
» The lowest value is since mid-20th century;
» There was significant modulation during Maunder minimum;
» The sudden decrease of \(^{10}\text{Be}\) level in 1700’s;
» Possible 5-y variations during low solar activity
» Is \(^{10}\text{Be}\) related to the minimum SN?

The 11-y average \(^{10}\text{Be}\) data from Dye-3, Greenland (McCracken, Beer & McDonald, SH3.5-1) and 24-y averaged data from South Pole (Bard et al., 1997).
$^{44}\text{Ti}$ (τ$_{1/2}=59.2$ year) in stony meteorites:

**space probing of CR in the past**

(Sh3.4-6 Cini Castagnoli et al.)
Maunder minimum (1645-1700)

The dominant 22-year cyclicity in sunspots (Usoskin, Mursula & Kovaltsov, 2000, 2001) and visual aurora occurrence (Křivsky & Pejml, 1988; Schröder, 1992; Silverman 1992); 14C data (Kocharov et al., 1995; Stuiver & Braziunas, 1998; Peristyh & Damon, 1998) NO(Y) data (Gladysheva, Kocharov, Usoskin, 2002) but 10Be data depict dominant 11-year cycle (Beer et al. 1998).

10Be data from Greenland (McCracken, Beer & McDonald, SH3.5-1)

Discrepancy between earlier 14C measurements (Stuiver & Braziunas, 1993; Kocharov et al., 1995). Damon, Eastoe & Mikheeva (1999) – intercalibration of the two series. Finally, new measurements have come (Masuda et al., SH3.5-6) closer to Kocharov’s series (similar variation range) but not exactly.

Regional effects?
Spörer minimum (1415-1540)

New $^{14}$C measurements during SM (Japanese cedar tree – Miyahara et al., SH3.5-5, 2P-222):
- Reduced 11-y cycle;
- Persistent 22-y cycle with constant amplitude;
- 7-y cycle (?)

Power spectrum of $^{14}$C content and of Greenland $^{10}$Be data during SM (1410-1550)
Nitrates in polar ice

• Seasonal variations (Shea, Smart, Dreschhoff, McCracken, SH3.6-14) – what is the reason? (Climate, atmospheric processes, relative Sun/Earth configuration?)

• Relation to geomagnetic storms / mid-latitude aurora sightings (Shea, Smart, Dreschhoff, McCracken, SH3.6-14)

Fig. 2. Impulsive nitrate events (top) and mid-latitude aurorae (bottom)
Cosmogenic $^7$Be

$^7$Be data provide information on the atmospheric transport (mixing between stratosphere and troposphere). Response to SEP events.

Data folded with the folding period 26 days (Sakurai et al. SH3.6-13). Note 13-day periodicity and 5-day shift.

Time variations of $^7$Be data (Yoshimori et al. SH3.6-12). Data suggest for an atmospheric mixing in Spring.
Modulation: Recent measurements

Recent measurements of cosmic rays include:

- Helium flux measurements (AESOP) and Positron flux (BESS) over the polarity reversal (~1.3 GeV).
- Direct evidence for the drift-effect in CR modulation.

New precise balloon measurements of p and He energy spectra.
High energy CR → shadow of the Moon (angular and energy resolution of air shower arrays) and the Sun (transport in corona, IMF) using different methods: Tibet (SH3.4-10, Amenomori et al.) and Milagro (SH3.4-11, Xu).

Yearly variations of the Sun’s shadow at 10 TeV energy region observed by Tibet-II in 1996-2002 (SH 3.4-10):
Sun shadow is strongly affected by IMF depicting the solar cycle dependence.
A south-eastwards displacement around maximum?
not confirmed by Milagro (SH3.4-11)

Yearly variations of the Sun’s shadow at 3 TeV region observed by Tibet-III in 2000-2002 (SH 3.4-10):
Gnevyshev gap in 2001?
Not observed in 10 TeV region.
Environmental monitoring

- Neutron flux (most important for radiation doses) at different altitudes/locations: measurements and simulations (Zanini et al., 2P-217)
- Measurements of the radioactivity level during rainouts (Cecchini et al., SH3.6-6)
- Gamma-rays in 3-15 MeV range (environmental radiation): measurements (Cattani et al., 2P-218)
- Environmental radioactivity measurements by SONTEL @ Gornergrat (Bütkofer et al., 2P-199)

*min. solar activity, max. latitude*
CR flux is reconstructed since 1610 using the present knowledge of modulation (Usoskin et al., SH3.4-5; Cini Castagnoli et al., SH3.4-6)

Beer et al., 2P-194 inverted the model, estimating the modulation efficiency in the past
Unusual modulation: cycle 20


CR modulation for different rigidity intervals (3–13, 3–6, and 6–13 GV) - see Storini, Massetti, Kudela, Rybak (2P-187)

Annual data of different CR detectors (Ahluwalia, SH 3.4-4)

McCacken, Beer & McDonald (SH3.4-3); McCracken & Heikkila (2P-193) suggested, using ionisation chamber (Neher data) and $^{10}$Be data, for anomalously high flux of lower (< 1 GeV) CR during the 19 cycle minimum (1954-1955).

Puzzle: increased $\lambda_{\perp}$; anomalous heliospheric structure with multiple HCS?
Gnevyshev gap in CR power spectrum (Storini, Laurenza, Fujii, SH3.4-7)

Median rigidity dependence of the Gnevyshev gap effect (Storini, Laurenza, Fujii, SH3.4-7)

Gnevyshev gap in the Sun’s shadow (3 TeV CR) (Tibet collaboration, SH3.4-10)
22-year CR modulation

• Jump in $e^+/e^-$ and $p^-/p$ ratios around 2000 (Clem & Evenson, SH3.4-1)
• Different CR modulation during odd- and even-cycles (Ahluwalia, SH3.4-4; Storini et al., 2P-187; McCracken & Heikkila, 2P-193)
• One-stage vs. two-stages modulation (Storini et al., 2P-187)
• Shift of the diurnal anisotropy phase towards earlier hours during $qA>0$ cycles (Dubey, Kumar, Kathal, Richharia, 2P-186)
• Different amplitude of the 27-day variations for odd- and even-cycles (Alania et al. 2P-185)
• 1.3-y and 1.7-y periodicity in open/closed solar magnetic flux; alteration between them during odd-even cycles (Valdes-Galicia, Lara, Mendoza, SH3.4-8).
Space weather

- Space weather is related to the variable radiation/magnetic conditions in the Earth’s environment.

Belov et al. (SH3.6-11) – studied the relations between malfunctions of satellites (6000 anomalies onboard 300 satellites): most important effect from CR.

Dorman (2P-211) reviewed principles of space weather forecasting using CR data.

Makhmutov et al. (2P-202) – semiannual variations in electron precipitation events: Russel-McPherron, Equinoctial and Axial effects.

Király (SH3.4-9) – solar cycle dependence of energetic ion anisotropy.

Dorman (2P-211) re
Changes of the geomagnetic field (orientation and strength of the virtual dipole) is important for CR on long-term scale.

Smart & Shea (SH3.6-8), Shea & Smart (SH3.6-9) and Flückiger et al. (2P-201) calculated the geomagnetic cutoff values on the long-term scale.

Changes are significant even during the last century and should be carefully taken into account.

Some detailed calculations of the geomagnetic cutoff and have been presented for ground-based locations (Storini, 2P-215) and low-orbiting satellites (Smart et al., 2P-204, Desorgher et al., 2P-214).
Secondary particles

• Interaction of CR with the matter of the Earth’s atmosphere $\rightarrow$ secondary particles $\rightarrow$ magnetically trapped and can be measured at low orbits:
  » Mikhailov et al. (2P-207) – measured spectra of trapped light isotopes by NINA-2;
  » Galper et al. (2P-208) – a model to calculate light isotopes;
  » Miyasaka et al. (2P-210) – a model for antiprotons secondary production;
  » Zuccon et al. (2P-206) – MC simulation of radiation environment at low orbit satellites (below Van Allen belts).

• Interesting result (Nakagawa et al., 2P-209):
  Using an X- and γ-ray instrument, they found an unusual time-variable increase of low energy electrons near SAA with a steep spectrum during/after geomagnetic storms.
Ermakov & Stozhkov (SH3.6-1) – qualitative generic model of the CR role in thunder cloud production: CR provide the necessary ionisation + channels for the lightning discharge.

Particle acceleration by electric field: Baksan & Mt.Norikura

Khaerdinov et al. (SH3.6-3; SH3.6-4; 2-P-198) – regression analysis for soft ($e$) and hard ($\mu$) components (88 events in 2000-2002). The $e$ bump: a signature of $e$ acceleration (runaway electrons) at higher level (see also Muraki et al. SH3.6-5) around the time of lightning. Is consistent with the idea of runaway $e$-$s$ driving the lightning channel.
(Humble & Duldig, SH3.6-7) studied asymptotic directions of a NM in a dynamical model. Daily and seasonal variations were found up to 7 GV which may lead to a (partly) spurious sedimental anisotropy.

(Alania et al., 2P-185) modelled the 27-day variations of GCR and found the odd-even cycle effect.

(Valdes-Galicia, Lara, Mendoza, SH3.4-8) 1.3-y and 1.7-y periodicity in open/closed solar magnetic field directions is a clear indication of solar activity cycles.

Atmospheric cascade Monte-Carlo simulations using GEANT package (Desorgher et al., 2P-213).

Light flashes observations onboard MIR and ISSI (Sileye coll., SH3.6-2; 2-P-205) and nuclear composition inside the space stations.

Relation between solar activity and the wheat price in Medieval England: nonlinear response in the risk agriculture region (Pustilnik, Yom Din, Dorman., SH3.5-3).

Estimates of the effective modulation region (Stozhkov et al., 2P-183; Dorman et al.).
THANK YOU!
Highlights

• New measurements of cosmogenic isotopes:
  » $^{14}\text{C}$ annual data for the Maunder and Spoerer minima;
  » $^{44}\text{Ti}$ in meteorites;

• Environmental monitoring;

• Charged particle fluxes during thunderstorms;

• Study of long-term geomagnetic cut-off rigidities;

• Measurements and models for trapped particles.