Long-term variations of cosmic rays and terrestrial environment

rapporteur talk on SH3.4, SH3.5, SH3.6

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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 → ^{10}Be*** ($\tau_{1/2}$ ~1.5 10^6 y)

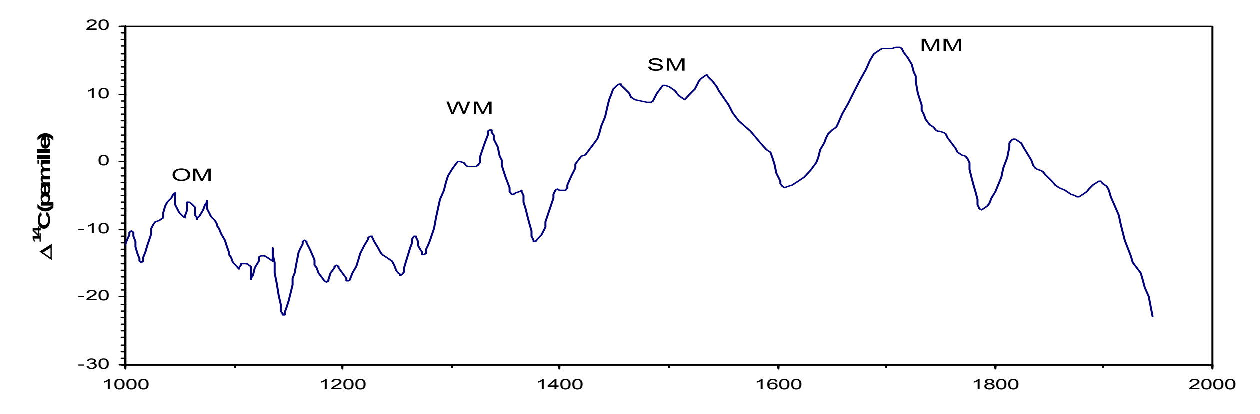
  Effective CR energy 1.3 GeV/n (local polar **Alanko et al., SH3.3-4**) ***to 2 GeV/n*** (global **McCracken, SH3.5-2)**;
- ^{7}**Be** ($\tau_{1/2}$ = 53.3 days) **in the air (similar process, Yoshimori et al. SH3.6-12; 2P-212; Sakurai et al., SH3.6-13)**
- **Radiocarbon ^{14}C : new measurements (H. Sakurai et al., SH3.5-4; Miyahara et al., SH3.5-5, 2P-222; Masuda et al., SH3.5-6)**

  n + N → ^{14}C ($\tau_{1/2}$ ~5730 y) ***→ CO_2 → carbon cycle → 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 Δ^{14}C for the last millennium (Stuiver & Braziunas, 1993)

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

  Effective CR energy > 70 MeV/n

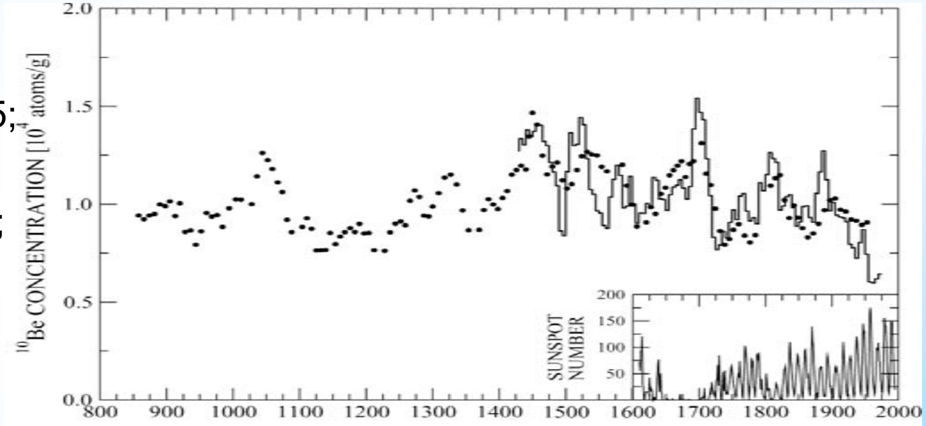
- **Nitrates in polar ice (ionisation by strongest SEP events > 10^9 cm^{-2} (> 30 MeV) ,** Zeller & Parker, 1981; Gladysheva & Dreschhoff, 1997; McCracken et al., 2001**)** - **Shea, Smart, Dreschhoff, McCracken, SH3.6-14**

Cosmogenic ^{10}Be isotope: CR modulation index

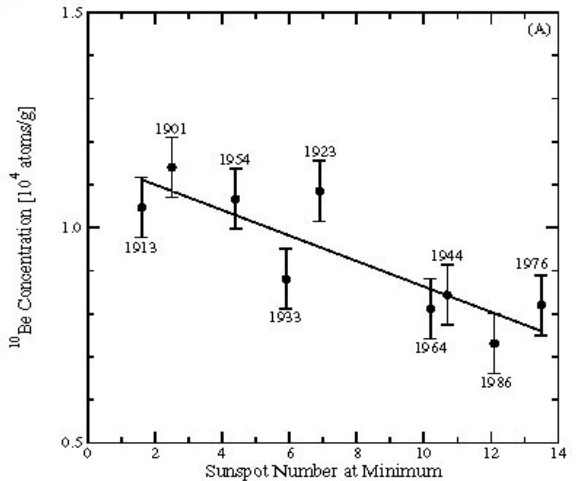
Models of ^{10}Be production (**McCracken, SH3.5-2; Beer et al., 2P-194**)

The results of ^{10}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}Be level in 1700's;
- »Possible 5-y variations during low solar activity
- » Is ^{10}Be related to the minimum SN?

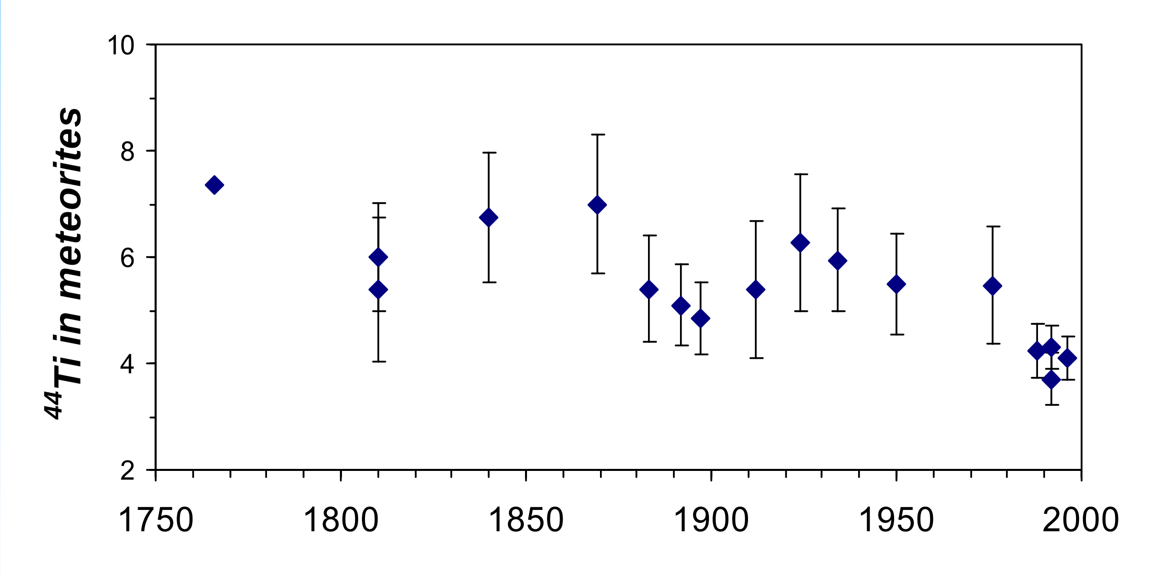


The 11-y average ^{10}Be data from Dye-3, Greenland (**McCracken, Beer & McDonald, SH3.5-1**) and 24-y averaged data from South Pole (Bard et al., 1997).



^{44}Ti in meteorites: a space probe

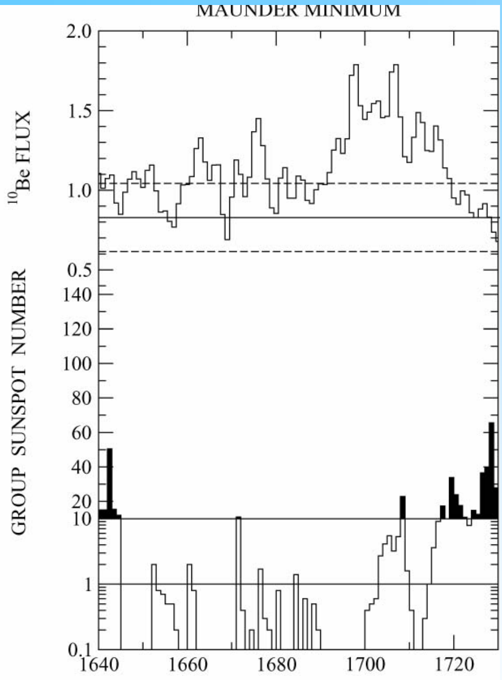
^{44}Ti ($\tau_{1/2}$=59.2 year) in stony meteorites:



space probing of CR in the past

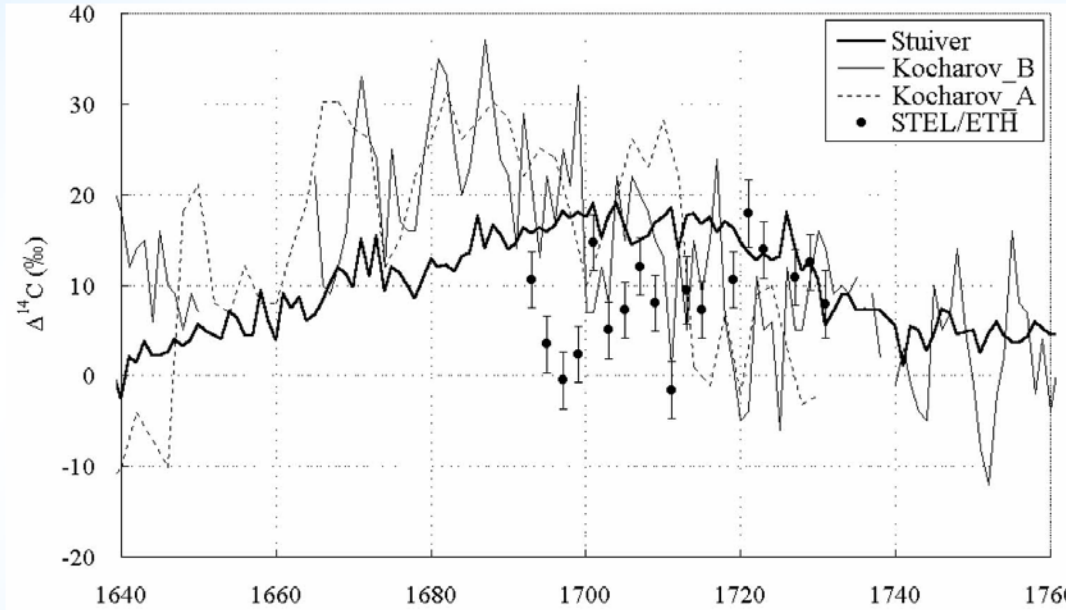
(**SH3.4-6 Cini Castagnoli et al**.)

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); **^{14}C data** (Kocharov et al., 1995; Stuiver & Braziunas, 1998; Peristyh & Damon, 1998) **NO(Y) data** (Gladysheva, Kocharov, Usoskin, 2002) but **^{10}Be** data depict **dominant 11-year cycle** (Beer et al. 1998).

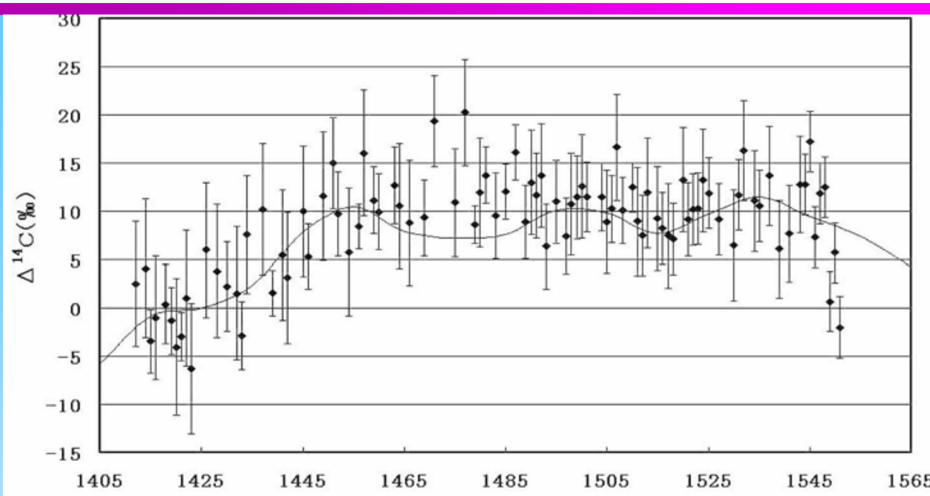
^{10}Be data from Greenland (**McCracken, Beer & McDonald, SH3.5-1**)



Discrepancy between earlier ^{14}C 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.

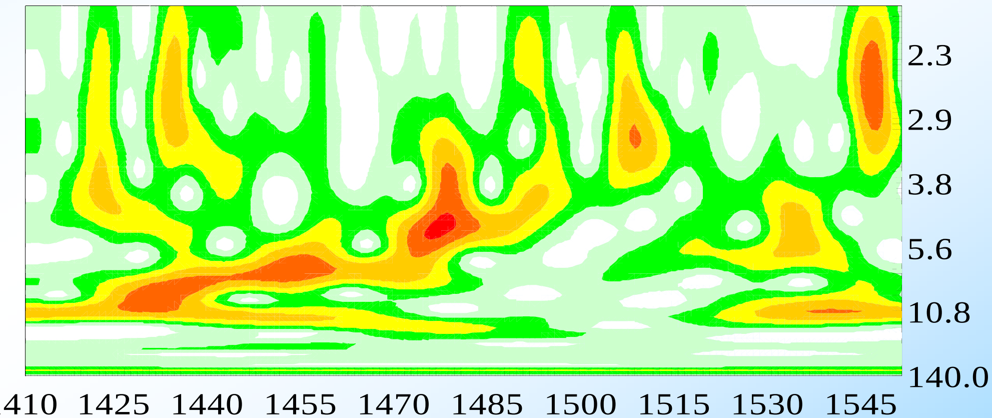
Regional effects?

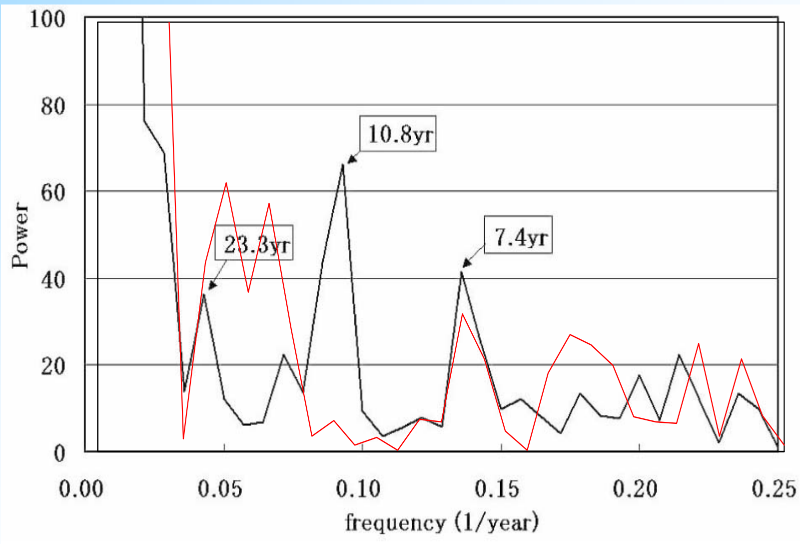
Spörer minimum (1415-1540)



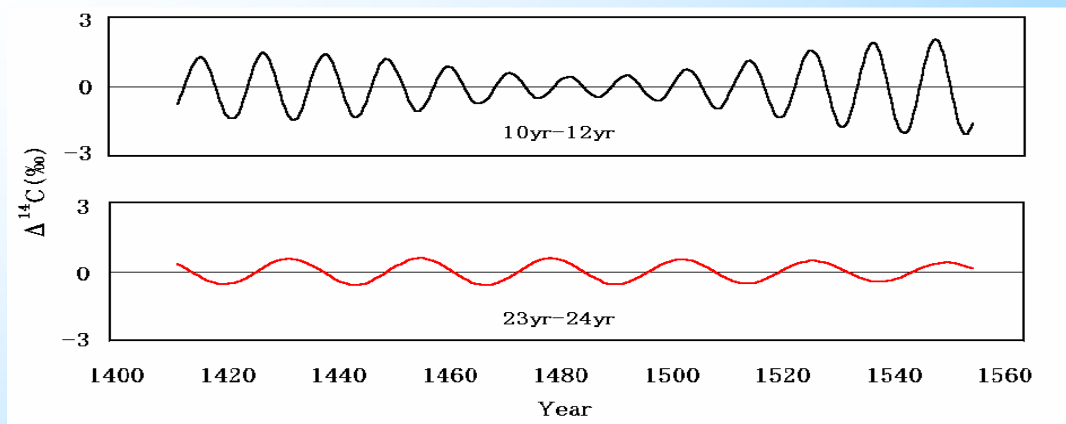
New ^{14}C measurements during SM (Japanese cedar tree – **Miyahara et al., SH3.5-5, 2P-222**):

- Reduced 11-y cycle;
- Persistent 22-y cycle with constant amplitude;
- 7-y cycle (?)



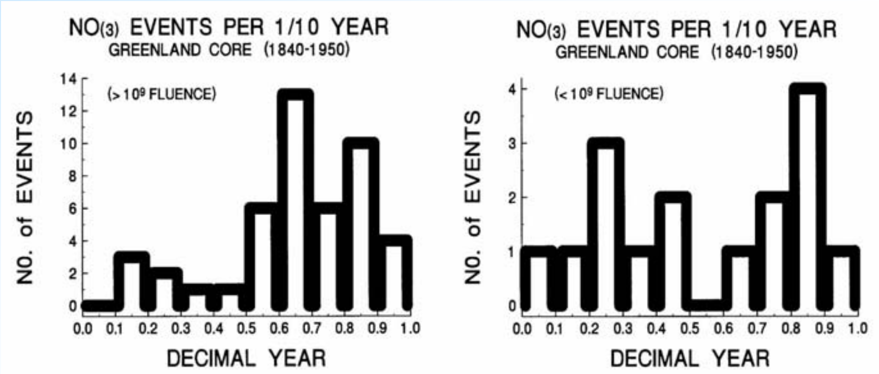


Power spectrum of ^{14}C content and of Greenland ^{10}Be data during SM (1410-1550)



Nitrates in polar ice

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

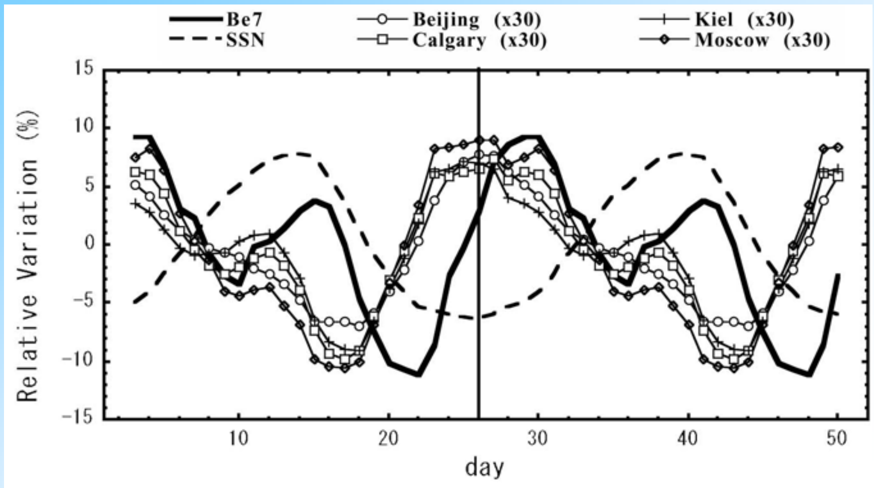


- Relation to geomagnetic storms / mid-latitude aurora sightings (**Shea, Smart, Dreschhoff, McCracken, SH3.6-14**)

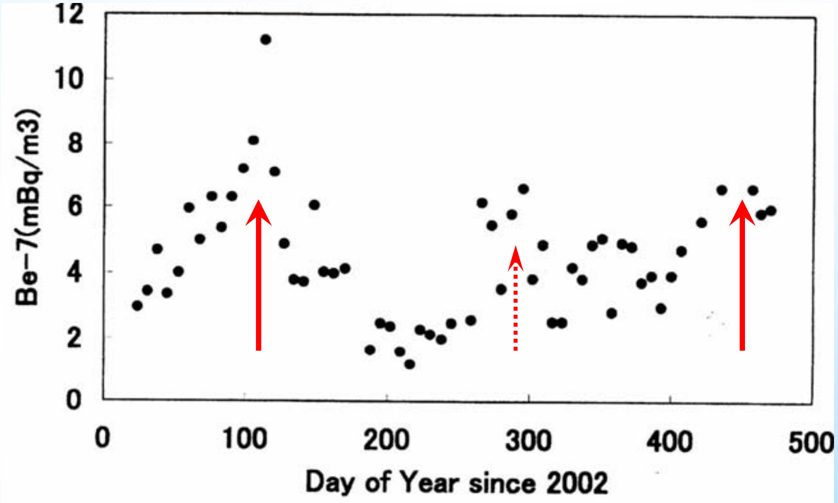
Fig. 2. Impulsive nitrate events (top) and mid-latitude aurorae (bottom)

Cosmogenic ^{7}Be

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

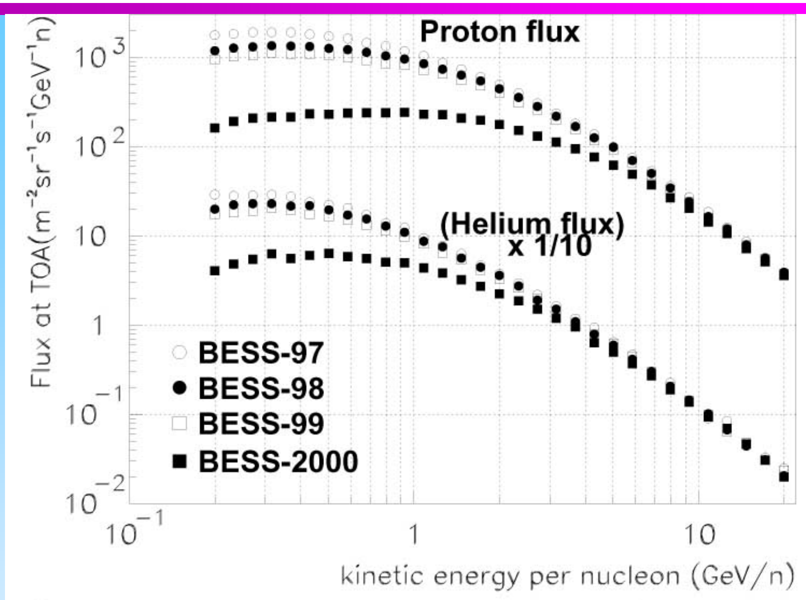


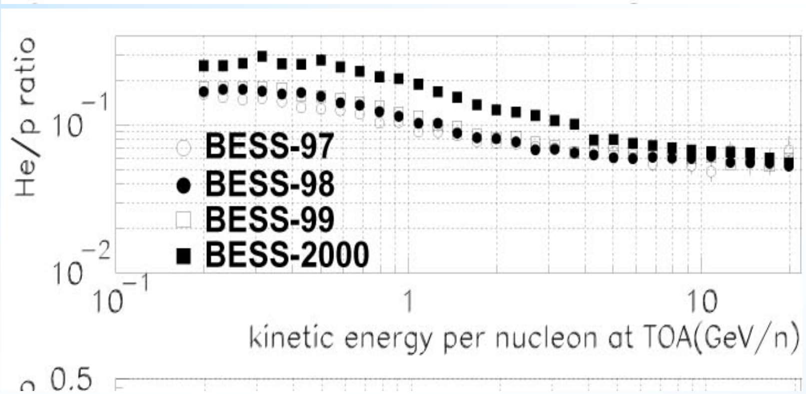
Data folded with the folding period 26 days (**Sakurai et al. SH3.6-13**). Note 13-day periodicity and 5-day shift.



Time variations of ^{7}Be data (**Yoshimori et al. SH3.6-12**). Data suggest for an atmospheric mixing in Spring.

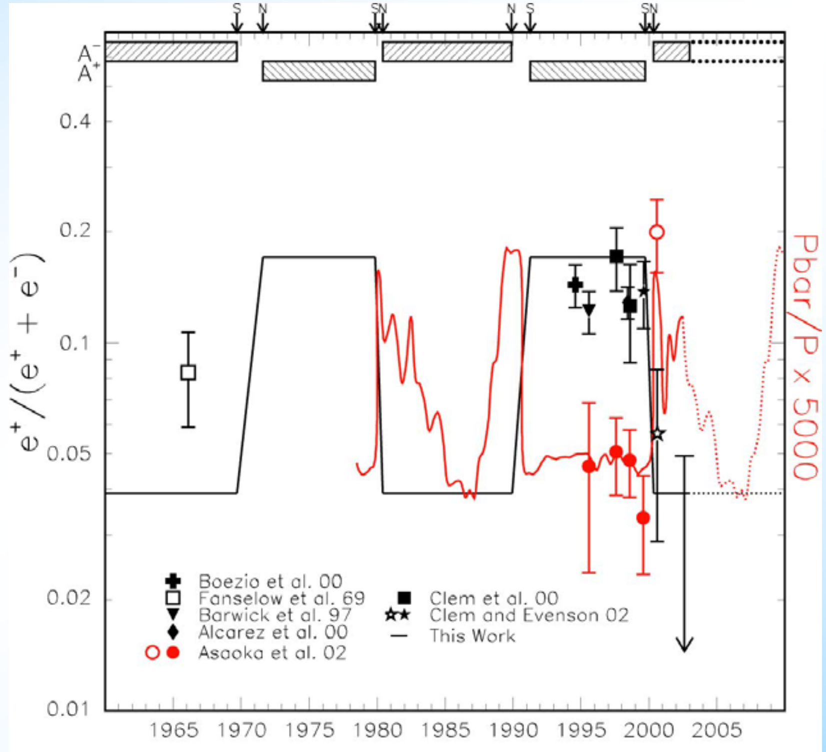
Modulation: Recent measurements





SH 3.4-2 (Shikaze et al. - BESS)

New precise balloon measurements of p and He energy spectra.

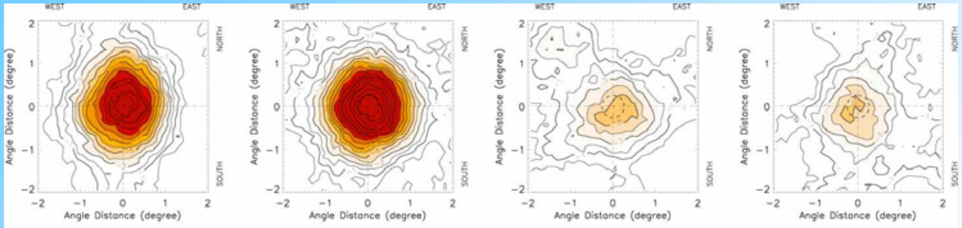


SH 3.4-1 (Clem & Evenson) – balloon measurements of **e^+ /e^-** (AESOP) and **p^- /p** (BESS) over the polarity reversal (~1.3 GeV).

Direct evidence for the drift-effect in CR modulation

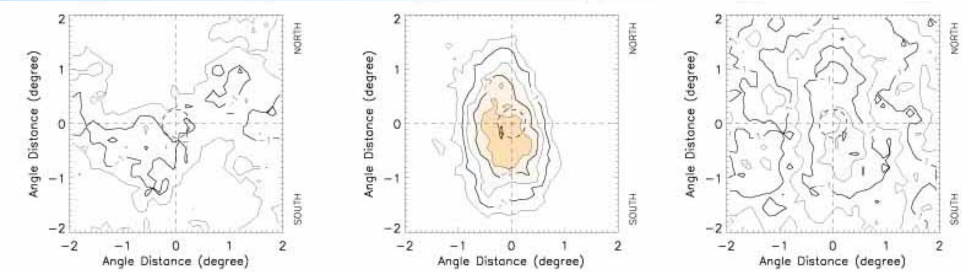
Sun's shadow

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**).

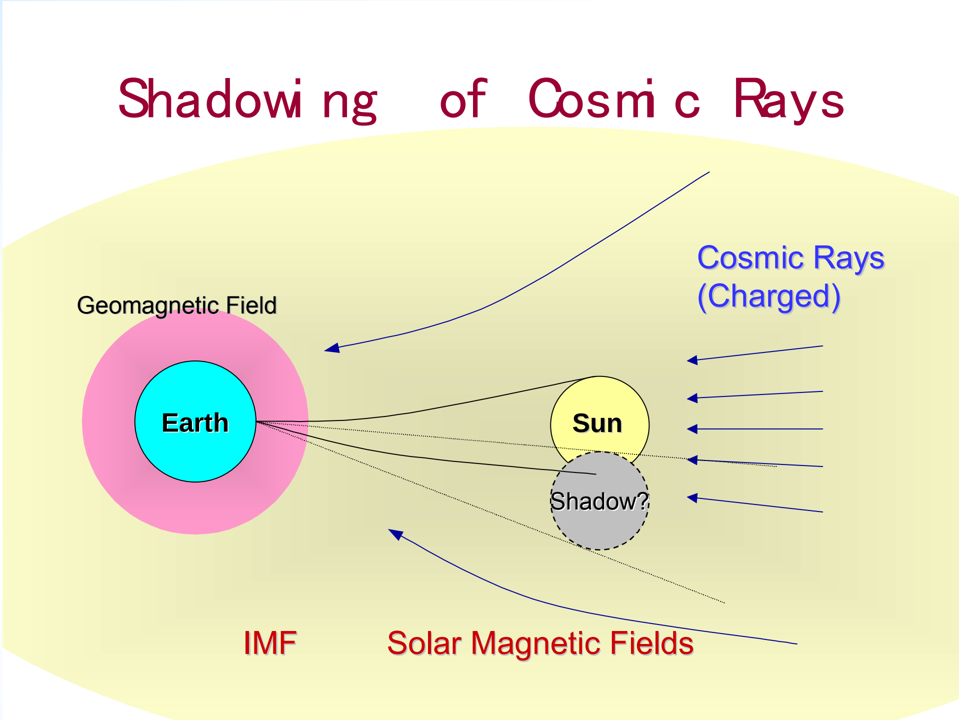


1996 (Tibet-II) 1997 (Tibet-II) 1998 (Tibet-II) 1999 (Tibet-II)

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**)



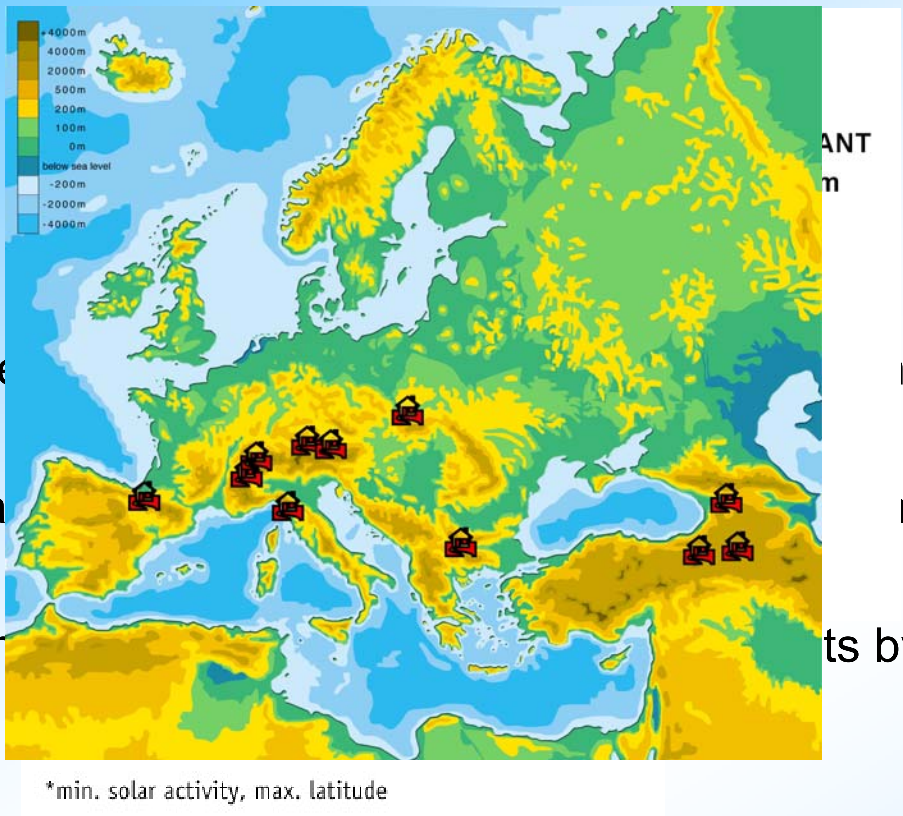
2000 (Tibet-III 3TeV) 2001 (Tibet-III 3TeV) 2002 (Tibet-III 3TeV)



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

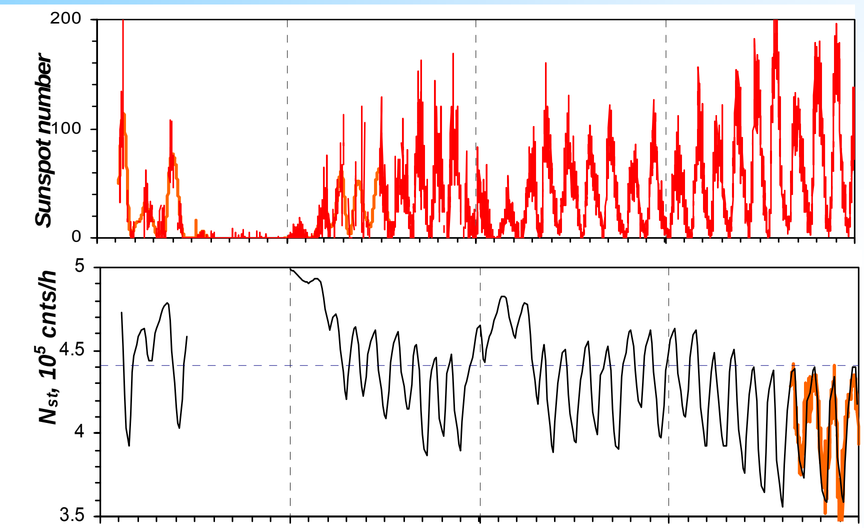
- Neutron flux (most important for radiation doses) at different altitudes/locations: measurements and simulations (**Zanini et al., 2P-217**)

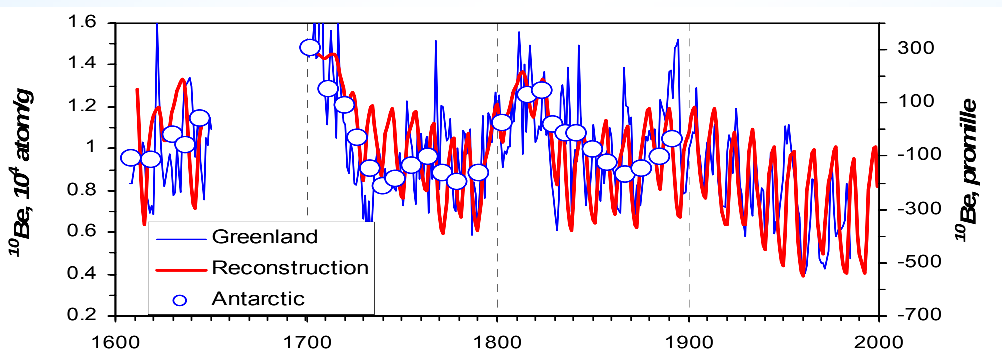


- Me … g rainouts (**Cecchini et al., SH3.6-6**)
- Ga … tal radiation): measurements (**Cattani et al., 2P-218**)
- En … ts by SONTEL @ Gornergrat (**Bütikofer et al., 2P-199**)

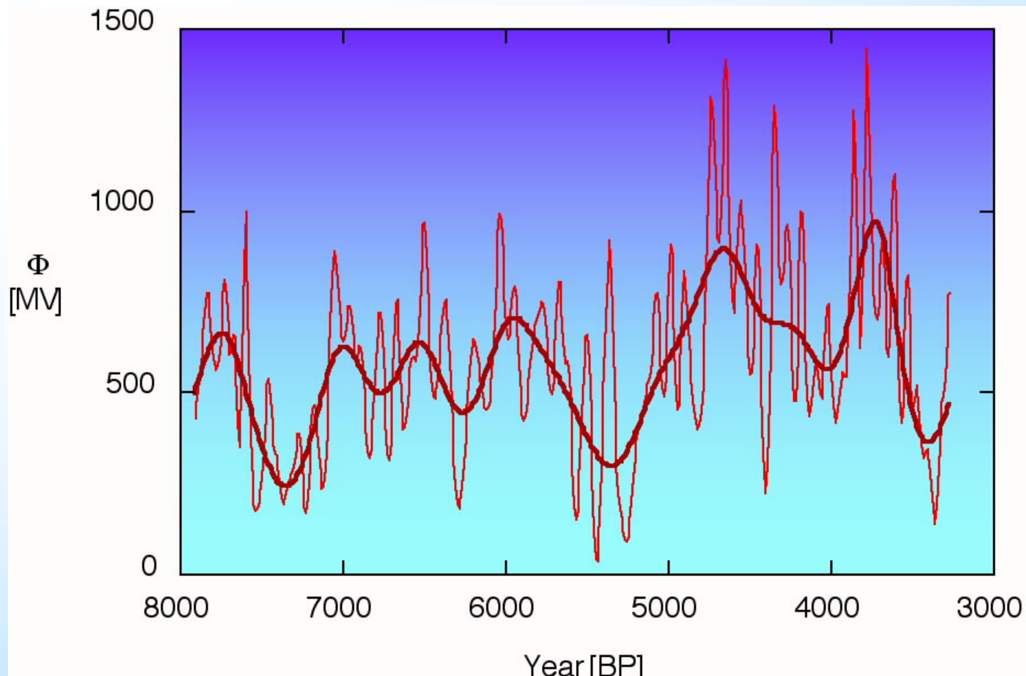
Long-term CR

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)**



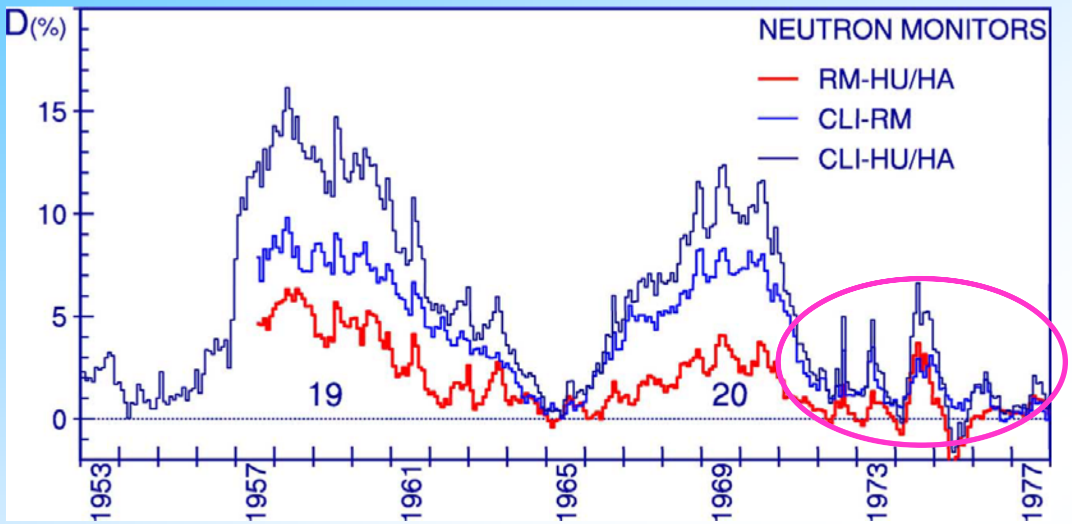


Beer et al., 2P-194 inverted the model, estimating the modulation efficiency in the past

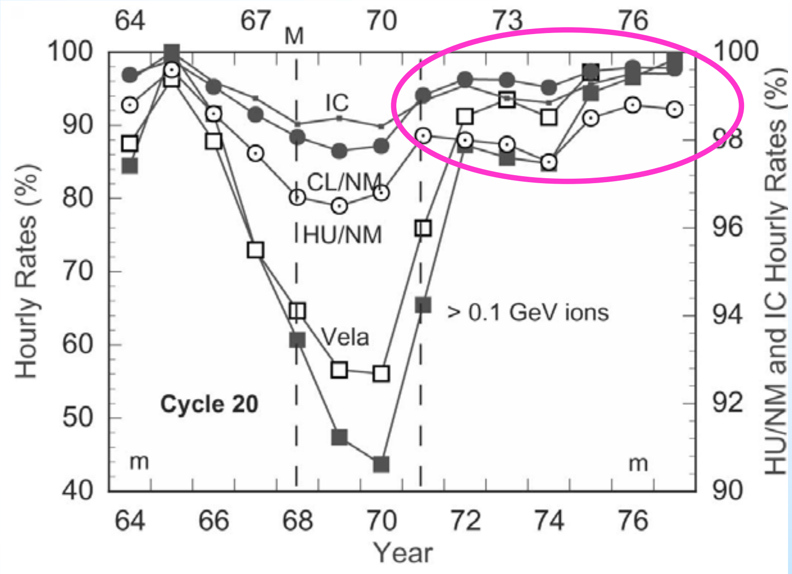


Unusual modulation: cycle 20

Solar cycle 20 (1965-1976): unusual modulation (Webber & Lockwood, JGR, 1988; Usoskin et al., ICRC, 1997; Usoskin et al., JGR, 1998; Wibberenz et al., JGR, 2002): **rigidity independent modulation and loss of the correlation to SA parameters.**



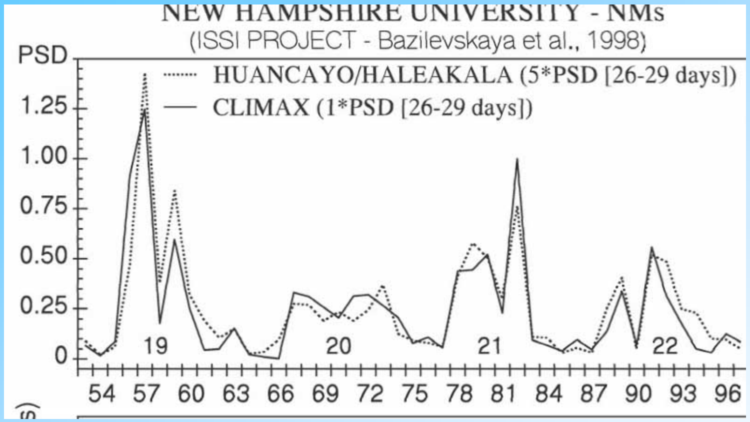
CR modulation for different rigidity intervals (3–13, 3–6, and 6–13 GV) - see **Storini, Massetti, Kudela, Rybak (2P-187)**



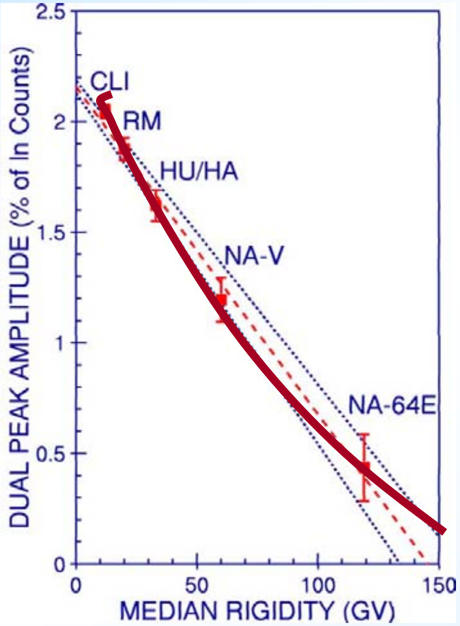
Annual data of different CR detectors (**Ahluwalia, SH 3.4-4**)

McCracken, 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?

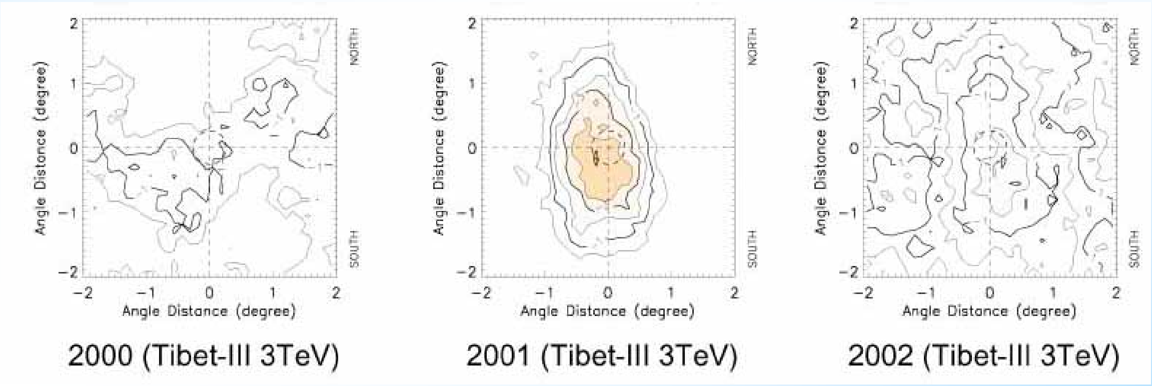
Gnevyshev gap in CR



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**)

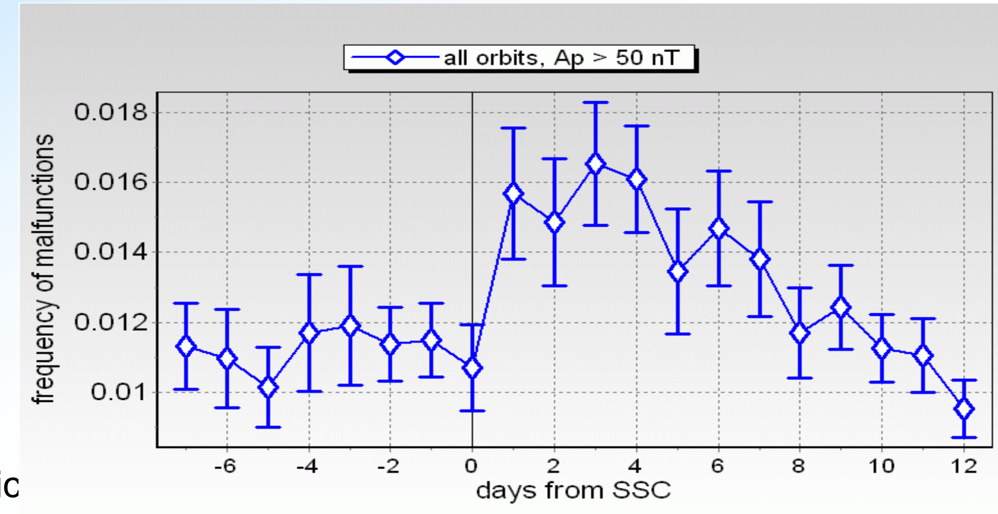
22-year CR modulation

- 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).**

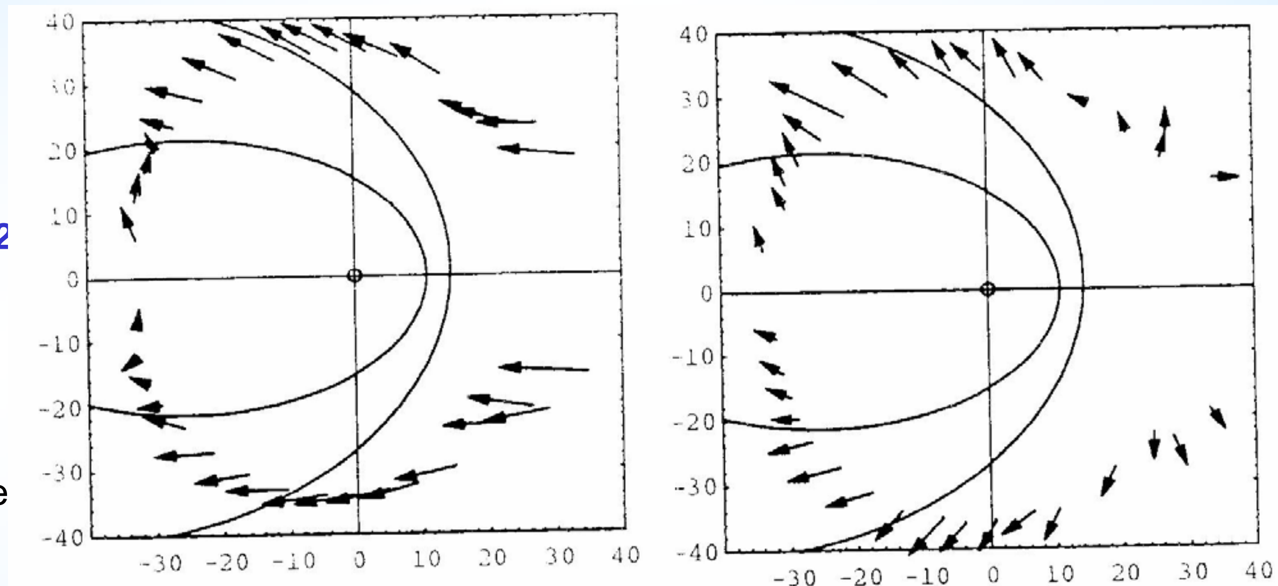
Space weather

- 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.



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

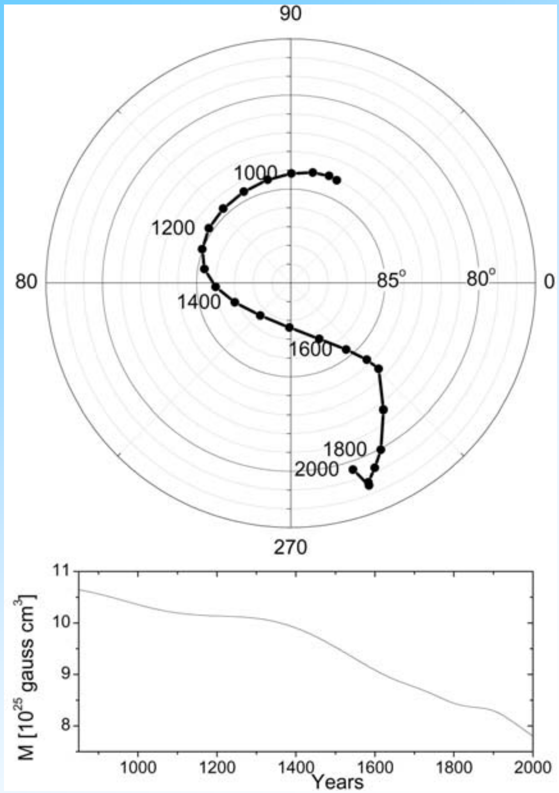


Makhmutov et al. (2 … erron, Equinoctial and Axial effects.

Dorman (2P-211) re

Geomagnetic rigidity cutoff

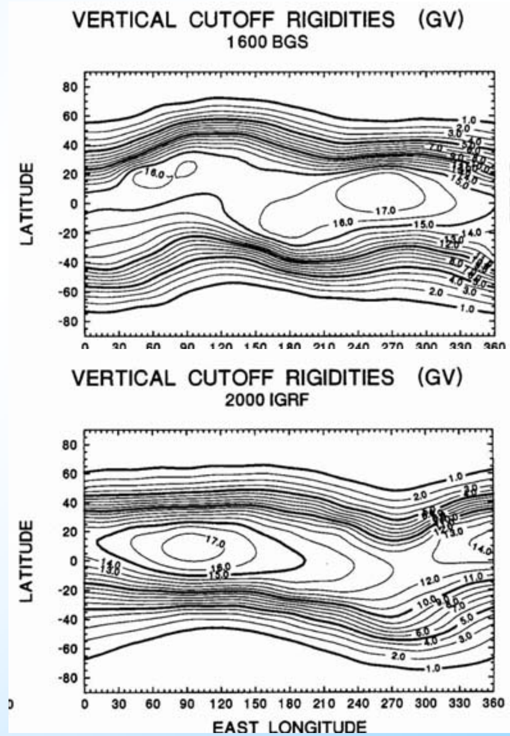
Changes of the geomagnetic field (orientation and strength of the virtual dipole) is important for CR on long-term scale.



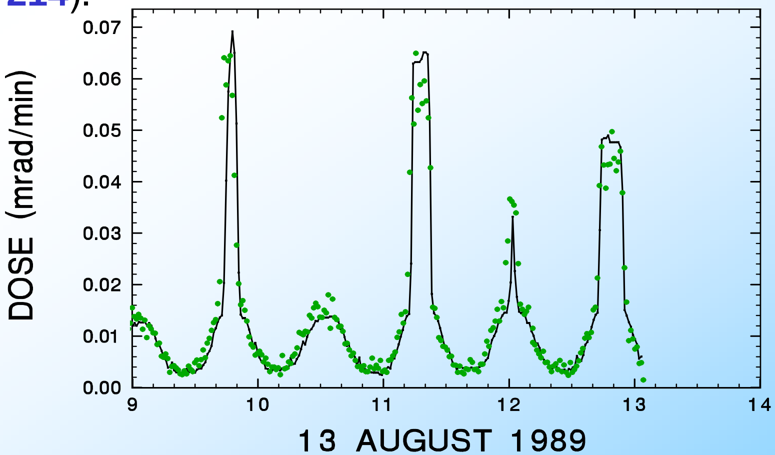
Geomagnetic dipole changes during the last millennium (after Hongre et al., 1998)

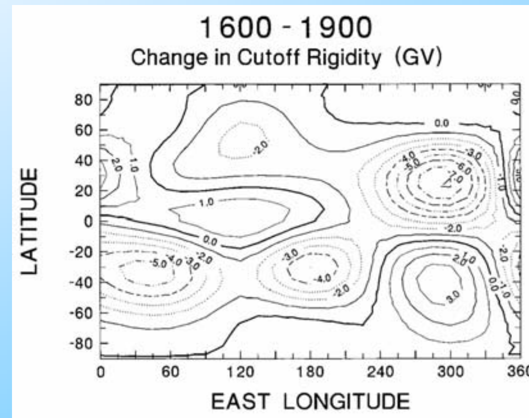
Smart & Shea (SH3.6-8), **Shea & Smart (SH3.6-9)** and **Flückiger et al. (2P-201)** calculated the geomagnetic cutoff values on the long-term scale.

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**).



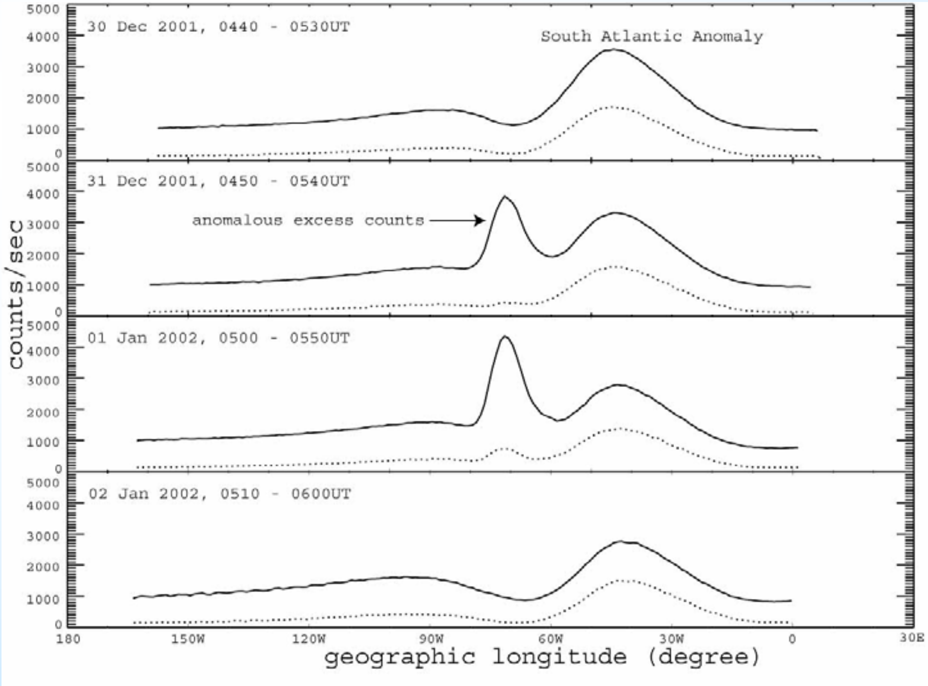


Secondary particles

- Interaction of CR with the matter of the Earth's atmosphere → secondary particles → 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**):

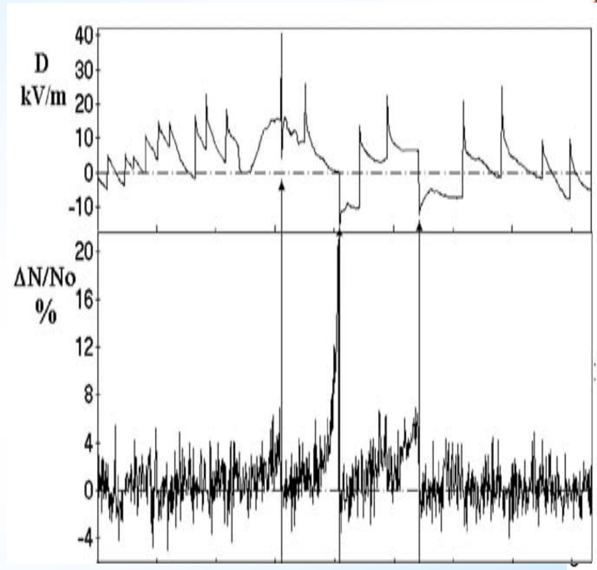
Using an X- and γ-ray instrument, they found an unusual time-variable increase of low energy electrons near SAA with a steep spectrum during/after geomagnetic storms

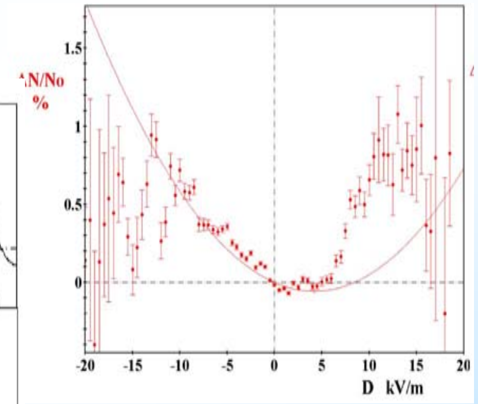


CR and thunderstorms

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.

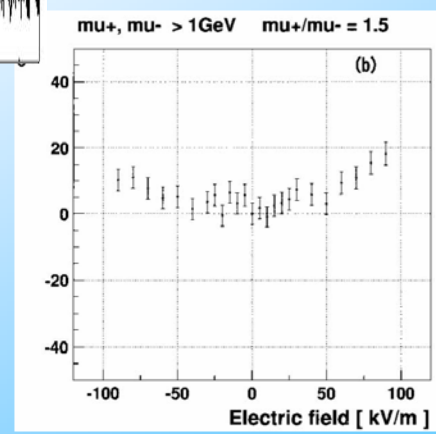
Particle acceleration by electric field: Baksan & Mt.Norikura

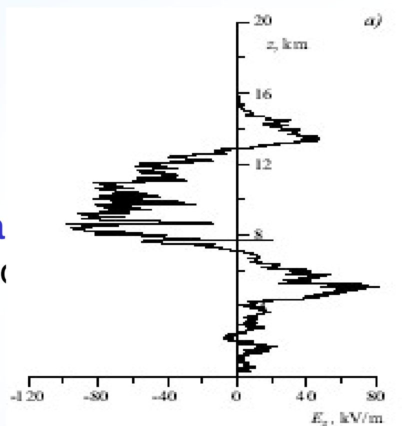




Khaerdinov et al. (SH3.6-3; SH3.6-4; 2-P-198) – regression analysis for soft (e) and hard (μ) components (88 events in 2000-2002).

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 lightining channel.





Muraki et a vidence for proton acceleration by electric field in thunder clou

Miscellaneous

- **(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 sederial 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 ma

$$
\begin{aligned}
\kappa_{11} &= \kappa_0\left[\cos^2\gamma\cos^2\psi + \alpha\left(\cos^2\gamma\sin^2\psi + \sin^2\gamma\right)\right] & \kappa_{21} &= \kappa_0\left[\sin\gamma\cos\gamma\cos^2\psi(1-\alpha) + \alpha_1\sin\psi\right] \\
\kappa_{12} &= \kappa_0\left[\sin\gamma\cos\gamma\cos^2\psi(1-\alpha) - \alpha_1\sin\psi\right] & \kappa_{22} &= \kappa_0\left[\sin^2\gamma\cos^2\psi + \alpha\left(\sin^2\gamma\sin^2\psi + \cos^2\gamma\right)\right] \\
\kappa_{13} &= \kappa_0\left[\sin\psi\cos\gamma\cos\psi(\alpha-1) - \alpha_1\sin\gamma\cos\psi\right] & \kappa_{23} &= \kappa_0\left[\sin\gamma\sin\psi\cos\psi(\alpha-1) + \alpha_1\cos\gamma\cos\psi\right] \\
\kappa_{31} &= \kappa_0\left[\cos\gamma\sin\psi\cos\psi(\alpha-1) + \alpha_1\sin\gamma\cos\psi\right] & & \\
\kappa_{32} &= \kappa_0\left[\sin\gamma\sin\psi\cos\psi(\alpha-1) - \alpha_1\cos\gamma\cos\psi\right] & & \\
\kappa_{33} &= \kappa_0\left[\sin^2\psi + \alpha\cos^2\psi\right] & &
\end{aligned}
\qquad (2)
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- Atm **(Desorgher et al., 2-P-2**
- Ligl **2-P-205)** and nuclear com
- 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}C*** annual data for the Maunder and Spoerer minima;
  - » ***^{44}Ti*** in meteorites;
- Environmental monitoring;
- Charged particle fluxes during thunderstorms;
- Study of long-term geomagnetic cut-off rigidities;
- Measurements and models for trapped particles.