Characteristics of solar particle events affecting aviation

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with Acknowledgements to

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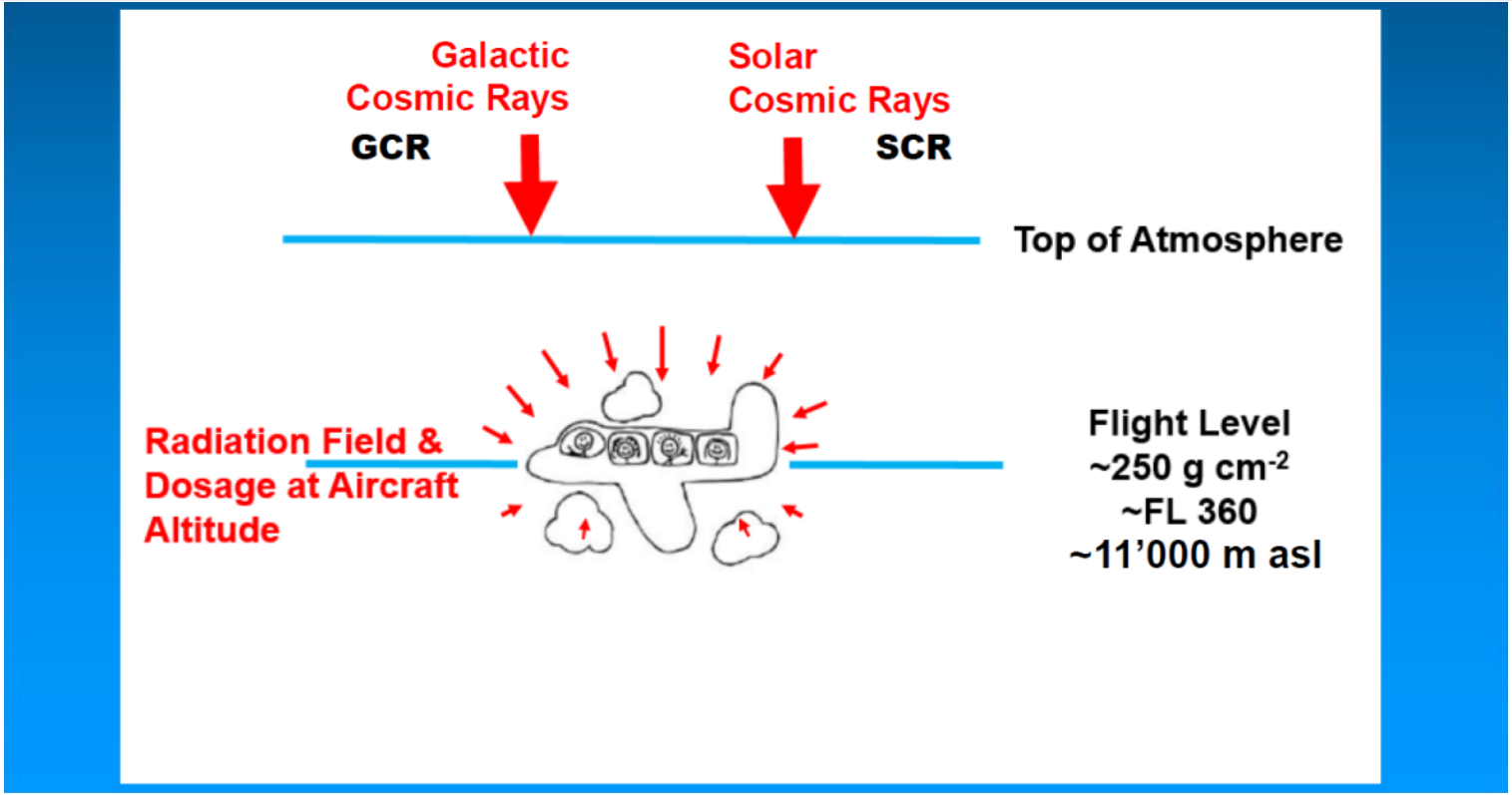
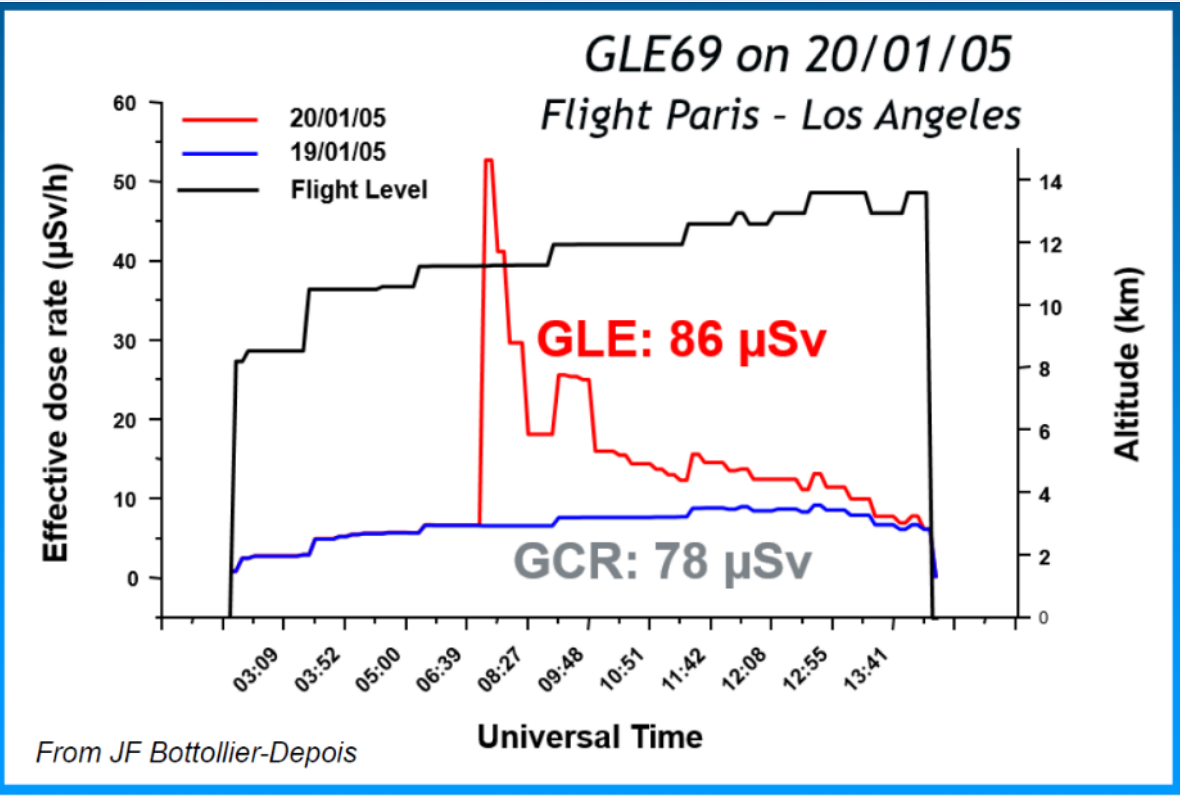
What are we talking about?



The Phenomenon



The Phenomenon

Some
Fundamental
Background Information

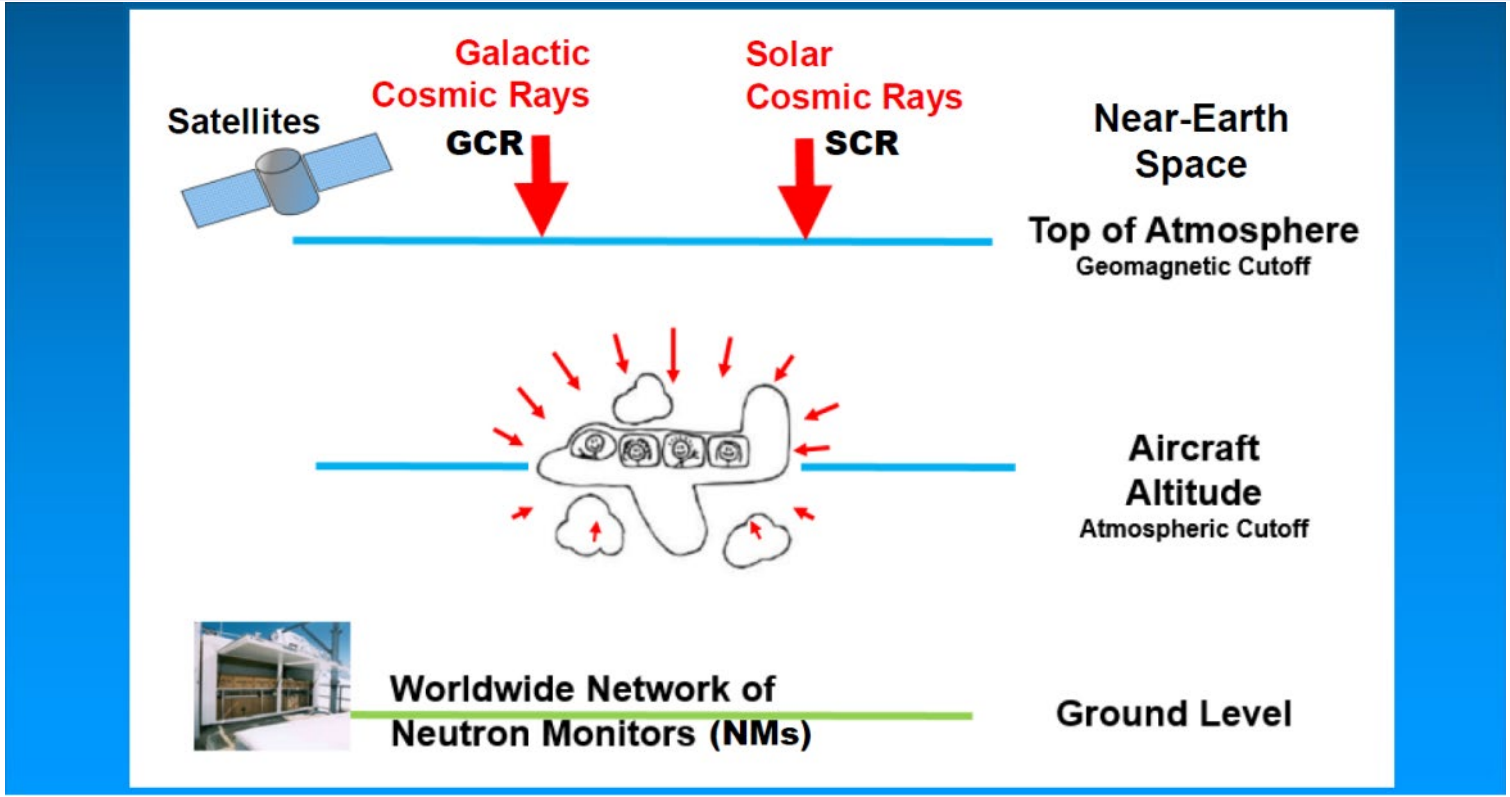
(with apologies to the experts)

The Phenomenon

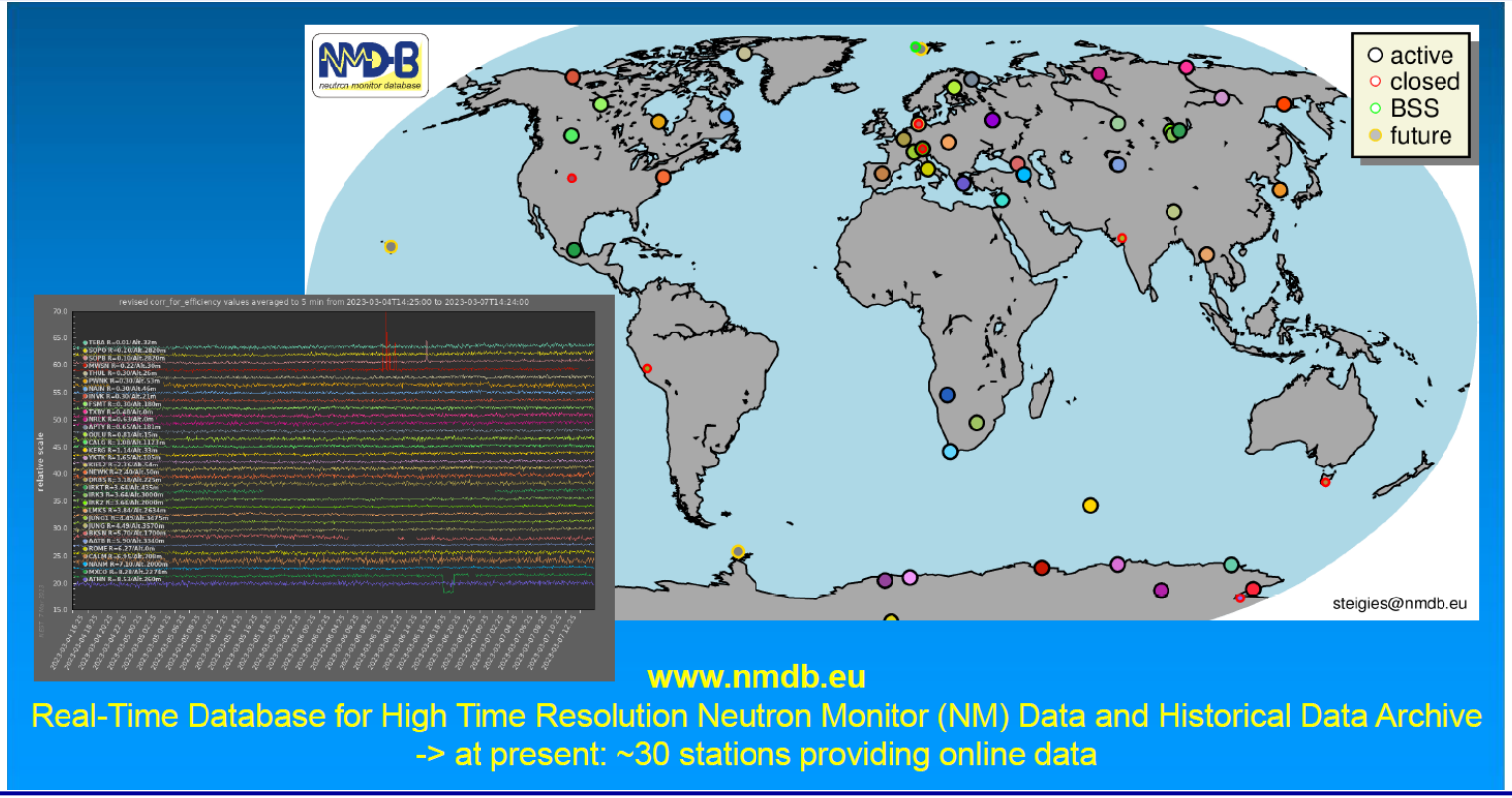
Fundamentals I

Observation / Manifestation of Solar Particle Events Affecting Aviation

Particle Detectors in Space and at Ground



NMDB Worldwide Neutron Monitor Network

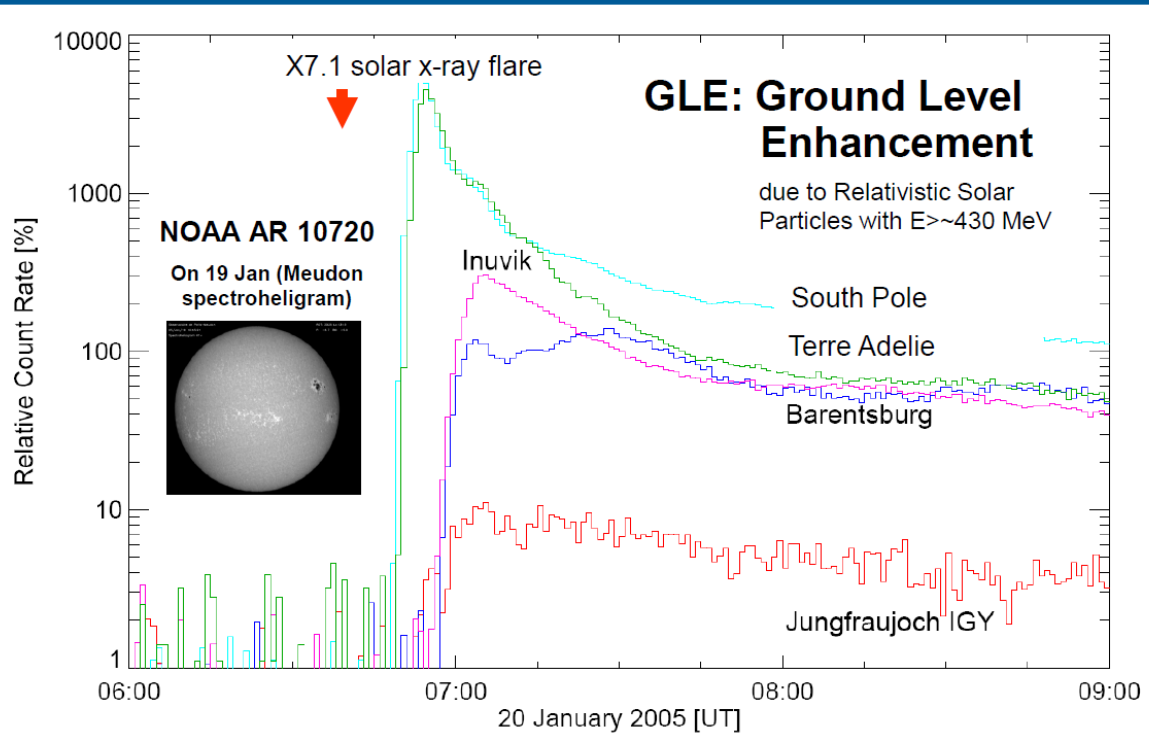


www.nmdb.eu

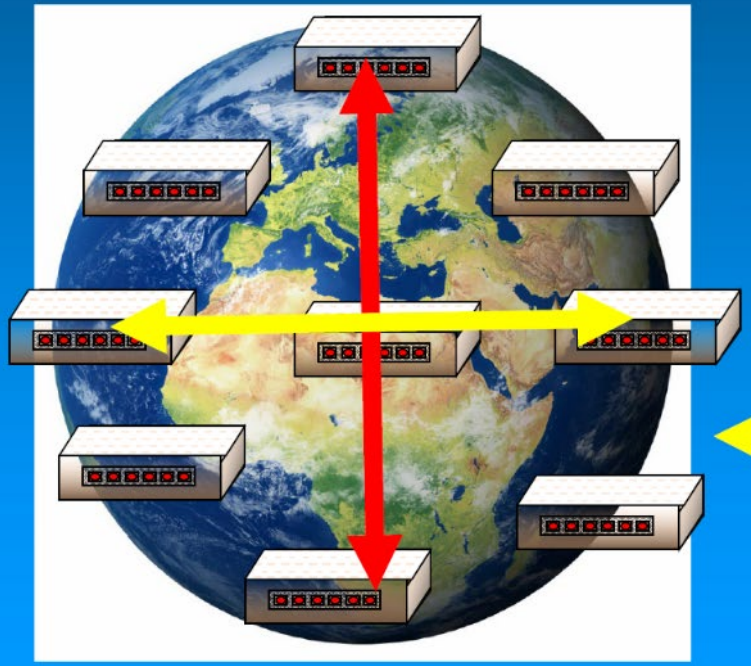
Real-Time Database for High Time Resolution Neutron Monitor (NM) Data and Historical Data Archive

-> at present: ~30 stations providing online data

Neutron Monitor Observations Example: 20 January 2005



Why a GLOBAL Network of Neutron Monitors ?



Latitudinal Spread:

-> Information about particle spectrum

-> N-S Anisotropy

Longitudinal Spread:

-> directional (longitudinal) Information

Terminology

Solar Particle Events Affecting Aviation
are
Energetic Solar Cosmic Ray (SCR) Events

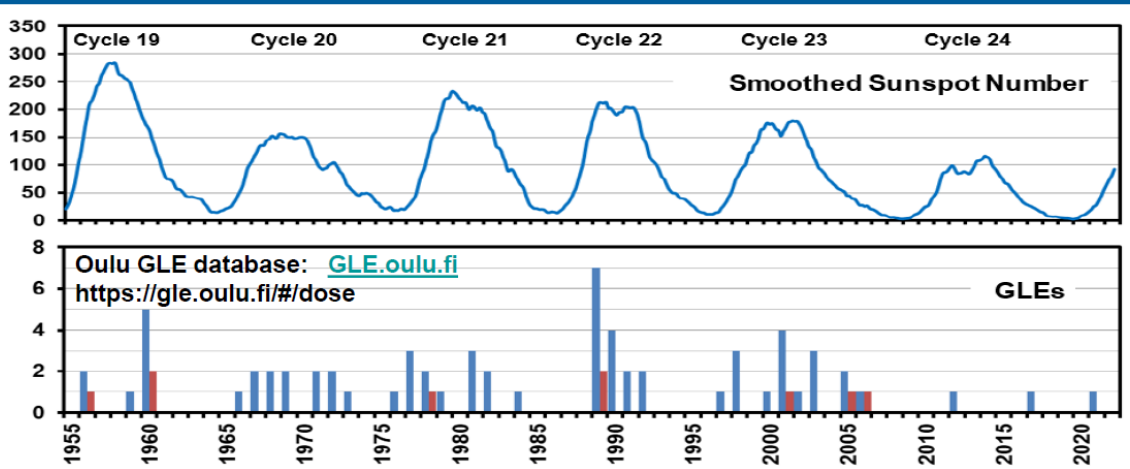
Ground Level Enhancements - GLEs

The Phenomenon

Fundamentals II

Occurrence Frequency of GLEs

GLE Observations



Smoothed sunspot number (top panel, source: WDC-SILSO, Royal Observatory of Belgium, Brussels) and the number of GLEs per year (bottom panel) during the solar cycles 19-25 (until February 2023). Blue bars: all GLEs, red bars: GLEs with amplitude >70%. Adapted from Shea and Smart 1993 and completed with data from Oulu GLE database.

- 73 GLEs since 1942
- 25 "strong" events since 1970 (enhancement > 10% of the permanent GCR Neutron Monitor count rate at sea level)
  ≈ 0.5/year (last one in Dec 2006)

Super Events: Historical Examples

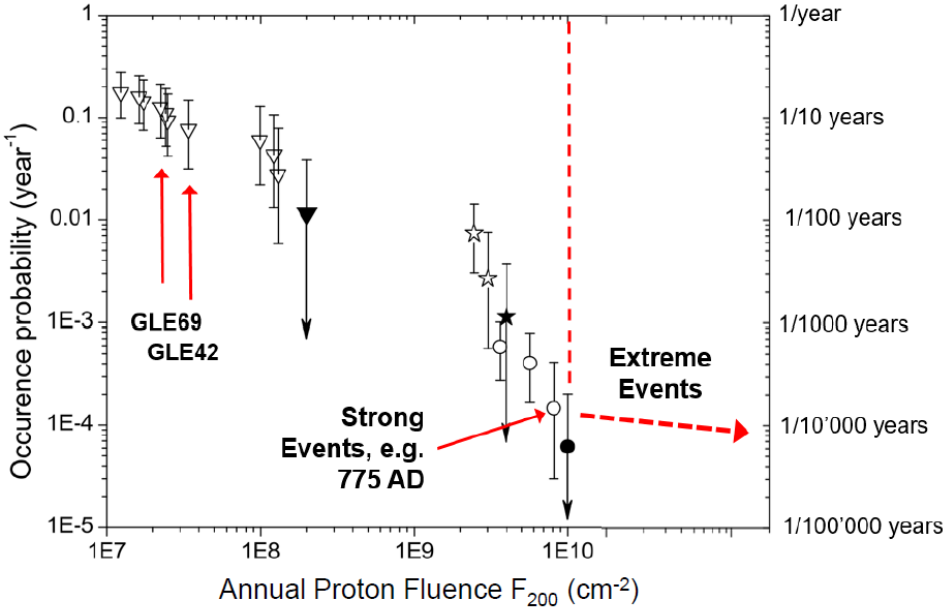
- **The Carrington Event on September 1, 1859**
  (Adv. Space Res. **38** (2), 2006; Cliver & Dietrich, J. Space Weather Space Clim., **3**, A31, 2013)
  $F_{30} \approx 2 \times 10^{10}$ p/cm^2; Dst ≈ -1600 nT
- **The 775 AD event**
  (Miyake et al., Nature, 486, 240–242, 2012)
  $F_{30} \approx 5 \times 10^{10}$ p/cm^2 (?)
- **The «Carrington» Storm that missed the Earth, July 23, 2012**
  (Baker et. al., SPACE WEATHER, VOL. 11, 585–591, 2013)
  estimated Dst ≈ -1200 nT

Occurrence Probability of GLEs

Size Distribution of GLEs
(proton fluences > 200MeV)

GLEs and historical events from terrestrial records
Y-axis: Cumulative occurrence probability density of annual fluences F_{200} greater than the value given on the X-axis.
X-Axis: Annual proton fluence F_{200} (cm^{-2})

Points correspond to the annual proton fluences F_{200} for the space era (since 1955, triangles), and to cosmogenic radionuclides in terrestrial archives for the Holocene (stars & circles)



adapted from Kovaltsov et al. 2014, Solar Phys., 289, 4691

see e.g. also Schrijver, ESWW 2014 & JGR **117**, A08103, 2012; Aulanier et al., A&A **549**, A66, 2013

The Phenomenon

Fundamentals III

Characteristics of GLEs

Characteristics of GLEs /SCR Particles near Earth

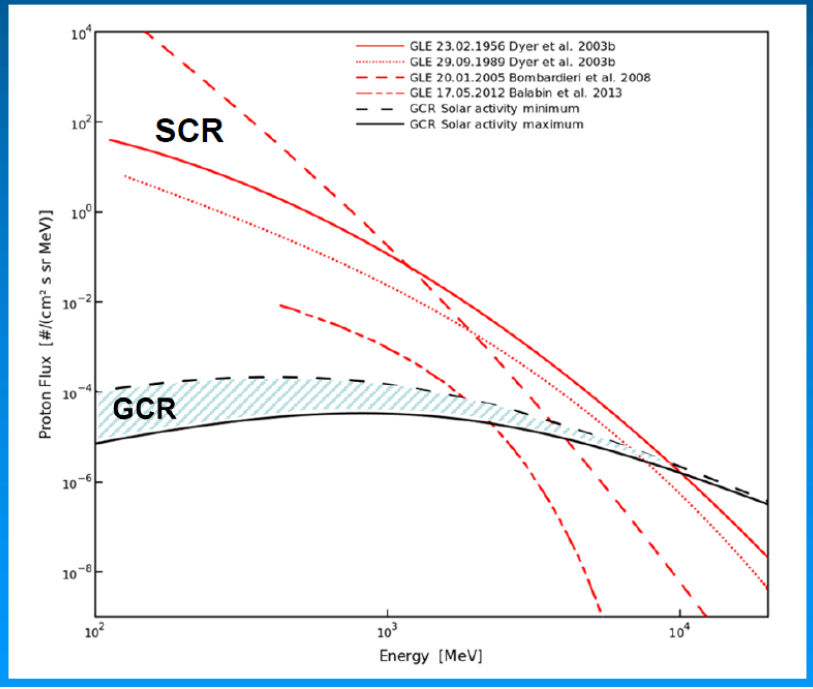
Particle Energy/Rigidity Spectrum

Pitch angle distribution / Anisotropy

Apparent source direction

….all these characteristics usually change with time

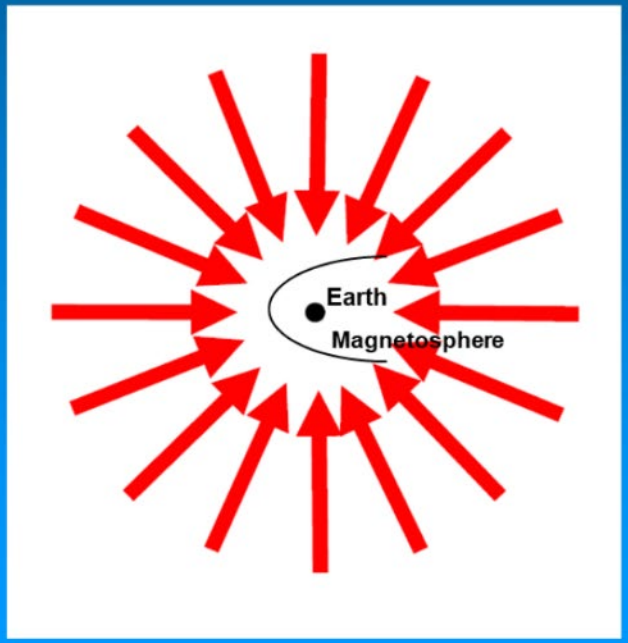
SCR Particle Spectrum



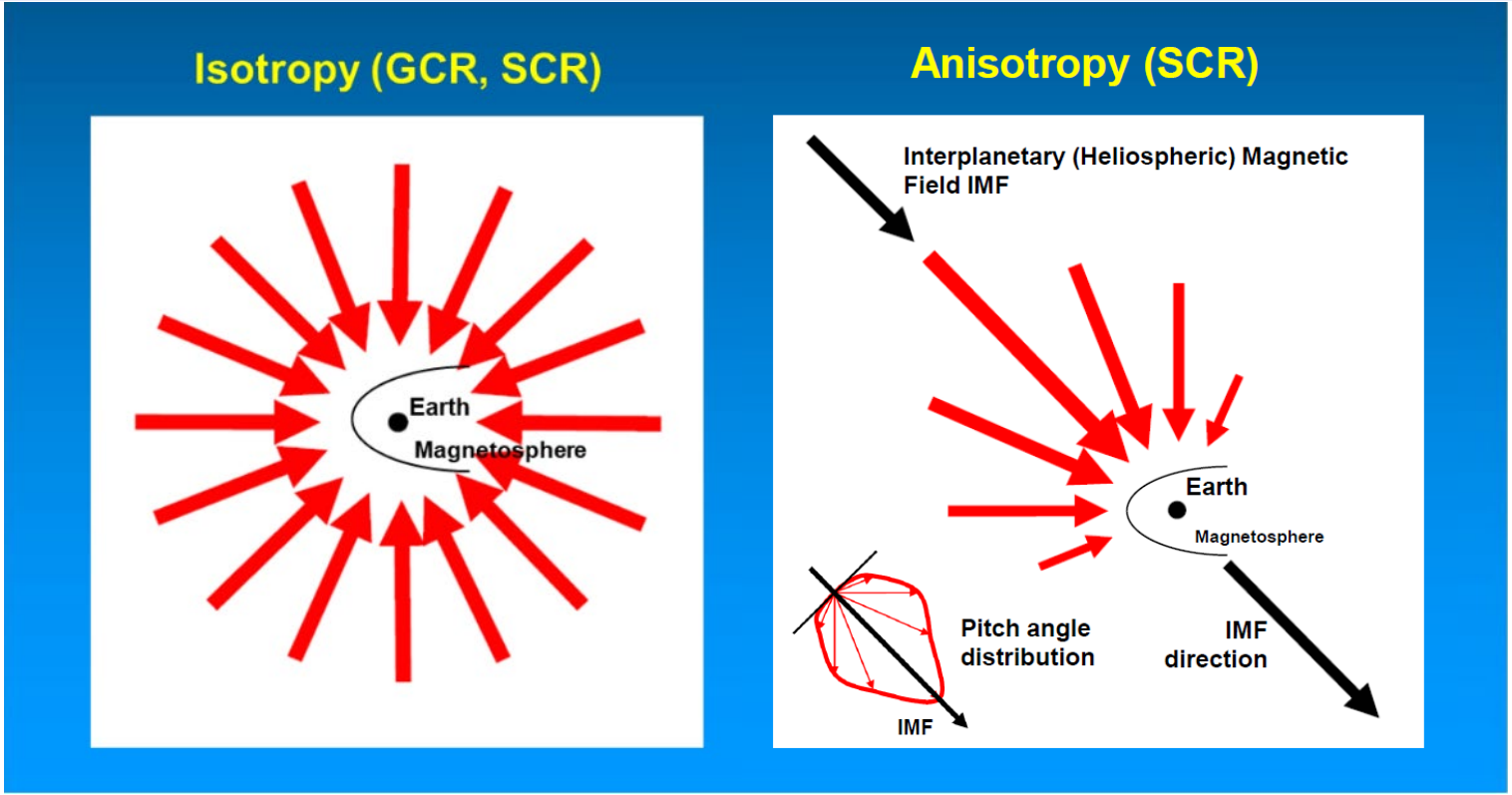
The SCR proton peak flux during selected GLEs as derived from data of the worldwide network of NMs, and the GCR proton spectrum during minimum and maximum solar activity (see e.g. Dyer, 2003, Bombardieri, 2008, Balabin, 2013).

SCR Isotropy / Anisotropy

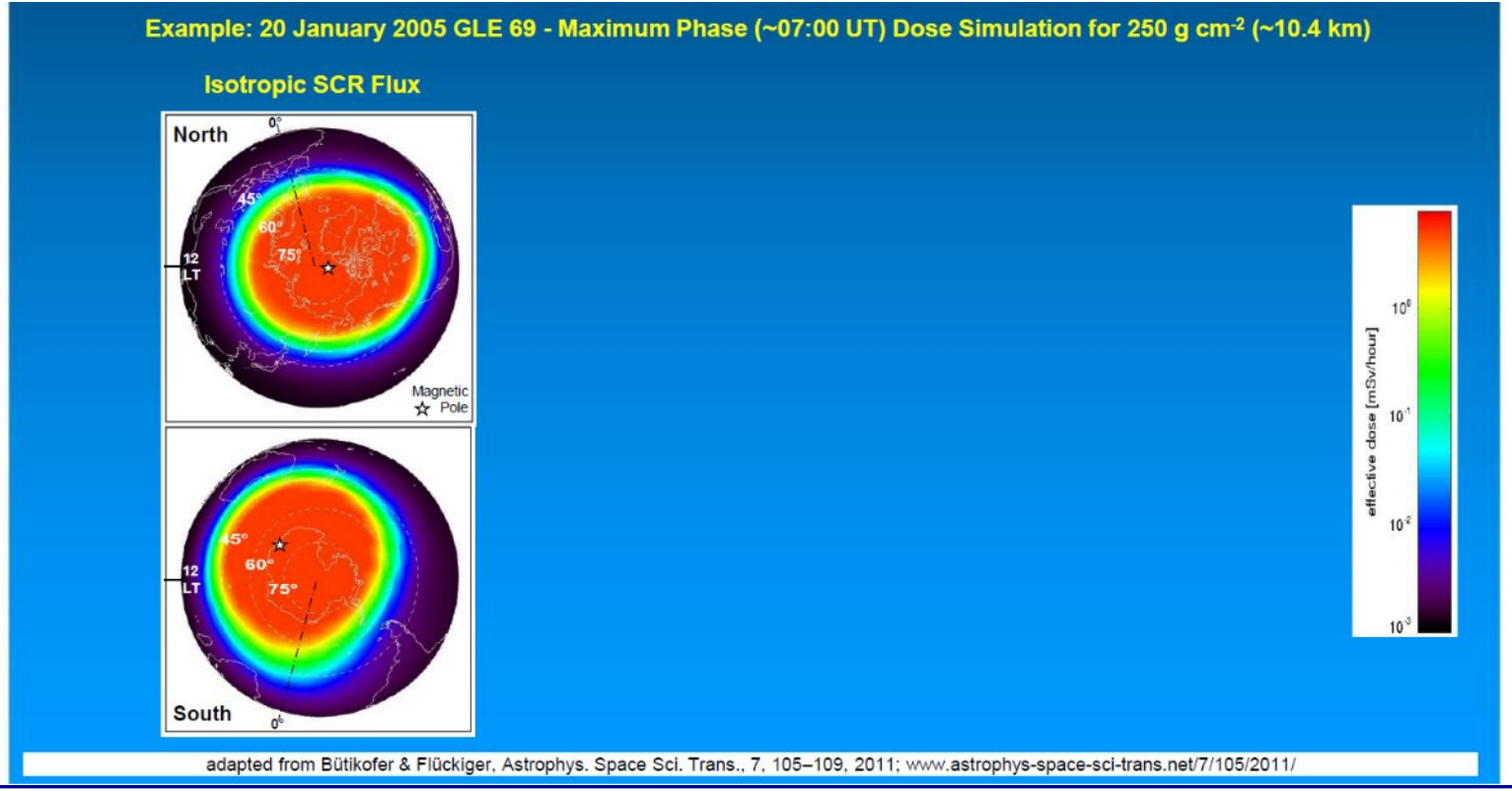
Isotropy (GCR, SCR)



SCR Isotropy / Anisotropy



SCR Isotropy / Anisotropy & Geomagnetic Effects



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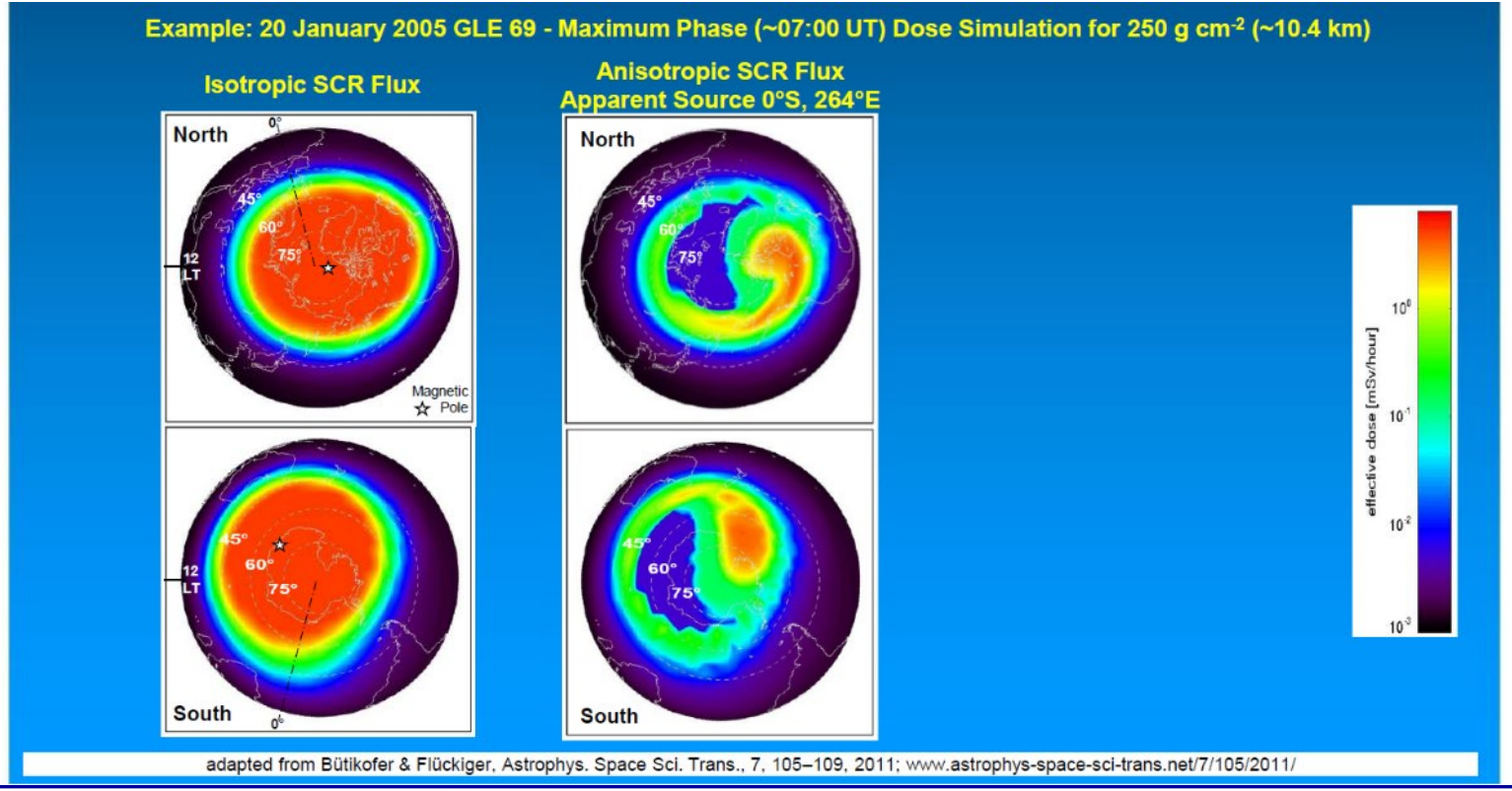

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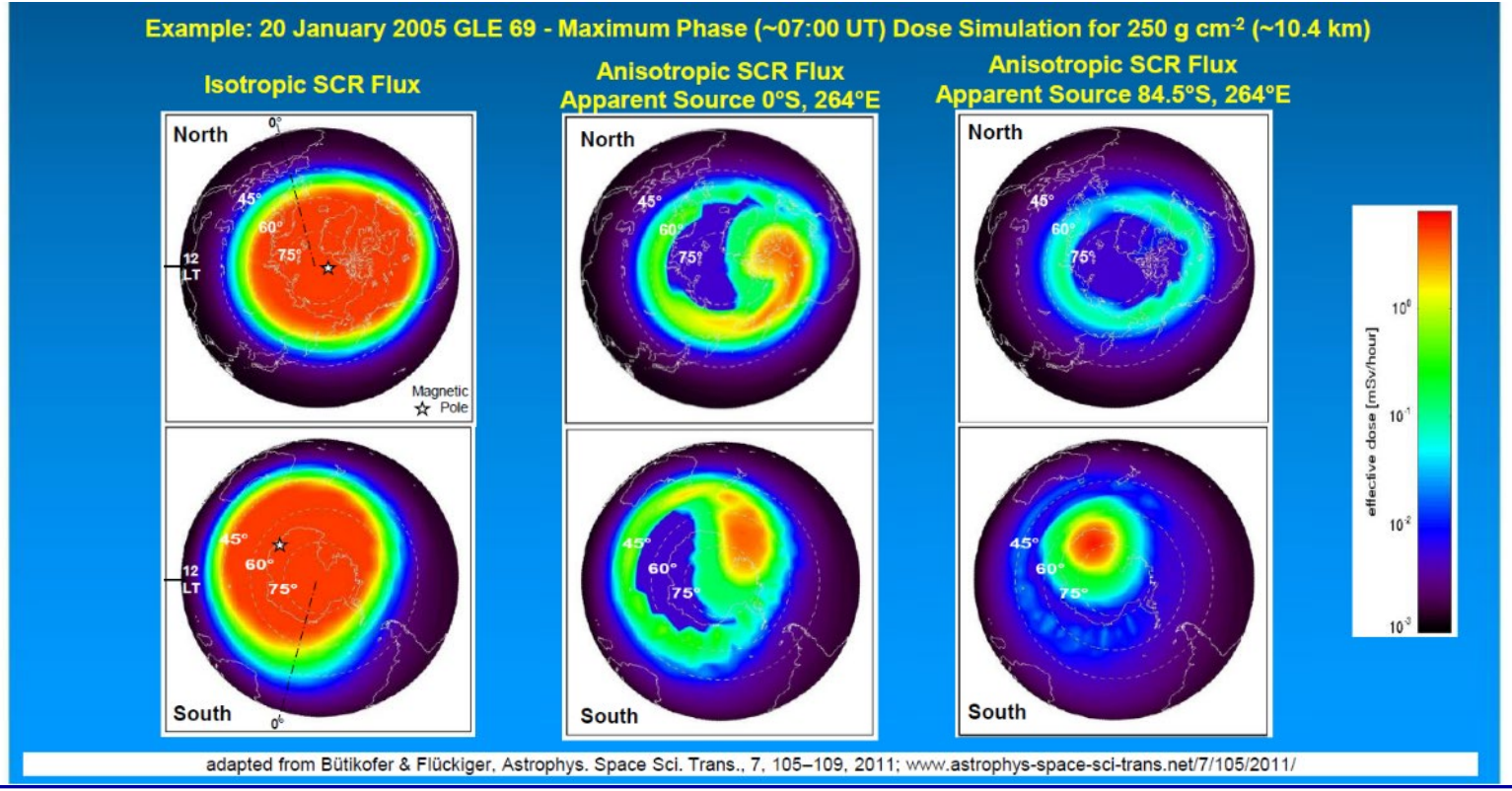


Radiation Field at Aircraft Altitudes…

…during GLEs - Solar Particle Events defined by

- Characteristics of Solar Particles near Earth, i.e.
  - Particle Energy/Rigidity Spectrum
  - Isotropy / Anisotropy
  - in case of Anisotropy: Arrival Direction

and

- Level of GCR radiation field
- Level of Geomagnetic Activity

Dose Calculations for GLEs

Fundamentals IV

Principle of Dose Calculations for Aircraft Altitudes during GLEs

-> 2 Elements

Dose Calculations for GLEs

Element 1:
Dose due to GCR

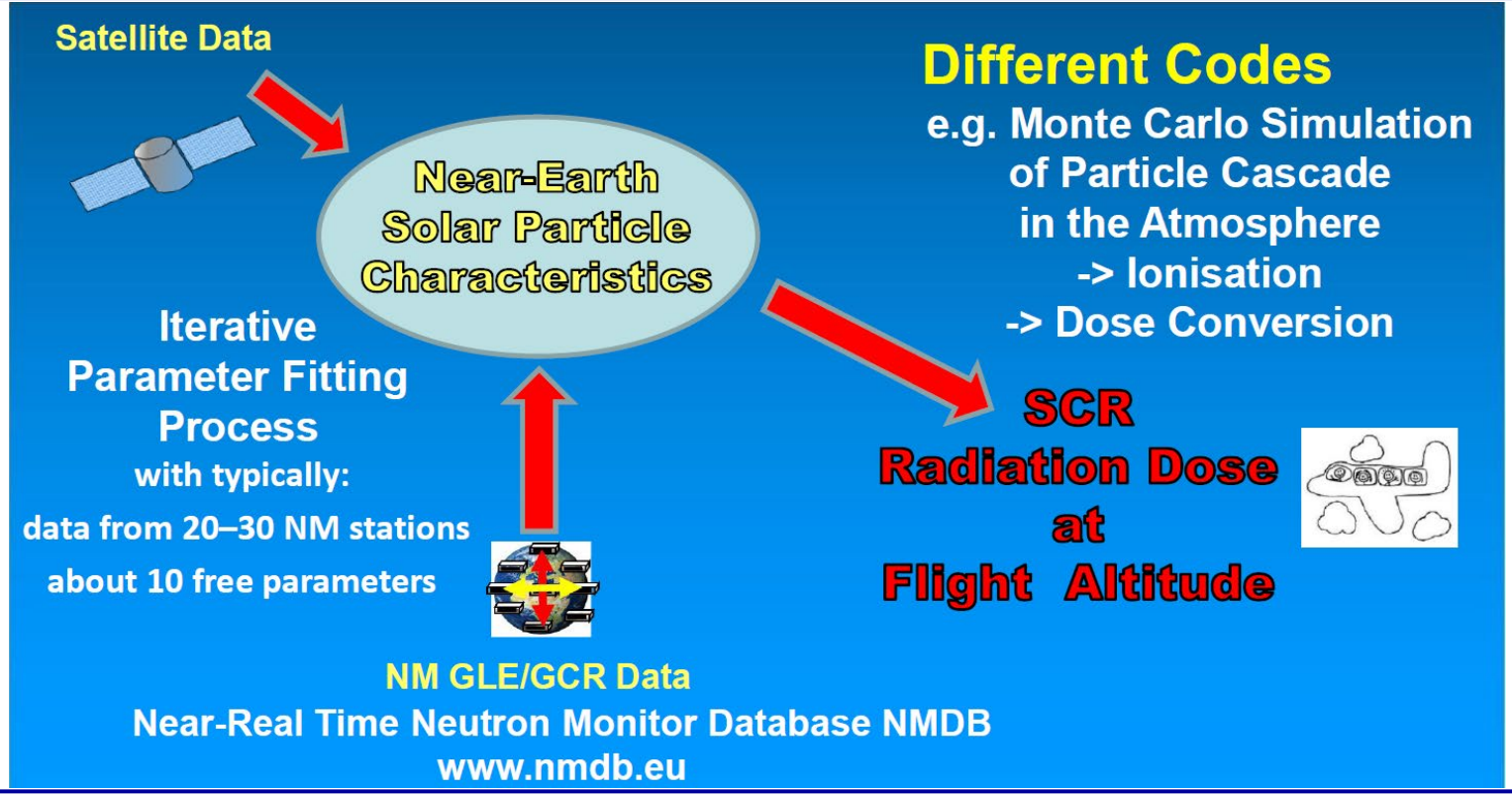
taking in to account modulation effects
(11-year cycle, Forbush decreases) and
level of geomagnetic activity

-> certified standard procedures

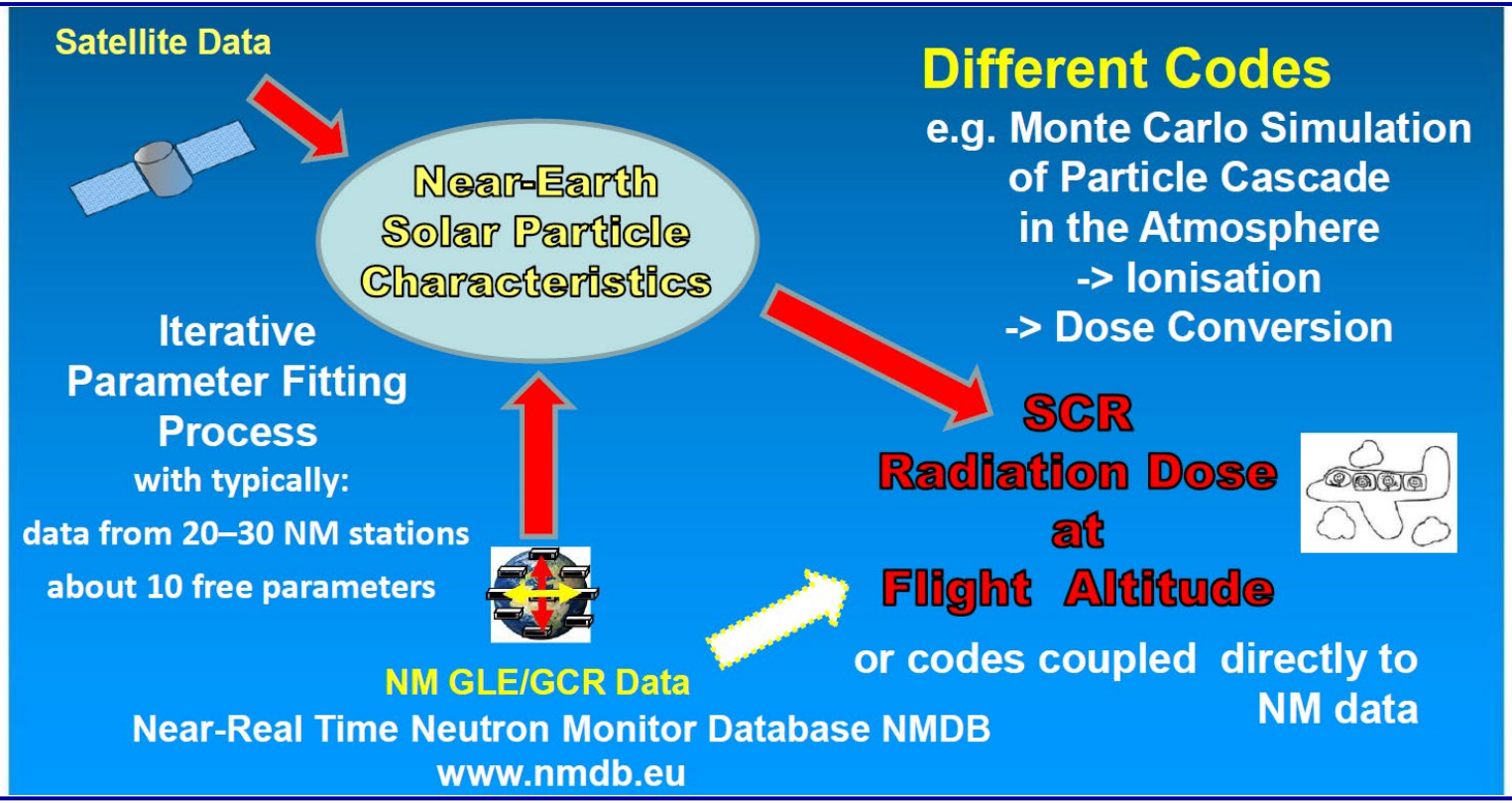
Element 2:
Dose due to SCR

taking into account GLE characteristics,
GCR modulation, and level of geomagnetic activity

Element 2: Analysis Procedure for SCR Dose



Element 2: Analysis Procedure for SCR Dose



The EURADOS/WG11 Study

The two GLEs selected for the Study:

Event 1: «synthetic» event
(based on GLE 42 / 29 September 1989)

Event 2: realistic case
GLE 69 / 20 January 2005

Event 1: «Synthetic» GLE42

(based on GLE42 / 29 September 1989)

Pre-determined GLE input parameters for all dose assessment procedures:

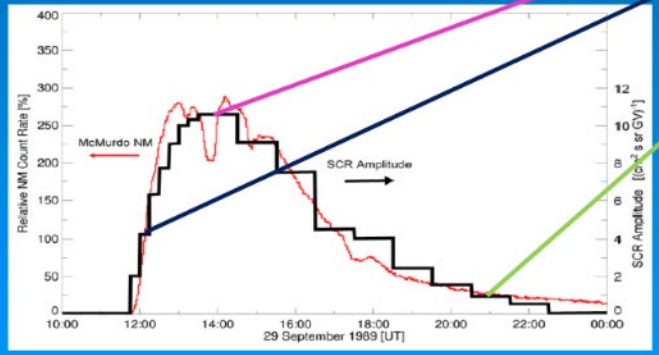
-> date and time

-> particle flux near Earth isotropic at all times

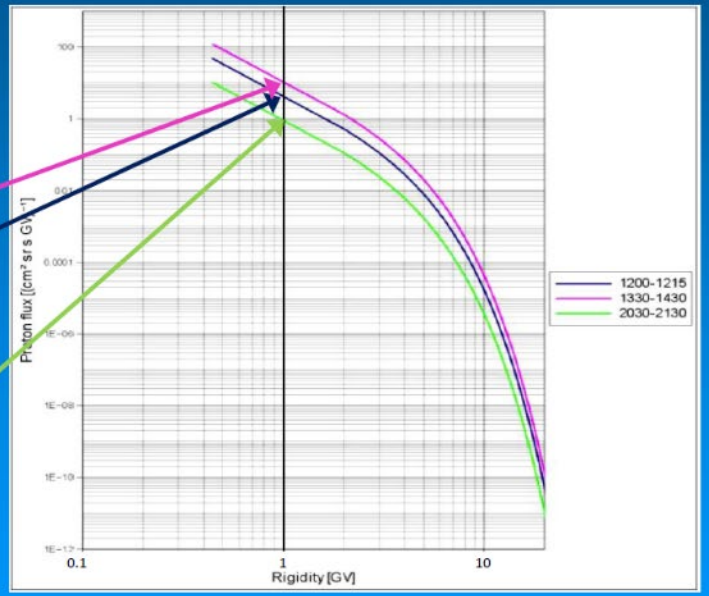
-> energy/rigidity spectrum of solar particles:
- spectral form constant with time
  (for details see EURADOS Report)
- variation of particle flux amplitude at 1GV as a function of time pre-set based on NM data

Event 1: «Synthetic» GLE42

based on GLE42 / 29 September 1989

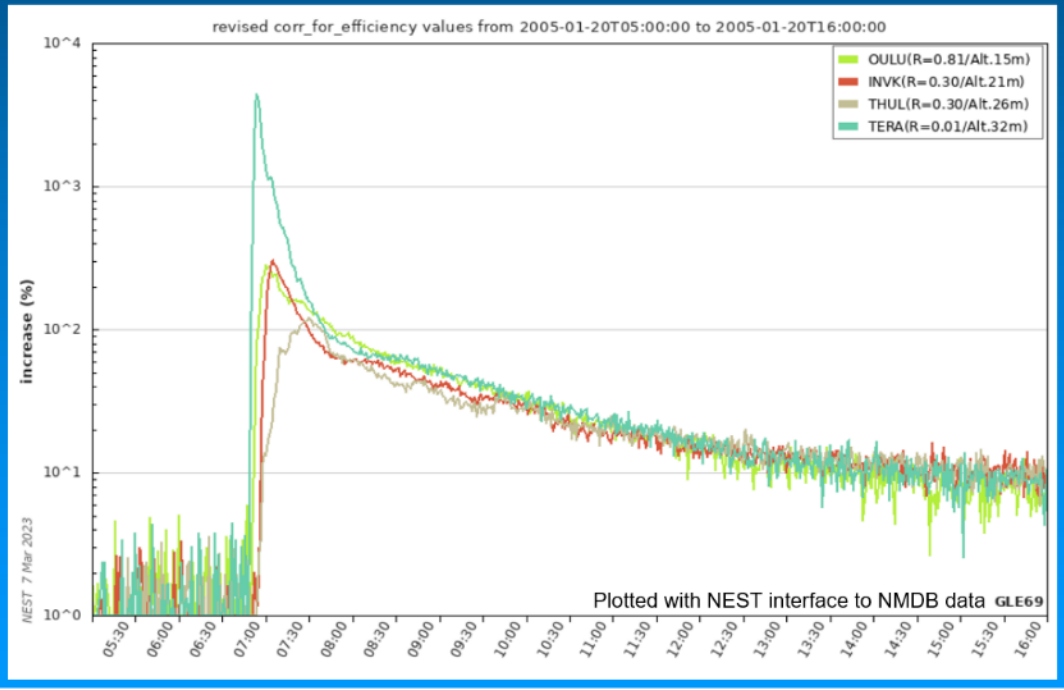


5-minute pressure corrected relative count rate (red) of the NM at McMurdo, Antarctica, and amplitude of the SCR flux at 1 GV (black) as defined for the study of the simplified GLE42.



Differential rigidity spectrum of solar particles for the time intervals 12:00-12:15 UTC, 13:30-14:30 UTC, and 20:30-21:30 UTC.

Event 2: GLE 69 / 20 January 2005



Relative neutron monitor count rate increases of selected stations during GLE69 provided by NMDB. Responses of NMs in Antarctica, Terre Adélie (TERA), recorded significantly different intensities than stations on the northern hemisphere, Oulu (OULU), Inuvik (INVK) and Thule (THUL).

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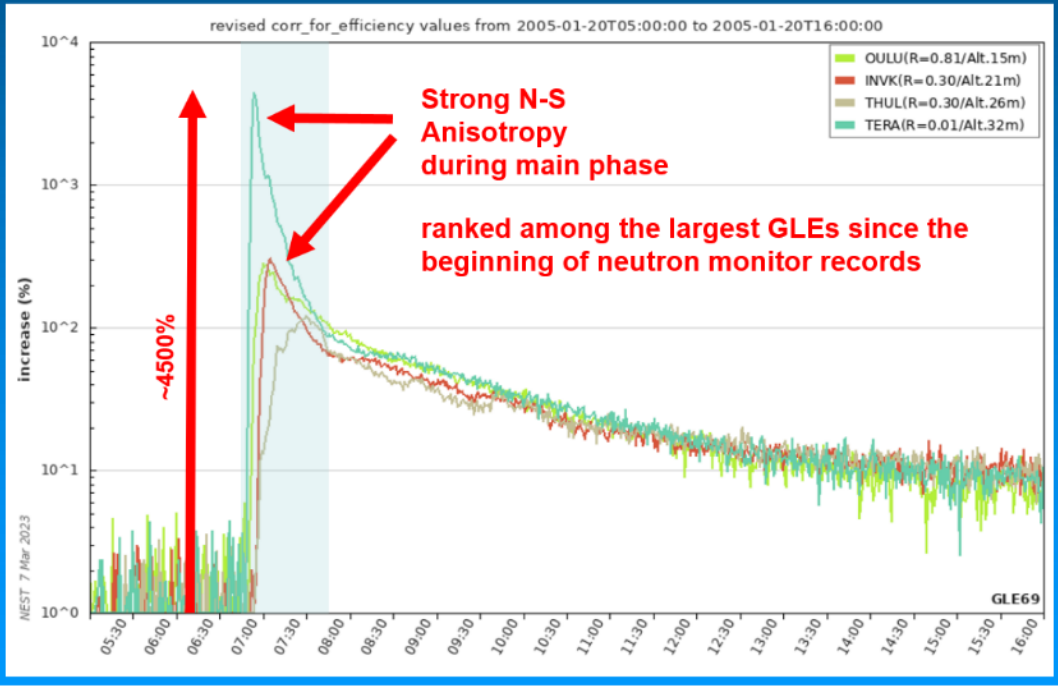

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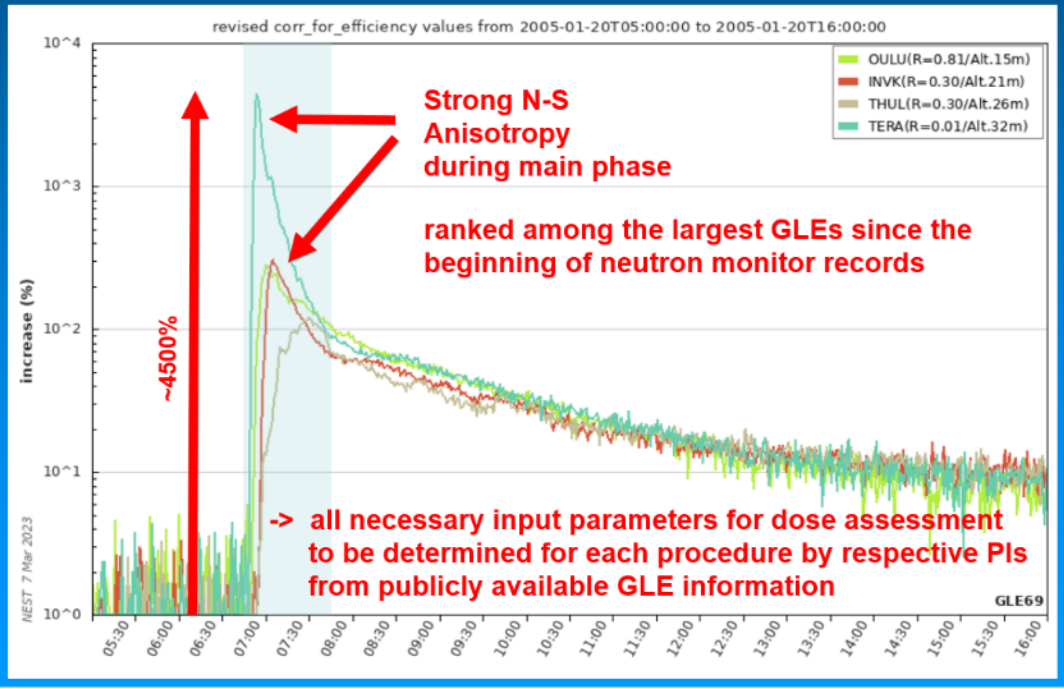

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