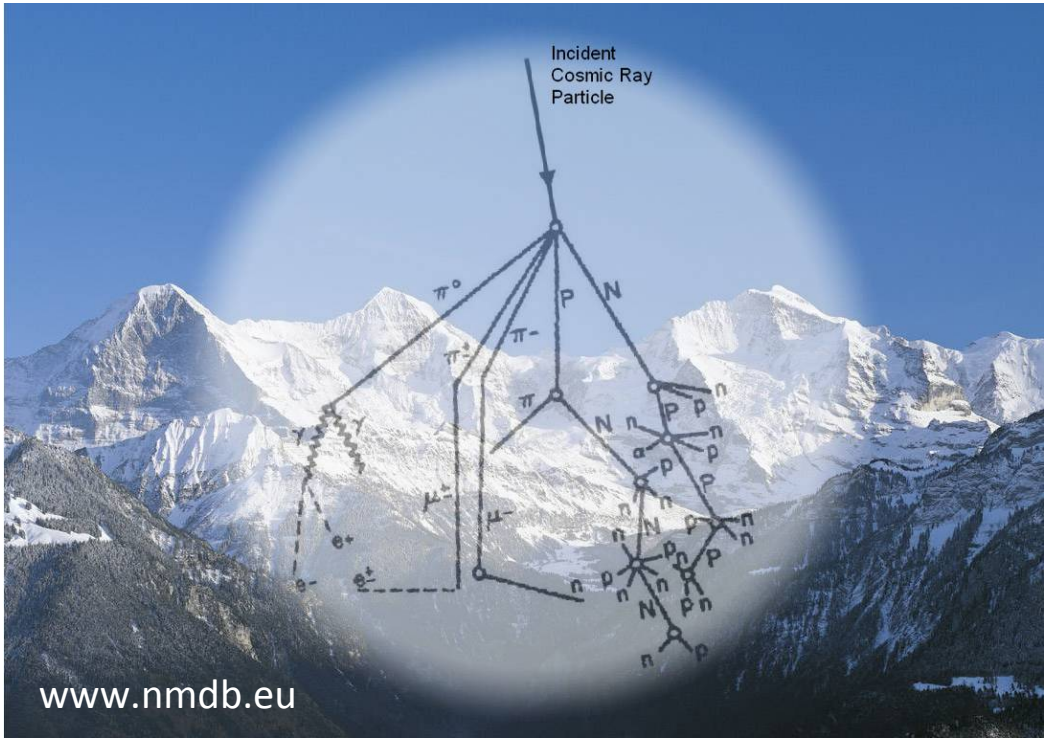
Cosmic ray-induced radiation doses in the terrestrial atmosphere



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What are cosmic rays
Origin, interaction with the terrestrial atmosphere

- Cosmic rays: protons & atomic nuclei with high energies from the Universe (continuous flow from our Galaxy named *galactic cosmic rays*, occasional enhancements of solar origin)

- Impact of an energetic particle on the Earth's atmosphere: nuclear reactions

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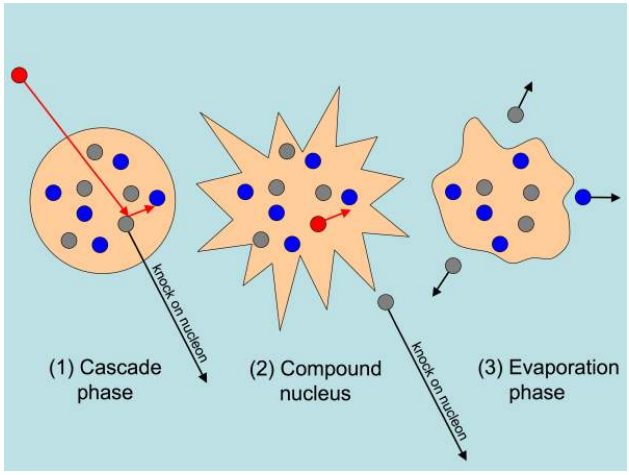

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- Impacting particle knocks protons, neutrons out of the impacted nucleus
  => secondary particles => cascades to lower altitudes

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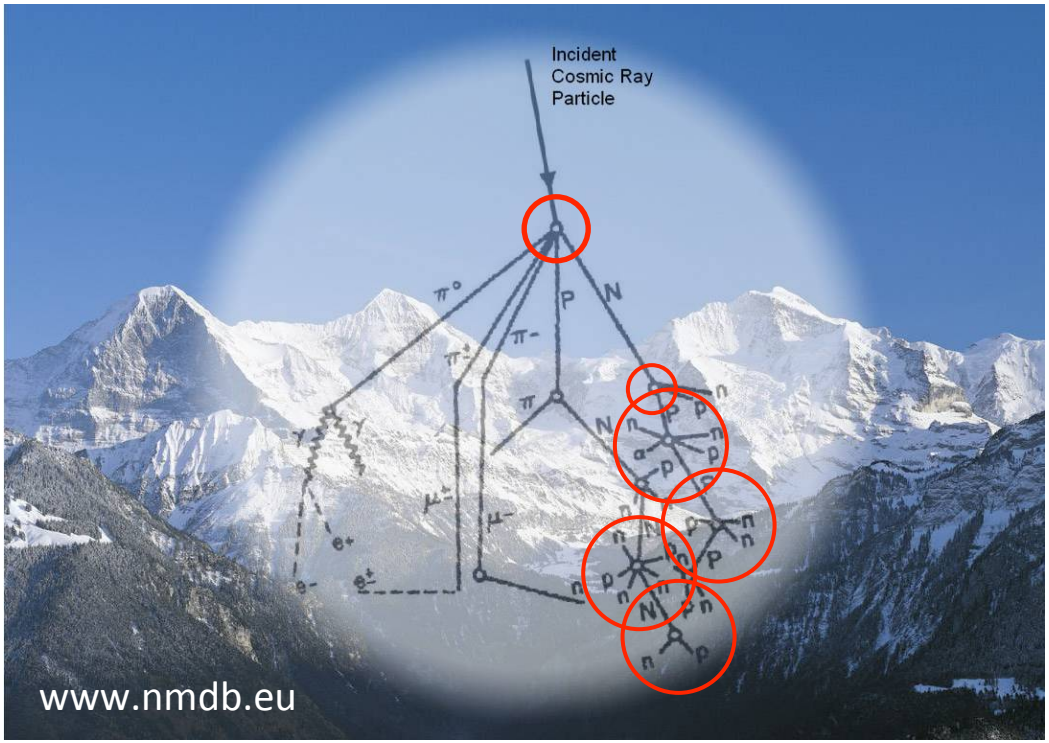

- Impacting particle knocks protons, neutrons out of the impacted nucleus
  => secondary particles => cascades to lower altitudes
- => height range depends on the energy of the primary particle: 10 km asl (>200 MeV), sea level (>430 MeV)

What are cosmic rays
Origin, interaction with the terrestrial atmosphere

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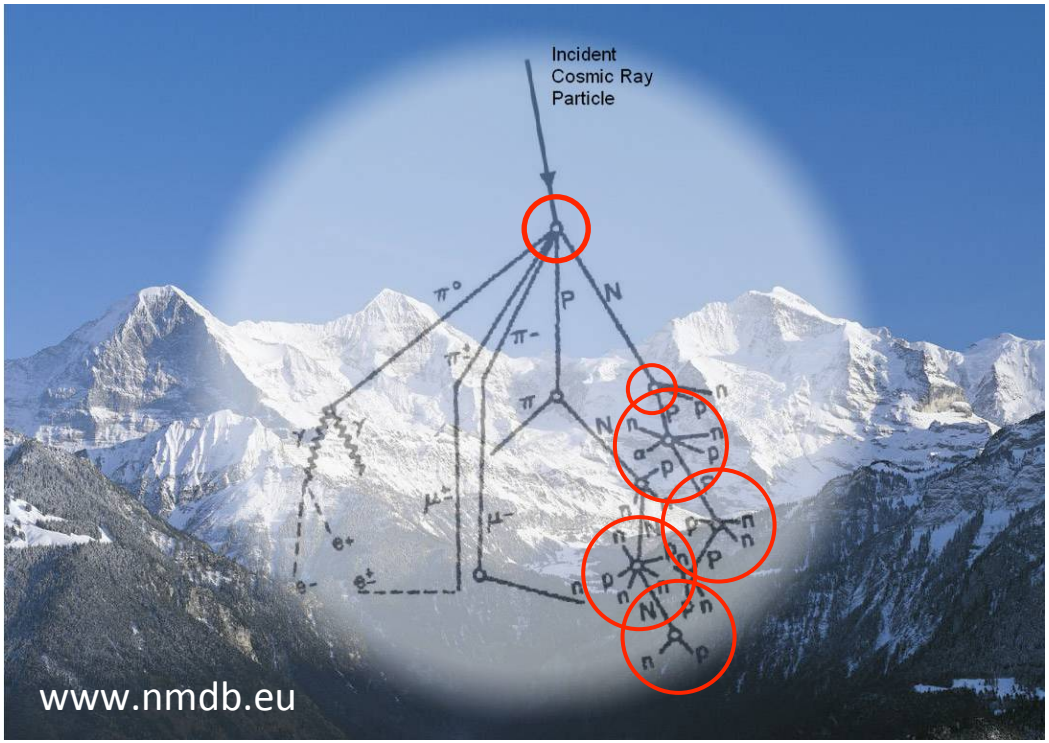
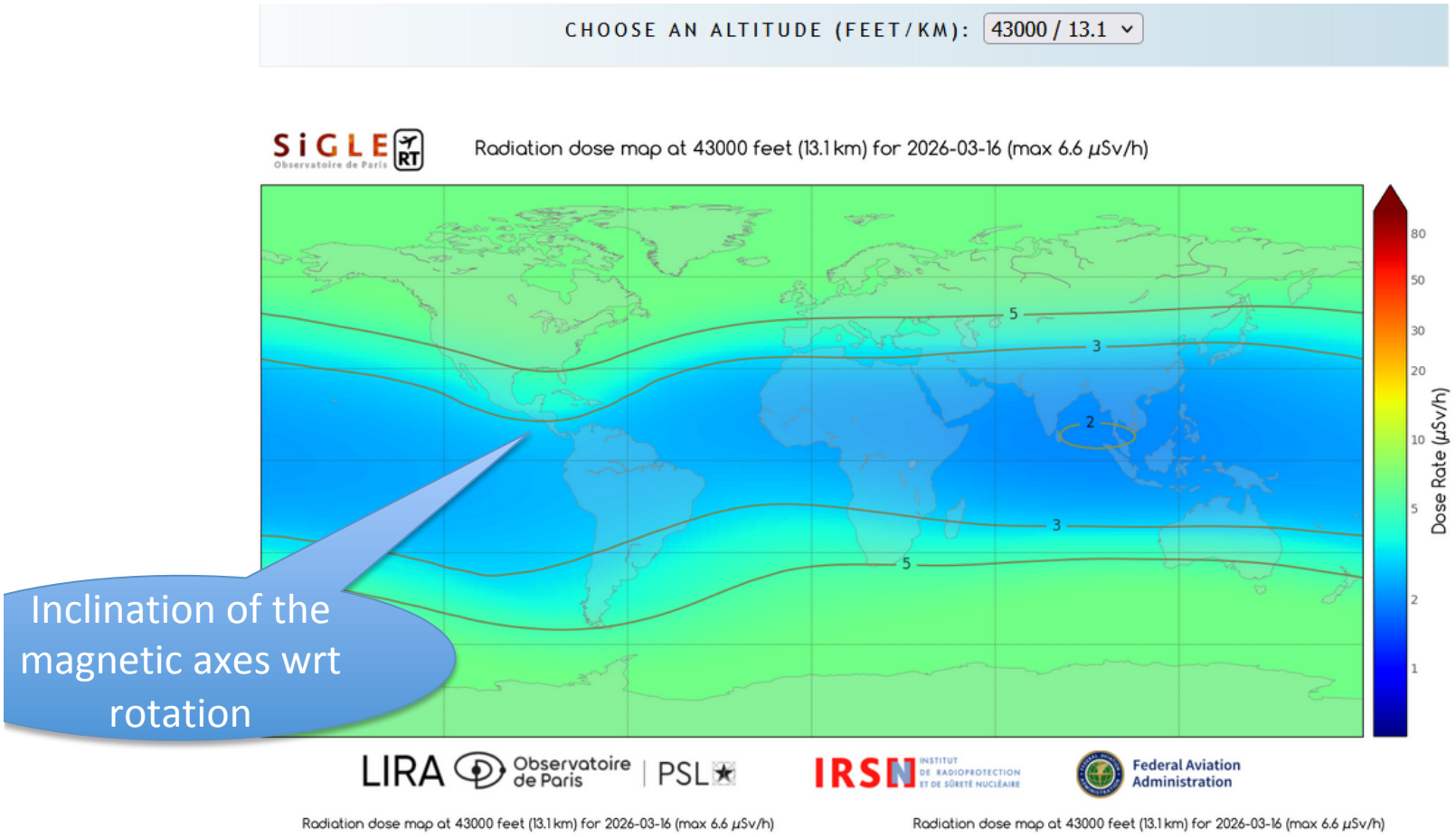


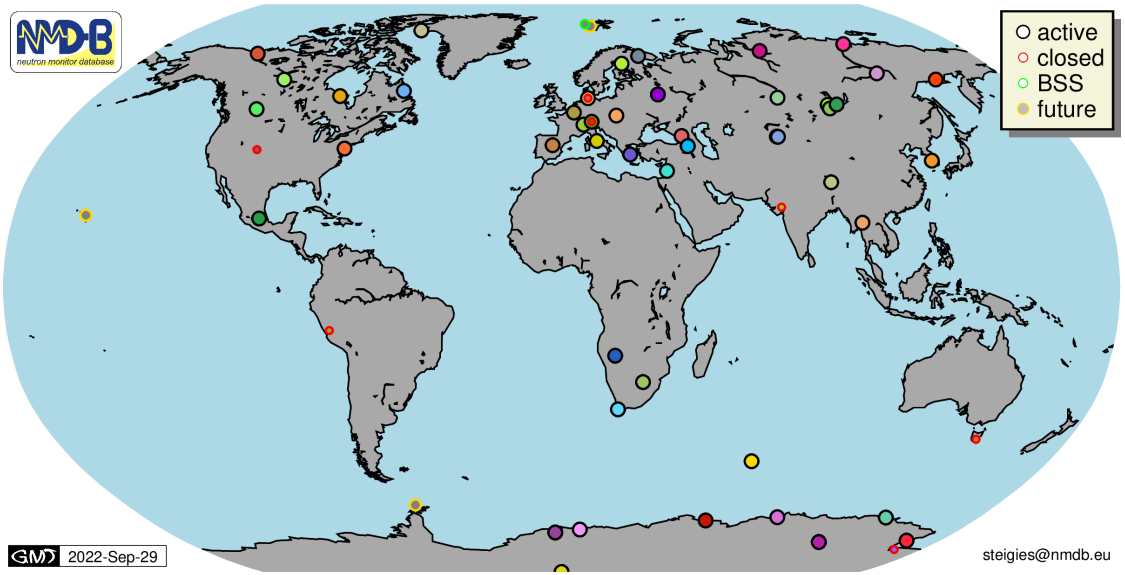
- Particles of the cascade referred to as ‘radiation’
- The intensity decreases
  - with decreasing altitude (absorption of particles by the atmosphere)
  - with decreasing magnetic latitude (shielding by the terrestrial magnetic field)

What are cosmic rays
Interaction with the terrestrial magnetosphere



- Measurement unit (human body): Sievert (Sv), relevant doses in mSv (10^{-3} Sv) or µSv (10^{-6} Sv)

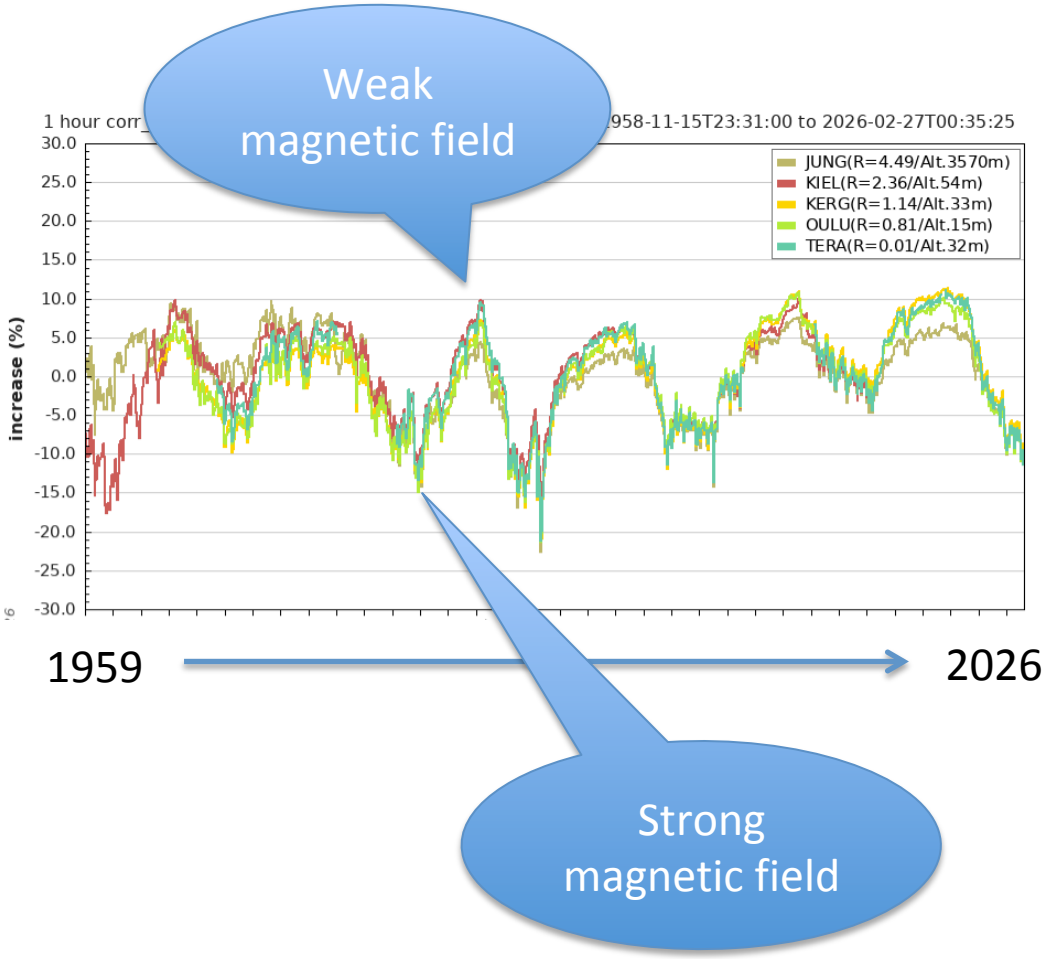
What are cosmic rays
Observations



- Measurement of the cascade on the Earth: neutron monitors
- A worldwide network of instruments operated by independent institutions
- www.nmdb.eu: database, ~ 30 in real time (1/min)
- Space borne measurements of the primary particles: GOES satellites (NOAA; *E*=330-700 MeV) – GOES 10 MeV relevant to radiation in space, not in the troposphere

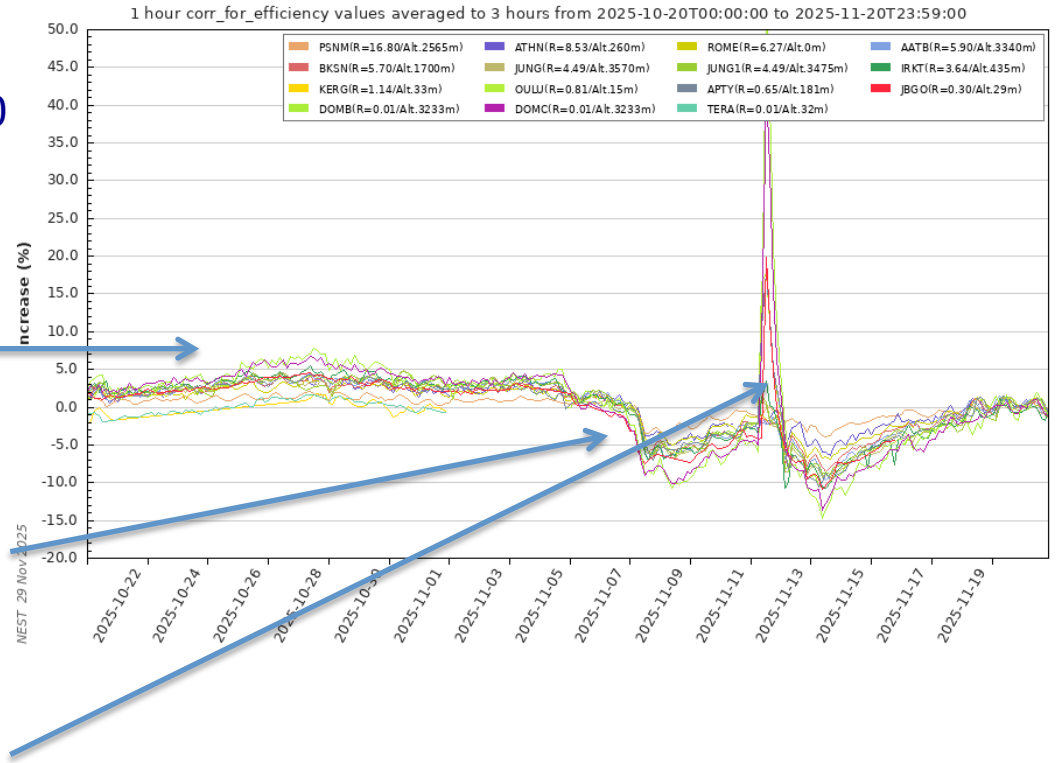
What are cosmic rays
Galactic cosmic rays – solar modulation

- Illustration of neutron monitor measurements:
  - 65 years (www.nmdb.eu)
  - The permanent component: galactic cosmic rays (GCR)
  - Modulation by the solar / heliospheric magnetic field (11-year sunspot cycle)



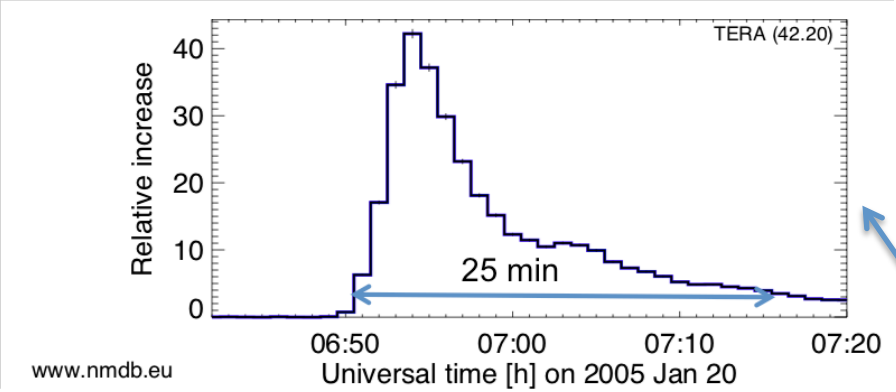
What are cosmic rays
Galactic cosmic rays and solar energetic particles

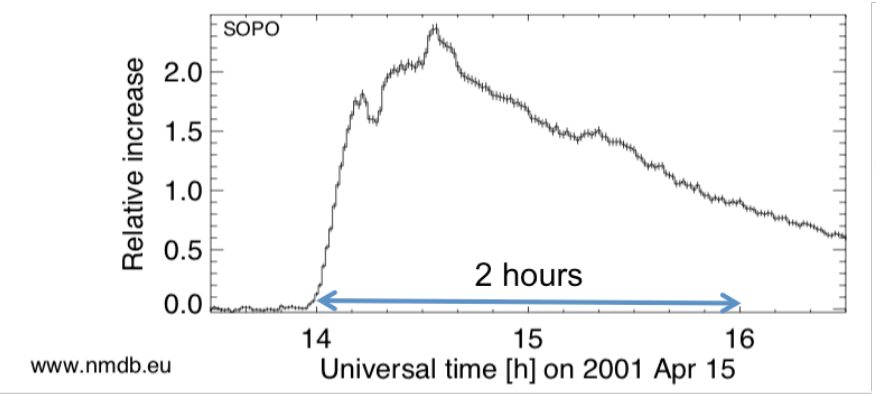
- Illustration of neutron monitor measurements:
  - 1 month 2025 Oct 10 – Nov 20 (www.nmdb.eu)
  - A permanent component: galactic cosmic rays (GCR)
  - Perturbations:
    - reduction of the GCR flux by magnetic fields ejected from the Sun
    - bursts of energetic particles accelerated at the Sun ("Ground level enhancement" = GLE)

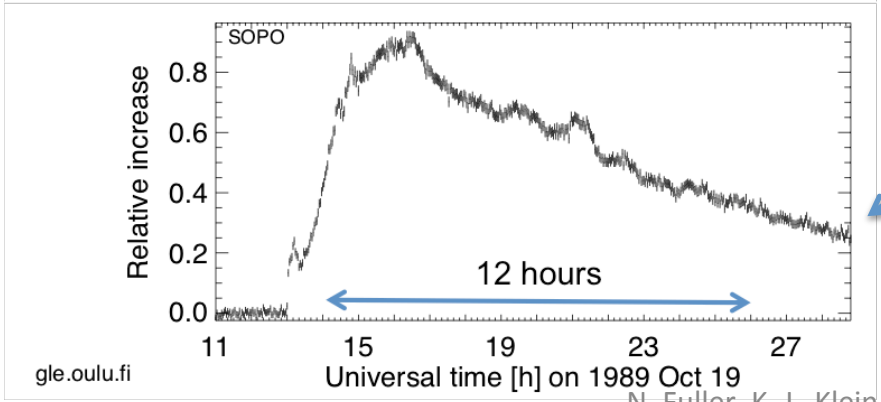


What are cosmic rays

Solar energetic particles = Ground Level Enhancements (GLEs)



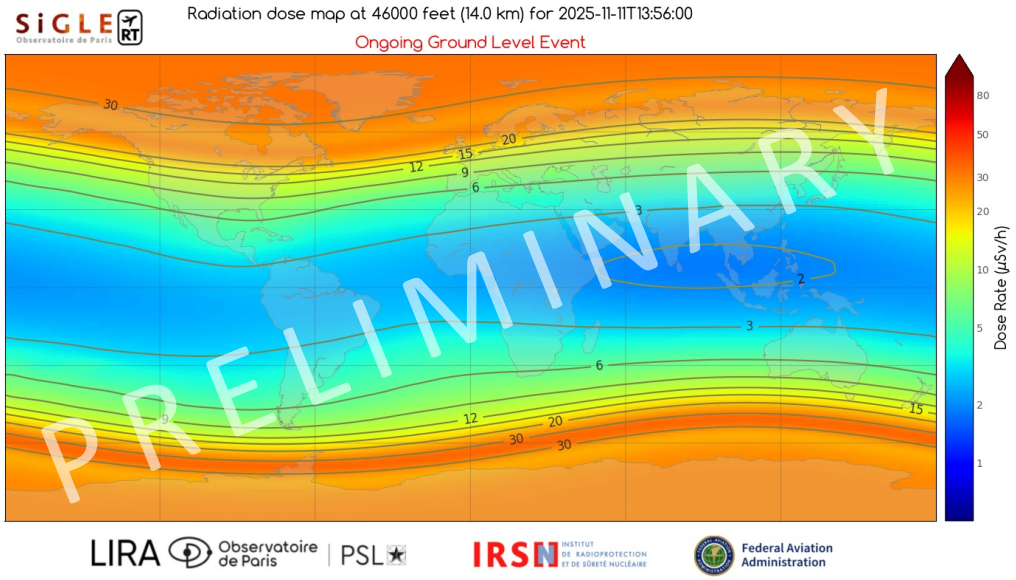


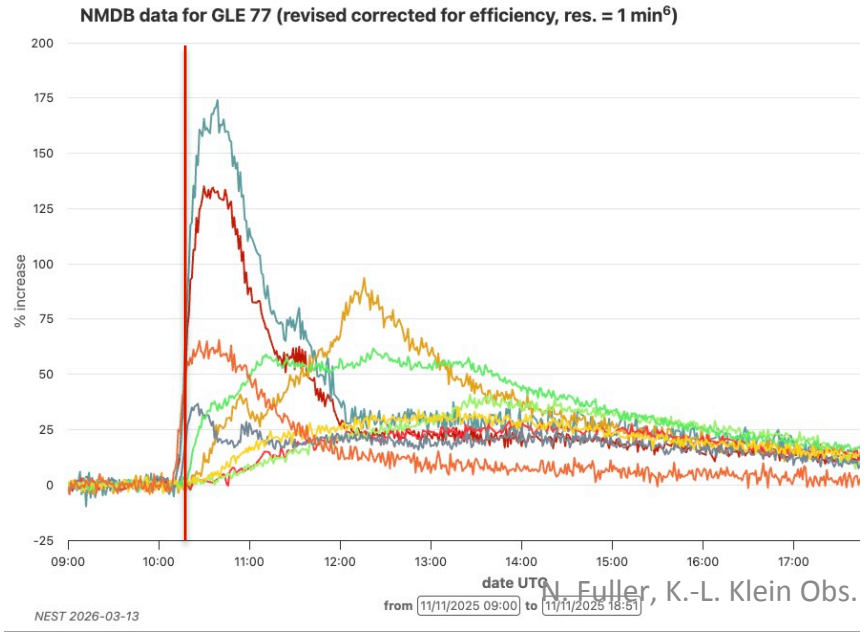


- GLEs: 77 recorded since 1942
- Many weak ones − irrelevant to ICAO thresholds
- Three GLE time profiles (note: different time axes)
  - 2005 Jan 20: strong peak / short duration
  - 2001 Apr 15: moderately strong, moderate duration
  - 1989 Oct 19: rather weak, long duration
- Associated with solar flares and mass ejections − GLE not predictable

Radiation doses in the terrestrial atmosphere

A moderate event: 2025 Nov 11

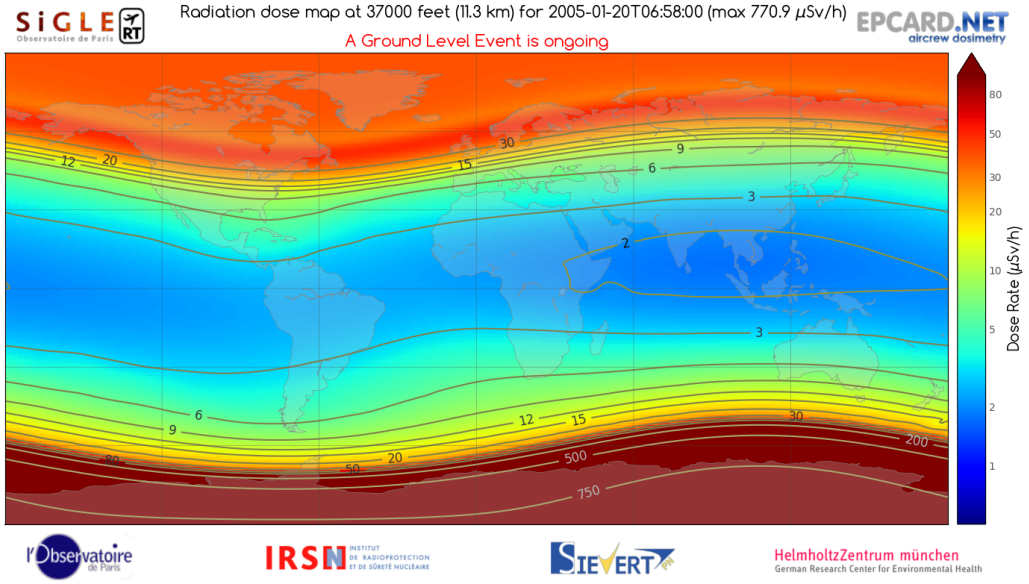


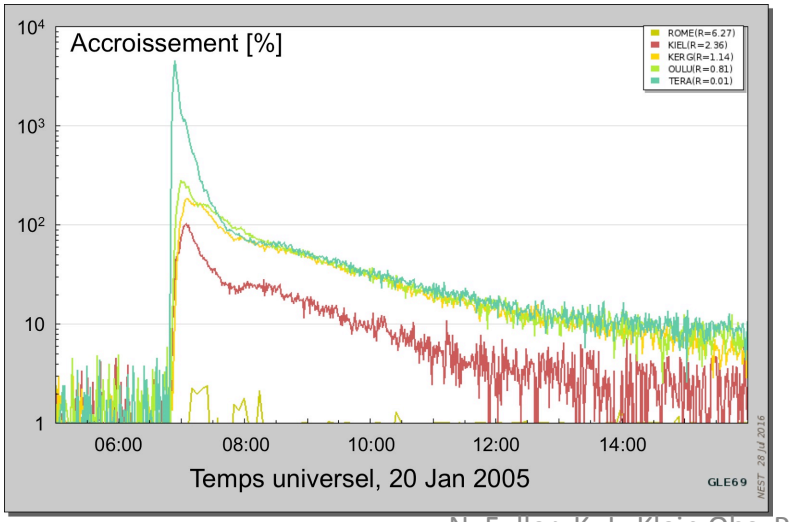


- Estimated doses at 46000 feet on on Nov. 11, 2025 (GLE77)
- Moderate (MOD), strong anisotropy during first hour
- Detection by SiGLE$_{RT}$ at 10h18
- First estimation: dose ~ x1.8 on a transatlantic flight

Radiation doses in the terrestrial atmosphere

A strong event: 2005 Jan 20

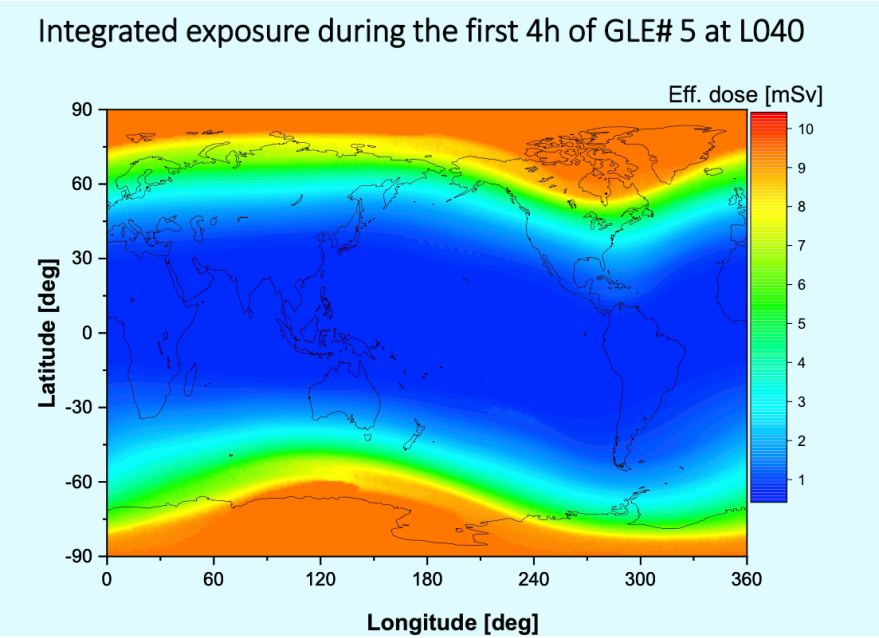




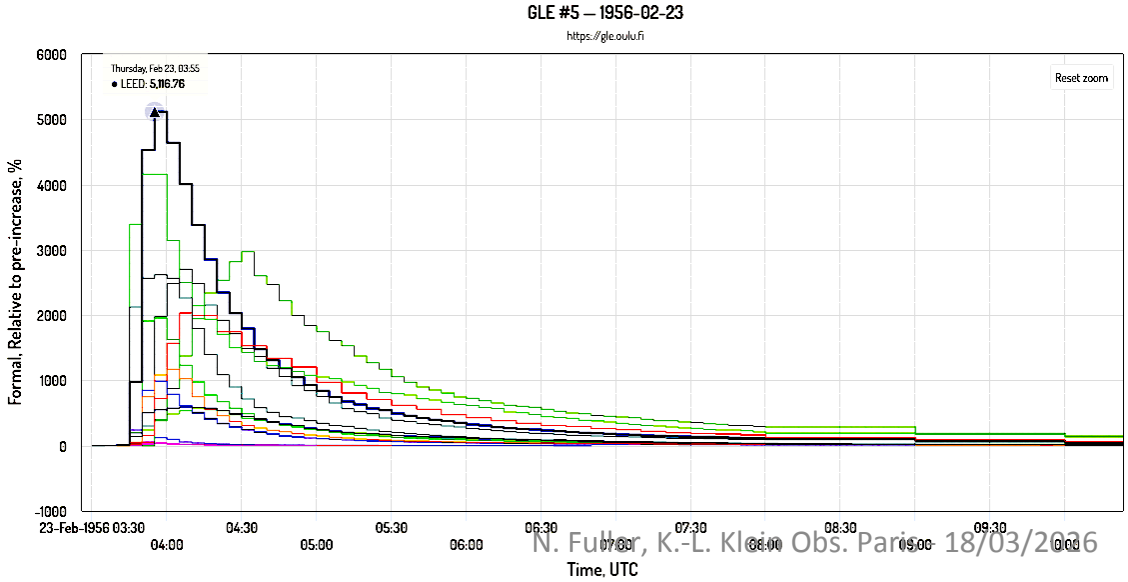
- Estimated doses at 37000 feet on Jan. 20, 2005 (GLE69 peak)
- Strong but very anisotropic event (max over the south pole)
- Dose x2 or x3 on a transatlantic flight during this event

Radiation doses in the terrestrial atmosphere

The strongest event observed by neutron monitors: 1956 Feb 23



Estimated integrated doses (4 hours) at 40000 feet on Feb. 23, 1956 (GLE 5), from Mishev et al.



Max of NM history recorded : Leeds NM +5116% (5min integration)

Cosmic-ray induced radiation doses in the terrestrial atmosphere
Summary

- Radiation induced by energetic particles from the Universe: from the Galaxy (permanent) or the Sun (sporadic - GLEs)
- Evaluation of past solar events: *x* 2 − *x* 3 the doses from galactic cosmic rays on typical Europe-USA or Asia-Europe routes during major events
- Strong particle fluxes (dose rates) limited to short durations (< 1 hr)
- The solar events occur during several years around the time of maximum activity.
- The solar events
  - have been rare in recent decades (since 2006), when solar maxima (sunspot numbers) were also weak. Activity will probably rise in coming decades (following experience with sunspot numbers since the 18th century)
  - are so far not predictable individually