SWESNET and PECASUS

Neutron Monitor Data as input to European projects

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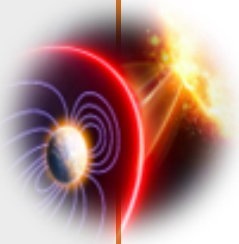
BIRA·IASB

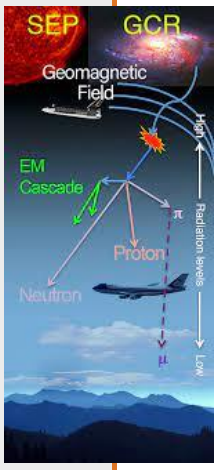
Royal Belgian Institute for Space Aeronomy

OUTLINE



- Introduction

- ESA SWE Service Network & SWESNET

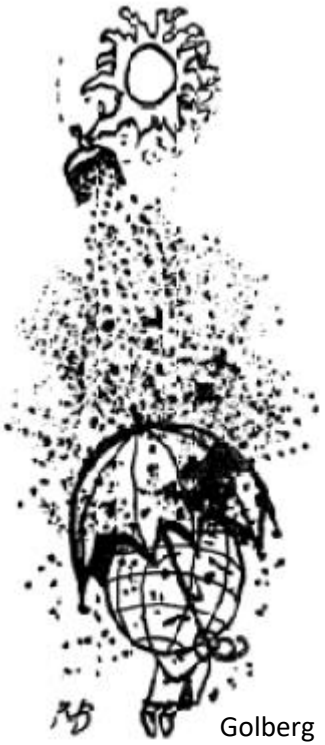


- PECASUS: Pan-European Consortium for Aviation Space weather User Services

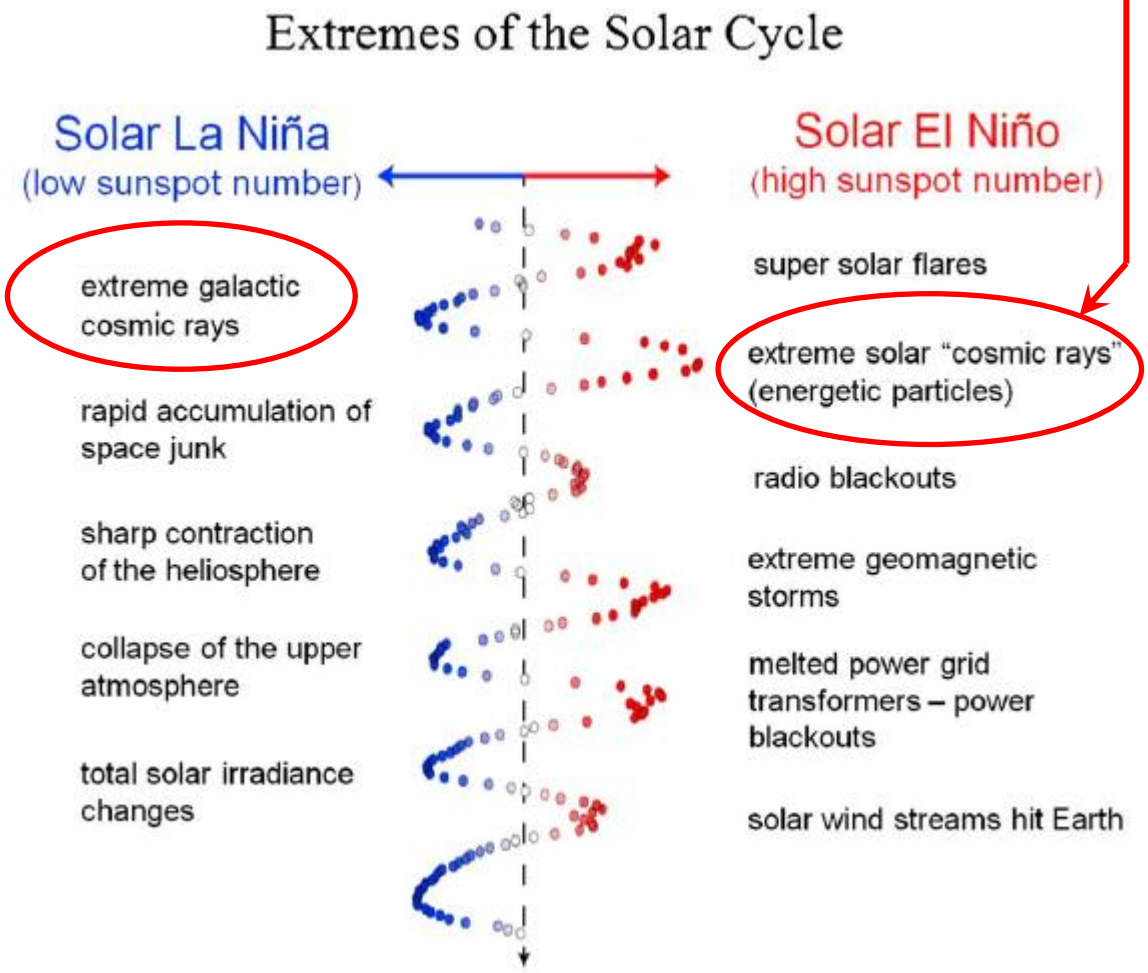
- Looking Forward

Introduction (1/2)
Solar Activity

GLE events form a particular case of high-energy SEP events associated with GeV protons.



Golberg (1961)

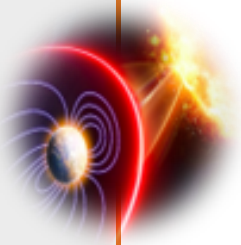


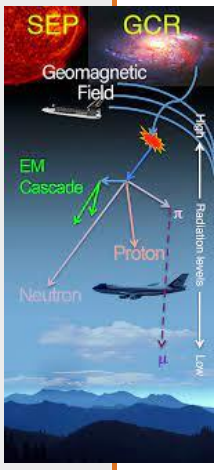
M. Guhathakurta and T. Phillips (2013)

Introduction (2/2)
Why care?

ENERGY RANGE	EFFECTS FOR AVIATION
Protons >500 MeV (GLE events)	Increases the radiation level at flight altitudes, especially in the polar regions. Technology • Can increase the radiation hazard to avionics (e.g., single event effects in micro-electronic devices). Human Health • Radiation dose received by humans: can be a risk for frequent flyers and particularly for aircrew. • Impacts on technology can also indirectly impact the health (e.g., flight passengers with pacemakers)

OUTLINE





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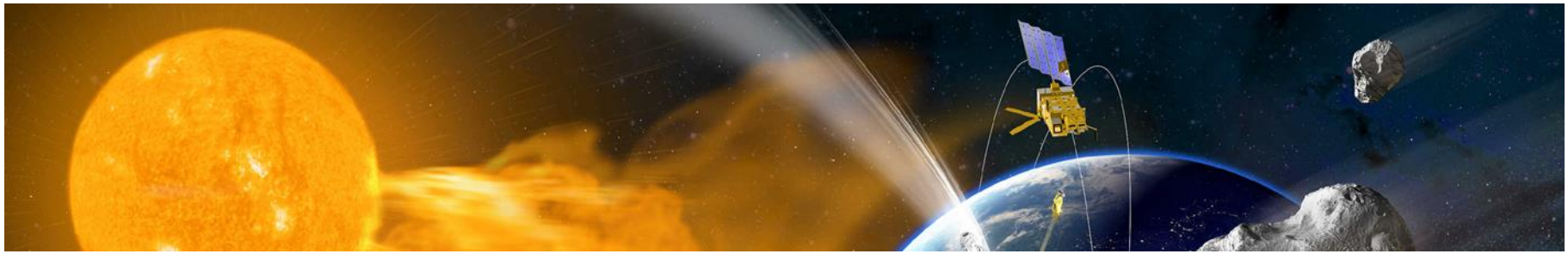
ESA SWE Service Network (1/2)

ESA Space Safety Program (S2P) Space Weather Service Network:

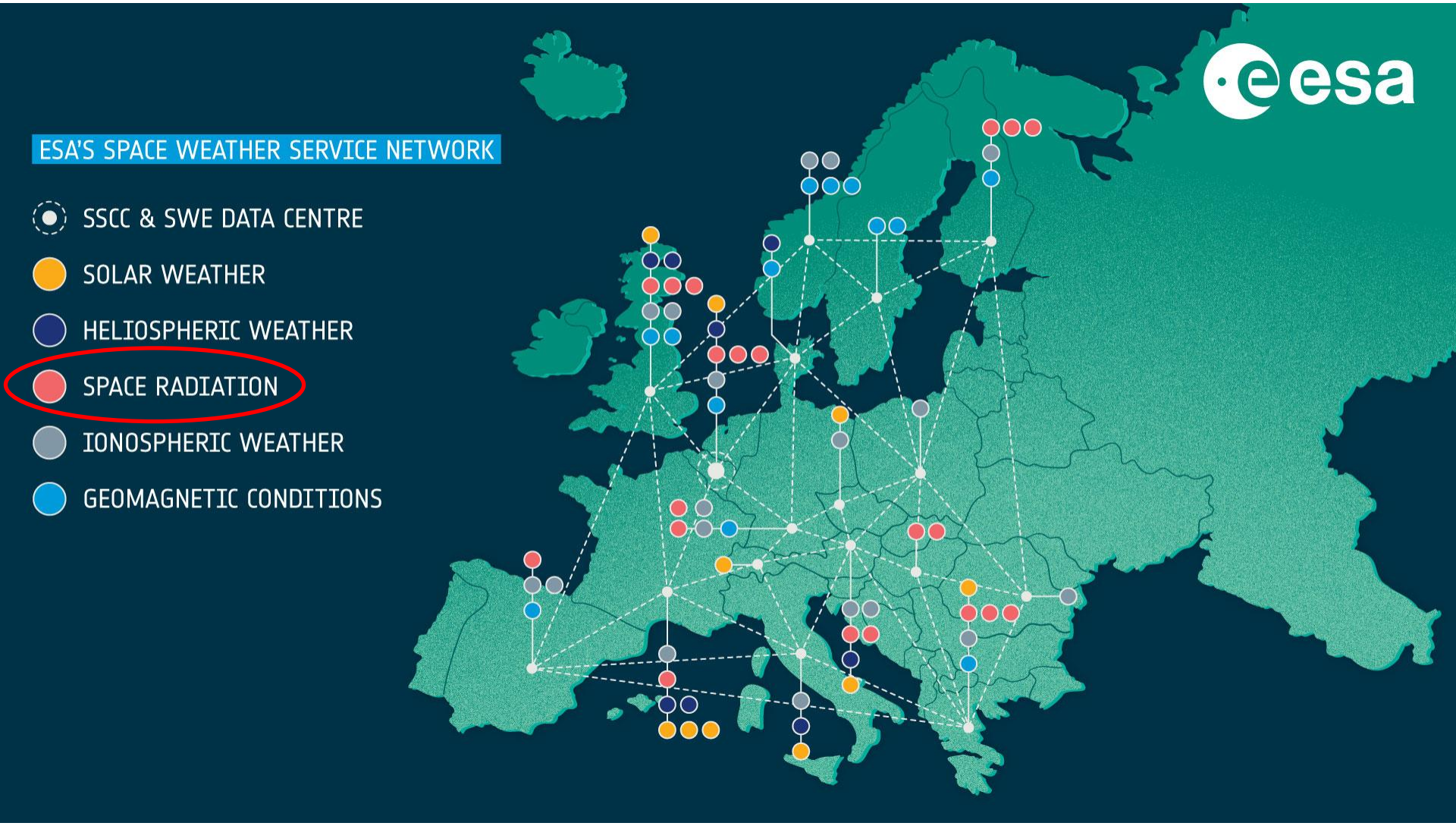
- Monitors and mitigates hazards from space due to space weather.

The SWESNET Project (https://swe.ssa.esa.int/swesnet-project):

- Consortium of 50+ groups bringing together the pre-operational activities of 5 Expert Service Centres (ESCs) & the SSA Space Weather Coordination Centre (SSCC), and developments to improve service capability, end-user engagement and network maturity.



ESA SWE Service Network (2/2)



Space Radiation Expert Service Centre (1/2)

Expert Groups	Radiation Hardness Assurance and Space Weather, Seibersdorf Laboratories Gmbh, Austria	
	Space Physics Division, Royal Belgian Institute for Space Aeronomy, Belgium	
	Center for Space Radiations, Université Catholique de Louvain, Belgium	
	Paul Buehler, Austria	
	Space Research Laboratory, University of Turku, Finland	
	Mullard Space Science Laboratory, University College London, U.K.	
	DLR Institute of Aerospace Medicine, Radiation Biology Department, Germany	
	Athens Neutron Monitor Station, National and Kapodistrian University of Athens, Greece	
	National Observatory of Athens, Greece	
	UK MetOffice, U.K.	
	British Antarctic Survey, U.K.	
	Space Applications & Research Consultancy, Greece	
	Office National d'Etudes et de Recherches Aerospatiales, France	
	SSE/ELTE, Hungary	
Expert Consultants	DH Consultancy BV, Belgium	Oulu group, University of Oulu, Finland
	Centre for Energy Research, Hungary	Extraterrestrial Physics Division Group, Christian-Albrechts-Universität zu Kiel, Germany
	Aboa Space Research Oy, Finland	Space Weather Group, Universidad de Malaga, Spain

Space Radiation Expert Service Centre (2/2)

Neutron monitor data is used by several products in the Space Radiation Expert Service Centre product portfolio:

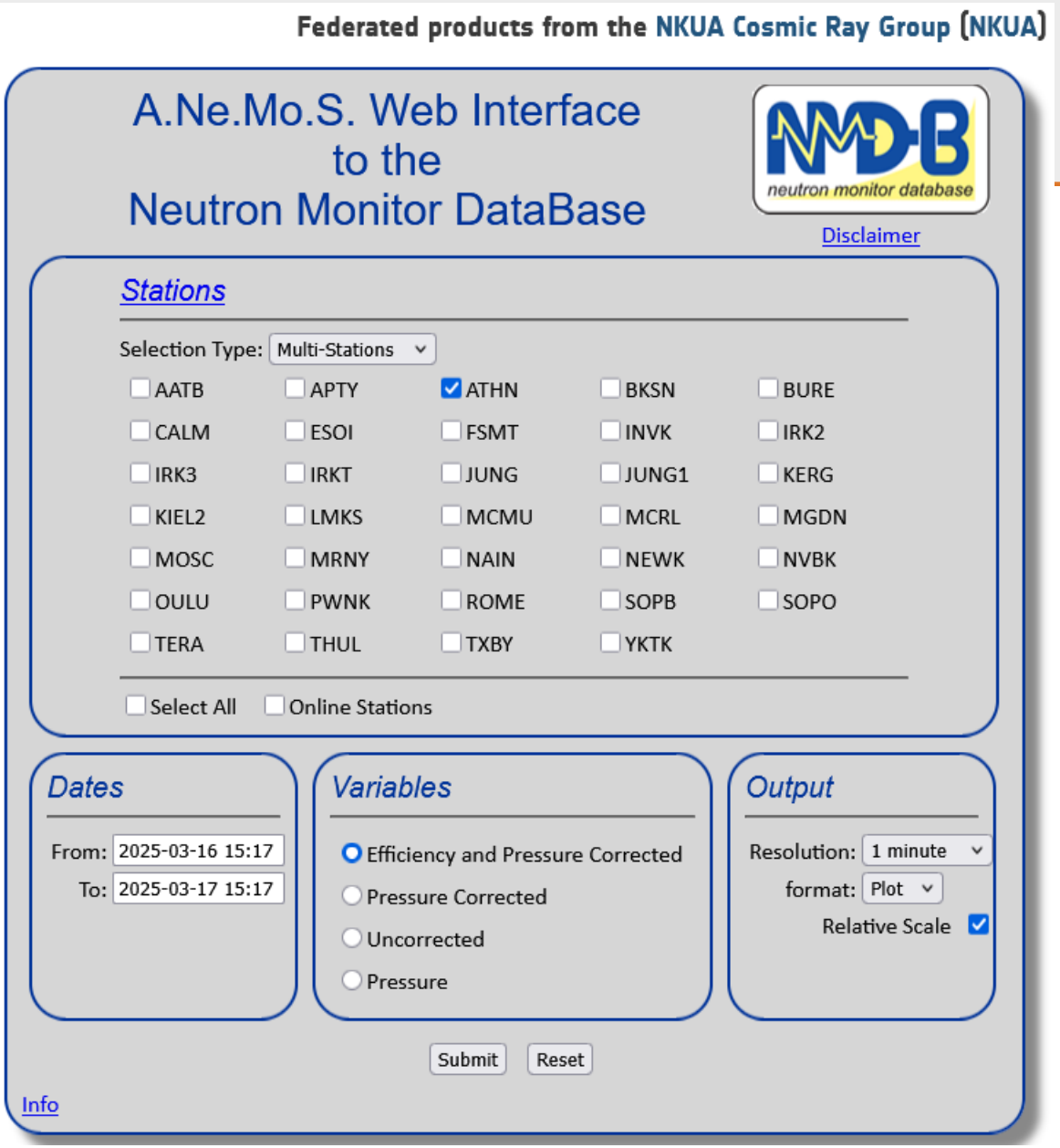
- ANeMoS products
- AVIDOS
- COMESEP
- RadSEP
- UTU-SEP products

ANeMoS (1/3)

Multi Station Neutron Monitor Data

Provides continuous measurements of galactic cosmic rays from neutron monitors located around the world.

Is a copy (slave server) of the NMDB database.

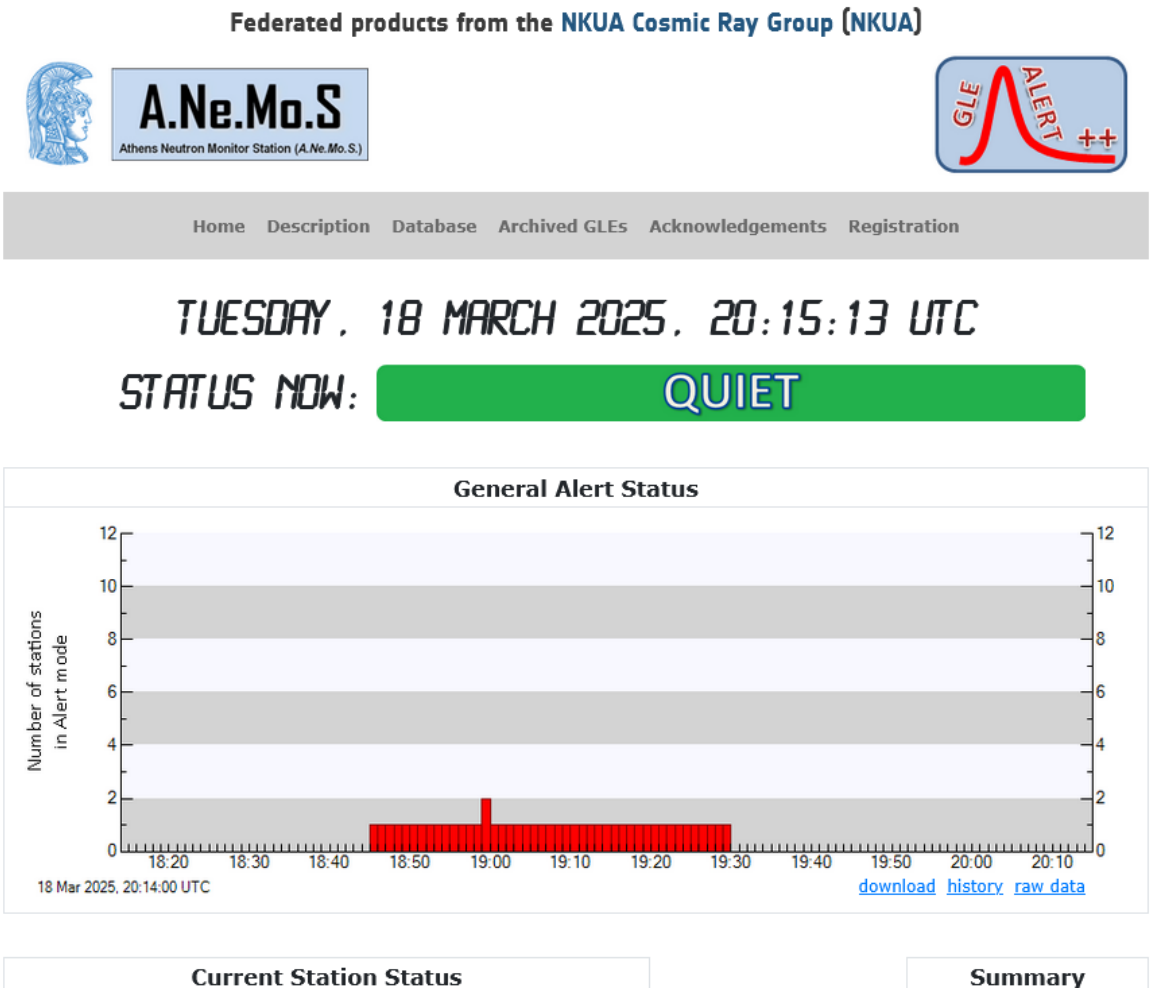


ANeMoS (2/3)

GLE Alert++ service

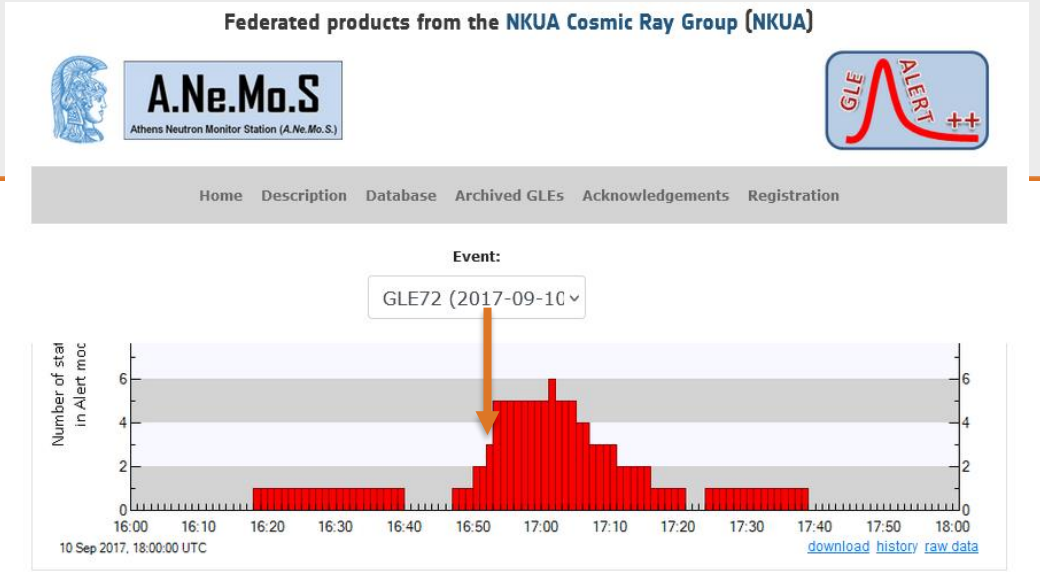
Produces every minute a General GLE Alert Graph and station alert graphs for all the stations participating in the Network.

GLE Alert++ issues alerts when a GLE event is starting to be recorded.



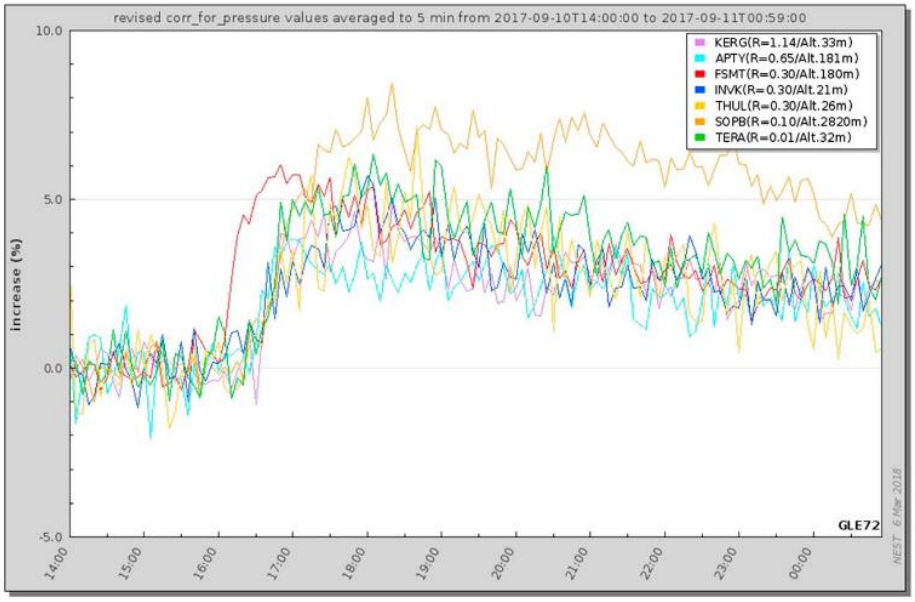
ANeMoS (3/3)

GLE72 Event



10 Sept. 2017

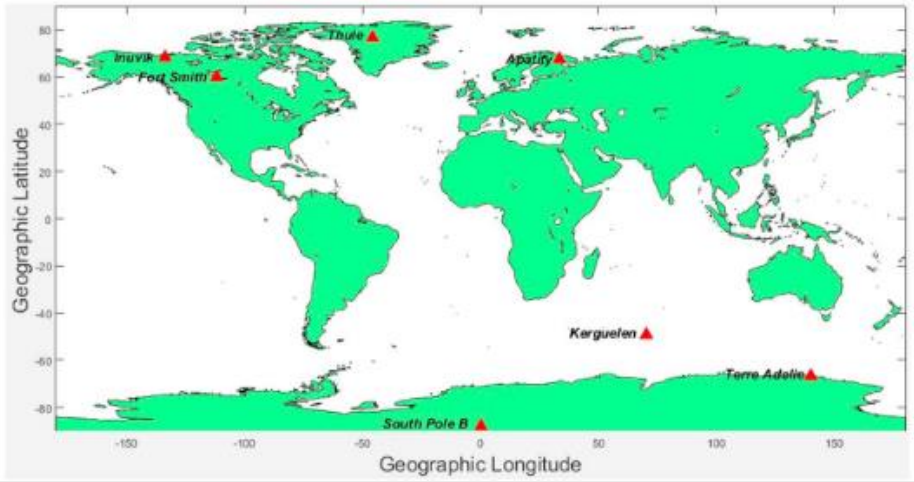
Intensity-time profiles in relative scale of the GLE72 event as it was recorded by the seven neutron monitor stations in Alert mode.



Mavromichalaki et al. (2017)

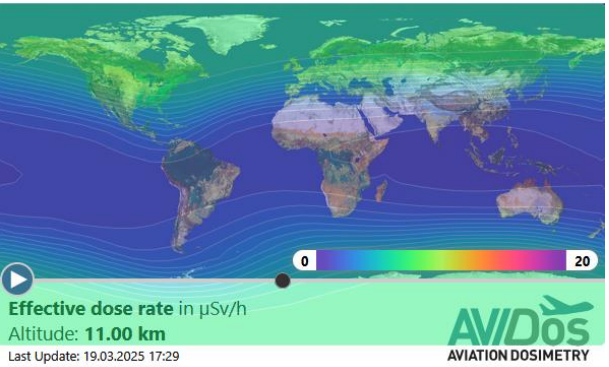
Onset Date/Time: 2017-09-10 16:47 UTC

Alert Date/Time: 2017-09-10 16:52 UTC



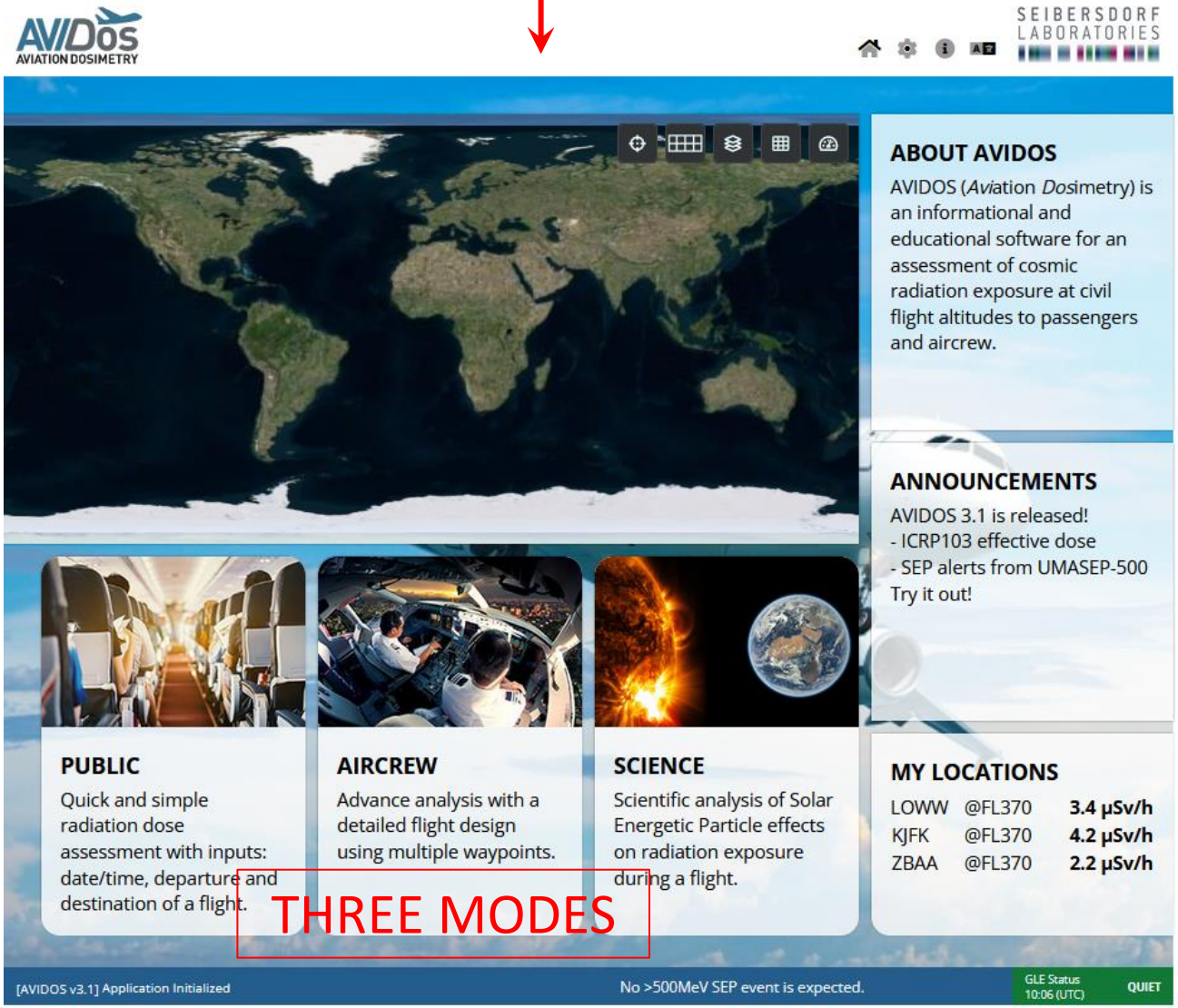
AVIDOS (1/3)

Nowcast



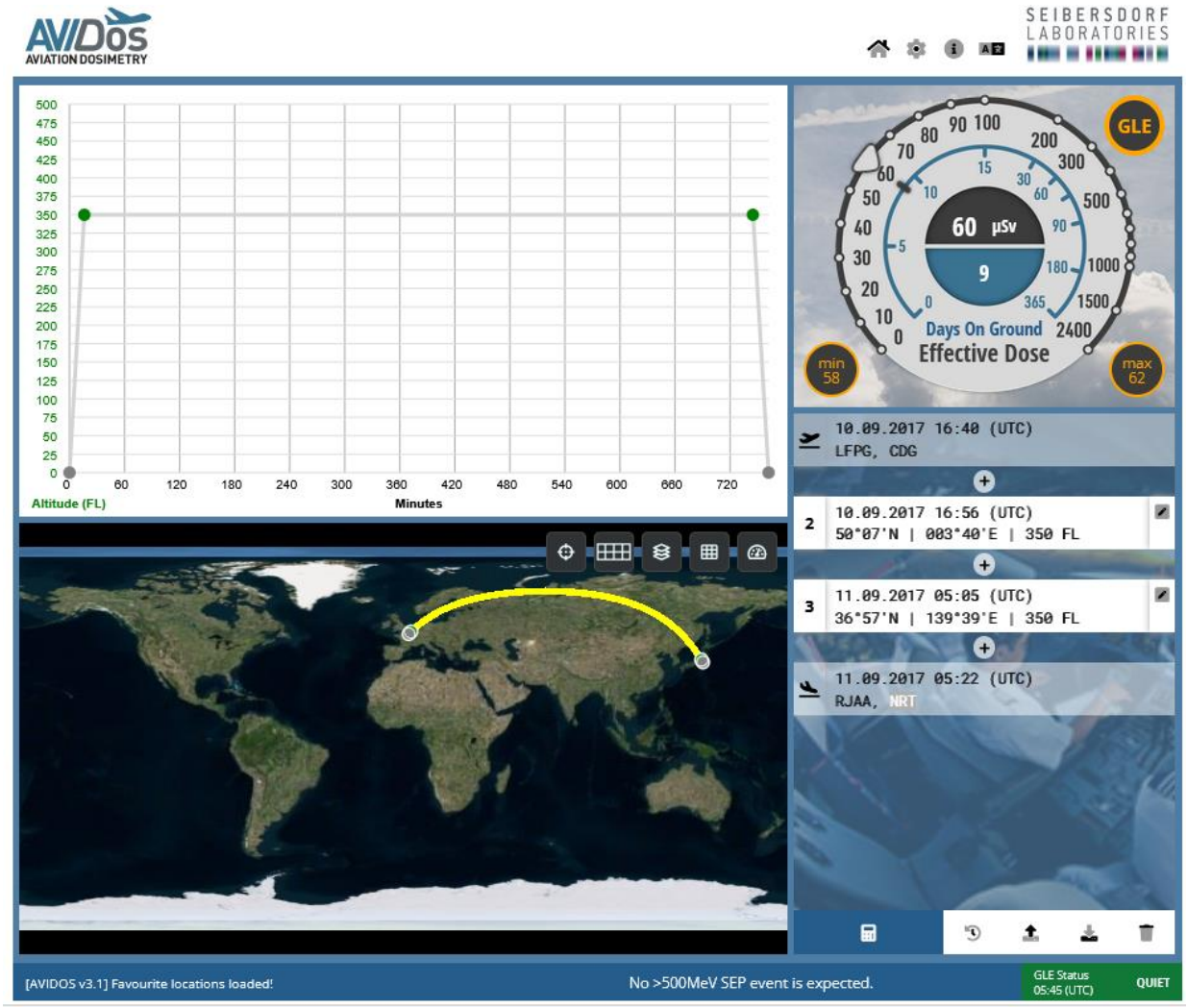
https://avidos.seibersdorf-laboratories.at/esa/map/

AVIDOS can calculate radiation doses not only due to galactic cosmic radiation, but also due to SEP events that result in GLEs.



AVIDOS (2/3)
Aircrew Mode

Advance analysis with a detailed flight route using multiple waypoints.



AVIDOS (3/3)

Science Mode: Flight analysis during a GLE

Gives calculations for past GLE events (up to GLE72 - Sept. 2017).

Currently there are three GLEs implemented:

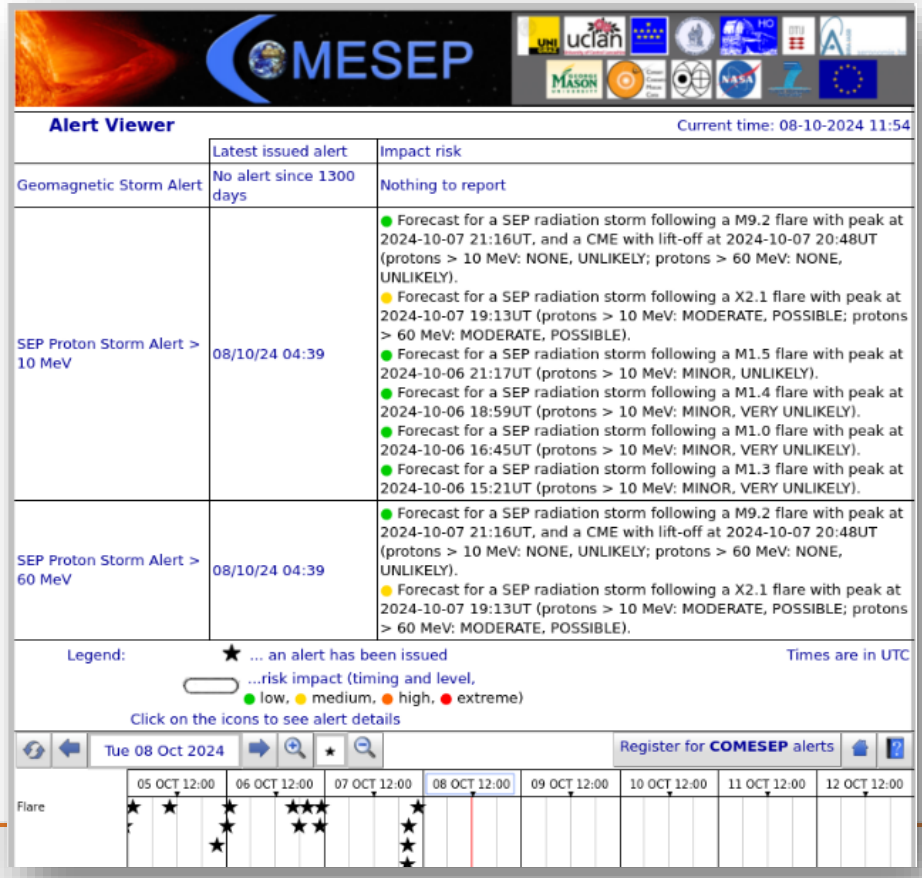
- GLE42 on 1989/09/29
- GLE69 on 2005/01/20
- GLE72 on 2017/09/10

Solar proton spectra

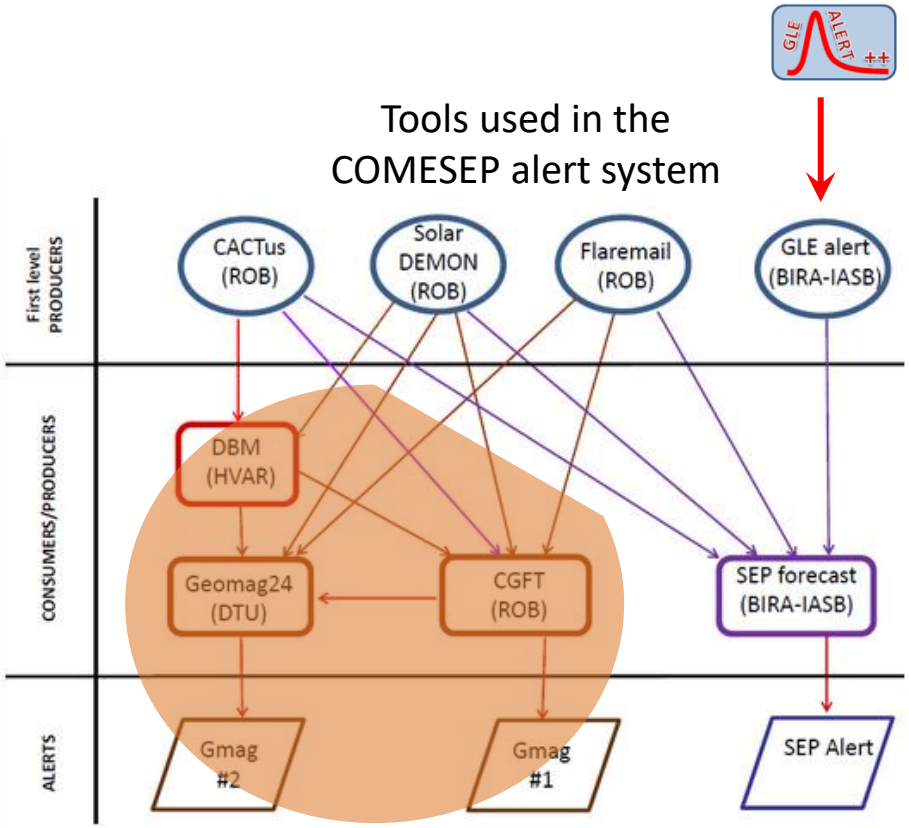
- Analyze how radiation dose changes due to different solar proton spectra for selected flight route or investigate different flight routes for the same solar proton conditions.
- Preloaded spectra for a few GLEs available, or define your own spectrum.

COMESEP

Alert System provides SEP (proton) storm alerts
(E > 10 MeV and E > 60 MeV)



Tools used in the
COMESEP alert system



RadSEP

Post-event analysis

- GLE69 (20 Jan. 2005)
- GLE70 (13 Dec. 2006)

Federated products from the Department Radiation Biology (DLR-IAM)

DLR SEP Post-event analysis

RadSEP GLE 69 GLE 70 Help and References

RadSEP - Short introduction

RadSEP provides post-event analysis of solar energetic particle events concerning the impact on the radiation environment at aviation altitudes. Ground level enhancements (GLE) are analysed and dose rates for generic flight profiles are calculated, which are caused by galactic cosmic rays and solar energetic particles as well as a spray of secondary particles produced in interactions with the atmosphere. For each analysed GLE, the user can select from a list of flights and for each flight the departure time with respect to the event onset can be selected. The calculated dose rates and flight parameters can be downloaded in a graphical or numerical data format.

List of Ground Level Enhancements:

GLE69 (2005.01.20 06:50 UTC)

GLE70 (2006.12.13 03:10 UTC)

DLR Post-event analysis GLE 69

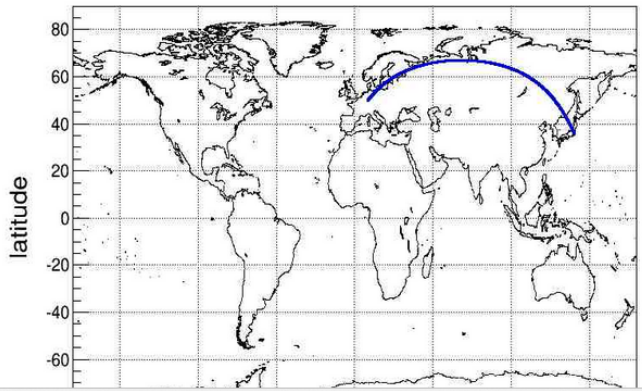
RadSEP GLE 69 GLE 70 Help and References

Post-event analysis of the impact on the radiation environment at aviation altitudes due to solar energetic particles during ground level enhancement GLE69 which occurred on 20 January 2005. Different flight routes and departure times relative to the event onset can be selected.

Select flightroute and departure time (relative to onset event in minutes):

Frankfurt - Tokyo | 0 | submit

Selected: 20th Jan 2005, 06:50h (GLE069), Frankfurt - Tokyo, +0 mins



ıd service development activities, and is supported under ESA contract number
k. E-mail: helpdesk.swe@esa.int

ment of Radiation Biology of the DLR Institute of Aerospace Medicine and The ESA

.int/spaceweather

UTU-SEP (1/4)

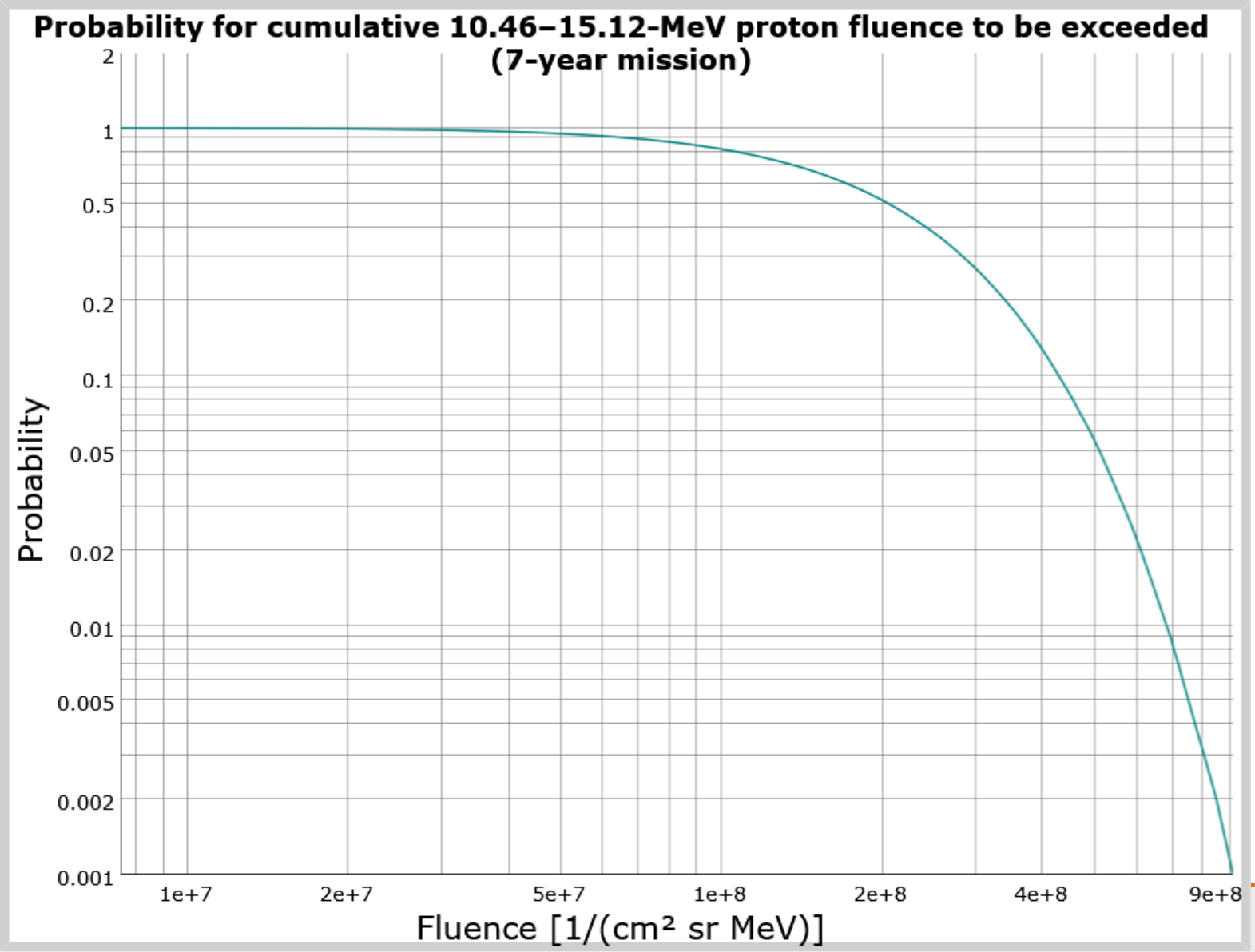
Very high-energy Solar Energetic Particle environment mission specification: Proton fluence (1/2)

- A calculator to evaluate the cumulative and worst-case event fluences for very high-energy (10-1000 MeV) protons for mission durations between 0.5 and 7 years.

- The model is based on an analysis of GLEs and sub-GLEs between April 1976 and December 2017.
  - Sub-GLEs refer to events that have been observed above 300 MeV, but that have not produced sufficient intensities at higher energies to be observed on ground.

UTU-SEP (2/4)

Very high-energy Solar Energetic Particle environment mission specification: Proton fluence (2/2)



UTU-SEP (3/4)

Very high-energy solar proton event database (1/2)

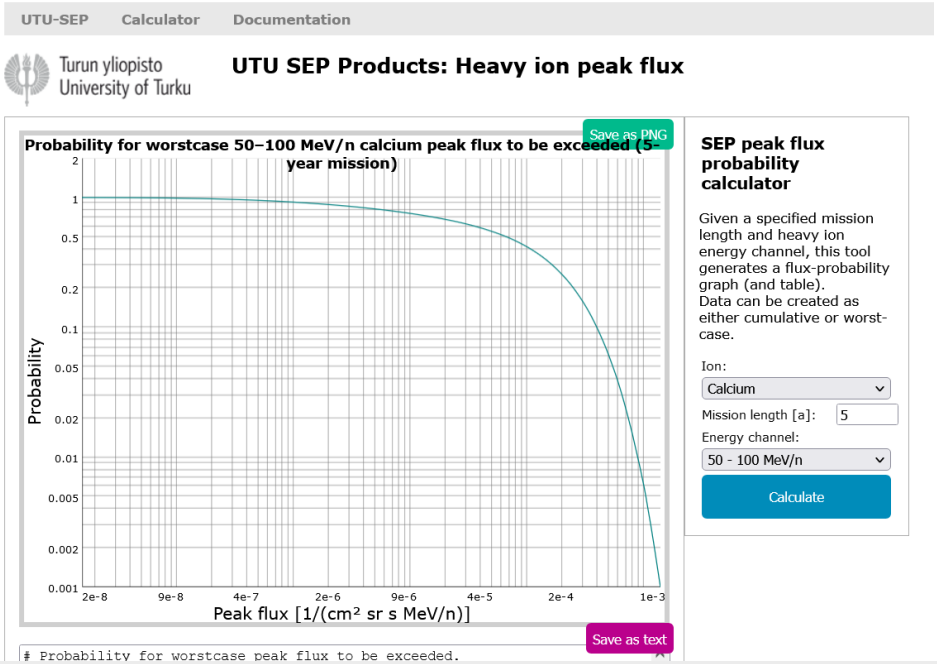
- A database of very high-energy (>300 MeV) solar proton events.
- Covers solar cycles 22-24, i.e., between Sept. 1986 and Dec. 2019.
- Provides fluence and peak flux spectra for all events, and flux spectra at 5-min resolution for selected well-observed GLEs.

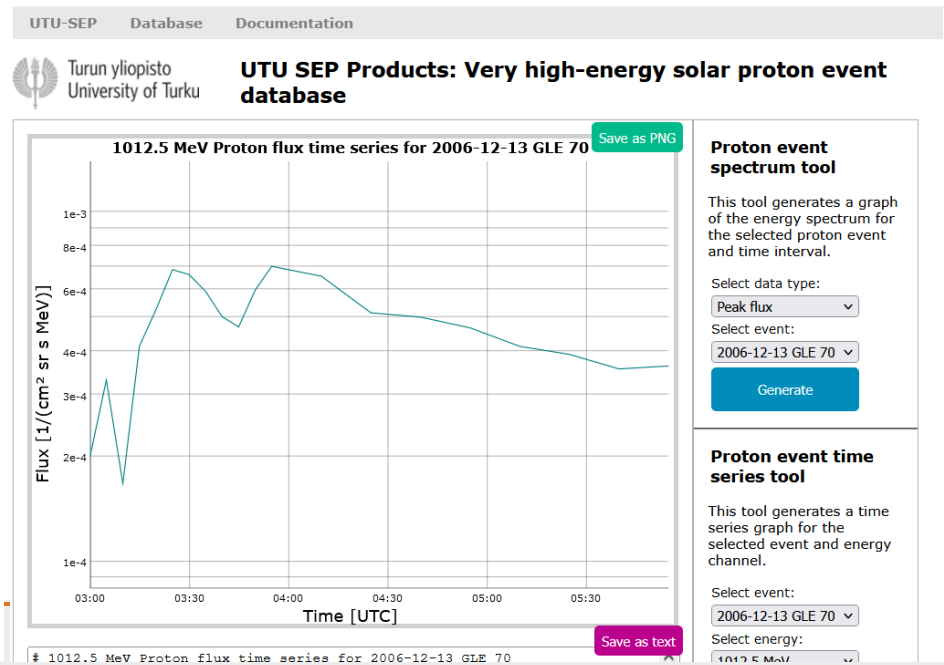
UTU-SEP (4/4)

Very high-energy solar proton event database (2/2)

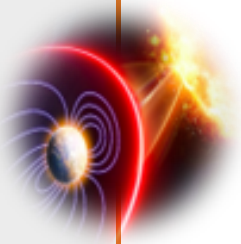
Database includes:

- 33 ground level events, which have been detected with neutron monitors (GLEs 40-72)
- 35 events which have been detected with space-borne detectors above 300 MeV but have not produced sufficient fluxes at high energies to be detected with ground level neutron monitors.





OUTLINE



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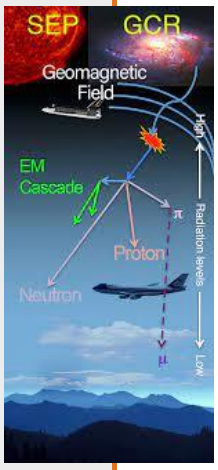
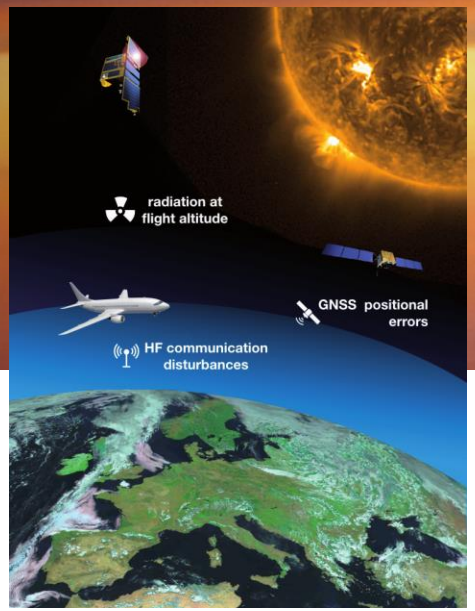


- PECASUS: Pan-European Consortium for Aviation Space weather User Services

- Looking Forward

PECASUS FOR ICAO

PARTNERSHIP OF EXCELLENCE FOR CIVIL AVIATION SPACE WEATHER USER SERVICES



https://pecasus.eu/

- One of the 4 International Civil Aviation Organization (ICAO) Global Space Weather Service Centres
- 24/7 operational
- Consortium: FMI(lead), UKMETOF(back-up), STCE, SL, INGV, DLR, SRC, FU, KNMI
- Service = delivering MOD/SEV advisories for HF COMM, GNSS and RADIATION

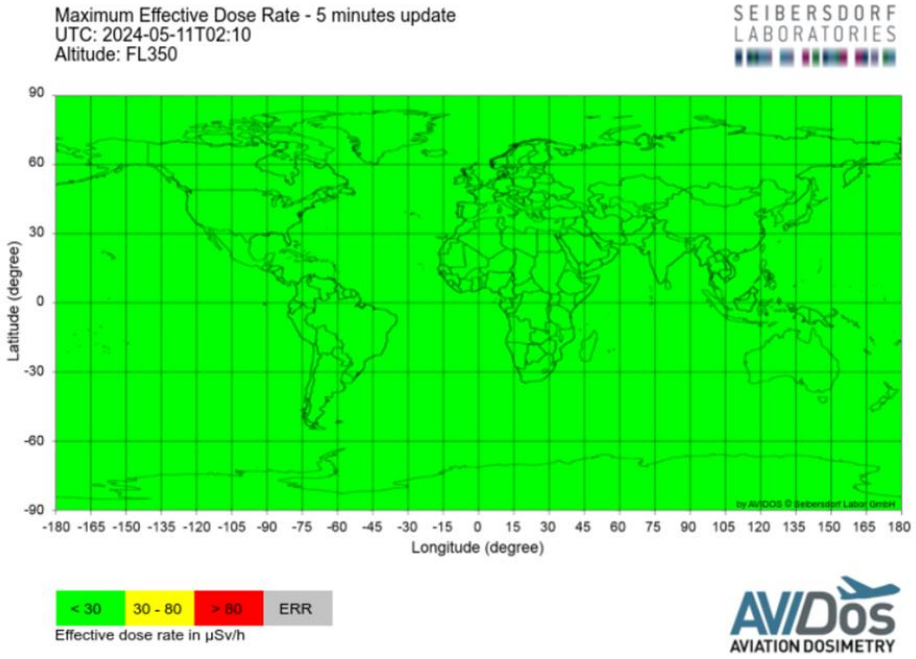
- ICAO Radiation thresholds: MOD : 30 < effective dose rate (microSv/h) ≤ 80
  SEV : 80 < effective dose rate (microSv/h)
- Role BIRA-IASB as member of STCE: data provision, on call scientific support, coordination PECASUS consortium RAD-WG

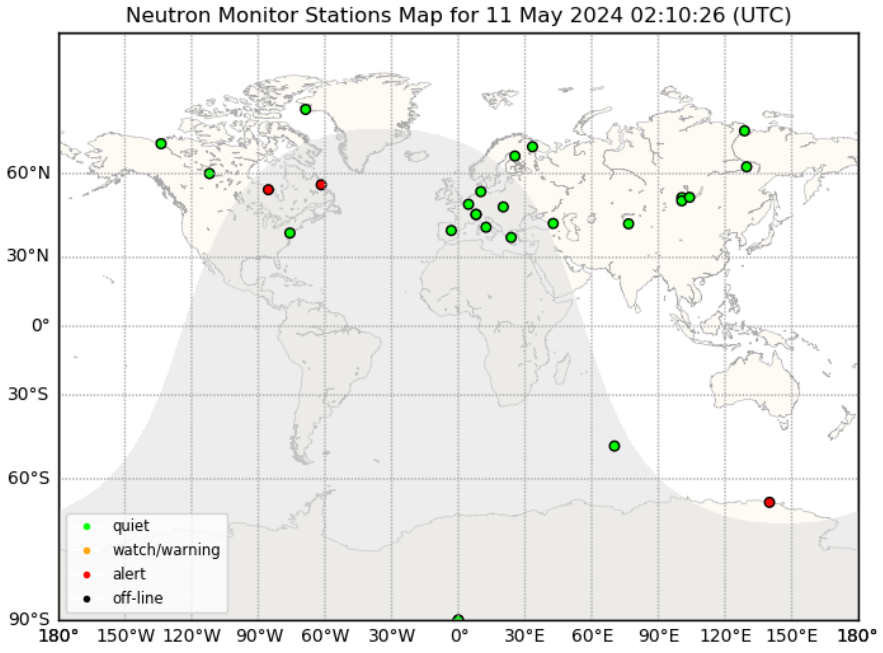
PECASUS relies on neutron monitor data to estimate the radiation exposure at flight level, a key input for compiling ICAO radiation advisories.

- AVIDOS (Oulu NM data) → world map with nowcast effective dose rate at different flight levels between FL250 – FL580
- GLE Alert++ (27 stations) → input PECASUS radiation alert table + verification increased radiation dose at flight level
- NM world map → visualization/position NM stations in alert modus, based on ANeMoS database

RADIATION DASHBOARD on 2024-05-11 02:10 UTC

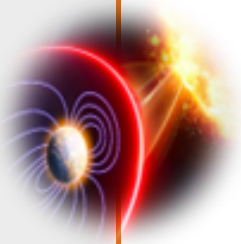
AVIDOS FL>460	AVIDOS FL≤460	GOES Proton	GLE Alert	COMESEP
Current status:	**Current status:**	**Current status:**	**Current status:**	**Current status:**
2024-05-11 02:10	2024-05-11 02:10	2024-05-11 02:10	2024-05-11 02:10	2024-05-11 02:10
QUIET	QUIET	ONGOING	GLE ALERT	SEP ALERT
Past 3-hour status:	**Past 3-hour status:**	**Past 3-hour status:**	**Past 3-hour status:**	**Past 3-hour status:**
QUIET	QUIET	ONGOING	GLE ALERT	SEP ALERT





FL350 ~11 km

OUTLINE



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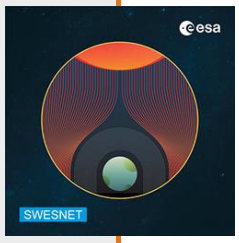

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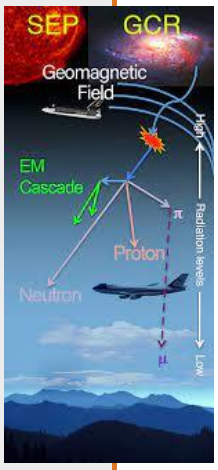

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- Looking Forward

Super Solar Events (1/3)

ENERGY RANGE	EFFECTS
Superstorm radiation	Systems with very high safety and reliability requirements (e.g., in the nuclear power industry) may need to take account of superstorm ground level radiation on microelectronic devices within the system.

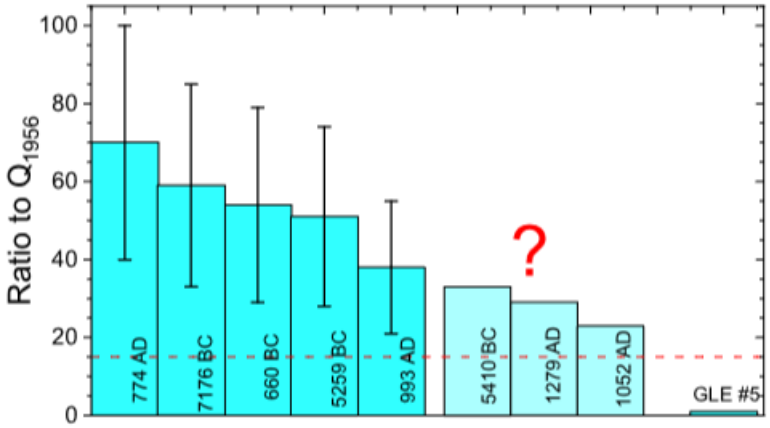
"In the case of nuclear power a Carrington event may not be a sufficient case since relevant timescales for risk assessment may be as long as 10,000 years."

(Paul Cannon, Extreme space weather: impacts on engineered systems and infrastructure, 2013)

Have SUPER solar events occurred in the past and could they occur in the future?

Super Solar Events (2/3)
The 775 AD Cosmic Event: Cosmogenic Isotopes

Miyake et al. found a significant enhancement of about 1.5% (15 permill) of ^{14}C content measured in Japanese cedars from around 775 AD (Nature, 2012).



Red question mark denotes the three recent event candidates

GLE #5 (1956 Feb. 23): strongest GLE event ever recorded

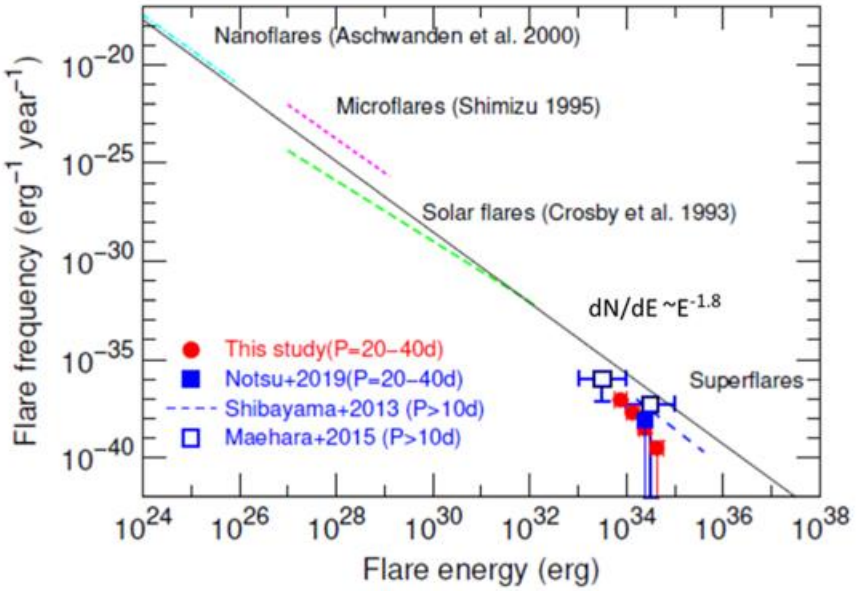
Edward W. Cliver, Carolus J. Schrijver, Kazunari Shibata, Ilya G. Usoskin "Extreme solar events", Living Reviews in Solar Physics (2022) 19:2

- Events are compared in the amount of ^{14}C produced (measured for historical events and computed theoretically for the GLE5 event).
- Threshold value (dotted red line) suggests that events weaker than 15x GLE5 cannot be reliably detected by a single ^{14}C dataset.
- Error bars are defined by both the measurement uncertainties of ^{14}C in tree rings and model uncertainties of the carbon cycle.

Super Solar Events (3/3)
Superflares

Using typical dynamo models Shibata et al. (2013) found that it is possible that the present Sun would generate a large sunspot to store sufficient magnetic flux for generating super flares with an energy of:

- 10^{34} erg (within one solar cycle period)
- 10^{35} erg (would take ~ 40 yr)



Cliver et al. (2022)

During simultaneous optical and radio monitoring of Proxima Centauri, a bright, long-duration optical flare, accompanied by a series of intense, coherent radio bursts was detected (Zic, Lynch, et al., 2020).

- Solar type IV bursts are strongly associated with CMEs and SEP events, suggesting that stellar type IV bursts may be used as a tracer of stellar CMEs.

Many superflares on solar-type stars have been found from Kepler Space Telescope data

- Vasilyev et al. (2024) investigated brightness measurements of 56,000 Sun-like stars and identified almost 3000 bright stellar flares with energies of about 10^{34} to 10^{35} erg.

Final Words (1/3)
Ensuring Funding

- Space weather applications: assessment of dose rates
- New applications (e.g., soil moisture monitoring using cosmic-ray background radiation)
- Involving other sensors at Earth and in space
    - Crosby, N., Mavromichalaki, H., Malandraki, O., Gerontidou, M., Karavolos, M., Lingri, D., et al. (2024). Very high energy solar energetic particle events and ground level enhancement events: Forecasting and alerts. Space Weather, 22, e2023SW003839. https://doi.org/10.1029/2023SW003839
        - GLE Alert++ issues alerts when a GLE event starts to register and is based on ground-based neutron monitor observations
        - HESPERIA UMASEP-500 provides forecasts of GLE events and >500 MeV protons relying on Soft X-Ray and high-energy proton observations
        - HESPERIA UMASEP-500 and GLE Alert++ are complementary tools that enhance space weather forecasting capabilities
- Environmental sciences, Collaboration with other communities, Education and Public Outreach activities, Citizen Science initiatives, …

Final Words (2/3)
Summary (1/2)

- To maintain products relying on neutron monitor data continued operation of neutron monitor stations must be ensured.

- Further extensions and support of the current neutron monitor network with new or updated stations and services in terms of reliable real-time data is thus encouraged.
  - Princess Sirindhorn Neutron Monitor in Thailand (2007/12/09 – present)
  - BUDApest neutron monitor (BUDA) has been added to the list of neutron monitors at the NMDB website and work is in the process to make the data available in NEST
  - Haleakalā Neutron Monitor Station on Maui
  - U.K. Space Weather Innovation, Modelling, Measurement and Risk (SWIMMR) programme includes an additional neutron monitor station based on a new detector design.

Final Words (3/3)
Summary (2/2)

- However, this will require a new generation of scientists and engineers with not only scientific neutron monitor expertise, but more importantly technical expertise in
  - Instrumentation/ Technical issues,
  - Data quality/ Cleaning data,

as well as in understanding the Needs of Users.

There is a bright future for the neutron monitor community, but new approaches to ensure funding must be pursued.

THANK YOU!
MORE INFO?

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