Space weather radiation impacts and mitigation for aircraft

Surrey Space Centre In Collaboration with MOSWOC

Including preliminary flight data from event of 11 November 2025

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Met Office

LESSONS FROM 11TH NOVEMBER 2025 GLE77.
KEY DATA COLLECTED !!

- 2 Balloon Flights at Lerwick, 1 at Camborne plus 1 at KNMI
- 2 Airflights London to New York
- MAIRE+ outputs in real-time driven by GLNMs at OULU and Dourbes
- UK NMs at Lerwick, Camborne, Lancaster, Guildford
- After event MAIRE+ driven by Lerwick and Dourbes

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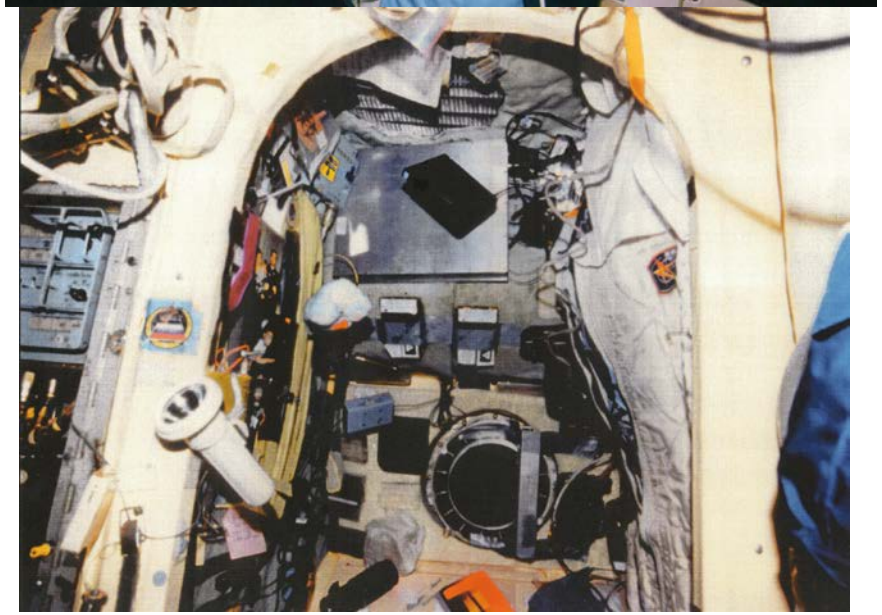
Surrey Team has 40 year experience in radiation measurement , effects and models
CREAM on Concorde 1988 to 1990

Dave Leestma and Dick Richards Deploy Shuttle Activation Monitor on STS-28 in August 1989.

CREAM on STS-44 in 1991with pilot Tom Henricks

CREAM in SpaceHab on STS-63 in Feb 1995 First MIR Rendezvous with Cosmonaut Titov and Astronaut Wetherbee.



CREAM on MIR in 1998

UK aircraft and radiosonde monitors (from early 2024)

Radiosonde

Rapid Reaction

Aircraft

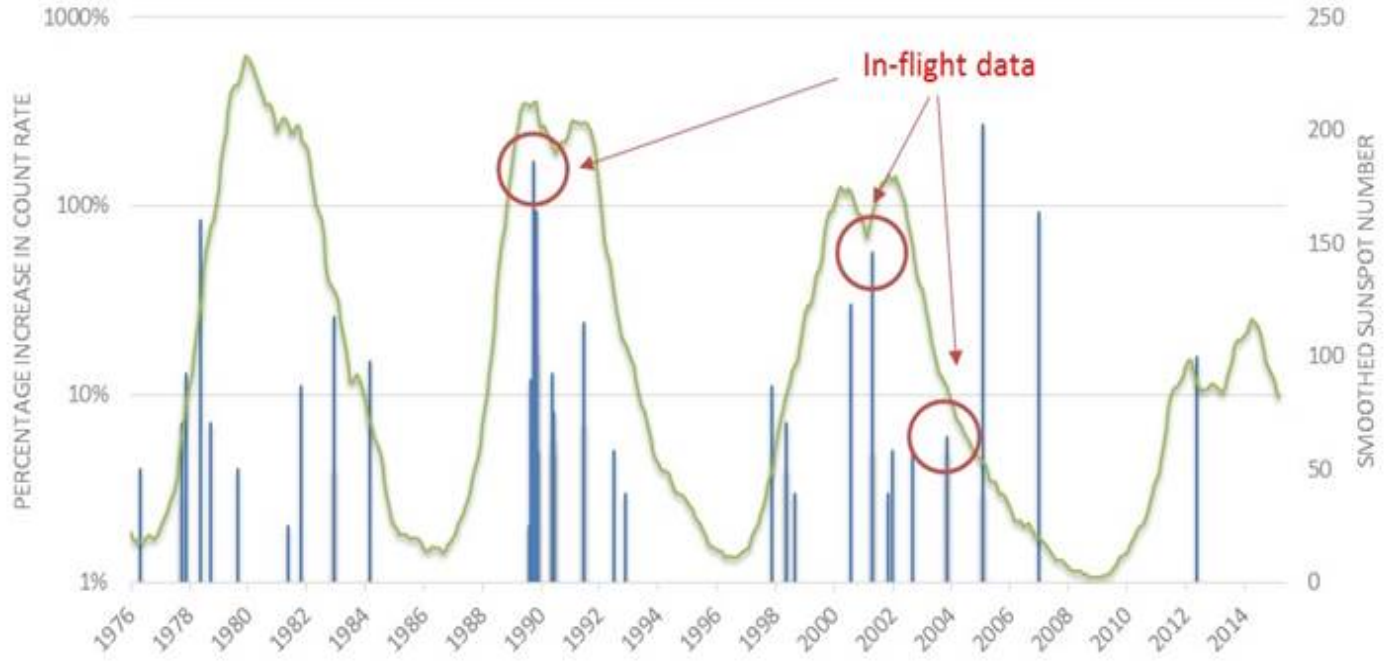
Semi–Permanent Onboard

Aircraft

787 Crew Rest Area Cupboard

Comparisons with Flight Data

- Best source for model validation is in-flight measurements
- Very few available for GLE periods

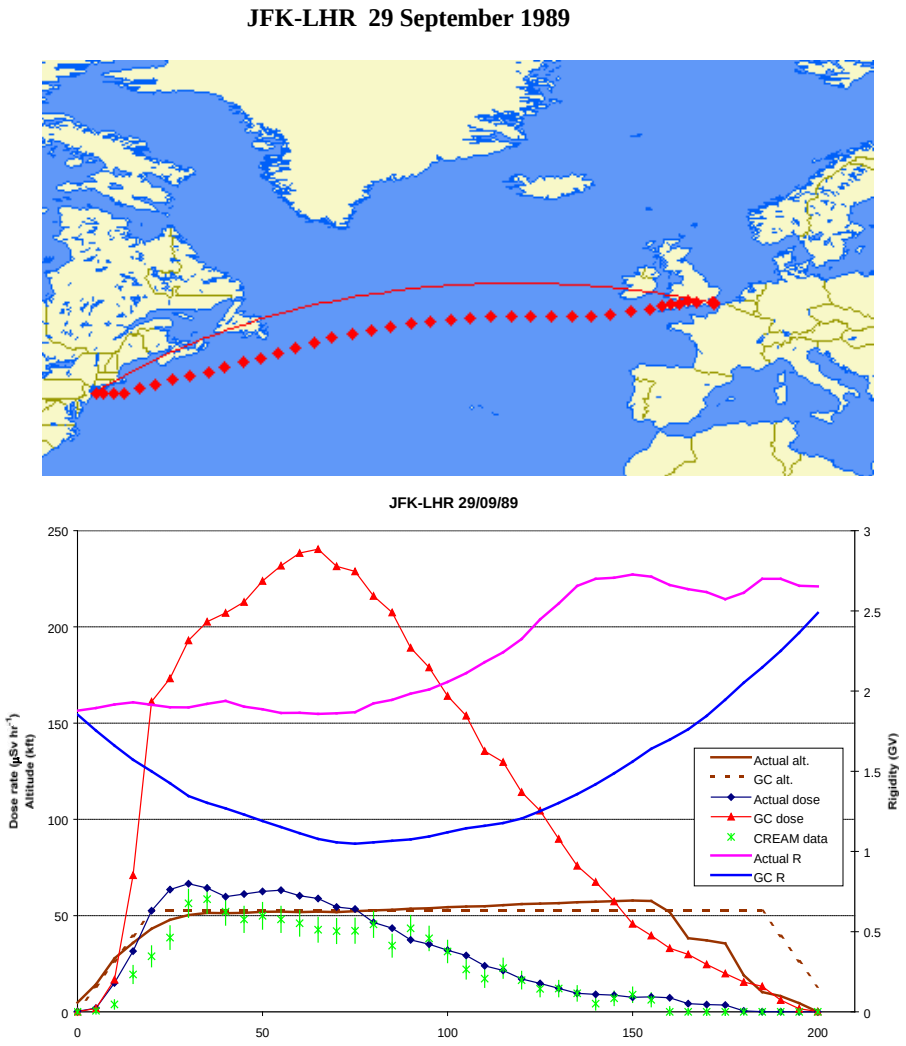


Sep / Oct 1989:
GLEs 42, 43, 44 & 45 (large increase in dose rate observed on Concorde during GLE42)

April 2001:
GLE60 (small increase in dose rate observed independently on two flights, Dachev and Beck)

October 2003:
GLE65 (small increase in dose rate)
GLE66 (small increase coincident with altitude rise), Beck

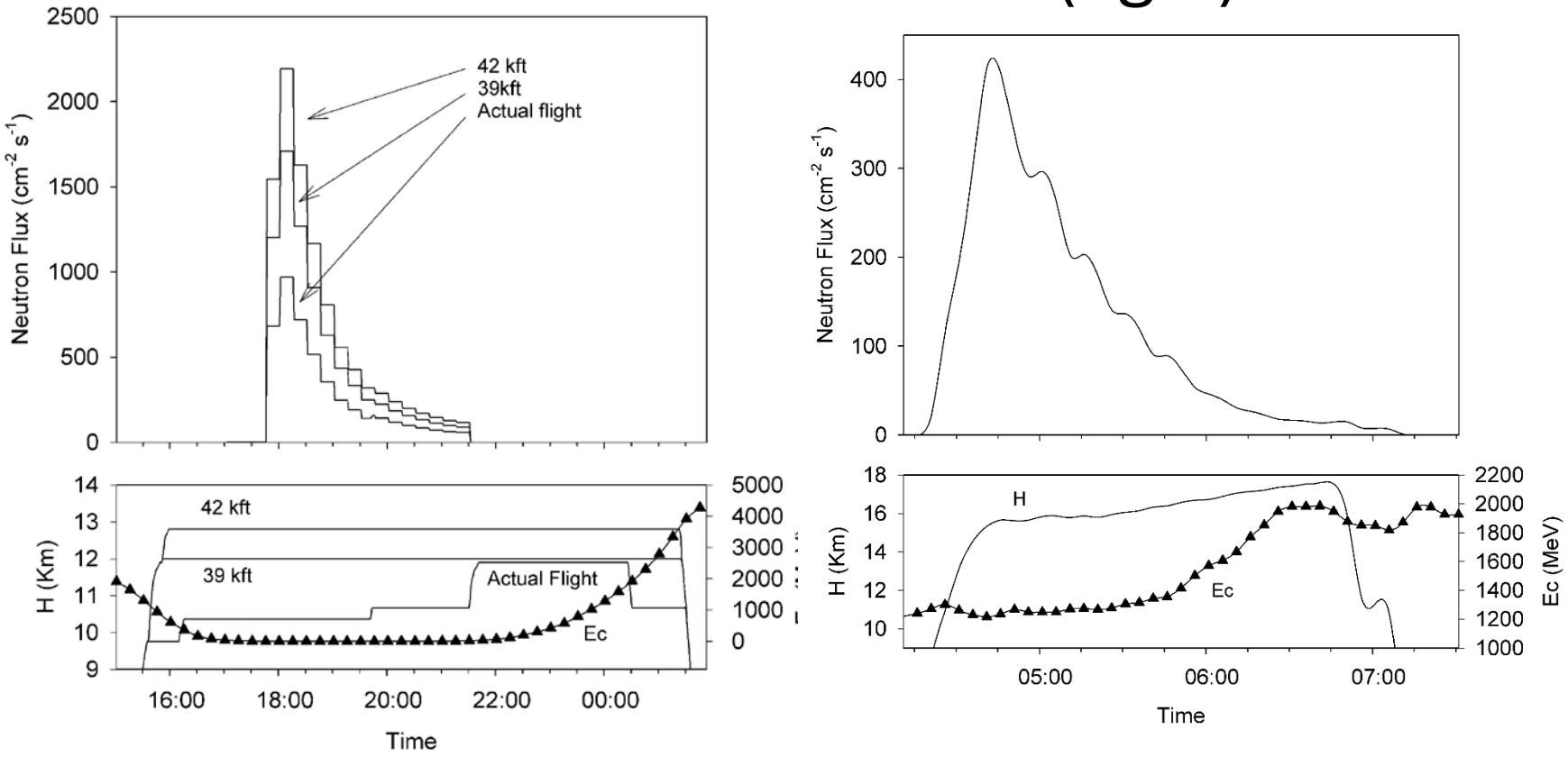
GLE42 (Kp =2): JKF-LHR
Great Circle vs. Actual Flight path



Concorde route during event of 29 September 1989 (Kp = 2). Data from CREAM.

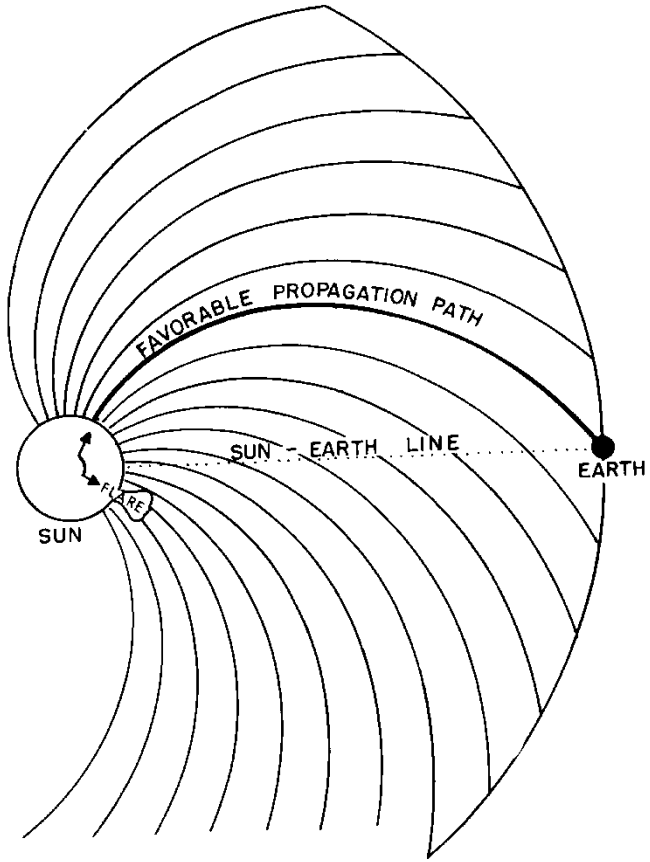
Peak dose rate on great circle route would have been factor 5 higher cf actual route.

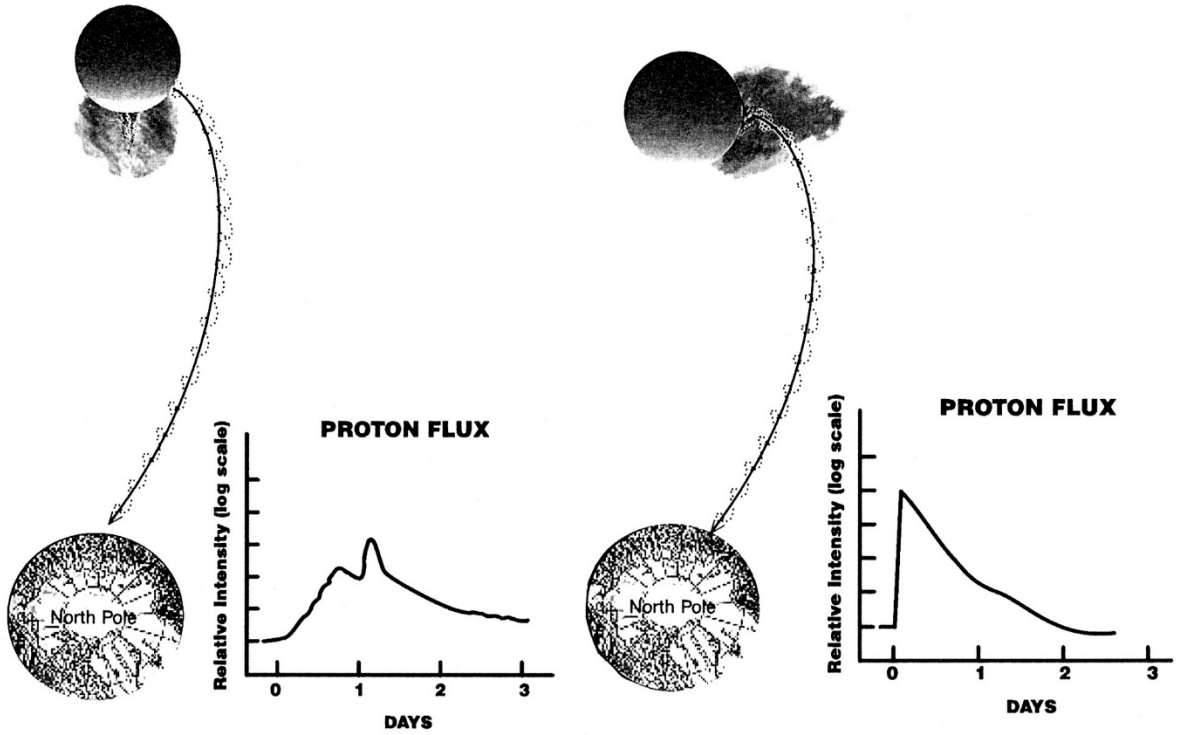
Calculated Neutron Fluxes for Feb 56 Event for London-Los Angeles Routes(left) cf New York- London on Concorde Route(right)



Radiation is higher for many subsonic routes than it was for Concorde. Concorde was compelled to carry a monitor and take action!

Particle Flux & Time Profile Depend On Event Location On Sun: Feb56 was highly anisotropic and proved the Parker spiral theory for IMF

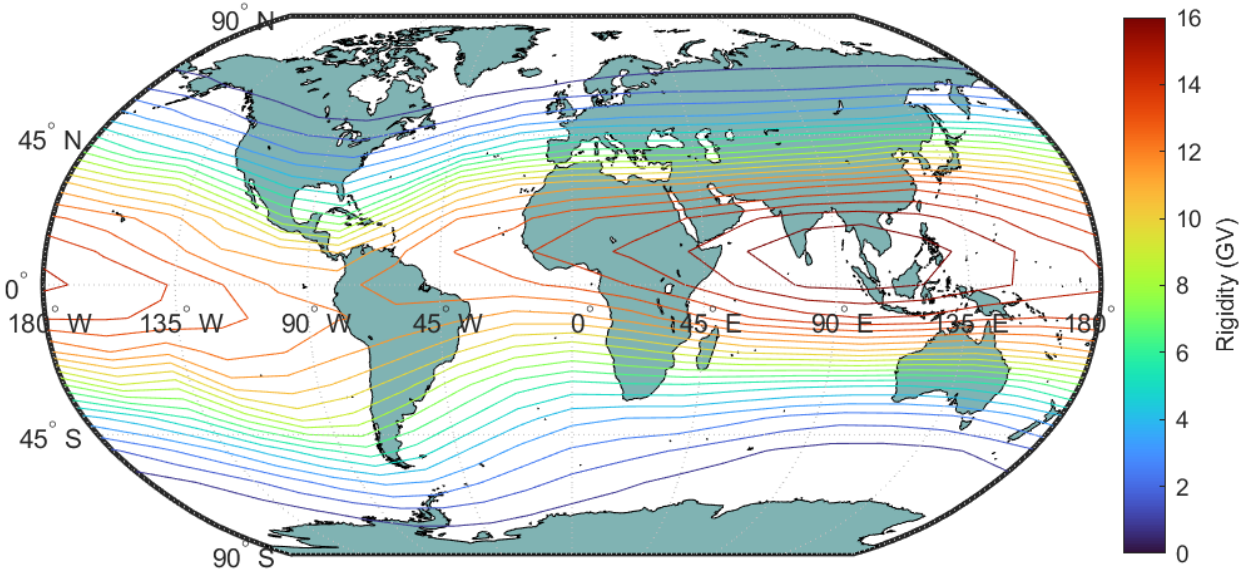


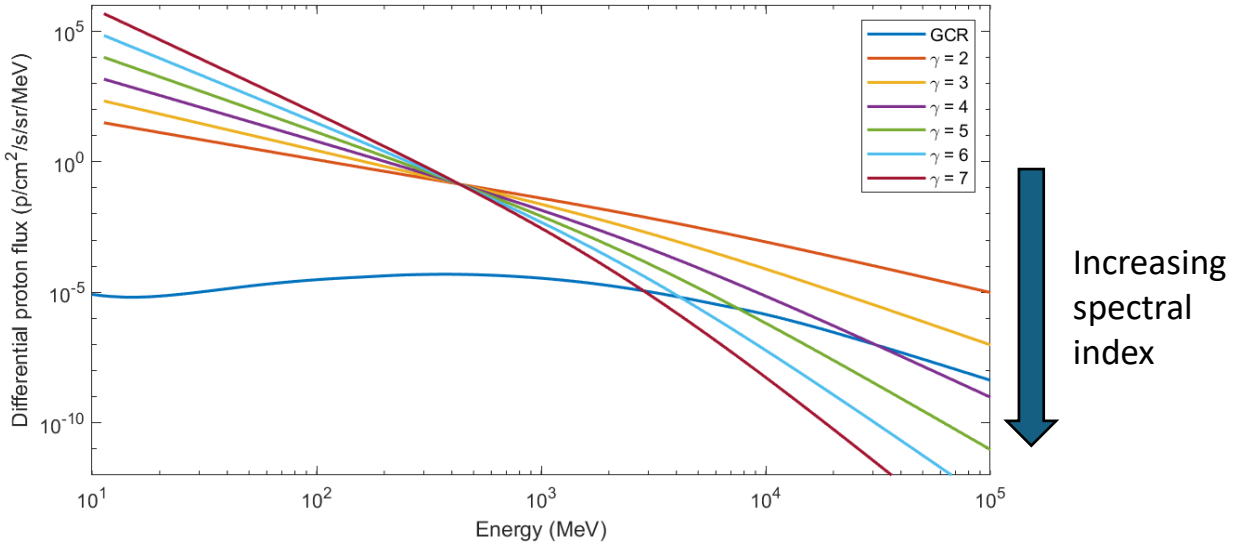


From Shea and Smart

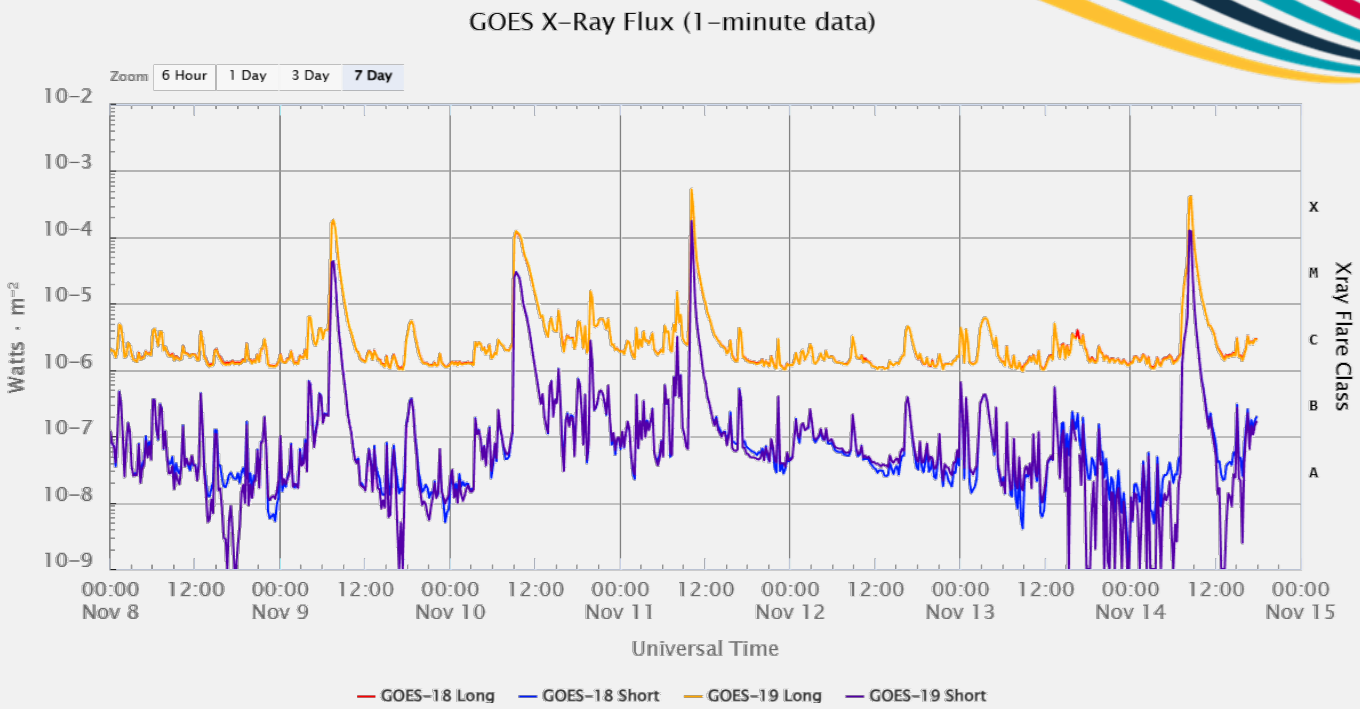
MAIRE+ Input Data

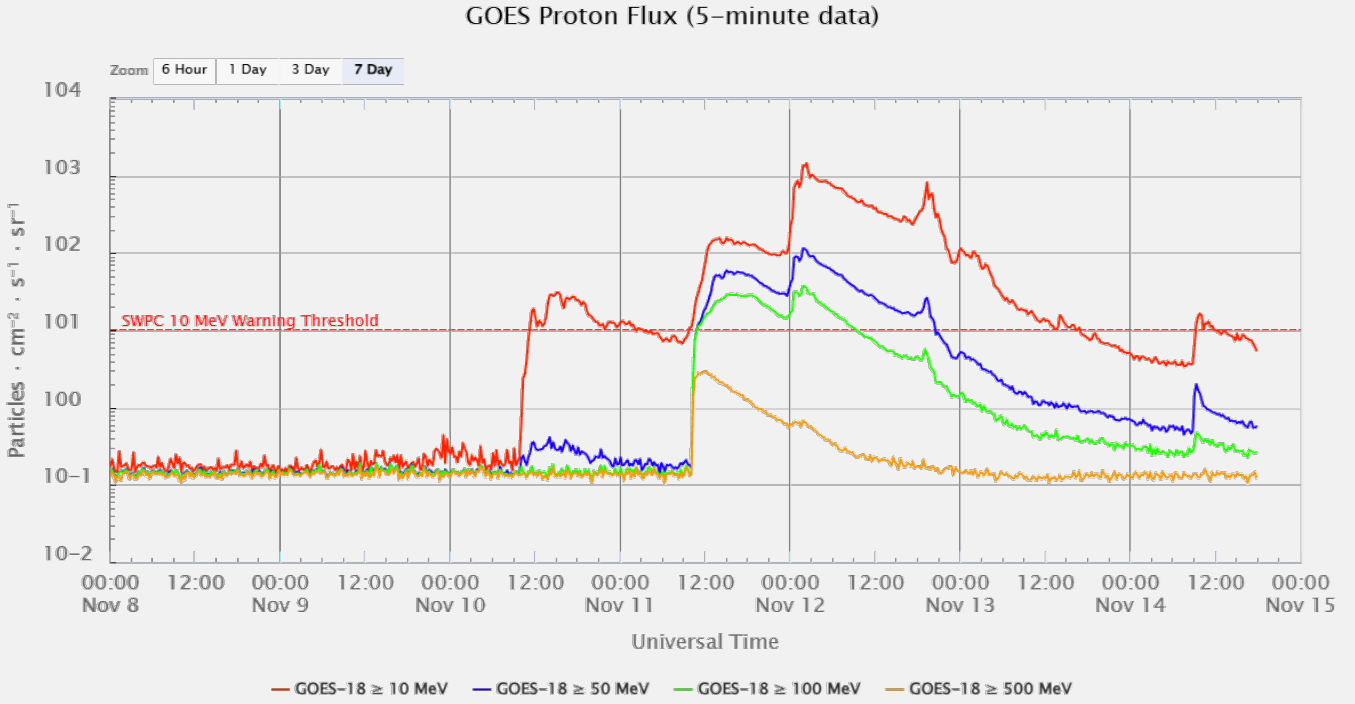
- For rapid calculation during GLEs, MAIRE+ uses data from two neutron monitors at different geomagnetic cut-off rigidities
- Higher spectral index → higher ratio between high latitude and low latitude count rate increases
- Key rigidity range is <1 GV – >2.5 GV (NB UK ideally situated for monitor locations)
- Monitors chosen based on rigidity, reliability and proximity to UK airspace:
  - Oulu, Finland ($R_c \approx 0.5$ GV)
  - Dourbes, Belgium ($R_c \approx 3$ GV)





GOES OBSERVATIONS





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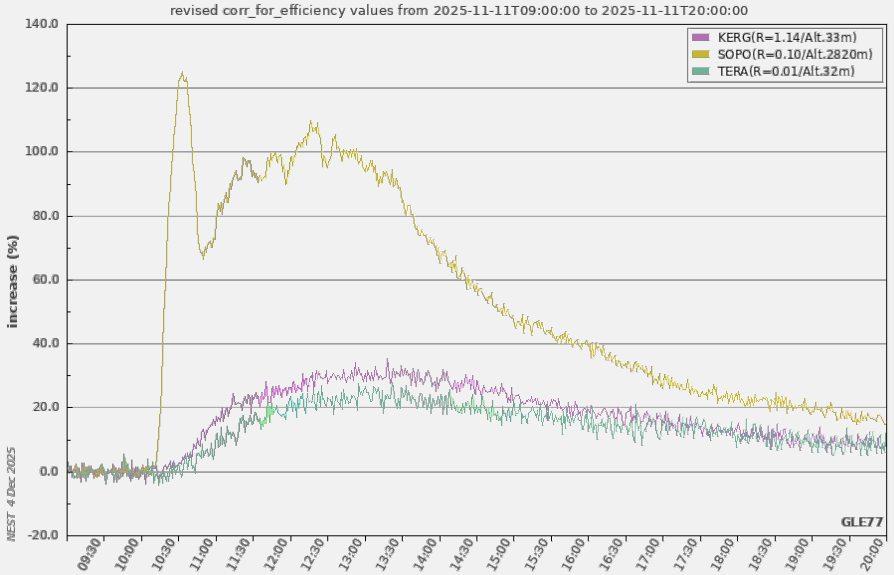
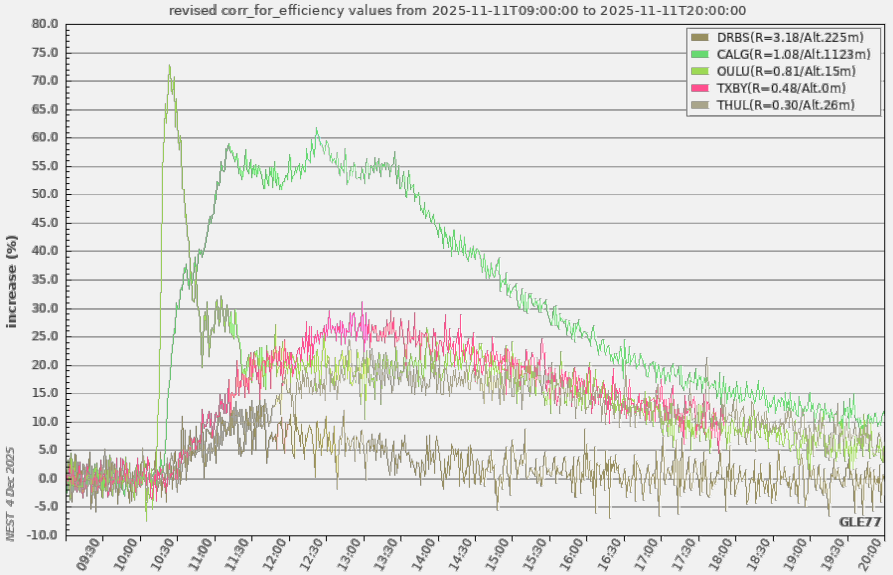
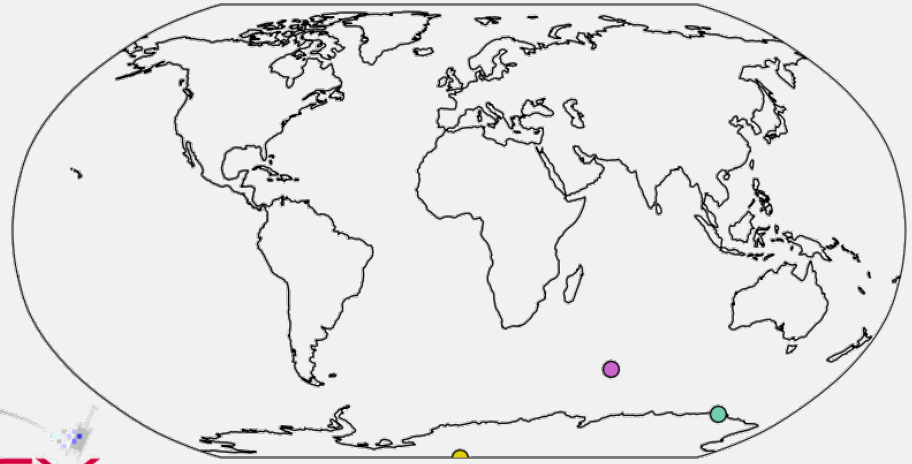
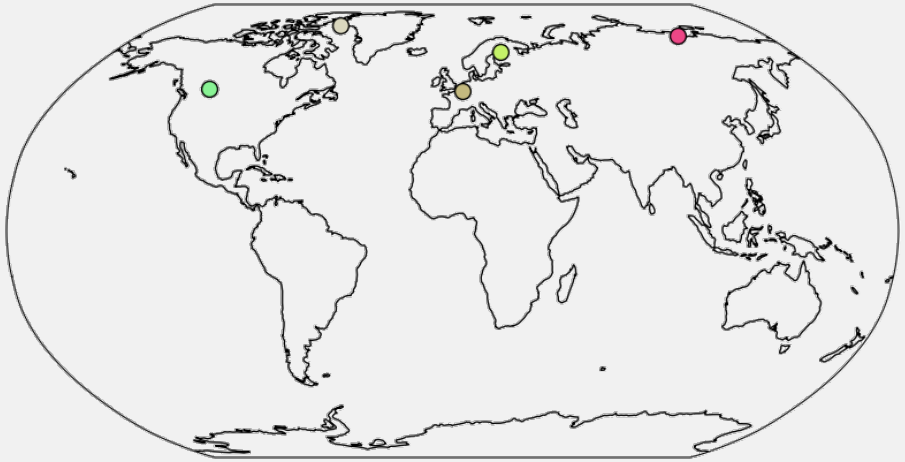
NOTE SOPO AT 2820KM.NEEDSCORRECTION TO SEA LEVEL OF ORDER FACTOR10 (DEPENDS ON SPECTRAL HARDNESS)



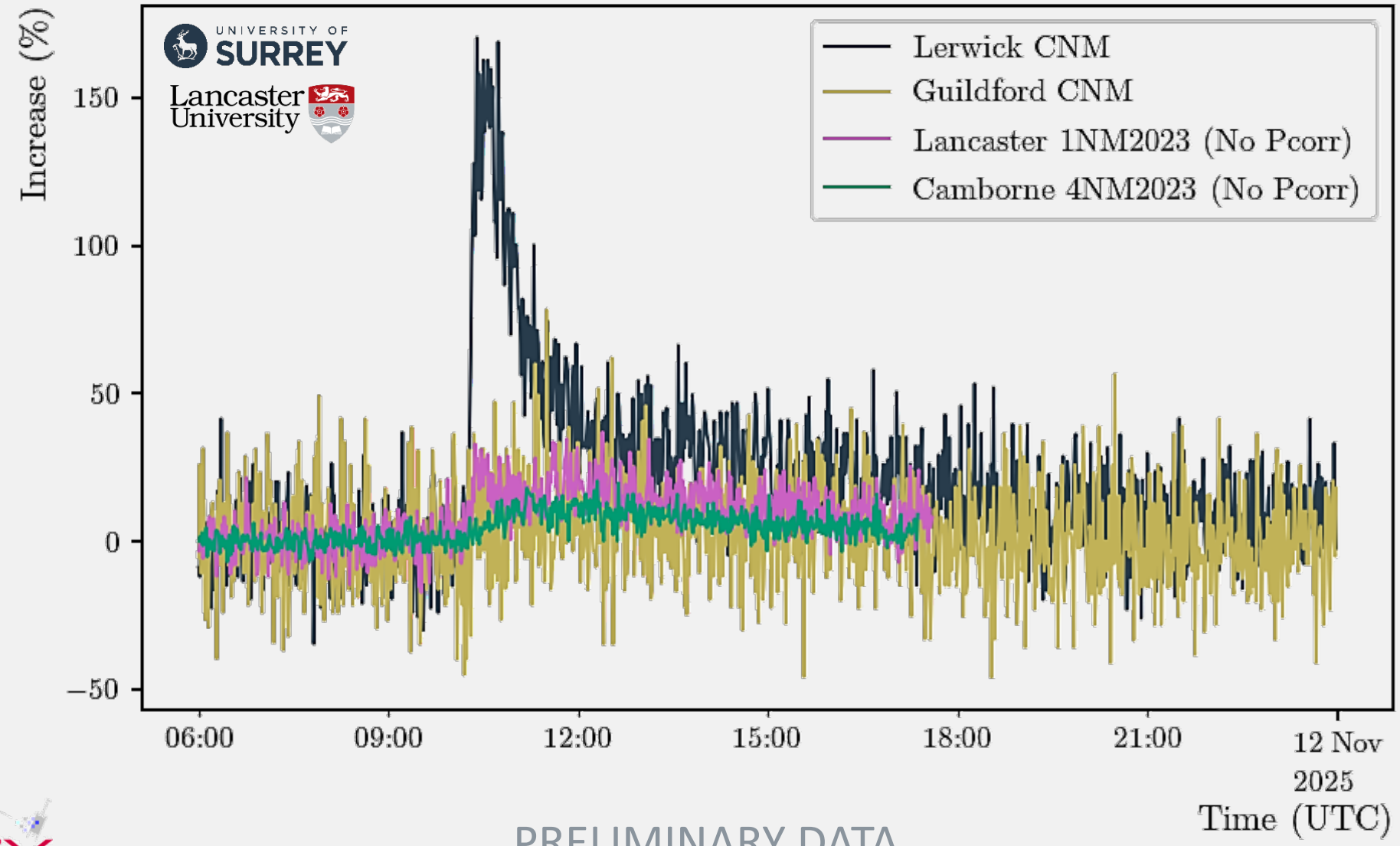






UK GROUND LEVEL MONITORS

NOTE CNM TO NM CONVERSION DIVIDE BY 1.32



PRELIMINARY DATA

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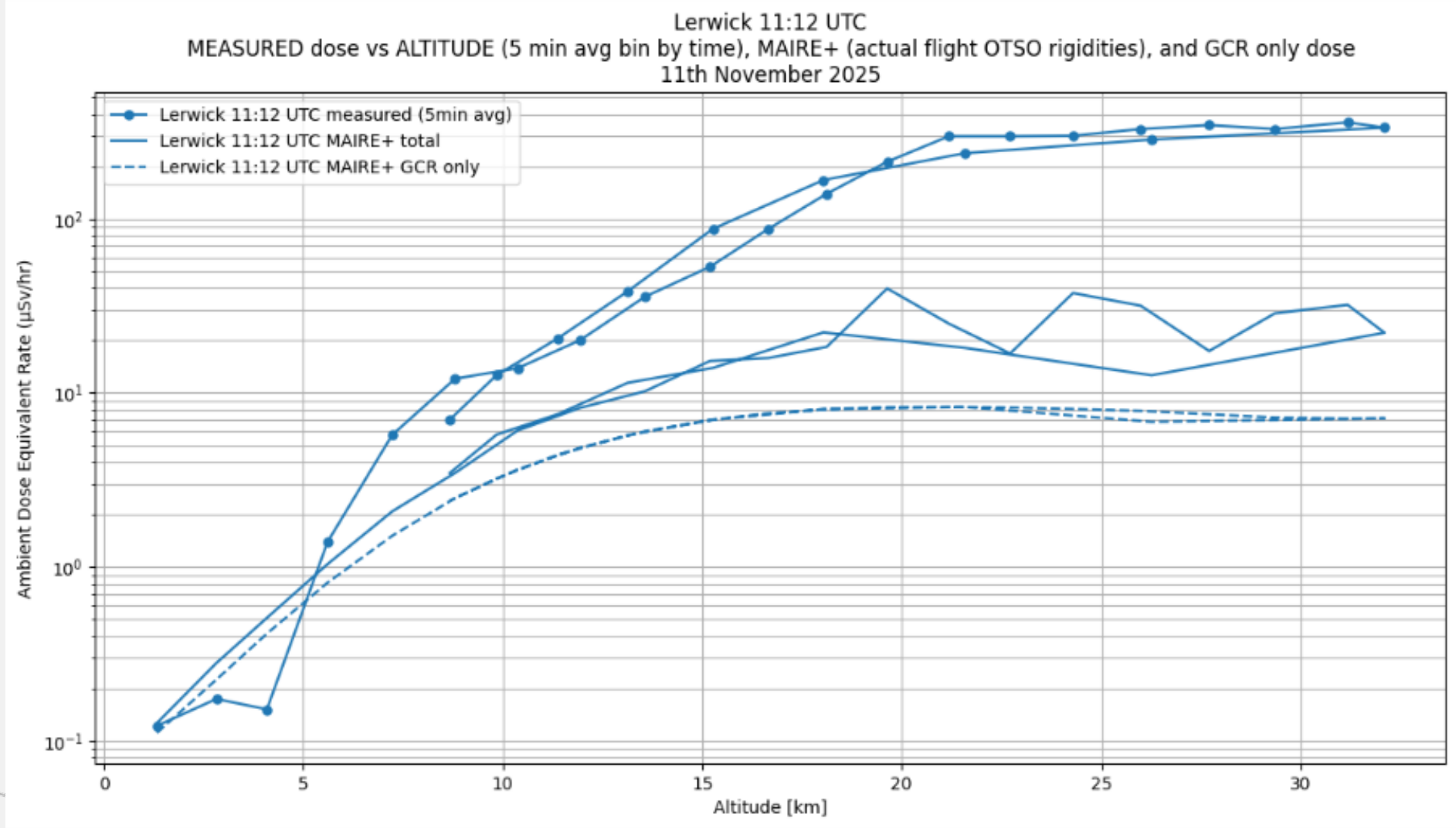
LERWICK BALLOON FLIGHTCOMPARED WITH MAIRE+PREDICTIONSBASED ON OULU-DOURBES



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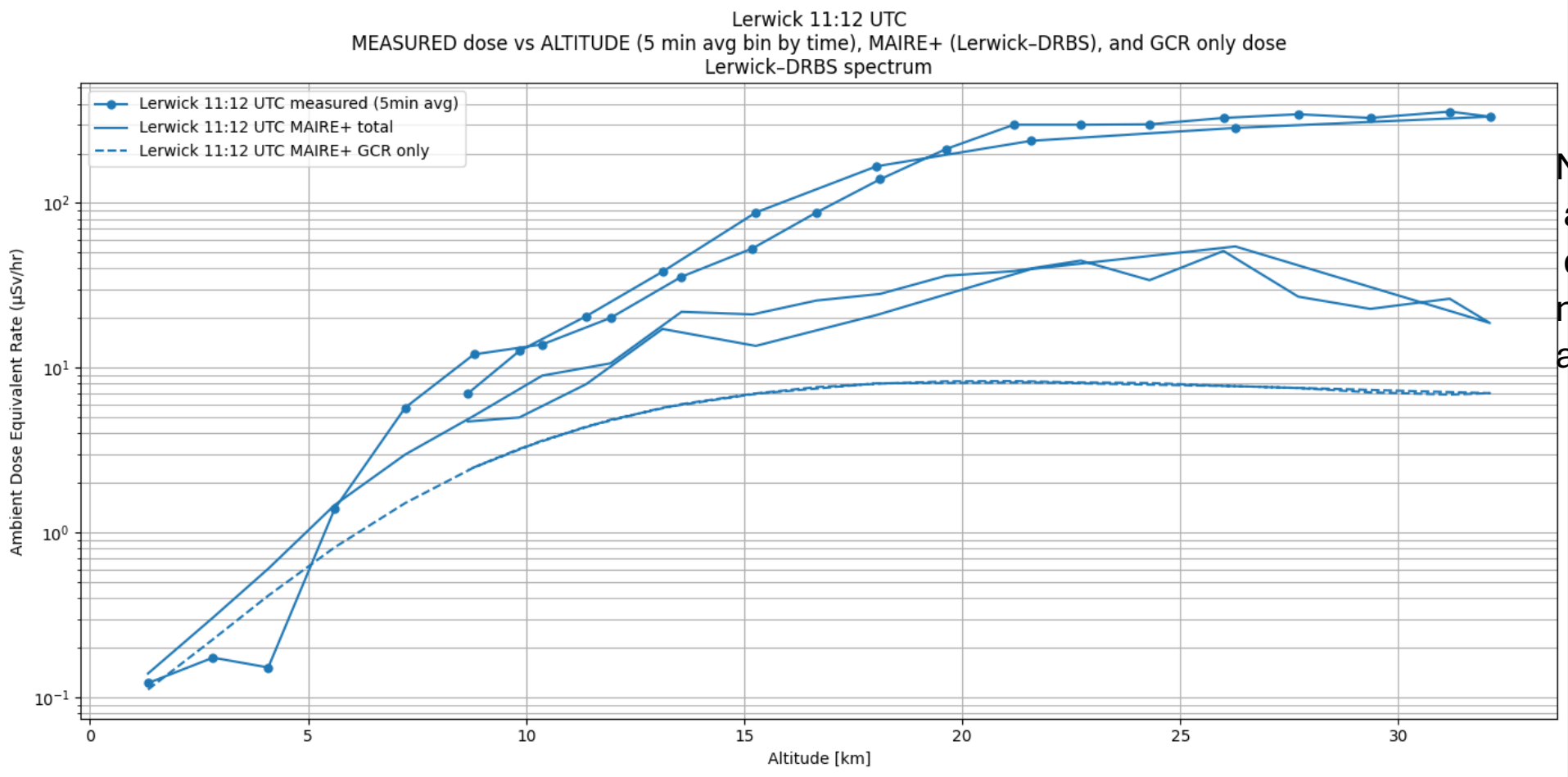
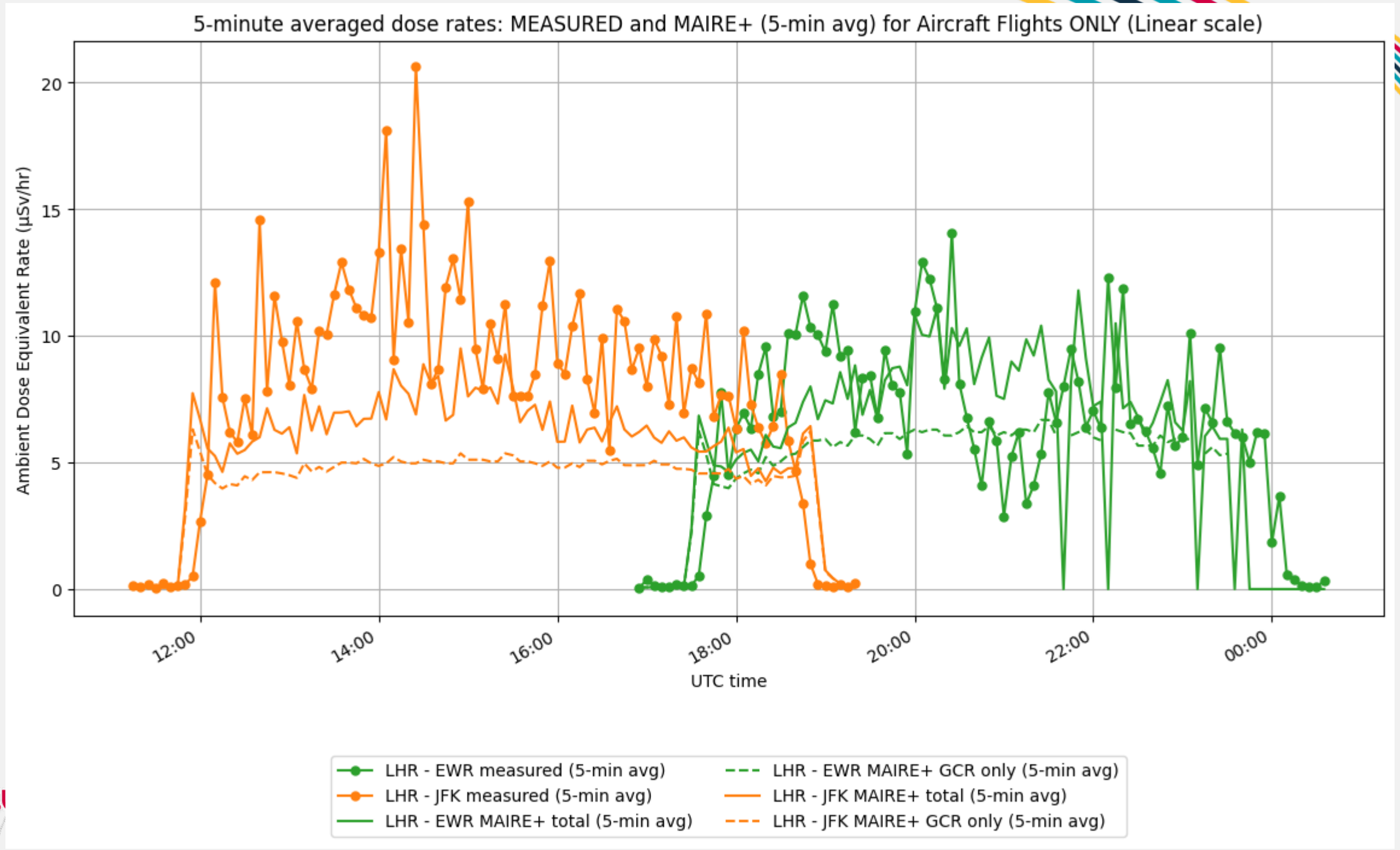
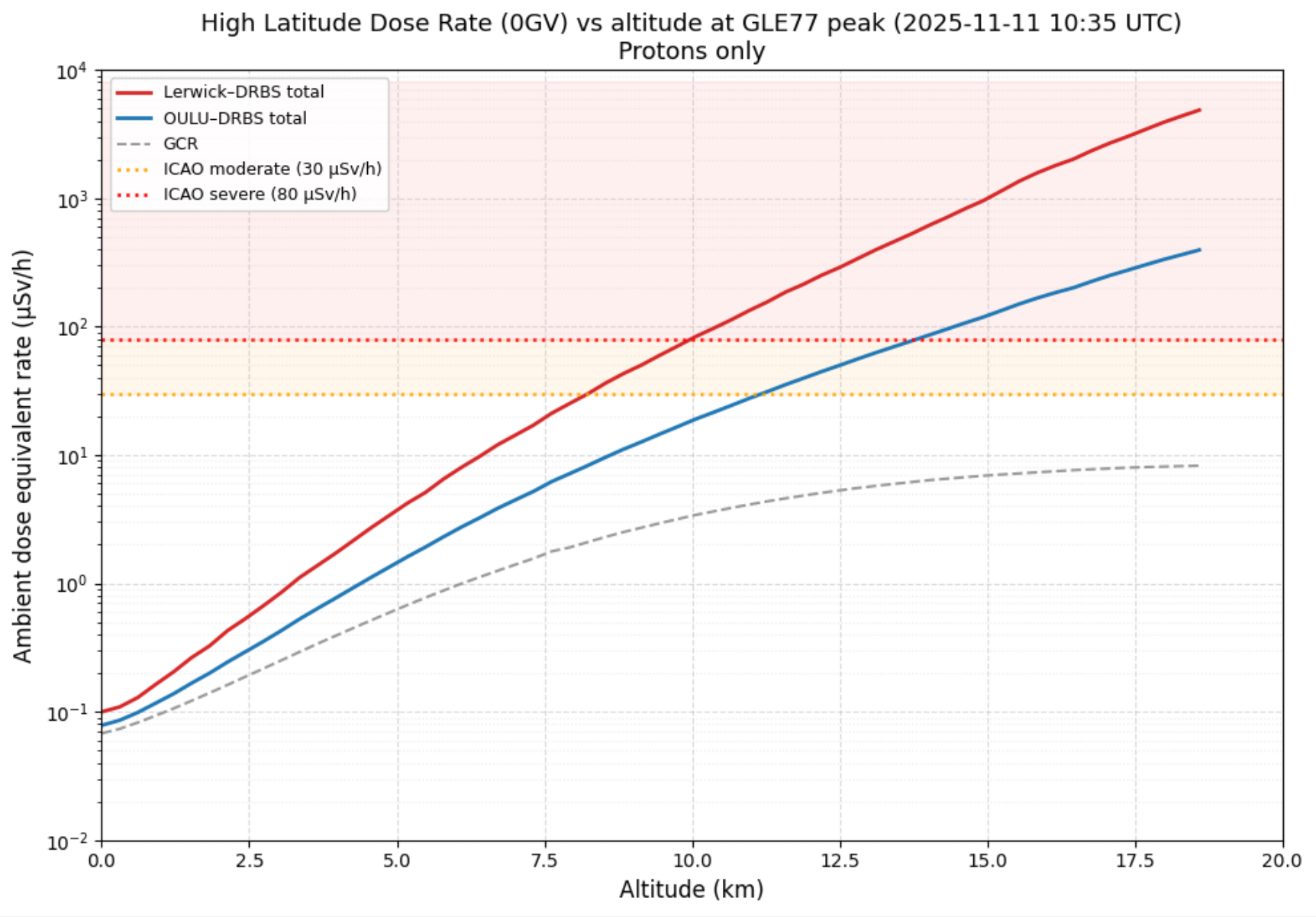
USING LERWICK NM GIVES BETTER FIT



Note 40000feet reached around 1200UT when event decayed by factor 4. Implies 80 microSv per hr above Lerwick at 1 GV cut-off

SURREY SPACE CENTRE


5-minute averaged dose rates: MEASURED and MAIRE+ (5-min avg) for Aircraft Flights ONLY (Linear scale)
Ambient Dose Equivalent Rate (µSv/hr)
0
5
10
15
20
12:00
14:00
16:00
18:00
20:00
22:00
00:00
UTC time
LHR - EWR measured (5-min avg)
LHR - JFK measured (5-min avg)
LHR - EWR MAIRE+ total (5-min avg)
LHR - EWR MAIRE+ GCR only (5-min avg)
LHR - JFK MAIRE+ total (5-min avg)
LHR - JFK MAIRE+ GCR only (5-min avg)



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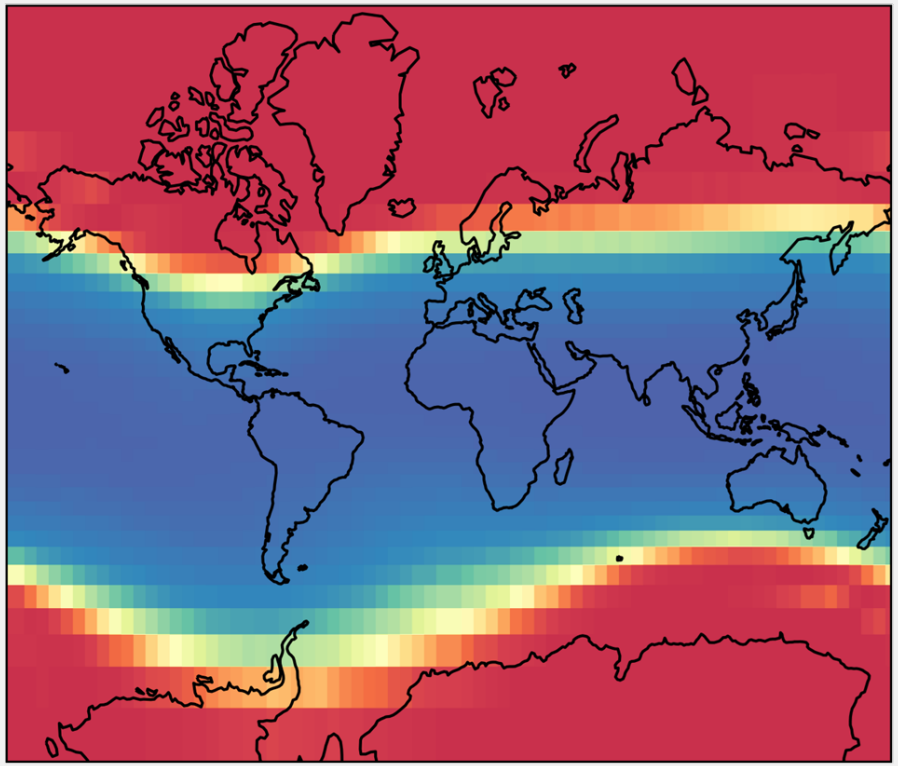
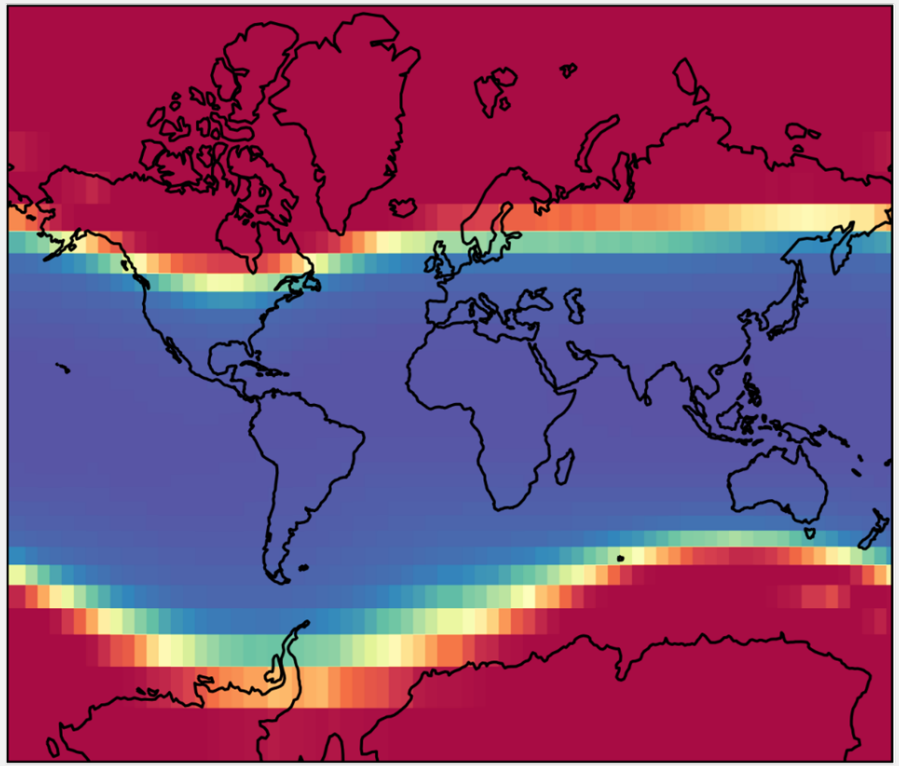
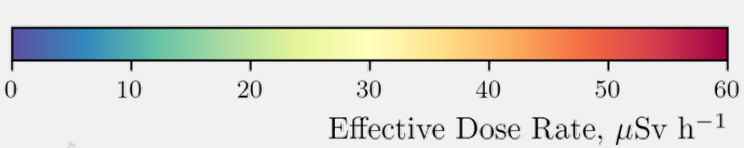
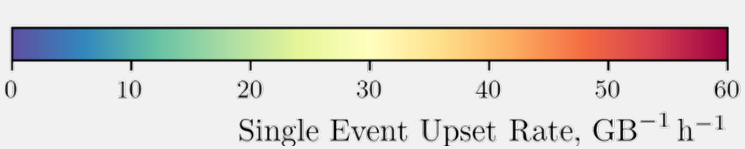
MAIRE-S SHOWS NEARLY60AT40KFT, 80 AT 43KFT









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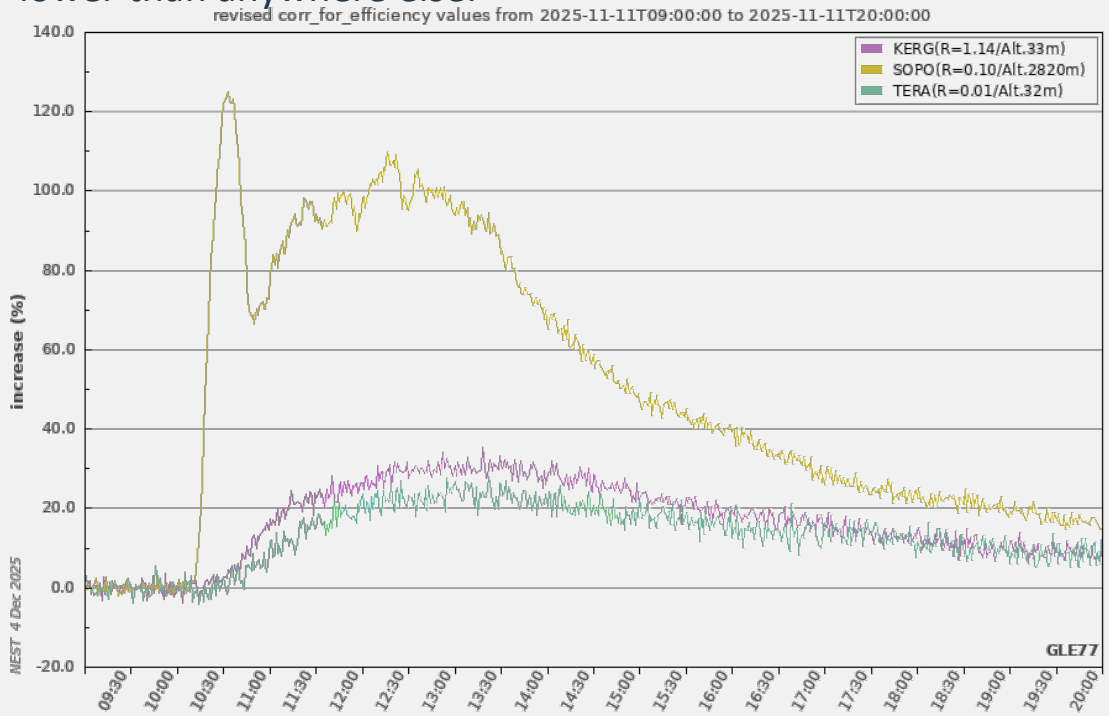
PRELIMINARY DATA

ICAO PROBLEMS

No RAD warnings!

ACFJ on duty maybe use NMs in Southern Hemisphere and/or not well connected to anisotropy

- lower than anywhere else.



2025-11-11 10:49:00

```
FNXX02 YMMC 111049
SWX ADVISORY
DTG: 20251111/1049Z
SWXC: ACFJ
ADVISORY NR: 2025/241
NR RPLC: 2025/240
SWX EFFECT: HF COM MOD
OBS SWX: 11/1043Z NO SWX EXP
FCST SWX +6 HR: 11/1700Z NOT AVBL
FCST SWX +12 HR: 11/2300Z NOT AVBL
FCST SWX +18 HR: 12/0500Z NOT AVBL
FCST SWX +24 HR: 12/1100Z NOT AVBL
RMK: EVENT UPDATE. END OF HF COM
(SOLAR FLARE) EVENT.
NXT ADVISORY: NO FURTHER ADVISORIES =
```

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PRELIMINARY CONCLUSIONS

- GLE 77 was ICAO SEV at 43 kft near UK North Coast
- Very anisotropic and probably RAD SEV at lower altitudes over NE America, North of Shetland, Greenland. NO ICAO ADVISORIES!!
- Use of centres needs total rethink!
- Might get more events this cycle.
- Need world coverage of GLNMS. Classic NMs too expensive but use of existing COSMOS tubes worldwide could quadruple coverage! A study using these is in hand.
- Improve MAIRE- use Lerwick, Camborne plus other pairs. Develop fast anisotropic model.
- Alternatively onboard monitors on all aircraft. Instant information
- Need for rapid and accurate dissemination to pilots!
- Anomaly reporting essential. No-fault-founds need neutron testing.
- Will probably take another solar cycle. Meanwhile AR scale would help??

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ATMOSPHERIC RADIATION SCALE WOULD HELP

19 Jan 2026
Event AR0 but S4

11Nov 2025 event
AR2/3 but S2

May 2024 event
GLE 4%, AR0 and S2, Extreme geomag storm.

Scale	Name	Potential Effects	Physical Measure	Average Frequency
AR5	Extreme	**Airflight:** 7 mSv per hr. European aircrew will exceed annual dose limits in 1-2 hours (route dependent). SEE rates at altitude at 4176 per Gbyte-hr. Avionic system errors are highly likely to occur regularly/continuously *Avoidance action should be mandatory* **Safety Critical Infrastructure :** Electronic system problems at ground level (SEU rates 2.7 per Gbyte-hr).	1xFeb56. 5000% increase in GLNM + >500 MeV protons at 240 pfu	Every 50 to 70 years
AR4	Severe	**Airflight:** 3.5 mSv per hr. Major contribution to annual crew dose. Passengers will exceed annual dose limits (1mSv, 0.5 mSv for pregnancy), European crew are likely to exceed annual limits in a single flight. Avionic system errors are likely to significantly increase. SEU rates at altitude at 2087 per Gbyte-hr. *Avoidance action highly recommended* **Infrastructure:** Possible electronic system problems at ground level (SEU rate 1.4 per Gbyt-hr).	0.5xFeb56. 2500% increase in GLNM + >500 MeV protons at 120 pfu	Every 30 years
AR3	Strong	**Airflight**: 700 µSv per hr. Passengers likely to exceed annual dose limits (1 mSv). Significant addition to crew dose limit. SEU rates at altitude at 418 per Gbyte-hr. *Avoiding action if possible. Maybe add to ICAO levels with new nomenclature for consistency.*	0.1xFeb56. 500% increase in GLNM + >500 MeV protons at 24 pfu	1 per 12 years
AR2	Moderate	**Airflight**: 80 µSv per hour. *Current ICAO Severe*. Change nomenclature. Add to annual records. Close to limits for pregnancy (FAA 0.5mSv per month) for 7 hr flight if no avoiding action. SEU rates at altitude at 42 per Gbyte-hr. *Strongly consider avoiding action*	0.01xFeb56. 50% increase in GLNM + >500 MeV protons at 2.4 pfu	1 per 3 years
AR1	Minor	**Airflight**: 30 µSv per hr (@40 kft and < 1GV for all ARs). *Current ICAO Moderate*. No dose limits exceeded but add to annual dose records. SEU rates at altitude at 13 per Gbyte-hr. *No satellite launches. (AR1>)*	0.003xFeb56. 18% increase in GLNM + >500 MeV protons at 0.8 pfu	1 per year

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Comparison between Exercise and GLE77 real event

1. ICAO SEV applies to both
2. Exercise allows 3-hour build-up to S4 and takes this as ICAO SEV.
3. GLE77 was ICAO SEV but only S2.
4. GLE77had very rapid rise and most radiation in first 2 hours.
5. Exercise presumed isotropic radiation and levels dependent only on geomagnetic latitude/cut-off rigidity.
6. GLE77 very anisotropic and complex.
7. **Real events are more like GLE77 than the exercise; E.g. GLE77, GLE69, GLE05**
8. In reality how do we analyse in real-time and get information to the pilot

SPACE WEATHER / RADIATION

DANGER TO MODERN ELECTRONICS

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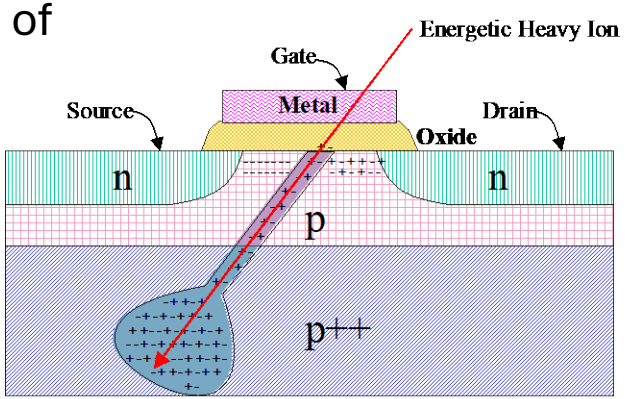
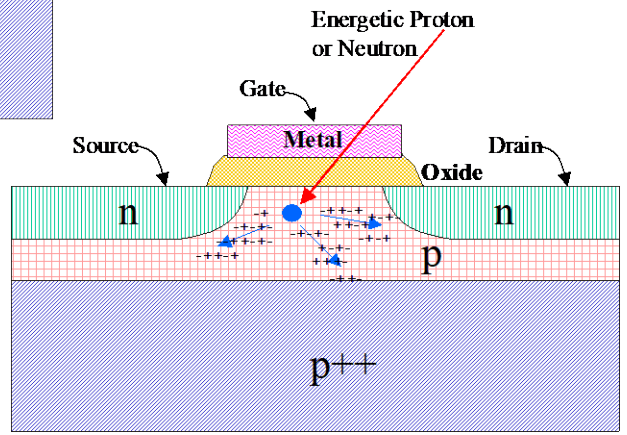
Single Event Effects

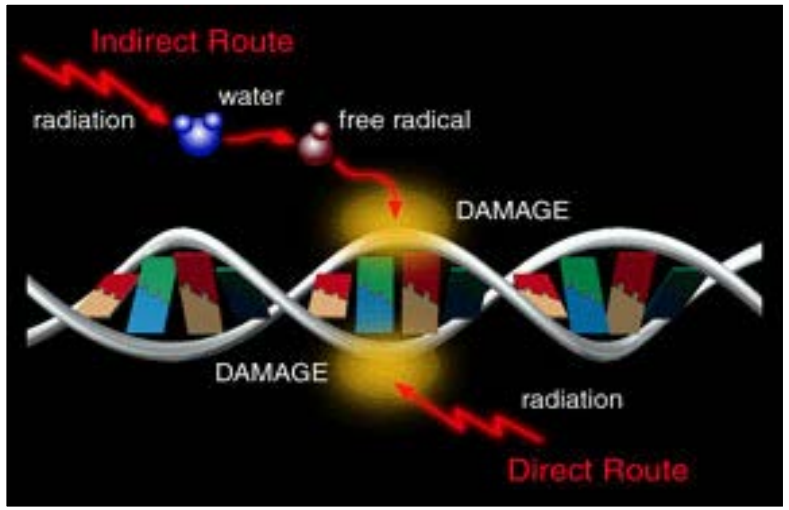
- SEE result from charge depositions of individual particles and include:
  - Upsets (bit-flips),
  - Multiple bit upsets
  - Transients
  - Functional Interrupts,
  - Latchup,
  - Burnout,
  - Gate rupture,
  - Dielectric failure,
  - DNA rupture



Direct Ionization

Nuclear Reactions





Airflight Experience of SEE

.Cosmic Radiation Effects & Activation Monitor flown on Concorde between 1988 & 1992, and on SAS in 1993. 5 solar particle increases seen.

• PERFORM computer withdrawn for tests in 1991 following accumulation of errors in SRAM memory.

• More than one upset per flight in 280 64K SRAMs on Boeing E-3 AWACS and NASA ER-2.

• Autopilot design altered after faults (every 200 flight hours) shown to correlate with altitude and latitude.

• Saab CUTE experiment in 1996 showed upset every 200 flight hours in 4 Mbit SRAM. 2% are multiple-bit upsets.

• At least 3 major equipments with latchup problem. Possible cause of smoke in cockpit.

• Probably implicated in QF72 accident in October 2008 when aircraft twice dropped several hundred feet.

•Recent Airbus A320 grounding probably from cosmic ray.

•Numerous pitch-down incidents- is there electronic turbulence?

Mitigation Techniques

- Parts selection by irradiation testing
- Facilities with atmospheric neutron spectrum
  - ChipIR in UK; TRIUMF in Canada, LANL, Japan etc
- By software -EDAC, Scrubbing etc
- By redundancy, majority voting
- Given lack of standards for space weather
  - Flight path alteration (lower altitude, latitude)
  - Grounding in extreme events
  - Needs accurate nowcast and rapid communication.
  - On board monitors visible to pilot

EASA Proposed CM - AS – 004 Issue: 01
Single Event Effects (SEE) Caused by Atmospheric Radiation

- Extreme space weather includes the effects of solar flares which can result in large bursts of solar particles arriving in the atmosphere creating an increase in atmospheric radiation of short duration (order of hours). During solar flare activity, the atmospheric radiation may rise to significantly higher levels than that normally expected and could increase by a factor of 300 or more (see document IEC62396-1, Section 5.6). This Certification Memorandum considers the **normal** atmospheric radiation levels, which could be experienced during a typical flight, and not those which could be experienced during a solar flare. It is expected that some prior notification of high solar activity, and thus possible solar flares, will be available to the operator of an aircraft via solar weather information websites. This should result in operational limitations relating to the routing of the flight (i.e. avoiding high latitudes). Further information regarding extreme space weather can be found in the following report: *Extreme Space Weather – Impacts on Engineered Systems and Infrastructure. Royal Academy of Engineering – February 2013 and EASA Safety Information Bulletin SIB No. 2012-09 Effects of Space Weather on Aviation.*

: AIRBUS ISSUES

AIRBUS

Press Release

Airbus update on A320 Family precautionary fleet action

Toulouse, France, 28 November 2025 – Analysis of a recent event involving an A320 Family aircraft has revealed that intense solar radiation may corrupt data critical to the functioning of flight controls.

Airbus has consequently identified a significant number of A320 Family aircraft currently in-service which may be impacted.

Airbus has worked proactively with the aviation authorities to request immediate precautionary action from operators via an Alert Operators Transmission (AOT) in order to implement the available software and/or hardware protection, and ensure the fleet is safe to fly. This AOT will be reflected in an Emergency Airworthiness Directive from the European Union Aviation Safety Agency (EASA).

Airbus acknowledges these recommendations will lead to operational disruptions to passengers and customers. We apologise for the inconvenience caused and will work closely with operators, while keeping safety as our number one and overriding priority.

EASA issues Emergency Airworthiness Directive for Airbus 320 family

28 Nov 2025

SUGGESTED

EASA has issued an Emergency Airworthiness Directive (EAD) for the Airbus A320 family to address a susceptibility introduced by a software update in one of its onboard computers.

The EAD addresses an issue which manifested itself in an event on JetBlue flight 1230 on October 30, 2025.

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HISTORY

- Have similar events been reported before? Some evidence from voluntary reporting in NASA Aviation Safety Reporting System (ASRS). Maybe 3 other cases since 2004. Could be the tip of a large iceberg?
- Are there mandatory formal reports to EASA, FAA etc?
- Who is performing accident investigation and where/when will it be published?
- Captain Kevin Sullivan, who saved QF72 and suffered PTSD in 2008, sees the similarity and suggests AIRBUS have created a smokescreen and should answer questions.
- Need for avionics standards to include space weather and for neutron beam testing of safety-critical systems!

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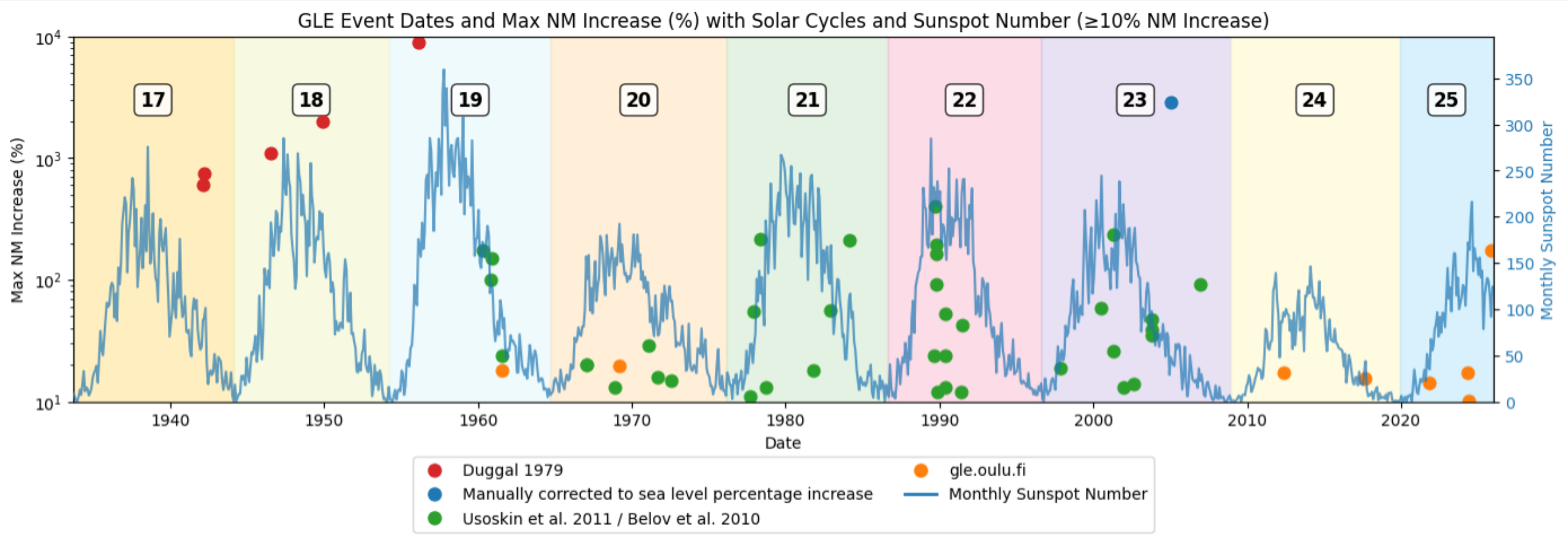
HISTORY OF GLES > 10%



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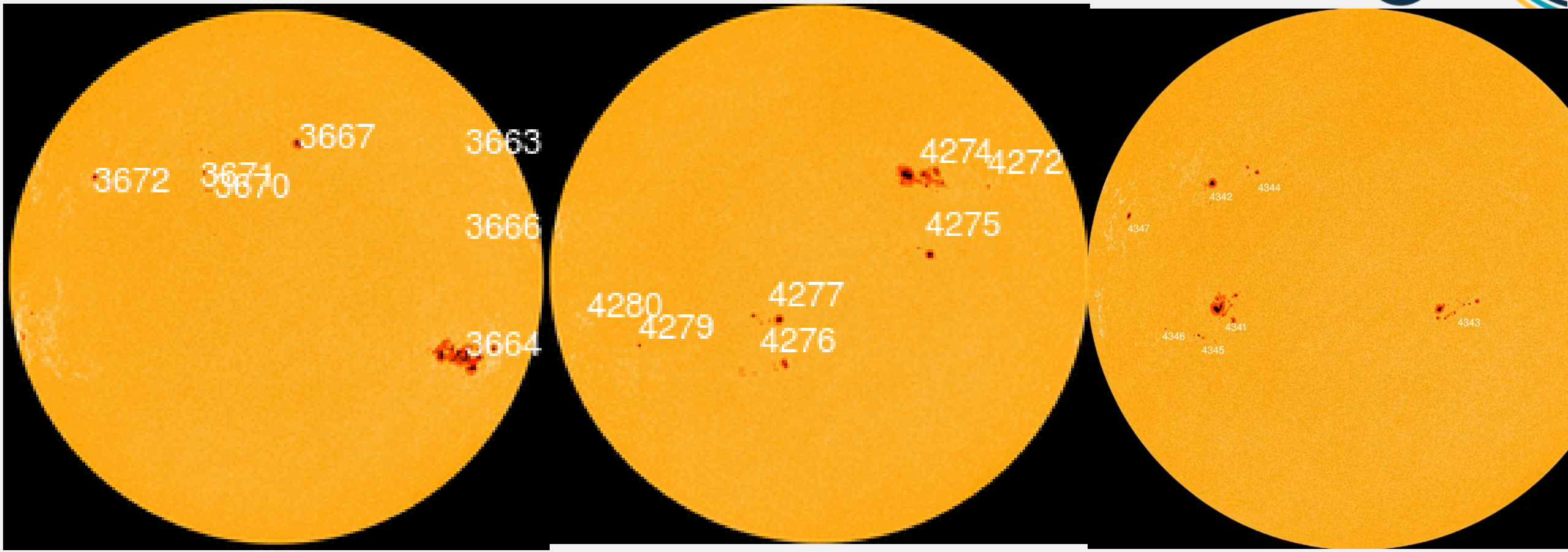
HOW DO WE PREDICT IN TIME FOR ACTION



May 2024 Nov 2025 Jan 2026

Spot the upcoming GLE! For the foreseeable future rapid nowcasting is best we can do.

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