

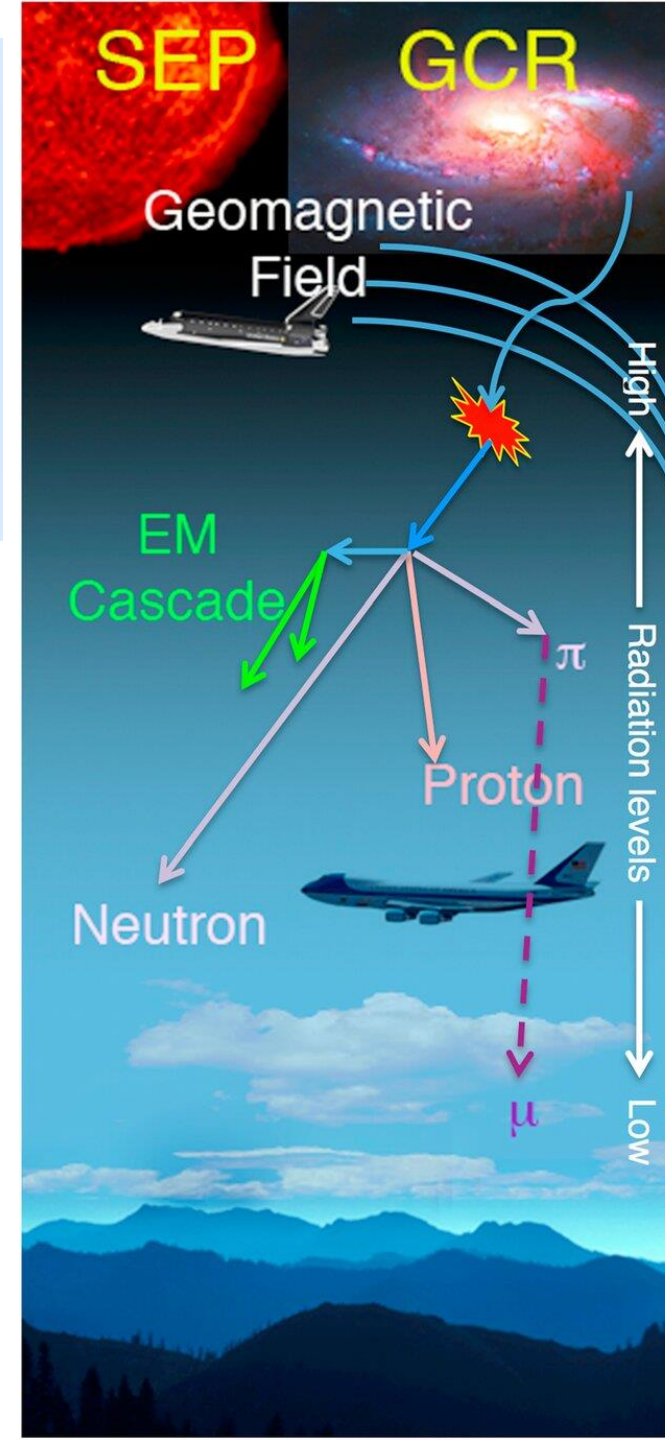
Radiation Impacts on Aviation

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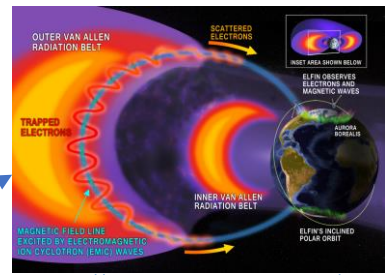
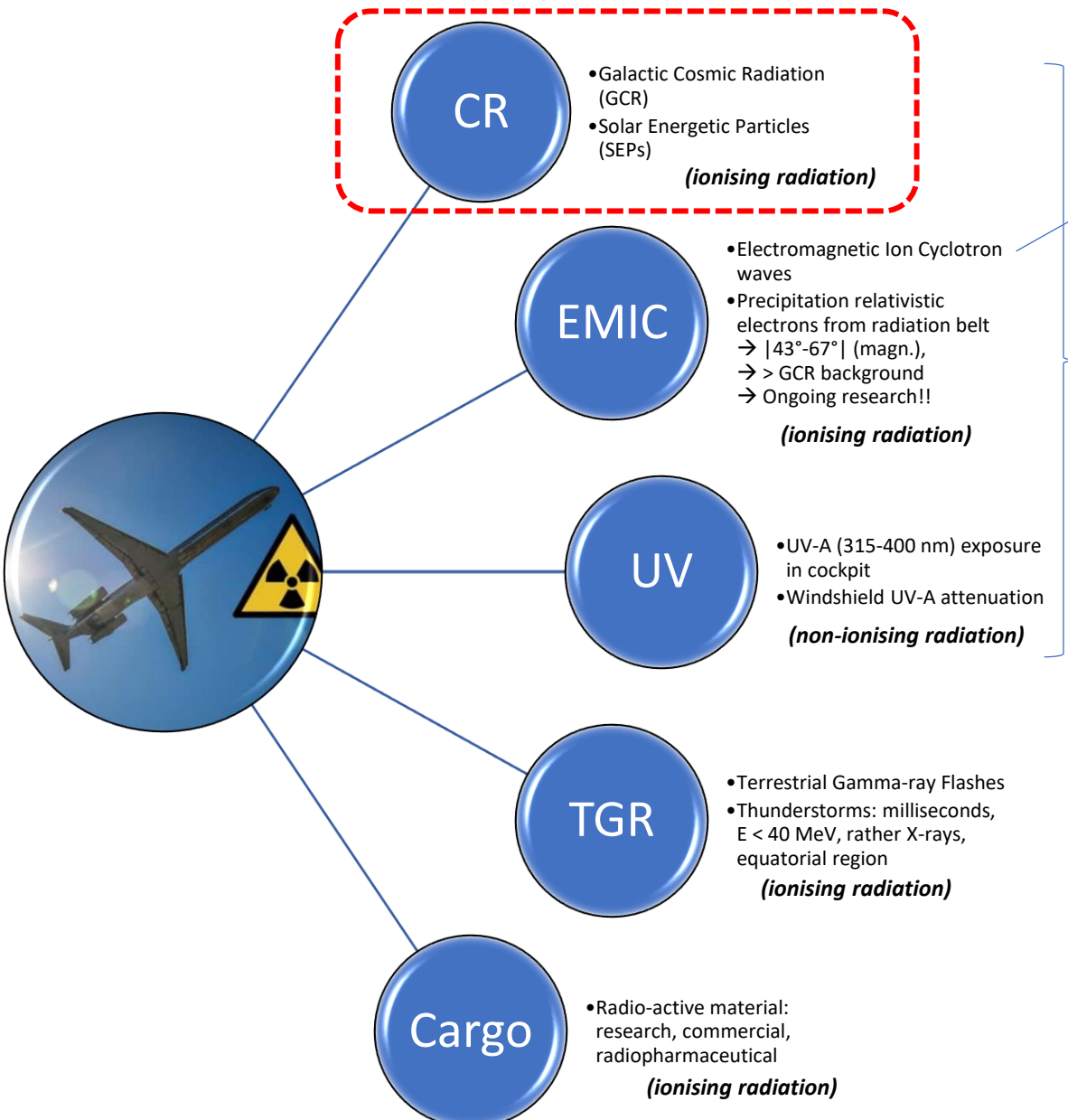
- Radiation sources
- Impacts
- Mitigation measures



SWIC 05/12/2024



Radiation sources producing 'Atmospheric radiation'



<https://spaceweatherarchive.com/2018/09/20/student-built-space-weather-satellite-targets-killer-electrons/>

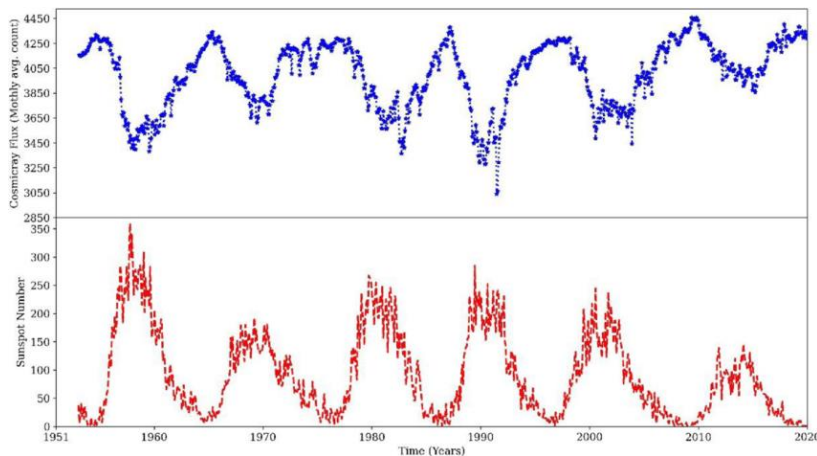
Space component

Primary cosmic radiation: GCR and SEP

Galactic Cosmic Radiation (GCR)

- Origin outside solar system (SNe, AGN, ...)
- Isotropic (equally from all directions)
- **ALWAYS PRESENT**
- High energetic fully ionized atomic nuclei (89% p⁺, 10% He, 1% Z>2)
- Modulated by sun's magnetic field (IMF): min. at solar max – max. at solar min. (~factor 2-3)

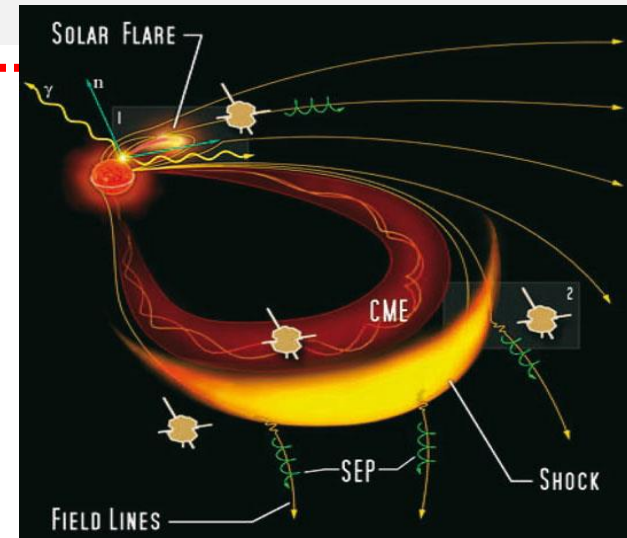
→ ~8 μSv/h @12 km



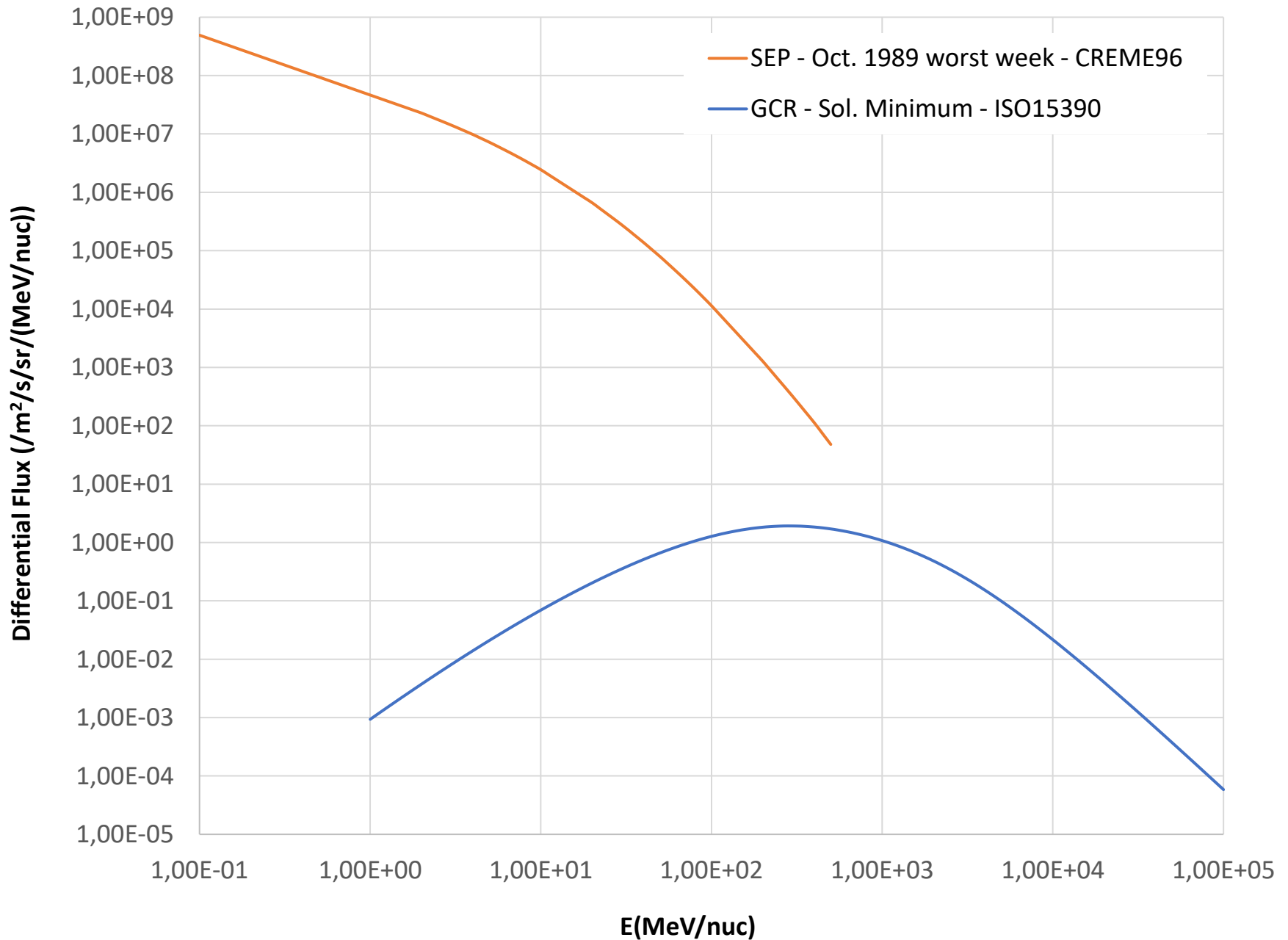
Solar Energetic Particles (SEP)

- Origin in solar flares and Coronal Mass Ejections (CME's)
- ~15-20 min to reach Earth, difficult to predict
- **SPORADIC**
- Similar composition as GCR with mainly protons
- Observed on the ground as Ground Level Enhancements (GLE) preceded by Forbush Decrease (FD)

→ ~3000 μSv/h @12 km



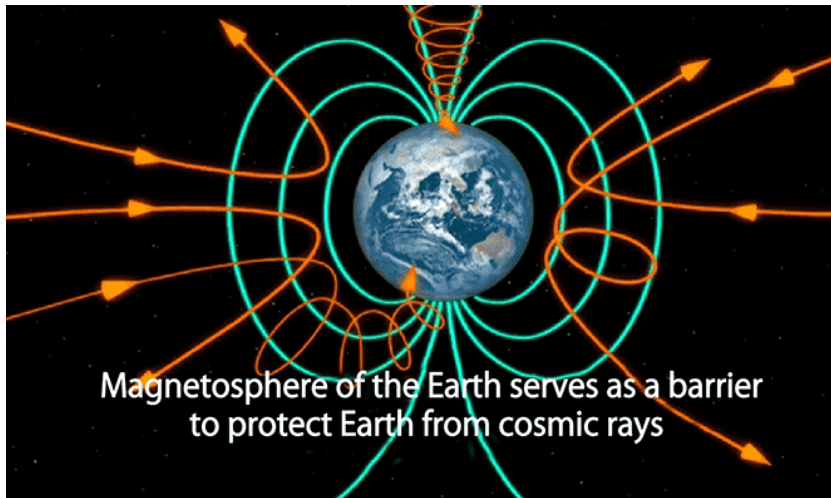
SEP vs. GCR energy flux spectrum at 1 AU



Magnetic shielding – rigidity cutoff (R_c)

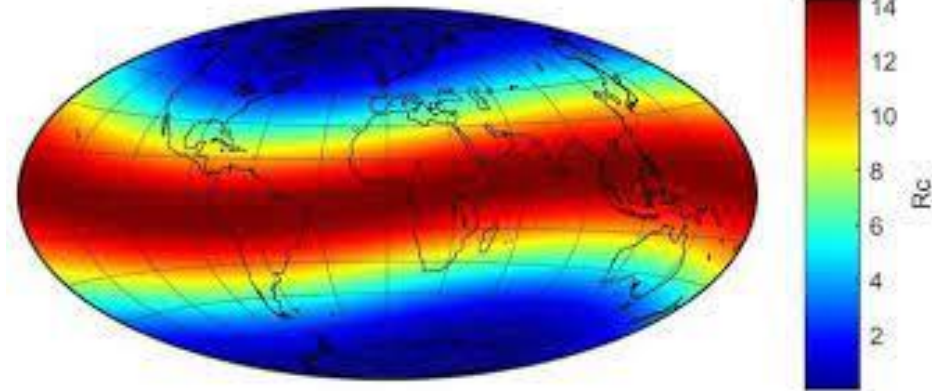
Particles are deflected by magnetic field depending on:

- Particle energy
 - Particle electric charge
 - Arrival direction w.r.t. orientation magnetic field line
- } **Rigidity “R”**



(Ref. <https://swc.nict.go.jp/en/knowledge/magnetosphere.html>)

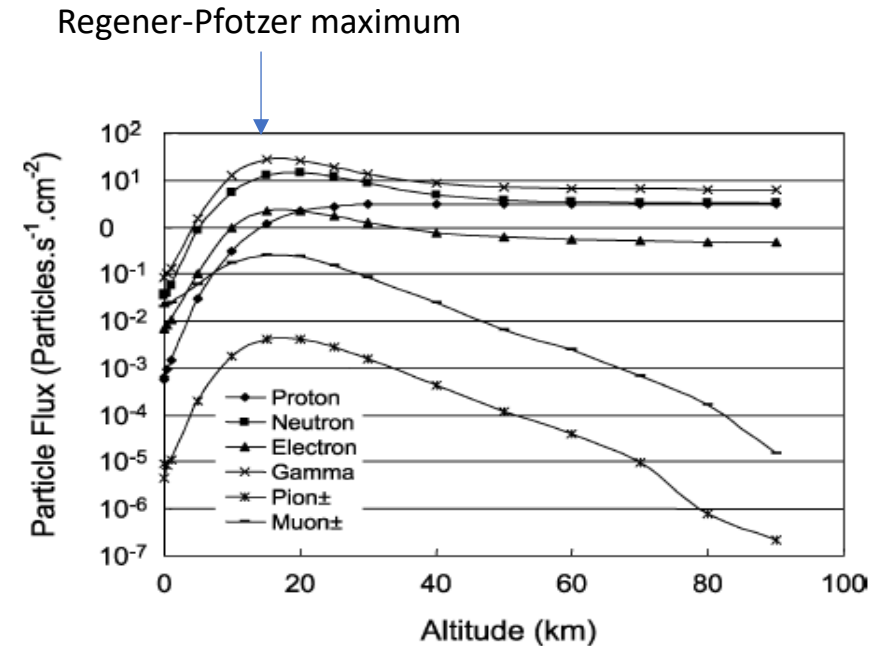
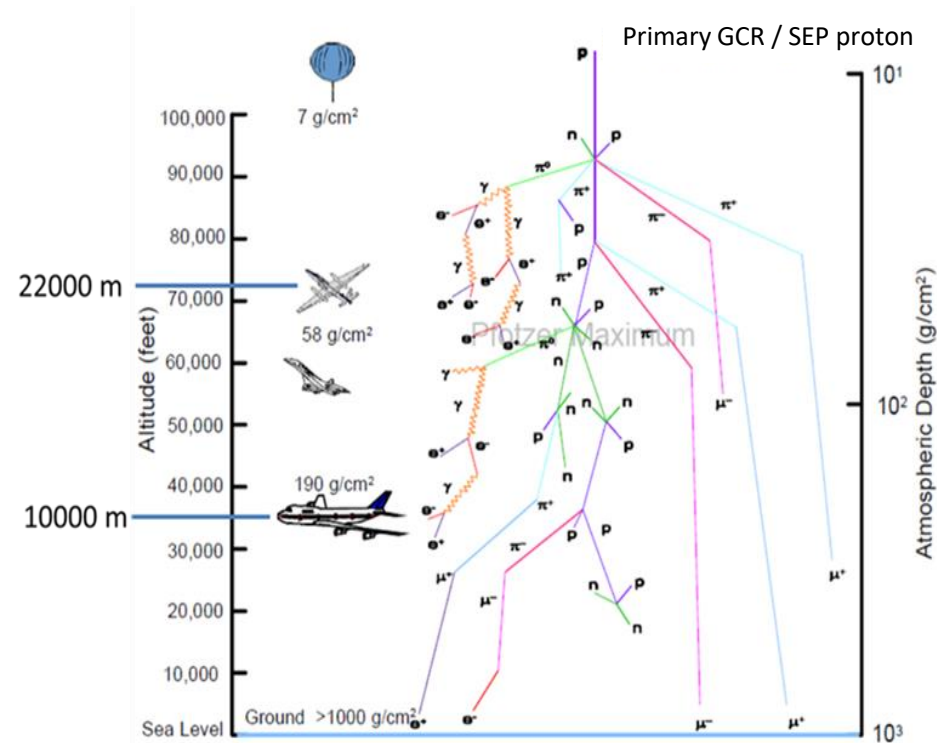
(Ref. E.S. Comedi et al., 2020)



→ Can change during geomagnetic storms!!

- Particles are more deflected towards the equator
- Radiation dose is higher at higher latitudes

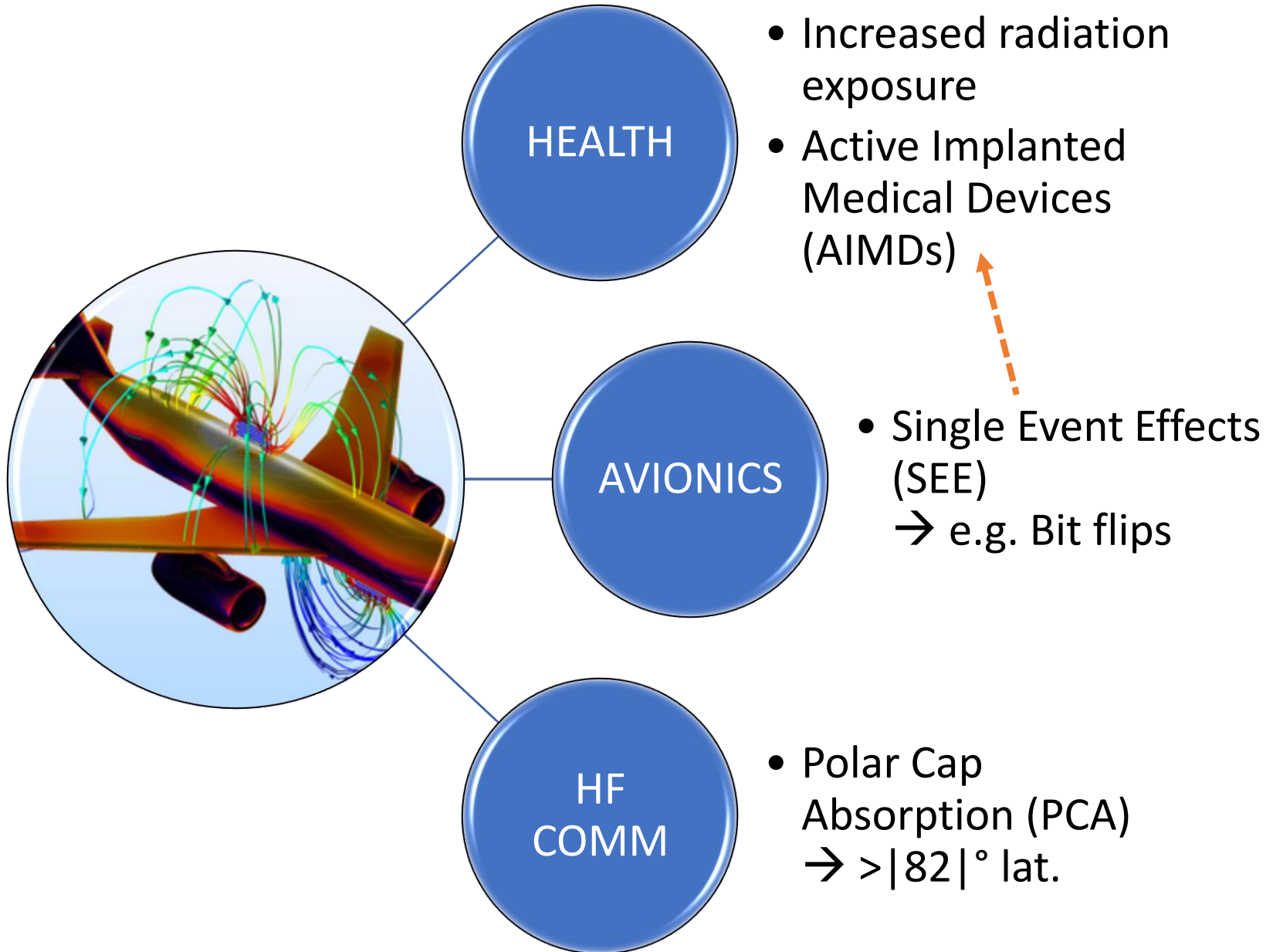
Atmospheric shielding – air showers



(Ref. Lei et al. 2004)

- The radiation increases with increasing flight altitude
- Normal conditions: radiation at flight level ~50-100 x radiation at sea level

Radiation impacts at flight level



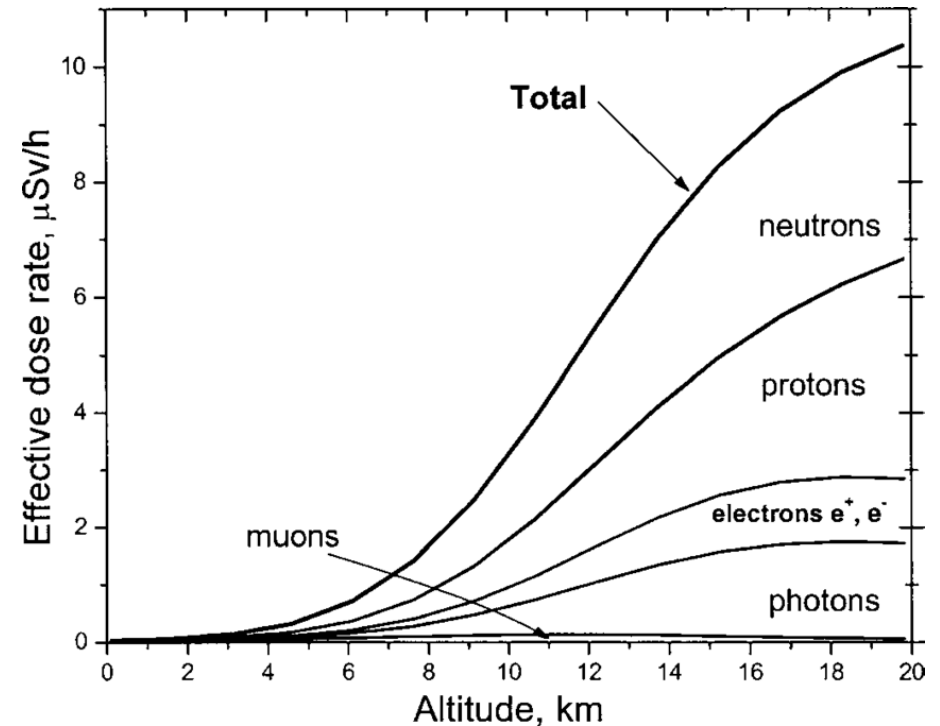
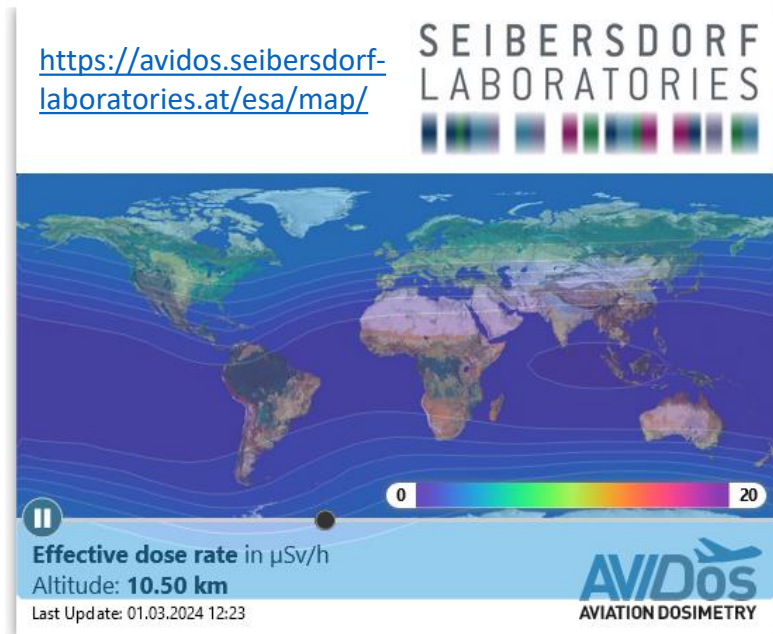
Radiation dose - Effective Dose

→ Calculated quantity used to assess the probability for radiation induced cancer and other genetic effects

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} \quad (\text{Sievert} = \text{Sv} = \text{J/kg})$$

tissue weighing factor radiation weighing factor absorbed dose by tissue T due to radiation type R

AVIDOS tool (AVIation DOSimetry)



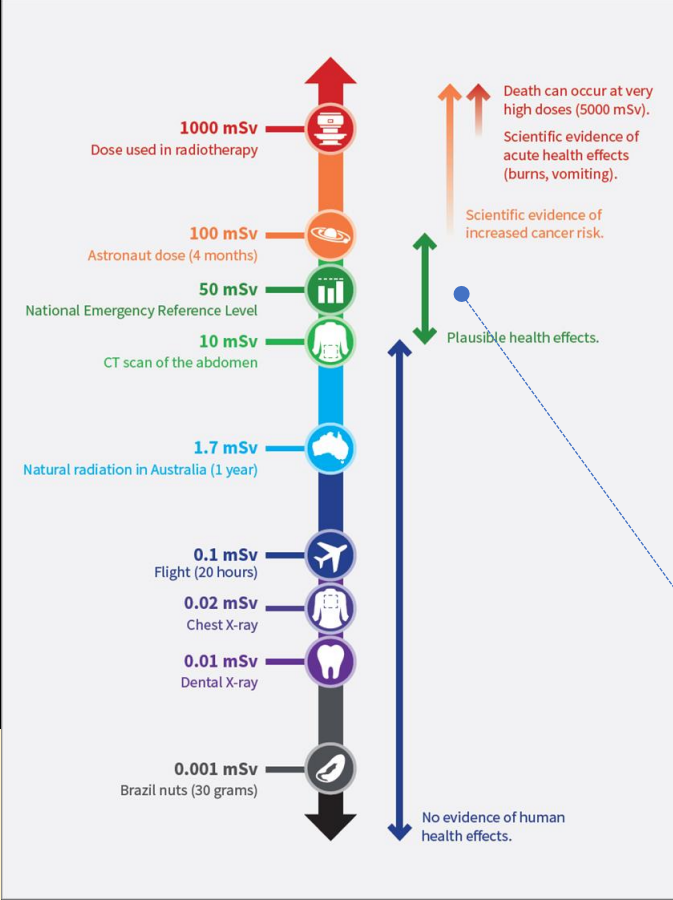
(Ref. P. Bilski et al., 2004)

How much radiation from air travel?

In general, **low** but it depends on:

- **Duration of the flight**
 - Longer → more radiation
- **Altitude**
 - Higher → more radiation
- **Latitude**
 - Closer to the poles → more radiation
- **Solar activity**
 - Higher solar activity → less radiation from GCR but more if strong SEP/GLE (>200-500 MeV)

Harvard T.H. Chan school of public health: crews of aircraft have higher rates of cancer than the general population



<https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/ionising-radiation-and-health>

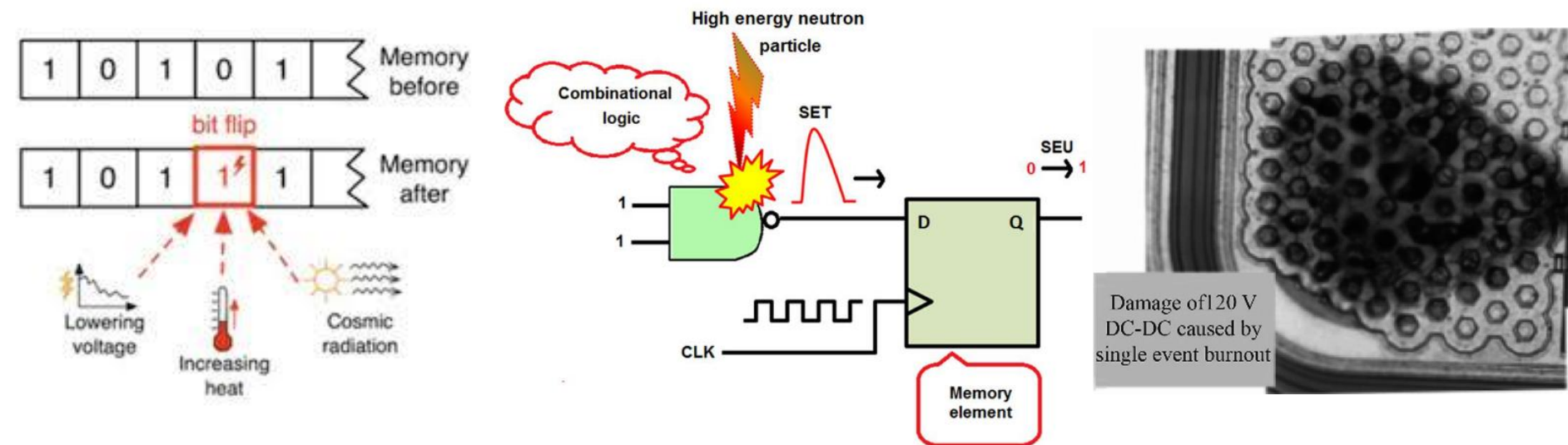
GLE	Date	Max. E [$\mu\text{Sv h}^{-1}$]	E_{GCR} [$\mu\text{Sv h}^{-1}$]
5	23.02 1956	2977	6.9
8	04.05 1960	57.3	5.0
10	12.11 1960	12.1	5.2
11	15.11 1960	140.5	5.2
13	18.07 1961	13.7	5.4
16	28.01 1967	15.8	6.4
19	18.11 1968	11.4	5.3
22	14.01 1971	25.1	6.2
25	07.08 1972	7.8	6.4
29	24.09 1977	8.8	7.3
30	22.11 1977	15.5	7.7
31	07.05 1978	35.4	6.4
32	23.09 1978	8.1	7.2
38	08.12 1982	22.4	4.7
39	16.02 1984	13.5	6.1
41	16.08 1989	10.8	5.0
42	29.09 1989	92.7	4.8
43	19.10 1989	41.9	4.5
44	22.10 1989	92.5	4.5
45	24.10 1989	61.0	4.5
47	21.05 1990	12.0	4.3
48	24.05 1990	17.0	4.3
51	11.06 1991	6.0	3.5
52	15.06 1991	11.2	3.5
55	06.11 1997	19.9	7.5
59	14.07 2000	48.1	4.9
60	15.04 2001	51.3	5.3
61	18.04 2001	9.0	5.3
65	28.10 2003	12.4	5.4
67	02.11 2003	15.6	4.6
69	20.01 2005	3592	5.9
70	13.12 2006	78.2	7.4
71	17.05 2012	32.9	7.2

(Tuohino et al., 2018 - ~11 km, $R_c < 1$ GV)

<https://oxsci.org/the-little-known-risk-of-cosmic-radiation-in-air-travel/>

Single event effects in avionics onboard airplane

- Single particle can deposit charge in sensitive volume of semiconductors and create transient pulses in logic or support circuitry, or as bitflips in memory cells or registers
- Soft (non-destructive) and hard (destructive) errors



Examples of possible impacts:

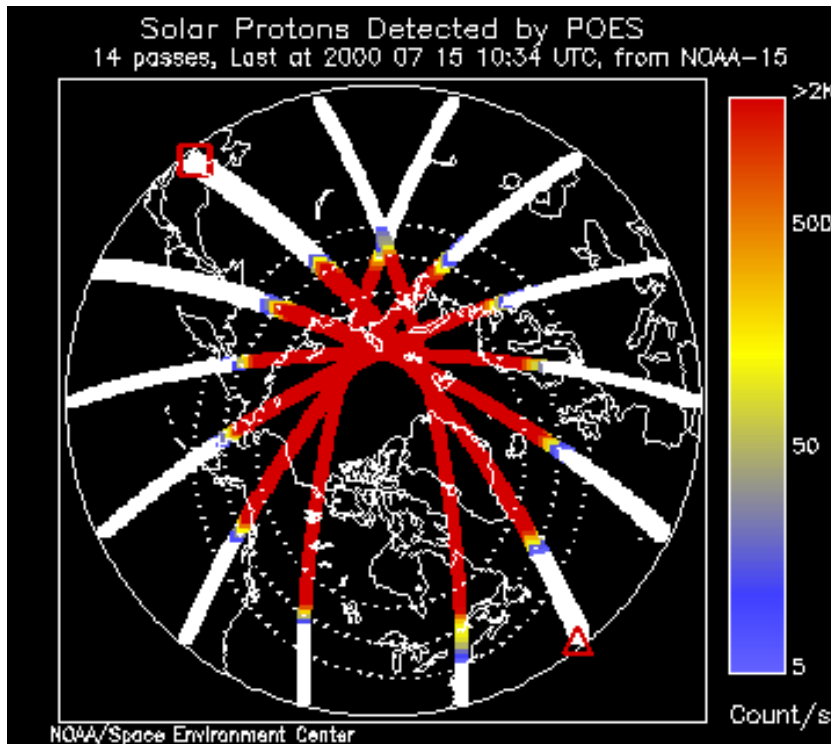
- Qantas airliner Flight 72 (2008): dropped ~300 feet all of a sudden due to erroneous computer data in the on-board systems misinterpreted the angle at which the aircraft was flying, causing two automated nose-dives
- Bit flips in medical devices (e.g. pacemaker, defibrillator, insuline pumps, ...)

<https://www.bbc.com/future/article/20221011-how-space-weather-causes-computer-errors?ocid=ww.social.link.email>

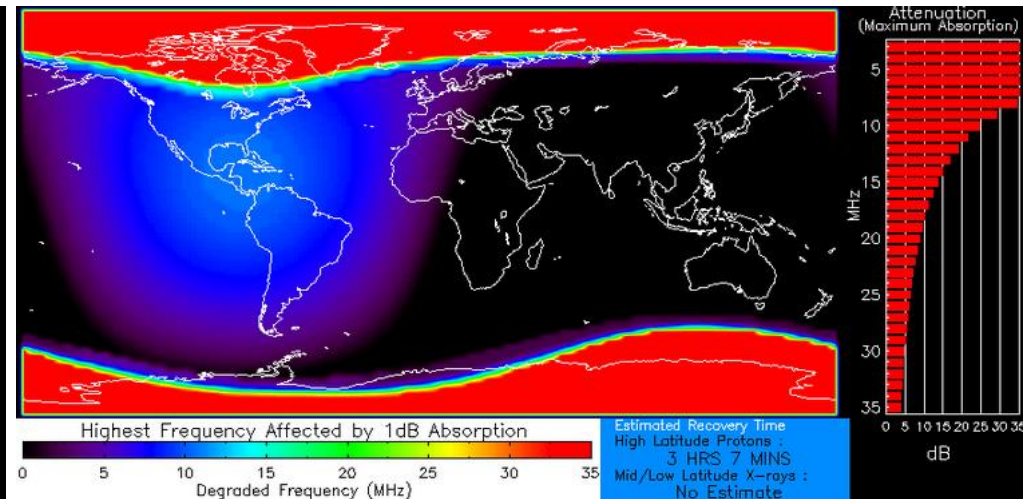
Polar Cap Absorption (PCA) during SEP events

During SEP events, high energy protons (>10 MeV) spiral along the Earth's magnetic field lines towards the polar ionosphere's D-region (50-90 km) (= proton precipitation)

- Significant increased ionization levels
- Severe absorption of HF radio waves (3 – 30MHz) used for long-range communication



Precipitating proton flux detected on several passes of the POES NOAA-15 satellite over the north polar region during the solar storm of July 15, 2000. (NOAA Space Weather Prediction Center).



Impact of the solar X-ray flux and SEP events on HF radio communication during the solar storm of 9 May 2023. The plot is generated by the D-Region Absorption Product (DRAP). (NOAA Space Weather Prediction Center).



Mitigation Measures

- Delay of flight if not time-critical (~hours)
- Change of flight route:
 - Lower latitude → geomagnetic shielding ↗
 - Lower altitude → atmospheric shielding ↗
- But:
 - Higher fuel consumption
 - Increased traffic density
 - Not necessarily solution for HF COMM degradation
- In-flight monitoring
- Radiation hardening of avionics + onboard redundancy
- Timely forecast/detection SWx events → ICAO advisories

Aviation community

Science community



“Apparently, flying no higher than 1,000 feet saves air travelers from the perceived ravages of cosmic radiation.”