Economic Impact and Effectiveness of Radiation Protection Measures in Aviation during a Ground Level Enhancement

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Motivation

- Radiation exposure increases with altitude
- Radiation exposure may increase during Ground Level Enhancements (GLE)
- Lowering flight altitudes is a potential mitigation scenario
- Effect of lower flight altitudes during a GLE is not quantified

→ Case study for GLE70
→ Realistic flight pattern, mitigation scenarios (VarMission)
→ Calculation of radiation exposure (PANDOCA)

VarMission - Flight planning tool

- Aircraft performance tool using engine and aircraft models, e.g. from Base of Aircraft DAta (BADA)
- Airbus A330-200 (75% load factor, 270 passenger + 10 tons of cargo)
- Specific range tables depend on weight, flight altitude, Mach number

→ Fuel burn along the flight path

→ Altitude profile

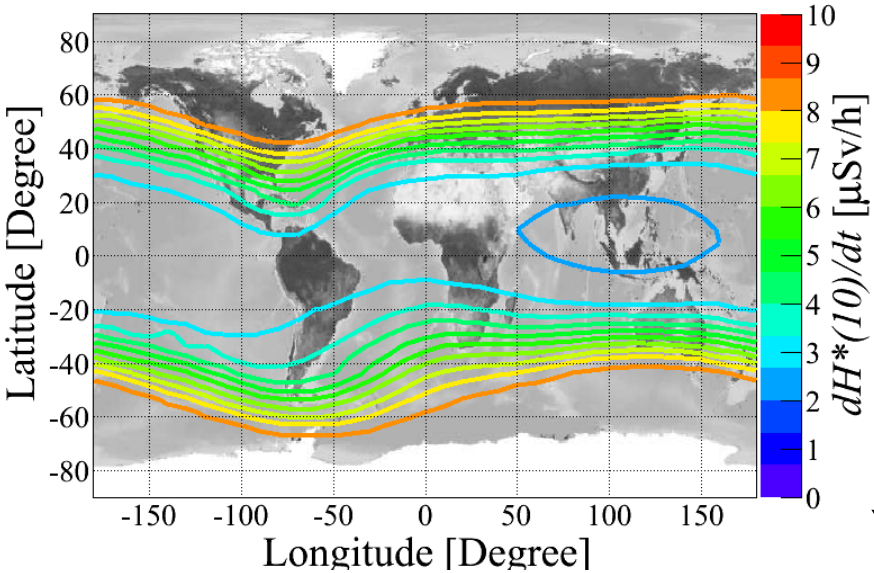
Additional 5% fuel contingency

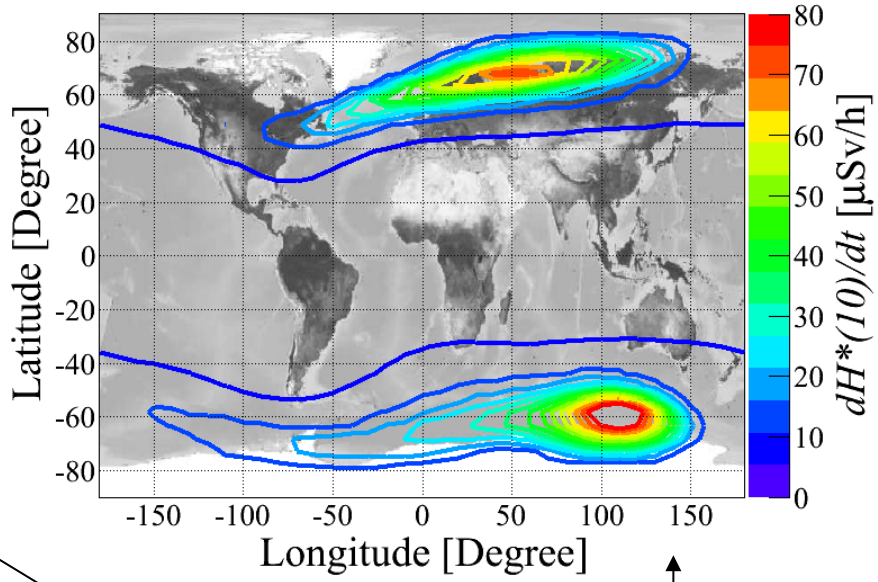
PANDOCA - Calculation of the radiation exposure

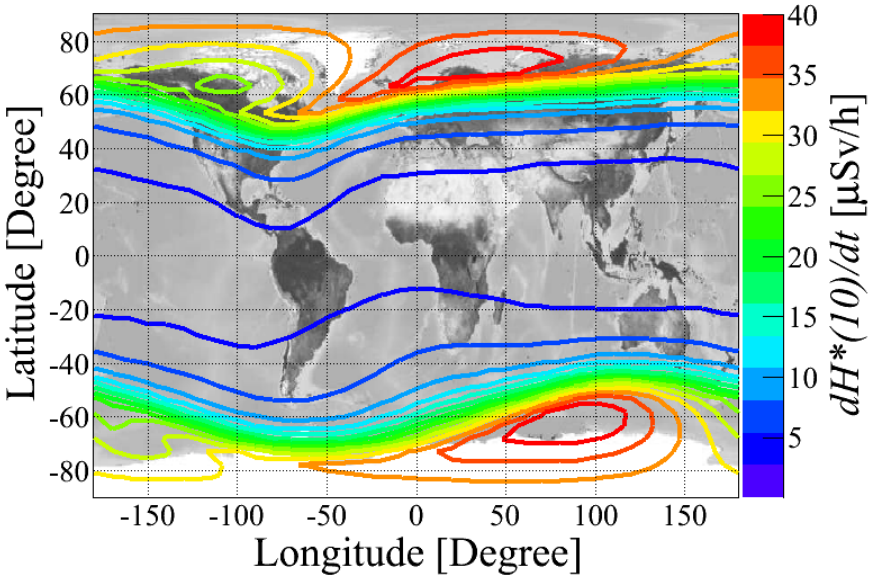
- Primary particle spectra:
  - **Galactic cosmic rays**
  - **Solar energetic particles** (Neutron monitors, GOES)
- Model of the magnetic shielding:
  - effective vertical cut-off rigidity R_C
- Atmospheric shielding / particle transport
  - Monte-Carlo Simulations, GEANT4
  - Calculation of secondary particle flux at arbitrary altitudes
- Conversion of particle fluxes to dose rates:
  - Conversion factors (fluence to dose)
- *Matthiä et al. (2014), Space Weather 12*

→ *POSTER M9, Thursday*

GLE70: Dose rates at FL390 (200 g/cm²)





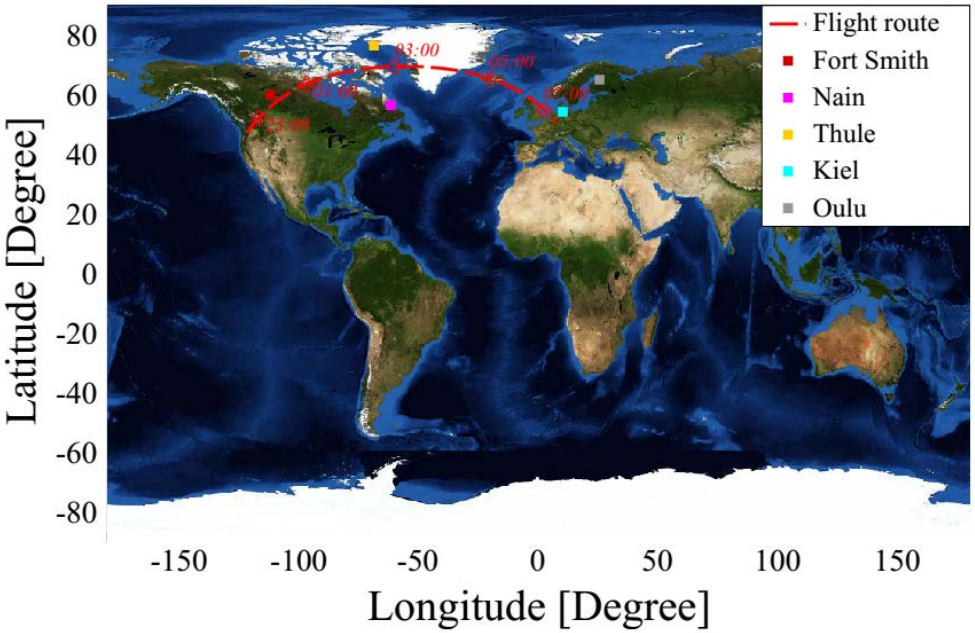


Pre-event

3.05 UTC

3.35 UTC

Mitigation measures during GLE 70, flight from Seattle to Cologne



- Select representative flight during GLE 70
- Seattle (SEA) – Cologne (CGN); departure at 22:00 UTC
- Define mitigation scenarios
  - using 5% fuel contingency
- Calculate the reduction in dose

Mitigation measures during GLE 70, flight from Seattle to Cologne

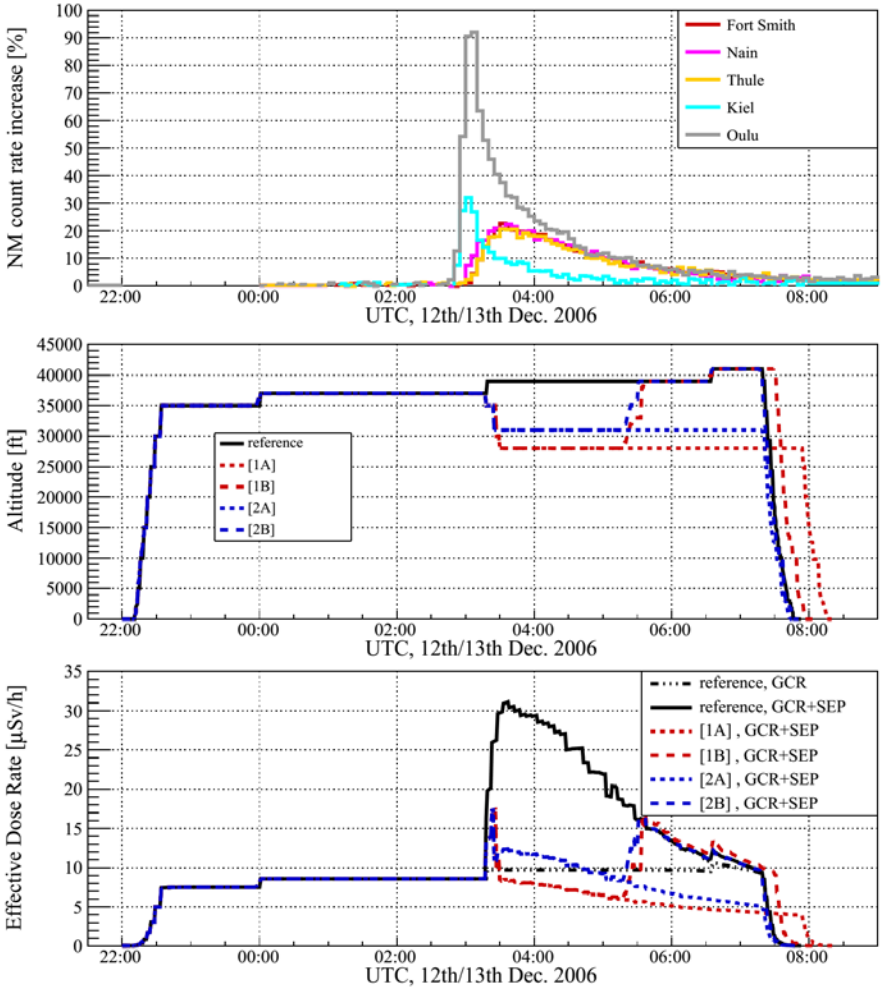


Table 1. Space Weather D-index with corresponding solar dose rate contributions $\dot{E}_{sol}$ given by equation (1).

Index D	Dose rate interval [µSv/h]
D0	$\dot{E}_{sol} < 5$
D1	$5 \leq \dot{E}_{sol} < 10$
D2	$10 \leq \dot{E}_{sol} < 20$
D3	$20 \leq \dot{E}_{sol} < 40$
D4	$40 \leq \dot{E}_{sol} < 80$
D5	$80 \leq \dot{E}_{sol} < 160$
D6	$160 \leq \dot{E}_{sol} < 320$
D7	$320 \leq \dot{E}_{sol} < 640$
D8	$640 \leq \dot{E}_{sol} < 1280$

Meier & Matthiä, J. Space Weather and Space Climate (2014)

- Define mitigation scenarios

  Mach number adapted → delay:
  - [1A] reduce altitude
  - [1B] reduce altitude, return to normal

  Mach number not adapted → no delay:
  - [2A] reduce altitude
  - [2B] reduce altitude, return to normal

Mitigation measures during GLE 70, flight from Seattle to Cologne

Scenario	Effective Dose [µSv]	Ambient Dose Equivalent [µSv]	Fuel Consumption [t]	Flight Duration [h]
GCR (reference)	80.2	67.2	53.9	9.90
GCR+GLE (reference)	119	112	53.9	9.90
GCR+GLE [1A]	68.7 (-42%)	62.7 (-44%)	56.5 (+4.8%)	10.37 (+4.7%)
GCR+GLE [1B]	83.6 (-30%)	74.3 (-34%)	55.2 (+2.4%)	10.06 (+1.7%)
GCR+GLE [2A]	75.2 (-37%)	69.3 (-38%)	56.6 (+5.0%)	9.83 (-0.7%)
GCR+GLE [2B]	87.3 (-27%)	78.9 (-30%)	55.2 (+2.4%)	9.86(-0.3%)

Mach number adapted:
[1A] reduce altitude
[1B] reduce altitude, return to normal

Mach number not adapted:
[2A] reduce altitude
[2B] reduce altitude, return to normal

Summary

- Increase of about 50% in Effective Dose for the reference flight from Seattle to Cologne during GLE70

- Lowering the flight altitude after the onset of the event results in

  - A maximum decrease in total Effective Dose of 42% (77% of SEP dose), +4.8% fuel, ~30 minutes delay
  - No delay, +2.4% fuel → 27% reduction in total Effective Dose (58% of SEP)
  - Temporary reduction of the radiation exposure associated with a decrease from space weather index *D3* to *D0*/*D1 (Poster M9)*

- Appropriate reaction to solar energetic particle events requires accurate information based on sophisticated tools