Radiation Effects on Satellites during Extreme Space Weather Events

Alex Hands[1], Keith Ryden[1], Nigel Meredith[2], Sarah Glauert[2], Richard B Horne[2]

[1]Surrey Space Centre, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom

[2]British Antarctic Survey, High Cross, Madingley Rd, Cambridge CB3 0ET, United Kingdom

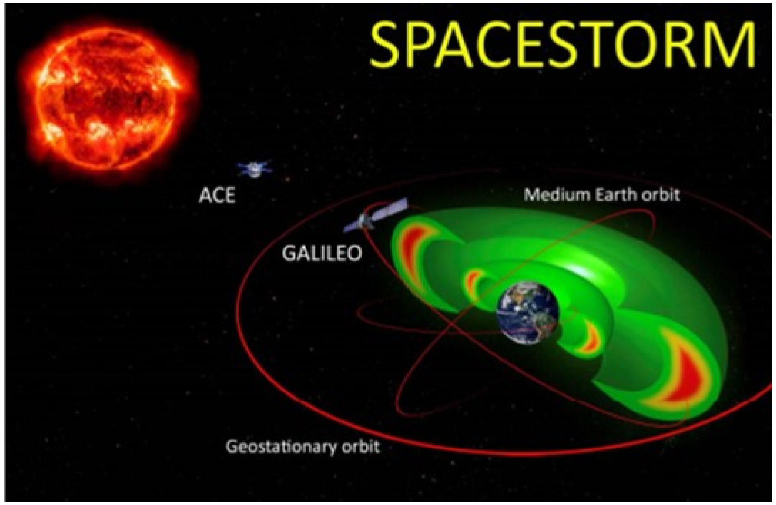
The research leading to these results funded in part by the European Union Seventh Framework Programme (FP7) under grant agreement No 606716 SPACESTORM

ESWW13, Ostend, Belgium, 17th November 2016

Spacestorm

- Funded under EU Framework 7
  (http://www.spacestorm.eu/)

The goal of the SPACESTORM proposal is to model space weather events and mitigate their effects on satellites through better mitigation guidelines, forecasting of events and experimental testing of new materials and methodologies to reduce satellite vulnerability.



WP8 – Risk assessment for internal charging and radiation dose

Objectives

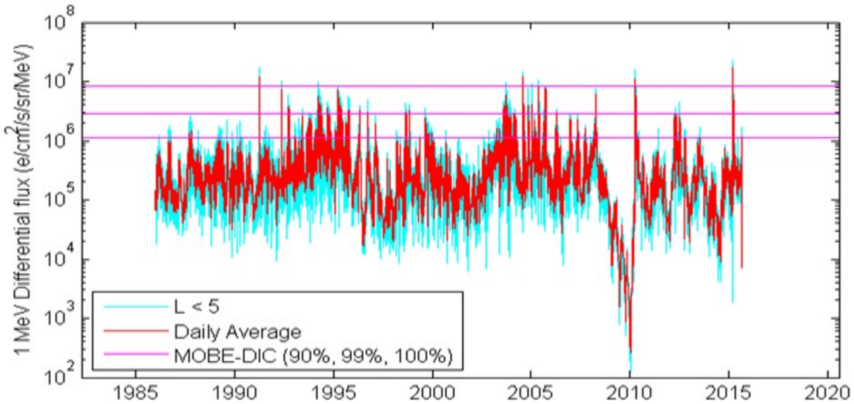
- To make an assessment of the risk to satellites in MEO and GEO from internal charging based on the reconstructed 30 year data set and under extreme conditions using the modelling outputs from other WPs
- Make an assessment of the cumulative dose for MEO and GEO satellites using the historical (30–year) and extreme storm environments to understand the degree of satellite ageing (if any) and the potential need for early replacement.

SPACESTORM

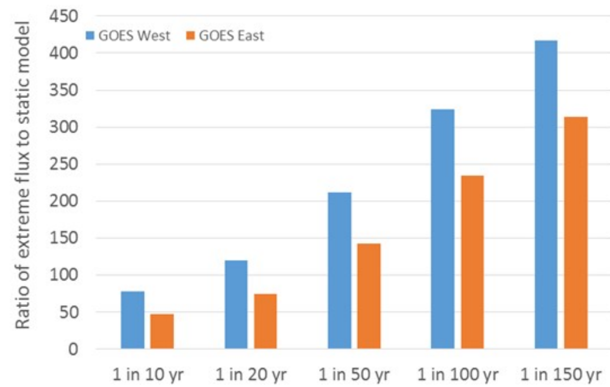
Detail of worked carried out

- Various environments (from other work packages) used to calculate effects:

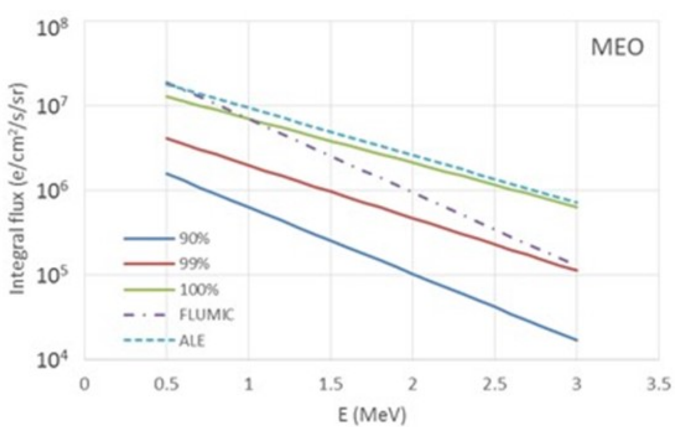
30 year reconstructed data set:



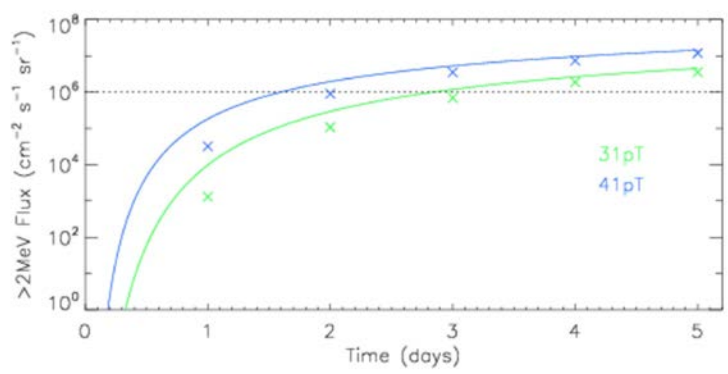
Statistical GEO fluxes:



Models:

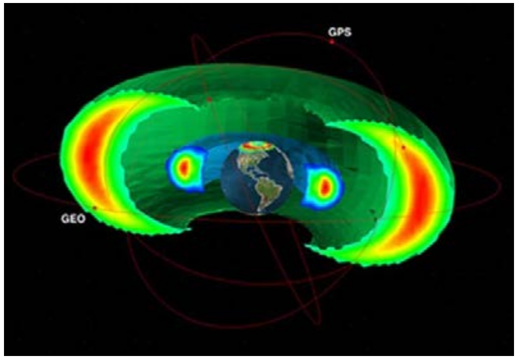


Extreme event from physical principles:



Detail of worked carried out

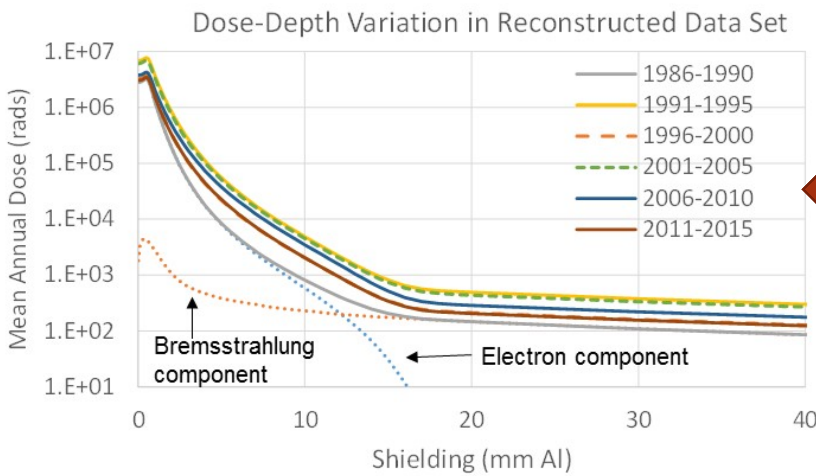
- Focus on key environments:
  - MEO (Galileo)
  - GEO
- Focus on three key areas of radiation damage:
  - Total Ionising Dose (TID)
  - Displacement Damage Dose (DDD)
  - Internal Charging
- 2 (orbits) x 3 (effects) x many (input conditions) x various (models) = many outputs (!)
- Only time for examples…



SPACESTORM

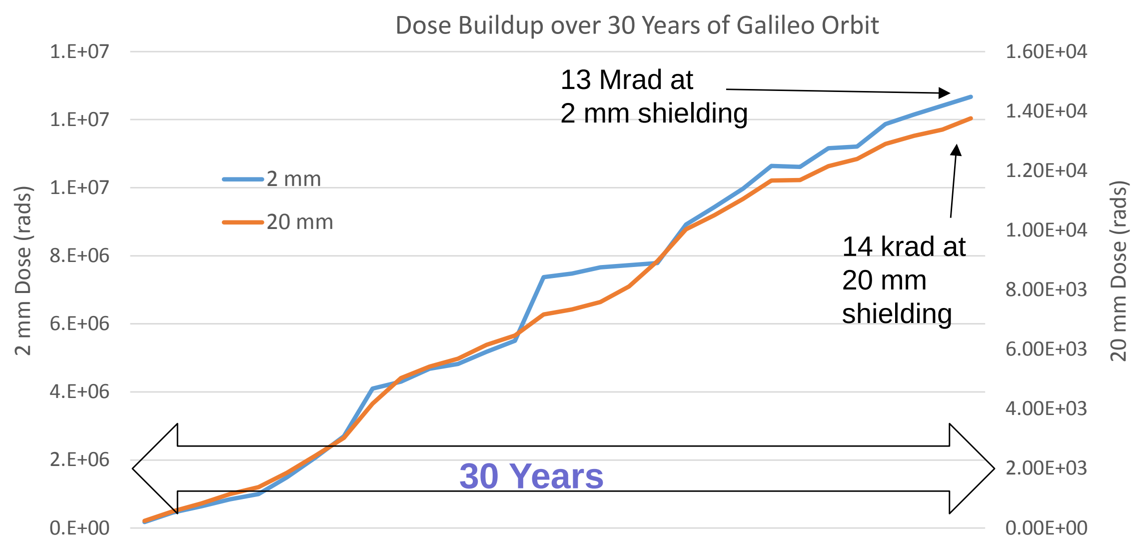
Detail of worked carried out

- Examples of Total Ionising Dose calculations (Shieldose)



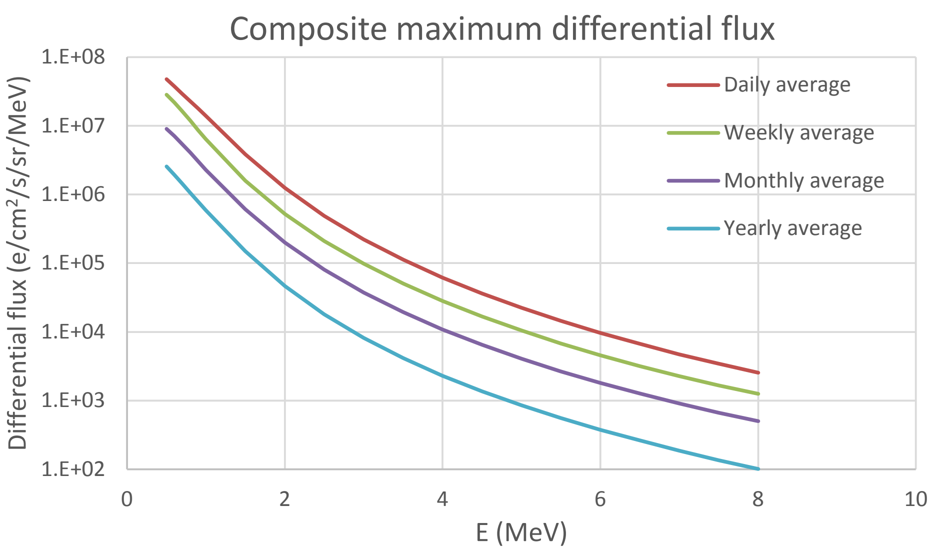
30 year reconstructed data set, broken up into 6 x 5 year components

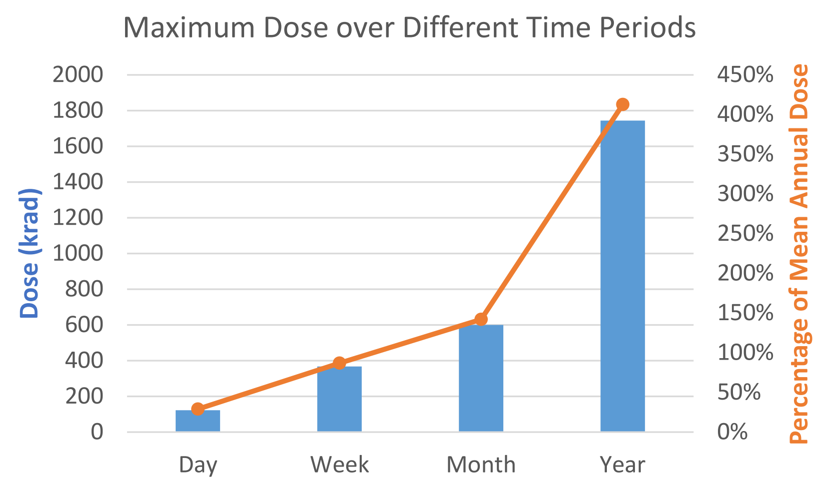
Dose accumulation year by year



Detail of worked carried out

- Examples of Total Ionising Dose calculations for short term extreme events





(2 mm Al)

I.e. "worst week" in reconstructed MEO data set ≈ 1 year mean dose (50x enhancement)

SPACESTORM

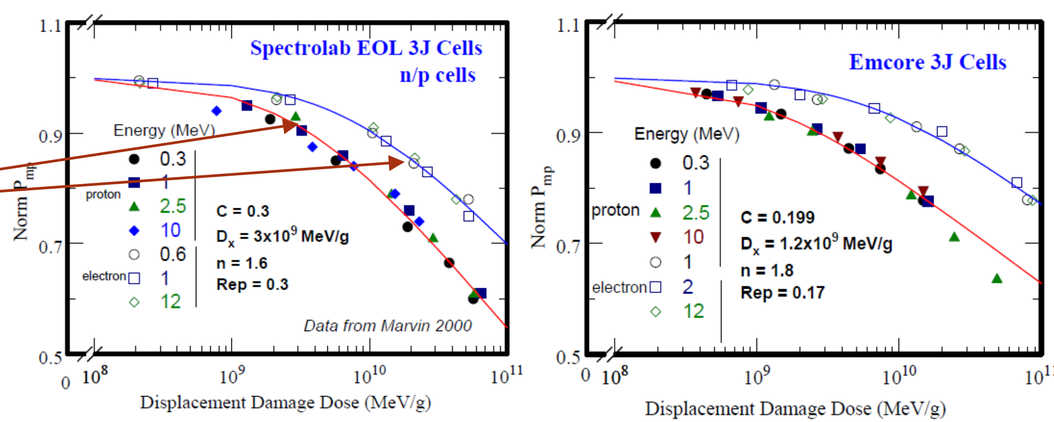
Detail of worked carried out

- Examples of Displacement Damage Dose calculations:
  - EQFLUX calculates equivalent electron fluxes for solar cell damage
  - MC-SCREAM calculates power degradation due to electron (and proton) flux (GaAs single junction used by default):

Separate curves for protons and electrons (given same DDD)

MJ Solar Cell Radiation Response in terms of D_d

*GaAs NIEL used in the correlation



$$D_d(E) = \Phi(E) \bullet NIEL(E)\left[\frac{NIEL(E)}{NIEL(E_{ref})}\right]^{n-1}$$

$$\frac{P(D_d)}{P_0} = 1 - C \cdot \log\left[1+\frac{D_d}{D_x}\right]$$

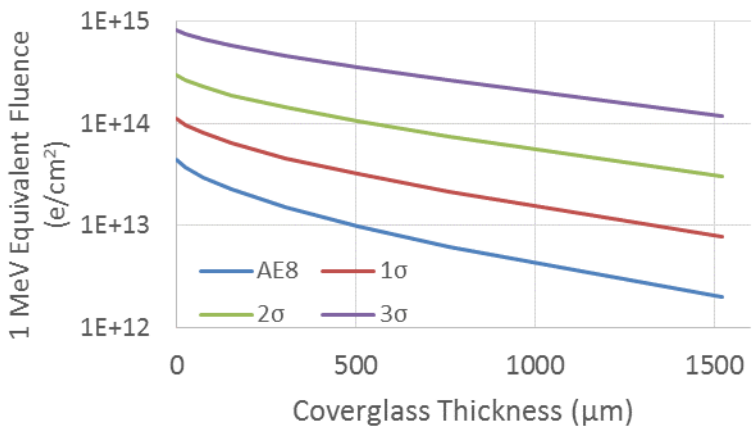
$$R_{ep} = \frac{D_{xe}}{D_{xp}}$$

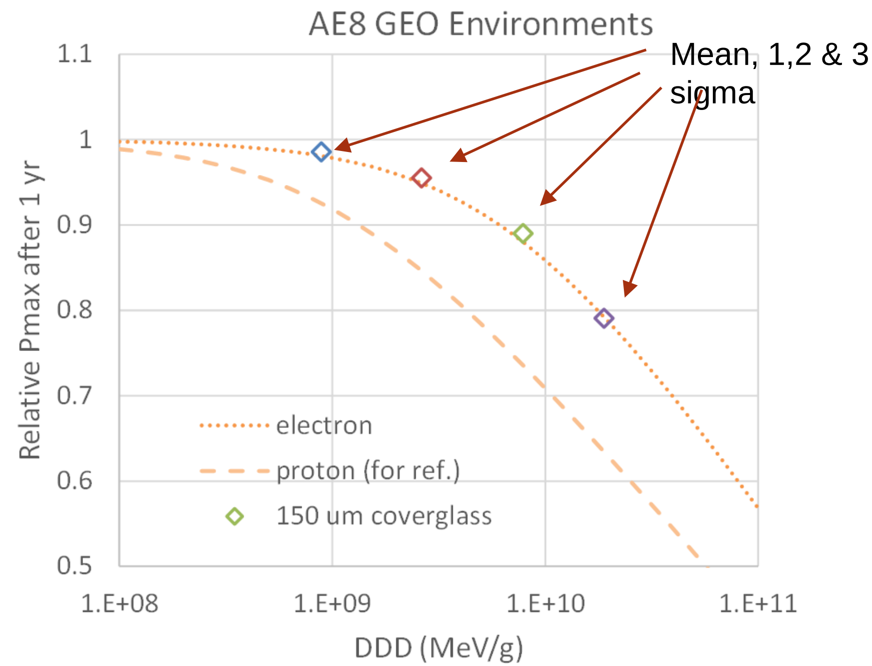
*Experimentally determined variables (C, D_{xp}, D_{xe}, n)

Detail of worked carried out

- Examples of Displacement Damage Dose calculations

1 year (at GEO):



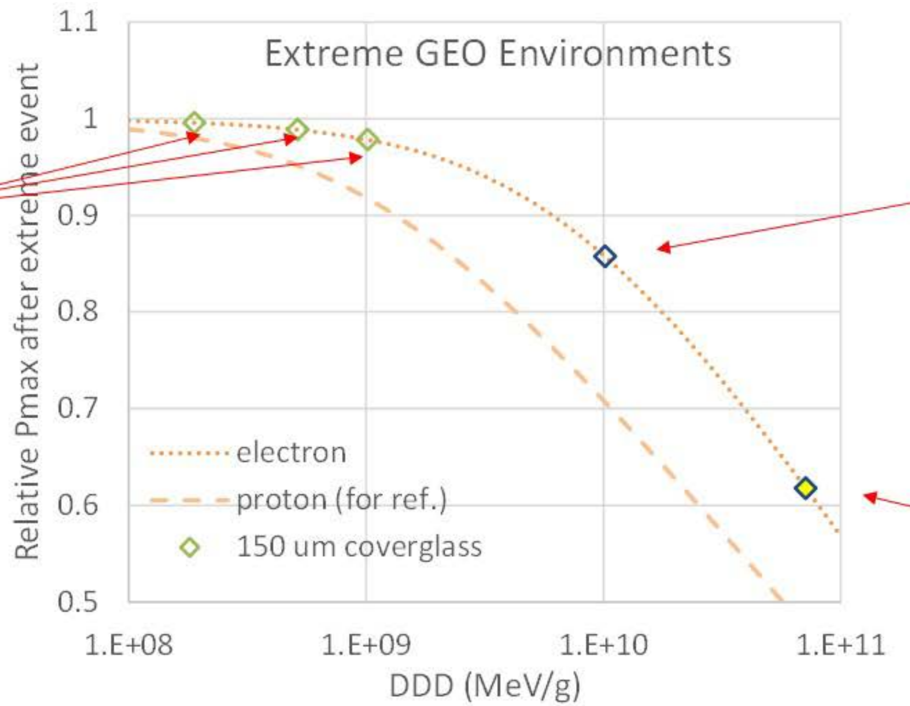


Detail of worked carried out

- Examples of Displacement Damage Dose calculations

Short term (at GEO):

Solar cell degradation from 1 in 10, 1 in 50 and 1 in 150 year events (one day duration) [not very significant]



Solar cell degradation from theoretical worst case (one day duration)

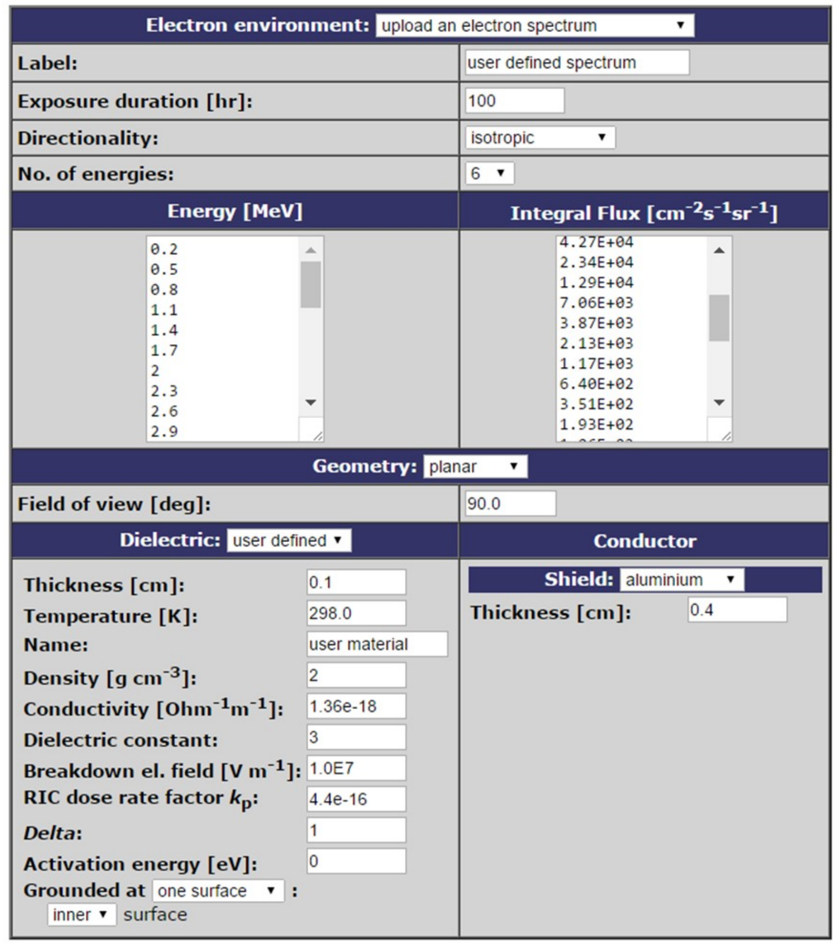
Degradation if theoretical worst case lasted 1 week [very significant !]

Detail of worked carried out

- Examples of Internal Charging calculations (DICTAT):

Spectrum

Material parameters



Detail of worked carried out

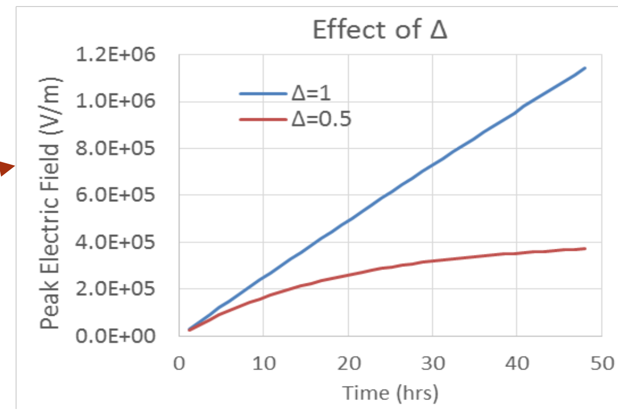
- DICTAT sensitivity analysis:

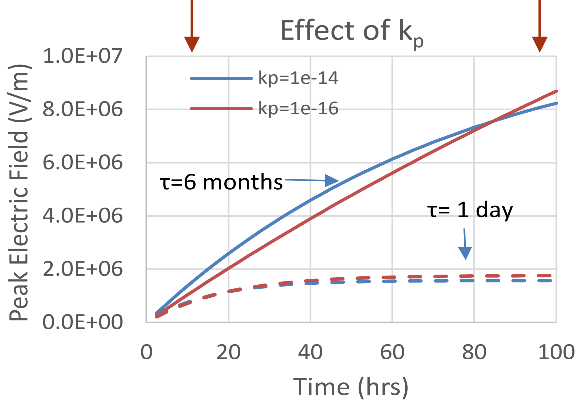
(Dose rate = environment)

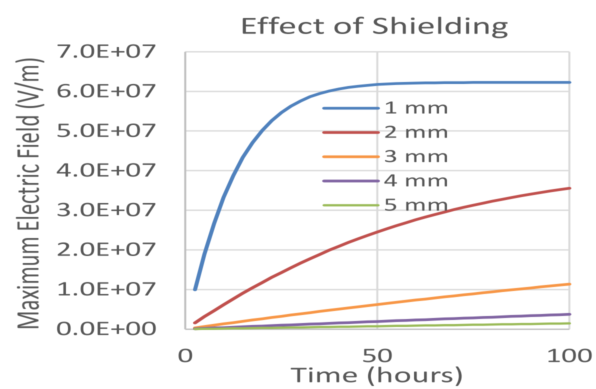
Key conductivity equations:

$$\sigma_{total} = \sigma_T + \sigma_{RIC}$$

$$\sigma_{RIC} = k_p . \dot{D}^{\Delta}$$







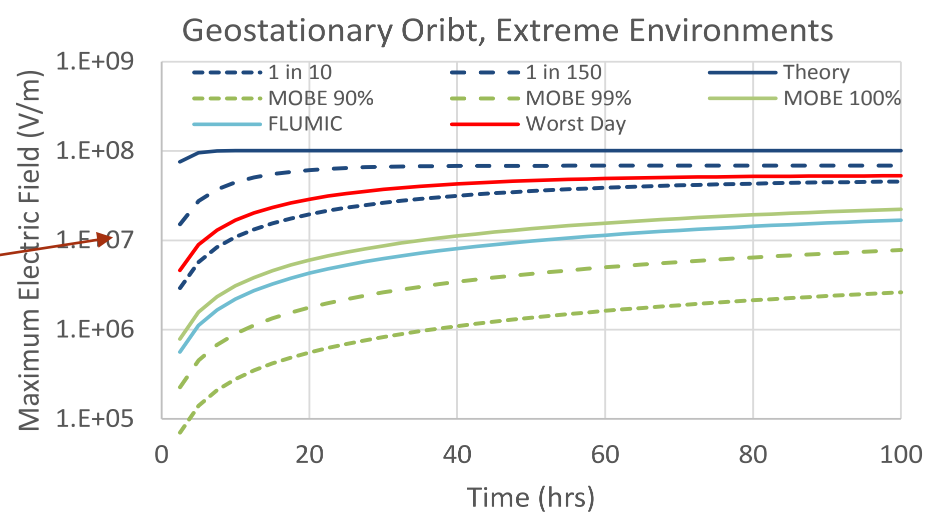
SPACESTORM

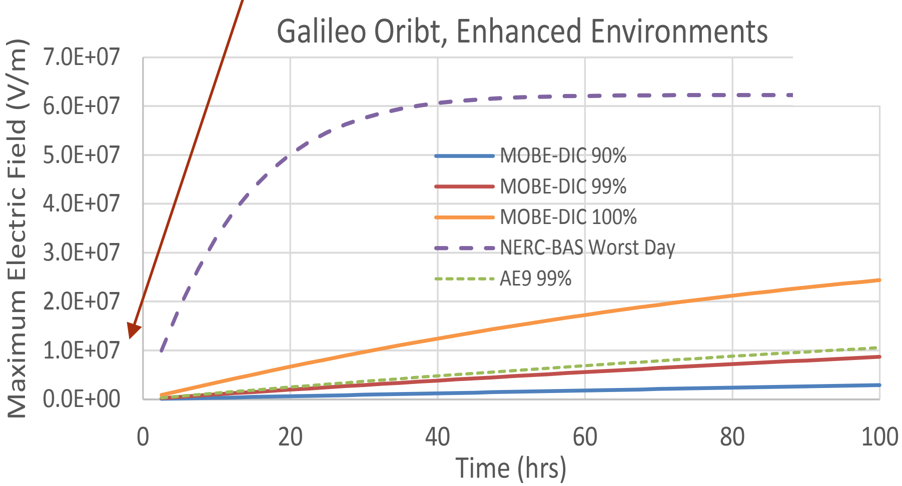
Detail of worked carried out

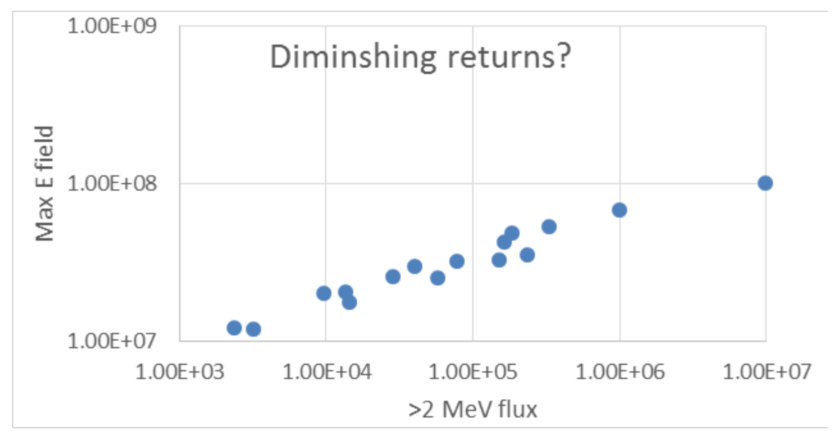
- MEO vs GEO (short-term):

(using PEEK parameters & 1 mm shielding)

Typical ESD breakdown threshold 10^7 V/m







MEO and GEO worst case evaluations are quite similar (likely sufficient for ESD in worst case)

Summary

Worst case MEO and GEO environments have been used to calculate radiation effects on satellites. Examples include:

- A "worst day" total ionising dose for the Galileo GNSS constellation could be equivalent to 30% of mean annual dose.
- If sustained for one week, the theoretical worst case GEO environment could result in a 40% loss in solar cell power.
- Radiation-induced conductivity limits the build-up of electric fields, however maximum fields of 10^7 - 10^8 V/m in PEEK have been calculated for a range of enhanced GEO and MEO environments from models, data and theory.

More work is planned based on new models of ESW events.

SPACESTORM