



Dose Rates at Aviation Altitudes During Ground Level Events

Daniel Matthiä^(1,2), Bernd Heber⁽²⁾, Günther Reitz⁽¹⁾,

Lembit Sihver⁽³⁾, Matthias Meier⁽¹⁾

***(1) Department of Radiation Biology/Institute of Aerospace Medicine, German Aerospace Center
(DLR), Germany***

***(2) Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität Kiel,
Germany***

(3) Chalmers University of Technology, Gothenburg, Sweden

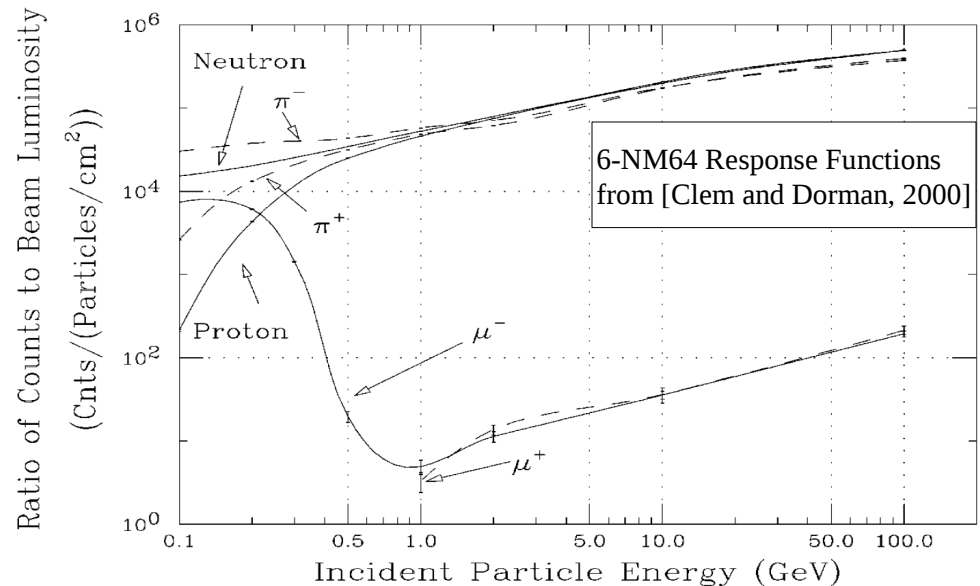
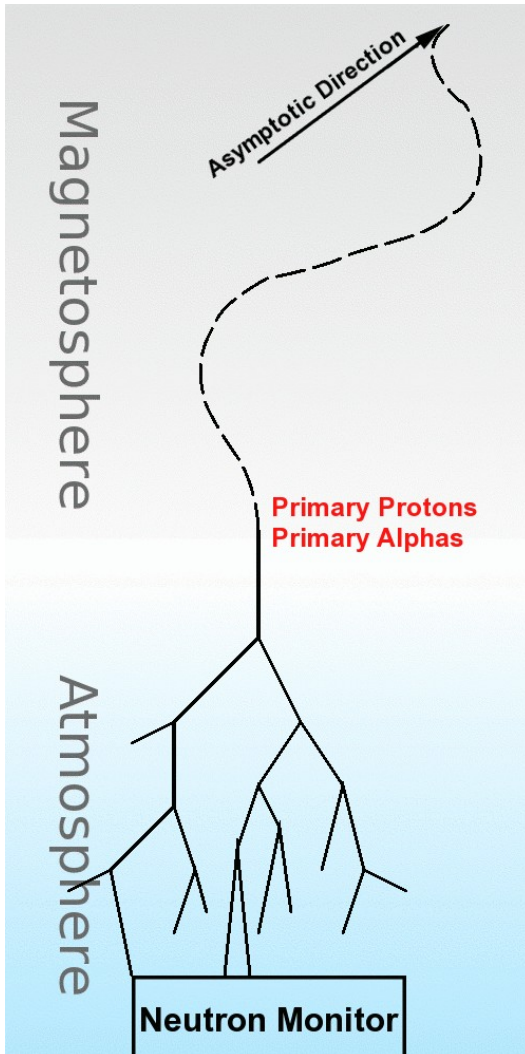


Overview

- Goal: Numerical determination of dose rates at aviation altitudes for Ground Level Enhancements/Events (GLE)
- Usage of Neutron Monitor network
 - **Transport of primary particles** through the magnetosphere and atmosphere of the Earth
 - Calculation of **Neutron Monitor count rate increases for a GLE above the background**
 - ⇒ Energy and angular distribution of primary particles at different times during the event
- Dose rate increases for the duration of the event (Flight routes/Fixed coordinates)
- Results for GLE 69 and GLE 70

How to calculate NM count rate increases

- Transport/Deviation of primary particles through the magnetosphere (PLANETOCOSMICS/GEANT4)
- Calculation of asymptotic direction in case of anisotropic primary spectrum
- Interaction of primaries with the atmosphere
 - ⇒ Secondary particle fluences
- Count rate = Sec. particle fluence * Neutron Monitor response



Determination of SEP spectrum

- Assume spectrum for Solar Energetic Particles at time t
- Calculate secondary particle fluences and Neutron-Monitor count rate increases for GCR and SEP
- Compare to measured count rates (~30 stations)
- Adapt spectrum for SEP

Minimization

Calculate secondary particle fluences at aviation altitudes
→ Conversion to effective dose

Primary Proton Spectrum

$$\frac{dI}{dR} = \frac{d^4 N}{dR dA dt d\Omega}$$
$$\frac{dI}{dR}(R) = \left(\frac{dI}{dR} \right)_0 \cdot R^{-\gamma} \cdot (1 - b \cdot \alpha(\lambda, \phi))$$

- **Power law in rigidity $R=p/q$**
- **Linear in pitch angle α**
- Five independent parameters: $(dI/dR)_0$, γ , b , ϕ , λ
- ϕ = longitude of the incoming direction
- λ = latitude of the incoming direction

GLE 69

➤ 20. January 2005 from 6.45 UTC until 17.00 UTC

–Determination of primary proton spectrum

–Modelling of NM count rates

➤ Calculation of effective dose rates and total doses during the event and for flights

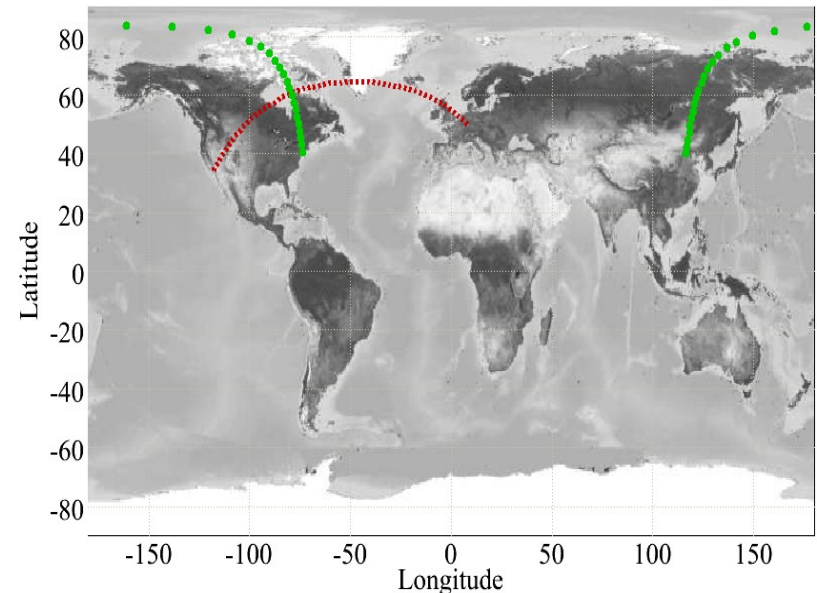
–FRA-LAX (North Atlantic)

–JFK-PEK (polar)

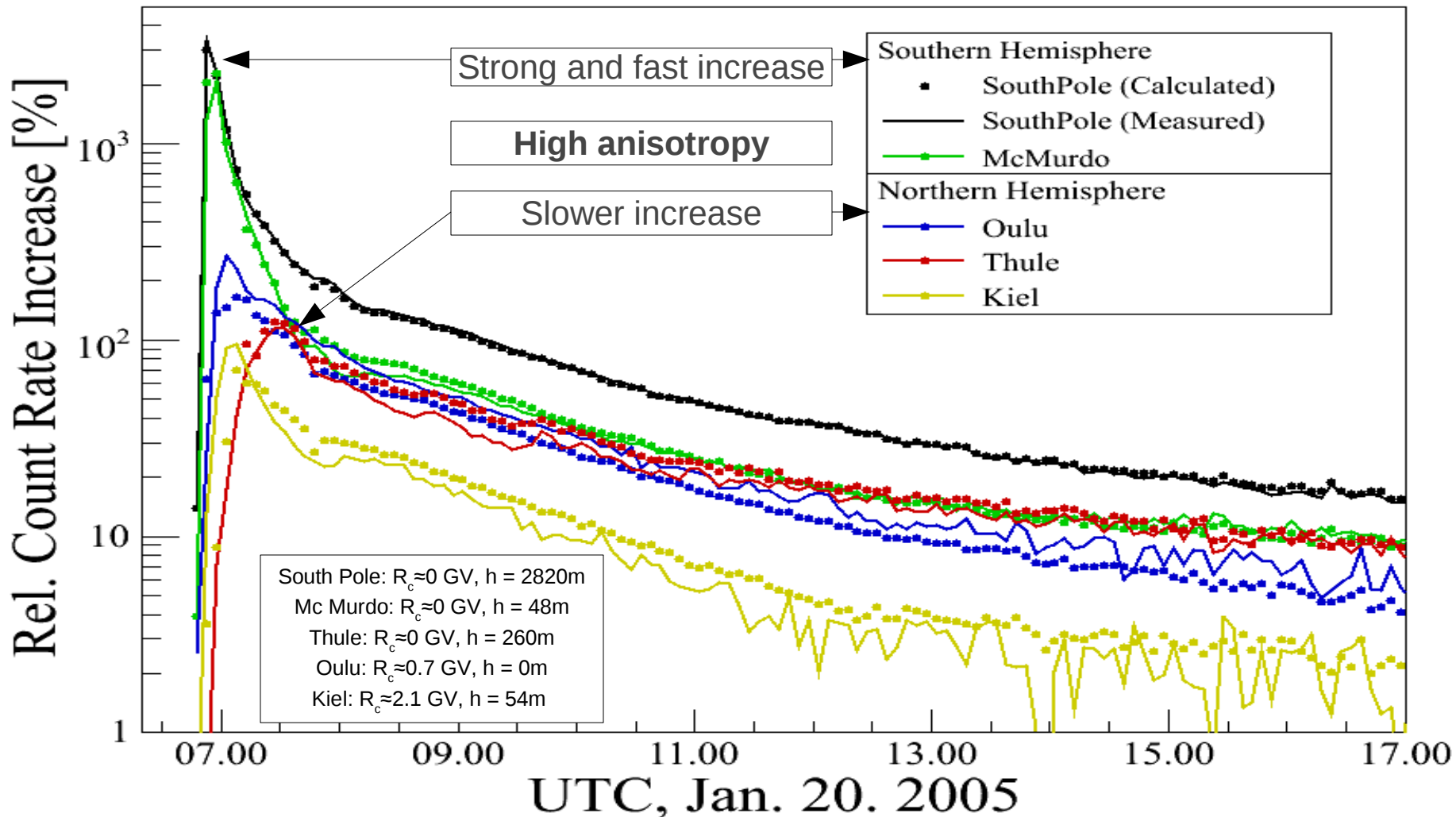
–great circle

–constant atmospheric depth / altitude

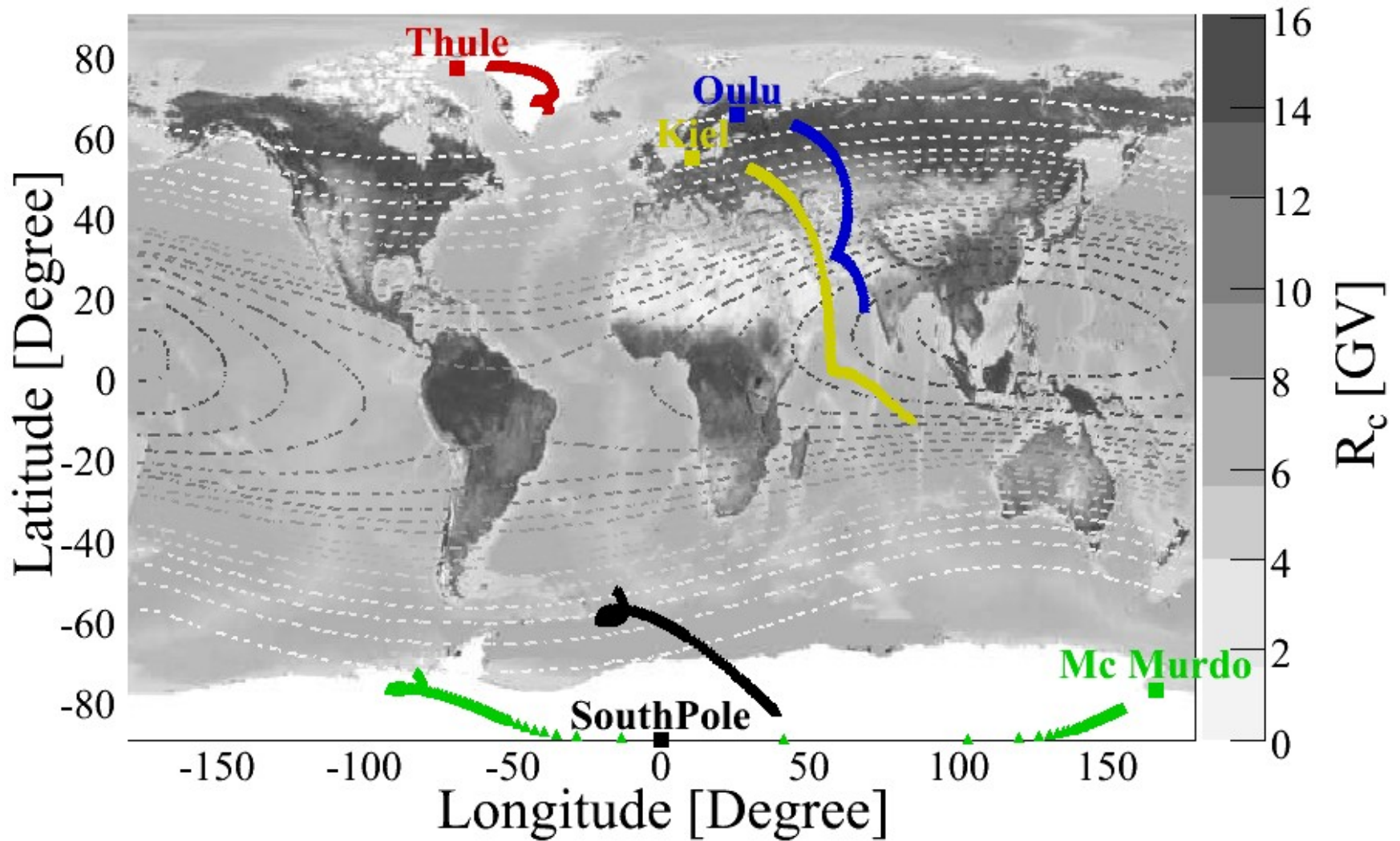
–constant velocity 900 km/h



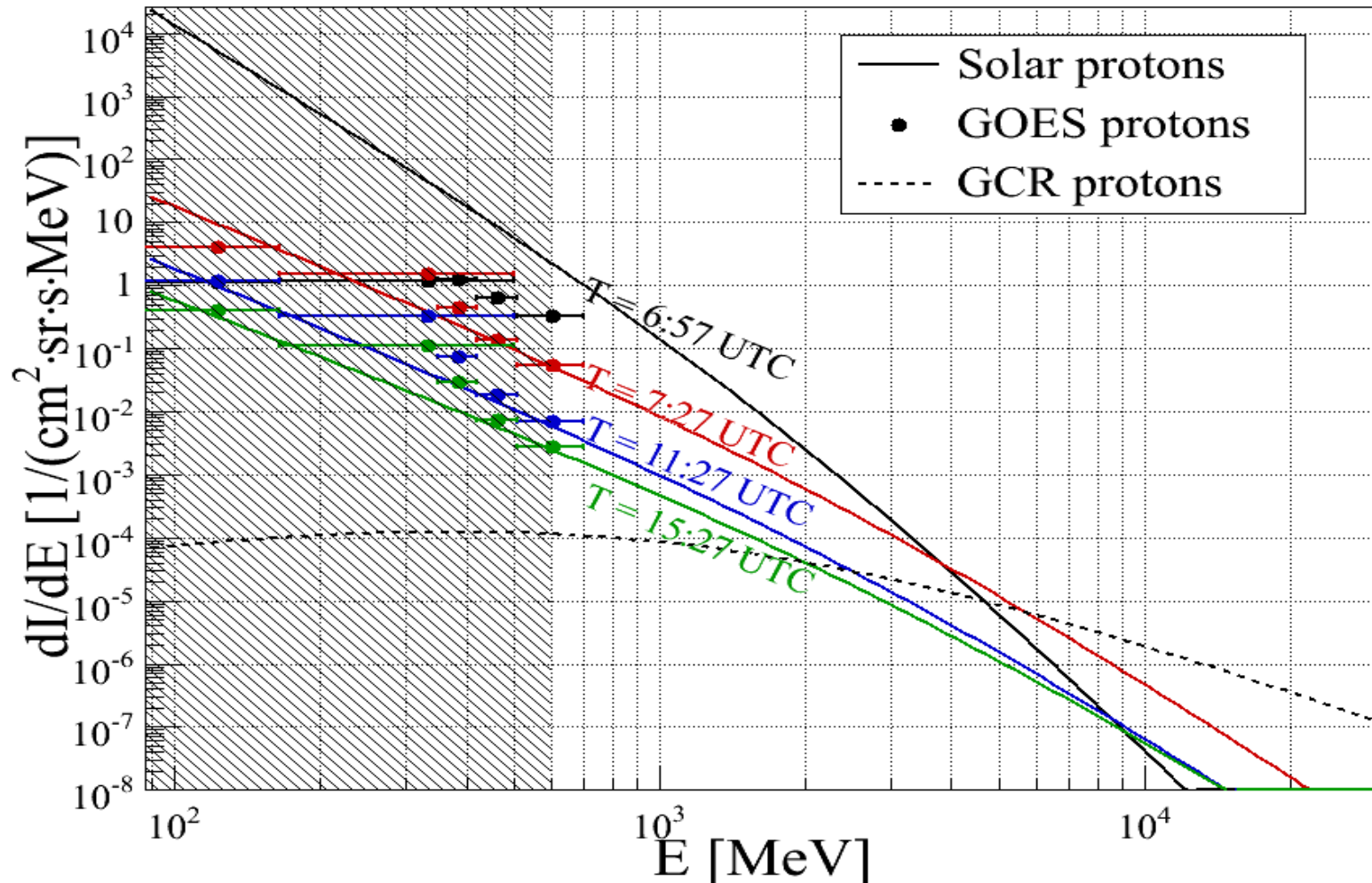
GLE 69: Selected Neutron Monitor Count Rate Increases



Asymptotic viewing directions

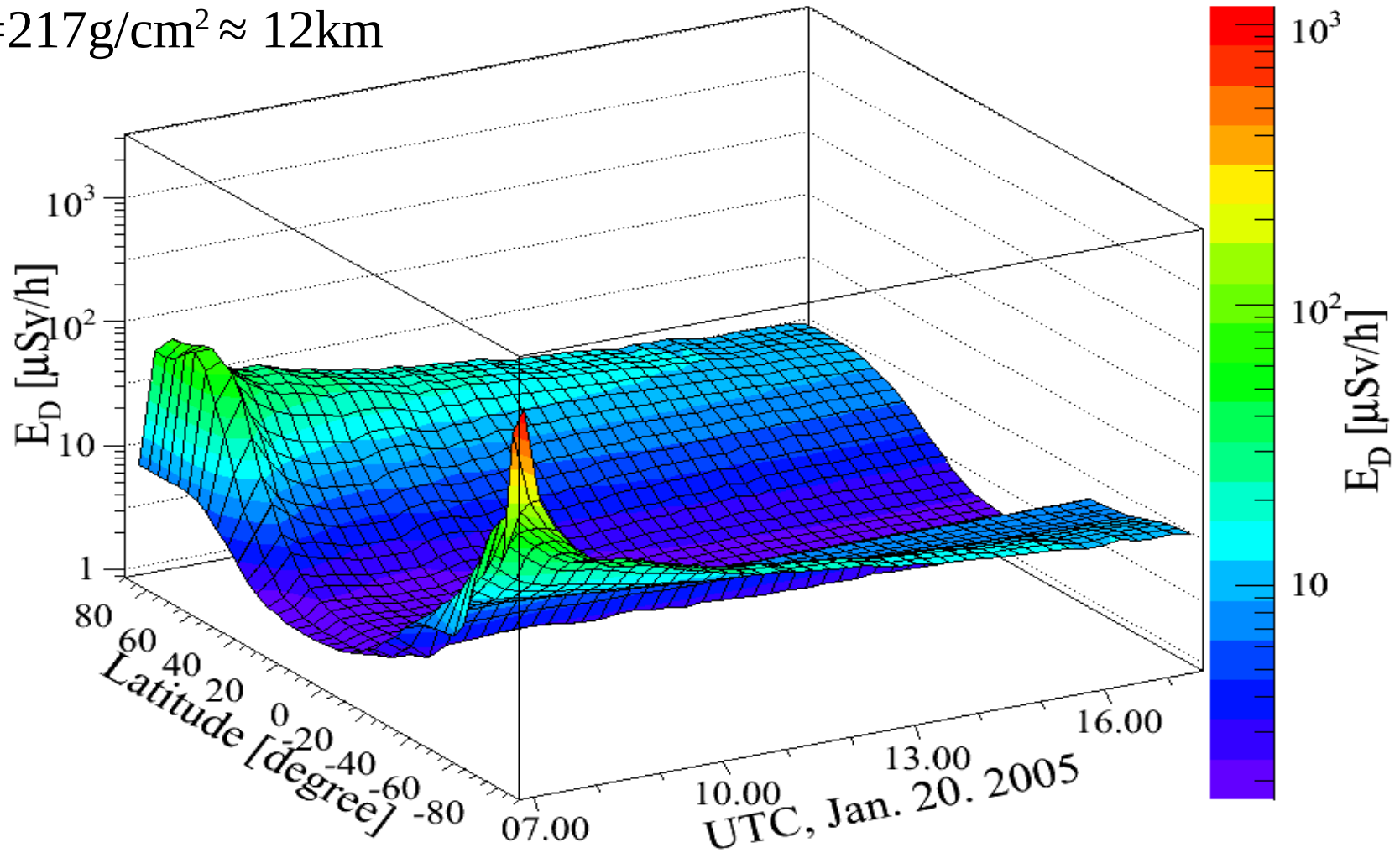


GLE 69: Primary Proton Spectrum at Different Times

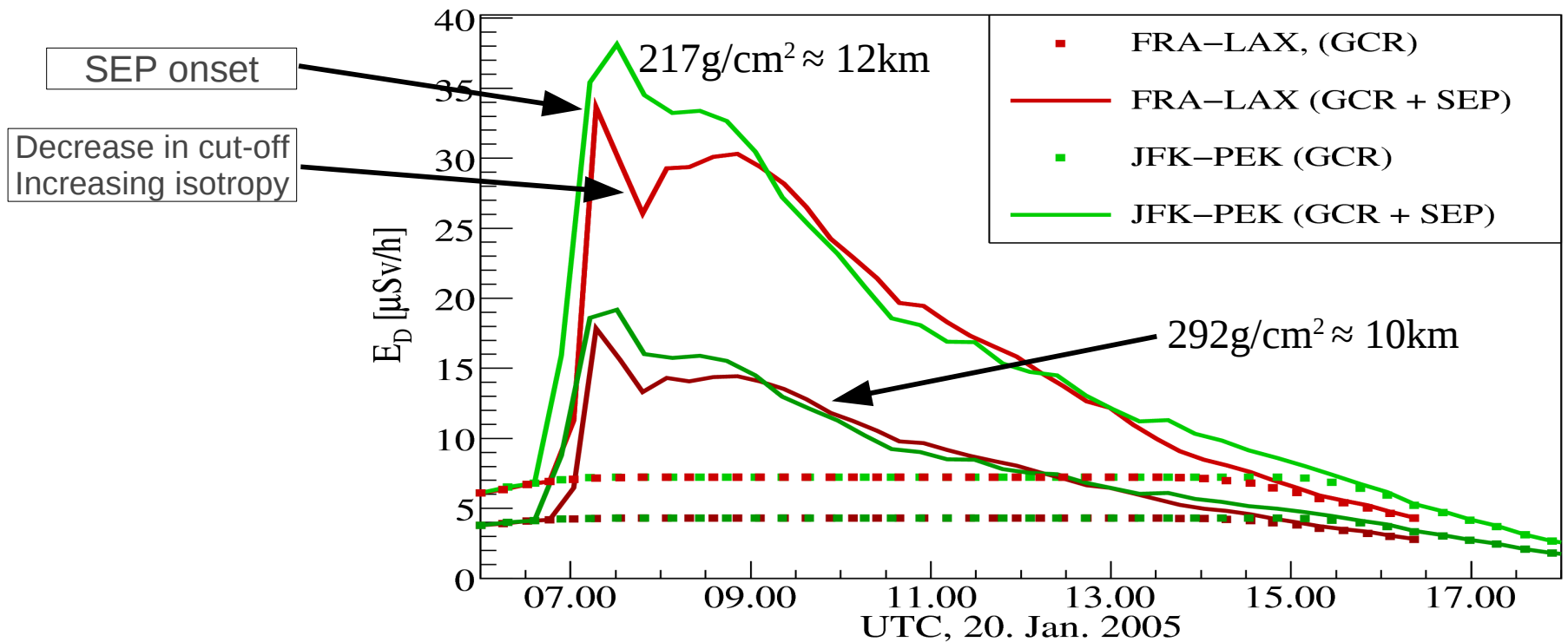


Effective Dose Rates During GLE69

$d=217\text{g/cm}^2 \approx 12\text{km}$



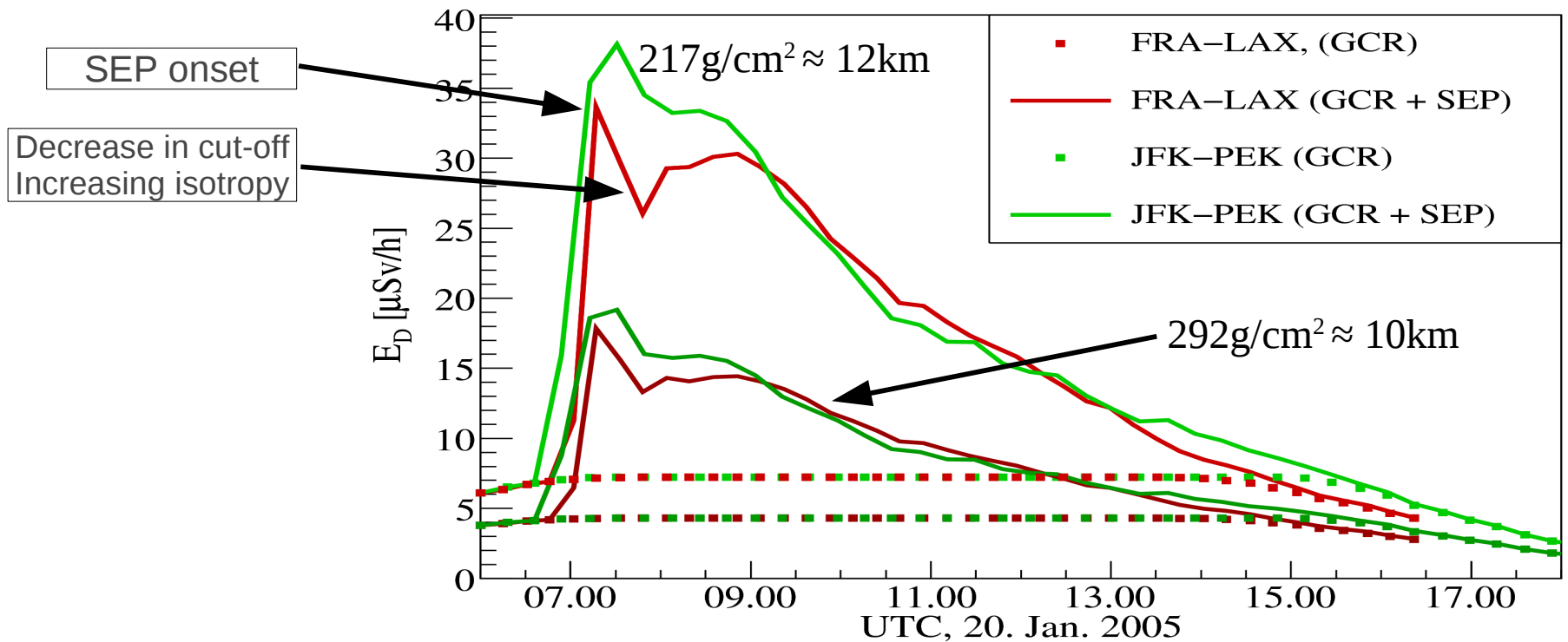
GLE 69: Dose Rates



Route	Depth [g/cm ²]	E_D^{GCR} [μ Sv]	$E_D^{GCR+SEP}$ [μ Sv]	Increase [%]
FRA-LAX	217	71.1	168	136
JFK-PEK	217	80.1	189	137
FRA-LAX	292	42.8	86.7	103
JFK-PEK	292	48.3	97.4	102



GLE 69: Dose Rates

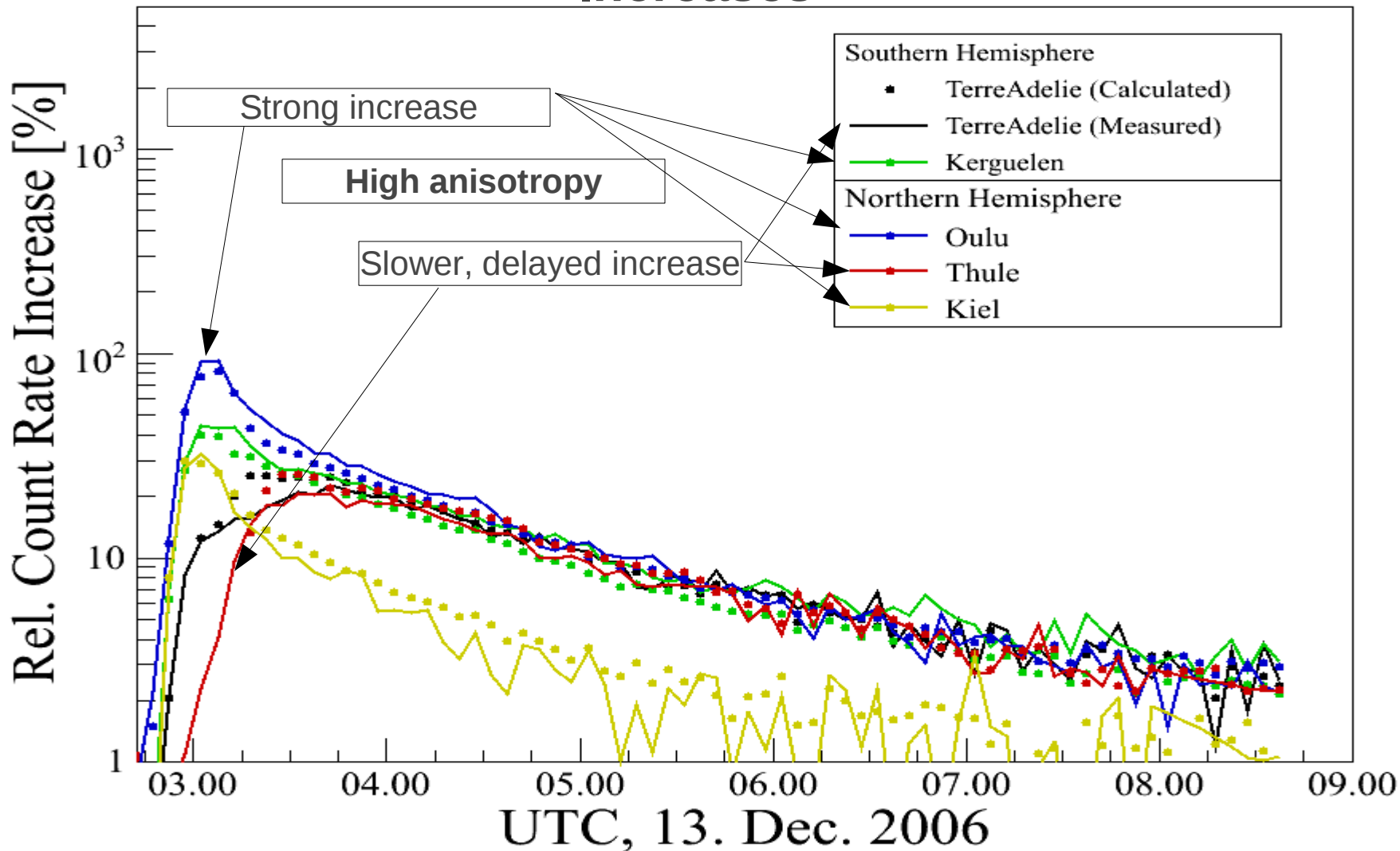


Route	Depth [g/cm ²]	E_D^{GCR} [μ Sv]	$E_D^{GCR+SEP}$ [μ Sv]	Increase [%]
FRA-LAX	217	71.1	168	136
JFK-PEK	217	80.1	189	137
FRA-LAX	292	42.8	86.7	103
JFK-PEK	292	48.3	97.4	102

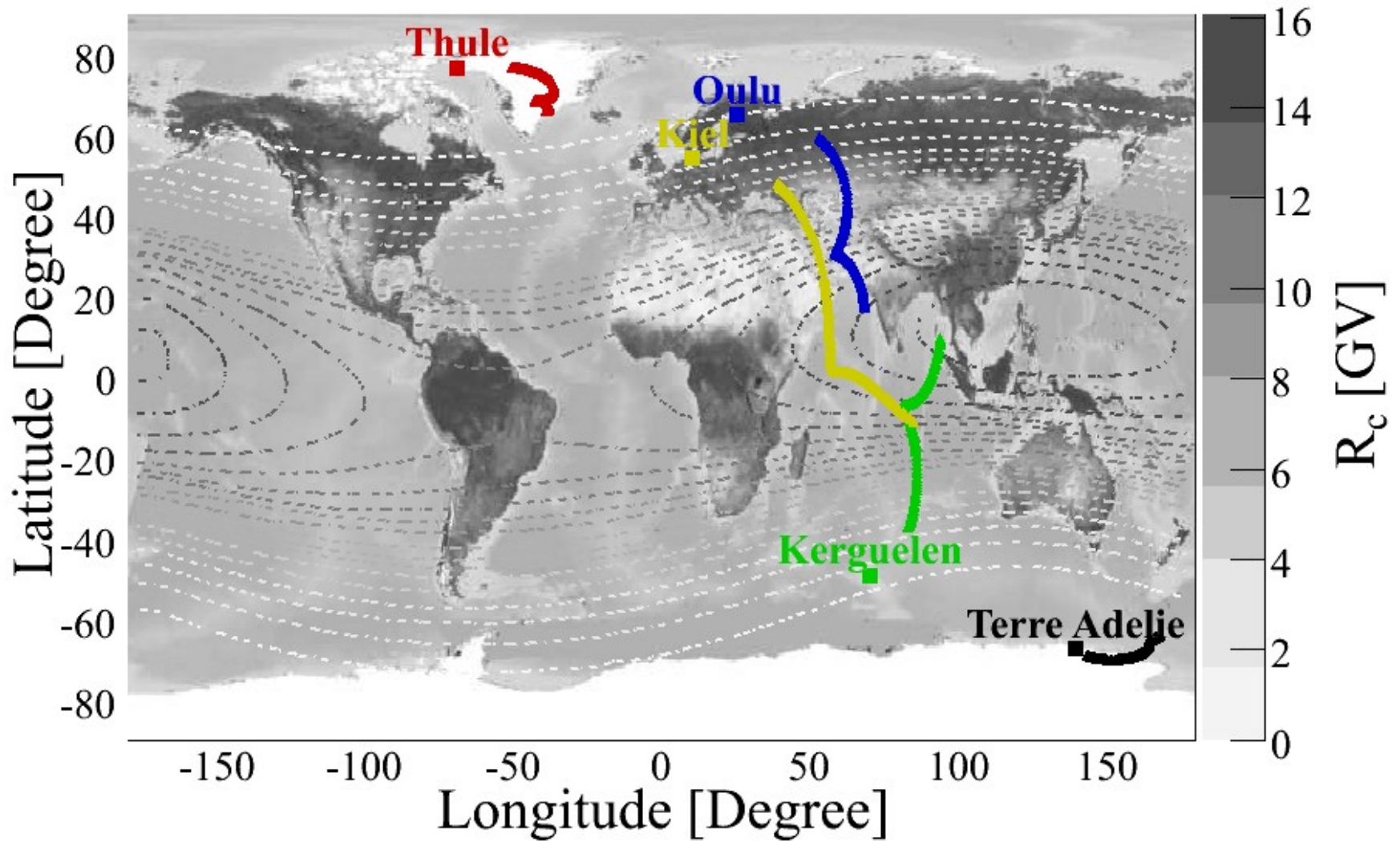
GLE 70

- 13. December 2006 from 2.45 UTC until 12.00 UTC
 - Determination of primary proton spectrum
 - Modelling of NM count rates
- Calculation of effective dose rates during the event and for flights
 - FRA-LAX (North Atlantic)
 - JFK-PEK (polar)
 - great circle
 - constant atmospheric depth
 - constant velocity 900 km/h

GLE 70: Selected Neutron Monitor Count Rate Increases

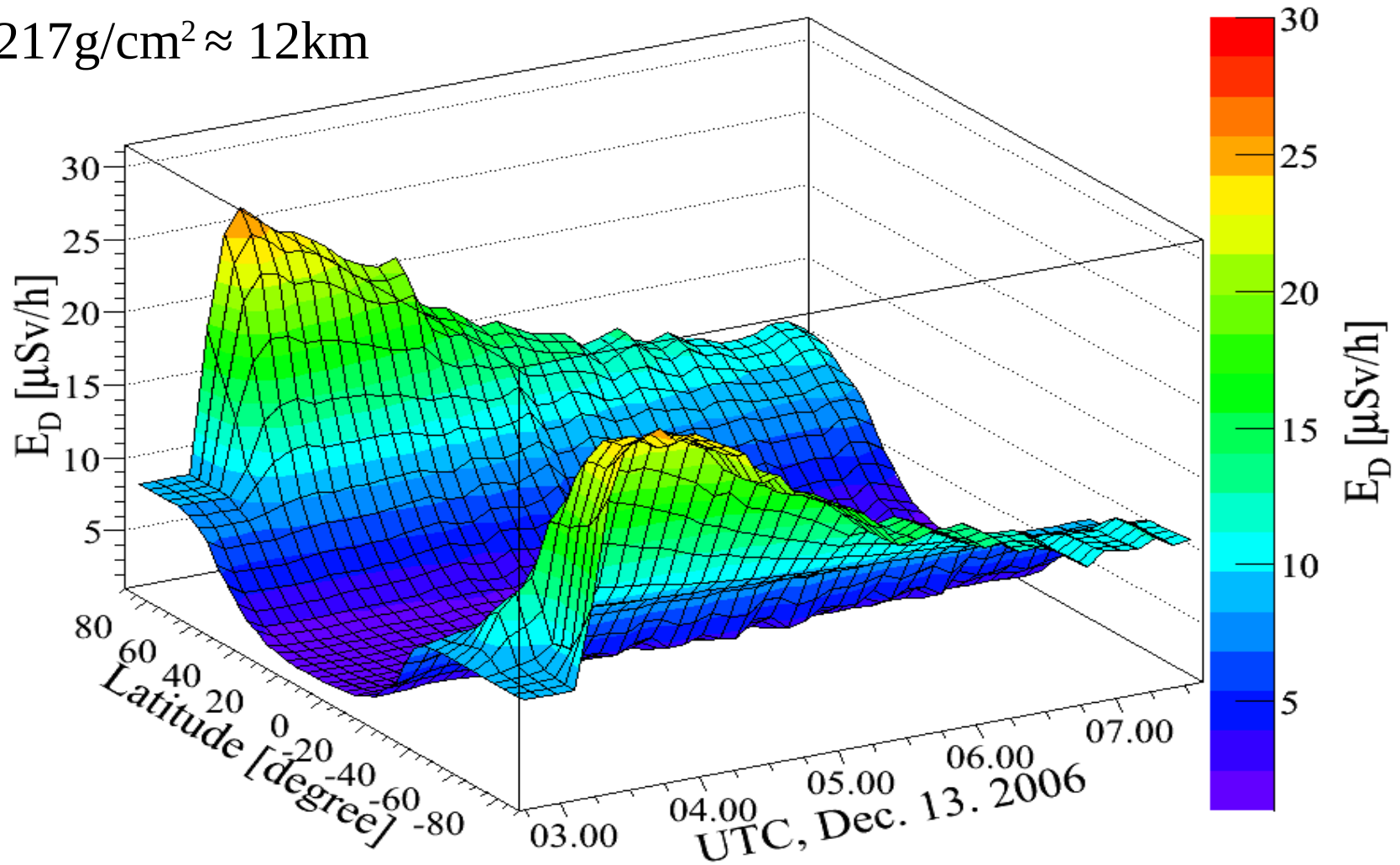


Asymptotic viewing directions

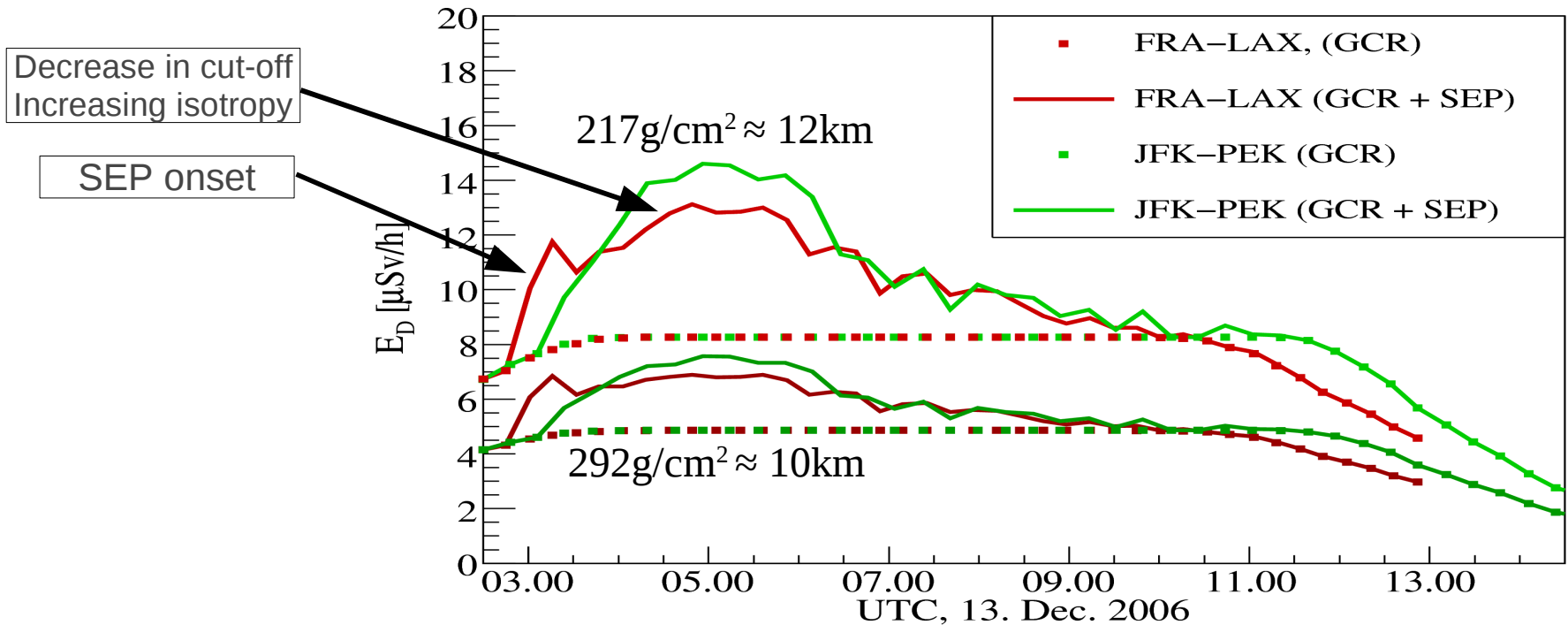


Effective Dose Rates During GLE70

$d=217\text{g/cm}^2 \approx 12\text{km}$

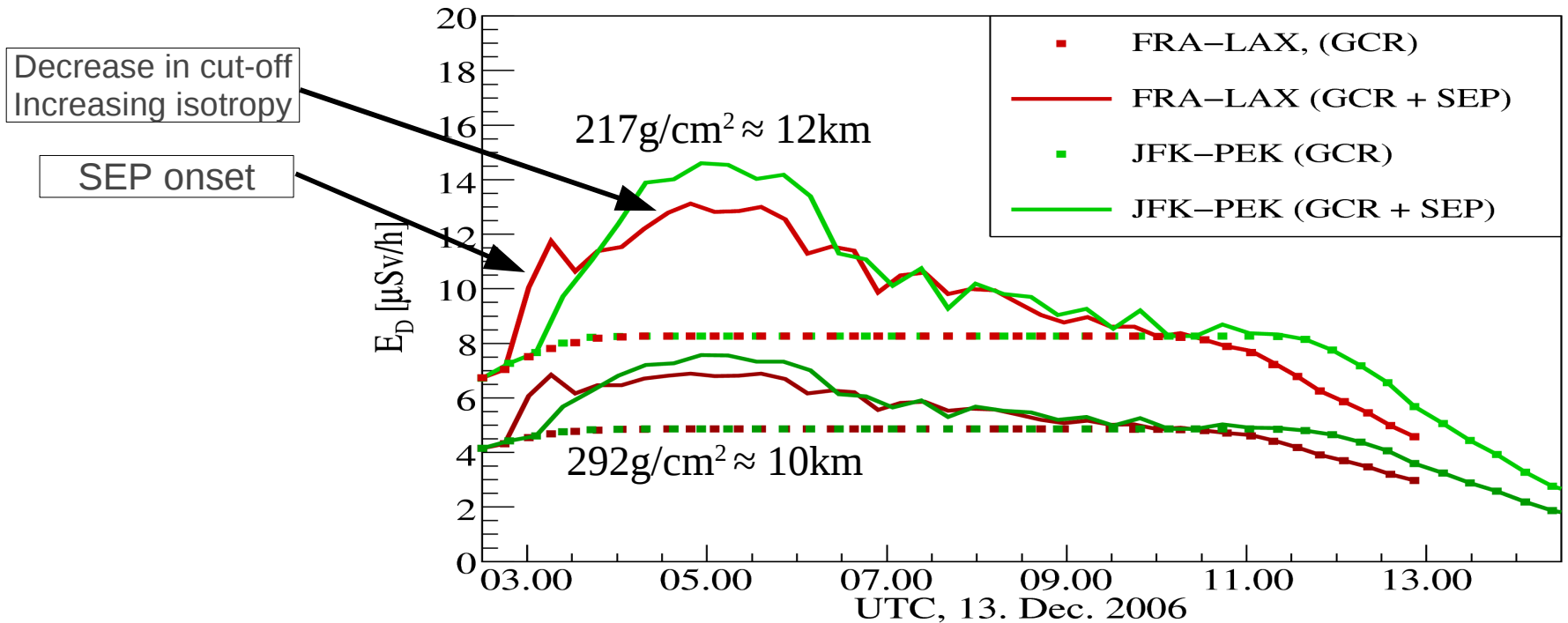


GLE 70: Dose Rates



Route	Depth [g/cm^2]	E_D^{GCR} [μSv]	$E_D^{\text{GCR+SEP}}$ [μSv]	Increase [%]
FRA-LAX	217	80.6	99.2	23
JFK-PEK	217	90.7	112	23.3
FRA-LAX	292	48	56.4	17.7
JFK-PEK	292	54.1	63.2	17

GLE 70: Dose Rates



Route	Depth [g/cm^2]	E_D^{GCR} [μSv]	$E_D^{\text{GCR+SEP}}$ [μSv]	Increase [%]
FRA-LAX	217	80.6	99.2	23
JFK-PEK	217	90.7	112	23.3
FRA-LAX	292	48	56.4	17.7
JFK-PEK	292	54.1	63.2	17



Summary

- **Energy and angular distribution of primary particles** during GLEs can be derived from Neutron Monitor count rate increases
- **Time evolution** of SEP events over several hours
- Total effective doses for polar and North-Atlantic flights increased by
 - ~100%-140% during GLE 69
 - ~20% during GLE 70



Thank you for your attention!
Questions?
Daniel.Matthiae@dlr.de



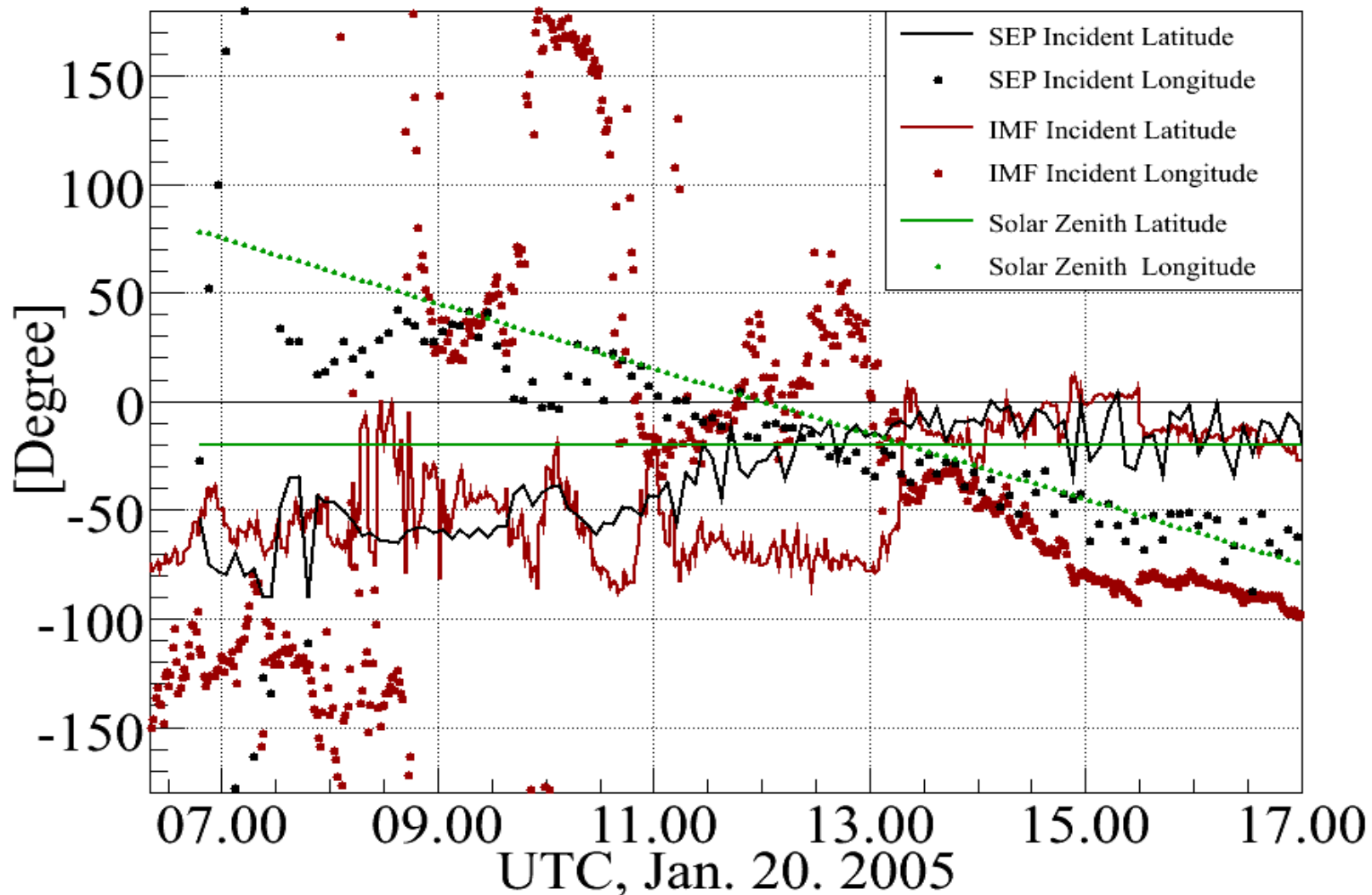
DLR

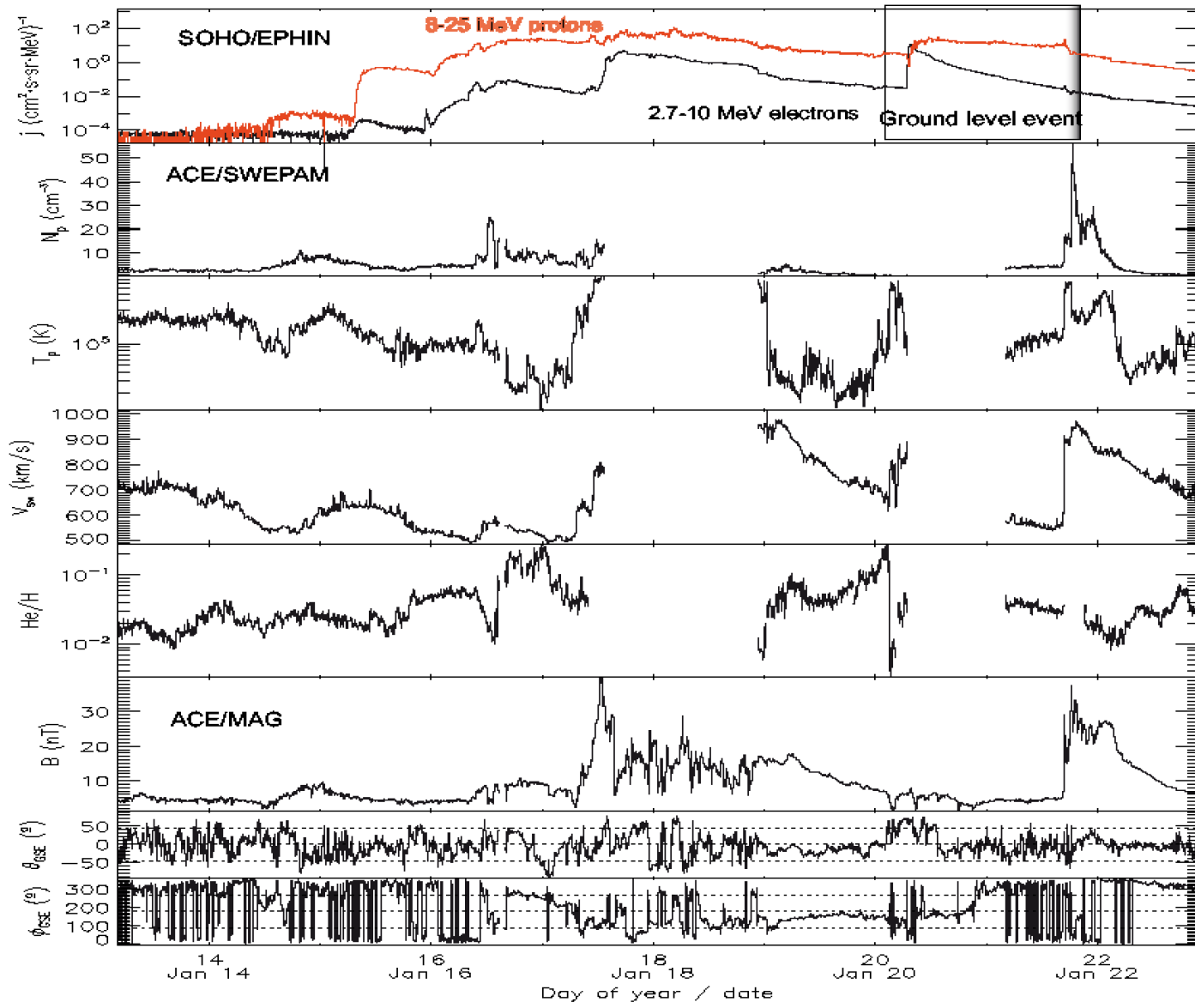
Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

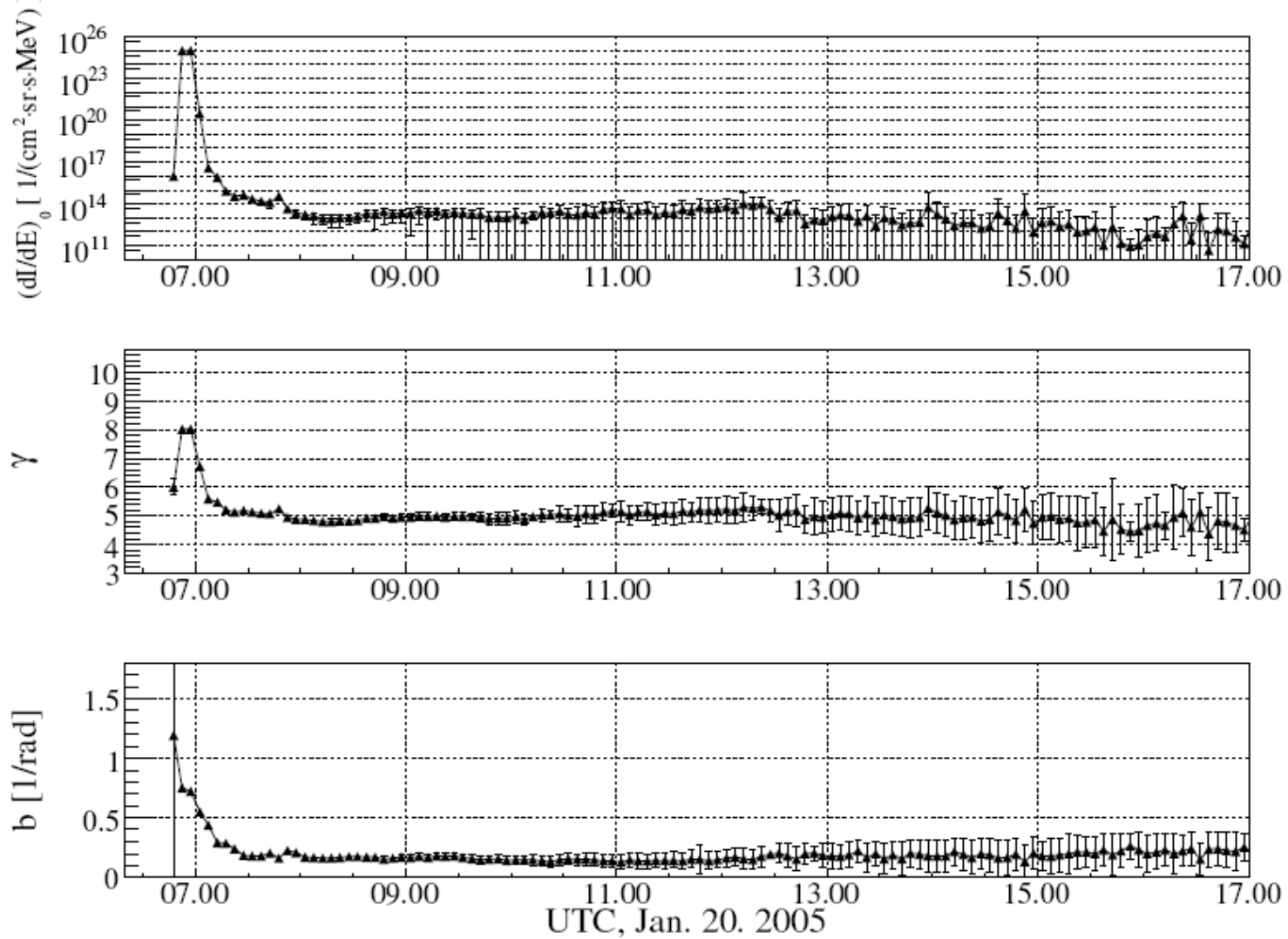


Slide 20

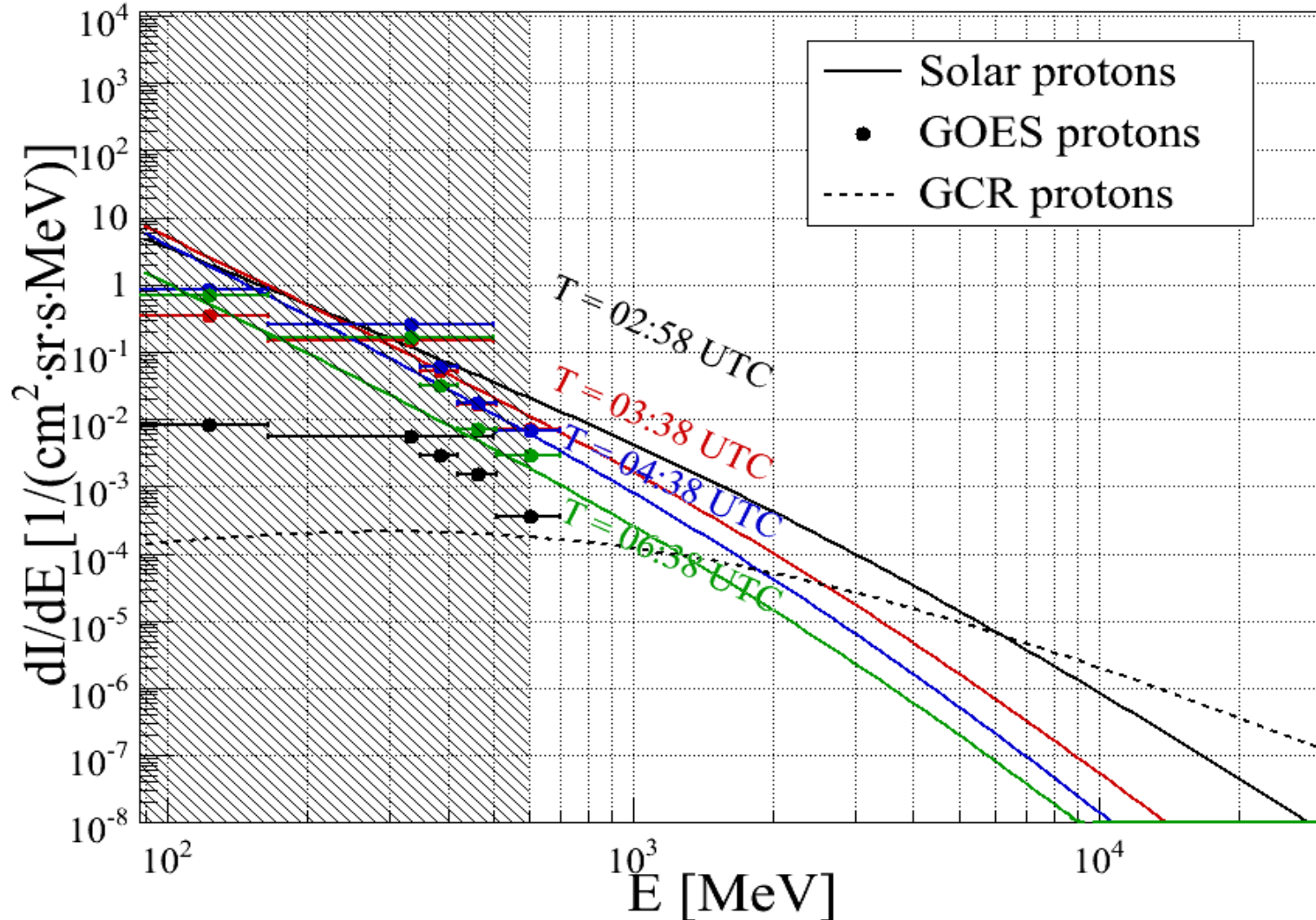
EURADOS 09 > Daniel Matthiae > 30.01.2009

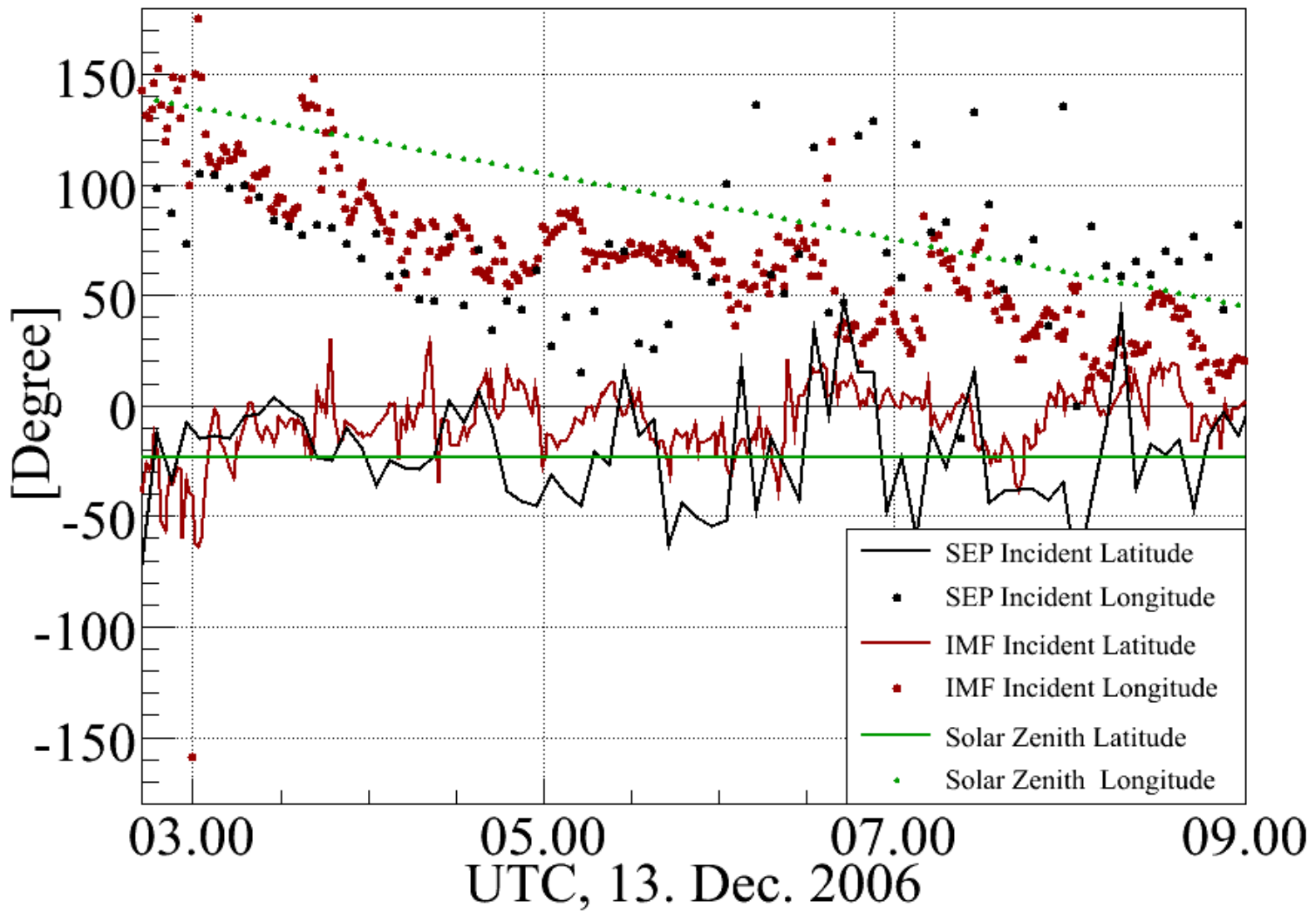


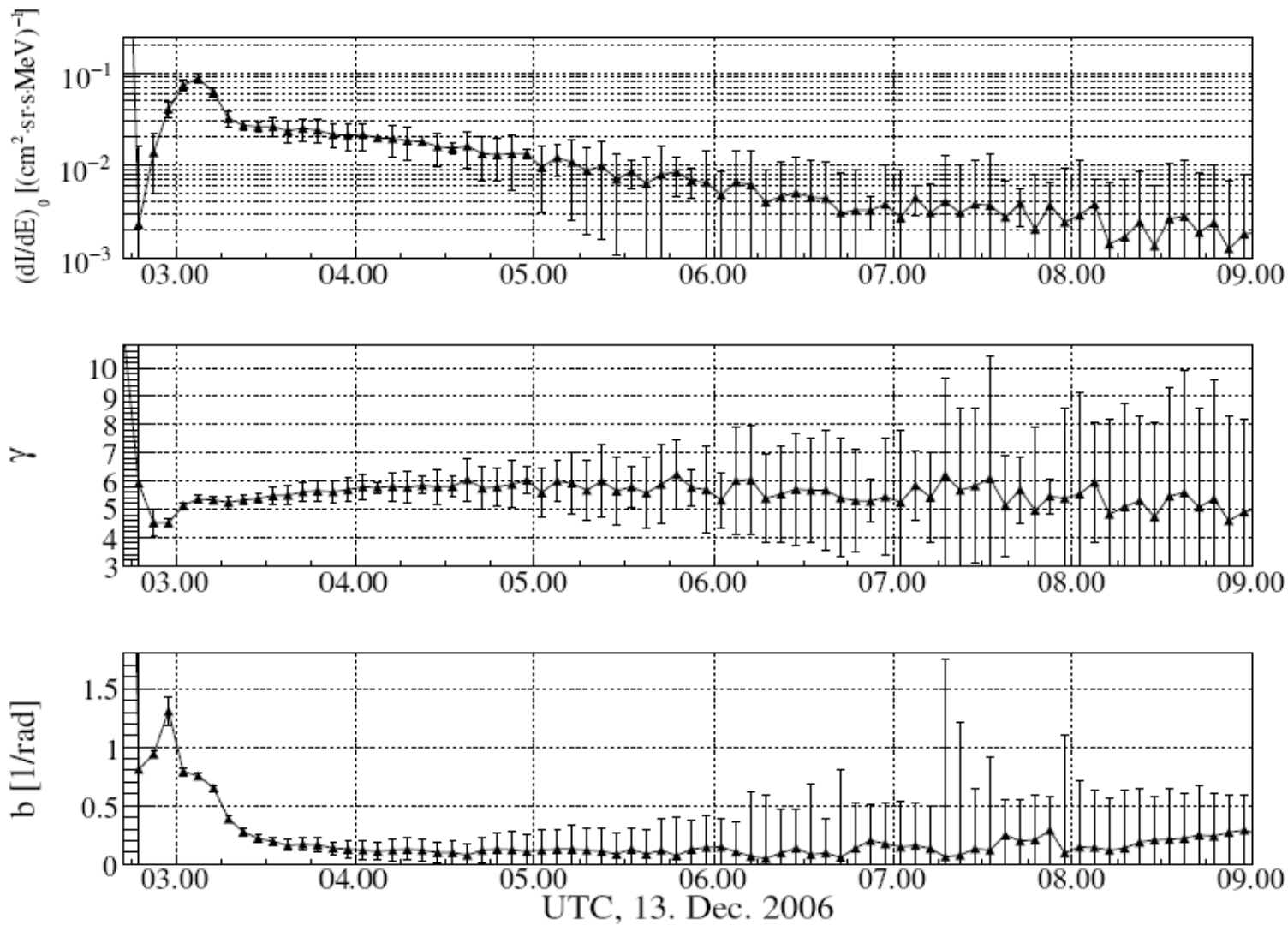




GLE 70: Primary Proton Spectrum at Different Times







Effective dose rate for a route point (θ, ϕ, t)

Primary spectrum:

- Calculate asymptotic directions for each route point
 - Calculate parameter of the primary solar energetic particle spectrum at time t
- Add GCR and SEP spectra

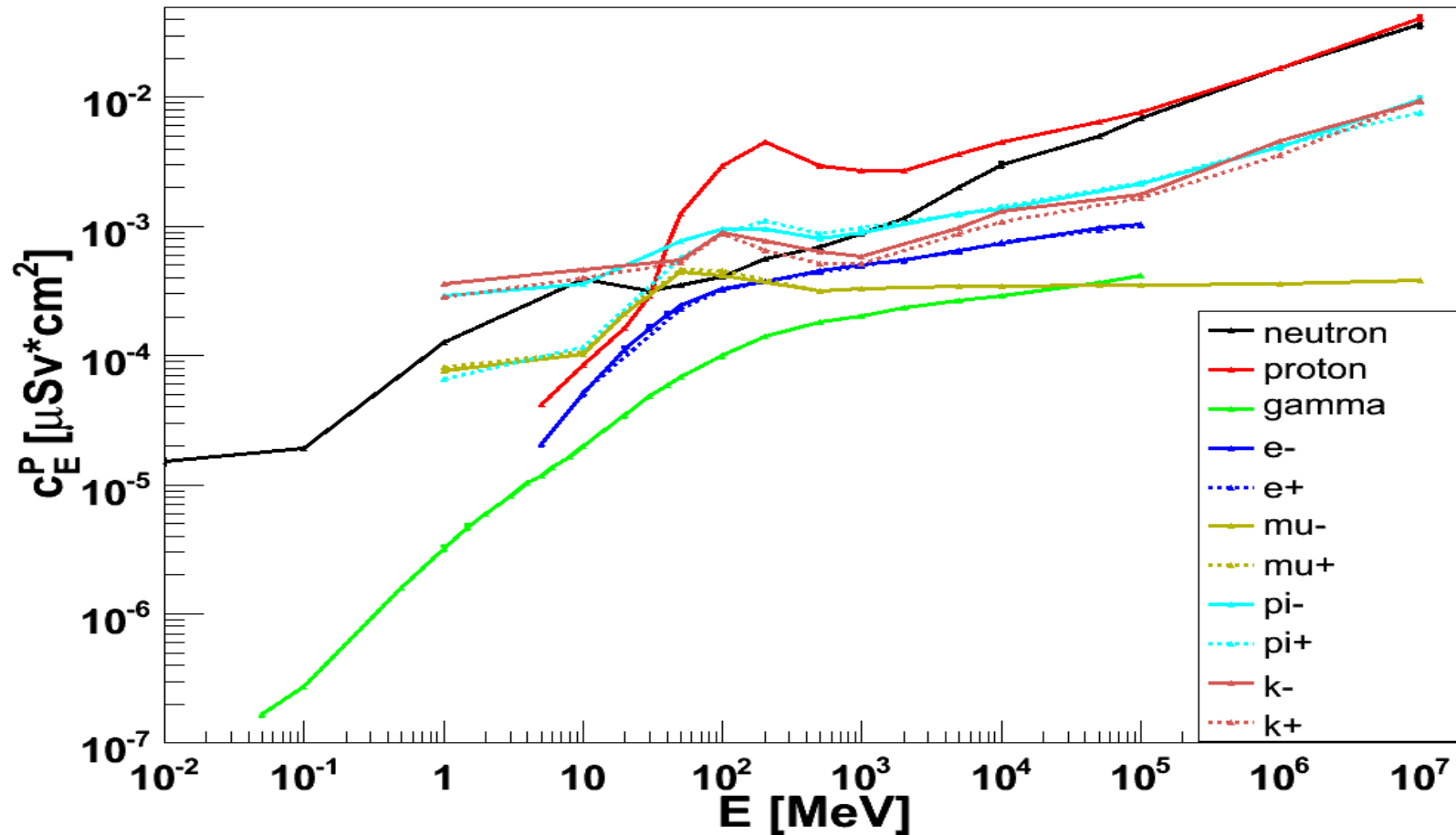
Effective Dose E_D :

- Calculate secondary particle spectra $J_p(E_i)$ from primary spectrum
- Use conversion factors $c_p(E_i)$ [Pellicioni, 2000]:

$$E_D = \sum_{p=1}^{N_p} \sum_{i=1}^{N_E} c_E^p(E_i) \cdot J^p(E_i)$$

Fluence-to-Effective Dose Conversion Coefficients

Pelliccioni, M.: Overview of Fluence-to-Effective Dose and Fluence-to-Ambient Dose Equivalent Conversion Coefficients for High Energy Radiation Calculated Using the FLUKA Code, Radiat. Prot. Dosim. 88(4), 279-297 (2000)



References

- Clem, J. and Dorman, L., Neutron Monitor Response Functions, Space Science Reviews 93: 335–359, 2000.
- Agostinelli, S. et al. J. GEANT4--a simulation tool kit, Nucl. Instruments and Methods A: Vol. 506, 3, Pages 250-303 [2003]
- Koi, T. et al., Interfacing the JQMD and JAM Nuclear Reaction Codes to GEANT4, SLAC-PUB-9978
- Desorgher, L; Planetocosmics, <http://cosray.unibe.ch/%7Elaurent/planetocosmics/>
- Pelliccioni, M.; Overview of Fluence-to-Effective Dose and Fluence-to-Ambient Dose Equivalent Conversion Coefficients for High Energy Radiation Calculated Using the FLUKA Code, Radiat. Prot. Dosim. 88(4), 279-297 (2000)