Usage of the global NM network for assessment of the radiation exposure at flight altitudes

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1. Introduction
2. Model for exposure to radiation at flight altitudes
3. Spectra of GLEs derived using NM data
4. Examples
5. Summary
An important topic of solar physics, space weather, atmospheric physics is the assessment of primary SEP parameters:

- energy spectrum
- anisotropy

using the information from NMs
New model for effective/ambient dose equivalent estimation based on a full Monte Carlo simulation of CR propagation and interaction with the atmospheric molecules. It is based on yield function formalism.

Extensive GEANT 4 simulation tool PLANETOCOSMICS is used with NRLMSISE 00 atmospheric model.

Exposure of air crew at flight altitudes of 35 & 50 kft

Good agreement with experimental and reference data
Effective dose rate

\[ E(h, R_c, \theta, \varphi) = \sum_i \int_{E_{\text{cut},i}(R_c)}^\infty \int J_i(T') Y_i(T', h) d\Omega dT' \]

Yield function

\[ Y_i(T', h) = \sum_j \int_{T^*}^T F_i,j(h, T', T^*, \theta, \varphi) C_j(T^*) dT^* \]

For GCRs

\[ E = 4\pi^2 \left[ \int_{E_{\text{cut}}}^\infty J_p(T') Y_p(T') dT' + \int_{E_{\text{cut}}}^\infty J_\alpha(T') Y_\alpha(T') dT' \right] \]
For the GCRs spectrum – force field model

\[ J_i(T', \phi) = J_{LIS,j}(T' + \Phi_j) \frac{(T')(T' + 2T_r)}{(T' + \Phi_j)(T' + \Phi_j + 2T_r)} \]

For SEPs

1. Data mostly based on NM data analysis, when available

2. The computations are performed for various reconstructions of SEP spectra, available in literature, thus for some events there are several results

3. An conservative isotropic distribution of SEPs is considered
Effective dose $[\mu Sv \, h^{-1}]$

Rigidity cut-off [GV]

- **1998**
- **2000**
- **2002**

**Reference data**

- $H^* (10)$
- $E$

Ambient dose equivalent $H^* (10) [\mu Sv \, h^{-1}]$
The GLE analysis procedure

1. Computation of asymptotic viewing cones and Pc of the NM stations:
   Computation of particle trajectory in a model magnetosphere.

2. Making an initial guess of the inverse problem

3. Application of a optimization procedure (inverse method)
   primary solar proton parameters:
   (energy spectrum, anisotropy axis direction, pitch-angle distribution)
Modeling of spectra and PAD of SEPs

Modified power law or exponent

\[ J_{\parallel}(P) = J_0 P^{-(\gamma + \delta \gamma(P-1))} \]

\[ J_{\parallel}(P) = J_0 \exp\left(-\frac{P}{P_0}\right) \]

PAD – Gaussian like

\[ G(\alpha) = \infty \sum_i \exp\left(-\left(\alpha_i - \alpha_i^\prime\right)^2 / \sigma_i^2\right) \]

From 5 Up to 14 parameters
Effective dose rate as function of altitude during main phase of GLE 72

Mishev & Usoskin Space Weather 2018
Distribution of effective dose rate at 35 kft altitude during GLE #72
Distribution of effective dose rate at 35 kft altitude during GLE #70
Effective dose rate ≈ 0.54 mSv h⁻¹ and 0.13 mSv h⁻¹
Effective dose at altitude of 50 kft during GLE #69 integrated over the first 3h of the event
Effective dose at altitude of 35 kft during GLE 69 integrated over the first 3h of the event
Effective dose at altitude of 50 kft during GLE #5 integrated over the first 3h of the event.
Effective dose at altitude of 35 kft during GLE #5 integrated over the first 3h of the event.
Conclusion

1. New NM yield function
2. Method for GLE and sub-GLE analysis based on NM data
3. Computation of effective dose rate at several altitudes
4. Upgrade of GLE database
THANK YOU
Effective dose yield function at 35 kft
Comparison with measurements and models

Rc=1.19 GV (14.05.2013)

Rc=4.03 GV (15.05.2013)

A

Ambient dose equivalent $H^*(10)$ [\(\mu Sv \cdot h^{-1}\)] vs. Altitude [kft]

B

Effective dose [\(\mu Sv \cdot h^{-1}\)] vs. Altitude [kft]

- HAWK
- PANDOCA
- OULU
- EPCARD
PAD distribution during GLE 72, 10 September 2017

![Graph showing flux vs. pitch angle](image-url)

- **Flux [Proton m\(^{-2}\)sr\(^{-1}\)s\(^{-1}\)GV\(^{-1}\)]**
- **Pitch Angle [deg]**
GLE # 5 spectra and PAD

![Graph A](image1.png)

![Graph B](image2.png)

- Flux [Proton m$^{-2}$sr$^{-1}$s$^{-1}$GV$^{-1}$]
- Pitch Angle [deg]
- GCR
- 0340
- 0345
- 0400
- 0415
- 0430
- 0445
- 0500
- 0530
- 0600
- 0630

\[7 \times 10^7\]
\[6 \times 10^7\]
\[5 \times 10^7\]
\[4 \times 10^7\]
\[3 \times 10^7\]
\[2 \times 10^7\]
\[1 \times 10^7\]