Analysis of sub-GLE and GLE events using NM data: space weather applications

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1. Introduction

2. General description of the method for GLE analysis

3. sub-GLE analysis

4. Examples

5. Summary
An important topic of solar physics, space weather, atmospheric physics is the assessment

Primary SEP parameters:

current spectrum
anisotropy

using the information from NM
Method for GLE analysis

The NM count rate modeling

\[ N(P_c, h, t) = \sum_i \int_{P_c}^{\infty} Y_i(P, h) J_i(P, t) dP \]

NM yield function

\[ Y_i(P, h) = G(P) \sum_i \int \int A_i(E, \theta) F_{ij}(P, h, E, \theta) dE d\Omega \]

NM rel. increase

\[ \frac{\Delta N(P_{cut})}{N} = \frac{\int_{P_{cut}}^{P_{max}} J_{\parallel sep}(P, t) Y(P) G(\alpha(P, t)) A(P) dP}{\int_{P_{cut}}^{\infty} J_{GCR}(P, t) Y(P) dP} \]
The GLE analysis procedure


2. Making an initial guess of the inverse problem

3. Application of an 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

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

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

PAD – Gaussian like

\[ G(\alpha) = \propto \sum_i \exp\left(-\frac{(\alpha_i - \alpha_i')^2}{\sigma_i^2}\right) \]

From 5 Up to 14 parameters
Rigidity spectra during GLE 71, 17 May 2012

GLE71, 17 May 2012

Flux [Proton m$^{-2}$ s$^{-1}$ sr$^{-1}$ GV$^{-1}$]

R [GV]

GCR

02:00 UT
02:10 UT
02:20 UT
02:30 UT
02:40 UT
02:50 UT
03:00 UT
03:10 UT
Asymptotic cones GLE 72 on 10 September 2017
Rigidity spectra during GLE 72, 10 September 2017

Flux [Proton m$^{-2}$ sr$^{-1}$ s$^{-1}$ GV$^{-1}$] vs. R [GV]

16:15 UT
PAD distribution during GLE 72, 10 September 2017

Flux [Proton m\(^{-2}\) sr\(^{-1}\) s\(^{-1}\) GV\(^{-1}\)]

Pitch Angle [deg]

16:15 UT
1. Justification of GLE and sub-GLE definition

A GLE event is registered when there are near-time coincident and statistically significant enhancements of the count rates of at least two differently located neutron monitors including at least one neutron monitor near sea level and a corresponding enhancement in the proton flux measured by a space-borne instrument(s).

A sub-GLE event is registered when there are near-time coincident and statistically significant enhancements of the count rates of at least two differently located high-elevation neutron monitors and a corresponding enhancement in the proton flux measured by a space-borne instrument(s), but no statistically significant enhancement in the count rates of neutron monitors near sea level.

Antarctic neutron-monitor stations operational in 2017
Problems:

Only two NM stations with statistically significant increase and five unknown parameters

ill-posed problem -> several solutions

Simplification -> reduce of model parameters

- we forced the apparent source position to be along the IMF derived from ACE satellite measurements, but not as a free parameter

- simple power law rigidity spectrum

- Single particle flux
Only three free parameters – however several solutions with equal quality

Full simulation of the global NM network response with this set of parameters and by fixing the PAD and spectral characteristics, but varying the apparent source position location over all geographic coordinates.

Result: new apparent source position and assessed set of spectra and PADs with a given confidence level, in our case 95%
Sub-GLE event of 29 October 2015 contour plot
Derived family of spectra and PAD sub-GLE 29 October 2015
Effective dose rate as function of altitude during main phase of GLE 72

![Graph showing the effective dose rate as a function of altitude. The x-axis represents the effective dose rate in µSv h⁻¹, ranging from 0 to 25. The y-axis represents the altitude above sea level (a.s.l.) in meters, ranging from 0 to 16,000. Two curves are shown, one solid and one dashed, indicating the relationship between effective dose rate and altitude.]
Distribution of effective dose rate at 35 kft altitude during GLE 72
Distribution of effective dose rate at 35 kft altitude during GLE 70

µSv.h⁻¹

Latitude (North)

Longitude (East)
Sub-GLE events effective dose rate in the polar region at 35 kft

<table>
<thead>
<tr>
<th>Effective dose $E$ $\mu$Sv.h$^{-1}$</th>
<th>sub-GLE 07/03/2012</th>
<th>sub-GLE 06/01/2014</th>
<th>sub-GLE 29/10/2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEP min</td>
<td>12.4</td>
<td>3.3</td>
<td>6.9</td>
</tr>
<tr>
<td>SEP max</td>
<td>14.1</td>
<td>4.1</td>
<td>8.2</td>
</tr>
<tr>
<td>GCR</td>
<td>5.51</td>
<td>5.63</td>
<td>5.67</td>
</tr>
<tr>
<td>Total</td>
<td>19.6</td>
<td>9.7</td>
<td>13.9</td>
</tr>
</tbody>
</table>

A. Mishev et al. JSWSC 2017
Conclusion

1. New NM yield function
2. Method for GLE analysis based on NM data
3. Method for sub-GLE analysis based on NM data
4. Computation of effective dose rate at several altitudes