Statistical error for cosmic rays modulation evaluation by 1-D model

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Abstract

- The propagation of cosmic rays through the heliosphere is solved for more than half a century by stochastic methods based on Ito's lemma. This work presents the estimation of statistical error of solution of Foker – Plank equation by 1D forward stochastic differential equations method.
- The error dependence on simulation statistics and energy is presented for different combinations of input parameters. The 1% precision criterium in intensities and 1% criterium in standard deviation are defined as a function of solar wind velocity and diffusion coefficient value.

Model Description

Forward-in-time see [1]. integration method was used to modulate of the stochastic path of charged particles from the border of the heliosphere to the Earth. The set of SDE for Forward integration with momentum p is:

$$dr = \left(\frac{2K_{diff}}{r} + V_{sw}\right)dt + \sqrt{2K_{diff}}dW$$

$$dp = -\frac{2V_{sw}p}{3r}dt$$

$$L = -\frac{4V_{sw}}{3r}$$

Here $K_{diff} = K_0\beta p$ is diffusion scalar where K_0 is the diffusion parameter in presented simulation is taken to be $K_0 = 5 \times 10^{22}\, cm^2\, s^{-1}\, GV^{-1}$. Solar wind speed V_{sw} in describing simulation is taken to be constant and equal to 400 $km\, s^{-1}$. β, is the particle velocity in speed of light units.

References

[1] Bobik, P., et al. (2016), J. Geophys. Res. Space Physics, 121.
[2] Yamada, Y., S. Yanagita, and T. Yoshida (1998), Geophys. Res. Lett., 25.

Results

For the data processing and obtain the spectra in one case was used so-called binning procedure, and approach well described in [1], with LIS from [2]. Thus the differential intensity, in this case, was taken to be $J \propto p(m^2c^4 + p^2c^2)^{-1.85}$.

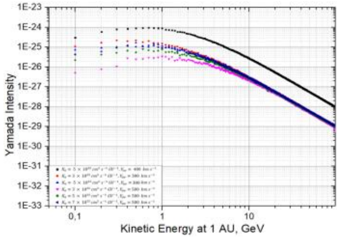

Fig. 1. Spectra at 1 AU evaluated for different sets of input parameters.

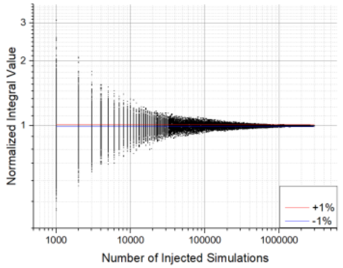

Fig.2. Normalized integral of whole spectrum[0 – 100GeV] value distribution with respect to number of injected simulations. For the chosen set of input parameters ($K_0 = 5 \times 10^{22}\, cm^2\, s^{-1}\, GV^{-1}$, $V_{sw} = 400\ km\, s^{-1}$).

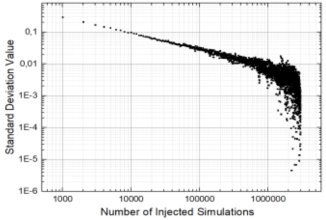

Fig. 3. Standard deviation evaluated from normalized integrals ($K_0 = 5 \times 10^{22}\, cm^2\, s^{-1}\, GV^{-1}, V_{sw} = 400\ km\, s^{-1}$).

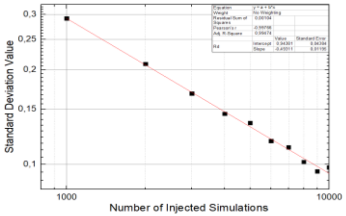

Fig. 4. Linear fit evaluated from standard deviation distribution in range from 1000 to 10000 simulations ($K_0 = 5 \times 10^{22}\, cm^2\, s^{-1}\, GV^{-1}$, $V_{sw} = 400\ km\, s^{-1}$).

Conclusions

The CR spectra at 1 AU were evaluated in the F-p method for Yamada LIS spectra for the energy range from 0.001 to 100 GeV, for six sets of input parameters (see Fig. 1). To show statistical error dependence to the number of injected simulations, integrals for the whole energy range were evaluated (see Fig. 2). Standard deviation distribution with respect to the number of injected simulations (see Fig. 3) was obtained from evaluated whole energy range normalized integrals. Linear fits of standard deviation in the range from 1000 to 10000 injected simulations were shown (see Fig 4).