NASA GCR ENVIRONMENT MODEL

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Solar Energetic Particles (SEP), Solar Modulation and Space Radiation:
New Opportunities in the AMS-02 Era

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INTRODUCTION

FOREWORD

As a foreword, I would like to state that I am presenting on behalf of S. Golge who was unable to attend this workshop; his and T. Slaba's efforts towards the improvement of the Badhwar - O'Neill model have been significant.

Also, a special thanks to P. O'Neill for his ongoing work and support in the development and improvement of the model.

INTRODUCTION

The ionizing nature of Galactic Cosmic Ray (GCR) particles poses a potential health risk for crew members in space, e.g., radiation exposure induced cancer [1].

Another significant concern arises from the interaction of GCR particles with the electronics inside and outside of a spacecraft, e.g., memory bit flips and latch-up, which are generically called Single Event Effects (SEE) [2].

To evaluate the potential risks induced by GCR, the Badhwar-O'Neill (BON) GCR flux simulation model has been developed to numerically solve the Fokker-Planck (FP) equation.

FOKKER-PLANCK (FP) EQUATION

The BON model takes into account diffusion, convection, and adiabatic deceleration within the heliosphere and provides the flux of GCR particles of a given charge, Z, as a function of energy at 1AU in free-space beyond the Earth's magnetosphere.

Fokker-Planck (FP) Equation

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 V_s U\right) - \frac{1}{3}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 V_s\right)\right]\left[\frac{\partial}{\partial T}\left(\alpha T U\right)\right] = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \kappa \frac{\partial U}{\partial r}\right)$$

where r is the radial position in units of AU;
T is the kinetic energy (MeV/n);
$U(r, T)$ is the GCR flux;
$V_s(r)$ the solar wind speed (~ 400 km/s);
$\kappa(r, T)$ the particle diffusion coefficient tensor;
and $\alpha(T) = (T + 2E_0)/(T + E_0)$, with E_0 being the rest energy of the GCR particle.

LOCAL INTERSTELLAR PARAMETERS

LIS PARAMETERS

At 100 AU, GCR modulation is negligible and therefore a constant GCR field, referred to as the LIS (Local Interstellar) flux spectrum (U_0), which represents one of the boundary conditions for BON.

LIS Flux Spectrum

$$U_0(Z,T)\mid_{R_b=100\ AU}= j_0(Z)(T_N+E_0)^{\gamma(Z)}\beta_N^{-1}\beta^{\delta(Z)}(T+E_0)^{-\gamma(Z)}$$

where j_0, δ, and γ are free parameters for each GCR ion;
$\beta = v/c$ is the relative velocity;
and β_N is the relative velocity at $T_N = 35$ GeV/n (selected arbitrarily for fitting).

LIS PARAMETERS

The LIS parameters are formulated by using GCR measurement data from detectors at or near 1 AU; e.g., satellite and balloon measurements. In the model, the flux of any ion beyond nickel ($Z > 28$) is obtained by scaling from the silicon result.

In BON14, the tuning of LIS parameters were influenced by a study that showed that GCR ions in the energy domain between 0.5 GeV/n and 4.0 GeV/n account for most of the exposure to the differential effective dose rate behind 20 g/cm^2 of aluminium shielding [3].

→ This will be discussed more in J. Norbury’s talk - “Impact of AMS-II measurements on reducing GCR model uncertainties”.

RESULTS

DATA SELECTION

In this revision of the BON model, BON14, we have included the GCR data beyond 1970, which spans Solar Cycles 20 to 24 (to date).

In the past, the LIS parameters of the BON were uniquely influenced by measurements from the Cosmic Ray Isotope Spectrometer (CRIS) on the NASA Advanced Composition Explorer (ACE) spacecraft.

CRIS is currently measuring the flux of ions and their isotopes from boron (Z=5) to nickel (Z=28), where the lowest and highest kinetic energy measurements are ion specific. CRIS provides kinetic energy of GCR isotopes between $\sim$ 50 - 500 MeV/n.

In BON14, greater emphasis was placed on the higher kinetic energies, a region not covered by CRIS. Nonetheless, we show that the updated model still accurately represents the lower energy regions.

PORTION OF DATA

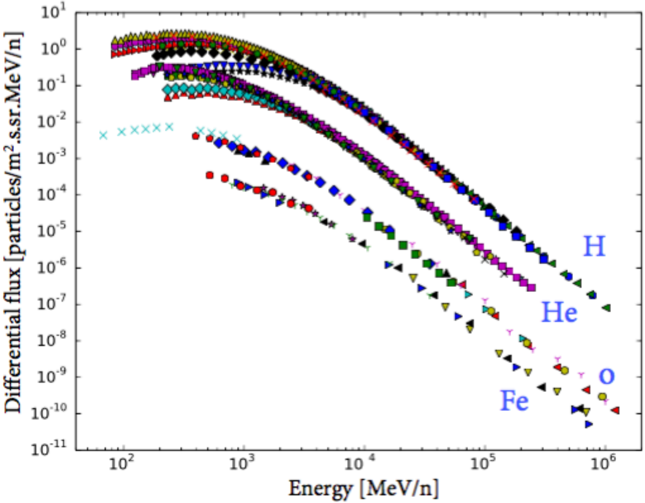

Figure 1: The flux data as a function of kinetic energy for H, He, O, and Fe are shown for all the data used for calibration (this plot excludes ACE/CRIS data).

COMPARISONS

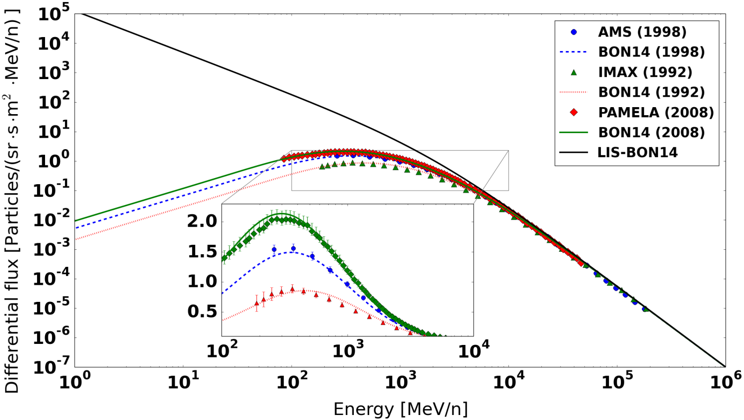

Figure 2: The differential flux for H ions as a function of energy is shown for various GCR measurements, AMS (1998), IMAX (1992), and PAMELA (2008). Those measurements are compared with BON14 for the same measurement periods. The solid black line (LIS-BON14) represents the LIS flux for H ion at R=100 AU.

COMPARISON METRICS

Comparison of BON14 with the GCR measurement data was completed by evaluating the relative differences (Rd). This metric is used to analyze under- and over-predicting time periods, and to adjust fit parameters.

The average of the residual Rd does not provide a complete picture of the model versus measurement agreement. Therefore, we also used the average absolute relative difference, $|Rd|$, to determine the overall difference between the model and the GCR. This metric better quantifies the overall fit agreement.

$$|Rd| = \frac{1}{N}\sum_{k=1}^{N}\frac{|Model_k - Data_k|}{Data_k}$$

BON14 - GCR COMPARISON

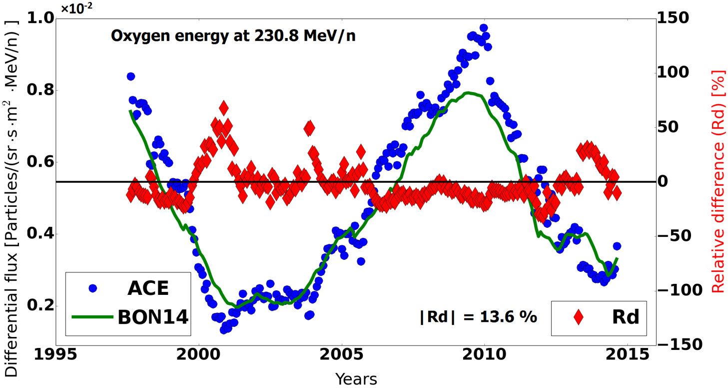

Figure 3: Although the BON14 parameters were focused more on the GCR energy region between 0.5 – 4.0 GeV/n, we show that the model is in good agreement with CRIS/ACE data as well. In the figure, the 27-day average differential flux for O ions at 230.8 MeV/n from ACE/CRIS (circle) as a function of date is compared with BON14 (solid line). On the right axis their Rd is shown (diamond).

BON MODEL COMPARISON

Table 1: The average relative difference metrics between the entire GCR database with BON11 and BON14.

	Average [%]	
	Rd	$\|Rd\|$
BON11	17.9	23.7
BON14	-0.4	13.0

As shown above in Table 1, the BON14 model has been improved significantly with respect to the previous BON model, BON11, both at low- and high-energy regions.

CLOSING REMARKS

CONCLUSION

The comparison of BON14 with an updated set of GCR measurements from various balloon, satellite, and space shuttle measurements is presented.

→ Much more information is available in NASA/TP–2015–218569: Badhwar - O'Neill 2014 Galactic Cosmic Ray Flux Model Description.

The new model LIS parameters were fitted with an updated approach based on a sensitivity analysis.

We have seen improvements over BON11 and anticipate significant model improvement in the energy region of interest with hydrogen and helium data when the new GCR measurements are available from AMS-02.

REFERENCES

[1] F. A. Cucinotta, M.-H. Y. Kim, and L. J. Chappell, *Space Radiation Cancer Risk Projections and Uncertainties-2012*, Tech. Rep. NASA/TP-2013-217375, (2013).

[2] L. Adams, *Cosmic ray effects in microelectronics*, Microelectronics Journal **16** (1985) no. 2, 17 – 29. **http://www.sciencedirect.com/science/article/pii/S0026269285802135**.

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[4] P. M. O'Neill and C. C. Foster, *Badhwar-O'Neill 2011 Galactic Cosmic Ray Flux Model Description*, Tech. Rep. NASA/TP-2013-217376, (2013).