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Prediction of solar particle event proton doses using early dose rate measurements

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Abstract

A methodology for predicting solar particle event doses using Bayesian inference is being developed. As part of this development, we have tested criteria for categorization of new solar particle events (SPE) using calculated asymptotic doses and dose rates for the 22 SPEs that occurred in 2001. In 9 out of 22 events, our criteria for categorization would have over-predicted the range of asymptotic doses in which the tested events would have fallen. In two cases, our methodology under-predicted the dose range in which the event would have fallen. In order to better predict a new event's group category and thus, to better restrict the Bayesian inference predictive model parameter space, we have reexamined our dose rate criteria for categorization of new events. We report the updating of the grouping criteria using data from the 22 SPEs of 2001, as well as five additional SPEs. Using the revised grouping criteria, we present an analysis of group categorization prediction results for the first ten SPEs of 2002.

1. Introduction

Dose due to solar particle event (SPE) protons may be the limiting radiation risk for long duration, crewed space missions and may be mission or life-threatening. An SPE is defined by the National Oceanic and Atmospheric Administration (NOAA) as an event during which the number of particles with energies greater than 10 MeV exceeds 10 particles $s^{-1}\,cm^{-2}\,sr^{-1}$ for more than 15 min. The SPE source consists of particles ranging from protons to iron. This work will only consider dose from SPEs since the emphasis of this research is directed towards the prediction of acute effects. Furthermore, since the majority of SPE absorbed dose may be attributed to protons and as only partial data exist for other species, this paper will only consider the proton contribution to SPE dose. Approximately 75% of an astronaut's space suit can be penetrated by 10 MeV protons while 30 MeV protons can penetrate to the mid-deck of the space shuttle. Efforts to link precursor solar observables (e.g., flare detection, coronal mass ejection speed) and resulting particle flux and radiation dose to humans and equipment have met, to date, with limited success [1]. As such, methodologies that utilize data after arrival of SPE particles (event-triggered methodologies) may provide

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the next best near-term solution for forecasting dose as a function of time (dose time profiles). Such early-warning forecasts might enable space mission operators to implement mitigative actions to protect equipment and personnel and to decide when it is safe to resume normal operations.

Previous event-triggered methodologies have utilized an innovative, sliding-time-delay artificial neural network (ANN) [2,3] and a hierarchical, Bayesian predictive technique [4]. Tehrani's ANN [2] provided predictions of asymptotic dose using calculated doses soon after SPE onset while Hoff's ANN [3] provided dose time profiles using calculated doses. The Bayesian technique has utilized either calculated dose and/or dose rate values soon after SPE proton arrival at Geostationary Operational Environmental Satellites (GOES) to make forecasts of dose and dose rate–time profiles out to 120 h beyond SPE onset time. Calculated doses obtained using measured fluxes are used as surrogate dose measurements since dose measurements in deep space are not available for most previous events in the manned space era. The validity of this model for predicting SPE doses in low-earth-orbit (LEO) is unknown since the spectra at lower proton energies are significantly altered by the geomagnetic field, which in turn is highly variable, depending on geomagnetic storm conditions. Markov Chain Monte Carlo (MCMC) sampling methods and non-linear, hierarchical, growth curve regression models have been used for forecasts of dose and/or dose rate time profiles for several large (in terms of asymptotic dose) SPEs. The remainder of this paper will be restricted to the Bayesian technique.

The Bayesian methodology uses dose rates soon after SPE onset to group the new event with similar historical events. Dose rates at 1-h intervals out to 5 h beyond SPE initiation were examined to determine the maximum dose rate in that 5 h period. The maximum value then determined the group into which the new event was placed. This grouping of similar events restricted the parameter spaces for the predictive models. Previous work [4] considered grouping criteria from a limited number of historical events prior to 2001. These historical events were chosen based on the significance of the events from a perspective of dose to human organs (i.e., blood-forming organs, skin, eye). Calendar year 2001 produced 22 SPEs. As a test of the initial grouping criteria, we applied those original criteria to the year 2001 SPEs. Not only did we want to examine the validity of the original criteria, we also wanted to examine the more basic assumption of the correlation of initial dose rate magnitude and asymptotic dose. After examining results for the year 2001 SPEs, we updated the grouping criteria using data from the 22 SPEs of 2001, as well as the August 12, 1989, November 9, 2000, May 9, 1992, February 20, 1994, and November 24, 2000 SPEs. Using the revised grouping criteria, we present an analysis of group categorization prediction results for the first ten SPEs of 2002.

2. Methodology

The methodology for categorization of new SPEs and prediction of dose and dose rate–time profiles was earlier reported by Neal and Townsend [4]. As before, dose rate values are used to initially categorize the SPE, and dose and/or dose rate values are used to make inferences about model parameters and predictions of future doses and dose rates. The following sections provide a brief review of the principal components of the Bayesian methodology.

2.1. Dose and dose rate calculations

Since dose and dose rate data in deep space are unavailable for these events, surrogate dose and dose rate data are obtained by calculation using measured proton fluxes. Differential and integral proton flux and fluence spectra were measured on the Geostationary Operational Environmental Satellite (GOES)-7 and GOES-8 for the NOAA Space Environment Center (SEC) and obtained via the NOAA SEC website. Five minutes average flux histories are parameterized by an exponential rigidity (momentum per unit charge) function. Parameter values are used as input to the deterministic, coupled neutron–proton space radiation computer code, BRYNTRN [5], for transport of protons and their reaction products (protons, neutrons, H-2, H-3, He-3, and He-4) through aluminum shield material (in this case, $1\,\mathrm{g\,cm^{-2}}$). Dose and dose rates are the BRYNTRN code output. These calculated values as a function of time form the data base of dose and dose rate–time profiles.