Understanding Radiation Environment at Earth and Beyond: Overview of Two Projects

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Radiation Data Portal: Integration of Radiation Measurements at Aviation Altitudes and Solar-Terrestrial Environment Observations

The impact of radiation dramatically increases at high altitudes in the Earth's atmosphere and in space. Therefore, monitoring and access to radiation environment measurements are critical for estimating the radiation exposure risks of aircraft and spacecraft crews and the impact of space weather disturbances on electronics. Addressing these needs requires reliable access to multi-source radiation environment data and enhanced visualization and search capabilities. The Radiation Data Portal provides an interactive web-based application for convenient search and visualization of in-flight radiation measurements.

Radiation Portal Data Sources:

- The Automated Radiation Measurements for Aerospace Safety (ARMAS) data, augmented with the integrated flight parameters and environment. The ARMAS project utilizes a micro-dosimeter integrated into a data processing and communication package to measure and report the absorbed dose rates at a one-minute cadence. ARMAS data are publicly available from Space Environment Technologies (SET) as individual files for each flight (https://sol.spacenvironment.net/ARMAS_Archive/).
- GOES Soft X-ray (SXR) radiation in the 0.5-4 Å and 1-8 Å channels. The Radiation Portal currently uses calibrated 1-min averaged GOES fluxes available from the National Oceanic and Atmospheric Administration National Centers for Environmental Information archive (NOAA NCEI, https://satdat.ngdc.noaa.gov/). Each measurement during the flight is connected to the nearest-time SXR measurement.
- Integrated GOES proton flux measurements. The Portal utilizes 5-min integrated calibrated measurements of the proton fluxes above the following thresholds: 1 Mev, 5 MeV, 10 MeV, 30 MeV, 50 MeV, 60 MeV, and 100 MeV. These data are also available via the NOAA NCEI archive (https://satdat.ngdc.noaa.gov/). Each measurement during the flight is connected to the closest-in-time GOES measurement.

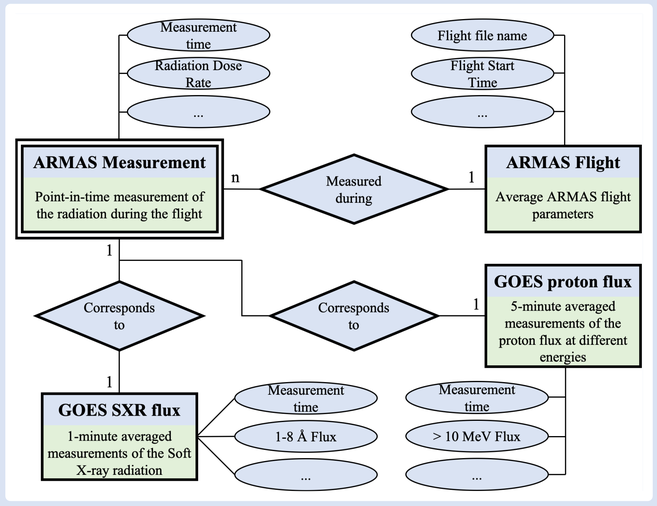
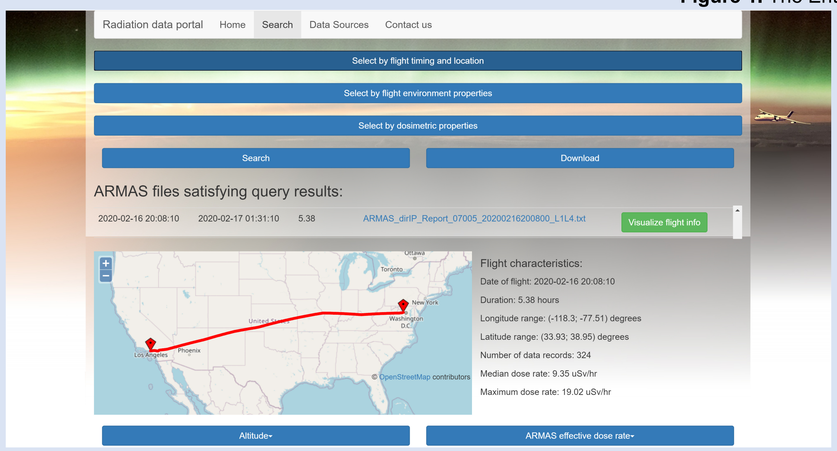


Figure 1. The Entity Relationship Diagram of the Radiation Data Portal.



Access the Radiation Data Portal temporarily located at https://solarflare.njit.edu/RDP/ or use a QR-code above

Figure 2. Illustration of the Radiation Data Portal web application.

Radiation Data Portal Features:

- The data sources are loaded to a MySQL relational database. The database structure is optimized for fast data retrieval.
- The Application Programming Interface (API) and Python routines have been developed to retrieve the database records directly, without interaction with the web interface.
- The application search engine contains a variety of filters (flight location and timing, environmental and dosimetric properties) allowing a user to customize flight selection.
- The search process and flight summary are supported by dynamic histograms of the flight parameters implemented with the Google Charts API and OpenLayers map API.

Use Case Example: ARMAS Measurements During an Enhanced Solar Proton Environment

- There are six ARMAS flights that occurred during Solar Proton events (SP-enhanced conditions). An SP event is defined as an increase of the >10 MeV proton flux above the 10 pfu (particle flux unit) level.
- All SP-enhanced flights were performed in September 2017 in a confined geographic region. We collected the flights that happened in the same region during September 2016 – September 2018 when no SP events were observed (SP-low group).
- The Student's and Welch's t-tests demonstrate that there is no statistically-significant difference between the ARMAS/NAIRAS* ratios and median effective dose rates for SP-enhanced and SP-low groups of flights (see Figure 3 for distributions). *NAIRAS: Nowcast of Aerospace Ionizing Radiation System.
- Possible explanations: 1) most of energetic protons were in the low-energy tail and did not penetrate deep into the atmosphere; 2) the data-driven NAIRAS model captures much of what ARMAS is measuring.

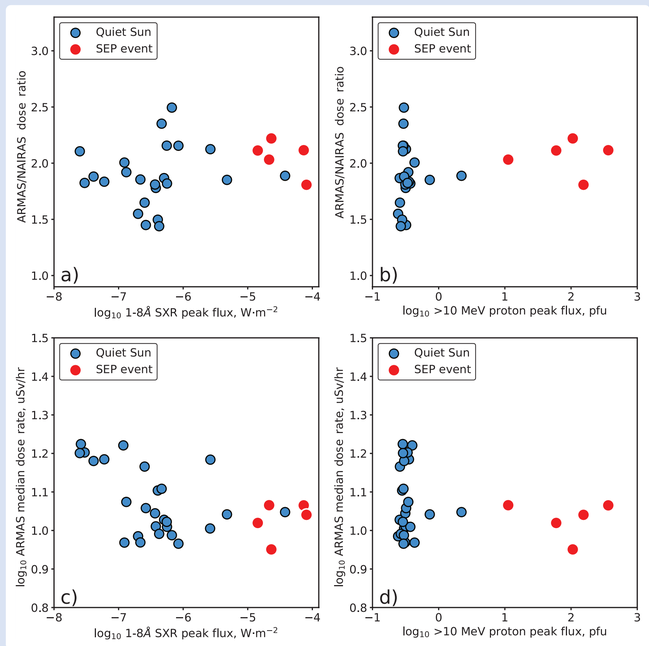


Figure 3. Correlations between the total dose ratios of ARMAS to NAIRAS to X-ray flux (panel a) and proton flux above 10 MeV (b). Dependence of the ARMAS median effective dose rate from the X-ray flux (panel c) and proton flux above 10 MeV (d). Red circles correspond to the flights when the peak value of > 10 MeV proton flux exceeded 10 pfu; blue circles indicate the flights when the flux was less than 10 pfu.

Plans and Broader Impact

The Radiation Data Portal will be expanded by including additional radiation measurement sources, adapting the existing data visualization capabilities, and adapting and improving the search engine to the new data sets. In particular, we plan to include measurements of ion flux and magnetic field in-situ measurements from the NASA Advanced Composition Explorer (ACE), Geomagnetic activity data from NASA's Coordinated Data Analysis Web (CDAWeb), the data from ground-based neutron monitors, and add more space-based measurements of energetic particles. We envision that the Radiation Data Portal will enhance our knowledge of solar-terrestrial interactions and Space Weather and grow further into a comprehensive collaborative effort involving many aspects of the aerospace radiation environment and the broader community.

Machine Learning Tools for Predicting Solar Energetic Particle Hazards: Project Description and Initial Steps

Solar Energetic Particles (SEPs) are among the most dangerous transient phenomena of solar activity. As hazardous radiation, SEPs may affect the health of astronauts in outer space and create difficulties for space exploration. Our primary objective is to develop "all-clear" forecasts of Solar Proton Events (SPEs) with low false-alarm rates using a state-of-the-art machine learning approach. Specifically, we plan to 1) develop an online-accessible automatically-updated database that integrates the solar and heliospheric data, metadata, and descriptors related to SPEs; 2) develop robust "all-clear" forecasts of SPEs with low false-alarm rates, targeted at different temporal scales (cadences and lead times), different energy and particle flux thresholds of SPEs, and adapted to the operational availability of data sources and gaps in the data.

The Team's Progress:

- The MySQL database has been developed and tested using an NJIT server. The database collects data related to SPEs (summarized in the table below; the data collection is still in progress) and is optimized for efficient data search and query. The relationships between SP events and the data for different prediction timescales are organized at the database level.
- The team analyzed the relationships between the SWPC NOAA operational probabilistic forecasts of proton events from 1992 to the present and the proposed all-clear forecast strategy. We found that the current operational forecasts are not suitable for the all-clear purpose: about 20% of SPEs occurred when only a 1% probability prediction of an SPE was issued. We have also investigated the probability thresholds that optimize the proposed Weighted TSS (WTSS) metrics as a function of a parameter α. See the detailed description below.

Solar Energetic Particle DB Data Sources (2010-2020)	
Polarity Inversion Line (PIL) properties of ARs	GOES proton flux measurements
Space Weather HMI Active Region Patches (SHARPs)	GOES soft X-ray measurements
Flare lists from various flare catalogs	GOES Temperatures and Emission measures
CME lists (LASCO/SOHO and CACTus catalogs)	Records of radio bursts (type II and IV)
Measurements of ground-based neutron monitors	Derived lists of SPE events and SPE-quiet periods

Testing "All-Clear" Strategies

Strategy 1. Optimization of the custom Skill Score.

The hyperparameters of the ML algorithm are typically optimized to maximize certain metrics (constructed from the outputs of the binary classification problem). We developed a parametric version of the True Skill Statistics (TSS) metrics, the Weighted TSS (WTSS):

$$WTSS(\alpha) = 1 - \frac{2}{\alpha+1}\left(\alpha\frac{FN}{P} + \frac{FP}{N}\right)$$

Here *FN/P* is the rate of missed events, *FP/N* is the false alarm rate, and α is the weighting factor for missed events. For all-clear purposes, α should be very large (high penalty for missed events). The WTSS(α) maximization for SWPC NOAA daily operational forecasts of solar proton events for 1996-2020 is illustrated in Figure 4. One can see that the optimal probability threshold is the same for α > 1, indicating that the forecasts are not suitable for all-clear purposes.

Strategy 2. Prediction of all-clear periods.

In addition to predicting SPEs, we plan to construct a ML-based model for predicting all-clear time periods (1-3 days ahead). The prediction will be predominantly done based on the magnetic field properties of ARs and event prehistory. Although the problem is similar to daily SPE predictions for the 1-day-ahead case, it has a smaller class-imbalance ratio (fewer positive and more negative samples) for 2- and 3-day-ahead setups.

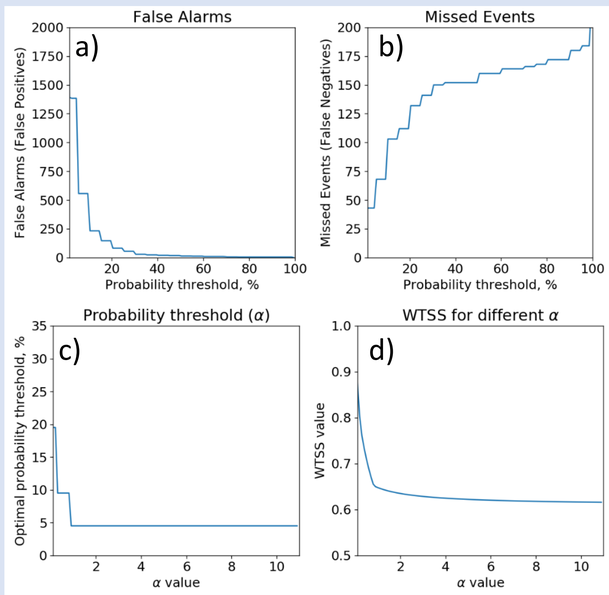


Figure 4. The number of false alarms (a) and missed events (b) as functions of the probability threshold applied to operational daily probabilistic forecasts of Solar Proton flares. The optimal probability threshold as a function of the weighting factor α (c), and the corresponding *WTSS*(α) score.

Plans and Broader Impact

- The team currently involves three graduate students: NJIT Computer Science students Yucheng Jiang and Patrick O'Keefe and NJIT Physics student Sheldon Fereira. Yucheng Jiang is working on the development and maintenance of the MySQL database. Patrick O'Keefe is working on the front-end web application for retrieval and of database entries and data visualization. Sheldon Fereira is working on data preparation and analysis. The team coordinates activities twice a week via virtual meetings.
- The team also organizes monthly teleconferences on Machine Learning-driven SEP prediction activities. The initial discussion took place during the COSPAR ISWAT meeting (February 2020). This activity connects more than 30 participants from Academia, NASA Centers, and non-profit organizations.

Acknowledgements

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