



NAIRAS Model Updates and Improvements to the Prediction of Ionizing Radiation from Earth's Surface to Cislunar Environment



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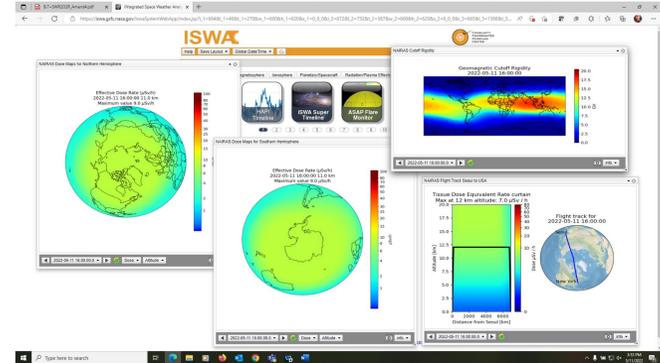
1.0 NAIRAS Model Description

- **Nowcast of Aerospace Ionizing Radiation System (NAIRAS) Model**
 - Running in real-time on LaRC computer cluster since 2011, results hosted on Space Environment Technologies server/website
 - Running in real-time at CCMC since 2020
- **Key Model Features**
 - Global ionizing radiation environment model
 - Physics-based HZETRN (High Charge (Z) and Energy TRAnsport) code
 - Real-time inclusion of solar energetic particle (SEP) radiation
 - Real-time solar-magnetospheric effects on radiation (cutoff model by Kress et al. [2004, 2010])
- **New/Current Model Development**
 - Improved SEP dose nowcast and forecast
 - Extend to low-Earth orbit (LEO) environment
 - Single-Event Effects (SEE) radiation risk assessment quantities
 - Run-on-Request (RoR) @ CCMC



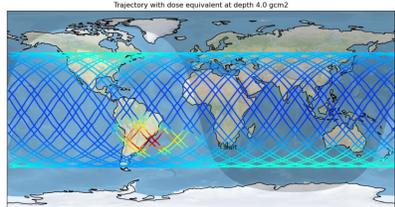
2.1 Real-Time Aviation Radiation Dose

Availability: CCMC Integrated Space Weather Analysis System (iSWA)

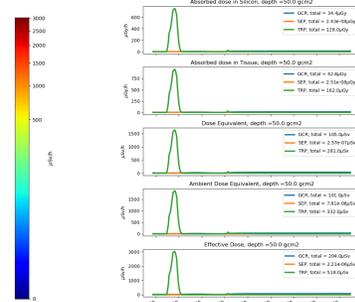
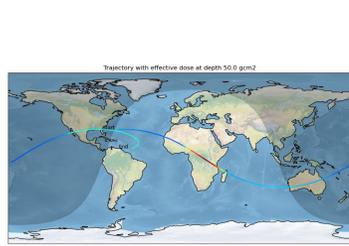


2.2 Near Real-Time International Space Station (ISS) Effective Dose

Availability: Under Development



2.3 Near Real-Time NASA Artemis 1 Dose



3.0 Run-on-Request (RoR) @ CCMC

<https://ccmc.gsfc.nasa.gov/models/NAIRAS-3.0>

Community Coordinated Modeling Center

NAIRAS ROR updates

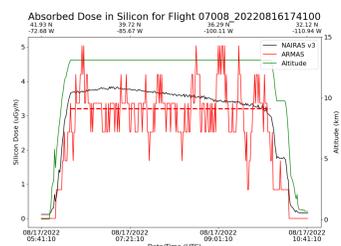
Dec 2006 SEP Events-ISS Radiation

Table: RoR Capability Summary and Description

Run Option	Output Quantities	User Input
Global Dosimetric	Absorbed dose in silicon, absorbed dose in tissue, dose equivalent, ambient dose equivalent, effective dose	Start/End Date-Time
Flight Trajectory	Dosimetric & Flux/Fluence	Trajectory file (date,time,lat,lon,alt)
	Dosimetric	Shielding depths for dosimetric calculations
Flux/Fluence	Dosimetric	Shielding depths for flux/fluence calculations
	Integral	Lower LET energy bounds of integral quantity
	Differential	N/A (full model differential spectra written to output)

3.1 RoR US Corporate Aircraft

KBDL-KTUS



EINN-KBDL

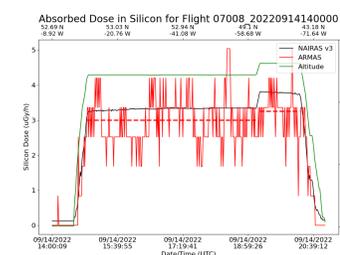
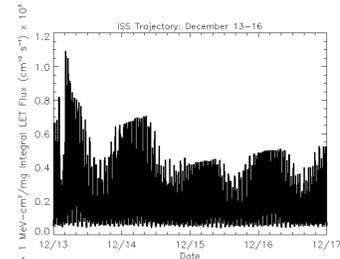
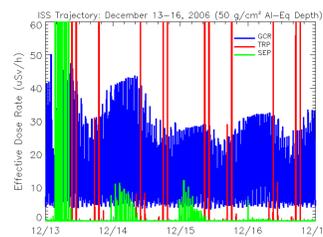


Table: Summary of NAIRAS/ARMAS Comparisons for 15 US Corporate (Raytheon) Flights from 2022 (cutoff: 1-3 GV).

Median Dose at Cruise Altitude	Silicon Dose (uGy/h)	Ambient Dose Eq. (uSv/h)	Dose Equivalent (uSv/h)	Effective Dose (uSv/h)
NAIRAS	3.3704	14.805	9.5782	14.6006
ARMAS	2.8995	13.4172	8.7183	18.9210
Percent Difference	16.24	10.34	9.86	-22.83

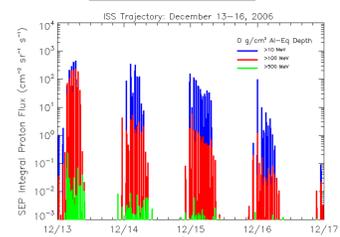
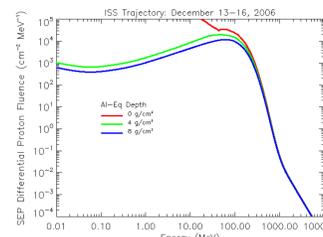
3.2 RoR SEP Events: ISS Radiation

December 13 00:00 UT – December 17 00:00 UT



Al Shielding: 50 g/cm²

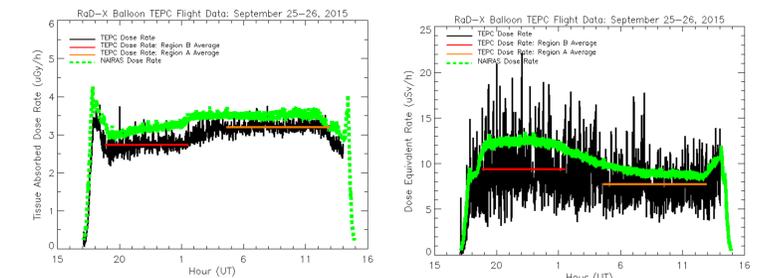
Al Shielding: 4 g/cm²



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3.3 RoR High-Altitude Balloon Dose

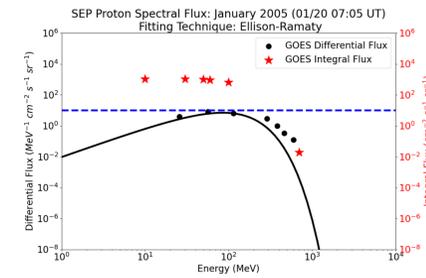
NASA Radiation Dosimetry Experiment (RaD-X) Balloon Flight



Region A: 21 km < Z < 27 km; Region B: Z > 32.5 km

4.0 Improved SEP Modeling

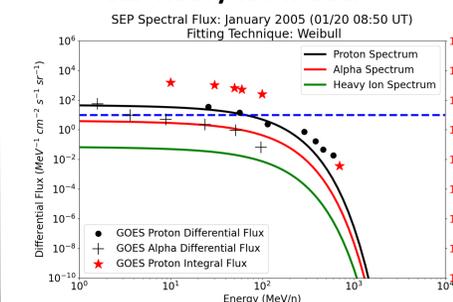
- **New Approach**
 - Fit spectrum to GOES integral proton flux rather than differential flux measurements
- **Benefits**
 - Improved robustness
 - Difficulty fitting GOES differential channels at event onset and for weak-to-moderate events
 - Extrapolation beyond highest differential energy channel (~500 MeV) requires introducing arbitrary and subjective criteria
 - 50% or more of SEP effective dose at large material depths (aviation altitudes) comes from > 500 MeV protons
 - Preliminary simulations using neutron monitor data suggest fitting to GOES integral proton flux may better represent the relativistic protons during GLEs
 - New integral flux fitting approach provides a pathway to develop a SEP proton spectrum forecast



SEP proton spectrum (black line) fit to GOES integral flux and comparison to GOES differential proton flux. Horizontal blue line indicates NOAA/SWPC SEP event threshold for >10 MeV proton flux.

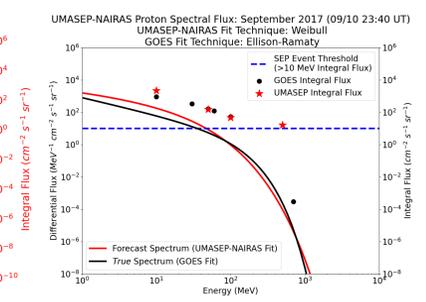
Under Development

SEP Heavy-Ion Model



SEP Heavy-Ions: ⁴He – ²³⁸U

UMASEP-NAIRAS SEP Forecast



7 hours after UMASEP >10 MeV integral proton flux forecast issue time

5.0 Summary

- **Major NAIRAS Code Deliverables to CCMC**
 - NAIRAS Real-Time Global Dosimetric Quantities (Publicly Available Now)
 - NAIRAS RoR Capability (Publicly Accessible)
 - NAIRAS Improved SEP Proton Spectral Fitting Algorithm (Fully Implemented)
- **Significant Improvements and Extensions to NAIRAS Model**
- NAIRAS predictions now include both dosimetric quantities to assess human radiation exposure and differential/flux quantities to assess SEEs in avionic system
- NAIRAS dose comparisons to measurement data: < 30% for all dosimetric quantities at altitudes from 0-40 km (RaD-X data and ARMAS aircraft data)
- SEP Heavy-Ion Model & SEP Dose Forecast Model Under Development: