The Radiation, Interplanetary Shocks, & Coronal Sources (RISCS) Toolset

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*The goal of this project is to serve the needs of space system designers and operators by developing an interplanetary radiation environment model within 10 AU: **R**adiation, **I**nterplanetary **S**hocks, and **C**oronal **S**ources (RISCS) toolset.*

- The RISCS toolset will provide specific reference environments for space system designers and nowcasting and forecasting capabilities for space system operators.
- We envision the RISCS toolset providing the spatial and temporal radiation environment external to the Earth's (and other planets') magnetosphere, as well as possessing the modularity to integrate separate applications (apps) that can map to specific magnetosphere locations and/or perform the subsequent radiation transport and dosimetry for a specific target.

Space System Designers & Operators: Needs & Deliverables

- Radiation in space arises primarily from three natural sources and can affect space systems and astronauts: 1) galactic cosmic rays; 2) solar energetic particles; and 3) energetic particles trapped in planetary magnetic fields.
- Two broadly defined space weather communities need to understand, anticipate, and mitigate such space radiation: *space system designers* and *space system operators*.
- *Designers* include engineers of crewed and non-crewed space systems and equipment for space-based activities (e.g., extra-vehicular activity).
- *Operators* include launch directors, spacecraft operators, and radiation exposure managers for crewed missions or commercial air travel.

Software Deliverables: An Operational Toolset as a Strategic Capability

- Serving these two space weather service provider communities requires three critical components:

a) probabilities for incipient solar activity (both “all clear forecasts” and the “when, where, and how strong” for outbursts);

b) the ability to use these probabilities and daily solar coronal and solar wind observations to continuously model the 3D time-dependent heliosphere within 10 AU; and

c) the ability to model the acceleration and transport of energetic protons and heavy ions based on “events” that are occurring or are forecast to occur in the heliosphere.

- RISCS toolset will provide all three elements:

1) MAG4: predicts active region outbursts with up to 72 hours warning (Falconer and colleagues)
2) Kinematic and MHD (MS-FLUKSS) modeling of interplanetary background and event-driven solar wind Pogorelov, Zank and colleagues)
3) **PATH**: **P**article **A**cceleration and **T**ransport throughout the **H**eliosphere code (Zank, Li and colleagues)

Figure 1: Conceptual Flow of the RISCS Toolset Serving Space Weather Service Providers

Figure 1a: RISCS Toolset for Space System Designers

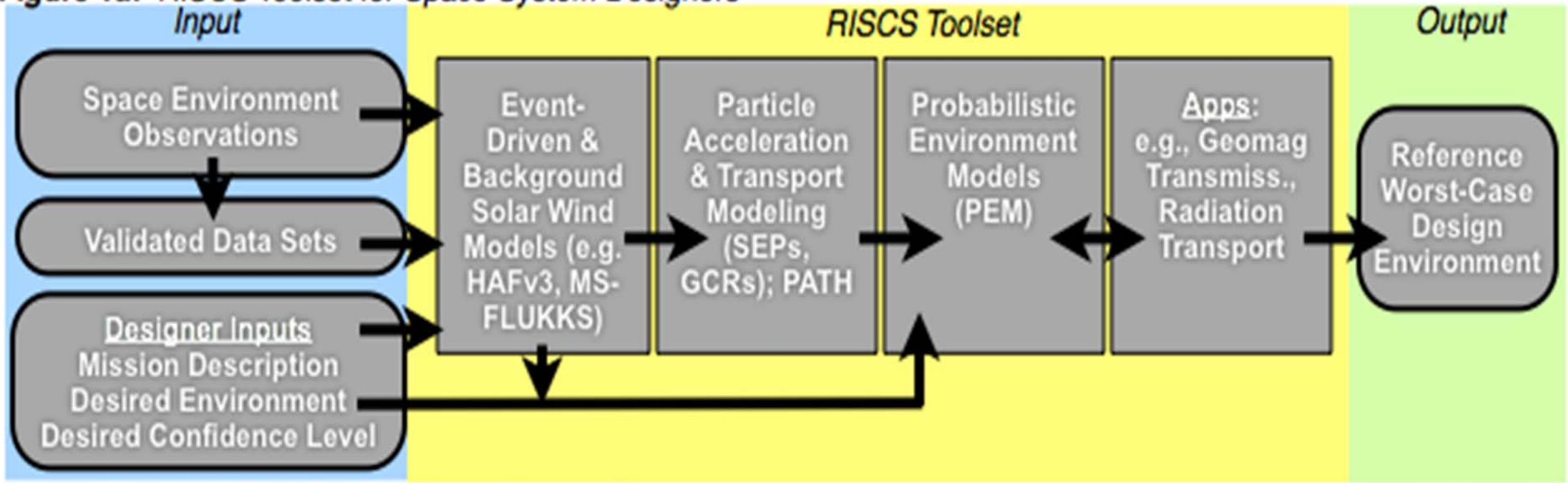
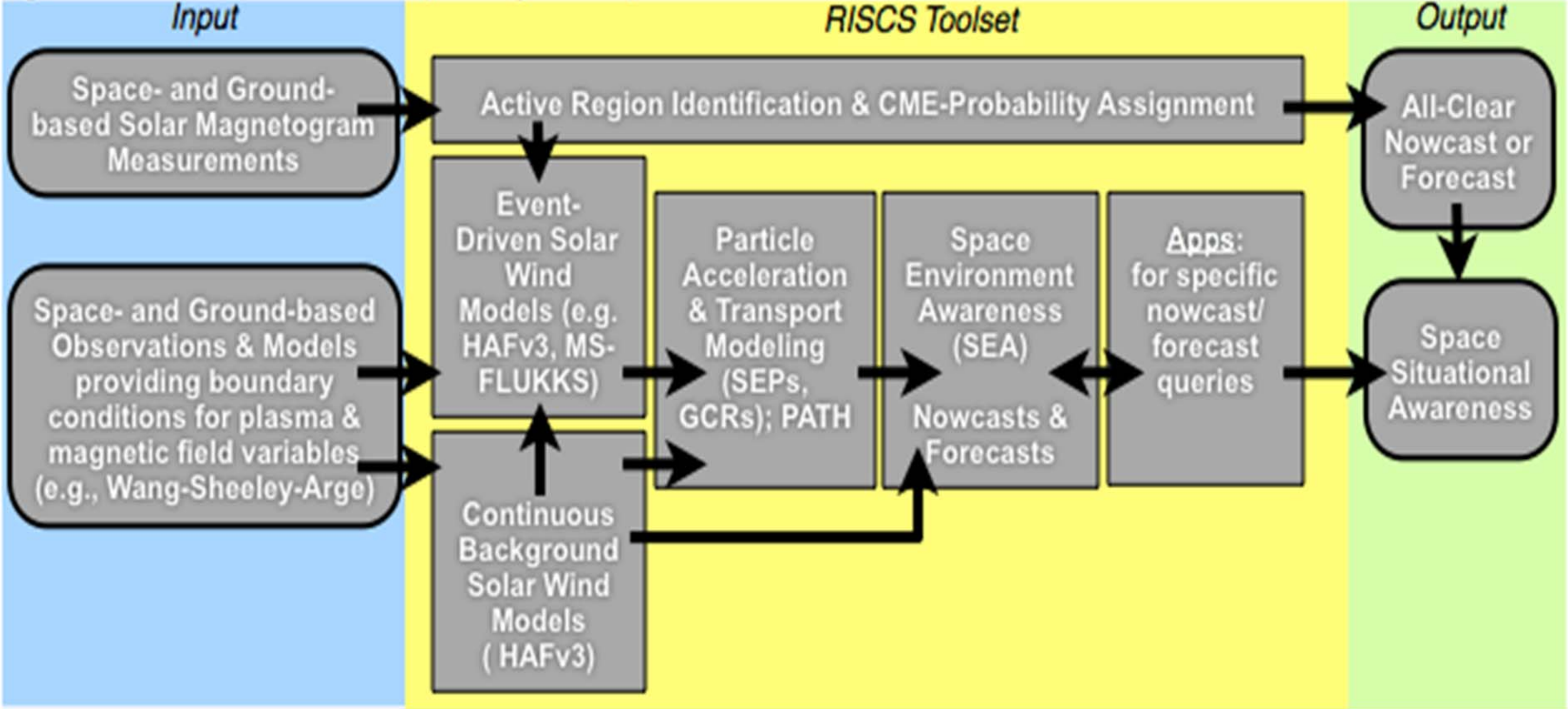


Figure 1b: RISCS Toolset for Space System Operators



Heritage: The PATH to RISCS

The three science elements underlying RISCS are

a) the prediction of solar activity,
b) the modeling of the inner heliosphere, and
c) the modeling of particle energization and transport throughout the heliosphere.

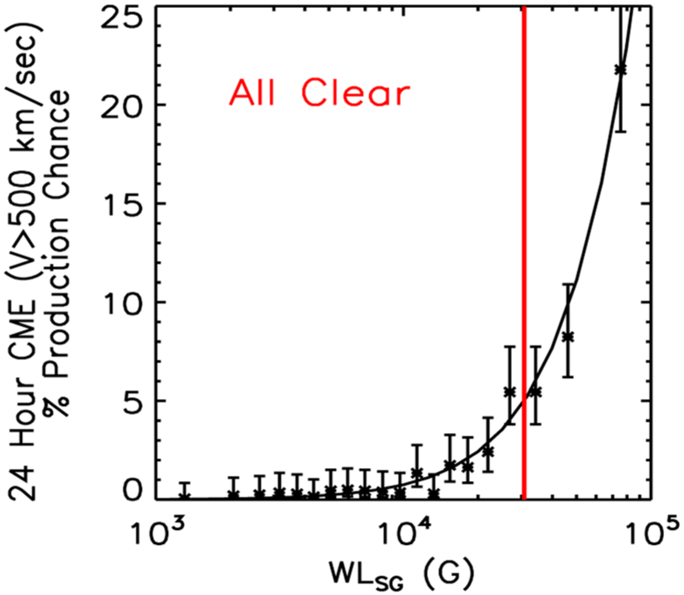
We discuss the Science Underlying RISCS

The Science Underlying RISCS

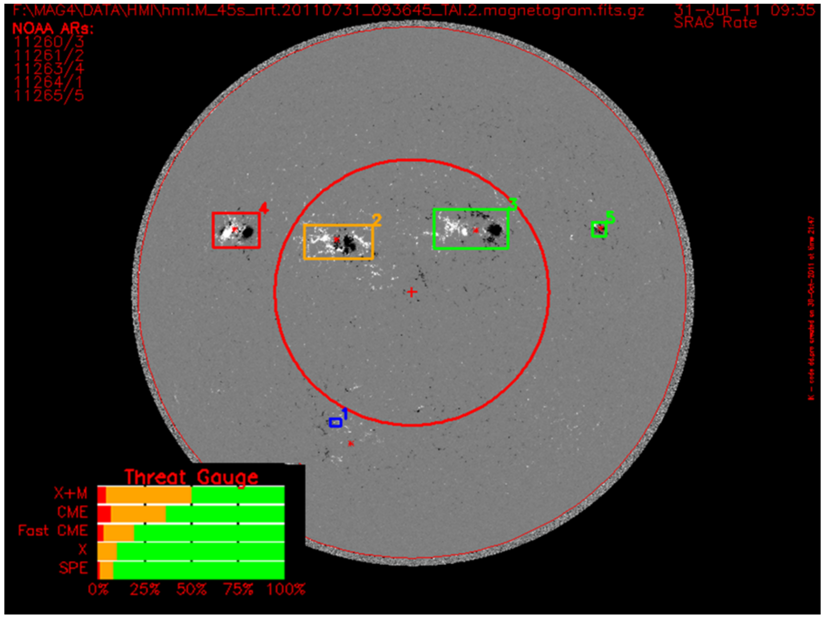
a) Predicting Solar Activity

- J. Adams et al. approach:
- Two key elements of our proposal rest on the use of a) extreme value theory to predict future extremes of solar activity based on the past history of solar activity, and b) probabilistic measures that allow us to i) predict All-Clear periods on the Sun, and ii) predict the probability of solar events in the near future.
- Feynman et al. (1990a, 1993) (size distribution of SEP events ~log-normal distribution); . Xapsos et al (1998, 1999a, 2000, 2007) (maximum entropy for probability of large events occurring, → model peak fluxes, event-integrated fluencies and later cumulative fluences of protons and heavy ions); Jiggens & Gabriel, 2009; Jiggens, 2010 (waiting-time distributions between SEP events not time-independent Poission distribution). Adams et al. (2011) applied extreme value theory to episodes of SEP activity and extended the evaluated database to the present and predicted worst-case proton differential energy spectra.
- This work and extensions will be included within RISCS with both the evaluated and a simulated data base providing reference worst-case environments at high confidence levels for designers.

- D. Falconer, R. Moore et al.
- Solar outbursts (flares and CMEs) result from the explosive release of free magnetic energy stored in the non-potential structure of active-region magnetic fields. The probability that an active region will have an outburst is correlated with the amount of free energy stored in the active region's coronal magnetic field.
- Falconer et al (2002, ++ 2013) have developed and tested various proxy measures of active-region free magnetic energy, quantities measured from photospheric magnetograms of active regions.



An active region with free magnetic energy WL_{SG} to the left of the red line (less than 5% chance of producing a fast CME within 24 hours) has an All Clear forecast. (Falconer et al., 2008)



MAG4: threat major eruption indicated for each active region on the disk (red for "dangerous," yellow for "caution," green or blue for All Clear). Threat Gauge graphic shows ±1-σ range of forecast aggregate chance of event in the next 24 hours. (Falconer et al. 2011)

The Science Underlying RISCS

b) Heliospheric modeling

- C. “Ghee” Fry, N. Pogorelov, G.P. Zank et al

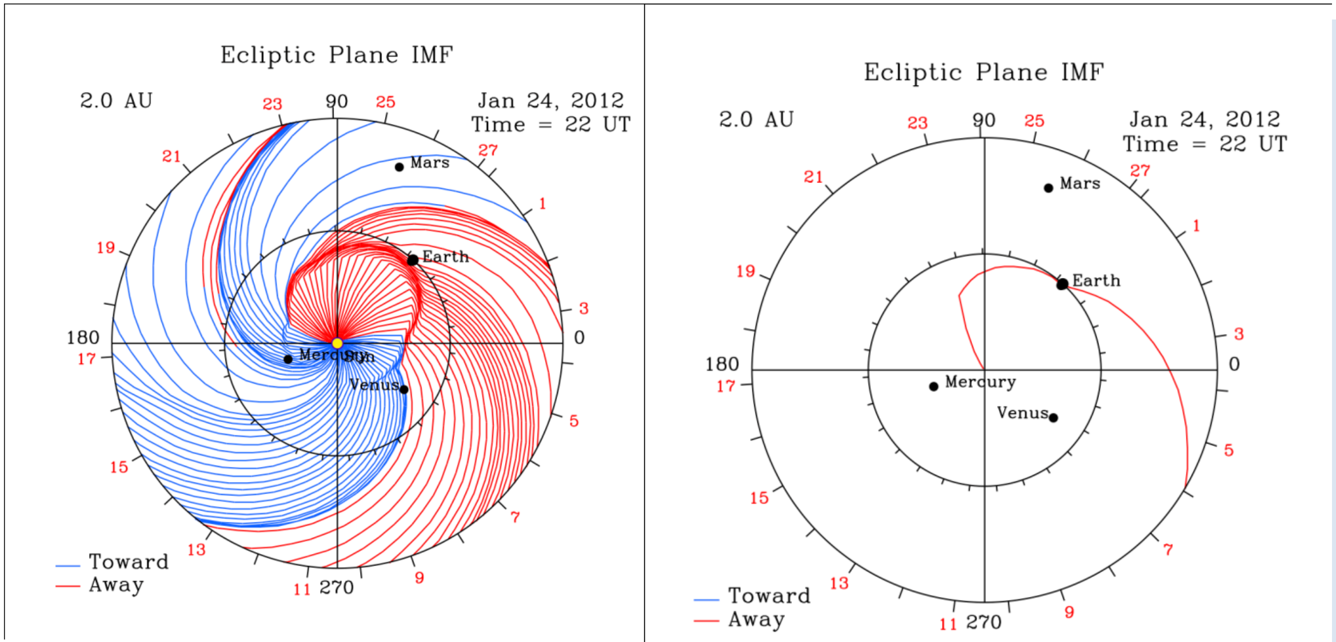
The PATH energetic particle code requires models of

1) the background solar wind,
2) interplanetary disturbances at which particles are accelerated (shocks), and
3) the interplanetary magnetic fields, along which particles propagate.

- PATH requires a 3D time-dependent code to model the heliosphere using as an inner boundary condition the observed and monitored solar wind data as base conditions.
- For RISCS, we will utilize two 3D time-dependent heliosphere codes: HAFv3 (a kinematic 3D MHD code, Fry) and MS-FLUKSS (a fully 3D MHD code, Pogorelov, Zank)

HAFv3

- The HAFv3 code is a 3D time-dependent kinematic solar wind MHD model developed by C. Fry, (Hakamada & Akasofu 1982; Fry et al. 2001; McKenna-Lawler et al., 2006), which extends the earlier well tested HAFv2 code. HAFv2 was transitioned into space weather operations at Air Force Weather Agency (AFWA) in August 2006. The advantages of this code are its speed of execution, its portability, and its very extensive testing and validation.



Left panel: HAFv3 real-time forecast of the IMF projected on the ecliptic plane. Right panel: Snapshot of the IMF line connecting the observer (at Earth) to and through the shock and mapping back to model's inner boundary at 2.5 Rs

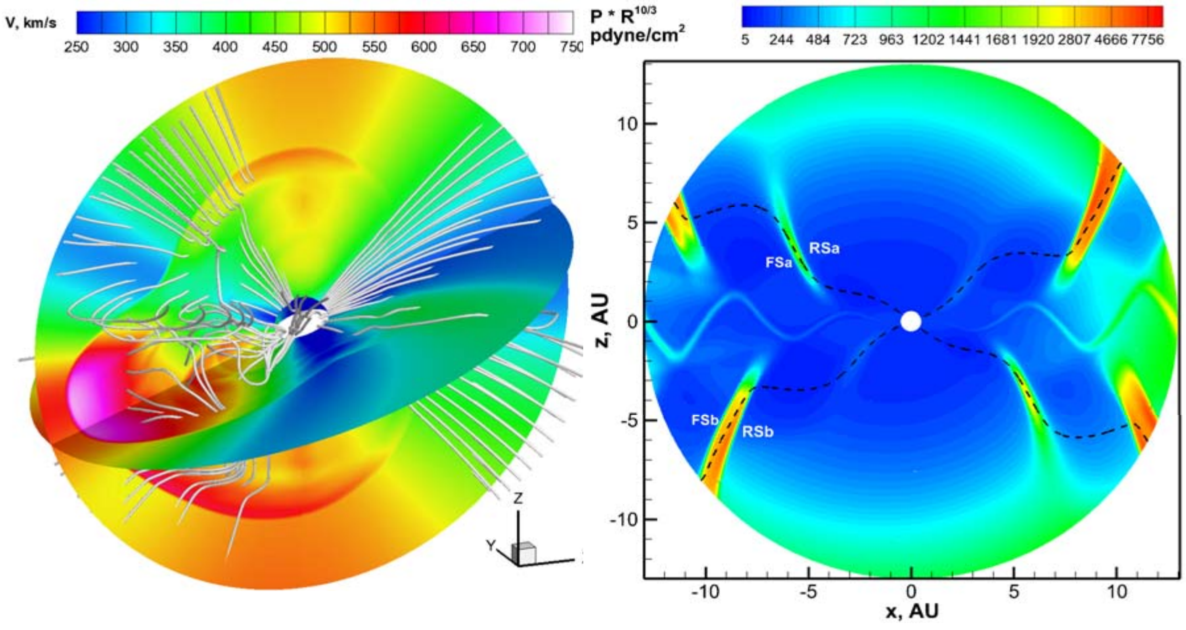
Key Features of HAFv3:

- Physics-based model using modified kinematic method
- Driven by solar observations
- Predicts shock arrival time at Earth
- Predicts plasma conditions at Earth and heliosphere to 10 AU and beyond
- User-specified temporal & spatial resolution
- Cross-platform portability
- Scalable via MPI
- Maps time-dependent, shock-observer field lines and connectivity to solar sources
- Extensive software documentation and User's Manual

MS-FLUKSS

MS-FLUKSS is a suite of numerical codes that model the flows of a partially analyzed plasma using adaptive mesh refinement (AMR) on Cartesian or spherical meshes [Pogorelov et al., 2004, 2008, 2009; Borovikov et al., 2009].
MS-FLUKSS exploits the Chombo framework (Colella et al. 2007), which enables AMR, dynamic load balancing, and other data choreography, and ensures excellent scalability up to 150,000 cores, running on different architectures, including the CSPAR cluster and the ORNL super-computers, Jaguar and Kraken.

a) *The velocity magnitude and magnetic field lines in the solar wind 20 hours after a CME eruption on November 4th, 1997.* ***b)*** *Plasma pressure distribution for a simulation of corotating interaction regions (Borovikov, et al., 2012).*

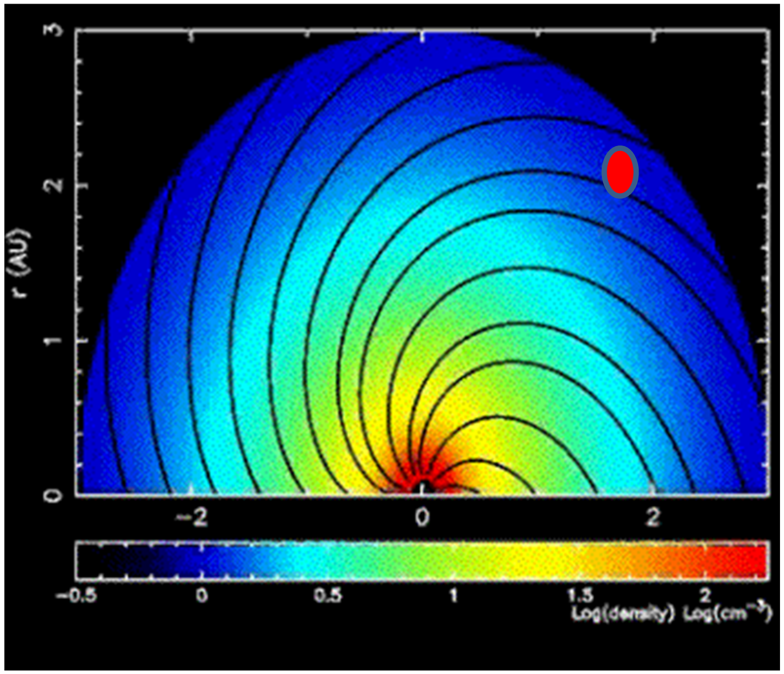


Key Features of MS-FLUKSS:

- ➢**3**D time-dependent MHD code
- ➢Includes physics-based MHD turbulence transport models
- ➢Uses Chombo framework: AMR, dynamic load balancing, data choreography
- ➢Cartesian and spherical mesh implementation
- ➢Portable and highly scalable
- ➢Flexible implementation of multiple boundary conditions for sub- and super-Alfvenic flows
- ➢Incorporates IPS data, WSO magnetograms, GONG LOS magnetic field and transverse velocity data, SOLIS vector magnetogram data, and multiple spacecraft data sets
- ➢Predicts plasma and magnetic field conditions at Earth and throughout the heliosphere, including shock arrival times
- ➢Can save time-dependent simulation data along available spacecraft trajectories

The Science Underlying RISCS
c) Particle energization and transport: the PATH code

- The heart of the RISCS toolset is our **P**article **A**cceleration and **T**ransport throughout the **H**eliosphere **(PATH**) code.
- The code models the energization of particles at interplanetary and CME-driven shocks via the process of diffusive shock acceleration and follows the transport of energetic particles throughout the heliosphere by solving the Fokker-Planck equation for particles experiencing scattering in low frequency magnetized turbulence



Red dot (spacecraft) connected to quasi-perpendicular shock initially and the connection gradually evolves to much more quasi-parallel configuration.

Summarizing the RISCS

The RISCS toolset will provide a web-based “front-end” operational forecast and “nowcast” capability. The front-end dashboard will provide

1) predicted solar energetic particle (SEP) intensities;
2) spectra of protons and heavy ions;
3) predicted maximum energies and their duration;
4) SEP composition;
5) cosmic ray intensities, and
6) plasma parameters, including shock arrival times, strength and obliquity at any given heliospheric location and time.
7) The toolset will have a 72 hour predicative capability, with associated probabilistic bounds, that will be updated hourly thereafter to improve the predicted event(s) and reduce the associated probability bounds.
8) This toolset will also provide designers with worst-case reference environments that can be use for mission planning and space system design.
9) The RISCS toolset will be highly portable and capable of running on a variety of platforms possibly including the Community Coordinated Modeling Center (CCMC).