Forecasting the Interplanetary Radiation Environment (FIRE)

SOUTHWEST RESEARCH INSTITUTE

Maher Dayeh, Robert Farrell, Alec Engell, Michael Starkey, Lan Jian, KD Leka, Elena Provornikova, Rachael Filwett, Heather Elliott, Rob Ebert, Subhamoy Chatterjee, and the FIRE Team

Objective

FIRE is a Multi-institution center dedicated to improving our understanding and forecasting of solar radiation using a synergistic feedback teaming approach. **Vision Statement & Research Objectives:** FIRE implements a synergistic approach that optimizes the R2O2R cycle through dynamic and interactive collaboration among research, technology, and space weather forecasting (SWF) end-users and operational agencies, held together by coherent and comprehensive feedback. FIRE focuses on a critical element of SWF, the energetic particle environment.

Interconnected modules: ***Science:*** (1) Understand the conditions of quiet solar periods and improve All-Clear forecasts. (2) Advance understanding of active regions and the likelihood of transient event emergence. (3) Advance IMF and SW lead-time forecasts and short term (<60 min) forecasts of SW structure near 1 au. (4) Utilize physics-based models to provide probabilistic forecasts of key CME SWx driving properties. (5) Advance understanding of SEP occurrence, acceleration, and transport and provide continuous assessment of particle levels in the IP medium near 1 au. ***Science-to-Technology Transition:*** Transform deterministic to probabilistic forecasts and improve the estimation of forecasting uncertainties. ***Technology:*** Develop a streamlined virtual ecosystem (R2O2R platform) to advance SWF.

Science Module (SM)

Objective: Identify and bridge main gaps in Space Weather forecasting.The SM comprises five submodules, as follows:

Quiet Sun: Identify and understand the conditions of All-Clear periods using multi-point and multi-perspective (magnetogram, extreme ultraviolet, white light, radio, plasma, magnetic field, particle flux levels at various energies, etc.) observations and improve All-Clear forecasts. **This includes** (i) identifying the important elements of All-Clear forecasts, and (ii) mapping of All-Clear parametric thresholds to end-users and operational requirements.

Active Sun: Provide improved forecasts of solar flares and Coronal Mass Ejections as they relate to the radiation environment **by focusing on** two specific forecasting gaps: (i) the flare-quiet to flare-active transition and (i) CME eruptions and their association to SEPs.

Iterplanetary Medium & Solar Wind: Provide multiday forecasts of the SW and IMF and detailed SW structure, origin, and dynamic evolution information at different heliospheric locations. **This covers** forecasts at extended location within the heliosphere

Space Weather Events: (i) Utilize operational physics-based models to advance interplanetary CME (ICME) forecasting, **including** providing probabilistic predictions of magnetic field variations in an ICME ejecta. (ii) Quantify the effects of ICME-induced IMF distortions on the propagation of SEPs from Sun to Earth,along with associated uncertainities.

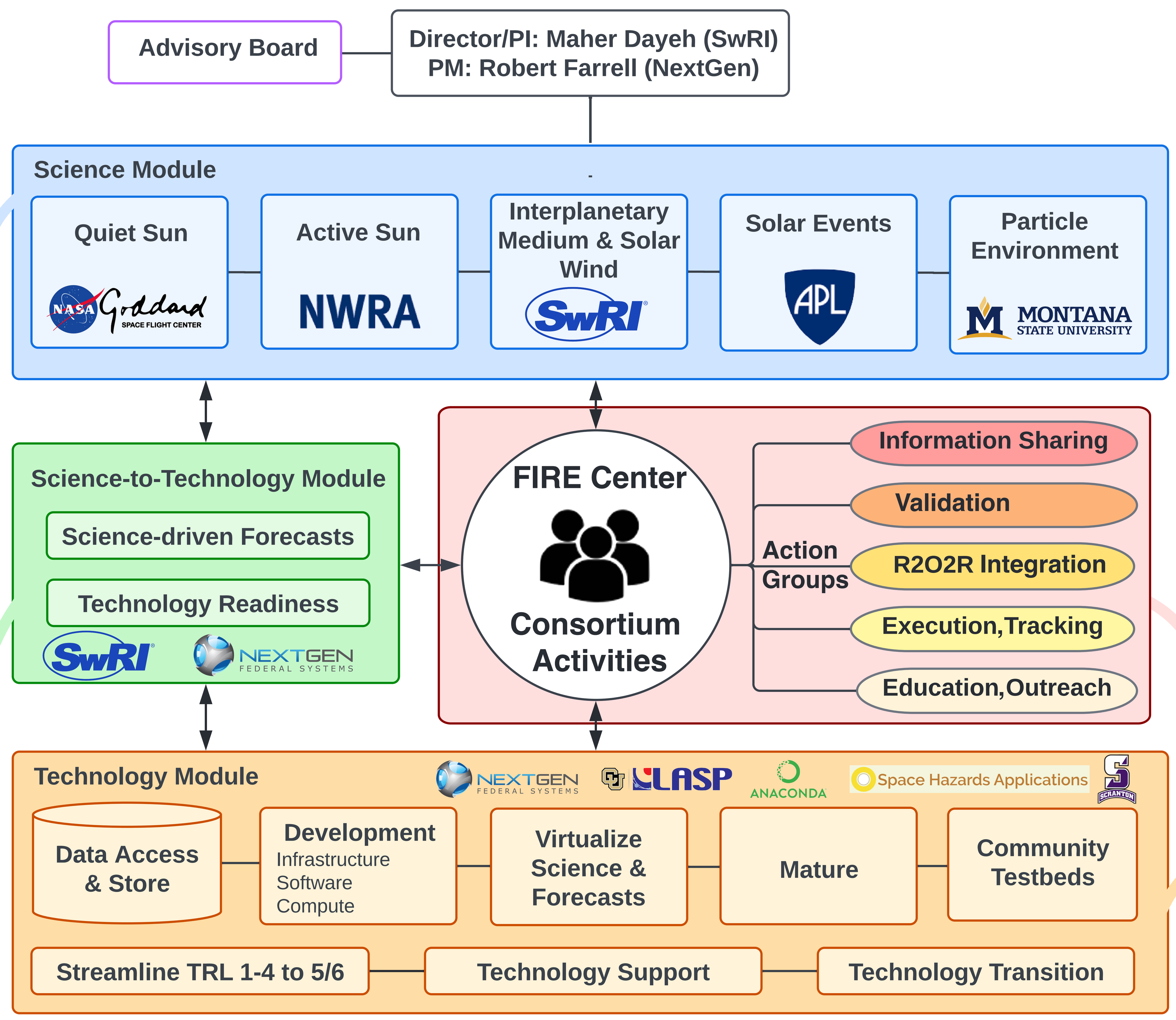
Space Particle Environment: (i) Characterize the suprathermal seed population during different activity levels. (ii) Determine how prior solar activity modifies SEP properties (e.g., the maximum energy and the spectral shape, acceleration and transport effects). (iii) Determine how magnetic connectivity affects SEP temporal profiles near Earth, **accounting for** realistic interplanetary IMF and SW conditions.

Science-to-Technology Module (S2TM)

Objectives:

1. Supports the Science Module and streamlines the transition to the Technology Module in order to escalate the Readiness Level (RL) of forecast products and transform deterministic into probabilistic forecasts.
2. Supports uncertainty quantification, implement model-ensemble approaches for estimating uncertainty and applicability of forecasts, and implement advanced Machine Learning (ML) algorithms, as appropriate.

S2TM enables effective transfer of scientific knowledge into forecasting technology. A large spectrum of deterministic and probabilistic metrics is obtained and compared to metrics determined from baseline physical models or heuristic approaches. This enables effective understanding of the shortcomings of our developed ML models and biases in the training data.



FIRE Consortium

A Consortium comprised of FIRE science and technology teams, SWx end-users , and collaborators ensures effective communication and engagement in a dynamic research environment focused on advancing SWF. **FIRE Consortium provides pathways for communities to share forecasting products information from-and-into FIRE, and provides iterative and constructive feedback.** FIRE focused Action Groups (below) work together to acheive this.

Information Sharing: Ensuring healthy flow of information and proper data sharing within FIRE and among the entire SWx community.
Validation: FIRE serves as benchmark for improving the accuracy of forecasts. Feedback is channeled properly for iterative implementation and improvement.
R2O2R Integration: FIRE members lead several R2O2R projects.This group ensures that R2O2R outcome is utilized effectively within FIRE.
Execution & Tracking: Tracks progress, resolves obstacles, and ensures transparency within FIRE.
Education & Outreach: Promotes SWx and the advances enabled by the FIRE Center. Supports FIRE students and conducts public outreach.

Technology Module (TM)

Objectives:

1. Develop a technology platform to advance SWF and streamline the R2O2R processes.
2. Support SM and S2TM virtualization processes including data, infrastructure, software, and computation.
3. Improve the science-technology-users chain of events and develop an effective feedback process for community engagement as forecasting capabilities advance from TRL 1 to 5/6.
4. Create web-deployed customizable dashboards to support research, modeling, and forecasting objectives of the SM.
5. Deploy TRL 5/6 capabilities to proving grounds.

Technology Development:
The FIRE TM provides a virtual ecosystem (VE) platform comprising five main elements that streamlines science-driven forecasting capabilities, developed by the SM and S2TM, from TRLs.

1. ***Data Access and Storage***: Improve data preparation efficiency to support SM and S2TM objectives; support the findable, accessible, interoperable, and reusable (FAIR) principles.
2. ***Development***: Provide the infrastructure, tools, and other engineering artifacts for Continuous Integration/Continuous Delivery (CI/CD) of SM and S2TM products and artifacts.
3. ***Virtualize Science & Forecasts***: Virtualize SM and S2TM code and data; provide development platforms to create and share reproducible results through repeatable software processes and workflows.
4. ***Maturation and Integration***: Package science forecasting software to meet requirements of targeted proving grounds & testbed environments; support coupling complementary science & forecasting outputs.
5. ***Community Testbeds***: Develop the VE into a cloud-agnostic platform enabling greater science sharing among resources such as NASA's HelioCloud; enable the transition of forecasting technology to CCMC-SWPC Architecture for Collaborative Evaluation (ACE) proving ground.

FIRE Benefits

1. Advance forecasting of the interplanetary solar energetic radiation environment.
2. Bridge advancements in science and technology with emphasis on effective technology transition.
3. Initiate an interactive synergy among the broad SWx stakeholders.
4. Implement an effective feedback system through the center.
5. Impact the SWF community through synergistic development, integration, and deployment of SWF capabilities at all readiness levels.

FIRE is committed to fostering, cultivating, and preserving a culture of diversity, equity and inclusion