NASA Living With a Star (LWS) Targeted Research and Technology (TR&T) Steering Committee Report on Recommended Focus Science Topics

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Strategic Science Areas: Development of Predictability and Interactions with User Communities

Over the past ten years, the LWS program has built a remarkable foundation of strategic capabilities and focused science topics (FSTs). We are now in the position to leverage these for the development of predictive capabilities in key areas of LWS science. This leverage is critical in these times of challenging budgets to maximize the scientific "return on our investments."

As such, rather than concentrating on devising FSTs on separate areas of Heliophysics, the LWS SC has formulated long-term targeted areas of *System Science*, requiring cross-disciplinary collaboration, for predictive development, termed "Strategic Science Areas (SSA)":

- **SSA-1, Physics-based Geomagnetic Forecasting Capability:** The goal is to develop scientific capabilities that enable 1-3 day (long lead-time) and 15-30 min (short lead-time) predictions of pending extreme GIC events;
- **SSA-2, Physics-based Satellite Drag Forecasting Capability:** The goal is to develop scientific capabilities that enable specification of the global neutral density in the thermosphere and its variations over time. This capability should provide the capability to predict the densities that satellites in low Earth orbit will encounter with a lead-time of at least one hour as well as longer-term predictions out to at least three days and preferably to seven days or longer. There should be quantifiable levels of uncertainty that are specified for different data conditions and levels of redundancy in data/models;
- **SSA-3, Physics-based Solar Energetic Particle Forecasting Capability:** The goal is develop scientific capabilities that enable probabilistic prediction of the intensity of SEP events, and increased time periods for all-clear forecasts with higher confidence level;
- **SSA-4, Physics-based TEC Forecasting Capability:** The goal is to derive a model, or coupled set of models, that enable specification of the global ion density in the topside ionosphere and plasmasphere and its variations over time under varying geomagnetic conditions. The model or coupled models should have the capability to predict the TEC observations globally, with a lead time of at least one hour (based on availability of real-time solar wind/IMF measurements), as well as longer-term predictions for up to three days based on solar wind forecasts;
- **SSA-5, Physics-based Scintillation Forecasting Capability:** The goal is the capability to predict scintillation occurrence utilizing limited sources of available data and ascertain how radio signals are degraded by ionospheric irregularities. Achieving this will require elucidation of the complete set of physical mechanisms responsible for producing ionospheric irregularities, the most important sources of free energy, and the causal chains that both generate and suppress irregularities leading to scintillations. We will develop the methods for maintaining signal lock when

scintillations occur. The resulting "clean" radio signals would themselves be incisive diagnostics of ionospheric irregularities. We will fold radio signal information back into irregularity analysis and modeling.

- **SSA-6, Physics-based Radiation Environment Forecasting Capability:** The goal is science-based predictive capability for the radiation environment and its effective dose as well as dose rates based on GCR, SEP, cutoff rigidity, atmosphere density, and gamma-ray/X-ray inputs. Other success measures will include the development and application of new observational methods, both in situ and remote, that lead to new data sets for assimilation into models on global and regional scales, and new insights into the spatial/temporal scales of radiation storm variations that are affected by space weather**.**

An imperative in the development of SSA goals is making a stronger link between the scientific community of LWS and user communities that can directly benefit from LWS strategic developments. The SSAs represent long-term goals of the LWS program that will be developed through Focused Science Topics, Strategic Capabilities and Targeted Science Teams. The FSTs/TSTs listed here were considered as opportune areas that both provide leverage for achieving the long-term goals of the SSAs and are uniquely positioned for rapid near-term progress.

Future FST, SC and TST teams should partner with members of key space weather centers (e.g., CCMC, NASA/SRAG, and NOAA/SWPC) to facilitate better interaction with user communities and the creation of deliverables that best serve user needs. Upon selection of future FSTs, SCs and TSTs, NASA/HQ will contact relevant modeling centers to identify liaisons to appropriate user communities.

Focused Science Topics

Physics-based Predictive Capability Development for Geomagnetically Induced Current (GIC) Events

Target Description: Violent changes in the near space electric currents systems such as ionospheric currents, magnetopause current and ring current drive rapid variations of the magnetic field on the surface of the Earth. These externally driven ground magnetic field fluctuations, or dB/dt, induce a geoelectric field on the surface of the earth. The geoelectric field that is strongly dependent on, for example, local ground conductivity conditions drives geomagnetically induced currents (GIC) that can flow in power grids, pipelines and railway systems. Large dB/dt can also hamper geophysical exploration surveys.

Any active GIC mitigation technique will require predictive information about the pending events. While major progress has been made on this front over the past 10 years, the state-of-the-art predictive techniques are only starting to approach the level of accuracy that will allow meaningful end user mitigative decisions. Consequently there is a great need for enhanced next generation capacity to predict the GIC events. In particular enhanced capability to predict extreme events such as March 1989 and Halloween storm of October-November 2003 and their GIC implications is of great interest.

We are seeking studies that will improve our capability to provide 1-3 day (long lead-time) and 15-30 min (short lead-time) predictions of pending GIC events. Ultimately, new prediction systems need to be tailored for the needs of individual power grid operators, and consequently studies should address local or regional aspect of GIC.

Goals and measures of success: The primary goal of this FST is to promote the development of physics-based prediction capabilities for the global GIC at long lead-time and short lead-time windows. As GIC are externally driven phenomenon we are seeking models that ultimately improve the capability to predict the near space electric current variations and geomagnetic induction process in complex three-dimensional geometries. The predictive modeling is of limited utility to the end user unless also information about uncertainty of predictions is provided. Consequently, successful projects need to address also realistic estimation of uncertainty associated with the provided predictions.

The projects need to quantify metrics that can be used to measure the predictive enhancements made in the project. The metrics need to be identified in close collaboration with end users to ensure the team measures the predictive capability that directly addresses the end user needs and requirements.

Types of investigations:

- Studies of three-dimensional ground structures in geomagnetic induction modeling and effects on predicted GIC amplitudes and distribution.
- Studies of improved modeling of electric current dynamics in the solar wind-magnetosphere-ionosphere system pertaining to GIC.
- Studies of CME magnetic field evolution during propagation from solar corona to 1 AU and interaction with the magnetosphere (pertaining to GIC).
- Studies of CME sheath (e.g. turbulent magnetic field fluctuations) evolution during propagation from solar corona to 1 AU and interaction with the magnetosphere (pertaining to GIC).

Development of predictability and interactions with users communities:

The proposing team will identify the requirements for developing or improving actionable predictive information provided to the end user such as power grid operators. To facilitate the systematic development of the prediction system and close interactions with the end user, systems engineering approach, while not required, is encouraged with the following basic elements used in NASA Applied Sciences Program projects:

a) *Evaluation*. The evaluation carried out in the beginning of the project identifies the end user and actionable information provided by the prediction system that can assist the end user in his/her decision making process. The team also needs to identify relevant observations, products or models that fully or substantially satisfy prediction system requirements and calls attention to remaining gaps to fulfilling the requirements.
b) *Verification and Validation (V&V).* This element includes identifying metrics and measuring the performance characteristics of data, information, technologies, and/or methods, and assessing the ability of these tools to meet the requirements identified in the evaluation element. V&V element will be used to quantify the improvements made in the predictability of GIC events.
c) *Benchmark.* In the benchmark phase the new predictive capability and the resulting impacts and outcomes are identified and documented. In the benchmarking phase the team characterizes the change in use and usefulness of the new predictive capability to the end user. Benchmarking also summarizes the overall conclusions of the systems engineering process and makes recommendations on potential future efforts to enhance the predictive capability.

Physics-based predictive capability development for changes in the composition of the thermosphere during extreme events

Target Description: With an increasing number of satellites in low Earth orbit, as well as an increasing amount of debris, there is a growing risk of collisions and damage to operational satellites and manned NASA missions. There is a need to be able to closely monitor the orbits of every object, in order to alert operators to the risk of collisions, as well as for national security concerns.

Low-altitude satellites move within the upper boundaries of the atmosphere, the thermosphere and exosphere. They may have their orbits perturbed by changes in the neutral atomic density, resulting from variable solar and auroral activity. After large geomagnetic storms, these perturbations make it difficult to track and predict the locations of satellites to avoid space debris. A long-standing goal of LWS science is to produce improved predictions of the thermosphere neutral density that will enable more accurate satellite drag and orbit calculations.

Goals and Measures of Success: The goal of the FST is to improve or develop models, or coupled sets of models, to better specify the density and composition of the global neutral density in the thermosphere, particularly during extreme events. This capability should be result in improved predictions of densities that satellites in low Earth orbit will encounter, particularly during extreme events, with a lead-time of at least one hour as well as longer-term predictions out to at least three days and preferably to seven days or longer. Potential users of these capabilities might include U.S. Air Force satellite and debris tracking systems, NASA conjunction risk management, and private-sector forecasters that may aid commercial space operators.

Successful individual investigations are expected to document their ongoing progress toward the goal through the use of appropriate metrics. These metrics should be based on specified or predicted neutral densities compared to those measured by CHAMP and GRACE or other high precision density sensors such as SWARM, POPACS, and DANDE. The USAF HASDM database also provides global, time-resolved mass densities of high accuracy that can be used to assess the validity of a thermospheric density prediction capability. A successful project will, in the end, make neutral mass density and composition predictions that are demonstrably better than the baseline existing models in CIRA and ISO 14222 such as JB2008 or NRLMSISE-00 that are used by operational communities.

Types of Investigations: A number of scientific problems need to be solved in order to achieve a fuller understanding of the variability in the thermosphere during extreme events. The topics of successful investigations may include, but are not limited to:

- New insights into changes in the composition of neutral species in the thermosphere during extreme conditions, including variability in regional cooling rates due to the effects of nitric oxide, particularly after large heating events.
- A characterization of the "weather" of rapid, global response of the thermosphere to sudden enhancements in polar, auroral heating, and the modes of propagation from high latitudes to the equator.
- For the purpose of long-term predictions, capabilities to specify active region evolution and solar rotation, as well as solar far-side monitoring.
- Predictive capabilities for the thermosphere's response to variable solar particle fluxes on short to longer timescales ranging from SPEs to high-speed stream passage and geomagnetic storm occurrence.

We solicit proposals for full teams or for team membership that covers the suggested areas, or other areas that the proposer can argue are critical to the goals.

Development of Predictability and Interactions with User Communities: An important component of the FST is to demonstrate relevance to user needs. Individual proposals should identify how they will contribute to the FST and aid with development to the point of predictive capability.

Proposed investigations should outline their target goals for predictability, and the data sources and metrics to be used to monitor their progress toward this goal. Successful investigation teams are expected to provide, with their annual reports, a description of their progress towards improved predictability.

Physics-based Predictive Capabilities for Solar Eruptions

Target Description: Solar Energetic Particle (SEP) events increase radiation hazards throughout the solar system and adversely impact our space- and ground-based assets. The initial particles can arrive in minutes to hours after an eruption on the Sun. A key difficulty in achieving the goals of the Strategic Science Area (SSA): "Physics-based Solar Energetic Particle Forecasting Capability" is forecasting the likelihood of a major eruption from active region(s) on the Sun, hours to days prior to the event. Present-day forecasts are empirical. For example, NOAA/SWPC currently relies on qualitative assessments of sunspot groups to produce a 24, 48, and 72 hour forecasts. Statistical methods that characterize prior flaring, solar magnetic field properties from magnetograms, etc., exist that could potentially improve these forecasts. These techniques typically have little theoretical or modeling insight incorporated into their methodologies. There has been significant theoretical, modeling and observational work on the eruptive properties of solar magnetic fields, as evidenced by a previous Focused Science Team (FST). However, it appears we are still many years away from an entirely first principles approach for predicting eruptions. An FST that combines insights from theory, modeling, and observations to improve probabilistic forecasts of major solar eruptions is required.

Goals and Measures of Success: The goal of this topic is to combine expertise in statistical methods, data analysis for relevant solar observations, and theoretical/modeling studies to improve upon or produce new methods for flare/CME forecasting. The measure of success and criterion for selection is a proposal's impact in using statistical methods, observations, models, or theories to improve prediction of large solar eruptive events (e.g. M/X class flares and/or > 1000 km/s CMEs). Ideally, the FST would produce prototype code(s) and/or method(s) for forecasting such events, and assess their validity using a database of past events. This would be compared against known methods (e.g., present NOAA/SWPC forecasts). An important part of this activity will be the selection and/or development of metrics and skill scores that are relevant from the perspective of user communities (for example, NOAA/SWPC or NASA/SRAG).

Types of Investigations:
Proposals that contribute new insights or techniques to improve solar eruption forecasts using observations, theory, modeling and statistical methods are encouraged, and could include:

- Theoretical, modeling, and/or observational studies that quantify the flux of magnetic energy stored, entering, or leaving solar active regions
- Theoretical, modeling, and/or observational studies that relate inferred/measured free magnetic energy to the likelihood of a major event
- Empirical/statistical studies/methods that use solar observations to provide probabilistic forecasts of major solar eruptions
- Theoretical, modeling and/or observational studies that identify signatures of stability and/or imminent eruption

Focus on Predictability and Interactions with User Communities: The SSA "Physics-based Solar Energetic Particle Forecasting Capability" requires the prediction of major solar eruptions hours to days in advance of their occurrence. An important component of the FST is to demonstrate relevance to user needs (for example, NASA/SRAG or NOAA/SWPC). This is especially true for the selection/development of metrics and skill scores to assess new or improved methods for forecasting in relation to present techniques. Individual proposals should identify how they will contribute to the FST and aid with development to the point of a predictive capability.

Physics-based methods to predict connectivity of SEP sources to points in the inner heliosphere, tested by location, timing, and longitudinal separation of SEPs

Target Description: Solar Energetic Particle (SEP) events increase radiation hazards throughout the solar system and adversely impact our space- and ground-based assets. An impediment to achieving the goals of the Strategic Science Area (SSA): "Physics-based Solar Energetic Particle Forecasting Capability" are significant gaps in our understanding of the connectivity of SEP events to their source locations back at the Sun. This realization has come about because of recent combined STEREO and ACE measurements that show that many SEP events extend over much larger ranges of longitude than previously estimated. For example in January and March of 2012 when ACE, STEREO-A and STEREO-B were nearly equally spaced around the Sun, instruments on all 3 spacecraft observed intensity increases from individual SEP events. This is well beyond the expectation of broad longitudinal extent that arises from CME size, solar magnetic field configuration, or cross-field transport in interplanetary space. Small ^{3}He-rich events have also been found to sometimes extend over much broader longitudinal extent than expected. The surprising longitudinal extent of these events shows that basic features of SEP acceleration and transport are not included in the standard picture. Therefore, even if a dangerous active region is recognized as likely to produce a major event, an essential question is whether/when those particles will connect to points of interest in the heliosphere, such as at Earth. This information is crucial for forecasting the onset of prompt events, increasing the time period of all-clear forecasts, and quantifying uncertainty.

Goals and Measures of Success: The goal of this topic is to combine theoretical studies, numerical modeling, remote and in situ observations in order to identify the mechanism(s) that result in SEP events with extremely large extents in longitude. The measure of success and criterion for selection is a proposal's impact in bringing observations, models, or theories that can lead to an understanding of the longitudinal extent and timing of the SEP intensity increases, and contributing to an overall FST goal of quantifying the predictability of SEP longitude extent. Ideally, the FST would produce a model or model(s) that predict the longitudinal spread of SEPs, with statistical quantification of the uncertainty.

Types of Investigations: Proposals that contribute to our basic understanding of the longitudinal extent of SEP events using observations, theory and modeling are encouraged, and could include:

- Theories and models for global acceleration events such as large CME-associated shocks
- Theories and models for particle access to a broad range of interplanetary magnetic field lines
- Global models of the coronal/heliospheric magnetic field that predict the field line connectivity of sources at the Sun to points in the heliosphere
- In-situ observations of energetic particle arrival times, composition, and spectra for events covering large longitude ranges

- Remote sensing of accelerating events at the Sun and in the inner heliosphere that constrain the acceleration, e.g., the range of magnetic field lines intercepted by a CME associated with particle acceleration
- Timing studies that relate radio bursts, CME heights, etc., to the rising intensity profile of the SEPs
- Models/observations that provide a better understanding of the initial phases of CMEs and how they couple into a range of SEP opening angles into the heliosphere.

Focus on Predictability and Interactions with User Communities: The SSA "Physics-based Solar Energetic Particle Forecasting Capability" requires a new level of understanding of the connectivity of SEP events to their source locations back at the Sun. This FST aims to achieve this understanding and to quantify the predictability of SEP longitudinal extent. An important component of the FST is to demonstrate relevance to user needs (for example, NASA/SRAG or NOAA/SWPC). Individual proposals should identify how they will contribute to the FST and aid with development to the point of a predictive capability.

Ion-Neutral Interactions in the Topside Ionosphere

Target Description: The topside ionosphere and its dynamics during storms is a poorly understood domain that has a major influence on developing a predictive capability for TEC. We solicit investigations to elucidate the dynamics governing ion-neutral interactions in the topside ionosphere and exosphere during geomagnetic storms, to the point of being able to represent these interactions accurately in numerical models. The specific question being solicited is how topside ion and neutral density and composition vary during geomagnetic storms and how these topside variations affect TEC during storms. To the extent this variation is controlled by the preceding quiet time background, quiet time variability in the topside is also of interest. Since TEC is a sum of both topside and bottomside density, but the physics governing these regions is distinct, for this investigation it is important to identify those conditions where storm-time TEC is most affected by topside variation. The distinct physics of the plasmasphere, although a region that is also important for predictive TEC capabilities, is of less specific interest in this solicitation.

Goals and Measures of Success: The primary goal of this FST is to elucidate the photochemistry and dynamics governing ion-neutral interactions in the topside ionosphere and exosphere, particularly during geomagnetic storms. This goal hinges on the empirical quantification of key upper atmospheric state parameters simultaneously, along with their incorporation into assimilative models. Data acquisition must fuse data from both ground- and space-based platforms using multiple observing modalities, and existing techniques to estimate fundamental state parameters from these observables must be further developed for widespread applicability. The improved understanding of storm-time ion-neutral coupling would derive from data-driven assessment of the validity of physics-based model assumptions, such as nonlinear feedback mechanisms. This assessment would also yield an identification of causal influences on storm-time responses.

A primary measure of success rests on numerical model capability to reproduce real-time behavior of key observables, which would imply that both the parameter estimation techniques and the understanding of physical coupling processes are valid. A secondary metric is the accuracy of models in reproducing historical climatologies of key observables. Specifically, models should be able to reproduce morphologies associated with storm-time and day-to-day variability of TEC, airglow emission brightness, or species abundance ratios.

Types of Investigations:

- Observation and interpretation of the topside component of TEC during quiet and disturbed conditions.
- Observations relevant to topside chemistry and ion-neutral interactions, such as observations of magnetospheric energetic neutral atom fluxes, which are the product of exospheric and plasmaspheric chemistry, and UV and optical airglow emission data acquired from NASA TIMED, ground-based photometer networks (constraining [H]) and the future GOLD mission.

- Observations of solar radiation flux data, e.g. from TIMED-SEE or SDO-EVE, and the airglow from emission production, that constrains [O] and [He] densities.
- Statistical fusion of [O]/[N2] abundance ratio data (derived from NASA TIMED and elsewhere) with ground-based neutral wind and O airglow emission measurements to resolve chemical and dynamical influences on storm-time responses of the topside.
- Development of inverse theoretical techniques that fuse multiple observing modalities to better estimate atmospheric state parameters.
- Observations and models of topside drivers such as neutral winds and electric fields.
- First-principles models of topside composition and densities of ions and neutral species.

Focus on Predictability and Interactions with User Communities: We solicit proposals with a focus on topside composition and density that make a convincing case that their investigations will lead to improved predictive capability of TEC during geomagnetic storms. Investigations should address the following Strategic Science Area of the LWS TR&T program: "Physics-based TEC Forecasting Capability". Proposers should identify how they will contribute to this Focused Science Team, and aid with development of a predictive capability for TEC. Reference to existing modeling and forecasting capabilities is useful.

Successful investigation teams are expected to provide yearly reports on how they are addressing objectives of the over-arching SSA. Elements of a successful team may include:

1) Assessments of current capabilities regarding forecasts and modeling of topside TEC variation during storms, as a function of latitude, longitude and local time.
2) Observational capabilities that increase scientific understanding or that can be used to develop empirically-based, forecast-oriented models.
3) Scientific understanding of the factors that most affect topside TEC variation during storms, which may include the relative roles of neutral dynamics, versus chemical recombination and loss, versus other transport processes. Specific investigations that elucidate the roles of these competing processes will improve forecast capabilities via modeling, and are therefore important to include in the team.

Proposals for full teams or for team membership are solicited that discuss these suggested areas or other areas that the proposer can argue are critical to the predictive goals of this topic.

Radio Scintillation Prediction in Mid-latitude Ionosphere

Target Description: Radio scintillations rank among the most obvious and disruptive manifestations of space weather and occur when radio ray paths transect regions of ionospheric irregularities caused by plasma instabilities and plasma turbulence. Plasma instabilities are widespread and occur at low, middle, and high latitude in the E and F regions of the ionosphere. Scintillations are strongest in the auroral zone during geomagnetically active periods and at low latitudes during equatorial spread F events, which occur in active and quiet periods. However, instabilities at middle latitudes have the greatest direct impact on North American residents but are the least well-understood and most difficult to forecast. While irregularities have definite climatologies, forecasting them has proven to be challenging, both because the most important ionospheric drivers can be difficult to measure and/or predict and because the ionospheric response to the drivers is often complicated and not obviously deterministic.

While previous FSTs related to this topic have focused mostly on theoretical studies of plasma instabilities in the equatorial region and the improvement of ionospheric models to include equatorial plasma instabilities, investigations aimed at ascertaining the precise effect of different irregularity classes on different radio signals, their amplitude and phase scintillation spectra, and on different propagation channels have been mostly neglected. A new focus topic with this emphasis is therefore required.

Reliable forecast models remain elusive, and forecasts incorporating assimilated data will remain ineffective so long as their theoretical foundations are incomplete. Managing scintillations also requires an improved understanding of radio wave propagation and scintillation and the different ways that signals are degraded by different classes of irregularities. This information will be essential for developing strategies for minimizing the effects of scintillations on operational communications and navigation systems.

Goals and measures of success: The overarching goal of this FST will be to elucidate the physical mechanisms responsible for producing ionospheric irregularities, and the causal chains that both generate and suppress irregularities leading to scintillations. The immediate goal will be to develop strategies for predicting scintillation occurrence utilizing limited sources of available data. A third goal will be to ascertain more completely how radio signals are degraded by ionospheric irregularities and to use this insight to develop methods for maintaining signal lock when scintillations occur. The resulting "clean" radio signals would themselves be incisive diagnostics of ionospheric irregularities, and a final goal of the FST is the explorations of means of folding this information back into irregularity analysis and modeling.

Types of investigations:

- The development of analytical and empirical models of instabilities at mid-latitudes demonstrating quantifiable limits of predictive capability.

- Theoretical and model studies aimed at ascertaining quantitatively the precise effect of different irregularity classes on different radio signals, their amplitude and phase scintillation spectra, and on different propagation channels.

- Development of rigorous signal processing schemes and novel algorithms to improve understanding of radio wave propagation and irregularities, and for coping with scintillations in real-time applications.

- Development of methods experimental methods such as diffraction tomography and other diagnostic uses of forward scatter radio signals to advance understanding of radio wave propagation and irregularities.

Development of predictability and interactions with users communities: This FST addresses the broad goals of SSA-5, Scintillation Forecasting. An important component of the FST is to demonstrate relevance to user needs. Individual proposals should identify how they will contribute to the FST, aid with development of predictive goals and make contributions relevant to user communities.

Consequences of scintillations include signal fading, distortion, data loss and, in the case of navigation systems such as GPS, loss of signal tracking. User sectors potentially benefiting from developments resulting from this FST include commercial aviation, transportation engineering and traffic management systems, precision agriculture, emergency response, autonomous vehicles, marine navigation, environmental sensing, and critical resource and infrastructure monitoring. Furthermore, all sectors relying on HF communication including defense and communication service providers in remote areas could benefit from the developments resulting from this FST.

As the magnitude of impact varies with the context and user community, it is imperative that the goals of prediction be articulated with close interaction with the targeted user community, leading to the definition of the needs and requirements. While irregularities have definite climatologies, their prediction has proven to be challenging and currently we do not have an understanding of the limits of predictability. A comprehensive study is needed to quantify statistically the spatial and temporal limits of predictability, and developments toward the goal of prediction should go beyond case studies and model runs and should establish rigorous statistical quantification of limits of predictability and demonstrate improved prediction capability resulting from the proposed innovations.

Physics-based predictive capability development for the radiation environment from the lower atmosphere to beyond the upper atmosphere during quiet and storm conditions

Target Description: The Radiation Environment Strategic Science Area outlines broad needs for advancing the characterization of the science of the radiation environment. The radiation environment between the troposphere and exosphere is variable and can change rapidly from Galactic Cosmic Ray (GCR) and Solar Energetic Particle (SEP) influx, i.e., heavy ions, neutrons, protons, beta particles, gamma-rays and X-rays. In addition, and of particular relevance to human tissue as well as avionics radiation dose and dose rate risks, secondary and tertiary particles from these sources can vary with changes of target atoms and molecules, such as in the tropospheric air mass or shielding properties. The GCR background is typically variable on the timescale of days with a long-term trend that changes slowly and is modulated by the solar Interplanetary Magnetic Field (IMF) varying with the approximate 11-year solar cycle. The SEP environment, however, can be highly time variable, with impulsive, order of magnitude changes associated with solar eruptive events occurring in a matter of seconds to minutes. Together, the GCRs and SEPs couple with the Earth's Magnetosphere-Ionosphere-Thermosphere (M-I-T) system and create the "weather" of the ionizing radiation environment.

Recent observations and modeling developments have permitted substantial progress in understanding the drivers to and responses in the radiation environment. For example, modeled global radiation climatology specifications from both Civil Aerospace Medical Institute (CAMI) and the Nowcast of Atmospheric Ionizing Radiation System (NAIRAS) exist. Measurement capabilities are rapidly expanding with the Automated Radiation Measurements for Aviation Safety (ARMAS) system that has demonstrated real-time dose rate measurements at commercial aviation altitudes. The energetic particle measurements throughout Earth's radiation belts on the NASA LWS Van Allen Probes mission, the boundary condition specification of the radiation environment measured by the NASA LRO/CRaTER instrument at the Moon, the NASA ACE mission at L1, the PAMELA observations of inner radiation belt protons within the thermosphere, and even the upcoming Rad-X high-altitude balloon flights all successfully show the maturity that radiation environment measurements have developed over the past several years. However, the variability and prediction potential of the coupled systems describing this radiation environment are not yet well quantified. First principles and empirically based models, combined with new data streams, are needed to achieve substantial progress toward predictability.

Goals and Measures of Success: The primary goal of this FST is to promote the development of prediction capabilities for the global radiation environment, ranging from the lower atmosphere to above the upper atmosphere during quiet to active conditions. Modeling systems, particularly those that include both in situ and remote observations in data assimilation methods, have the highest probability of prediction success for the "weather" of the radiation environment. An additional goal is to promote the continued innovative expansion as well as development of calibrated data sources that can specify this radiation environment in near real-time.

A critical measure of success for investigations through this FST will be the demonstrated prediction of the temporal, spatial, and magnitude variability in the radiation environment, from tropospheric to exospheric altitudes, and reported with appropriate metrics of uncertainty.

Types of Investigations: This FST intends to bring together modelers and observers who can make progress toward validating new or substantially improved existing modeling systems. These systems should be able to specify the domains of the radiation environment ranging from the troposphere to the exosphere. Individual proposals should show how they support the FST in a systematic approach for comparing and validating modeling approaches that lead to predictions. Innovation in data assimilation systems for radiation environment specification is of particular interest. Investigations that can demonstrate calibrated dose and dose rate measurements for data assimilative modeling systems will not only help validate those systems but can help modify climatological estimates into weather predictions. These capabilities are also especially solicited.

Development of Predictability and Interactions with User Communities: A driving need in this second decade of the 21st Century is to integrate the scientific advances in space weather specification with the technology engine that enables progress and benefits our society. Risks from space weather to commercial and private aviation and high-altitude crew and passengers, space tourists and astronauts, aeronautical and space avionics, and even our national defense capabilities in UAV and satellite systems can be mitigated, in part, by an ability to predict the occurrence, timing, location, and magnitude of radiation effects. This FST promotes the development of temporal and spatial radiation environment prediction that can further the goal of risk mitigation, especially from extreme space weather events.

Individual proposals should identify how they will contribute to the FST and aid with development to the point of predictive capability. An important component of the FST is to demonstrate relevance to user needs in at-risk industries and demographics. At-risk users can help these FST investigations define future needs for products as well as assist in validating and verifying the risk mitigation capabilities developed through these studies.