NASA Living With a Star (LWS) Targeted Research and Technology (TR&T)
Steering Committee Report on Recommended Focus Science Topics
October 26, 2012

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This year the committee was given two tasks, first to recommend Focused Science Topics (FSTs) for upcoming NASA Research Announcements, and second to carry out an assessment of the TR&T program over the period since its initiation about 10 years ago. This report deals with the FST recommendations.

Because of programmatic reasons, the committee was told that two elements of the TR&T program, Strategic Capabilities and Tools and Methods, would not be solicited this year. The committee's work was carried out by telecon, e-mail, and three meetings in the Washington, DC area on April 10-11, August 15-16, and October 15-16, 2012.

The scope and rationale of Focused Science Topics have been described in prior reports of the Steering Committee and this description will not be repeated here (see, e.g., http://lwstrt.gsfc.nasa.gov/LWS_2011_SCReport.pdf, pages 3 and 4). This year's committee concurred with last year's initiation of 4-year maximum grant durations.

Ideas for new FSTs were solicited from the community through the annual announcement at Fall AGU meeting Town Hall, and through broadly distributed newsletters (AGU SPA Section Newsletter Vol. XIX, No., 25, April 17, 2012 and AAS SPD Newsletter Vol. 2012, No. 8, April 16, 2012). The newsletter announcements pointed to a website where community members could submit topics. Members of the Steering Committee also suggested topics based on current areas of interest discussed at community scientific meetings and with colleagues, as well as previous Steering Committee potential FSTs that had not been selected for inclusion in an AO.

Our recommended FSTs follow; the ordering is not prioritized.

AI-1

Thermospheric wind dynamics during geomagnetic storms and their influence on the coupled magnetosphere-ionosphere-thermosphere system

Target Description:
The role of winds in modifying the ionosphere during geomagnetic disturbances, and how this varies with disturbance magnitude, remains an important unsolved problem in upper atmosphere science. An improved understanding of the global thermospheric wind system and the sources of its variability is essential for improving our ability to develop useful predictive models of satellite drag and ionospheric electron density variations during geomagnetic storms. Thermospheric winds, both horizontal and vertical, are excited in complex ways by magnetospheric energy and momentum inputs at high latitudes, affecting global circulation patterns and electrodynamics. The winds modify thermospheric density and composition, and strongly impact the ionosphere both directly, through ion transport, and indirectly, through influences on the production and loss of plasma and the generation of dynamo electric fields.

Recent observations and modeling developments now permit substantial progress on this question. New global observations from GPS-equipped satellites such as the COSMIC/FORMOSAT-3 constellation, CHAMP and GRACE, from CINDI observations onboard C/NOFS, and expanding ground-based networks, are providing unprecedented global coverage needed to understand the role of neutral wind dynamics. Recent developments in modeling, such as first-principles and empirically based disturbance time wind models, and the development of assimilative models that can derive winds, are useful new resources that permit substantial progress.

Goals and Measures of Success:
The primary goals of this focused science topic are to improve modeling and characterization of thermospheric wind processes during disturbed periods, and to improve understanding of the role of winds in ionospheric stormtime dynamics. Measures of success include improved predictive capability of thermospheric winds based on solar wind inputs, development and application of new direct and indirect wind observations that measure storm-time wind dynamics on global scales, new coordinated data sets of ionospheric electron density, electric fields and thermospheric properties, and new insights into the spatial/temporal scales of storm-time thermospheric variations that affect terrestrial space weather.

Types of Investigations:
Substantial progress on this Focused Science Topic is possible with the following investigations:

- New observation and characterization of global wind field dynamics using direct and indirect measurements from ground and satellite
- New methods for obtaining global wind fields using data assimilative techniques

- Analyses of thermospheric wind responses to solar and magnetospheric energy inputs
- Analyses that elucidate the role of thermospheric dynamics in ionospheric storm-time variability, taking into account transport, electrodynamics, and thermospheric composition
- Developing and/or using first-principles and empirical models to characterize winds and the relationship between winds and ionospheric storm time response
- Theoretical and modeling studies that elucidate the role of winds in causing thermospheric and ionospheric variability
- Improved use of past data sets in light of current understanding

AI-2

Acoustic Gravity Waves, TIDs and Coupling between Atmospheric Regions

Target Description:
An improved understanding of acoustic gravity waves (AGWs) is essential for improving our ability to develop predictive models of the global upper atmosphere. The global climatology of gravity waves is relatively unknown. Gravity waves can be excited by many sources in the lower atmosphere, and by Joule heating and momentum forcing in the auroral regions. There is also evidence that the breaking of primary waves can generate secondary waves. AGWs have a large number of space weather impacts throughout the upper atmosphere. For example, they transfer energy and momentum between different atmospheric regions; they interact strongly with tides, planetary waves, and the mean circulation; and their breaking produces eddy mixing and transport of constituents. Gravity wave breaking produces the momentum forcing responsible for the temperature minimum at the summer mesopause. The semiannual thermospheric density variation is important for satellite drag, and is thought to be caused by seasonal variations in AGW breaking, which is parameterized in global models. AGWs propagating in the upper atmosphere perturb the ionospheric electron density, forming traveling ionospheric disturbances (TIDs), and sometimes initiating equatorial plasma bubbles (EPBs), which affect radio systems. While the effects of AGWs are large, they are poorly characterized in global models at present. New measurements have become available over the last few years from space and from the ground that could provide insight into the climatology and variability of waves propagating into the upper atmosphere. Improved models of wave propagation have also been developed. Thus new tools are available to advance the science of AGWs and their effects on the upper atmosphere and ionosphere.

Goals and Measures of Success:
The goals of this focused science topic are to improve our understanding of gravity waves and their role in the thermospheric energy, momentum and eddy diffusion budgets, and their variability in space and time. This will be accomplished through better quantification of the AGW and TID climatology from space-based and ground-based measurements, and better understanding of how the waves interact with the surrounding medium, and studies of how thermospheric and ionospheric parameters vary with AGW fluxes. The results of this FST will lead to new capabilities in understanding and modeling.

Measures of success will be:

- *Quantification of AGW and TID climatologies, including seasonal variations, on a regional and global scale;*
- *New insights into the spatial/temporal variability of AGW/TIDs that affect space weather;*
- *Coordinated database of AGW/TID measurements and thermospheric parameters such as temperature, winds, composition and density;*
- *Improved modeling of AGW influences on thermospheric temperatures, winds, composition and density – and their variability;*

- *Improved predictive capabilities for AGW influences on thermospheric temperatures, winds, composition and density – and their variability;*

Types of Investigations:
Satellite and ground-based observational analysis of AGW/TID climatology and variability; coordinated observations of gravity wave fluxes with thermospheric temperatures, winds, composition and density; modeling studies of the coupled thermosphere/ionosphere response to gravity waves; and modeling/theoretical studies that elucidate the role of AGWs in causing thermospheric and ionospheric variability.

AI-3

AI-3 ***Understanding and mitigating the effects of ionospheric irregularities on radio communication and navigation***

Target Description:

Radio scintillations rank among the most obvious and hazardous manifestations of space weather. Radio scintillations 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. Instabilities at middle latitudes have the greatest direct impact on North American residents but are the least 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. Consequences of scintillations include signal fading, distortion, data loss and, in the case of navigation systems like GPS, loss of signal tracking. As society becomes more dependent on GPS navigation in time-critical applications such as aircraft approach, the impact of ionospheric scintillations will become increasingly intolerable.

Mitigating ionospheric scintillations requires an improved theoretical understanding of the plasma instabilities underlying them. It is unclear, for example, whether the main sources of free energy and physical processes at work have been correctly identified in all cases, and both the seasonal and day-to-day variability of irregularities are not well accounted for by existing theory as a result. 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 various ways that different classes of irregularities degrade signals. 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:

One goal of this FST will be to elucidate completely the 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. Another 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. The research would involve theoretical analysis, numerical modeling and simulation, measurement and signal processing, and algorithm specification, design, and testing. Observations from NASA investments such as those on TIMED, C/NOFS, and FORMOSAT-3/COSMIC will be leveraged to elucidate the salient processes responsible for scintillations and advance understanding.

Measures for success include the ability to reproduce unfolding irregularity climatologies through numerical modeling and simulation, to model the onset times, growth times, scale sizes, propagation characteristics, and general morphologies of irregularities consistent with individual observations, and to predict the day-to-day variability in irregularity occurrence with an accuracy surpassing forecasts based on climatology and persistence alone. Measures for success also include the development of increasingly robust radio signal decoding schemes able to maintain data integrity and signal lock when scintillations occur. Establishing quantitative benchmarks (skill scores) for success in these areas should be considered part of the FST.

Types of investigations:

- Theoretical studies of plasma instabilities and turbulence including nonlinear, nonlocal, and nongaussian effects.

- The development of fluid, hybrid, and particle simulations of plasma waves and instabilities at high, middle, and/or low latitudes demonstrating improved predictive capabilities.

- Experimental studies of plasma waves and instabilities establishing their gross morphology, revealing causal relationships to background driving parameters and geophysical conditions, and fully specifying their climatology.

- Tools that use heoretical and model studies 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.

- Tools that develop 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 for diffraction tomography and other diagnostic uses of forward scatter radio signals to advance understanding of radio wave propagation and irregularities.

- Investigation of climatologies using C/NOFS products and investigation of amplitude and phase scintillations using FORMOSAT-3/COSMIC measurements.

AI-4

Advancing TEC forecasting through data-driven understanding of ion-neutral coupling in the topside ionosphere and exosphere

Target description:

A compelling and long-standing challenge for Space Weather forecasting is the accurate formulation of physics-based models of the coupled neutral atmosphere, ionosphere, and plasmasphere. While GPS techniques to measure total electron content (TEC) in real-time have been a significant advance for the Space Weather community, the ability to forecasting global TEC remains a significant challenge. In order to move toward reliable physics-based TEC forecasting, improved global models of the plasmaspheric electron content are necessary. In order to accurately specify the electron density profiles in the topside ionosphere, which can be responsible for more than half of the TEC encountered by GPS signals traversing from satellites to ground, models must include reliable quantification of proton sources and sinks, which depend in turn on H, O, and O+ density, with additional accuracy gained by inclusion of He and He+.

Several techniques exist to estimate these upper atmospheric species densities based on observations of their airglow emission signatures (in conjunction with forward emission model inversion) or via quantification of continuity, momentum, or energy balance equations. However, the reliability of these techniques depends crucially on accurate knowledge of other atmospheric state parameters such as neutral winds and temperatures. The key requirement for successful determination of atmospheric composition, and consequently improved Space Weather forecasting capability, is thus the statistical fusion of multiple state parameter data together with their assimilation into physics-based models of the upper atmosphere. The NASA TIMED mission has been highly successful in yielding global and continuous observations of a potentially powerful predictive metric of Space Weather activity, the [O]/[N2] ratio, as well as airglow emission features that enable estimation of exospheric [H]. Similarly, the NASA SORCE mission provides crucial measurements of solar radiation for modeling both energy deposition as well as airglow excitation rates. Leveraging these assets with complementary ground-based platforms, such as the widespread network of photometers (measuring airglow brightness), interferometers (measuring neutral winds and temperatures), and incoherent scatter radars (measuring ionospheric state parameters), would yield a comprehensive experimental foundation to overcome current model limitations and develop much-needed understanding to improve Space Weather prediction capabilities.

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 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:

- Reconciliation of observations of magnetospheric energetic neutral atom fluxes, which are the product of exospheric and plasmaspheric chemistry, with UV and optical airglow emission data acquired from NASA TIMED and ground-based photometer networks (constraining [H]).

- Incorporation of storm-time NASA SORCE solar radiation flux data into models of airglow emission production (constraining [O] and [He]).

- 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.

- Development of inverse theoretic techniques that fuse multiple observing modalities to better estimate atmospheric state parameters.

AI-5

Magnetosphere-Ionosphere Coupling and Influences on Radiation Belt Particles

Target Description:
Magnetosphere-ionosphere (MI) coupling is a major driver of space weather impacts. Research over the past decade has shown how understanding and predicting these impacts requires an understanding of several interacting systems within the geospace domain, including properties of the solar wind at the magnetopause, the magnetospheric plasma sheet and ring current, magnetospheric particle populations, ionospheric outflow, the plasmasphere, the neutral wind system, and solar radiation. The recent launches of the Radiation Belt Storm Probes mission, and BARREL mission, provide an opportunity for the upper atmosphere community to increase understanding of how MI coupling is linked to conditions in the magnetosphere and the ring current and energetic particle populations. At the same time, there is an opportunity to improve our understanding of how radiation belt dynamics during storms are linked to MI coupling factors.

RBSP's multipoint three-dimensional measurements of electric fields may answer fundamental questions about the magnetospheric origins of prompt penetration electric fields into the ionosphere. These same measurements will provide insight into inner magnetospheric electric fields that are responsible for plasmasphere erosion, which has been linked to significant ionospheric structuring. Highly structured plasmaspheric distributions excite waves, such as EMIC waves, that cause precipitation and loss of radiation belt particles. RBSP will provide information on energetic electron populations that precipitate into the ionosphere, a significant source of upper atmosphere heating and ionospheric conductivity variability. RBSP will provide insights into the acceleration of precipitating particles, and how their distribution changes throughout geomagnetic storms, helping to understand this important source of energy input into the ionosphere during storms.

Ring current build up, thought to contribute to shielding by Region 2 currents, strongly influences radiation belt losses associated with magnetopause shadowing and other types of drift losses (e. g. bifurcation of drift orbits). The global electric field response due to Region 2 currents closing in the ionosphere strongly influences the mixing of different plasma populations, also affecting generation of EMIC and whistler waves affecting energization and loss processes. Ionospheric conductance patterns and the neutral wind "flywheel" also alter the global electric field, affecting the magnetospheric particle environment. Ionospheric conductance is in turn altered significantly by energetic particles precipitating from the magnetosphere and radiation belts. Conductance is an important quantity to specify but considerable uncertainty exists about its overall pattern and how and why it changes.

Goals and Measures of Success:
The overarching goal of this FST is to achieve a consistent understanding of the coupling between ionosphere and magnetosphere and how this coupling affects and is affected by electric fields, hot and cold plasma and energetic particle distributions in the magnetosphere. Successful

investigations will improve quantitative understanding of this coupling and provide for better understanding of how inner magnetosphere particle populations and plasma influence ionospheric variability and structure during geomagnetic storms. An equally important goal is improved understanding of the role of the ionosphere in determining how radiation belts respond to geomagnetic storms.

Type of Investigations:
The following are potential investigations that will lead to a successful Focused Science Topic team:

- Combining ground and space observations to improve our understanding of the relationship between ionospheric electrodynamics and magnetospheric conditions.
- Improving our understanding of energy deposition into the ionosphere and conductivity changes during storms by simultaneously measuring ionospheric properties and magnetospheric particle populations.
- Employing simultaneous observations of the ionosphere, plasmasphere, radiation belt particles and wave distributions to understand how these complex interactions vary during geomagnetic storms.
- Using physics-based modeling of these interactions and new empirical formulations that improve characterization of MI coupling and radiation belt impacts.
- Comparing measurements of mid-latitude electric fields and currents with magnetospheric measurements from RBSP and other assets to improve understanding of ionospheric electrodynamics.

MAG-1

Connection between Solar Interplanetary Structures and the response of Earth's radiation belts

Target Description

We have learned over the last two decades that the response of Earth's hazardous MeV-class outer Radiation Belts to such interplanetary structures as Coronal Mass Ejections (CME's), Corotating Interactions Regions (CIR's), high-speed streams and other structures, is highly unpredictable. An interdisciplinary team is needed to resolve the outstanding issues. There has been much discussion in the literature about the controlling parameters, whether they are pressure, density, velocity, magnetic field magnitude and orientation, and energetic particles that can find their ways into the magnetosphere. But the response to interplanetary structures clearly also depends on the space-time structures of these interplanetary features and the consequential hysteresis of responses of the magnetosphere to those structures. Mechanisms that might communicate the influences of interplanetary structures on the radiation belts could include: 1) ULF waves (that drive RB radial diffusion) generated by external variations and magnetopause K-H wave generation; 2) The relative stimulations of storms and substorms as each has their respective roles in the dynamics of the radiation belts; 3) Global magnetospheric response to external pressure disturbances; 4) Past history (hysteresis, seeding, existing boundary structures) and the consequences on wave generation (e. g. whistlers). Our objective is to sort out the factors associated with the interplanetary structures on the radiation belts and to move towards an understanding of the mechanisms by which those factors exert their influences.

Goals and Measures of Success

The goal of this Focus Science Team topic is to determine and quantify the relationships between specific solar and interplanetary structures, Coronal Mass Ejections (CME's), Corotating Interaction Regions (CIR's) and other structures, and the dynamic responses of hazardous radiation conditions near and inside the geosynchronous orbit. Success will be achieved when we: A) Understand the phenomenological connections between the different space-time parametric structures of interplanetary events and the responses of the >MeV outer radiation belt: whether the intensities increase or decrease, whether they move inward or outward, whether they lose their outer layers; B) Demonstrate the ability to correlate interplanetary structure characteristics and radiation belt responses and develop a scheme for characterizing radiation belt responses; C) Identify the most important mechanisms by which these interplanetary states regulate the radiation belt responses: generation of storms and substorms, generation of ULF waves; role of seeding, past history, and existing boundaries; global magnetospheric responses to pressure disturbances; and D) Move towards an understanding about how these mechanisms influence and regulate the >MeV radiation belts.

Types of investigations.

The FST participants will address the structure and evolution of interplanetary structures, and the interaction of such structures with the dynamics of Earth's radiation belts. Possible investigations include:

- Observational studies correlating characterize the detailed space-time structures of interplanetary features impinging on Earth's magnetosphere (CME's CIR's, high speed streams, etc.) with observations (e. g. SAMPEX and RBSP, etc.) of the response of the radiation belts.
- Global simulations of the magnetospheric response to Solar Wind structures that provide the plasma and fields in the inner magnetosphere. These results will be compared to the in situ observations of RB probes, and provide the context for wave studies.
- Observational and theoretical studies of wave generation and damping (ULF, Chorus, EMIC, etc.), and the resulting wave-particle scattering.

MAG-2

Coupling of Interplanetary Energetic Particles and Earth's space environment.

<u>Target description</u>:
The highly variable energetic charge particles within the interplanetary environment, such as solar energetic protons (SEPs; 50keV to 10 GeV) can increase the energetic population near the Earth by a factor of 10-1000, and lead to the formation of new high energy ion radiation belts trapped within Earth's magnetosphere. Magnetospheric dynamics, the interconnection between the terrestrial and the interplanetary magnetic field, and the distortion of the magnetosphere caused by the arrival of interplanetary shocks, control the entry of such particles with energy up to tens of MeV, as well as the formation of new radiation belts. The transport of interplanetary energetic particle populations in geospace involves the complex interplay of the source population in interplanetary space, the state of solar wind-magnetosphere coupling, and the internal magnetic field configuration. Within geospace, these energetic particles are a hazard to satellites and to humans, and they are known to have important effects on atmospheric chemistry. This focused science topic includes theoretical, modeling and observational studies that quantify how the coupling of energetic particles within the interplanetary environment, for example solar energetic particles (SEPs), to the Earth's magnetosphere, ionosphere, and atmosphere is affected by heliospheric structures and the time variation of the magnetospheric magnetic field, as controlled by lower energy populations in the Earth's magnetosphere. What is new and urgent about this topic is that a new asset is now available, the RBSP mission, that will allow us to do a much better job at making the connection between interplanetary populations and populations, structures, and dynamics that comprise the middle to inner magnetospheric regions.

<u>Goals and measures of success</u>:
The research objectives include: (1) studies of the character of the interplanetary particle populations and their correlation with the energetic particles and populations within the magnetosphere for different geomagnetic conditions, (2) observational determination of spatial and spectral properties of energetic particle of interplanetary origin within in the magnetosphere, again for different geomagnetic conditions, and (3) theoretical models and simulations of the entry and transport of interplanetary energetic particles in the magnetosphere and ionosphere. The results would be a quantitative understanding of the importance of interplanetary energetic particles (for example SEP's) on the particle populations in the magnetosphere and ionosphere. An important metric of success would be the direct comparison of the observations and empirical models with theoretical models and simulations.

Criteria for the success of this focus group include a) progress in the physical understanding of interplanetary energetic particle access to the inner magnetosphere (causes, morphology, temporal variation), and b) improvement in the predictive capabilities of geospace models including ring current and substorm effects. Success would be demonstrated by achieving the following objectives: 1) understanding observed variations in interplanetary particle fluxes at various locations and 2) acquiring the ability to model variations in interplanetary particle access caused by geomagnetic storms and substorms. This topic complements the work of focus groups that have investigated foundational topics such as solar wind plasma entry and transport in the magnetosphere, the effect of heliospheric structures on energetic particle transport, and the integration of kinetic effects into global models.

Types of Solicited Investigations:
It is anticipated that the availability of the new magnetospheric asset, RBSP, will greatly enable this topic. Proposals that address this topic should use external assets like ACE and Stereo together with magnetospheric assets like RBSP, to consider mechanisms that control entry and transport of interplanetary energetic charged particles in the magnetosphere. The research objectives of proposals include: (1) statistical or empirical characterization and correlation of the particles and their effects, (2) physical modeling of the energetic particle populations in the magnetosphere, and (3) investigations of the types of magnetospheric dynamics conducive to interplanetary charge particle trapping and de-trapping.

SC-1

Short-term solar/atmospheric variability and climate

Target Description:

Both observations and models demonstrate that short term solar variations can produce significant effects in Earth’s upper, middle, and lower atmosphere. Impulsive solar events, such as x-ray flares and solar energetic particles, occur on times scales of minutes to days which is very short compared to climatological time scales. Despite their short duration, these phenomena produce intensity changes at short wavelengths and in the energetic particle populations of several orders of magnitude, leading to dramatic changes in atmospheric response, often localized in space, time, or both.

As elucidated in “The Effects of Solar Variability on Earth's Climate: A Workshop Report" (NAP press, publication 13519, ISBN-10: 0-309-26564-9), a key question remains, namely, where does the role of short-term solar variability (both at short wavelength and in energetic particle populations) fit into the larger effort to understand the influence of the Sun on climate? Although total solar irradiance is the main solar driver of climate variability, whether, and by what mechanisms shorter-time-scale variations have an impact on climate are presently unclear.

The goal of this Focused Science Topic is to develop understanding of the complex response of the atmosphere to these short-term solar variations in order to know how these effects translate into the historical records of solar variability and their long-term impacts on climate. We presently have unprecedented observations of these non-visible elements of solar variability (short wavelength solar photons and solar energetic particles) and of the atmosphere which responds to these highly-variable solar drivers. We also now have modeling capabilities to explore the complex interactions and responses throughout the affected portions of the atmosphere to the inputs. If we can quantify these short-term responses through combined model development and data validation, then this knowledge can be used to address the more subtle, but potentially important, slow variation of these same drivers, and the atmosphere’s response occurring on climatological timescales.

Goals and Measures of Success:

The goal of this Focused Science Team is to advance our understanding of the short-term responses of the atmosphere to impulsive solar events such as flares and solar particles by:

- Progress in quantifying the range and sensitivity of the atmosphere’s complex response to rapid inputs of energy in the form of x-ray flares and solar particles.

- Progress in understanding what aspects of the flares and solar energetic particles (intensity, duration, spectral shape, etc.) control the atmosphere's response and what other factors might control the response (such as prior condition of the atmosphere).

- Use of modern observations to validate and calibrate models which in turn can be used to explore recent historical trends of these drivers and their predicted responses.

- Progress on how to extend our knowledge on the short-time scale, to address the slower variability of these same mechanisms occurring on climatological time scales.

Types of Investigations:

- Numerical models of atmospheric responses to a full range of impulsive solar energetic particles and flare photon inputs.

- Integration of observations of actual impulsive inputs and atmospheric models, combined with models, to establish the complex response function and its sensitivity to input and boundary parameters.

- Validated models to explore and to quantify whether longer-term variations in these rapid-timescale phenomena contribute to climate variability.

SH-1

The Magnetic Energy Budget of Solar Active Regions

Target Description: The CMEs/flares that drive space weather disturbances with the greatest societal impacts are driven by the sudden release of magnetic energy stored in the solar corona in active regions. Therefore, in order to predict the occurrence and magnitude of such events, it is critical to have accurate measurements of the magnetic free energy in active regions. Substantial progress has been made in quantifying the energy released by CMEs/flares, including accelerated particles (flare electrons and ions, as well as SEPs), heating and enhanced radiation (X-ray and bolometric), and kinetic and gravitational potential energies of the ejecta; however, the input: the magnetic free energy available is not accurately known. Despite its fundamental role in driving space weather, our understanding of ***how magnetic energy enters and is stored in the solar atmosphere*** remains limited.

Quantifying the buildup of free magnetic energy in the corona is critical to efforts to understand and predict eruptive events. ***With the launch of SDO, data crucial to studying these processes are now available.*** The HMI instrument is providing sequences of photospheric vector magnetograms --- which, until now, were not routinely available. These measurements enable quantitative analyses of the transport of magnetic energy into the corona by flux emergence and subsequent photospheric evolution, as well as extrapolations of non-potential coronal magnetic fields. The suite of telescopes that comprise AIA can constrain both pre-event coronal magnetic structure and event dynamics at high cadence and ubiquitous coverage. In addition, EVE can constrain variations in radiance resulting from the introduction, storage, and release of coronal magnetic energy. Other spacecraft and available data, including NASA's RHESSI, STEREO, WIND, ACE, and Fermi missions, the upcoming IRIS mission, and the joint Japan-US-UK Hinode mission, can provide critical observations complementing those of SDO.

As a result of these advances, ***new theoretical and numerical tools have been developed to utilize these data*** (e.g., a recent Strategic Capability), including methods to estimate the flux of magnetic energy across the photosphere and to determine the atmospheric magnetic field, in some cases using both photospheric and coronal observations. Therefore, the time is right for a coordinated effort to accurately determine the magnetic energy budgets of active region magnetic fields by quantifying, as functions of time, the input of magnetic energy into the corona, the available free magnetic energy in the corona, and the output of energy (in all forms). Given the varied manifestations of energy transport into and out of the solar atmosphere, ***this proposed FST demands a multidisciplinary team.***

Goals and Measures of Success:
The goal of this proposed Focused Science Topic is ***to improve our quantitative understanding of the introduction, storage, and loss of magnetic energy in active regions*** by making progress in measuring/understanding the:

- Transport of magnetic energy from the interior into the solar atmosphere during flux emergence, and the injection and release of magnetic energy into the corona by the subsequent evolution of the emerged field;

- Spatial distribution and time scales of the storage of free magnetic energy in the solar corona;

- Amount and form of energy losses from active regions, in particular during CME/flare events

Type of Solicited Investigations:

- Theoretical and observational studies quantifying the flux of magnetic energy through the photosphere based on measurements of the photospheric magnetic field;

- Development of methods for estimating the instantaneous free energy of active region magnetic fields based on observational data;

- Studies that use observational data to validate numerical models of active region magnetic fields;

- Observational and modeling studies that identify signatures of stored magnetic energy and characterize coronal stability;

- Studies that relate the measured/inferred magnetic free energy to likelihood of an eruptive event;

- Studies of the energy budget of active regions using models of the evolution of active region magnetic fields.

SH-2

Understanding the Large Longitudinal Extent of SEP Events

TARGET:
With SC 24 now routinely producing CME-associated SEP events that can be observed over ~360° for the first time, it is becoming increasingly clear that many events extend over much larger ranges of longitude than previously estimated. Some recent events have been observed over longitude ranges nearing 360°. 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 extend 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, and this same large extent has important implications for space weather and early warning capability since it is now clear that an observer may be affected by events over a much larger longitude range than previously believed. Additionally, the fast intensity rises observed during some backside events is an important feature. Such events would require a quick warning since they can reach maximum intensity near the onset.

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.

TYPES OF SOLICITED INVESTIGATIONS
Proposals that contribute to our basic understanding of the longitudinal extent of SEP events using observations, theory and modeling are encouraged, specifically:

- 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
- 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

- analysis of observations of the solar corona from multiple perspectives, and/or model large segments of the solar corona, to better understand the initial phases of CMEs and how they couple into a range of SEP opening angles into the heliosphere.

SH-3

Topic: Understanding the Physical Links between CMEs in the Low Corona and Prompt High Energy SEP events

Target Description: Solar Energetic Particle (SEP) events increase radiation hazards throughout the solar system and adversely impact our space- and ground-based assets. The most prompt SEP events that extend to high energies are typically associated with both large solar flares and fast coronal mass ejections, and it is now generally believed that these types of SEP events are caused by fast, large-scale CME-driven distrubances from the low corona. However, despite the strong circumstantial evidence accumulated over the last decade or so, the detailed physical association between prompt high-energy SEP events and their association with fast CMEs in the low corona remains poorly understood. For instance, timing studies of the earliest arriving particles have indicated that they must have been accelerated in the low solar corona well below ~5 Rs, where shock formation is not certain. Progress has been hampered because these types of events are rare and very little information about the coronal conditions and CME properties at these distances were available in prior solar cycles. Other factors that also play important roles include CME-shock speed and geometry, CME-CME interactions, turbulence levels, seed populations, magnetic field topology and connectivity, and self-generated waves.

The availability of high cadence, high resolution, multi-point remote sensing observations of the Sun from SDO, STEREO, RHESSI, Hinode, and SoHO in combination with sophisticated multi-point in-situ measurements from ACE, Wind, GOES, and STEREO now provides a distributed observatory that can, for the first time, constrain many of the above parameters that were previously poorly determined. Additionally, new ground-based low frequency radio arrays such as LOFAR in Europe and MWA in Australia are being commissioned in 2012 and are expected to produce significantly higher quality images and spectra of radio emission from shocks and flares. Simultaneously, with the aid of advanced and parallel computer power, the LWS modeling community has also made substantial progress in the development of highly sophisticated, time-dependent, multi-dimensional models in two key areas, namely, (1) CME formation and their subsequent propagation and evolution through a realistic medium from the low corona to beyond 1 AU, and (2) CME-shock acceleration of SEPs by including self-consistent wave-particle interactions, pitch-angle focusing and scattering, etc.

The time is therefore ripe for a broad cross-disciplinary team to make substantial progress in establishing definitive physical links between fast CMEs in the low corona and prompt high-energy SEP events.

Goals and measures of success:
It is anticipated that this FST will:

- Observationally quantify the roles played by various factors during prompt high-energy SEP events that originate from the low corona

- Significantly advance existing CME and SEP models in the low corona by direct comparison with remote observations.
- Establish definitive physical links between the properties of fast CMEs, low coronal conditions and the characteristics of prompt high-energy SEP events.
- Provide the groundwork for future investigations of prompt SEPs from Solar Orbiter and Solar Probe Plus.
- Develop a new modeling capability to predict whether CMEs will generate prompt high energy SEP events from the low corona

Types of solicited investigations:
This FST seeks a broad interdisciplinary team composed of remote and *in situ* observers and modelers. The team must have the expertise to identify candidate prompt SEP events, perform timing studies that identify potential locations of SEP sources, and model coronal conditions and particle acceleration during SEP events under study. The following types of investigations are targeted:

- Advanced CME and SEP modeling efforts that detail CME initiation, compression and shock formation, and associated particle acceleration from the low corona.
- Detailed multi-point remote sensing observations of the Sun prior to the occurrence of the prompt high-energy SEP events, properties of associated fast CMEs, and how they interact with and evolve during propagation from the low corona through the inner heliosphere to beyond 1 AU.
- Sophisticated multi-point in-situ observations of seed populations, CME and shock properties, SEP observations, waves and turbulence.

SH-4

Magnetic Flux Ropes from the Sun to the Heliosphere

Target Description: Magnetic flux ropes are widely believed to play a central role in space weather. Essentially all models for the magnetic field that emerges from below the photosphere to form active regions assume a flux rope structure. Observations of coronal cavities, prominences and active region sigmoids suggest a flux rope structure for the pre-eruption field, and coronagraph observations invariably show a flux rope for the eruption itself. Furthermore, many models for the pre-eruption coronal magnetic field of CMEs/eruptive flares invoke a twisted flux rope topology, and all CME models predict a highly twisted flux rope for the eruption, irrespective of the pre-eruption structure. Ground truth is provided by in situ measurements of the field in the heliosphere. These generally show a twisted flux rope. Hence, flux ropes are a unifying theme across Heliophysics, and understanding the mechanisms of their formation, evolution, and propagation is critical to predicting space weather.

Despite their central importance to space weather, many basic questions on flux ropes remain. For example, where, when, and how flux ropes are formed on the Sun remains highly controversial. Some observations and models support emergence of fully or partially formed flux ropes from the convection zone, while others support local formation in the corona due to magnetic reconnection preceding or during eruptions. We also do not understood how a flux rope, once formed, evolves and eventually erupts. Finally, the post-eruption transport and evolution of flux ropes through the heliosphere remain unclear. Even though all current eruption and propagation models predict a flux rope at 1 AU, in situ measurements frequently appear to show a non-rope structure for ICMEs. We are also far from understanding how the observed fields at the Sun determine the IMF at Earth, which is critical to space weather prediction.

It is timely to undertake investigations that unify the observation of flux ropes at the Sun by SDO and Hinode, as well as propagation in the heliosphere by LASCO and STEREO, and their in situ measurement by ACE, WIND, and STEREO. In addition, a growing network of ground-based instrumentation including interplanetary scintillation arrays, muon detectors, and low-frequency radio telescopes, has been deployed that has the potential to detect the propagation of heliospheric structures as they travel through interplanetary space. As flux-rope related activity increases over the current solar cycle, we now have new observational, numerical, and theoretical capabilities with the potential to make great progress. For example, SDO and Hinode have provided unprecedented high-resolution (spatial and temporal) observations of coronal cavities, prominences/filaments, and sigmoids and early development of CMEs in active regions. SDO/HMI and Hinode/SOT also provide vector magnetic field observations that are critical to determining the magnetic roots of flux ropes in the photosphere. Such observations, in combination with those from STEREO and ACE, can now monitor flux ropes continuously from the Sun to the heliosphere. Meanwhile, 3D MHD models covering a wide domain ranging from the convection zone to the corona and heliosphere can now simulate flux ropes that can be directly compared with new observations. These numerical efforts are being complemented by parallel theoretical/analytical modeling of relevant elementary processes, such as those leading to prominence formation in flux ropes.

Goals and measures of success:
The overall objective of this Focused Science Team is to advance our observation and understanding of the "life cycle" of a magnetic flux rope, from its birth in the Sun, through its evolution and growth phase in the corona, to its eruption and transport through the heliosphere. Measures of success will in all cases be sought to reconcile observations/measurements and predictions with model-based simulations and/or theoretical investigations, as well as the elimination of theoretical ideas demonstrably not supported by observations. The primary goals are fourfold:

- Identify the formation mechanisms of flux ropes in the solar atmosphere
- Understand the evolutionary processes leading to eruptions
- Understand the evolution of flux ropes in the interplanetary medium, and in particular, relate the flux rope IMF at 1 AU to solar observations
- Determine the role of flux rope eruptions in the magnetic flux budget of the heliosphere

Types of solicited investigations:
This FST seeks broad interdisciplinary studies that tie together the heliospheric and solar observations. Possible studies include:

- Observational studies of flux rope formation and evolution, such as vector field data from SDO or from the ground and high-resolution coronal imaging/spectroscopy from SDO, Hinode, and STEREO
- Observational studies of flux rope propagation through the heliosphere, such as those from coronagraphs, heliospheric imagers, and ground-based networks
- Studies of in situ measurements of flux rope magnetic and plasma structure, especially plasma properties that can be related to the solar observations, such those from STEREO, ACE, and WIND
- Theoretical/modeling studies of flux rope formation/emergence, evolution and propagation in the heliosphere