Report of the Steering Committee for the TR&T Program of LWS

Spiro Antiochos (Chair), Nick Arge, Janet Barth, John Bieber, Tom Bogdan , John Eddy, Bela Fejer, Tamas Gombosi, Michael Hesse, Marty Lee, Bill Lotko , Robert McCoy, Douglas Rabin, Jimmy Raeder, John Raymond, David Rind, Sam Yee

April 14, 2005

This document reports the results of the deliberations of the FY05 TR&T Steering Committee (TSC). The TSC held two 'in person' meetings, Nov. 9 – 10, 2004 near Washington DC and Feb. 15 – 16, 2005 in Boulder CO, one 'town hall' meeting at the Fall 2004 AGU meeting, and several teleconferences. In addition to the Steering Committee members listed above, the LWS Project Manager, Lika Guhathakurta, and the TR&T Project Scientist, David Sibeck, were present at all the meetings/teleconferences.

Most of the deliberations concerned three topics:
(1) implementation and selection of the FY06 *focused science topics*,
(2) implementation and selection of the FY06 *strategic capabilities*, and
(3) possible partnerships of the TR&T Program with the NSF and NCAR.

Consequently this report is structured according to these three topics.

CONTENTS:

I. Proposed FY06 Focused Science Topics

Storm effects on the global electrodynamics and TEC of the middle and low latitude ionosphere

Target Description: Magnetic storms cause large departures of the mid- and low latitude electric fields from their quiet values. These perturbations cover a broad range of spatial and temporal scales and strongly affect plasmaspheric erosion and reconfiguration, ionospheric dynamics and plasma distribution, and the occurrence of ionospheric plasma instabilities which can severely disrupt communication and navigation systems over a large area of the Earth. Recently, significant progress has been achieved on the general climatology of mid and low latitude storm-time electrodynamics and TEC, but there are fundamentally important unresolved questions dealing with their large spatial and temporal variability. The understanding of this variability and of the involved processes from a global perspective is essential for realistic storm time ionospheric forecasting, which is increasingly important for a number of space based systems.

Goals and Measures of Success: The goal of this project is to produce an improved understanding and forecasting capabilities of time dependent storm ionospheric electrodynamics from subauroral to equatorial latitudes and their effects on TEC, in response to different solar wind and magnetospheric conditions, and its variation with longitude, season, and solar flux. The forecasting of these storm effects from numerical models will be validated against global electric field and TEC measurements.

Types of Solicited Investigations: Proposals that address this broad topic are expected, ideally, to consider storm electrodynamics from a global ionospheric-magnetospheric perspective. The research objectives of proposals will include, but not limited to, investigations that deal with (1) techniques to improve the specification and forecasting of magnetospheric parameters which play fundamental roles on middle and low latitude storm electrodynamics; (2) techniques that substantially enhance the database of global mid- and low latitude electric field measurements; (3) the generation of mid-latitude polarization electric fields, their temporal and global spatial dependence, and their relationship to lower latitude storm electrodynamics; (4) the global distribution of prompt penetration electric field and TEC, their storm time dependence, from subauroral to equatorial latitudes under different solar, ionospheric and magnetospheric conditions.

Determine the effects of changes in the atmospheric abundance of greenhouse gases on the temperature and dynamics of the upper atmosphere and ionosphere, and separate these effects from those that are solar driven, as an aid to the study and attribution of global greenhouse warming

Target description: Of the three terrestrial planets, the Earth's upper atmosphere is unique in that it is characterized by a high-temperature thermosphere as compared to Venus and Mars whose upper atmospheres are cooler and described as cryospheres. The lack of triatomic molecules in the terrestrial upper atmosphere makes cooling to space inefficient and the major heat loss is downward transport to regions with more IR active molecules which can radiate to space. This unique feature of our upper atmosphere means that even small increases in the abundance of these molecules will provoke additional cooling of the upper atmosphere, with potentially dramatic effects on the neutral and ionized upper atmosphere. Additionally, the upper atmosphere lacks feedback mechanisms; as a result any increase in anthropogenic greenhouse gases will lead to cooling. This makes the thermosphere and ionosphere an ideal laboratory to look for and study the effects of global greenhouse warming. The major complicating factor is that the temperature and ionization in these layers are driven by variable UV and X-ray flux from the Sun. Hence, any effect of anthropogenic origin must be separated from external effects due to solar forcing.

Goals and measures of success: The underlying goal of this focused science target is to clarify the attribution of documented global warming by refining our understanding of the response of the Earth's upper atmosphere to increased levels of global greenhouse gases. One measure of success is a clearer understanding of the relative effects of solar forcing and radiative cooling at various altitudes in the upper atmosphere as a function of varying levels of solar forcing. A quantification of the expected impacts of anticipated increases in atmospheric greenhouse gases of anthropogenic origin would be another important and highly useful measure of success. Characterization of the effects of increased IR gases on the upper atmosphere in the context of predicted effects in the lower atmosphere and in comparison to conditions in the cryospheres of the other terrestrial planets is an additional goal.

Types of investigations: Both theoretical and experimental investigations are encouraged. Modeling of the existing thermosphere in comparison to the upper atmospheres of the other planets and also in terms of its response to varying amounts of greenhouse gases would be an integral activity of this focus group. Analysis of existing data or new observations of the thermal structure, composition and density distribution of the thermosphere and ionosphere could be used to help establish the baseline structure of the upper atmosphere and to look for the effects of global greenhouse warming. These investigations would need to be performed in the context of strong solar forcing and will require quantification of the flux of energetic radiation and atomic particles from the Sun and their variation in response to short-term impulsive events and to the slower changes in background radiation that occur over the course of the solar cycle .

Causal relationship of ionospheric outflows to high-latitude forcing

Target description: The interaction between the earth's magnetosphere and ionosphere produces massive auroral, cusp and polar outflows of ionospheric ions, primarily H^+ and O^+, which are especially abundant during geomagnetic storms and substorms. This transport of mass modifies the state of the ionosphere and magnetosphere, including the magnetotail, plasmasheet and ring current. These modifications, in turn, couple into the evolution of storms and substorms. The bulk characteristics of the outflows are regulated by solar and magnetospheric inputs. The causal relationships between the outflows and high-latitude forcing are not well understood, empirically or theoretically, particularly when collisionless energization processes mediate the low-altitude response to forcing. Such effects currently are not included in global simulations of the magnetosphere. Future progress in developing forecast-quality simulations of magnetospheric and ionospheric variability and associated space weather effects depends crucially on the development of models of these causal relationships.

Goals and measures of success: The research will produce empirical and first-principles models that relate spatiotemporal bulk characteristics of the outflow such as number flux, mass composition, and energy to ambient conditions of the ionosphere and thermosphere and to magnetospheric forcing of the high-latitude region in the form of Poynting fluxes, precipitating particle number and energy fluxes, and Joule heating. The models will be validated using data derived from ground- and space-based platforms. Empirical models should include error bars on predicted relations. An overarching goal is to improve the predictions of large-scale simulations of geospace, including storm and substorm dynamics, by providing modules that may be imbedded in the simulations to specify causal mass exchange between the ionosphere and magnetosphere.

Types of solicited investigations: The focus group is expected to make substantial progress towards fundamental understanding of ionospheric upwelling and auroral, cusp and polar ionospheric outflows and their causal relationships to high-latitude electromagnetic and plasma forcing. Research objectives include: (1) observational and correlative studies of spatial and temporal distributions of Poynting fluxes, precipitating particle number and energy fluxes, and ionospheric-thermospheric Joule heating, and their relationships to bulk characteristics of outflows; (2) determination of the length- and time-scale dependence of these relationships; (3) development of empirical outflow models; (4) development of first-principles outflow models that include relevant collisionless mediation between forcing and response; (5) assembly of statistical and event databases for model development and validation; (6) development of numerical schemes for embedding outflow models in global simulations, e.g., through boundary conditions and/or flux coupling; and (7) evaluation of the effects of outflows in global models. Collaboration with the global modeling community is encouraged.

Solar wind plasma entry and transport in the magnetosphere

Target description: Prolonged exposure to suprathermal magnetospheric plasmas has deleterious effects upon spacecraft. Examples include leakage, sputtering, and spacecraft surface charging. Determining the characteristics of the plasma population within the magnetosphere as a function of location, geomagnetic activity, solar wind conditions, and solar cycle is therefore a question of fundamental importance to spacecraft designers. Predicting the characteristics of the population requires knowledge of the locations and mechanisms by which solar wind plasma enters the magnetosphere, the processes by which it is energized and transported inward to geosynchronous orbit and closer, and the interactions by which it is lost.

Goals and measures of success: The ultimate objective of this targeted research area is a global model for the solar wind-magnetosphere interaction capable of accurately predicting the plasma environment within the Earth's inner magnetosphere ($R < 10\ R_E$) as a function of prevailing solar wind conditions. Steps towards this goal might include (1) development of empirical models for the geospace plasma as a function of solar wind conditions, geomagnetic activity, and solar cycle, (2) submodules that account for plasma entry at the magnetopause and energization/transport within the magnetosphere, (3) validation of the simulations against a variety of observational case studies and the empirical models, and (4) development of a quantitative understanding of the relative roles of solar wind and ionospheric plasma sources in populating the magnetosphere.

Types of Solicited Investigations: Proposals that address this broad topic are expected to address the mechanisms by which plasma crosses the magnetopause, the means by which this plasma is energized and transported to the inner magnetospheric regions relevant to spacecraft operations, and the characteristics of the plasma within the magnetosphere. The research objectives of proposals include, but are not limited to, investigations that predict and quantify: (1) the amount of solar wind plasma entering the magnetosphere as a function of location on the magnetopause, (2) the processes by which this plasma is transported from the magnetopause into the magnetosphere to form the plasma sheet, and (3) the mechanisms by which it is injected into the inner magnetosphere for different solar wind, geomagnetic, and solar cycle conditions.

Shock acceleration of solar energetic particles by interplanetary CMEs.

Target description: Understanding large, gradual solar energetic particle (SEP) events is central to space weather and space climate. Gradual events observed at Earth are accelerated near the Sun and in the heliosphere by shocks associated with interplanetary CMEs (ICMEs). However, direct comparisons between observations, models, and theories have been unimpressive. It is now clear that in order to make progress in understanding the solar particle radiation environment near Earth, a cross-disciplinary approach is needed. It is necessary to combine studies of shock acceleration of energetic-particles, their propagation, and the evolution of CMEs in the heliosphere,

Goals and measures of success: The goal of this topic is to establish the spatial and temporal evolution of large geoeffective gradual SEP events throughout the heliosphere including acceleration of the SEPs at the CME-driven shock wave, SEP electron and ion composition, SEP propagation in the solar wind, wave excitation by SEPs upstream and downstream of the shock, and the resulting radiation environment in interplanetary space from Earth to Mars orbit.

Types of solicited investigations: Proposals are encouraged which contribute to our understanding of gradual SEP events using either observations or theoretical analysis. Numerical and analytical models are both relevant. Proposals are further encouraged to target fundamental features of these events including particle injection at the shock, the evolution of the CME-driven shock in the corona and solar wind, the formation of the upstream wave spectrum, particle diffusion, particle escape from the shock to Earth orbit, particle anisotropies, ion fractionation, the role of magnetic field obliquity, and the special behavior of gradual events close to the Sun or at long times and/or large heliocentric radii. Theoretical proposals should relate proposed analytical and numerical model results to observations.

Determine the mechanisms that heat and accelerate the solar wind

Target description: The solar wind creates the heliosphere, and determines our space environment from the low corona, past the planetary magnetospheres, to the solar wind termination shock and the boundary with interstellar space. In spite of its importance as the medium of the Sun-Earth connection, its origins as either “fast” or “slow” wind remain unclear. The heating of the ions perpendicular to the magnetic field and the preferential heating of the heavy ions are important clues to the origin of the fast wind, but these observations have not yet identified specific heating/acceleration mechanisms. It is also unclear whether any of the same mechanisms apply to the slow wind, when more frequent collisions are incorporated, or whether different mechanisms are operative.

Goals and measures of success: The goal of this topic is to combine theoretical studies, numerical simulations, and in situ or remote observations to understand how the fast and slow solar wind are heated and accelerated. The measure of success, and the criterion for proposal selection, is the potential impact of the work on our understanding of the solar wind, including both the fast and the slow wind, and a possible relation between them.

Types of solicited investigations: Proposals may be based on theoretical investigations of specific acceleration mechanisms, modeling the effects of specific mechanisms on the solar wind flow, or observations pertaining to the identification of the operative mechanisms. Acceleration mechanisms include wave-particle interactions, turbulent heating, magnetic mirroring, and the consequences of magnetic reconnection at or above the coronal base (e.g. enhanced heating or reconnection-driven plasma jets). Models might include solar wind flows with specified physical heating mechanisms and appropriate magnetic field configurations. Relevant observations include ion and electron distribution functions, and their density, speed and temperature moments, ion composition, average magnetic field, magnetic field and plasma fluctuation spectra, and remote sensing of plasma properties in the corona.

Predict CME initiation and early development

Target description: It is well-known that the most destructive forms of space weather are driven by fast CMEs/eruptive flares; consequently, achieving the physical understanding required for predicting these giant disruptions of the Sun's magnetic field is a major objective of the LWS program. Observation of CME initiation at the Sun can yield a 1 - 2 day warning for some forms of space weather, but energetic particle and UV/X-ray radiation require prediction of the initiation itself in order to obtain a useful warning time. Prediction of CME/eruptive flare onset is especially important for the Exploration Vision. It is now timely to focus a concerted attack on the CME initiation problem for several reasons. First, there is a rich wealth of information presently available from both solar and heliospheric missions on the emergence of fast-CME producing solar active regions, on the magnetic and velocity fields prior to CME initiation, and on the properties of the coronal plasma in the initiation region. Observations from the soon-to-be launched STEREO and SOLAR-B missions will add greatly to this wealth of data. Second, a number of promising CME initiation theories have now reached a relatively mature state in that they make well-defined predictions that can be tested with observations and modeling. Third, numerical simulations have reached the state where they can calculate the explosive dynamics of realistic, 3D coronal systems using observations as input and constraints. Finally, CME initiation is highly relevant to SDO, which will provide the highest-resolution observations of the pre-CME subsurface and coronal conditions.

Goals and measures of success: The primary objective of this focused topic is to develop the physical understanding required for developing a 'first-principles' prediction scheme for CME initiation. At present, operational methods for CME/flare prediction are based on empirical/statistical procedures. One measure of success for this focused topic would be a quantifiable improvement to these procedures. Full success would be the development of a useful procedure, even if rudimentary, for CME prediction with one or more hours warning. It is not expected that a robust prediction scheme will be developed on the three-year time scale of this focused topic, but demonstrable progress towards this goal would be an acceptable measure of success. A quantitative improvement in the ability to predict the severity of a particular CME's space weather effects would also constitute success for this topic.

Types of investigations: It is expected that the focus team will include, but certainly not be limited to, the following types of investigations:

1. Theory, modeling, and data analysis relating to understanding the pre-CME magnetic and plasma structure.
2. Theory, modeling and data analysis relating to understanding the trigger mechanism(s) for initiating the eruption.
3. Theory, modeling and data analysis relating to understanding the early development of and predicting the space weather severity of CMEs.

II. Guidelines for Strategic Capabilities Proposals

A primary goal of the LWS Program is the development of first-principles-based models of the coupled Sun-Earth system, similar in spirit to the first-principles models for the lower terrestrial atmosphere. Such models can act as tools for science investigations, as prototypes and test beds for prediction and specification capabilities, as frameworks for linking disparate data sets at vantage points throughout the Sun-Earth system, and as strategic planning aids for testing new mission concepts. To begin the process of developing and integrating models for all the components of the Sun-Earth chain, the TR&T Science Definition Team identified these component models and their integration as *strategic capabilities* (SC) that are critical to LWS and recommended that they be funded as a distinct program element within the TR&T. This new element will be initiated this year, in FY06.

The TR&T SDT also identified four defining characteristics for a successful SC proposal:

1) The project delivers a model that is deemed by the review panel to be essential for making progress toward the ultimate goal of forecasting and specifying the coupled Sun-Earth system.
2) The model can serve as a prototype for operational capability; it must use actual data as input and produce useful output.
3) The project delivers a tool that is deemed by the review panel to have broad, cross-disciplinary science applicability. The size of the likely user base for the proposed tool should be a major factor in its selection.
4) The project provides easy access to the model, either directly by the developers or through a modeling center. In the case of software, the source code and documentation should be required to be delivered to one of the modeling centers utilized by LWS.

General Requirements for All Strategic Capabilities Proposals:

Following the recommendations of the SDT, the TR&T Program requests proposals for the three SCs described in detail below. Note that SC programs will be treated much like flight hardware projects, in that requirements will be outlined by the NASA project team and a capability with specified features is to be delivered to NASA on a specified schedule. Therefore, all SC proposals must satisfy the requirements below. Proposals that do not adhere to these requirements will be deemed to be **non-responsive** to this call for proposals. Furthermore, the extent to which proposals satisfy these requirements will be used as selection criteria by the peer-review panels.

1. **Deliverables:**

The proposed Strategic Capability, **including all source code**, must be delivered to a NASA modeling center, such as the CCMC, for unrestricted use by NASA. The source code must be the fully functioning version described in the proposal and be clearly documented according to standard software “best-practices”. In all cases, a working and useful version of the SC should be delivered to NASA by the end of the third year of the project. After evaluation of this version, NASA may elect to renew the project for up to another two years in order to obtain a final version of the SC.

2. **Schedule and Milestones:**

As with all flight projects, a schedule for the proposed deliverables (code, documentation, validation procedures, etc.) must be clearly described in the proposal, along with regular milestones for major phases of the project and for the deliverables. The schedule and milestones are expected to be set by the proposers, but milestone completion must be readily verifiable by the TR&T Project Office.

3. **Verification and Validation:**

A separate section is expected in the proposal that describes clear procedures for verifying and validating the Capability. These procedures must be such that they can be readily performed by the CCMC and/or the outside community, and they must yield quantitative measures of the Capability's accuracies and inaccuracies.

4. **Documentation and Access:**

A defining characteristic of SCs is that they can serve as community tools; consequently, all SC projects are required to include comprehensive user documentation and easy user access. For example, if the SC involves a first-principles model, all equation solved, numerical algorithms used, input parameters, etc. must be clearly documented in the Users manual. Easy user access, such as GUI interfaces to run the model and to analyze the output, will be a selection criterion for winning SC proposals.

5. **Interoperability:**

Although the ultimate goal of the TR&T is a comprehensive Sun-to-Earth model, the SCs called for at present are component models that address only one part of the complete system. For this reason, any SC that is proposed must have the flexibility to interoperate with other models in a coupled chain. The interoperability features of the SC should be clearly described in the proposal and in the delivered documentation.

6. **Potential for Transitioning:**

An SC is **not** expected to be an operational capability. However, a section must be included in the proposal that describes the possible transition path(s) for the SC to space system design tools and space weather operations. The potential for using the SC as a prototype for an operational tool will also be an important selection criterion.

III. Proposed FY06 Strategic Capabilities

LWS Simulation Framework

Capability Description: A production-ready high-performance computational framework that contributes to the development of an end-to-end LWS simulation capability using "plug-and-play" methodology.

LWS Strategic Need:
The highly coupled, multiscale, "system-of-systems" nature of the solar-terrestrial environment presents a formidable challenge for first-principles based end-to-end numerical models. The system is broad scale in that structures ranging from the full system size (several AUs) to the dissipation regions of a few kilometers must be resolved. It is also broad scope in that more complex physical models must be used at the smaller sales, or even different regimes. The structure and evolution of the solar atmosphere and the heliosphere is largely determined by the emergence of magnetic flux thought to be generated at the base of the convection zone. These intense loops of magnetic flux form active regions (~200,000 km) that contain the bulk of magnetic flux in the photosphere and corona; the release of part of this magnetic energy results in flares and CMEs that occur on kinetic scales. The global plasma and magnetic field structure of the magnetosphere, spanning hundreds of earth radii (~10^6 km), is determined by the flow of momentum and energy, both particle and magnetic field from the solar wind, which is determined in thin boundary layers (~ 100 km) such as the bow shock, magnetopause, and downstream current sheet. The very fast wave speeds along field lines couple dissipation in these thin current layers almost instantaneously across the magnetosphere to the ionosphere. In the coupled ionosphere-thermosphere system chemical reactions and finite electrical conductivity are important where collisions between ions, electrons, and atoms are frequent. The disparity of scale is in physical regime as well as in spatial and temporal scale. Fluid descriptions such as MHD can address the global structure of the magnetosphere, while particle drifts not described by MHD are important near the Earth and kinetic physics is required to understand the boundary and dissipation regions This multitude of domain models need to be tied together with a "plug-and-play" type computational framework to form a "system-of-systems" modeling capability.

Expected Features:

- Facilitate the development of advanced models and components by providing a common modeling infrastructure that isolates developers from ever-changing computing architectures and provide shared repository of commonly used tools and functionality
- Facilitate the coupling of models and components into more and more complex system models, improving interoperability and ease-of-use for system model evolution

- Provides a flexible "plug-and-play" model coupling capability for the wide class of models required by LWS, (e.g., global 3D MHD, particle acceleration and propagation, Earth and Mars upper atmosphere).
- The framework is readily accessible to the LWS community and a copy of it resides at CCMC.
- The developers will organize regular community workshops and seek community input for the selection and coupling of physics models.

Desirable Features:

- Framework needs to minimize science code modifications and provide templates for coupling science codes to the LWS framework,
- LWS framework must be readily expandable to couple additional physics models as the need arises.

A Comprehensive Magnetosphere-Ionosphere Model

Capability Description: A comprehensive, coupled, quantitative 3D model for the outer magnetosphere, inner magnetosphere (plasmasphere, ring current, and radiation belts), and the ionosphere.

LWS Strategic Need: A primary objective of LWS is to enable the development of physics-based predictive modeling of Geospace based on solar wind and IMF input. Such models would forecast parameters that directly impact technological systems, for example, radiation belt particle fluxes, ionosphere/plasmasphere TEC, and ionospheric currents. Currently a patchwork of models exists for different regions. MHD based models cover the outer magnetosphere and the electrodynamic aspects of the ionosphere but neglect the inner magnetosphere which is governed by non-MHD processes. Separate models exist for the inner magnetosphere treating the plasmasphere, the ring current, and the radiation belts, and for the ionosphere-thermosphere system. These models are highly complementary, for example the MHD models can provide the magnetic and electric fields for the drift physics in the inner magnetosphere, whereas the inner magnetosphere models can provide important corrections to the MHD models and precipitation parameters to the ionosphere models, and the ionosphere-thermosphere models provide ionospheric conductances and dynamo currents. Overall, the magnetosphere response to the SW/IMF input is known to be nonlinear and highly complex, yet no contemporary model can treat the interaction yet in a comprehensive way. More comprehensive coupled models are thus badly needed, and the building blocks are for the most part in place.

Expected Features:

- Uses IMF and solar wind data from L1 monitors or from heliospheric prediction models and F10.7 or some other EUV proxy as input.
- Determines the 3D magnetic and electric fields from the bow shock to the ionosphere E region at all latitudes. Although not explicitly an expected feature this requires proper kinetic treatment of the ring current
- Determines the electron density in the ionosphere and plasmasphere. Implicitly, this requires a comprehensive ionosphere-thermosphere model that includes forcing from below through tides and gravity waves.
- Determines radiation belt electron and ion populations.
- Provides ionospheric currents and the resulting ground magnetic perturbations.
- Is numerically robust and tested to handle worst known magnetic storm conditions.
- Fast enough to be executed in real time with reasonable computer resources.
- Metrics and skill scores are established for the primary predicted quantities, in particular TEC, RB fluxes, and ground perturbations.

Desirable Features:

- Can use input from several SW/IMF monitors.
- Allows for ionospheric ion outflow and multiple ion species in the outer magnetosphere, ring current, and plasmasphere.

- Automatic quality assessment of output trough concurrent real time data.
- Some rudimentary data assimilation.

A Time-Dependent 3d Model of the Corona and Ambient Solar Wind

Capability Description: A 3D time-dependent model that provides the structure and properties of the slowly-varying corona and ambient solar wind.

LWS Strategic Need: A primary objective of LWS is to enable the development of physics-based modeling of the Sun-Heliosphere and Sun-Earth systems. There is presently a great need in both the research and forecast communities for a robust, relatively easy to use, time-dependent, 3D model of the corona and heliosphere driven by updated photospheric magnetic field observations. A model that provides a quantitative, time-varying description of key coronal and solar wind parameters is essential for 1) having a 3D description of the state of the large-scale corona and heliosphere at any give instant in time, 2) accurately predicting/modeling recurrent interplanetary disturbances, 3) providing a global context for the propagation of transients (i.e., CMEs) and particles, and 4) more fully understanding the dynamics and evolution of the corona and heliosphere. Such a model is critically needed and will prove to be an invaluable, highly used, practical tool for a large segment of both the research and forecast communities.

Expected Features:

- Provides a 3D, quantitative description of the structure and properties of the large-scale corona and heliosphere at any give instant in time.
- The capacity to use as its input line-of-sight (LOS) photospheric magnetic field data currently available from the ground and in space as well as those from future spacecraft and ground based solar observatories.
- Provides user-friendly interfaces and graphics for runs on demand by the general research community. Provides the flexibility for quick-turn-around runs

Desirable Features:

- Can use both LOS and vector magnetic field observations as input.
- Readily provides time series' of solar wind parameters for any point or object (Earth, Mars, spacecraft) in space.
- Includes the capacity to initiate simple transients (e.g., pressure pulses).
- Sufficiently modular to permit the inclusion of routines containing new or more sophisticated physics (e.g., improved energetics, erupting CMEs).

Earth – Moon – Mars Radiation Model

Capability Description: Predict radiation exposure anywhere on the surface or in the atmosphere of Earth, on the Moon, on Mars, and in interplanetary space between Earth and Mars. The deliverables will be models that can be used by mission planners and space system designers for space exploration missions.

LWS Strategic Need: Radiation exposure from solar, Galactic, and anomalous cosmic rays is of concern for pilots and flight crews who spend a great amount of time at high altitudes, especially those who frequently traverse high latitude regions where the geomagnetic field affords no protection. Cosmic rays of any origin can damage electronic components in sensors deployed in space. For humans venturing to the Moon, Mars, and beyond, radiation exposure from solar, Galactic, and anomalous cosmic rays is dangerous and is among the foremost concerns for human exploration of space beyond low-Earth-orbit.

Expected Features:

Given a cosmic ray distribution in the solar wind that specifies

1. energy spectrum,
2. angular distribution, and
3. elemental composition,

predict radiation exposure for humans anywhere on the surface of Earth, the Moon, or Mars, in the atmosphere of Earth, and in the space between Earth and Mars. The deliverable product should be, in physics terms, a "Green function" for radiation exposure. The model should define clear procedures for integrating this Green function with an arbitrary specified cosmic ray distribution, to produce a prediction of radiation exposure.

The project must specifically address the following issues:

- What are the error bounds on the radiation predictions?
- What are the major sources of error; in particular, what future research can be done to narrow the error bounds? (Illustration: Are uncertainties in nuclear cross sections a major uncertainty in Earth's atmosphere? Is the atmosphere profile a limiting uncertainty on Mars?)
- What are the implications of the radiation model to critical electronic components?
- How important is backscatter / albedo from lunar or Martian soils?
- Is soil composition a significant factor?
- Is magnetism from local surface features on the Moon or Mars a significant factor?
- Is magnetism from Mars's induced magnetosphere a significant factor?
- How significant is shadowing from local landforms such as mountains or canyon walls?

Desirable Features:

- Define representative spectra for Galactic and anomalous cosmic rays, under solar minimum and maximum conditions and in both states of solar magnetic polarity. Interface these with the model to illustrate use of the radiation model.
- Define representative spectra for solar cosmic rays, considering various scenarios for anisotropy, and interface these with the radiation model.
- To the extent possible, validate the radiation model, or identify future validation strategies:
    - Validate Earth and Earth-atmosphere predictions with inexpensive aircraft, balloon, or ground-based instruments.
    - Identify optimal strategies for validating and improving models on the Moon, Mars, and in interplanetary space.

Seamless Ocean to Space Model

Capability Description: A quantitative 3D model of the entire Earth's atmosphere from the ocean surface through the ionosphere

LWS Strategic Need:
An objective of LWS is to enable the development of physics-based modeling of the Sun-Heliosphere and Sun-Earth systems with an ultimate goal of continuous models from the ocean surface to the Sun. An important element is the development of seamless model from the bottom of the atmosphere through the ionosphere. Conventional atmospheric efforts divide the atmosphere into regions (troposphere, stratosphere, mesosphere, thermosphere, ionosphere) with each region modeled independently and using appropriate boundary conditions. There are several limitations of this approach one of which is that boundary conditions invariably introduce artificial physical forcing into the modeling. Also, there are increasing indications that communication of energy and momentum between highly separated atmospheric regions is important to accurate specification and forecast. Examples include indications of El Nino in the mesosphere and the seeding of ionospheric scintillation storms seeded by gravity waves generated in tropospheric weather disturbances. Improved weather forecasts would be available from the elimination of the upper boundary which complicates the specification of the high altitude steering winds which is important for major weather systems. An integrated seamless model from the surface of the ocean to through the ionosphere would improve specification and forecast capabilities of the entire atmosphere and lead to new insights into couplings throughout the atmosphere.

Expected Features:

- Combines terrestrial weather models with models of the upper atmosphere and ionosphere
- Describes energy and momentum transfer from ocean surface upwards and downwards
- Includes coupling and communication (dynamical and chemical) between atmospheric regions
- Provides user-friendly interfaces and graphics for runs on demand by the general research community

Desirable Features:

- Able to assimilate a wide range of ground-based and space-based data
- Allows for a variety of user-selectable altitude regions of interest
- Regional model to study interactions of severe tropospheric weather with upper atmosphere

IV. Memorandum of Understanding Between the TR&T Program and NCAR

A core objective of the NASA LWS Targeted Research and Technology Program (TR&T) is to understand and model space weather with sufficient depth to produce demonstrable benefits for life and society. To meet this challenge, the TR&T has developed an implementation plan incorporating several elements: a team approach to attack major focused science topics, a large-scale-modeling program to obtain critical strategic capabilities, and an infrastructure building program including, for example summer schools, workshops, post-docs, etc, to help develop a cross-disciplinary science community. All these elements can benefit from an easily accessible facility with a staff that spans Sun-Earth science, where the cross-disciplinary science teams can meet, where modeling expertise is available, and where infrastructure-building activities can be hosted.

NCAR, for its own purposes, has embarked on an ambitious program to develop a vertically-integrated center for Earth-Sun science. NCAR is already a national center for terrestrial weather and climate research and modeling, and has had a long-term interest in community modeling of the upper atmosphere. As part of its program, NCAR plans to extend its science and modeling capabilities outward to eventually include all space weather. An important element of NCAR's plans for its Earth-Sun center is the establishment of a service role for NCAR with the outside space weather research community. Close collaborations and partnerships with the outside community are also vital elements of NCAR's mandate as an NSF-funded national facility.

There is thus a natural alignment of interests between the LWS TR&T and NCAR. In order to realize mutual benefits from these common interests, NCAR will provide – at its discretion and as appropriate for meeting its goals – facilities and science/modeling expertise and capabilities, while the TR&T will provide an outside community funded to work on space weather, as convenient to that community and as appropriate for meeting the TR&T goals. Toward this end, both the TR&T and NCAR will encourage this outside community to utilize meeting facilities at NCAR to hold focused science team meetings, and to take advantage of other Sun-Earth science infra-structure-building programs at NCAR, and to make use as appropriate of NCAR's expertise and facilities in the development of TR&T strategic capabilities.

The proposed TR&T/NCAR partnership will not involve any exchange of funds, but NCAR scientists are free to compete in any of the TR&T programs, as is presently the case. If it is found that the types of community services to be provided by NCAR are of substantial benefit to the TR&T program, then the TR&T may call for proposals for LWS centers that would be funded to provide such services on a contractual basis. Such centers would be selected by the usual NASA peer-review process. All institutions, including NCAR, would be encouraged to compete for such centers.

In order to monitor and assess the benefits of the proposed TR&T/NCAR partnership, a committee consisting of three community representatives selected by NASA and one

NCAR representative will be formed. Another goal of this committee will be to determine additional partnering activities that will be beneficial to both the TR&T and NCAR. The Committee's primary goal will be to prepare, at the end of two years, a recommendation to the TR&T as to whether the types of services provided by a facility such as NCAR are of sufficient benefit to be formally contracted in a call for proposals for LWS centers.

V. Guidelines for a TR&T NSF Partnership

A partnership has been proposed between NASA and the NSF in funding space weather modeling programs. Such a partnership would be beneficial to both agencies. Combining their resources allows the two Agencies to develop the large-scale models that are essential for demonstrating that the research supported by NASA and the NSF will benefit life and society. Consequently, the TSC strongly encourages NASA to pursue such a partnering opportunity with the NSF.

If this partnership is to involve the Strategic Capability element of the TR&T Program, however, then it must satisfy the following two requirements.

1. The Strategic Capability element and its implementation plan have been explicitly designed by the SDT to meet certain critical needs of the LWS Program. Any partnering with the NSF or with any other agency must preserve the essential features of Strategic Capabilities. The TSC believes that, in fact, the SC program as presently defined will best serve the interests of the NSF as well as NASA, but the NSF needs to agree to the program definition and implementation described in this report.

2. In order for the TR&T Program to obtain the best possible SCs, it is essential that the least possible restrictions be placed on proposers. Fair and open competition has long been NASA's policy, and the TSC strongly endorses this policy for all TR&T funding. On the other hand, the TSC recognizes that the NSF is restricted in its ability to fund certain types of institutions. Consequently, the TSC recommends the following rules for any joint NASA/NSF SC program.

- All institutions are free to propose, and PIs are free to select whatever collaborations they feel would result in the strongest possible proposal.
- Proposals are to be submitted to both NASA and the NSF, if possible. If the PI institution does not have access to the NSF FastLane system, the proposal can be submitted to NASA only.
- The winning proposals will be selected by a joint peer-review panel.
- In order for a proposal to receive funding from the NSF, either whole or partial, it must be submitted to the NSF, subject to the restrictions on NSF funding of certain types of institutions.