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

Spiro Antiochos (Chair), Janet Barth, Sunanda Basu, Geoff Crowley, John Eddy, Lennard Fisk, Joe Giacalone, Mary Hudson, Neal Hulburt, Charles Jackman, Boon-Chye Low, Jimmy Raeder, Pete Riley

April 16, 2004

The TR&T Steering Committee (TSC) held its first meeting on March 30 - 31, 2004. All members were in attendance, as well as representatives from NASA HQ including the LWS Program Officer, Lika Guhathakurta, and the TR&T Project Scientist, David Sibeck. As a result of its deliberations the TSC reached the following conclusions:

Overall Program Structure:

- The TSC reviewed the needs of the TR&T program and endorsed the three program element strategy defined by the SDT, *targeted investigations, strategic capabilities,* and *cross-discipline infrastructure building programs*.

- The TSC devoted the bulk of the meeting to developing an innovative implementation plan for the *targeted investigations* element and to determining possible strategies for the *cross-discipline programs*. Given the time constraint on preparing the amendment to this year's NRA, and given the uncertainty in the funding, the TSC concluded that it would be prudent to postpone implementation of the *strategic capabilities* element until next year's NRA. The TSC will develop a concrete implementation plan for this element during the coming year.

Targeted Investigations:

- The TSC recommends restructuring the *targeted investigations* program element into three components that are described below: *focused science targets*, *tools and methods*, and *independent investigations*. Approximately 75% of the resources within the *targeted* program element would be allocated to the *focused science targets*, 10% for *tools and methods* and 15% for *independent investigations*.

- The *tools and methods* component would support studies which, by themselves, may not deliver significant new science understanding, but deliver instead tools/methods that enable critically needed science advances. Examples include the development of new empirical methods or analysis techniques, such as local helioseismology, that can be used to predict the occurrence of solar, interplanetary, and geospace activity, and the development of software tools that identify, retrieve, assimilate, or portray data and model results from different sources for LWS forecasting and research objectives.

- The *independent investigations* component would support exceptionally high-priority studies that are not appropriate for either the *focused science targets* or *tools and methods* components. Simply failing to fit into the other two components does **not** make a project suitable for the *independent investigations* component. Among the criteria that will be used to determine whether a proposed study should be supported by this component are **urgency** and **impact**. Examples include studies that are urgently needed in preparation for the imminent launch of a new mission that supports LWS science and goals, or investigations that would have high impact on operational capabilities or government policy decisions.

- The TSC defined a new implementation strategy for the *focused science targets* component; therefore, we describe this implementation and its motivation in some detail in the section below.

Implementation Plan for *Focused Science Targets* Component:

The stated goal of LWS, achieving Sun-Earth system understanding that has direct impact on life and society, poses two great challenges for the TR&T program. First, the TR&T must tackle large-scale problems that cross discipline and technique (data analysis, theory, modeling, etc) boundaries. Second, the TR&T must identify how the new understanding will have a direct impact on life and society.

To address these requirements, the TR&T SDT recommended that the TR&T program be focused on major science targets at each proposal cycle. The TSC not only reaffirms this recommendation, but also emphasizes that the program must be structured so that the proposed TR&T investigations can be coordinated into a coherent attack on the large-scale science targets. Furthermore, maximizing the impact of the TR&T science advances on life and society will invariably require integration of the results of all the investigations aimed at a particular target. Therefore the TSC recommends the following implementation plan for the TR&T targeted investigations.

- At the start of each funding cycle a set of *focused science targets* will be recommended to NASA by the TSC. For this first year of the implementation plan, the targets will be defined by the TSC, but for subsequent years, target recommendations will be solicited from the community and a set of these will be selected by the TSC for forwarding to NASA. The *focused science targets* recommended by the TSC for this year are attached below.

- Individuals or small groups will propose to work on some aspect of the science targets. The scope of the investigations is expected to be similar to that of previous funding cycles. A key difference from the previous cycles, however, is that the peer review panels will be organized according to the *focused science* *targets*. The selection criteria will be scientific and technical merit, as before, but relevance to the *target* will be essential for selection.

- It is expected that of order 5 -10 selections will be made for each *focused science target*. Once selected, these investigators will form a team and coordinate their research programs, much like the winning PIs and instruments of a NASA hardware mission form a coordinated science team and program. The team will define a plan for structuring their work into an integrated research program that will address the complete *focused science target*. The team will also define success measures and deliverables for their integrated program, develop strategies for disseminating their results to the science community and NASA, and prepare a final report at the end of the three-year duration of the selected investigations.

- As part of the peer-review process, one of the winning PIs will be selected to be team coordinator for that *focused science targets*. The team coordinator will take the lead role in organizing the team, setting up the necessary team meetings and interactions, and delivering the success of the project as a whole. The coordinator will also act as the lead liaison with the TR&T project office, which will monitor and assist the progress of each team. The team coordinator will receive supplemental funding to support costs associated with these duties, of order $30K. Proposers are encouraged to volunteer to act as team coordinator and to include a brief section in their proposal describing how they would lead the team effort.

The advantages of this implementation plan are clear. Substantial teams can be formed to attack the large-scale, cross-discipline problems that are vital to LWS. These teams will have a broad range of expertise and will naturally be cross-disciplinary. Formation of the science team **after** the peer-review process ensures that the best investigations from throughout the community are selected to constitute the team. The TSC strongly believes that implementation of this plan will lead not only to major science advances, but to the development of a truly Sun-Earth-system science community.

Cross-Discipline Infrastructure Building Programs:

- The TSC recommends that approximately 15% of the annual TR&T funding be allocated to the *cross-discipline programs* element. Requests for funding from this element should be openly competed through peer-reviewed proposals as much as possible. The TSC recommends, however, that some funds be held for supporting, at NASA HQ's discretion, small requests that may arise occasionally for cross-discipline workshops/campaigns.

- The TSC recommends that the community be encouraged to propose summer schools that would be funded, in part, by the TR&T. LWS needs researchers who can perform Sun-Earth system science, but few universities have depth across all the disciplines of SEC. Summer schools with lecturers from various institutions (including non-university organizations) would be an effective mechanism for training graduate students in Sun-Earth system science. The particulars of the summer school: format, location, duration, etc., would be up to the community to define in the proposal to the TR&T.

- The TSC also recommends the creation of an LWS Post-Doctoral program. The program would support a new Post-Doc, within three years of PhD, for up to two years. This program would be run much like the NRC post-doctoral programs, with the student and prospective advisor submitting a brief (no more than five page) proposal that describes in three clearly identified sections: **(1) the proposed research, (2) the cross-discipline aspects of the project, and (3) the relevance to LWS**. The requested funding would be only for support of the Post-Doc. The TR&T expects to award approximately two LWS Post-Docs per year.

- The issue of an LWS community science center(s) was discussed, but lacking a concrete description of the role and cost of such a center, no decision was reached. The TSC will take up this issue again at the next meeting, and will invite presentations from interested institutions.

FOCUSED SCIENCE TARGETS FOR FY05
TR&T Steering Committee, April 16, 2004

Quantify the sensitivity of regional and global climate to solar forcing in the full context of the interactive climate system.

Target description: A critical parameter in climate attribution is the inherent sensitivity of climate to any change in the receipt of solar energy at the top of the Earth's atmosphere (customarily expressed as the response in mean surface temperature to given change in forcing, $S = \delta T/\delta F$). First order approximations of S for the case of simple solar radiative forcing, acting alone, are unable to explain the apparent observed responses in in the temperature of surface ocean and lower atmosphere. What is clearly needed to resolve the apparent discrepancies and to answer the more fundamental question of the relative role of the Sun in past or present climate change are intensive investigations of the likely-nonlinear interactions in the climate system that couple solar forcing with other internal and external climate drivers, including atmosphere-ocean oscillations such as ENSO and NAO, and changes in greenhouse gases, aerosols, and volcanism.

Goals and measures of success: Success in this endeavor will be measured by the ability of climate models to specify global and regionally-specific impacts of interactive solar and other external and internal forcing of the coupled climate system, and the abililty of solar-coupled-climate models to replicate global and regional climatic records.

Types of investigations: A focused, coordinated study to addresses this science high visibility target will require collaboration between solar and climatological data and modeling communities, and contributions from all of the following elements: (1) Specification and recovery of established changes in total and spectral irradiance and other energetically-significant inputs from the Sun; (2) Multivariate analyses of empirical climatic data, as a function of geographic region, height in the atmosphere, and the phase and amplitudes and combined impacts of other climate drivers; and (3) Theoretical modeling of responses of the coupled climate system for comparison and validation.

Quantify the influence of the upper atmosphere on the lower atmosphere over a solar cycle.

Target description: The impact of the upper atmosphere (thermosphere, ionosphere, mesosphere) on the lower atmosphere (stratosphere, troposphere) is very difficult to quantify over an 11-year solar cycle. The upper atmosphere is continuously being perturbed by solar output including X-rays, extreme ultraviolet light, and charged particles, which cause changes over several different timescales from minutes (solar and geomagnetic storm periods) up to seasonal and longer variations. The upper atmosphere is also impacted in several ways by the lower atmosphere (e.g., the upward propagation of atmospheric waves redistributing energy and momentum from below and the upward transport of certain minor constituents like H_2O, CO_2, CH_4, etc. from below). Conversely, the more dense lower atmosphere may also be influenced by the tenuous upper atmosphere. Although there may be other ways, the most plausible upper atmospheric influence on the lower atmospheric levels occurs during polar night, when very significant downward transport of upper atmospheric constituents is likely. Several past data analysis and modeling studies suggest that the upper atmosphere does impact the lower atmosphere in this way. The magnitude of this effect is somewhat controversial with certain studies indicating a significant impact on the lower atmosphere (primarily, the stratosphere) from upper atmospheric variations and others indicating a much smaller impact.

Goals and measures of success: This focus area has as its goal the development of usable models that determine quantitatively the impact of the upper atmosphere on the lower atmosphere over a solar cycle. These models need to be validated quantitatively using observations from satellite instruments observing the atmosphere, especially the mesosphere and stratosphere where the coupling is thought to be the largest. The new models are to provide the understanding that is necessary for the development of a predictive capability for the dynamic Sun-Earth system. This should allow further clarification of the effects of solar variability on the atmosphere and climate.

Types of investigations: It is expected that the focus group will include, but certainly not be limited to, the following types of investigations: the analysis and interpretation of upper and lower atmospheric observations particularly related to their coupling; the development of theories for the fundamental processes that control the source of upper atmospheric constituents that may impact the lower atmosphere and the transport these constituents to the lower atmosphere; the study of other processes that show upper atmospheric impacts on the lower atmosphere; and the development of numerical models that incorporate the relevant physical processes and that can be tested with the observations.

Quantify the response of thermospheric density and composition to solar and high latitude forcing.

Target description: Thermospheric density variations exist on the global and local scale. These fluctuations create variable satellite drag, adversely affecting our ability to identify and track objects in space, and to predict or control their re-entry into the atmosphere. Underlying the neutral density variations are global and local composition changes that produce dramatic effects on ionospheric electron densities. Both the composition and density changes are produced by wind systems driven from high latitude heat and momentum sources. We are currently unable to simulate accurately the behavior of thermospheric density and composition, and the dynamics driving them. Much of the uncertainty in existing global first-principles thermosphere models is due to uncertainty in specifying high-latitude particle precipitation and electric fields, and the inputs of solar fluxes at a range of wavelengths. There is an urgent need to improve thermosphere-ionosphere models, including improved specification of solar and high latitude forcings, in order to understand and quantify the thermospheric density and composition responses.

Goals and measures of success: The research will produce improved first principles thermosphere-ionosphere models, and their input specifications, that will specify thermospheric density and composition, and their variability with latitude, longitude, local time, solar flux, season, magnetic activity level, and changes in the IMF. The predictions will be validated against both empirical models and data. The research will also produce improved ability to specify solar radiative and high latitude inputs for first principles models. Progress will result in an ability to quantify thermospheric density and composition variations, and to accurately simulate observed responses to high latitude and solar variability.

Types of investigations: It is expected that the focus group will include investigations that deal with: techniques to improve specification of solar radiative inputs to the T-I system; techniques to improve the specification of high latitude inputs for global first principles thermosphere-ionosphere models; energy transfer from the magnetosphere to the T-I system; thermosphere-ionosphere coupling; neutral wind responses; fundamental understanding of processes driving thermospheric density and composition; improved numerical models of these thermospheric fields; validation of the resulting thermospheric simulations by comparison with related data sets.

Quantify the effects of ionospheric electrodynamics on plasma structuring at middle and low latitudes.

Target description: The middle and low latitude ionosphere are constantly changing, controlled both by processes that are driven internally within the ionosphere-thermosphere system and others that are imposed externally by the solar wind-magnetosphere interaction. One of the main drivers is the electric field, which strongly controls the magnitude and altitude distribution of electron density. The day-to-day variability of the internally driven dynamo electric field is most pronounced in the equatorial region resulting in extreme variations of the F-region density distribution. At night such variability is associated with presence or absence of ionospheric irregularities of electron density and scintillation of satellite signals that greatly impact space weather and space climate. During magnetic storms, the penetration of high latitude electric fields, and coupling with the equatorial region cause plumes of enhanced ionization density to form at mid-latitudes that convect very rapidly towards high latitudes. The convecting plumes, associated with plasma density irregularities, severely impact communication and navigation systems within the continental United States. The changed neutral wind patterns resulting from energy deposition at high latitudes during magnetic storms also affect the ionization distribution, neutral composition and dynamics. Current models are unable to reproduce the observed large and small scale ionospheric variability during magnetically quiet and active periods.

Goals and measures of success: This focus area has as its goal the development of coupled models that determine quantitatively the impact of electric fields and neutral winds on the ionospheric plasma density, composition and dynamics during magnetically quiet and active periods. The models should include the self-consistent coupling of magnetospherically driven penetration electric fields into low latitudes. The models should specify and predict the effects of the internal and external forces and their variability with solar flux; changes in the solar wind density, velocity and IMF; magnetic activity level; latitude, longitude, local time, and season. In addition, such models should have the capability to specify conditions conducive to the generation of sub-km plasma density structures at middle and low latitudes.

Types of investigations: It is expected that the focus group will include, but not be limited to, the following types of investigations: the analysis and interpretation of solar wind-magnetosphere coupling; energy transfer from magnetosphere to ionosphere-thermosphere system; electric field penetration and disturbance dynamo processes; measurements of spatial and temporal variations of neutral and plasma parameters and their dynamics including small scale irregularity generation and scintillation effects of satellite signals; the development of coupled models that incorporate the relevant physical processes and that can be validated against related datasets.

Develop solar cycle dependent specification models of the energetic particle distribution[s] in the Earth's radiation belts in the tens of eV to GeV energy range. The models can be used as empirical tools for mission planning, spacecraft design, and validation of physics-based models of the radiation belts.

Target description: Current specification models of the Earth's radiation belts (AE-8 and AP-8) predict the trapped radiation environment over long-term averages (6-years for solar maximum and 5 years for solar minimum), and they are based on instrument data that were collected in the 1970s and 1980s. The poor representation of solar cycle variations and the inaccuracies in the AE-8 and AP-8 models impose large margins on system designs and mission planning in order to reduce risks. The current models hamper efforts to reduce health risks to astronaut during extra-vehicular activities (EVAs) and transits through the radiation belts, limit the use of radiation-sensitive breakthrough technologies, and prevent the deployment of missions into regions of the radiation belts not previously exploited. New data from more recent science and operational missions can be incorporated into improved specification models for the radiation belts that also take advantage of recent progress in understanding particle loss and acceleration processes and the effects of solar storms.

Goals and measures of success: This focus area has as its goal time-dependent specification models of the Earth's trapped particles in the 10s of eV to GeV energy range. The models will be candidates for standardization for use in NASA, DoD, and industry programs.

Types of investigations: In the past five years, NASA and the DoD have funded several small projects to acquire, calibrate, and analyze trapped particle measurements from science and operational missions and to develop prototype models of various regions of the radiation belts. In addition, recent successes in understanding particle loss and acceleration and the effects of solar storms on the radiation belts will be essential to explain measurements and infuse physics-based knowledge into the models.
It is expected that the focus group will include but not be limited to these efforts.

Determine the mechanisms responsible for the formation and loss of new radiation belts in the slot region in response to geo-effective solar wind structures.

Target description: The prompt trapping of Solar Energetic Particles (SEPs) in the inner magnetosphere slot region around L=2-3, including protons and heavier ions, is observed upon arrival of fast ICMEs. Detrapping is also observed in this region in conjunction with ring current buildup during major geomagnetic storms (Dst < -300 nT), typically driven by the same type of geoeffective solar wind structures. Relativistic electrons fill the slot region during such events with a typical delay of a day or two following shock arrival for storms driven by ICMEs. While SEP events and their geoeffective trapping and loss occur with greater frequency around solar maximum, relativistic electron fluxes on average are greater during the declining phase of the solar cycle, when geomagnetic storms are driven primarily by high speed solar wind stream interaction with the magnetosphere.

Goals and measures of success: This focus area has as its goal the development of usable models that determines quantitatively, and can be validated quantitatively, the dynamic evolution of the radiation belt slot region and adjacent outer zone flux peak around L=4.
Such models must include losses as well as injection rates, and use particle flux measurements at geosynchronous and other orbits (HEO and LEO loss-cone measurements) which provide input on radial distribution of fluxes. Measurements of input solar wind conditions are essential both for MHD and empirical models of the magnetospheric response to solar wind driving conditions. Input solar wind and plasma sheet particle measurements further constrain model calculations of evolving particle phase space density.

Types of investigations: It is expected that the focus group will include, but not be limited to, the following types of investigations: the analysis and interpretation of measured solar wind parameters, including the variables needed as specification to MHD simulations (solar wind density, velocity, IMF) and magnetospheric observations, both in the ULF and VLF frequency ranges; particle measurements both in the solar wind for ions, the inner plasma sheet for electrons and at geosynchronous for both, as well as in the L=2-3 slot region and the region around the plasmapause (L ~ 4), for validation of modeling both ICME injection and diffusive processes; the development of numerical models that incorporate the relevant physical processes and that can be tested with the observations.

Relate solar-energetic particles to their origin at the sun and inner heliosphere.

Target description: Understanding high-energy radiation in the form of cosmic rays is central to space weather and space climate. Solar-energetic particles observed at Earth are accelerated near the Sun and in the inner heliosphere. 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 radiation environment near Earth, a cross-disciplinary approach is needed. It is necessary to combine studies of energetic-particle acceleration and propagation, CME eruption and evolution in the heliosphere, and coronal and heliospheric magnetic fields.

Goals and measures of success: The goal of this focus group is to have usable, quantitative, models of solar-energetic particles accelerated near the Sun by realistic CMEs, and which propagate in realistic coronal and heliospheric magnetic fields, in the heliosphere. Another goal of this focus group is to identify the particle sources and to assess their relative contributions to intensities observed at 1 AU.

Types of investigations: We encourage proposals that relate solar-energetic particles to their origin at the Sun and inner heliosphere, and to characterize their variability at L1. Proposals involving numerical models should emphasize combining particle acceleration and transport with realistic, three-dimensional CME structure, and coronal and heliospheric magnetic fields. They should also emphasize comparisons with observations, including various particle species, including ultra-heavy ions (trans Ni) which cause system damage. Theoretically based proposals should target aspects of this problem which lead to basic scientific understanding of the necessary coupling described above. They are also important for providing feedback to modelers regarding the importance of necessary assumptions. Proposals involving spacecraft observations should make specific constraints for numerical and analytic models. These include: (a) what is the time scale for accelerating particles? (b) where does the acceleration take place? (c) what are the observed particle distributions? (d) what is the variability at L1?

Determine the topology and evolution of the open magnetic field of the Sun connecting the photosphere through the corona to the heliosphere.

Target description: The open magnetic flux of the Sun, which creates the heliospheric magnetic field, is in dynamic evolution, driven by processes occurring in the photosphere and corona. The resulting distribution of magnetic flux and its evolution are a fundamental property of the Sun, essential for understanding the coupling of the Sun and the heliosphere, the propagation of Coronal Mass Ejections, acceleration of energetic particles, etc. Current models for the distribution and evolution of open flux have not captured the dynamic evolution or the complexity of the open flux.

Goals and measures of success: This focus area has as its goal the development of useable models that determine quantitatively, and can be validated quantitatively, the dynamic evolution and complexity of the open magnetic flux of the Sun from input of the type of observations expected from LWS missions. The new models are to provide the understanding that is necessary for the development of a predictive capability for the dynamic Sun-heliosphere system.

Types of investigations: It is expected that the focus group will include, but certainly not limited to, the following types of investigations: the analysis and interpretation of solar and/or heliospheric observations, the development of theories for the fundamental processes that control the evolution of open and heliospheric flux, the development of numerical models that incorporate the relevant physical processes and that can be tested with the observations.

Determine the solar origins of the plasma and magnetic flux observed in an Interplanetary Coronal Mass Ejection.

Target description: Interplanetary Coronal Mass Ejections (ICME) are the primary drivers of the most destructive forms of space weather, such as energetic particle events and major geomagnetic storms and, therefore, are of great interest to NASA's human exploration and LWS programs. In order to develop the capability of nowcasting and forecasting ICMEs at 1 AU, it is essential that we develop an understanding of how their measured physical properties, such as speed, magnetic field strength and direction, are related to the observed properties of their onset at the Sun. Extensive observations of solar CMEs are presently available from a variety of instruments, such as magnetographs, white light and XUV imaging telescopes, and coronagraphs. Detailed in situ measurements of ICME particles and fields at L1 and other locations in the heliosphere are also available. Furthermore, large-scale numerical models for CME development and propagation are now in use. Consequently, it is timely to mount a focused attack on this problem of determining ICME properties from CME observations.

Goals and measures of success: The goal of this focused science target is to advance our understanding of the relation between the physical properties of ICMEs and CMEs. The prime measure of success for this work would be a quantitative improvement in our ability to predict the geo-effective properties of ICMEs at Earth from solar/heliospheric observations. However, the development of models/understanding that directly enable such an improvement in capability would also constitute a measure of success for this target.

Types of investigations: It is expected that the focus group will include, but certainly not be limited to, the following types of investigations: the analysis and interpretation of solar and/or heliospheric observations, the development of theoretical, empirical and numerical models for the initiation and evolution of a CME as it propagates through the corona and heliosphere.

Develop and validate local helioseismology techniques for forecasting solar activity.

Target description: Long-duration missions to the moon and beyond will be highly dependent on our ability to make predictions of solar activity on timescales of weeks to months. The only means available for such forecasting relies on helioseismic techniques.

Goals and measures of success: We seek projects that can bring these techniques to the point where they could be delivered to the CCMC for transition to operations.

Types of investigations: We anticipate that this will entail investigations into local helioseismology techniques and their optimization; artificial datasets based on models; and cross-comparisons with other observables and alternative inversion techniques.