DATE: July 30, 2009

FROM: NASA Heliophysics Subcommittee
Dr. Roy Torbert (Chair), University of New Hampshire
Dr. David Alexander, Rice University
Dr. Stuart Bale, University of California, Berkeley
Dr. Ed Deluca, Harvard-Smithsonian Center for Astrophysics
Dr. Sarah Gibson, NCAR/High Altitude Observatory
Dr. Mary Hudson, Dartmouth College
Dr. Charles Kankelborg, Montana State University
Dr. Janet Kozyra, University of Michigan
Dr. Richard Mewaldt, California Institute of Technology
Dr. Zoran Mikic, Predictive Science, Inc.
Dr. Donald Mitchell, Johns Hopkins University Applied Physics Laboratory
Dr. Craig Pollock, Southwest Research Institute
Dr. Harlan Spence, Boston University
Dr. Michelle Thomsen, Los Alamos National Laboratory
Dr. Allan Tylka, Naval Research Laboratory
Dr. Daniel Winterhalter, NASA/JPL

TO: Dr. Jack Burns, Chair, NASA Advisory Council Science Committee

SUBJECT: Report of the Heliophysics Subcommittee

Dear Jack,

The Heliophysics Subcommittee (HPS) met at NASA Headquarters on July 13 and 14, 2009. A total of 13 of the 16 members attended all or part of the meeting. The meeting agenda is attached to this letter.

NASA gave several charges to the subcommittee for this meeting. First, the subcommittee was asked to provide an assessment of Heliophysics science performance for FY2009. This assessment is to be included in the yearly Performance and Accountability Report (PAR) submitted as part of NASA's yearly Government Performance Results Act (GPRA) requirements. Equally important, the subcommittee was asked to review the final draft of the Heliophysics Roadmap produced by the roadmap subpanel and to recommend, or note, this community-based roadmap to NASA. The subcommittee was also asked to comment on the draft Lunar Exploration Analysis Group roadmap and on proposed revisions to the Heliophysics Data Policy.

The Heliophysics division provided briefings on several additional topics: the NRC Heliophysics mid-term performance assessment, status of the SMD and Heliophysics EPO programs, a description of the study on "mission enabling" R&A activities, and a status briefing on NASA-based space weather planning.

Our list of findings is attached. We summarize the outcome of items discussed in the paragraphs that follow.

Administrative Matters
The Subcommittee welcomed new members, Dr. David Alexander of Rice University, Dr. Stuart Bale of the University of California at Berkeley, Dr. Charles Kankelborg of Montana State University, and Dr. Zoran Mikic of Predictive Science Inc. It was noted that one vacancy remains on the subcommittee, a seat nominally to be filled by someone with expertise in ionospheric-thermospheric-mesospheric science.

NASA provided an ethics briefing to orient these new members and to refresh the ethics training of continuing members.

Regular Business
We heard an overview presentation from the Heliophysics Division Director, Richard Fisher. Deputy Division Director, Victoria Elsbernd provided a status briefing for the on-going and future projects managed by the division.

There was a discussion of the mid-term progress report by the NRC, entitled "A Performance Assessment of NASA's Heliophysics Program." The NASA response to this report has not been released from the Office and Management and Budget (OMB). Consequently, this agenda item has been deferred to the subcommittee's meeting in September.

The subcommittee was provided a final draft of the Heliophysics Roadmap for review and comment. A subpanel of experts developed the roadmap with oversight by this subcommittee. The Heliophysics subcommittee recommends this roadmap to NASA and has provided a finding with that recommendation below.

The subcommittee also reviewed the latest draft of the Lunar Exploration Analysis Group (LEAG) roadmap for lunar-based science. The subcommittee approved of the progress made and provided a finding below to endorse the approach to date. The work of James Spann, as lead for the section containing Heliophysics science, was especially recognized and appreciated.

The subcommittee saw a demonstration of the on-line analysis tools underlying the Heliophysics virtual observatory and resident archive organizational structures. The subcommittee also continued its discussion from the May meeting re modifications to the Heliophysics Data Policy. The subcommittee supports the proposed modifications, a finding on this topic is provided below.

The subcommittee heard a briefing from the Heliophysics representative to NASA's Office of the Chief Engineer regarding agency space weather activities. The efforts appear to be proceeding well. A finding supporting this work is provided below.

We had a very helpful and productive discussion with the SMD Associate Administrator, Ed Weiler.

The subcommittee spent a significant portion of its time on the Heliophysics science performance assessment task. The subcommittee discussed performance metrics and formulated a list of significant science accomplishments for the year. The three annual performance goals were individually assessed as "green" by unanimous vote. The subcommittee's detailed report is attached to this letter as an appendix.

The HPS finished its meeting by reviewing its future work plan. The next meeting is planned for September 30 to October 2 in Washington D.C.

Agenda Items for Future Meetings
The HPS recommends that the following items be included on the subcommittee's agenda for its September, 2009 meeting:

- Status of inter-agency efforts to continue solar wind monitoring at L1 and in particular, the status of the DSCVR mission.
- Approaches for the next Heliophysics Decadal Survey
- Status of the Low Cost Access to Space (LCAS) programs
- NASA response to the NRC mid-term assessment of progress against the Decadal Survey

We hope that the NAC Science Committee will find our recommendations useful and we are at your disposal for further information.

Respectfully Submitted,

[signature on original]

Roy B. Torbert, Chair

cc:
Edward Weiler, Associate Administrator, NASA Science Missions Directorate
Richard Fisher, Director, NASA Heliophysics Division
Marguerite Broadwell, Executive Director, NASA Advisory Council
Greg Williams, Executive Secretary, NAC Science Committee
Barbara Giles, Executive Secretary, NASA Heliophysics Subcommittee
Heliophysics Subcommittee

FINDINGS TO BE CONSIDERED BY THE NAC SCIENCE COMMITTEE:

2009 Heliophysics Roadmap

The HPS reviewed and approved the final draft of its 2009 NASA Heliophysics Roadmap. We reiterate our strong support for this document. In particular, we feel that its innovative approach of prioritizing science objectives within broad cost envelopes, with specific mission architectures and implementation tactics to be determined within constraints at the time of mission formulation, is an effective technique for maximizing flexibility and at the same time controlling costs. The HPS commends the roadmap team for providing a clear and compelling plan for accomplishing vital Heliophysics science objectives.

NASA Space Weather Activities

HPS received an update on NASA Space Weather activities being coordinated by the Office of the Chief Engineer. The subcommittee was pleased to learn about activities across NASA Directorates ranging from Heliophysics missions and investigations to astronaut safety management. The HPS commends this comprehensive internal assessment and encourages using this knowledge to further heliospheric goals within the inter-agency National Space Weather Program.

Lunar Exploration Roadmap

The HPS reviewed a draft of the Lunar Exploration Roadmap (LER). This report is an initial assessment of an integrated and sustainable plan for lunar exploration. We found that the discussion of the Moon as a platform for Heliophysical studies was consistent with our 2008 report, "Heliophysics Science and the Moon", and we strongly endorse the continued efforts of the Lunar Exploration Analysis Group (LEAG).

FINDING OF INTEREST PRIMARILY TO HELIOPHYSICS DIVISION:

Heliophysics Data Policy

The HPS heard a presentation on a proposed revision to the Heliophysics Data Policy, to include the establishment of "Final Archives" where legacy data will reside in *a usable format*. We strongly endorse this plan, to be implemented by the Heliophysics Data and Model Consortium (HDMC), which has representation from various component groups involved in heliophysics data and modeling management. We applaud the important work the HDMC is undertaking to build a comprehensive and user-friendly infrastructure to the "Heliophysics Great Observatory".

MEETING AGENDA:

Heliophysics Subcommittee Meeting
July 13-14, 2009

ver 3: 13 July 2009

L'Enfant Plaza Hotel, Renoir Room, 480 L'Enfant Plaza, SW, Washington, DC

Monday, July 13		
8:00	Subcommittee Room Open	
8:30	Welcome, overview of agenda, introduction of new members	Roy Torbert, HPS Chair
8:45	Heliophysics Division Overview	Richard Fisher, NASA HQ
9:30	Flight Program Status	Victoria Elsbernd, NASA HQ
10:00	BREAK	
10:15	NASA Response to NRC report, A Performance Assessment of NASA's Heliophysics Program *Link to NRC report: http:// www.nap.edu/catalog.php?record_id=12608*	Richard Fisher, NASA HQ
11:00	Discussion of Final Draft of Heliophysics Roadmap	Subcommittee
11:30	Discussion of Draft LEAG Roadmap	Subcommittee
NOON	LUNCH IN ROOM: Potential Cross Scale PathFinder using MMS, Surja Sharma, University of Maryland	
1:15	Preparation for tomorrow's NAC Science Committee meeting	Roy Torbert, HPS Chair
2:15	Heliophysics Data Policy Revision – incl. Demonstration	Aaron Roberts, NASA GSFC
2:45	Discussion	Subcommitee
3:15	BREAK	
3:30	NASA Space Weather: Status of activities within the Office of the Chief Engineer	Chris St. Cyr, NASA GSFC
4:00	Heliophysics Science Performance Assessment, input for the FY2009 NASA PAR – Overview	Barbara Giles, NASA HQ
4:15	Heliophysics Science Performance Assessment, input for the FY2009 NASA PAR – Review and Assignments	Subcommittee
5:00	Discussion	Subcommittee
5:30	END OF DAY	
7:00	Group Dinner, Petits Plats, 2653 Connecticut Avenue, NW, 202-518-0018, Woodley Park Metro Station	

Tuesday, July 14		
8:00	Subcommittee Room Open	
8:30	SMD and Heliophysics EPO Program	Stephanie Stockman, Jeffrey Hayes, NASA HQ
9:00	Mission Enabling R&A Activities	Paul Hertz, NASA HQ
9:30	Discussion	Subcommittee
10:00	BREAK	
10:15	Annual Ethics Briefing	NASA Ethics Team
11:15	Heliophysics Science Performance Assessment, input for the FY2009 NASA PAR – Final Work and Voting	Subcommittee
NOON	LUNCH IN ROOM	
1:00	Heliophysics Science Performance Assessment, input for the FY2009 NASA PAR – Final Work and Voting Continued	Subcommittee
3:00	BREAK	
3:15	Subcommittee Work Session	Subcommittee
4:00	Debrief with Heliophysics Director	Richard Fisher, NASA HQ Subcommittee
5:00	ADJOURN	

HELIOPHYSICS DRAFT INPUT TO FY09 PERFORMANCE ASSESSMENT REPORT

Sub-goal 3B: Understand the Sun and its effect on Earth and the solar system.

Theme Description: Heliophysics explores the Sun's connection with, and effects on, the solar system to better understand the Earth and Sun as an integrated system, protect technologies at Earth, and safeguard space exploration.

Our planet is immersed in a seemingly invisible yet inherently dangerous environment. Above the protective cocoon of Earth's atmosphere is a plasma soup of electrified and magnetized matter intertwined with penetrating radiation and energetic particles. The Earth's magnetic field interacts with the Sun's outer atmosphere to create this extraordinary environment.

The Sun's explosive energy output, which varies on time scales from milliseconds to billions of years, forms an immense, complex magnetically active structure. Hugely inflated by the solar wind, this colossal bubble of magnetism known as the heliosphere stretches far beyond the orbit of Pluto, from where it controls the entry of cosmic rays into the solar system. On its way to these far reaches, this extended atmosphere of the Sun affects all planetary bodies in the solar system. In fact, the Sun's extended atmosphere drives some of the greatest changes in our local magnetic environment affecting our own atmosphere, ionosphere, and potentially our climate.

This immense volume is our cosmic neighborhood; it is the domain of the science called Heliophysics.

Over the past two years, the Sun has been the quietest in almost a century. There has been a 50-year low in solar wind pressure, a 55-year low in solar radio emissions, and the total solar irradiance is the lowest since scientists started measuring it from space in 1975. This especially deep minimum in solar activity has consequences far beyond the sun itself. Because the solar wind shields the inner solar system from galactic cosmic rays, a deep minimum increases the Earth's exposure to this energetic cosmic ray radiation. A further consequence is that the Earth's ionosphere is significantly less heated and therefore less expanded. Satellites in low Earth orbit experience less atmospheric drag and space junk remains longer in orbit. Scientists cannot yet accurately predict what will come next; we do not sufficiently understand the physics driving the solar cycle and therefore how long a given solar minimum or how strong a given solar maximum will be.

To achieve Sub-goal 3B, Heliophysics Theme researchers will study the Sun, the heliosphere, the local interstellar medium, near-Earth space, and all planetary space environments as elements of a single, interconnected system. Using a group of robotic science spacecraft to form an extended network of sensors, the missions address problems such as solar variability, the responses of the Earth and other planets to such variability, and the interaction of the heliosphere with the galaxy.

Benefits

Recent years have witnessed the growing national importance of space weather and its economic and societal effects. Space weather affects radio and radar propagation through the ionosphere, induces errors to GPS-derived position coordinates, endangers astronauts, spacecraft, and high-altitude aircraft, substantially modifies the ozone layer and, for extreme solar cycle shifts, has the potential to induce climate variations. Society is increasingly dependent on technologies that are vulnerable to space weather events. The prediction of solar events and mitigation of their effects is important to the public safety and the Nation's economy and security.

Equally important, our local space environment provides a convenient venue for studying at close hand the plasmas that make up most of the visible universe. Under the control of magnetic fields, plasmas organize into galactic jets, radio filaments, supernova bubbles, accretion disks, galactic winds, stellar winds, stellar coronas, sunspots, heliospheres, magnetospheres, and radiation belts. Studies of our local space environment provide knowledge relevant to remote astrophysical plasma systems that are inaccessible to direct study.

Risks to Achieving Sub-goal 3B

Of primary concern for the Heliophysics Division is the increase in cost, and the reduction of Expendable Launch Vehicle (ELV) options. Over the course of the last decade, the Delta II has been the workhorse for SMD, its loss leaving only costlier EELVs (Delta IV, Atlas V) for many of the missions identified in the NASA Science Plan, or much smaller launch vehicles with insufficient capability. NASA is aggressively exploring options to maintain a vital Heliophysics flight program. Given many common goals with the Department of Defense in the area of space weather, an initiative that utilizes the capabilities of military vehicles, such as the Minotaur, could alleviate this concern.

One of the key capabilities of the Heliophysics program is the coordination of its many spacecraft to observe the interacting system as a whole. Recently several Heliophysics spacecraft have ceased operation after long mission lives, or lost critical instruments after their prime science phase. While well beyond their operational lifetimes, the loss of these observatories/instruments means that critical measurements with which to gain knowledge about the end-to-end Sun to Earth connection are now not available. Some of these capabilities will be replaced and improved upon by future missions, but these will not be launched for a number of years. This is of rising concern because of the potential to impede the scientific advances needed to understand our extended space environment and provide the capability to predict space weather.

FY 2010 Performance Forecast

- The Research and Analysis Program will hold its annual competition for new research awards: approximately $9 million will be available for the competition, resulting in approximately 65 new awards.

- NASA will continue to execute space-based solar and space physics investigations and will hold its annual guest investigator competition.
- The Sounding Rockets Program will launch approximately 15 payloads from domestic and international locations.
- Science Data and Computing Technology will hold its annual competition for the Applied Information Systems Research Program where approximately $2 million will be available for new research awards.
- NASA will launch and commission the Solar Dynamics Observatory (SDO). SDO will image the Sun to study variations in solar irradiance that influence Earth's climate, how the solar magnetic field is structured and how its energy is converted and released into the heliosphere in the forms of solar wind and energetic particles.
- Heliophysics will complete its critical design review (CDR) of the Magnetospheric Multiscale (MMS) mission by the end of FY2010. MMS is a four-spacecraft mission to study magnetic reconnection in key boundary regions of Earth's magnetosphere, providing better understanding of this primary process by which energy is transferred from the solar wind to Earth's magnetosphere.
- Heliophysics will complete its critical design review (CDR) of the Radiation Belt Storm Probes (RBSP) mission early in FY2010. RBSP is a two-spacecraft mission to investigate how populations of relativistic electrons and ions in space are formed or changed in response to the variable inputs of energy from the Sun.
- Heliophysics will solicit instruments for the Solar Probe mission via the Announcement of Opportunity (AO) process. Approaching as close as 8.5 solar radii above the Sun's surface, the Solar Probe will employ a combination of in situ measurements and imaging to achieve the mission's primary scientific goal: to understand how the Sun's corona is heated and how the solar wind is accelerated.
- Heliophysics will complete the mission design review (MDR) for the Interface Region Imaging Spectrograph (IRIS) mission recently selected for the Explorer Program. The IRIS mission will trace the flow of energy and plasma through a dynamic solar interface region, the chromosphere and transition region, which lies between the solar surface and the solar corona.

Outcome 3B.1: Progress in understanding the fundamental physical processes of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium.

Particle acceleration in the heliosphere: Several of the NASA Heliophysics missions provided important new insights this year into energetic particle acceleration mechanisms in a number of different helio- and space physics regimes. This new knowledge will help us understand the fundamental processes that generate high-energy particles in solar flares, interplanetary shocks, the Earth's radiation belts, the aurora, and by extension, astrophysics. 1. *New constraints on Solar Flare Particle Acceleration:* Observations of the low energy cutoff in the electron spectra of solar flares from the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) enabled limits to be placed on the number of electrons that can be accelerated in these events. RHESSI also imaged for the first time gamma ray flare sources high in the solar atmosphere. This imaging shows the origin of the highest energy photons associated with solar flares, providing indications of the elusive location of the particle acceleration process itself. The Solar TErrestrial RElations Observatory (STEREO) has made the first unequivocal detection of energetic neutral hydrogen from solar flares. These neutral atoms, thought to originate as flare protons which recombine with electrons in the solar corona, travel from the Sun quickly without being deflected by the Sun's magnetic fields, yielding important information about the timing of ion acceleration in flares. 2. *Particle Acceleration in the Magnetosphere:* The 'double layer' mechanism that accelerates particles via electric fields aligned parallel to magnetic fields has been directly observed for the first time in the Earth's magnetotail by the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission. This same mechanism accounts for strong, long-lived particle acceleration in the Earth's aurora and is supported by the presence of hot electrons. In addition, analysis of ten years of observations from the Geotail satellite showed the importance of interactions between particles and electromagnetic waves in the formation of the radiation belts.

Dust in the Solar System: Dust plays an important role in the origin and evolution of the solar system. Many processes including collisions of small planetary bodies, cometary perihelion passages, and inflow of dust from the interstellar medium maintain the dust populations now prevalent in the heliosphere. NASA missions have led to new insight on the removal process of dust from the system through dust-plasma interactions. The STEREO spacecraft have revealed that the smallest dust grains move away from the sun at extreme speeds. These nanosized particles move at speeds approaching a million miles-per-hour. Nanoparticles are electrically charged by sunlight and so lightweight that the solar wind magnetic field picks them up and rapidly transports the particles away from the Sun. Such dust constantly bombards the Earth's atmosphere, generating meteoritic smoke. Observed by the Aeronomy of Ice in the Mesosphere (AIM) mission and by the Mesospheric Aerosol Sampling Spectrometer (MASS) suborbital sounding rocket, it is believed that this meteoritic smoke plays a role in high-altitude ozone-hole chemistry and cloud formation.

Magnetic reconnection as a ubiquitous process in Heliophysics: Understanding how the outer atmospheres of the Sun and other stars are heated to multi-million degree temperatures is one of the cornerstone problems of space science. Hinode observations during the extended minimum in the solar activity cycle have confirmed that magnetic reconnection is a driving force behind many classes of solar eruptive events, e.g. solar flares, coronal mass ejections and X-ray jets. Impulsive energy release from magnetic reconnection is found to be important, not only in large-scale eruptions, but also in the acceleration of solar wind and the heating of the solar corona. The combination of Hinode's magnetic field measurements, extreme ultraviolet spectroscopic and X-ray imaging data provided the first complete picture of the interaction of the Sun's photospheric magnetic field with the overlying corona, providing the description of how energy is released and particles are energized. Hinode detected the smoking gun by showing that coronal heating takes the form of small impulsive energy bursts called nanoflares, exactly as predicted by theoretical models.

Significant progress has also been made in understanding the timing and spatial structure of near Earth releases of stored magnetic energy from the solar wind. These explosive energy releases, called magnetic storms and substorms, send currents and energetic particles into the Earth's upper atmosphere, causing communication and power system disruptions. They also inject energetic particle fluxes to geosynchronous orbit, where they endanger the health of orbiting spacecraft. Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission researchers have found that undulating auroral features and ripples in the ionosphere's magnetic field immediately propagate away from the location of initial energy release at speeds on the order of 60,000 miles/hour, much like the blast wave from a explosion. The THEMIS scientists have confirmed the timing and rapid spatial spreading of the initial substorm, which began deep within the Earth's magnetic tail. Other researchers, including those using Geotail and Cluster data, identified an enormous substorm current system that deposited millions of amperes of current into the earth's atmosphere.

<table>
<tr><th>FY2008 Annual Performance Goals</th><th>FY05</th><th>FY06</th><th>FY07</th><th>FY08</th><th>FY2009</th></tr>
<tr><td rowspan="4">APG 9HE01 Demonstrate progress in understanding the fundamental physical processes of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium. Progress will be evaluated by external expert review,</td><td>5SEC9 Blue</td><td>6ESS11 Green</td><td rowspan="4">7ESS13 Green</td><td rowspan="4">Green</td><td rowspan="4">Green</td></tr>
<tr><td>None</td><td>6ESS12 Green</td></tr>
<tr><td>5SEC12 Blue</td><td>6ESS14 Green</td></tr>
<tr><td>5SEC13 Green</td><td>6ESS15 Green</td></tr>
<tr><td>APG 9HE2 Develop missions in support of this Outcome, as demonstrated by completing the Magnetospheric Multiscale (MMS) Spacecraft Preliminary Design Review (PDR)</td><td>None</td><td>None</td><td>7ESS15 Red</td><td>8HE02 Green</td><td></td></tr>
<tr><td>APG9HE3 Develop missions in support of this Outcome, as demonstrated by completing the Geospace Radiation Belt Storm Probes Confirmation Review</td><td>5SEC4</td><td>6ESS18</td><td>7ESS16 Green</td><td>8HE04 Green</td><td></td></tr>
<tr><td>APG9HE4 Develop missions in support of this Outcome, as demonstrated by completing the Explorer down-select.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>APG9HE5 Conduct flight program in support of this outcome, as demonstrated by achieving mission success criteria for STEREO, Hinode, AIM, THEMIS, and IBEX.</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Outcome 3B.2: Progress in understanding how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields.

Upper atmosphere boundary regions and the critical role of coupling processes: The transition region between Earth's upper atmosphere and the space environment is a critical boundary in the Sun-Earth system. NASA is making significant advances in our understanding of this boundary by studying the several ways in which it couples to regions above and below it, as well as within itself. The Aeronomy of Ice in the Mesosphere (AIM) mission provided major advances in understanding polar mesospheric clouds (PMCs), the highest clouds in the Earth's atmosphere. PMCs have been becoming brighter and more frequent since their discovery in the late 1800's. It is important to understand these trends because of the possible relationship between these clouds and global warming. AIM data show a connection between polar clouds present in the *summer* mesosphere and increased stratospheric wind speeds in the *winter* mesosphere. PMC occurrence is sharply seasonally dependent: transitioning in May from no clouds to 100% occurrence within a matter of days and then reversing that trend at the season end in August. In addition, AIM has made first global measurements of meteoric smoke particles in Earth's upper atmosphere. These particles are important to understanding a variety of phenomena including mesospheric ion and neutral chemistry, nucleation of polar stratospheric clouds, and the accumulation of extraterrestrial material in polar ice. These results go beyond simple characterization, giving us insight into the coupled interactions between temperature, water vapor, and nucleation particles, the three parameters that control cloud formation. There is also new information on the relationship between PMCs and atmospheric waves: observations have shown that upward-propagating waves produce transient and localized heating at higher altitudes that in turn leads to ice sublimation and hence dimmer PMCs. We made remarkable progress in identifying and understanding these processes, leading to a greater appreciation of the centrality of coupling in the upper atmosphere boundary region.

Atmospheric Hydrogen Loss. A new analysis technique has been applied to data from the ESA/NASA Cluster mission, making it possible to quantify the amount of hydrogen escaping each year from the Earth's atmosphere. This hydrogen outflow has been shown to be of the order of thousands of tons per day. While this rate means that Earth is in no danger of losing its atmosphere for several more billion years, Earth is losing more of its atmosphere per day than Venus and Mars, which have negligible magnetic fields. Understanding why the Venus, Mars and Earth atmospheres behave differently when initially the planets were similar will help determine the history and likely fate of our Earth's atmosphere. On the other hand, TIMED scientists have seen strong seasonal and latitudinal structure and, in particular, a dramatic decline in atomic hydrogen at high summer latitudes. These surprisingly low hydrogen values are thought to result from the dehydration of the mesopause region as water vapor (a source of the hydrogen) is sequestered in polar mesospheric clouds (PMCs). Up to this point, models of the escape of hydrogen from the terrestrial atmosphere have consistently emphasized the importance of transport processes over chemical effects and, in fact, contrary to the implications of these TIMED results, would predict a peak in hydrogen under these conditions.

Solar plasma entry into the magnetosphere: Multi-satellite missions such as THEMIS (Time History of Events and Macroscale Interactions during Substorms) and Cluster have shown that many particles of solar origin gain entry to Earth through our magnetic shield. During intervals when the Interplanetary Magnetic Field (IMF) is oriented northward, reconnection can occur nearly simultaneously above the northern and southern poles, trapping particles in a thick layer. Twenty times more particles cross Earth's shield at this time compared to intervals of southward IMF. The newly trapped particles flow into either the northern or southern cusp and then into the plasma sheet in the magnetotail. Processes within the magnetosphere subsequently energize the particles causing geomagnetic storms. The significance of the discovery lies in the fact that it provides the information needed to determine when most solar wind particles enter the magnetosphere, the first step towards developing a predictive model for the storms.

FY 2008 Annual Performance Goals	FY05	FY06	FY07	FY08	FY2009
APG 9HE2 Develop missions in support of this Outcome, as demonstrated by completing the Magnetospheric Multiscale (MMS) Spacecraft Preliminary Design Review (PDR)	None	None	7ESS15 Red	8HE02 Green	
APG9HE3 Develop missions in support of this Outcome, as demonstrated by completing the Geospace Radiation Belt Storm Probes Confirmation Review	5SEC4	6ESS18	7ESS16 Green	8HE04 Green	
APG9HE4 Develop missions in support of this Outcome, as demonstrated by completing the Explorer down-select.					
APG 9HE6 Demonstrate progress in understanding how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields. Progress will be evaluated by external expert review.	5SEC8 Green 5SEC11 Green	6ESS10 Green 6ESS13 Green	7ESS19 Green	Green	**Green**
APG 9HE7 Conduct flight program in support of this outcome, as demonstrated by achieving mission success criteria for AIM and THEMIS.					

Outcome 3B.3: Progress in developing the capability to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers.

The origins, propagation and consequences of the solar events that are most effective in producing magnetic storms at Earth and radiation storms throughout the heliosphere: Transition Region and Coronal Explorer (TRACE) high resolution observations and global observations from SOHO of Coronal Mass Ejections (CMEs) are providing key insights into the very beginnings of these events. The data have revealed the importance between the emergence and structure of electric currents within the solar atmosphere, their relationship to the surrounding magnetic field, and the ability to forecast CMEs. The twin Solar TErrestrial RElations Observatory (STEREO) spacecraft have provided scientists with their first view of the true speed, trajectory, and three-dimensional shape of CMEs. This new capability is dramatically enhancing scientists' ability to predict if and how these solar tsunamis could affect Earth, and improving the accuracy of storm arrivals at Earth from the current 12 hours to just 2 or 3 hours. STEREO researchers have reported the first observations of energetic neutral atoms (ENAs) from a solar flare/CME. This emission burst began hours before the main solar energetic particle (SEP) event and will lead to an important forecasting tool. STEREO observations have definitively identified a previously hypothesized class of CMEs, namely, “stealth CMEs.” These events arise high in the solar corona and do not have any of the typical low coronal or disk signatures. These advances provide an important observational basis for developing the capability to model and forecast the flow of particles (including solar energetic particles, CMEs, solar wind plasma) from the Sun throughout the heliosphere.

Complementary numerical modeling efforts within the LWS-TR&T program are being developed to characterize time-dependent radiation exposure in the Earth-Moon-Mars and interplanetary space environments. Contemporary state-of-the-art, physics-based particle radiation models, validated using direct and contemporaneous measurements near

Earth, at the Moon and Mars, provide the ability to predict radiation exposure throughout the inner heliosphere. LWS-TR&T models characterize the extremes, statistics, and variations over time of radiation exposure caused by solar energetic particles and cosmic rays, thereby significantly reducing uncertainties in radiation exposure predictions and improving risk assessment models for future space exploration.

A Peculiar Solar Minimum: The Sun has a strong 11-year cycle related to variations in its magnetic activity. No solar cycle is exactly the same as another, however, and recent observations indicate that sunspot activity during this 2007-2009 minimum is surprisingly low as compared to cycles of the last century. This has a major impact on models predicting solar activity, and for our understanding of the underlying physics of the sunspot cycle. In the last few years, the Sun has set the following records: *A 50-year low in solar wind pressure and magnetic field at the poles*: Measurements by the Ulysses spacecraft reveal a 35% drop in solar wind polar magnetic field strength, and a 20% drop in solar wind pressure since the solar minimum of 1996. This is important because the solar wind shields the inner solar system from galactic cosmic rays and a weaker solar wind also means fewer geomagnetic storms and auroras on Earth. *A long term low in solar irradiance:* Measurements by several NASA spacecraft show that the sun's brightness has dropped by 0.02% at visible wavelengths and 6% at extreme ultraviolet wavelengths since the solar minimum of 1996. The changes are not enough to affect the course of global warming, but the Earth's upper atmosphere is significantly less heated and therefore less expanded. Satellites in low Earth orbit experience less atmospheric drag and space junk remains longer in orbit. *A 55-year low in solar radio emissions:* Radio telescopes are recording the dimmest radio emissions from the sun since 1955. Some researchers believe that the lessening of radio emissions is an additional indication of weakness in the sun's global magnetic field.

Powering the earth's aurora: The first magnetic activity dependent FUV-based model of global precipitating auroral average energy and flux was developed using 4 years (2002–2005) of TIMED GUVI data. This new model encompasses geomagnetic activity levels from quiet to major storming. Because the model is based on FUV-imaging which has large spatial coverage compared to in-situ measurements, it provides a more consistent estimation of the energy that pours into the high latitude regions during magnetic storms, altering the temperatures, composition and dynamics of the atmosphere. The GUVI hemispheric power model is an important advance that will increase the accuracy of global ionosphere-thermosphere simulations, as well as space weather forecasting and nowcasting.

Supercharged ionosphere: Dramatic longitudinally confined enhancements in ionospheric total electron content (TEC) develop in the afternoon sector during major space storms. The edges of these TEC regions migrate poleward and westward through the cusp forming "tongues of ionization" against a backdrop of low plasma densities in the polar cap. The mechanisms that produce these dense large-scale structures are still not completely understood but they have devastating effects on GPS systems, and the sharp density gradients at their edges drive severe radio scintillation. Observational evidence suggests that these structures may actually be fed by vertical and horizontal transport of plasmas created near the equator by sunlight. However, new results from the Utah State University Time Dependent Ionosphere Model (TDIM) demonstrate that the transport of plasma from the equatorial region is not required to generate the narrow storm-enhanced density structures, at least during the November 1991 super storm. The primary driver is the penetration of high latitude magnetospheric electric fields to low-latitudes. The longitudinally-structured "penetration" electric fields force plasma to move upward along slanted middle-latitude magnetic field lines in certain local time sectors, decreasing collisional losses and producing impressive but longitudinally-confined fingers of storm-enhanced density.

FY2009 Annual Performance Goals	FY05	FY06	FY07	FY08	FY2009
APG 9HE3 Develop missions in support of this Outcome, as demonstrated by completing the Geospace Radiation Belt Storm Probes Confirmation Review	5SEC4	6ESS18	7ESS16 Green	8HE04 Green	
APG 9HE08 Demonstrate progress in developing the capability to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers. Progress will be evaluated by external expert review.	15.1 Green	3B.3 Green	Green	Green	**Green**
APG 9HE9 Conduct flight program in support of this outcome, as demonstrated by achieving mission success criteria for STEREO.					

APPENDIX 1: SUPPORTING MATERIAL FOR SCIENCE ASSESSMENTS

Sub-goal 3B: Understand the Sun and its effects on Earth and the solar system.

APG 9HE1: Demonstrate progress in understanding the fundamental physical processes of the space environment from the Sun to Earth, to other planets, and beyond to the interstellar medium. Progress will be evaluated by external expert review.

Major Activities / Accomplishments / Impediments

The Solar Dynamics Observatory (SDO) development is completed and is scheduled for launch in November 2009. SDO will image the Sun to study how the solar magnetic field is generated in the solar interior, detail its structure in the solar atmosphere, and provide key observations for the understanding of the solar cycle.

The Magnetospheric Multiscale (MMS) mission has completed Phase B preliminary design. MMS is a four-spacecraft mission to study magnetic reconnection, providing better understanding of this primary process by which energy is transferred from the solar wind to Earth's magnetosphere.

Major Scientific Findings or Discoveries

Particle acceleration in the heliosphere: Several of the NASA Heliophysics missions provided important new insights this year into energetic particle acceleration mechanisms in a number of different helio- and space physics regimes. This new knowledge will help us understand the fundamental processes that generate high-energy particles in solar flares, interplanetary shocks, the Earth's radiation belts, the aurora, and by extension, astrophysics. 1. *New constraints on Solar Flare Particle Acceleration:* Observations of the low energy cutoff in the electron spectra of solar flares from the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) enabled limits to be placed on the number of electrons that can be accelerated in these events. RHESSI also imaged for the first time gamma ray flare sources high in the solar atmosphere. This imaging shows the origin of the highest energy photons associated with solar flares, providing indications of the elusive location of the particle acceleration process itself. The Solar TErrestrial RElations Observatory (STEREO) has made the first unequivocal detection of energetic neutral hydrogen from solar flares. These neutral atoms, thought to originate as flare protons which recombine with electrons in the solar corona, travel from the Sun quickly without being deflected by the Sun's magnetic fields, yielding important information about the timing of ion acceleration in flares. 2. *Particle Acceleration in the Magnetosphere:* The 'double layer' mechanism that accelerates particles via electric fields aligned parallel to magnetic fields has been directly observed for the first time in the Earth's magnetotail by the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission. This same mechanism accounts for strong, long-lived particle acceleration in the Earth's aurora and is supported by the presence of hot electrons. In addition, analysis of ten years of observations from the Geotail satellite showed the importance of interactions between particles and electromagnetic waves in the formation of the radiation belts.

REFERENCES:

Andersson, L., D. L. Newman, R. E. Ergun, M. V. Goldman, C. W. Carlson and J. P. McFadden, Influence of suprathermal background electrons on strong auroral double layers: Observations, *Physics of Plasmas, 15*, DOI:10,1063/1.2938751, 2008

Newman, D. L., L. Andersson, M. V. Goldman, R. E. Ergun, and N. Sen, Influence of hot background electrons on strong auroral double layers: Vlasov-simulation parameter study, *Physics of Plasmas, 15*, DOI:10.1063/1.2938753, 2008

R. E. Ergun, L. Andersson, J. Tao, V. Angelopoulos, J. Bonnell, J. P. McFadden, D. E. Larson, S. Eriksson, T. Johansson, C. M. Cully, D. N. Newman, M. V. Goldman, A. Roux, O. LeContel, K.-H. Glassmeier, and W. Baumjohann, Observations of Double Layers in Earth's Plasma Sheet, *Phys. Rev. Lett. 102*, 155002 (2009)

E. P. Kontar, E. Dickson, and J. Kasparova. Low-Energy Cutoffs in Electron Spectra of Solar Flares: Statistical Survey. *Sol. Phys.*, 252:139-147, October 2008a.

S. Krucker, G. J. Hurford, A. L. MacKinnon, A. Y. Shih, and R. P. Lin. Coronal Gamma-Ray Bremsstrahlung from Solar Flare-accelerated Electrons. *ApJ*, 678:L63-L66, May 2008.

Mewaldt, R. A., et al., STEREO Observations of Energetic Neutral Hydrogen Atoms During the 2006 December 5 Solar Flare, Astrophys. J., 693, L11-L15, 2009.

Newman, D. L., L. Andersson, M. V. Goldman, R. E. Ergun, and N. Sen, Influence of hot background electrons on strong auroral double layers:Laminar and turbulent regimes, *Physics of Plasmas, 15*, DOI:10.1063/1.2938754, 2008

Ono, Y. M. Nosé, S. P. Christon, and A. T. Y. Lui, The role of magnetic field fluctuations in non-adiabatic acceleration of ions during dipolarization, *J. Geophys. Res*., in press, doi:10.1029/2008JA013918, 2009.

Dust in the Solar System: Dust plays an important role in the origin and evolution of the solar system. Many processes including collisions of small planetary bodies, cometary perihelion passages, and inflow of dust from the interstellar medium maintain the dust populations now prevalent in the heliosphere. NASA missions have led to new insight on the removal process of dust from the system through dust-plasma interactions. The STEREO spacecraft have revealed that the smallest dust grains move away from the sun at extreme speeds. These nanosized particles move at speeds approaching a million miles-per-hour. Nanoparticles are electrically charged by sunlight and so lightweight that the solar wind magnetic field picks them up and rapidly transports the particles away from the Sun. Such dust constantly bombards the Earth's atmosphere, generating meteoritic smoke. Observed by the Aeronomy of Ice in the Mesosphere (AIM) mission and by the Mesospheric Aerosol Sampling Spectrometer (MASS) suborbital sounding rocket, it is believed that this meteoritic smoke plays a role in high-altitude ozone-hole chemistry and cloud formation.

REFERENCES:

Dust detection by the wave instrument on STEREO: nanoparticles picked up by the solar wind? Meyer-Vernet, N., M. Maksimovic, A. Czechowski, I. mann, I. Zouganelis, K. Goetz, M.L. Kaiser, O.C. St.Cyr, J.-L. Bougeret, and S.D. Bale, Solar Phys. (2009), DOI10.1007/s11207-009-9349-2.

St. Cyr, O.C., M.L. Kaiser, N. Meyer-Vernet, R.A. Howard, R.A. Harrison, S.D. Bale, W.T. Thompson, K. Goetz, M. Maksimovic, J.-L. Bougeret, D. Wang,and S. Crothers, STEREO SECCHI and S/WAVES Observations of Spacecraft Debris Caused by Micron-Size Interplanetary Dust Impacts, Solar Physics, DOI10.1007/s11207-009-9362-5, 2009.

First satellite observations of meteoric smoke in the upper atmosphere, Hervig, Mark E., Larry L. Gordley, Lance E. Deaver, David E. Siskind, Michael H. Stevens, James M. Russell III, Scott M. Bailey, Linda Megner, and Charles G. Bardeen, Submitted to Nature, April, 2009.

First in situ measurement of the vertical distribution of ice volume in a mesospheric ice cloud during the ECOMA/MASS rocket-campaign, M. Rapp, I. Strelnikova, B. Strelnikov, R. Latteck, G. Baumgarten, Q. Li, L. Megner, J. Gumbel, M. Friedrich, U.-P. Hoppe, and S. Robertson, Ann. Geophys., 27, 755-766, 2009

The ECOMA 2007 campaign: rocket observations and numerical modelling of aerosol particle charging and plasma depletion in a PMSE/NLC layer, A. Brattli, Ø. Lie-Svendsen, K. Svenes, U.-P. Hoppe, I. Strelnikova, M. Rapp, R. Latteck, and M. Friedrich Ann. Geophys., 27, 781-796, 2009

Signatures of mesospheric particles in ionospheric data, M. Friedrich, K. M. Torkar, W. Singer, I. Strelnikova, M. Rapp, and S. Robertson, Ann. Geophys., 27, 823-829, 2009

Large mesospheric ice particles at exceptionally high altitudes, L. Megner, M. Khaplanov, G. Baumgarten, J. Gumbel, J. Stegman, B. Strelnikov, and S. Robertson, Ann. Geophys., 27, 943-951, 2009

The noctilucent cloud (NLC) display during the ECOMA/MASS sounding rocket flights on 3 August 2007: morphology on global to local scales, G. Baumgarten, J. Fiedler, K. H. Fricke, M. Gerding, M. Hervig, P. Hoffmann, N. Müller, P.-D. Pautet, M. Rapp, C. Robert, D. Rusch, C. von Savigny, and W. Singer, Ann. Geophys., 27, 953-965, 2009

Mass analysis of charged aerosol particles in NLC and PMSE during the ECOMA/MASS campaign, S. Robertson, M. Horányi, S. Knappmiller, Z. Sternovsky, R. Holzworth, M. Shimogawa, M. Friedrich, K. Torkar, J. Gumbel, L. Megner, G. Baumgarten, R. Latteck, M. Rapp, U.-P. Hoppe, and M. E. Hervig, Ann. Geophys., 27, 1213-1232, 2009

Electric field measurements in a NLC/PMSE region during the MASS/ECOMA campaign, M. Shimogawa and R. H. Holzworth, Ann. Geophys., 27, 1423-1430, 2009

Small-scale structures in neutrals and charged aerosol particles as observed during the ECOMA/MASS rocket campaign, B. Strelnikov, M. Rapp, I. Strelnikova, N. Engler, and R. Latteck, Ann. Geophys., 27, 1449-1456, 2009

Magnetic reconnection as a ubiquitous process in Heliophysics: Understanding how the outer atmospheres of the Sun and other stars are heated to multi-million degree temperatures is one of the cornerstone problems of space science. Hinode observations during the extended minimum in the solar activity cycle have confirmed that magnetic reconnection is a driving force behind many classes of solar eruptive events, e.g. solar flares, coronal mass ejections and X-ray jets. Impulsive energy release from magnetic reconnection is found to be important, not only in large-scale eruptions, but also in the acceleration of solar wind and the heating of the solar corona. The combination of Hinode's magnetic field measurements, extreme ultraviolet spectroscopic and X-ray imaging data provided the first complete picture of the interaction of the Sun's photospheric magnetic field with the overlying corona, providing the description of how energy is released and particles are energized. Hinode detected the smoking gun by showing that coronal heating takes the form of small impulsive energy bursts called nanoflares, exactly as predicted by theoretical models.

Significant progress has also been made in understanding the timing and spatial structure of near Earth releases of stored magnetic energy from the solar wind. These explosive energy releases, called magnetic storms and substorms, send currents and energetic particles into the Earth's upper atmosphere, causing communication and power system disruptions. They also inject energetic particle fluxes to geosynchronous orbit, where they endanger the health of orbiting spacecraft. Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission researchers have found that undulating auroral features and ripples in the ionosphere's magnetic field immediately propagate away from the location of initial energy release at speeds on the order of 60,000 miles/hour, much like the blast wave from a explosion. The THEMIS scientists have confirmed the timing and rapid spatial spreading of the initial substorm, which began deep within the Earth's magnetic tail. Other researchers, including those using Geotail and Cluster data, identified an enormous substorm current system that deposited millions of amperes of current into the earth's atmosphere.

REFERENCES:

Lui, A. T. Y., M. Volwerk, M. W. Dunlop, I. V. Alexeev, A. N. Fazakerley, A. P. Walsh, M. Lester, A. Grocott, C. Mouikis, M. G. Henderson, L. M. Kistler, C. Shen, J.-K. Shi, T.-L. Zhang, and H. Rème, Near-Earth substorm features from multiple satellite observations, J. Geophys. Res., 113, A07S26, doi:10.1029/2007JA012738, 2008.

Rae, I. J. and I. R. Mann, Press Conference, Spring Meeting of the American Geophysical Union, Toronto, Canada, May, 2009.

Rae, I. J., I. R. Mann, K. R. Murphy, D. K. Milling, A. Parent, V. Angelopoulos, H. U. Frey, A. Kale, Andy; C. E. J. Watt, S. B. Mende, and C. T. Russell, Timing and localization of ionospheric signatures associated with substorm expansion phase onset, J. Geophys. Res., 114, 10.1029/2008JA013559, 2009.

Harra, L.K. et al., "Coronal Nonthermal Velocity Following Helicity Injection Before an X-Class Flare", 2009, ApJL, 691, L99

Heggland, L.; De Pontieu, B.; Hansteen, V. H., "Observational Signatures of Simulated Reconnection Events in the Solar Chromosphere and Transition Region", ApJ, submitted 2009.

Langangen, Ø.; De Pontieu, B.; Carlsson, M.; Hansteen, V. H.; Cauzzi, G.; Reardon, K., "Search for High Velocities in the Disk Counterpart of Type II Spicules", The Astrophysical Journal, Volume 679, Issue 2, pp. L167-L170.

McIntosh, S. W., "The Inconvenient Truth About Coronal Dimmings", 2009, ApJ 693, 1306-1309

Nagashima, K. et al., "Helioseismic Signature of Chromospheric Downflows in Acoustic Travel-Time Measurements from Hinode", 2009, ApJL, 694, L115.

Patsourakos, S. & Klimchuk, J. A. "Spectroscopic Observations of Hot Lines Constraining Coronal Heating in Solar Active Regions," 2009, ApJ, 696, 760.

Raouafi, N.-E. Et al. "Observational Evidence for Coronal Twisted Flux Rope", 2009, ApJL, 691, L128

Reale, F., Testa, P., Klimchuk, J. A., & Parenti, S. "Evidence of Widespread Hot Plasma in a Non-Flaring Coronal Active Region from Hinode/XRT," Ap.J. 698, Issue 1, pp. 756-765, 2009.

Schmelz, J. T., Saar, S. H., DeLuca, E. E., Golub, L., Kashyap, V. L., & Klimchuk, J. A. "Hinode X-Ray Telescope Detection of Hot Emission from Quiescent Active Regions: A Nanoflare Signature?", 2009, ApJ Lett, Volume 693, Issue 2, pp. L131-L135.

Saint-Hilaire, P. et al. ""The X-ray Detectability of Electron Beams Escaping from the Sun", 2009, ApJ, 696, 941

Savcheva, A., Cirtain, J. W., Golub, L., DeLuca, E. E., "Do solar coronal jets follow a Hale-like law?", Astrophysical Journal Letters, submitted.

Tan, C. et al., "Evolution of Optical Penumbral and Shear Flows Associated with the X3.4 Flare of 2006 December 13", 2009, ApJ, 690, 1820

Tripathi, D., Mason, H. E., Dwivedi, B. N., Zanna, G. D. & Young, P. R., "Active Region Loops: Hinode/Extreme-Ultraviolet Imaging Spectrometer Observations", 2009, ApJ 694, 1256-1265

Wang, T. J., Ofman, L. & Davila, J. M., "Propagating Slow Magnetoacoustic Waves in Coronal Loops Observed by Hinode/EIS", 2009, ApJ 696, 1448-1460

APG 9HE6: Demonstrate progress in understanding how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields. Progress will be evaluated by external expert review.

Major Activities / Accomplishments / Impediments

The Radiation Belt Storm Probes (RBSP) mission has completed Phase B preliminary design. RBSP is a two-spacecraft mission to investigate how populations of relativistic electrons and ions in space are formed or changed in response to the variable inputs of energy from the Sun.

The Solar-Terrestrial Relations Observatory (STEREO) mission met its full mission success criteria as planned. The STEREO mission met the objectives of (1) understanding the causes and mechanisms of CME initiation; (2) characterizing the propagation of CMEs through the heliosphere; (3) discovering the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium; and (4) developing a 3D time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind.

The Aeronomy of Ice in the Mesosphere (AIM) met its full mission success criteria as planned. The AIM mission met the objective of resolving why polar mesospheric clouds form and why they vary.

The Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission met its minimum mission success criteria as planned. THEMIS met the objective to understand the onset and macroscale evolution of magnetic substorms. Full mission success is expected in FY2010.

The IBEX mission met its minimum mission success criteria as planned. IBEX met its objective to understand the global interaction of the solar wind with the local interstellar medium. Full mission success is expected in FY2010.

The FAST and Ulysses missions have been terminated. Both missions were well beyond their operational lifetimes. The loss of these observatories/instruments means that critical measurements with which to gain knowledge about the end-to-end Sun to Earth Connection are now not available. Some of these capabilities will be replaced and improved upon by future missions, but these will not be launched for a number of years. This is of rising concern because of the potential to impede the scientific advances needed to understand our extended space environment and provide the capability to predict space weather.

Major Scientific Findings or Discoveries

Upper atmosphere boundary regions and the critical role of coupling processes: The transition region between Earth's upper atmosphere and the space environment is a critical boundary in the Sun-Earth system. NASA is making significant advances in our understanding of this boundary by studying the several ways in which it couples to regions above and below it, as well as within itself. The Aeronomy of Ice in the Mesosphere (AIM) mission provided major advances in understanding polar mesospheric clouds (PMCs), the highest clouds in the Earth's atmosphere. PMCs have been becoming brighter and more frequent since their discovery in the late 1800's. It is important to understand these trends because of the possible relationship between these clouds and global warming. AIM data show a connection between polar clouds present in the *summer* mesosphere and increased stratospheric wind speeds in the *winter* mesosphere. PMC occurrence is sharply seasonally dependent: transitioning in May from no clouds to 100% occurrence within a matter of days and then reversing that trend at the season end in August. In addition, AIM has made first global measurements of meteoric smoke particles in Earth's upper atmosphere. These particles are important to understanding a variety of phenomena including mesospheric ion and neutral chemistry, nucleation of polar stratospheric clouds, and the accumulation of extraterrestrial material in polar ice. These results go beyond simple characterization, giving us insight into the coupled interactions between temperature, water vapor, and nucleation particles, the three parameters that control cloud formation. There is also new information on the relationship between PMCs and atmospheric waves: observations have shown that upward-propagating waves produce transient and localized heating at higher altitudes that in turn leads to ice sublimation and hence dimmer PMCs. We made remarkable progress in identifying and understanding these processes, leading to a greater appreciation of the centrality of coupling in the upper atmosphere boundary region.

REFERENCES:

Chandran, Amal, David W. Rusch, S. E. Palo, G. E. Thomas, M. Taylor, Gravity wave observation from the Cloud Imaging and Particle Size (CIPS) Experiment on the AIM Spacecraft, J. Atmos. Solar-Terr. Phys., doi:10.1016/j.jastp.2008.09.041.

Chandran, Amal, David W. Rusch, A. W. Merkel, S. E. Palo, G. E. Thomas, M. Taylor, S. M. Bailey, and J. M. Russell III, Longitudinal variability of PMC structures observed from the CIPS experiment on the AIM spacecraft: Are gravity waves a driver for large--scale PMC occurrence variability? J. Atmos. Solar-Terr. Phys. In review, 2009.

Hervig, Mark E., Larry L. Gordley, Lance E. Deaver, David E. Siskind, Michael H. Stevens, James M. Russell III, Scott M. Bailey, Linda Megner, and Charles G. Bardeen, First satellite observations of meteoric smoke in the upper atmosphere, Submitted to Nature, April, 2009.

Hervig, Mark E., Michael H. Stevens, Larry L. Gordley, Lance E. Deaver, James M. Russell III, and Scott M. Bailey, Relationships between PMCs, temperature and water vapor from SOFIE observations, Submitted to J. Geophys. Res., April, 2009.

Karlsson, Bodil, Charles McLandress, and Theodore G. Shepard, Inter-hemispheric mesospheric coupling in a comprehensive middle atmosphere model, J. Atmos. Solar-Terr. Phys., doi:10.1016/j.jasp.2008.08.006.

Merkel, W. Aimee, David W. Rusch, Scott E. Palo, James M. Russell III, and Scott M. Bailey, Mesospheric planetary wave activity inferred from AIM-CIPS and TIMED-SABER for the northern summer 2007 PMC season. J. Atmos. Solar-Terr. Phys., doi:10.1016/j.jasp.2006.05.01

Atmospheric Hydrogen Loss. A new analysis technique has been applied to data from the ESA/NASA Cluster mission, making it possible to quantify the amount of hydrogen escaping each year from the Earth's atmosphere. This hydrogen outflow has been shown to be of the order of thousands of tons per day. While this rate means that Earth is in no danger of losing its atmosphere for several more billion years, Earth is losing more of its atmosphere per day than Venus and Mars, which have negligible magnetic fields. Understanding why the Venus, Mars and Earth atmospheres behave differently when initially the planets were similar will help determine the history and likely fate of our Earth's atmosphere. On the other hand, TIMED SABER sees strong seasonal and latitudinal structure and, in particular, a dramatic decline in atomic H at high summer latitudes. These surprisingly low H values are thought to result from the dehydration of the mesopause region as water vapor (a source of H) is sequestered in polar mesospheric clouds (PMCs). Up to this point, models of the escape of hydrogen from the terrestrial atmosphere have consistently emphasized the importance of transport processes over chemical effects and, in fact, contrary to the implications of these TIMED/SABER results, would predict a peak in H under these conditions.

REFERENCES:
Engwall, E., et al., (2009), Earth's ionospheric outflow dominated by hidden cold plasma, Nature Geoscience, January 2009. DOI:10.1038/ngeo387http://www.msnbc.msn.com/id/31068574/

Siskind, D. E., D. R. Marsh, M. G. Mlynczak, F. J. Martin-Torres, and J. M. Russell III (2008), Decreases in atomic hydrogen over the summer pole: Evidence for dehydration from polar mesospheric clouds; Geophys. Res. Lett., 35, L13809, doi:10.1029/2008GL033742.

Solar plasma entry into the magnetosphere: Multi-satellite missions such as THEMIS (Time History of Events and Macroscale Interactions during Substorms) and Cluster have shown that many particles of solar origin gain entry to Earth through our magnetic shield. During intervals when the Interplanetary Magnetic Field (IMF) is oriented northward, reconnection can occur nearly simultaneously above the northern and southern poles, trapping particles in a thick layer. Twenty times more particles cross Earth's shield at this time compared to intervals of southward IMF. The newly trapped particles flow into either the northern or southern cusp and then into the plasma sheet in the magnetotail. Processes within the magnetosphere subsequently energize the particles causing geomagnetic storms. The significance of the discovery lies in the fact that it provides the information needed to determine when most solar wind particles enter the magnetosphere, the first step towards developing a predictive model for the storms.

REFERENCES:
Sibeck, D. G.,M. Oieroset, J. Raeder, and W.-H. Li, Press Conference, Fall Meeting of the American Geophysical Union, San Francisco, December 2008.

Li, W., J. Raeder, M. Oieroset, and T.-D. Phan, Cold dense magnetopause boundary layer under northward IMF: Results from THEMIS and MHD simulations, J. Geophys. Res., 114, 10.1029/2008JA013497, 2009.

Oieroset, M., T.-D. Phan, V. Angelopoulos, J. P. Eastwood, J. McFadden, D. Larson, C. W. Carlson, K.-H. Glassmeier, M. Fujimoto, and J. Raeder, Multi-spacecraft observations of magnetosheath plasma penetration into the magnetosphere for northward and strong By IMF, Geophys. Res. Lett., 35, 10.1029/2008GL033661, 2008.

G. K. Parks, E. Lee, A. Teste, M. Wilber, N. Lin, P. Canu, I. Dandouras, H. Reme, S. Y. Fu, and M. Goldstein, Transport of transient solar wind particles in Earth's cusps, Physics of Plasmas, 15, 080702 (2008).

APG 9HE08: Demonstrate progress in developing the capability to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers. Progress will be evaluated by external expert review.

Major Activities / Accomplishments / Impediments

A small heliophysics mission has been selected as a Small Explorer mission. The Interface Region Imaging Spectrograph (IRIS) mission will trace the flow of energy and plasma through a dynamic solar interface region, the chromosphere and transition region, which lies between the solar surface and the solar corona. Here all but a few percent of the non-radiative energy leaving the Sun is converted to heat and radiation. The remaining few percent create the corona and solar wind. IRIS will provide the observations necessary to reveal the forces at work in this little understood region near the surface of the Sun.

Members of the Advanced Composition Explorer (ACE) mission have developed an automated interplanetary shock alert system for Space Weather warnings. The automated data are available with less than 10 minutes delay and are widely monitored by government agencies and commercial firms to anticipate risks to electrical power grids, reductions in the accuracy of GPS systems, and deteriorating near-earth communications.

REFERENCES:
http://www.srl.caltech.edu/ACE/ACENews_Archives.html
Vorotnikov, Vasiliy S.; Smith, Charles W.; Hu, Qiang; Szabo, Adam; Skoug, Ruth M.; Cohen, Christina M. S. Space Weather, Volume 6, Issue 3, CiteID S03002 10.1029/2007SW000358, (2008)

Major Scientific Findings or Discoveries

The origins, propagation and consequences of the solar events that are most effective in producing magnetic storms at Earth and radiation storms throughout the heliosphere: Transition Region and Coronal Explorer (TRACE) high resolution observations and global observations from SOHO of Coronal Mass Ejections (CMEs) are providing key insights into the very beginnings of these events. The data have revealed the importance between the emergence and structure of electric currents within the solar atmosphere, their relationship to the surrounding magnetic field, and the ability to forecast CMEs. The twin Solar TErrestrial RElations Observatory (STEREO) spacecraft have provided scientists with their first view of the true speed, trajectory, and three-dimensional shape of CMEs. This new capability is dramatically enhancing scientists' ability to predict if and how these solar tsunamis could affect Earth, and improving the accuracy of storm arrivals at Earth from the current 12 hours to just 2 or 3 hours. STEREO researchers have reported the first observations of energetic neutral atoms (ENAs) from a solar flare/CME. This emission burst began hours before the main solar energetic particle (SEP) event and will lead to an important forecasting tool. STEREO observations have definitively identified a previously hypothesized class of CMEs, namely, “stealth CMEs.” These events arise high in the solar corona and do not have any of the typical low coronal or disk signatures. These advances provide an important observational basis for developing the capability to model and forecast the flow of particles (including solar energetic particles, CMEs, solar wind plasma) from the Sun throughout the heliosphere.

Complementary numerical modeling efforts within the LWS-TR&T program are being developed to characterize time-dependent radiation exposure in the Earth-Moon-Mars and interplanetary space environments. Contemporary state-of-the-art, physics-based particle radiation models, validated using direct and contemporaneous measurements near Earth, at the Moon and Mars, provide the ability to predict radiation exposure throughout the inner heliosphere. LWS-TR&T models characterize the extremes, statistics, and variations over time of radiation exposure caused by solar energetic particles and cosmic rays, thereby significantly reducing uncertainties in radiation exposure predictions and improving risk assessment models for future space exploration.

REFERENCES:

Liu, R., Alexander, D., Gilbert, H., 2009, ApJ 691, 1079.

Schrijver, C.J., 2009, Adv. in Space Research 43, 739.

Su, Y., van Ballegooijen, A., Lites, B., Deluca, E., Golub, E, Grigis, P., Huang, G., Haisheng: 2009, ApJ 691, 105.

Tripathi, D., Gibson, S.E., Qiu, J., Fletcher, L., Liu, R., Gilbert, H. Mason, H.E., 2009, Astron. Astrophys. 498, 295.

Thernisien, A., A. Vourlidas, and R. A. Howard, Solar Physics, DOI 10:1007s110207-009-9346-5, 2009.

Davies, J. A., et al., Geophys. Res. Lett., 36, L02102, doi:10:1029/2008GL036182, 2008.

Mewaldt, R. A., et al., Astrophys. J., 693, L11-L15, 2009.

Robrbrect, E. Patsourakos, S., and Vourlidas, A, arXiv:0905.2583v1, ApJ (1) 701, (2009).

Reconnectionless CME Eruption: Putting the Aly-Sturrock Conjecture to Rest, Rachmeler, L. A.; DeForest, C. E.; Kankelborg, C. C., Astrophysical Journal, 693, 1431, 2009

A Peculiar Solar Minimum: The Sun has a strong 11-year cycle related to variations in its magnetic activity. No solar cycle is exactly the same as another, however, and recent observations indicate that sunspot activity during this 2007-2009 minimum is surprisingly low as compared to cycles of the last century. This has a major impact on models predicting solar activity, and for our understanding of the underlying physics of the sunspot cycle. In the last few years, the Sun has set the following records: *A 50-year low in solar wind pressure and magnetic field at the poles*: Measurements by the Ulysses spacecraft reveal a 35% drop in solar wind polar magnetic field strength, and a 20% drop in solar wind pressure since the solar minimum of 1996. This is important because the solar wind shields the inner solar system from galactic cosmic rays and a weaker solar wind also means fewer geomagnetic storms and auroras on Earth. *A long term low in solar irradiance:* Measurements by several NASA spacecraft show that the sun's brightness has dropped by 0.02% at visible wavelengths and 6% at extreme ultraviolet wavelengths since the solar minimum of 1996. The changes are not enough to affect the course of global warming, but the Earth's upper atmosphere is significantly less heated and therefore less expanded. Satellites in low Earth orbit experience less atmospheric drag and space junk remains longer in orbit. *A 55-year low in solar radio emissions:* Radio telescopes are recording the dimmest radio emissions from the sun since 1955. Some researchers believe that the lessening of radio emissions is an additional indication of weakness in the sun's global magnetic field.

REFERENCES:
Chamberlin, P. C., T. N. Woods, D. A. Crotser, F. G. Eparvier, R. A. Hock, and D. L. Woodraska, New, Higher Resolution Solar Extreme Ultraviolet (EUV) Irradiance Results for Solar Cycle Minimum Conditions on April 14, 2008, Geophys. Res. Lett., 36, L05102, doi:10.1029/2008GL037145, 2009.
Harder, J. W., J. M. Fontenla, P, Pilewskie, E. C. Richard, and T. N. Woods, Trends in Solar Spectral Irradiance Variability in the Visible and Infrared, Geophys. Res. Lett., 36, L07801, doi:10.1029/2008GL036797, 2009.
I. G. Hannah, H. S. Hudson, G. J. Hurford, and R. P. Lin. Constraining the Properties of Hard X-ray Nano flares with RHESSI Observations of the Quiet Sun. 12th European Solar Physics Meeting, Freiburg, Germany, held September, 8-12, 2008. Online at http://espm.kis.uni-freiburg.de/, p.2.83, 12:2{+, September 2008.
Issautier, K., G. Le Chat, M.-V. N., M. Moncuquet, S. Hoang, R. J. MacDowall, and D. J. McComas (2008), Electron properties of high-speed solar wind from polar coronal holes obtained by ulysses thermal noise spectroscopy: Not so dense, not so hot, Geophys. Res. Lett., L19101, doi:0.1029/2008GL034912.
McComas, D. J., R. W. Ebert, H. A. Elliott, B. E. Goldstein, J. T. Gosling, N. A. Schwadron, and R. M. Skoug (2008), Weaker solar wind from the polar coronal holes and the whole sun, Geophys. Res. Lett., 35, L18103, doi:10.1029/2008GL034896.
Smith, E. J., and A. Balogh (2008), Decrease in heliospheric magnetic flux in this solar minimum: Recent ulysses magnetic field observations, Geophys. Res. Lett., L22103, doi:10.1029/2008GL035345.
Woods, T. N., P. C. Chamberlin, J. W. Harder, R. A. Hock, M. Snow, F. G. Eparvier, J. Fontenla, W. E. McClintock, and E. C. Richard, Solar Irradiance Reference Spectra (SIRS) for the 2008 Whole Heliosphere Interval (WHI), Geophys. Res. Lett., 36, L01101, doi:101029/2008GL036373, 2009.
http://science.nasa.gov/headlines/y2009/01apr_deepsolarminimum.htm
http://science.nasa.gov/headlines/y2008/30sep_blankyear.htm

Powering the earth's aurora: The first magnetic activity dependent FUV-based model of global precipitating auroral average energy and flux was developed using 4 years (2002–2005) of TIMED GUVI data. This new model encompasses geomagnetic activity levels from quiet to major storming. Because the model is based on FUV-imaging which has large spatial coverage compared to in-situ measurements, it provides a more consistent estimation of the energy that pours into the high latitude regions during magnetic storms, altering the temperatures, composition and dynamics of the atmosphere. The GUVI hemispheric power model is an important advance that will increase the accuracy of global ionosphere-thermosphere simulations, as well as space weather forecasting and nowcasting.

REFERENCES:
Zhang, Y., and L. J. Paxton, An empirical Kp-dependent global auroral model based on TIMED/GUVI FUV data, J. of Atmos and Solar-Terr Phys, 70 (2008) 1231– 1242

Supercharged ionosphere: Dramatic longitudinally confined enhancements in ionospheric total electron content (TEC) develop in the afternoon sector during major space storms. The edges of these TEC regions migrate poleward and westward through the cusp forming "tongues of ionization" against a backdrop of low plasma densities in the polar cap. The mechanisms that produce these dense large-scale structures are still not completely understood but they have devastating effects on GPS systems, and the sharp density gradients at their edges drive severe radio scintillation. Observational evidence suggests that these structures may actually be fed by vertical and horizontal transport of plasmas created near the equator by sunlight. However, new results from the Utah State University Time Dependent Ionosphere Model (TDIM) demonstrate that the transport of plasma from the equatorial region is not required to generate the narrow storm-enhanced density structures, at least during the November 1991 super storm. The primary driver is the penetration of high latitude magnetospheric electric fields to low-latitudes. The longitudinally-structured “penetration” electric fields force plasma to move upward along slanted middle-latitude magnetic field lines in certain local time sectors, decreasing collisional losses and producing impressive but longitudinally-confined fingers of storm-enhanced density.

REFERENCES

Heelis, R. A., and S. Mohapatra (2009), Storm time signatures of the ionospheric zonal ion drift at middle latitudes, J. Geophys. Res., 114, A02305, doi:10.1029/2008JA013620

Heelis, R. A., J. J. Sojka, M. David, and R. W. Schunk (2009), Storm time density enhancements in the middle-latitude dayside ionosphere, J. Geophys. Res., 114, A03315, doi:10.1029/2008JA013690.

Pfaff, R.F., C. Leibrecht, J.J. Berthelier, M. Malingre, M. Perot and J.P. Lebreton, (2009) DEMETER satellite observations of plasma irregularities in the topside ionosphere at low and middle sub-auroral latitudes and their dependence on magnetic storms, AGU Geophys. Monograph, 181, ed., Kintner, et.al. 297.