HELIOPHYSICS DRAFT INPUT TO FY08 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 Earth and Sun as an integrated system, protect technologies at Earth, and safeguard space exploration.

Life on Earth prospers in a biosphere that is sustained by energy from the Sun. The Earth's upper atmosphere and magnetic field buffers this biosphere against the more dangerous electromagnetic radiation and particles emanating from the Sun. In turn, the extended magnetic field of the Sun shields the Earth from the very high-energy radiation that originates at supernovae and other cataclysmic events outside the solar system.

The average energy output of the Sun is fairly constant, yet its photon spectrum and charged particle output are highly variable on numerous timescales. Disturbances in the solar chromosphere and corona, such as solar flares and coronal mass ejections (CMEs), can sharply increase the amount of high-energy photons (UV) and energetic particles, respectively, arriving at Earth. Normally, the Earth upper atmosphere protects from the high-energy photons, while the Earth' magnetosphere protects from the charged particles. However, variation in the solar wind magnetic field introduced by CME's as well as other disturbances such as co-rotating interaction regions, deposit energy into the magnetosphere. The release of this energy results in "space weather" (magnetic storms and substorms) that disrupts communications, navigation, and power grids, damage satellites, and threaten the health of astronauts.

To achieve Sub-goal 3B, Heliophysics Theme researchers study the Sun, the heliosphere, the local interstellar medium, near-Earth space, and all planetary environments within the heliosphere as elements of a single, interconnected system. The studies encompass the scientific disciplines of solar physics, heliospheric physics, magnetospheric physics, and aeronomy (the study of planetary upper atmospheres). Using a group of robotic science spacecraft that 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 need to predict solar events and mitigate their effect is important to the public safety and the Nation's economy and security.

The science that underlies this space weather predictive capability is an integral part of NASA's other science endeavors as well. Space plasmas, the fourth state of matter, are ubiquitous throughout the universe. Plasmas make up intergalactic space, interstellar space, interplanetary space, and the space environments of the planets including the Earth. 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 may be inaccessible to direct study.

Risks to Achieving Sub-goal 3B

Of primary concern for the Heliophysics Division is the seemingly exponential increase in cost, and the precipitous 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 Evolved ELVs (Delta IV, Atlas V) for many of the missions identified in the NASA Science Plan, or much smaller launch vehicles with significantly reduced capabilities. NASA is aggressively exploring options to maintain a vital Heliophysics flight program including the development of dual payload launch capability and alternate launch providers for mid-range payloads. 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, might alleviate some of these concerns.

Prime, if not unique, science data was provided by the Ulysses, Polar, IMAGE, TIMED, and FAST missions. These spacecraft have ceased operations after long mission lives, or lost some critical instruments after their prime science phase. The loss of these observatories/instruments means that critical data with which to gain knowledge about the end-to-end Sun to Earth Connection will be absent, and that is of rising concern. Specifically, continued observations of the Earth's global current system driving space weather – revealing itself as aurora – are needed, along with cause-and-effect surveillance of the Earth's polar magnetosphere. The end of Ulysses out-of-ecliptic measurements impedes further progress on understanding the generation of solar winds and magnetic fields at the Sun's polar latitudes and their long-term trends.

FY 2009 Performance Forecast

NASA will complete development of the Solar Dynamics Observatory (SDO), working towards launch in December 2008. 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 formulation and start implementation for the Magnetospheric Multiscale (MMS) mission. 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 formulation and start implementation for the Radiation Belt Storm Probes (RBSP) mission. 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 initiate formulation for Solar Probe mission. 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 achieve its mission success criteria for the Solar Terrestrial Relations Observatory (STEREO), Aeronomy of Ice in the Mesosphere (AIM), Time History of Events and Macroscale Interactions during Substorms (THEMIS).

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.

On August 30, 2007 Voyager 2 made the first of several crossings of the solar wind termination shock at southern heliographic latitudes, and joined Voyager 1 in exploring the heliosheath, the turbulent region that separates the solar wind from the local interstellar medium. At the Voyager 1 location at southern heliographic latitudes the location of the termination shock was 7 to 8 AU closer to the Sun than when Voyager 1 crossed the termination shock at northern latitudes in 2005. Unlike Voyager 1, Voyager 2 has a working plasma instrument, which measured a very dynamic shock that is constantly evolving and reforming. The Suprathermal Electron Instruments on STEREO have provided the first clear detection of energetic neutral atoms (ENAs) from the distant heliosphere. These ENAs are generated by charge exchange interactions of energetic ions in the heliosheath with the neutral interstellar gas and are found to be coming from the nose of the heliosphere, which is the direction the solar system is moving relative to the interstellar gas.

Although it has long been known that Earth's magnetosphere and solar corona are extremely efficient accelerators of relativistic particles, the acceleration mechanisms have been a source of controversy. Recently, observations from several NASA satellites have confirmed the essential role wave-particle interactions play in accelerating particles to hazardous energies. *In the Magnetosphere*, the Solar Terrestrial Relations Observatory (STEREO) measurements revealed large-amplitude whistler-mode waves in the radiation belts that energize electrons to MeV energies in less than 0.1 second. Cluster mission scientists have determined key properties of plasma wave emissions in Earth's inner magnetosphere, including the range of directions of chorus waves and the variation of the wave source frequencies as a function of time. *In the Heliosphere*, scientists used simultaneous gamma-ray, X-ray, EUV and radio-wave observations from multiple missions to identify the key elements of particle acceleration during solar storms. These elements include the origin, structure, and evolution of CME shocks, and the nature of the turbulence associated with these shocks and wave-particle acceleration processes driven by it. They further determined the distribution and composition of seed populations, which feed the acceleration process and the manner in which the interplanetary medium affects the transport of the energetic particles to Earth. These is the observational background needed to build a physics-based system that can be used to forecast the intensities and properties of energetic charged particles from the Sun through to the radiation environment they create near Earth and in space. *In the solar atmosphere*, Hinode observations have shown that small-scale reconnection in the chromosphere is ubiquitous and may be a significant contributor to coronal heating and particle acceleration. Coronal observations reveal a form of magnetic reconnection in the solar corona in which field lines release energy by slipping past each other. Hinode scientists also presented the first observational evidence for the existence of magnetohydromagnetic waves in the solar atmosphere that may lead to the efficient acceleration of particles. NASA-supported scientists advanced theories of plasma turbulence and magnetic reconnection that directly accelerate electrons with high efficiency. These findings point to magnetic reconnection as the process through which the solar magnetic field can fuel explosive events.

The Geotail mission has addressed important questions regarding how the Earth's magnetosphere responds when the magnetic field associated with the solar wind points northward. It has long been unknown how solar wind particles enter the magnetosphere during periods of northward interplanetary magnetic field. Geotail data has shown the importance of a plasma instability that produces vortices at the boundary layer separating the magnetosphere from the solar wind. Magnetic reconnection processes within these vortices capture the solar wind plasma and incorporate it in the magnetotail plasma sheet. This demonstrates a combination of diverse fundamental processes yielding net plasma transport between otherwise isolated regions in space, in this case, significantly impacting the state of Earth's magnetosphere.

The Solar Terrestrial Relations Observatory (STEREO) mission has made valuable contributions to the understanding of comets. Observations of the extremely bright Comet McNaught revealed evidence of a dust tail consisting of neutral iron atoms pushed out by the pressure of sunlight – the first ever detected neutral iron tail from a comet. The iron atoms are thought to originate in dust grains from the comet nucleus. The STEREO mission also witnessed the collision between a coronal mass ejection (CME) and Comet Encke that resulted in a spectacular detachment of the comet's ion tail. The analysis suggests the process of magnetic reconnection may have caused the detachment. Extended STEREO observations of Comet Loneos show that disruptions of comet tails by high-speed solar wind streams are likely to be a frequent occurrence.

<table>
<tr><th>FY2008 Annual Performance Goals</th><th>FY04</th><th>FY05</th><th>FY06</th><th>FY07</th><th>FY2008</th></tr>
<tr><td rowspan="4">APG 8HE01 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>4SEC11
Green</td><td>5SEC9
Blue</td><td>6ESS11
Green</td><td rowspan="4">7ESS13
Green</td><td rowspan="4">June 12:
HPS
voted
GREEN</td></tr>
<tr><td>None</td><td>None</td><td>6ESS12
Green</td></tr>
<tr><td>4SEC14
Green</td><td>5SEC12
Blue</td><td>6ESS14
Green</td></tr>
<tr><td>4SEC15
Green</td><td>5SEC13
Green</td><td>6ESS15
Green</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.

NASA has made significant progress in understanding how Earth's magnetic field stores energy from the solar wind until it is released, producing "substorms." Substorms are episodic space-weather events that inject energetic particles into the near-Earth magnetosphere, resulting in potentially damaging spacecraft charging and strong currents in the upper atmosphere. Observations from the THEMIS (Time History of Events and Macroscale Interactions during Substorms) mission have shown compelling evidence for the 'reconnection' model of substorms, in which substorms originate in the mid-magnetotail, followed by the Earthward propagation of energized particles, field-aligned currents, plasma flows, and magnetic field perturbations. In addition, data from several Heliophysics missions suggest that the substorm onset location is typically inside of 20 R_E of Earth, which is closer than previously thought. Geotail scientists demonstrated that the location depends on solar wind energy input, with the location being closer to Earth when the energy input is high, and Cluster observations revealed new properties of the substorm trigger mechanism and showed that the trigger region can propagate and spread to other regions. Cluster scientists also completed a classification of the level of turbulence present for different stages of a substorm; this will reveal whether turbulence has a significant causative contribution to substorm onset.

The heliospheric magnetic field is tied to variability of the solar cycle and cosmic ray intensity. This is important for interpreting long historic records of solar and terrestrial change. During the current solar minimum Ulysses finds that the magnetic field strength in the heliosphere is about 40% lower than during any solar cycle since the space age began. At the same time SOHO measurements indicate that the Sun's polar fields are smaller by a factor of two than at the previous minimum in 1996. The ratio of the interplanetary and polar fields depends on the processes in the corona that heat and accelerate the solar wind. The change in strength suggests that the upcoming solar cycle may be significantly different than previously well-observed cycles. The smaller heliospheric flux implies that the heliosphere as a whole will temporarily shrink in size and, therefore, the intensity of the galactic cosmic rays at Earth may rise to record levels

Noctilucent Clouds (NLCs) that exist 50 miles above the Earth's surface vary in ways that appear to be connected with global climate change and with solar variability. NLC cloud structures observed for the first time by the AIM (Aeronomy of Ice in the Mesosphere) mission exhibits complex features surprisingly similar to those present in normal tropospheric clouds. These features may be caused by small-scale convective activity high in the summer mesosphere, which suggests that the mesosphere may share some of the same dynamical processes that are responsible for weather nearer to Earth's surface. Convection so high above the surface was unexpected because this region is the coldest part of the entire planet, so the presence of convective motion would indicate an entirely different understanding of how noctilucent clouds form and vary. AIM has also observed a previously suspected but never before seen population of very small ice particles at high altitudes where they first form and throughout the altitude range where they fall and grow to become NLCs. These observations are thus providing the full picture from the genesis of the clouds, to their later birth, to their ultimate removal.

TIMED data have revealed that the multiple, strong, high-speed solar wind streams that are a persistent feature of the present solar minimum period have remarkable geospace and atmospheric consequences. Auroral activity driven by these recurrent solar wind structures produces long-duration perturbations to the chemistry, dynamics and energetics of the upper atmosphere. A surprising result is the TIMED discovery of a strong nine-day periodicity in the daily global power radiated by nitric oxide and carbon dioxide in the thermosphere. The same periodicity has been identified in other data sets and in high speed stream parameters, but not in F10.7 (a measure of the solar spectral irradiance changes), demonstrating a strong and direct connection between the Earth's upper atmosphere and coronal holes in the Sun's upper atmosphere, which are the source of the high speed streams. Nitric oxide is energetically important for the Earth's upper atmosphere. It acts as a natural thermostat, radiating away auroral energy and cooling the atmosphere back to pre-storm levels. Nitric oxide created in the polar night can also be transported downward into the stratosphere within the polar vortex and destroy ozone; thus it has potential significance for climate variability.

By combining detailed measurements from ACE, Hinode, Wind, RHESSI, SOHO, TRACE, and GOES, space scientists have identified coronal jets as the origin of a distinctive class of solar energetic particle events, which are highly enriched in rare isotopes and high ionic charge states. The origin of these events, which were first discovered in the 1970s and occur by the thousands during solar-active years, has been one of the most puzzling phenomena in space physics. The jet location pinpointed the site of the activity, where magnetic flux emerged near field lines that were open to interplanetary space. These small particle events are also as an important source of the seed particles for the very large particle events that can affect spacecraft and endanger astronauts.

FY 2008 Annual Performance Goals	FY04	FY05	FY06	FY07	FY2008
APG 8HE03 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.	4SEC10 Blue	5SEC8 Green	6ESS10 Green	7ESS19 Green	June 12: HPS voted GREEN
	4SEC13 Green	5SEC11 Green	6ESS13 Green		

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 Solar Terrestrial Relations Observatory (STEREO) imagers have exceeded expectations with their ability to image the slow solar wind and co-rotating interaction regions in addition to the coronal mass ejections (CMEs) they were designed to image. During May to September of 2007, STEREO observed a succession of solar wind wave fronts sweeping past Earth. As each of these wave fronts moved past Earth, the Wind spacecraft, located only 200 Earth radii sunward, recorded a succession of density compressions in front of recurrent solar wind high-speed streams that has been identified as the corresponding in-situ counterpart to the STEREO observations. This unexpected capability to follow recurrent solar wind structure will lead to advances in our understanding of solar wind propagation and the formation of geoeffective compressions through the inner solar system during this unusual solar minimum period discussed in Section 3B.2.

New Living with a Star research-to-operations tools provide commercial aviation groups up-to-the-minute and 72-hour global forecasts of high frequency (HF) radio frequency ranges along specific flight routes. All air carriers in and out of U.S. airspace are mandated to maintain reliable communications over the entire flight route (FAR 121.99). The Communication Alert and Prediction System (CAPS) system, linked to NOAA space weather decision scales, provides air carriers with information to minimize costly last-minute flight rerouting due to HF space weather outages. Earth-orbiting satellites feed the system up-to-the-minute information on space weather activity; the measurements are then converted to actionable quantities by physics-based computer codes developed by the NASA-supported researchers. The CAPS system can be used with the new "4D-ionosphere" model released through Google Earth. Refreshed every 10 minutes, a flight controller can examine the ionosphere from the flyer's point of view and use that information to anticipate problems that could cause a flight to be delayed or diverted.

A comparison of numerical simulations with imaging and spectral data from several NASA missions reveals that the solar corona is heated by mechanisms that are likely to be highly impulsive, or concentrated close to the solar surface, or both. The X-ray and UV radiation from the Sun – the solar spectral irradiance – controls the dynamics, chemistry, and ionization state of the Earth's upper atmosphere. Variations in the radiation affect radio signal propagation and satellite drag and thereby impact communication, navigation, surveillance, and space debris collision avoidance. Predicting the spectral irradiance is therefore a major goal of the NASA Heliophysics program. Having this capability requires an understanding of the mysterious mechanism that heats the outer part of the solar atmosphere, the corona, to multi-million degree temperatures. Traditional models of the corona that assume steady and uniform heating have been shown to be inconsistent with observations. Efforts are now underway to use this new result to build realistic models of solar active regions – models that may one day be used for space weather forecasting of the spectral irradiance.

FY2008 Annual Performance Goals	FY04	FY05	FY06	FY07	FY2008
APG 8HE05 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.	1.3.1 Green	15.1 Green	3B.3 Green	Green	June 12: HPS voted GREEN

APPENDIX 1: SUPPORTING MATERIAL FOR SCIENCE ASSESSMENTS

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

APG 8HE01: 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

NASA has delivered the Interstellar Boundary Explorer (IBEX) to the launch provider, working towards launch in August 2008. IBEX will reveal the global properties of the interstellar boundaries that separate our heliosphere from the local interstellar medium.

The Magnetospheric Multiscale (MMS) mission has completed Phase A formulation. 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.

The Solar Dynamics Observatory (SDO) is completing the integration work of its development phase, working towards launch in December 2008. SDO will image the Sun to study how the solar magnetic field is structured and how its energy is converted and released into the heliosphere in the forms of solar wind, energetic particles, and variations in solar irradiance.

Major Scientific Findings or Discoveries

Significant progress has been made for a long-standing problem in space and astrophysical plasmas, determining the mechanism that accelerates particles to relativistic energies. Although it has long been known that Earth's magnetosphere and the solar corona are extremely efficient accelerators of relativistic particles, the mechanisms via which acceleration occurs have been a source of controversy. Recently, observations from several NASA satellites have confirmed the essential role of wave-particle interactions play in accelerating particles to hazardous energies. *In the Magnetosphere,* the Solar Terrestrial Relations Observatory (STEREO) measurements revealed large-amplitude whistler-mode waves in the radiation belts that energize electrons to MeV energies in less than 0.1 second. Cluster mission scientists have determined key properties of plasma wave emissions in Earth's inner magnetosphere, including the range of directions of chorus waves and the variation of the wave source frequencies as a function of time. *In the Heliosphere,* scientists used simultaneous gamma-ray, X-ray, EUV and radio-wave observations from multiple missions to identify the key elements of particle acceleration during solar storms. These elements include the origin, structure, and evolution of CME shocks, and the nature of the turbulence associated with these shocks and wave-particle acceleration processes driven by it. They further determined the distribution and composition of the seed populations, which feed the acceleration process and the manner in which the interplanetary medium affects the transport of the energetic particles to Earth. Living with a Star supported scientists reported the first attempts to couple the output of a sophisticated multi-dimensional, time-dependent magnetohydrodynamics (MHD) model to four different CME shock acceleration models. These are the first steps toward building a physics-based system that can be used to forecast the intensities and properties of energetic charged particles from the Sun through to the radiation environment they create near Earth and in space. *In the corona,* Hinode observations have shown that small-scale reconnection in the chromosphere is ubiquitous and may be a significant contributor to coronal heating and particle acceleration. The observations further indicate a form of magnetic reconnection in the solar corona in which field lines release energy by slipping past each other. Hinode scientists also presented the first observational evidence for the existence of magnetohydromagnetic waves in the solar atmosphere that can lead to efficient acceleration of particles.

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The Source and Acceleration of Interplanetary Particles Accelerated in Corotating Interaction Regions: During the declining phase and current minimum of the 11-year sunspot cycle, the prevalent sources of energetic particles in interplanetary space are the so-called “corotating interaction regions” (CIRs). They are formed by the collision of low- and high-speed solar wind streams whose typical speeds are roughly 1.4 – 2.5 million km/hour. The faster streams overtake and interact with the slower ones, forming shocks which in turn produce energetic particles. Scientists using NASA’s ACE spacecraft have studied CIRs over the past solar cycle with unprecedented accuracy, and compared the energetic particle population with the presumed source material, the bulk solar wind itself. Surprisingly, the presence of ions extremely rare in the solar wind (such as singly ionized He, and the light isotope 3He) shows that the bulk solar wind is not the source as previously assumed, but rather the accelerated material is from the suprathermal region whose particles have speeds 3-10 times that of the solar wind. The suprathermal ions accelerated in CIRs are thus a mixture of heated solar wind, neutral interstellar He that is ionized and "picked-up" in the interplanetary magnetic field, and remnant material from small solar flares. This study also found that the Fe content in CIRs was strongly correlated with the solar wind Fe content 2-4 days before the CIR was observed on the spacecraft. This identifies the location of the particle acceleration at 2-4 days solar wind travel time beyond Earth orbit (45-150 million km).

Mason, G. M., R. A. Leske, M. I. Desai, C. M. S. Cohen, J. R. Dwyer, J. E. Mazur, R. A. Mewaldt, R. E. Gold, and S. M. Krimigis, "Abundances and energy spectra of corotating interaction region heavy ions observed during solar cycle 23", *Astrophys. J., ,675,* 1458-1470, May 2008.

The spatial structure and temporal evolution of basic plasma physical processes coupling Earth's magnetosphere and ionosphere were resolved for the first time using multiple, closely-separated spacecraft. In a series of studies published in a special issue of GRL, multispacecraft observations of magnetic fields from the ST-5 mission allowed, for the first time, the separation of temporal and spatial variations in field-aligned current (FAC) perturbations, which couple magnetospheric and ionospheric motions, measured in low-Earth orbit on time scales of ~10 sec to 10 min. The constellation measurements were used to directly and unambiguously determine field-aligned current sheet motion, thickness, waves, and current density. In a complementary NASA-supported study, a similar two-DMSP constellation at low altitudes was used to resolve for the first time the spatial structure and temporal evolution of particle precipitation in the auroral zone. Such multispacecraft measurements have opened a new window on the fundamental processes coupling the magnetosphere and ionosphere, allowing NASA scientists to constrain the models and theories of these physics.

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NASA-supported scientists advanced theories of plasma turbulence and magnetic reconnection that directly accelerate electrons with high efficiency. Hinode observations have shown that small-scale reconnection in the chromosphere is ubiquitous and may be a significant contributor to coronal heating. Evidence was found further for a form of magnetic reconnection in the solar corona in which field lines release energy by slipping past each other. Hinode scientists also presented the first observational evidence for the existence of magnetohydromagnetic waves in the solar atmosphere that are suggested as the power source for the solar wind. These findings point to magnetic reconnection as the process through which the solar magnetic field can fuel explosive events. The Cluster mission made the first direct measurement of the wave number spectrum for magnetic fluctuations in the solar wind and confirmed earlier, less definitive findings that two-dimensional turbulence dominates in the solar wind. Also studying solar wind turbulence, scientists supported by the Heliophysics Research and Analysis

(R&A) program showed that the energy carried by large-scale solar wind structures, including solar wind stream structures and solar ejecta, cascades to small-scale dissipative fluctuations in an energy-conserving fashion that is independent of solar wind speed. In this way, large-scale structures drive dissipation and heating of the background plasma in a process that does not differ with the type of solar wind. Cluster, downstream of Earth's bow shock and imbedded in very thin current sheets, observationally confirmed that magnetic reconnection dissipates turbulent eddies and transforms magnetic field energy into plasma acceleration and heating.

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The Solar Terrestrial Relations Observatory (STEREO) mission has made valuable contributions to the understanding the physics and dynamics of comet tails. Observations of the extremely bright Comet McNaught revealed evidence of a tail consisting of neutral iron atoms pushed out by the pressure of sunlight – the first ever detected neutral iron tail from a comet. The iron atoms are thought to originate in dust grains from the comet nucleus. The STEREO mission also witnessed the collision between a coronal mass ejection (CME) and Comet Encke that resulted in a spectacular detachment of the comet's ion tail. The analysis suggests the detachment may have been caused by the process of magnetic reconnection. Extended STEREO observations of Comet Loneos show that disruptions of comet tails also by high-speed solar wind streams are likely to be a frequent occurrence.

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During August 30 through September 1, 2007, Voyager 2 crossed the solar wind termination shock multiple times at 83.7 AU at southern heliospheric latitudes, 7 to 8 AU closer to the sun than Voyager 1 saw at north latitudes. This asymmetry probably indicates that the local interstellar magnetic field presses our solar system inward more strongly in the south. In 2004, the faster of the two spacecraft, Voyager 1, became the first human-made object to reach the termination shock. There, the solar wind – made of charged particles from the Sun – suddenly falters as it feels pressure from gas in the interstellar medium lying outside the solar system. But scientists missed observing the crucial moment because of the high demand on the radio dishes on Earth needed to hear the Voyager-1's transmissions. The Voyagers can no longer store their observations onboard, so they are lost forever if they are not received on Earth. Now, Voyager 2, which unlike Voyager 1 has a working plasma instrument, has provided three fully resolved crossing of this boundary, discovering a dynamic shock that is continuously evolving and reforming.

Reference:

Press Release: http://space.newscientist.com/article/dn13029-voyager-2-probe-reaches-solar-system-boundary.html

E. C. Stone et al., L. Burlaga et al., J. Richardson et al., R. Decker et al., D Gurnett et al., Accepted for publication in Nature, July 2008.

The SuperThermal Electron (STE) instruments on both STEREO spacecraft have detected Energetic Neutral Atoms (ENAs) from the boundary of the heliosphere. ENAs are generated in the interaction between the solar wind and the local interstellar medium. This is the first clear detection of ENAs from the distant heliosphere, although ENAs have been used at both Earth and Saturn to map their magnetospheres. The particles are coming from near the nose of the heliosphere, which is the direction the solar system is moving relative to the interstellar gas right outside the heliosphere. Later this year, the Interstellar Boundary Explorer (IBEX) will launch and more thoroughly map the interaction region in lower energy ENAs, but the serendipitous STEREO measurements are both a proof of principle and a complement to the future IBEX measurements.

Reference:

Press Release: coming soon (publication in Nature, 1st week in July)

The Solar and Heliospheric Observatory (SoHO) mission has discovered that solar flares can drive global oscillations in the Sun in the same way that the entire Earth is set ringing for several weeks after a major earthquake. Discovering how the oscillations originate and then move around the Sun will provide valuable information about the Sun's interior conditions.

References:

Karoff and Kjeldsen, "Evidence That Solar Flares Drive Global Oscillations in the Sun," ApJ, 678, L73, 2008;

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The Geotail mission has addressed important questions regarding how the Earth's magnetosphere responds when the magnetic field associated with the solar wind points northward. An important question has been how solar wind particles enter the magnetosphere during periods of northward interplanetary magnetic field. Geotail data has shown the importance of a plasma instability that produces vortices at the boundary layer separating the magnetosphere from the solar wind. Magnetic reconnection processes within these vortices capture the solar wind plasma and incorporate it in the magnetotail plasma sheet. The subsequent transport of such plasma is also controlled by this interplanetary magnetic field direction and can influence magnetic storms. The extensive data record from Geotail provided the means to investigate conditions when the Earth's magnetotail becomes colder and denser during northward IMF conditions.

References:

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Nishino, M. N., M. Fujimoto, T. Terasawa, G. Ueno, K. Maezawa, T. Mukai, and Y. Saito, Geotail observations of temperature anisotropy of the two-component protons in the dusk plasma sheet, Ann. Geophysicae, 25, 769-777, 2007a.

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APG 8HE03: 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 A formulation. 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.

Time History of Events and Macroscale Interactions during Substorms (THEMIS), an Explorer-class mission designed to determine the cause of the fundamental geomagnetic disturbances known as substorms, fulfilled its primary scientific objectives during its first season in the nightside magnetosphere. As planned, from January to March 2008, the five THEMIS spacecraft lined up within the Earth's magnetotail once each 4 days over a dedicated array of ground observatories located throughout Canada and Alaska.

The IMAGE, POLAR, and Ulysses spacecraft are no longer operational, and critical instrumentation on the TIMED and FAST observatories have ceased providing prime science data. Specifically, observations of the Earth's global current system driving space weather – revealing itself as aurora – have been lost along with cause-and-effect surveillance of the Earth's polar magnetosphere. The loss of Ulysses out-of-ecliptic measurements impedes further progress on understanding the generation of solar winds and magnetic fields at the Sun's polar latitudes and their long-term trends.

Major Scientific Findings or Discoveries

NASA has made significant progress understanding how Earth's magnetic field stores energy from the solar wind until it is released, producing "substorms". The Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission observations have shown compelling evidence for the 'reconnection' model of substorms in which substorms originate in the mid-magnetotail followed by the Earthward propagation of energized particles, field-aligned currents, plasma flows, and magnetic field perturbations. The THEMIS data, consistent with the results from several Heliophysics missions, suggest the location of the origination, or onset, is typically inside of 20 R_E of Earth, which is closer than previously thought. Geotail scientists demonstrated that the onset location depends on solar wind energy input, with the location being closer to Earth when the energy input is high. Cluster observations revealed new properties of the onset mechanism and showed that the activity in the onset region can propagate and spread to other regions. Cluster scientists have also completed a classification of the level of turbulence present for different stages of a substorm, which will help to determine whether turbulence has a significant causative contribution to substorm onset.

References:

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Parks, G. K., E. Lee, N. Lin, F. Mozer, and M. Wilber, Solitary Electromagnetic Pulses Detected with Super-Alfvénic Flows in Earth's Geomagnetic Tail, Phys. Rev. Lett, 98, 265001, 29 June, 2007.

During the recent solar minimum, Ulysses mission data showed that the magnetic field intensity at the Sun is lower than during any solar cycle since the space age began. This observation coincides with SOHO measurements of the polar magnetic fields on the Sun that indicate they, also, are smaller than in the past. The ratio of the interplanetary to solar fields depends on the processes that heat and accelerate the solar wind. The fact that the fields are different implies that the coming solar cycle may be significantly different than any previously well-observed cycle. Further Ulysses observations show that with the decrease in magnetic field, also the solar wind proton and electron densities and the solar wind speed and dynamic pressure are decreased This implies that the heliosphere will, at least temporarily, reduce in spatial extent, and expectations are that intensities of galactic cosmic rays at Earth will rise to record levels. These measurements suggest that there are unknown solar magnetic dynamo processes that generate the polar fields and the solar cycle.

Reference:
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Electron Properties of High-Speed Solar Wind from Polar Coronal Holes Obtained by Ulysses Thermal Noise Spectroscopy: Not so Dense, not so hot, K. Issautier,1 G. Le Chat,1 N. Meyer-Vernet,1 M. Moncuquet,1 S. Hoang1, R.J. MacDowall2, and D.J. McComas, Geophys. Res. Lett., submitted, 2008.

MDI Synoptic Charts of Magnetic Field: Interpolation of Polar Fields, [Liu et al.(2007)]{2007AAS...210.2405L} Liu, Y., Hoeksema, J.~T., Zhao, X., \& Larson, R.~M.\ 2007, American Astronomical Society Meeting Abstracts, 210, \#24.05.

The Sun's Polar Magnetic Flux from 1996-2006 Observed With SOHO/MDI, [Hoeksema et al.(2006)]{2006SPD....37.0702H} Hoeksema, J.~T., Benevolenskaya, E.~E., Liu, Y., Scherrer, P.~H., \& Zhao, X.\ 2006, Bulletin of the American Astronomical Society, 38, 228

Noctilucent Cloud structures observed for the first time by the Aeronomy of Ice in the Mesosphere (AIM) mission exhibit complex features similar to those present in normal tropospheric clouds. Surprisingly, these features may be caused by small-scale convective activity high in the summer mesosphere, suggesting that the mesosphere may share some of the same dynamical processes that are responsible for weather nearer to Earth's surface. Atmospheric convection is the process by which air parcels transfer heat between layers of the atmosphere. In the low atmosphere near the surface, it is often responsible for the formation of clouds, precipitation, and severe weather. Convection so high above the surface was unexpected because this region is the coldest part of the entire planet. This is an entirely different view of why noctilucent clouds form and vary. The AIM observatory has also observed a previously suspected but never before seen population of very small ice particles theorized to be responsible for strong radar echoes observed from the ground in the polar summer mesosphere. AIM has now proven the capability to measure ice particles at high altitudes where they first form and throughout the altitude range where they fall and grow to become NLCs. This ability provides the full picture from the genesis of the clouds, to their later birth, and removal yielding critical information to determine why NLCs form and vary.

References:

Gordley, L.L., et. al., The Solar Occultation For Ice Experiment (SOFIE), J. Atmos. Solar-Terr. Phys., in review,2008.

Hervig, M.E., et al., Interpretation of SOFIE PMC measurements: Cloud identification and derivation of mass density, particle shape, and particle size, J. Atmos. Solar-Terr. Phys., in review, 2008.

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http://aim.hamptonu.edu/library/index.html

TIMED data have revealed that the multiple, strong, high-speed solar wind streams that are a persistent feature of the present solar minimum period have remarkable geospace and atmospheric consequences. Auroral activity driven by these recurrent solar wind structures produces long-duration perturbations to the chemistry, dynamics and energetics of the upper atmosphere. A surprising result is the TIMED discovery of a strong nine-day periodicity in the daily global power radiated by nitric oxide and carbon dioxide in the thermosphere. The same periodicity has been identified in other data sets and in high speed stream parameters, but not in F10.7 (a measure of the solar spectral irradiance changes), demonstrating a strong and direct connection between the Earth's upper atmosphere and coronal holes in the Sun's upper atmosphere, which are the source of the high speed streams. Nitric oxide is energetically important for the Earth's upper atmosphere. It acts as a natural thermostat, radiating away auroral energy and cooling the atmosphere back to pre-storm levels. Nitric oxide created in the polar night can also be transported downward into the stratosphere within the polar vortex and destroy ozone; thus it has potential significance for climate variability.

References:

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Lei, J., J. P. Thayer, J. M. Forbes, E. K. Sutton, and R. S. Nerem, (2008) Rotating solar coronal holes and periodic modulation of the upper atmosphere, Geophys. Res. Lett., 35, doi:10.1029/2008GL033875, in press.

Thayer, J. P., J. Lei, J. M. Forbes, E. K. Sutton, and R. S. Nerem, Thermospheric Density Oscillations due to Periodic Solar Wind Fast Streams, in press, J. Geophys. Res., 2008.

By combining detailed measurements from ACE, Hinode, Wind, RHESSI, SOHO, TRACE, and GOES, space scientists have identified coronal jets as the origin of a distinctive class of solar energetic particle events, which are highly enriched in rare isotopes and high ionic charge states. The origin of these events, which were first discovered in the 1970s and occur by the thousands during solar-active years, has been one of the most puzzling phenomena in space physics. The jet location pinpointed the site of the activity, where magnetic flux emerged near field lines that were open to interplanetary space. These small particle events are also as an important source of the seed particles for the very large particle events that can affect spacecraft and endanger astronauts.

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Kartavykh, Y. Y., W. Dröge, B. Klecker, G. M. Mason, E. Möbius, M. Popecki, and S. Krucker, "Evidence for a two-temperature source region in the ^{3}He-rich solar energetic particle event of 2000 May 1st", *Astrophysical J., 671,* 947-954, Dec. 2007.

Scientists working with Hinode observations have revealed a new understanding of the mechanisms responsible for heating the corona to million degree temperatures and found observational evidence pointing to a source of the slow solar wind. With high-precision Hinode imaging, the atmosphere above active regions has been found to behave very differently from regions away from them. The strongest magnetic fields in solar active regions appear to have the highest densities while the long loops that dominate quieter solar coronal images are regions of lower density. A nano-flare scenario has been proposed, in which many energy-releasing reconnection events occur throughout the corona. This process would distribute heated plasma over adjacent field lines as they are repeatedly cut and spliced onto their neighbors. Hinode observations further suggest that the open magnetic field at the edges of active regions, which are areas of strong heating but closed magnetic fields, may be one possible source of the slow solar wind.

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Patsourakos and Klimchuk, "The Cross-Field Thermal Structure of Coronal Loops from Triple-Filter TRACE Observations", 2007, ApJ 667, 591; Schrijver, "Braiding-induced Interchange Reconnection of the Magnetic Field and the Width of Solar Coronal Loops", 2007, ApJL 662, 119; Tripathi et al., "Density structure of an active region and associated moss using Hinode/EIS", 2008, Astron. Astrophys. 481, L53; Winebarger et al., "Modeling X-Ray Loops and EUV ``Moss" in an Active Region Core", 2008, ApJ 676, 672.

Cluster mission scientists have determined key properties of plasma wave emissions in Earth's inner magnetosphere. The range of directions of chorus waves has been determined and the variation of source frequencies as a function of time [this sentence is incomplete]. Cluster scientists also made the first direct determination of the directional properties of the radio emission associated with the Earth's aurora ('northern lights'). The radio emission, known as auroral kilometric radiation, is the most intense, naturally occurring radio emission from Earth. Equivalent radiation is seen on all planets with global magnetic fields. The Cluster data showed that the radio waves are highly beamed much like a searchlight pointed away from Earth. This discovery has important consequences for understanding radio emission from the Jovian planets, and in the search for habitable planets outside the solar system.

References:
A. Breneman, C. A. Kletzing, J. Chum, O. Santolik, D. A. Gurnett and J. S. Pickett, Multispacecraft Observations of Chorus Dispersion and Source Location, J. Geophys. Res., 112, A05221, doi:10.1029/2006JA012058, May 26, 2007.
Mutel, R.L., Christopher, I.,W., and Pickett, J. S., Cluster multispacecraft determination of AKR angular beaming, Geophys. Res. Letters, Volume 35, Issue 7, CiteID L07104.
Web reference: http://astro.physics.uiowa.edu/~rlm/research/research.html

The spacecraft of the Heliophysics Great Observatory continue to be an important contributor to the large magnetosphere database that underpin increasingly sophisticated models of the Earth's extended magnetic field in space. The most recent model update now describes radial variations and azimuthal asymmetries in field aligned and equatorial currents. This widely used model continues to be an essential tool in relating outer magnetosphere phenomena to their ionospheric counterparts.

Reference:
Tsyganenko, N. A., and M. I. Sitnov (2007), Magnetospheric configurations from a high-resolution data-based magnetic field model, J. Geophys. Res., 112, A06225, doi:10.1029/2007JA012260.

APG 8HE05: 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

NASA has launched two missions of opportunity in partnership with the Department of Defense. The Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) mission provides a new capability for stereoscopically imaging the magnetosphere. TWINS will enable the first 3-dimensional visualizations of large-scale structures and dynamics within the magnetosphere. The Coupled Ion Neutral Dynamic Investigation (CINDI), a key component of the Communication/Navigation Outage Forecast System (C/NOFS) undertaken by the Air Force Research Laboratory and the Space and Missile Command Test and Evaluation Directorate, will study the behavior of equatorial ionospheric irregularities that cause major problems for communications and navigation systems.

Scientists are now testing a new method that uses SOHO data to predict, in real-time, the approach and intensity of hazardous solar particles that would threaten astronauts and technology in space. This recently-developed method shows how results from basic heliophysics research can be rapidly transferred to operational applications critical to space exploration. The new forecasting method monitors fast-moving electrons that propagate down magnetic field lines in front of the more hazardous ion radiation events. The arrival of hazardous radiation is imminent once the electrons are detected, which alerts astronauts to take protective measures and spacecraft operators to secure sensitive electronics.

Major Scientific Findings or Discoveries

The Solar Terrestrial Relations Observatory (STEREO) imagers have exceeded expectations with their ability to track solar wind disturbances such as co-rotating interaction regions in addition to coronal mass ejections (CMEs) from the Sun to Earth's distance and beyond. During May to September of 2007, STEREO observed a succession of recurring solar wind wave fronts sweeping past Earth,. As each of these wave fronts moved past Earth, the Wind spacecraft, located only 200 Earth radii sunward, recorded a succession of density compressions in front of recurrent solar wind high-speed streams that has been identified as the corresponding in-situ counterpart to the STEREO observations. This unexpected capability to follow quiet, recurrent solar wind structure will lead to advances in our understanding of solar wind propagation and the formation of geoeffective compressions through the inner solar system during this unusual solar minimum period discussed in Section 3B.2..

References:
Sheeley et al., Heliospheric Images of the Solar Wind at Earth, *Astrophys. J.*, *675*, 853-862, 2008.
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New Living with a Star research-to-operations tools provide commercial aviation groups up-to-the-minute and 72-hour global forecasts of HF radio frequency ranges along specific flight routes. All air carriers in and out of U.S. airspace are mandated to maintain reliable communications over the entire flight route (FAR 121.99). The Communication Alert and Prediction System (CAPS) system, linked to NOAA space weather decision scales, provides air carriers with information to minimize costly last-minute flight rerouting due to HF space weather outages. Earth-orbiting satellites feed the system up-to-the-minute information on space weather activity; the measurements are then converted to actionable quantities by physics-based computer codes developed by the NASA-supported researchers. The CAPS system can be used with the new "4D-ionosphere" model released through Google Earth. Refreshed every 10 minutes, a flight controller can examine the ionosphere from the flyer's point of view and use that information to anticipate problems that could cause a flight to be delayed or diverted.

References:
Press Release: *IPS MeteoStar and Space Environment Technologies Announce Space Weather Products for Commercial Aviation*, April 30, 2008; Press Release: *4D Ionosphere*, April 30, 2008.

A comparison of numerical simulations with imaging and spectral data from several NASA missions reveals that the solar corona is heated by mechanisms that are likely to be highly impulsive, or concentrated close to the solar surface, or both. The X-ray and UV radiation from the Sun–the solar spectral irradiance–controls the dynamics, chemistry, and ionization state of the Earth's upper atmosphere. Variations in the radiation affect radio signal propagation and satellite drag and thereby impact communication, navigation, surveillance, and space debris collision avoidance. Predicting the spectral irradiance is therefore a major goal of the NASA Heliophysics program. Having this capability requires an understanding of the mysterious mechanism that heats the outer part of the solar atmosphere, the corona, to multi-million degree temperatures. Traditional models of the corona that assume steady and uniform heating have been shown to be inconsistent with observations. Efforts are now underway to use this new result to build realistic models of solar active regions–models that may one day be used for space weather forecasting of the spectral irradiance.

References:
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Mok, Y., Mikic, Z., Lionello, R., & Linker, J. A. 2008, "The Formation of Coronal Loops by Thermal Instability in Three Dimensions," ApJ Letters, in press.
Warren, H. P., and Winebarger, A. R. 2007, "Static and Dynamic Modeling of a Solar Active Region," ApJ, 666, 1245.

A plasma instability due to shear of the low-lying field of active regions has been identified as the primary mechanism responsible for coronal mass ejections (CMEs). This new finding is aided by TRACE's unique high-resolution observations of the solar corona and of the underlying domains of the atmosphere. A recent study concludes that primarily an instability related to the increasing shear of the low-lying field is responsible for CMEs. Detailed comparisons of observations and models show that some filament configurations are indeed very nearly internally unstable. And when such instability occurs, the best-observed filament eruptions are consistent with the torus instability pushing a flux rope outward, which describes the CMEs velocity profile out to at least a full solar radius from the Sun. What complicates space-weather forecasts is that a flare and CME can involve only a fraction of the total available energy, as found from the observation that the energy release is best measured by the change in the field's shear angles rather than by the initial shear angle itself.

References:
Bobra et al., "Modeling Nonpotential Magnetic Fields in Solar Active Regions", 2008, ApJ 672, 1209.
Schrijver et al., "Observations and Modeling of the Early Acceleration Phase of Erupting Filaments Involved in Coronal Mass Ejections", 2008, ApJ 674, 586.
Su et al., "What Determines the Intensity of Solar Flare/CME Events?", 2007, ApJ 665, 1448.
Ugarte-Urra et al., "The Magnetic Topology of Coronal Mass Ejection Sources", 2007, ApJ 662, 1293.

A data-driven physical model is running in real time to now-cast Earth's radiation belt dynamics and the frequently extreme radiation conditions found there. This model, funded by the LWS TR&T program, uses state-of-the-art physical, numerical modeling driven by data from spacecraft (including ACE and SAMPEX) to model 10 keV to 6 MeV electron populations in Earth's inner magnetosphere. This three-dimensional, time-dependent model, called the Radiation Belt Environment (RBE) model, includes realistic, time-varying magnetic fields and wave-particle interactions with whistler-mode chorus waves. The RBE model reproduces the temporal evolutions of the radial and pitch angle distributions of energetic electrons of a major radiation belt particle enhancement and demonstrates a pathway to significantly improved predictive capability of this hazardous environment.s

References:
Fok et al., "Radiation Belt Environment Model: Application to Space Weather Nowcasting", 2008, JGR, 113,.