Objective H - Understand the Nature of Our Home in Space

Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields

We do not live in isolation. Our past, present, and future are intimately coupled to the relationship between the Earth and Sun - and with the universe beyond. Increasingly we are sensitive to changing conditions on the Sun and in the space environment because of our technology; increasingly we have a practical interest in the habitability of planets and solar system bodies we plan to explore; and increasingly we recognize how astrophysical phenomena influence life and climate on our home planet. Variability in this environment affects the daily activities that constitute the underpinning of our society, including communication, navigation, and weather monitoring and prediction. We are living with a star.

[[Solar Sail Thumbnail here]]

With this objective SSSC researchers strive to understand our place in the Solar System. We investigate the interaction of the space environment with Earth and its impact on us and on our home, either directly or by what can be learned about life on Earth by studying other environments in our solar system and beyond. This effort builds on the understanding of the fundamental physical processes addressed in Objective F. Our scientific goal is to understand the web of linked physical processes connecting Earth with the space environment. Our applied goal is to protect society and its technological infrastructure from space hazards and understand the external drivers of long-term climate change. We will improve technological efficiency of future operational systems by exploiting our understanding of Earth and its place in space. Human life and society provide the context for our investigations.

This context is not limiting. As we extend our presence throughout the solar system, we are interested in the planetary environments awaiting us and how the study of these environments can be applied to our home on Earth. Habitability, for humankind in particular, requires a rare congruence of many factors. These factors, especially the role of the Sun as a source of energy to planets and the role of magnetic fields in shielding planetary atmospheres, are a subject of immense importance. We understand some of the features contributing to make planets habitable, but key questions remain.

The interactive couplings of solar system processes, in the Sun and interplanetary space, with the interstellar medium, and throughout the near-Earth environment, require comprehensive study of these linked systems through a series of investigations covering these regions. Investigations of impacts on humankind must begin with the Sun, understand the cause of eruptive events and solar variability over multiple time scales, follow propagation and evolution of solar wind disturbances and energetic particles through the heliosphere to Earth, and finally investigate the interaction of solar radiative emission and the solar wind with Earth's coupled magnetosphere-ionosphere-atmosphere system.

Our four Research Focus Areas (RFAs) have been formulated to understand: the Sun so we can predict solar variability and the evolution of solar disturbances as they propagate to the Earth; the response of the coupled near-Earth plasma environment to space weather and the impacts on society; the role of the Sun as the principal energy source in our atmosphere, including the impact of long-term solar variability on Earth's climate; and, in a broader context than just the Earth, the solar photon and particle impact on other solar system bodies and how stellar activity and magnetic fields affect the evolution of planetary habitability over time.

It is not enough to study just variability and change. Coupled systems have complex internal forcings, e.g. gravity waves breaking in the upper atmosphere. The internal dynamics of the near-Earth coupled systems that protect us must be understood, even in the absence of solar variability. The program outlined below focuses on both internal linkages and external forcing mechanisms.

[[Thumbnail of CME here]]

Solar Variability & Heliospheric Disturbances. RFA H.1 aims to understand the Sun, determine how predictable solar activity truly is, and develop the capability to forecast solar activity and the evolution of solar disturbances as they propagate to Earth. It focuses on both short-term and long-term variability. X-ray flares can immediately and severely degrade radio communications through ionospheric effects. Precursors to solar disturbances observable above and below the solar surface will initially serve as predictive tools for disruptive events. Coronal mass ejections that create large magnetic storms at Earth evolve significantly over their multi-day travel time to Earth. We will learn how disturbances initiate, propagate, and evolve from the Sun to Earth and incorporate this knowledge into a predictive model of geoeffectiveness at Earth to enable a warning and mitigation system for our technological assets. Solar energetic particle events can pose serious threats to technological assets and astronauts in near-Earth orbit; we will learn how particles are accelerated in the inner heliosphere and how they propagate. We must also understand the long-term changes in total and spectral irradiance and the solar cycle variations that have significant impacts on Earth’s climate and human society.

[[Thumbnail of Airplane here]]

Variability in the magnetosphere, ionosphere, and upper atmosphere. RFA H.2 will develop understanding of the response of the near-Earth plasma regions (magnetosphere, ionosphere, and thermosphere) to space weather. This complex highly coupled system protects Earth from the worst solar disturbances, but it also redistributes energy and mass throughout. A key element involves distinguishing between the responses to external and internal drivers, as well as the impact of ordinary reconfigurations of environmental conditions, such as might be encountered when Earth crosses a magnetic sector boundary in the solar wind. This near-Earth region harbors space assets for communication, navigation, and remote sensing needs and conditions there can adversely affect their operation. Ground based systems, such as the power distribution grid, can also be affected by ionospheric and upper atmospheric changes. Investigations emphasize understanding the nature of the electrodynamic coupling throughout geospace (the near-Earth plasma environment), how geospace responds to external and internal drivers, and how the coupled middle and upper atmosphere respond to external forcings and how they interact with each other.

[[Thumbnail of a storm cloud here]]

Solar Variability and Atmospheric Responses. RFA H.3 addresses the role of the Sun as the primary energy source for Earth’s atmosphere. We seek to understand not only the atmospheric response to solar variability, but also the importance of steady-state processes in maintaining our atmosphere. It also considers long-term climatic impacts of solar variability on humankind. We need to understand the changing inputs - both spectral changes in the electromagnetic radiation and changing levels of energetic particles throughout the atmosphere. Two fundamental problems are delineating what processes convert and redistribute solar energy within the atmosphere and determining how this is accomplished. Other specific processes can have significant impact on Earth's atmosphere and climate and merit dedicated investigations. For example, the role of energetic particles from aurora, the radiation belts, and solar flares on ozone chemistry in the upper atmosphere is not well understood. As another example, non-solar external processes, for example cloud nucleation from galactic cosmic rays, may affect Earth's climate but the details of this impact are uncertain.

[Thumbnail of the aurora here]]

Stellar Variability and Magnetic Shielding. Other planets and other stars provide illuminating perspectives for understanding the Earth and Sun. RFA H.4 addresses the long-term impact of interactions of the solar wind with Earth and other solar system bodies and the study of activity on stars other than our Sun. We need to understand the role plasmas and magnetic fields play in planetary formation and in the evolution of planetary atmospheres because this relates to the ultimate habitability of planets. A particular goal is to understand the importance of planetary magnetic fields for the development and sustenance of life. Observing activity on other stars will tell us how conditions change with time. One applied investigation that stems from these studies is to determine the implications of past and future magnetic field reversals at Earth. Such investigations provide important opportunities for linkages with other NASA fields of study.

RFA H1 Understand the causes and subsequent evolution of solar activity that affects Earth's space climate and environment.

The climate and space environment of Earth are primarily determined by the impact of plasma, particle, and electromagnetic radiation outputs from the Sun. The solar output varies on many time scales: from explosive reconnection, to convective turn over, to solar rotation, to the 22-year solar magnetic cycle, and even longer, irregular fluctuations, such as the Maunder minimum. The variability is linked to the emergence of magnetic field from below the photosphere, its transport and destruction on the surface, and the eruption into the heliosphere of energy stored in the atmosphere as flares and coronal mass ejections. The large-scale heliosphere also modulates the propagation of incoming galactic cosmic rays. Longer-term changes that can affect Earth's climate include solar total and spectral irradiance.

The solar wind, embedded disturbances, and energetic particle populations evolve as they travel through the heliosphere. Shocks accelerate particles and interact with other irregularities. CME's can even interact with each other. Current observations generally depend only on near-Sun and 1AU observations. Understanding the three-dimensional time-varying propagation of solar disturbances is one of the greatest challenges facing us. Understanding the internal configuration of the structures is another.

Precursors will provide useful information about solar and interplanetary events; however more complete predictive models based on physical principles are required. Like terrestrial weather, it is not yet clear how long in advance solar activity is predictable. Improved continuous observations of the solar vector magnetic field and high resolution observations of the atmosphere are as critical for resolving this question as helioseismology is for revealing the subsurface conditions.

Four investigations are associated with this RFA:

Investigation H1.1- What are the precursors of solar disturbances?

Future enabling missions: Solar B, STEREO, SDO, SIRA, SHIELDS/Farside, and SEPM.

SSSC Great Observatory missions supporting this investigation include: SOHO, TRACE, and RHESSI.

Investigation H1.2 - How do solar wind disturbances propagate and evolve from the Sun to Earth?

Future enabling missions: STEREO, SOLAR-B, SDO, IH Sentinels, SIRA, SEPM, Doppler, SHIELDS, Solar Orbiter, Heliostorm/L1, and Solar Weather Buoys.

SSSC Great Observatory missions supporting this investigation include: ACE, RHESSI, SOHO, TRACE, Ulysses, and Wind.

Investigation H1.3 - Predict solar disturbances that impact Earth.

Future enabling missions: SDO, Solar-B, STEREO, IH Sentinels, Heliostorm/L1, SEPM, SHIELDS, and SIRA.

SSSC Great Observatory missions supporting this investigation include: ACE, RHESSI, SOHO, TRACE, and Wind.

RFA H2 Determine changes in the Earth’s magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects.

The near-Earth space environment, geospace, is unique in the solar system and central to the protection of Earth and its inhabitants. This region includes the magnetosphere, ionosphere, and thermosphere (MIT) bound together as a tightly coupled system that interacts with the neutral atmosphere below and the Sun and heliosphere above. The variability within geospace and the nearby interplanetary environment is our local space weather. Much of space weather is driven by the external processes discussed in the previous section. In addition, internal drivers of the MIT region such as the upward propagation of gravity waves, wave-particle interactions, and auroral current systems are equally important and must be investigated. The consequence of internal drivers is that even in quiet solar wind conditions, there can be significant variability within the MIT region.

Geospace is the location of most of our space activities. Communication, navigation, Earth weather and remote sensing, emergency location, defense reconnaissance, and NASA missions are all affected by space weather. Space weather also causes disturbances of electric power grids and sensitive electronic systems on the ground. These include navigation systems used by commercial airliners. The technological systems sensitive to disturbances in geospace are increasing in importance and urgency to human society.

The detailed nature of the electromagnetic coupling between the inner and outer regimes of geospace is not well understood. We need to understand how mass and energy are exchanged between these regions in quiescent conditions and during disturbed times. Chemistry and pressure forces become increasingly important in understanding linkages with the middle atmosphere, down to 50 km altitude.

Three investigations are associated with this RFA:

Investigation H2.1 - What role does the electrodynamic coupling between the ionosphere and the magnetosphere play in determining the response of geospace to solar disturbances?

Future enabling missions include both geospace storm probes, RBSP and ITSP, MMS, GEC, GEMINI, and MagCon.

SSSC Great Observatory missions supporting this investigation include: *Cluster, IMAGE, Polar, and TIMED.*

Investigation H2.2 - How do energetic particle spectra, magnetic and electric fields, and currents evolve in response to solar disturbances?

Future enabling missions include both geospace storm probes, RBSP and ITSP, MMS, GEC, GEMINI, and MagCon.

SSSC Great Observatory missions supporting this investigation include: *Cluster, IMAGE, Polar, and TIMED.*

Investigation H2.3 - How do the coupled middle and upper atmosphere respond to external drivers and with each other?

Future enabling missions include ITSP, ITM Waves, SECEP, Tropical ITM Coupler.

SSSC Great Observatory missions supporting this investigation include: AIM, IMAGE, Polar, and TIMED.

RFA H3 Understand the role of the Sun as an energy source to Earth's atmosphere, and in particular the role of solar variability in driving change.

Solar energy in the form of photons and particles drives the chemical and physical structure of Earth's atmosphere. For example, ultraviolet and more energetic radiation deposited globally throughout the stratosphere, mesosphere, and thermosphere is responsible for formation of the ionosphere. Also, while particles primarily deposit their energy at high latitudes, the resulting ionization, dissociation, and excitation of atoms and molecules can have a global effect due to dynamical processes that transport energy around the globe. Ultimately these processes combine to drive the temperature and chemical composition of the entire Earth's atmosphere. A key example of how atmospheric modification by the Sun affects life is stratospheric ozone, which acts as a human UV shield. The very existence of the ozone layer is a direct result of solar energy deposition. Nitric oxide created at higher altitudes by processes involving solar energy may be transported to lower altitudes where it can destroy ozone.

Because life depends on the atmosphere and its climate, study of solar energy driven atmospheric variations is critically important. Solar energy and its changes have effects throughout the atmosphere including the troposphere where humans live. Despite this, the strength and variability of atmospheric solar energy deposition remain poorly understood. In addition, coupling processes that spread effects of energy deposition in altitude and latitude are not well understood. Addressing these issues requires spectral observations of solar energy deposition resolved in space and time as well as theory and modeling of dynamical processes that distribute effects of solar energy.

Three investigations are associated with this RFA:

Inves*tigation H3.1 – How do solar energetic particles influence the chemistry of the atmosphere, including ozone densities?*

Future enabling missions are AIM, ITSP, GEC, L1-Monitor, SECEP, ITM Waves, and CNOFS.

SSSC Great Observatory missions supporting this investigation include: IMAGE and TIMED.

Inves*tigation H3.2 – What are the dynamical, chemical, and radiative processes that convert and redistribute solar energy and couple atmospheric regions?*

Future enabling missions are ITSP, GEC, L1-Monitor, SECEP, ITM Waves, and CNOFS.

SSSC Great Observatory missions supporting this investigation include: AIM**,** IMAGE and TIMED.

Inves*tigation H3.3 – How do long term variations in solar energy output affect Earth's climate?*

Future enabling missions are AIM, ITSP, GEC, L1-Monitor, SECEP, ITM Waves, and CNOFS.

SSSC Great Observatory missions supporting this investigation include: IMAGE and TIMED.

RFA H4 Apply our understanding of space plasma physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability.

Plasmas and their embedded magnetic fields affect the formation, evolution and destiny of planets and planetary systems. Our habitable planet is shielded by its magnetic field, protecting it from solar and cosmic particle radiation and from erosion of the atmosphere by the solar wind. Planets without a shielding magnetic field, such as Mars and Venus, are exposed to those processes and evolve differently. And on Earth, the magnetic field changes strength and configuration during its occasional polarity reversals, altering the shielding of the planet from external radiation sources. How important is a magnetosphere to the development and survivability of life? Planetary systems form in disks of gas and dust around young stars. Stellar ultraviolet emission, winds, and energetic particles alter this process, both in the internal structure of the disk and its interaction with its parent star. The role of magnetic fields in the formation process has not been fully integrated with other parts of the process. The study of similar regions in our solar system, such as dusty plasmas surrounding Saturn and Jupiter, will help explain the role of plasma processes in determining the types of planets that can form, and how they later evolve.

Four investigations study how and when planets become habitable:

Inves*tigation H4.1* - *What role do stellar plasmas and magnetic fields play in the formation of planetary systems?*

Future enabling missions are SDO, Solar Probe, RBSP, ADAM, Jupiter Polar Orbiter/Juno, Stellar Imager.

Future contributing missions are Widefield Infrared Survey Explorer, Space Interferometry Mission, Terrestrial Planet Finder, and the James Webb Space Telescope.

SSSC Great Observatory missions supporting this investigation include: TIMED.

Inves*tigation H4.2* - *What is the role of planetary magnetic fields for the development and sustenance of life?*

Future enabling missions are ITSP, GEC, SDO, L1 Monitor, ADAM, and the Venus Aeronomy Probe.

SSSC Great Observatory missions supporting this investigation include: TIMED and ACE.

Inves*tigation H4.3* - *What can the study of planetary interaction with the solar wind tell us about the evolution of planets and the implications of past and future magnetic field reversals at Earth?*

Future enabling missions are: ITSP, GEC, SDO, L1 Monitor, ADAM, L1 Mars, VAP.

SSSC Great Observatory missions supporting this investigation include: ACE and TIMED.