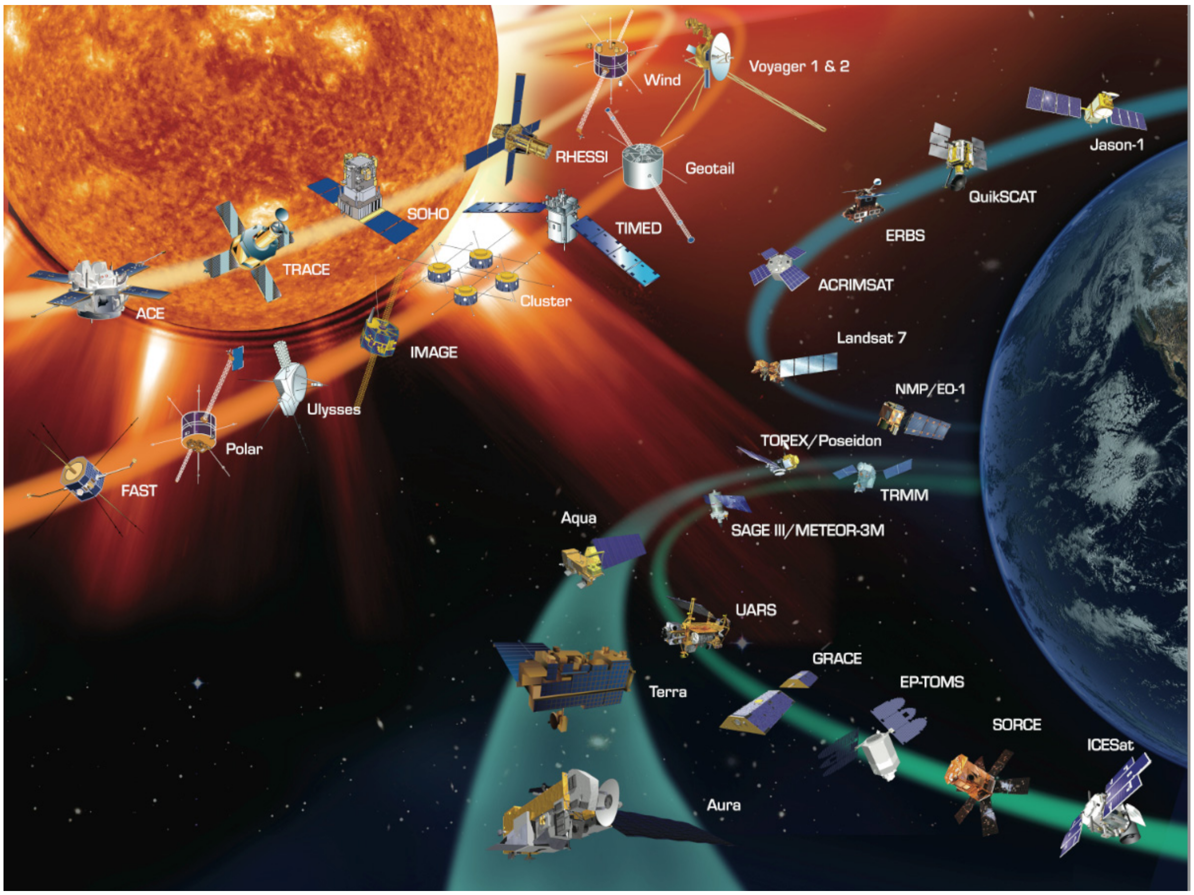
# GSFC Earth-Sun Exploration Division

## Activities, Challenges, and Strategic Plan




# Our Mission

## "To Improve Life on Earth and to Enable Space Exploration through the Use of Space-Based Observations"

**October 2005**

**National Aeronautics and Space Administration**
**Goddard Space Flight Center**
**Greenbelt, MD 20771**

# Table of Contents

# Preface

Welcome to the first description and strategic plan of the Earth-Sun Exploration Division (ESED) at the Goddard Space Flight Center (GSFC). This Division, Code 610, was created in January 2005 and consists of all of the Earth science elements of the previous Earth Sciences Directorate, the old Code 900, minus the solid Earth and planetary components and the laser remote sensing branch, but with the addition of the solar and space physics parts of the Space Sciences Directorate, the old Code 600. The ESED organization roughly mirrors the present Headquarters (HQ) organizational structure of the Science Mission Directorate (SMD).

Many things have taken place since the last report for the old Earth Sciences Directorate was written in September 2003. The last two years have been a complex and uncertain time, with the unprecedented overlapping of somewhat unrelated events: (1) Full Cost Accounting (FCA); (2) the new financial management system, (3) concern that the National Oceanic and Atmospheric Administration (NOAA) activities may impinge on climate areas that we have historically studied; (4) the new Presidential Exploration Initiative and its potential impact on science funding at NASA; (5) the reorganization both at HQ and at Goddard; (6) the yet to be determined impact of the Decadal Survey that is being carried out by the National Academy of Sciences to define missions and research activities in NASA and NOAA; and (7) last but certainly not least, the funding situation, especially for Earth Sciences programs, by Congress. All of these issues are discussed in this document.

This document is divided into two parts. The first part is a description of the Division, its internal components, processes, and management challenges. The second part describes our intellectual focus and strategic plan. The Executive Summary highlights the main points of the document. Although the overall NASA strategic plan is the responsibility of NASA Headquarters, it behooves us to emphasize which areas we want to focus our energies and capabilities on which is the subject of Section II.

The general form of this document is as follows: Who are we? What are we doing? What do we want to do? How are we going to do it? Strictly speaking the last question is not strategic but tactical, a strategic plan is not very useful if its implementation is unattainable. Thus the last question, basically an implementation plan, provides a sanity check on the strategic plan elements.

As Dwight D. Eisenhower wrote *"... I have always found that plans are useless, but planning is indispensable."*

The important part of generating the strategic plan part of this document is not the plan itself but the concentrated focus by the authors on what the vision of ESED will be and how we are going to carry it out. The strategic plan as a whole will probably have a short lifetime, but elements of the plan and the vision of what we are and what we do will influence our approach to new opportunities and ongoing initiatives beyond the specific plan.

There is never a convenient time to develop a document like this. However, right now the Earth sciences component of our Division is, as mentioned above, at a crossroads. With the launch of Earth Observing System (EOS) Aura, the EOS program has changed focus from mission implementation to mission operations and data analysis. In addition, the reorganization that created ESED has broadened our scientific focus to include the Sun and the response of the Earth's high altitude plasma environment and upper atmosphere to solar variability. Thus developing a strategic plan now is of utmost importance.

Many people have contributed to this document. The tireless leadership of Mark Schoeberl of the Strategic Planning Team was essential. The time, energy, and creativity that Mark devoted to the project were a great incentive for all members of the team over the last several months. These members include: Waleed Abdalati, Bob Connerton, Jim Gleason, Shahid Habib, Jim Hansen, Peter Hildebrand, Tom Moore, Paul Newman, Doug Rabin, Lorraine Remer, Michele Rienecker, Lars Peter Riishojgaard, Mike Seablom, Darrel Williams, Warren Wiscombe, and Dot Zukor. They met almost weekly for several months. Many other managers, scientists, and engineers of the Division have made comments and contributed sections to

this document. I would rather not mention them by name for fear of forgetting someone. Diane Elben also contributed to the activities of the committee, compiled most of the data in the report, and formatted the entire document. To all I express my gratitude.

Franco Einaudi
Director of the Earth-Sun Exploration Division

# Executive Summary of the ESED Strategic Plan

Earth-Sun science is conducted at NASA because NASA provides the infrastructure and technology to make significant measurements from space. ESED is the largest Earth-Sun science group within NASA and it falls on our shoulders to serve the science community in developing and implementing new space missions, serving mission data to the community, analyzing the results from these missions and interacting with decision makers and the public. This unique role of ESED is codified in our Mission Statement "*To improve life on Earth and to enable space exploration through the use of space-based observations.*"

There are four overarching Earth Science Questions:

(1) How does the Earth work?
(2) How is the Earth changing?
(3) What are the causes of solar variability and how does the Earth respond?
(4) What do all of these changes mean for life on Earth?

These questions are naturally linked. The first question relies on data taken by satellite and other sensors to focus on individual processes and feedbacks. The second question can be answered using the long-term data sets complied by NASA and NOAA scientists using space observations which began in the mid-1970s. The third question encompasses the possible effects of long-term changes in solar irradiance, the nature of "space weather" and the development of forecast capabilities. The last question involves prediction, the true test of our understanding. It also indicates our role in communicating our results to decision makers.

Members of ESED are working on observations being gathered by a new generation of satellites, the EOS platforms, and next generation solar missions. The EOS era began with the launch of EOS Terra a few days before the turn of the century. The last EOS mission, Aura, was launched in mid-2004. ESED scientists are now working on the most complete and compelling Earth-Sun observational data set ever gathered. Already, significant new discoveries have been made in ocean, land and atmospheric systems. These new data are allowing the improvement of climate, land surface, ocean, weather, cryosphere, and air-quality prediction models that have direct societal applications.

In a similar manner, new measurements of the Sun and its output of light, solar wind plasma and energetic particles, their propagation through the interplanetary medium and the response of the Earth's magnetosphere, thermosphere and mesosphere are being collected by a wide-ranging fleet of spacecraft. The solar, interplanetary and terrestrial missions (e.g., SOHO, Wind, RHESSI, Polar, Cluster, FAST, TIMED, etc.) that are making these observations collectively are termed the "Great Observatory." The Great Observatory is producing the discoveries and helping develop the numerical models that will eventually lead to a national capability to forecast long-term changes in solar irradiance and the massive space storms that originate in the Sun's corona. These storms produce sudden, large increases in energetic particle radiation throughout the solar system which modify the Earth's upper atmosphere and adversely affect robotic and manned exploration missions.

ESED is at the forefront of interdisciplinary science – more and more, we see our planet as one system with the most exciting discoveries occurring at the interfaces between the traditional disciplines. It is from the vantage point of space that the global view of the planet is most compelling. The overall science questions ESED will be attacking are given in Table 1. These science questions are consistent with Earth Science and Applications from Space Strategic Roadmap and the Sun-Solar System Connection Roadmap. Note that the Earth Science roadmaps are currently being revised by the National Academy of Science's Decadal Survey. The Decadal Survey's final report will be available toward the end of 2006. These Earth Science questions are also consistent with the Climate Change Research Initiative (CCRI) launched in 2001 to accelerate progress on the most important issues and uncertainties in climate science.

**Table 1. Major ESED Science Focus Areas**

| Major ESED Research Focus Areas | Administrative area (see Section I.4.1) |
|---|---|
| **Understand the Nature, Origins, and Terrestrial Impacts of Solar Variability** | |
| Understand the long-term variations of solar activity and irradiance that affect Earth's space climate and thermal balance. | 611, 612, 613, 614 |
| Quantify the response of the Earth's mesosphere, thermosphere, and magnetosphere to solar variability. | 612.2, 612.3 |
| Apply new understandings of space plasma physics to the role of stellar activity and magnetic shielding to planetary system evolution and habitability. | 612.1, 612.2 |
| **Understand the Global Carbon Cycle** | |
| Quantify the carbon budget. | 613, 614, and 610.1 |
| Quantify land cover and ecosystem change. | Mostly within 614 |
| Predict the impact of climate change on the biosphere. | 614 and 611 |
| **Understand the Global Water Cycle** | |
| Quantify changes in ice sheets and glaciers. | Mostly within 614 |
| Determine the extent, storage of water and variability of global snow cover. | Mostly within 614 |
| Quantify variability and changes in precipitation, clouds, and water vapor. | 613, 610.1, and 611 |
| Determine the global water cycle and energy cycle budgets and changes associated with climate trends. | 613, 614.1 and 610.1 |
| **Understand/Predict Climate Variability and Change** | |
| 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. | 612, 613, and 611 |
| Predict the ocean circulation changes. | 614 and 611 |
| Predict Long-Term Climate Change due to greenhouse gases and other forcings. | 611 and 610.1 |
| Determine the effect of aerosols and clouds on climate change. | 611, 610.1 and 613 |
| Quantify changes in sea ice. | Mostly in 614 |
| Determine predictability limits for climate from subseasonal to decadal timescales. | 610.1 and 613 |
| Predict regional climate variability. | 611 and 610.1 |
| **Understand/Predict Atmospheric Composition** | |
| Determine the impact of long-range transport on local air quality. | Across 613 and 610.1 |
| Determine the interaction of aerosols, rainfall, clouds, and the large-scale circulation. | 611 and 613 |
| Predict the recovery of the stratospheric polar ozone depletion. | 613 and 610.1 |
| **Enable the Improvement of Weather Prediction** | |
| Determine which observations are likely to have the highest impact on prediction skill. | Mostly within 610.1 |
| Develop technology, instruments, and space missions that will lead to improvements in weather prediction. | Mostly within 610.1 |
| Develop analysis methodologies suitable for assimilation of data into predictive models. | Mostly within 610.1 |

**Table 1. Major ESED Science Focus Areas (continued)**

| Major ESED Research Focus Areas | Administrative area (see Section I.4.1) |
|---|---|
| **Understand the Fundamental Processes Necessary to Support Space Weather Prediction** | |
| Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms. | 612.1, 612.2, 612.3 |
| Understand the plasma processes that accelerate and transport particles. | 612.1, 612.2, 612.3 |
| Understand the role of plasma and neutral interactions in nonlinear coupling between the thermosphere and magnetosphere. | 612.2, 612.3 |
| Develop models and forecast tools for solar flares and coronal mass ejections, their propagation through the heliosphere, and the response of geospace to extreme solar events. | 612.1, 612.2 |
| **Safeguard our Outward Journey** | |
| Characterize typical and extreme space environments to be encountered by robotic and manned exploration missions. | 612.1, 612.2, 612.3 |
| Develop the capability to predict the origin and onset of solar activity and disturbances that produce potentially hazardous space weather events. | 612.1, 612.2, 612.3 |

While ESED is in a good position to respond to opportunities regarding the listed research activities, strategic hires discussed in Section II and summarized in Table 5, shown later, will strengthen the program considerably. In Section II, we detail our specific activities and plans with regard to the science questions in Table 1. These plans vary from research group to group as the science focus itself varies, but all of the plans discuss strategies to analyze remote sensing data and/or improve models that can be verified using such data. Ultimately this kind of analysis will reduce uncertainty in model predictions of weather, climate change, solar variability, the near-space environment and will impact health and safety of the people on our planet and of the astronauts making the journey outward.

With the launch of EOS Aura in 2004, the EOS era has reached its peak, but by 2010 all of the EOS spacecraft will be beyond their planned lifetime. It is time to begin the next generation of space observations, observations that will answer the new science questions developed from EOS measurements and observations that will use the new technologies that have been developed over the last 10 years. These next generation missions also need to track our changing planet: Are ice sheets continuing to melt? Is air quality getting better? Is the ozone layer recovering? Will the next solar cycle be different from the last? Table 2 lists NASA space missions approved for launch in the next five years. Starting around 2010, many measurements made by the current EOS instruments will be continued by the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the European Organization for the Exploitation of Meteorological Satellites (EUMetSat) series.

Beyond 2005, the Sun-Solar System Connection community also has a series of important new missions (Table 2). These missions include Solar B, Solar-Terrestrial Relations Observatory (STEREO), Solar Dynamics Observatory (SDO), Time History of Events and Macroscale Interactions During Substorms (THEMIS), Aeronomy of Ice in the Mesosphere (AIM), Radiation Belt Storm Probes, and Magnetospheric MultiScale. These missions will reveal the roles of magnetic field intensity and topology on energy release and transport in the solar coronal and the terrestrial magnetosphere, how large coronal flares and mass ejections accelerate charged particles and propagate though the “heliosphere” (i.e., interplanetary space) and how these solar drivers produce large variations throughout “geospace” from the high altitude magnetosphere down to the mesosphere.

## Table 2. Near-Term Approved Missions

| Mission Name | Launch Date | Science Focus |
|---|---|---|
| ***Earth Science*** | | |
| CALIPSO | Early 2006 | Aerosol/ Cloud height |
| CloudSat | Early 2006 | Cloud particles |
| NPP | 2007 | Multiple instruments for land, atmosphere and ocean science – NPOESS precursor |
| OCO | 2007 | Carbon dioxide |
| Glory | 2008 | Aerosols |
| Aquarius | 2008 | Ocean salinity |
| Hydros* | 2010 | Soil moisture |
| ***Solar and Space Physics*** | | |
| C/NOFS | 2006 | Ionospheric turbulence; communication and navigation outages |
| AIM | 2006 | Noctilucent cloud formation and long-term variability |
| STEREO | 2006 | Propagation of coronal mass ejections |
| THEMIS | 2006 | Magnetospheric substorms |
| Solar-B | 2007 | Solar magnetic fields and convection |
| SDO | 2008 | Helioseismology; origin of coronal mass ejections |
| IBEX | 2009 | Interstellar Boundary Explorer |
| TWINS | 2006 | Imaging magnetosphere plasma cloud and geospace storms |

Because mission development takes at least five years, we must look beyond 2010 in our planning process and sometimes much longer. To propose new missions we must prepare carefully. This preparation includes investing in new technology and engineering, crystallizing science questions, making suborbital measurements, and simulating processes in Earth and Space system models. Part of this document is devoted to suggestions on the improvement and coordination of these processes.

## Challenges and Opportunities for ESED

Our first challenge is to retain a vibrant creative workforce. Figure I.5.2 shows that nearly a fifth of the ESED workforce can retire within the next five years. The figure also shows that about one tenth of our workforce is between ages 30-40. If the hiring is not increased, the total civil servant workforce will drop by two thirds in the next 30 years. Table 5, shown later, outlines our immediate hiring needs.

The second challenge is also an opportunity. The NASA Exploration Initiative emphasizes the outward journey, first to the Moon and then to Mars. Some of the cost of this activity will no doubt come from funds for Earth exploration; however, many of the models and techniques developed for Earth observations are also relevant to observations of the Moon, Mars, and newly discovered extra-solar planets. It is a challenge to ESED to take advantage of the Exploration Initiative opportunities as they avail themselves.

* Funding of this mission is uncertain.

## Development and Management of Long-Term Data Sets

Earth and space observing satellites have been flown by NASA since the mid-1970s. After launch scientists continue to develop algorithms and explore techniques for improving the data obtained from the sensors. This effort often extends well beyond our own satellites and sensors to those launched by other organizations – both domestic and international. In this way, Goddard scientists lead the scientific community in developing a space-based understanding of the Earth and solar environments.

Over time, the collection and reprocessing of the data from these early sensors and the process of combining data from more recent sensors with older data has led to the development of what is called "long-term data sets." The scientific community regards these long-term data sets as an important resource. For example, the column ozone data from the first BUV instrument flown on Nimbus 4 in the mid-1970s combined with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS)/ Solar Backscatter Ultraviolet (SBUV), the NOAA SBUV-2 series, Meteor TOMS, Earth Probe (EP) TOMS, up to the recent Aura Ozone Monitoring Instrument (OMI) instrument has provided the stratospheric community with a near continuous measure of changes in the stratospheric ozone layer.

The development of long-term satellite data sets is time consuming, specialized work. Knowledge of both remote sensing and sensor performance is required, and these data sets also incorporate ground-based measurements as well. The development of long-term data sets from satellite systems is an appropriate function for NASA, although for some of the Earth science data sets, we expect this activity will eventually transition to NOAA as the NPOESS system comes on-line. We view the maintenance and improvement of these data sets as a serious responsibility of ESED and an important service to the community.

Table 3 below lists some of the key data sets that ESED maintains and the sensor suites from which the data sets are derived. This list does not include all the data sets held or being developed by ESED, but includes those data sets that merge data products from multiple sensors as in the column ozone example given above.

### Table 3. Long-Term Data Sets

| Focus Area | Description of Data Set | Source of Data |
|---|---|---|
| Atmospheric Composition | Satellite ozone data sets – total ozone and ozone profile data set since 1970, surface UVB and aerosol absorption data since 1978. (http://jwocky.gsfc.nasa.gov) | SBUV, TOMS, OMI |
| | Global Aerosol Climatology Project (GACP) data set since 1983. (http://gacp.giss.nasa.gov) | NOAA/AVHRR |
| | Aerosol products for land and ocean since 2000. | Terra, Aqua, MODIS |
| | Aerosol products from ground-based network since 1993. (http://aeronet.gsfc.nasa.gov/) | AERONET |
| Global Water Cycle | Global precipitation data set – global three hourly, daily, and monthly averages precipitation data sets since 1979. (http://precip.gsfc.nasa.gov) | TRMM, SSM/I, geosynchronous IR observations, TOVS data, and rain gauges |
| | ISCCP cloud products since 1983. (http://isccp.giss.nasa.gov) | International constellations of weather satellites |

**Table 3. Long-Term Data Sets (continued)**

| Focus Area | Description of Data Set | Source of Data |
|---|---|---|
| Global Carbon Cycle | Satellite ocean color and biology data sets – global ocean chlorophyll concentrations, optical attenuation coefficients, and water-leaving radiances beginning in 1996. (http://oceancolor.gsfc.nasa.gov/) | Routine global data from OCTS, SeaWiFS, MODIS; Sparse global sampling from CZCS (1978-1986) |
| | Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI) data set since 1981. (http://glcf.umiacs.umd.edu/data/gimms) | NOAA/AVHRR |
| | Land surface albedo since 2000. | Terra, Aqua, MODIS |
| Climate Variability and Change | Global radiation budget data sets – short-wave and long-wave radiative fluxes at the surface, top-of-atmosphere, and other levels since 1983. (http://isccp.giss.nasa.gov/projects/flux.html) | ISCCP data set combined with TOVS, SAGE, TOMS, and other satellites |
| | Total solar irradiance since 1978. | Nimbus-7 ERB,ACRIM I, II, ACRIM III, SORCE, SOHO/VIRGO |
| | Sea Ice extent, concentration, and type (ESMR since 1973; SMMR since 1978). | ESMR (extent only), SMMR, SSM/I, and AMSR |
| | Ice sheet elevation changes since 1978. | SeaSat, ERS-1/2, Envisat, ICESat, airborne laser altimetry |
| | Spatial extent and water equivalent of snow. | AVHRR and MODIS SMMR, SSM/I, AMSR |
| Solar wind – magnetosphere | Single 1963-2005 data set with hourly solar wind magnetic field, plasma, energetic proton, and geomagnetic activity index data inter-calibrated. (http://omniweb.gsfc.nasa.gov/) | ACE, Wind, All 9-IMP's, ISEE-1, ISEE-2, Prognoz, HEOS, OGO 5, Vela |
| Heliospheric plasma and magnetic field | Commonly formatted, spacecraft-specific magnetic field and plasma data sets for >140 spacecraft-years spanning 1962 - 2005. (http://cohoweb.gsfc.nasa.gov/) | Ulysses, 2 Voyagers, 5 Pioneers, Helios-1, Helios-2, Mariner 2. |
| Solar Flares | X-ray and gamma ray intensity histories and spectra, 1980 – 1989, 1991 – 2000, 2002 to present. | SMM, CGRO, RHESSI |
| Coronal Mass Ejections | Times, locations, and velocities of CMEs, 1980 – 1989, 1996 to present. | SMM, SOHO |
| Solar Magnetic Field | Photospheric magnetograms, synoptic maps, and computed coronal fields since 1973. | SOHO combined with ground-based data |
| Solar Interior Structure | Helioseismic mode frequencies and widths since 1995. | SOHO combined with ground-based data |

## Winning New Business for ESED

As part of our strategic plan, we intend to develop a small staff specifically devoted to responding to new science mission opportunities and improving our coordination with the Mission Support and Engineering Directorates. This group will also coordinate the expenditure and application for Bid and Proposal (B&P) funds, coordinate with the Center's New Business Office (NBO), and review the ongoing new business activities. The current list of new missions and concepts under development within ESED along with the technology requirements are shown in Table 4 and briefly described in Section II.2.2. Notional and approved missions derived from NASA HQ roadmaps are given in Appendix VI.

## Table 4. Future ESED Satellite Science Missions

This table illustrates the connection between the science themes and the technology investments. The mission acronyms are described in Section II. The mission opportunities [either Earth System Science Pathfinder (ESSP) or "Roadmap" indicates the mission appears on a HQ roadmap] are given when relevant; no opportunity is given if the mission has already been selected. The term "roadmap" indicates that the mission is either on the Earth Science or the Solar Science/Space Physics roadmap given in Appendix VI.

| Major Research Focus Area | Science Objective | Measurement Objective | Mission-Opportunity | Technology Investment |
|---|---|---|---|---|
| Understand the Global Carbon Cycle | Quantify the carbon budget. | Accurate assessment of carbon sequestration on land and ocean | BIOMM - ESSP | Pulse resolved lidar |
| | | | Flora* - ESSP | Hyperspectral Imager |
| | | Quantify $CO_2$ amounts. | $CO_2$ Profiler – mission – Roadmap | Laser profiling of $CO_2$ and $O_2$ column |
| | | | $CO_2$ Column – mission – Roadmap | Passive FP Imager for $O_2$ and $CO_2$ |
| | | Ocean Carbon Assessment | OCEaNS - ESSP | UV/Vis Imager |
| | Quantify land cover and ecosystem change. | Vegetation Biomass | BIOMM - ESSP | Vegetation Canopy Lidar |
| | | Vegetation Recovery | Flora* - ESSP | Hyperspectral |
| | | Quantify light use efficiency and evapo-transpiration | GEOTRACE - Roadmap | High resolution Imaging spectrometer (GEO) |

* Joint with JPL

**Table 4. Future ESED Satellite Science Missions (continued)**

| Major Research Focus Area | Science Objective | Measurement Objective | Measurement - Mission Category | Technology Investment |
|---|---|---|---|---|
| Understand the Global Water Cycle | Quantify changes in ice sheets and glaciers. | Ice sheet height and thickness | Altimetry of Ice Sheets - Roadmap | Topographic Lidar |
| | | | Ice sheet Thickness-Roadmap | Radar |
| | Quantify surface water storage and discharge. | Surface water height and flow | WatER-Roadmap | Laser altimetry |
| | Quantify global soil moisture. | Soil microwave emission and backscatter | HYDROS* | Active/passive μ-wave |
| | Quantify ground water storage and exchanges. | Ground water volume changes | GRACE-II-Roadmap | Earth gravity mapping |
| | Determine the extent, storage of water and variability of global snow cover. | Snow and ice cover | CLPP*- ESSP | Active/passive μ-wave |
| | Quantify variability and changes in precipitation, clouds, and water vapor. | Rainfall | GPM*-Roadmap | Active radar, passive μ-wave |
| | | Atmospheric water vapor | GIFTS - NMP | Geostationary IR imager |
| Understand/ Predict Climate Variability and Change | 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. | Total Solar Irradiance | Glory | Active cavity radiometers |
| | | | Janus | Solar observing sensors |
| | Predict the ocean circulation changes. | Salinity | Aquarius* | Active/passive μ-wave |
| | Assess changes in sea ice and their associated implications for climate. | Sea ice freeboard height | Altimetry of sea ice Roadmap | Topographic lidar and radar |

* Joint with JPL

**Table 4. Future ESED Satellite Science Missions (continued)**

| Major Research Focus Area | Science Objective | Measurement Objective | Measurement - Mission | Technology Investment |
|---|---|---|---|---|
| Understand/ Predict Atmospheric Composition | Determine the effect of aerosols and clouds on climate change. | Earth Radiation Budget | Janus Geo-Trace | UV/Vis imagers |
| | | Aerosol effects on cloud properties | CLAIM-3D – ESSP | Passive imagers/ polarimetry |
| | Determine the impact of aerosols on climate forcing. | Aerosol optical properties, composition and size distribution | Glory | Passive imagers/ polarimetry |
| | Predict Long-Term Climate Change due to greenhouse gases and other forcings. | Cloud ice for validation of climate models | SIRICE* – ESSP | High frequency µ wave radiometer |
| | Determine the impact of long-range transport on local air quality. | Column ozone and aerosols | Janus - Roadmap | UV/Vis/NIR imaging @ L1 |
| | Predict the recovery of the stratospheric polar ozone depletion. | Column ozone and aerosols | GEOTRACE - Roadmap | UV/Vis/NIR imaging |
| Enable the improvement of weather prediction | Determine the interaction of aerosols, rainfall, clouds, and the large-scale circulation. | Aerosol effects on cloud properties | CLAIM-3D - ESSP | Passive imagers and polarimeters |
| | | Distinguishing anthropogenic and natural aerosols and their effects on climate | Advanced aerosol mission – Roadmap | Multi-angle spectropolarimetric imaging (LEO) and scanning aerosol profiling (LEO) |
| | Develop technology, instruments, and space missions that will lead to improvements in weather prediction. | Polar meteorology | Molniya-ESSP | Vis/IR Imager |
| | | Tropospheric winds over land and ocean | Global tropospheric winds – Roadmap | Lidar measurements from either aerosol or molecular backscatter (LEO) |

* Joint with JPL

## Table 4. Future ESED Satellite Science Missions (continued)

| Major Research Focus Area | Science Objective | Measurement Objective | Measurement - Mission | Technology Investment |
|---|---|---|---|---|
| Understand the Fundamental Processes Necessary to Support Space Weather Prediction - and - Safeguard our Outward Journey | Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms. | Measure reconnection in situ and observe remotely | STEREO Solar-B THEMIS SDO MMS | High-resolution spectral imagers (gamma ray to visible); constellations |
| | Understand the plasma processes that accelerate and transport particles. | Measure energetic particle spectra | RBSP Heliostorm GEC | Constellations; solar sails |
| | Understand the role of plasma and neutral interactions in nonlinear coupling of regions throughout the solar system. | In situ and remote sensing | STEREO IBEX RBSP GEC | Advanced neutral winds analyzer; miniaturized plasma instrumentation |
| | Understand the creation and variability of magnetic dynamos and how they drive the dynamics of solar, planetary, and stellar environments. | Measure magnetic fields and their effects on particles | Solar-B SDO GEC | Helio-seismographs and magnetographs; ultra-high resolution imagers |
| Understand the Nature, Origins, and Terrestrial Impacts of Solar Variability | Understand the causes and evolution of solar activity that affects Earth's space climate. | Observe flares, coronal mass ejections, and their effects | STEREO Solar-B SDO Heliostorm Janus | Constellations; High-bandwidth communications |
| | Determine changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects. | Measure magnetic and electric fields and particle distributions | RBSP MMS GEC TWINS | Neutral atom imaging refinements |
| | Apply our understanding of space plasma physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability. | Measure magnetic fields and the solar wind | SDO RBSP GEC | High-bandwidth communications |

* Joint with JPL

From the modeling viewpoint, ESED stands at the forefront of atmosphere, land surface, ocean, and space environment modeling as well as satellite data services. With proper leadership and collaborative partners, ESED could move forward toward the development of an Earth System Model.

## Strengthening Strategic Areas and New Hires

The exciting and interdisciplinary nature of ESED work attracts scientists from all over the globe. With our aging work force, we expect staff turnover to rise within the next few years. Table 5 shows a distillation from Section II of our hiring needs for the next few years. This table is an evolving document whose implementation depends on many factors, including the rate of retirement and the rate of winning missions and research proposals. The ESED needs to develop an aggressive recruiting/retention plan for new hires and for retaining critical personnel that should include some of the following elements:

*(1) Long-term hiring plan*
The Division needs to think down stream and specify the kinds of hires it will need in the next five years and begin developing a strategy for filling those positions before (not after) vacancies occur. Table 5 describes only the most critical and current staffing needs. Based on changing priorities and on the aging staff demographics (Figure I.5.2), the longer-term view for the Division requires that we plan for a science priority-driven replacement of 30-50% of our science staff over the next five years.

*(2) Use of different hiring strategies*
NASA has special programs for hiring individuals that ESED does not use to full potential. They include: Exceptional Hires – four-year hire at salaries above the GS level. Intergovernmental Personnel Actions (IPAs) – temporary hires from University or Industry, and the Internship Program –usually includes student engineers, but could also include individuals who want a break from their academic career.

*(3) Recruitment/Retention Package*
This package would provide tangible benefits such as quality office space and start up funding for new recruits. For existing employees, sabbatical programs, proposal cost sharing, and fast track promotions would aid in retention. In the near term, we intend to develop an ESED brochure that highlights the science activities within ESED.

## Table 5. Hiring Needs within ESED

Hiring needs, distilled from this strategic plan, are shown below. Critical hires are in bold.

| Scientific Area | Hiring Need | Plan Section |
|---|---|---|
| Atmospheric hydrologic processes | Aerosol, cloud and precipitation physics, remote sensing, and modeling expert – 1 hire | II.1.1.1.3, II 1.1.1.4 |
| | Assimilation of cloud and rain-impacted data – 1 hire | |
| Atmospheric Physics Cloud modeler | Improve the current generations of cloud models – 1 hire | II.1.2.4 |
| Cloud/Aerosol Microphysics and Remote Sensing | Develop improved capability to use remote sensing data to determine cloud properties – 1 hire | II.1.2.4 |
| | Improve physics of global climate models using satellite observations and cloud resolving models – 1 hire | |
| **Cryospheric Processes** | Remote sensing based ice sheet modeling and sea ice/air-sea exchange science – 2 hires | II.1.2.2 |
| **Earth system model and assimilation system** | Develop next generation modelers for Earth system science and develop expertise for assimilation within the complex interacting Earth system – 3 hires, one each of atmosphere, ocean, and land | II.1.4 |
| **Geostationary Satellite Expert** | Specialist in geostationary observations from space to work on the NOAA GOES R project – 2 hires | II.2.3.2 |

**Table 5. Hiring Needs within ESED (continued)**

| Scientific Area | Hiring Need | Plan Section |
|---|---|---|
| Global vegetation dynamics mapping | Terrestrial Ecologist with strong quantitative remote sensing background using satellite imagery – 1 hire | II.1.3.3 |
| Helioseismology | Needed for interpretation of SDO data – 1 hire | II.1.5.5.3 |
| Ionospheric Dynamics | Theorist required to complement experimental program and to bridge space and atmospheric dynamics – 1 hire | II.1.5.3 |
| Land surface hydrology | Evaluate global water cycle budget and two major components: storage of water in snow, and land surface water storage and discharge – 3 hires | II.1.2.3 |
| **Magnetic fields** | Vector magnetometry instrumentation specialist for both solar, space and planetary exploration missions – 1 hire | II.1.5.1, II.1.5.2, II.1.5.3 |
| Magnetohydrodynamic Theory | Needed to regain critical mass for Sun-Solar System Connections Theory Program – 2 hires | II.1.5.1-3 |
| Neutral Atom Imaging Spectroscopy | Growth area in which Goddard has led (IMAGE, TWINS, IBEX) and should continue to lead (GEMINI) – 1 hire | II.1.5.2 |
| **Observing System Simulation Experiments** | Synoptic meteorologist to lead development of the technique to quantify potential impact of new space-based observations – 1 hire | II.1.4.1 |
| | **Develop a robust infrastructure for OSSEs and linkages to emerging mission concepts – 1 hire** | |
| Ocean Biology | UV/Vis imager remote sensing of ocean biology specialist – 1 hire | II.1.3.1.2 |
| **Physical Oceanography** | Physical oceanographers to provide expertise in modeling and interpretation of Aquarius salinity, air/sea interaction and ocean altimetry data – 3 hires | II.1.2.1 |
| Precipitation | Radar remote sensing of precipitation specialist – 1 hire | II.1.2.4 |
| **Solar Forcing of Climate** | Needed in the areas of solar spectral variability, influences on climate, geology or geochemistry, shortwave radiative transfer and atmospheric interactions to form a group of critical mass – 3 hires | II.1.4.5 |
| **Tropospheric Chemistry** | Use and develop improved tropospheric chemistry models for assimilation of Aura data and for future tropospheric chemistry missions and instruments – 2 hires | II.1.1.1.2 |
| **UV-Vis Instrument Specialist** | UV-Vis Image spectrometers using state-of-the-art sensors to provide crosscutting instrument technology for both Earth and Solar/Space Science – 2 hires | II.1.1.1.1 |
| | **Total Number of Hires = 36** | |

## ESED Education and Public Outreach

Education and Public Outreach (EPO) is a significant function within ESED and communication of our results to the public and decision makers is a core function. We must translate our science into clear, understandable concepts. Within ESED, this plan raises EPO activities to a high degree of visibility at the Division level. As with the NBO, described above, this EPO panel will coordinate education and public outreach plans and opportunities. Reviews of ongoing activities will take place quarterly.

## Implementation and Updates of Our Strategic Plan

Strategic planning must take place continuously. Although this document is intended to provide an assessment and a five-year plan, NASA is an agency imbedded in a political organization. Within the next five years, there will be a new head of the Executive Branch and NASA's mission may be broadened, restricted, or shifted. New directions in Earth Science will emerge next year with the completion of the National Academy of Sciences decadal survey. We believe that a new version of this plan should be issued every two to three years. This will allow us to incorporate new opportunities and develop responses to new pressures on the organization. Immediate needed revisions of sections of this plan should be produced as needed – in other words, the plan should be a living document.

We also recommend that a few members of the strategic planning committee form the nucleus of an implementation committee whose goal is to help implement specific recommendations in this plan, to track what works and does not work, to identify where adjustments need to be made, and to update sections of the plan as needed.

# I. The Earth-Sun Exploration Division

## I.1 The NASA Vision and Mission

NASA GSFC Earth, Solar, and Space Science are all part of the NASA Vision and Mission.

***The NASA Vision***
***To improve life here,***
***To extend life to there,***
***To find life beyond.***

***The NASA Mission***
***To understand and protect our home planet***
***To explore the universe and search for life***
***To inspire the next generation of explorers***
***...as only NASA can.***

The phrase "as only NASA can" that appears in the NASA mission statement has resulted in a continuing debate on which activities are appropriate for NASA. "Why NASA?" is a particularly significant question in Earth-Sun and Space science since other agencies have involvement in and responsibility for the operational monitoring and prediction of the Earth-Sun system. Understanding where NASA's role begins and ends is critical to developing a Strategic Plan.

The ability and flexibility to respond to new and evolving science questions and to take global measurements that have not yet been identified as requirements by operational agencies is critical to understanding global environmental change and improving predictions. Thus, the reason scientists are employed at NASA is to support additional crucial space-based measurements of our planet and of the space domains of interest to human and robotic exploration. For example, within the Earth science domain, two Presidential directives for NASA to participate in are the Climate Change Science Program (CCSP), and the international Global Earth Observation System of Systems (GEOSS) underscore the legitimacy of this perspective and the legitimacy of Earth Science activities at NASA. A similar mandate for NASA Space Science derives from the President's Vision for Space Exploration, which requires a thorough understanding of the medium through which explorers might travel to their destinations.

The ESED follows an end-to-end approach in studying the Earth-Sun system that goes beyond the formulation of new missions and the development of attendant cutting edge technologies to the delivery of validated data to the scientific and operational communities. The end-to-end mission is not complete until the measurements gathered by NASA's satellites are turned into information that is useful – either by expanding human understanding, or by providing immediate value to society. Examples of the latter are measurements applied to weather or space weather forecasting. Measurements become useful only after validated physical parameters are extracted from the raw observations and their scientific implications are understood. The observations reveal new phenomena and they are used to define fundamental physical and chemical processes. The ultimate test of the quality of the data is the ability to combine the observed information with models to describe and understand the current and past state of the environment and its variability sufficiently well that it can confidently be applied to predict the future. The observations are, therefore, vetted by scientists whose collective expertise must encompass knowledge of both the instrument qualities and the theories of Earth and space science. The scrutiny of the observations, in a hierarchy of validation steps and data analysis applications, gives NASA-funded scientists, both at NASA Centers and across the entire research community, confidence in the utility and accuracy of the measurements. These scientists then become the first to communicate these results to the broader community, initiating the diffusion of information of NASA's technological innovations into society as a whole.

NASA data stand at the foundation of a set of science questions and predictive applications used by many government agencies. As an enabling organization, in partnership with operational agencies that rely on quality environmental data to execute their missions, NASA supports the technological transfer from research to applications, thus facilitating the incorporation of new knowledge and tools into services these agencies provide to the Nation. This technology transfer results in new and more capable instruments, more resilient and reliable spacecraft, and cutting edge data processing and analysis techniques. The research instruments deployed by NASA lead to the operational instruments of other agencies, which collect information on a routine basis. The direct use of NASA's research observations by other agencies allows the Nation to realize the advantages brought by NASA's technologies while the operational systems are being developed. NASA's role in this regard is unique across the Federal Government.

The role of the NASA Center is to provide a core competency to conceive, design, and deploy satellite missions that can be used by NASA directly, or used by the broader research community as a resource to enable satellite missions proposed and executed by a mixture of governmental and non-governmental individuals. NASA scientists, engineers and managers form teams whose activities range from defining measurement needs, developing new instruments, and characterizing their in-flight performance, to integrating the data into operational products in support of environmental monitoring and prediction as appropriate, and assessing the new data impact on scientific knowledge. The NASA Centers provide a first-line validation and analyses of the observations, including the incorporation of the observations into models, either directly via assimilation or indirectly via the use of knowledge derived from analyzing the data to improve parameterizations, to testing model performance and predictive skill. The scientists and engineers at the Centers also collect and integrate the knowledge of NASA-funded researchers outside of the centers, and help focus this knowledge on future exploration. Completing the cycle, the scientists at the NASA centers serve as the liaison between the program offices at NASA HQ and the discipline based external/academic community.

## I.2 The Earth-Sun Exploration Division Mission and Goals

There are seven fundamental Earth and Solar Science questions that drive the Earth-Sun Program at NASA HQ and at Goddard's ESED.

**Earth-Sun Science:**

- ***How is the Earth-Sun system changing?***
- ***What are the underlying physical causes of solar variability and dynamic coronal events?***
- ***What are the primary forcings of the Earth climate system?***
- ***How has the Earth system responded to natural and human-induced changes?***
- ***What are the consequences of change in the Earth-Sun system for human life and society?***
- ***How does the Earth's ionosphere and magnetosphere respond to solar variability?***
- ***How well can we predict future changes in the Earth system?***
- ***How can the effects of space weather on astronauts and space-based systems be forecast and mitigated?***

Using our view from space, the Division conducts a broad theoretical and experimental research program to study all aspects of the Earth systems.

The ESED mission and goals are:

***The ESED Mission***

***To improve life on Earth and to enable space exploration through the use of space-based observations.***

***The ESED Goals***

***Advance understanding of the Earth-Sun system through exploration from the vantage point of space.***

***Improve predictions of the Earth-Sun system through measurements and models.***

***Provide leadership in Earth-Sun system science and technology including the development of new instruments, measurement missions and models.***

***Establish partnerships to promote Earth science and Sun-Solar System science.***

***Enhance the nation's scientific and technological literacy.***

Our mission and goals provide the strategic foundation for ESED activities. The challenges for our nation are to have an understanding of the Earth-Sun system and how it is changing and then to predict changes or likelihood of changes. In order to address these two challenges, NASA has developed substantial national assets that include satellites, aircraft, instruments, and people. These assets are programmatically managed by the Earth-Sun Exploration Division at NASA HQ, but are conceived, designed, implemented, and operationally managed at the various NASA Centers, in collaboration with the academic community and the private sector.

The Goddard Space Flight Center has a broad mix of resources for conceiving and flying satellite missions. Goddard has well-recognized strengths in flight dynamics, engineering, scientific management, data production, and data distribution. GSFC has developed and managed a wide range of missions from large multi-instrument platforms like EOS Terra, Aqua, and Aura to small single-instrument satellites like the Earth Probe Total Ozone Mapping Spectrometer. In support of the overall GSFC projects, the ESED provides the expertise behind developing science questions, instrument and mission definition, scientific oversight, and scientific management. A large number of ESED civil servants function as Principal Investigators and Project Scientists for major satellite efforts. Oversight and management of these satellite projects requires a centralized competency of civil servant scientists and engineers. A list of Project Scientists and Deputy Project Scientists is provided in Appendix III.

In order for NASA scientists to function effectively in support of NASA missions, they must maintain their own scientific efforts and continue to publish. First-rate science missions require first-rate scientists and engineers for their conception, design, and implementation. First-rate scientists must be recruited, nurtured, and developed over a number of years to maintain an overall high quality in the work force.

# I.3 Inside the Earth-Sun Exploration Division

## I.3.1 What the Earth-Sun Exploration Division Does

The purview of the Earth-Sun Exploration Division includes:

- the Sun, including its interior, atmosphere, and emissions (electromagnetic and particulate)
- the heliosphere, from the Sun to the heliopause
- the magnetospheres of the Earth and other planets
- the Earth's
    - ionosphere, thermosphere and mesosphere
    - troposphere and stratosphere
    - biosphere
    - cryosphere
    - hydrosphere

Interactions between these components take place at different time scales from a few minutes in cloud evolution and auroral fluctuations to millions or billions of years in tectonic plate motions and solar evolution. ESED scientists do research in all the recognized components of the Earth-Sun system except the solid-Earth which has its home in the Solar System Exploration Division.

Earth-Sun system studies at Goddard follow an end-to-end approach, patterned after the SMD approach at NASA HQ. ESED's scientists play an important role in every aspect of scientific mission development from defining the scientific questions and needed measurements, to developing new technologies for those measurements, to planning space missions, to processing and distributing the data from those missions, to analyzing the data and carrying out related modeling to understand the scientific and practical implications of the data.

Major science areas in ESED are based on core competencies that have their development rooted in the past. Table 1, shown earlier, outlines the core science research focus areas that exist both within the Laboratories and as crosscutting activities. The SMD Focus Areas provide a broad, but not one-to-one mapping onto the objectives shown in Table 1.

We measure the success of our Division by the usual metrics applied to scientific organizations of this size and breadth. Our win rate for proposals, based on selections from the period of July 2004 to October 2005, ranged from 0-55% with an average success rate of 27%. As another measure of our engagement with the community, we report in Appendix IV the number of field campaigns we have led or participated in and the number of workshops we have sponsored from 2004-2005. Appendix V shows the number of professional awards and honors bestowed on our staff.

## I.3.2 Research and Operational Partnerships

Interaction with the national and international scientific community is essential and is an integral part of the Division activities. Scientists in the academic community and in government research laboratories at home and abroad are involved in our research activities, ground-based observational programs, aircraft campaigns and satellite missions. Indeed these programs are often jointly funded by other agencies and co-sponsored by the international community. Our data sets are created with major contributions from the community and serve as a resource for the community.

#### I.3.2.1 Partnerships with the Academic Community

In addition to individual interactions among scientists, the Division has established research institutes with a number of universities around the country for the purpose of involving first-rate scientists in our research activities. A substantial effort is underway to encourage graduate students at these institutes to interact with our scientists, use our data sets, and work with our models.

#### I.3.2.2 Partnerships with Operational Agencies

The ESED is fully supportive of the SMD's goal of optimally exploiting satellite data for operational and application purposes. We recognize the challenge of "Crossing the Valley of Death," [From Research to Operations in Weather Satellites and Numerical Weather Prediction, 2000] a term often used in industry to describe the difficulties of transitioning from research to operations. To address this challenge, we have formed the Joint Center for Satellite Data Assimilation (JCSDA) with NOAA and the Department of Defense (DoD). We recognize the importance of actively cooperating with other operational agencies and transitioning our research techniques and software into decision support tools (see Section I.3.3).

The ESED is also supporting the SMD's Valley of Death challenge in another way. Can data from operational satellites be used to create research quality data sets for answering climate change questions? ESED is home to several measurement teams that have created long-term data sets from combined research and operational satellites (see Table 3). These measurement teams in ESED are preparing to extend their EOS expertise into the NPOESS Preparatory Project (NPP) and NPOESS era.

### I.3.3 Development of Applications for Decision Makers, Technology Transfer and Commercialization of NASA Technology

The Applications Program focuses on providing NASA's space-based observations and predictions to decision makers and service providers both in government and in the private sector. The purpose of NASA's Commercialization and Technology Transfer Program is to successfully spin off NASA developed technologies into the general commercial sector for eventual product development and profit. Indeed, such value-added products may eventually be purchased by the same NASA organizations that initially developed the technology, thereby coming full circle in technology development, transfer and commercialization.

#### I.3.3.1 The Applications Program

Applications initiatives are coordinated by Goddard's Office of Science Utilization [which is in the Sciences and Exploration Directorate (SED), but not in ESED – see Section I.4.1]. This office is responsible for identifying potential applications of SED science discoveries, scientific observations, data analyses, and technology that could benefit other government agencies, industry, and the public. The Office works with Directorate scientists to identify scientific activities that may have potential use, and with external organizations to explore needs, feasibility, and benefits. The primary thrust of the Office is to implement NASA's Applied Sciences Program in partnership with other NASA Centers. The Applied Sciences Program has identified 12 applications of national priority as listed below.

| National Applications | | |
|---|---|---|
| Air Quality | Agricultural Efficiency | Aviation |
| Carbon Management | Coastal Management | Disaster Management |
| Ecological Forecasting | Renewable Energy | Homeland Security |
| Invasive Species | Public Health | Water Management |

A major focus of each area is to partner with an operational agency to identify partner requirements in order to leverage NASA science products for societal benefit.

NASA's Applied Sciences Program's approach, to extend the benefits of NASA science observations and predictions to decision-support tools, is based on fundamental systems engineering principles. The program uses these principles in working with its partners to validate and document integrated system solutions which partners can adopt in their operations and decision making. In collaborating with partners to pursue integrated system solutions, the program employs the functional systems engineering steps of evaluation, verification and validation, and benchmarking.

The ESED has a substantial number of application activities that involve local and regional organizations and some national organizations. Several examples of ESED's applications include:

- Invasive Species
- Public Health
- Air Quality ($PM_{2.5}$) Indexing Benchmark
- Disaster Management
- Water Management
- Carbon Management

In addition to the above programs, Goddard's Office of Science Utilization recently initiated activities that aim at the utility of Space Weather-related research and development within ESED. This new thrust reflects the growing maturity of space science research, the increasing societal needs in space weather forecasting, and NASA's Vision for Space Exploration.

Details are given in Appendix I.

## I.3.4 Education and Public Outreach

Our challenge in EPO is to establish the cognitive and technological "bridges" necessary to effectively share the new data and the new knowledge that we produce. To meet this challenge, ESED actively participates in NASA's efforts to serve the formal and informal education communities at all levels, and to provide data and information to all segments of the public. Sharing the new information that the Division generates is a core part of our overall mission. Our public communications emphasize new Earth-Sun system science results, remote sensing data from NASA's space-based missions, and predictive modeling of the Earth's climate system—all drawing upon assets that are unique to GSFC. Likewise, we recognize that our customers are unique in their needs, wants, and expectations for scientific information. Thus, the Division takes a "customer-oriented" approach to education and outreach by tailoring our communications efforts to meet their needs.

### I.3.4.1 Education

To help develop the next generation of Earth and heliospheric scientists, the ESED supports a number of student programs spanning the full range of the educational spectrum. These programs include:

- Undergraduate and graduate summer programs where students and mentors interact.
- Programs to historically minority universities.
- Adjunct professorships at local colleges and universities.
- Direct support of graduate student research topics that result in mutual advantage to the universities and to the ESED.
- Membership in thesis committees.
- Courses taught by ESED scientists.
- Post-graduate programs.
- K-12 programs.
- Informal education programs.

Details are given in Appendix IIa.

#### I.3.4.2 Public Outreach

The Division's scientists and engineers, working with the Public Affairs Office and NASA HQ, continue to pass their knowledge and interest in Earth and space sciences to the general public by enabling and empowering our communication partners, e.g., museums, science centers, and media providers. Currently the Division makes use of Web-based and multimedia resources as its primary tools for public outreach. The existing activities are described in Appendix IIb.

## I.4 How the Earth-Sun Exploration Division Operates

Because of the interdisciplinary nature of our activities, the ESED generally deals with projects that require the collaborative efforts of many scientists with various backgrounds. These activities are appropriate for a government laboratory that focuses on complex interdisciplinary problems in collaboration with and support of the community at large. The science process follows (more or less) an 11 step process described below. ESED scientists participate in each of these steps:

(1) Defining new scientific questions;
(2) Identifying critical new measurements;
(3) Developing the instrument technology needed for new observations;
(4) Conceiving, formulating, designing, implementing, and participating in day-to-day operations and management of satellite missions;
(5) Planning and managing experimental campaigns to validate satellite data and improve our knowledge of underlying processes;
(6) Developing algorithms to create data sets;
(7) Developing and operating data processing, archives, and distribution systems that facilitate use of NASA science data;
(8) Developing models to create and interpret data sets;
(9) Analyzing data and models to understand the underlying processes;
(10) Developing applications for decision makers;
(11) Providing education and outreach materials to the public.

Steps (1) and (2) take place as part of the scientific community in which ESED scientists are embedded. This usually involves extensive planning and roadmapping with university, other government agencies, and NASA scientists.

Steps (3) and (4) Instrument development and mission design are core functions of the Center that engage its engineering workforce. NASA Goddard's strengths are the technology base for space remote sensing and in-situ measurement capabilities, and the science base for technical development. Goddard scientists and engineers work together in developing new technology, and in developing concepts and designs for instrument systems for orbital and sub-orbital missions. Goddard Project Scientists provide scientific guidance to Project Managers while acting as the interface among the instrument Principal Investigators (PIs), NASA HQ, and the scientific community at large. Developing instruments and designing missions is one of ESED's primary tasks.

Step (5) Planning and managing validation campaigns are significant post-mission launch activities in which ESED is engaged. Remote sensing observations, such as those from satellites, require careful validation. (Validation is the process of proving to the science community that the advertised estimates of measurement precision and uncertainty are correct using correlative measurements.) Intense validation campaigns take place shortly after a satellite is commissioned, but validation activities continue over the course of the mission to ensure that instrumental changes are understood. Validation activities usually involve measurements by ground-based facilities, aircraft, rockets, or balloons during satellite overflights. In coordination with NASA HQ and other NASA Centers, ESED scientists develop validation plans and lead validation missions.

Step (6)  Measurement data sets are developed by teams of instrument algorithm specialists, and the creation of long-term highly calibrated data sets is necessary to study the Earth's climate and the variability of the Sun.  ESED scientists have proven most effective at the task of converting observed signals (e.g. photon counts at a detector) from space-based instruments into the desired physical quantities.  Data reanalysis activities in the U.S. and Europe have shown that inconsistencies in data quality are a large source of uncertainty in the climate record.  Some inconsistencies can be traced to changes in sensor calibration, to sensor degradation, and to algorithm changes.  Developing long-term data records with high enough quality to be used to detect Earth-Sun System changes is an important activity within ESED.

Step (7)  Data and information management systems are a critical component to ensure the availability, accessibility, and quality of mission and research science data products.  Science leadership coupled with technical expertise in information science, information technology, computing engineering, and in specific scientific disciplines is required to make system design and operation decisions that anticipate and address scientific insights and priorities.  Having in-house expertise in these areas reduces data system start-up cost/risk and enables data system evolution to address changing science requirements and priorities.

Step (8)  Numerical modeling and data assimilation provide the only tools that address the prediction and process definition questions of the SMD research agenda.  Models summarize the theoretical underpinnings of our understanding of the Earth-Sun system, integrating across the timescales and research themes.  Data assimilation provides a rigorous method for bringing the observations and models together in a systematic way that balances the information from different sensors and platforms.  It also provides information that has not or cannot be observed.  Assimilation requires core competencies in all aspects of the Earth-system science. ESED scientists are leaders in both global modeling and data assimilation.  Among their many activities, they evaluate new methodologies for assimilating data from specific observing systems, and they aid in the design of new observing systems by performing what are known as Observing System Simulation Experiments (OSSEs).

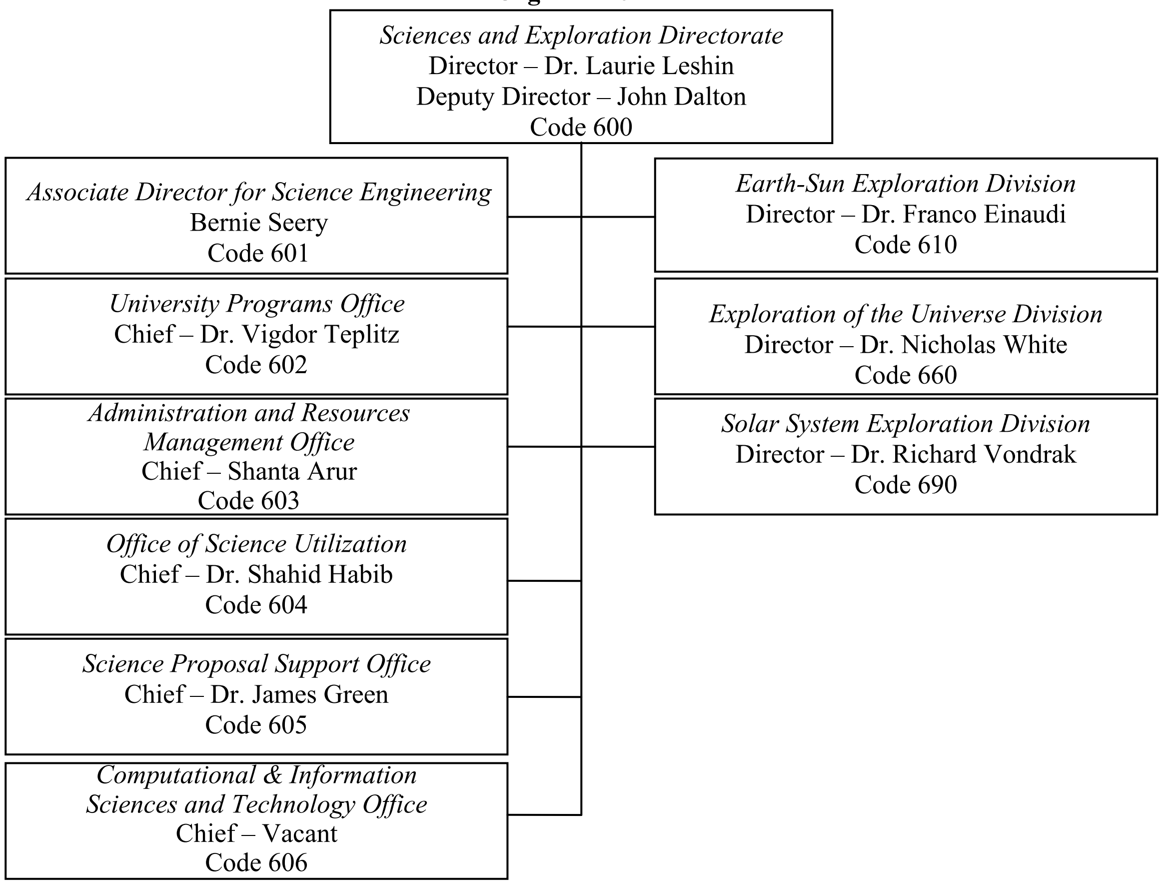
Step (9)  The utility of satellite data, assimilation products, and global prediction models is not fully realized until these can be combined to further our basic understanding of the Earth-Sun system.  Satellite data, alone or in combination with assimilation products, must be analyzed to derive information about the modes of variability of the Earth system and the interactions between climate processes and environmental parameters that control the various feedback loops in the system.  The knowledge gained is then implemented into the models via improved parameterizations to enhance prediction capabilities.  Since many forced and unforced influences may operate simultaneously, innovative approaches to analyzing and comparing large data sets and models must be pursued.  As the home to both data production and model development activities, ESED expertise must serve as an example to the broader community of how to integrate data and models.

Steps (10) and (11)  Applications and education/public outreach are described in the previous sections.

### I.4.1 Organizational and Administrative Structure

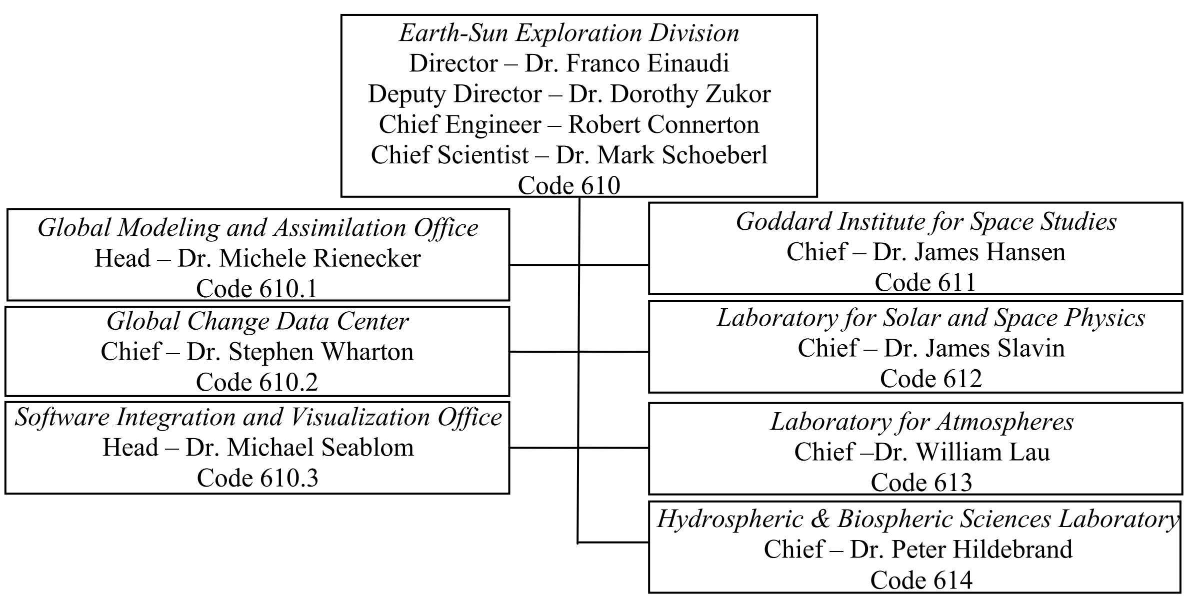
Goddard's SED consists of the ESED, the Exploration of the Universe Division, the Solar System Exploration Division, and a number of support offices. The organizational structure is shown next.

**Sciences and Exploration Directorate Organization**




The Directorate head of SED reports to the Goddard Center Director. This structure roughly mirrors the organization of NASA Headquarters.

**Earth-Sun Exploration Division Organization**



The organizational structures of the Laboratories and Offices are shown in Appendix VII. The administration of the ESED is organized according to disciplines—atmosphere, biosphere, hydrosphere, solar and space physics, data services, and software services/data visualization, and the interdisciplinary modeling and assimilation. Experimental activities are distributed across the Division, with three Laboratories, the Goddard Institute for Space Studies (GISS), and the Global Modeling and Assimilation Office (GMAO), which are all predominantly dedicated to research and technology development. In addition to these areas, the Software Integration and Visualization Office (SIVO) is responsible for advanced software integration, and scientific visualization as a scientific resource for the Division; and the Global Change Data Center (GCDC) leads the development of science data systems for product generation, data management, and distribution for the Division and the Enterprise.

### I.4.2 Crosscutting Themes

As mentioned above, the ESED is formally organized around science disciplines and foci of technical expertise. A comprehensive program in the Division, however, requires integration across these discipline-based organizations. The challenges of effective integration are evident on several levels: Lidar technology, for instance, has the potential to provide breakthrough observations in several Earth and space science disciplines, and lidar activities have grown in these disciplines; scientific discovery often resides in taking observations that describe the interaction of parameters that are traditionally studied in their separate disciplines; finally, all aspects of Earth and space science require modeling to analyze observations and to perform predictions. The interdependencies that must be addressed to perform state-of-the-art experiments and to test scientific hypotheses require the consistent consideration of processes that are, again, traditionally studied in their separate disciplines.

A challenge that confronts the ESED is how to promote the integration across Branches and Laboratories. Strategies are required that advance the integration across disciplines, but that at the same time respect and maintain the rapid and productive progress that is made in discipline-based research.

To respond to these challenges, a series of teams were formed for each of the main areas of activities of the Division, often referred to as crosscutting themes. These are interdisciplinary science teams that cut across the disciplinary organization of the Division, described in this chapter. The responsibilities of these teams include: devise research plans across the Division to answer the scientific questions; prioritize areas of activities and identify hiring priorities; work with engineers to develop measuring requirements and formulate mission concepts; work with HQ to maximize the effectiveness of ESED investments; and help HQ to develop and focus their strategic plans and implementation tactics.

Eight scientific themes have been identified:

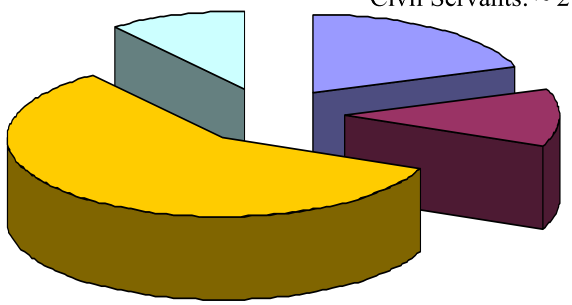
- Aerosols
- Atmospheric Chemistry
- Carbon Cycle
- Global Water and Energy Cycle
- Long-term Climate Change
- Solar Impacts on Climate
- Space Weather Forecasting
- Weather and Short-term Climate Forecasting

These teams have performed at different levels, with some good successes. In the next few months, an analysis will be carried out to determine their effectiveness and their influence on the management of the Division.

### I.4.3 The Workforce Composition

The composition of the ESED workforce has evolved substantially in the last several years, in part because of the general reduction of the civil servant workforce, and in part in recognition of the scientific advantages of increasing the work done through joint institutes with universities.

The relative composition of the ESED Division is summarized below.




The human capital of the ESED includes:

- Civil servants

  *Civil servants* are federal employees who are not part of the military. Civil servants are the core research staff in ESED. This category also includes annual term appointments, civil servant positions that are renewable up to six years. The ESED currently has ~275 civil servants. NASA civil servant scientists are:

  - Research scientists with national and often international reputations.
  - Involved in research activities that match our major focus areas.
  - Largely integrated into NASA's engineering and technical infrastructure for the development, implementation, and operation of missions.

- Scientists from Joint Centers, National Research Council (NRC), etc.

  Most of the non-civil servant scientists come from the Joint Centers that the ESED has established with the University of Maryland at Baltimore County (UMBC), the University of Maryland at College Park (UMCP), George Mason University in Virginia, and Columbia University in New York. Others are Fellows from the NRC or the ESED Visiting Fellows Program. Some of the scientists at the Joint Centers develop their own research activities through proposals written to various agencies including NASA, and thus serve as principal investigators who work cooperatively with the civil servants. See Appendix II.

- Contractors

  A major component of the work force is with the private sector. The contractor workforce includes technicians, programmers, information technologists, engineers, and scientists with MS and Ph.D. degrees.

- Students

  A large number of students are mentored by and work with ESED personnel. In addition to the students who participate in our summer programs, both undergraduate and graduate students are carrying out their research in collaboration with the ESED scientists. About 20% of these students are at GISS. See Appendix II.

# I.5 Challenges and Opportunities

The Earth-Sun Exploration Division faces many challenges; most of them interesting, scientifically and technically. Two significant management challenges have recently developed: difficulties with NASA's switch to FCA, and demographics issues relating to the aging workforce. These are discussed below.

## I.5.1 The Funding Process and Full Cost Accounting

More than 95% of our research activities are supported by NASA Headquarters via competitive proposals or from internal funds for the pre-formulation and formulation mission activities. With the advent of FCA in 2004, civil service (CS) salaries, General and Administrative expenses (G&A), and administrative overhead charges are now included in proposal costs. Prior to this change, CS charges were handled through Center manpower requests to NASA HQ. Thus, in the old financial system the typical civil servant appeared to be "free" in the sense that there was a minimal charge to the customer for actual work. Now, the CS salary funding comes through the NASA HQ Proposal or Program Manager. Although this change appears on the surface to be a zero-sum change—each of the HQ managers should have received an increase in their budget to account for each of the civil servants funded by their program—the situation, in practice, has had a multitude of consequences, many with negative effects.

(1) Not all civil servants have active funding through HQ Program Managers. No mechanism was established to account for their salary except through overhead charges on the Center.

(2) Not all the HQ Program Managers received all of the funds needed to cover the CS costs.

(3) Some HQ Program Managers have treated the increase in their program funds pool (for CS costs) as a funding windfall and refused to increase the funding sent to the Center.

(4) The Center has had a hard time determining its own costs outside of salary and G&A.

(5) The new accounting system, implemented to accommodate FCA, has been unable to track resources to the individual proposal level, thus requiring agglomeration of the funding for many projects into large funding pools. Further, the accounting system is unable to provide reliable monthly reports, thus leaving PIs in the dark as to the status of their research funds.

(6) The manpower planning cycle for the Center is out of synchronization with the funding cycle. The request for manpower projections occurs in the spring. At that point, the Center develops a data base for use in assessments to cover overhead charges, uncovered manpower, etc. If, however, the manpower projection is incorrect, the assessment activity is not able to respond to the new information. This problem is especially irksome when proposals are not funded, yet the Center demands assessments on non-existent manpower.

Prior to FCA, there wasn't a strong incentive for the Center to cut costs and reduce unfunded manpower. With FCA, the CS workforce is under much more pressure to be funded by HQ since unfunded workers are carried on Center overhead and this drives up Center costs - making Center proposals less cost competitive. Keeping Center costs low and our proposals competitive is going to be one ESED's major challenges. A number of Center initiatives are underway to correct these problems, but it will take time during which ESED may experience shortfalls in funding.

## I.5.2 Retention of Skills and New Hires

The ESED faces significant problems relating to its aging CS workforce, coupled with the low number of hires for more than a decade, the reduction in CS workforce in the 1990s, and various freezes imposed by NASA HQ. Adding to this problem are the low CS salaries, which generally fall well below corresponding university salaries, especially in urban areas. The mean age of an ESED CS employee is 53.6 years and the number of retirements in the next 10 years will significantly deplete the core ESED CS staff, particularly in the leadership ranks (see Figure I.5.2).

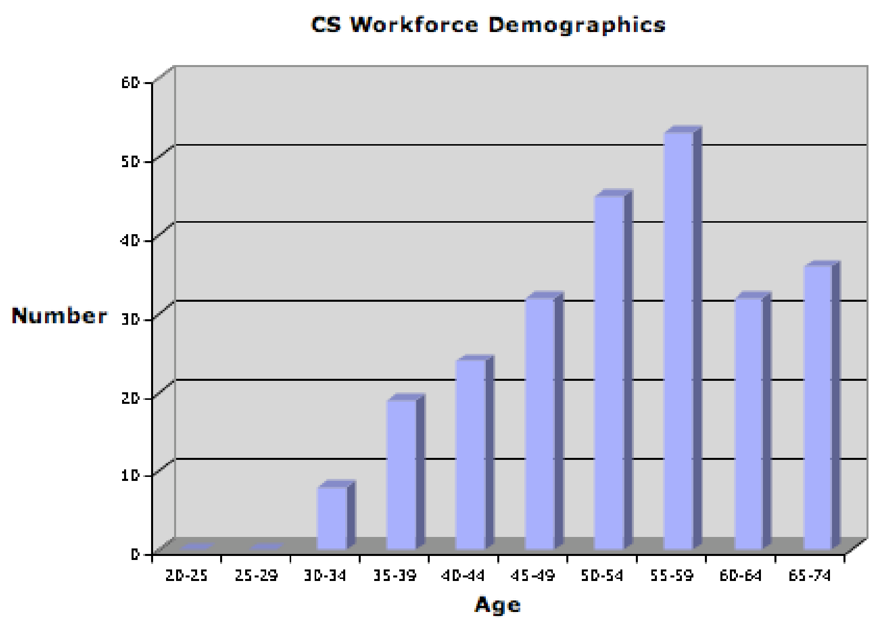



**Figure I.5.2. Demographics for the Division's science/engineering workforce. It is clear that almost half the work force is eligible for retirement within the next ten years, and that there are few young scientists being hired to replace the senior scientists.**

It may take 10 to 15 years for a newly minted Ph.D. to develop the scientific credentials and management skills to lead a major scientific mission. Thus it is crucial that we continue to replace core positions in ESED as retirements occur. Of course the projected loss of staff in the next few years will allow us the opportunity to hire young people in new disciplinary areas, and will likely provide an opportunity to meet the challenges of the future. In the Executive Summary, we suggest key hires and a recruitment strategy.

## I.5.3 The Opportunity to Apply Terrestrial Knowledge to Other Planets

The new NASA Exploration Initiative places a renewed emphasis on understanding conditions on other planets in order to understand the conditions conducive to the emergence of life and to prepare for an eventual enhanced role of humans in space exploration. ESED promotes the perspective of Earth as a planet through its satellite missions and global modeling activities. The extensive expertise of ESED scientists in these areas, as well as the roots that many ESED scientists have in planetary science, should be leveraged to bring that knowledge to bear more fully in the study of other planets. Collaboration with colleagues in the other two divisions in the Directorate and in university planetary science and astronomy departments should be encouraged to explore potential avenues of research.

Within the solar system, ESED expertise in the development and implementation of active remote sensing instruments has many potential applications in planetary research, which has thus far only scratched the surface of the possibilities of radar and lidar observing. Global assimilation techniques refined to optimize the impact of terrestrial satellite data might profitably be applied to development of global analyses of atmospheric conditions from future unmanned Mars orbiters. Global climate models used by ESED to predict anthropogenic climate change might serve as the basis for state-of-the-art general circulation models of other planetary atmospheres. Outside the solar system, ESED has a possible role to play in future missions such as the Terrestrial Planet Finder, in the development of optimal remote sensing techniques, the interpretation of electromagnetic spectra from extrasolar planets, and the use of global models to more realistically define the extent of possible habitable zones on such planets.

# II. Our Scientific Foci and Strategic Plan

In this section of the document, we outline the actual activities within the research and technical groups in the Division and identify the proposed activities for the next five years. This part of the document is organized by scientific research area, and links to the activities outlined in Table 1 of the Executive Summary.

## II.1 Science/Research Areas

### II.1.1 Atmospheric Composition

Atmospheric composition research within the Division includes the chemical changes in the atmosphere and research on aerosols. Both areas of research involve extensive measurements from space to assess the current composition and to validate the parameterized processes that are used in chemical and climate prediction models. The area of chemical research dates back to the first satellite ozone missions and the Division has had a strong satellite instrument, aircraft instrument, and modeling presence in the community. Both the EOS Aura satellite and the OMI instrument U.S. Science team come from this group. Atmospheric aerosols are a relative new area of research in which the Division is responsible for aerosol retrievals from the Advanced Very High Resolution Radiometer (AVHRR) on the Polar Orbiting Environmental Satellite (POES), the Moderate Resolution Imaging Spectroradiometer (MODIS) on EOS Terra and Aqua, and Aerosol Polarimetric Sensor (APS) on Glory, as well as from modeling.

#### II.1.1.1 Atmospheric Chemistry

**ESED Research Focus Areas:**
**Predict the recovery of the stratospheric polar ozone depletion.**
**Determine the impact of long-range transport on local air quality.**

The major goal of the atmospheric chemistry research at Goddard is to understand both the composition of the Earth's atmosphere and its changes in response to human-produced compounds, especially in regard to recovery of the ozone layer. A new strategic goal is to understand long-term changes in the chemistry of the troposphere and the importance of long-range transport and the relationship of both to climate change. To attack these goals we use a combination of observations and modeling activities.

##### II.1.1.1.1 Observations of Chemical Constituents

Atmospheric chemistry encompasses radiative and dynamical processes associated with tropospheric-stratospheric exchange, ozone recovery and its relationship to climate change, transport of various chemical species, and heterogeneous chemistry—including aerosols. The main efforts of ESED scientists in atmospheric composition over the last 25 years have been on stratospheric ozone. First, we have produced daily observations of total column ozone that give near complete global coverage beginning in late 1978 with TOMS. A major achievement of TOMS was the first mapping of the Antarctic ozone hole. TOMS data have a long-term precision that is better than 1% per decade, and it has become the principal data set used for assessing global ozone trends. The total ozone data was initially derived with a simple algorithm that has evolved to produce the present high quality data that are used in the international assessments of ozone change (Table 3). As a by-product of this algorithm research, new data products such as $SO_2$, column aerosols, and UV-B levels have been developed. In addition to TOMS, a number of other instruments have been developed and flown to assess ozone profile information. These other instruments include SBUV, the Shuttle Solar Backscatter Ultraviolet (SSBUV), and the combined Shuttle Ozone Limb Scattering Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE). In the near future, we will be involved with developing algorithms for the Ozone Mapper Profiler Suite (OMPS) which will be flown on NPP and NPOESS.

Observational analysis in atmospheric chemistry during the past two decades has been driven by data from the Upper Atmosphere Research Satellite (UARS). The products from these missions provided a better understanding of the trends and variability of stratospheric ozone and have helped guide government policy for the regulation of ozone depleting substances.

With the launch of EOS Aura, a significant portion of the research staff is analyzing and validating Aura data. This includes Division led validation missions, research and the archiving of data products. Validation activities will decline as the mission matures. The Division continues to work with other data sets including occultation instruments [Polar Ozone and Aerosol Measurement (POAM), Statospheric Aerosol and Gas Experiment (SAGE) III, Aerosol Characterization Experiments (ACE), and the Halogen Occultation Experiment (HALOE)] as well as data from the Global Ozone Monitoring Experiment (GOME) and the ENVIronment SATellite (ENVISAT).

The strong atmospheric chemistry group at GSFC has been involved in a number of mission formulation activities. Our experience with ultraviolet (UV)/Vis technologies dates back to the original backscatter ultraviolet (BUV) instruments flown in the 1970's and we continue to be at the cutting edge with funded Instrument Incubator Program (IIP) proposals. However, with the retirement of experimental scientists in UV detection and calibration, new hires are needed to continue this activity and maintain our world leadership.

Development of future satellite observations depends on the lessons-learned from ongoing efforts with currently flying satellite instrumentation: Aura's OMI instrument, TOMS, SBUV-2, and the European instruments GOME and SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY). Future Aura ozone monitoring will be done by Ozone Monitoring and Profiling Suite (OMPS) to be flown on NPP and subsequent NPOESS missions. SMD at NASA HQ is developing the "Measurement Team" concept, putting the responsibility for scientific satellite data sets as close to the users of that data set as possible. ESED staff, in particular the ozone group, have pioneered the "measurement team" concept, taking responsibility for retrieval algorithms, instrument calibration and working with data users toward the goal of creating the highest quality data sets, using satellite data from NASA and European research instruments, as well as NOAA operational instruments. ESED staff will continue this model of scientific data set production creating a science quality ozone data set from Nimbus 7 TOMS (1978), through EOS OMI (2004), onto OMPS on NPP (2008) and onto the NPOESS era (2012) as indicated in Table 3.

ESED will continue to work with NASA HQ to develop systems to: (1) predict global ozone change in the stratosphere and troposphere, (2) determine the impact of climate change and intercontinental transport of pollution on local air quality, and (3) establish aerosol distributions, aerosol effects on atmospheric constituents and clouds, and the combined effects on climate. ESED scientists are formulating two atmospheric chemistry satellite missions for ESSP type opportunities: a geosynchronous satellite for tropospheric chemistry observations [GEostationary Observatory for TRopospheric Air ChEmistry (GEOTRACE)], and a Lagrangian point mission for full disk observations.

Over the next five years, ESED ground and aircraft ozone observations will be focused on continued support for satellite measurements including OMI and OMPS, the Network for Detection of Stratospheric Change (NDSC) ground network, and the Southern Hemisphere Additional Ozonesondes (SHADOZ) balloon network. In particular, the NDSC will be supported with the Stratospheric Ozone Lidar Trailer Experiment (STROZ-LITE) mobile lidar system measuring ozone, aerosols and temperature; the tropospheric ozone lidar will provide observations for Aura OMI comparisons. The ground-based UV/Vis measurements system, Sky Radiometers (SkyRAD) will be used to provide long-term calibration and performance monitoring of backscatter satellite instruments (SBUV, TOMS, GOME, SCIAMACHY, and OMI). We will also collaborate with Brewer/Dobson networks. ESED scientists will continue to lead aircraft-based field experiments such as the Aura Validation Experiment (AVE) over the next five years by providing project scientist direction and flight planning support. In addition, the Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL) is a DC-8 based lidar system that will be used in support of the Intercontinental Chemical Transport Experiment (INTEX) and the Tropical Composition, Cloud, and Climate Coupling Experiment (TC-4) to provide validation data for the Aura satellite instruments. In the near-term instrument development pipeline, we are working on a ground Carbon Dioxide ($CO_2$) laser system to make routine, high precision $CO_2$ profiles for long-term monitoring and field mission support. A Mini-AROTAL with down-looking capability is under development for high altitude aircraft such as UAVs, the WB-57F, or the ER-2.

### II.1.1.1.2 Chemical Modeling

ESED chemical models are used in five areas: (1) forecasting on the decadal and century time scale to predict future atmospheric composition, (2) modeling of events after they have occurred to aid data interpretation, (3) sensitivity studies to understand how certain processes affect the model and atmosphere, (4) field campaign and satellite support to provide a complete atmospheric composition picture, and (5) support for development of new satellite instruments and sampling strategies.

There are a number of modeling efforts in the atmospheric chemistry group: (1) the Global Modeling Initiative (GMI), (2) the Finite Volume General Circulation Model (FVGCM), (3) the Code 613.3 stratospheric chemistry and transport 3-D model [Chemical Transport Model (CTM)], (4) the Global Ozone Chemistry Aerosol Radiation Transport Model [Goddard Chemistry Aerosol and Radiation Transport (GOCART), described in the aerosol section], and (5) mesoscale modeling. These are used in different applications but have a strong common element, the use of constituent observations to evaluate and improve the model representation of processes and the reliability of predictions.

A CTM requires meteorological fields for the transport of chemical species. One source is the Atmospheric General Circulation Model (AGCM), developed within the Division and also used for the Goddard Earth Observing System (GEOS)-4 data assimilation project. The present AGCM relies on ozone climatology, and there is no feedback between chemistry and the other components. In a nascent version of this ACGM, constituents are transported online. Chemical changes to ozone and other constituents are calculated, and computed fields of ozone and other radiatively active constituents are input to the radiation module. The GMAO has developed a new, computationally efficient model (GEOS5 AGCM) with updated physics. This model also serves as the core of the new atmospheric data assimilation system and of the coupled climate prediction system. Meteorological fields from this model are also used for transport by GMI, the CTM, and the GOCART model. Hence, one of the foci for improvements to the GEOS5 model is to provide better meteorological fields for GMI and GOCART in addition to the assimilation, weather, and climate prediction applications. Over the next five years, the chemical modeling group and the assimilation group will be jointly developing chemical forecasting models as discussed in Section II.1.4.4, Prediction of Constituents. More details on the chemical models are given below.

***Global Modeling Initiative***
GMI is a broad community effort funded by NASA HQ that is managed by ESED. The goal of GMI is to develop and maintain a state-of-the-art modular 3-D CTM that can be used for assessment of the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry. A particular focus of GMI is to reduce the uncertainty in assessment by making it possible to determine the sensitivity of results to various model components. GMI will be mainly used for producing hindcasts, forecasts, and for sensitivity studies. GMI will be the comprehensive tool used by NASA for World Meteorological Organization (WMO)/United Nations Environment Programme (UNEP) and Intergovernmental Panel on Climate Change (IPCC) assessments.

***Chemical Transport Model***
The CTM is conceptually similar to the GMI Transport Model; this research tool is used for applications that are outside the relatively narrow scope of assessment calculations. The CTM currently provides only stratospheric trace gas concentrations, but will soon incorporate a tropospheric modeling capability in order to fully realize the benefits of the trace gas measurements in the lower stratosphere and troposphere that are being made by instruments on Aura. Such applications are a prerequisite to interpretation of simulations using the fully coupled version of GEOS-5 (see below). In addition, there are a number of improvements to the CTM that are planned in conjunction with the GOCART model (see Section II.1.1.2).

***Mesoscale Chemical Modeling***
Global scale models are currently too computationally costly to reasonably resolve urban scale (<10 km) chemical composition. For the urban scale chemical composition, mesoscale models have been developed that include large-scale boundary inputs from global scale models. The mesoscale modeling effort currently being developed to support satellite and field missions, sensitivity studies, and satellite mission development. In the next five years, we will be developing a regional scale model is for aerosols and chemistry which is (1) flexible in terms of spatial resolution (from sub-100 km to a few km) and geographic location and is ready to run in forecast, analysis, and testing modes, and (2) can be nested within the global model to study the regional-global interactions.

***Future Chemical Research***
In the near term, we are focusing on how atmospheric composition affects climate. First, how does climate change affect the recovery of the ozone hole as ozone depleting substances are removed from the atmosphere over the next few decades? Second, how does ozone depletion affect the climate and how will it affect future climate? The current coupled-chemistry climate model will be used to produce a simulation running from 1950 to 2100. The model output will be used in the next WMO/UNEP ozone assessment and the next IPCC assessment. In the next year the CTM, GEOS5, and the GMI chemistry module will be combined to produce a more computationally efficient fully coupled chemistry-climate model. In the next few years, the combined tropospheric-stratospheric chemistry from GMI will be integrated into the GEOS5 AGCM. The GEOS5 AGCM will then couple the chemistry to efforts in aerosol chemistry and atmosphere-ocean interaction.

The GEOS5 AGCM with the combined tropospheric-stratospheric chemistry will provide an important tool for determining the impact of climate change and ozone recovery on air quality. Longer term plans call for the inclusion of biogeochemical processes in this coupled model. This advanced model will be used for assessing the interaction of human produced greenhouse gases and ozone depleting substances with biological processes.

The mesoscale chemical model will be used in the next few years for studies showing how high-resolution satellite measurements of tropospheric pollution will lead to a better understanding of pollutant transport from local sources to regional and global scales. It will also be used for satellite mission support and data analysis for aircraft and other specific field experiments.

### II.1.1.2 Aerosols

**ESED Research Focus Areas:**
**Determine the impact of aerosols on climate forcing.**
**Determine the interaction of aerosols on clouds and climate change.**

The goal of aerosol research at Goddard is to improve our prediction of the impact of aerosols on climate, and to enhance our understanding of the chemical, physical, radiative, and meteorological processes of aerosols. Because aerosols, clouds, and climate are inherently linked within the hydrological cycle, much aerosol research in the future will coincide with research of hydrospheric processes described in Section II.1.2.4. Although there have been several new CS hires in this focus area, we are still missing some key expertise to address the interaction of aerosols, rainfall, clouds, and large-scale circulation. These hiring needs were described earlier in the Executive Summary.

Cloud, aerosol and radiation areas, research priorities have focused on the retrieval of optical and radiative properties of clouds and aerosols. These data sets are listed in Table 3. Data from the AVHRR, Terra [Multi-angle Imaging Spectroradiometer (MISR) and MODIS], Aqua (MODIS), TOMS, and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) were used in this research. With the launch of EOS Aura, the OMI instrument is also providing aerosol observations. The "A-Train" – a series of satellites [Aqua, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), CloudSat, Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) and Aura] will be making near simultaneous observations because they are clustered together along the same orbit path. This enables us to develop joint retrieval algorithms using individual strengths from individual sensors, and to focus on cloud-aerosol-climate interaction. Key to remote sensing of aerosol processes will be the measurement of aerosol height by CALIPSO's lidar and the polarization from the POLarization and Directionality of the Earth's Reflectance (POLDER) (on PARASOL). Over the next five years, the aerosol group will be analyzing the aerosol data from the A-Train. Much more precise aerosol retrievals will be obtained from polarization measurements from the Glory Aerosol Polarimetry Sensor - a passive instrument with unparalleled capability to diagnose aerosol chemical composition as well as retrieve detailed aerosol and cloud particle size distribution and shape information. Measurements of the key parameters will continue through NPP and NPOESS, and we look forward to the implementation of a specific measurement team for clouds and aerosols in the NPP era.

A strong modeling component will continue to be part of the satellite program. The GOCART aerosol transport model has proven to be very successful in providing information on sources and sinks and transport of various aerosol and chemical species. With the coupling of GOCART with the GEOS5 AGCM, we are beginning to expand the studies of chemical transport modeling and assimilation, including the feedbacks that impact not only climate but also weather prediction.

Within the next five years, the aerosol research focus will be:

***Description of the Global Aerosol Distribution and Optical Properties***
We are moving toward a synthesis of sensors and techniques to improve remote sensing of the aerosol properties. Using the new satellite data from MODIS, CALIPSO, PARASOL and (later) Glory APS along with the AERosol Robotic NETwork (AERONET) and new techniques that include 3-dimensional radiative transfer, we intend to create a long-term climate data record and a new aerosol assimilation system. The satellite data can be combined with comprehensive ground-based remote sensing and in-situ measurements and used to constrain aerosol models. The models assimilate the data, generating cohesive data sets, and also interpolate into cloudy regions and regions where the satellite cannot detect the aerosol with sufficient accuracy. We will use the hybrid of observations and model simulations to determine sources and sinks of aerosol, and of processes not well understood. This global distribution of aerosol can then be used to assess the effects on climate, human health, and natural hazards.

***Determining the Effect of Aerosols on the Direct Forcing of Climate***
Our current assessment of aerosol radiative forcing is hindered by our incomplete knowledge of aerosol optical properties, especially absorption, and our current inability to determine the aerosol distribution near, under, and above clouds. New sensors such as OMI for absorption and CALIPSO for separating aerosol and clouds, along with the assimilation system will help alleviate our current difficulties. We will then be able to confidently compute the direct radiative forcing of the aerosol in the presence of clouds and over varying surface properties

***Effect of Aerosols on Clouds, Precipitation, and Indirect Forcing***
The direct radiative forcing by aerosol constitutes only part of the aerosol effect on climate. Aerosols also have an effect on clouds and precipitation. These effects depend on the aerosol size- and composition-dependent hygroscopicity, on the dynamical properties of the cloud field, and on the perturbations to atmospheric stability caused by vertical distributions of absorbing aerosol. Simultaneous precise measurements of aerosol properties and the cloud field from satellites, coupled with cloud resolving models such as the Goddard Cumulus Ensemble (GCE), should provide the basic relationships between aerosols, microphysical properties, reflectivity of clouds, and rate of precipitation. In order to establish a definitive cause and effect relationship between the aerosol and the cloud / precipitation field, the models need to assess the likelihood of alternative causes for the apparent correlation between aerosol and clouds. To help address these issues, we need to employ global models that represent the circulations of the atmosphere and plan to improve the model physics by incorporating aerosol microphysics within the convective parameterization scheme of GEOS. Then, carefully controlled model experiments and comparisons with observations will be needed to sort out the complex relationships.

***Assessing Past Climate Forcing by Aerosols***
We study today's aerosol-laden atmosphere, and using reanalyzed historical data sets we can describe past aerosol distribution and forcing using the 25 year record of AVHRR and TOMS (Table 3). Because these sensors are now flying simultaneously with the more modern suite of instruments, the data sets can be compared with MODIS and AERONET to improve the measurements. In essence we can "calibrate" the old data with the new, and then assess the past with a "calibrated" time series. This time series will itself become the testbed for predictive models that will use the lengthy observational record for evaluating the models' ability to simulate interannual variability and interdecadal trends. The Global Aerosol Climatology Project will provide a satellite-based data set spanning these multiple sensors (Table 3). The tuned models then travel even further back in time to give us a glance at pre-satellite and pre-industrial aerosol distribution. At present, a coupled aerosol-GEOS-5 climate model (aerosol direct effect only) is being developed and tested. In a few years, a fully interactive aerosol-GEOS-5, including direct and indirect effects will be available. This model can be used to simulate past climate, and provides future climate projections under various greenhouse gases forcing scenarios, with realistic aerosol forcing and dynamical responses. The climate data record and model assimilation will continue beyond the Terra and A-train era, as NPP and NPOESS provide a continuing high quality data stream.

***Assessing the Effects of Aerosols on Air Quality and Human Health***
Satellite observations are currently expanding the capability of air quality forecasting in the United States. As remote sensing techniques improve to better characterize the 3-dimensional spatial distribution and properties of the aerosol, we will continue to work with our partners in other federal agencies to improve air quality forecasting techniques. Satellite data coupled with global models will also bring a global perspective and quantification of the long-range transport of air pollutants.

## II.1.2 Hydrospheric Processes

Hydrospheric processes encompass all aspects of the Earth's global water cycle, including the cryosphere, land surface hydrology, physical oceanography, coastal zone processes, atmospheric precipitation and moisture, plus the techniques for observing, modeling and prediction of these processes. There is significant overlap between the hydrospheric and atmospheric research activities within ESED.

### II.1.2.1 Physical Oceanography

**ESED Research Focus Areas:**
**Predict ocean circulation changes.**
**Quantify the global water and energy cycles and changes associated with climate trends.**
**Determine the predictability limits and controls for climate from subseasonal to decadal timescales.**

The Division's physical oceanography research has its roots in ocean surface topography and wind measurements that led to the Ocean TOPography EXperiment (TOPEX)/Poseidon and QuickScat missions, and the realization that measurements of sea surface topography, temperature, and winds were all required to describe the ocean surface variability associated with El Niño/Southern Oscillations (ENSO). The Division continues to support satellite altimeter and ocean vector wind measurements through collaborations with the French on JASON, the TOPEX follow-on, and with the U.S. Navy on the GeoSat Follow-On (GFO) Mission. An important off-shoot of this research has been the laser altimetry capabilities resulting in the Ice, Cloud, and Land Elevation Satellite (ICESat) and the Mars Orbiter Laser Altimeter (MOLA). The Division's ocean altimetry-circulation-climate research efforts of the past have included the NASA Seasonal to Interannual Prediction Project (NSIPP), that studied relationships between global ocean dynamics and seasonal to inter-annual climate variability. (This research is described in greater detail in Section II.1.4.1.) A variety of important air-sea interaction research studies are conducted by Division staff at Wallops, ranging from air-sea exchange processes as measured in the unique Wallops wave tank, a rain-sea-surface simulation laboratory, and studies of coastal zone processes including coastal zone ocean circulations, ocean surface characterization measurements, and coastal topography. Using our airborne laser altimetry capabilities, Division staff has mapped the entire U.S. coastal topography for the U.S. Geological Survey (USGS). These efforts increasingly support research and calibration/validation efforts needed for NASA flight missions and a growing list of other-agency support needs.

The new challenge of sea surface salinity adds the remaining state parameters to our oceanographic observations. Goddard leadership of the *Aquarius* sea surface salinity ESSP-3 mission includes the project Co-PI, the mission-critical radiometer (instrumentation and algorithm development), the ground data system, and post-launch project operations. These broad commitments to monitoring changes in the ocean surface in response to climate variability are a Divisional major five-year research goal. In support of this effort, the physical oceanography science staff is being rejuvenated to address the ocean salinity algorithm, and to support and lead the post-launch Aquarius project. New staff will therefore be added to the Aquarius/physical oceanography effort. These new recruits will address satellite retrievals of ocean salinity, roughness, and other parameters including air-sea interaction. They will coordinate with existing staff in ongoing research including data analysis and modeling of the general ocean circulation; the linkages between altimetry, salinity, sea surface temperature (SST), vertical mixing, and ocean circulation; and improved understanding of the linkages between sea ice and ocean circulation. With the added new staff, we will have the capability to investigate how incorporating data from other missions such as MODIS, the Advanced Microwave Scanning Radiometer (AMSR)-E, and ICESat, (and follow-on capabilities) can improve understanding of the density driven ocean circulations, particularly the longer time scale thermohaline circulations, and the vertical mixing processes that are critical to understanding exchanges of properties between the ocean and atmosphere.

### II.1.2.2 Cryospheric Research

**ESED Research Focus Areas:**
**Quantify changes in sea ice, ice sheets, and glaciers.**
**Assess changes in sea ice and their associated impact on climate.**

***Water Storage in Ice Sheets, Ice Caps and Glaciers***
Our studies of Greenland and Antarctic ice sheet mass balance, ice sheet dynamics, ice sheet history, and other glacier and ice sheet processes require extensive use of satellite data from radar altimetry, visible and microwave imagery and, most recently, ICESat laser altimetry – NASA's first satellite mission designed specifically to measure polar ice cover. In addition, we have led the way in developing precise airborne survey capabilities to enable measurements of ice sheet topography and elevation changes over small ice caps, significant portions of Greenland, and some actively changing areas in Antarctica. These airborne measurements were the precursor to ICESat and have also enabled verification of the satellite's data. By combining these activities with modeling and in-situ observations, we develop critical insights into the mechanisms that drive ice sheet and glacier behavior. Our glaciologists have uncovered the dynamics of dramatically changing ice streams in the West Antarctic and Greenland ice sheets, revealing new information about their behavior that has only recently been made possible by our remote sensing perspective. As a result, our scientists participate in and often lead major international polar science programs including the upcoming International Polar Year (IPY).

Our land-ice five-year primary focus will continue to be on determining how Greenland and Antarctic ice sheets contribute to sea level in a changing climate. However, we will also work to assess the mass balance of the smaller ice caps and glaciers as a complement to these ice sheet studies and will add staff to address ice sheet modeling needs. We will further strengthen our modeling capabilities to enable a comprehensive understanding of the changes in ice on Earth, applying this expertise as applicable to the ice cover on Mars or elsewhere in the Solar system in order to support NASA's initiatives. A major goal during the five-year period is development of the ICESat follow-on instrument and mission, which will extend ICESat's measurements another seven to ten years to complete the work originally planned for the project. In addition, we will extend our leadership in the analysis of radar altimetry data on ice sheets to include advanced processing of data from the European Space Agency (ESA) CryoSat mission to enable new insights into processes that are important for understanding ice sheet changes. Partnering with colleagues at NASA's Jet Propulsion Laboratory, we will be developing our experience with Interferometry Synthetic Aperture Radar (InSAR) and applying these capabilities to the studies of ice sheets morphology and dynamics.

In the past few years, we have transitioned our airborne topographic measurement capabilities from the long-range and large P3 aircraft to the more economical and agile Twin-Otter aircraft. This improvement in efficiency and agility has resulted in our expertise being sought by the National Science Foundation (NSF) to map the Antarctic Dry Valleys, and by NOAA to precisely map coastal beaches and erosion processes. In the upcoming five years, we will complement our topographic mapping capability with an Ice Penetrating Radar developed by the University of Kansas, to provide critical thickness measurements throughout the ice sheet. We will also transition these capabilities to a UAV for an improved sampling capability. Our partnership with NSF-funded Science and Technology Center at the University of Kansas will continue as we jointly incorporate new capabilities into our ice mapping system.

***The Role of Sea Ice in Air-Sea Interaction***

Sea ice—a key component of the ocean-ice-air system and a strong indicator of polar thermal variability through its influence on albedo—is a major research topic within the Division. Our development and analysis of long-term sea ice records from passive microwave satellite observations has defined sea ice variability, including hemispheric, seasonal, and regional trends. See Table 3 for the specific instruments. Our scientists serve on the Aqua AMSR-E science team with responsibility for the sea ice algorithms and leading sea ice algorithm validation field campaigns, and one is the Aqua Project Scientist.

Our numerical models of sea-air-ice interactions address the dynamic and thermodynamic processes associated with sea ice variability. Other efforts focus on the sensitivity of surface air temperatures to polar sea ice conditions, the relationships between low frequency atmospheric variability and sea ice transport, the relationships between interannual to decadal oscillations and hemispheric sea ice and SSTs, the response of sea ice and ecosystems to warming trends in the Arctic, the relationships between sea ice motion and sea surface winds, the measurement of marginal ice zone studies with Synthetic Aperture Radar (SAR), and the role of Arctic and Antarctic coastal polynyas in deep ocean water production.

Our five-year goals will add indirect measurement of sea ice thickness to our measurement capabilities, and will investigate approaches for measurement of snow on sea ice. These technologies include ICESat, the ICESat follow-on and Cryosat combined with radiometry from AMSR-E and other sensors, SAR and scatterometry. Adding staff to offset anticipated retirements, we will take advantage of our strength in passive microwave remote sensing to seek opportunities on missions led by organizations other than NASA such as NPP/NPOESS, and we will pursue utilization of active sensors, such as SAR and scatterometry. We plan to position ourselves to take advantage of the opportunities the Aquarius mission will offer to study processes of sea ice formation, brine rejection, and the implications on ocean circulation. We will further develop the linkages between these new measurement capabilities, and numerical modeling to understand the detailed interactions between sea ice and climate, as satellite and model resolution and physics continue to evolve.

## II.1.2.3 Global Water Budget and Terrestrial Hydrology

**ESED Research Focus Areas:**
**Determine the extent, storage of water, and variability of global snow cover.**
**Determine the predictability limits and controls for climate from sub-seasonal to decadal timescales.**
**Quantify the global water and energy cycle and changes associated with climate trends.**
**Quantify surface water storage and discharge.**
**Quantify ground water storage and exchanges.**
**Quantify global soil moisture.**

Our terrestrial hydrology research strives to understand and predict all components of the terrestrial hydrological cycle, over their broad range of spatial and temporal scales. This research therefore includes efforts to translate the remotely sensed measurements into geophysical properties such as soil moisture content, snow mass, precipitation, ground water, evapotranspiration, vegetation density, etc. and feed that information into land surface hydrological models. Key parameters in which we are involved in understanding are:

***Soil Moisture***
Soil moisture has shown to be a predictive factor of summer rainfall over continents in model experiments. Soil moisture also plays a crucial role in vegetative processes, and links the physical climate system (water and energy cycle) to biogeochemical cycles. Through numerous field and/or airborne campaigns, Division staff has convincingly demonstrated soil moisture remote sensing capabilities in terrain covered by thin or moderately dense vegetation (e.g. typical crops), using passive microwave emission radiometry at low microwave frequencies (1.4 to 3 GHz). This work has resulted in the development of the ESSP-3 Hydros mission, the implementation of which is a major five-year goal for the Division. Hydros will provide the first systematic measurements of Earth's changing soil moisture and of the freeze/thaw status of land surface. Together, these measurements link the water, energy, and carbon cycles over land and will open new frontiers in our understanding of how these global cycles interact in the Earth system and improve the accuracy of numerical weather prediction models by incorporating real observations.

***Ground-water Mass***
Division research uses space-based gravity gradiometer systems to measure changes in ground-water mass. These gravity field measurements are sensitive enough to detect the minute gravitational signature of the discharge/recharge of underground aquifers, as well as changes in soil moisture or snow water equivalent over continents. The current Gravity Recovery and Climate Experiment (GRACE) mission has demonstrated the ability to detect changes in mass distribution equivalent to ±1cm variation in water storage over a 500x500 $km^2$ area, from which we have validated ground water wells and numerical ground water models. The five-year goal for this research includes implementation of the planned GRACE follow-on mission, which will provide the higher spatial resolution gravity measurement needed to resolve large basin aquifers around the globe. These measurements will provide important closure to basin-scale terrestrial hydrologic models.

***Snow Cover and Water Storage***
The snow research activity seeks to quantify the extent, storage of water, variability and albedo of global snow cover. Our research on instruments and algorithms for passive-microwave sensors, Visible Infrared (VIS IR) (AVHRR and MODIS), has a five-year goal of providing all-weather global snow cover and Snow Water Equivalent (SWE) observation capabilities (see Table 3). Understanding the extent, timing, and nature of snow cover throughout the world is essential to determining its role in the climate system. The need for operational global SWE data on continental, regional, to local scales is based on the importance of runoff from snow melt in the water budget and hydrologic dynamics in many locations. Our strategy for improving our ability to measure and predict SWE and impact of snow on regional-scale hydrology concentrates on an advanced Cold Land Processes Pathfinder (CLPP) mission that combines active and passive microwave instruments to measure the snow pack. The CLPP concept is being developed by Laboratory scientists and others working in the Cold Land Processes Working Group, who are defining a comprehensive effort that includes the Cold Land Processes Field Experiment (CLPX), the CLPP concept, and other community efforts. The CLPX combines satellite data from MODIS, AMSR-E and other sensors with field airborne and ground-based microwave observations, plus in-situ field measurements of snow cover in the Rocky Mountains. This effort is helping to quantify errors in SWE estimates, and supporting development of a new global snow-mapping/SWE algorithm. A new staff member, replacing a recent departure, will be added in support of this task. ICESat data is also being investigated for its application to snow thickness estimation.

***Surface Water Storage and Discharge***
The capability to coherently monitor inland waters is an essential future development of Earth-system models that monitor the biosphere and land-to-ocean linkages. Accordingly, a five-year goal is strong participation in the national effort to develop the Surface Water Mission (WatER) that will provide global surface runoff and storage information. This mission must provide high spatial resolution that can resolve the channels, floodplains, and lakes that contribute most of a basin's discharge, short temporal resolution that can capture short flood events, and precise vertical resolution that will measure the subtle height changes that can be responsible for significant discharge. WatER will, in effect, be a topographic imager that will yield a water map of volumetric gain or loss after each overpass. It will enable hydrologists to move beyond the point-based gauging methods of the past century to measurements of the spatial variability inherent in surface water hydrology. Global coverage will ensure that, despite local economic

and logistic problems, all countries could access measurements critical for forecasting floods and droughts, both of which have dramatic economic and human impacts. An additional staff member will be required to support this task.

***Land Data Assimilation Systems***
The full terrestrial and global water budgets are exceedingly complex and not all components can be adequately measured. As a consequence, Land Data Assimilation Systems (LDAS) are used to combine the measurements with the physical constraints of the terrestrial water budget, and other physical constraints. A spectrum of land data assimilation models are used depending on the analysis need, ranging from the newly developed large-scale LDAS, down to the 1 km scale Land Information System. These models provide new approaches to the analysis of diverse water cycle data sources—satellite-based precipitation, radiation, and surface parameters, in addition to model-derived surface meteorology—in a computer forecast venue, and support fresh water budget studies as well as a wide variety of applied uses. Our five-year goal is to continue improving our LDAS models, and to continue our close linkage with the research, observational, and numerical weather prediction communities. These models are maintained in such a manner as to enable parallel research activities with the other major land surface hydrology research laboratories around the nation. This will require continued improvements in our access to the high-end highly parallel processing support needed for the high resolution numerical LDAS models.

***Global Water Budgets and Variability with Climate Change***
The combination of the many observations of water cycle components, together with our advanced LDAS systems allows us to evaluate the contribution of each component of the water cycle to the full water cycle. As a result we are greatly improving our understanding of how to measure individual water cycle components and the relative importance of measurement improvements to error reduction of the water cycle as a whole. Our five-year goal is to continue this research to the point that we can define the needed capabilities for a complete global water cycle observational system. Development of such a system would enable us to observe and understand the global water cycle well enough to be able to predict variability due to changes in weather and climate. If we can do this, then we should be able to predict changes in the availability of clean water due to future global ecosystem changes, weather and climate variability, and human impacts including population growth. These water cycle questions address the fundamental ability of Earth to support life. Within this broad area of inquiry are fascinating and important science questions, the answers to which will help understand our future prospects. An additional staff member will be required to support this task.

### II.1.2.4 Atmospheric Component of the Hydrological Cycle

**ESED Research Focus Areas:**
**Quantify variability and changes in precipitation, clouds and water vapor.**
**Quantify the global water and energy cycle and changes associated with climate trends.**

There are three key science questions that dictate the research priorities in atmospheric water and energy cycles: (1) How do condensation and radiative heating associated with cloud and precipitation processes affect global weather and climate? (2) How do clouds and precipitation processes respond to aerosol forcings, and to climate change? (3) How can we use satellite cloud and rainfall measurements to improve representation of atmospheric moist processes in climate models, so as to provide better weather and climate predictions?

Central to the global water cycle are the space-based Precipitation Measuring Missions (PMM), beginning with the Tropical Rainfall Measuring Mission (TRMM), extended by the CloudSat mission, and now continued on with the Global Precipitation Measurement (GPM) Mission. PMM provides not only state-of-the-art estimates of different types of rainfall, but also various products such as water vapor, cloud liquid water, cloud ice (from GPM), and vertical profiles of raindrop size distribution from the precipitation radar and the TRMM Microwave Imager (TMI), as well as the CloudSat radar. Combined with long-term records from the International Satellite Cloud Climatology Project (ISCCP, Table 3), the Earth Radiation Budget Experiment (ERBE), the High Resolution Infrared Sounder (HIRS), the Global Aerosol

Climatology Project (GACP), and NOAA's TIROS Operational Vertical Sounder (TOVS), these measurements are critical in advancing understanding of fundamental aspects of the atmospheric water and energy cycle.

The conception and formulation of the TRMM mission in the late 1980s helped to focus the Division's precipitation research efforts and, as a result, Goddard has emerged as the preeminent leader in precipitation research. This leadership role will continue as new missions such as the GPM and NPP are planned to provide continuous multiyear observations of precipitation to the end of the decade. The upcoming CALIPSO and CloudSat missions should provide opportunities for in-house technology developments for lidar to define the vertical distribution of clouds and water vapor. The ESED will focus on the development of an airborne wind lidar system and related technologies for water vapor transport, in anticipation of future mission opportunities. An ESED priority should be close interactions with the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS) as a means of translating cloud resolving model information into improved global climate model parameterizations.

In the next five years, the overall objective of atmospheric water cycle research will be to determine the correlated time and space varying characteristics of rainfall, water vapor, clouds and aerosols, and associated atmospheric diabatic heating, and how these characteristics are related to variations and long-term trends in the overall water and energy cycles. The main thrusts of our research effort on atmospheric water cycle are:

***Precipitation, Cloud, and Water Vapor Climatology, Variability, and Trends***

We will continue to improve and employ novel approaches to combine satellite rain information from multi-satellites in preparation for the eventual GPM rainfall product, which will consist of a core satellite with a dual-frequency precipitation radar, and a microwave imager, together with a constellation of microwave radiometers. The multi-satellite rain products will be used to validate model simulations of severe storms, spiral rainband structure in developing hurricanes, and to develop definitive climatology of mesoscale convective systems in different regions around the world. The global precipitation data set listed in Table 3 represents the global monthly average precipitation estimates for the period January 1979 to the present. This data set is a major component of the Global Precipitation Climatology Project (GPCP), established to develop global precipitation data sets using satellite and conventional observations.

The possibility of TRMM continuing to fly for the next couple of years, narrowing or even filling the gap between TRMM and GPM (scheduled launch in 2010), has offered an exciting opportunity for a unique long-term global precipitation data set to better define the detailed diurnal, and seasonal climatology of rainfall, and for determination of variability and trend in rainfall and water vapor, as they relate to climate change. Moreover, the possibility of overlapping observations by the TRMM and CloudSat radars will give a more complete picture of global precipitation in both liquid and ice phases. In addition to trend analysis of total rain, we will also focus on the long-term statistics of convective versus stratiform rain, cold versus warm rain processes, continental versus oceanic rainfall, mesoscale convective complexes, and their relationships with other components of the atmospheric water cycle, i.e., water vapor and sea surface temperature.

Cloud variability and trends will be documented in the ISCCP and MODIS data sets. Analysis of ISCCP-derived radiative fluxes will enable observed variations in the planetary energy balance to be associated with specific cloud types, and thus, physical processes and feedbacks. The combination of TRMM latent heating profiles with ISCCP radiative heating profiles will create the first long-term record of total diabatic heating variations that force observed circulation anomalies on interannual and decadal time scales.

***Data Assimilation and Improved Climate Model Physics***

Satellite rainfall, cloud, and water vapor products will be used for assimilation into the NASA GEOS-5 GCM for improving weather prediction and climate simulations. Unlike observations in clear-sky regions, rainfall data are difficult to assimilate because rain estimates from forecast models can have large biases. The PMM Science Team will provide leadership to the data assimilation community to explore innovative approaches to use rainfall data to improve atmospheric analysis and forecast. These new approaches range from variational rainfall assimilation using the model as a constraint, to super-ensemble forecasting techniques. In addition, new information on drop size distribution and cloud liquid water from TRMM/GPM, will provide more information on the rain microphysics and latent heating profile with regard to fundamental processes in the atmosphere such as diurnal cycle, seasonal and intraseasonal variability, which need to be properly represented in order to increase reliability in long-term climate model projections. The resulting global analysis products will provide the most accurate possible estimates of long-term atmospheric circulation anomalies. These will be used to drive simulations of the column physics in climate models, which can then be directly compared to the satellite rainfall, cloud and water vapor fields to evaluate the fidelity of parameterized model physics and to provide clues for model improvements.

***Clouds and Aerosols Interactions***
Clouds and aerosols have been identified by the IPCC (2001) as two of the most crucial factors responsible for the uncertainties in model projections of climate change. The ESED has a long tradition of excellence in research of radiative transfers in clouds and aerosols. In the context of atmospheric water cycle, clouds and aerosols research are inseparable, because of aerosols' ability to modify cloud and rainfall formation (see discussion of aerosol/chemistry research in Section II.1.1.2). In the near term, a major focus will be to conduct integrated satellite observation and modeling work over key regions, where clouds and aerosols are expected to have large impacts on the water cycle. One of these is the Asian monsoon region, where aerosols from natural dusts and industrial pollution are increasing at an alarming rate, and where satellite analysis from MODIS, TOMS, TRMM, and field campaigns such as ACE-Asia have yielded some very promising results. Other areas of research will be the effects of Saharan dust on the West African monsoon, and suppression of rainfall and tropical cyclone geneses over the tropical Atlantic and their impacts downstream in the Caribbean and the Southeast U.S. These studies should focus on the interaction between aerosols-cloud-precipitation, radiation and dynamics as prime drivers of the regional and global water cycle. The results will in turn provide a context for understanding observed multi-decadal variability in the interactions between GACP aerosol products, ISCCP cloud and radiative fluxes, and GPCP precipitation. We will continue to develop innovative measurement technology of lasers and lidars, radars for clouds, aerosol and rainfall measurements to augment and calibrate data from pending satellite missions such as CALIPSO/CloudSat, Glory and possible ESSP mission for ice clouds [Submillimeter and Infrared Ice Cloud Experiment (SIRICE)], and a 3D Cloud-Aerosol Interaction Mission (CLAIM-3D) for lateral viewing of cloud-aerosol microphysics (see Table 4), and also to maintain the strong collaboration with the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) programs.

***Integrated Modeling – Toward the Earth System Model***
In addition to the aforementioned GEOS-5 global modeling effort on precipitation, clouds and aerosol (see also Section II.1.1.2), modeling activities for atmospheric water cycle will focus on the improvement of cloud microphysics using cloud-resolving models such as cumulus ensemble models and large-scale eddy simulation models, to take advantage of the high vertical resolution data expected from CALIPSO and CloudSat, and other planned satellite missions. Modeling activities will be focused on improving the representation of atmospheric hydrologic processes including clouds, radiation, and aerosols, in climate models. Experiments and observation validations will be carried out to evaluate the ability of models to simulate fundamental phenomena such as the diurnal water cycle. As high performance computing resources continue to increase, multi-model approaches such as embedding cloud resolving models into climate models, in the so-called "super-parameterization," will be a priority in the next five years. These models will eventually lead to the development of non-hydrostatic cloud resolving, and coupled chemistry next-generation climate models to study scale interactions in global water cycle processes. On a longer time scale, the Division is working toward the development of the Earth System Model which links climate, ocean, chemistry, and land models.

***Transition to Applications***
We will enhance our effort in areas with potential applications to tools affecting rainfall and water resource distributions. We will provide real-time data from NASA satellites, such as TRMM, the Atmospheric Infrared Sounder (AIRS), and QuickScat, and collaborate with scientists from other agencies to improve skills of numerical weather forecasts. Near real-time TRMM-based estimates of tropical cyclones and flood warnings will be provided to various disaster relief agencies in the U.S., and overseas where conventional information is lacking. We will collaborate with NOAA's National Environmental Satellite

Data and Information Service (NESDIS) to provide rainfall data as part of its Tropical Rainfall Potential Program to estimate flood potential in hurricanes. NASA's Multi-satellite Precipitation Analysis will be made available to numerous groups and countries globally, to help in detecting floods and monitor rain for agricultural uses. Similar activities to transition Goddard's developments in the remote sensing of clouds, water vapor, and radiation will be conducted as well.

## II.1.3 Biospheric Processes

The goals of ESED biospheric research are to quantify changes in terrestrial and ocean biospheric processes, understand the forces driving the changes, and study and predict the consequences of these changes. The Division fosters and enables Earth observation technologies for monitoring and modeling the dynamics of biological activity in the oceans and on land and seeks to improve our understanding of the Earth as a system through multiscale modeling and global satellite observations.

### II.1.3.1 The Carbon Cycle

The largest and best understood of the factors that contribute to global warming is the rapid and continuing increase in atmospheric concentrations of "greenhouse" gases; trace gases that are transparent to the Sun's shortwave radiation, but absorb longwave radiation emanating from the Earth's surface warming the atmosphere. $CO_2$ released by fossil fuel combustion and deforestation is the most rapidly increasing atmospheric greenhouse gas, and the one that is widely accepted as the largest contributor toward global warming. On average, about half the $CO_2$ released into the atmosphere through human activities each year remains there, steadily increasing atmospheric $CO_2$ levels, now over 360 ppm, 30% above the maximum levels of the past 400,000 years. The other half is being absorbed by the Earth's surface, oceans and land. There is much uncertainty as to the locations and mechanisms that take $CO_2$ out of the atmosphere and provide the service of ameliorating the increase in atmospheric $CO_2$. Will these sinks for $CO_2$ continue to operate in the future or will they reverse and aggravate the greenhouse warming trends? Answering this question is a scientific imperative of this century. Until we can locate these sinks and sources for $CO_2$, quantify their strengths, and understand their biological and physical mechanisms, predictions of future atmospheric $CO_2$ concentrations, hence climate change, will be unreliable. The U.S. Climate Change Science program has identified a number of specific science questions focused on addressing the carbon sink issues:

(1) What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

(2) What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?

(3) What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?

(4) How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?

(5) What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?

(6) How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?

Currently, the biggest uncertainties involve the land contributions to the carbon budget. Interdisciplinary collaborations are needed to address these questions because of the importance of the interactions between the land and the oceans, and because the atmosphere carries the signature of the land and ocean carbon fluxes. ESED capabilities in atmosphere, oceans, and land studies span the breadth of the interdisciplinary requirements needed to address the questions listed above. Goddard scientists actively collaborate with each other and with the outside community through proposals and interactions within the ESED supported Carbon Cycle Science Theme Team.

#### II.1.3.1.1 Terrestrial Carbon Cycle

**ESED Research Focus Areas:**
**Quantify the carbon budget.**
**Predict the impact of climate change on the biosphere.**

The uncertainties in the land carbon stocks and fluxes of carbon are larger for the land than for the atmosphere and oceans. A number of mechanisms have been proposed to explain the inferred land sinks, including biomass accumulation due to land use activities and the responses of ecosystems to climate change. Satellite remote sensing has contributed critical information leading to new insights and represents the most promising approach for further improvements in understanding and monitoring the terrestrial carbon cycle.

ESED has an active group of terrestrial carbon cycle scientists with strong connections to the rest of carbon cycle science community. Division activities investigating the terrestrial carbon cycle span scales from short-term local to long-term global processes. Using existing satellite resources (e.g. AVHRR, MODIS, Landsat) and extensive field studies, Division members have developed indicators of vegetation activity, land surface carbon stocks, disturbance and fire activity. Division members are using computer models driven by remote sensing data to understand the process controlling ecosystem productivity and carbon fluxes over the past two decades. The advances gained from understanding recent phenomena are being used to improve model forecasts of the future. Collaborations within the ESED include the modeling of atmospheric carbon and the development of a unified land surface model (coupled water, energy, and carbon cycles) to incorporate requirements to address terrestrial carbon cycle studies. Paleovegetation studies have a key role to play in understanding the interplay between vegetation dynamics mediated by climate and the carbon cycle. Particularly important is the role of soil carbon, which represents 2/3 of the terrestrial carbon budget, and is visible in the paleovegetation records. Future development plans include a coupled modeling and assimilation system to quantify air-land and air-sea carbon fluxes. Scientists in ESED are working closely with scientists and engineers in Code 690 to develop laser technologies that can be flown in space and can be used to measure carbon stocks in vegetation and in the atmosphere. The need for these capabilities is explicitly addressed in NASA HQ Roadmap for The Carbon Cycle and Terrestrial Ecosystems Program.

In the next five years, we plan to ensure continued advances in understanding the area of carbon cycle research which include: the development of a coupled model and assimilation system to quantify air-land and air-ocean carbon fluxes; the study of the variability of trace gases in the atmosphere, and their dependence on biomass burning and land cover change; development of global disturbance maps at fine spatial resolutions (50m-1km); development of laser techniques and algorithms to measure vegetation biomass using lidar instruments on aircraft and space platforms; development of new ways of analyzing EOS data for the purposes of extracting carbon cycle related information; analysis of the Orbiting Carbon Observatory (OCO) data to measure the location and concentrations of atmospheric $CO_2$; the development of new proposals for carbon related missions under the next ESSP (see Table 4); and the development of concepts for larger missions that use lidar, imaging spectrometry, and thermal sensors.

#### II.1.3.1.2 Biological Oceanography

**ESED Research Focus Area:**
**Quantify the carbon budget.**
**Predict the impact of climate change on the biosphere.**

NASA Biological oceanography research spans the fields of ocean color and its relationship to oceanic primary productivity and the carbon cycle. The research and development activities extend from space missions and mission data delivery, to ocean biology laboratories that investigate phytoplankton growth and optical properties, to in-situ and remote measurement research. Scientific studies and an extensive array of ocean biology laboratories focus on the relationship between phytoplankton development and light levels in the sea, on global ocean productivity, on dissolved organic carbon and the ocean carbon cycle, and tropical ocean biogeochemistry. These studies are buttressed by shipboard field observations, and by development of optical systems for observing the characteristics of phytoplankton both in the laboratory and at sea.

The Division has provided quantitative global ocean bio-optical data products from the SeaWiFS Project to the Earth science community over the past eight years. We now support MODIS/Aqua ocean color processing and the ocean color activities associated with the NPOESS program. Additionally, we provide community ocean color data product validation, sensor calibration, data merger algorithm evaluation, and satellite data processing. Our carefully focused ocean biology laboratories provide new insights into ocean color/phytoplankton physiology algorithms, and with mission proposals such as Ocean Carbon Ecosystems and Near-Shore (OCEaNS) (see Table 4), we are leading to the next generation of ocean color research satellites. Our five-year goals include continuing our responsibility for future ocean color algorithms for the Visible Infrared Imager Radiometer Suite (VIIRS) on NPP/NPOESS and subsequent ocean color sensors, and we will provide mission data processing for the upcoming Aquarius ocean salinity mission.

Another major five-year Divisional goal is our ongoing climate data record effort that develops and maintains a consistent multi-decadal time series of ocean color data, extending across a multitude of sensors, from the early Coastal Zone Color Scanner (CZCS) data (ca. 1978-1986), through the Ocean Colour and Thermal Scanner (OCTS) (a Japanese sensor, 1996-1997), SeaWiFS (1997-present), top current data stream from MODIS (2000-present), and then on to VIIRS in the future (see Table 3). This effort is a critical aspect of assessing climate change – primary productivity issues, and relates closely to our coupled physical-biological modeling and ocean color data assimilation, that addresses the large-scale variations in ocean color data observed from satellite. Since ocean satellites observe only the near-surface of the ocean, sophisticated assimilation systems are essential to tie the surface observations to variations beneath the surface. This is an essential step, together with other biogeochemical modeling and assimilation, toward the development of a comprehensive Earth system assimilation system that will provide a consistent synthesis of observations across all components of our complex environment.

### II.1.3.2 Terrestrial Ecosystems and Land Cover

**ESED Research Focus Area:**
**Quantify land cover and ecosystem change.**
**Predict the impact of climate change on the biosphere.**

Land Cover describes the distribution of vegetation and land types around the globe. It provides the lower boundary condition for atmospheric transport, and mediates biochemical exchange between the atmosphere and hydrosphere. In addition, since human populations live on the land, human appropriation of Earth's environment for food and fiber can be directly observed through changes in land cover (e.g. deforestation, urbanization, increases in irrigated agriculture, etc). Land cover and land cover change occur over a large range of temporal and spatial scales. For example, while boreal fires mark the landscape at scales of >100 $km^2$, human driven disturbance in third world countries often occurs at sub-hectare spatial scales, but when these disturbances are aggregated to regional scales they represent large impacts on the carbon cycling, hydrology and resources. The rate at which these changes occur fluctuates with climate and politico/socio/economic conditions, but it is the long-term trends that affect climate and the sustainability of resources needed to support human populations and natural ecosystems. It is for these reasons that the study of land cover and its changes often requires fine spatial resolution measurements over decades. Space-based observations are the only plausible method of monitoring land cover change processes at continental to global scales in a consistent way over annual to decadal time periods.

The Division has a long and productive history of developing satellite concepts and validating satellite algorithms to map land cover change over the entire period of record of land satellites. These capabilities have permitted us to map changes in ecosystems from regional to global scales. The Division is also engaged in modeling ecosystem processes and patterns in response to natural and anthropogenic effects. The research uses coupled ecosystem models and remote sensing observations to monitor and predict ecosystem change in a variety of vegetated systems: boreal, tropical, temperate, and semi-arid. Monitoring land cover change using satellite imagery reveals the extent and rates of natural and anthropogenic impacts on vegetation. The data for these studies come from Landsat, Earth Observing-1 (EO-1), Defense Meteorological Satellite Program (DMSP), and the polar orbiting operational satellites. The Division plays a leading role in Landsat and EO-1, in fact, we are hosting the Land Cover Satellite Project Science Office (LPSO), responsible for ensuring the science integrity, including sensor calibration. Using high-resolution imagery, forest disturbance is being mapped across North America using decadal Landsat imagery as part of the Landsat Ecosystem Disturbance Adaptive Processing System. A new project is focusing on correlating long-term trends in North American vegetation indices with changes in land cover, to separate climate-driven trends from human activities. Forest-cover change and disturbance are also being mapped in Siberia and Northern China.

Our near-term goal begins with ensuring data continuity for coarse resolution (1 km) and higher (30 m) resolution sensors. These long-term, systematic measurements include data continuity from AVHRR to MODIS to VIIRS on NPP and later on NPOESS. Higher resolution data continuity resides in the Landsat series. Division efforts are required to ensure this long-term record continues and that it is appropriately calibrated and validated to ensure science goals are attained. For coarse resolution data, efforts will continue with MODIS on Terra (proposal pending), work on the NPP Project Science and NPP Science teams. For Landsat, a data gap looms with the failing health of Landsat 5 and Landsat 7, so the Landsat Data Continuity Mission must be carried forward in the near term and Division's scientists have the responsibility for its scientific integrity.

Over the next five years, questions of terrestrial ecosystem and land cover change will be addressed by combining data from more than one sensor, either for current or long-term analysis. Opportunities for exploiting this data fusion concept will be sought out through the Research Opportunities in Space and Earth Sciences (ROSES). In addition, analyzing large numbers of Landsat or other higher resolution data sets simultaneously will facilitate analyses of regional to global ecosystem processes. We must look to have global coverage capability by 2010 to continue the assessment of decadal global land cover change. Over the next decade, there will be an evolution from land cover change analysis to the monitoring of ecosystem functioning such as productivity, stress and structure. New technology is required to accomplish this. Imaging spectroscopy can provide the fundamental measurements required. In low Earth orbit, such a mission can be used to map and quantify ecosystem type processes. To meet these needs, we are working on the Flora ESSP missions (see Table 4).

### II.1.4 Climate and Weather Prediction

The linkage across the disparate fields of atmospheric, hydrological, and biospheric sciences comes through the interface between these disciplines: the atmospheric prediction models need oceanic and land surface boundary conditions, the ocean models need atmospheric wind stress, the biospheric models need rainfall, etc. These interface requirements are needed in the development of climate and weather prediction models, and this area is the true focus of interdisciplinary science. Ultimately, the interfaces must be represented within a completely integrated model – coupled ocean, atmosphere, land, sea-ice, chemistry, biosphere – with the system components fully interactive for a consistent representation of the Earth as an integrated system. Within the ESED, the weather and climate forecast groups link the other disciplinary activities and are the avenue for the development of this integrative Earth system model and an accompanying assimilation system, one of the major five-year goals of the Division.

Why should weather and climate modeling be done at NASA? NOAA and NASA have different missions. NOAA has operational climate, ocean, river, and weather observation and forecast responsibilities for the nation. NASA's SMD emphasizes remote sensing from space and attendant technologies to provide continuous observations needed to understand the Earth system as a whole and the effects of natural and human-induced changes on the global environment. Though the agencies have distinct missions, they are united in their common reliance on access and use of global satellite data to accomplish their goals. ESED has led the development of the JCSDA. The mission of the JCSDA is to accelerate the quantitative use of satellite data in weather and climate prediction models for operational and research purposes. This collaborative approach represents a commitment of NASA and NOAA to focus on research and operational issues related to improving the forecast of high impact weather events and extending accurate weather forecasts to day seven and beyond.

NASA also has a distinct and formal role in weather and climate processes. NASA's role in climate change can be traced back to the United Nations Framework Convention on Climate Change, which the United States was the first industrial country to ratify, states that its goal is to stabilize atmospheric composition to "prevent dangerous anthropogenic interference with the climate system" and to achieve that in ways that do not disrupt the global economy. This global agreement raises fundamental scientific and practical issues that must be addressed if decision makers are to have the quantitative information needed to most effectively carry out the treaty. The President's multi-agency Climate Change Research Initiative (CCRI) and CCSP to address these issues includes NASA as one of its core agencies. In addition, the President has asked NASA to participate in both the GEOSS and the Collaborative Oceans Research Program.

NASA climate modeling focuses on the satellite era because the most detailed observations are available for that period. Assimilation tools are developed to optimize the use of the high-resolution information from satellite observations and diagnose their impact on predictions. Research-quality assimilated data sets, including clouds and precipitation, trace gas, aerosol, and climate products, and also ocean and land surface products, are generated for use by NASA instrument teams and for research analyses. To achieve its goals, strong collaboration exists between the Division's scientists and NOAA/National Centers for Environmental Prediction (NCEP) through the JCSDA, and with the other major modeling centers [National Center for Environmental Prediction (NCAR) and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL)].

To address the cross disciplinary nature of long-term weather and climate modeling, the Division has two very active groups, one at GISS which focuses on long range climate modeling and one at GMAO which focuses on data assimilation, long-term weather and short-range climate prediction. These groups have active collaborations with other scientists in the Division to address discipline science questions. Our goal over the next five years is to strengthen and further these collaborations to benefit from the integrative power of models and assimilation system on the one hand, and the observational expertise needed for input to these tools on the other.

Strategic hires within ESED will be needed to address interdisciplinary modeling for the development of a comprehensive Earth System model and assimilation system. Expertise in global atmospheric and ocean model development is needed to replace scientists who have left the Division in recent years or who can be expected to retire in the coming decade. Although in recent years model development has shifted from the paradigm of an entirely internal development cycle to that of an integrative development, a paradigm that is facilitated by the integration of GEOS-5 under the Earth System Modeling Framework (ESMF), expertise is still required for the scientific integration of components and for developments that are not undertaken elsewhere to meet NASA's requirements. Because of our focus on the interplay of models and observations, hires are also required to address the observing system elements of our plans – better use of satellite observations as well as input to mission design. In particular, a critical hire is an experienced scientist to lead the development of infrastructure for OSSEs and the linkages and support for emerging mission concepts. Our priority, commensurate with the scientific focus on clouds and precipitation, is for a civil service hire to lead the development in assimilation of data in cloudy and rainy regions and of high resolution imagery data. As we prepare to tackle the challenge of assimilation into a comprehensive Earth System model for carbon and water cycle research, hires are also needed in ocean and land data assimilation to ensure that we have the expertise dedicated for the long term to these topics.

### II.1.4.1 Assimilation

**ESED Research Focus Area:**
**Develop analysis methodologies suitable for assimilation of satellite data into predictive models.**

In assimilation, models are used to synthesize diverse in-situ and satellite data streams into a single product that combines the strengths of each data set and of the model itself. The need to generate initialization fields for numerical weather prediction has driven the direction of atmospheric assimilation development. Ocean assimilation products are now emerging to initialize ocean weather forecasts and seasonal predictions with coupled models, as well as to improve estimates of ocean climate. Satellite altimetry makes global state estimation both feasible and meaningful. Land data assimilation is also emerging, stimulated by the availability of satellite-derived soil moisture and surface temperature measurements.

Assimilation efforts in the Division focus on: (1) improvements in NASA satellite data usage for scientific analyses and initialization of models used for prediction; (2) guidance on observing system development; and (3) production of research-quality assimilated data sets. These efforts include the developments for meteorological, oceanographic, and land surface analyses, atmospheric constituent assimilation for air quality/pollution forecasts, and assimilation of ocean color measurements.

In addition to the synthesis of existing (historical) data into a consistent time series, assimilation efforts in the Division are especially focused on the use of new data types to enhance weather and climate prediction. In the next five years, the focus will be on new NASA missions such as the upcoming NPP and NPOESS missions, but also on currently available data types that are more difficult to process such as high-resolution imagery, cloud properties, and data in cloudy and rainy regions.

The atmospheric data assimilation system (DAS) currently being implemented for a new set of meteorological analyses is a radiance-based analysis system, the Grid-point Statistical Interpolation (GSI) analysis, adopted from a collaboration with NCEP coupled to the updated atmospheric model, the GEOS-5 AGCM. This system is being used, in collaborations through the JCSDA, to advance the use of hyperspectral data from AIRS and to use multiple instruments, such as AIRS and MODIS, together effectively. The large number of channels and the large data volume of these new instruments bring challenges, such as optimal data selection, to the assimilation problem. In addition to advancing the use of these new data streams, the developments for AIRS and the Advanced Microwave Sounding Unit (AMSU) help prepare for the Infrared Atmospheric Sounding Interferometer (IASI) which uses similar technology, and for the Crosstrack Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS) on NPP. Like AIRS, CrIS will provide information on ozone and the major greenhouse gases in addition to temperature and moisture soundings needed for weather prediction.

Developments underway include observing system sensitivity tools based on adjoint methods to evaluate the impact of different data types and distributions on weather forecast skill. Observing System Experiments (OSEs) are also used to evaluate the current observing system. We are developing an OSSE framework to investigate the potential of new missions and to advance our error covariance models. Over the next five years, the next phase of development will be to advance the system so as to bring in the time dimension – a 4 dimensional variational approach – considered to be essential for precipitation assimilation and to make best use of imagery data. As mentioned in Section II.1.2.4, we will continue to explore innovative approaches to use rainfall data to improve atmospheric analyses and forecasts.

The execution of a successful OSSE requires a specialized skill set, and this area is a core competency of the Division. For many missions or new instruments under consideration, OSSEs help determine quantitatively the potential impact of the data, and trade-offs in requirements or design. Such experiments can also prepare for the assimilation of new data so that it achieves its potential impact quickly. OSSEs can

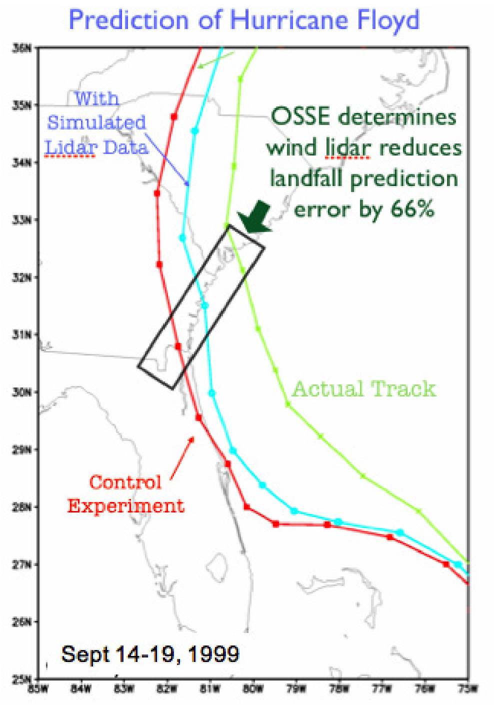



**Figure II.1.4.1. OSSE experiment in which the impact of a wind lidar instrument was assessed. The experiment demonstrates the potential effect of adding wind lidar data during assimilation on predictive skill of the subsequent forecast of Hurricane Floyd in 1999.**

also aid in the design of optimum observing systems for Earth, Mars, and other planets when the full capability is achieved. If discontinued, unique expertise and a critical aid to mission planning would be lost. The Division's OSSE capability represents the state-of-the-art in the field. In Figure II.1.4.1, an OSSE was conducted to help determine the potential impact of a lidar instrument on a hurricane track prediction. In this case, the OSSE concluded that the inclusion of the new data type reduced the landfall prediction error by roughly 66%.

The ocean and land surface data assimilation capabilities focus on using satellite data to enhance seasonal prediction. The Division has pioneered advanced techniques such as the Ensemble Kalman Filter (EnKF) for the multivariate assimilation needed to take advantage of surface altimetry. The techniques developed for altimetry should also prove effective for ocean color data and the surface salinity data anticipated from Aquarius. Over the next five years, we will focus on making progress with these new data types, especially as they provide information on air-sea fluxes needed for carbon cycle and water cycle studies. We also plan to develop observing system simulation expertise to contribute to future mission design. The EnKF has also been developed to help in dealing with the highly inhomogeneous nature of the errors in land surface models, as well as the multivariate assimilation needed to take advantage of surface soil moisture and snow observations. The combination of these activities within the Division places us in the unique position for contributing to coupled assimilation for Earth system science.

### II.1.4.2 Weather Prediction

**ESED Research Focus Area:**
**Determine which observations are likely to have the highest impact on prediction skill.**
**Develop technology, instruments, and space missions that will lead to improvements in weather prediction.**

The primary responsibility for obtaining routine meteorological observations and for providing model and data assimilation output for operational weather prediction in the U.S. rests with NOAA. However, for a number of reasons NASA plays an important role in assisting NOAA to reach its operational goals.

One reason is that future improvements in weather forecast skill are most likely to be achieved by producing better observations and by using them better in a data assimilation context. Weather forecasting is largely an initial value problem, and beyond the three-day range, observations covering the full global domain are required in order to establish sufficiently accurate initial conditions. The only realistic way to obtain this global coverage is by using satellite data. Even though NOAA owns and operates a constellation of operational meteorological satellites, data from many of NASA's research satellites are routinely used by NOAA and other operational agencies along with data from many other sources. Scientists from the Division are therefore working closely with their NOAA colleagues on testing impacts of new NASA data and on developing data processing and assimilation methodologies that are appropriate for specific kinds of satellite data.

As assimilation and modeling methodology continues to develop and observing system technology continues to progress, certain satellites and sensors become obsolete and new generations of satellite observing systems will have to take their place. GSFC also manages the development of future sensors and observatories for NOAA, thereby ensuring a continued transition of new technology to the operational systems. These efforts are generally managed out of Code 400 with support from Code 500. However, the ultimate success of these developments is determined to a large extent by having access to the scientific understanding and the modeling and data assimilation expertise represented in the Division. This will ensure that the requirements to which new systems are developed become not only technically and economically feasible, but also that they accurately represent the state of the art of scientific understanding and future user needs.

Another reason that NASA is involved in weather forecasting is the intimate connection between weather and climate on the modeling side. Historically, the vast majority of three-dimensional general circulation models used for climate simulations have evolved from numerical weather prediction models. Conversely, among the most valuable data for process studies and climate trend analysis are the so-called reanalysis data sets generated by letting a fixed version of a numerical weather prediction/data assimilation system "sweep" through several decades of observational data. The primary thrust behind the development of these systems and the only objective method for verifying their performance both come from weather forecast applications. Access to and expertise in state-of-the-art data assimilation systems is critical to the climate research activities of the Division and therefore we maintain an active research and development program in data assimilation that is closely coordinated with similar activities undertaken by NOAA.

Currently, the Division is focused on improving the use of EOS data, particularly AIRS, MODIS and AMSR, for weather prediction. One of the challenges is how to make best use of the huge volumes of data in a computationally efficient manner. As we move to higher resolution models, we are able to reduce the model biases and more effectively use the data. One of the key elements being addressed is improvement of the GEOS-5 model's convective parameterization to help reduce the precipitation shock noticed in GEOS-4 when data are introduced into the system. A major thrust over the next five years will be the use of a Cloud Resolving Model with the high resolution data from CALIPSO and CloudSat to help improve the convective processes in the global model. In addition to focusing on assimilation of cloud properties and precipitation, we plan to keep advancing the use of hyperspectral imagery, such as AIRS, and of high resolution data from geostationary satellites which hold much promise for improving weather forecast skill. EOS data will also be used to prepare the assimilation system for data from NPP and NPOESS, and we will increasingly bring the models and assimilation system to bear on design of the observing system to support weather prediction applications.

### II.1.4.3 Subseasonal-to-Decadal Climate Variability and Prediction

**ESED Research Focus Areas:**
**Determine the predictability limits and controls for climate from subseasonal to decadal timescales.**
**Predict regional climate variability.**

One of the key questions that the SMD seeks to answer is how well transient climate variations can be understood and predicted. The Division has developed advanced assimilation techniques to improve seasonal prediction skill by using the information in satellite altimetry. We have also shown that soil moisture data can significantly influence predictions of summertime precipitation over some continental regions. Seasonal predictions are contributed regularly to the consensus forecasts at NCEP and at the International Research Institute for Climate Prediction (IRI).

Over the next five years, our modeling efforts will continue to explore the impact of coupled prediction strategies and observations on prediction skill at seasonal to interannual timescales, with a focus on identifying the role that specific observations play in extending prediction skill. We will continue to undertake research to identify what controls predictability and identify the limits to predictability of El Niño and other major modes of climate variability. One of the current detriments to prediction skill may lie in the tropical biases that are found in all existing coupled models. These biases, such as deficiencies in the representation of the cold tongue in the eastern Equatorial Pacific, or the too narrow atmospheric response to equatorial SST, will be the focus of a collaborative national project in which we plan to participate. Reducing these biases will require, among other things, model developments that improve the boundary layer processes at the air-sea interface. Research will also extend to the shorter (subseasonal) timescales, beyond deterministic weather, including phenomena such as the Madden-Julian Oscillation which may be important to the evolution of El Niño, or the monsoons which have a major societal impact in their own right. Model developments will be undertaken to improve the representation of all the major climate modes of variability. On decadal timescales, we will focus on understanding the sources and predictability limits of long-term droughts. Collaborations with NOAA through its Climate Test Bed are anticipated.

To date, the focus of the coupled climate modeling and prediction effort has been on tropical climate variations and their mid-latitude teleconnections. Over the next five years, we plan to extend the scope of the coupled climate modeling effort to include processes at the higher latitudes so that we can have a system to address global water budgets and variations. To enhance realism of climate simulations and forecasts, one of the thrusts of the climate modeling group will be to take advantage of the large computational resources available through Project Columbia at the NASA Advanced Supercomputing (NAS) Facility to run models at high resolution and in large ensembles. Such improvements are essential as we aim to address the questions of societal relevance – the likelihood of changes in the statistics of weather extremes embedded in climate variations or the likelihood of extended drought conditions across different regions of the nation. The use of high resolution models will also allow us to undertake regional climate prediction, now usually undertaken with limited regional climate models or with statistical downscaling techniques.

### II.1.4.4 Prediction of Constituents – Chemical Weather Prediction

**ESED Research Focus Area:**
**Determine the impact of long-range transport on local air quality.**

The assimilation and prediction of atmospheric constituents leverage from and augment the meteorological data assimilation system. In GEOS-4, ozone is currently assimilated in a univariate framework, using assimilated meteorology. Ozone column data from TOMS, SBUV, and OMI along with profile data from EOS-Microwave Limb Sounder (MLS), the High Resolution Dynamics Limb Sounder (HIRDLS), and several occultation sensors are assimilated. This effort is currently transitioning to the new GSI analysis system being used for GEOS-5, in which ozone is included in the multivariate meteorological assimilation. In GEOS-5, the ozone assimilation will be enhanced with the use of measurements from the EOS sensors AIRS and the Tropical Emission Spectrometer (TES), and these developments will prepare for use of OMPS and CrIS data from NPP. Both meteorological forecasts and ozone forecasts have been generated in real-time to support Aura validation field campaigns. Ozone forecasts have used either parameterized or complete chemical mechanisms in the middle atmosphere and linearized schemes in the troposphere. Future development will incorporate increasingly comprehensive chemistry modules throughout the atmosphere, treating a large number of gases and their interactions with the atmospheric radiation balance. The same models are being used in chemistry-climate mode, to address questions related to past variations of ozone and their impact on the climate, as well as future prediction.

Tropospheric constituent modeling, including aerosols, is motivated by the radiative impacts on the circulation and by the important impacts of pollution on human life and ecosystems. Currently, carbon monoxide and several types of aerosols, tagged according to their sources, are used to support field campaigns. Support of the INTEX-NA mission in 2004 and the AVE/Houston campaign in 2005 gave considerable exposure to Division products and capabilities, demonstrating the realism of many aspects of inter-continental transport predictions in the analyses and forecasts. We are expanding the assimilation capability of the GSI system to include tropospheric constituents, in order to monitor and predict pollutant distributions that are related to air quality. GEOS-5 will be augmented to assimilate aerosol data from a number of EOS A-Train instruments, such as MODIS, OMI and CALIPSO, as well as from historical observations (TOMS and AVHRR). Scientific analysis of the aerosols will include studies of their effect on the atmospheric hydrological cycle. Consistent with the nature of most EOS observations of CO, $NO_2$ and other species, which contain geophysical information in the middle troposphere and higher, we will focus our study of tropospheric pollutants on long-range transport. Research will also focus on inclusion of the carbon cycle, with the intention of assimilating a range of observations of $CO_2$ and other relevant parameters, and of developing inversion techniques to infer surface sources and sinks.

### II.1.4.5 Long-Range Climate Prediction

**ESED Research Focus Area:**
**Predict Long-Term Climate Change due to greenhouse gases and other forcings.**

Climate simulations need to cover the industrial era, because of the long response time of the ocean and the need for policy makers to consider anthropogenic effects. Paleoclimate history must be considered because of the insights and model tests that it provides. The climate simulations need to include high spatial resolutions, so that they can contribute to climate impact studies and to climate process studies on regional scales. Climate time scales require that the vertical extent of the model include the full ocean and the middle atmosphere, as well as the troposphere. NASA has given attention to natural and anthropogenic climate forcings. Quantitative understanding of forcings is needed to evaluate the effectiveness of climate mitigation strategies. To make progress on the climate sensitivity issue will require evaluating feedbacks, especially those due to clouds, water vapor, and sea ice. Key climate diagnostics derived from satellite observations, analyzed with the help of appropriate modeling, can yield advances in understanding of climate change. Precise measurements of ice sheet topography are but one example of these important activities. In combination with modeling and field studies, these measurements may allow investigation of possible non-linear responses of ice sheets to growing anthropogenic climate forcing. Our modeling emphasizes the role of climate forcings, defined with the help of outside experts, and climate feedback processes.

In the future, a new approach is needed for climate model development. It is not practical for a single group to have expertise in all the components of a global model, as the models are becoming more complex and include more physical and biological processes. Models for long-term climate must extend from the deep ocean to the upper atmosphere, and beyond to the variable output of the Sun. Components of the global system that were once treated as specified boundary conditions or neglected altogether must now be simulated and allowed to interact with other parts of the model. Processes that need to be simulated include the carbon cycle in the ocean and on land, atmospheric gaseous composition, aerosol properties, and even heterogeneous chemistry. One implication of all of this is the need for an open standard for building Earth system models; this is the objective of the ESMF project. The strategy for further model development is to take advantage of the improved modularity of the model to test and compare alternatives for key parts of the model. It still can be a major task to replace one module with another, because the climate model inevitably has been 'tuned' to be compatible with existing components. This implies that significant effort is required to test new methods, and it may not be easy to judge the ultimate potential of a new method from the first climate simulations.

Several recent studies—e.g., *New Opportunities in Sun-Climate Research* (NASA, 2003) and *Strategic Plan for the U.S. Climate Change Science Program* (CCSP, 2003)—have identified high-priority scientific issues in Sun-Climate research relevant to NASA, the nation, and the world community. Recognizing that ESED has broad expertise in both solar and climate physics, the Division charged a Goddard Sun-Climate Task Force with developing a crosscutting research framework incorporating analysis, theory, modeling and measurement. The Task Force has recommended that NASA establish a *Sun-Climate Center of Excellence*, coordinated through Goddard, with the mission to promote an integrated program of observational systems and research to improve the understanding and prediction of the response of Earth's climate to solar forcing from monthly to multi-centennial time scales. The Center should enhance the conduct of core research in support of NASA Earth-Sun Exploration, accelerate the use of existing NASA data, (such as the multi-satellite record of total solar irradiance since 1978, Table 3), develop new mission concepts, and coordinate the application of solar and planetary science to protect the Earth and solar system explorers. Several new hires will be required over the next five years to implement and support a Sun-Climate Center.

## II.1.5 Solar and Space Physics

Researchers in solar, heliospheric, and geospace physics lead the definition and development of missions in support of these goals and perform research including: solar structure and magnetic activity, generation of the solar wind, heliospheric structure and dynamics produced by solar disturbances, magnetosphere-ionosphere coupling in response to the solar wind, upper atmospheric effects, and possible effects on the Earth's climate. We develop coupled models of the solar-terrestrial system and design, propose, and fly state-of-the-art instrumentation in the areas of photon and neutral atom imaging, electric and magnetic fields, and plasma and energetic particles. We also develop unique data sets and data systems that manage a wide range of solar-terrestrial data to enable rapid access and sophisticated analysis across mission and discipline boundaries for the international space science community. The scientists interpret and evaluate data gathered from instruments and archival data, draw comparisons with computer simulations and theoretical models, and publish the results.

ESED scientists in the space physics groups maintain two major data sets used extensively by the science community. A comprehensive data set that is used to study the coupling of the solar wind with the magnetosphere called OMNI data (see Table 3) spans over 40 years (more than 3.5 solar cycles). This data set is requested more than any other in the field of space physics. Heliospheric plasma and cosmic ray processes are studied with the Coordinated Heliospheric Observations (COHO) data set (see Table 3) that also spans more over 40 years. Both OMNI and COHO data are derived from instruments on 17 and 11 spacecraft, respectively, and must be intercalibrated to provide a consistently high quality set of merged parameters.

NASA's goal for future research and exploration within its Sun-Solar System Connection program is to observe and understand the complex phenomena associated with space weather by studying the Sun, the heliosphere and planetary environments as a single, interconnected system. Such an understanding will represent not just a grand intellectual accomplishment for our times - it will also provide knowledge and predictive capabilities essential to future human and robotic exploration of space and will serve key societal objectives in important ways.

The same explosive event on the Sun that produces power outages on Earth can also degrade solar panels on interplanetary spacecraft, produce mission-ending damage to instrumentation at Mars, produce radio waves and aurora at the outer planets, and even change the fundamental interaction of our heliosphere with the interstellar medium. We will develop not only a predictive capability to address hazards to space travelers and important technological assets closer to home, but we will also learn how the fundamental space processes interplay to affect the habitability of other distant environments. Our strategic plan for the future consists of three broad scientific objectives:

***Understanding the Nature, Origins, and Terrestrial Impacts of Solar Variability***

We are expanding our understanding of our place in the solar system by investigating the causes and effects of solar variability. By studying the interaction of solar variability with the Earth, we will assess the effect of this interaction on humankind. Building on our new knowledge of fundamental processes, we can characterize and develop a predictive knowledge of Earth's space environment and its long-term impact on society, technology, and our planet. This will be accomplished both by direct investigation of the local environment and by what can be learned about life on Earth through studying other environments.

***Understand the Fundamental Processes Necessary to Support Space Weather Prediction***

High-fidelity space weather predictions are impossible without understanding the fundamental physical processes that govern the chain from the Sun to the Earth or throughout the solar system. As the foundation for our long-term research program, we therefore have to develop a complete understanding of the fundamental physical processes of our space environment–from the Sun to the Earth, to other planets, and beyond to the interstellar medium. We will systematically examine similar processes in widely different regimes with a range of diagnostic techniques to both test our developing knowledge and to enhance overall understanding. The universal themes of energy conversion and transfer, cross-scale coupling, turbulence and nonlinear physics have been chosen as near-term priority targets. The five fundamental processes that have been identified as the critical immediate steps are: magnetic reconnection, particle acceleration and transport, the generation and variability of magnetic fields, cross-scale coupling across boundaries and large structures, and nonlinear energy and momentum transport and coupling in atmospheres. Both in-situ and remote sensing observations will be required, providing a three-dimensional large-scale perspective as well as a detailed small-scale microphysics point of view. With our increasingly sophisticated understanding of such basic processes, we will open the frontier of predictive modeling of space weather across the solar system.

***Safeguard Our Outward Journey***
The great variety of space environment conditions will have a significant impact on our future space explorers, both robotic and human. We will vigorously pursue the research necessary to assure the safety and the maximum productivity of our explorers. We strive to develop the capability to predict space environment conditions from low Earth orbit to the Moon and Mars. Addressing space weather issues is necessary for optimizing the design of habitats, spacecraft and instrumentation, and for planning mission and operations scenarios, ultimately contributing to mission success.

## II.1.5.1 Solar Physics

### II.1.5.1.1 Solar Magnetic Variability

**ESED Research Focus Area:**
**Understand the long-term variations of solar activity and irradiance that affect Earth's space climate and thermal balance.**

Helioseismology has transformed our understanding of the interior of the Sun, revealing its thermodynamic structure with fidelity unimagined 20 years ago, while invalidating long-held notions about the operation of the solar magnetic dynamo, and opening new areas of theoretical investigation. The record of helioseismic mode frequencies and widths, which now spans a full solar cycle (Table 3) and will be continued by the SDO, is a key data set that becomes even more powerful when combined with long-term satellite and ground-based measurements of the solar surface magnetic field (Table 3). The Laboratory for Solar and Space Physics (LSSP) has a strong presence in helioseismology due to the contributions of a single researcher who made pioneering observations and invented the technique of time-distance helioseismology, which will play a major role in the scientific program of the SDO. During the next five years, LSSP plans to augment its capabilities in helioseismology for the SDO era with a hire to replace a retired magnetograph scientist.

### II.1.5.1.2 Exploration of Solar Coronal Dynamics

**ESED Research Focus Areas:**
**Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms.**
**Develop models and forecast tools for solar disturbances, their heliospheric evolution, and the response of planetary atmospheres to typical and extreme solar events.**

The pervasive dynamism of the outer solar atmosphere, on all observed spatial scales, has been the most striking lesson of the most recent generation of solar remote-sensing satellites: Yohkoh [a joint Japan Aerospace Exploration Agency (JAXA)/NASA mission], the Solar and Heliospheric Observatory (SOHO, a joint ESA/NASA mission), the Transition Region and Coronal Explorer (TRACE), and the Ramaty High Energy Solar Spectroscopic Imager (RHESSI). The Division maintains key project science and co-investigator roles in SOHO and RHESSI while developing the next generation of missions, including the Solar-Terrestrial Relations Observatory (STEREO), Solar-B (JAXA/NASA), and the SDO. We recently delivered two coronagraphs (COR1) for STEREO and are continuing technology development of X-ray and gamma-ray spectroscopic imaging for the post-RHESSI era. We also maintain and expand key data sets (Table 3) of X-ray and gamma-ray emission from solar flares extending back to 1980.

The Division pursues a highly successful sounding rocket program to observe the corona at extreme ultraviolet wavelengths and to develop cutting-edge technology applicable to orbital missions. The Solar Extreme ultraviolet Research Telescope and Spectrograph (SERTS) had ten successful flights, returning a wealth of high-resolution spectra and pioneering technology such as intensified charge-coupled devices (CCD) detection (incorporated in SOHO), multi-layer coated gratings, and precision lithographic slits (both incorporated in Solar-B). Currently, the Extreme Ultraviolet Normal Incidence Spectrograph (EUNIS), a successor to SERTS with over 100 times greater sensitivity, is in integration and test for launch in the fall of 2005. The EUNIS/SERTS program has given dozens of young scientists, from high school students to postdoctoral fellows, hands-on experience with flight hardware and new data.

During the next five years, the Division plans to strengthen the instrument development capabilities exemplified by RHESSI, COR1, and EUNIS by hiring 1-2 scientists with expertise in detectors and optical systems (these positions may be a shared among several ESED laboratories).

#### II.1.5.1.3 Coronal Mass Ejections, Flares, and Space Weather

**ESED Research Focus Areas:**
**Understand the long-term variations of solar activity and irradiance that affect Earth's space climate and thermal balance.**
**Develop the capability to predict the propagation and evolution of solar disturbances.**

Particles from coronal mass ejections (CMEs) and particles and photons from solar flares are the major determinants of space weather, which has effects ranging from disruption of terrestrial communications to hazards to space travelers. The Division has been in the forefront of identifying observational precursors to geo-effective CMEs and studying the interaction of CMEs with the interplanetary medium. Catalogs maintained by the Division (Table 3) of the times, locations, and velocities of CMEs are an essential tool for understanding the systematic properties of CMEs. Recently, RHESSI data have shown that direct radiation from large flares can rival or surpass the energy in the CME.

As part of a thrust to integrate the study of heliospheric disturbances and broaden the concept of "geophysical" on the 50$^{th}$ anniversary of the first International Geophysical Year, we conceived the International Heliospheric Year 2007 (http://ihy.gsfc.nasa.gov) and continue to play a leading role in the multi-nation consortium of researchers.

The Division plans to expand its capabilities in the area of integrative modeling of the Sun, heliosphere, geospace, and planetary environments and needs to hire a high-energy solar physicist in the post-RHESSI area after the retirement of the Mission Scientist.

#### II.1.5.1.4 Fundamental Atomic Physics of Space Plasmas

**ESED Research Focus Area:**
**Understand the plasma processes that accelerate and transport particles.**

The quantitative understanding of physical processes in the solar atmosphere rests squarely on the ability to analyze high-resolution spectra. In turn, this ability is anchored in the bedrock of atomic and molecular physics. Often taken for granted, our knowledge of energy levels, transition rates, and cross sections is still deficient for many ions of known astrophysical importance. LSSP conducts basic theoretical research on the calculation of atomic and molecular parameters. Although this program has introduced important techniques and produced literally hundreds of refereed papers over the years, LSSP expects that the program will diminish due to retirements and the lack of NASA proposal opportunities.

### II.1.5.2 Heliospheric Physics

**ESED Research Focus Areas:**
**Understand the plasma processes that accelerate and transport particles.**
**Understand the role of plasma and neutral interactions in nonlinear coupling of regions throughout the solar system.**
**Develop the capability to predict the propagation and evolution of solar disturbances.**

The plasmas, energetic particles and associated electromagnetic fields generated and emitted by the Sun, constitute the heliospheric interplanetary environment. Its properties set the parameters controlling the mechanical and electromagnetic interactions between the heliosphere and the planets, their moons, other solar system bodies such as comets and asteroids, and, at the outer boundary of the solar system, the interstellar medium. Disturbances of the interplanetary medium are generated most dramatically by eruptive dynamic events in the solar atmosphere, such as coronal mass ejections or flares, leading to the disruptive phenomena of space weather. Longer term solar variations, such as the Maunder minimum and solar development along the main sequence, control what might be termed “space climate.” Heliospheric physics deals with all these processes over all time scales.

***Heliospheric and Planetary Space Plasmas***
The relevant direct in-situ observations of plasmas include density, temperature, and winds by species including electrons, ions by mass and in general by charge state. Since space plasmas are routinely far from thermodynamic equilibrium, the full velocity distribution is usually measured in three dimensions for the thermal core, and in two dimensions for the energetic hot tail distributions (parallel and perpendicular to the local magnetic field). Close coordination with field measurements is always required. Plasma measurements are in general based upon energy resolving charged particle optics, combined with time-of-flight velocity measurements to obtain mass, with microchannel plate electron multiplication detectors and energy resolving solid state detection when charge state is required. The Goddard space plasma instrument group has developed such instruments for the International Sun-Earth Explorer (ISEE 1, 2, 3) mission, the Wind and Polar missions, the Triana PlasMag instrument, and will develop the Fast Plasma Instrument for the Magnetospheric MultiScale (MMS) mission, which was selected for Phase B development in May 2005. It also developed the Low Energy Neutral Atom (LENA) instrument for the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission, and is currently participating in the development of the Small Explorer Interstellar Boundary Explorer (IBEX)-Lo sensor for the IBEX mission. The Division maintains an extensive set of common-format data on the plasma and magnetic properties of the heliosphere extending back to the early 1960’s (Table 3).

***Heliospheric and Planetary Electromagnetism***
Electromagnetic fields are generated by the conducting solar wind plasma as it expands throughout the solar system and links the entire heliosphere into a coupled plasma cell. The properties of interplanetary space and their interactions with planets and other bodies vary with the solar magnetic activity cycle and with the development of eruptive events on the solar surface, as they propagate outward through the heliosphere. The effects of electromagnetic fields extend across the frequency spectrum from DC to radio frequencies. LSSP has a long and distinguished record of pioneering observations of such fields, extending, with the recent crossing of the solar wind termination shock by Voyager 1, to the limits of the solar system. LSSP has also been closely involved in heliospheric and planetary studies based on the ACE and Wind missions from Earth to the L1 upstream libration point, and for the Ulysses mission out of the ecliptic to the polar regions of the heliosphere. LSSP co-investigators will participate in the STEREO mission, which will add substantially to our understanding of the three-dimensional structure of solar eruptive events, and in the MESSENGER mission to study the solar wind interaction with Mercury’s exosphere and magnetosphere.

*Magneto-plasma-dynamic Theory and Modeling*
Theoretical understanding of the heliospheric medium and its interactions with solar system bodies is based largely on magnetohydrodynamic descriptions, complemented by kinetic studies of particle motions and augmented by hybrid studies of turbulence and wave-particle interactions. The Division scientists have pioneered the full three-dimensional description of heliospheric dynamics including turbulence and related stochastic phenomena, across the full range of space and time scales of the solar system.

## II.1.5.3 Geospace Physics

**ESED Research Focus Areas:**
**Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms.**
**Understand the plasma processes that accelerate and transport particles.**
**Understand the role of plasma and neutral interactions in nonlinear coupling of regions throughout the solar system.**
**Develop models and forecast tools for solar disturbances, their heliospheric evolution, and the response of planetary atmospheres to typical and extreme solar events.**

The solar wind interaction with the geomagnetic field surrounds the Earth in a *magnetosphere* whose volume exceeds $10^5$ cubic Earths (or ~ $10^{17}$ $km^3$). The electrodynamics of this interaction transfers energy from the solar wind to the magnetosphere at typical rates of $10^{10}$ to $10^{11}$ W. This energy powers the electric currents that support the magnetic structure of the magnetosphere, maintains the typical 50 to 100 kV electric potential drop across the system, heats its internal reservoirs of plasma to coronal temperatures ($10^6$ K), accelerates some charge particles to cosmic ray energies ($10^1$ to $10^3$ keV) to populate the radiation belts, and transfers up to $10^{12}$ W into the high latitude ionosphere during *storms* and *substorms.* The great changes that take place in the Geospace environment during storms and substorms constitute "space weather" which can seriously affect commercial and government spacecraft and space infrastructure supporting the manned space program.

*Magnetic Reconnection*
The flares and coronal mass ejections on the Sun and magnetic storms and substorms in the magnetosphere are driven by the spontaneous, rapid conversion of energy stored in magnetic fields into fast plasma flows with speeds sometimes exceeding 2000 km/s. The physical process responsible for this explosive release of energy is *magnetic reconnection.* The Division scientists are among the world leaders in the measurement and theoretical modeling of reconnection. We possess extensive capabilities in the development, operation and analysis of magnetometers, electric field double probes and plasma analyzers used to observe reconnection as well as theoretical modeling utilizing magnetohydrodynamic and kinetic numerical simulations. Our scientists have leading roles on such reconnection oriented missions as Geotail, Cluster, and, most recently, Magnetospheric Multi-Scale.

*Magnetosphere - Ionosphere Coupling*
The primary coupling between the high altitude magnetosphere and lower altitude ionosphere is electrodynamic. Magnetospheric convection generates large flows of electric current along the magnetic flux tubes connecting these two regions and results in energy transfer rates ranging up to $10^{12}$ W. This energy heats the ionosphere and, via ion - neutral collisions, drives high altitude neutral winds in the thermosphere. The lesser amounts of kinetic energy deposited by the charge carriers for these electric currents, mostly electrons with kilovolt energies, power the optical emissions emanating from the transitions in neutral oxygen and nitrogen atoms that they excite. Division scientists carry out a broad range of experimental investigations of these coupling processes using particles and fields instruments on low-latitude satellites and sounding rockets. Our scientists have major roles on such magnetosphere - ionosphere coupling missions as Dynamics Explorer, Fast Auroral SnapshoT (FAST), POLAR, and the soon to be launched Communication/Navigation Outage Forecasting System (C/NOFS) and ST-5. In addition, we are leaders in the conception and execution of sounding rocket campaigns to measure Ionosphere Thermosphere Mesosphere (ITM) processes.

***Space Weather***
The great changes that take place in the high altitude magnetosphere, the radiation belts, and the ionosphere - thermosphere - mesosphere regions of Geospace during storms and substorms are termed *space weather.* Storms are long intervals with durations of many hours to 5 - 10 days of continuous, rapid magnetospheric convection usually driven by coronal mass ejections. During storms there is continuous magnetic reconnection that results in a steady "injection" of energetic ions into the radiation belts of the inner magnetosphere where differential drifts between the electrons and ions produce the famous "*ring currents*" that quickly surround the planet and then slowly decay. The Division maintains an extensive, long-term set of intercalibrated solar wind and geomagnetic data (Table 3) that enables many studies of the physical connections between the Sun and the magnetosphere.

Substorms, in contrast to storms, are intervals of short-lived, ~ 1- 3 hrs, but extremely fast magnetospheric convection, that often occur several times per day. In contrast with storms, the far more frequent substorms appear to be caused by the spontaneous release of stored energy in the nightside magnetosphere through reconnection. In contrast with the storms, substorms are not generally related to any specific forms of solar activity. Division scientists are leaders in the experimental and theoretical investigation and modeling of many areas of space weather. In particular, our scientists will be proposing electric fields, magnetic fields, plasma and ultra-violet imaging investigations for the Living with a Star Radiation Belt and Ionosphere - Thermosphere Storm Probe missions. Furthermore, Division theorists and modelers are active in most aspects of space weather and support the inter-agency Community Coordinated Modeling Center (CCMC) conceived and operated by GSFC scientists to support the development and transition to operations of space weather forecast models.

## II.1.6 Managing and Analyzing Data

The Division plays a leading role in the development and evolution of science data systems to generate and manage Earth-Sun System Science data and information; some of the long-term data sets maintained by the Division are listed in Table 3. ESED does cutting-edge research in the form, nature, and structure of large data systems, as evidenced by the various data systems listed below, each of which represents a unique research effort more or less invented within ESED. Thus, rather than the "one size fits all" model of the original EOS data information system, ESED has presented to the research community many models of what a data system can be, and this has immeasurably enriched the knowledge of data systems. Our data system capabilities include science algorithm development and integration, operational product generation and reprocessing, archive management, data search and access services, and data distribution. Our GCDC and CCMC are active in the development and application of advanced capabilities that maximize the availability and usefulness of science products. There is an extensive outreach effort to build awareness and encourage use of the available products and services from Earth-Sun Science missions, models, and field campaigns. In addition to managing, processing and distributing data sets, ESED performs original applied research in computer science areas such as artificial intelligence, data compression, computer graphics, and image processing that provide both short-term and long-term benefits to NASA data and information systems. The ESED develops advanced computer data acquisition systems to meet the research needs of oceans, weather, land, climate, hydrology, solar, and space sciences and develops advanced data storage, data compression, and analysis techniques and distributed system architecture technologies.

### II.1.6.1 Data Services and Modeling for Earth Science

The GCDC develops operational mission-focused data processing systems that ingest sensor data records and generate calibrated geophysical parameters on an operational basis. The architecture of GCDC science data processing systems is being upgraded to address multiple missions, to provide greater flexibility to modify and interchange processing algorithms, to port to different hardware platforms and operating systems, and to minimize human interaction.

The GCDC manages the Goddard Distributed Active Archive Center (DAAC) data system. The DAAC archives, provides search and order access, and distributes science data from Earth-Sun Science missions, interdisciplinary studies, models, and field experiments. Data support preparations include definition of data format and metadata, development of data acquisition and ingest tools, definition and development of tools for data search and access, and development of data set documentation. The DAAC develops customized, value-added products including subsets, data mining services, ancillary data, Geographic Information System (GIS) products, and visualization and analysis tools. The DAAC also provides user support services including Help Desk, usage statistics and surveys, and outreach to science conferences and workshops to publicize and build user awareness of the data product availability and utility.

Some of the data systems listed below were developed in response to a specific mission or project. Others were developed by the Goddard Earth Sciences (GES) DAAC (GES DAAC) as an element of the EOS Data and Information System (EOSDIS).

Data and information systems developed and operated within the ESED include the following:

- ***Data Assimilation System (DAS)****:* The DAS is responsible for the production of assimilated global data sets and for their distribution to the community at large. The GMAO developed both the model and the assimilation system used to process the data.

- ***Global Change Master Directory (GCMD):*** The GCMD provides summary descriptions of more than 10,400 Earth-Sun Science data sets and more than 220 Earth-Sun Science-related services. More than 1300 data centers, government agencies, universities, research institutions, and private researchers have contributed descriptions to GCMD. It maintains one of the world's most popular hierarchical set of Earth-Sun Science keywords and represents NASA on the U.S. Global Change Research Program (USGCRP) Data and Information Working Group providing interagency support for locating global change data.

- ***Moderate Resolution Imaging Spectroradiometer (MODIS) Data Processing System (MODAPS):*** MODAPS produces MODIS Level 2 and higher data products from the Level 1 data produced by and received from the GES DAAC. For archiving and distribution, the atmospheres and oceans data produced at MODAPS are sent to the GES DAAC for archiving and distribution. Likewise, the land products are sent to the Eros Data Center (EDC), and the snow and ice products are sent to the National Snow and Ice Data Center (NSIDC).

- ***Sea-viewing Wide Field of view Sensor (SeaWiFS) Data Processing System (SDPS)****:* SDPS is responsible for acquiring SeaWiFS data, as well as ancillary data. SDPS also processes (and reprocesses) the data to higher level products, stages the data for further data manipulation, and sends the data to the GES DAAC for public archive and distribution.

- ***Tropical Rainfall Measuring Mission (TRMM) Science Data and Information System (TSDIS):*** TSDIS is responsible for processing and post-processing of the TRMM science data. Working with the TRMM principal investigators and science algorithm developers, TSDIS maintains the operational science data processing system and ensures the timely processing of all TRMM science instrument data.

- ***GES DAAC*****:** Version 0 (V0) was developed to ingest, archive, and distribute data from Earth-Sun Science missions originating prior to 1998. Missions include: AVHRR, CZCS, the former Data Assimilation Office (DAO), SeaWiFS, TOMS, TOVS, and UARS. Version 1 was developed to support TSDIS, and Version 2 (the EOSDIS Core System) was developed by the Earth Science Data and Information System (ESDIS) project and operated by the GES DAAC to ingest, archive, and distribute data from Terra, Aqua, and the Solar Radiation and Climate Experiment (SORCE). This system also produces MODIS Level 1 and all AIRS data products.

### II.1.6.2 Data Services and Models for Solar and Space Physics

- ***Community Coordinated Modeling Center (CCMC):*** In response to national needs for the development of space weather specification and forecast models, the CCMC was created here in the Division through a multi-agency memorandum of understanding. With funding and in-kind support from NASA, NSF, NOAA and various DoD agencies, the CCMC forms a value-added bridge between the numerical models developed in the research community and the needs of the operational community for robust, well-documented, measurement-validated space weather forecast models. In addition, the CCMC provides the research community with access to modern space science simulations. By means of this activity element, CCMC adds to NASA's "open data policy" a new "open model policy." The CCMC's goals, operations, and achievements are reviewed on a regular basis by a steering committee composed of representatives of all of the major stakeholder agencies.

- ***Solar Data Analysis Center (SDAC)*:** The SDAC is responsible for serving scientifically useful data from Principal Investigator instruments on active and recently completed solar physics missions, including SMM, Yohkoh, SOHO, TRACE, and solar flare data from the Compton Gamma Ray Observatory Burst and Transient Source Experiment (BATSE) instrument, to the worldwide scientific community over the Internet (see Table 3). The SDAC will serve as the "active archive" (STEREO Science Center) serving data from the upcoming STEREO mission and as the U.S. scientific archive mirror for the upcoming JAXA Solar-B mission. SDAC staff also test and deploy new, low-cost technologies for archiving, retrieving, and analyzing solar data.

- ***Space Physics Data Facility (SPDF):*** The Space Physics Data Facility (SPDF) leads in the design and implementation of unique multi-mission and multi-disciplinary data services, innovative ground data system concepts, educational programs and crosscutting data, modeling, and visualization research to strategically advance NASA's solar-terrestrial program and our understanding of the Sun-Earth system. SPDF maintains the OMNI and COHO data sets (see Table 3).

- ***Virtual Solar Observatory (VSO):*** Staff at the SDAC, in cooperation with scientific and IT team members at Stanford University, Montana State University, and the National Solar Observatory, have developed and deployed a first-generation VSO for the identification and manipulation of metadata from online solar physics data archives distributed around the nation and around the world. The VSO enables scientific users to select observations matching their metadata requirements (based on instrument type, physical observable, data provider, and/or time), and download the selected date objects directly from the data providers. The VSO is currently enlarging its network of data providers and offering the basis for the date retrieval capabilities planned for the STEREO Science Center (SSC) and the upcoming SDO mission. In addition to human-usable interfaces, the VSO provides an applications programming interface (API) and Web Services (WSDL) interface for machine-to-machine queries. These machine communication methods allow VSO services to be utilized by the broader Sun-Solar System Connections community through the Virtual Space Physics Observatory (VSPO) and Collaborative Sun-Earth Connector (CoSEC).

- ***L1 data system:*** The L1 data system is a distributed data environment for near L1 solar wind observations. This project brings together six universities and government research labs to improve both the quality and speed of science data distribution from the PI sites to the end users. The results of this project form the basis of a more comprehensive Virtual Heliospheric Observatory proposal that will include several more university teams and data products.

- ***Sun-Solar System Connection Active Archive (S3CAA):*** S3CAA's work is to develop, operate, and evolve unique multi-mission and international cross-disciplinary data, models, and correlative services enabling S3C strategic areas; to work with the community, with other data services and sites, and with the Permanent Archive at the National Space Science Data Center (NSSDC) to best ensure that important S3C data are preserved and made accessible; and to evolve capabilities that will support the future S3C Virtual Observatory. Major data services include the multi-mission CDAWeb, supporting current data from almost all instruments on almost all current and planned space physics missions;

SSCWeb, an orbit service for science and conjunction planning and data analysis; the Common Data Format (CDF), a self-describing, self-documenting common format in use by a wide range of present and future space physics missions; the OMNIWeb (manages the OMNI data of Table 3), 1-AU standardized reference for interplanetary fields, plasma and particle data; and several other specialized systems. The effort includes software and data flow supporting partner international mirror sites in the United Kingdom, Germany, and Japan.

### II.1.6.3 High Performance Computing

High performance computing is the life-blood of numerical modeling for climate, weather, the space environment, and solid Earth science. Currently, the Agency provides clusters of leading-edge computing platforms through two primary sources. To assist scientists in using the supercomputing facilities at Goddard and Ames, SIVO's Advanced Software Technologies Group (ASTG) provides a number of software and hardware support services to the community. The functions of SIVO are described in Section II.1.6.4. ASTG staff members are also matrixed to the applications support group at Ames such that an integrated support environment is enabled, no matter which facility scientists choose for their computing. Services include Level 2 help desk support to user training, code migration, performance tuning, parallelization, algorithmic development, software engineering, and code modernization. We plan to continue this activity as new and faster supercomputers come on-line.

Over the next five years, supercomputers are likely to evolve in a manner predicated by the so-called Moore's "Law," which states that effective computing capabilities double every eighteen months. Based upon computing resources currently provided by NASA, and assuming that the Agency will continue to invest in leading-edge systems at present-day funding levels, it is not difficult to extrapolate to the ESED supercomputer of 2010. Such a supercomputer will likely be comprised of 20-30 thousand processors, half a petabyte of random-access memory, 20 petabytes of on-line disk storage, and will likely have the capability of delivering a performance of nearly 1 peta-FLOP/s. Perhaps more interesting but less clear will be the impact of high performance computing networks, which currently deliver in excess of 10 gigabits per second (Gb/s). This technology is perhaps on the fastest growth path over the next five years. By 2006, the first 100Gb/s networks will be introduced, with 1Tb/s and 10Tb/s networks expected to be available in 2008 and 2010, respectively. At the very least, such networks are anticipated to greatly enhance the ability for ESED scientists to share information with peers at other government facilities, universities, etc. In the most fervent instance, the advanced grid technology would enable highly distributed, heterogeneous computing and data services across geographically dispersed resources, thus enabling the Agency to "purchase" computing cycles from vendors over high-speed networks. This could satisfy some of the Agency's "capacity computing" requirements, however "capability computing" requirements are likely to remain attainable only through the use of large, in-house systems.

It will be imperative for SIVO to establish a good working relationship with the high-performance computing facilities at Ames and Goddard such that technology trends are closely monitored. SIVO must also maintain a close working relationship with the science community in order to fully comprehend their needs. NASA must retain leadership to bring new technologies to bear on Earth and Space science modeling activities. Under this strategic implementation plan, SIVO will provide at a minimum 1 Full-Time Equivalent (FTE) dedicated to studying technology trends in high performance computing and identifying those areas that are relevant to the ESED's research efforts. This individual would be responsible for providing the necessary two-way linkage between the research scientists and the ongoing information technology research at Goddard and at Ames, and would assist in developing technology roadmaps that would link specific research requirements (e.g., increased model resolution, better parameterizations, etc.) with enabling technologies (e.g., National Lambda Rail, Earth System Grid, new paradigms to address memory bandwidth latencies, etc.).

### II.1.6.4 Advanced Software Development

***The Earth System Modeling Framework (ESMF)***
Applications software is at the core of computational modeling and serves as the interface between the scientist and computer. The challenges inherent in modeling weather, climate, and the solid Earth require the integration of model components developed by a large number of research groups. These models were developed to solve a specific scientific problem and they were generally not designed to be integrated as components of a larger model. Recognizing this issue, NASA initiated the development of the ESMF as a software framework to provide an interface between model components. Leading university and government researchers have joined together to develop software frameworks that will enable more realistic simulations of natural phenomena and interpretation of vast quantities of observational data on high-end computers. The ESMF, Version 1.0, has just been released and is a key NASA contribution to the U.S. Climate Change Science Program. The ESMF software will allow weather and climate models from different researchers to operate together on parallel supercomputers, enabling comparison of alternative scientific approaches and ultimately improving predictive capabilities. In the next phase of development, ESMF will be extended to encompass space weather applications, including the capabilities developed in the NASA-funded Space Weather Modeling Framework. As ESMF continues to evolve, SIVO will be participating in the development of this standard.

***Software Integration and Visualization Office (SIVO)***
It is SIVO's responsibility to provide leadership to the Division and to the Directorate in addressing the issues of cost, risk, complexity, and performance of large numerical modeling codes. Between now and 2010, the biggest challenge will be adapting legacy codes to take advantage of new, complex architectures and customized architectural features. Petaflop computing, expected to arrive on the scene by 2010, will likely be delivered through the use of tens of thousands of processors in a clustered computing environment. Scaling numerical models to make use of all available processors will become increasingly difficult. Load imbalances and communication overhead will be exacerbated as parallelism requirements and the number of processors increase. By 2010, the computing software and hardware must be able to support a factor of four improvement in horizontal resolution.

In addition to addressing the issues related to performance, SIVO will continue to promote and implement ESMF for elements of numerical models. If successful, ESMF will enable multiple configurations of a coupled ocean-atmosphere-chemistry-land model with multi-model data assimilation capabilities by 2010. The promotion of ESMF will be very important to achieve the goal of interoperable model components for climate, weather, and data assimilation applications. A component-based architecture that provides a standard set of data types and reusable methods will be the only way to reduce the overall complexity of the models and thus simplify future development and reduce the overall cost and risk.

## II.2 Instruments, Technology, and New Missions

Space missions are the main mechanism through which NASA gathers new observations to attack the science questions. Missions are also a major source of funding for ESED personnel and the GSFC. Winning future mission work is critical for the ESED. The Division has a long history in the development of UV/visible-, lidar-, and microwave-instruments and remote sensing technology on the Earth science side, and magnetometry, electric field, plasma, and extreme UV imaging instrumentation on the solar and space science side. Most of these activities date back to the 1960s.

Working closely with the outside community, ESED's scientists formulate the scientific questions that need to be answered to understand the physical processes of the Earth-Sun system; develop observational requirements and attending technologies; and devise the overall mission plan. Notional mission plans are cast in the form of roadmaps. Appendix VI shows the roadmapped missions for Earth and solar/space science distilled from NASA HQ roadmaps. Both notional and selected missions are shown in this appendix.

In order to win missions, the ESED's scientists work together with engineers to develop new concepts and design new instruments not only for space missions, but also for ground-, balloon-, and aircraft-based observations. The latter serve as steppingstones in the development of the spaceborne instruments, their calibration and validation. Furthermore, ground-based systems provide surface or near-surface measurements while balloon and airborne platforms facilitate viewing processes such as precipitation, cloud systems, surface vegetation, water or ice from a high-altitude vantage point and with high spatial and/or spectral resolution. Major field campaigns supported by the Division frequently need observations at multiple levels and thus require simultaneous ground, air, and space observations.

## II.2.1 Instruments

Instrument technologies are constantly being pushed to meet more stringent demands required by new measurements. These new measurements often require enhanced spatial, spectral, and temporal characteristics, or require the instrument to operate in a new environment or vantage point.

Technology development occurs in the instrument area (new detectors, lasers, radar components, etc.), in the spacecraft (large apertures, deployable structures, low power rad-hard electronics, small deployable sensorcraft, station keeping/pointing/formation flying activities…) and/or others which may still be in the information technology arena (data compression, high speed downlink, redeployment).

The requirements for better spectral and spatial measurements necessitate substantial improvements to our detectors, detector sizes, and optical components. The need for improvements in temporal coverage has driven many of the advanced observing scenarios to take advantage of new vantage points such as Geosynchronus/Geostationary Earth Orbit (GEO) and L1/L2 orbits. Unfortunately, these new vantage points will require additional improvements in the Signal to Noise Ratio (SNR) of our detectors, the size of our apertures, greater on-board processing capability, and more efficient and more powerful active measurement components (such as lasers) than traditional vantage point locations.

On the space plasma side, the relevant direct in-situ observations of plasmas include density, temperature, and winds by species including electrons, ions by mass and in general by charge state. Since space plasmas are routinely far from thermodynamic equilibrium, the full-velocity distribution is usually measured in three dimensions for the thermal core, and in two dimensions for the energetic hot tail distributions (parallel and perpendicular to the local magnetic field). Close coordination with field measurements is always required. Space plasma measurements are in general based upon energy-resolving charged-particle optics, combined with time-of-flight velocity measurements to obtain mass.

Funding for technology development activities are usually obtained through a competitive process. For low Technology Readiness Level (TRL) activities, funding may come from either broadly competed programs, directly from existing instrument programs, or from programs funded internally by Goddard, such as the Director's Discretionary Fund (DDF) and Internal Research and Development (IR&D) funds. As technology progresses beyond the low TRL levels, scientists and engineers may compete for potential funding from one of the Mid-TRL technology programs available via the ROSES NRA solicitation or through GSFC's IR&D. If a technology is mature enough that it might make a substantial difference toward a winning proposal, it might also be eligible to B&P funding.

Table 4 shows the current group of ESED missions being developed. This table also shows the kinds of instrument technology developments needed for both kinds of missions. We note the dominance in lidar, passive microwave and UV/Vis imaging technology for Earth Science Missions. Missing from the list of Earth Science technologies are active microwave (and radar) along with thermal infrared imaging. The former is dominated by the Jet Propulsion Laboratory (JPL) and the later is dominated by the Langley Research Center (LaRC). We believe that, given the broad scientific capability of ESED, we should begin to strategically invest in active microwave and thermal infrared instruments.

Below we summarize instrument activities:

***Lidars***
The MOLA and the Geoscience Laser Altimeter System (GLAS) laser instruments are two examples that have clearly demonstrated the tremendous advancement that can be provided with laser- and lidar-based space measurements. The ESED is currently working on the design and development of lidars for topographic information, cloud and aerosol height, and wind measurements. Trace gas lidars are able to resolve vertical gradients in trace gases by targeting different parts of the pressure-broadened absorption line. These systems provide a new means of measuring ozone, water vapor, and $CO_2$ profiles. Wind lidars use the Doppler shift in backscattered Rayleigh or aerosol scattering to estimate the velocity of the air mass. The problems associated with space-based laser instruments like the Vegetation Canopy Lidar (VCL), CALIPSO, and GLAS also demonstrate the difficulties associated with making these types of measurements from space. As a major five-year Divisional goal, we are addressing the technology challenges associated with the limited laser power, ground footprint, and diode lifetime of these types of instruments, with the goal of solving these problems within the next five years. Other long-term goals build upon our transportable ocean biology lidars and our altimetric lidar systems that provide topographic measurements of ice caps, sea ice, coastal topography and land surface water and runoff. The next five years will see improved capabilities in resolution and vastly improved transportability, including application to UAV platforms. A new staff member will replace anticipated departures in this area.

***Microwave Remote Sensing***
The capabilities of microwave instruments such as TMI, The ER-2 Doppler radar (EDOP), the NASA Polarization radar (N-POL), and radiometers such as the Airborne Earth Sciences Microwave Imaging Radiometer (AESMIR), the Conically Scanning Millimeter-wave Imaging Radiometer (CoSMIR), and the Conical Scanning Submillimeter-wave Imaging Radiometer (CoSSIR) have had profound effects on Earth Science measurements. Through the development and application of these instruments we have fundamentally changed our ability to observe and understand important aspects of the Earth system, including ocean salinity, precipitation, soil moisture, cold land processes, sea ice, and ocean wind measurements. Present and proposed future missions are based on these developments. Our ongoing support of space missions, including GPM, requires planning for anticipated retirements in the area of precipitation radars operating in space, and on aircraft and the ground. Our present observational capabilities include innovative scanning aircraft microwave radiometers operating through the 1 – 1000 GHz spectrum, and transportable radars (EDOP, N-POL), scatterometers and radiometers. The next five years will see significant advances in these instruments, including digital beam forming, synthetic aperture radiometry, multiple frequency/polarization radars, SAR and interferometric radars, etc.—that greatly extend the capabilities of these systems. Additionally, there will be a continued move to smaller and more flexible airborne platforms, including UAVs. Our remote sensing measurements will continue to be buttressed by our focused in-situ sensing program, with its innovative UAV program and autonomous ocean-sensing systems. The Division's instruments are available on a cost-reimbursed facility basis in support of NASA scientific research, and have been used by our sister agencies, including NOAA, DoD and USGS, as well as by academia.

***Visible/UV and Near IR***
Historically, the ESED has developed sensors in the UV-visible range, such as for the SBUV and TOMS instruments and SOHO/Coronal Diagnostic Spectrometer (CDS). However, new measurements from Low Earth Orbit (LEO), GEO, and the Libration point require better spatial and spectral observation and drive the need for better and larger detector systems. New technology developments include UV-visible polarimeters, and micro-bolometer infrared sensors. Large-format, fast readout detectors from the visible to the extreme ultraviolet (EUV) are central to remote imaging and spectroscopy of the solar atmosphere. The Division has extensive experience with EUV spectrographs and detectors and will propose spectrograph concepts for Solar Orbiter and an L-1 Earth-Sun mission. Imaging of ultraviolet emissions from the thermosphere is an essential Geospace measurement for magnetosphere - ionosphere coupling, ITM processes and space weather. The Division has recently recruited and hired a scientist with extensive experience in all aspects of UV flight instrumentation design, development, and operations; and initiated a

new flight hardware development program. In collaboration with Code 500, a proposal was submitted for a multi-spectral UV/Far UV (FUV) space weather imaging investigation in response to the Living with a Star Radiation Belt Storm Probes Announcement of Opportunity.

***Space Plasma Velocity Analyzers***
In situ space plasma measurements are dependent upon electron and ion velocity analyzers that acquire a full view of the sky from diverse spacecraft, including non-spinning or slowly spinning spacecraft. The challenges are: to image the sky using charged particle optics techniques; to reject solar UV, penetrating energetic particles; to analyze the selected electrons for energy, and the selected ions for energy, mass and charge state; and to do so with an aperture sufficient to obtain statistically meaningful distribution samples in very short exposures in the millisecond range. The last requirement arises from the filamentary nature and rapid motion of the plasma structures thought to exist in regions of strong plasma interactions, for example, the diffusion region of the magnetic reconnection process. To satisfy the needs of future Sun-Solar System Connection (SSSC) missions, these challenges must be met to the greatest degree possible by instruments with very low resource profiles that can be copied inexpensively to populate constellation class missions with 10-50 small spacecraft. In the next five years, we must meet these technology challenges as we simultaneously build and deploy plasma velocity analyzers for the MMS mission, and propose for the Radiation Belt Storm Probe mission, with four and two spacecraft, respectively.

***Electric Field Double Probes***
Vector electric field measurements are essential to the understanding and modeling of important physical processes in all regions of Geospace. These measurements are made through the measurement of comparison of electric potential drops between conducting spheres located beyond the Debye sphere of the spacecraft by placing them at the ends of long deployable booms. Division scientists are expert in all aspects of the design, fabrication, operation, and data analysis for electric field double probe instrumentation. Currently, we are supporting electric field investigations on FAST, POLAR and Cluster and leading the investigation to be launched on the NASA/DoD C/NOFS mission that will launch in the second quarter of Fiscal Year 2006.

***Magnetometry***
Vector magnetic field measurements are also necessary for essentially all measurement-based investigations of Geospace because of the decisive role of the magnetic flux tubes in determining particle motion, energy transfer, and Magnetohydrodynamic (MHD) stress balance. These measurements are usually made using the fluxgate technique, but a second technique based on optical pumping of helium-4 is also used for some applications. Division scientists are not usually responsible for the design and fabrication of magnetometer flight units, but they support all other aspects of these investigations including spacecraft magnetic cleanliness, pre- and post-launch calibration, operations, data processing and science analysis. We currently have important roles in the magnetometer investigations on Voyager, Solar Wind Mission (WIND), POLAR, Cluster, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER), Bepi Colombo, MMS, and the soon-to-be launched C/NOFS and Space Technology 5.

***Fast Atomic Beam Facility***
Neutral atom remote sensing and imaging has been proven by the IMAGE mission to be extremely effective for obtaining a global understanding of space plasma systems. Currently, it is being applied to the problem of heliospheric structure through development of the IBEX mission. During 2004, the atomic beam facility of the University of Denver (DU) ceased to function or be available for future missions, owing to the untimely death of its principal investigator, Professor Thomas Stephen. NASA GSFC invested heavily in this facility in support of the calibration of the LENA imager on IMAGE, but it was also supported in the past by the U.S. Air Force (for atomic oxygen erosion studies), and by the NSF (for fundamental surface physics and chemistry studies). The only facility worldwide that is remotely competitive with the DU facility is at the University of Bern, Switzerland. However, that facility does not produce a ground state atomic beam, nor can it measure beam flux with the accuracy of the DU facility. It is not therefore as capable as the DU facility has been for the study and calibration of space flight instrumentation techniques.

In the next five years, we must establish a fast atomic beam facility in the U.S., preferably in the GSFC area, or on the Goddard campus. Such a facility would represent an investment in future SSSC missions that use the energetic neutral atom imaging techniques for remotely sensing plasma environments throughout the solar system, including future missions planned to study Mars (ADAM), Venus (Vesper, VAP), Mercury (Bepi Colombo), and the outer planets (JUNO), as well as future missions to globally monitor the solar wind interaction with Earth (GEMINI). It would also be in demand as a facility for fundamental surface physics studies, which may themselves lead to advances in our application of this technology to space observations. Such studies would help to assure continuous work for this facility during any intervals between space flight development projects.

## II.2.2 Mission Development

### II.2.2.1 Earth Science Missions

Often the development of instruments and technology leads to proposals of new mission concepts. There is currently one regular proposal opportunity for new missions in Earth Science – the Earth System Science Pathfinder (ESSP) Program. Directed and expedition-class mission opportunities occur through a different pathway, one that has not been clearly established.

ESSP is an opportunity that occurs roughly every two years or longer. ESSP is cost-capped at an amount of about $200 M including launch costs. This program size cap severely constrains the options that can be considered for ESSP missions, e.g., instrument size and observation vantage point. For example, since the launch cost for a geostationary mission is above this cost cap, proposers would need to find a partner who could fund the added geostationary mission costs.

About a year before an ESSP announcement, ESED begins to collect mission ideas for review. ESED also works with partner centers (e.g. JPL) and universities to formulate the mission concepts. ESED then recommends the expenditure of B&P funds to develop the mission concept or to bring an instrument to a higher TRL level appropriate to a flight mission. The ESSP missions being developed are drawing resources from the Center, but the ESSP 4 announcement from HQ has been delayed by more than a year. This has created a challenge for the Center – should the development activities continue or be put on hold until the NASA HQ decision making process is clarified?

Outside the ESSP line, NASA is moving back toward directed missions. With a new Administrator, and a pending National Academy review, there is a new opportunity for the development of mission concepts in the post EOS area. Below, we list and define acronyms for the mission candidates listed in Table 4.

**BIOMM** is a large footprint lidar system designed to sample three-dimensional vegetation structure to provide, among other things, measurements of above-ground carbon, especially in heavily forested regions.

**CLAIM-3D** uses a side-scanning spectrometer and a polarimeter to determine the impact of aerosols on cloud and precipitation processes.

**CLPP** is a combined passive and active microwave imager to estimate snow depth and cover, and frozen soils.

**Flora** is a hyperspectral imager and is designed to provide global measurements of the structure and function of terrestrial vegetation, for example, fractional vegetation cover and vegetation community composition.

**GEOTRACE** is a geostationary atmospheric composition satellite with both UV- visible and near IR sensors for looking at high time resolution changes in atmospheric composition.

**Janus** is a UV/VIS imager and Earth radiation budget experiment viewing from L1. Janus also has a payload of solar instruments. The L1 observation point will provide the first comprehensive and continuous observation of the Earth's whole dayside atmosphere, together with measurements of the contributions to the critical solar spectral irradiance that drive the upper atmosphere. The solar payload will be similar to the instruments on SOHO.

**Molniya Orbit Imager** is a pathfinder mission aimed at demonstrating the capability of this highly eccentric orbit for high temporal and high spatial resolution imaging of regions that cannot be seen by the geostationary observatories. The data obtained by the imager will be used for a wide-range of Earth science applications and are expected to have a significant positive impact on global medium-range weather forecast skill.

**OCEaNS** is a passive UV/VIS high spatial resolution imager designed to assess ocean carbon and phytoplankton amounts. The goal is to develop a better quantification of ocean carbon flux.

**SIRICE** is an infrared and microwave imager mission to determine the amount of cloud ice to constrain precipitation parameterization schemes used in climate models.

### II.2.2.2 Solar and Space Science Missions

These missions are executed as Solar-Terrestrial Probes and the Living With A Star line. Both groups are dedicated to research on understanding and mitigating the effects of space weather. The Explorer line of missions is smaller than the others and presents opportunities for open competition to address scientific investigations that are relevant and timely. Some solar and space science missions receive external funding, either from other parts of NASA, other agencies, or other national entities. Below, we list and define acronyms for near-term SSSC mission candidates listed in Table 4.

**Aeronomy of Ice in the Mesosphere (AIM)**
The primary goal of the Aeronomy of Ice in the Mesosphere (AIM) mission is to resolve why Polar Mesospheric Clouds (PMCs) form and why they vary.

**Bepi-Colombo**
Bepi-Colombo is an ESA mission to Mercury. In Mercury orbit, it will study the interaction of solar disturbances with a planetary magnetosphere, and in transit, it will research the solar wind structure and dynamics.

**Geospace Electrodynamic Connections (GEC)**
GEC will determine the fundamental processes of how the ionosphere and magnetosphere are coupled. The upper atmosphere is the final destination of the chains of fields, particles, and energy that start at the Sun, transit the heliosphere, and are modified by the magnetosphere and upper atmosphere.

**Living With a Star Sentinels**
The primary objective of the LWS Sentinels is to discover, understand, and model the heliospheric connection between solar phenomena and the resulting interplanetary and geospace disturbances. Sentinels is envisioned as a multiphased mission starting with a 4-spacecraft inner heliospheric mission to 0.25 AU. The next Sentinels phase will be composed of two Imaging Sentinels, one providing solar far side remote observations and another whole disk coronal spectroscopy from near Earth.

**Interstellar Boundary Explorer (IBEX)**
IBEX will remotely sense the edge of the solar system and beyond in order to discover the global interaction between the solar wind and the interstellar medium.

**Janus**
See above.

**Magnetospheric Multi-Scale (MMS)**
MMS will determine the fundamental physical properties of magnetic reconnection. It is a four-spacecraft mission designed to study magnetic reconnection, charged particle acceleration, and turbulence (cross-scale coupling) in key boundary regions of the Earth's magnetosphere.

**Radiation Belt Storm Probes (RBSP)**
The RBSP mission focus is to understand the variability and extremes of energetic radiation belt ions and electrons by identifying and evaluating their acceleration processes and transport mechanisms plus identifying and characterizing their sources and losses.

**Ionosphere-Thermosphere Storm Probes (ITSP)**
The ITSP missions will enable the development of models that predict optimal frequencies for radio communications, communication disruptions, and intervals of enhanced geomagnetic activity. An improved knowledge of neutral densities within the thermosphere will help mission planners select spacecraft orbits with the least drag and greatest lifetimes.

**Solar-B**
Solar-B will reveal the mechanisms of solar variability and study the origins of space weather and global change. NASA is a 1/3 partner with JAXA on this mission to investigate the detailed interactions between the Sun's magnetic field and the corona.

**Solar Dynamics Observatory (SDO)**
SDO will help us to understand the mechanisms of solar variability by observing how the Sun's magnetic field is generated and structured and how this stored magnetic energy is released into the heliosphere and geospace.

**Solar Orbiter**
Solar orbiter is an ESA mission with U.S. participation that will fly as close as 45 solar radii to the Sun in order to study the solar atmosphere with unprecedented spatial resolution (~100 km pixel size).

**Solar Probe**
Solar Probe is the first flight into the Sun's corona, only three solar radii above the solar surface. Solar Probe's instruments measure plasma, magnetic fields and waves, energetic particles, and dust that it encounters.

**STEREO**
The Solar-Terrestrial Relations Observatory (STEREO), to be launched in 2006, will describe the 3-D structure and evolution of CMEs from their eruption on the Sun through the inner heliosphere to Earth's orbit.

**Time History of Events and Macroscale Interactions During Substorms (THEMIS)**
THEMIS is a MIDEX Explorer mission that addresses the spatial and temporal development of magnetospheric substorms.

**The Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS)**
TWINS provides stereoscopic viewing of the magnetosphere by imaging charge-exchanged energetic neutral atoms (ENAs) over a broad energy range (~1-100 keV) using identical instruments on two widely spaced high-altitude, high-inclination spacecraft.

### II.2.3 Improving the Instrument and Mission Development Process

With implementation of FCA and fall-off of support from the EOS missions, the ESED is under pressure to develop and win more instrument and mission proposals. The current process starts with an open call for new mission concepts. These concepts are reviewed by the New Business Review Panel (NBRP) which is chaired by the Chief Scientist. Positively reviewed concepts are funded using B&P allocated resources to strengthen the concept through Integrated Mission Design runs, for example. Progress is periodically re-reviewed by the NBRP, and a mission concept may be deselected if cost is too high (concept is too expensive for the cap) or progress is insufficient.

Recently, our Center Director has re-invigorated the proposal process at Goddard, with the goal of becoming more competitive. ESED will also move strongly to better support proposals at every step of their development and improve the win rate for instrument mission concepts. ESED will establish a permanent NBO at the Division level. The responsibility of this office would be to proactively connect research activities with proposal opportunities both within and external to Goddard, to track progress on major proposal activity, to provide advice for proposers, and help proposers obtain resources. An opportunities review group that would include Laboratory Heads would meet regularly (biweekly) to provide information and oversight for the NBO.

## II.2.4 New Platforms and Vantage Points

NASA is always seeking to push the envelope of technology and observations. This section discusses the potential opportunities of using new airborne platforms and new space vantage points to make observations.

### II.2.4.1 Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) provide a new observational capability that is complementary to current and future satellite missions. Currently, there is a significant observation gap between the high resolution capabilities of aircraft measurements, which are limited in spatial and temporal coverage, and satellite observations, which provide a global view, but often without adequate vertical and horizontal measurement resolution necessary to discern important fine scale features. A high-altitude and long-endurance UAV fills this critical observation gap and expands the observational domain with high-resolution data combined with near-global coverage. UAVs developed for military reconnaissance have large payload capacity, long duration, and high altitude capabilities. Operational UAV flights could impact a broad range of scientific applications, including synoptic weather systems, hurricanes, air quality, stratospheric ozone, ozone depleting substances, greenhouse gases, ice sheets, forest fires, droughts, and storm damage, as well as satellite validation. Additional flights could be allocated for research tasks, including targeted flights with payloads for specific science questions, satellite instrument development, and support of U.S. Government science and applications missions.

A UAV program would become a new and vital component of the emerging GEOSS 10-year implementation plan, which is now supported by over 60 countries around the world. In addition, a UAV program would be similar in cost to a large five-year satellite mission, but the UAV effort would be ongoing and would address a broader range of high-priority science missions, whose societal benefits would greatly improve the quality of life on our planet. GSFC ESED scientists have a number of aircraft instruments developed for the NASA ER-2 that could be integrated onto UAVs, along with instruments that are being specifically developed for UAVs.

In the next five years, the Aura Project intends to prototype the use of UAVs in validation. We are currently designing an experimental campaign that will leverage off the INTEX-B mission using the Altair. Based on our experience with that mission, we will be in a strategic position to propose to lead other UAV missions.

### II.2.4.2 Ultra-Long-Duration Balloons and High-Altitude Sounding Rockets

Balloon and sounding rocket programs – sometimes considered together under the rubric "low-cost access to space" – have a distinguished record of scientific discovery, technology development, hand-on training of students, and the incubation of future principal investigators on orbital missions. New capabilities are being developed that have the potential, if adequately funded, to provide a much-needed bridge between brief suborbital experiments of limited scope and powerful but expensive and infrequent orbital missions.

Super-pressure balloons are being developed with the ability to loft a 1-ton payload to altitudes in excess of 35 km for a duration of up to 100 days. This holds exciting scientific promise for solar spectrophotometric imaging above the influence of atmospheric turbulence and for the study of solar X-ray and gamma-ray flares.

Commercially available suborbital rockets can now carry larger-diameter payloads (important for imaging instruments) than any vehicles in the current NASA fleet. GSFC's Wallops Flight Facility (WFF) has developed a concept for a High-Altitude Sounding Rocket that would offer mission durations almost an order of magnitude longer than those available today, opening to investigation new regimes of short-term solar variability at UV and FUV wavelengths. Agile vehicles are being developed that can execute complex trajectories in the mesosphere and thermosphere. Finally, rapid developments in the world of low-cost commercial space vehicles have an unknown but tantalizing potential for scientific use.

ESED currently carries out a vigorous sounding rocket program with both solar and geospace components; the NASA Project Scientist for Sounding Rockets is based in ESED. We also have extensive past experience with balloon programs. We are following closely the development of suborbital capabilities and will be ready to propose for new opportunities as soon as they become available.

### II.2.4.3 Geostationary Orbit

Geostationary orbit has long been exploited for weather monitoring, but underused with regard to the EOS class multispectral sensors developed for Low Earth Orbit (LEO). There are some distinct advantages to the geostationary orbit. First, sensors in geostationary orbit can make high time resolution measurements, e.g. every 15 minutes over the same spot (Sun synchronous low Earth orbit satellites can make two measurements per day). The Geostationary Earth Orbit (GEO) allows good monitoring of rapidly changing conditions such as occur during severe weather outbreaks. Since GEO is 60 times further from the Earth than a typical LEO, larger apertures for sensors are needed to achieve the same ground resolution as from LEO. On the other hand, GEO satellites can stare at the same spot for a longer period and thus achieve equivalent or better signal-to-noise that a low Earth orbit sensor can achieve. Finally, because GEO is farther, GEO satellites need to be smaller and thus the instruments more compact, power conserving and light-weight.

NOAA is developing requirements for the procurement of the next generation of geostationary satellites (GOES-R) and there are plans to provide space for experimental instruments on the GOES-R. The Division already provides NOAA with a geostationary satellite Project Scientist and the NOAA GOES-R activity will be hosted at Goddard. We expect that ESED will be asked to provide an additional Project Scientist for the GOES-R effort. In addition to the GOES-R activity, the Division is already developing proposals to either provide instruments for the GOES-R or develop complete geostationary science packages looking, for example, at tropospheric air-quality.

In addition to Earth science objectives, the geostationary orbit also offers clear advantages to space science research. For example, the proximity to Earth of GEO permits transmitting the high data rates provided by the measurements of the Solar Dynamics Observatory with substantial ESED involvement. In the future, GEO may also become a vantage point from which to observe the generation of high-energy particles within the Earth's magnetosphere.

Over the next five years, we expect that more opportunities will appear for GEO instruments and science.

### II.2.4.4 Molniya Orbit

Three decades of experience with imagery from geostationary orbit have demonstrated the wide range of applications in both research and operations of these observations. However, an important limitation of these data is that regions beyond 55 to 60 degrees of latitude are not covered from this orbit. Both the successes and the limitations of MODIS have made it clear that there is a growing need for temporally and spatially coherent imagery also for these high-latitude regions. One of the most surprising fallouts from MODIS is the highly successful application of feature-tracking winds over the polar regions in global assimilation and forecast systems. The positive impact of these winds generally extends well into the lower latitudes (outside the observed region), and the impact tends to be largest when the forecast skill is lowest.

The Molniya orbit – a highly eccentric high inclination orbit used by Russia for communications satellites for more than 30 years – provides a quasi-stationary vantage point suitable for high-latitude imaging for a period of 8 hours out of a total orbit duration of 12 hours. The satellite spends about two-thirds of the time near its apogee (nominal altitude 39750 km) where it provides a quasi-geostationary vantage point located in the high latitudes of one hemisphere. During most of the imaging period, a Molniya satellite will thus be within 10% of the geostationary orbit height, and most of the available geostationary technology in terms of spacecraft, instrumentation, communications, etc. can therefore be reused with only minor modifications.

Goddard is currently developing a proposal for an atmospheric imager flying in a Molniya orbit as a pathfinder for a high-latitude extension of the GOES-type imagery and as a natural MODIS follow-on mission from a satellite winds perspective. This will extend the rapid-repeat rate imagery coverage to the pole and will enable the near-real time (30 minutes or better) production of high-latitude feature tracking winds, also based on clear-sky water vapor imagery. The possibility of co-flying space weather/aurora imaging instruments is also being investigated.

### II.2.4.5 The Lagrange Points, L1 and L2

The five Sun-Earth Lagrange points are locations where a spacecraft can "park" to make observations. The unstable Lagrange points L1 and L2 are of particular interest. L1 lies between the Earth and the Sun while L2 lies behind the Earth. Both are about 1.5 million km from the Earth.

The advantage of L1 is that it can provide excellent solar observations, in-situ plasma observations (and thus provide a warning of particle events) and also constantly observe the sunlit side of the Earth. The disadvantage of L1, for Earth observations, is that it is much farther than the moon and thus requires a sizeable telescope (e.g. 1 meter) for observations at high spatial resolution. For backscattered UV-Vis-IR observations, L1 is ideal since measurements may be made continuously as the planet turns beneath the sub-solar point. We are currently developing a mission concept called Janus which would exploit the L1 vantage point (see Table 4). This mission would be an advance over the innovative-but-never-launched Triana mission.

L2 has the unusual property that the Sun peaks around the limb of the Earth at L2, and thus L2 could be exploited for continuous solar occultation observations. The Division is already developing mission concepts for L1 and L2 that exploit their unique vantage point characteristics.

### II.2.4.6 The Lunar Vantage Point

The Vision for Space Exploration calls for NASA to return humans to the Moon. It is likely that a base crew up to 20 astronauts will be built on the Moon's near side. Although the Moon is a harsh and dusty environment, its near side continually observes almost half the Earth. With astronauts available for maintenance, instruments could be repaired and refurbished.

There are at least four Earth-observation projects for which ESED is uniquely qualified:

(1) Full-magnetosphere observation system: including instruments which take advantage of the Moon's passage through the Earth's magnetotail; the Moon is nearly ideal for such observations – better than LEO and GEO which are well inside the magnetosphere, and better than L1 or L2 which are too far outside it.

(2) A simulation of Terrestrial Planet Finder (TPF): observes the Earth in all its phases just as TPF would see most extra-solar planets. None of the other vantage points -- LEO, GEO, L1, or L2 – can provide an observing geometry that mimics TPF.

(3) Low frequency microwave and radar observations: important aspects of clouds, precipitation, sea ice, soil moisture, and other variables can be best observed by microwave and radar; this technology is currently constrained to LEO by the need for large apertures antennas. Much like the large radio telescopes, Earth-viewing radar and microwave antennas on the Moon could be many square kilometers in area and maintained by astronauts. From the Moon, we could also observe half the Earth, compared to 1/5 from GEO.

(4) Microwave limb sounding of the entire Earth limb for constituent measurements: in a single day, would provide greater coverage than LEO because the Earth limb can be scanned continuously and simultaneously (the whole limb at once) using ideas developed in ESED for limb-scanning from L-2. Large light-weight phased-array antennas can be used to achieve 1-km vertical resolution from 3 km altitude to the top of the atmosphere - μ-wave range 65-640 GHz.

In addition, there is important Earth science to be gleaned from the planned Lunar drilling program: (1) measuring the temperature profile down the boreholes, as is now done on Earth, and using it to reconstruct the solar "constant" over at least the past 500 years; the past solar constant remains one of the wild cards in global change and many climate sensitivity questions now unanswerable could be answered with such data, especially because it pre-dates the era of anthropogenic influence; (2) analyzing the radionuclides and isotopes in the lunar soil for evidence of past solar activity; (3) searching for material ejected from Earth by past bolide impacts; for this purpose, the Moon is sometimes called “Earth's Attic” and we hope to learn much about the role of bolides in past sudden climate change from this data.

We intend to develop an ESED working group to focus on Lunar mission opportunities to be linked to the Moon-Mars Initiative.

## II.3 Applications

Applications research is and will continue to be a very important activity for the ESED. However, the main focus will still be dominated by the Earth Science research products. Our present strategy has been to invest our time and resources in those areas which we can effectively support and excel in. There are many areas such as air quality, disaster management, which require multiyear commitment to produce tangible results. There is also the risk that some of the measurements may not be available in the future because of aging satellites and operational funding issues. At the same time, there will be opportunities for new kinds of measurements from Hydros, OCO, CALIPSO, and CloudSat which can help us improve our air quality, agricultural efficiency, and energy management and other application areas by providing additional data and products. Therefore, it is important to recognize that we may have to adapt our strategy based on the availability of future data and products.

We plan to continue our investments in the areas of Public Health, Water, Carbon, and Disaster Management. There will be significant attention given to expanding the Disaster Management portfolio to include earthquakes, drought, landslides and wildfires. The current Air Quality effort will grow beyond its current focus of determining air quality indices using MODIS data to becoming a full forecasting activity encompassing both models and data for validation. We will continue to work in the Air Quality applications area with support for the Environmental Protection Agency (EPA) forecast models. This will include drought monitoring and assessing and forecasting wildfire damage by calculating fire radiative energy from the remotely sensed data. More detail is given in the Office of Science Utilization Strategic Plan but two important initiatives are discussed below.

***Homeland Security***
We are working with the Department of Homeland Security, Lawrence Livermore Labs, DOE, and Stennis Space Center to define our involvement in this area. There is a potential for several joint activities that will benefit the nation. For example, we are investigating how NASA data can be used in predicting the plume trajectory from a nuclear or chemical explosion. This would make use of MODIS and Landsat data, as well as, a data assimilation model. We are also investigating the use of TOMS and OMI instruments to derive surface UV radiation, which is crucial in predicting the destruction of pathogens and other harmful biological agents as a function of time and distance from their source.

***International Coordination Commitment***
Earth science is truly an international activity and involves many countries and international organizations throughout the world. This is especially true because of our involvement with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) to share our data for minimizing the loss of human lives in case of any major disasters such as floods, earthquakes, drought and more. We will also be coordinating our efforts with the GEOSS activities because seven out of nine GEOSS application areas (e.g., water, air quality, public health, disasters, agriculture, energy, and ecology) directly link with our application disciplines.

## II.4 Education and Public Outreach

With the Earth Observing System and other large Earth science programs facing declining budgets, it is important that we demonstrate the significance of the work performed by the Division. The Center Director has also requested that ESED develop a more coherent plan for "selling Earth science." Given the challenges of FCA and limited resources, the management of outreach programs and activities must be well integrated, strategic, and sustainable. Organizing all the ideas and approaches to education and public outreach has always been a challenge as many of them began as *ad hoc* initiatives with little or no attempt to integrate into a "big picture" strategy for the Division, and no long-term plan for sustaining them. Many of our EPO initiatives were born out of new flight missions, which are by their nature, transitory (~3-6 year activities).

Historically, the Division's EPO community has not focused on formally assessing the effectiveness of its programs and products, nor on the sharing of lessons learned and other information horizontally across the Agency in a timely manner. In short, we are at risk of our EPO community degenerating into an unhealthy working model in which our personnel are competing for dwindling EPO funds. The ideal situation would involve increased coordination, the growth and sustenance of effective projects while at the same time, encouragement of creative approaches for translating our scientific results to public outreach forums.

Over the next five years, the Division seeks to refocus and reinvigorate its outreach to the public, public media, the research community, policy makers, and formal and informal educators. Specifically, we will form a new EPO Committee that reports to the Head of the ESED and that determines the priority for the new science stories and data products to highlight for our target audiences. This EPO Committee will also identify or make available resources as needed for special EPO projects. This Committee will ensure there is good coordination in the development and evaluation of our programs and products. Over time, the Committee will seek ways to stabilize the funding base that enables concurrent development of communications packages aimed at four main target audiences. The first objective of the Committee is to clearly identify the marketing target and to quantify their current perceptions of NASA's Earth science programs. In parallel, the ESED is exploring with NASA HQ the proper communications channels in reaching out to this segment of the public. We recognize the need to be highly sensitive to already-established channels for communicating with science and energy policy leaders and the protocols for doing so.

EPO Committee working groups will be formed to ensure that our programs and products are inclusive, effective, and efficient. In the pre-launch phase, the EPO efforts need to focus on the new mission measurements and the potential for new science. In the post-launch phase, the EPO strategy must combine publicizing new results along with integrating the new results into the mission of the Division. In the post-launch phase, the working groups must operate less in terms of promoting individual flight missions and/or laboratories, and more in terms of the interests and cognitive and technological capacities of their target audiences. The working groups will operate in something like a federation in that they retain their own autonomy, identity, and funding, and yet they work cooperatively together when required to by the EPO Committee. Such a decentralized model can work well by delegating intelligently and distributing the burden of work and cost while bypassing decision-making bottlenecks that are inherent in more traditional top-down management hierarchies.

We will emphasize the Web as our primary medium of choice for distributing information because research shows it has become the medium of choice by all of our target audiences when seeking scientific information for their jobs, for school work, or for just keeping up with what's new. Moreover, the Web is a robust medium in that it allows easy translation to other media, including print, television, radio, and live presentations. In short, the Web gives us a focal point for better internal cooperation as well as the means to better serve our audiences. Figure II.4 illustrates how the EPO Committee will work through these four working groups to communicate with the Division's target audiences.

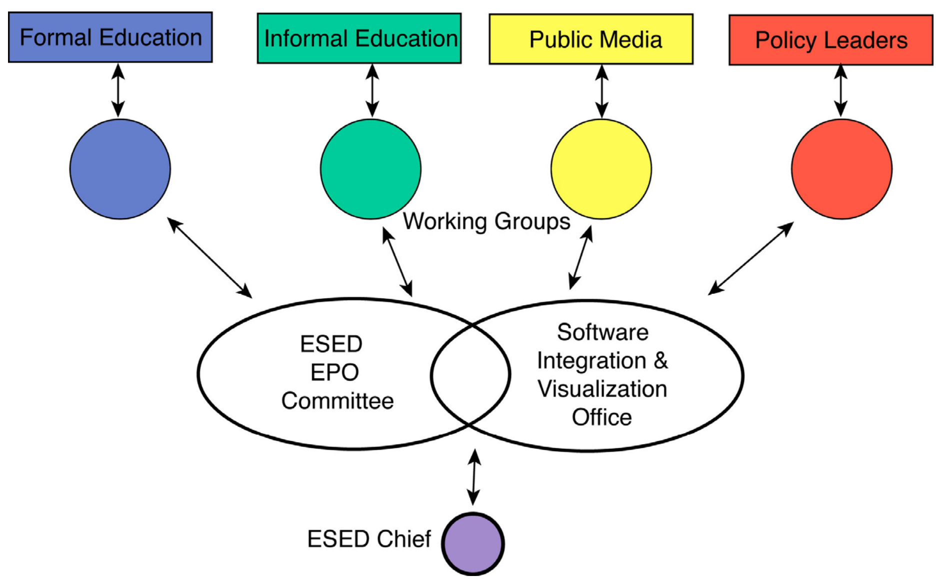



**Figure II.4. Notional Committee Workflow for Special Projects**

The first objective is to establish the four working groups and to establish the proper channels for internal communications, with particular sensitivity to protocols and procedures for policy-relevant communications. In general, our EPO programs and products will emphasize information assets that are unique to the ESED: (1) our new science results, (2) our measurement capabilities and data products, and (3) our data integration and analysis tools, and predictive models.

For formal education, our strategy will be to target our communications toward curriculum decision makers at the national and state levels. Our goal is to insert NASA Earth-Sun imagery and information into the science curriculum at all grade levels (kindergarten through graduate). We will increasingly promote the complementary use of real NASA remote sensing data along with models in inquiry-based lessons designed to instruct about the electromagnetic spectrum and cause-and-effect relationships at work in Earth's climate system. We will develop and refine easy-to-use software tools for visualizing and analyzing our remote sensing data, while storing data subsets in file formats and file sizes that readily lend themselves to in-classroom use.

For informal education, our strategy will be to continue with the professional development workshops and to establish and evolve networks through which to broaden and amplify exposure to NASA's Earth-Sun science missions. By building cooperative relationships with other informal education institutions and professional communications and science advocacy organizations, we take a more "massively parallel" approach to promoting Earth-Sun science literacy among the public. Ultimately, our aim is to establish Earth observation as a hobby analogous to amateur astronomy. Again, we must provide easy access to our remote sensing data, and easy-to-use tools for analysis, but most of these elements are already in place. Our next steps are to synthesize these elements into a cohesive, complementary framework, and then support programs that help amateurs learn what to look for and "cookbook" procedures for how to perform basic analyses.

For the public media, our strategy will be to focus more on quality and less on quantity, meaning fewer overall press releases done better. Emphasis will be placed on our greatest asset—our visuals. Moreover, we should time our press releases so that we issue the same "stories" to all four of our target audiences simultaneously, keeping in mind of course that adaptations must be made for each.

For influencers of space and science policy, we will develop a new suite of communications products designed for live presentations and accessible via the Internet. The idea will be to frame our stories around key questions or "mysteries" about how the climate system works that our scientists are working to resolve. Our communications to this audience should visually demonstrate what our current and future Earth and Sun observing technologies look like. In addition to presentations about our new science results and new measurement capabilities, we will also emphasize applications and benefits to society. We should try to quantify economic return on investments in our Earth-Sun missions wherever possible.

# Appendix I. Application Activities

The examples of ESED's Applications mentioned in the main text of this report are detailed below.

***Invasive Species Management***
We are collaborating with the USGS to develop a National Invasive Species Forecasting System (ISFS) for the management and control of invasive species on Department of Interior and adjacent lands. There are many types of invasive species which collectively do over a hundred billion dollars of damage annually in the United States alone. In this activity, we have targeted a specific botanical specie commonly known as "cheat grass." It establishes itself in the forests and open fields and deprives other plants from soil moisture which, at the same time increases fuel loading for the wildfires. The project is using early detection and monitoring protocols, and predictive models developed at the USGS Fort Collins Science Center to process NASA Earth science and commercial data obtained from Landsat/Enhanced Thematic Mapper (ETM), MODIS, EO-1, and Système Pour l'Observation de la Terre (SPOT).

***Public Health***
The overall goal of the Environment and Health activity is the application of NASA Earth Science space-based remote sensing data to better understand the links between human health and the environment, weather, and climate, and to develop new tools for health-related surveillance, decision support, and early warning systems. Data from satellite sensors such as Landsat/ETM, AVHRR, MODIS, TOMS, TRMM, and SeaWiFS are utilized in this effort. The initial applications research is focused on demonstrating two vector-borne diseases detection and prediction: Mekong Malaria and Filariasis for the Malaria prone area of Thailand; and the bubonic plague in the southwestern region of the U.S.

***Air Quality Indexing Benchmark***
Data from MODIS have been used to derive the first aerosol product over land and have allowed us to get a better understanding of source regions for aerosols. The analysis of MODIS-derived columnar aerosol loading has shown good correlation (correlation coefficient ~0.8-0.9) with $PM_{2.5}$ (particulate matter with particle size less than 2.5 μm) data collected by the EPA at the surface in metropolitan areas (e.g., New York City, Chicago, Houston) and also over broad regions including 11 states and Washington, D.C. At present, the EPA, Regional Planning Organizations, and state and local governments use a multitude of decision support tools to assess, control, and report the nature of air pollution related to PM.

***Disaster Management***
There are a number of activities which are underway and at various stages of maturity. They include improvement of hurricane track prediction, wildfires detection and emission inventories, and landslide forecasting. In addition to these tasks, drought is also being added to the disaster portfolio.

***Water Management***
Through the Global Land Data Assimilation System (GLDAS), NASA can now provide a synoptic data set of water storages and fluxes improving the performance of other federal agency Decision Support Systems (DSSs). This includes Bureau of Reclamation, the U.S. Department of Agriculture (USDA), and EPA for input of NASA data to their DSSs. Currently, some of the most critical NASA input parameters for DSSs used in water management applications are soil moisture, surface runoff, snow properties (depth and cover), evapotranspiration, and atmospheric forcing data (precipitation and solar radiation). These parameters help these agencies in snow pack and river flow estimates, which are extremely valuable in hydro production and agriculture commodity forecasts.

***Carbon Management***
Researchers at NASA GSFC are working with the USDA Forest Service Forest Inventory and Analysis (FIA) program to better integrate remote sensing observations into FIA operations and assessments of forest carbon. Specifically, the current implementation of the FIA database has limited capabilities for mapping forest change and disturbance. By using automated techniques developed for processing Landsat

and MODIS imagery, the FIA can better track changes in forest area, biomass, and carbon stocks. The project is currently applying this approach to a collection of "focal" scenes of particular interest to regional FIA managers.

***Energy Management***
This activity has a great deal of potential in terms of socio-economic benefits. We plan to develop this applications area by making use of three sources of NASA data: (1) solar data products which can be crucial in further understanding the high voltage transmission grid corona discharge and vulnerability to solar storms; (2) atmospheric temperature, sea surface winds, and moisture data that will help in improving the electric utilities load forecast; and (3) soil moisture and snow water equivalent data products which will help in improving the river flow models for the hydropower production.

***Forecasting Space Weather***
Space weather effects can cause a wide range of problems, from radiation effects on astronauts and electronics to induced currents that may lead to power outages. ESED scientists are leading in the research of the fundamental physical processes which determine the generation, propagation, and impact of solar disturbances. We will also expand our program to develop predictive space weather models based on our growth of physical understanding.

***Long-term Space Travel***
High energy particles and radiation emanating from the Sun have the potential for serious effects on long-term space travelers. We plan to further our understanding of such radiation on the astronaut's long-term health issues to aid in decision making on optimal shielding to protect against this. This will require us to coordinate with the Exploration Directorate at NASA HQ to secure their initial support.

# Appendix II. Education and Public Outreach Activities

Below are the education and public outreach activity details mentioned in the main text of this report.

## a) Education

### Summer Programs

The following have been supported by the Division in the past and represent the types of programs the ESED expects to maintain in the future:

- ***Undergraduate Students Summer Program*****:** Organized through the University of Maryland – College Park, the program has been funded through the Division via assessments.

- ***Graduate Student Summer Program*****:** Consisting of roughly 10 students, this program is organized by the GEST Center of the University of Maryland – Baltimore County.

- ***Research and Discover Summer Internship Program with the University of New Hampshire (UNH):*** The objectives of this program are to recruit outstanding young scientists into research careers in Earth sciences and Earth remote sensing, and to support Earth science graduate students enrolled at UNH through a program of collaborative partnerships with NASA Goddard scientists and UNH faculty.

- ***The NASA Academy*****:** Designed to develop space leaders at a number of NASA Centers, this educational program has targeted late undergraduates/early graduate students. This program is managed by the University Programs Office.

- ***Minority University-SPace Interdisciplinary Network (MU-SPIN):*** To help train the next generation of minority scientists and engineers, NASA created the Minority University-SPace Interdisciplinary Network (MU-SPIN) in 1990. This program helps provide minority colleges and universities with network infrastructure for accessing data and other information resources via the Internet and provides financial support for the coordination of activities to facilitate collaboration among minority universities to conduct research and educational outreach.

### Joint Centers Collaborative Support of Graduate Students

The Joint Centers have fostered partnerships with academic institutions wherein the two entities can employ their complementary talents and facilities to enhance Earth and space science research and the education of present and future generations of scientists. A list of the active Joint Centers are shown in the table below:

**Partnerships between ESED and the Academic Community**

| |
|---|
| Center for Earth-Atmospheric Studies (CEAS), with Colorado State Univ. |
| Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA), with Howard Univ. |
| Cooperative Center for Atmospheric Science and Technology (CCAST), with Univ. of Arizona |
| Cooperative Institute for Atmospheric Research (CIFAR) Graduate Student Support, with UCLA |
| Cooperative Institute of Meteorological Satellite Studies (CIMSS) with Univ. of Wisconsin, Madison |
| Earth System Science Interdisciplinary Center (ESSIC), with Univ. of Maryland, College Park |
| Goddard Earth Sciences and Technology Center (GEST Center), with Univ. of Maryland, Baltimore County |
| Joint Center for Earth Science (JCES), with Univ. of New Hampshire |
| Joint Center for Earth Systems Technology (JCET), with Univ. of Maryland, Baltimore County |
| Joint Interdisciplinary Earth Science Information Center (JIESIC), with George Mason Univ. |

These partnerships are meant to result in joint research proposals and joint efforts to provide instruction and training. To foster such interactions, coordinated efforts have taken place at the Joint Centers to identify students (as they enter the graduate programs or as they are about to choose their thesis topic) whose interests are shared by a University professor and an ESED scientist. In such cases, ESED pays for the student support for the first year and the University professor and the ESED scientist share the responsibility for supporting the student to the completion of his/her degree. Typically, the ESED scientist becomes a member of the student's thesis committee. The students are encouraged to spend time at Goddard. See the table below for the list of graduate students supported.

**Graduate Students Selected at the Joint Centers**

| Student Name | University | Field | Advisor/Sponsor |
|---|---|---|---|
| Toshihisa Matsui * | Colorado State University (CSU) | Aerosol effects on the microphysics of clouds | Roger Pielke Sr. (CSU)<br>W.-K. Tao (GSFC) |
| Derek Posselt** | Colorado State University (CSU) | Assimilation of satellite-observed cloud properties into GCMs | Graeme Stephens (CSU)<br>Arthur Hou (GSFC) |
| Kevin Mallen*** | Colorado State University (CSU) | Radar analyses and studies of precipitation systems | Michael Montgomery (CSU)<br>Scott Braun (GSFC) |
| Maike Ahlgrimm**** | Colorado State University (CSU) | GLAS-derived cloud climatologies | Dave Randall (CSU)<br>Jim Spinhirne/Steve Palm (GSFC) |
| Shaima L. Nasiri * | University of Wisconsin | Satellite-MODIS observed cloud properties | Steve Ackerman (UW)<br>Michael King/Steve Platnick (GSFC) |
| Robert Holz** | University of Wisconsin | Spectral properties of clouds and impact of clouds on climate | Steve Ackerman (UW)<br>Matthew McGill (GSFC) |
| Chris Danforth * | UMCP | Chaos processes in general circulation models/GCMs | David Levermore/Eugenia Kalnay (UMCP)<br>Robert Cahalan (GSFC) |
| Elana Klein** | UMCP | GCM data assimilation | Eugenia Kalnay (UMCP)<br>Ricardo Todling (GSC)/<br>Ron Gelaro (GSFC) |
| Wilfred Schroeder*** | UMCP | Fire characterization over large scales using satellite data | Ruth DeFries (UMCP)<br>Jeff Morisette (GSFC) |
| Christopher Blakely*** | UMCP | Spectral approximations of discrete data defined on a sphere | Ferd Baer (UMCP)<br>Ricky Rood (GSFC) |
| Hezekiah Carty**** | UMCP | Interactions between the oceans and the atmosphere as related to TRMM observations | Sumant Nigam (UMCP)<br>Eric A. Smith (GSFC) |
| Stephen Penny**** | UMCP | Innovative numerical methods in geophysical problems | Charles D. Levermore (UMCP)<br>Warren Wiscombe (GSFC) |
| Felicita Russo * | UMBC | Micropulse lidar extinction measurements using Raman Lidar | Ray Hoff (UMBC)<br>David Whiteman (GSFC) |
| Antonia Gambacorta** | UMBC | Raman Lidar studies of water vapor, cirrus cloud optical depth, particle size, and ice water content | Ray Hoff (UMBC)<br>David Whiteman (GSFC) |

*** Started in 2002 ** Started in 2003 *** Started in 2004 **** Started in 2005**

**Additional Interactions**

Interactions with graduate and undergraduate students also take place outside the formal programs just outlined and are encouraged by all levels of management in the Division. About 50 students spent time in the Earth Sciences Directorate during the 2004 year. In addition, many members of the ESED staff are part of MS and Ph.D. thesis committees, supporting students at universities from across the country. In the past, much of this collaboration has been through the Joint Centers. See the table below for a list of ESED scientists that were thesis advisors.

**ESED Scientists that were Thesis Advisors in Academic Year 2004-2005**

| Scientist | | |
|---|---|---|
| Robert Adler * | Jay Herman * # | Steven Platnick * # |
| Thomas Bell * # | Gerald Heymsfield * | Jeffrey L. Privette * # |
| Francis L. Bliven * # | Gordon Holman * | Lorraine Remer * # |
| Michael Bosilovich * | Arthur Hou * | Michele Rienecker * |
| Lahouari Bounoua # (Co-Advisor) | Joanna Joiner * | Gavin Schmidt (2) * |
| Robert Cahalan* | Alex Klimas * | Christopher Shuman * |
| Donald Cavalieri * | Prasun Kundu * # | James A. Slavin * |
| Allen Chu * # | William Lau (2) * | James Smith * |
| Peter Colarco * | David Le Vine * | David Starr * |
| Joey Comiso * | Elizabeth M. Middleton # | Ellsworth Welton * |
| Anthony Del Genio (5) * (2) # | Ronald Miller * # | David Whiteman * |
| Belay Demoz * # | Michael Mishchenko * | Hongbin Yu * # |
| Thomas Duvall * | Dorothy Peteet * # | |
| Adolfo Figureroa-Viñas * | Christa Peters-Lidard (5) * | |

* PhD committees # Masters committees

The table below lists courses taught by ESED scientists.

**Courses Taught by ESED Scientists in Academic Year 2004-2005**

| Location | Title of Course | Instructor |
|---|---|---|
| American Meteorological Society (AMS) Annual Mtg., San Diego, CA | Atmospheric Lidar Principles & Applications * | Belay Demoz |
| AMS Annual Mtg., San Diego, CA | Lidar Principles & Applications * | Geary Schwemmer |
| AMS Annual Mtg., Seattle, WA | Lidar for Meteorologists 101 * | Geary Schwemmer |
| George Mason University | Thermodynamics or Physical Climate | Yogesh Sud |
| George Mason University | Land-Atmosphere Interaction | Randal Koster |
| Howard University | Atmospheric Chemistry II | Richard Stewart |
| Johns Hopkins University | Soils in Natural and Anthropogenic Ecosystems | Elissa Levine |
| Johns Hopkins University | Statistical Mechanics & Thermodynamics | Prasun Kundu |
| UMCP | Combining Satellite Data and Models to Study Earth System Climate | Lahouari Bounoua |
| UMCP | ESSIC 234, Cycles in the Earth System | Warren Wiscombe |
| UMBC | Physics 602, Statistical Mechanics | Prasun Kundu |
| UMBC | Physics 622, Atmospheric Physics II | Steven Platnick |
| UMCP/Earth System Science Interdisciplinary Center | METO 401, Global Environmental Problems | Warren Wiscombe & Zhanqing Li |

* Short course held in conjunction with Society meeting.

**Post-Graduate Programs**

The Division expects to maintain its support of post-graduate programs, which help foster new, innovative ideas for research. These programs include:

- ***National Research Council (NRC) Postdoctoral Fellowships*:** The NRC conducts the Resident Research Associateship Program (RRAP) on behalf of NASA and other federal research agencies. By carrying out research at NASA Centers, the awardees contribute directly to the NASA mission while advancing their professional development. Supporting approximately 15 fellows, the program is funded by the Agency.

- ***Summer Faculty Fellowship Program*:** A program provided by NASA Headquarters, Research Fellowships have been awarded to qualified engineering and science faculty members and some non-science disciplines for specific projects, as summer research in a NASA-University cooperative program. Recently the program has supported 5-10 faculty members within the Division.

- ***GSFC Visiting Fellows Program in the Earth Sciences:*** This program has been organized by the Goddard Earth Sciences and Technology (GEST) Center and has been designed to attract professors on sabbatical leave and researchers at all levels of seniority within the Division. Selected through a competitive process, those chosen are typically pursuing independent research of their choice and have full access to NASA computing facilities and other resources at either the Greenbelt or the New York campus. See the table below for list of Fellows.

**GSFC Visiting Fellows Program in the Earth Sciences**

| Name | Institution | Research Plan | Relevant ESD Lab |
|---|---|---|---|
| **FY 2005** | | | |
| Zev Levin * | Tel Aviv University | Cloud-dust interactions | 613 |
| David Salstein | Atmos. & Environ. Research Inc. | Interactions of Earth rotation parameters with atmospheric dynamics | 690 |
| Toshiihiko Takemura | Research Institute for Applied Mechanics Kyushu University | Simulation of spectral radiation transport model results | 613.3/613.2 |
| **FY 2004** | | | |
| Warren Cohen * | Dept. of Agriculture Forest Service | Forest inventory/ carbon | 690 |
| Carlos Garcia * | Univ. of Rio Grande, Brazil | Ocean color/primary production | 614 |
| Virginia Garcia * | Univ. of Rio Grande, Brazil | Ocean color/primary production | 614 |
| Marvin Geller * | State University of New York, Stony Brook | Atmosphere dynamics; stratosphere/ mesosphere; climate | 611 |
| Maeng-Ki Kim * | Kongju National Univ., South Korea | Global circulation modeling | 613 |
| Roger Lang * | George Washington Univ., Washington, DC | Soil moisture measurements | 614 |
| Robert Numrich * | Univ. of Minnesota, Minneapolis, MN | Climate model computing | 606 |
| Friedman Freund * | San Jose State Univ., San Jose, CA | Crustal Dynamics | 690 |

## GSFC Visiting Fellows Program in the Earth Sciences (continued)

| Name | Institution | Research Plan | Relevant ESD Lab |
|---|---|---|---|
| Susanne Bauer | Lab. Science, Climate & Environ., Paris, France | Climate modeling/chemistry | 611 |
| Hyung Rae Kim | Ohio State Univ., Columbus, OH | Terrestrial physics | 690 |
| **FY 2003** | | | |
| Nadine Bell | Earth & Planetary Science, Harvard Univ. | Chemical and dynamical processes in the atmosphere | 611 |
| William Chameides * | Earth & Atmos. Sci., Georgia Inst. of Technology, Atlanta, GA | Coupling between atmospheric aerosols, climate, and carbon uptake by terrestrial ecosystems (National Academy of Sciences) | 611 |
| James A. Coakley * | Oceanic & Atmos. Sci., Oregon State Univ., Corvallis, OR | Cloud and aerosol retrievals to include an ensemble of aerosol-cloud interaction cases | 613.2 |
| Harshvardhan * | Earth & Atmos. Sci., Purdue Univ., West Lafayette, IN | Indirect cloud forcing by anthropengenic sulfate (Dept. Chair) | 613.2/613.3 |
| Dan Lubin * | Scripps Inst. of Oceanography, Univ. Cal, San Diego, La Jolla, CA | UV radiation at the surface and its effects on near surface biology | 613.3 |
| Michael E. Mann * | Environmental Sciences, Univ. of Virginia, Charlottesville, VA | Oceanic dynamical responses to atmospheric forcing of northern hemisphere ocean temperatures over the past 1000 years | 611 |
| Jacques Hinderer * | Univ. of Strasburg, Strasburg, France | Gravity measurements to validate/calibrate GRACE, use GRACE data for hydrological studies | 697 |
| Katherine Whaler * | Univ. of Edinburgh, Edinburgh, England | Modeling satellite magnetic data for the Earth and Mars | 698 |
| Wookap Choi * | Earth & Environ. Sciences, Seoul National Univ., Seoul, Korea | Stratospheric trace gas distributions, stratosphere-troposphere exchange, stratospheric cooling from $CO_2$ | 613.3 |
| Ken Minschwaner * | Geophys. Research Center, New Mexico Institute of Mining and Technology, Socorro, NM | Processes near the tropical tropopause responsible for transfer of mass and humidity from the troposphere to the stratosphere; studies of tropical cirrus cloud systems | 613.3/613.2 |
| Peter Colarco | Univ. of Colorado, Boulder, CO | Aerosol radiative properties using models, field and satellite measurements | 613 |
| David J. Lary | Chemical Informatics, Univ. of Cambridge, Cambridge, UK | Chemical Data Assimilation, produce a multi-annual analysis of chemical state of the atmosphere from UARS (Royal Society Fellow) | 610.1 |

* On sabbatical leave

**Kindergarten to Grade 12 (K-12) Programs**

- Support of early education programs remains a priority to the Division. The ESED has produced educational materials and lesson plans for grades K-12, thereby contributing to the pipeline that will produce tomorrow's Earth scientists. The Division's scientists routinely present lectures and demonstrations to K-12 schools and youth groups to help develop an early interest in science. They also mentor students, and serve as judges at local science fairs. ESED scientists also mentor a number of high school students through individual initiatives and projects.

- SUNBEAMS (Students United with NASA Becoming Enthusiastic About Math and Science) is an award-winning education program focused on sixth grade teachers and students in District of Columbia Public Schools that serve a population historically under-represented in scientific professions. SUNBEAMS involves teachers as an integral part of the program, starting with paid summer internships at Goddard that pair teachers with active scientists as mentors in developing standards-based, hands-on lesson plans. The program then brings the students of these teachers to Goddard for a week-long immersion in science and math activities and follows up with subsequent activities, including a family night at the school where the students share what they have learned and done with their families, other students, and their community. Now in its eighth year, SUNBEAMS is led by a full-time coordinator and has reached over 50 schools, 60 teachers, and 1500 students.

## b) Public Outreach

- **Earth Observatory**

  The Earth Observatory (http://earthobservatory.nasa.gov) is a Web-based Earth science magazine that publishes NASA satellite imagery and scientific information about climate and environmental change (including natural hazards) and the use of space-based sensors for Earth science research and applications. There are more than 41,000 subscribers, and the site receives about 27,000 unique visits per day. The primary target audience is the "science attentive" general public. Additional content targets other audiences, including teachers, students, scientists, and public media. The site won Webby Awards in consecutive years (in the "Science" and "Education" categories), as well as endorsements by Scientific American, Popular Science, TERC, and the National Science Teachers Association (NSTA). The site is funded by the EOS Project Science Office.

- **Visible Earth**

  Visible Earth (http://visibleearth.nasa.gov) is a Web-based repository of Earth science-related images, animations, and data visualizations. The site is designed to serve as a one-stop shopping gateway to all NASA's publicly available image assets. The site currently holds about 7,000 records and all assets are stored at multiple resolutions. Since all of VisEarth's assets are extensibly indexed, the site lends itself particularly well to content syndication for NASA's communications partners (i.e., museums, formal education lesson developers, the mass media, etc.). The VisEarth receives an average of 6,500 unique visits per day and serves 120 GB in daily image requests. The EOS Project Science Office funds this site.

- **Climate Change Information Resource, New York Metropolitan Region (CCIR-NY)**

  The CCIR-NY is an information resource for educators, policymakers, and the general public on the impacts of climate change and variability in the tri-state New York metropolitan area. This Web site provides scientific answers to basic questions about climate change, and how changes might impact New York City. While the site is specifically focused on the Big Apple, some lessons learned here apply to other urban areas. NASA provided the science used to answer basic and specific questions regarding climate change in the New York Metropolitan region. The site includes a series of questions relating to climate change and then answers them in a way accessible to a wide-ranging audience. It was developed under a grant from NOAA to the Center for International Earth Science Information Network (CIESIN), Columbia University, with the collaboration of NASA GISS and Hunter College. (http://ccir.ciesin.columbia.edu/nyc/)

- **Print Publications**

  The EOS Project Science Office produces and prints a range of publications about the ESED's many research programs and satellite missions. Specifically, they maintain a small library of CDs, brochures, lithographs, posters, fact sheets, and lesson plans about Earth science topics and EOS satellites. The EOS Project Science Office funds most of these publications.

- **Public Media**

  The ESED has adopted a two-pronged approach to communications with the public media. Our primary emphasis is on providing press releases and imagery to the NASA Public Affairs Office (PAO) through the efforts of the Earth-Sun Science News and Information Team. In an effort to proactively mine new story ideas, for the past five years, this team has been identifying and developing press releases for PAO. The team reached an all-time high in productivity over the last year and has had many of their stories play in major television and print media outlets. Our secondary emphasis has been to enable "direct to information consumer" communications via our Web sites and the NASA Portal.

- **Data Visualizations**

  There are three outstanding data visualizations teams supported within the ESED – the Scientific Visualizations Studio (SVS), the Visualizations Analysis Laboratory (VAL), and the Visual and Technical Arts Lab (VITAL). All of these teams produce superior quality images, animations, and data visualizations in support of a wide range of the ESED's communications and science activities, including NASA Public Affairs press releases, live presentations, various print publications, television, and video documentaries, etc.

- **Earth Today**

  Earth Today is a unique stand-alone presentation system for showing satellite and other Earth science data in a kiosk style display. There are six data sets currently on display. Display systems are running at the GSFC Visitor Center, the Baltimore Museum of Science, and at the Smithsonian Air and Space Museum. New data sets are being added and the exhibit has developed a new interactive capability. The project is funded by various Goddard and EOS Project sources. Earth Today will be co-developing applications with Science on a Sphere (below).

- **Science on a Sphere**

  Science on a Sphere, originally developed by NOAA to enhance outreach, is a system which uses high-speed computers, video projectors, and advanced imaging techniques to project images onto a sphere to create the illusion of a planet, the Sun, a moon, or any other celestial body in space. Science on a Sphere is intended to help communicate science to the public, foster science education, and aid scientific visualization by providing a unique and engaging way of looking at the Earth in its "native format" rather than as a distorted flat representation. An agreement was recently reached with NOAA to place Science on a Sphere capability in Goddard's Visitor Center. The latest in space-based Earth observations from imagery and/or data acquired by NASA's many Earth observing satellites will be processed and formatted for display on the Sphere.

- **The Electronic Theatre**

  The Electronic Theatre produces interactive, high-definition live presentations about Earth system science and NASA's remote sensing missions as an adjunct activity that leverages off the resources produced by the ESED's visualizations teams. This activity reaches tens of thousands of live audience members around the world per year.

- **Sun-Earth Day**

  Sun-Earth Day is an annual national event (usually in March) supported by the Sun-Earth Connection Education Forum, Sun-Solar-System-Connection scientists and spacecraft missions. The goal is to share the science of the Sun with educators, students, and the general public via informal learning centers, the Web, television, etc. through high-profile, well-supported annual events. Sun-Earth day activities have a broad reach. For example, the 2004 Sun-Earth Day Web site received 40 million hits in 40 hours. There were 1000 news reports on various television channels, including 40 interviews with NASA scientists. More than 12,000 packets of educational materials were distributed to teachers, museums, and amateur astronomers in support of the 2004 Sun-Earth day programming. In 2004-2005, the Ancient Observatories: Timeless Knowledge Web site (http://sunearthday.nasa.gov) and the Traditions of the Sun Web site (http://www.traditionsofthesun.org) were launched to allow users to explore Chaco Canyon and other areas.

- **Educational GCM (EdGCM)**

  Computer-driven Global Climate Models (GCMs) are one of the primary tools used today in climate research. Unfortunately, few educators have access to GCMs, which have generally required supercomputing facilities and skilled programmers. In collaboration with NSF, NASA GISS has created EdGCM, software that allows teachers and students to run a state-of-the-art climate model on desktop computers. With EdGCM, one can explore the fundamentals of climate science using tools which are identical to those used in major climate research programs. Many simple climate experiments are possible (e.g. How does a changing Sun warm or cool the planet?), but, it is also possible to investigate current events as they are being studied by climate scientists. EdGCM comes with some prepared scenarios – for example for global warming and ice ages – but teachers can also construct their own scenarios to satisfy curricular requirements. EdGCM allows teachers to produce their own instructional materials (text, charts, images) and easily scales for use at levels from middle school to graduate school.

- **Sun-Earth Connection Education Forum**

  The Sun-Earth Connection Education Forum (SECEF) is a partnership between GSFC and University of California Berkeley's Space Sciences Laboratory. SECEF's mission is to increase science literacy and steward Sun-Earth Connection science resources. This partnership shares the exciting discoveries and knowledge from NASA missions and research programs with educators, students, and the general public. SECEF brings together the rich expertise of scientists, educators, and museums to develop innovative products and programs with the goal to increase science literacy and focus attention on the active Sun and its effects on Earth. The program includes organized events such as Solar Week and Sun-Earth Day, the development and testing of "ready-to-go" classroom activities and products, links to the Web sites of all NASA missions that study the Sun and Earth's space environment, an active "Ask a Scientist" site from participating NASA missions, as well as collections of images, movies, and artwork to enhance and update the classroom learning environment.

- **Student Observation Network**

  Student Observation Network (SON) develops educational modules, each organized around a question to be answered or problem to be solved. Examples include: "How can we predict solar storms to protect satellites and astronauts?"; "How can falling snow, snowpacks, and ice cores help us understand climate and climate change?"; "How can humans live in space?"; "Are there places in our Solar System, other than Earth, that may harbor life?" Each essential question is sub-divided into several sub-questions to guide inquiry. Students develop their own questions as they proceed with the investigation. Using the JigSaw approach, small groups of students become "experts" on one part of the larger question (or puzzle). The small, expert groups come together to share their expertise and to solve the problem. Each SON module provides tutorials to help students understand the scientific data and step-by-step guides to using the data, plus background information and connections to NASA scientists.

- **Public Outreach, Education, Teaching and Reaching Youth**

  Public Outreach, Education, Teaching, and Reaching Youth (POETRY) is the IMAGE mission's education and public outreach Web site, providing teachers, students and the interested public with the latest information about auroral science, and the study of Earth's magnetic field. The goal of POETRY is to explain how solar storms affect the Earth, and to correct misconceptions about Earth's magnetic field, its radiation belts, and why we have aurora. It includes a variety of education resources, multimedia materials and an "Ask the Space Scientist" feature.

- **SOHO Explore**

  SOHO Explore is the SOHO education and outreach Web site, including an introduction to "Our Star the Sun" with images and videos, activities and lesson plans using SOHO data, educational materials, and an "Ask Dr. SOHO" feature.

# Appendix III. Project Scientists and Deputy Project Scientists

**Project Scientists/Deputy Project Scientists**

| Project | Project Scientist |
|---|---|
| **Missions in Operation** | |
| Aqua | Claire Parkinson<br>Steve Platnick (Deputy) |
| Aura | Mark Schoeberl<br>Anne Douglass (Deputy for Science & Validation)<br>Joanna Joiner (Deputy for Instruments, Tech., Outreach) |
| CLUSTER | Melvyn Goldstein |
| EOS | Michael King<br>David Starr (Validation Scientist)<br>James Butler (Calibration Scientist) |
| EOSDIS | Skip Reber |
| EP TOMS | Pawan Bhartia |
| FAST | Robert Pfaff |
| GEOTAIL | Douglas Fairfield |
| ICESat | Jay Zwally<br>Chris Shuman (Deputy) |
| IMAGE | Thomas E. Moore |
| Landsat 7 | Darrel Williams<br>James Irons (Deputy) |
| New Millennium EO-1 | Stephen Ungar<br>Tom Brakke (Deputy) |
| POLAR | John Sigwarth<br>Mark Adrian (Deputy) |
| RHESSI | Brian Dennis |
| SeaWiFS | Chuck McClain<br>Stan Hooker (Deputy) |
| SOHO | Joseph Gurman<br>Therese Kucera (Deputy) |
| SORCE | Robert Cahalan<br>Douglas Rabin (Deputy) |
| Space Science Missions Operations | Joseph Fainberg |
| Terra | Jon Ranson<br>Si-Chee Tsay (Deputy) |
| TIMED | Richard Goldberg |
| TRACE | Joseph Gurman |
| TRMM | Robert Adler<br>Scott Braun (Deputy)<br>Erich Stocker (Deputy for Data Systems) |
| UARS | Charles Jackman<br>Anne Douglas (Deputy) |
| WIND | Keith Ogilvie<br>Michael Desch (Deputy) |

**Project Scientists/Deputy Project Scientists (continued)**

| Project | Project Scientist |
|---|---|
| **Missions in Development** | |
| Aquarius | David Le Vine (Deputy mission PI) |
| CINDI | Robert Pfaff |
| EUNIS | Douglas Rabin |
| Geospace/RBSP | David Sibeck<br>Joseph Grebowsky (Deputy) |
| Glory | Michael Mishchenko |
| GOES (Geostationary Operational Environmental Satellite) | Dennis Chesters |
| GPM | Arthur Hou<br>Marshall Shepherd (Deputy)<br>Erich Stocker (Deputy for Data Systems) |
| Hydros * | Peggy O'Neill (mission co-PI) |
| Landsat Data Continuity Mission * | James Irons<br>Jeffrey Masek (Deputy) |
| Magnetospheric MultiScale | Steven Curtis |
| New Millenium Space Technology-5 | James Slavin |
| NPOESS Preparatory Project (NPP) | James Gleason<br>Jeffrey Privette (Deputy)<br>James Butler (Deputy for Instruments and Calibration) |
| POES (Polar Operational Environmental Satellite) | Joel Susskind |
| SDO | Dean Pesnell<br>Barbara Thompson (Deputy) |
| Sounding Rockets | Robert Pfaff |
| STEREO | Michael Kaiser<br>Therese Kucera (Deputy) |
| THEMIS | David Sibeck |
| TWINS | Mei-Ching Fok |
| **Missions in Pre-Formulation** | |
| Geospace Electrodynamic Connections | Joseph Grebowsky |
| Ionosphere-Thermosphere Storm Probes | Joseph Grebowsky |
| Mag Con | Thomas E. Moore<br>Alexander Klimas (Deputy) |
| Solar Probe | Edward Sittler |
| Solar Sentinels | Adam Szabo |
| **Senior Project Scientists** | |
| Living With a Star | Orville St. Cyr |
| Solar Terrestrial Probes | James Slavin |

* situation under discussion

# Appendix IV. Field Campaigns and Workshops

**Field campaigns where scientists in the Division were Principal Investigators in FY2004 and FY2005**

| Field Campaign | Principal Investigator |
|---|---|
| All Micro-Pulse Lidar Network (MPLNET) Sites (2004/2005) | Ellsworth Welton |
| Arctic Ice Mapping deployment to Arctic Canada and Greenland, May 2005 | William Krabill |
| Arctic Ice Mapping deployment to Alaska, August/September 2005 | William Krabill |
| Calibration/validation of the Special Sensor Microwave/Imager/Sounder on board the Defense Meteorological Satellite Project F-16 satellite with GSFC Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR), March 2004-March 2005 | James R. Wang |
| EQUatorial Ionospheric Study (EQUIS) II Campaign, Kwajalein Atoll | Robert F. Pfaff |
| Interplanetary Monitoring Platforms (IMP)-8 Goddard Medium Energy (GME) Experiment | Robert McGuire |
| MMS – Plasma | Thomas E. Moore |
| NDSC Ozone Intercomparison – Table Mountain Observatory (2004) | Thomas McGee |
| NDSC Water Vapor Intercomparison – Table Mountain Observatory (2005) | Thomas McGee |
| NOAA Hurricane Field Program/2005 | Edward Walsh |
| NASA Polarimetric radar (N-POL) Oyster Rain Measurements | Francis Bliven |
| Office of Naval Research Coupled Boundary Layers Air/Sea Transfer (CBLAST)/2004 | Edward Walsh |
| Polar Aura Validation Experiment, Jan.-Feb. 2005 | Mark Schoeberl |
| Siberian Disturbance Field Expeditions | Jon Ranson |
| Tropical Cloud Systems and Processes (TCSP) (2005) | Gerald Heymsfield |
| USDA/NASA: RS of N induced physiological changes in crops, Beltsville, MD | Elizabeth Middleton |
| USDA/NASA: RS of N induced physiological changes in trees, Beltsville, MD | Elizabeth Middleton |
| Vector Electric Field Instrument experiment on C/NOFS satellite | Robert F. Pfaff |
| WIND Magnetic Field Investigation | Ronald. P. Lepping |

**Field campaigns where scientists in the Division were Co-Principal Investigators in FY2004 and FY2005**

| Field Campaign | Co-Principal Investigator |
|---|---|
| Antarctic AMSR-E Sea Ice Validation | Josefino Comiso |
| Atmospheric Brown Cloud Gosan Campaign: East Asian Regional Exp. (2005) | Ellsworth Welton |
| Biological-Physical Interactions in Ocean Margin Ecosystems 1 | Antonio Mannino & Tiffany Moisan |
| C/NOFS Vector Electric Field Instrument (VEFI) experiment | Guan Le |
| Chesapeake Bay Plume-1 Dynamics of Coastal Organic Matter | Antonio Mannino |
| Cluster Plasma Electron And Current Experiment (PEACE) | Ramona Kessel |
| Cluster Electric Fields Investigation | Michael Hesse & Robert F. Pfaff |
| Cluster Magnetic Field Investigation | James A. Slavin |
| Cluster spacecraft magnetic field experiment | Donald Fairfield |
| Duke University Drop Collision | Francis Bliven |
| Extreme-Ultraviolet Normal-Incidence Spectrometer (EUNIS) | Roger Thomas |
| FAST Electric Fields Investigation | Robert F. Pfaff |
| Flux Exchange Dynamics Study 2004 (FEDS.4)/ | Steven Long |
| Geotail magnetic field experiment | Donald Fairfield |
| GLOBE One | Elissa Levine |
| High Winds, studying the effects of spray droplets on radar measurements | Steven Long |
| IMAGE | Shing Fung |
| Intex-NA field mission: meteorological support, July-August 2004 | Steven Pawson |
| Lake Placid Snow Study | Francis Bliven |
| MESSENGER Magnetic Field Investigation | James A. Slavin |
| Micro-macro Coupling, Space Physics Theory Program | Michael Hesse |
| Multi-Order Solar EUV Spectrograph (MOSES) | Roger Thomas |
| North Dakota University Snowflake Measurements | Francis Bliven |
| North Dakota University Visibility Study | Francis Bliven |
| Polar Plasma Laboratory (POLAR) VIS experiment | John Sigwarth |
| POLAR Electric Fields Investigation | Michael Hesse & Robert F. Pfaff |
| POLAR Hydra plasma experiment | Donald Fairfield |
| Rapid Acquisition Imaging Spectrograph Experiment (RAISE) | Roger Thomas |
| RHESSI | Gordon Holman |
| RHESSI | Brian Dennis |
| Soil Moisture Experiments (SMEX) 04 | Peggy O'Neill |
| SMEX 05 | Peggy O'Neill |
| SOHO, Solar UV Measurements of Emitted Radiation (SUMER) | Roger Thomas |
| SOHO, Coronal Diagnostic Spectrometer (CDS) | Roger Thomas |
| Solar Ultraviolet Magnetograph Investigation (SUMI) | Roger Thomas |
| Solar-B, Extreme-ultraviolet Imaging Spectrometer (EIS) | Roger Thomas |
| STEREO COR1 Instrument | Chris St. Cyr |
| STEREO/WAVES (SWAVES) Instrument | Chris St. Cyr |
| THEMIS | David G. Sibeck |
| Tidal Modulation of Antarctic Ice Streams (2004 and 2005) | Robert Bindschadler |
| United Arab Emirates Unified Aerosol Experiment (UAE2), United Arab Emirates (2004) | Ellsworth Welton & Si-Chee Tsay |
| University of Delaware Gas Flux | Francis Bliven |
| USDA/NASA: RS of N induced physiological changes in crops, Beltsville, MD | Petya Entcheva Campbell |
| USDA/NASA: RS of N induced physiological changes in trees, Beltsville, MD | Petya Entcheva Campbell |
| Voyager magnetometer investigations | Ronald Lepping |
| WIND Magnetic Field Investigation | James A. Slavin |

**Workshops Convened by ESED Scientists in FY2004 and FY2005**

| Workshop | Organizer |
|---|---|
| ACE/RHESSI/WIND joint workshop, Taos, New Mexico, Oct. 2003 | Brian Dennis |
| AERONET Workshop (2004) | Alexander Marshak |
| Aerosol Cloud Update (2005) | Yoram Kaufman |
| Aerosol Workshop (2005) | Yoram Kaufman & Mian Chin |
| American Geophysical Union (AGU) Fall Meeting: Land Measurements from NPOESS, Dec. 2005 | J. Privette, D. Tarpley & J. Feuquay |
| AGU Fall Meeting: Aerosol Special Session, Dec. 2004 | Yoram Kaufman |
| AGU Fall Meeting: Constraining Substorm Models, Dec. 2005 | David Sibeck |
| AGU Fall Meeting: Session A11C-Measurement-Based Assessment of the Global Aerosol Effect on Climate I: Measurement Posters, Dec. 2004 | Ellsworth Welton |
| AGU Fall Meeting: Using Radial Alignments to Address Magnetospheric Problems, Dec. 2004 | David Sibeck |
| AGU Joint Assembly – Remote Sensing of Precipitation (2004) | Thomas Bell |
| AGU Special Session: User Requirements for Future Data Systems Architecture Design in Support of the Ionosphere, Thermosphere, and Mesosphere Research Community, Dec. 2004 | Robert McGuire & Dieter Bilitza |
| AGU Special Session: Mars, Space Physics, and Life, Dec. 2004 | John F Cooper |
| American Institute of Aeronautics and Astronautics Space 2004 – Session on Climate Change Observations (2004) | Robert Cahalan |
| Aqua Science Working Group Meeting, GSFC, Greenbelt, Maryland | Claire Parkinson, Steve Platnick, and Moustafa Chahine |
| Calibration/cross Calibration Workshop for the AM Constellation Instruments, College Park, MD | Jim Butler |
| CEOS Cal/Val Subgroup on Atmospheric Chemistry (2004/2005) | Ernest Hilsenrath |
| Committee on Space Research (COSPAR): Session C4.2, Advances in Specifying Plasma Temperatures and Ion Composition in the Ionosphere, Paris, France | Dieter Bilitza |
| Data System Working Group Workshop (2004) | Kathy Fontaine |
| Early Results From NASA's EOS Aqua Spacecraft Mission" (five sessions at the AGU Fall Meeting), San Francisco, California | Claire Parkinson & Steve Graham |
| Eleventh Annual West Antarctic Workshop, Sterling, VA, September 2004 | Robert Bindschadler |
| Energetic Particles in the Inner Magnetosphere, Asia Oceania Geosciences Society (AOGS) 2nd Annual meeting | Mei-Ching Fok |
| Fifth General RHESSI Workshop, Locarno/Ascona, Switzerland, June 2005 | Brian Dennis |
| Fourth General RHESSI Workshop, Centre International d'Ateliers Scientifiques du Chateau de Meudon, Paris, France, July, 2004 | Brian Dennis |
| Fourth WMO Symposium on Assimilation of Observations in Meteorology and Oceanography, Prague, Czech Republic | Stephen Cohn |
| GCM Reality Intercomparison Project for Stratospheric Processes and their Role in Climate (SPARC) (GRIPS), Bologna, Italy, March 2004 | Steven Pawson (with Elisa Manzini) |
| GRIPS, Toronto, Canada, March 2005 | Steven Pawson (with David Sankey) |
| GEWEX Radiation Panel Working Group, Darmstadt, Germany (2005) | William Rossow |
| GEWEX Radiation Panel Working Group, Kyoto, Japan (2004) | William Rossow |
| Global Interactions Campaign of the Geospace Environment Modeling (GEM) program | David Sibeck |

**Workshops Convened by ESED Scientists in FY2004 and FY2005 (continued)**

| Workshop | Organizer |
|---|---|
| International Association of Geomagnetism and Aeronomy (IAGA)/Plasma sources, sinks, and transport | Thomas E. Moore |
| IPCC Workshop on Observed Impacts | Cynthia Rosenzweig |
| Landsat Calibration Workshops, Brookings, SD (June 2003), South Lake Tahoe, CA (December 2003), GSFC (June 2004), Tucson, AZ (December 2004), Rochester, NY (May 2005) | Brian Markham |
| New satellite and ground data for IRI, and comparison with regional models, Tortosa, Spain | Dieter Bilitza |
| Observational and Modeling Requirements for Predicting Drought on Seasonal to Decadal Time Scales, College Park, MD, May 2005 | Siegfried Schubert & Randy Koster (with Marty Hoerling, Richard Seager, Dennis Lettenmaier, Arun Kumar, & David Gutzler) |
| RHESSI Data Analysis Workshop, Berkeley, California, October 2004 | Brian Dennis |
| RHESSI/SOHO/TRACE joint workshop, Sonoma, California, December 2004 | Brian Dennis |
| SeaFlux Workshop, Long Beach, CA | William Rossow |
| Second Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) International Workshop on Surface Albedo Product Validation, April 2005 | Baret, F., J. Morisette, C. Schaaf, & J. Privette |
| Second Symposium on Lidar Atmospheric Applications (2005) | Belay Demoz |
| The Development of Improved Observational Data Sets for Reanalysis: Lessons Learned and Future Directions, Greenbelt, MD | Siegfried Schubert (with Dick Dee, John Bates, Sakari Uppala, Jack Woolen & Steven Worley) |
| Third CEOS LPV International Workshop on Leaf Area Index (LAI) Product Validation, August 2004 | Jeff Morisette & Jeff Privette |
| Total Solar Irradiance Workshop, National Institute of Standards and Technology, Gaithersburg, MD | Jim Butler |
| Twelfth Annual West Antarctic Workshop, Sterling, VA, September 2005 | Robert Bindschadler |
| U.S. GEO Meeting, Data Management Session, Washington, DC (2005) | Kathy Fontaine |
| Wallops Coastal Ocean Observing Laboratory (Wa-COOL) | John Moisan & Tiffany Moisan |
| When the Sun Went Wild, Solar Physics Division Special Session, Denver, Colorado, June 2004 | Brian Dennis |

# Appendix V. Professional Activities, Honors, and Awards

**Members of Academies**

| Academy | Name |
|---|---|
| National Academy of Engineering | Norden Huang |
| National Academy of Engineering | Michael King |
| National Academy of Sciences | James Hansen |

**Fellows of Professional Societies**

| Society | Name |
|---|---|
| American Association for the Advancement of Science | Mark Schoeberl |
| American Association for the Advancement of Science | James A. Smith |
| American Astronomical Society | Roger Thomas |
| American Geophysical Union | Robert Bindschadler |
| American Geophysical Union | James Hansen |
| American Geophysical Union | Michael Mishchenko |
| American Geophysical Union | William Rossow |
| American Geophysical Union | Mark Schoeberl |
| American Geophysical Union | Richard Stolarski |
| American Geophysical Union | Warren Wiscombe |
| American Geophysical Union | Leonard F. Burlaga |
| American Geophysical Union | David G. Sibeck |
| American Geophysical Union | Donald H. Fairfield |
| American Meteorological Society | Robert Adler |
| American Meteorological Society | Robert Atlas |
| American Meteorological Society | Anne Douglass |
| American Meteorological Society | Franco Einaudi |
| American Meteorological Society | Yoram Kaufman |
| American Meteorological Society | Michael King |
| American Meteorological Society | William Lau |
| American Meteorological Society | Claire Parkinson |
| American Meteorological Society | William Rossow |
| American Meteorological Society | Mark Schoeberl |
| American Meteorological Society | Eric A. Smith |
| American Meteorological Society | Wei-Kuo Tao |
| American Meteorological Society | Warren Wiscombe |
| American Physical Society | Brian R. Dennis |
| American Society of Agronomy | Cynthia Rosenzweig |
| Institute of Electrical and Electronics Engineers | David Le Vine |
| Institute of Electrical and Electronics Engineers | James A. Smith |
| Institute of Electrical and Electronics Engineers | James R. Wang |
| International Association of Geomagnetism and Aeronomy | Charles Jackman |
| International Astronomical Union | Roger Thomas |
| International Society for Optical Engineering (SPIE) | James A. Smith |
| Optical Society of America | Michael Mishchenko |
| Paul Brandwein Institute For Science Education | Elissa Levine |
| Royal Meteorological Society | Franco Einaudi |

**ESED Scientists that are Goddard Senior Fellows**

| |
|---|
| Robert Bindschadler |
| James Hansen |
| Norden Huang |
| Yoram Kaufman |
| Michael King |
| Mark Schoeberl * |
| James A. Smith |
| Compton Tucker |

* Current Chair

Goddard Senior Fellows form a very small group of individuals selected for their contributions to science, engineering, and technology.

**Members of Committees of Professional Societies in FY2004 and FY2005**

| Society | Committee Name | Member |
|---|---|---|
| American Astronomical Society | Division for Planetary Science, E/PO Vice Chair | L. Mayo |
| American Astronomical Society | Solar Physics Division Committee, 2005 | Gordon Holman |
| American Astronomical Society | Solar Physics Division Nominating Committee (chair), 2005 | Brian Dennis |
| American Astronomical Society | Solar Physics Division Nominating Committee, 2004 | Brian Dennis |
| American Astronomical Society | Solar Physics Division Nominations Committee Member | Therese A Kucera |
| American Astronomical Society | Solar Physics Division Website committee | Joseph B Gurman |
| American Geophysical Union | Committee on Remote Sensing | Christa Peters-Lidard |
| American Geophysical Union | Cryospheric Focus Group | Christopher Shuman |
| American Geophysical Union | Precipitation Committee | Thomas Bell |
| American Geophysical Union, Space Physics and Aeronomy Section | Education and Public Outreach Committee Member | Therese A Kucera |
| American Meteorological Society | CLAS/Committee for Laser Application Studies | Belay Demoz |
| American Meteorological Society | Committee on Hydrology | Christa Peters-Lidard |
| American Meteorological Society | Committee on Laser Atmospheric Studies | Geary Schwemmer |
| American Meteorological Society | Committee on Development | Claire Parkinson |
| American Meteorological Society | President Elect | Franco Einaudi |
| CLIVAR (World Climate Research Programme International Research Program on Climate Variability and Predictability) | Pan American Implementation Panel | Christa Peters-Lidard |
| Committee on Space Research | International Reference Ionosphere, Steering Committee | Dieter Bilitza |
| Committee on Space Research | Panel on Standard Radiation Belt | Shing Fung |

**Members of Committees of Professional Societies in FY2004 and FY2005 (continued)**

| Society | Committee Name | Member |
|---|---|---|
| IEEE | Accreditation Board for Engineering and Technology (ABET) Program Evaluator for Engineering Accreditation Commission (EAC) | James Smith |
| IEEE | Accreditation Board for Engineering and Technology (ABET) Program Evaluator for Computation Accreditation Commission (CAC) | James Smith |
| IEEE | Accreditation Board for Engineering and Technology (ABET) International Program Evaluator | James Smith |
| IEEE | Committee on Engineering Accreditation Activities | James Smith |
| IEEE Geoscience and Remote Sensing Society (IGARRS) | Chair, Northern Virginia/Washington Chapter | Guoqing Sun |
| IEEE Geoscience and Remote Sensing Society (IGARRS) | GRS Society Representative to IEEE Sensors Council, IGARSS Technical Program Committee, Frequency Allocations in Remote Sensing Committee | Edward Kim |
| International Association of Meteorology and Atmospheric Sciences | International Commission of Clouds & Precipitation | David Starr |
| International Glaciological Society | Immediate Past President | Robert Bindschadler |
| International Glaciological Society | Symposium on Sea Ice/Science Steering and Editorial Committee | Joey Comiso |
| International Society for Optical Engineering (SPIE) | Conference of Remote Sensing in Atmospheric Pollution Monitoring & Control | D. Allen Chu |
| International Union of Radio Science | ICSU Panel on World Data Centres | Dieter Bilitza |
| National Academy of Sciences | Panel on Climate Variability and Change | Claire Parkinson |
| National Science Foundation | Advisory Committee on Environmental Research and Education (ERE) | J. Marshall Shepherd |
| Soil Science Society of America Smithsonian Soil Museum Committee | Working Member | Elissa Levine |
| World Meteorological Organization/ International Aerosol-Precipitation Science Assessment Group | Panel to assess effects of natural and anthropogenic particles on precipitation | J. Marshall Shepherd |

**Editorships of Professional Journals in FY2004 and FY2005**

| Journal | Editor |
|---|---|
| Annals Of Glaciology- Volume 39 | Weili Wang |
| Chinese Journal of Oceanology and Limnology - Editorial Board Member | Norden Huang |
| Journal of Climate | Anthony Del Genio |
| Journal of Glaciology | Robert Bindschadler |
| Journal of Glaciology | Weili Wang |
| Journal of Hydrometeorology | Christa Peters-Lidard |
| Monthly Weather Review | Stephen Cohn |
| Solar Physics - Editorial Board Member | Joseph B Gurman |

## Associate Editorships of Professional Journals in FY2004 and FY2005

| Journal | Associate Editor |
|---|---|
| Climate Change | Cynthia Rosenzweig |
| Earth, Space and Planets | James A. Slavin |
| EOS, Space Physics and Aeronomy section, Corresponding Editor | David G. Sibeck |
| EOS, Transactions AGU | David G. Sibeck |
| Geophysical Research Letters | David G. Sibeck |
| IEEE Transactions on Geoscience and Remote Sensing | Ernest Hilsenrath |
| IEEE Transactions on Geoscience and Remote Sensing | James Smith |
| IEEE Geoscience and Remote Sensing Letters | Edward Kim |
| Journal of Atmospheric Sciences | Michael Mishchenko |
| Journal of Climate | William Rossow |
| Journal of Climate | Gavin Schmidt |
| Journal of Geophysical Research – Atmospheres | Alexander Smirnov |
| Journal of Geophysical Research – Atmospheres (until December 2004) | Steven Pawson |
| Journal of Geophysical Research – Atmospheres (2005) | Belay Demoz |
| Journal of Hydrometeorology | Michael Bosilovich |
| Journal of Quantitative Spectroscopy and Radiative Transfer | Michael Mishchenko |

## Editors of Special Issues in FY2004 and FY2005

| Name of Special Issue | Editor |
|---|---|
| Advances in Space Research: Path Towards Improved Ionosphere Specification and Forecast Models | Dieter Bilitza |
| Astrobiology - Mars, Space Physics, and Life | John F. Cooper |
| Icarus - Jovian Magnetospheric Environment Science | John F. Cooper |
| IEEE Transactions on Geoscience and Remote Sensing | Anne Douglass |
| IEEE Transactions on Geoscience and Remote Sensing | Ernest Hilsenrath |
| IEEE Transactions on Geoscience and Remote Sensing | Mark Schoeberl |
| IEEE Transactions on Geoscience and Remote Sensing AMSR-E Arctic Sea Ice - Special Section | Donald Cavalieri and Thorsten Markus |
| IEEE Transactions on Geoscience and Remote Sensing Landsat Special Issue | James Irons, Brian Markham and James Storey |
| International Journal of Remote Sensing Southern African Regional Science Initiative (SAFARI) 2000 Special Issue | Jeff Privette |
| International Association of Urban Climatology | J. Marshall Shepherd |
| Space Weather | David G. Sibeck |
| Quarterly Journal of the Royal Meteorological Society. Special Issue devoted to the Fourth WMO Symposium on Assimilation of Observations in Meteorology and Oceanography | Stephen Cohn |

**List of GSFC Awards Received in FY2004 and FY2005**

| GSFC Award | Recipient |
|---|---|
| **FY2004** | |
| Excellence in Outreach | Richard Stewart |
| Excellence in Outreach | Sun-Earth Connection Education Forum Venus Transit Team |
| Exceptional Achievement | Winston Chao |
| Exceptional Achievement | George Hayne |
| Exceptional Achievement | Stephen Palm |
| Group Achievement | ICESat Science Data Processing Team |
| Group Achievement | Space Science Data and Operations Office (SSDOO) Team |
| Lindsay Award | Brian Dennis |
| Outstanding Leadership | Wayne Esaias |
| Outstanding Leadership | Michael Seablom |
| Secretarial and Clerical Excellence | Natalie Simms |
| Special Act Award | Robert Benson |
| **FY2005** | |
| Award of Excellence | Earth Observatory Team |
| Award of Excellence | MODIS Aerosol Algorithm Team |
| Award of Merit | H. Jay Zwally |
| Excellence in Outreach | Carol Krueger |
| Excellence in Outreach | Earth Connection Education Forum |
| Exceptional Achievement | Mian Chin |
| Exceptional Achievement | Elissa Levine |
| Group Achievement | AERONET Team |
| Group Achievement | Aura Missions Operations and Science Systems Test Team |
| Group Achievement | Aura Team |
| Group Achievement | ICESat Science Data Processing Team |
| Group Achievement | Land Information Systems |
| Secretarial and Clerical Excellence | Nancy Gessner |
| Secretarial and Clerical Excellence | Kristine Glass |
| William Nordberg Memorial Award for Earth Sciences | Robert Bindschadler |

## List of NASA Awards Received in FY2004 and FY2005

| NASA Award | Recipient |
|---|---|
| **FY2004** | |
| Exceptional Achievement Medal | James A Slavin |
| Group Achievement | RHESSI Data Analysis Team |
| Group Achievement | Cluster Science Team |
| Group Achievement | Community Coordinated Modeling Center |
| Group Achievement | ICESat Mission Development Team |
| Group Achievement | NASA Earth Science Vision Movie Team |
| Group Achievement | RHESSI Data Analysis Team |
| Group Achievement | SHADOZ Team |
| Group Achievement | STS 107 SOLSE-2 Team |
| Group Achievement | Sun-Earth Day Team |
| NASA Acquisition Improvement | Robert Benson |
| Outstanding Leadership Medal | Pawan Bhartia |
| Outstanding Leadership Medal | Brian Dennis |
| **FY2005** | |
| Exceptional Scientific Achievement Medal | Mian Chin |
| Exceptional Scientific Achievement Medal | Yogesh Sud |
| Exceptional Technology Achievement Medal | Norden Huang |
| Exceptional Technology Achievement Medal | James Spinhirne |
| Group Achievement | Aura Project Science Team |
| Group Achievement | SIMBIOS Project |
| Group Achievement | SOLVE 2 Science Team |
| Group Achievement | Jupiter Icy Moons Orbiter Science Definition Team |
| Group Achievement | Sun-Earth Connection Education Forum Venus Transit Team |
| Public Service Medal | Oleg Dubovik |
| Software of the Year | Land Information System Software, led by Christa Peters-Lidard |

## List of National and International Honors and Awards Received in FY2004 and FY2005

| National and/or International Awards | Recipient |
|---|---|
| 40 Under Forty Honoree (Network Journal Magazine) | J. Marshall Shepherd |
| American Astronomical Society Award for Popular Writing on Solar Physics | Kenneth Phillips |
| American Meteorological Society Sigma Xi Lecturer | Mark Schoeberl |
| Committee on Space Research (COSPAR) Commission A Zeldovich Medal | Christa Peters-Lidard |
| Elected to be an Academician for the Academia Sinica (Republic of China, Taiwan) | Norden Huang |
| Galathea-Medal of the Royal Danish Geographical Society | Compton Tucker |
| Joint USGS/NASA William T. Pecora Award | William Krabill |
| National Capital/Chesapeake Bay Chapter: Regional Emmy Award in Informational Programs (2005) | NASA Connect - The Venus Transit Team |
| Presidential Early Career Award for Scientists and Engineers (PECASE) 2004 | Michael Bosilovich |
| Richard P. Goldthwait Polar Medal (Byrd Polar Research Center, Ohio State University) | Claire Parkinson |
| Scientific American Top 50 Research Leader citation | Gavin Schmidt and Drew Shindell |
| Verner E. Suomi Award | William Rossow |

# Appendix VI. Actual, Proposed, or Notional Missions Contained in NASA Strategic Roadmaps

| Name or Notional Mission | Acronym | Roadmap(s) | Launch |
|---|---|---|---|
| Multi-angle spectropolarimetric imaging; 3-D aerosol profiling (LEO) | | Earth Science | 2005-2015 |
| UV/Vis/NIR Imaging (Sentinel Orbit, L1, or GEO) | | Earth Science | 2005-2015 |
| Cal/Val free-flyer (LEO) | | Earth Science | 2005-2015 |
| High-resolution ice altimetry (LEO) | | Earth Science | 2005-2015 |
| 3-D ocean altimetry (LEO) | | Earth Science | 2005-2015 |
| Hyperspectral imaging instrument for solar UV, EUV, and X-rays (L1) | | Earth Science | 2005-2015 |
| Synthetic Aperture Radar and/or passive microwave | | Earth Science | 2005-2015 |
| Combined 3-D structure and multispectral imaging (LEO) | | Earth Science | 2005-2015 |
| 3-D laser profiling (LEO) | | Earth Science | 2005-2015 |
| Precision geodetic imaging (LEO) | | Earth Science | 2005-2015 |
| Wide-swatch microwave 30D sounding (MEO) | | Earth Science | 2015-2025 |
| Continuous, spectrally resolved Solar occultation (L2) | | Earth Science | 2015-2025 |
| High-resolution ice altimetry (LEO) | | Earth Science | 2015-2025 |
| Ice penetrating radar (LEO) | | Earth Science | 2015-2025 |
| Combined ocean surface/lower atmosphere winds (LEO) | | Earth Science | 2015-2025 |
| 3-D Clouds – CloudSat-Calipso follow-on (LEO) | | Earth Science | 2015-2025 |
| Cal/Val instruments for NPOESS follow-on (LEO) | | Earth Science | 2015-2025 |
| Wide-swath 3-D cloud and aerosol profiling (LEO) | | Earth Science | 2015-2025 |
| Precision/ interferometric altimetry (LEO) | | Earth Science | 2015-2025 |
| Microwave radar/ radiometry - Aquarius/ Hydros follow-on (LEO) | | Earth Science | 2015-2025 |
| Time-variable gravity – GRACE follow-on (LEO) | | Earth Science | 2015-2025 |
| 3-D profiling -- CloudSat-Calipso follow-on (LEO) | | Earth Science | 2015-2025 |

**Actual, Proposed or Notional Missions Contained in NASA Strategic Roadmaps (continued)**

| Name or Notional Mission | Acronym | Roadmap(s) | Launch |
|---|---|---|---|
| 3-D rain profiling (LEO) | | Earth Science | 2015-2025 |
| Hyperpectral imaging (LEO) | | Earth Science | 2015-2025 |
| Ground penetrating active microwave (LEO) | | Earth Science | 2015-2025 |
| High performance ocean color imaging (UV/Vis/NIR) (LEO or GEO), supporting sea surface temperature and salinity measurements. | | Earth Science | 2015-2025 |
| Upper ocean profiling (e.g., via blue/green lidar) (LEO) | | Earth Science | 2015-2025 |
| Hyperspectral imager (GEO or L1) | | Earth Science | 2015-2025 |
| High performance Hyperspectral UV/Vis/NIR imaging (LEO or GEO) | | Earth Science | 2015-2025 |
| Combined 3-D structure and multispectral imaging (e.g., radar, lidar, & multispectral Visible imaging) (LEO) | | Earth Science | 2015-2025 |
| Frequent, precision geodetic imaging (MEO constellation) | | Earth Science | 2015-2025 |
| Distributed magnetometry (e.g., 12-sat constellation, LEO, 300-800 km, low inclination & polar orbits) | | Earth Science | 2015-2025 |
| Passive/ active microwave (MEO) | | Earth Science | 2025-2035 |
| Active/ passive microwave (3 GEO) | | Earth Science | 2025-2035 |
| Cal/Val instruments for NPOESS follow-on | | Earth Science | 2025-2035 |
| High performance ocean color imager (UV/Vis/NIR) (GEO); supporting sea surface temperature and salinity measurements. | | Earth Science | 2025-2035 |
| Hyperspectral UVVis/NIR imaging (LEO) | | Earth Science | 2025-2035 |
| Combined 3-D structure and multispectral imaging (e.g., lidar and multispectral Vis imaging) (LEO) | | Earth Science | 2025-2035 |
| High temporal resolution geodetic imaging (GEO) | | Earth Science | 2025-2035 |
| Multispectral imaging in thermal IR (LEO) | | Earth Science | 2025-2035 |
| 3-D land structure (e.g., Lidar and/or InSAR) (LEO) | | Earth Science | 2025-2035 |
| Aerosol Properties | Glory | Earth Science | 2005-2010 |
| $CO_2$ mapping with high resolution spectrometer | OCO | Earth Science | 2007 |
| Ocean Surface Topography | OSTM | Earth Science | 2005-2010 |

**Actual, Proposed or Notional Missions Contained in NASA Strategic Roadmaps (continued)**

| Name or Notional Mission | Acronym | Roadmap(s) | Launch |
|---|---|---|---|
| Pre-Cursor to the NPOESS suite | NPP | Earth Science | 2006 |
| Cloud properties by radar | CloudSat | Earth Science | 2005 |
| Cloud-Aerosol Lidar | CALIPSO | Earth Science | 2005 |
| Global Precipitation Measurement | GPM | Earth Science | 2010 |
| Soil moisture | Hydros | Earth Science | 2010 |
| Ocean salinity variations | Aquarius | Earth Science | 2008 |
| Landsat Data Continuity Mission | LDCM | Earth Science | 2009 |
| Aeronomy of Ice in the Mesosphere | AIM | Sun-Solar System | 2005-2015 |
| Geospace Electrodynamic Connections | GEC | Sun-Solar System | 2017 |
| Farside Sentinel | FS | Sun-Solar System | 2025-2035 |
| Heliostorm | | Sun-Solar System | 2016-2020 |
| Inner Heliospheric Sentinels | HIS | Sun-Solar System | ~2013 |
| Ionosphere-Thermosphere Storm Probes | ITSP | Sun-Solar System | 2015 |
| L1 Earth-Sun | | Sun-Solar System | 2015-2020 |
| Magnetospheric Multi-Scale | MMS | Sun-Solar System | 2011 |
| Radiation Belt Storm Probes | RBSP | Sun-Solar System | 2011 |
| Solar-B | | Sun-Solar System | 2006 |
| Solar Dynamics Observatory | SDO | Sun-Solar System | 2008 |
| Solar Sail Demo | | Sun-Solar System | 2010-2014 |
| Solar Orbiter | | Sun-Solar System | 2015-2025 |
| Solar Probe | | Sun-Solar System | 2005-2015 |
| Solar-Terrestrial Relations Observatory | STEREO | Sun-Solar System | 2006 |
| Time History of Events and Macroscale Interactions During Substorms | THEMIS | Sun-Solar System | 2006 |
| Aeronomy and Dynamics at Mars | ADAM | Sun-Solar System | 2015-2020 |
| Auroral Acceleration Multiprobe | AAMP | Sun-Solar System | 2015-2025 |
| Dayside Boundary Constellation | DBC | Sun-Solar System | 2025-2035 |
| Doppler | | Sun-Solar System | 2015-2020 |
| Geospace Magnetospheric and Ionospheric Neutral Imager | GEMINI | Sun-Solar System | 2015-2025 |
| Inner Magnetospheric Constellation | IMC | Sun-Solar System | 2025-2035 |
| Ionosphere Thermosphere Mesosphere Waves | ITM-Waves | Sun-Solar System | 2020-2025 |
| Interstellar Probe | IP | Sun-Solar System | 2025-2035 |

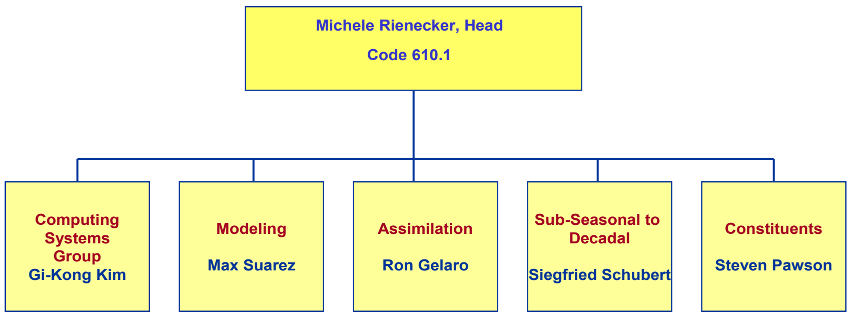
**Actual, Proposed or Notional Missions Contained in NASA Strategic Roadmaps (continued)**

| Name or Notional Mission | Acronym | Roadmap(s) | Launch |
|---|---|---|---|
| Io Electrodynamics | IE | Sun-Solar System | 2015-2035 |
| Magnetospheric Constellation (MagCon) | MC | Sun-Solar System | 2015-2025 |
| Magnetosphere-Ionosphere Observatory | MIO | Sun-Solar System | >2035 |
| Magnetic Transition Region Probe | MTRAP | Sun-Solar System | 2025-2035 |
| Reconnection and Microscale | RAM | Sun-Solar System | 2020-2035 |
| Solar Heliospheric and Interplanetary Environment Lookout in Deep Space | SHIELDS | Sun-Solar System | 2025-2035 |
| Solar Connection Observatory for Planetary Environments | SCOPE | Sun-Solar System | >2035 |
| Solar Energetic Particle Mission | SEPM | Sun-Solar System | 2015-2035 |
| Solar Polar Imager | SPI | Sun-Solar System | 2020-2035 |
| Solar Weather Buoys | SWBs | Sun-Solar System | 2022 |
| Sun Earth Coupling by Energetic Particles | SECP | Sun-Solar System | 2020-2025 |
| Stellar Imager | SI | Sun-Solar System | 2025-2030 |
| Tropical ITM Coupler | T-ITMC | Sun-Solar System | 2020-2035 |
| Venus Aeronomy Probe | VAP | Sun-Solar System | 2025-2035 |

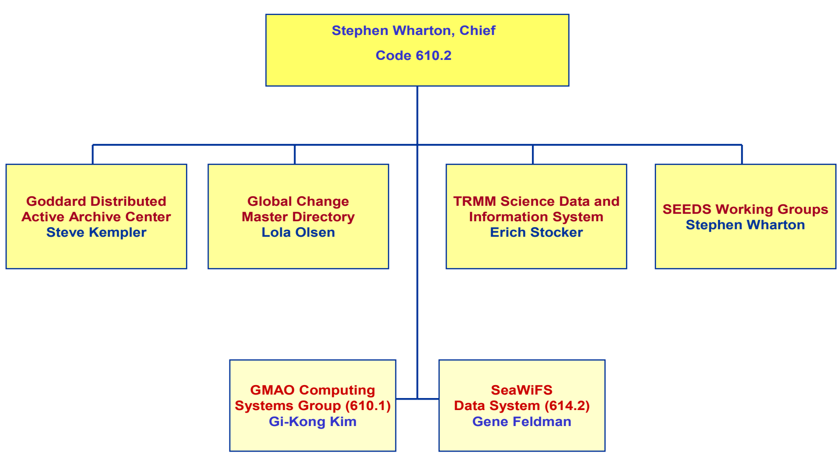
# Appendix VII. The Organizational Structure of the Division's Laboratories and Offices

Note: Code 611 will not be addressed here since it has no branch structure.

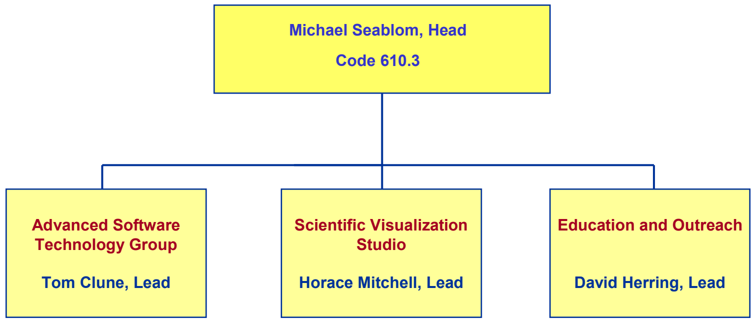
## Global Modeling and Assimilation Office, Code 610.1



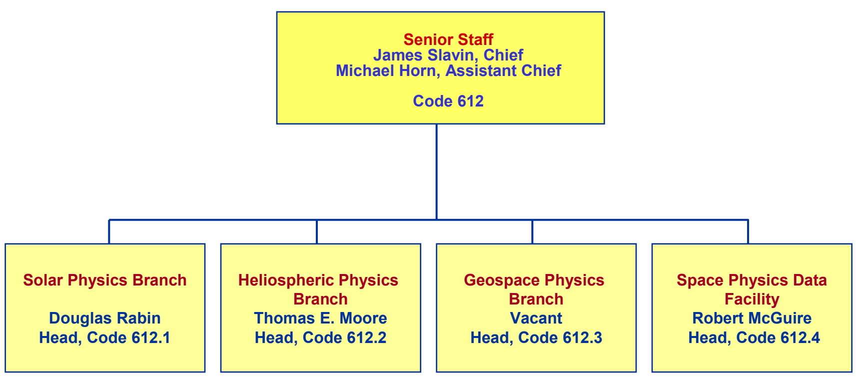

## Global Change Data Center, Code 610.2



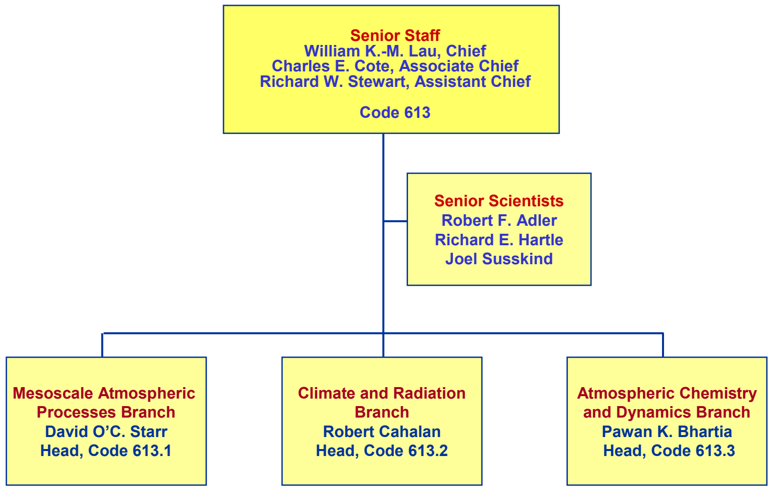
## Software Integration and Visualization Office, Code 610.3



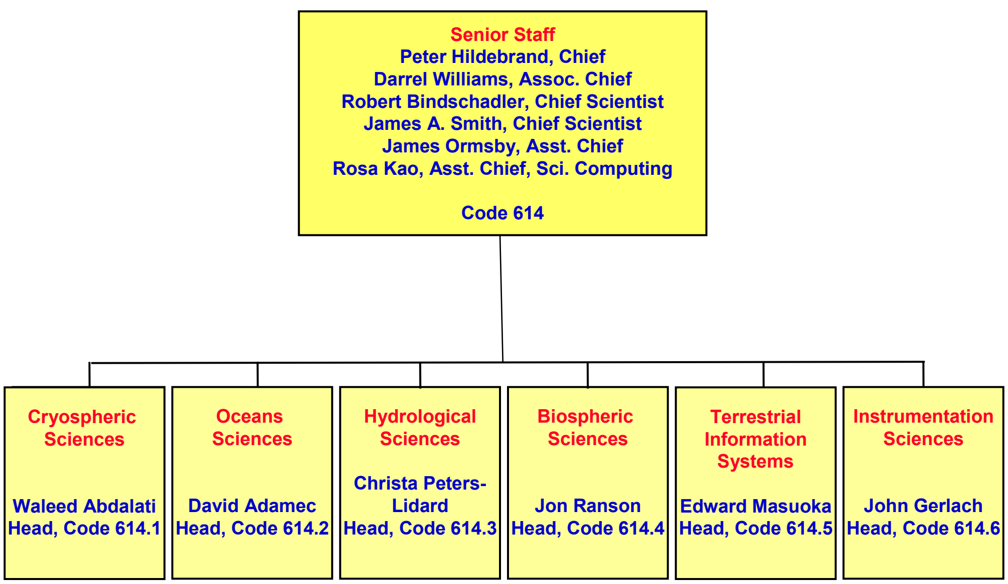

## Laboratory for Solar and Space Physics, Code 612



## Laboratory for Atmospheres, Code 613




## Hydrospheric and Biospheric Sciences Laboratory, Code 614



# Appendix VIII. Acronyms

| | |
|---|---|
| AAMP | Auroral Acceleration Multiprobe |
| ABET | Accreditation Board for Engineering and Technology |
| ACE | Aerosol Characterization Experiments |
| ADAM | Aeronomy and Dynamics at Mars |
| AERONET | AERosol RObotic NETwork |
| AESMIR | Airborne Earth Sciences Microwave Imaging Radiometer |
| AGCM | Atmospheric General Circulation Model |
| AGU | American Geophysical Union |
| AIM | Aeronomy of Ice in the Mesosphere |
| AIRS | Atmospheric Infrared Sounder |
| AIS | Agricultural Information System |
| AMS | American Meteorological Society |
| AMSR | Advanced Microwave Scanning Radiometer |
| AMSU | Advanced Microwave Sounding Unit |
| AOGS | Asia Oceania Geosciences Society |
| API | applications programming interface |
| APS | Aerosol Polarimeter Sensor |
| ARM | Atmospheric Radiation Measurement |
| AROTAL | Airborne Raman Ozone, Temperature, and Aerosol Lidar |
| ASPRS | American Society of Photogrammetry and Remote Sensing |
| ASTG | Advanced Software Technology Group |
| ATMS | Advanced Technology Microwave Sounder |
| A-Train | Afternoon Satellite Constellation |
| AVE | Aura Validation Experiment |
| AVHRR | Advanced Very High Resolution Radiometer |
| B&P | Bid and Proposal |
| BATSE | Burst and Transient Source Experiment |
| BIOMM | Biomass Monitoring Mission |
| BUV | backscatter ultraviolet |
| C/NOFS | Communication/Navigation Outage Forecasting System |
| CALIPSO | Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations |
| CBLAST | Coupled Boundary Layers Air/Sea Transfer |
| CCAST | Cooperative Center for Atmospheric Science and Technology |
| CCD | Charge-Coupled Devices |
| CCMC | Community Coordinated Modeling Center |
| CCRI | U.S. Climate Change Research Initiative |
| CCRI-NY | Climate Change Information Resource, New York |
| CCSP | Climate Change Science Plan |
| CDF | Common Data Format |
| CDS | Coronal Diagnostic Spectrometer |
| CEAS | Center for Earth-Atmospheric Studies |
| CEOS | Committee on Earth Observation Satellites |
| CGRO | Compton Gamma Ray Observatory |
| CIFAR | Cooperative Institute for Atmospheric Research |
| CIMSS | Cooperative Institute of Meteorological Satellite Studies |
| CLIVAR | World Climate Research Programme International Research Program on Climate Variability and Predictability |
| CLPP | Cold Land Processes Pathfinder |
| CLPX | Cold Land Processes Experiment |
| CMEs | Coronal Mass Ejections |
| $CO_2$ | Carbon Dioxide |
| COHO | Coordinated Heliospheric Observations |
| COR1 | Coronograph 1 (on the two STEREO satellites) |

| | |
|---|---|
| CoSEC | Collaborative Sun-Earth Connector |
| CoSMIR | Conically Scanning Millimeter-wave Imaging Radiometer |
| COSPAR | Committee on Space Research |
| CoSSIR | Conical Scanning Submillimeter-wave Imaging Radiometer |
| CrIS | Crosstrack Infrared Sounder |
| CSTEA | Center for the Study of Terrestrial and Extraterrestrial Atmospheres |
| CSU | Colorado State University |
| CTM | Chemical Transport Model |
| CZCS | Coastal Zone Color Scanner |
| DAAC | Distributed Active Archive Center |
| DAO | Data Assimilation Office |
| DAS | Data Assimilation System |
| DBC | Dayside Boundary Constellation |
| DDF | Director's Discretionary Fund |
| DMSP | Defense Meteorological Satellite Program |
| DOE | Department of Energy |
| DSSs | Decision Support Systems |
| DU | University of Denver |
| EDC | Eros Data Center |
| EdGCM | Educational Global Climate Models |
| EDOP | ER-2 Doppler radar |
| EIS | Extreme-ultraviolet Imaging Spectrometer |
| ENAs | Energetic neutral atoms |
| EnKF | Ensemble Kalman Filter |
| ENSO | El Niño/Southern Oscillations |
| ENVISAT | ENVIronment SATellite |
| EO-1 | Earth Observing-1 |
| EOS | Earth Observing System |
| EOSDIS | Earth Observing System (EOS) Data and Information System |
| EP TOMS | Earth Probe Total Ozone Mapping Spectrometer |
| EPA | Environmental Protection Agency |
| EQUIS | EQUatorial Ionospheric Study |
| ERBE | Earth Radiation Budget Experiment |
| ESA | European Space Agency |
| ESDIS | Earth Science Data and Information System |
| ESED | Earth-Sun Exploration Division |
| ESMF | Earth System Modeling Framework |
| ESSIC | Earth System Science Interdisciplinary Center |
| ESSP | Earth System Science Pathfinder |
| ETM | Enhanced Thematic Mapper |
| EUMetSat | European Organization for the Exploitation of Meteorological Satellites |
| EUNIS | Extreme Ultraviolet Normal Incidence Spectrograph |
| EUV | extreme ultraviolet |
| FAST | Fast Auroral SnapshoT |
| FAVOR | Facility for AURA Validation and Observations Regional |
| FCA | Full Cost Accounting |
| FIA | Forest Inventory and Analysis |
| FPICC | Fabry-Perot interferometer for column $CO_2$ |
| FS | Farside Sentinel |
| FTE | Full Time Equivalent |
| FUV | Far ultraviolet |
| FVGCM | Finite volume general circulation model |
| G&A | General and Administrative |
| GACP | Global Aerosol Climatology Project |
| GCDC | Global Change Data Center |
| GCE | Goddard Cumulus Ensemble |

| | |
|---|---|
| GCMD | Global Change Master Directory |
| GCMs | General Circulation Models |
| GCSS | Global Energy and Water Experiment's Cloud System Study |
| GEC | Geospace Electrodynamic Connections |
| GEM | Geospace Environment Modeling |
| GEMINI | Geospace Magnetospheric and Ionospheric Neutral Imager |
| GEO | Geosynchronus/Geostationary Earth Orbit |
| GEOS | Goddard Earth Observing System |
| GEOSS | Global Earth Observation System of Systems |
| GEOTRACE | GEostationary Observatory for TRopospheric Air ChEmistry |
| GES | Goddard Earth Sciences |
| GEST | Goddard Earth Sciences and Technology Center |
| GEWEX | Global Energy and Water Cycle Experiment |
| GFDL | Geophysical Fluid Dynamics Laboratory |
| GFO | GeoSat Follow-On |
| GIFTS | Geosynchronous Imaging Fourier Transform Spectrometer |
| GIS | Geographic Information System |
| GISS | Goddard Institute for Space Sciences |
| GLAS | Geoscience Laser Altimeter System |
| GLDAS | Global Land Data Assimilation System |
| GMAO | Global Modeling and Assimilation Office |
| GME | Goddard Medium Energy |
| GMI | Global Modeling Initiative |
| GOCART | Goddard Chemistry Aerosol and Radiation Transport |
| GOES | Geostationary Operational Environmental Satellite |
| GoHFAS | Goddard Howard University Fellowship in Atmospheric Sciences |
| GOME | Global Ozone Monitoring Experiment. |
| GPCP | Global Precipitation Climatology Project |
| GPM | Global Precipitation Measurement |
| GRACE | Gravity Recovery and Climate Experiment |
| GRIPS | Global Climate Model (GCM) Reality Intercomparison Project for Stratospheric Processes and their Role in Climate (SPARC) |
| GSC | General Sciences Corporation |
| GSFC | Goddard Space Flight Center |
| GSI | Grid-point Statistical Interpolation |
| HALOE | Halogen Occultation Experiment |
| HIRDLS | High Resolution Dynamics Limb Sounder |
| HIRS | High Resolution Infrared Sounder |
| HIS | Inner Heliospheric Sentinels |
| HPCC | High Performance Computing Challenges |
| HQ | Headquarters |
| HU | Howard University |
| IASI | Infrared Atmospheric Sounding Interferometer |
| IBEX | Interstellar Boundary Explorer |
| ICESat | Ice, Cloud, and Land Elevation Satellite |
| IE | Io Electrodynamics |
| IEEE | Institute of Electrical and Electronics Engineers, Inc |
| IGARSS | Institute of Electrical and Electronics Engineers, Inc (IEEE) Geoscience and Remote Sensing Society |
| IIP | Instrument Incubator Program |
| IMAGE | Imager for Magnetopause-to-Aurora Global Exploration |
| IMC | Inner Magnetospheric Constellation |
| IMP | Interplanetary Monitoring Platform |
| InSAR | Interferometry Synthetic Aperture Radar |
| INTEX | Intercontinental Chemical Transport Experiment |
| IP | Interstellar Probe |

| | |
|---|---|
| IPA | Intergovernmental Personnel Action |
| IPCC | Intergovernmental Panel on Climate Change |
| IPY | International Polar Year |
| IR | Infrared |
| IR&D | Internal Research and Development |
| IRI | International Research Institute for Climate Prediction |
| ISCCP | International Satellite Cloud Climatology Project |
| ISEE | International Sun-Earth Explorer |
| ISFS | Invasive Species Forecasting System |
| ITM | Ionosphere Thermosphere Mesosphere |
| ITM-Waves | Ionosphere Thermosphere Mesosphere Waves |
| ITSP | Ionosphere Thermosphere Storm Probes |
| JAXA | Japan Aerospace Exploration Agency |
| JCES | Joint Center for Earth Science |
| JCET | Joint Center for Earth Systems Technology |
| JCSDA | Joint Center for Satellite Data Assimilation |
| JIESIC | Joint Interdisciplinary Earth Science Information Center |
| JPL | Jet Propulsion Laboratory |
| LAI | Leaf Area Index |
| LaRC | Langley Research Center |
| LDAS | Land Data Assimilation System |
| LENA | Low Energy Neutral Atom |
| LEO | Low Earth Orbit |
| LPSO | Land Cover Satellite Project Science Office |
| LPV | Land Product Validation |
| LSSP | Laboratory for Solar and Space Physics |
| MC | Magnetospheric Constellation (MagCon) |
| MESSENGER | MErcury Surface, Space ENvironment, GEeochemistry, and Ranging |
| MHD | Magnetohydrodynamic |
| MIO | Magnetosphere-Ionosphere Observatory |
| MISR | Multi-angle Imaging Spectro-Radiometer |
| MLS | Microwave Limb Sounder |
| MMS | Magnetospheric MultiScale |
| MODAPS | Moderate Resolution Imaging Spectro-radiometer (MODIS) Data Processing System |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MOLA | Mars Orbiter Laser Altimeter |
| MOSES | Multi-Order Solar EUV Spectrograph |
| MTRAP | Magnetic Transition Region Probe |
| MU-SPIN | Minority University-SPace Interdisciplinary Network |
| NAS | NASA Advanced Supercomputing |
| NBO | New Business Office |
| NBRP | New Business Review Panel |
| NCAR | National Center for Atmospheric Research |
| NCEP | National Centers for Environmental Prediction |
| NDSC | Network for Detection of Stratospheric Change |
| NESDIS | National Environmental Satellite Data and Information Service |
| NMP | New Millennium Program |
| NOAA | National Oceanic and Atmospheric Administration |
| NPOESS | National Polar-orbiting Operational Environmental Satellite System |
| N-POL | NASA Polarization radar |
| NPP | NPOESS Preparatory Project |
| NRC | National Research Council |
| NSF | National Science Foundation |
| NSIDC | National Snow and Ice Data Center |
| NSIPP | NASA Seasonal to Interannual Prediction Project |

| | |
|---|---|
| NSSDC | National Space Science Data Center |
| NSTA | National Science Teachers Association |
| NWP | Numerical Weather Prediction |
| OCEaNS | Ocean Carbon Ecosystems and Near-Shore |
| OCO | Orbiting Carbon Observatory |
| OCS | Ocean Color Scanner |
| OCTS | Ocean Colour and Thermal Scanner |
| OGO | Orbiting Geophysical Observatory |
| OMI | Ozone Monitoring Instrument |
| OMPS | Ozone Mapping and Profiler Suite |
| OSEs | Observing System Experiments |
| OSSEs | Observing System Simulation Experiments |
| OSTM | Ocean Surface Topography Mission |
| PAO | Public Affairs Office |
| PARASOL | Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar |
| PEACE | Plasma Electron And Current Experiment |
| PECASE | Presidential Early Career Award for Scientists and Engineers |
| PI | Principal Investigator |
| PMCs | Polar Mesospheric Clouds |
| PMM | Precipitation Measuring Missions |
| POAM | Polar Ozone and Aerosol Measurement |
| POES | Polar Orbiting Environmental Satellite |
| POETRY | Public Outreach, Education, Teaching, and Reaching Youth |
| POLAR | Polar Plasma Laboratory |
| POLDER | POLarization and Directionality of the Earth's Reflectance |
| RAISE | Rapid Acquisition Imaging Spectrograph Experiment |
| RAM | Reconnection and Microscale |
| RHESSI | Ramaty High Energy Solar Spectroscopic Imager |
| ROSES | Research Opportunities in Space and Earth Sciences |
| RRAP | Resident Research Associateship Program |
| S3CAA | Sun-Solar System Connection Active Archive |
| SAFARI | Southern African Regional Science Initiative |
| SAGE | Stratospheric Aerosol and Gas Experiment |
| SAMPEX | Solar Anomalous and Magnetospheric Particle Explorer |
| SAR | Synthetic Aperture Radar |
| SBUV | Solar Backscatter Ultraviolet |
| SCIAMACHY | SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY |
| SCOPE | Solar Connection Observatory for Planetary Environments |
| SDAC | Solar Data Analysis Center |
| SDO | Solar Dynamics Observatory |
| SDPS | Sea-viewing Wide Field of view Sensor (SeaWiFS) Data Processing System |
| SeaWiFS | Sea-viewing Wide Field-of-view Sensor |
| SECEF | Sun-Earth Connection Education Forum |
| SECP | Sun Earth Coupling by Energetic Particles |
| SED | Sciences and Exploration Directorate |
| SEEDS | Strategic Evolution of Earth Science Enterprise Data Systems |
| SEPM | Solar Energetic Particle Mission |
| SERTS | Solar Extreme ultraviolet Research Telescope and Spectrograph |
| SHADOZ | Southern Hemisphere Additional Ozonesondes |
| SHIELDS | Solar Heliospheric and Interplanetary Environment Lookout in Deep Space |
| SI | Stellar Imager |
| SIRICE | Submillimeter and Infrared Ice Cloud Experiment |
| SkyRAD | Sky Radiometers |
| SMD | Science Mission Directorate |

| | |
|---|---|
| SMEX | Soil Moisture Experiments |
| SMM | Solar Maximum Mission |
| SNR | Signal to Noise Ratio |
| $SO_2$ | Sulfur Oxides |
| SOHO | Solar and Heliospheric Observatory |
| SOLSE/LORE | Shuttle Ozone Limb Scattering Experiment/ Limb Ozone Retrieval Experiment |
| SON | Student Observation Network |
| SORCE | Solar Radiation and Climate Experiment |
| SPARC | Stratospheric Processes and their Role in Climate |
| SPI | Solar Polar Imager |
| SPIE | International Society for Optical Engineering |
| SPOT | Système Pour l'Observation de la Terre |
| SSBUV | Shuttle Solar Backscatter Ultraviolet Spectrometer |
| SSC | STEREO Science Center |
| SSSC | Sun-Solar System Connection |
| SST | Sea Surface Temperature |
| STEREO | Solar-Terrestrial Relations Observatory |
| STROZ-LITE | Stratospheric Ozone Lidar Trailer Experiment |
| SUMER | Solar UV Measurements of Emitted Radiation |
| SUMI | Solar Ultraviolet Magnetograph Investigation |
| SUNBEAMS | Students United with NASA Becoming Enthusiastic About Math and Science |
| SVS | Scientific Visualizations Studio |
| SWBs | Solar Weather Buoys |
| SWE | Snow Water Equivalent |
| $TC^4$ | Tropical Composition, Cloud and Climate Coupling Experiment |
| TCSP | Tropical Cloud Systems and Processes |
| TES | Troposphere Emission Spectrometer |
| THEMIS | Time History of Events and Macroscale Interactions During Substorms |
| TIMED | Thermosphere Ionosphere Mesosphere Energetic and Dynamics |
| T-ITMC | Tropical Ionosphere Thermosphere Mesosphere Coupler |
| TMI | TRMM Microwave Imager |
| TOMS | Total Ozone Mapping Spectrometer |
| TOPEX | Ocean TOPography EXperiment |
| TOVS | NOAA's Tiros Operational Vertical Sounder |
| TPF | Terrestrial Planet Finder |
| TRACE | Transition Region and Coronal Explorer |
| TRL | Technology Readiness Level |
| TRMM | Tropical Rainfall Measuring Mission |
| TSDIS | Tropical Rainfall Measuring Mission (TRMM) Science Data and Information System |
| TWINS | Two Wide-angle Imaging Neutral-atom Spectrometers |
| UAE2 | Unified Aerosol Experiment 2 |
| UARS | Upper Atmosphere Research Satellite |
| UAV | Unmanned Aerial Vehicle |
| UMBC | University of Maryland at Baltimore County |
| UMCP | University of Maryland at College Park |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific, and Cultural Organization |
| UNH | University of New Hampshire |
| USDA | U.S. Department of Agriculture |
| USGCRP | U.S. Global Change Research Program |
| USGS | U.S. Geological Survey |
| UV | Ultraviolet |
| UW | University of Wisconsin |
| VAL | Visualizations Analysis Laboratory |
| VAP | Venus Aeronomy Probe |

| | |
|---|---|
| VCL | Vegetation Canopy Lidar |
| VEFI | Vector Electric Field Instrument |
| VIIRS | Visible Infrared Imager Radiometer Suite |
| VIS IR | Visible Infrared |
| VITAL | Visual and Technical Arts Lab |
| VSEP | Visiting Students Enrichment Program |
| VSO | Virtual Solar Observatory |
| VSPO | Virtual Space Physics Observatory |
| Wa-COOL | Wallops  Coastal Ocean Observing Laboratory |
| WatER | Surface Water Mission |
| WFF | Wallops Flight Facility |
| WIND | Solar Wind Mission |
| WMO | World Meteorological Organization |
| WSDL | Web Services |