Biospheric Sciences

Biospheric Science, within the Laboratory for Terrestrial Physics, encompasses a broad range of basic and applied research to study terrestrial ecosystems and their interactions with the atmosphere using multi-scale remote sensing, modeling, and advanced analytical techniques. Experiments and investigations of a scientific nature utilizing Earth observations, new techniques and capabilities enhance our understanding of global processes for Earth System Science. In these studies we utilize ground, aircraft, and satellite remote sensing instruments to measure variables that describe the temporal and spatial dynamics of natural ecosystems, especially the vegetation condition, soils and links to atmospheric constituents. We also develop mathematical models that predict land surface conditions and processes related to rates of vegetation, soil and atmosphere exchanges as functions of remotely sensed and ground based observations.

Specifically, our Biospheric Sciences efforts can be grouped into several categories, as follows:

Flight Projects: To ensure the scientific integrity of new Earth remote sensing systems developed to improve space-based Earth observations, we serve as project managers and project and instrument scientists on biospheric oriented satellite missions. In 2003, the Laboratory had science management responsibilities for 6 existing or planned missions/projects: Landsat-7, EO-1, EOS Terra, Landsat Data Continuity Mission, NPOESS Preparatory Project and the Earth System Science Pathfinder Project. For the past 3 decades we have provided the science leadership in the Landsat series of satellites. Summary of activities in ’03 on these projects can be found on pages 54-59.

Enabling Efforts: We are very active in projects that support the broader community. That is, projects which enable the university, government and private communities in their study or application of terrestrial remote sensing. Here, again, we have a long history, especially in managing large, international field studies (e.g., FIFE, BOREAS, LBA). In this section you will find reports on large, international field studies in the Amazon and southern Africa, as well as planning for a new international project in northern Eurasia. Also you will find articles on a network of spectral radiometers which supply to the community global aerosol optical properties, a project which develops maps of disturbance in North America over a 25 year period, and two groups which coordinate activities in calibration and carbon cycle work. Articles on these subjects can be found on pages 60-66.

Research, which leads to the definition and development of new technologies, sensors, and missions to advance state of the art capabilities for monitoring global changes, is the third, and possibility the busiest, broad category of the Laboratory’s work in the Biospheric Sciences. In this section you will find 4 articles on atmospheric aerosol optical properties, 2 articles on the effect of burning and land use on the carbon cycle, 3 on broad ecosystem dynamics, 4 on sensor characterization and development, 1 on astrobiology, and 4 on outreach or applications of remote sensing. They are on pages 67-84

Data Processing: A fourth category of work in Biospheric Sciences can be characterized as acquiring, producing and distributing large, comprehensive, integrated, high quality land data sets incorporating ground, airborne, and/or satellite observations. Two such efforts in ’03, from the MODIS sensor on the EOS missions, Terra and Aqua, are described on pages 85-86.

Through such efforts, the Laboratory assesses and predicts environmental changes due to natural and anthropogenic processes at local to global scales, to improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. Past studies include assessment of deforestation, desertification, land use, land cover, vegetation anomalies, primary productivity, famine early warning, biomass burning, ecologically-influenced pests and diseases, and the extent and impact of urbanization.

Over 100 Civil Service and contractor personnel are working on biospheric sciences related activities, comprising about one-third of the Laboratory activities. A total of 83 refereed journal papers and 15 proceedings papers in the Biospheric Sciences were authored/co-authored by Laboratory scientists in 2003. A list of these publications is provided on pages 87-92. Authors associated with the Laboratory are shown in bold print. From the mix of authors, it can be seen that the Laboratory works with a very wide array of colleagues, both nationally and internationally. (Note: If 2003 papers are cited in the following articles, full references can be found in the publication section.)

For additional information see:

http://ltpwww.gsfc.nasa.gov/bsb/Home.gtml

Landsat and the Land Cover Satellite Project Science Office

On July 23, 1972, NASA launched the first Landsat satellite, beginning what is now the longest, continuous record of the Earth's continental surfaces as seen from space. The Laboratory for Terrestrial Physics (LTP) has made significant contributions to the success of the Landsat Program, particularly in ensuring the scientific integrity of the various missions. Drs. Louis Walter, Vincent Salomonson and Darrel Williams have served in Project Scientist roles during the Thematic Mapper era dating back to the development of instrument specifications in the mid-1970's. Today, the Land Cover Satellite Project Science Office (LPSO) within the LTP is responsible for long-term calibration / validation of Landsat-7 ETM+ data, Landsat-5 TM data, and for ensuring the scientific success of the Landsat mission. Working jointly with personnel from the U.S. Geological Survey (i.e., USGS, the agency that is now responsible for mission operations), the LPSO team tracks the radiometric and geometric character of acquired data, and makes recommendations to USGS to enhance the quality and scientific utility of the data. As described in the next page of this annual report, the LPSO is also actively involved in formulating the Landsat Data Continuity Mission – the follow-on to Landsat-7.

During the first five months of 2003, through May 30th, both Landsat-5 and Landsat-7 continued to operate routinely, gathering multispectral imagery of the Earth. On May 31st, the Scan Line Corrector (SLC) mechanism within the Landsat-7 ETM+ instrument stopped functioning, and this results in about 22% of the area of a normal scene not being acquired. Landsat-7 data acquisitions were halted until mid-July as NASA worked with USGS and the instrument and satellite vendors to determine exactly what had happened, whether normal operations could be recovered via some other mode of operations (e.g., such as using redundant electronics, etc.), and if not, could additional harm be done to the instrument if it were operated in a more normal fashion but with the SLC powered off. Intensive efforts to restore SLC operations during the late summer period were not successful – the failure appears to be permanent. The ETM+ continues to acquire useful data for approximately 78% of any particular scene. The missing data form alternating wedges that increase in width from the center to the edge of a scene (Fig. 1), and this malfunction has had an impact on the utility of the imagery. USGS and NASA have been focusing their efforts on providing useful ETM+ image products from data acquired after the failure. This team has been developing and testing two types of gap-fill products: Phase 1, to fill in the missing data by using a normal scene acquired about one year prior to the impaired scene, and Phase 2, to use multiple SLC-off scenes acquired 16 – 32 days before and/or after a particular scene of interest in order to fill in the gaps of missing data. Plans call for Phase 1 products to be released no later than June 1, 2004, while Phase 2 products are targeted for release in early 2005. To view example products and get the latest status update, visit :http://landsat7.usgs.gov/slc_enhancements/.

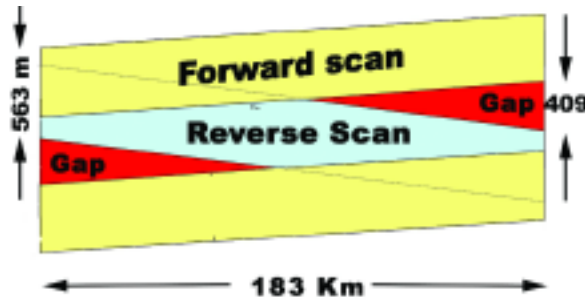

Figure 1. Scan Gap Dimensions

Other activities during 2003 included: develop-ment of a web-based calculator for atmospheric correction parameters to assist users with the application of Landsat-7 thermal band data; completion of NASA 508 compliance for the Landsat-7 Calibration Research website making it accessible for people with disabilities; continued efforts to complete a lifetime calibration analysis of Landsat-5 TM data; and generation of numerous image products and educational materials for outreach. These latter two topics will be addressed in greater detail in other sections of this annual report.

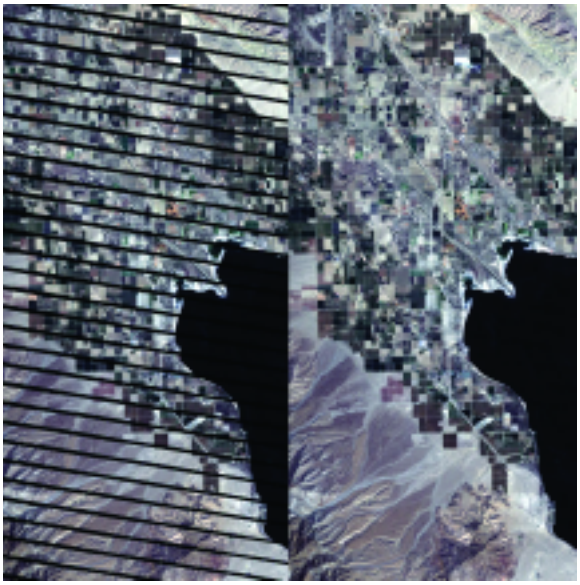

Figure 2. Left image of Salton Sea illustrates the edge portion of an original SLC-offs cene after Level 1G processing (17 Sept. 2003). The right image illustrates the same location after gap-fill, using histogram-matched data from a previously acquired SLC-on scene with equivalent seasonality.

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Landsat Data Continuity Mission

Personnel in the Laboratory for Terrestrial Physics have been deeply involved for the past several years in the development of a follow-on mission to Landsat-7. Dr. Jim Irons, of the Biospheric Sciences Branch, serves as the Mission Scientist. Efforts to begin implementing a successor mission to Landsat 7, called the Landsat Data Continuity Mission (LDCM), suffered a set back in 2003. NASA and the Department of Interior (DOI) / U.S. Geological Survey (USGS) currently manage the Landsat Program as an interagency partnership. The two agencies had planned to purchase data meeting LDCM specifications from a privately owned and commercially operated satellite system beginning in March, 2007. This approach represented a departure from the traditional procurement of a government owned and operated satellite system. NASA, however, cancelled a Request-for-Proposals (RFP) for providing the required data after an evaluation of proposals received from private industry. Alternative options for an LDCM are now under consideration.

The RFP began the second phase of the attempt to procure LDCM data from a commercial source. The first phase consisted of formulation studies conducted independently by two contractors, Resource 21 of Englewood, Colorado, and DigitalGlobe of Longmont, Colorado. NASA awarded $5M contracts to each contractor in March of 2002 following a formulation phase RFP and a competitive selection process. The formulation phase culminated in November, 2002 with preliminary design reviews of each contractor's satellite system concept. The release on January 6, 2003 of a second RFP for the provision of data by a single provider followed the preliminary design reviews.

Proposals responding to the second RFP were due on February 25, 2003. NASA decided not to award a contract and to cancel this RFP at the end of September following an evaluation of received proposals. NASA concluded that the proposals failed to meet a key objective and expectation of the RFP, namely, to form a fair and equitable partnership between the Government and private industry. It was expected that the Government's cost of acquiring Landsat data would be reduced by private industry's equity investment for developing a privately owned system capable of meeting both commercial and Government requirements. The proposals left the Government with a disproportionate share of the costs and risks of system development.s

The Executive Office of the President formed an interagency working group on the LDCM following the RFP cancellation. The working group is considering other options for implementing a successor system to Landsat 7 consistent with the Land Remote Sensing Policy Act of 1992 (Public Law 102-555). This Act lists four management options for consideration: 1) private sector funding and management; 2) an international consortium; 3) funding and management by the U.S. Government; and 4) a cooperative effort between the U.S. Government and the private sector. The working group is currently attempting to minimize the risk of a Landsat data gap through development of a management strategy that quickly leads to a Landsat 7 successor mission.

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EO-1 Mission Activites in 2003

The Earth Observing One (EO-1) Baseline Mission met all of its prescribed goals by the end of calendar year 2002. The original intent of this mission was to validate the onboard technologies through one year of data collection followed by an additional year of analysis. The EO-1 Science Validation Team (SVT) completed their analyses of the data gathered during the entire Baseline Mission period, from December 2001 through January 2002, by the end of 2002. A special issue of IEEE Transactions on Geoscience and Remote Sensing (TGARS), devoted to the SVT EO-1 validation results, was published in June 2003. The initial results of the science validation activities reported in this issue are contained in 28 papers, occupying 277 pages. As of December 19, 2003, 262 EO-1 related science and technology papers have appeared in transactions, proceedings and refereed journals. Approximately 200 additional external presentations, not resulting in full papers, were given by members of the EO-1 Mission Science Office (MSO), SVT, and EO-1 engineering/technology staff.

Although the EO-1 Mission has formally concluded, processing and distribution of EO-1 data continues at the USGS EROS Data Center (EDC) as part of the EO-1 "Extended Mission." The EO-1 Extended Mission offers users in various government agencies, the commercial sector, and general research community, the opportunity to investigate the potential of applying technology and techniques developed for EO-1 to solving problems in their own areas of interest. EO-1 uniquely offers a space-borne spectral imaging capability that is not currently available from any other source. The MSO continues to support EO-1 during the extended mission through calibration and validation of the EO-1 instrument suite as well as the formulation of science scenarios for sensor web development activities.

EO-1 sensor web activities have centered around the Wildfire Sensor Web Experiment. This project's goals are to: a) more effectively exploit existing space assets by using multiple on-orbit instruments in a coordinated and complementary fashion, b) optimize for timely acquisition of cloud free, near nadir imagery for science and applications users, c) develop and exercise targeting and tasking technology with an eye toward the design of future operational systems, d) provide data of immediate use to address strategic national objectives (i.e., National Fire Plan) and e) develop new analysis methods in concert with end users in federal and state agencies.

The EO-1 Wildfire Sensor Web Experiment design implemented in 2003 is as follows:: a) stratify priority wildfires using ICS-209 (Situation Report) database at National Interagency Fire Center, Boise; b) intersect with potential EO-1 acquisitions for the day; c) select largest unmapped incident (new development in 2004 uses GOES to choose between two potential targets based on cloud detection); d) refine targeting using MODIS active fire detections since the incident began; e) build EO-1 tasking load and relay to spacecraft; f) acquire image, hold onboard; g) downlink at USGS EROS Data Center, Sioux Falls and process to Level-1; h) transfer to University of Maryland, College Park, for assembly of silicon chip assembly strips and conversion to ERDAS format (image processing standard for federal land managers); i) transfer to USFS Burned Area Emergency Rehabilitation (BAER) desk at Remote Sensing Applications Center, Salt Lake City; j) create burn extent image; and k) transfer to BAER personnel at appropriate fire camp.

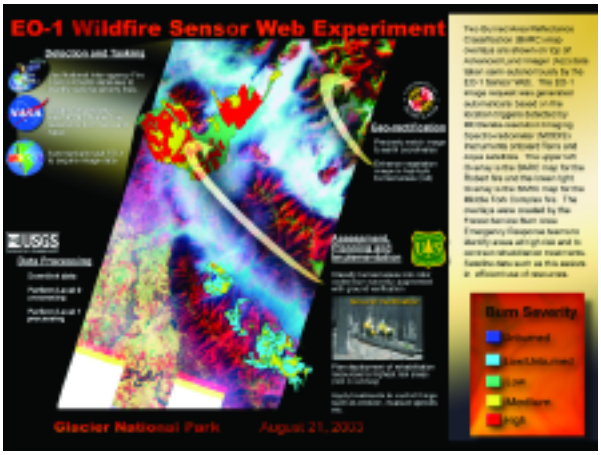

Figure 1. EO-1 Sensor Web Experiment conducted with University of Maryland and the Forest Service on August 21, 2003. EO-1 ALI image with Burned Area Reflectance Classification (BARC) map overlay for areas of interest (Robert fire and Middle Fork Complex fire).

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NASA's EOS Terra Mission

NASA's Terra spaceraft is providing a comprehensive global picture and set of initial-condition measurements for quantitatively monitoring the Earth's lands, oceans, and atmosphere. Terra, along with other EOS spacecraft (Landsat 7, Aqua, ICESAT) is acquiring many of the measurements required to advance understanding of the Earth system. Launched in December 1999, Terra has been acquiring science data since February 2000. Terra flies in a near-polar, sun-synchronous orbit that descends across the equator around 10:30am when cloud cover over the land tends to be minimized. Terra's orbit follows the Worldwide Reference System, along with Landsat 7 (USGS), EO-1 (NASA) and SAC-C (Argentina CONAE) all crossing the equator within 25 minutes. These four spacecraft comprise the "Morning Constellation." A Constellation working group meeting was hosted by CONAE in Buenos Aries in November 2003.

Terra has five complementary scientific instruments: ASTER for close-up land studies, CERES for a broad view of long- and shortwave radiation, MOPITT for studies of pollution, MISR for bidirectional-reflectance studies of clouds, aerosol and land features and MODIS for global analysis of land, ocean and atmosphere properties and their interactions. The role of the Project Science Office, currently in the Laboratory for Terrestrial Physics, is to organize and moderate regular communication among the Terra instrument teams through regular telephone conferences, science team meetings, and organization of special issues in journals, topical workshops and conference sessions.

A role of the Terra Project Scientist is to be the science liaison to the Terra Flight Operations team. This ensures that the science requirements are considered during routine operations and anomaly mitigation. Despite several anomalies to MODIS, and Terra's science formatting equipment, and solid state recorder, all Terra instruments and systems are functioning well and acquiring high quality science data.

The past year's highlights include release of several important scientific data sets. ASTER completed their first global acquisition data set. Through a new agreement with Japan, U.S. Geologic Survey's EROS Data Center (EDC) is now able to process level 1B data. CERES continued to produce validated ERBE like products and is preparing to release new data products. MISR released global cloud, surface and aerosol products and demonstrated 3-D cloud structure and dynamics. MODIS released validated data sets for several science products, including surface albedo, vegetation leaf area index, sea surface temperature, and aerosol optical depth and net primary productivity (see Figure 1). MOPITT is producing carbon monoxide data products and releasing them through the Langley DAAC. Currently, the majority of planned Terra science products are available through the EOS Data Gateway. For the latest information on the status and availability of data from Terra and other EOS missions, see: http://eosdatainfo.gsfc.nasa.gov/terra.

Early in the Terra mission, instrument-team scientists called for a series of on-orbit pitch-over maneuvers to allow Terra's instruments to view cold deep space or the sunlit lunar surface. The maneuver required a reverse pitch during eclipse (spacecraft night) within about 33 minutes. The first deep-space calibration maneuver was successfully performed on March 26, 2003 followed by an identical and flawless maneuver with the moon in the viewing plane of the instruments on April 14, 2003. NASA's EO-1 ALI, and Hyperion instruments and OrbView's SeaWIFs instrument acquired data of the moon around the time of Terra's maneuver. Calibration data acquired enabled CERES to confirm offsets for its long wave radiation measurements and enable MODIS to better characterize response with mirror scan angle. ASTER, MISR, and MODIS used measurements of the lunar surface for radiometric calibration and intercomparison purposes. The Terra Flight Operations Team performed the maneuvers in an exceptional manner.

The Terra Project Science Office continues to work with and support the Earthobservatory web site. This site has become known as a world class Earth science remote sensing educational site and was recently awarded a 2003 Webby Award for Education and a Webby Peoples Choice Award by The International Academy of Digital Arts and Sciences. The site can be viewed at http://earthobservatory.nasa.gov/

The scientific community now has unprecedented quantitative data sets to study the Earth as a system and answer the questions of how is the Earth changing and how humans will be affected by these changes. Terra, as the flagship observatory for NASA's Earth Observing System, is contributing new insights about our Earth. For additional information about the Terra spacecraft and links to each of the five instruments, the reader is invited to visit the Terra Project Science homepage at http://terra.nasa.gov.

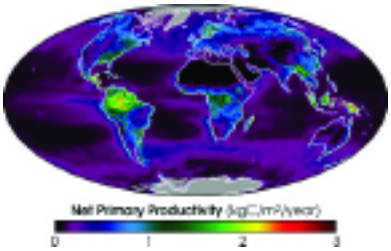

Figure 1. MODIS derived global, annual average of net productivity of vegetation on land and phytoplankton in the ocean during 2002. See also http://modis.gsfc.nasa.gov/

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NPOESS Preparatory Project (NPP)

The NPOESS Preparatory Project (NPP) is a satellite mission designed to provide NASA and the broader Earth-science community with continuation of high quality global imaging and sounding products beyond the Earth Observing System (EOS) missions (e.g., Terra, Aqua and Aura), and to provide risk reduction for the National Polar-orbiting Operational Environmental Satellite System (NPOESS, with flights starting in ~2010). NPP effectively bridges the EOS missions to the NPOESS missions, supporting the transition of selected long-term systematic Earth-science measurements from EOS to operational systems. The mission is a combined effort of NASA's Earth Science Enterprise and the Integrated Program Office (IPO, a joint agency office operated by Department of Defense, NOAA and NASA). NASA's Project and Deputy Project Scientists are in the Laboratory for Terrestrial Physics.

With a launch in 2006 and a mission duration of 5 years, NPP has been formulated using an end-to-end mission-life-cycle methodology. Four instruments will fly on NPP (see Fig. 1): Visible Infrared Imaging Radiometer Suite (VIIRS), Cross-track Infrared Sounder (CrIS), Advanced Technology Microwave Sounder (ATMS) and the Ozone Mapping and Profiler Suite (OMPS).

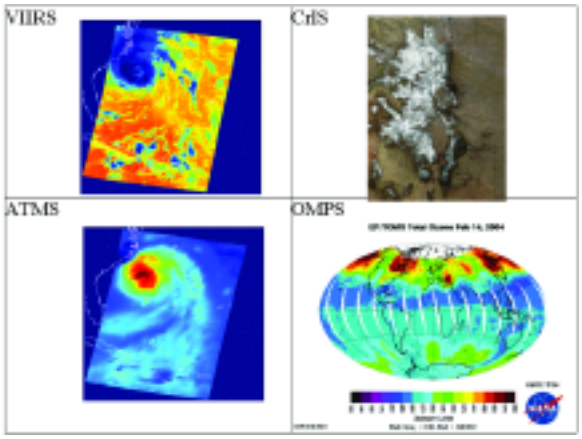

Figure 1. Sample images representative of each sensor's data products.

VIIRS will have 22 spectral bands which together span the visible to thermal infrared wavelengths. Each band has either 375 m (6 bands) or 750 m resolution (16 bands) at nadir, and a swath width of 3029 km. The sensor will provide images of atmospheric, land and ocean parameters.

The CrIS and ATMS sensors will work together to provide atmospheric temperature and moisture profiles. CrIS is a Michelson interferometer with 1142 channels between 3.5 and 16 microns. The ATMS sounder will combine the passive-microwave observation capabilities of three heritage instruments (AMSU A1/A2 and MHS) using advanced microwave-receiver electronics technologies. It will sample in 22 bands between 23 and 183 GHz over a 2300 km swath. The OMPS system, with both nadir and limb-looking sensors, will provide both the daily ozone total column and vertical profiles.

NPP will cross the equator at 10:30 a.m. local time in its 833 km high orbit. On each orbit, the spacecraft will transmit stored mission sensor data to a receiving station in Svalbard, Norway, and will also provide continuous direct broadcast of real-time sensor data. The mission data will be routed on communications networks from Svalbard to the continental United States.

The NPOESS Interface Data Processing Segment (IDPS) will process the mission data for immediate use by the operational community. Two IDPS installations will simultaneously process the raw data. NASA will primarily interact with the installation at National Environmental Satellite, Data, and Information Service Center in Suitland, MD. The NESDIS IDPS will produce instrument, radiometric and low level products (Environmental Data Records, or EDRs) using industry-developed algorithms.

The operational EDRs potentially address 12 of the 23 NASA Earth Science Enterprise key research questions, and provide 16 of the 24 key EOS long-term measurements. In September 2003, NASA competitively selected 24 scientists for its NPP Science Team. The team is charged with assessing the viability of NPP's operational products for NASA's climate change research needs, and with assisting NASA in developing NPP calibration, validation, and operations plans. NASA may provide additional processing capability to further support the research community with improved calibration and validation activities or other products. All products will be archived and distributed through NOAA's Comprehensive Large Array-data Stewardship System (CLASS).

The IPO will provide the communication, command, control and IDPS systems and NASA will provide the spacecraft. NASA will also provide hardware, algorithm and system technology insertion to the operational program. The prime contractor for the NPOESS mission is Northrop Grumman Space Technology, and the prime contractor for the NPP spacecraft is Ball Aerospace Corporation.

The NPP Project successfully completed its Mission Confirmation Review in October 2003, and the spacecraft is scheduled for delivery to the Vandenburg AFB launch facility in late summer of 2006.

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Earth System Science Pathfinder Program

NASA's Earth System Science Pathfinder Program (ESSP) is a program consisting of multiple space flight missions intended to address unique, specific, highly focused scientific issues and provide measurements required to support Earth science research. ESSP missions are principal investigator (PI) led, relatively low to moderate cost, small to medium sized missions capable of being built, tested and launched in short-time intervals. These missions support a variety of scientific objectives related to Earth science, including the atmosphere, oceans, land surface, polar ice regions and solid Earth. Investigations include development and operation of remote sensing instruments and research investigations using data from these instruments.

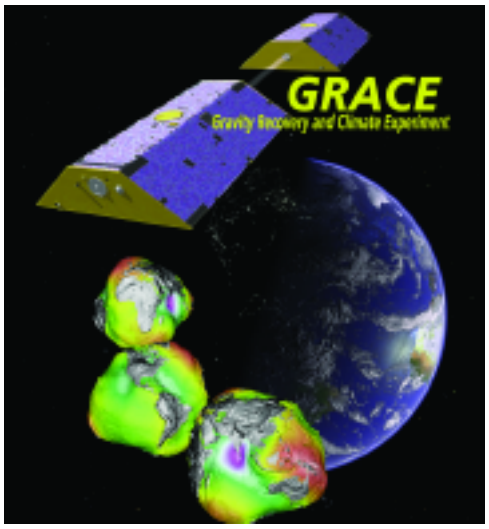
There have been three calls for ESSP Missions. Selected under ESSP-1&2, were the Gravity Recovery and Climate Experiment (GRACE) and CloudSat. The GRACE mission, a twin satellite configuration designed to more accurately map Earth's geoid, was launched on March 17, 2002. CloudSat, a 94 GHz radar designed to map the vertical structure of clouds, is scheduled for launch in 2004 along with CALIPSO, a three channel aerosol measuring lidar system. The ESSP-3 Announcement of Opportunity was released in December of 2000 and mission selection took place in FY03.

The role of the ESSP Project Scientist is to support the ESSP Program in all aspects regarding mission science. This includes the development of the ESSP Announcements of Opportunity, formulation of risk mitigation processes, and assisting in the review, evaluation, and selection of missions. It also includes supporting science outreach efforts for selected missions.

During this past year, the final risk mitigation reviews were held for ESSP-3 proposals and three missions were chosen to proceed to the instrument development phase; the Orbiting Carbon Observatory (OCO), Aquarius, and Hydros. OCO consists of three grating spectrometers (0.76 mm, 1.58 mm, 2.06 mm) designed to measure CO2 concentration in the atmosphere for the identification of terrestrial sources and sinks of carbon dioxide. Aquarius is a combined active and passive L-band microwave instrument designed to measure sea surface salinity. Hydros is also a combined active/passive L-band microwave instrument but is designed to measure soil moisture. Both Aquarius and Hydros support water cycle research. A special session announcing and describing the new ESSP missions was presented at the EOS Interdisciplinary Working Group Meetings.

This past year also saw the release of the first official data set from the GRACE mission upon the completion of its commissioning phase. GRACE consists of two identical satellites flying in the same orbit - one 220 km (137 miles) ahead of the other. As the pair circle the Earth, areas of slightly stronger gravity will affect the lead satellite first, pulling it away from the trailing satellite. The K-band ranging instrument is capable of measuring the distance between the satellites with a precision better than the width of a human hair. By monitoring this distance, GRACE detects fluctuations in the gravitational field and therefore differences in the mass beneath the satellites. Using GRACE data a new gravity model of the Earth was generated. This model shows a significant improvement over previous models exceeding by a factor of 10 to 50, the accuracy achieved using the gravity measurements collected over the previous 30 years.

The ESSP Project Scientist was responsible for developing outreach materials for the GRACE mission that included a brochure, a Fact Sheet, a Lithograph of GRACE data, and an article in the Earth Observer describing the potential for GRACE to measure continental water storage. Outreach materials for other ESSP missions were also developed. These include a Fact Sheet for the A-Train featuring ESSP missions and an outreach plan for CloudSat and CALIPSO.



Front cover of GRACE Brochure, NP-2002-2-427-GSFC.

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LBA-ECO Project Office Activities in 2003

The Large Scale Biosphere-Atmosphere Experiment in Amazonia is led by the Ministry of Science and Technology in Brazil, with international cooperation from NASA and the European Union. The LBA Project is composed of various independently funded components. NASA currently funds the LBA-ECO component, which is managed out of the LBA-ECO Project Office in the Laboratory for Terrestrial Physics. LBA-ECO activities have been continuing since a formal agreement was signed in 1998, and field infrastructure was put in place to start field activities in 1999.

With the completion of Phase I of LBA in 2002, the LBA-ECO Project Office began focusing its efforts on supporting the Phase II investigations which began in late 2002. These investigations continue some Phase I data collection and analysis activities, but also explore new lines of research that were developed from Phase I results. The nature and characteristics of wetland fluxes emerged as important research topics in Phase I. In cooperation with Brazilian partners, a tower was erected in a wetland at Bananal Island in the Tocantins State of Brazil. Instrumentation mounted on the tower has been collecting data continuously since October 2003. Project Office staff also successfully completed upgrades to a flux tower in Manaus to support expanded Phase II research activities in that region. A communications system was also installed in Juruena in the State of Mato Grosso. The Juruena site, along with the Santarem site developed during Phase I, provides complementary data on the effects of reduced impact logging in the Amazon region.

LBA-ECO results are being widely published in scientific journals. In 2003, an LBA special issue of Remote Sensing of Environment was published with 12 articles by LBA researchers from the U.S. and Brazil. One notable advance published in this issue was the use of an automated Monte Carlo unmixing technique on Landsat-7 imagery to detect logging gaps in the forest (Fig. 1). Research has shown that gaps are an important factor in the drying out of slash after logging, which increases fire susceptibility. IKONOS imagery was also used to examine small-scale heterogeneity around flux tower sites. These types of data products increase scientists' ability to simulate land use, fire impacts, and carbon exchange in the Amazon at various spatial and temporal scales.

Scientific results are also being presented at conferences and meetings, such as the November 2003 LBA-ECO Science Team Meeting in Fortaleza, Brazil attended by approximately 200 scientists. The Project Office enhanced the LBA-ECO web site and web-based tools to support and track conference registration, abstract submission, agenda scheduling, and venue information.

Maintaining the LBA Data and Information System (DIS) remains a major task of the LBA-ECO Project Office. As the Phase I activities have ended, the staff continue to assist researchers in registering their data and making their data available in accordance with NASA data policy. In addition, the staff of the LBA-DIS is educating Phase II scientists on the requirements by NASA and Brazil to register and submit data within one year of its collection. The registration and submission of these data are critical to any follow-on data analysis sponsored by NASA or Brazil.

Although the airborne science contribution of LBA-ECO, known as LBA-Air-ECO, was cancelled in 2003, the Project Office supported the reprogramming of aircraft activities in North America during the summer and early fall of 2003. The Project Office also coordinated the development of a science plan for these activities, arranged for aircraft and instrument scheduling, and created a web site to communicate data collection plans and the sharing of data.

In summary, LBA-ECO has matured to the point of having world-class field infrastructure, remote sensing and data resources, and scientific publications in various journals. Since the Amazon is such a logistically difficult region in which to do field research, the data and scientific results of LBA-ECO will undoubtedly be a significant contribution to the scientific community for years to come. More information about LBA can be found at www.lbaeco.org/lbaeco/.

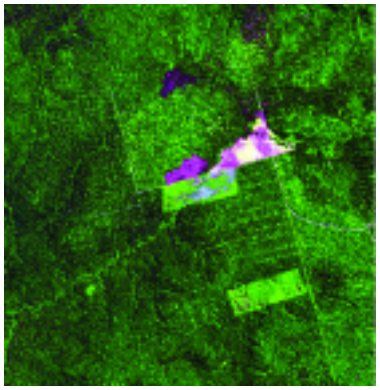

Figure. 1. 578 x 596 pixel Landsat-7 sub-image of the Cauaxi area, south of Belem (Path/Row 223/062, 08/03/01). This image shows a few different types of disturbance in the forest (e.g., clearcut, strip cut, selective logging, etc.).

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Northern Eurasia Earth Science Partnership Initiative (NEEPSI)

The Northern Eurasia Earth Science Partnership Initiative, or NEESPI is a currently active, and strategically evolving program of internationally-supported Earth systems science research, which has as its foci issues in Northern Eurasia that are currently relevant to regional and global scientific and decision-making communities (http://neespi.gsfc.nasa.gov). NASA developed a formal agreement with the Russian Academy of Sciences for collaboration in the NEESPI development.

By establishing a large-scale, multidisciplinary program of funded research, NEESPI is aimed at developing an enhanced understanding of the interactions between the ecosystem, atmosphere, and human dynamics in Northern Eurasia. Specifically, the NEESPI overarching science question is: "How do the land ecosystems and continental water dynamics in Northern Eurasia interact with and alter the climatic system, biosphere, atmosphere, and hydrosphere of the Earth?"

The Northern Eurasian region is important because it is the largest land mass in the extra tropics, the largest terrestrial reservoir of carbon in the biosphere, one of the regions with the largest climatic variations, and an area of active land use changes during the last century. Overlaid upon this are the dramatic political and social changes resulting from the breakup of the Soviet Union. Past observations and model projections of the future indicate that globally relevant changes in Northern Eurasia will be among the largest in the world. Northern Eurasia has a unique capacity to generate non-linear large-scale, sometimes abrupt, changes in regional carbon, surface energy and water balance. These changes may (and are likely to) feed back to the global climate, biosphere and society.

Figure 1. General Science Structure of the NEESPI

The NEESPI Science Plan underwent intensive development by the international scientific community during 2003, beginning with the Suzdal, Russia Workshop in April. A first draft of the Science Plan was then produced with contributions from more than 50 scientists. It was reviewed by a panel of experts drawn from academic, governmental, and non-governmental agencies at a workshop in the Crimea at Yalta (Ukraine) in September. The Committee, consisting of specialists in the disciplines of ecology, hydrology, biogeochemistry, land cover change, climate modeling, and remote sensing, characterized the NEEPSI Science Plan as a broad thematic study cast at the continental scale and encompassing a complex set of biogeophysical and anthropogenic processes, which together are likely to provide critical controls on the larger Earth system. It was recognized that the interplay between the natural and human-induced sources of disturbances in this region is an important new arena of research. The Committee's suggestions, including a greater integration across themes, increased specificity in the human interactions, and clearer development of short-term, realizable goals, are currently being applied to further development of the NEESPI Science Plan.

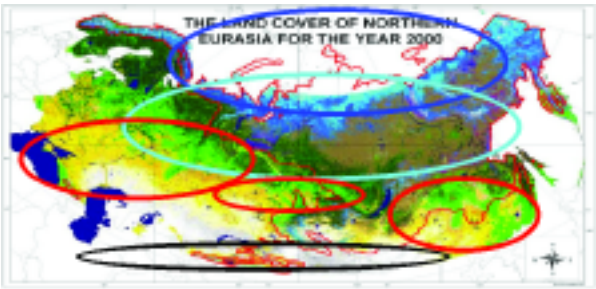

Figure 2. NEESPI research strategy: Understanding major controls that define relationships between major ecosystems and climatic variations with a focus on four transition zones (represented by the differently colored ovals).

With strong interest in the boreal ecosystems by the Russian partner in the NEESPI, key elements of the Science Plan focus on the taiga and tundra (peatlands) with its tremendous underground carbon pools under now thawing permafrost. Other key elements focus on terrestrial ecosystem dynamics, the biogeochemical cycle, energy and water cycles, land use change and interactions, as well as societal-ecosystem linkages. Cross-cutting themes for NEESPI include remote sensing, data technologies, modeling, and education.

NEESPI is intended to be a broad-based international program of supported research, and it is currently on a developmental path to realize this goal. However, bringing all potential stakeholders into the process requires time, and advocates to develop the strategy, inform the potential partners and follow through in organizing their involvement into the program. NEESPI additionally seeks to operate synergistically with a variety of national and international science programs – particularly those relevant to global change research. Ultimately, NEESPI-developed enhanced knowledge of this region will be able to be applied to specific concerns that face national and international decision-makers of the partnering institutions and countries.

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AERONET - A Decade of Observations and Analysis

AERONET is an internationally collaborative network of sun and sky scanning spectral radiometers designed to retrieve aerosol optical properties from direct sun and diffuse sky radiance measurements. The program developed in 1993 from a need to remove atmospheric effects in remotely sensed satellite imagery, but evolved for satellite validation of aerosol extinction (aerosol optical depth), and more recently developed into a globally distributed network for accurately characterizing basic properties of size (particle size distribution) and absorption (single scattering albedo), for naturally and anthropogenically occurring marine, urban, biomass burning and dust aerosols. Since the inception of the program the supported AERONET sites has grown from 3 to approximately 220 systems distributed on all continents (Fig. 1). A standard AERONET system is an eight channel filtered radiometer that is pointed under robot control at the sun and scans the sky nominally at 15 minute intervals in predefined protocols. Within hours of collection, the data are transmitted via geostationary satellites to receiving stations, FTP'd to the AERONET server, processed, analyzed, stored and posted to the AERONET website (http://aeronet.gsfc.nasa.gov) for use by the scientific community, policy makers, educators and the general public. The result is a systematically collected data set that allows analysis for short-term aerosol variations and long-term aerosol characterizations with an accuracy of 0.01 to 0.02 in optical depth and 0.03 in single scattering albedo.

AERONET activities in 2003 supported field campaigns, internal research, developed new products and enabled numerous research opportunities in addition to expanding the global distribution and fostering new research directions by synergism with related data sets. Certain regions of the world are lacking any characterization of aerosol properties, thus leaving a vacuum in our knowledge of their radiational effects on the region and health effects on mankind. In 2003 AERONET made significant gains establishing a network in Siberia that is subject to arctic haze and summer biomass burning. The southern hemisphere's small land mass area offers minor resistance to the marine aerosol generating winds of the roaring forties and fifties. By collaboration with the French Polar Institute, we established two unique sites in the southern Indian ocean at Crozet and Amsterdam Islands to compliment the tropical and northern hemisphere island observations (See Smirnov et al. 2003a and b). AERONET supports field campaigns for synergism with satellite observations. As such SE Asia from January through April is a significant source of biomass burning aerosols that interacts with the monsoon clouds to cause smaller cloud droplets that are less efficient for precipitation, potentially affecting the hydrological cycle. To document the aerosol component of this process, AERONET established a network of 6 sites in Thailand and Vietnam and has cultivated a collaborative network in China that will develop in 2004. A previous field campaign in southern Africa, SAFARI2000, yielded the most comprehensive biomass burning aerosol characterization during a massive fire year over the region (see Eck et al., 2003). Finally the AERONET research team (see O'Neill et al., 2003) developed a technique to assess fine mode aerosols that are typically associated with human activity and coarse mode aerosol particles that generally are caused by natural phenomenon such as dust storms, using the ubiquitous aerosol optical depth parameter. This is a significant step forward as it is based on a single instantaneous measurement as opposed to the particle size distribution that is an ensemble of observations made over several minutes.

Plans for AERONET in 2004 and beyond call for continued expansion of the network into Africa, Asia and the high latitudes. A new initiative called BAMGOMAS will bring ancillary data sets together making AERONET sites mini-observatories for surface characteristics as well as aerosol properties. Plans for synergism with chemical transport models and satellite imagery to understand radiative forcings due to aerosols will further enhance the value of AERONET to global climate change investigators. We will support a new field campaign in the United Arab Emerates to begin characterizing mixed aerosols (dust and industrial) and a multi-year campaign in east China. We expect to begin supporting two new instruments that measure surface-leaving radiances in addition to atmospheric properties, SeaPRISM for ocean-leaving radiances and BRDF instruments for developing terrestrial cover-type models. Finally, because of the international growth of the network we plan to hold an international workshop in Spain dedicated to data analysis and operational coordination of the project with the more than 75 international collaborators and AERONET PI's.

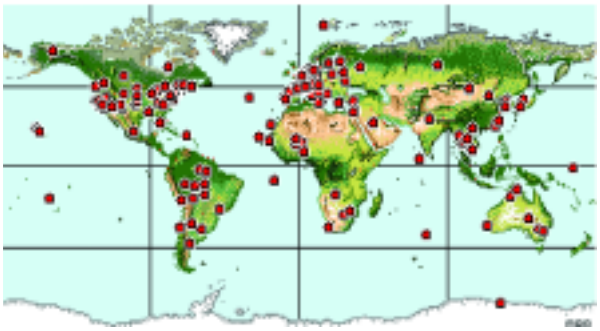

Figure 1. The global distribution of AERONET sites in 2003.

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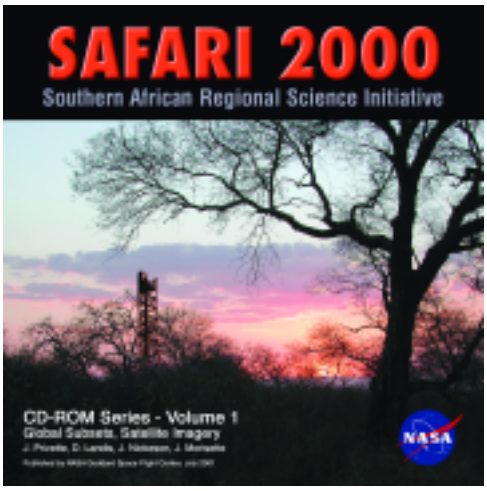
SAFARI 2000 CDROMs Deliver African Environmental Data

SAFARI 2000 was an international coordinating umbrella designed to increase synergism, efficiencies and economies of scale among scientific studies of the southern Africa land-atmosphere-human system. The data compilation, distribution and archive system for SAFARI was leveraged on existing facilities as much as possible, including those of NASA's EOS and international partners. However, the use and adaptation of these facilities for SAFARI required significant coordination and development. Further, the relatively low-speed Internet access to U.S. facilities by African SAFARI participants underscored the need for widely readable, durable media alternatives. Data CDROMs met the criteria.



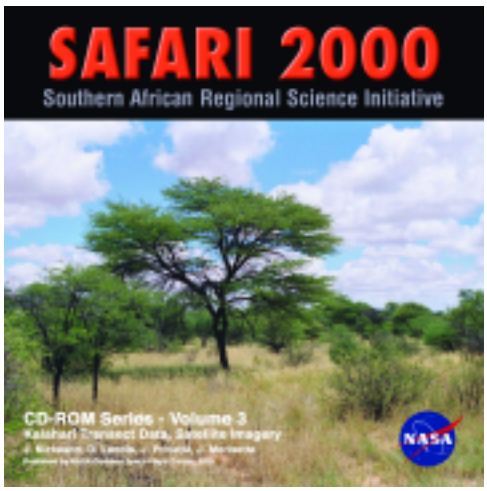
The Laboratory for Terrestrial Physics' 3-person SAFARI Data Team initiated these activities in early 2000. In addition to organizing the data policy, metadata registration and data distribution protocols among researchers and data facilities, the Team compiled and distributed three multidisk CDROM volumes, including:

- Volume I (2001): a 2-disk compilation of AVHRR, SeaWiFS and subsets of global data,

- Volume II (2002): a 5-disk compilation of in-situ and aircraft remote sensing data from the SAFARI Dry Season Campaign of August 2000 and a unique set of MODLAND, Landsat 7 and DAO products, and

- Volume III (2003): a 5-disk compilation primarily containing data from the SAFARI Wet Season Campaign (March 2000), including in situ data from the Kalahari Transect, and Dry Season aircraft data.

In sum, more than 100 different data sets were published in these volumes. Extensive reference material, data documentation, tutorials, software tools, and WWW data link lists are provided on each. The CDROMs were written with an HTMLL interface and work with any web browser. The three volumes interact seamlessly with each other, such that scientists can peruse the contents of all 12 disks upon mounting one disk on their computers. Five hundred copies of each volume were produced. Each is available through the Oak Ridge National Laboratories (ORNL) Distributed Active Archive Center (DAAC).



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Carbon Cycle Theme Group

In 2000, NASA Headquarters requested Goddard to formulate a 10-year NASA Carbon Cycle research plan. A series of workshops involving NASA centers, Code Y program managers, and federal agency and science community representatives was organized by the Goddard study team who delivered a plan to Code Y in June 2001. The carbon cycle science study identified the major issues that must be addressed, as well as the analysis framework that should be followed, to fully understand the role of the carbon cycle in climate change. The study examined NASA's and other agencies' existing capabilities required to implement this framework, and developed recommendations where additional capabilities were needed. The primary technologies identified were hyperspectral passive radiometry (low density biomass), lidar and/or synthetic aperture radar (high density biomass), high spectral resolution passive radiometry (column CO_2), lidar (CO_2 profiles), and advanced ocean color radiometry (in the ultraviolet). Lidar and hyperspectral satellites augmenting existing capabilities would fill the observational gaps identified by the carbon cycle study. The Carbon Cycle Theme group continues to work to assist Goddard scientists and engineers in anticipating, preparing for and responding to announcements of opportunity within NASA's Carbon Cycle research program, including mission formulation, technology development, and science.

Current GSFC Land Carbon Research and Technology Development Activities

Instruments and Sensors: NASA provides a number of mechanisms for addressing technology development needs, including the Instrument Incubator Program (IIP), the New Millennium Program, the laser risk reduction program, the GSFC Director's Discretionary Fund (DDF), and the GSFC Internal Research and Development (IRAD) program. GSFC scientists and engineers have a number of instrument and sensor development studies supported by these programs. Specific developments include the recent selection of an IIP proposal for the design of a hyperspectral radiometer for low density biomass ocean and atmospheric measurements at geostationary (GEO) altitudes. Building on the airborne lidar systems developed at GSFC (e.g., LVIS), advanced lidar concepts such as dual frequency and imaging lidars are being designed under DDF and other support for application in high density biomass environments.

Missions and Projects: At this time, the GSFC land missions most relevant to the carbon cycle are a biomass lidar mission, Landsat, future hyperspectral low earth orbiting (LEO) and GEO missions, MODIS, ICESat, and NPP. Hyperspectral is central to low-density biomass estimation and potentially to monitoring land-atmosphere carbon and water exchange. ICESat is of interest because, in low relief forested landscapes, waveform returns can provide information on biomass. While NPP is not scheduled for launch until late 2006, GSFC is managing the project and much effort is going into the evaluations of the VIIRS sensor design, the data processing algorithms, and the data system.

Data Sets: Key to achieving the Carbon Cycle goals and those defined in the NASA Carbon Cycle roadmap are long-term high-quality data records free of instrument artifacts. GSFC is working closely with NASA HQ in formulating a strategy for generating long-term multi-sensor climate data records (LTDRs). Recently, three GSFC proposals relevant to the carbon cycle were selected to process and maintain multi-sensor data records (one ocean biogeochemistry and two terrestrial). One of those funded is to process the 30-year Landsat record to surface reflectance and produce disturbance maps for North America. A continuation of the ISLSCP data synthesis activity has also been approved.

Future Directions and Strategy

The Carbon Cycle Theme group's focus is on positioning GSFC to compete successfully in the areas of technology development, discipline data systems and LTDR production, calibration and validation, missions, and earth system research including field programs like the North American Carbon Program (NACP). The theme group assists HQ by providing technical and scientific information for NASA roadmaps, formulation of NASA's role in the NACP, and the Ocean Carbon Plan. A major role of the team is to develop and anticipate new funding opportunities, both within Goddard and from NASA HQ, to help GSFC staff prepare for these solicitations, and coordinate their responses.

One of the strengths of the Carbon Cycle Theme group is its interdisciplinary nature and the cross-discipline interaction that it fosters. Discipline groups (land, ocean, atmosphere) often deal with the same issues and technical problems, and the sharing of information across these boundaries has resulted in a number of tangible benefits. This interaction is also being actively fostered across GSFC organizations, particularly with Codes 400 (project formulation and management) and 500 (engineering).

In summary, the Carbon Cycle Theme Group seeks to assist GSFC staff and organizations respond to the new science goals of NASA Code Y, a more competitive NASA environment, and a more performance metrics-oriented approach to agency deliverables by fostering a long-term vision for Goddard's role and increased cooperation among the science and engineering disciplines.

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A Landsat-based Record of North American Disturbance

Quantifying the rate and geography of forest disturbance is a key element for understanding the continental carbon cycle. Forest fires, insect defoliation, harvest, and other disturbance processes emit carbon to the atmosphere as biomass is burned or decomposes. Recovery changes forest age structure, which has a strong influence on net ecosystem production. In order to account for these carbon sources and sinks within carbon models, a record of recent disturbance events must be assembled for continental regions.

Moderate resolution remote sensing is well suited to detect recent disturbances and forest-cover change at fine scales. Although we now have a 30+ year record of Landsat observations, to date there has been no comprehensive attempt to "mine" this archive for forest change information across North America. A new project, the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS), is attempting to fill this gap. LEDAPS will produce surface reflectance and forest disturbance products for all of North America in support of the upcoming North American Carbon Program. LEDAPS is a collaborative venture between scientists within the Laboratory for Terrestrial Physics (Code 923 and 922), Oregon State University, University of Maryland, the US Forest Service, USDA, the Canadian Forest Service, and the Canadian Center for Remote Sensing.

LEDAPS makes use of the Landsat GeoCover product suite developed by Earth Satellite Corporation. This dataset consists of orthorectified Landsat scenes centered on 1975, 1990, and 2000 epochs. As such, it is ideal for decadal analyses of land-cover change. To create surface reflectance maps, LEDAPS atmospherically corrects Landsat TM/ETM+ imagery. Aerosol thickness is derived from dark, vegetated target radiances within each image. Water vapor and ozone are extracted from NCEP reanalysis grids. Given these atmospheric parameters, LEDAPS uses the 6S radiative transfer code to retrieve surface reflectance (SR). Conversion of older (MSS) imagery to surface reflectance relies on image rectification to later, overlying SR products. The approach relies on selecting bright and dark targets in Kauth-Thomas space, and using these as "invariant targets" for linear regression against SR data. Validation of SR products relies on comparison with simultaneous MODIS reflectance products, as well as comparison with airborne radiometer data from past research campaigns.

The decadal surface reflectance imagery will then be used to map forest disturbance, recovery, and permanent conversion. Initial concepts for mapping disturbance / forest-cover change revolve around (i) spectral decomposition of SR values into "physically based" components (e.g. canopy, background, shadow) for each mapping epoch (1975, 1990, 2000); and (ii) relating changes in these components to stand-clearing disturbance (biomass loss) or regeneration (biomass gain) within particular ecoregions.

Future work will concentrate on using canopy reflectance models to directly relate changes in end-member components to quantitative changes in biomass and/or fractional cover. In this way, subtle changes in biomass (e.g. non-stand clearing disturbance, gradations of regrowth) can be mapped. It is also expected that these concepts will be refined (or changed) in collaboration with the land science community. Validation will rely on comparison with high-resolution imagery (e.g. IKONOS), existing disturbance maps (e.g. Canadian fires database), and county-level forest inventory data, which record disturbance and stand-age parameters.

In addition to providing disturbance maps to the carbon modeling community, it is anticipated that both the reflectance and disturbance products will have considerable value for the remote sensing applications community. To explore these opportunities, we are working with the USDA to improve crop mapping practices and with the US Forest Service to improve stratification of forest inventory plots and biomass assessments.

Initial surface reflectance products will be made available on a regional basis by April, 2004, and across North America a year later. Forest disturbance maps will be available regionally in late 2004, and across North America in late 2005. Additional validation and reprocessing is slated for 2005-2007.

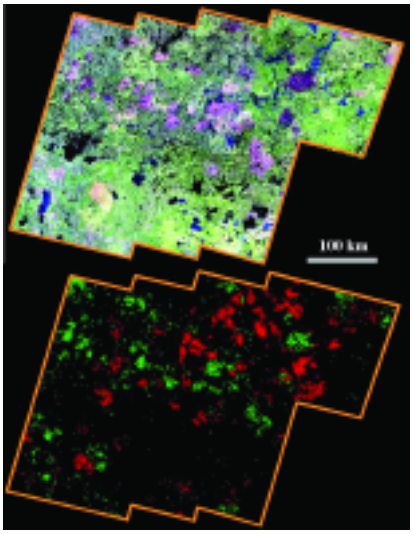

Figure 1. Example of seven-scene 1990's TM surface reflectance mosaic from Canada (top) and disturbance map(change from 1990 to 2000, bottom) showing areas of forest loss through fire (red) and forest recovery (green)

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Committee for Earth Observing Satellites: Working group for Calibration and Validation

The Committee on Earth Observation Satellites (CEOS) is an international organization charged with coordinating international civil spaceborne missions designed to observe and study planet Earth. Comprising 41 space agencies and other national and international organizations, CEOS is recognized as the major international forum for the coordination of Earth observation satellite programs and for interaction of these programs with users of satellite data worldwide. In 2003, Dr. Stephen Ungar was selected to chair the Working Group for Calibration and Validation.

Individual participating agencies implement CEOS recommendations. The main goal of CEOS is to ensure that critical scientific questions relating to Earth observation and global change are covered and that satellite missions do not unnecessarily overlap each other. The three primary objectives of CEOS are to optimize benefits of spaceborne Earth observations through co-operation of its participants in mission planning and in development of compatible data products, formats, services, applications, and policies; to serve as a focal point for international coordination of space-related Earth observation activities; and to exchange policy and technical information to encourage complementarily and compatibility of observation and data exchange systems.

The COES has two standing working groups - the Working Group on Information Systems and Services (WGISS) and the Working Group on Calibration and Validation (WGCV). The objectives of the WGCVare to enhance coordination and complementarity, to promote international cooperation, and to focus activities in the calibration and validation of Earth observations for the benefit of the CEOS members and the international user community. Meeting these objectives requires exchange of technical information and documentation; investigation of possibilities for technical coordination and cooperation for space and ground segments; and coordination of calibration and validation campaigns and programs optimizing and sharing of available facilities, expertise, and resources as appropriate.

The WGCV coordinates its work with other international groups involved in related activities. Subgroups may be established to perform detailed technical work in specific areas. Subgroups are established by the consensus of the WGCV.

The term of office of Chair of the WGCV runs for three years. With the impending expiration of the term of the then current Chair, Yves-Louis Desnos in November of 2003, nominations for the WGCV Chair were solicited from member agencies in the summer of 2003. NASA selected Dr. Stephen Ungar, (Code 923) as its nominee for Chair-elect to the WGCV. Dr. Ungar was subsequently selected as Chair-elect candidate of the WGCV, by unanimous vote, at the WGCV Plenary meeting in Beijing, China during October of 2003. Dr. Ungar was officially named Chair, by acclamation, at the CEOS Plenary meeting in Colorado Springs, USA during November of 2003.

For more information, see: http://www.ceos.org/

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Variability of Biomass Burning Aerosol Optical Characteristics

A regional network of several Aerosol Robotic Network (AERONET) sun-sky radiometers was established in southern Africa for the SAFARI 2000 dry season campaign in August-September 2000, to augment the AERONET long-term monitoring sites in the region. Data from 10 primary sites in this network were utilized to investigate the spatial, temporal, and spectral variance of the total column-integrated radiatively effective aerosol optical properties in the region. The aerosol at many of these sites is dominated by biomass burning aerosols (smoke) in this period. However airborne soil dust, fossil fuel combustion aerosols, and maritime aerosols also contribute to the mixture at some sites, especially in the south (South Africa and Mozambique). The principal findings of our study are summarized as follows:

1. Long-term monitoring (7 years) in Mongu, Zambia of biomass burning aerosols shows that the August 2000 monthly mean aerosol optical depth (τ_a) was lower than normal (τ_{a500}=0.31 versus 0.39 for the multi-year mean), while the September 2000 aerosol optical depth was much higher than the mean September value (τ_{a500}=0.86 versus a mean of 0.65). This very large increase of aerosol optical depth between these two months in 2000 resulted largely from significant shifts in regional circulation.

2. Within Zambia, a clear North-South gradient in τ_a was observed in August, while in September there is a lack of such a gradient, as episodes of large scale transport of air with high smoke concentrations dominate. However, over the larger regional scale throughout southern Africa (sites in Zambia (ZAM), Namibia (NAM), South Africa (RSA), and Mozambique (MOZ)) in September, there was a large north-south gradient due to the location of major biomass burning regions in the north and the dispersion and deposition of smoke as it was advected southward. The size distribution retrievals at both Skukuza, RSA and Inhaca Island, MOZ showed significantly greater coarse mode (> 1 micron radius) contributions than the biomass burning dominated size distributions in Mongu, ZAM and Etosha Pan, NAM.

3. Significant average diurnal trends of τ_a were observed for all six sites in Zambia, with a typical minimum to maximum range of ~25% (August-September average), with the minimum occurring one hour before local noon and a maximum at sunset. This is related to the diurnal trends in fire count number which peak at ~3 hours after noon in this active burning region. In contrast, there was little or no significant average diurnal τ_a trend observed for sites located to the south of Zambia, since aerosol advection by winds is dominant at these sites, and this has more random temporal variation.

4. The single scattering albedo, ω_o (a measure of the fraction of light extinction from scattering rather than absorption) inferred from AERONET retrievals at all of the Zambian sites showed no significant trend as a function of τ_a for the wide range of τ_{a440} from 0.4 to 2.5. The wavelength dependence of ω_o was very similar for all the sites in Zambia, however ω_o spectral variability was much greater on the regional scale throughout southern Africa. Although the $\omega_o$at visible wavelengths of 440 and 675 nm for Skukuza, RSA and Inhaca, MOZ were very similar to values in Zambia, the ω_o at near-infrared wavelengths of 870 and 1020 nm were significantly higher than in Zambia (~0.06 higher at 1020 nm). These differences are partly the result of greater coarse mode aerosol contributions at Skukuza and Inhaca (possibly from airborne soil dust), which results in relatively greater scattering optical depths in the longer near-infrared wavelengths. Other factors are the differences in aerosol types, with fossil fuel combustion and industrial emissions affecting the South African and Mozambique sites in addition to the biomass burning aerosols.

5. Single scattering albedo retrieved from another technique, the fitting of Photosynthetically Active Radiation (PAR) flux measurements to modeled fluxes, yielded a September-August, 2000 average mid-visible ω_o in Mongu, Zambia of 0.84. This is similar to the average mid-visible estimates from the 440 and 675 nm AERONET retrievals of ~0.85, well within the uncertainties of the retrievals for both methods.

6. Spectral ω_o was also independently retrieved from spectral radiative diffuse flux fraction measurements at Mongu. The slope of the spectral dependence of ω_o (415 – 870 nm) from these retrievals is similar to those from the AERONET retrievals, with ω_o from diffuse fraction retrievals being ~0.02-0.04 lower (greater differences at longer wavelengths, possibly due to combined measurement error and model assumptions). Retrievals of the imaginary part of the refractive index (an index of absorption) show relatively constant values as a function of wavelength for both AERONET and diffuse fraction techniques. This is consistent with the flat spectral absorption of black carbon or soot, which is the main absorbing species in smoke.

Therefore although the biomass burning aerosol optical properties measured at several sites in Zambia during August-September 2000 were relatively uniform, over the broader region the observations suggest significant aerosol variability. The observed regional differences in aerosol single scattering albedo and size distributions, due to aerosol aging during transport and from contributions by other aerosol sources (i.e. airborne soil dust, fossil fuel combustion aerosols, etc.), need to be considered when assessing regional aerosol radiative forcings for climate studies and in the retrieval of aerosol properties from satellites.

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Maritime Component in Aerosol Optical Models Derived from AERONET

The quality of bio-optical products of satellite ocean color sensors is strongly dependent on the accuracy of atmospheric correction algorithms. Aerosol optical properties over the oceans vary considerably, depending on contributions of major aerosol components, i.e. urban/industrial pollution, desert dust, biomass burning and maritime. The optical characterization of these aerosols is fundamental to the parameterization of radiative forcing models as well as to the atmospheric correction of ocean color imagery. In the last decade significant experimental data was collected over the oceans by AERONET (Aerosol Robotic Network) radiometers at operational sites in the Pacific (Lanai, Hawaii), in the Atlantic (Bermuda) and in the Indian Ocean (Kaashidhoo, Maldives). This database allows the estimation of a number of candidate aerosol models and, perhaps, better aerosol modeling in the atmospheric correction of ocean color imagery.

In the current study we consider primarily pure oceanic air. In order to retrieve a "pure maritime" component we limited our analysis to aerosol optical depths (τ_a) at 500 nm smaller than 0.15 and Angstrom parameters (α) less than 1. This choice is based on the following considerations. Summary of aerosol optical depth measurements in maritime and coastal areas indicate a more transparent atmosphere (small aerosol concentrations) over the Pacific Ocean as compared to the Atlantic and Indian Ocean. The spectral dependence of aerosol optical depth above the Pacific Ocean is more neutral than in the regions affected by continental sources, owing to a large fraction of coarse-mode aerosol of sea origin (sea-salt) in the size distribution. Available statistics for the Pacific sites (Midway, Lanai, Nauru and Tahiti) demonstrate that the majority of τ_a(500 nm) and α values (85%-99% and 75-97% correspondingly) are smaller than 0.15 and less than 1.0 respectively. Among several island sites in the Pacific we have chosen only Lanai for our consideration simply because it has a reliable long-term record.

Aerosol volume size distributions in the total column were retrieved from sun and sky radiance measurements. They reveal similarity among "maritime" averaged columnar volume size distributions for Bermuda, Lanai and Kaashidhoo. The inferred maritime component in the columnar size distribution which was found to be very similar for the three study sites, is bimodal with a fine mode at an effective radius (r_{eff}) ~0.11-0.14 mm and a coarse mode r_{eff} of ~1.8-2.1 μm. The results are comparable with size distributions reported in the literature. The refractive index is spectrally independent and estimated to be 1.37-0.001i (single scattering albedo is about 0.98), based on the single component homogenous particle composition assumption. Fractional contributions of the fine and coarse modes to the computed τ_a(500 nm) are within the range of τ_{fine} ~0.03-0.05 and τ_{coarse} ~0.05-0.06 correspondingly. Angstrom parameters vary from ~0.8 to 1.0 computed in the UV-visible (340-670 nm) and from 0.4 to 0.5 estimated in the near IR (870-2130 nm) spectral ranges. Aerosol phase functions are very similar for all 3 sites considered.

Several comparisons on the simultaneous in-situ aerosol size distribution measurements (surface or aircraft) and columnar retrievals from AERONET radiometric measurements showed close similarities for the fine mode during the SAFARI 2000 campaign, INDOEX, EOPACE 1999 and PRIDE experiment. Coarse mode inversions from AERONET sun/sky data, however, were not always consistent with the columnar integrated size distributions.

Generally speaking, we may or may not find agreement between columnar retrievals and in-situ measurements. There are a variety of reasons for this, starting with the fact that measurements in the total column are quite different from the measurements in the local volume. AERONET measures the aerosol scattering and absorption in its ambient state at the ambient relative humidity. It is not possible to make any humidity related adjustments, simply because the aerosol concentration profile and relative humidity profile are not known. The aerosol vertical profile is usually not known (except in the case of lidar or multi-altitude flights) and aerosol layers with different aerosol composition and species may exist. On the other hand methodological and instrumental biases of the in-situ measurement technique inhibit direct comparisons of size distributions. The AERONET columnar retrievals that match sun and sky radiances are best considered as "optically equivalent" volume size distributions.

We present a model of the maritime aerosol component derived using AERONET data from three island locations: Bermuda (Atlantic Ocean), Lanai, Hawaii (Pacific Ocean), and Kaashidhoo, Maldives (Indian Ocean). The aerosol optical model includes information about optical parameters (aerosol optical depth and its spectral dependence, phase function and single scattering albedo) and microphysical characteristics (size distribution and its parameters, refractive index). The aerosol model can be employed as a maritime look up table (LUT) kernel in coupled atmospheric retrieval and correction algorithms. It can also be advantageously employed as a LUT inversion kernel in pure aerosol retrieval schemes or in algorithms for the classification of aerosol mixtures. The maritime aerosol model can be used as the defining single component of pure maritime air masses or in combination with various aerosol types (dust, biomass burning etc.). Finally, the model can serve as a source of input to aerosol transport models and radiative forcing simulations. The model encompasses a variety of maritime conditions in the simplest manner possible. It requires further validation based on the accumulated evidence of microphysical and optical measurements tied to radiative transfer closure experiments.

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Effect of Wind Speed on Columnar Aerosol Optical Properties

The world ocean covers approximately 70% of Earth's surface and is one of the major sources of natural aerosols. The effect of wind speed on the concentration and size distribution of aerosols over the oceans was comprehensively studied during the last several decades. Definite correlation was found between surface wind speed and sea-salt aerosol concentration (for various size ranges and for total). However, only part of the variance could be explained by the current wind speed. Considerable scatter remains because of a few days residence time of aerosols and other factors such as advection and vertical mixing.

The influence of wind speed on aerosol optical depth in the whole atmospheric column is a much more difficult problem. A link between optical turbidity and particle generation by wind is not easy to detect, since it can be masked by the background aerosol (of continental origin in coastal areas, for example). Accordingly surface generation effects can be clearly noticed only when measurements are taken in a reasonably transparent atmosphere.

In the current paper we analyze aerosol optical properties over Midway Island in the subtropical Pacific Ocean in conjunction with information on surface wind speed. More than one year of data is considered. Because of the unique location of Midway (very far from continental landmasses and almost in the middle of the Northern Pacific Ocean) air that reaches it spends enough time over the ocean to be dominated by oceanic sources, at least in the vast majority of cases.

Aerosol optical properties were derived from direct sun and sky radiation measurements performed at the operational AERONET site on Midway Island. Midway Island is situated in the Northwestern Pacific Ocean at 28º12´ N and 177º22´ W almost equidistant from the United States and Japan (~4,500 km from San Francisco and 3,500 km from Japan). Midway actually consists of two islands, the larger one (Sand Island) has a total land area of ~6 km^2 and we will refer to it as "Midway Island". Because of its small area and flat surface (elevation ~ 4 m) Midway is an ideal site for investigating aerosol optical properties over the oceans. If using a ship is the correct way of studying aerosols over the oceans, then Midway can be considered a stationary platform, which in a sense looks like a large ship deck.

Wind speed determines sea-state (wave height, whitecaps etc.) and various formulations for the sea-salt aerosol generation functions use current wind speed or average wind speed over a previous time period. Correlation coefficients at Midway between various instantaneous measured aerosol optical parameters and current or averaged wind speeds showed that correlation coefficients have maximum close to 24 hours. In the further analysis we will consider surface wind speed averaged within 24 hours prior to the instantaneous optical measurement.

In general, optical conditions over Midway resemble aerosol found over other maritime locations in the Pacific Ocean (Lanai, Tahiti, Nauru). The most frequently occurring value of aerosol optical depth at 500-nm wavelength and Angstrom parameter are 0.06 and ~0.40 respectively. A link was established between directly measured aerosol optical parameters and 24 hour averaged surface wind speed. Increased wind speed emission of sea-salt aerosols most strongly influenced the aerosol optical depth at infrared wavelengths. Aerosol optical depth at the 1020-nm wavelength has a significant dependence on wind speed (correlation coefficient of 0.52 is statistically significant at a 99% confidence level). The influx of the large particles causes the Angstrom parameter to anti-correlate with the wind speed (correlation coefficient of -0.58 is statistically significant at a 99% confidence level).

Columnar aerosol volume concentration (retrieved from the direct sun and diffuse sky radiances) of the coarse mode is found to be very well correlated with 24 hour averaged wind speed (r=0.56). Within the wind speed range considered, the effective radii of the fine and coarse fractions of the retrieved columnar size distributions are independent of wind speed.

Averaged within various wind speed ranges the aerosol size distributions over Midway can be reasonably well predicted with a maritime aerosol component model that combines elements of both remotely sensed and in-situ relationships of oceanic aerosols.

We note that in considering some other island sites of the AERONET network (Lanai, Nauru, Tahiti, Ascension Island) we did not find any significant correlation between optical parameters and wind speed. Correlation coefficients between optical depth at a 1020-nm wavelength and wind speed are ~ 0.10-0.20, being slightly lower for the 500-nm channel. The Angstrom parameter at all of those sites showed to some extent the same trend as over Midway with the correlation coefficients a little over 0.20. A variety of factors can mask the correlation, for example, narrow range of wind speeds, mountainous terrain, non-uniform meteorological conditions, island aerosol influence, etc. Even attempts at elimination of possible volcanic, dust and biomass burning residual aerosol contamination did not make the correlations any stronger at those sites.

Recently, a new and potentially very promising AERONET site has been established near the "roaring forties" of the Southern hemisphere (Amsterdam Island). After a number of years of data collection it will perhaps offer a more comprehensive data set to consider, especially for the conditions of very high wind speeds (over 10 m/s).

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Spectral Discrimination of Coarse and Fine Mode Optical Properties

The CIMEL sunphotometer / sky radiometer instruments of the AERONET network provide operational multi-wavelength measurements of aerosol optical depth (τ_a) on a world wide basis. The τ_a spectrum is related to the aerosol concentration and particle size distribution (PSD) in the overhead vertical column. Formal inversions for the PSD are performed on combined τ_a and sky brightness measurements. The fact that these inversions are applied to only a relatively small fraction of the τ_a database means there is an underexploitation of available PSD-related information. In particular the spectral information embodied in τ_a can be employed to yield simple and robust optical depth indicators of the fine and coarse mode contributions to the PSD.

The recognition that the aerosol PSD from about 0.05 to 15 mm is effectively bimodal permits the extraction of the fine and coarse mode optical depths (τ_f and τ_c) from the spectral shape of the total aerosol optical depth ($\tau_a = \tau_f + \tau_c$). This purely optical technique avoids intermediate computations of the PSD and yields a direct optical output that is commensurate in complexity with the spectral information content of τ_a. The separation into τ_f and τ_c (typically at a reference wavelength of 500 nm) is a robust process and yields aerosol optical statistics which are more intrinsic than those obtained from a generic analysis of τ_a.

Partial validation was provided by (1) demonstrating the physical coherence of the simple model employed, (2) demonstrating that τ_c variation is coherent with photographic evidence of thin cloud events and that τ_f variation is coherent with photographic evidence of clear sky and haze events, and (3) showing that the retrieved values of tτ_f and τ_c are well correlated relative to formal inversions of combined τ_a and sky brightness data. Our τ_a inversion technique permitted a closer scrutiny of a standard (temporally based) cloud-screening algorithm. Perturbations of monthly or longer-term statistics associated with passive or active shortcomings of operational cloud screening were inferred to be small to moderate over a sampling of cases. Diurnal illustrations were given where it was clear that such shortcomings can have a significant impact on the interpretation of specific events; (1) commission errors in τ_f due to the exclusion of excessively high-frequency fine mode events and (2) omission errors in τ_c due to the inclusion of insufficiently high-frequency thin homogeneous cloud events.

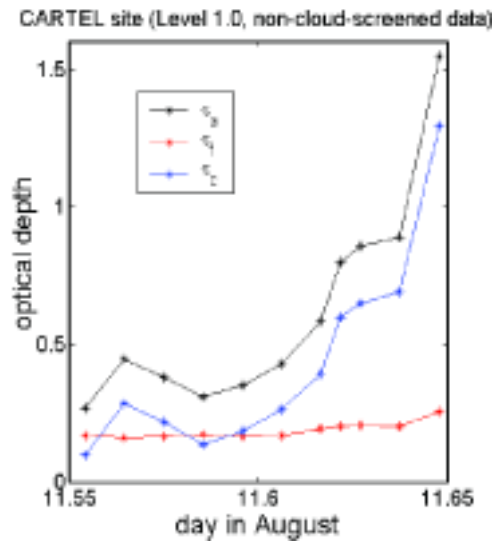

Figure 1 .Variation of derived aerosol optical depth components (at 500 nm wavelength) in the presence of thin cloud (coarse mode) event.

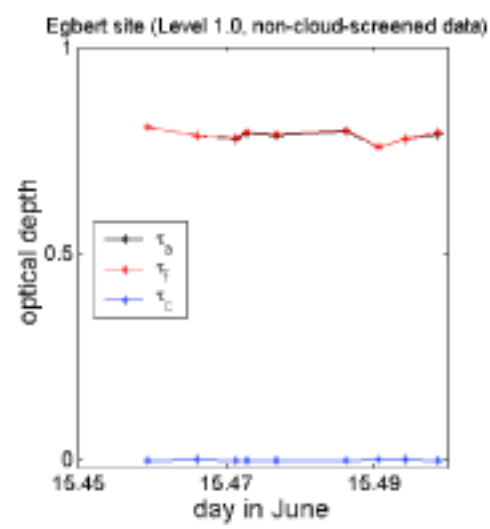

Figure 2. Variation of derived (500 nm) aerosol optical components during a pollution (fine mode) event.

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Impacts of Global Fire Emissions on Atmospheric Composition

Atmospheric CO_2 is increasing at a rate of about 0.5% per year (~3.5 x 10^{15} gC/yr) and is currently 30% higher than in preindustrial times as a result of fossil fuel burning and land use. However, on average only about half of human derived emissions remain in the atmosphere and year to year variations in atmospheric CO_2 growth rate range from nearly 100% of the CO_2 emitted by human activities to nearly 0%. The mechanisms responsible for these responses are poorly understood. The important scientific and societal issues are: (I) where is the missing carbon going, (ii) why does the sink vary so much from year to year, and (iii) what are future atmospheric CO_2 concentration going to be?

A team of scientists from the Laboratory for Terrestrial Physics, University of California Irvine, Duke University and the University of Maryland have uncovered some of the mystery surrounding the processes responsible for the year to year variations in important greenhouse gases. Armed with satellite observations of the Earth's land surfaces, models of the cycling and movement of carbon on land and in the atmosphere, and measurements of atmospheric composition, we have shown that a large part of the interannual variability in atmosphericCO$_2$ and CH_4 results from the response of global fires to climate cycles such as El Ninos.

Initially we focused on the El Nino/La Nino period from 1997 through 2001 because this period includes one of the strongest El Ninos of the century. During this period the CO_2 concentrations in the atmosphere increased faster than any time since atmospheric measurements began 50 years ago. It is also a period when better satellite measurements of fires became available.

Our approach can be summarized in six steps.

1) Measurements of fire events referred to as "hot spots" were obtained from satellite instruments (the Visible and Infrared Scanner and the Along Track Scanning Radiometer) providing information as to where and when fires occurred. More recently (since 2000) Earth observations by the MOderate resolution Imaging Spectrometer (MODIS) instrument have allowed mapping of burned scars which we do for specific sites to calibrate our hot spot observations to burned areas.

2) With climate information and estimates of vegetation extent (also from satellite measurements) we modeled the global distribution of fuel loads and fuel combustibility.

3) Using model derived emissions of carbon from fires, of combustibility and of proportions of various trace gases emitted by fires we estimated the monthly amount of CO_2, CH_4 and CO emitted from each 1°x1° grid cell of the global land surface for the period 1997-2001 (forward model).

4) The modeled CO emissions were fed to an atmospheric transport model to predict the atmospheric distribution of CO.

5) Since year to year variability in atmospheric CO is most likely caused by fires we used atmospheric observations of CO distributions and back calculated (inverted) for the timing and distribution of sources of CO (inverse model).

6) We compared our inverse and forward model predictions of CO distribution and then multiplied the forward model CO_2 and CH_4 emissions by the inverse to forward model ratio of CO emissions.

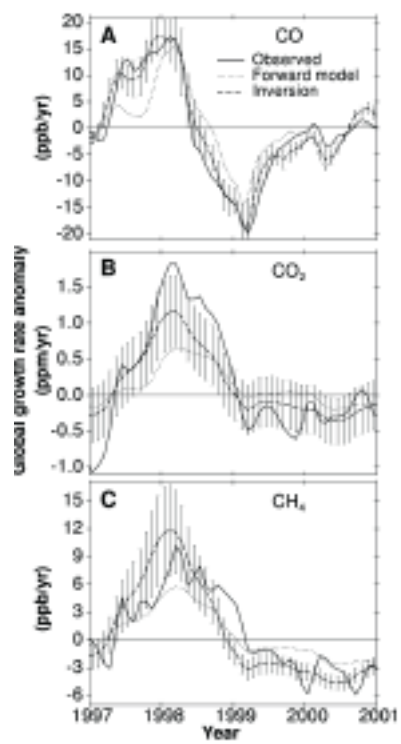

Figure 1. This figure shows that by accounting for the variability in CO caused by fire we can explain ~2/3 of the variability in CO_2 and all of it in CH_4. Previous explanations put forward for variability in CO_2 and CH_4 involved physiological processes (photosynthesis/respiration in the case of CO_2 and wetland emissions in the case of CH_4). These results show that fire plays a major role in the atmospheric composition of important greenhouse gases (van der Werf et al, 2003).

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Land Use and Local Climate: A Case Study near Santa Cruz, Bolivia

The Tierras Bajas regions of eastern Santa Cruz, Bolivia have undergone among the most rapid rates of concentrated deforestation during the 1980s and 1990s. We investigated the sensitivity of local climate to these land cover changes as observed from Landsat images acquired between 1975 and 1999. The Simple Biosphere model (SiB2) is used to assess the effects of both morphological and physiological changes in vegetation and the implications for fluxes of water, energy and carbon between the vegetation and the atmosphere during the rainy season.

Our results show that conversion from tropical forest to cropland implicates morphological changes in vegetation as the primary drivers for a daily maximum warming of about 2º C and a slight nighttime cooling, suggesting that clearing of tropical forests for agricultural use may increase the diurnal temperature range, mainly by increasing the maximum temperature. On the other hand, conversion of wooded grassland to cropland resulted in a similar daily warming and drying but exclusively due to vegetation physiological activity.

Our results show the area-averaged monthly mean response for each conversion type resulted in a warming of about 0.6º C for the conversion of broadleaf evergreen and 1.2º C for conversion of wooded grassland. These temperature differences represent an augmentation in the local heat source associated with a reduction in evapotranspiration due to land cover conversion and do not reflect variations forced by changes in atmospheric circulation. When averaged over the entire domain, however, the effect of landscape conversion results in a large-scale apparent heat source of 0.5º C during January. This warming is in line with an increasing trend observed in monthly mean temperature in Santa Cruz, Bolivia during the same period.

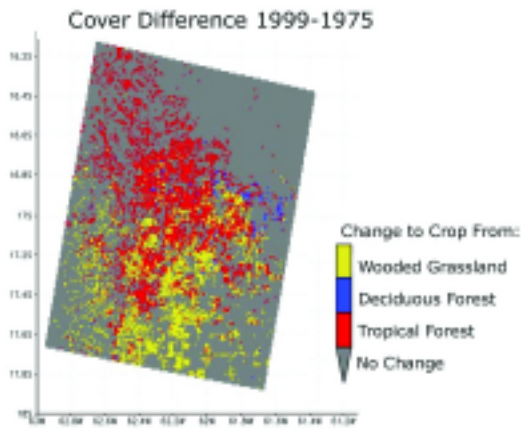

Figure 1.

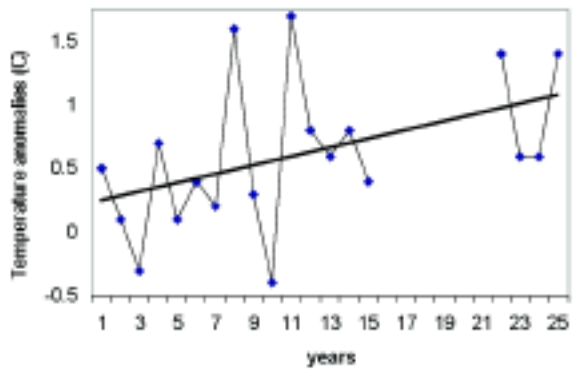

Figure 2. Observed January mean temperature anomalies (ºC) over Santa Cruz, Bolivia between 1975 and 1999. Blanks represent missing data

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Northern Hemisphere Photosynthetic Trends 1982-99

Increasing global temperatures have been reported from ground measurements over the past century, with particularly significant warming occurring during the past two decades and at mid to high northern latitudes; 1998 was the warmest year in the instrumental record. Presumably, any such global warming may lead to a change in photosynthetic activity: plant metabolic rates may be directly stimulated for ecosystems in which temperature is a growth-limiting factor, and a longer frost-free period may permit a longer growing season and therefore increased plant growth. Furthermore, recent studies of tropospheric carbon dioxide (CO_2) concentrations indicate increased vegetative activity. Measurements of tree phenology from 1959 to 1993 in Europe indicate a lengthening of the growing season of approximately 11 days over this period.

Changes in gross photosynthetic activity have important implications for global carbon cycles, and therefore global warming itself. Remotely sensed satellite observations can aid in the geographical quantification of these photosynthetic dynamics. Specifically, the normalized difference vegetation index (NDVI) is a remotely observable variable that responds strongly to healthy, green vegetation.

The purpose of our research was to determine whether statistically significant NDVI trends were evident in NDVI data sets from NOAA's Advanced Very High Resolution Radiometer (AVHRR) instrument, over the 1982-99 period for latitudes of 35º N and higher. To do so, we computed NDVI trends for both large regions (either latitudinal bands or broad landcover types; figure 1) and for individual image pixels (at 8-km resolution; figure 2), and applied both linear and nonlinear trend analysis techniques.

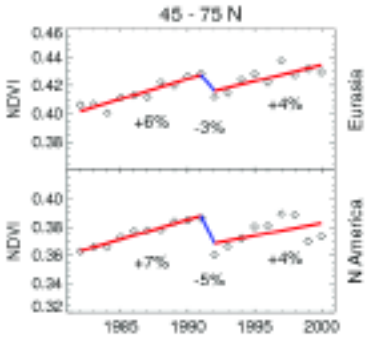

Figure 1. Linear trends in NDVI averaged yearly over latitudes 45-75 N, and the corresponding percent change.

The analysis was complicated by the June 1991 eruption of Mt Pinatubo in the Philippines, which initiated a short-term, but measurable, global cooling (see 1991-1992 pane of Figure 2).

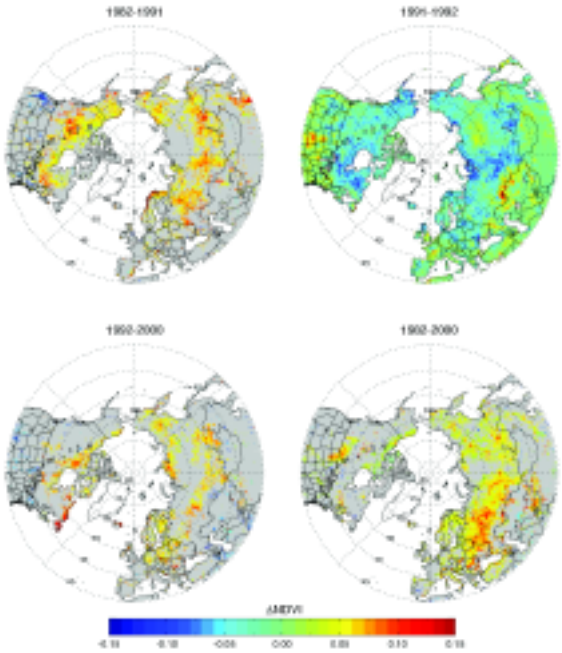

Figure 2. Trends in NDVI for the pre-Pinatubo (1982-1991), post-Pinatubo (1992-2000), and entire period, as well as the global depression in vegetation that occurred following the Pinatubo eruption (1991-1992). Gray areas indicate non-significant trends.

We consistently found significant positive trends in averaged NDVI for latitude bands above 35ºN in all but one data set; this one data set lacked corrections for sensor drift and instrument calibration. A pixel-level analysis shows the trends to be widespread, with large areas of Canada, Europe and northern Asia experiencing significant positive increases across all vegetated landcovers.

Following publication of these results (Slayback et al., 2003), we extended the study to 2000 using an improved dataset, with better corrections for solar zenith effect and satellite drift, and found similar overall results. The trends from this dataset are displayed in the figures here.

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Seasonal to Interannual Variability of Vegetation

The long-term objective of this activity is to understand the linkages between ecosystems dynamics at the seasonal to interannual time scales associated with El Niño / Southern Oscillation (ENSO). ENSO induced interannual variations in climate regime result in different patterns of rainfall during ENSO warm phase (El Niño) or cold phase (La Niña). In arid and semi-arid regions such as southern Africa, the ecosystems' response is revealed through drought or wet conditions with the changing phases of ENSO. This is important in understanding the influence of ENSO on vegetation dynamics, fire regime, agriculture and disease patterns. As part of the land surface component of Southern Africa Fire-Atmosphere Research Initiative 2000 (SAFARI-2000), this activity provides the foundation to study linkages between land-atmosphere processes and their relationship to regional fire patterns. In this study, heritage normalized difference vegetation index (NDVI) time series data from the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) are used as a proxy for biomass production to study the patterns of seasonal to interannual variability in biomass for the region, with emphasis on the conditions and associated fires during the 2000 campaign.

A comparison of accumulated rainfall for the period July - September between 1991 to 1992 and 1999 to 2000 shows that most of the region received < 400 mm of rainfall during 1991-1992 period (Figure 1a) compared to between 500 - 1200 mm during the 1999-2000 period (Figure 1b).

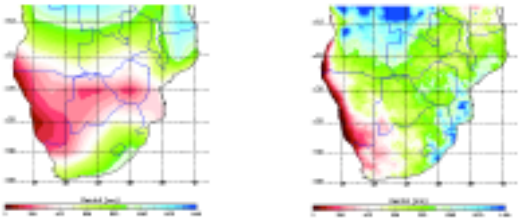

Figure 1. Accumulated rainfall for July 1991 - September 1992 (a-left) and July 1999 - September 2000 (at right). During the 1991-1992 period, drought conditions prevailed in contrast to the 1999-2000 period with most areas receiving above normal rainfall.

The ecosystem response to these differing rainfall patterns is illustrated by NDVI anomalies for the period March-May (MAM) shown in Figure 2a and 2b. During the 1992 MAM period drought prevailed over the region especially over the area located between 20oS and 25oS with NDVI departures of ~ 40% - 60% below normal. This drought was associated with the occurrence of a warm ENSO event, which resulted in a large rainfall deficit and reduced photosynthetic activity over most of the region. In contrast, during the 2000 MAM period most of the region south of 15oS had above normal NDVI, with magnitudes of 20% over the eastern portion of the region and ~80% over the arid western half of the region. The magnitude and temporal persistence of positive NDVI anomalies during this period was the highest recorded for the entire NDVI record for the region from 1981 to 2000. The above normal NDVI conditions were a result of above normal rainfall associated with La Niña conditions during the 1999-2000 period.

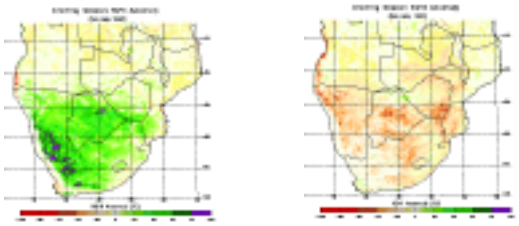

Figure 2. Average March-May (MAM) NDVI anomalies expressed as percent departures from normal showing drought conditions during the 1992 El Niño event (a-left) and above normal vegetation conditions during the 2000 La Niña event (b-right).

These differences in NDVI patterns resulted in different patterns of fire distribution. More satellite detections of active fires were observed in 2000 (Figure 3a) than in 1992 (Figure 3b), especially for Botswana, Namibia, southern Zimbabwe and southern Mozambique where there was increased biomass production. Comparisons between in situ and airborne measurements collected in 2000 and 1992 require an understanding of the extremely different climate and vegetation conditions associated with those years. Generalizations from results of SAFARI 2000 and 1992 field campaigns should consider the large interannual variability in land surface conditions encountered in southern Africa, as depicted by the long-term record of satellite vegetation measurements.

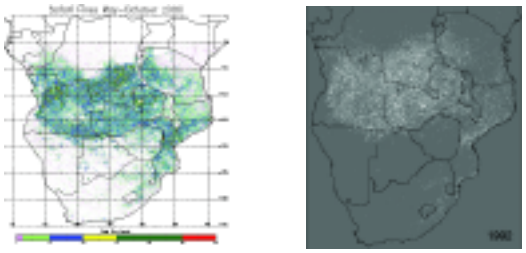

Figure 3. Spatial distribution of accumulated fire counts during the period May - October for 2000 (a) and May to October 1992 (b-right: after Kendall et al. 1997). The spatial extent of fires increased southwards during the 2000 dry season following above normal rainfall and NDVI compared to 1992.

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Disturbance Recognition in the Boreal Forest using Radar and Landsat-7

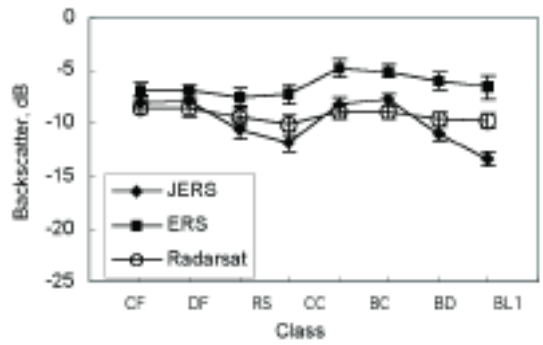
Disturbance is an important factor in determining the carbon balance and succession of forests. Until the early 1990s researchers focused on using optical or thermal sensors to detect and map forest disturbances from wild fires, logging or insect outbreaks. As part of a NASA supported Siberian mapping project, this study evaluated the capabilities of radars flown on the European Resource Satellite (ERS), Japanese Earth Resources Satellite (JERS) and Canada's Radarsat spacecraft and the ETM+ optical sensor on-board Landsat 7 to detect fire scars, logging and insect damage in the boreal forest.

The utility of using different radar systems and Landsat 7 for identifying forest landscape classes, especially those related to disturbance, was examined. The results were limited when using any single channel radar. However JERS and ERS were found to be useful for identifying certain classes. JERS was most useful for separating forest from disturbed classes with no standing trees. ERS was more useful for separating forest classes from disturbed classes where trees are left standing. Radarsat, on the other hand, was the least effective individual radar for this study. Combining the radars improved the identification of classes.

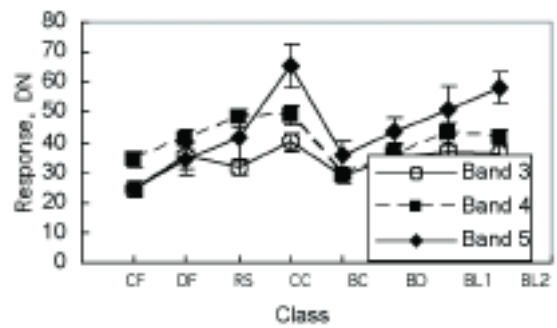
Generally, if one radar sensor was found to have high separability for a pair of classes, adding additional radars did not greatly increase the separability. If all radars had low separability, combining the radars had very little benefit. The low separabilities found between coniferous and deciduous forests, and burned and insect damaged forest classes indicates that classes that have both large trunks and leaves present on them were not possible to separate using even combined radar sensor data. We also recognize that radiometric correction of terrain effects is necessary for optimum classification in our area. We plan to use Shuttle Radar Topographic Mapper data for future analysis of these combined data sets.

Landsat 7 data proved the most useful of any single remote sensing system for recognizing forest type and discriminating between disturbance types. Even with non-growing season images, as was the case for the fire damaged site, the results were promising. Combining the Landsat data with the available radar data improved the forest type classifications. The results also indicated that the combination of radar and Landsat 7 may be especially useful for recognizing other forest types by utilizing the structural information of radar and spectral information of Landsat 7. As radar and Landsat 7 data become more widely available, combining these data sets should improve the accuracy of forest mapping activities.

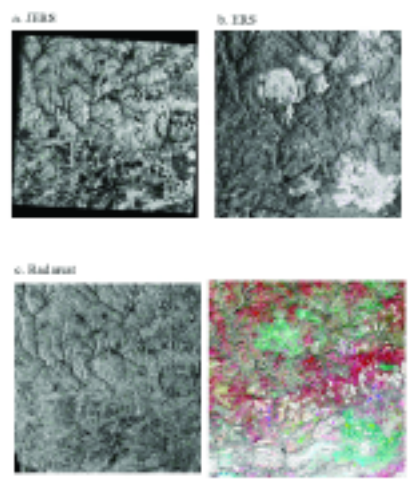
The top set of graphs provides examples of the average radar backscatter coefficient for cover types found in area covered by the images in the lower panel. The lower graph is the spectral reflectance from Landsat-7 in three selected bands. Differences in backscatter and reflectance between classes suggest better classification performance. Differences in backscatter are related to wavelength and polarization differences between the radars and inherent scene variability.



CF-coniferous forest DF- deciduous forest RS-regeneration
CC – clear cut BC - burned coniferous BD – burned deciduous
BL1 – burned clear cut BL2 - burned open land



Example images for a forested area used in this study are shown below. The images covered the same terrain within a year of each other. Bright areas in ERS image and blue areas on Landsat show location of recent burned areas. Small black rectangles on JERS image and corresponding white polygons on Landsat are recent clear cuts.



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Searches for the Amino Acid Glycine in Star Forming Regions

Astrobiology is the study of the origins, evolution, distribution, and future of life in the universe. At the simplest level it asks the questions: Where do we come from? Are we alone? Where are we going? The NASA Astrobiology Roadmap provides guidance for research and technology development across the NASA Enterprises that encompass the space, Earth and biological sciences. The Roadmap is formulated in terms of seven Science Goals that outline key domains of investigation. For each of these goals, science objectives outline more specific high priority efforts. In particular, goal 3 is to understand how life originates from cosmic and planetary precursors, and objective 3.1 specifically seeks to characterize the cosmic sources of organic matter for potentially habitable environments in the solar system and in other planetary systems.

Stars are continually forming out of the dust and gas that litter our galaxy, and planets are known to have formed around more than 100 stars. Astronomical studies of organic matter around star forming regions offer insight into how this matter could contribute to potentially habitable planets. In particular, radio astronomy can probe the density, temperature, velocity and spatial distribution of prebiotic molecules, so named because these molecules are the building blocks of life. The first molecule containing carbon, hydrogen, and oxygen (formaldehyde = H_2CO) was discovered 35 years ago by Snyder et al., and since then over 120 molecules have been identified in space, primarily by their microwave spectral signatures.

Glycine (or NH_2CH_2COOH) is the simplest amino acid and thus is a particularly important prebiotic molecule. Searches for interstellar glycine have been carried out over the past 25 years, including Hollis and Snyder in 1980. Pedelty teamed with Hollis (Code 930), Snyder (U. Illinois) and others to use the Very Large Array (VLA) radio telescope in September & December, 2001 and January, 2003 to search for glycine in two star forming regions, the Orion Molecular Cloud (OMC-1) and the B2 source in Sagittarius (SgrB2). The latter region is the richest source of large molecules in our galaxy: it has been dubbed the Large Molecule Heimat (LMH) by Snyder. Glycine was not detected in either region. These two searches are the most sensitive carried out with an interferometer, and so provide the best upper limits yet on small-scale (< 5≤ in angular extent) glycine emission.

However, the VLA permits simultaneous observations of more than one molecule, so the organic molecules ethyl cyanide (CH_3CH_2CN), formic acid (HCOOH), and methyl formate ($HCOOCH_3$) were also observed and detected. These molecules contain structural elements in common with glycine, e.g. the carboxyl group (COOH), so studying them is important for understanding possible formation routes for glycine or more complicated molecules.

The VLA is an imaging spectrometer that generates maps of the spatial and velocity distribution of the molecules, as illustrated in Figure 1 for ethyl cyanide. The grayscale values show the radio emission from ionized gas while the contour levels indicate the radio brightness of ethyl cyanide. Features at two distinct velocities are seen: Both emission and absorption are seen at a velocity of ~ 62 km/sec while two emission regions are moving at 72 km/sec. More detailed analyses of the brightest ethyl cyanide emission reveal a clear east-west velocity gradient indicative of a rotating disk of gas containing ~2600 solar masses of material.

These results were published in two papers in 2003: "A Sensitive Very Large Array (VLA) Search For Small-Scale Glycine Emission Toward OMC-1," J. M. Hollis, J. A. Pedelty, L. E. Snyder, et al. 2003, Astrophysical Journal, 588, 353, and "Kinematics of the Sagittarius B2 (N-LMH) Molecular Core," J. M. Hollis, J. A. Pedelty, L. E. Snyder, et al. 2003, Astrophysical Journal (Letters), 596, L235.

The future for astrobiology at Goddard is bright. Goddard became part of the NASA Astrobiology Institute (NAI) when its proposal "Origin and Evolution of Organics in Planetary Systems" was selected in June, 2003. The Goddard Center for Astrobiology (GCA) has recently been established, and includes co-investigators from several universities as well as international collaborators. The GCA asks the question, "Did delivery of carbon-containing molecules and water to the early Earth enable the emergence and evolution of life?" Pedelty is a co-investigator in the GCA, where he will be focusing on radio and infrared observations of organic material in young stellar objects, and also serves as the IT coordinator for remote participation in the NAI, which operates as a virtual institute.

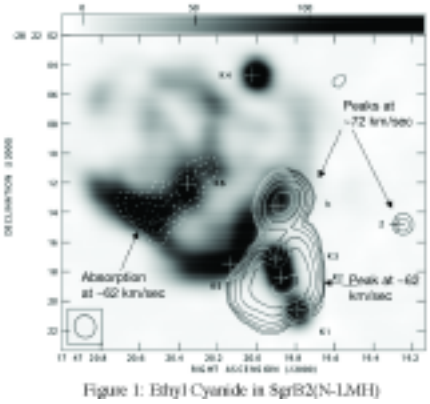

Figure 1. Ethyl Cyanide in SgrB2(N-LMH)

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Landsat 5 TM and Landsat 7 ETM+ Radiometric Calibration

Radiometric characterization and calibration activities for the Landsat-5 Thematic Mapper (TM) and the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) continued during 2003 under the auspices of the Landsat Project Science Office, within the Laboratory for Terrestrial Physics, in conjunction with the Land Cover Land Use Change (LCLUC) Landsat Calibration Study and the USGS Landsat Image Assessment System (IAS). The LCLUC study concentrates on the vicarious calibration of the reflective and thermal bands of the two instruments. The University of Arizona (UAz), South Dakota State University (SDSU), Rochester Institute of Technology (RIT) and NASA's Jet Propulsion Laboratory (JPL) participate in the LCLUC study. The IAS performs the systematic characterization of the ETM+ data and updates the operational calibration parameter files for the processing of ETM+ data. The LPSO analyzes the instrument response using the on-board calibration systems and integrates the results of the vicarious calibration with the on-board results.

Thermal band calibration for Landsat-7 and Landsat-5 (Barsi et al., 2003): Early in the Landsat-7 mission a bias in the calibration of the thermal band was detected using vicarious calibration. An update to the data processing system removed this bias effective December 2000. Since this date and up to the failure of the ETM+ scan line corrector on May 31, 2003, there is no apparent bias, to an uncertainty of ± 0.6K in the ETM+ thermal band calibration relative to the lake water temperatures and atmospheric propagation used in the vicarious calibration (Figure 1). Since the scan line corrector failure, the scan line corrector electronics have been turned off resulting in cooler optical components in the ETM+. Research is continuing into assessing whether this introduced a bias into the thermal band calibration. Several studies have been conducted to reassess the Landsat-5 thermal band calibration, which was last examined in the 1980's. A reexamination of data acquired during the FIFE field experiment in 1987 and 1989, which indicated the calibration was off by as much as 7K, showed that recently processed data from that time period were within 1K of ground propagated temperatures. It is now believed that the ground processing system at times failed to correctly calibrate the data. This still apparently occurs at times with the current processing system, and the cause is being investigated. RIT analyses of wintertime non-frozen Lake Ontario, with an assumed temperature of 1.5C, did not show any apparent mis-calibration, although the error bars are about ± 2C. Finally recent calibrations using the Lake Tahoe buoy network, in operation since 1999, show the current Landsat-5 TM calibration to be within 1C of the ground based measurements. Overall, between the three studies, the estimated bias in the Landsat-5 TM band 6 calibration is -0.7 ± 0.2K at 300K with Landsat-5 data being colder than the ground truth.

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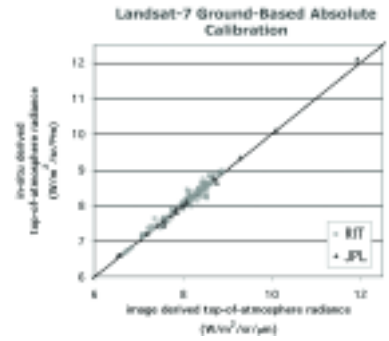

Figure 1.

Landsat-5 TM Reflective Band Calibration:(Chander and Markham, 2003): An effort to improve the radiometric calibration of the reflective bands of the Landsat-5 TM culminated in 2003. A cross calibration of the Landsat-5 TM with the Landsat-7 ETM+ had occurred previously. A reconstruction of the Landsat-5 TM calibration history based on the internal calibrator was tied to this cross calibration. A comparison to historical vicarious calibration data agreed to within the error bars of the combined datasets. This reconstructed "lifetime" calibration history was operationally implemented into the US ground processing system for Landsat-5 TM data in May 2003. This replaced a scene-by-scene calculation of the gain using the internal calibration lamps. Each calibration has degraded differently and thus rendered the previous calibration methodology invalid. A revised calibration, G_{new} compared to the previous calibration, G_{old} is shown in Figure 2.

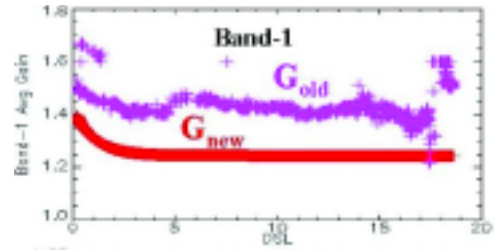

Figure 2.

Landsat-7 ETM+ Reflective Band Calibration:(Markham et al., 2003): The Landsat-7 calibration continues to be remarkably stable since launch, based on the combined results of the on-board calibration systems, vicarious calibration and "invariant" sites. Four desert sites in the Arabian peninsula and northern Africa were selected for regular acquisition and processing. These sites were treated as invariant with time and used to assess the instrument stability. The combined results of all the methods indicate that no band is changing by more than 0.5% per year in gain and the best estimates for change with time are typically about 0.3% per year.

Validation of Surface Height From Shuttle Radar Topography Mission Using Shuttle Laser Altimeter

Spaceborne Interferometric SAR (InSAR) technology used in the Shuttle Radar Topography Mission (SRTM) and spaceborne lidar such as Shuttle Laser Altimeter-02 (SLA-02) are two promising technologies for providing global scale digital elevation models (DEMs). Each type of these systems has limitations that affect the accuracy or extent of coverage. In this study surface height measured independently by SRTM and SLA-02 was cross-validated. SLA data was first verified by field observations and examinations of individual lidar waveforms.

The geolocation accuracy of the SLA height data sets was examined by checking the correlation between the SLA surface height with SRTM height at 90m resolution, while shifting the SLA ground track within its specified horizontal errors. It was found that the heights from the two instruments were highly correlated along the SLA ground track, and shifting the positions did not improve the correlation significantly. Absolute surface heights from SRTM and SLA referenced to the same horizontal and vertical datum (World Geodetic System (WGS) 84 Ellipsoid) were compared. The effects of forest cover and surface slope on the height difference were also examined. After removing the forest effect on SRTM height, the mean height difference with SLA-02 was near zero. It can be further inferred from the standard deviation of the height differences that the absolute accuracy of SRTM height at low vegetation area is better than the SRTM mission specifications (16m). The SRTM height bias caused by forest cover needs to be further examined using future spaceborne lidar (e.g. GLAS) data.

For more information, please see Sun, G. et al 2004.

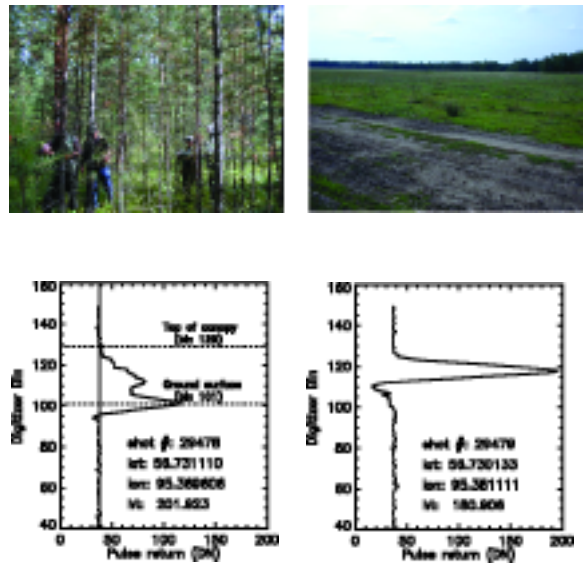

Figure 1. SLA02 lidar waveforms of two sites near Krasnoyarsk, Russia.

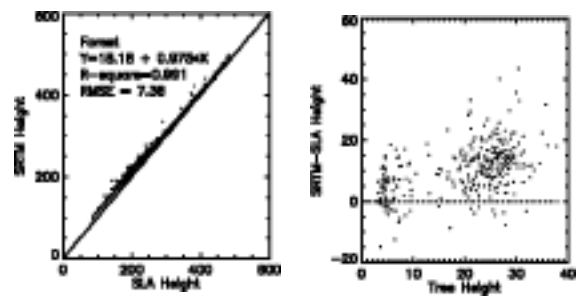

Figure 2. SRTM vs. SLA comparison (left) and Affect of tree height (right).

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Monitoring Photosynthesis and C/N Cycling with Optical Techniques

A joint NASA and USDA project is being conducted at the Agricultural Research Service in Beltsville, MD to study photosynthetic efficiency in agricultural and tree species using spectral techniques with actively induced fluorescence emissions and passive reflectance of foliage. The major focus of this project is to understand the interaction of the N and C cycles affecting plant productivity. Reflectance (400-2400 nm) and fluorescence excitation (300-700 nm) by emission (300-800 nm) properties of field corn (Zea mays L.), soybean (Glycine max L.; Fig. 1), tulip poplar (Liriodendron tulipifera L.), red maple (Acer rubrum L.), and sweet gum (Liquidambar styraciflua L.) grown under varying levels of nitrogen (N) supply were characterized in conjunction with photosynthesis and leaf chemistry.

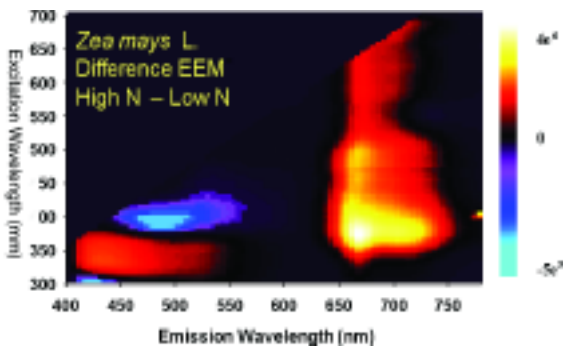

Figure 1. The fluorescence difference excitation by emission matrix (EEM) dictates that there are several discrete regions where significant N induced changes in primary plant emission bands can be observed.

In 2003, our focus was on seasonal measurements of tree foliage and on experiments with soybean mutants having reduced chlorophyll levels and altered chlorophyll a/b ratios. Through spectral sensitivity analysis, a number of reflectance and fluorescence algorithms have been established with strong relationships to measures of plant condition, such as: photosynthetic rate/efficiency (Fig. 2), pigment contents, C:N ratio, leaf area index (LAI), and grain/biomass yield (Corp et al., 2003). During 2003, we continued to study solar-stimulated chlorophyll fluorescence in our 5 species to quantify the contribution of fluorescence to "red edge" reflectance and the fluorescence expected in the atmospheric Fraunhofer wavebands. Our findings support the integration of leaf and canopy reflectance with fluorescence parameters to describe key biophysical attributes of plant growth, which could potentially lead to the site specific monitoring of N utilization for C sequestration in crop and forest systems.

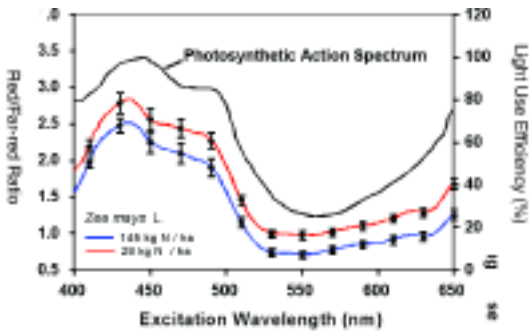

Figure 2. Chlorophyll fluorescence is an indicator of the efficiency by which light is being utilized for photosynthesis.

In addition to continuous hyperspectral sensing, two active fluorescence imaging systems were employed to acquire fluorescence emission images in four spectral bands, namely, the leaf level Fluorescence Imaging System (FIS), and the canopy level Laser Induced Fluorescence Imaging System (LIFIS). FIS acquires high resolution images of individual plant organs (e.g., leaves) under darkened laboratory conditions, while LIFIS acquires images of plant canopies under ambient sunlit conditions.

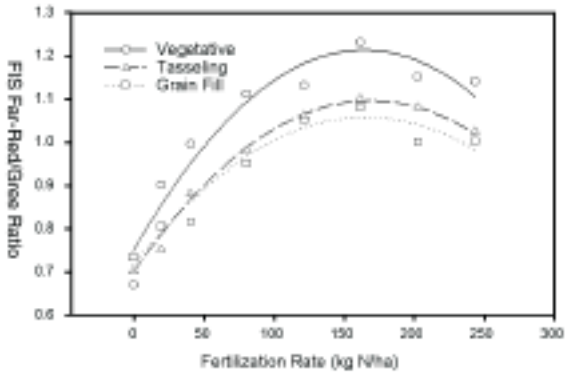

Figure 3. FIS imaging ratios in response to varying levels of N fertilization indicate curvilinear relationships.

A successful demonstration of LIFIS on field grown corn established that fluorescence image ratios appeared more sensitive to N deficiency than to over-supply of N, but most importantly, the trends in fluorescence image ratios (e.g., far-red/green) were consistent across the FIS leaf level (Fig. 3) and LIFIS canopy level measurements (Corp et al., 2003). Further efforts are being placed on the development of both active and passive fluorescence sensing technologies.

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Assessing Land Surface Temperature Errors Due to Sun-Sensor Geometry

The long term goal of this project is to improve estimates of vegetation status and functioning by using daily (day and night) satellite observations of surface temperature. Land surface temperature (LST), defined as the effective kinetic temperature of the earth surface "skin," is a key climatological variable and contributes to the magnitude and partitioning of energy fluxes at the earth's surface. Knowledge of the land surface temperature allows us to infer information about surface heat fluxes, vegetation properties and soil moisture, and serves as a proxy for the prediction of vegetation hydric stress and crop water requirements.

The NOAA Advanced Very High Resolution Radiometer (AVHRR), onboard the NOAA polar orbiter series, has measured earth brightness temperature, a function of LST, for more than 20 years. However, orbit and sensor characteristics, combined with surface vegetation structure, have been shown to impart major temporal and spatial artifacts in the AVHRR shortwave (visible and near infrared) bands. These artifacts increase the 'noise' of the vegetation signals, leading to erroneous results and mischaracterization of surface conditions. Our initial goal was therefore to assess whether traditional AVHRR LST products also suffer from these effects.

We hypothesized that for non-homogeneous, structured vegetated surface, the variable observation geometry determined by the sun and sensor positions determines the relative proportions of the surface endmembers (e.g., sunlit grass, shaded tree) viewed by the sensor. If we assume that sunlit and shadowed trees and grass have different temperatures, the variability in observed endmember proportions would be lead to angular variability in LST.

To test these hypotheses, we combined field measurements of land surface temperature with development of a new daily LST product from the NOAA-14 AVHRR. We focused on the African continent since its widespread savannas and woodlands exhibit highly variable structure. We applied cloud masks and "split-window" algorithms to the AVHRR data and retrieved atmospherically-corrected estimates of surface temperature. The 8 km resolution data set covers all day and night orbits from 1995-2000 (see Fig. 1).

To model the variability in endmember fractions observed by AVHRR, we used a "geometric optics" computer model. Given maps of African vegetation structure (e.g., tree coverage, tree shape, grass coverage) and AVHRR sun-view geometry, the model estimates the fraction of sunlit and shadowed tree and grass observed by AVHRR for each pixel and orbit. This allowed us to simulate the retrieved LST for different AVHRR sun-view geometries (Fig. 2). Since adequate vegetation structure maps of Africa did not exist, we combined land cover maps with structural information in the literature.

To test our hypothesis, we attempted to correlate our model-predicted endmember fractions with the actual AVHRR LST measurements at various locations. For example, we found that sunlit background can determine more than 40% of the temporal LST variability for one woodland site, and "hot-spot" LST observations (i.e., where the sun and satellite are aligned) can exceed non hot-spot observations by ~9 kelvins. We considered subsets over a short period (e.g., 16 days) to limit the effects of natural forces on LST variability, e.g., due to meteorology (e.g., air temperature, cloudiness), surface conditions (e.g., soil moisture) and the natural diurnal cycle (solar heating).

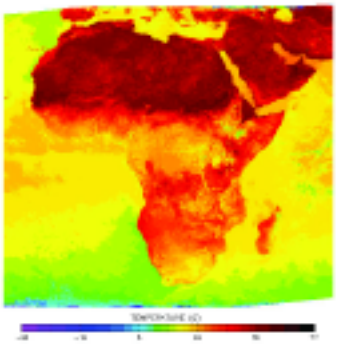

Figure 1.

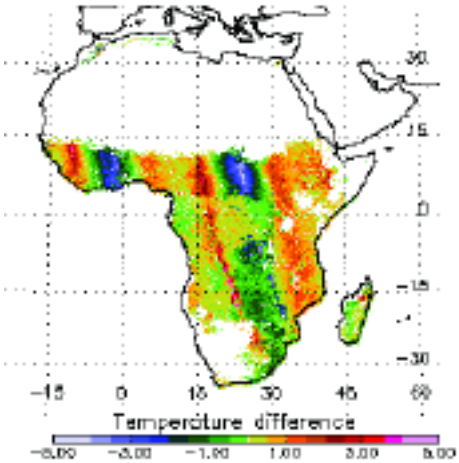

Figure 2.

Overall, we demonstrated that there is a bias in the 6-year NOAA-14 AVHRR LST data set that results from the orbit and sensor characteristics. This bias is not uniform in time or in space and responds not only to the latitudinal and seasonal patterns of sun-view, but also to the differences in tree cover density. Our results suggest the need to account for sun-view geometry in AVHRR LST data. One component of our current work seeks to develop an approach to normalize all LST observations to a common geometry.

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The Baltimore Children's Asthma Project

An epidemic of pediatric asthma is underway in the US with children diagnosed with asthma having more than doubled in the last 15 years. National data also show that poor, minority children are disproportionately affected, requiring higher rates of hospitalization for asthma and incurring higher mortality rates. In Baltimore MD asthma is the most common chronic illness of children, accounting for up to 20% of pediatric hospital admissions with rates more than double the national rate. Temporal and spatial trends in hospital admissions and emergency room visits in Baltimore show some relationship to environmental and socioeconomic trends, but these are difficult to understand because of the many possible variables involved and their complex, non-linear relationships.

A team of medical researchers, modelers, GIS and remote sensing experts, and programmers, led by Elissa Levine and Dan Kimes, of the Laboratory for Terrestrial Physics, focused on trying to identify environmental causes of pediatric asthma in Baltimore, the State of Maryland, and other areas. This effort provides a prototype for similar studies in other regions, and with other health issues.

Accomplishments included: 1) The development of a robust tool for data integration and manipulation, visualization and scenario building, and applied mathematical modeling and prediction that could be used by the medical and public health communities in their decision support systems, 2) collection of a comprehensive environmental, remotely sensed, clinical, and socioeconomic dataset, 3) production of remote sensing products from Landsat, Terra, SPOT, Ikonos, and Aeronet data including: land cover classification and land use change, urban characteristics, timing of greenness, key landmark features, and particulate matter load, size, and characterization.

Figure 1. Terra/ASTER 4-04-2000

Preliminary Research Results: Asthma rates are high in Baltimore City, compared with national rates, with 5-14 year olds disproportionately affected. There is a strong seasonal pattern in pediatric asthma hospital admissions in Baltimore City and the other areas studied with peaks in spring and fall and lows in summer and winter. This pattern supports relationships between asthma and certain classes of environmental triggers and contradicts relationships previously linked with asthma (e.g. high atmospheric ozone).

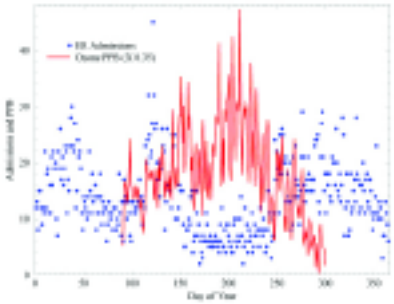

Figure 2. Daily Ozone and Pediatric Emergency Department Admissions, 1999, Baltimore, MD

Predictions of temporal asthma hospital admissions in Baltimore City can be made with relatively high accuracy based solely on historical trends (r^2 = .80).

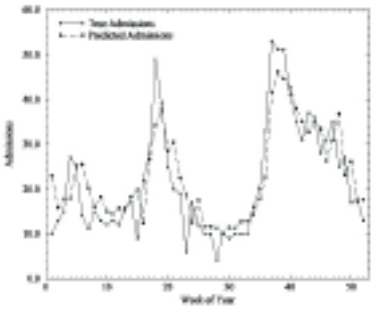

Figure 3. Predicted and true hospital admissions in 1999 for children (0-18) in Baltimore , MD (r^2=0.80)

Highly accurate (r^2 = .95) spatial predictions of asthma hospital admissions were made in Baltimore City using satellite based information (Landsat) combined with socio-economic data. The characteristics of zip codes areas with high pediatric asthma hospitalization rates were: highest proportion of families headed by single parent, highest levels of poverty, highest proportion of built areas, lowest vegetation cover, and highest thermal IR radiant temperatures. Schools with the highest prevalence of asthma were identified (using school nurse data) and chosen for further study of indoor triggers. Results showed that indoor allergens within Baltimore City Public schools do not appear to be high enough to be the primary trigger of pediatric asthma in Baltimore City (Amr et al., 2003).

As of this writing, this project has been discontinued because of funding cuts.

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National Park Vegetation Mapping and Monitoring Using Landsat Data

Our National Park System is a cherished national asset. However, our National Parks do not exist in a vacuum. Pressures from within (e.g. invasive species, fire) and from without (e.g. urbanization, air/water pollution) threaten the health of the varied ecosystems protected by the National Park Service (NPS), and thus the preservation of these resources for future generations. As we look to the future we can expect many of these pressures to intensify, even as new pressures emerge. Clearly, it is imperative to develop sound and scientifically defensible park monitoring protocols in order to provide park managers with the tools needed to make important management decisions and to develop effective mitigation options.

The NPS and the Biological Resources Division of the USGS are managing a Vegetation Mapping Program (VMP). The objective of the VMP is to provide each of the over 270 park units managed by the NPS with high spatial resolution, standardized maps of the vegetation occurring within the park units. The VMP has been producing high-quality, detailed vegetation maps of many NPS park units based on peer-reviewed, sound protocols. The mapping protocols developed for these projects principally employ aerial photography, manually interpreted in conjunction with ancillary field data and incorporates independent accuracy assessment based on field observations (see http://biology.usgs.gov/npsveg/).

At the current rate of progress, which ranges from two to five years per park unit, the VMP may require up to 50 years to map all NPS park units. Many units require more immediate vegetation information for resource management, environmental assessment, monitoring, and planning. Moreover, the approach is not easily repeatable to support an active monitoring effort of the vegetation resources of the park units and adjoining areas. The goal of the research reported here was to use satellite remotely-sensed data to provide the NPS with a cost-effective, robust, and flexible vegetation mapping approach that would augment the VMP, and which could be potentially implemented at the national level. Satellite-based instruments such as the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper-Plus (ETM+) currently provide well-calibrated, synoptic, multispectral, and multi-temporal imagery for each and every NPS park unit at a cost of less than 0.03 cents per ha.

Results from a pilot project conducted at Delaware Water Gap National Recreation Area (DEWA) (Fig. 1) indicate that an approach using multi-date ETM+ scenes (e.g. Fall/Winter) with a state-of-the-art decision tree classifier can yield results that are within the standards of the VMP (i.e. 82% overall accuracy) and may be widely applicable to the entire NPS system (Brown de Colstoun et al. 2003). Decision tree classifiers have received much recent attention, particularly with regards to land cover classifications at continental to global scales. Despite their many benefits and general flexibility, the use of decision trees with high spatial resolution data such as Landsat has not yet been fully explored. The maps generated with our approach are less detailed than those produced from the air photography but can provide a more regional classification product that can be used to study the parks within a larger area context (Fig. 2). The Landsat data are made available to support other research activities at the particular park and the maps can also be used as educational and/or interpretive tools. Current research aims at using the strengths of Landsat data for active monitoring of National Park lands.

Figure 1. Location of the Delaware Water Gap National Recreation Area (http://www.state.nj.us/drbc/spw2.gif).

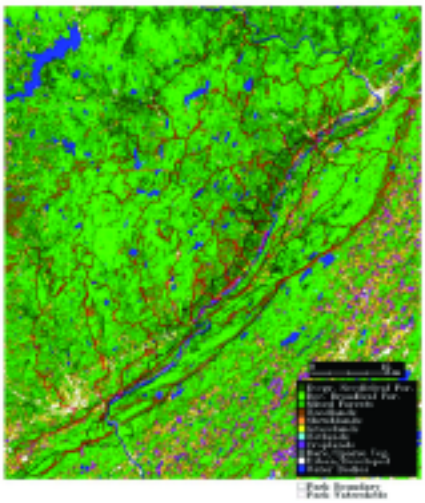

Figure 2. Final land cover map of Delaware Water Gap National Recreation Area using a decision tree classifier and multi-date ETM+ data.

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Measuring Multiple Resources in Delaware with Airborne LiDAR

A simple, lightweight, inexpensive, portable airborne laser profiling system has been assembled from off-the-shelf, commercially available components. The system, which costs approximately $30,000 USD, is designed to fly aboard small helicopters and single or two-engine aircraft without airframe modification. The system acquires first-return range and amplitude measurements at data rates up to 2000 hz (operator-controlled) and has an operational envelope up to 300m above terrain. The airborne laser profiling system includes the laser transmitter/receiver, differential GPS, a CCD video camera and recorder, and a laptop computer which interleaves and records the GPS and laser range/amplitude data. The portable airborne laser system - PALS - was designed to acquire forest height measurements along linear flight transects in order to conduct regional or subcontinental forest inventories worldwide. This economical laser system now puts airborne laser mensuration within reach of operational foresters and researchers interested in making rapid forest structure and/or timber surveys in remote areas. PALS has been used to acquire over 5000 km of flight transect data over the state of Delaware.

Figure 1. The Portable Airborne Laser System used to measure Delaware forests.

The systematic forest height measurements collected by PALS over the entire state in y2000 were used to estimate (1) forest volume, biomass and carbon, by cover type (e.g., conifer, mixedwood, hardwood, wetlands, agriculture, residential, urban) and county; (2) impervious surface area, including area under roof and asphalt/concrete; (3) open water area; and (4) area of Delmarva fox squirrel habitat, an endangered ground squirrel on the Eastern Shore of the Chesapeake Bay. Forest height measurements are related to the amount of wood on the ground and are used to map potential squirrel habitat (squirrels populate tall, dense forest stands). Laser transect crossing lengths are used in con-junction with linear sampling techniques (Line Intercept Sampling) to estimate impervious surface and water area.

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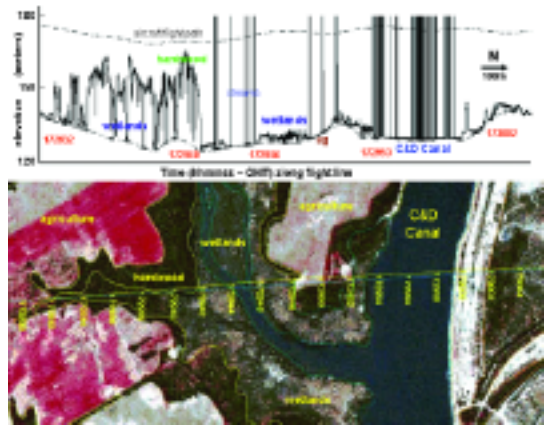

Figure 2. A 1.7 kilometer section of PALS data acquired over the Chesapeake and Delaware Canal. Water absorbs the near-infrared laser pulses which, on the topmost graph, are plotted as tall, flat-topped spikes. The laser flight line is superimposed on a color-infrared airphoto; the laser aircraft's location is updated every 2 seconds, connoted by the yellow GMT times spaced about 100m apart.

The PALS-based forest inventory estimates were compared with a US Forest Service state inventory conducted in 1999. Study results indicate that laser-based merchantable volume estimates are within 24% of US Forest Service estimates at the county level and within 15% statewide. Total above-ground dry biomass estimates are within 19% of USFS estimates at the county level and within 16% statewide. Various types of impervious surface (roofs, concrete/asphalt) and open water are tallied along the flight lines to estimate percent and areal coverage statewide, by land cover and county. Laser estimates of impervious surface area are within 28% of satellite-based estimates at the county level and within 3.1% at the state level. Laser estimates of open water are within 7% of photointerpreted GIS estimates at the county level and within 3% of the GIS at the state level. Stands identified using the airborne laser height data as being potentially suited to supporting fox squirrel populations were visited in the field. Field measurements were collected so that a habitat suitability model could be run on each of the 32 stands visited statewide. Twenty five of the 32 sites (78%) were judged by the model as being capable of supporting the squirrel.

For more information, see Nelson, Parker, and Hom, 2003 and Nelson, Short, and Valenti, 2003.

MODIS Rapid Response System – Support to Near-Real-Time Applications and Outreach

In 2003, the MODIS Rapid Response System solidified a partnership with the U.S. Department of Agriculture's Foreign Agricultural Service (FAS). The FAS is using MODIS satellite data to improve the accuracy and timeliness of information needed to make decisions affecting U.S. agriculture, trade policy, and food aid.

MODIS provides daily, high-quality, photo-like images used to observe large areas across the world. MODIS products allow FAS analysts to distinguish between different crops like wheat and rice and permit analysts to measure other features like surface temperature and snow cover. Analysts can gauge the overall health of agriculture by comparing current data with previous years. MODIS products, first used by FAS in the summer of 2003, demonstrated their utility by helping analysts identify new areas of irrigated agriculture in the Middle East, as shown in the below images.

Figure 1. Large planted areas are visible on April 11, left, during the wet season. On August 24, only the irrigated land is still green.

MODIS collects data twice daily, from the Terra satellite in the morning and the Aqua satellite in the afternoon, which helps analysts observe how events such as fires, volcanic eruptions, floods, storms, or extreme temperatures affect crops. The MODIS Rapid Response System processes and delivers MODIS data to the USDA within three to four hours after it is acquired.

The MODIS Rapid Response staff also initiated collaboration with the U.S. military, in response to the need for imagery in the war in Iraq. Since mid-February 2003, the Rapid Response System has been providing near real-time images of Iraq to the Air Force Weather Agency, and the U.S. Naval Research Laboratory. The images show the extent of dust storms and smoke plumes from oil well and toxic sulfur fires. The military is also given access to near-real-time imagery from other areas in the world where weather conditions, snow cover, smoke, fires, volcanic eruptions, and other things could impact military operations.

The Rapid Response staff continued to provide near-real-time information to the USDA Forest Service and the international fire community. The Forest Service uses MODIS data to allocate firefighting resources during the fire season. The Rapid Response staff also supplies the Forest Service with science software to generate rapid fire products from the MODIS data collected regionally by their Direct Broadcast antenna.

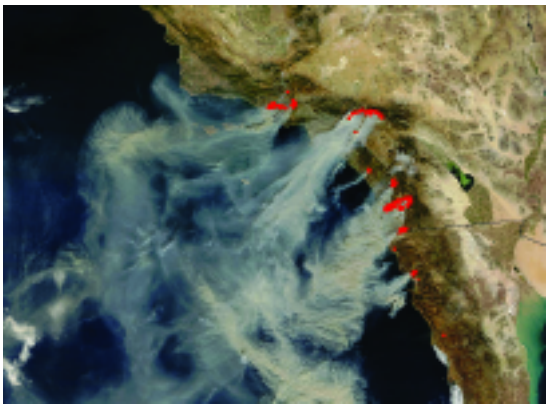

Figure 2. The above image shows fires raging across Southern California on October 26, 2003. The red dots indicate the locations where MODIS detected a fire.

The MODIS Rapid Response staff continued to support the Earth Science Enterprise's outreach effort by providing MODIS imagery of newsworthy events such as natural hazards to the Earth Observatory and other image publishers. A number of MODIS Rapid Response images were aired on regional and national TV, and many more were featured in various web news stories. In 2003 over 3.3 millions images were downloaded from the MODIS Rapid Response web site alone by 275,000 unique visitors. The total volume of downloaded images was 2.7 terabytes. The Rapid Response System also remains the main single contributor of MODIS images to NASA's Visible Earth database.

For more information: http://rapidfire.sci.gsfc.nasa.gov

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Coordinated Use of High Spatial Resolution Commercial Satellite Imagery for Validation of MODIS Land Products

The MODIS land discipline team (MODLAND) has utilized commercial data available through the NASA "Scientific Data Purchase" (SDP) program in support of land product validation. Research and infrastructure within the Terrestrial Information Systems Branch has coordinated MODLAND's use of high-resolution commercial imagery, with a focus on the EOS Land Validation Core Sites. These sites provide a globally distributed network of sites where field, aircraft, and satellite data are being collected. As much as possible, uniform data sets useful for validation are being made available for the Core Sites.

The globally consistent, high-resolution imagery available from IKONOS are being used for their geolocation accuracy and ability to characterize the landscape at the 1 to 4m spatial resolution. A recently published paper provides an overview of the MODIS Land Team's validation strategy to incorporate high-resolution imagery and presents three case studies as examples of the use of IKONOS data for MODIS land validation activities. Figure 1 shows the various level of detail available from 1km MODIS data, 30m ETM+ data, and 4m IKONOS data over the Mongu, Zambia Core Site.

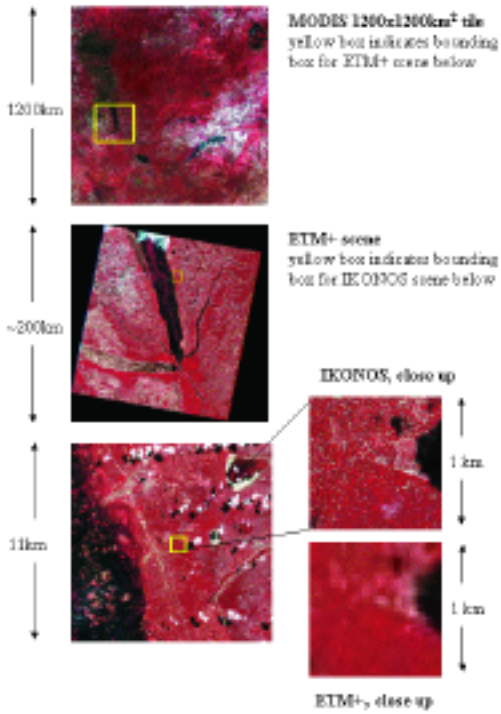

Figure 1.

The validation of global products requires consistent data with which to compare the global products. A main concern for validating the relatively coarse resolution products from the MODLAND team is that of relating field or ground based "point" measurements with the large area represented by a MODIS pixel. The approach used by the MODLAND team is to use imagery at intermediate scales to bridge between the two. The 1m panchromatic and 4m multispectral data from IKONOS, available in a consistent format and quality throughout the globe, has provided a complement to the 30m Landsat-7 ETM+ data. Without the high-resolution imagery available through the SDP, the only other option for such data would have been airborne imagery. Flight planning, digital image acquisition, and post processing are extremely time consuming and expensive. Furthermore, companies or agencies supplying such imagery typically work within a finite range, thus making it difficult (or impossible) to acquire consistent data over the globally distributed EOS Land Validation Core Sites. Lastly, there are some regions of the world where airborne image acquisition is either impossible or unsafe. In light of these considerations, NASA's investment in high-resolution imagery available through the SDP has supplied the EOS Land Validation Core Sites with unique, globally-consistent, critical validation data sets at a reasonable cost.

For more information see Morisette, J.T., et al, 2003

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Improvements to the Global Processing System for MODIS

The MODerate resolution Imaging Spectroradiometer (MODIS) instrument on the EOS Terra and EOS Aqua spacecraft images the Earth in 36 spectral bands in visible through thermal infrared wavelengths (459nm-9.58mm) with spatial resolutions of 250m, 500m and 1 kilometer. From an initial daily volume of 70GB of raw instrument data, 44 global science products are produced with an average volume of 760GB per MODIS instrument. These products extend the data record from heritage sensors, such as the Advanced Very High Resolution Radiometer (AVHRR), and offer finer spatial resolution, better calibration and more precise Earth-location of pixels. An advantage that the MODIS instrument has over finer resolution sensors for global studies is that it acquires a nearly complete image of the Earth's surface each day.

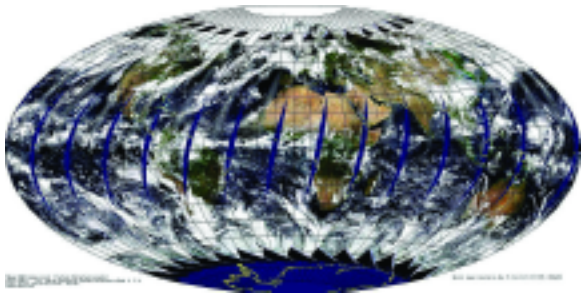

Figure 1. The above image is a composite of all MODIS surface reflectance data acquired on May 21, 2003. The surface reflectance product is not produced for the Antarctic but coverage exists over the Poles. Areas where orbits do not overlap near the Equator are shown in blue. Complete coverage of the Earth is achieved with data from two consecutive days or by combining data from both MODIS instruments from a single day.

On any given day, the MODIS Adaptive Processing System (MODAPS) will produce and ship 800 GB to 2,500 GB (billion bytes) of global science products to Distributed Active Archive Centers (DAACs) for distribution to the public. To produce these global products, the MODAPS system handles 34,000 to 102,000 files each day and ships over 500GB of products to MODIS quality assessment and product validation teams who monitor and assess the quality and accuracy of each science product.

When the first MODIS image from EOS Terra was received and processed on February 25, 2000, large Silicon Graphics Inc. (SGI) Origin supercomputers were used to produce the global MODIS science products. These computer systems were operated round the clock by a team of 9 production analysts supported by a sustaining engineering team of 10 developers, system administrators and database administrators. During the early years, operating the MODAPS system, coordinating production with the DAACs and shipping products to the 24 member MODIS science team and related investigators required a great deal of manpower.

Over the last year and a half, a number of factors enabled us to reduce the MODAPS yearly processing budget by 50% while increasing the MODIS processing rate and support for the MODIS Science Team. First, integration of low cost Linux clusters enabled us to deploy a 5-fold increase in processing capacity at less than half of the cost of comparable SGI systems. Second, an unattended processing capability was added to the system to allow it to be operated with one third less staff. Third, enhancements were made to the system to minimize human interactions in product delivery including a machine-to-machine interface for product ordering, as well as a full automated accounting of products delivered and products received between MODAPS and the DAACs that distribute MODIS products. Fourth, falling disk prices enabled us to keep more products online which simplified operations and improved the speed and reliability of processing and distribution.

By reusing MODAPS software other teams have been able to develop and operate processing systems for Landsat and AVHRR studies with no more than 3 analysts for science software development, sustaining engineering, science processing and distribution and quality assessment of products. The Earth Science Enterprise is shifting from large mission/instrument-based data systems to small science-based measurement systems, which are developed to focus on key science questions and the products needed to answer them. Building flexible low cost data systems by reusing existing systems like MODAPS or its sister system for ozone processing, OMI-DAPS (Ozone Monitoring Instrument Data Processing System), will enable scientists to leverage existing investments in software to minimize the cost of processing and distributing global data products.

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