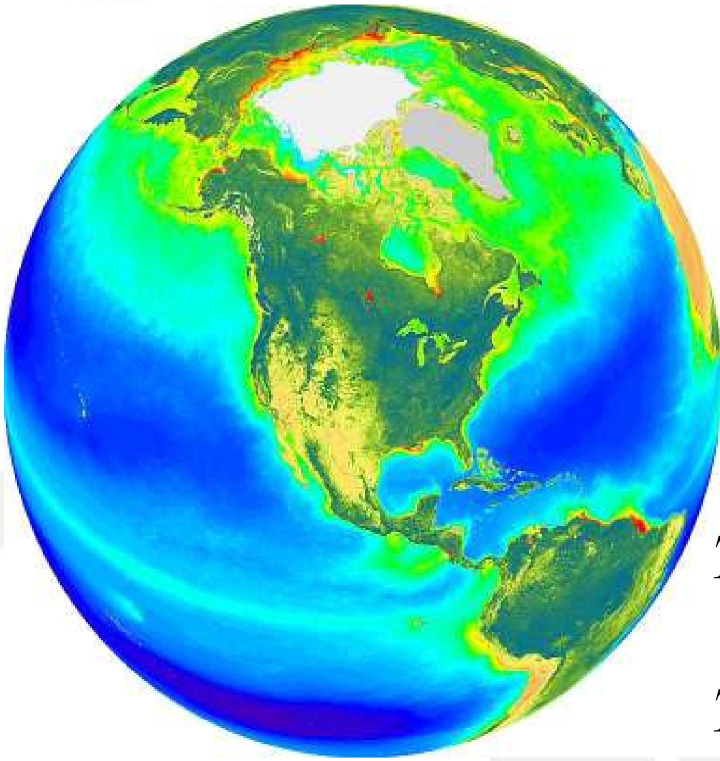
Carbon Cycle & Ecosystems

Diane E. Wickland, Focus Area Lead

The NASA Vision & Mission



To improve life here,

To extend life to there,

To find life beyond.

To understand and protect our home planet

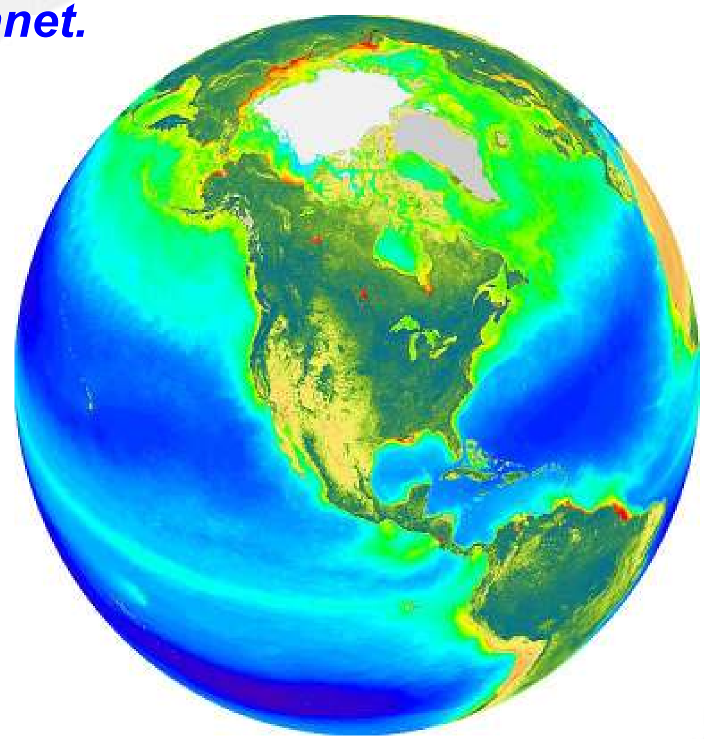
To explore the universe and search for life

To inspire the next generation of explorers

. . . as only NASA can

Carbon Cycle and Ecosystems

Knowledge of the interactions of global biogeochemical cycles and terrestrial and marine ecosystems with global environmental change and their implications for the Earth's climate, productivity, and natural resources is needed *to understand and protect our home planet.*

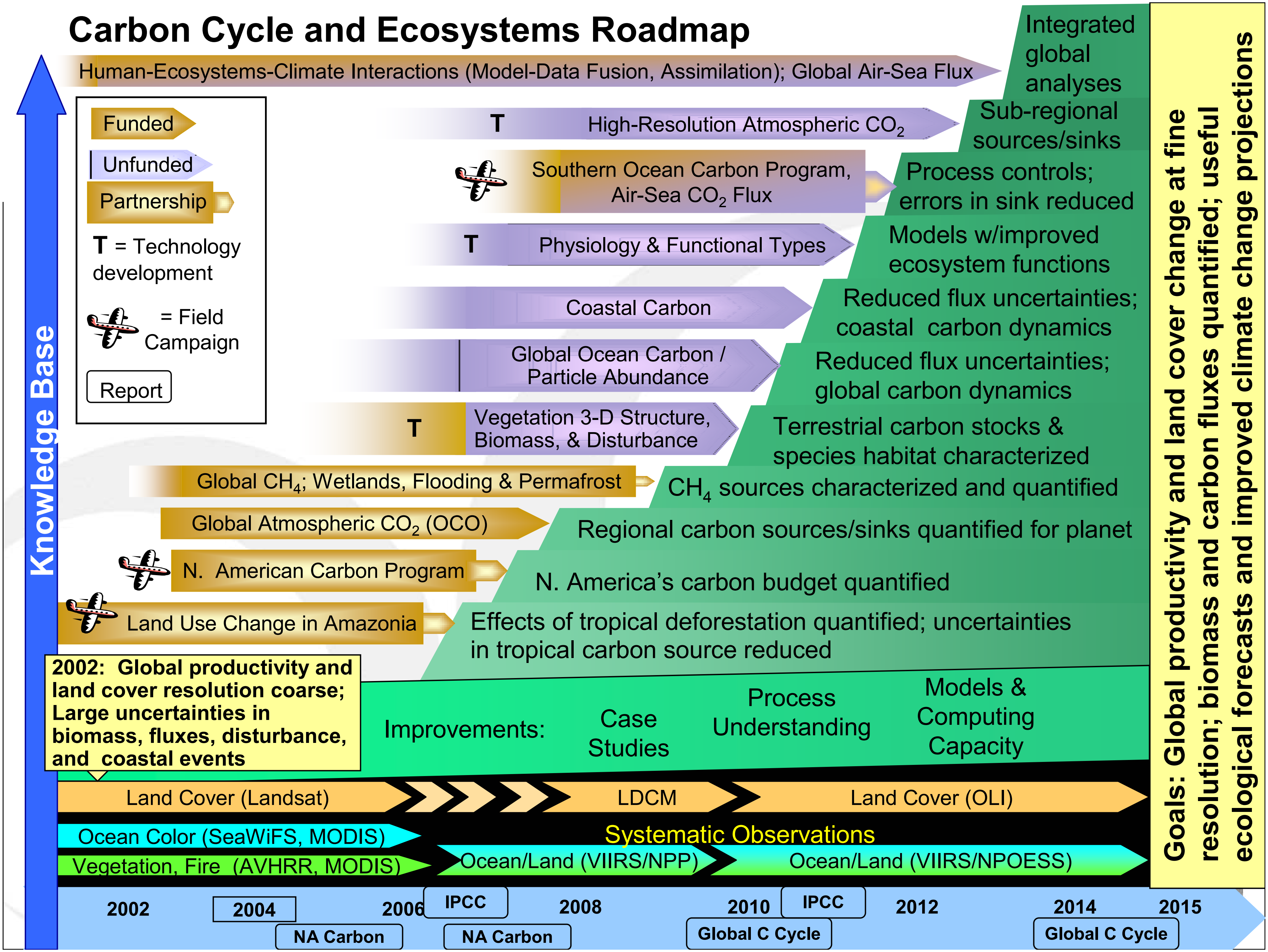


Important Concerns:

- **Potential greenhouse warming (CO_2, CH_4) and ecosystem interactions with climate**
- **Carbon management (e.g., capacity of plants, soils, and the ocean to sequester carbon)**
- **Productivity of ecosystems (food, fiber, fuel)**
- **Ecosystem health and the sustainability of ecosystem goods and services**
- **Biodiversity and invasive species**

NASA provides the global perspective and unique combination of interdisciplinary science, state-of-the-art Earth system modeling, and diverse synoptic observations needed to document, understand, and project carbon cycle dynamics and changes in terrestrial and marine ecosystems and land cover.

Carbon Cycle and Ecosystems Roadmap



Carbon Cycle & Ecosystems Program Elements

Ocean Biology and Biogeochemistry

Paula Bontempi

Terrestrial Ecology

Diane Wickland & Bill Emanuel

Land Cover and Land Use Change (LCLUC)

Garik Gutman

Biodiversity

Woody Turner

Carbon Cycle & Ecosystems Questions

- *How are global ecosystems changing?*
- *What trends in atmospheric constituents and solar radiation are driving global climate? ***
- *What changes are occurring in global land cover and land use, and what are their causes?*
- *How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?*
- *What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?*
- *What are the consequences of climate change and increased human activities for coastal regions? ***
- *How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?*

*** Question shared with other Focus Areas*

Research Challenges: Carbon Cycle

- **Closing the global carbon budget (& quantifying components)**
  - quantifying North America's carbon sources and sinks, understanding their interannual variability, and explaining causes
  - locating and explaining the Northern Hemisphere terrestrial sink
  - determining the size, function, and controls on oceanic sinks
  - clarifying carbon source/sink dynamics and trends in the tropics
- **Projecting future concentrations of CO_2 and CH_4 and changes in terrestrial and aquatic carbon cycling dynamics**
  - developing capable carbon cycle, ecosystem, and carbon data assimilation models
  - quantifying errors and characterizing uncertainties associated with model inputs and outputs
  - collaborating with modelers in other Focus Areas to develop fully coupled, integrated Earth system models that incorporate projections of future carbon cycle dynamics

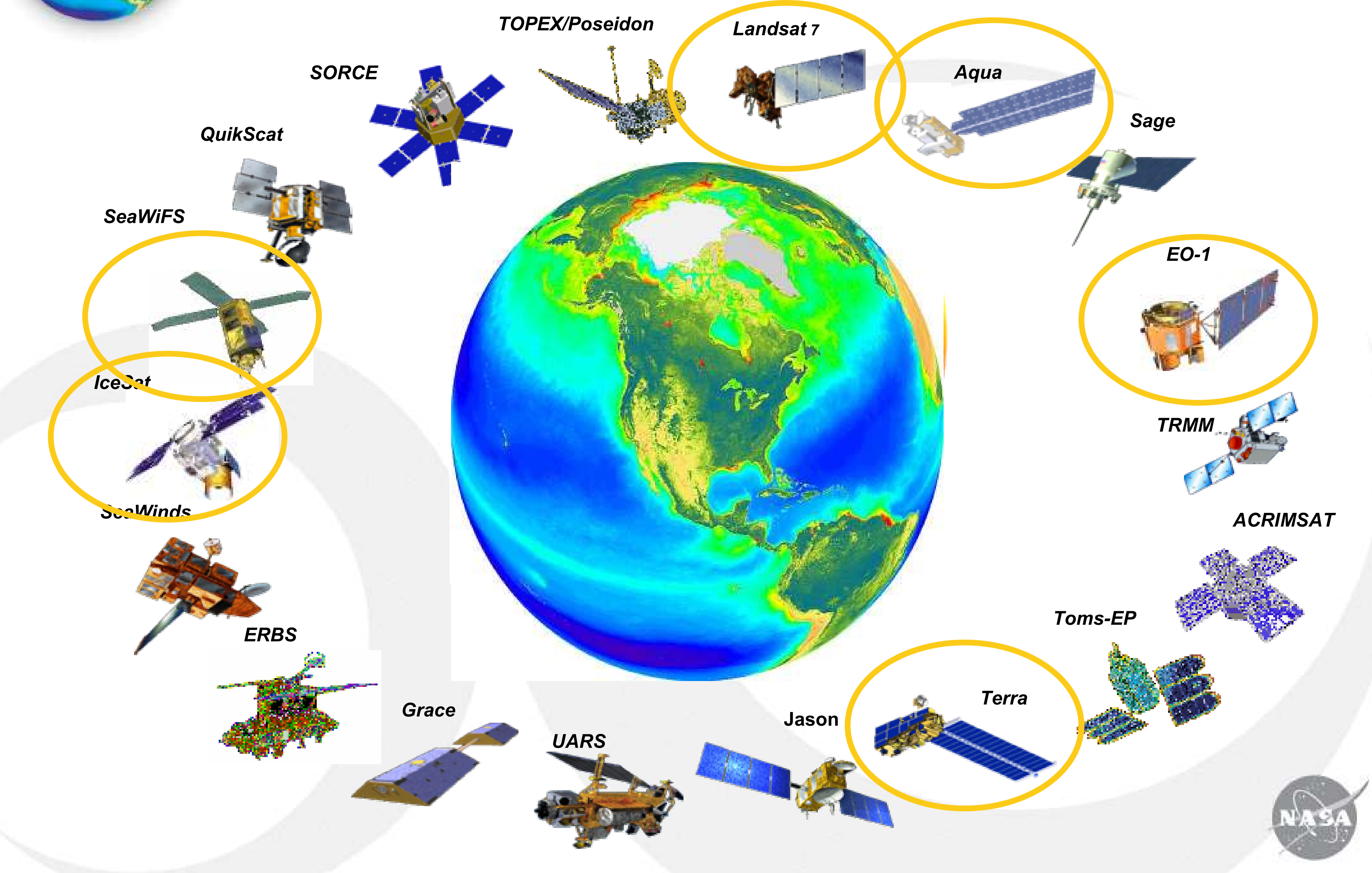
Research Challenges: Ecosystems & Biodiversity

- **Understanding the effects of global climate change on terrestrial and aquatic ecosystems**
  - evaluating the combined effects of multiple, interacting influences and stresses on ecosystem structure and function
  - characterizing and quantifying disturbances
  - understanding threshold effects and regime shifts
  - developing the capability to effectively model ecosystem dynamics and changes
- **Characterizing and quantifying feedbacks to the climate system (physical and chemical)**
- **Learning how to manage ecosystems for multiple end uses**
- **Documenting the range and distribution of organisms of importance (species with vital functions, invasive species, pathogens, etc.) and modeling to predict future distributions**
- **Understanding relationships between biodiversity and ecosystem functioning (e.g., productivity, biogeochemical cycling, biological services, resilience & adaptability)**

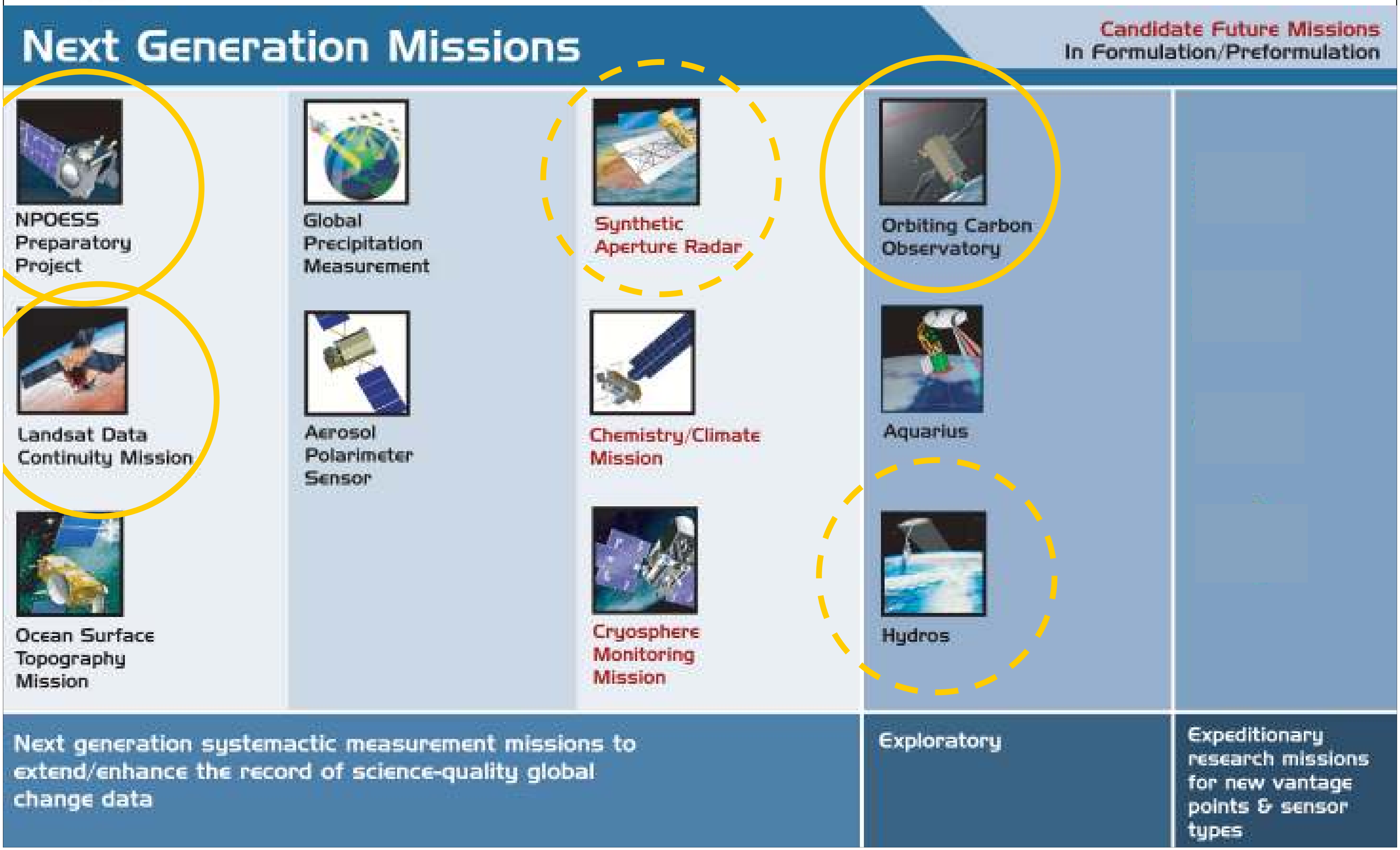
Research Challenges: Land Cover and Land Use Change

- Documenting the spatial and temporal dynamics of land cover and land use change
- Developing understanding of the combined human and natural causes of land cover and land use changes and how they interact at regional and global scales
- Characterizing and quantifying the role of fragmentation and degradation, the role of multiple drivers of change, the role of institutions, and the interactions among drivers and types of land use change
- Projecting land use and land cover ~5-50 years into the future

Spaceborne Earth Observation Systems



Next Generation NASA Earth Science Missions



Anticipated Products and Uses

- Derived data products and maps of land cover and vegetation
  - for use in decision support
  - for use in ecological, climate and Earth system models
- Monitoring and evaluation tools
  - to assess carbon management
  - to estimate agricultural, forest, fisheries and ecosystem productivity
  - to verify carbon emissions/sequestration reporting
- Ecological Forecasts (e.g., invasive species, harmful algal blooms (HABs), habitat change)
- Inputs for Climate Projections (CO_2, CH_4, ecosystem responses)
- Synthesis and Assessment analyses and reports
  - Contributions of Amazonia to the global carbon budget
  - State of the Carbon Cycle: North America (SAR 2.2)
  - IPCC analyses

Applications of National Priority


Agricultural Efficiency

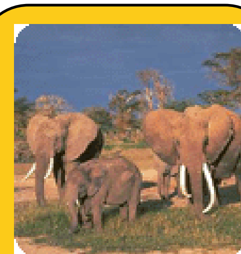

Air Quality


Aviation


Carbon Management

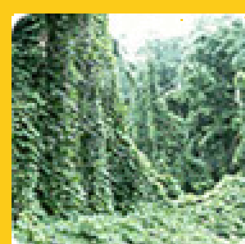

Coastal Management


Disaster Management


Ecological Forecasting


Energy Management


Homeland Security


Invasive Species


Public Health

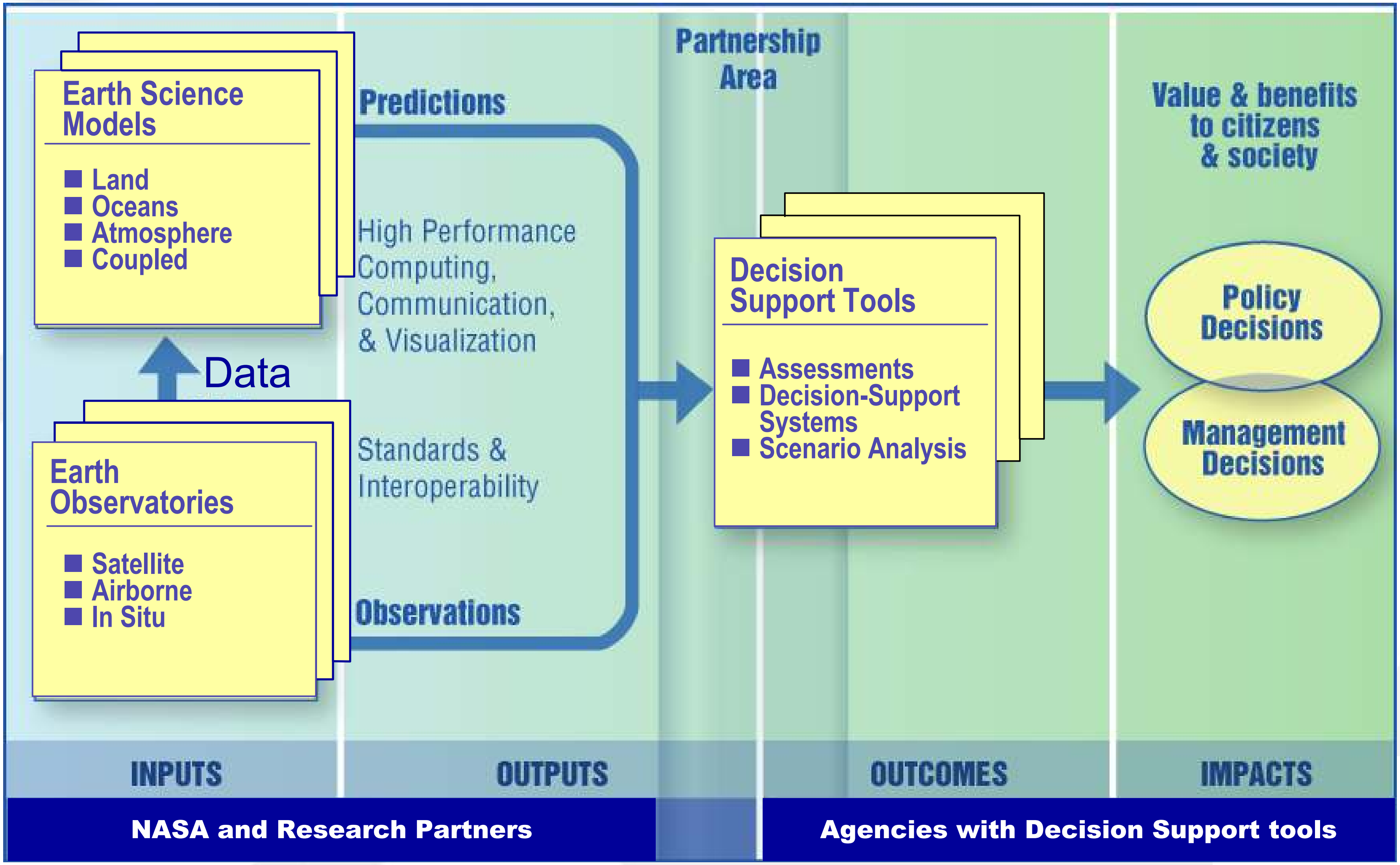

Water Management

Draw upon carbon, ecosystems, and land use/cover science

Research Challenges: Carbon Cycle & Ecosystems Research → Applications

- **Developing remote sensing, spatial analysis, information management, and decision support tools to evaluate management and mitigation options for responding to**
  - climate change
  - management of carbon in the environment
  - threats to sustainable resource use and the productivity of agricultural systems and coastal fisheries
  - changes in or loss of habitat and reductions in biodiversity
  - non-indigenous species invasions

Integrated System Solutions



NASA Focus Areas & Climate Change Science Program (CCSP) Research Elements

NASA	CCSP
Climate Variability & Change	Climate Variability & Change
Weather	
Atmospheric Composition	Atmospheric Composition
Carbon Cycle & Ecosystems →	**Land Use/Land Cover Change**
	Global Carbon Cycle
	Ecosystems
Water & Energy Cycle	Global Water Cycle
Earth Surface & Interior	
	Human Contributions & Responses

Recent Events and Milestones

- Research Opportunities in ROSES-2005
  - Land Cover/Land Use Change (14 selections; 3 funded by USDA))
  - LBA Phase 3 Synthesis and Integration (22 selections; 3 funded by W&EC)
  - Ocean Biology and Biogeochemistry (pending)
  - Remote Sensing Science for Carbon and Climate (pending)
  - Terrestrial Ecology & Biodiversity (pending)
  - North American Carbon Program (in review)
  - ICESat and Cryosat, Decisions, New Investigator Program
- OCO CDR completed
- Senior Review conducted for extended operations of satellite missions (Terra received high priority)
- 9th LBA-ECO Science Team Meeting
- Landsat Data Continuity Strategy Adjustment memo (Dec. 2005)
- NPOESS/NPP budget overruns / schedule delays

Recent Events and Milestones

- NRC Decadal Survey for Earth Science Observations initiated
- Approval for CC&E Management Operations Working Group, also Atmospheric Composition; other Focus Areas to follow
- Ocean Biology Measurement Team well underway; Land Measurement Team still spinning up

Recent Events and Milestones: CCSP

- U.S. Climate Change Science Program (CCSP) November 2005 workshop on decision support; 2006 Our Changing Planet published
- CCSP Carbon Cycle Interagency Working Group (CCIWG)
  - NACP Science Implementation Strategy published
  - NASA offers to provide NACP Office and Coordinator
  - OCCC and North American Continental Margins workshops conducted
  - Synthesis and Assessment Report (SAR) 2.2 (first SOCCR): Prospectus posted for public comment; drafting in progress
- CCSP Ecosystems Interagency Working Group (EIWG) report in press
- CCSP Land-Use/Land-Cover Change Interagency Working Group (LUIWG)
  - Interagency solicitation (through NASA's ROSES-2005)
  - LULCC Steering Group formed and active

Recent Events and Milestones: GEO

- Societal Benefit Areas for U.S. IEOS (GEO):
  - Improved Weather Forecasting
  - Reduce Loss of Life and Property from Disasters
  - Protect and Monitor Our Ocean Resource
  - Understand, Assess, Predict, Mitigate and Adapt to Climate Variability and Change
  - Support Sustainable Agriculture and Combat Land Degradation
  - Understand the Effect of Environmental Factors on Human Health and Well-Being
  - Develop the Capacity to Make Ecological Forecasts
  - Protect and Monitor Water Resources
  - Monitor and Manage Energy Resources

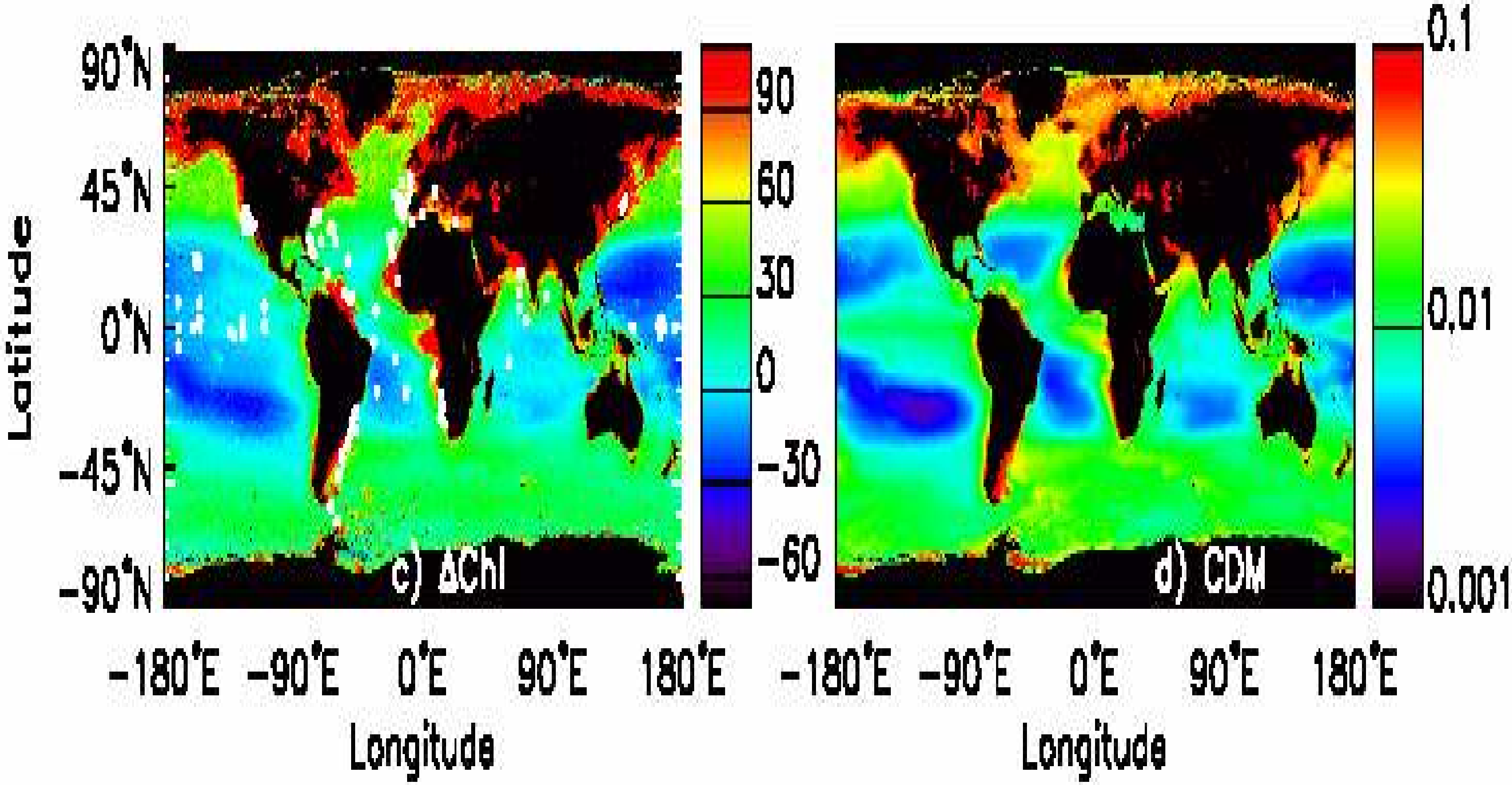
- Near-Term Opportunities:
  - Integrated Data Management
  - Sea Level Observing System
  - National Integrated Drought Information System
  - Air Quality Assessment and Forecast System
  - Global Land Observing System
  - Improved Observations for Disaster Management

Importance of Bio-Optical Model on Global Ocean Biosphere Assessment

- Two phytoplankton chlorophyll a algorithms (one empirical and one semi-analytical) were compared to test how well the information included in the two types of algorithms retrieved phytoplankton biomass. Results from a comparison on the same data set showed that chlorophyll a concentrations differ, with the percentage differences approaching 100% in high latitudes.
- The authors found a strong relationship between the difference in phytoplankton chlorophyll a concentrations and colored dissolved organic material (CDOM) concentrations indicating that the currently-used empirical algorithm overestimates chlorophyll a in regions of high CDOM. The conclusion is that the differences in the high latitude estimates is caused by the fixed CDOM to chlorophyll a relationship in the currently-used empirical algorithm.
- If we are to ever get at true carbon cycling in not only global but coastal areas (North American Carbon Program and Ocean Carbon and Climate Change Program), research needs to have the tools on orbit to rigorously separate chlorophyll a from CDOM. This will require passive measurements in different bands (UV and farther near-infrared) from LIDAR or a similar technology, as well as some new thinking about the absorbing aerosol issue.

Citation: Siegel, D. A., S. Maritorena, N. B. Nelson, M. J. Behrenfeld, and C. R. McClain (2005), Colored dissolved organic matter and its influence on the satellite-based characterization of the ocean biosphere, *Geophys. Res. Lett.*, 32, L20605, doi:10.1029/2005GL024310.

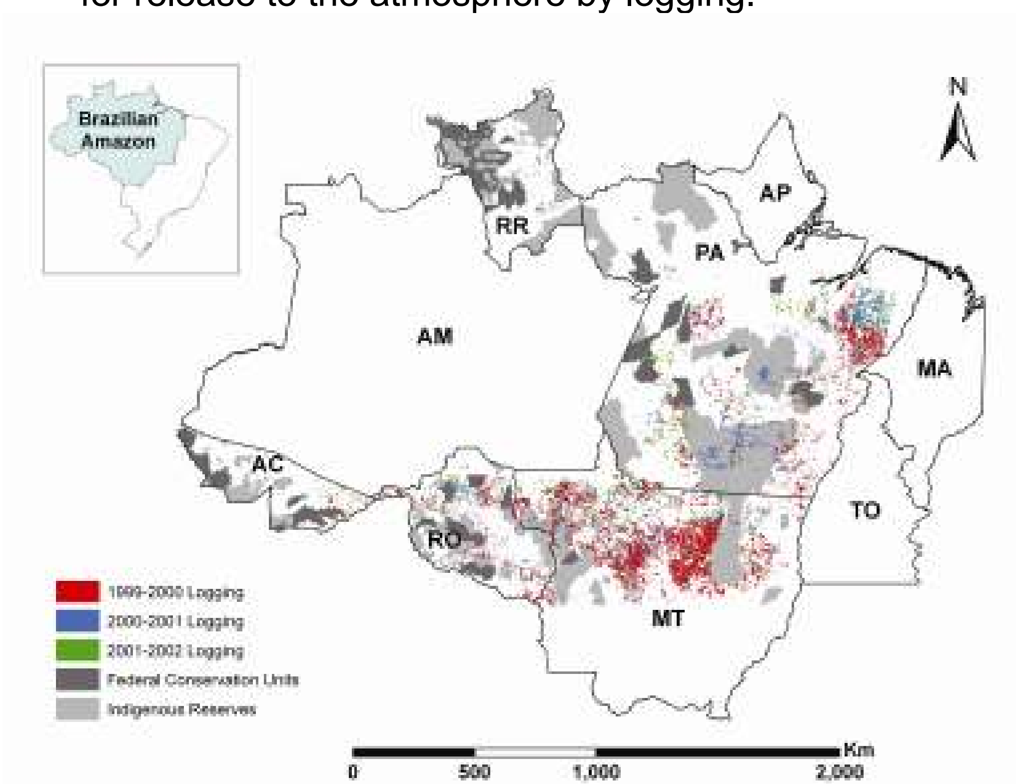
Importance of Bio-Optical Model on Global Ocean Biosphere Assessment

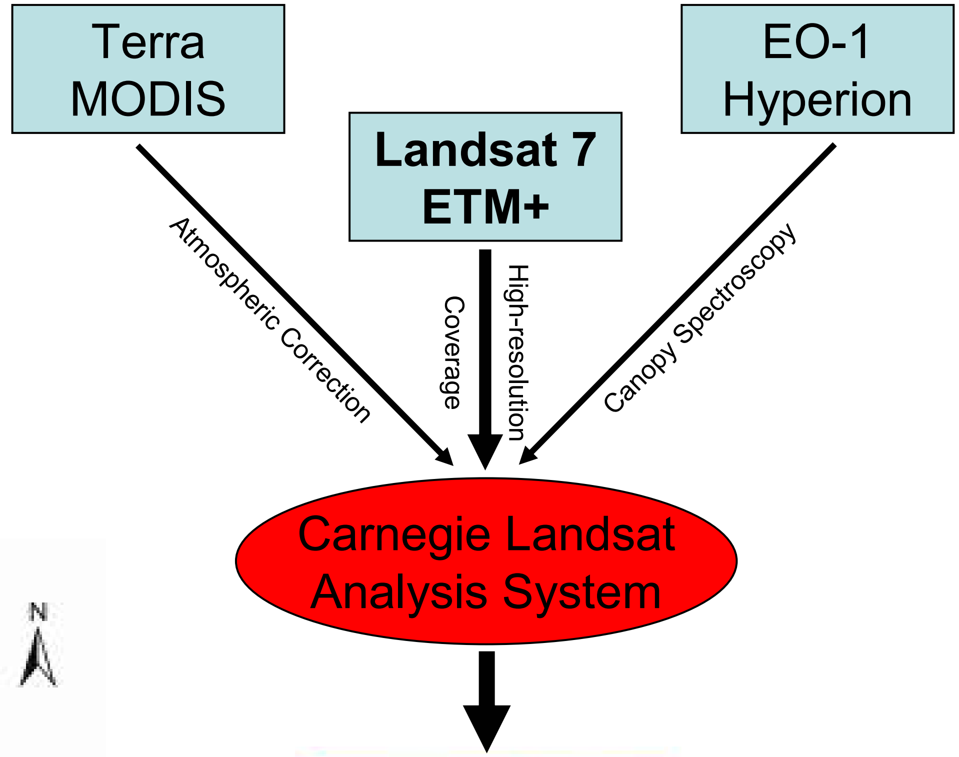


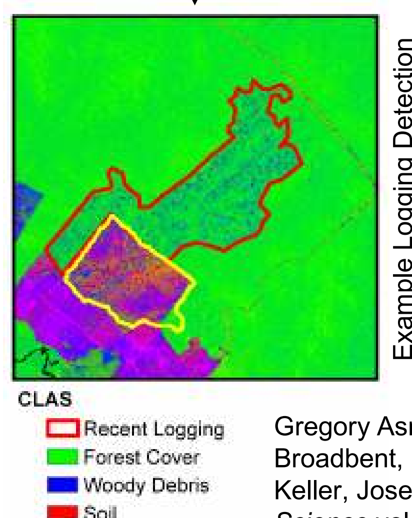
Data from the comparison of the two algorithms. Chlorophyll a concentrations differ (Delta Chl or difference in chlorophyll concentration map). Note the percentage differences approaching 100% in high latitudes. The right hand panel shows the global estimate of CDOM for comparison.

Selective Logging in the Brazilian Amazon

Amazon selective logging has been mostly invisible to satellites. The authors developed a large-scale, high-resolution, automated remote sensing analysis of selective logging in the top five timber producing states of the Brazilian Amazon. Logged areas between 1999 and 2002, were equal in area to 60-123% of previously reported deforestation area. Up to 1,200 $km^2\ yr^{-1}$ of logging was observed on conservation lands. Each year a gross flux of ~0.1 Gt C was destined for release to the atmosphere by logging.





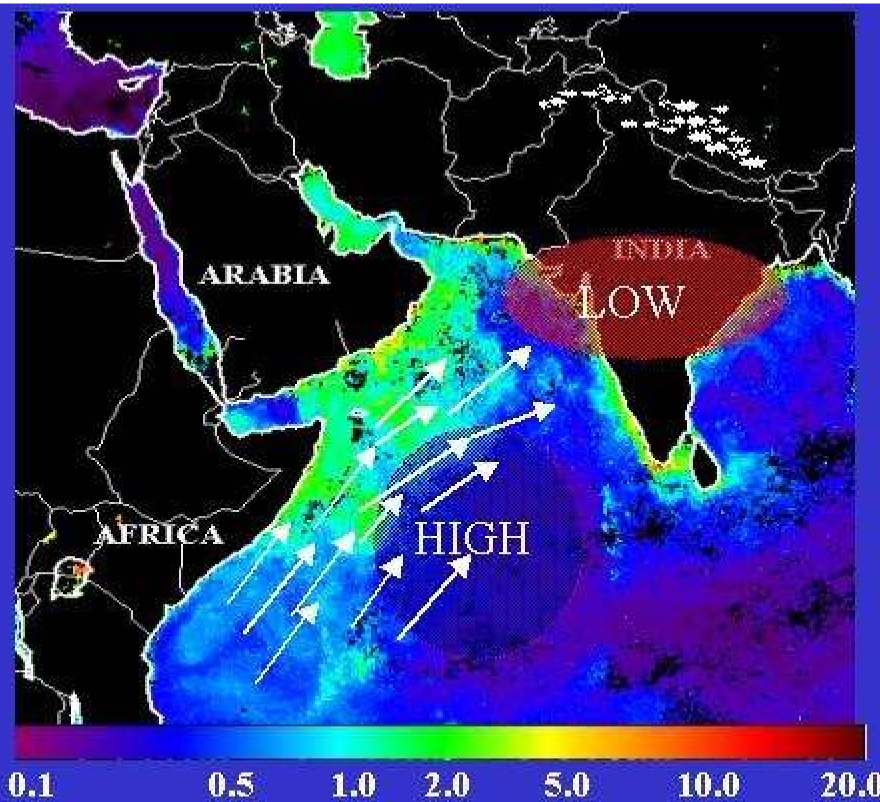


Gregory Asner, David Knapp, Eben Broadbent, Paulo Oliveira, Michael Keller, Jose Natalino Silva
Science vol. 310, p. 480-482, 21 October 2005

THE ARABIAN SEA MONSOON AND LAND-SEA TELECONNECTIONS

- Scientists have used NASA data from ocean color satellites to show that phytoplankton concentrations in the Western Arabian Sea have increased by over 350 percent over the past seven years.
- This increase in phytoplankton coincided with satellite observations of a decrease in the amount of snow cover in Eurasia. Since 1997, a decline in snow cover has resulted in a temperature and pressure discrepancy between land and water that is greater than subsequent years, which lead to this phenomenon.
- While blooms of phytoplankton can enhance fisheries, they could be detrimental to the local ecosystems, causing eutrophication and oxygen depletion (hypoxia or anoxia) that could lead to a decline in fish populations and the production of chemically-relevant trace gases such as nitrous oxide.

Citation: Goes, Joaquim I., Prasad G. Thoppil, Helga do R Gomes, and John T. Fasullo. 2005. Warming of the Eurasian Landmass Is Making the Arabian Sea More Productive. *Science* 308: 545-547



Schematic showing the reversal in wind direction during the southwest monsoon (Jun-Sept) resulting from changes in the land-sea pressure gradient. This pressure gradient is largely regulated by the extent of winter-time snow over SW Asia and the Himalayan-Tibetan Plateau region. Schematic has been superimposed on an ocean color chlorophyll image for the southwest monsoon season which shows elevated chlorophyll concentrations (mg m^{-3}) in the western Arabian Sea resulting from upwelling

Invasive Species Alter Biogeochemistry

• Data from NASA's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) were used to map biological invasions and determine how they altered the biogeochemistry of a montane rain forest in Hawaii Volcanoes National Park.

• AVIRIS measurements of nitrogen (N) in the canopy top and water content of the total canopy volume were used

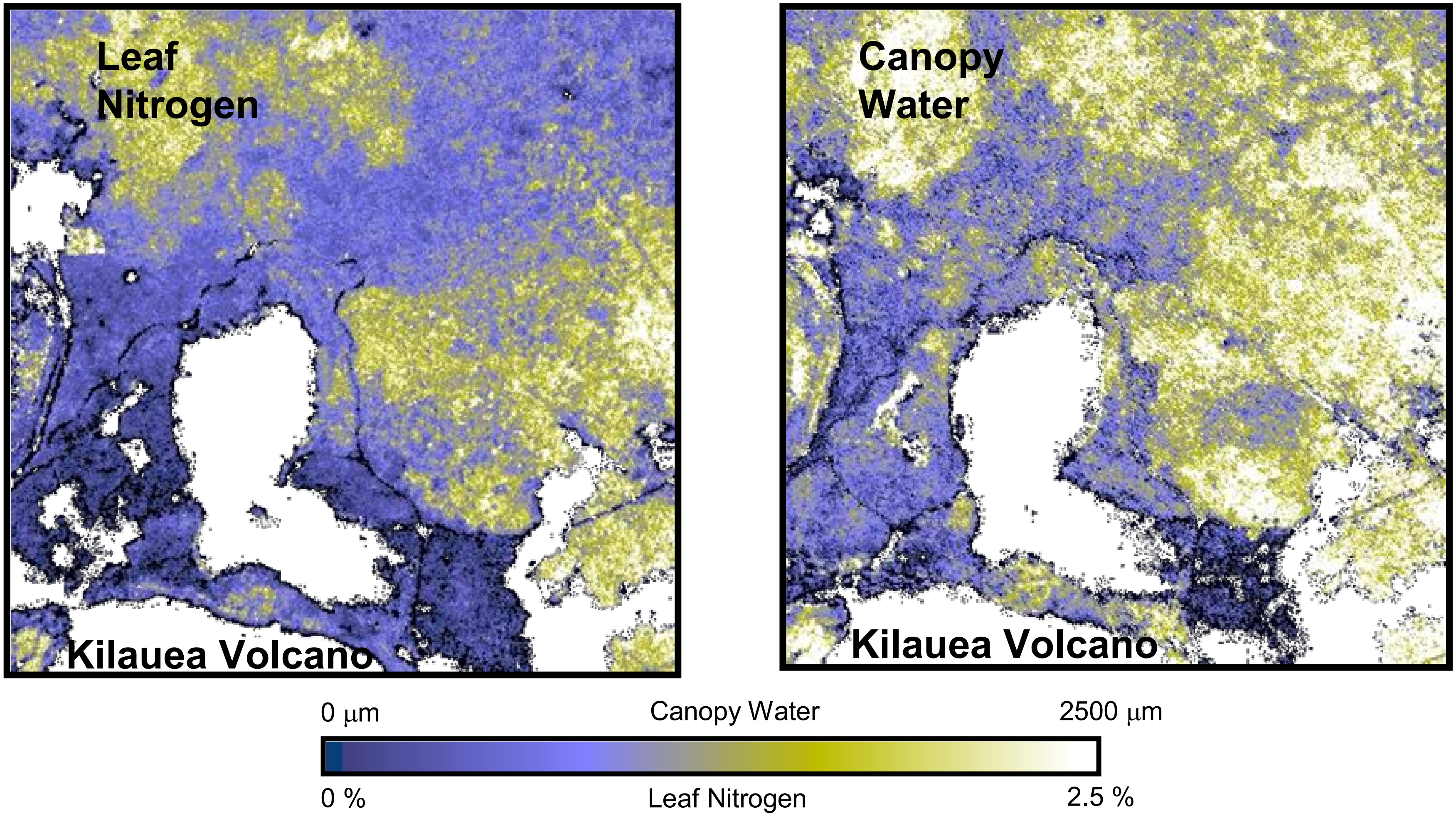
- native forest canopy is low in water and N
- invasive N-fixing tree canopy is high in water and N
- invasive understory herb is high in water and appears to be low in N in AVIRIS images

Invasive Species Alter Biogeochemistry

- Invasive N-fixing tree has doubled canopy N over the entire region imaged, causing major changes in ecosystem biogeochemical functioning
    - faster leaf turnover and decomposition
    - greater N availability and fluxes of N-containing trace gases
    - invasion by nutrient-demanding species
- Distribution of invasive understory herb was “discovered” in the AVIRIS data because of its high water content; it appears to lower the N content in the native overstory tree canopy and proliferates to exclude native plants from the understory. Its own higher N content is masked by the overstory tree foliage and is therefore invisible to AVIRIS

Asner, G.P. and P.M. Vitousek. 2005. Remote Analysis of Biological Invasion and Biogeochemical Change. *PNAS* 102(12): 4383-4386.

Invasive Species Change Biogeochemistry



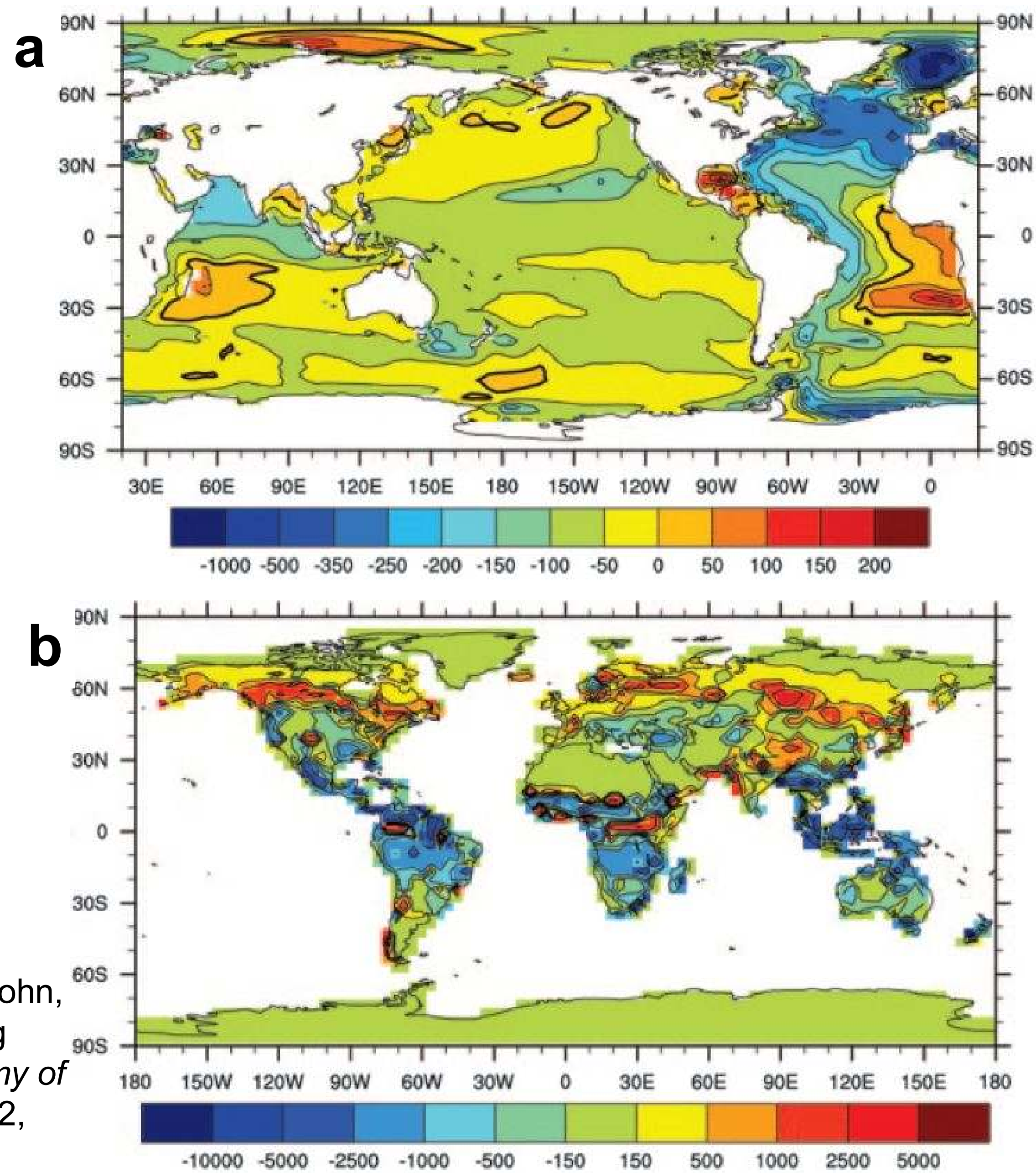
Airborne imaging spectrometry provides a unique, spatial understanding of the biogeochemical impacts of invaders.

Asner, G.P. and P.M. Vitousek. 2005. *Remote Analysis of Biological Invasion and Biogeochemical Change.* PNAS 102(12): 4383-4386.

Carbon Cycling in a Changing Climate

Sensitivity of terrestrial and oceanic carbon storage to climate. Differences in carbon storage (gC/m2) simulated by a fully coupled climate and carbon cycle models and without the effects of atmospheric CO2 increase on radiation are displayed. Future fossil fuel emissions follow a business as usual scenario. (a) Total column inventory of dissolved inorganic carbon. (b) Total terrestrial carbon inventory in vegetation and soils.

Fung, I. Y., S. C. Doney, K. Lindsay, and J. John, 2005: Evolution of carbon sinks in a changing climate. *Proceedings of the National Academy of Sciences of the United States of America*, 102, 11,201–11,206.



Carbon Cycling in a Changing Climate

- Simulations over the period using the NCAR Community Climate System Model fully coupled to a land carbon model, developed and tested using satellite and atmospheric CO_2 data, and an ocean carbon cycle model with marine biology and carbonate chemistry show decreases in both terrestrial and oceanic uptake of fossil fuel CO_2 as rates of fossil fuel emissions rise.
- Compared to simulations with constant CO_2 radiative forcing, in 2100 the fully-coupled model forced by "business-as-usual" fossil fuel emissions has 1.2 K higher globally averaged sea surface temperature, 17% slower North Atlantic overturning, and 5% lower global efflux of CO_2. These effects lead to approximately 20 Pg less total carbon in the oceans.
- On land, the fully-coupled simulation has less net carbon uptake in the tropics and greater uptake at high latitudes than with constant CO_2 radiative forcing. These regional differences approximately offset such that there is only about 20 Pg difference between total terrestrial carbon sinks.
- Turnover times of terrestrial carbon pools affect the longevity and magnitude of land sinks, and the more rapid turnover of terrestrial carbon, validated by the simulation of the contemporary atmospheric CO2 cycle, leads to a weaker sink on land with less sensitivity to climate.

NASA Performance Goals

Reduce land cover errors in ecosystem and carbon cycle models, and quantify global terrestrial and marine primary productivity and its interannual variability.

- 5ESS3 Specific output: Produce a multi-year global inventory of fire occurrence and extent.
- 5ESS4 Specific Output: Release first synthesis of results from research on the effects of deforestation and agricultural land use in Amazonia.
- 5ESS5 Specific output: Improve knowledge of processes affecting carbon flux within the coastal zone, as well as sources and sinks of aquatic carbon, to reduce uncertainty in North American carbon models.

→ Progress toward achieving outcomes will be validated by external review.

Accomplishments in Support of our 2005 Performance Assessment: 5ESS3

- ***A multi-year global fire inventory has been created with observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's Terra and Aqua satellites. This inventory documents the temporal and spatial patterns in fire occurrence and extent. August maximum fire activities for 2001 and 2002 were shown to be due to the combination of a dry season in the Southern Hemisphere tropics and the warm season over the Northern Hemisphere. The number of fires in 2001 and 2002 differed by less than 3%. [Reference: four-year inventory available at http://edc.usgs.gov/products/satellite.html; Csiszar, I., Denis, L., Giglio, L., Justice, C. O., and Hewson, J., 2005,Global fire distribution from MODIS. International Journal of Wildland Fire, 14, 117-130.]***
- ***A new burned area data product for Africa and selected validation regions will be released in provisional form before the end of FY2005 at http://rapidfire.sci.gsfc.nasa.gov/. Global production will start in 2006.***

Accomplishments in Support of our 2004 Performance Assessment: 5ESS4

- ***Contributions from NASA's Terrestrial Ecology and Land Cover and Land Use Change Programs to the Large -Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) have improved the characterization and quantification of deforestation and other types of land use change in Amazonia. New unmixing methods applied to Landsat imagery provided quantitative measurements of forest degradation due to selective logging. Logging increases the likelihood of fire, which leads to further carbon loss to the atmosphere. Thus far, land-use change has had only a minor effect on basin-wide emissions of methane and nitrous oxide. Overall, LBA results indicate that for the Amazon, intact forests are a small sink for carbon dioxide; wetlands and soils are a net source of methane and nitrous oxide, and possibly carbon dioxide; and deforestation and reforestation result in a net release of carbon dioxide. Summing the 100-year greenhouse warming potentials of these sources and sinks indicates the region may be in near balance with regard to the overall radiative forcing from long-lived gases. [Reference: two special journal issues, The Large-Scale Biosphere-Atmosphere Experiment in the Amazon. Ecological Applications, 2004, Vol. 14, No. 4 and Thematic Issue: The Large Scale Biosphere-Atmosphere Experiment in Amazonia — LBA. Global Change Biology, 2004, Vol. 10, No. 5]***

Accomplishments in Support of our 2004 Performance Assessment: 5ESS4 (cont.)

- *Data from NASA's Moderate Resolution Imaging Spectrometers (MODIS) on the Terra and Aqua satellites are being used by LBA researchers in Brazil to conduct near-real time monitoring of deforestation and alert government authorities and the public to unknown , and sometimes illegal, locations of forest clearing.. One system, called DETER, focuses on the legal Amazon; another, called SIAD, includes also the woodlands and savannas of Brazil's cerrado region. This information is being used by regulatory agencies for rapid response and by private conservation organizations interested in prevention and control of deforestation. [References: Morton, Douglas C., Ruth S. DeFries, Yosio E. Shimabukuro, Liana O. Anderson, Fernando Del Bon Espírito-Santo, Matthew Hansen, Mark Carroll. 2005. Rapid Assessment of Annual Deforestation in the Brazilian Amazon Using MODIS Data. Earth Interactions (on-line journal available at: www.earthintereactions.org); http://www.ufg.br/modisbrasil and http://www.obt.inpe.br/deter/index.html]*

Accomplishments in Support of our 2004 Performance Assessment: 5ESS5

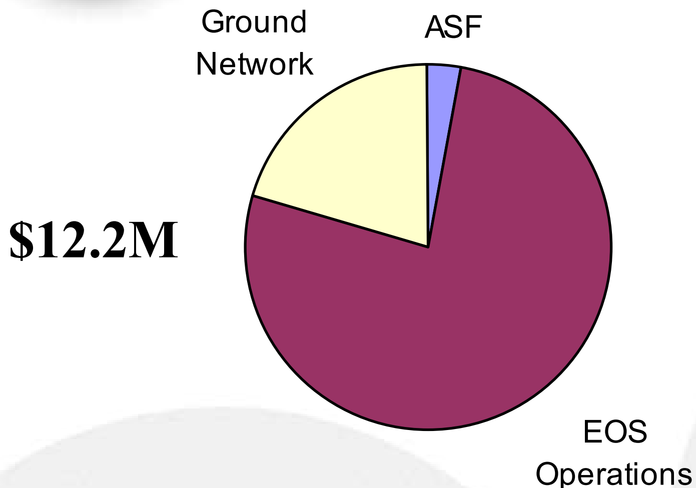
- *Researchers supported by NASA's Ocean Biology and Biogeochemistry Program have estimated the previously unknown phytoplankton growth rate term. It has been incorporated into the calculation of primary productivity from space in order to improve carbon stock estimates. Marine net primary production estimates will be achieved with higher fidelity and will improve capacity for detecting real trends in global ocean carbon cycling. [Reference: Behrenfeld , MJ, E. Boss, DA Siegel, and DM Shea. 2005. Carbon-based ocean productivity and phytoplankton physiology from space, Global Biogeochemical Cycles, Vol. 19, GB 1006]*

- *Improved carbon budget calculations and nested ecological and biogeochemical models are being coupled with general circulation models for the Mid-Atlantic Bight (MAB) and South Atlantic Bight (SAB) of the east coast of the United States. The critical dynamic of shelf-slope front transport has been greatly improved in these models, and the nitrogen-cycle baseline model version has been extended to explicitly include inorganic carbon cycling and oxygen. [Reference: Several papers already have been presented at international scientific meetings and/or submitted for publication, e.g., Fennel, K., J. Wilkin, J. Levin, J. Moisan, J. O'Reilly, D. Haidvogel, Nitrogen cycling in the Mid Atlantic Bight and implications for the North Atlantic nitrogen budget: Results from a three-dimensional model -- submitted to Global Biogeochemical Cycles.]*

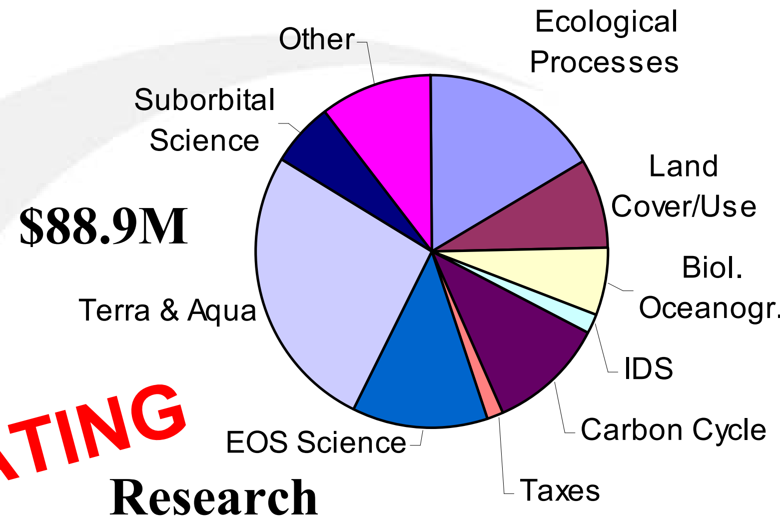
Accomplishments in Support of our 2004 Performance Assessment: 5ESS5 (cont.)

- *Results and analyses from the Sea-viewing Wide Field-of-View Sensor (Sea-WiFS) mission provide unprecedented views and understanding of ocean phenomena, ranging from small-scales processes such as quantification and dynamics of phytoplankton blooms within U.S. coastal waters, to utilization of a continuous time series of ocean color data to detail shifts in climate and the impact and feedbacks on ocean ecology and biology, and applications of SeaWiFS data to follow local and global whale migration and distribution. Improved ocean color information is critical for improvements to primary productivity, carbon, and ecological models. [Reference: Deep-Sea Research II, Vol. 51/1-3(2004) 1-318 and Vol. 51/10-11(2004) 911-1204]*
- *Scientists have used NASA data from ocean color satellites to show that phytoplankton concentrations in the Western Arabian Sea have increased by over 350 percent over the past seven years. This increase in phytoplankton coincided with satellite observations of a decrease in the amount of snow cover in Eurasia. Since 1997, a decline in snow cover has resulted in a temperature and pressure discrepancy between land and water that lead to this phenomenon. While blooms of phytoplankton can enhance fisheries, they could be detrimental to the local ecosystems, causing eutrophication and oxygen depletion that could lead to a decline in fish populations and the production of nitrous oxide, a greenhouse gas. [Reference: Goes, Joaquim I., Prasad G. Thoppil, Helga do R Gomes, and John T. Fasullo. Warming of the Eurasian Landmass Is Making the Arabian Sea More Productive,. 2005. Science 308: 545-547]*

Carbon Cycle & Ecosystems FY2005 Budget: $200.2M (as of Sept. 2004)

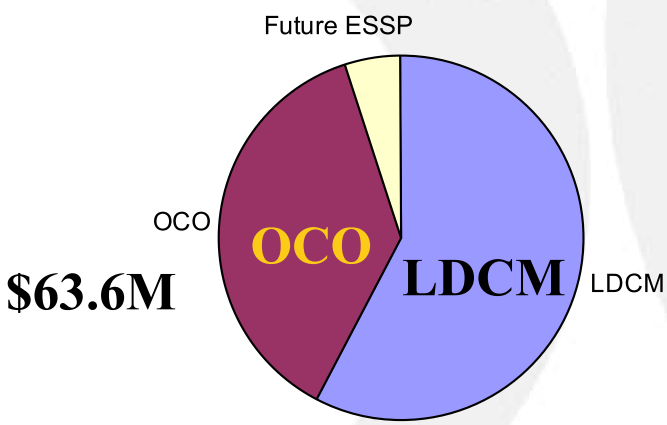


Operations

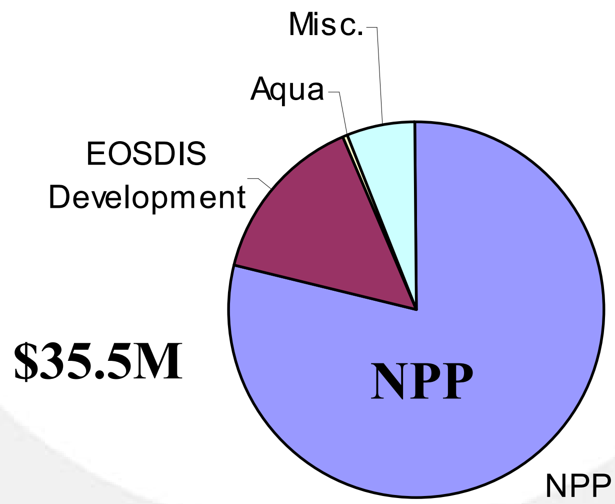


Research

NEEDS UPDATING



Missions in Formulation



Development

Needed Inputs and Cooperation

Other NASA Focus Areas

- Water and Energy Cycle
- Climate Variability and Change
- Atmospheric Composition
- Earth Surface and Interior
- Weather

Applied Science

Education, Outreach, Public Affairs, & Legislative Affairs

Data and Information Systems

Technology

CCSP Program Elements

International Programs

Continuing Challenges: Science

- Carbon data assimilation -- developing the models, scoping our computational requirements, securing needed input data sets
- Human-Environment Interactions -- making sure what people do is in our models and forecasts; blending natural and social science approaches
- Synthesis and Assessment – characterizing and quantifying errors and uncertainties; reporting in useful ways
- Cross-, Multi-, Trans-Disciplinary scientific cooperation on Earth system questions and application of the knowledge achieved to societal needs

Continuing Challenges: Program Management

- Securing the time series of Earth System Data Records – inter-calibration of sensors; algorithms to make a seamless record; periodic reprocessing
- Evolution of Data and Information Systems support from core EOSDIS to more Focus Area responsibility
- Securing our new observations in light of limited opportunities for new missions, future budget prospects, and transformation
- Securing needed *in situ* ocean observations and process understanding
- Transitioning our use of aircraft for field campaigns and cal/val
- Working our partnerships (lots of interfaces!)
  - research and applications, science and operations
  - interagency (CCSP, GEO, NACP, plus many others)
  - international (e.g., GEOSS, validation coordination)

What is New or Coming Soon?

- NASA science planning to set agency strategy in light of new vision for NASA, agency-wide transformation, and Decadal Survey report
- Advance planning for Carbon Cycle and Ecosystems focus area through CC&E MOWG
- Significant budget challenges for FY2006 (and probably following years) . . .
- Research Opportunities in Space and Earth Science (ROSES) – 2006 (omnibus for another12-month period)
- All electronic proposal / review process; proposal submission through NSPIRES or grants.gov
- Task Book for progress reporting to be adopted across Focus Area