NASA Earth Science Enterprise's

Biology and Biogeochemistry of Ecosystems and the Global Carbon Cycle

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ESE Questions for Biology/Ecosystems/Carbon:

How are global ecosystems changing? (Variability)

What changes are occurring in global land cover and land use, and what are their causes? (Forcing)

How do ecosystems respond to and affect global environmental change and the carbon cycle? (Response)

What are the consequences of land cover and land use change for the sustainability of ecosystems an economic productivity? (Consequences)

What are the consequences of climate and sea level changes and increased human activities on coastal regions? (Consequences)

How well can cycling of carbon through the Earth system be modeled, and how reliable are predicted future atmospheric concentrations of carbon dioxide and methane by these models? (Prediction)

Biology and Biogeochemistry of Ecosystems and the Global Carbon Cycle

Why we care

- Food, fiber, and fuel production (agriculture, forests & fisheries)
- Ecosystem goods & services (timber, pharmaceuticals, habitat, air & water quality)
- Sustainability of uses
- Carbon management (for climate mitigation and/or sustainability)

Forcings

<-- Growing human population & consumption levels

<-- Land cover and use change

<-- Environmental pollution & nutrient deposition

<-- Climatic variability & change (including solar radiation and ocean circulation)

<-- CO_2 “fertilization”

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What we need to know

• Regular (~ every 3-5 yr) quantification of the rate, areal extent, and type of global land cover changes, and reliable estimates of their effects on above-ground biomass and carbon stocks.

• Land use history and the fate of lands subject to clearing and various forms of land use (i.e., recovery).

• Identification and characterization of trends in the strength and persistence of global sources and sinks for carbon (CO_2, CH_4 and others).

• A basic understanding of how ecosystems respond when subjected to multiple, interacting, changing environmental factors -- some outside the range of past variations.

• The impacts of changes in the ocean, especially the coastal ocean, on primary productivity, carbon storage, and overall ecosystem health.

What is required to characterize changes in ecosystem properties

- **Land cover** and **land cover change**, classified by type and/or structural attributes. Also, **coral reef** distribution and change.

- **Ocean color** to estimate primary productivity and phytoplankton biomass (i.e., carbon stocks) in the coastal ocean as well as the open ocean.
  - **fluorescence** to assess physiological status and discriminate phytoplankton from non-living components in coastal waters.

- **Vegetation indices** and other **biophysical properties** to estimate primary productivity on land and to assess physiological status.

- **Vegetation height** and/or vegetation **canopy volume** to estimate above-ground biomass (i.e., carbon stocks).

What is required to <u>understand</u> ecosystem responses and impacts on carbon cycling

• **Atmospheric CO_2 concentrations** to identify and quantify regional sources and sinks of CO_2.

• Ecosystem responses to **disturbance**, the course of the ensuing **recovery processes**, and the resultant carbon accumulation or loss.

• Identification of **phytoplankton functional groups** that influence carbon dynamics, and information on the **dynamics of phytoplankton blooms** and the environmental controls on them.

• **Physiological state** of primary producers (photosynthetic capacity, stress, canopy chemistry).

•Ocean mixed layer depth and **vertical structure of planktonic ecosystems**.

What is required to predict ecosystem responses and impacts on carbon cycling

- **Ecosystem models** that capture process-level understanding of multiple, interacting, changing environmental factors .

- **Carbon cycle and budget models** that incorporate realistic mechanisms and the couple land, ocean, and atmosphere.

- **Atmospheric CO_2 and CH_4 measurements** that can constrain inverse models of atmospheric transport.

Systematic Observations

- **Land cover and land cover change**: Landsat 7 now
  Plan ==> Land cover inventory (data buy option)
  (30 m resolution, seasonal coverage)

- **Ocean color**: SeaWiFS, MODIS and SIMBIOS now
  Plan ==> Transition to NPP and operational NPOESS
  (continue SIMBIOS data merger project)
  (1 km resolution, near-daily coverage)

- **Vegetation indices, biophysical properties, and land cover**: AVHRR and MODIS now
  Plan ==> Transition to NPP and operational NPOESS
  (1 km resolution, near daily coverage)

Exploratory / Process-Oriented Observations

- **Vegetation recovery**: vegetation height and/or canopy volume to estimate changes in above-ground forest biomass (i.e., carbon accumulation or loss) following disturbance; also vegetation index for non-forest recovery and hyperspatial imagery (for sub-pixel information on causal factors).

- **Dynamics of marine ecosystems**: productivity, carbon export, and temporal dynamics of the coastal ocean; bloom phenomena; identification of functional groups.

- **Global sources and sinks of carbon**: atmospheric CO_2 concentrations to constrain inverse models of atmospheric transport and identify/quantify source and sink regions.

- **Cold climate processes:** freeze-thaw transitions and estimates of growing season length.

Technology

• High pulse-repetition rate imaging **lidar** systems and/or multi-frequency **radar** systems for vegetation height, canopy profiles, and canopy volume; also, **lidar** for vertical distribution of biomass in the ocean.

• **Lasers** and/or **passive techniques** for precise measurements of total atmospheric column and/or vertical profile abundance of CO_2 ($^{13}CO_2$, $C^{18}OO$, CH_4, and CO are also of interest).

• **Hyperspectral systems** (~ 10 nm resolution spanning visible and, for land, near to short-wave infrared spectrum) for identification of phytoplankton functional groups, enhanced discrimination of land cover classes, and assessing the physiological status of primary producers.

• Small **visible area array imager** for geostationary-based observation of coastal oceans as frequent as every ten minutes.

Research and Field Campaigns

- Identify, characterize, and quantify global and regional sources and sinks for carbon using available remote sensing data.

- Validate MODIS terrestrial and marine net primary productivity (NPP) data products and test relationships with measures from *in situ* networks.

- Characterize responses and understand impacts of disturbances on carbon dynamics (e.g., fire, deforestation, coastal nutrient/sediment loading).

- Develop techniques, algorithms, and data sets for monitoring of forest cover and carbon stocks for Global Observations of Forest Cover (GOFC).

- Conduct the LBA-Ecology campaign to study the effects of tropical forest conversion in Amazonia on carbon storage and exchanges.

- Support research on the biophysics underlying remote sensing of biomass, freeze-thaw processes, functional groups and/or species assemblages, and vertical structure of planktonic ecosystems.

Modeling

- Develop and improve ecosystem models to:
  - incorporate actual land cover
  - integrate global ocean carbon data
  - dynamically couple land - climate, ocean - atmosphere
  - realistically portray multiple, interacting stresses.
  - support and/or respond to periodic model intercomparisons
  - utilize remote sensing data products
  - achieve spatial and temporal scaling

- Develop and improve global carbon models, including new models that couple land, ocean, and/or atmospheric components.

- Advance inverse and forward modeling of atmospheric carbon dioxide concentrations and transport processes.

Priorities

- Systematic observations of ocean color, vegetation properties, and land cover ==> cheaper, more accurate/precise, increased temporal coverage, better calibration
- New exploratory missions: 1) quantifying carbon cycle dynamics (atmospheric CO_2 and biomass) and 2) impacts of disturbance and stress on ecosystems ==> lasers! (but also SAR, hyperspectral, etc.)
- Field campaigns and process studies ==> autonomous *in situ* capabilities (especially for ocean), airborne prototypes, information technology
- Modeling ==> information technology for handling data sets of varying type, complexity and volume

Measurement Goals (interpret with care) ???

- Spatial resolution: Global coverage ==> Land - ~ 30 m; Ocean - 1 km (~ 100 m coastal?)
- Temporal resolution: Global coverage as often as possible ==> Land - Daily (~ hourly for fires?); Ocean - Daily (diurnal variations in coastal zone)
- Tall poles:
    - Lasers, lasers, lasers
    - High spatial resolution, frequent coverage (polar orbit or geostationary)
    - Handling large data volumes routinely (input/output!)
    - Moving systematic observations to operational sponsors (management and technology)