Terrestrial Ecology, Carbon Cycle, Land Use / Land Cover Change, and Biodiversity (TECLUB): Priority Science Questions and Measurements

A workshop was held at Goddard Space Flight Center in October 2014 to address the challenge of advanced planning for the NASA Earth Science Division. The workshop, organized and managed by Dr's. Forrest Hall (NASA GSFC) and Scott Goetz (WHRC), involved 50 scientists from institutions and agencies including NASA, USGS, USFS, NSF, NOAA and DOE engaged in terrestrial ecology, carbon cycle, land use and land cover change, and biodiversity (TECLUB) research. A draft report was posted online for comment by a wider community and the comments were addressed in a final report (http://cce.nasa.gov/cce/pdfs/TECLUB_Final_Report.pdf) from which this summary is drawn.

Key challenges/questions for Earth System Science in the coming decade

Rapid changes in climate and ecosystems are driving the concerns of policy makers, as important societal functions become increasingly impacted. Climate change, carbon management, biodiversity protection, food security and other key issues require policy and science knowledge to address key unanswered questions of societal relevance. TECLUB measurement priorities address four key questions:

1. How long can Earth's ecosystems sustain their functions as they are modified by climate and human activities?
2. How will water and food security be affected as climate changes and human consumption intensifies; how will they respond to various policies aimed at adapting to and mitigating these effects?
3. What are the consequences of significant changes to existing ecosystem services? Terrestrial and marine ecosystems influence the rate of climate change, currently absorbing half of fossil fuel emissions. Which terrestrial ecosystems are most responsible for this mitigation, and by how much? How are climate and anthropogenic changes affecting their ability to sequester carbon?
4. Biodiversity and ecosystem sustainability are changing as a result of human alterations to the landscape. What are the consequences for human well-being?

Data Requirements and Research Needs

To address these scientific questions, the science community must quantify the state and dynamics of terrestrial ecosystems at finer temporal and spatial scales. The TECLUB priority needs address (1) continuity in the current observational data and capabilities, (2) improved temporal frequency, and spectral and spatial resolution of remote sensing observations, and (3) new kinds of observations already available but leveraging current technologies and approaches. The identified measurements require both the continuation of existing assets, as well as new measurements using technologies developed in the past decade.

In addition to global data needs, regional studies are needed to address uncertainties in global observations and improve models for better understanding of underlying mechanisms. These requirements can be addressed with sub-orbital missions and targeted orbital observations coupled with *in situ* measurements to (a) permit policy makers to assess and mitigate *regional* impacts in arctic, boreal, temperate and tropical ecosystems and (b) assess and validate remote sensing algorithms and analysis frameworks needed to generate the required information.

Global Observations: Space-based observations to address key scientific questions and societal needs

Only global, periodic, long-term, spatially contiguous data series can satisfy global policy information needs to understand and mitigate the impacts of climate and land use change on human societies, agricultural security, and biological diversity.

The first global measurement priority for all disciplines emerging from the workshop was to increase the observational frequency of the legacy 30m spatial resolution data to acquire ~weekly observations.

Weekly cloud free observations will permit finer temporal scale resolution of vegetation composition, vegetation function and condition. These data were identified as essential to enable detection, quantification and characterization of rapidly changing land use patterns. Frequent, repeat, moderate resolution data were also identified as important for characterizing phenology, taxonomic diversity, and their dynamics in persistently cloudy areas. Frequent data are essential to link modeling results to continuously operating flux measurements. Cloud-free, spatially explicit spectral observations at ~weekly intervals require a 3 to 4 day repeat overpass, particularly in regions with high cloud cover.

Higher temporal resolution would also enable improved vegetation structure, function and dynamics information by exploiting multi-date phenology information and much-improved landcover type discrimination (particularly for global agricultural monitoring). Adding capacity to acquire selected high spectral resolution data would provide essential information on vegetation condition (i.e. structure, function and health) at critical time steps. In all disciplines better coordination between US, European, Japanese, Brazilian and other satellites, sensors and data products are needed to improve the spatial and temporal resolution of land change dynamics, in continuity with the 40-year Landsat record.

The second priority measurement need identified by all discipline groups was the missing vertical dimension of vegetation structure.

It is critical to add vertical information to the two-dimensional maps of vegetation community composition. At a minimum, annual measurements of three-dimensional vegetation structure at meter-scale horizontal resolution and sub-meter vertical resolution are required to enable enhanced characterization and quantification of LULCC, and to quantify forest biomass for global carbon cycle and terrestrial ecosystem studies, as well as habitat for better understanding patterns of biodiversity, habitat use and conservation efforts.

The third global priority was quantification of primary productivity and agricultural yields of food and fiber through improved global measurements of vegetation and biogeochemical composition, function, and photosynthetic capacity and rates.

This priority could be satisfied by augmenting the Landsat and Sentinal2 multispectral imagery with an additional satellite carrying an imaging spectrometer with appropriately selected narrow spectral bands spanning the vegetation chlorophyll-a to thermal spectral domains. The additional bands are desired to quantify the biochemical status of vegetation, photosynthetic capacity and rates of surface-atmosphere carbon, water and energy exchange. A full spectrum imager would provide additional spectral flexibility. Trade studies to quantify the added value of full spectrum imaging over selected narrow-band imagers in terms of their relative operational complexity, data handling and cost will be needed to determine best approaches.

Measurement requirements associated with each of these priorities are summarized in Table 2 of the full TECLUB report.

Regional Observations

The top TECLUB priorities for regional data are high-resolution imagery for validating and understanding medium resolution measurements of land use change and ecosystem function, and accurate, dense atmospheric carbon concentration measurements particularly in the tropics and the arctic.

The report called for dense regional measurements in key regions, which is strongly echoed by other recent reports (CEOS 2014; Moore et al. 2015). Some of these requirements will be met via programs like the DOE's Next Generation Ecosystem Experiments, the Arctic Boreal Vulnerability Experiment, and projects under NASA's Earth Venture class of missions. In the next decade these and additional work and science are needed.

Models that use global data must be improved and validated at high resolution, best accomplished at regional scales. Interdisciplinary work that links human, social, and environmental observations across scales also will benefit from high spatial and temporal resolution regional observations complementing global observations.

Links with existing and planned U.S. and international programs

It is important to note the TECLUB participants identified measurement needs independently of planned remote sensing technology from U.S. and international partners. For example, the first priority measurement need for more frequent acquisitions recognizes this may be partially addressed via planned missions.

As TECLUB measurements priorities are met by new international missions (e.g. Sentinel2, Landsat8, GEDI, IceSat2, NI-SAR, BIOMASS, etc), priorities should be adjusted to accommodate unfilled measurement needs.

What additional investments are needed?

Satellite monitoring of the terrestrial carbon cycle is a missing key to achieve scientific understanding of climate feedbacks and realistic prediction of climate scenarios. To date, these feedbacks are the single most critical factor limiting the accuracy of those predictions. This lack of spatially and temporally comprehensive information results in large model uncertainties (about ±40%).

Using selected narrow spectral band imagers or full spectrum imaging (spectroscopy) can provide critical additional information to quantify the components of gross primary production (PAR, Fpar and Light Use Efficiency) and related fluorescence emissions. Multi-angle narrow spectral imaging of the landscape adds information for estimating these variables. To reduce uncertainties, a synergistic measurement framework is needed with specific data requirements across spatial scales.

Anticipated scientific and societal benefits

The Group on Earth Observation identified nine societal benefit areas including: disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity. The previous NRC2007 report identified three science themes: disruption of carbon, water and nitrogen cycles; changing land and marine resource use; and changes in disturbance cycles. Most recently, Working Group3 of the IPCC-AR5 identified four key "knowledge gaps" including: improved global high resolution crop production data, globally standardized and homogenized data on soil and forest degradation, improved understanding of land-based climate mitigation options, and better understanding the effects of climate change on terrestrial ecosystem productivity and carbon stocks. In 2010, Congress directed NASA to develop a prototype Carbon Monitoring System to provide data products required by carbon trading protocols and national-scale reporting and monitoring efforts. The TECLUB effort was conducted with this background and context.

Science communities involved

The research communities involved in TECLUB represent a broad spectrum of scientists listed in the report posted online (http://cce.nasa.gov/cce/pdfs/TECLUB_Final_Report.pdf). Many of the participants were involved in related efforts (IPCC AR5, GEO, CEOS, and the prior NRC Decadal Survey).