NASA TE New Directions Working Group – Summary Report

Members: P. Siqueira, A. Elmore, J. Kellndorfer, M. Litvak, P. Moorcroft, and D. Morton

The following white paper provides a list of topics and discussion points that have been part of the NASA terrestrial ecology new directions working group, assembled at the request of Diane Wickland.

The purpose of the group was to

> "Identify what is new, compelling and important in terrestrial ecology that can be significantly informed or advanced using remote sensing capabilities."

In what follows are two sections, one, a bulleted list of ideas, meant to be short and succinct, for the purpose of soliciting further thought and interaction. The second section contains more descriptive text, which provides detailed thought on a selected set of topics that are meant to be responsive to the request made of this group. This is intended to serve as a living document that summarizes this group's thoughts and deliberations on the topic of *non-carbon* related remote sensing applications and needs for NASA's terrestrial ecology program.

1. Bulleted list

There are a number of interesting areas that are ripe for further development and could lead to new avenues of research, understanding, and applications of remote sensing for terrestrial ecosystems. These are:

- Ecosystem function for land-water-atmosphere coupling, leveraging capabilities with GRACE, SMAP, SWOT
- Evolving remote sensing science to support terrestrial ecology: fusion, airborne focus, targeted multi-sensor data collection, scaling re: NEON
- Climate change adaptation: changing ecosystem structure, function, and composition
- Human-dominated ecosystems, growing role of management for ecosystem function
- (please add as desired)

2. Detailed description of selected topics

There are a total of four topics that were identified during the interactions that our group had in a one month period. These are:

i.) On the interaction of ground water and terrestrial ecosystems and on the role of these ecosystems in land/atmosphere exchange

ii.) On the human adaptation to changes in ecosystem services

iii.) On the changes in, and quantification of, ecosystem functions, via monitoring of terrestrial biogeochemical cycles (e.g. Nitrogen) in the environment

iv.) On the science of remote sensing; this was broken into two parts

a.) scaling from ground-based, localized observations to airborne and satellite regional assessments of ecosystem characteristics

b.) the need for better developing methods for making use of remote sensing time series and multi-sensor data sets,

a. Impacts of changes in ground water on terrestrial ecology.

Nearly a decade of drought in the desert southwest of the United States combined with increased demands for water from growing urban populations has increased the need to understand relationships between desert vegetation and groundwater quantity and quality. Processes examined in response to ground water alterations could be ecological and/or hydrological and could manifest themselves by observed changes in land cover, ecosystem structure, the balance of species within forest cover, vegetation physiological processes, variations in flooding and water dynamics, desertification, *etc*. Therefore, a wide variety of sensors (active, passive, and across the electromagnetic spectrum) could be effectively employed to gain the necessary understanding required to sustainably manage groundwater resources. Methods established over the past several decades to quantify photosynthetically active vegetation cover in deserts could be combined with new technologies that more directly measure vegetation structure such as LiDAR and repeat acquisitions of microwave RADAR. New advances in sensors that could be used to directly characterize the state of the ground water include GRACE, SMAP or SWOT. However, there remains a need to establish how well these sensors work across various geographic regions and if they are sensitive enough to link changes in ground water availability to associated changes in terrestrial ecological and hydrological processes. Synergistic approaches employing modeling and remote sensing observations over time are likely required to determine how important observed changes in ground water availability are to driving the changes in ecological and hydrological processes discussed above. Throughout this work an emphasis should be placed on temporal patterns in soil moisture and vegetation demands for water, and less on analysis of single acquisitions which are prone to over interpretation and insensitive to the highly variable nature of hydrology in water limited environments. Work that further links changes in vegetation with geomorphologic changes (e.g., wind erosion and dust emissions) and land atmosphere exchanges of water and greenhouse gasses have the potential to add continental and global relevance to regional studies.

b. Human Adaptation to Changes in Ecosystems Services

Studies of human adaptation to climate change would ideally integrate the full range of activities traditionally relevant to NASA's terrestrial ecology program with activities relevant to the applied sciences program. Investigators should fill the important role of identifying specific threats and vulnerabilities that influence environmental management actions, hazard assessment, and in some cases, human health considerations. For example, sea level rise will affect all coastal regions, necessarily influencing conservation programs that seek to maintain regional biodiversity and ecosystem services provided by coastal wetlands. NASA data products and models could be instrumental in defining risk and identifying lands most suitable for wetland migration corridors and other conservation options. More generally, range shifts of economically important species are expected to play a central role in any climate adaptation plan. Such considerations might be most important for agriculturally important species, with perennial species requiring the earliest and most thoughtful considerations. Similarly, the geographic range of invasive species will require management responses that might be new to a particular geographic area. Pathogens, parasites, and diseases will experience range shifts, and shifts in their phenology, which will require land and resource managers to adapt. NASA data that identifies and characterizes specific biota experiencing range shifts, or changes in ecosystem functioning related to range shifts (*e.g.,* phenological changes) would be particularly relevant to adaptation policy.

NASA data and products can play a strong role in evaluating ways in which ecosystems mediate or enhance hazards related to climate change. Many hazards can be characterized as extreme climate events (*e.g.* intense precipitation extremes, hot and cold weather events), which have a strong role in shaping ecosystem responses to climate change. Hazards that are mediated by ecosystem structure are ideally suited for study by terrestrial ecologists and should be specifically considered when designing adaptation management plans. For example, interactions between vegetation and flooding risk, urbanization and heat waves, and land cover and air quality are all relevant to NASA's terrestrial ecology program. Studies of land surface phenology are particularly relevant in that adaptation to many climate-driven changes in ecosystems will manifest themselves in phenological changes, hence prediction of phenological change will lead to predictions in other areas of interest to terrestrial ecology. Examples include wildfire risks, species invasions, ecohydrological changes influencing water quantity and quality, and shifts in the timing and intensity of allergy seasons.

c. Changes in and Quantification of Ecosystem Functions and Biogeochemical Cycles

The terrestrial ecology program should work to contribute towards a unified approach for maintaining the terrestrial ecosystems and biological resources in the face of climate change. NASA scientists have studied the impacts and projected future impacts of climate change on ecosystems for decades. These studies have described a complex, spatially and temporally dependent relationship between climate and ecosystem functioning that influences human activities in many ways. Informing society (particularly governmental decision makers) on these relationships is the first step towards defining appropriate ways to adapt to future changes. Satellite and sub-orbital remote sensing data have unique characteristics that make such data ideally suited for preparing for adaptation. For example, future changes to the environment and human adaptive responses are likely to be spatially complex. Management options will therefore be highly dependent on geographical position and history of land use.

There is a continuing need for the locating and mapping ecological resources that are vulnerable to future climate change, for which NASA data would form a critical role. The time-dependent characteristics of adaptation favor studies that utilize remote sensing data to produce information at regular intervals. Studies that identify threshold responses of ecosystems to climate change, and their commensurate human adaptation responses, are particularly relevant.

New remote sensing methodologies, such as imaging spectrometry, and active remote sensing techniques, such as LiDAR and RADAR, are providing new forms of information about the composition and structure of terrestrial ecosystems. Multispectral optical remote sensing measurements have been successfully applied to classify landcover and biome types, and to estimate canopy properties such as leaf-area index, vegetation greenness, and fraction of photosynthetically active radiation absorbed by vegetation (fPAR). Hyperspectral observations have been shown to be capable of *mapping biogeochemical cycles* (e.g. the Nitrogen cycle) and for mapping ecosystem stress and decline. An important new direction for NASA terrestrial ecology research will be to identify how these new sources of remotely sensed information can be used to better inform our understanding of the nature of the terrestrial ecosystems function in different areas of the globe and how they are changing as a result of natural processes, climate change and other human activities.

For example, recent studies have shown how imaging spectrometry, when combined with LiDAR- and RADAR-based observations of vegetation structure, can be used to resolve within-biome differences in the composition of plant canopies. These observations are perhaps most useful when performed at the species-level, or when plant function of individual organisms is remotely inferred.

The ability to remotely characterize terrestrial vegetation offers new opportunities to better understand landscape variation in phenotypic response to changes in environment. When combined with appropriate process-based models, this information on plant composition, functioning and structure can give new insights into the fluxes of carbon, water and energy within ecosystems. In addition, improved measurement of spatial and temporal variation in ecosystem composition and structure, can be used to determine the ability of different ecosystems to provide key ecosystem services, such as important habitat for particular species that are of conservation or management interest, and the ability of ecosystems to provide long-term carbon storage or buffer the impact of flooding events.

d. Remote Sensing Science

While not an ecological outcome in of itself, the continued evolution of remote sensing as a science remains an important component of NASA's Terrestrial Ecology program. This is because of the multi-faceted nature of terrestrial ecosystems and the need for using multiple observing methods, dispersed over time, in order to characterize and quantify ecological systems. For this reason, a special heading his also made here regarding the need for continuing the development of remote sensing as a science, as it applies to the above-mentioned applications and others that mature over time.

i. Scaling between ground-based, airborne to spaceborne remote sensing capabilities.

In recent years a variety of new ground and airborne sensors has become available (or will become available); sufficiently so that, even in a limited sense, it is possible to pose the question on how to make best use of multisensor observations and how to configure these assets (for instance, for airborne sensors, in terms of altitude, viewing angle, seasonality). Fixed, ground-based remote sensing observations from gigipixel photography and more standard webcam instrumentation offer opportunities to scale from field sites to airborne and satellite sensors. Scaling has historically been accomplished through the development of empirical relationships, which should continue. However, future work might effectively progress through the development of analytical and semi-analytical models that quantitatively relate observations made at multiple scales. The need for making best use of airborne and ground-based studies may be especially relevant in the upcoming five years in light of NASA's Earth Ventures calls.

ii. Data fusion and multi-temporal data mining for ecosystem process understanding.

There is a need within NASA's terrestrial ecology program to focus on the mining of now readily available decadal-scale time series from medium resolution remote sensing data. The 30+ year observations of land surfaces with Landsat data is at the core of this opportunity, but also more recently available synthetic aperture radar (SAR) observations from the European ERS-1/Envisat, the Canadian Radarsat, and the Japanese ALOS and JERS-1 missions provide an invaluable data stream for sub-hectare scale measurements of terrestrial ecosystems. Optical and SAR data provide complementary measurements based in physically different remote sensing principles. While passive optical measurements are based on a photo-chemical interaction, active SAR measurements are in principal determined by physical and dielectric (moisture) properties of the measured land surface. The continuous processes of ecosystem degradation and recovery are still poorly understood globally, yet with the multi-temporal and multi-sensor data streams at medium resolution, new discoveries of underlying ecosystem processes both from natural and anthropogenic causes would be explored.

Research focused on data fusion and time-series analysis of optical and SAR data is now also timely as the developments in high performance computing, geometric and radiometric calibration of the data records with globally available elevation data, as well as progress in data mining algorithms and tools provide unprecedented advances in affording continental- to global-scale medium resolution data mining. The coupling of these data streams with ecosystem process models will allow finer calibration and validation of the models (e.g. in model initializations or parameter inversions at finer model scales), and thus foster progress in the prognostic validity of models. Also the fusion with and upscaling of systematic large area airborne (e.g. hyperspectral and LiDAR) and field observations (e.g. national forest inventories, data from the NEON and LTER networks) needs to be better understood as the scale of field and remote sensing observations converge.