NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2011
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A.4 Terrestrial Ecology
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The National Aeronautics and Space Administration (NASA) solicited proposals for Terrestrial Ecology investigations within the NASA Earth Science Program. The following types of research investigations were requested:

- New analyses of impacts to and vulnerability of terrestrial ecosystems and critical terrestrial components of the global carbon cycle to global environmental changes.
- Science investigations to advance the development and utilization of new and/or multisensor remote sensing approaches to estimate important terrestrial ecosystem and carbon cycle properties. Studies using advanced airborne sensors to evaluate approaches relevant to future satellite missions are of special interest.
- Studies to analyze coastal ecosystem impacts of the 2010 Gulf of Mexico oil spill utilizing NASA airborne data collected in support of the national response.
- Successor studies that offer to significantly advance the results of prior NASA Terrestrial Ecology research toward meaningful answers to important NASA and USGCRP carbon cycle and ecosystems research questions.

A total of 107 proposals was received, and 16 have been selected for funding at this time. The total funding to be provided for these investigations is approximately $10.7 million over three years. The investigations selected are listed below. The Principal Investigator, institution, investigation title, and a project summary are provided. Co-investigators are not listed here.

Michael Coe/The Woods Hole Research Center
Climate and Land Use Change at the Amazonian Agro-Frontier: Historical and Future Effects on the Surface Energy Balance

The recent expansion of pastures and agricultural monocultures has resulted in 730,000 km2 of the Amazon Basin being deforested. Despite recent declines in the rates of forest clearing, the deforested area of the Amazon Basin is projected to jump from ~18% today to as much as 40% by 2050 as the global demand for agricultural commodities continues to rise. Influences of land use change (LUC) on ecosystem processes are thus expected to become increasingly important for the region; forest conversion into pastures and crops tends to reduce evapotranspiration and albedo, altering the regional energy balance in ways that increase surface temperature and alter precipitation patterns. Until recently, our ability to quantify these LUC effects on ecosystem processes was constrained by the lack of spatial-temporal information that captured the complex land use transitions in Amazonia. However, with the high temporal resolution and decade-long span of the MODIS dataset, we have new opportunities to not only map these complex dynamics, in

spatial as well as temporal detail, but also to quantify their consequences for the regional energy balance. Here we will use MODIS products combined with a dynamic vegetation model to quantify the influences of LUC on the albedo and latent and sensible heat fluxes in the southeastern Amazon, where deforestation rates are greatest. The overarching questions we address in this study are: How does LUC (historical and future) affect the regional energy balance and partitioning in Amazonia? How do these effects compare with those associated with changes in the radiative forcing from increased atmospheric CO2 concentration? To do so, we will use existing MODIS products to (i) map the spatial-temporal patterns of LUC from 2000-2012 in the Brazilian states of Mato Grosso and Pará and (ii) quantify LUC effects on the local and regional energy balance (latent heat, sensible heat, and albedo). This information will serve as the basis for predicting how future (2012-2050) land use transitions will alter the energy balance, using spatial models that simulate deforestation, cattle ranching, and soybean expansion. Future radiative forcing associated with these changes in land use will then be compared to the radiative forcing caused by increased atmospheric CO2, providing an estimate of future net radiative forcing in the region. Finally, we will scale up the analysis to the entire Amazon Basin, simulating combinations of several LUC and CO2 emissions scenarios. Global demand for agricultural products is expected to increase substantially in the next few decades and tropical regions such as Amazon are the only remaining areas with available land to meet these demands. This increased incentive for deforestation may be exacerbated by proposed changes in the Brazilian forest code, which currently requires private landowners to conserve substantial tracts of forest. The proposed research will provide critical insights into how these changes may impact radiative forcing and, ultimately, alter regional and global climate and carbon cycles.

Ralph Dubayah/University of Maryland
Exploring the Potential of Single Photon Lidar for Ecosystem Structure Derivation

Vegetation vertical structure has been identified by the ecosystem community at large, and by scientific panels, such as the NRC Decadal Survey, as the highest science priority, and lidar is universally acknowledged as the most accurate means of deriving that structure. The loss of the lidar segment from the DESDynI mission has left the ecosystem community with no planned structure observations other than what the ICESAT-2 (I2) mission will obtain, to be used by themselves, or in fusion with the DESDynI radar segment (DESDynI-R) and other data sources.

Two decades of experience with waveform sampling lidar have given us a clear knowledge of what is achievable from spaceborne waveform lidar, allowing us to inform space mission development and determine the implications of such missions on science priorities for terrestrial ecology. Unfortunately, there is no comparable background information for the single photon-counting lidar (SPL) technology of the ATLAS instrument on the ICESAT-2 mission. As a consequence there is tremendous uncertainty about its capabilities as deployed in space, and the role such observations can play, either alone, or in fusion with other sensors, in the study of ecosystems and the carbon cycle. This uncertainty leads to a set of basic questions that must be addressed regarding the efficacy of SPL and which form the central basis of our proposed research.

The overall goal of our study is to explore the efficacy of SPL for deriving ecosystem structure. In particular, we seek to answer the following questions:

1) What methods are most appropriate for retrieval of canopy height and vertical structure using SPL?

2) What accuracies are likely achievable for the estimation of ecosystem structure from ICESAT-2 and how will these vary as a function of environmental and canopy conditions?

3) What are the impacts of the difference in expected performance of ICESAT-2/DESDynI-R vs. the original DESDynI mission on biomass estimation and habitat characterization?

Our methodological approach is to first determine how the wealth of existing waveform and discrete lidar, and the very limited airborne SPL data may be used to simulate spaceborne SPL. Given its very low energy return, the performance of SPL is hypothesized to vary strongly with canopy cover and other environmental gradients. To explore this issue more fully, we propose to acquire new SPL data using a proven commercial SPL system over a strong gradient in the Sierra Nevada where the researchers have existing lidar and field data. These data sets will allow us to develop and test algorithms for estimating canopy height and canopy structure, and to understand the potential dependency of algorithm efficacy on canopy architecture, among others. These algorithms will then provide us with sets of simulated structure retrievals, from which ICESAT-2 performance may be assessed geographically.

Our proposed research falls into five major categories of activities: (1) identify appropriate methods of simulating MPC space observations using existing waveform, discrete return and MPC airborne lidar data sets; (2) acquire new MPC data across a strong geographic environmental gradient in the Sierra Nevada; (3) develop and test algorithms for retrieving canopy height and vertical structure from MPC; (4) assess the expected performance of MPC data from I2 and understand how this performance varies as a function of geographic canopy and environmental variability; (5) test I2-like data sets, by themselves, and in fusion with other remote sensing data to assess impacts on biomass estimation and habitat characterization relative to Decadal Survey recommendations as proposed for DESDynI.

Ultimately, our research will help define the efficacy of MPC for the retrieval of ecosystem structure, and in doing so provide direct guidance to the Terrestrial Ecology program on the carbon and ecosystem science achievable during the I2/DESDynI-R era.

Andrew Elmore/UMCES Appalachian Laboratory
Assessing the Influence of Local Phenology on the Response of Forest Productivity to Changes in Growing Season Length

A trend towards a longer growing season, here defined by the number of days between the spring onset and autumn offset of greenness, has been observed in regional- to global-scale remote sensing time-series spanning the past 30 years. This phenological change is thought to be occurring in response to human-induced changes in climate and atmospheric chemistry. Although observed phenology trends contain uncertainties and depend, in part, on algorithm selection, such shifts are likely to have large impacts on water and carbon cycling, as well as energy balance, in temperate forests. For example, satellite data and atmospheric CO2 concentration ([CO2]) data suggest that a longer growing season has led to increased plant growth in the northern hemisphere. Increased tree productivity might create a negative feedback to increasing atmospheric [CO2] and climate change, although uncertainty surrounds this hypothesis due to complexity between phenological timing and ecosystem responses. Thus there are strong scientific imperatives for developing a mechanistic understanding of the relationship between phenological changes and carbon uptake by forest ecosystems. Remote sensing scientists have long been interested in relating temporal trends in phenology to field observations of the carbon cycle. However, such work requires a 30-year record of ecosystem processes that is easily, and relatively inexpensively, scaled from trees to forest stands, thus enabling assessment of ecosystem responses to variations in phenology over broad spatial extents. We propose that dendroecological analysis provides the ideal opportunity to meet this challenge and to comprehensively investigate the influence of changes in phenology on the productivity of forest trees in the eastern US.

The proposed research will be conducted in two regions of the deciduous-forest biome that exhibited contrasting trends in the onset of spring greenness over the past 30 years. If annual variation and long-term trends in growing season length are influencing forest productivity, we hypothesize that this influence will be a function of phenological variability occurring at local scales. The project would specifically investigate the importance of growing-season stability in canopy greenness on the response of tree productivity to a change in growing season length. Conceptually, the stability of summer greenness (i.e., the degree to which canopies ¿greendown¿ throughout the growing season) is directly related to the capability of forests to utilize a longer growing season for carbon assimilation. We will test this concept using measurements of multi-species tree productivity and indicators of plant stress and nitrogen availability (carbon and nitrogen isotopes in tree rings) at sites spanning gradients of spring onset and greendown. The specific objectives of the project are: (1) assess the influence of environmental factors on medium-resolution spatial patterns in the spring onset, growing-season stability, and autumn offset of greenness; and (2) determine how change in the timing of spring onset, recorded by coarse-resolution sensors, has influenced forest productivity across gradients in medium-resolution phenology and growing-season greenness stability. The project would meet these objectives through synergistically use of phenology observations at coarse- and medium-resolution, LiDAR observations of canopy complexity, and tree ring records of carbon and nitrogen isotopes to understand the influence of growing season length on tree productivity, measured as tree basal area increment. Overall, the proposed research provides an unparalleled opportunity to understand cross-scale linkages between spatial and temporal phenology patterns and how these patterns influence tree productivity.

Michael Falkowski/Michigan Technological University
Fuel Consumption and Carbon Cycling in Northern Peatland Ecosystems: Understanding Vulnerability to Burning, Fuel Consumption, and Emissions via Remote Sensing of Fuel Moisture and Fire Radiative Energy

Peatland ecosystems represent 3-5% of the land surface, but sequester 12-30% of soil organic carbon (Gorham 1991). Current trends and climate models predict a general pattern of decreased water availability as a likely outcome of climate change. These climate changes can lead to increased amplitude of water table variation, including large mid-summer declines in water table height. Although peatlands have conventionally been considered resistant to wildfire due to their relatively wet soil conditions, recent studies have shown that the extent of wildfires in boreal North America, where peat fuels are common, has been steadily increasing in recent decades. The increasing extent of burning is likely due to warmer and drier climate conditions, which effectively extends the fire season and increases fire risk and subsequent CO2 emissions. Consumption of fuels and the subsequent emission of carbonaceous species into the atmosphere are dependent on fuel moisture content. Wetter fuels are more likely to exhibit smoldering combustion; this in turn has consequences for the quality of the remaining organics, as well as the composition of particulate emissions to the atmosphere. Understanding peat moisture content will enable an assessment of susceptibility and vulnerability to burning, ultimately allowing a means to model subsequent emissions. State-of-the-art remote sensing techniques are beginning to provide surface moisture maps over large areas. As such, datasets for a given platform may be able to provide surface moisture characteristics leading up to and following individual burning events in different peatlands. While there is a substantial literature describing drought codes and fuel moisture indexes in upland ecosystems, equivalent data describing thresholds for fire behavior in peatland ecosystems is lacking. Long-term surface peat moisture datasets derived from remote sensing data may indicate threshold conditions for severe and extensive peatland burning. However, key uncertainties associated with differences in peat structure, water table height, and moisture characteristics from thesedata have to be addressed. Taken together, coupling field assessments with remotely sensed data in recent and historically very severe burns will provide an understanding for the potential for scaling with each application. Considerable research has sought to characterize biomass combusted from wildfires via the remote measure of fire radiative energy (FRE). The utility of this approach is apparent given the availability of MODIS active fire products. Research has shown a strong relationship between FRE and the quantity of biomass combusted. However, FRE research has focused on fuels with low moisture contents, with increasing uncertainties apparent when rates of consumption are low. As a result experimental and modeling research is needed to quantify the uncertainty in using such products to infer consumption in wet fuels. Objectives: - Explore the utility of diverse sensor systems in detecting changes in peat moisture and moss spectral characteristics in relation to vegetation type, physical characteristics, and vegetation structure; - Characterize patterns of drying in diverse peatlands in the Great Lake States,

Canada, and Alaska; - via experimental lab and field peatland fires, characterize the effect that moisture content has on FRE, and subsequently scale-up and model the impact of peatland fuel moisture on the ability of satellite based FRE products to infer biomass combusted; - Compare the carbonaceous emissions inferred from the FRE methodology to emission rates evaluated using common fire effects modeling systems [CONSUME/CANFIRE] and field data to independently evaluate the uncertainties in satellite and model based consumption estimates.

Douglas Morton/Goddard Space Flight Center
Dynamics of Amazon Forest Disturbance and Recovery from Multi-Temporal Airborne LiDAR

Tropical forests ecosystems respond dynamically to climate variability and disturbances on time scales of minutes to millennia. The Brazilian Amazon accounts for approximately 25% of tropical forest carbon stocks, and nearly 50% of tropical deforestation in recent decades. Coupled with drought-related increases in canopy mortality and fires, the synergistic interactions between climate and land use in Amazonia threaten the forests and their large stocks of carbon.
Rates of forest disturbance and recovery determine the net impact of changes in Amazon forest carbon stocks from climate variability and human activity. To date, our knowledge of the effects of disturbance and recovery processes in tropical forests on forest structure and carbon content is derived almost exclusively from networks of forest inventory plots. These plots sample small areas (typically <1 ha), and few plot-based studies provide a regional understanding of forest disturbance from human activity, such as logging or fire. Sampling from ICESat-I provided a valuable snapshot of Amazon forest structure but fails to inform us of the dynamism of intact or degraded forests. Amazon forests with frequent disturbances from human activity remain under-studied. Ongoing negotiations on REDD+ (Reducing Emissions from Deforestation and Forest Degradation plus enhancing forest carbon stocks) have placed additional emphasis on quantifying changing carbon stocks in both degraded and intact tropical forests.
Here, we propose to evaluate dynamics of forest disturbance and recovery in the Brazilian Amazon using multi-temporal airborne LiDAR data and coincident field measurements. The proposed work is centered on eight main research sites spanning both climatic and land-use gradients. Large area coverage with airborne LiDAR at each site (1,000 ha) will provide data on fine-scale variability in forest structure for intact and degraded forest types. Coincident field data collection at each site will be used to calibrate and validate LiDAR-based estimates of canopy structure and biomass and provide complementary data on species composition, understory vegetation, and coarse woody debris. LiDAR and field data will be collected from 2011 through 2013 under separate funding from USAID. Together, the multi-temporal LiDAR and field data will be used to evaluate questions related to the dynamics of forest disturbance and recovery, including: How do forest structure and biomass vary over small spatial (10-1000m) and temporal scales (1-3 years)? Do changes in forest structure and post-disturbance recovery vary with the frequency or intensity of forest degradation from logging and fire? We will also assess the spatial and temporal variability in forest structure, biomass, and disturbance rates across all research sites, to answer questions including: How do canopy

height, crown cover, and biomass vary across the Brazilian Amazon? What are the rates of canopy tree mortality in intact and degraded tropical forests? Within-site and across-site comparisons are designed to provide a regional perspective on the impacts and vulnerability of Amazon forests to climate variability and human activity.
Multi-temporal airborne LiDAR data and coincident field measurements in this study will provide unprecedented detail on disturbance and recovery processes in intact and degraded Amazon forests. Methodological objectives of the proposed work complement the scientific goals, including assessments of the detection threshold of changes in forest structure from small footprint LiDAR and the lifetime of space-based LiDAR data due to temporal de-correlation from disturbance and recovery dynamics in tropical forests. Improved understanding of recent disturbance-driven changes in Amazon forests, and the strengths and limitations of different LiDAR technologies for this work, are critical advances in the study tropical forest responses to climate variability and human activity.

Scott Ollinger/University of New Hampshire
Exploring Relationships Among Water Use Efficiency, Canopy Nitrogen and Carbon Cycling across North American Ecosystems to Improve Land Surface Models

Cycles of carbon (C), nitrogen (N) and water in terrestrial ecosystems are tightly coupled through a shared set of biophysical processes. The N status of plants is a key control on C assimilation, and both affect water fluxes from land to atmosphere. In turn, water availability is one of the most important controls on plant growth globally and can set an upper bound on the availability of N. How ecosystems respond to changes in the availability of water and its temporal variability will likely be among the most important effects of climate change and one of the most challenging for models to capture.

Recent analyses have demonstrated significant, broad-scale relationships between canopy %N and both whole-canopy photosynthesis and shortwave canopy albedo. These results stem from the constraints imposed by acquisition of multiple resources, which drive plants toward functional convergence among a variety of leaf and canopy level traits. The resulting patterns suggest a greater degree of coupling between C, N and energy balances than has previously been considered and provide a basis for using canopy spectral data to improve understanding of ecosystem-climate interactions.

To date, efforts to develop similar scaling approaches for plant water use and water use efficiency (WUE) have lagged, despite abundant evidence suggesting strong relationships between WUE and plant C and N status. Contributing factors include: (1) incongruency of the spatial and temporal scales at which ET and WUE are derived, (2) incomplete understanding of the mechanisms driving WUE across species and ecosystems, (3) the challenge of relating species-level measurements to water fluxes over diverse canopies, and (4) a scarcity of analysis that have considered WUE in relation to plant traits and plant functional types across space and time.

Based on results from our prior NASA-funded research, combined with documented relationships between C and water cycles, the objectives of the proposed work are to

examine how evapotranspiration (ET) and WUE in forests relate to variation in foliar N and canopy photosynthesis and to use the resulting information to improve a model of ecosystem C, N and H2O cycles. We also propose that the vulnerability of ecosystems to altered precipitation amount and variability is influenced by the N status of vegetation and by the diversity of species present. We plan to achieve these goals through the following objectives:

1. Build on a previous, NASA-supported analysis of hyperspectral remote sensing and C flux data to determine how ET and WUE relate to canopy nitrogen, carbon assimilation and albedo in North American ecosystems.
2. Examine the degree to which WUE and its relation with N availability over space and time can be estimated using 13C, 18O and 15N isotope measurements in leaf and woody tissues.
3. Examine the degree to which ecosystem response to climate variability is influenced by species diversity and the N status of species present.
4. Evaluate canopy spectral properties related to WUE, canopy water content and species diversity using high spectral resolution aircraft remote sensing. This will be repeated after degrading imaging spectrometer spatial resolution to 60 m in order to evaluate future applications using HyspIRI.
5. Integrate results from objectives 1-4 to determine how WUE varies with C, N and energy fluxes, along with canopy reflectance, and use the results to improve a continental upscaling analysis of C fluxes, ET and WUE.
6. Use results from objective 5 to constrain parameters in a widely used ecosystem model and run the model forward to evaluate changes in C-N-H2O interactions under scenarios of future climate and altered biodiversity.

Elijah Ramsey/US Geological Survey, National Wetlands Research Center
Assessing Impacts and Monitoring
Response of Coastal Wetlands to the Gulf Oil Spill

In response to the Deepwater Horizon oil spill, UAVSAR PolSAR data were collected of the Gulf of Mexico waters containing oil slicks near the spill site, and of inland waters and coastal wetlands potentially at risk of impact by the oil. Analyses of the 2010 PolSAR data found unique signatures within the oil spill potentially due to variations in oil properties and that are separable from ocean returns. We will extend this work to small scales by specifically tracking and characterizing oil signatures from the spill site transported into the coastal waterways and shorelines, near inland rigs, along pipelines, or on ships transporting oil to and from refineries. Tracking and characterization of oil near shorelines will be particularly important in order to establish the link between marsh impact and exposure to oil. Detecting changes brought about by oil injection into the marsh ecosystem is critical; however, in the dynamic coastal marshes it is often difficult to clearly identify the source of change. Analyses of both pre-spill 2009 and post-spill 2010 UAVSAR PolSAR scenes have produced confirmation of oil detection in marshes located along and in the near vicinity of impacted shorelines. A preponderance of evidence from the polarimetric decomposition products suggest oil impacts observed at the shorelines extended much further into the interior marshes. We will extend those analyses based on a small area of impacted coastal marshes to cover the majority of

potentially impacted marshes of coastal Louisiana. Results of these analyses will provide a map of impacted, likely impacted, and non- impacted marshes. Two to three co-located and anniversary collections of PolSAR data will also provide an assessment of polarimetric products to identify changes related to oil occurrences and other biophysical changes. In support of oil occurrence mapping in coastal Louisiana marshes, this proposal adds another validation measure to assess whether analyses based on PolSAR data detected oil impacts in the interior marshes. A combination of 2010 ground-based measurements and polarimetric response signature analyses of indicator marshes throughout the central gulf coast showed for the first time the ability to structurally discriminate or separately map these important marsh types. Extending this to 2011 ground-based and PolSAR data provide a more representative baseline dataset for determining future change to wetlands in this region and elsewhere from detrimental impacts of oil spills and to linking results based on field data collected from non-impacted marshes to marshes likely impacted by oil. Analyses of nearly co-occurring AVIRIS and UAVSAR collections during the oil spill of impacted to non-impacted marshes will be used to assess the plausibility and value of an advanced radar-optical integrated system with improved optical pigment assessments and complete structural descriptions. Our work will determine whether more can be gained from the ecosystem monitoring effort through coordinated optical and radar collections over wetlands in the future. Although completed products have already advanced the state of knowledge of oil detection in wetlands and the linkage between marsh structures and polarimetric response signature, this proposal is put forward to ensure that the data already collected is completely analyzed to meet the science goals of the campaign and to improve wetland characterization with remote sensing in the future.

Jon Ranson/Goddard Space Flight Center
Multisensor Airborne and Ground Studies of Siberian Arctic Forests

Arctic ecosystems,i.e., boreal forests and tundra, play an important role in the climate system and have been warming in recent decades. Larch dominated forests are an important component of the global circumpolar boreal forest. In Russia, larch forests cover some 278 million ha (42% of
forests) with stem volume of more than 25 billion m3. These forests range from the Yenisei ridge on the western edge of Siberia to the Pacific Ocean on the east, and from Lake Baikal on the south to the 73rd parallel in the north. Larch stands comprise the world¿s northern-most forest stands at Ary-Mas (72º28´ N, 102° 15´ E;). Larch dominated forests occupy about 70% of the permafrost areas in Siberia. Larch competes effectively with other tree species due to its higher resistance to harsh climatic conditions. Since larch is deciduous with thick, dense bark this secies is protected from winter desiccation and snow abrasion. Larch surpasses the other tree species in water use efficiency and survives at a semi-desert level of precipitation (<250 mm/yr) typical of the Arctic. Larch forms high closure stands as well as open forests is found mainly over permafrost, where other tree species barely survive.
The vast areas of larch-dominant forests is generally considered as a ¿carbon sink"; however, positive long-term temperature trends at higher latitudes are expected to result

in an increase of fire frequency e.g.,. This increase, alongside warming-induced permafrost thawing, may convert this area to a source for greenhouse gases.
The larch forests are huge and there exists very little quantitative information about them. Careful attention must be paid when developing algorithms for quantifying larch structure. Earlier work by members of this proposal team found GLAS lidar data shows little sensitivity larch biomass. PALSAR L-band radar on the other hand appeared more sensitive to larch cover though biomass relationships were poor.. Passive sensors such as hyperspectral and thermal have not been exploited.
We propose a study to fully understand and develop the relationships of multisensor instrument data with larch canopies. This study will employ a unique and well-tested instrument package called the Goddard Lidar, Hyperspectral and Thermal (GLiHT) system with imaging waveform lidar, visible and near infrared hyperspectral, and multispectral thermal capabilities. GLiHT is an off-the-shelf portable instrument system suitable for installation on a Russian light aircraft. The system will be flown over portions Arctic Siberia areas where the proposers already have significant ground data. In addition these areas will be revisited by field personnel and additional ground information collected. It is expected that these high resolution data sets combined with additional ground truth of forest stands will lead to improved methods for mapping and monitoring these vast larch forests. These data will be made available to the ecology community and should serve as a basis for advances in satellite remote sensing of these Arctic forests.

Sassan Saatchi/Jet Propulsion Laboratory
Quantifying Variations of Tropical Forest Structure and Biomass along Altitudinal Gradient

Tropical montane forests on altitudinal gradients have complex structure and biogeographic histories, are responding rapidly to climate change, and are vulnerable to severe natural and anthropogenic disturbance. According to recent estimates from ground and remote sensing observations, Neotropical montane forests cover an area of more than 1.5 million km2 and potentially contain ~ 20% as much carbon as the total amount stored in the Amazon basin (Saatchi et al., 2011).
However, due to the complexity of the terrain and the relatively continuous cloud cover, extensive field surveys or analysis of satellite observations of these ecosystems have been near to impossible. Active remote sensing techniques from Radar (InSAR) and Lidar sensors provide a unique opportunity to measure forest structure along altitudinal gradients over complex terrains. In this study, we propose to advance the development and utilization of active remote sensing approaches from Lidar altimetry and Radar Interferometry to estimate important terrestrial ecosystem and carbon dynamic properties of tropical montane forests such as the variation of three-dimensional structure, biomass, its dynamics, and tree composition along altitudinal gradients.
In this study, we propose to advance the development and utilization of active remote sensing approaches over complex terrains by focusing on estimation of forest structure of tropical montane forests. We will focus on two study areas with extensive field data and remote sensing measurements from airborne sensors in Volcan Barva region of Costa Rica and the elevational transect along Kosnipata Valley and Manu National Park in Southern Peru. The two study areas cover similar gradients in elevation (300-3000 m)

but have different geomorphology, climate, and species composition, providing opportunities for cross-validation of methodologies and comparative study of ecosystem and carbon cycle properties. The objectives of this proposal are centered on three questions: 1. What are the main determinants of variations of forest structure, biomass, and composition along the altitudinal gradient in netropical montane forests (variations in elevation, slope, aspect, soil, nutrient, climate) ? 2.To what extent can the dynamics of forest structure and carbon (growth, mortality, recruitments) of the tropical montane forests be explained by variations in biotic (composition) and abiotic factors (landscape, soil, climate)? 3. To want extent (spatial and temporal scales) can remote sensing measurements from Lidar, Radar (polarimetry and interferometry), and multispectral sensors individually or in fusion be used to estimate the variations in structure and carbon and their dynamics over tropical montane forests?

The proposed research will focus on the physically based models and/or multisensor approaches by developing fusion of Lidar and Radar interferomerty (InSAR and PolInSAR) techniques for estimating forest three-dimensional structure in complex terrains. We believe the choice of the two study areas in Costa Rica and Andeas in southern Peru with available and extensive ground and airborne data will allow us to address some of the most challenging problems in remote sensing studies. The results of the study will enable us to provide detailed information on the capability of the new and future NASA sensors to accurately address the carbon stock and dynamics of the vast area of tropical montane forests globally.

Christopher Schwalm/Northern Arizona University
Using Observations to Assess the Aensitivity of Land-Atmosphere Carbon Exchange to Climate Variability

This project directly addresses NASA¿s Terrestrial Ecology program stated goal of improving our understanding of the structure and function of ecosystems in the cycling of major biogeochemical elements between the land and the atmosphere. We propose to quantify the sensitivity of terrestrial carbon cycling to climate variability using eddy-covariance based observations and remotely sensed indices, and use these sensitivities to derive a comprehensive set of benchmarks for improving land-surface and terrestrial biospheric models. This project will also scale the calculated sensitivities to generate global maps of carbon flux anomalies from 1900-2100 linked to specific environmental drivers. As a result, this proposed effort directly supports NASA¿s program emphasis on 1) improving understanding of the global carbon cycle, 2) quantifying how large and variable fluxes of carbon within the Earth system are, and 3) quantifying how carbon cycling will change over longer-term time scales. Our approach is data-driven, and integrates eddy-covariance FLUXNET observations with remotely sensed and retrospective data to attribute past and future terrestrial carbon fluxes anomalies to key environmental drivers. Scaling is achieved through merging sensitivities with environmental driver variability (quantified using retrospective analysis or IPCC future scenarios) and dynamic land cover data. This will be the first time that sensitivity surfaces, such as those proposed here, have been generated. The derived sensitivities express the change in carbon flux relative to a unit change in environmental driver, and

provide strong observational constraints on modeled functional relationships between carbon flux and different environmental drivers. Terrestrial biospheric models are valuable tools for improving our understanding of biophysical and biogeochemical process, and these models use, to differing extents, observed and remotely sensed data for model calibration and initialization. In addition to generating an independent and observationally-based estimate of carbon-climate sensitivities, this product will also provide needed reference standards and valuable benchmarks for refining terrestrial carbon cycling models. This proposed effort builds upon past carbon cycle research to create a new synthesis, advance the results of prior research, and enhance model and decision support system utility. There are four main steps in this study: 1) generate dynamic land-cover maps from 1900-2100; 2) estimate carbon flux sensitivities to climatic drivers (evaporative fraction, air temperature, downwelling radiation, humidity) from in situ, site-based observations; as well as remotely sensed indices (enhanced vegetation index, leaf area index, land surface temperature); 3) benchmark terrestrial biospheric model output using the spatially-scaled sensitivities; and 4) using retrospective analysis and IPCC scenarios, translate the derived sensitivities to carbon flux anomalies from 1900 to 2100. Through steps 1 and 2 we will generate maps of spatially varying sensitivities to environmental drivers that can be used to evaluate how well models replicate observed responses of the carbon cycle to changes in environmental factors. Furthermore, the flux anomalies derived from the sensitivities provide an independent and observationally-based estimate of past and future variability in the carbon cycle due to changing climate. Overall this project will foster an improved understanding of climate-induced variability of the carbon cycle by integrating land-based and satellite observations, and will provide several critical benchmarks needed to improve our ability to model and understand the global carbon cycle.

Robert Treuhaft/Jet Propulsion Laboratory
Tropical Moist Forest Structure and Biomass Estimation from Bistatic InSAR at X-Band (TanDEM-X), Small- and Large-Spot Lidar, and Field Measurements

Because tropical forests contain about 50% of the Earth's forested biomass and because they are very poorly surveyed on the ground, this proposal investigates the global measurement of tropical forest structure and biomass with remote sensing. It will advance the development and utilization of a multisensor approach to structure and biomass estimation from interferometric synthetic aperture radar (InSAR)/polarimetric InSAR (PolInSAR) and lidar. The proposal uses data from the German satellite system TanDEM-X, which consists of two spacecraft carrying X-band (wavelength 3.1 cm) radar and flying in tandem, with separations (baselines) of 100 m to more than 1000 m. TanDEM-X will take data from June 2011 through 2014, between 10 and 30 baselines for this project per year. The proposal also uses data from airborne lidar in areas where field measurements have been taken in the time period 2009-2011, and further uses spaceborne ICESat historical data. Our proposed work will emphasize development of new methods and comparison among sensors, which prompts our selection of a very well characterized site, the Tapajos National Forest in Brazil that has been studied in great detail. Of particular relevance are large data sets of small-spot lidar, and infrastructure for extensive field acquisition via the Brazilian Co-I's.

The objectives of the proposal are to 1) Develop methods for height and profile estimation from multibaseline X-band InSAR and PolInSAR; 2) Determine the structural metrics for biomass estimation from optimal vertical and horizontal vegetation relative density scales, thereby producing local, state-of-the-art biomass estimates by regression of InSAR and lidar to field data; and 3) Make regional, mission-simulated structure and biomass maps of Tapajós from TanDEM-X and lidar.

The approach to developing methods for height and profile estimation from TanDEM-X will involve using uniform-volume models, as has been done in the literature. We will also look at field data in hand, taken from 2009 to the present to compare InSAR-estimate heights to field-measured heights. We will experiment with modifications to the uniform-volume model based on small-spot lidar measurements, which are a part of this proposal.

The approach to identifying structural metrics which best correlate with stand biomass will be based on identifying vertical and horizontal scales over which vegetation density is changing, primarily with lidar. As has been done frequently in the literature, we will try various height metrics in regression of field biomass estimates. We will also try the Fourier transform of the lidar vertical profile at a few vertical frequencies as a correlate to stand biomass. Horizontal Fourier transforms of lidar metrics will also be done. State-of-the-art structure and biomass maps will be generated over the 20-30 km^2 area of field sites from TanDEM-X and small-spot lidar, using field acquisitions as "truth" measurements.

The approach to the regional (15 x 66 km) structure and biomass maps will be to aggregate small-spot lidar to the anticipated size of ICESat-2 spots and demonstrate fusion, mission-relevant methods of combining InSAR and lidar. GLAS historic lidar may be used as well, if we can show sufficient structure and biomass accuracy comparing GLAS, forward-propagated with growth models, and ICESat-2-like spots from contemporaneous, aggregated small-spot lidar. 30 additional field sites will be measured in this work, either within planned lidar acquisitions or in more remote parts of Tapajos for validating the regional map.

InSAR, whether multibaseline and/or polarimetric, will be an important component of any global strategy for forest structure and consequent biomass monitoring. The performance of biomass estimation strategies in tropical moist forests will bear heavily on the design of NASA space-based monitoring systems.

David Turner/Oregon State University
Time Series Analysis of Disturbance Impacts on the Pacific Northwest Regional Carbon Balance

Large tracts of forestland in the Northwestern U.S. are subject to recurrent clear-cut harvest, thinning, variable intensity fire, and insect outbreak. These disturbances have significant impacts on the local and regional carbon balance. The Northwest forests also offer the opportunity for mitigation of climate change by acting as carbon sinks through positive net ecosystem production (NEP, the balance of net primary production and heterotrophic respiration) in undisturbed stands. The proposed research will examine

decadal trends in climate, NEP, and net ecosystem carbon exchange (NEP - fire emissions - logging removals) in the Pacific Northwest region using a combination of time series Landsat data and ecosystem carbon cycle modeling.

Our objectives include 1) addressing science questions related to understanding the spatial and temporal patterns in forest disturbance and carbon flux, 2) addressing policy relevant questions about the relative magnitude of fire emissions and background forest carbon sequestration, and 3) developing maps of carbon stocks and flux with well characterized uncertainty that can be used in uncertainty assessments of carbon cycle studies based on alternative scaling approaches.

Our study area provides excellent contrasts over which to characterize ¿impacts to and vulnerability of terrestrial ecosystems and critical terrestrial components of the global carbon cycle to global environmental change¿. The study region (WA, OR, ID, western MT) extends across a broad climatic gradient from cool, mesic coastal forests used primarily for wood production, to drier forests on the east side of the Cascade Mountains, and into the Northern Rocky Mountains with its more continental climate regime and higher incidence of insect outbreaks. Our study period (1985-2010) includes a wide range of interannual climate variability, notably 2002 when the Biscuit Fire burned over 200,000 ha in Southwestern Oregon and 2010, a strong La Niña year with virtually no wild fires in the region.

Our approach relies on Landsat-based time series analysis of forest disturbance. It will permit attribution of disturbance type (fire, insects, and harvest) and quantification of disturbance intensity. We will use the Landsat-based disturbance information as input to a well-established modeling infrastructure for simulating regional carbon flux based on the Biome-BGC model. For this study, we will add algorithms to Biome-BGC that simulate partial disturbances, notably forest thinning, which is becoming more prevalent in the PNW region. Our approach will make extensive use of plot scale and aggregated USDA Forest Service Forest Inventory and Analysis (FIA) data for model parameterization and uncertainty assessment.

Because quantifying terrestrial carbon sources and sinks is of policy significance in relation to addressing the climate change issue, this research contributes to the NASA strategic goal of advancing scientific understanding of Earth and meeting societal needs. It will further the NASA research objective of improving carbon cycle models, and results will inform the on-going assessments of the state of the carbon cycle.

Susan Ustin/University of California, Davis

Coastal Wetland and Near Shore Ecosystem Impacts from the Gulf of Mexico Horizon BP Oil Spill Monitored by NASA¿s AVIRIS and MASTER Imagers

In response to the request for studies to analyze coastal ecosystem impacts of the 2010 Deep-water Horizon Oil Spill in the Gulf of Mexico utilizing NASA airborne data, this proposal addresses early and longer-term impacts in the ecologically sensitive coastal wetlands, focused on analysis of NASA¿s Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) airborne data. These coastal salt marsh and wetland ecosystems

are among the most productive coastal ecosystems and support a critical regionally important economic base. These data will be processed to produce baseline maps of oiled shorelines, vegetation types, and evidence of injury to the wetland communities, specifically to answer the series of science questions we pose about the effect of crude oil, extent of injury in different wetland types, from single or multiple impacts of crude oil. These data will be compared to USGS and Tulane University acquired field data at impacted and non-oil impacted sites around the coastal wetlands of Louisiana and Mississippi. In addition, we will work with local groups who have data from other sites to use in validating our maps of oil damage. The airborne data are discontinuous strips and therefore, these high spectral resolution datasets will be used to train synoptic WorldView-2 and/or Landsat data to obtain continuous maps of the shoreline. These data will be compared to AVIRIS airborne data acquired in 2011 to determine the extent of continuing impacts on ecologically sensitive wetlands. More than 240 flightlines were collected in 2010 between May and October, extending from Louisiana to Florida, and 208 lines that were reflown between April and November, 2011.

We respond to Section 2.3 of the A.4. Terrestrial Ecology program announcement (NNH11ZDA001N-A4_TE), by proposing a two year study to exploit existing airborne and satellite data collected over the wetland communities of the Gulf Coast in 2010 and 2011. We address both aspects of the requested studies: 1) characterize and understand the effects of the oil spill on the coastal ecosystems adjacent to the Gulf of Mexico, and/or 2) assess terrestrial ecosystem responses (i.e., degradation and recovery to assist management) in the U.S. Gulf coastal environment to the oil spill and clean-up effort. We propose to characterize the effects of the BP Horizon oil spill along the Gulf of Mexico to the coastal wetland ecosystem and assess the response as a way to improve general understanding of oil impacts to coastal wetland and near shore ecosystems.

We will concentrate on Barataria and Terrebonne Bays, the Birds Foot area of the Mississippi delta, and Lake Borgne/Black Bay, which have known oil landfall and damage to ecosystems, and where validation data is available or can be collected efficiently. We will also apply our analysis methods to AVIRIS and other data collected over the Barrier Islands of Mississippi (Cat, Ship, Horn, Petit Bois and Dauphin) and the Chandeleur Islands. This study will lead to better methods to predict environmental degradation and better management of recovery efforts in clean-up and revegetation efforts. In addition to AVIRIS, data includes the MODIS and ASTER Simulator (MASTER), and the Uninhabited Aerial Vehicle Synthetic Aperature Radar (UAVSAR), and the Spatially Enhanced Broadband Array Spectrograph System (SEBASS) and the WorldView-2 and Landsat satelllites. We have already begun to produce baseline maps of vegetation types using MESMA method and evidence of injury to the wetland communities for oiled and unoiled beaches using spectral indexes and PROSAIL radiative transfer model for Barataria Bay from the 2010 AVIRIS data, demonstrating that the methods we propose will answer the TE call¿s science questions about the locations and types of injury in different wetland and coastal margin ecosystem types.

Lee Vierling/University of Idaho

Quantifying Thresholds in Arctic Tundra Vegetation Structure and Ecosystem Function Using LiDAR and Multispectral Remote Sensing

Quantifying thresholds in arctic tundra vegetation structure and ecosystem function using LiDAR and multispectral remote sensing

Evidence accumulating from many disciplines shows that the Arctic is undergoing significant climatic warming, and that North American Arctic tundra is already responding to warming with increased vegetation greenness in both spatial and temporal domains. In northern Alaska, this greening has at least in part resulted from recent increases in the size, abundance, and range of deciduous shrubs, mainly in valley bottoms and hillslopes, and there is mounting evidence that upland tundra will also respond strongly to warming via increased shrub dominance. Changes in canopy height and other ecosystem properties in response to greater shrub dominance can cause shifts in carbon pools and fluxes that may have far-reaching consequences. In addition, habitat quality and availability for local fauna are likely to be affected in ways yet to be determined.

Quantifying fine-scale variation and change in shrub structure across the full continuum of shrub heights is therefore likely to reveal several important biophysical and ecological shifts occurring in Arctic tundra communities. Until now, mapping variation in shrub density and height across the full range of Arctic shrub types using passive remote sensing approaches has been challenging. While light detection and ranging (LiDAR) is an excellent remote technique for quantifying variation in three-dimensional canopy structure across a wide range of ecosystems, we are aware of no studies that have used LiDAR to quantify the canopy structure of tundra vegetation communities.

Given the sensitive links between shrub dominance and tundra ecological function, detecting subtle changes in canopy stature and density could serve as an early warning sign or indicator that a cascade of ecological changes is unfolding. Further, these transformations of the tundra ecosystem may act as harbingers of new feedbacks that may occur as warming continues at high latitudes. Our overarching goal is therefore to develop novel remote sensing-based methods for identifying, scaling, and understanding the onset of a cascade of immediate/near-term ecological shifts - related to both canopy carbon pools and exchange and trophic dynamics at the base of the terrestrial Arctic food chain - that are associated with increases in shrub height, shrub density, and canopy leaf area in the tundra ecosystem. We will use terrestrial laser scanning (TLS), airborne laser scanning (ALS), and ground-based spectral data in combination with field-collected physiological, entomological, and micrometeorological data collected on the North Slope of Alaska to build and test relationships among ecological variables and remote sensing metrics across the full ranges of shrub height, leaf area, and species composition. We will then use these statistical relationships to scale across the broader Arctic landscape using fine spatial resolution WorldView-2 satellite imagery.

This work will directly address two of the main priorities of the NASA Terrestrial Ecology program 2011 NRA. By characterizing subtle changes in the sensitive Arctic

ecosystem using combined TLS, ALS, and spectral remote sensing methods, we will address (a) the impacts of warming on a cascade of ecosystem vulnerabilities in the Arctic (TE RFP priority 2.1) using (b) powerful combinations of remote sensing datasets that have never before been employed to study Arctic ecosystem change (TE RFP priority 2.2). This work also addresses key issues important for the development and evaluation of the NASA ICESat-2 laser altimetry mission.

Qingyuan Zhang/Universities Space Research Association
Carbon Monitoring and Ecosystem Feedbacks Prediction Using fAPARchl and the Community Land Model (CLM)

An important science goal for NASA is to quantify the terrestrial carbon cycle and ecosystem feedbacks which requires accurate estimate of photosynthetic CO2 uptake. Vegetation photosynthesis is a pigment-level (primarily chlorophyll) process. Existing global climate models have been unable to accurately describe the intensity of photosynthetic activity or to discriminate this functionality among terrestrial vegetation canopies/ecosystems. Many satellite-based production efficiency models (PEMs), land surafce models and biogeochemical models (e.g., SiB, CLM and CASA) have used the concept of fraction of photosynthetically active radiation (PAR) absorbed for photosynthesis to estimate GPP for their modeling work. These models use satellite-based estimates of fAPAR for the entire canopy (i.e., fAPARcanopy, which is widely denoted as FPAR or fAPAR) to estimate fAPAR for photosynthesis. However, FPAR has been shown to be physiologically insufficient to reliably describe or retrieve terrestrial ecosystem photosynthesis. A much better alternative is to utilize the fraction of PAR absorbed only by chlorophyll throughout a canopy/ecosystem (fAPARchl) to replace fAPARcanopy when estimating APAR for photosynthesis and GPP. A recent study by Bonan et al. (2011) reported that more accurate radiative transfer parameterization within the canopy (e.g. fAPAR) can significantly improve output from CLM and the simulated GPP would be much closer to FLUXNET tower-based GPP. We will directly calculate fAPARchl of terrestrial ecosystems using available remote sensing data including Terra/MODIS, Aqua/MODIS, EO-1 Hyperion and Landsat through inversion of a physically-based radiative transfer model (Zhang et al., 2005, 2006, 2009, 2011b). This study will first produce 9x9 MODIS fAPARchl maps with available remote sensing images for globally sampled flux tower sites with a focus on EOS Land Validation Core Sites in a wide variety of ecosystems. Secondly, we will implement fAPARchl into a production efficiency model (PEM) to estimate GPP based on calibration/validation over the globally selected tower sites. Thirdly, we will produce regional maps of fAPARchl and GPP from MODIS. The MODIS fAPARchl results will be implemented into CLM (version 4, CLM4). For initial accuracy assessment and calibration and validation, we will first focus on our globally selected flux tower sites and nearby local regions. We will then extend our progress to continental and global scale. For the continental US, GPP determined from the fAPARchl+CLM4 approach will be compared with that obtained from fAPARchl+PEM and from fAPARcanopy+PEM (e.g. MODIS MOD17 product). Their spatial and temporal anomalies will be examined. Specific intensive regions for this evaluation will include the New England/Mid-Atlantic and California/Pacific. At global scale, similar validation procedure outlined in Bonan et al. 2011 will be utilized. The GPP obtained using fAPARchl+CLM4 approach will be compared with the conventional

default CLM GPP and FLUXNET-MTE GPP at global scale.At global scale, we will couple our fAPARchl+CLM4 results with COLA AGCM in the GLACE-like framework described in (Wei et al. 2010b; Wei et al. 2010c). We will investigate how this improved parameterization affects atmospheric and climate simulations. Our focus will be on the global geographic variations of model uncertainties and land-atmosphere feedbacks, which still have not been addressed well enough today. We will also explore the difference in the output of the climate estimate (e.g. surface air temperature and evapotranspiration) with/without the implementation.

Xuesong Zhang/Pacific Northwest National Laboratory
Anticipating Agroecosystem Impacts of and Feedbacks to Climate Change in the Midwest US through Integration of a Coupled Climate-Agroecosystem Model with Satellite Data

Climate change is expected to play an increasingly important role on agricultural productivity and associated socio-ecosystem services. Extensive research has been conducted to evaluate responses and vulnerability of agroecosystems to climate change without accounting for their feedbacks to the climate system. Changes in climate stresses may lead to the need for more intensive crop management (e.g. irrigation). As well, increasing demand for biofuels may lead to large-scale removal of crop residues and cultivation of bioenergy crops. These activities are bound to perturb land surface characteristics and alter energy, water, and momentum fluxes between agroecosystems and the atmosphere. As such, it is imperative to consider two-way interactions between climate and agroecosystems for an effective evaluation of the vulnerability and risks of agroecosystems and associated socio-ecological services (e.g. food and energy production, water cycling, carbon sequestration and regional climate regulation) in a changing climate. Therefore, the goal of the proposed research is to enhance our ability to anticipate vulnerability of agroecosystems in a changing climate through better representation of climate-agroecosystem interactions in regional climate models.
To achieve this goal, we will [1] expand the CWRF regional climate model capability to fully interact with the DSSAT crop growth and management; and [2] apply this coupled modeling system (CWRF-Agro) to predict climate change effects on and feedbacks from agricultural productivity and provision of food, fuel and other socio-ecosystem services in the US Midwest. Extensive NASA satellite data will be integrated with the CWRF-Agro model to improve predictions of complex climate-agroecosystem interactions and understanding consequences that may result from the interactive and changing climate and human stresses in the future (to 2050).. Using the CWRF-Agro, we will conduct a suite of experiments to address several compelling scientific questions: [a] How will agroecosystems respond in terms of productivity and sustainability to the CO2 increase and climate change? [b] What is the vulnerability of carbon stocks and flows in agroecosystems to climate change? and [c] How will biofuel land expansion impact regional climate and water cycling?
The outcome of this research will represent a unique contribution to the NASA Terrestrial Ecology research goals by improving our understanding of structure and function of global terrestrial ecosystems, their interactions with the atmosphere and

hydrosphere, and their role in the cycling of the carbon and water. The CWRF-Agro modeling system that couples regional climate with crop growth and management will represent a significant advance to the existing assessments of climate change impacts on agroecosystems, which ignore their feedbacks. As such the proposed research will provide a more credible assessment of unintended consequences and related uncertainties of management strategies and decisions.