Research Opportunities in Space and Earth Sciences – 2015
NNH15ZDA001N
The NASA Land-Cover/Land-Use Change (LCLUC) Program, NASA Headquarters

This synopsis is for the Land-Cover and Land-Use Change (LCLUC) part of the NASA Research Announcement (NRA) ROSES-2015 NNH15ZDA001N-LCLUC. This NRA offered opportunities for research to develop and use NASA remote sensing technologies to improve understanding of human interaction with the environment, and thus provide a scientific foundation for understanding the sustainability, vulnerability and resilience of land-cover and land-use systems. NASA LCLUC research contributes toward the goals of the U.S. Global Climate Research Program (USGCRP) by providing critical scientific information about LCLUC-climate interactions and the consequences of land-cover and land-use change on environmental goods and services, the carbon and water cycles and the management of natural resources. NASA received 27 proposals and selected 13 proposals for a total funding of $8.8M for three years. More details are available at: http://nspires.nasaprs.com.

Ariane de Bremond/University of Maryland
The Global Land Rush: A Socio-Environmental Synthesis

This project conducts an integrated global synthesis of large-scale land acquisitions (LSLAs), a growing phenomenon in the global South as governments and transnational investors seek to secure access to land in developing countries to produce food, bio-fuels, and non-agricultural commodities. Distant connections between land systems are not new, but rising evidence indicates that such cross-scaled telecoupled socio-economic and environmental interactions as a result of LSLAs have grown stronger, with more rapid feedbacks. The overarching question motivating our research is, What are the processes through which telecoupled LSLAs do or do not result in LCLUC globally, and with what consequences? Our general research question translates to the following specific questions: 1) What are the timing, type, and extent of land changes (or no change) associated with LSLA deals across the globe, and how are these land change outcomes related to variations in global, national, and sub-national social, economic, political, and biophysical contexts? 2) How are the socio-economic and indirect land-use change (iLUC) consequences of LSLA deals associated with particular causal factors and land change outcomes as reported in the local case-study literature? 3) What are the linked causal factors, land changes outcomes, and socio-economic and iLUC consequences (i.e., global archetypical pathways) of LSLA land change by region and intended-use? This project will employ several cutting-edge synthesis approaches and meta-analytic methods recently advanced in the land change science literature that combine interpretive synthesis of causal processes and consequences derived from the case study literature on LSLAs with integrative synthesis of remotely sensed land change outcomes of LSLAs and correlated with contextual variables. Specifically, we will use a combination of variable- and case-oriented meta-analysis methods to synthesize: findings from a now abundant set of localized case studies of LSLAs conducted from disciplinary perspectives as diverse as political ecology, land change science, and economic geography; satellite-based remote sensing data of verified LSLA sites (200+); time series of global, national, and sub-national geospatial datasets describing social, environmental, political, and economic contexts; and international agricultural commodity trade data to link changes in the supply of LSLA-related commodities to global production networks and final

demand. Insights from the synthesis of these various sources of evidence will enable the construction of causal configurations (also referred to as archetypes, or pathways connecting LSLA causes, land change outcomes, and consequences globally. This analysis will build an understanding of the global patterns and regional nuances of LSLAs, and test a newly developed conceptual framework that promises to advance broader theory of LCLUC in a globalized world. This synthesis study promises to augment current regional-scale LCLUC research with a global view enabling not only understanding of telecoupling dynamics of LSLAs, but also the inter-regional differences of LSLA causes and consequences. This project will also advance synthesis methodology in LCLUC research by combining multiple meta-analytic techniques and remote sensing analysis to systematically test hypotheses about the location, timing, and consequences of LSLAs observed globally. The primary outcomes of this project include a unified explanatory model that links causes, land change outcomes, and socioeconomic consequences of LSLAs and archetypical pathways of LCLUC associated with LSLAs as well as methodological innovations that will enrich our knowledge about the recent and rapid expansion of LSLAs across the global South and, more broadly, advance the theory of telecoupled land change using LSLAs as the study system.

Ruth DeFries/Columbia University
Tropical Deciduous Forests of South Asia: Monitoring Degradation and Assessing Impacts of Urbanization

This project proposes to 1) develop remote-sensing methods to monitor forest degradation and regeneration in tropical deciduous forests of South Asia and 2) assess how off-farm employment associated with urbanization alters uses of forest resources that lead to degradation. While remote sensing to map deforestation are now well-developed, methods for mapping degradation (i.e. reduction in biomass or canopy cover) and regeneration are more complex and less mature. Moreover, considerable research has examined urban demands for agricultural commodities on deforestation. But the impact on forest resources of increasing urban migration and off-farm employment in South Asia, where rural populations rely heavily on forests for energy, fodder and income-generation from non-timber forest products, is not well understood.
We will focus on a study region in central India, a globally important landscape for tiger conservation and home to millions of people whose livelihoods depend on forest resources. The region covers 250,000 sq. km. (approximately 8 percent of Indias land area). Remaining patches of tropical deciduous forests, the native vegetation, provide crucial connectivity for large mammals to travel between protected areas. Similar to other places in South Asia, rapid urbanization is generating off-farm employment that is changing resource use in rural households. Consequences for forest degradation and regeneration are not currently known. For example, increased income from off-farm employment could exacerbate grazing pressures through increased cattle ownership or alleviate pressures through reduced reliance on fuelwood.

The project builds on our experience in the study region, prior work on remote sensing of forests, and household surveys on resource use in India. Initial efforts to map changes in biomass in the study region using L-band ALOS PALSAR and Landsat data show

moderate success. Recently available radar (e.g., ALOS PALSAR 2, Sentinel 1 C-band) and optical (Sentinel 2, Quickbird and other very high resolution sensors) open opportunities to further develop methods for mapping forest degradation and regeneration. We will collect approximately 100 biomass measurements across the landscape to test multiple algorithms to predict biomass. We will interpret optical data to identify visible signs of degradation such as footpaths. The goal of the remote sensing analysis is to identify the data sources and algorithms to monitor forest degradation and regeneration efficiently, accurately, and with as minimal data processing as possible. The ultimate objective is to establish an operational monitoring system, maintained by Indian scientists, which will enable targeting efforts to reduce degradation, such as alternative livelihood projects, evaluate effectiveness of such efforts, and monitor progress towards reforestation goals.

The social science aspect of the project will identify how rapid urbanization is changing demand for forest products and hence altering patterns of forest degradation and regeneration. We will develop a sampling strategy for 5,000 household surveys in 500 villages to cover the range of conditions across the study region. The surveys will quantify cattle ownership, dependence on fuelwood for energy, and collection of non-timber forest products in relation to off-farm employment and migration of family members to urban areas. We will test whether resource use is statistically related to employment of household members in urban areas (controlling for confounding factors). Results will indicate whether future urbanization is likely to alleviate pressures and lead to forest regeneration or to exacerbate pressures and lead to further degradation.

Liping Di/George Mason University
Understanding Changes in Agricultural Land Use and Land Cover in the Breadbasket Area of the Ganges Basin 2000-2015: A Socioeconomic-Ecological Analysis

In South Asia, agriculture faces the remarkable challenge of feeding a growing population, projected to increase 43.8% by 2050, with extremely limited per capita arable land. Adding to the complexity of the challenge is the rapid economic development and urbanization over recent years, which competes for land with the agricultural sector and threatens the remaining forest cover. The Ganges Basin is the breadbasket of South Asia. Its agricultural outputs feed almost one-tenth of the world population. The densely populated region is home to numerous cities that have undergone rapid expansion in recent decades. Forest and wetland ecosystems are under increasing threats from intensified agricultural land use and pressure from urban spatial expansion. South Asia plays a central role in the global effort (such as the United Nations Sustainable Development Goals) to achieve sustainable development and food security. A deeper understanding of the drivers and socioeconomic and ecological impacts of land cover and land use change (LCLUC) in the basin is essential to better inform land use policies.

This proposed project will combine remote sensing and geographic information system (GIS) techniques with an integrated modeling approach to 1) identify and assess LCLUC that occurred in the major agricultural area of the Ganges Basin (including India and Bangladesh) during 2000; 2015; 2) identify and quantify the primary socioeconomic

drivers of LCLUC; 3) develop scenarios of future LCLUC (up to 2030) based on projected changes of key drivers; 4) evaluate the main impacts of LCLUC on key indicators of food and nutrition security, income, ecosystem services, land degradation, and resilience; and 5) disseminate research findings and reach out to stakeholders to ensure that the research helps to inform sustainable development strategies and responds to the needs of policy makers. In this project, LCLUC includes changes in agricultural land cover/use at three levels: 1) land use change from agricultural to non-agricultural use, or vice versa; 2) change in cropping systems, such as from rice to maize; and 3) change in the intensity of agricultural land use. The integrated modeling framework includes three modeling components: 1) a global agricultural partial equilibrium model, 2) a spatially explicit econometric land use model, and 3) an ecosystem services evaluation model. This research will enable us to answer some of the key scientific questions related to LCLUC in the basin: What are the dominant LCLUCs, including agricultural intensity and cropping system changes, in the breadbasket region of the Ganges Basin during 2000'2015? What are the major socioeconomic drivers of LCLUCs during 2000'2015 and how did economic development, population growth, and the accompanying structural transformation such as urbanization affect the changes? What are the impacts of LCLUCs on key indicators of food and nutrition security, income, ecosystem services, land degradation, and resilience?

This proposed project will make two novel contributions to NASAs LCLUC program. First, it will develop state-of-art remote-sensing techniques to identify level-2 and level-3 LCLUC in developing country context where farm and field sizes tend to be small. Second, this project will employ economic theories and methods, particularly an integrated modeling framework, to identify and quantify major drivers and impacts of LCLUC in the study area. This proposed project will contribute to the scientific knowledge base regarding integrated dynamics of LCLUC and socioeconomic systems at regional, national, and global scales, enhance evidence-based and science-guided decision-making concerning food security and sustainable agricultural development, and support the United Nations 2030 Sustainable Development Goals.

Forrest Fleischman/Texas A&M University
Impacts of Afforestation on Sustainable Livelihoods in Rural Communities in India

Artificial afforestation programs are emerging as important policy interventions globally to increase carbon sequestration, yet there has been little systematic study of the impacts of afforestation programs on the livelihoods of forest dependent people. Afforestation projects do not simply improve ecosystem service provision, as widely assumed; they replace other land-cover types such as grasslands, savannas, or degraded forests thus changing the mix of goods provided by these ecosystems. Depending on the species planted and the success of the plantation, afforestation may increase the availability of timber and fuelwood while decreasing availability of fodder and some non-timber forest products. Livelihood impacts will depend on the importance of these goods and services to different households, the availability of alternatives, and the capacity of households to respond. As a result, plantations may improve the livelihoods of some households while hurting others, particularly those dependent on non-forest resources produced on lands converted to plantation. Better understanding of the effects of plantations on livelihoods

is crucial for designing policies that maximize the positive benefits and mitigate negative impacts of afforestation.

We propose to study the impact of afforestation programs in India, a country in which afforestation efforts are extensive, on the livelihoods of the rural poor. We will do so by combining recent government data on afforestation with long-term estimates of afforestation based on NASA satellite data and household surveys in 140 villages with varying levels of exposure to afforestation. In April of 2016, we obtained government records for all 2252 plantations made by the state forest department in the Kangra district of the Western Himalayan state of Himachal Pradesh between 2005-2015. We will combine this data with ground-truthing in a subset of these plantations. We will conduct land-cover/land-use change (LCLUC) analysis based upon use of an advanced image endmember-estimation algorithm and spectral unmixing/endmember mapping. This will allow us to detect and differentiate different types of small plantations using historical Landsat data. We will conduct household livelihood surveys in a sample of 140 villages which have been exposed to different types of plantations. Combining estimates of afforestation activities with household livelihood data will allow us to estimate, using regression and propensity score matching techniques, the impacts of afforestation on the livelihoods of households with different characteristics. These analyses will allow us to develop guidelines, which will help Indian policy-makers develop and implement plantation programs that align the imperative for carbon sequestration with the needs and interests of the poor.

Meha Jain/University of Michigan

The Future of Food Security in India: Can Farmers Adapt to Environmental Change?

Food security will become increasingly threatened over the upcoming decades, due to a growing population, climate change, and natural resource degradation. This is particularly true in India, where climate change impacts are expected to be especially large, with up to a 30% loss in yield for some staple crops by mid-century (Lobell et al. 2008). Furthermore, over 40% of agricultural production relies on groundwater irrigation, however groundwater reserves are becoming rapidly depleted, with some studies estimating that a large proportion of deep wells will dry up by mid-century (Shah et al. 2009). While the impacts of environmental change on production have been well established, there is little understanding of how farmers respond to this change. Yet, it is important to account for farmer behavior as farmers may be able to reduce or eliminate the negative impacts of environmental change by adapting their cropping practices. For example, farmers may be able to reduce the impact of warming temperatures by switching to new hybrid crop varieties that are more heat-tolerant. Understanding how, why, and how effectively farmers may adapt their cropping strategies to environmental change will better identify whether India will be able to produce enough food over the upcoming decades.

This proposal will examine land use and land cover change (LCLUC) of agricultural systems, and attribute these changes to long-term environmental drivers, like climate change and groundwater depletion. This will allow us to understand how

effectively farmers have adapted to environmental change, and how vulnerable current agricultural systems still are to future change. Specifically, we will derive novel remote sensing products that quantify smallholder crop production, including cropped area and yield from 1995 to the present. To date, mapping the production of smallholder farms has been difficult for several reasons. First, the size of individual farms is smaller than the resolution of readily-available satellite imagery, like Landsat and MODIS, leading to issues with mixed pixels. Furthermore, ground data rarely exist to calibrate models that translate satellite vegetation indices to production measures like yield. We propose to develop unique methods to overcome these problems that build on previous work by the PIs (Jain et al. 2013, Lobell et al. 2015). We will also use remote sensing to quantify adaptation decisions, including shifting sow date, switching crop variety, and increasing irrigation. We will link these remote sensing datasets with gridded weather, groundwater depth, and panel household datasets to examine how farmers are responding to climate change and groundwater depletion. This study will be one of the first to identify specific adaptation strategies farmers adopt in response to medium to long-term environmental change. We will also evaluate how effective these strategies are in bolstering future food security.

Peter Leimgruber/Smithsonian Institution
Complex Forest Landscapes and Sociopolitical Drivers of Deforestation - The Interplay of Land-use Policies, Armed Conflict, and Human Displacement in Myanmar

This project responds directly to the solicitation for LCLUC studies in South Asia region by mapping Myanmars forest and deforestation over the past decade. In response to the LCLUC program goals, our research will also seek to understand human-nature interaction, specifically the relationship between deforestation and commercial plantation policies, armed conflict, and human displacement.

Myanmar is one of the most forested countries in Asia. In the past, the country had retained high levels of biodiversity and forest cover, partly due to its political and economic isolation. Since 2010, the political and economic reforms that have come with democratization have improved access to global markets and increased international aid, trade, and investment. The speed and magnitude of sociopolitical changes in the country make urgent the need for detailed remote-sensing-based mapping of different forest systems to provide a baseline for forest risk and forest vulnerability assessments. At the same time these drastic changes provide an opportunity to evaluate the impact of a range of sociopolitical factors on deforestation at broad geographical scales.

The proposed project is built on our previous studies of global forest and forest change characterization and a decades worth of remote sensing and conservation projects in Myanmar. Our study showed in 2004, that the country retained much of its forest cover, and that forests had declined by 0.3% annually between 1990 and 2000. Our recent work demonstrates that deforestation rates may have doubled in the past decade, with most of the forest losses occurring in intact, closed-canopy forests. However, different types of forest have unique economic and conservation values, and they are being threatened at

various degrees. Existing forest change products did not differentiate the different types of forest loss, nor did they differentiate between natural forest and plantations.

The overall goal of the project is to study forest-cover and land-use change in Myanmar, to understand the drivers of deforestation of different forest types, especially in Myanmar's border regions, and to advance forest monitoring in the South Asia region. Our specific objectives are to: 1.Map the different types of forests across Myanmar circa 2016 to provide a baseline of forest condition by combining passive (optical) and active (radar) remote sensing data to discriminate natural forests from plantations;
2.Incorporate extensive reference data and multiple remote sensing datasets (including: Landsat, Sentinel-2, PALSAR, UAV images) to map annual tree cover and deforestation Myanmar between 2000 and 2018;
3.Examine the impact of agricultural policies, armed conflicts, and human migration on forest-cover change in Myanmar, as well as the feedback of deforestation on human displacement.

We will firstly combine the optical and active remote sensing data to classify major forest types and plantation types. Secondly we will produce 18 years of annual forest cover dataset. And lastly we will produce annual forest-change maps between 2000 and 2018. The calibration and accuracy assessment of both parts of the project will rely on high resolution satellite or unmanned aerial vehicle imagery and extensive ground truth carried out in collaboration with our local partners in Myanmar.

Our proposed research will provide free access to the final products through the Global Land Cover Facility, and continue our collaboration with EcoDev to provide training and data directly to Myanmars CSOs and NGOs committed to sustainable forest governance. The proposed project will help us understand how sociopolitical forces interact with diverse forest landscapes within the context of Myanmars society, and it will also provide a scientific foundation for assessing forest vulnerability and facilitating sustainable forest governance.

Tatiana Loboda/University of Maryland
Understanding the Role of Land Cover/Land Use Nexus in Malaria Transmission Under Changing Socio-Economic Climate in Myanmar

Myanmar is an emerging democracy that bears by far the heaviest malaria burden in Southeast Asia, the region that has been the historical gateway for the global dissemination of drug-resistant malaria. For almost fifty years, Myanmar has been mostly closed to outside influences and economic interactions also effectively isolating the population within the country from international activities aimed at the global malaria elimination. The greater integration of Myanmar into the global and regional economy comes with greater freedom in flow of people across the region, however, this poses a concern regarding the spread of malaria in general and particularly dissemination of ACT-resistant malaria in South Asia. In this study, we propose to examine the role that land cover and use play in determining population exposure to malaria in Ann Township of Rakhine State. As a remote and isolated region with a current high level of endemic malaria and limited access to treatment, this region has the potential to become a notable

source of malaria infection across Myanmar and South Asia (particularly towards Bangladesh and India). With the post-election anticipation of a more open society and a greater integration in the country-wide and regional economic activity, malaria control within Rakhine State is a crucial component of a successful malaria elimination agenda in South and Southeast Asia and globally. The major scientific goal of this proposal is to develop a deeper understanding of the malaria exposure and transmission as a function of human activities, land use, and human mobility at various scales for remote rural populations in Myanmar where malaria levels are high. In this study we plan to pursue the major overarching research question: What environmental and land use factors are contributing to the observed differences in malaria presence and prevalence between the villages in Ann Township of Rakhine State in Myanmar? We also aim to make substantial methodological advancements in prototyping components (mapping of malaria-relevant land surface properties at the village scale, observations of changes in environmental conditions at 8-day repeat cycle, and human flow patterns) for an active satellite data-based monitoring system to forecast potential for malaria outbreaks at the high-to-moderate scale in support of targeted malaria elimination agenda in regions of endemic malaria. Specifically, we will develop methods to support integration of multi-sensor data streams into a high-to-moderate resolution monitoring system, that would use data fusion from coarse (MODIS, VIIRS), moderate (Landsat and Sentinel 2), and very high (e.g. WorldView and GeoEye systems) optical and thermal and microwave (Sentinel 1) data to assess dynamic malaria outbreak potential at the village scale. The proposed project directly addresses the first component of the current solicitation aimed at studying the implication of land cover and land use changes in terms of their impacts on the vulnerability of populations in South Asia. This is a highly interdisciplinary project that brings together experts in remote sensing, geospatial analysis, social science and public health to further the global malaria elimination agenda and build the in-country capacity for research and public health management. The proposing team has a wide group of in-country collaborators and will specifically aim to train local Myanmar scientists, promote capacity building, and transfer the knowledge and management of the developed system to local scientists in accordance with the priorities of the South Asia Research Initiative (SARI) agenda.

Karen Seto/Yale University

Urban Growth, Land-Use Change, and Growing Vulnerability in the Greater Himalaya Mountain Range Across India, Nepal, and Bhutan

Home to about 210 million people and extending over eight countries, the Hindu Kush Himalayan (HKH) region is at the confluence of two major trends that together are transforming one of the most dynamic mountain systems in the world. First, the region is a hotspot for four natural hazards: earthquakes, fires, floods, and landslides. Over the past few years, the HKH region has experienced a number of devastating natural disasters, including a 7.5 magnitude Pakistan-Afghanistan earthquake in 2015, a glacial lake outburst flood in northern Bhutan in 2015, floods in Uttarakhand in 2013 that left nearly 6,000 dead and more than 100,000 people trapped, and the 7.8 magnitude earthquake in Nepal in 2015, that killed more than 9,000 people and injured more than 23,000.

Second, the HKH region is rapidly urbanizing. Fueled by migration from rural areas, valleys and plains, the growth of religious, ecological and adventure tourism, and recent social unrest, towns and urban centers are expanding. Although the region is still predominantly agrarian, migration to urban centers is increasingly an important livelihood strategy for rural households, and non-farm income is an increasing component of household incomes. The growing urban population, an urbanizing economy, and associated land use and land cover changes are transforming the Himalayas. Yet despite the vulnerability of the region and its people, the 2015 Nepal earthquake highlighted the lack of accurate and up-to-date information about urban settlements in the region and those most at risk in this coupled social-environmental system.

The proposed research aims to fill these knowledge gaps by using multi-scale and multi-source satellite data applied to novel and holistic vulnerability frameworks to answer five research questions about the HKH region:

1. How and where are urban settlements changing, and what are the associated land use and land cover changes with these changes?

2. What are the frequency, magnitude, and duration of the four dominant natural hazardsâ€”earthquake, fire, flood, and landslides, and how do they vary over time and space?

3. What is the sensitivity of the socio-economic system to different stressors?

4. Where are urban settlements most vulnerable and to what stressors are they most vulnerable?

5. What explains differences in the vulnerability of urban settlements across the HKH region?

The two primary goals of the proposed research are to 1) characterize and quantify LCLUC associated with urban settlement change, and 2) assess the vulnerability of these urban settlements to hazards.

The project will be undertaken at two spatial extents. A 30m resolution analysis will be conducted for 41 contiguous scenes for the entire Landsat TM archive (1984-present) covering an area of approximately 1.289 million km. This wall-to-wall approach using the entire Landsat archive is a marked departure from most other urban studies in the region that focus solely on a few capital or large cities and their immediate surroundings. To examine the accuracy of the Landsat analysis, we will use 2.5m resolution imagery to analyze LCLUC in three sites.

Expected project results and benefits include: New remote sensing algorithms to characterize changes in urban settlements and associated LCLUC in high mountain regions of South Asia. Empirical estimates of urban LCLUC, including transport

infrastructure and the built environment in the HKH region of India, Bhutan, and Nepal. Improved scientific understanding of the spatio-temporal patterns of land use change in the HKH region.

Valerie Thomas/Virginia Polytechnic Institute and State University
Regionally Specific Drivers of Land-Use Transitions and Future Scenarios: A Synthesis Considering the Land Management Influence in the Southeastern US

Land-use and land-cover change are a significant factor in regional and global carbon cycles. Further, land cover dynamics play an important role in the ecological and economic resilience of the landscape to future conditions. Predicting the influence of land-use and land-cover change on global carbon cycling, food and fiber production, and climate requires gridded inputs defining the land-use and land-cover change (Taylor et al. 2009). These gridded land-use inputs describe how the area of the region in different land-use and land-cover classes change over time (Hurtt et al. 2006). In global models, different land-use and land-cover classes are often simulated as a fraction of each model grid-cell, thus allow for sub-grid scale variation in land-use. Two major weaknesses in the regional to global simulations are 1) a lack of regionally specific drivers of land-use transitions and regionally specific scenarios of future land-use, and 2) an explicit consideration of management practices on the carbon cycle and land cover dynamics. Recent work by Hansen et al. (2013) shows a number of regions on the global forested landscape that are experiencing significant changes (mostly forest loss). The southeastern United States stands out as a unique region in terms of land change dynamics. The region is highly productive and largely forested, but with an anthropogenic dominance in the ecosystem. In the southeastern US private owners (from individuals to corporations) control a vast majority of lands (about 90%) and economic factors dominate their decisions. Existing land use studies explicitly address the influence of returns to alternative uses in determining land use choices (Hardie et al. 2000, Lubowski et al. 2002, Wear 2011). We argue that a limiting feature of previous studies has been the treatment of secondary forests as a single land use, in effect lumping passively managed or unmanaged forests with those that are intensively managed. As planted and intensively managed forests have expanded in the southeastern US and now account for a majority of harvests, it seems clear that these managed forests are distinct land uses with very different costs, benefits and service flows when compared with naturally regenerated and unmanaged forests.

We propose a synthesis project that integrates four major projects, decades of research on land use and forest management in the Southeastern United States, and NASA remote sensing products (Landsat) and algorithms to develop a regionally specific land-use transition matrix that considers the economic structure of land management and land use decisions under varying scenarios. This matrix will be incorporated into the Global Land-Use Model (GLM) to generate new Land-Use Harmonization datasets, paving the way for future integration of regionally specific land-use decisions into global climate projections.

Deliverables for the project include: 1) Landsat-based classification and transitions that include managed forest lands for the Southeast, 2) an integrated assessment of socio-

economic drivers of land-use transitions in a management-driven region, 3) regionally-refined land-use transition matrix derived from an economic conceptual framework that considers management, and 4) harmonization of the regional results with the GLM. Our overall framework could be modified and applied elsewhere to develop regionally appropriate matrices that could feed into the global products.

Philip Townsend/University of Wisconsin-Madison

Landscapes In Flux: The Influence of Demographic Change and Institutional Mechanisms on Land Cover Change, Climate Adaptability and Food Security in Rural India

While there has been a considerable reduction in the number of undernourished people in the past two decades, India still has among the largest malnutrition rates in the world. Increasing pressures from population growth and urbanization have subsequently affected land use patterns in India, with as much as 36.6% of all land in India degraded. Climate change will likely exacerbate these issues through additional stresses on food production.

Regionally, a range of socioeconomic factors also play a role, such as: lack of availability of and access to resources, land degradation, food insecurity and landlessness. Geographically differentiated strategies are needed to address these issues, but current strategies are severely hampered by the paucity of spatially-explicit information on food security and agriculture. This information is crucial for early detection of trends and to disentangle the complex relationships between food security and land use. Of critical need are spatially-explicit data on the factors that define dimensions of food security, and methods that allow the combination of these data into holistic synthetic indicators that explain causal factors in an integrated manner. Identifying, estimating and mapping spatial variations in the proportional strengths of these interrelationships will help identify the factors influencing food security and eventually land-use and land-cover change in rural as well as peri-urban areas.

The specific objectives of this proposal are to: 1) generate spatially downscaled data of key demographic and socio-economic indicators that putatively define dimensions of food security in India, 2) use a hypothesis-driven approach to integrate economic, social, policy, infrastructural, and behavioral facets of food security into a holistic modeling framework, and, finally to 3) assess land cover change as an emergent outcome of patterns of socio-economic, demographic and policy instruments at local to regional scales. To do this, we will use small area estimation techniques to spatially disaggregate household-scale data on critical demographic, socioeconomic and food security indicators to the village scale. Subsequently, using a structural equation modeling framework, we will integrate indicators of food security with extant socioeconomic and demographic patterns, indicators of climate adaptability and metrics of infrastructural and policy instruments. Maps of latent vectors of the SEM will allow the first-ever spatialized representation of the combined effects of institutional support, accessibility to markets and extension services on regional indicators of poverty and malnutrition. Further, we will develop a generalized methodology for mapping land cover and producing probabilistic pixel-wise maps of classification uncertainties. We will eventually combine

land cover change probabilities with indicators of food security derived from structural equation models to assess the influence of food security indicators on patterns of land cover change. These analyses will provide the first-ever assessments of the relative strengths of drivers of land cover change in the study regions at local to regional scales. The proposed research directly addresses NASAs high-priority science goals with a central focus on Land Cover Land Use Change science within the larger Carbon Cycle and Ecosystems program. In addition, the proposal directly addresses the influence of socio-economic drivers on land cover change. By developing a strong socio-ecological context to all our study sites and analyses, we will ensure the interdisciplinary application of space-borne technologies to help address issues of high societal relevance. The proposed research is therefore directly responsive to the NASA LCLUC program themes: detection and monitoring of change, predictive land use modeling, climate variability and change, and drivers of change and food security.

Jeffrey Vincent/Duke University
Consequences of Changing Mangrove Forests in South Asia on the Provision of Global Ecosystem Goods and Services

Mangrove forests in South Asia provide essential ecosystem services to the regions dense coastal population, and they support important functions of the biosphere. They are under threat, however, from natural and anthropogenic forces. Scientific understanding of rates, patterns, and causes of mangrove cover change and resulting impacts on ecosystem services is limited for the region. To help fill this gap, we propose a three-year project to examine mangrove cover change from 1985 to the present in Bangladesh, India, Myanmar, Pakistan, and Sri Lanka, and to assess the consequences for two globally important ecosystem services, carbon sequestration and biodiversity conservation. We will:
Objective 1: develop an operational methodology for annual monitoring of mangrove cover changes;
Objective 2: create a comprehensive database of annual mangrove cover changes from 1985 to the present at 30 m resolution;
Objective 3: quantify the impacts of mangrove cover changes on carbon stock changes and species extinction risks on an annual basis from 1985 to the present; and
Objective 4: analyze the effectiveness of existing mangrove protection programs, and prospective cost-effective expansions of them, in reducing carbon emissions and species extinctions.

The project will integrate research in remote sensing, conservation biology, and environmental economics. Research to achieve the first two objectives will emphasize analysis of Landsat data. We will preprocess Landsat data using a new automated algorithm, and we will evaluate three approaches for classifying the annual mosaic. We will compare the approaches using interpreted high resolution satellite data and field survey data from four sites and select the most accurate ones for the annual change analysis.

For the third objective, we will estimate carbon stock changes by combining area data from the mangrove cover change database with carbon densities per unit area. We will

use meta-analysis to estimate the latter, and we will value carbon stocks changes using published estimates of the social cost of carbon. We will investigate mangroves role in biodiversity conservation by using data from the mangrove cover change database to assess how much original forest remains and how fragmented it is, and down-scaled species range maps to determine which areas have the most endemic species facing the greatest extinction risks as a result of habitat loss and fragmentation.

For the fourth objective, we will build on the other research and conduct three types of economic studies: conventional retrospective evaluations of the impacts of protection programs on avoided mangrove deforestation and degradation in all five countries; and, for Bangladesh and India, novel retrospective evaluations of the impacts of protection on carbon sequestration and biodiversity conservation, and prospective analyses of new mangrove areas to protect in order to cost-effectively enhance carbon sequestration and biodiversity conservation.

Duke University and the United States Environmental Protection Agency will implement the project in collaboration with researchers at South Asian institutions. The project team is well-positioned to implement the project successfully given the team members prior collaborations and complementary expertise. We will disseminate results to the research community in the usual ways (publications, seminars, conferences), generating at least six peer-reviewed publications in high-impact journals. We will use policy briefs and newsletters to reach national authorities responsible for mangrove protection decisions and national and international authorities working on financial mechanisms for conservation (e.g., carbon payments). We will build capacity in research and applications by involving junior researchers in the project, integrating findings into courses we and our collaborators teach, and linking the project to a nascent South Asia Regional LCLUC Initiative.

Stephen Walsh/University of North Carolina, Chapel Hill
Synthesis of Drivers, Patterns, and Trajectories of LCLUC in Island Ecosystems

(1) Primary Island Sites (Hawaiian Islands, Galapagos Islands, Puerto Rico) will be characterized using an assembled social-ecological data set, including, population censuses, tourism data, household surveys, environmental data, local & community infrastructure data, and a blended satellite image stack populated by LANDSAT & MODIS imagery, but also SENTINEL, ASTER, HYPERION & ADVANCED LAND IMAGER data. Existing image archives will be consulted for all available imagery, including the USGS Global Visualization Viewer, USGS EarthExplorer, and NASA Earth Exchange web portals. The nominal periods of study are 1990, 1995, 2000, 2005, 2010 & 2015.

(2) Published information will be distilled from LCLUC case studies for Primary & Secondary Island Sites (Fiji, Azores, Canary Islands, Madagascar, Seychelles, Tahiti) and for islands more generally. LCLUC classification schemes (e.g., USGS National Land Cover Database & NOAA C-CAP Program) will be examined and a suite of LCLUC classes selected that best represent island ecosystems, particularly, those that suggest a transition from natural to human systems (e.g., forest to urban & built-up) and from

human to natural systems (e.g., reforestation of abandoned land). Our classification focus will be on urban & built up (low, medium, high intensity), forest (deciduous, evergreen, mixed), cultivated crops, pasture, agroforestry, grasslands, wetlands, open water, beaches, shrub/scrub, and barren. High spatial resolution imagery, e.g., Worldview-2, QuickBird, Google Earth Pro & Google Earth Engine images, will be used for calibration & validation. Using our defined LCLU classes, a suite of change-detections will be generated that represent from-to transitions, with a focus on (1) intensification of urban & built-up, (2) rural to urban, (3) deforestation & reforestation, (4) agricultural extensification & land abandonment, (5) transitions among cultivated crops, pasture & agroforestry, and (6) coastal & interior island development and the transition of beaches, wetlands, forest, shrub/scrub, and open water. We will also track the fragmentation patterns and changes in vegetation & environmental indices. Further, we will construct LCLUC trajectories using derived sequences, focusing on the timing, magnitude, and stability/dynamism of LCLUC relative to the six transitions listed above.

(3) Findings will be synthesized based mainly on models developed for the Primary Sites, informed through statistical functions that link variables and rates of LCLUC documented in the literature. We will develop a Dynamic Systems Model that is sufficiently robust and capable of capturing the main social-ecological variations and dynamics of the drivers of LCLUC on the Primary Sites. We will then test the Model to see how well it represents the variation in the Primary Sites, including performing sensitivity analysis to assess model performance. The Dynamic Systems Model will also be tested through what if scenarios of change.

(4) We will expand the degree to which the model can be applied in the Secondary Sites by compiling population censuses, tourism data, household surveys, environmental data, and fused satellite assets to assess LCLUC patterns and the drivers of change. We will secure archival satellite image data as done for our Primary Sites. We will apply the Dynamic Systems Model to the Secondary Sites with necessary modifications and test model performance using sensitivity analysis.

(5) As further demonstration of the generalizability of our Dynamic Systems Model, we will develop and test our models using MODIS imagery and globally available & gridded population and socio-economic data maintained by (a) CIESEN, Columbia University, the GRUMP databases, (b) LandScan Global Data Set, Oak Ridge National Laboratory, (c) Global data sets including the Pacific Climate Information System, NASAs Earth Observing System Data & Information System, NOAAs Coastal Change Analysis Program.

Randolph Wynne/Virginia Polytechnic Institute and State University
Spatiotemporal Drivers of Fine-Scale Forest Plantation Establishment in Village-Based Economies of Andhra Pradesh

The Indian state of Andhra Pradesh, our study area, has decreased in overall forest cover in recent years, with concomitant (though not commensurate) increases in forest plantation area, largely through conversion of degraded and existing agricultural land. Unfortunately, however, accurately mapping forest plantations in India using remotely-

sensed data has been difficult because: (1) many plantations are small relative to moderate resolution earth resource satellite data, (2) newly established plantations are very difficult to identify, and (3) the surrounding cropland area is very variegated in both time and space. A concomitant socio-economic issue is the relatively unknown incentives and risks associated with establishing plantations within the broader land use context at the decision maker level in this region. Leveraging forest industry partnerships and strong extant approaches pioneered by our team, our overall goals are to (1) improve the accuracy and precision by which forest degradation and plantation establishment can be remotely-sensed using data from ResourceSat-1, Landsat, SPOT, and/or RapidEye; and (2) determine the most predictive local, regional, village, and household based drivers of plantation forest establishment (the social science aspect of the proposed study). Our proposed research is particularly responsive to the solicitation, as it (1) couples remote sensing observations (using both NASA and synergistic non-NASA assets) from which land-cover can be derived with research on the human dimensions of land-use change, (2) is explicitly focused on the South Asia geographic region of interest, (3) improves the detection, monitoring, and predictions of land cover and land use change in the region, (4) attributes land cover and land use changes to their primary causes, and (5) provides a formal means and rigorous method for evaluating the socially best land use mix over time as the region develops. The primary expected outcomes are as follows: (1) improvements to algorithms from which both discrete and continuous land use and land cover change variables can be remotely-estimated in this tropical, fine-scale, temporally dynamic, and spectrally variegated landscape, and (2) an empirical realization of forest plantation establishment in village-based economies where smallholders establish forest plantations on previously degraded lands for both timber and non-timber use, using a unique data set developed over time and space through the period covered by the proposal. Deliverables will include, but not be limited to, the following: (1) a map of plantations, natural forests, degraded forests, and primary non-forest land uses in East and West Godavari, (2) a system of equations resulting from the econometric analysis, with a rent function describing the net returns from each land use option for a household, and a response model of the decision to establish forest plantations on existing and new land as a competing land use with other uses such as agriculture and grazing. Our tentative schedule is as follows: Year 1: (1) develop econometrics survey instrument, (2) use high-resolution remotely-sensed data in concert with in situ reference data to (a) develop tree canopy cover dependent variable distributions (b) map plantations and other key land uses in East and West Godavari circa 2016, (3) use resulting map and ancillary data to develop sampling strata for survey, (4) distribute and collect survey instruments. Year 2: (1) refine tree canopy cover (both static and dynamic) estimation approaches using Landsat data, (2) analyze survey data; develop econometric models. Year 3: (1) map canopy cover and change in the region, (2) assess how property rights risks and future market opportunities for competing uses affect forest plantation establishment, (3) quantify the errors associated with non-integrated land use change modeling. Overall, our study has strong potential to help enrich LCLUC science in South Asia.