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:

- Focused studies to document the scientific foundation and requirements for new remote-sensing measurements from space (1) of vegetation physiological properties and plant functional types and (2) to complement and fill gaps among ongoing investigations of vegetation three-dimensional (3-D) structure, biomass, and disturbance measurements that evaluate technological options and data analysis methodologies;
- Integrative studies that significantly advance the results of prior Terrestrial Ecology research toward meaningful answers to NASA’s and the U.S. Climate Change Science Program’s (CCSP’s) carbon cycle and ecosystems research questions; and
- Studies to develop and implement advanced ecological models or ecological model components focused on incorporating all major drivers, especially the human system drivers, of ecosystem function and all relevant processes that affect ecosystem function.

A total of 59 proposals was received, and 11 have been selected for funding at this time. The total funding to be provided for these investigations is approximately $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.

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Ralph Dubayah/University of Maryland
Integrating Vegetation 3D Structure And Ecological Modeling For Continental Scale Assessments Of Biodiversity, Biomass And Disturbance

With the advent of new satellite remote sensing technology, particularly the Geoscience Laser Altimeter System (GLAS) on board ICESAT, and proposed future missions, such as DESDynI, there is new opportunity to derive information on the vertical structure of vegetation canopies of the utmost relevance to terrestrial ecology applications. The overall science goal of this proposal is to link lidar remote sensing of vegetation structure and ecosystem modeling to improve the characterization and predictability of terrestrial systems for both ecosystem dynamics and associated patterns of biodiversity. In addressing this science goal we will also answer questions of direct relevance to this NRA concerning the development of requirements for space missions focused on the observation of vertical vegetation structure and the ecosystems models that will use these observations. In particular we seek to answer the following three questions:
(1) How can patterns of ecosystem structure be observed and modeled at region- to continental- scales using an approach that combines remotely-sensed observations of canopy structure with ecosystem modeling?

(2) What are the satellite measurement requirements, derived from ecosystem model requirements, needed to accurately quantify patterns of ecosystem structure and improve model predictions of future dynamics for carbon and biodiversity studies?

(3) What are the relationships between bird species richness, vegetation structure and ecosystem productivity at regional to continental-scales?

The proposed research falls into five categories: (1) New LVIS flying along important ecosystem gradients, and analysis of existing LVIS data, to assess the relationship between structure and biodiversity at fine scales; (2) Production of North American forest height and 3D structure distributions from ICESAT at various model grid resolutions; (3) development of a continental-scale framework and subsequent modeling of carbon stocks, fluxes and productivity using and ecosystem model (ED) initialized with ICESAT; (4) validation and sensitivity studies of ED model outputs of carbon stock, flux and productivity to variations in vertical canopy structure inputs at different spatial scales to determine measurement requirements for carbon and biodiversity studies; (5) application of the derived and modeled products along LVIS gradients, and continentally using ICESAT/ED in national scale assessments of structure, productivity and biodiversity.

This proposal directly addresses Sub-element 1 of the this NRA, vegetation 3-D structure, biomass and disturbance, and Sub-element 2, integrative studies. In the first case, we will explore (a) how ecosystem models will use structure measurements from space, and (b) how these model requirements then determine measurement requirements of vegetation structure for DESDynI or ICESATII. With regards to Integrative Studies, our research brings together work on ecosystem modeling, remote sensing of vegetation structure and biodiversity to answer important questions outlined in the U.S. Climate Change Science Program’s (CCSP’s) carbon cycle and ecosystems program with regards to the controls on continental scale distributions of species richness and abundance. In particular, this research lays the required groundwork for addressing the effects of future land use and climate change on biodiversity, a priority area for the CCSP.

Josef Kellndorfer/The Woods Hole Research Center
Ecosystem Structure Measurements From Desdynti: Studies Of Technological Options And Data Fusion Using Icesat/Glas, Airborne Lidar And Alos/Palsar Datasets Over Central Chile

The overall goal of the proposed research is to investigate technological options and data fusion algorithms for ecosystem structure measurements from the proposed NASA DESDynI mission. The experiments described in this proposal are possible given the timely confluence of highly relevant remote sensing and ground reference data sets. Through collaboration with the leading geospatial information company in Chile,
Digimapas Chile, we will have access to 75,000 km2 of 1-meter resolution full-waveform small footprint lidar (SFPL) data and 0.5 m resolution digital orthophoto imagery covering the commercial forests of Arauco, one of the largest cellulose producers in Latin America. Arauco is a collaborator on this proposal and will provide access to relevant timber survey data, which is regularly acquired across their land holdings. The SFPL acquisitions commenced in October of 2006 and are scheduled to be completed in mid-2008. The area covered with the SFPL data has also been mapped by the ALOS/PALSAR at several resolutions and acquisition modes. In addition, multi-spectral optical imagery from ALOS/AVNIR-2 and CBERS-2, as well as lidar data from ICESat/GLAS are available for use. All remote sensing data will have been acquired during a very narrow time frame spanning less than two years.

Given the size of the study area (75,000 km2), the availability of very high resolution lidar and optical imagery, and the dense network of field reference data, very realistic simulations of spaceborne lidar sampling design covering multi-scene radar and optical imagery can be conducted. In turn, these simulations provide an ideal framework within which to test various approaches to DESDynI lidar/radar data fusion leading to canopy height and aboveground biomass retrievals. Data fusion will be accomplished using randomForest, a state-of-the art statistical modeling approach based on ensemble machine learning techniques.

Four specific objectives are proposed to achieve this overall goal:

1. Evaluate multi-sensor data-fusion strategies for canopy height (CH) and aboveground biomass (AB) retrieval.
2. Study the effect of lidar sampling density on the accuracy of CH and AB predictions.
3. Study the effect of lidar footprint size on the accuracy of CH and AB predictions.
4. Study the effect of radar resolution on the accuracy of CH and AB predictions.

One of several key DESDynI mission science questions involves the performance of off-nadir multi-beam lidar data for CH and AB retrieval. As part of the proposed research, approximately 300 km2 of Arauco forest holdings will be remapped with Digimapas Chile’s SFPL at off-nadir angles of up to 10°. This acquisition will facilitate an investigation into how the off-nadir pointing affects the lidar waveforms and hence the accuracy of CH and AB predictions.

The proposed work addresses the following research needs identified in the DESDynI Workshop Report (2007): (1) studies to develop and evaluate algorithms and analysis strategies that address the merger of lidar and radar measurements (data fusion), and (2) studies to quantify the effects of sampling design and measurement accuracy, frequency, and resolution on the ability to improve our quantitative knowledge of global carbon dynamics and ecosystem structure and function. This focused study was designed as a two-year project so as to make results available as early as possible for the purposes of informing the development of the DESDynI mission concept.
We propose to develop a comprehensive measure of global vegetation phenology that exploits the high temporal repeat, all-weather capabilities of satellite radar and is sensitive to dynamic changes in both vegetation structure and water status. We will utilize a radar backscatter modeling framework with biophysical measurements from regional station networks to quantify sensitivities of alternate frequencies (Ku-, C- and L-band) and polarizations to canopy phenology across regional biomass and moisture gradients using time series satellite radar backscatter measurements from the SeaWinds scatterometer, ALOS PALSAR and ASCAT. We will examine potential synergies between radar based phenology and vegetation indices derived from satellite optical-IR remote sensing. This investigation builds on previous work, wherein we successfully applied SeaWinds for monitoring North American grassland response to regional drought, and seasonal changes in vegetation canopy biomass and LAI for a diverse set of global biomes. We will extend this effort to the full global vegetated domain by exploiting robust Ku-band backscatter sensitivity to surface structure and dielectric properties, as well as the daily temporal fidelity and global coverage of the SeaWinds scatterometers. These attributes will enable us to develop a comprehensive measure of global phenology, incorporating dynamic variability in landscape moisture and canopy structure. Satellite Radar backscatter time series are sensitive to spatial and temporal variations in landscape freeze/thaw state, which is a fundamental environmental constraint to the growing season for more than two-thirds of Earth's vegetated land area. It also provides a mechanism for disaggregating annual time series into growing and non-growing seasons where cold temperatures constrain water mobility and ecosystem activity. Radar backscatter time series can also be analyzed to assess temporal changes in canopy structure and water status, including the capacity to identify significant plant stress (e.g., drought) and associated plant physiological constraints to canopy evaporation, ecosystem productivity and terrestrial carbon sequestration of atmospheric CO2. Radar backscatter sensitivity to canopy condition is a function of sensor frequency and polarization, as well as land cover type and vegetation biomass. We will assess coincident satellite radar backscatter time series encompassing a range of different sensors, frequencies and polarizations using forward radar scattering models to quantify the physical basis of observed backscatter behavior and for developing improved phenology algorithms. These results will also be evaluated using current satellite remote sensing measures of global vegetation dynamics and site based ecosystem model simulations to determine linkages between radar backscatter behavior and landscape biospheric processes. This study will provide a comprehensive measure of global phenology that incorporates information on both canopy structure and water status and provides relatively precise global daily mapping and monitoring capabilities regardless of solar illumination, cloud cover, smoke and other optical aerosol effects. The proposed high-temporal resolution mapping of this critical variable will substantially augment and enhance current information from EOS visible-IR remote sensing (e.g., MODIS, AVHRR), which is commonly limited to coarse temporal composites of standard
products required to mitigate cloud cover and atmospheric aerosol contamination, and substantial data loss at high latitudes from shadowing and reduced solar illumination for much of the year.

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**Ranga Myneni/Boston University**  
**A Synergistic Study For Lidar And Passive Optical Remote Sensing Of Forest Horizontal Structure In Support Of Desdyni Mission**  

The motivations for this study are two twofold: (a) the need for spatially resolved accurate estimates of forest woody biomass to improve our understanding of the dynamics of source/sink relations in the terrestrial carbon cycle, (b) characterizing changes in the three-dimensional structure of forests in relation to natural and anthropogenic disturbances and subsequent recovery within the context of habitat preservation, biodiversity and resource management. The objective of this study is to develop the research basis for remote sensing of variables descriptive of 3D forest structure (tree height, crown height and diameter, ground cover and tree density). The methodology is based on the novel idea of retrieving the pair correlation function that uniquely characterizes the horizontal structure of a forest stand by synergistically exploiting the information content of lidar, multispectral and hyperspectral remote sensing data. We propose to develop the theoretical basis of this methodology and test it with experimental data using existing ground and aircraft-based remote sensing data from various sites in the USA. This proof-of-concept study is expected to contribute to the development of operational algorithms for retrieval of forest 3D structure as part of the proposed NASA DESDnyI mission.

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**Michael Palace/University of New Hampshire**  
**Scaling Forest Biometric Properties Derived From High Resolution Imagery To The Amazon Basin Using Moderate Resolution Spectral Reflectance Data**  

We propose to integrate field-measured tropical forest biometric variables with multi-scale remote sensing data from numerous sensors, for the purpose of characterizing and understanding patterns of forest structure across Amazonia. The Amazon basin contains the largest continuous tropical forest on the Earth (6 million km2) and constitutes 40% of the remaining area for this ecotype. The dynamic processes of growth and disturbance are reflected in the structural components of forests. Because Amazonia contains a large stock of biomass and because unmanaged Amazon forests currently may be a significant sink for carbon, understanding Amazonian forest dynamics reflected in forest structure is important for understanding regional and global carbon and biogeochemical cycles. A lack of comprehensive estimates of forest structural properties across the Amazon basin currently limits our ability to map carbon balances in this region. Recent observations from plots and eddy flux towers of carbon sink activity in Amazonian forests could be caused by recovery from disturbance, Because many or most of the currently studied forest plots were not randomly selected, and because their geographic distribution leaves vast areas unstudied, regional remote sensing data is required to understand the rate and frequency of forest disturbance in Amazonia and the linkage of disturbance to ecosystem
carbon flux. We will use high resolution optical data to quantify forest structural properties including stem frequency, crown dimensions, and canopy gap fraction. We will extrapolate these estimates of forest structure from the local and regional scale to the basin scale by linking them statistically with synoptic reflectance data from moderate resolution sensors (MODIS/MISR). This will be done annually for seven years (2002-2008) using linear and non-linear statistical methods. The resulting temporal and spatial distributions of forest structural properties will provide insight into changes in carbon cycling at regional scales.

Stephen Prince/University of Maryland
Vegetation Dynamics In Drylands And Implications For Regional Climate: Analysis Of Two Decades Of Observations In The African Sahel

This study will investigate the dynamics of vegetation in the Sudano-Sahelian region of Africa to improve the understanding of dryland ecosystems functions and interactions with the climate. Regional vegetation productivity and phenology and their environmental correlations are well-known, but the mechanisms are little understood at this scale, and unexplained relationships challenge current understanding. The effects of important aspects of dryland environments, such as episodic rainfall pulses, are little known at this scale. Time lags between pulses of rainfall, for example, presumably have a threshold beyond which the vegetation does not respond. Extensive areas with poor correlations between annual vegetation growth and rainfall have been reported, notwithstanding the existence of strong regional correlations. Current knowledge of surface water and energy fluxes suggests that these anomalies will affect the climate. The objectives are: 1) Systematically survey and inventory periodicities in vegetation cover, leaf area index and net production for 27+yrs using high temporal resolution satellite data; 2) Form hypotheses about endogenous and environmental causes of the various types of vegetation dynamics, develop algorithms relating the two, and define new plant functional type properties; 3) Modify an existing, coupled soil-vegetation-atmosphere-transfer model (SSiB-4) and a dynamic vegetation model (TRIFFID) to simulate observed vegetation dynamics and use a mesoscale climate model (WRF) to determine the impact on the regional climate. The West African monsoon has not been modeled satisfactorily, and evidence indicates that poor specification of vegetation processes contributes to the inaccuracy. We intend to make a more complete description of the principal temporal and spatial patterns of variation in vegetation in the Sudano-Sahelian region, to assess the roles of endogenous and exogenous environmental processes, including anthropogenic land cover changes, and to determine their effects on the regional climate. Significant improvements in understanding dryland ecosystem processes at the regional scale and its climate are anticipated.
Dar Roberts/University of California, Santa Barbara
Spatial, Spectral And Temporal Requirements For Improved Hyperspectral Mapping Of Plant Functional Type, Plant Species, Canopy Biophysics, And Canopy Biochemistry

Hyperspectral data have considerable potential for mapping plant functional types (PFTs), species and for providing improved estimates of canopy biophysics and biochemistry. We propose using high-spatial resolution Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and multitemporal AVIRIS and SPOT-5 to evaluate spatial, spectral and temporal requirements for a spaceborne hyperspectral mission. We will use a common set of analysis tools, primarily centered around Multiple Endmember Spectral Mixture Analysis and hyperspectral indices applied to AVIRIS data acquired over a diversity of North American ecosystems with a variety of PFTs. AVIRIS data will be spatially and spectrally degraded to synthesize several broadband sensors and more spectrally limited hyperspectral sensors at spatial scales ranging from 4 to 60 m. Ecosystems include temperate rainforest, semi-arid shrublands, interior mixed conifer forest, oak savanna, broadleaf deciduous and evergreen forest and forested wetlands. All study sites include high quality field data, existing high-resolution AVIRIS, and existing or planned lidar.

Key questions addressed include: 1) What are the optimal sensor (spatial and spectral) requirements needed to map plant species and PFTs across sites representative of several major ecosystems within North America? ; What are the optimal sensor requirements for accurate estimates of canopy biophysical, chemical and physiological properties, including photosynthetic and non-photosynthetic cover, canopy moisture, above ground biomass and light use efficiency?; 3) What is the impact of temporal sampling on the ability to discriminate PFTs and estimate cover fractions?; and 4) What are the synergies between hyperspectral-physiology/biochemistry and lidar vertical structure including how height and height change improve PFT mapping and quantify the value of a hyperspectral measure?

This proposal addresses Sub Element 2.1.1 of the Terrestrial Ecology RFP, but also addresses key components of 2.1.2 and 2.2 by investigating synergies between lidar and hyperspectral data and building off of findings from our current Carbon Cycle Science research.

Marc Simard/Caltech/ Jet Propulsion Laboratory
3D Vegetation Structure Using L-Band Insar And Lidar

We propose to quantify the potential of L-band polarimetric and interferometric synthetic aperture radar (PolinSAR) and lidar to characterize the 3D structure of vegetation. In particular, this proposal addresses issues related to the application of the DESDynI (Deformation, Ecosystem Structure and Dynamics of Ice) mission to characterize 3D vegetation structure. This mission combines the ability of lidar to measure localized canopy height profiles (CHP) and of radar to provide wide area estimates of canopy height. The overall objective of this proposal is to study the most likely scenarios for
DESDynI and quantify their performance and the remaining uncertainty in the retrieval of vegetation structure parameters (i.e. height, density, biomass, and canopy/biomass dynamics). Most importantly, we will find the best compromise between long (greater lidar spatial coverage and lower interferometric correlation) and short repeat cycle (lower lidar coverage but higher interferometric correlation).

Our approach uses existing data from spaceborne (ICEsat/GLAS) and airborne lidar data (LVIS) in addition to spaceborne (ALOS/PALSAR) and airborne (UAVSAR) L-band polarimetric inSAR data. Our team already possesses the available ICEsat/GLAS waveforms, LVIS and ALOS/PALSAR data covering all 10 proposed test sites. Much of this data has been processed as part of previous NASA projects by the investigators and we are ready to perform the proposed tasks. UAVSAR is a new airborne L-band polarimetric repeat pass interferometer. To achieve the overall objective, we propose to collect new data with UAVSAR to study temporal interferometric decorrelation over a wide range of vegetation types at six time intervals: 1 hour, 2-days, 5-days, 8-days, 12-days and 16-days. To sample a variety of important vegetation types, we will collect UAVSAR data over 6 of the 10 sites in California, New England and Central America.

Using the ALOS/PALSAR and UAVSAR data, we also propose to assess and compare the accuracy of two SAR-based techniques to estimate 3D vegetation structure and in particular canopy height, density and biomass. The techniques are: 1) SAR interferometry (inSAR); 2) SAR polarimetric interferometry (PolinSAR). Finally, we propose to combine lidar data to the SAR techniques to improve characterization of 3D vegetation structure. For the InSAR technique, we will combine lidar and inSAR data to estimate ground topography in addition to vegetation height. On the other hand, the PolinSAR technique does not require knowledge of ground topography and exploits the full potential of a mission like DESDynI. Thus, PolinSAR is the most promising technique to characterize canopy structure and is based on the fact that ground and vegetation scattering mechanisms are different and so are polarimetric signatures. In order to retrieve heights, a simple polarimetric scattering model is fitted to the data which depends on several parameters, including canopy extinction and vegetation height. We will use lidar height estimates to constrain the polarimetric scattering model and derive canopy extinction. This analysis will also enable us to characterize the relationship between canopy closure and extinction in the canopy.

This proposal directly responds to Sub-element 1 of this NRA (Vegetation 3-D Structure, Biomass and Disturbance), which states that of "particular interest are: (1) studies to develop and evaluate algorithms and analysis strategies that address the merger of lidar and radar measurements".

Philip Townsend/University of Wisconsin-Madison
Characterization Of Forest Functional Types And Their Role In Mediating Ecosystem Response To Environmental Change

Terrestrial ecologists are now called upon to provide regional scale predictions of the delivery of key ecosystem services from complex forest environments that are increasingly subjected to multiple agents of global environmental change. This
necessitates the identification of the spatial pattern and fundamental mechanistic linkages among (1) forest functional types (FFT), (2) the magnitude of ecosystem perturbations, and (3) the magnitude of ecosystem responses. We propose to use field and imaging spectroscopic measurements to test an overall hypothesis that for a given perturbation, spatial variability in ecosystem response can be characterized by using spectroscopy to measure a key suite of leaf-based functional traits that define FFT.

We will characterize FFT by canopy-based measurement of three key functional traits: cell structure, shade tolerance, and recalcitrance. A synthesis of the literature and our recent research results indicate that these three traits describe fundamental axes of variability in plant physiology. Moreover, they synthetically define a spectrum of FFT ranging from “open” to “closed” patterns of forest nutrient cycling. We will use field spectroscopy, laboratory measurements, and assessments of species composition to directly measure canopy-based values of the biophysical and biochemical properties (i.e. Wm [ratio of leaf water mass to leaf dry mass], chlorophyll, lignin, foliar delta N-15, and leaf mass per area) that are hypothesized to define variation in cell structure, shade tolerance, and recalcitrance. By relating these field measurements to spectra obtained from AVIRIS or Hyperion, we propose to demonstrate the spectroscopic basis and quantify the error and uncertainty in our characterization of FFTs. Moreover, by collecting this field and hyperspectral information across a range of forest ecosystems (15 study sites ranging from boreal to tropical forests), we will identify the degree to which our characterization of FFT may be generalized to all forest ecosystems. Finally, we will test our overall hypothesis by relating characterizations of FFTs to field and remote sensing data describing ecosystem perturbations and ecosystem responses.

Our research meets several key NASA programmatic and scientific objectives. First, we will test and validate methods for using imaging spectroscopy to characterize plant physiology and assess ecosystem-relevant FFTs (program sub-element 1). This provides a basis for the development of algorithms suitable for future hyperspectral sensors. Second, we will integrate these assessments of FFTs with our ongoing work utilizing remote sensing information for characterizing disturbance and ecosystem response (program sub-element 2). Finally, our proposed work will generate the data, geographic scope, and synthetic focus that is urgently needed in the ongoing development of a general theory linking plant ecophysiology, ecosystem ecology, and global change science.

Robert Treuhaft/Jet Propulsion Laboratory, Caltech

The Performance Of Structure And Biomass Estimation From Insar 3-D Vegetation Missions At L-Band Over Tropical Forests

Remote sensing of vertical structure bears on forest biomass, ecosystem function, and biodiversity. Most interferometric SAR (InSAR) proof-of-concept tests of structure and biomass estimation to date involve sufficient baseline length and/or polarization diversity to estimate structural parameters at the few-m level. Some involve uniform forests in relatively flat terrain. All use fixed baselines or repeat-track interferometry (RTI) in which temporal decorrelation-changes in the scene between data acquisitions defining a
baseline-is essentially zero. However, for a single-spacecraft, repeat-track mission such as the proposed DESDynI, smaller observation sets affected by temporal decorrelation may yield performance characteristics quite different from previous results. This proposal therefore bridges the gap between the performance of published InSAR tests and that of a repeat-track, L-band mission. Structure- and biomass-estimate performance will be evaluated as a function of realistic operation and analysis modes by 1) assessing the limiting or best possible accuracy of structure and biomass estimation over a variety of complex tropical forests, with many repeat-track polarimetric baselines; and 2) assessing the scenario-dependent accuracy for smaller numbers of baselines which may characterize DESDynI. We will use airborne L-band RTI InSAR data taken in 2004 over the wet tropical forests of La Selva Biological Station, Costa Rica, data from the currently flying Japanese PALSAR over Costa Rica, and PALSAR data in Brazil. The La Selva data set will determine limiting accuracy by using many polarimetric baselines selected for minimal temporal decorrelation. Subsets of the data, with larger temporal decorrelation signatures, will simulate possible configurations of DESDynI, supplemented by L-band InSAR data from PALSAR. In order to sample a diversity of tropical forests, we will estimate vegetation structure and biomass using PALSAR data combined with field work at moist tropical forests of the Tapajós National Forest and Purus River Basin in Brazil.

Michael White/Utah State University
Understanding And Predicting Continental-Scale Disturbances With Prognostic And Diagnostic Models: Bark Beetle Outbreaks In North America

We propose to model ecosystem stress precursors to epidemic disturbances by conducting a new synthesis of prior NASA investments in remote sensing, modeling, and climatology. Our method will be generalizable for many disturbance systems; here we will develop and implement our approach using the bark beetle (Scolytinae [Coleoptera: Curculionidae]) forest disturbance system in western North America. Bark beetles are a societally relevant disturbance because they are spectacularly destructive, ecologically well-studied, and likely to respond to changing climates. We will use a combination of three main methods: (1) for forested areas of the North America west of 100W longitude, 1km resolution ensemble simulations of ecosystem stress metrics derived from prognostic (run without remote sensing) and diagnostic (run with remote sensing) models; (2) gridded estimates of bark beetle disturbance from 1980 to 2007 derived from aerial detection surveys and NASA remote sensing; and (3) conditional probability modeling to link stress metrics, including lagged effects, to bark beetle disturbance. We will conduct research at the scale of ecoregions; depending on the analysis, results will be presented within- or among-ecoregions. Through the use of ensemble approaches and scaling analyses we will consider uncertainties and accuracy assessment for each methodology. Using these approaches, our central questions will be:

1. What ecosystem forcings increase the probability of outbreaks?
2. Are there non-linear or threshold forcings of epidemic outbreaks?
3. Can a comparison of prognostic and diagnostic models be used to identify disturbance effects on subsequent ecosystem function?
4. Which extrinsic climate forcings are most responsible for ecosystem stress leading to epidemic outbreaks?

5. What is the likely response of bark beetle disturbance to climate change?

Our proposed work strongly leverages other NASA investments, will produce results leading to improved disturbance processes in prognostic ecological and climate models, and illustrates the ability of NASA research, data, and remote sensing to address compelling societal questions. Our research is also responsive to programmatic and agency goals: for the Terrestrial Ecology program, we respond to section 2.2, Integrative Studies, which seeks proposals “that offer to conduct a new or to enhance an ongoing synthesis of past research results”; for Earth Science, we study carbon cycles and ecosystems, water and energy cycles, climate variability and change, and weather; for NASA, our research will “Study planet Earth from space to advance scientific understanding and meet societal needs”.

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