A. 36 New (Early Career) Investigator Program (NIP) in Earth Science

The New (Early Career) Investigator Program (NIP) in Earth Science is designed to support outstanding scientific research and career development of scientists and engineers at the early stage of their professional careers. The program aims to encourage innovative research initiatives and cultivate scientific leadership in Earth system science. The Earth Science Division (ESD) places particular emphasis on the investigators' ability to promote and increase the use of space-based remote sensing through the proposed research. The NIP supports all aspects of scientific and technological research aimed to advance NASA’s mission in Earth system science (http://science.nasa.gov/about-us/science-strategy/).

In basic research and analysis, the Focus Areas include: Carbon Cycle and Ecosystems, Climate Variability and Change, Water and Energy Cycle, Atmospheric Composition, Weather, and Earth Surface and Interior. In applied scientific research, the ESD encourages efforts to discover and demonstrate practical uses of NASA Earth science data, knowledge, and technology (see http://appliedsciences.nasa.gov). In technological research, the ESD aims to foster the creation and infusion of new technologies into space missions in order to enable new scientific observations of the Earth system or reduce the cost of current observations (see http://esto.nasa.gov). The ESD also promotes innovative development in computing and information science and engineering of direct relevance to ESD.

Of the 141 proposals received for the NIP program element in ROSES 2017, 32 proposals have been selected for awards. The total funding for these investigations, over a period of three years, is approximately $8.2 million. The selected projects are:

**Shannon Capps/Drexel University**  
**Assimilating Ammonia Observations to Improve Emissions Impact Estimates**  
17-NIP17-0094

Ammonia in the atmosphere contributes to the formation of particles that diminish human health. Additionally, deposition of excess ammonia can lead to eutrophication of ecosystems. Currently, anthropogenic emissions of ammonia, primarily from agriculture, contribute a substantial portion of the budget of atmospheric nitrogen. Nevertheless, estimates of ammonia emissions are quite uncertain since a variety of natural processes that produce ammonia and emissions rates from anthropogenic sources are poorly constrained. Strategies for reducing concentrations of particles are evaluated with models of the atmosphere which represent the movement of air as well as the chemical reactions that transform ammonia and other gases such as oxides of nitrogen and sulfur dioxide into particles. The models depend on estimated particle precursor emissions rates, which are relatively uncertain compared to the chemistry and meteorology in the model. In the U.S., particle concentrations have declined over the last four decades as the National Ambient Air Quality Standards (NAAQS) have been tightened. Emissions
controls of oxides of nitrogen and sulfur dioxide on fossil fuel combustion sources are largely responsible for these declines. As such, developing emissions mitigation strategies to reduce particles has become more challenging and has highlighted the importance of reducing ammonia concentrations, which had largely been neglected in emissions control strategies.

The Cross-track Infrared Sounder (CrIS) instrument, which flies on the Suomi National Polar-orbiting Partnership satellite in the Joint Polar Satellite System, provides regular observations of ammonia concentrations across the globe. This work will leverage these observations as a constraint for improving ammonia emissions estimates in a regional four-dimensional variational (4D-Var) data assimilation framework. Additionally, the augmented atmospheric chemistry model integral to the 4D-Var framework will enable efficient calculation of spatially-heterogeneous influences of ammonia emissions on concentration-based metrics such as the damages particles cause to human health or the eutrophication induced by it.

The refined estimates of ammonia emissions from application of the data assimilation approach will provide two key products. First, with refined estimates of ammonia emissions, the scientific community will have a better understanding of atmospheric composition. Secondly, the efficient, adjoint-based estimates of the heterogeneous impacts of ammonia emissions on health and ecosystem endpoints will be more accurate. In concert with one another, these refined estimates of atmospheric composition and emissions impacts will serve environmental decision makers who are seeking optimal routes to reducing damages from particles concentrations or nitrogen deposition.

NASA has supported scientific applications of satellite-based observations that enhance understanding of atmospheric composition, which this work will accomplish through improving modeled values of atmospheric ammonia by refining the most uncertain model parameters, emissions rates. Through the Health and Air Quality Applied Sciences Team (HAQAST), NASA has demonstrated an interest in developing modeling tools that directly improve the quality and efficiency of the endeavors of air quality and human health stakeholders. This work will serve environmental decision makers by transferring the use of the CMAQ adjoint to this community for efficient elucidation of the emissions most impacting the area of interest. Finally, this effort would establish a framework for leveraging CrIS-based ammonia observations, which could be extended to other atmospheric constituents in the future.

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Megan Cattau/University of Colorado, Boulder
Ecological Stability and Disturbance - Recovery Dynamics in Southern Rockies forests: Upscaling from the tree- to the Landsat-level
17-NIP17-0104

Forests of the Southern Rocky Mountains have recently experienced larger, more intense, and more frequent wildfires, resulting in extreme environmental and social consequences, including altered regional water resources, billions spent annually on fire suppression, and a widespread increase in tree mortality. Also, human land use, both historical legacies and current intermixing along the wildland-urban interface, alters forest dynamics and introduces more anthropogenic ignition sources. The interaction of fire
with other disturbances and land management activities across large spatial scales is not well understood. These interactions may lead to unpredictable outcomes in recovery dynamics, leaving long-term disturbance legacies on the structure and function of ecosystems. A major challenge in exploring resilience following disturbance is the lack of widely available fine-scale forest data that cover a sufficiently large spatio-temporal extent.

The proposed work takes advantage of the wealth of data available through NASA’s space-based remote sensing program to help address a fundamental question related to ecological resilience and stability: How do disturbance interactions affect tree mortality and forest recovery across the Southern Rockies? We hypothesize that, over the past three decades (over the Landsat record, 1984-present): the rate of forest recovery will be slower and / or the probability of a state transition will be higher following fire, H1: if fire is preceded by an insect epidemic, blowdown, or timber harvest; H2: if there is a sustained, multi-year drought during the initial recovery phase; and H3: as a function of distance from undisturbed area, particularly for dispersal-dependent plant functional groups.

In the proposed work, we will unmix Landsat data, compile data on disturbance, and integrate these data under a Bayesian framework to address how disturbance dynamics alter recovery trajectories. To unmix Landsat, species-specific hyperspectral profiles will be aggregated to the level of plant functional group and used to develop endmembers, resulting in maps of the percent of each Landsat pixel occupied by the following land cover classes: coniferous forest, deciduous forest, shrub, herbaceous cover, and bare ground, 1984-2017 at an annual timestep, and validated with unmanned aircraft systems (UASs) collects. To compile disturbance data, we will use a suite of satellite products, aerial surveys, census and housing data, and government records. Using a Bayesian framework, we model the change in the mixing proportion of each vegetation class for each pixel, as well as project changes in vegetation states over time under different conditions. Our methodological approach and modeling framework allow estimating error from various sources and tracking that error as it propagates throughout the model.

This proposed work will promote the utility of space-based remote sensing in the field of disturbance ecology, and will contribute to our fundamental scientific knowledge of Earth’s ecological cycles. Understanding how interacting disturbances precipitate vegetation transitions across large spatial scales using NASA and other data will provide an important test of classic ecological theory on resilience and stability, indicating how forests in the region may change over time. The framework we provide here and the scalable sampling design leverages emerging technologies to engineer solutions that will accelerate scientific discovery and conservation efforts and could ultimately be applied at a continental scale. Furthermore, the unmixed Landsat data layer described above will be made publically available as a new NASA-derived product, thus expanding on the capabilities of using the Landsat archive. This proposed work will help us meet the challenges associated with changing climate and disturbance regimes by identifying what factors most strongly influence land cover changes at large spatial scales.
Dramatic global losses of wetland extent, biodiversity and ecosystem functions over recent centuries represent a massive ecological perturbation, the consequences of which require continued research and monitoring. Despite the widely acknowledged contribution of biodiversity to critical ecosystem services such as productivity, stability and resilience to stressors, the ability to monitor biodiversity and these contributions across regional extents remains limited. Although a number of remote sensing instruments, particularly hyperspectral sensors, have been promising in such efforts, their applications are still limited by the lack of globally observing platforms and universally robust complex data processing algorithms. These constraints are especially pronounced in wetlands that are often biologically diverse due to unique environmental gradients yet continue to decline and disappear at alarming rates globally. Further aggravated by spatial complexity and field survey limitations in wetlands, these issues create an urgent need for cost-effective yet generalizable and robust approaches for monitor wetland biological diversity and its change. To address this need, this study proposes a novel strategy using spatio-temporal phenological information from the publicly available, long-term repeatedly collected NASA satellite products and an unprecedented rigorous and comprehensive field survey of 967 USA wetland sites by the 2011 National Wetland Condition Assessment (NWCA) by the Environmental Protection Agency. Although phenological information highlighting spectral-temporal heterogeneity of landscapes has been used for mapping elements of biodiversity in both wetland and terrestrial regions, it has not been yet rigorously investigated for quantitative, repeatable monitoring of biodiversity and ecosystem stability at regional scales. The main objectives are thus to determine 1) how biological diversity of vegetation affects spatio-temporal variation of wetland phenological characteristics and 2) the potential of using these relationships to monitor ecological condition and stability at regional and continental scales. To address these objectives, the analysis will focus on three major hypotheses: 1) wetland vegetation diversity increases spatial phenological variability and heterogeneity, 2) vegetation diversity increases short-term inter-annual phenological variability but also enhances the long-term phenological stability, and 3) wetlands with higher levels of ecological stress are more likely to exhibit directional shifts in their long-term phenological trajectories. These hypotheses will be tested by quantifying Landsat satellite-based phenological metrics for seasonal trajectories of spectral vegetation indices, their local spatial variation and inter-annual spatio-temporal covariance for the NWCA wetland field-surveyed units and testing statistical models using these metrics as candidate predictors of field-based vegetation diversity and ecological condition indicators. Modeling outcomes will be ranked to determine the predictive potential of phenological indicators and validated using the recent follow-up 2016 NWCA survey. Different sources of uncertainty will be also assessed by estimating statistical model errors, the effects of geographic differences in remote sensing data availability, confounding factors of tidal effects and the effects of spatial resolution. Study outcomes will provide critical new insights on the linkages
among wetland biodiversity, ecological condition and phenological dynamics and
generate a reproducible research framework to support both regional, broad-scale
accounting of wetland ecosystem services and local wetland restoration efforts with cost-
effective NASA satellite products in the USA and globally. The project will also generate
rich opportunities for undergraduate and graduate student science training and academic
curricular innovation in applied remote sensing and environmental planning.

Ardeshir Ebtehaj/University of Minnesota
Reducing Uncertainties in GPM Snowfall Retrievals: Applications for Improved
Prediction of Snowstorms
17-NIP17-0021

Snowfall is the main input for accumulation of glaciers and snowpack in winter and
release of snowmelt in summer. More than 2 billion people worldwide and 60 million
Americans rely on snowmelt as the main source of freshwater. The grand questions are ‘
how is snowfall changing in a global to regional scales and how can we improve
predictions of extreme snowstorms? Ground measurement of snowfall is costly and often
infeasible over remote and high-altitudes. Therefore, monitoring of snowfall from space
is the key to answer those questions. Unlike well-studied satellite rainfall, there are
significant knowledge gaps and remaining challenges for snowfall retrievals because of
several reasons. First, the snowfall radiative transfer properties are much more
complicated than the rainfall. Second, the snowpack scatters the upwelling surface
emission strikingly similar to the snowfall and further weakens its scattering signals.
Third, the emission of supercooled cloud liquid water often masks the snowfall signal. As
a result, currently, the largest uncertainty in satellite precipitation is related to snowfall
over snow-covered surfaces.

The goal of this proposal involves formalizing the ways we can combine the knowledge
of land and atmospheric radiative transfer models to understand why, when, and to what
extent the microwave signals of snowfall, cloud liquid water, and snow cover are
different as well as developing fundamentally new algorithms for improved passive
retrievals and forecasts of snowfall, using data from the GPM satellite. The PI's research
has already had a number of successes such as developing modern Bayesian algorithms
for rainfall and snowfall retrievals using the TRMM and GPM data and demonstrating
the impacts of multi-satellite data assimilation for improving precipitation and soil
moisture forecasts. In this proposal, the PI will pursue three objectives:

- Bayesian retrieval algorithms rely on an a priori database that relates physical properties
  of precipitation profiles to their brightness temperatures. Due to the explained knowledge
gaps, operational databases are currently observational and unable to consistently encode
snowfall physical properties, especially over snow cover. The PI proposes to implement a
coupled snow-cover and snowfall radiative transfer modeling system. This suggests a
new set of questions and techniques, whereby we can systematically explain the
differences between the snowfall and snow-cover microwave signals under a wide range
of feasible boundary conditions.
- Develop a fundamentally new algorithm to retrieve precipitation rates and types over snow-covered surfaces with unprecedented accuracy. This algorithm will follow a new paradigm by linking the temperature and precipitation profiles through their weighting functions and considering the land signal as a piece of valuable information rather than a background noise. The solutions will be conditioned on the highest quality observations from the CloudSat and GPM radars to identify, quantify, and reduce the uncertainty of snowfall retrievals using innovative ideas in optimal estimation of the weighting functions and covariance of correlated channel errors.

- The research will also explore the design of a new variational technique whereby the forecast uncertainties in timing of snowstorms could be significantly reduced through GPM snowfall data assimilation.

The scientific outcomes will help to improve retrievals of snowfall from space, which can set the stage for increased understanding about the changes in solid part of the hydrologic water and energy cycle. The applied outcomes will demonstrate how the GPM data can improve prediction skills of severe snowstorms through a novel data assimilation technique using the NASA Unified-WRF model. The research would also pave the way for thinking about new algorithms that enable simultaneous retrievals of precipitation and snow-cover physical properties using the GPM data.

Leila Farhadi/George Washington University
Coupled Estimation of Evapotranspiration and Recharge from Remotely Sensed Land Surface Moisture and Temperature
17-NIP17-0077

The PI's goal in this project is to advance the understanding and modeling of large-scale evapotranspiration and recharge flux. Recharge to the aquifers and evapotranspiration from the landscape are two critical fluxes in the water cycle that play a pivotal role in (1) global water, energy and biogeochemical cycles; (2) crop productivity; (3) sustainability of aquifers; (4) ecosystem health; and (5) climate. These water fluxes are intimately related to the distribution and functioning of vegetation cover and type and therefore are sensitive to human alteration of the landscape. As a result, these fluxes have already changed dramatically over time and by orders of magnitude. In addition, evapotranspiration and recharge flux amplify changes in precipitation and radiative forcing that result from climate change. Small changes in the magnitude, seasonality and intermittency of precipitation and radiation can be magnified in the recharge and evapotranspiration signals. Therefore, the future of these two critical fluxes may be even more uncertain under a changing atmospheric composition. Despite the importance of these fluxes and their historical change, there are no direct measurements -in situ or by remote sensing- that can allow any mapping or any global or regional estimation. Long-term and spatially explicit (mapped) monitoring of evapotranspiration and recharge flux have been elusive goals and a grand challenge for hydrologists (NRC 2012).
The research objective of this proposal is to quantify/map the patterns and dynamics of evapotranspiration and recharge flux using remotely sensed land surface state observations that are widely available across a range of spatial and temporal scales, landscapes and climates. In order to achieve this objective, the PI will develop and integrate state-of-the-art computational and data driven techniques to yield first order accurate estimates of key state and parameters (e.g., estimation control variables) of evapotranspiration and recharge flux from implicit information contained in the multi-platform remotely sensed Land Surface state observations of Temperature (LST) and Soil Moisture (SM). The developed approach is based on the variational data assimilation (VDA) scheme that assimilates state observations of LST and SM into a coupled system of surface energy balance and surface water balance. The cost function consists of the LST and SM misfit terms and deviations of parameter estimates from prior values. Parsimonious heat and moisture diffusion equation are adjoined to the cost function as strong constraints. Efficient solution procedures (Euler-Lagrange) are available for such systems. The Hessian of the cost function, which yields a measure of uncertainty in the estimation, will be derived and used in this study to guide the formulation of a well-posed estimation problem. The accuracy of this method will be tested at point scale using synthetic and field site measurements of turbulent heat fluxes and soil moisture profiles. The method will be applied to regional scale using multi-platform and frequency remote sensing data. Categorical land classifications will be used to test the consistency of the retrieved variables. The retrievals will be verified against tower-flux and soil moisture profile field site measurements, and physiographic characteristics of the region.

This project will advance NASA's mission in Earth system science by utilizing satellite-based remotely sensed data obtained from multiple NASA missions to characterize evapotranspiration and recharge flux and their scale, landscape and climate dependence. Accurate estimation and characterization of these fluxes will facilitate the answers to the overarching research questions of NASA's Water and Energy Cycle focus area.

Peter Gaube/University of Washington, Seattle
Developing a Mechanistic Understanding of the Influence of (Sub)Mesoscale Features on the Distribution and Behavior of Pelagic Predators
17-NIP17-0027

Meso- and submesoscale features make up the internal weather of the ocean, exciting vertical fluxes and transporting pelagic communities hundreds to thousands of kilometers. Yet, while the application of satellite technology now allows us to view these features in almost real time, the influence of these structures on pelagic predators remains largely unknown. With the latest satellite tagging technologies, we now have the ability to observe the movement of large oceanic predators in high-resolution, three-dimensional space. Here, we propose to investigate the use of mesoscale eddies, meanders, and submesoscale fronts by pelagic predators in the North Atlantic. We will collocate trajectories obtained from satellite-tagged sharks with (sub)mesoscale structures identified and tracked in maps of sea level anomalies and sea surface temperature, which will improve understanding of how pelagic predators use these ubiquitous structures. Furthermore, by comparing observed patterns of feature use by the predators to satellite
observations of ocean currents, surface temperature, and ocean color, we will link observed behavior to known (sub)mesoscale physical/biological processes. Thus, the goal of the research proposed here is to determine the influence of (sub)mesoscale oceanographic features on the movements of pelagic predators through the synergistic analysis of individual fish movement and concurrent satellite observations of (sub)mesoscale features, allowing us to link predator behavior to physical/biological mechanisms.

We will address the following specific objectives:
1. Collocate the movement trajectories of predators with mesoscale eddies, meanders, and submesoscale thermal fronts.
2. Compare how five species of pelagic sharks (blue, tiger, oceanic whitetip, mako and white sharks) use (sub)mesoscale oceanographic features across oceanographic regimes of the Northwest Atlantic.
3. Evaluate concurrent satellite observations of the ocean environment with shark behavior to diagnose mechanistic drivers of and behavioral responses to oceanographic features.

The anticipated results of the work proposed here will help inform future efforts to identify and appropriately manage critical oceanic habitats used by pelagic predators. Knowledge of the physical processes structuring pelagic ecosystems is necessary for a mechanistic and predictive understanding of the distribution and population dynamics of oceanic predators. Ultimately, the future of fisheries management relies on a comprehensive understanding of pelagic predator movements and appropriate habitat models, coupled with synoptic remote sensing products of the high seas and satellite vessel tracking, to provide managers with the data to dynamically optimize management based on the ever-changing marine environment (e.g. NASA-funded WhaleWatch).

This proposed effort advances NASA research objectives through improving space-based prediction of ocean ecosystems and improving our understanding of the physical and biological causative controls on pelagic ecosystems at multiple scales. We seek to leverage the unique capabilities of NASA and skills of the PI to generate knowledge directly applicable to societal needs that can be applied to ecosystem-based management of the oceans at scales relevant to emerging technologies and planned NASA missions. The development of analytical tools and generation of specific hypotheses, proposed here, are critical for improving our ability to integrate remote sensing of ocean motion with fine-scale data on the movement of marine animals and debris. These efforts will become increasingly important as submesoscale sensing becomes more widespread (e.g. upcoming PACE and SWOT missions). The analysis techniques developed through this project will be made publicly available following publication and will offer the community new tools with which to analyze movement data in the context of a growing suite of remotely sensed products.
Intra-urban and intra-pixel variability in the concentrations of short-lived atmospheric trace gases complicates the interpretation and application of satellite-based observations. Urban-scale variability in surface concentrations of nitrogen dioxide (NO2) is frequently acknowledged in air pollution research, but how this ground-level variability manifests in the vertical column and affects satellite remote sensing is not well understood. Even less is known about intra-urban variability of tropospheric formaldehyde (HCHO), another important atmospheric trace gas with a short atmospheric lifetime. The DISCOVER-AQ campaigns clearly showed that local variations in NO2 measured by ground-based instruments are not captured by current satellite-based instruments. These campaigns also demonstrated that there are still uncertainties in the retrievals that can result in disagreement. In the end, the need for spatially dense and long-term ground-based measurements of tropospheric composition emerged as a key theme from DISCOVER-AQ, and has come up repeatedly in discussions about future geostationary observations.

This proposal will address the scientific need to quantify and explain intra-urban variability in tropospheric column densities of two key reactive trace gases, NO2 and HCHO, and to reconcile satellite remote sensing with ground-based measurements of surface air quality. To achieve this, I propose to establish a network of five ground-based Pandora spectrometers within a single urban region (in Boston, MA), capable of retrieving continuous NO2 and HCHO tropospheric columns during the day. The network will have collocated ground-level in situ measurements of NO2 at each location, and LIDAR-derived aerosol profiles at a central site to derive urban boundary layer height. In addition to instrumentation already available in my lab, I will leverage existing instrument capabilities from collaborators at several institutions in the region and from government-run air quality monitoring stations.

The new ground-based observations will be combined with satellite-based remote sensing of tropospheric NO2 and HCHO from OMI, GOME-2, and eventually TROPOMI to evaluate the satellite retrievals and to explore the importance of heterogeneity within a satellite footprint. I am interested in determining whether robust relationships between tropospheric column density and surface concentrations can be demonstrated at the intra-urban scale. I will explore intra-urban spatial scaling relationships and determine how persistent these relationships are across time scales of hours to seasons. A state-of-the-art high-resolution pollutant emission inventory based on local vehicle data will provide hourly estimates of surface NOx sources, and output from a regional atmospheric chemistry model (WRF-Chem) will help interpret the importance of atmospheric chemistry, transport, and mixing. Together, these datasets will be uniquely positioned to answer important unresolved science questions about intra-urban variability in air pollutant concentrations within the tropospheric column and at the surface, and advance the applications of satellite remote sensing of surface air quality.
Overall, the main objectives of the proposed research will be to:
1) Quantify and explain intra-urban variability in air quality at the surface and in the tropospheric column, and reconcile these observations by considering surface emissions, meteorology and planetary boundary mixing, and chemistry
2) Determine the extent to which limited agreement between satellite- and ground-based tropospheric column observations results from a lack of spatial representation versus uncertainty in the individual observations
3) Evaluate predictions of intra-urban pollutant variability from a state-of-the art emissions inventory and chemical transport modeling, and explore how hourly-resolved satellite observations could inform air quality research and monitoring

Colin Gleason/University of Massachusetts, Amherst
Global Mapping of River Discharge
17-NIP17-0008

"Accurately predict how the global water cycle evolves in response to climate change."- Earth Science Directorate (ESD) Overarching Science Goal #4, NASA 2014 Science Plan

In its 2014 Science Plan, NASA’s ESD clearly identified the global water cycle as a top research priority and specifically called for better understanding of water quantity around the globe as the climate system enters an uncertain future. NASA identified this as a key focus because our understanding of global freshwater fluxes remains poor: coupled land surface/circulation models that account for global water are fundamentally limited by a lack of observations. Perhaps no observation is more important for this purpose than measurement of river discharge, which is an indicator of the sum effect of all hydrologic processes in a basin used to tune and parameterize models of the rest of the water cycle. Unfortunately, the gauges that commonly provide this critical data are unavailable for much of the planet, meaning that an additional data source is needed to accurately inform hydrologic models. I have spent my career to date developing methods to use remote sensing to estimate these critical discharge data. My major publication in this area was titled "Toward global mapping of river discharge," where I proposed the first discharge estimation method able to be deployed using Landsat measurements of river width, without in-situ calibration data. This method was based on the novel geomorphic principle of at-many stations hydraulic geometry (AMHG). Here, I propose to use the now-mature Bayesian AMHG Manning (BAM) method and the deep temporal archive of Landsat data to estimate discharge in every river on Earth wider than 120m from 1984-present: a true global mapping of river discharge. This ambitious undertaking is possible within the duration of the award thanks to recent advances in cloud computing for Landsat processing via Google Earth Engine and novel data products that map river networks and river widths globally- e.g. the Global River Widths from Landsat database (GRWL). These advances make it possible to focus work efforts on accurate discharge estimation rather than identifying and measuring rivers from space.

This proposal represents the largest such discharge mapping ever attempted and would improve understanding of freshwater flows in gauged and ungauged basins: directly
addressing the ESD's science goals. The primary outcome of this proposal will be a validated discharge map with well-defined uncertainty for every mass conserved river reach on Earth wider than 120m. In addition, other work products of this proposal will include updated discharge estimation algorithms and an organized global river topology complete with attributes of ancillary satellite data pertinent to the global water cycle. In addition, this work is highly relevant to NASA's forthcoming Surface Water and Ocean Topography (SWOT) mission, as it will provide a required baseline of global discharge against which SWOT will undoubtedly improve. By making this first global discharge map in advance of launch, the SWOT Science Team (of which I am a member) will benefit directly from having this baseline as a Bayesian prior distribution of global discharge, the organization of global rivers into coherent network topologies, the global organization of relevant ancillary data, and any new computing architecture deemed necessary for global deployment of BAM. Thus, once SWOT launches and ~1 year of data has been collected, I can redeploy BAM from SWOT observations on the same river networks, thus efficiently disseminating SWOT discharge estimates to NASA and the public.

Kelly Gleason/Portland State University
Forest Fire Effects on Snow Albedo: Improving Remote Sensing of Snow in Burned Forests (17-NIP17-0048)
17-NIP17-0144

Mountain snowpack serves as an important natural reservoir of water, recharging aquifers, sustaining streams, and providing important ecosystem services. Snow provides important spring moisture for forests, while forests fundamentally alter snow accumulation and ablation. Under average conditions, these interactions have important connections with western US water resources, ecohydrology, and forest management. The warming climate and subsequent reduction in seasonal snowpack, has resulted in an increase in forest fires across the western US. The hydrologic implications of these changes remain uncertain. Consequently, the demand for accurate estimates of snow cover, snow albedo, snow melt, and duration will increase as global climate changes simultaneously alter the extent and duration of snow-water resources, as well as the extent and heterogeneity of forest cover.

Forest fires modify the snow energy balance and the spatio-temporal pattern of snow accumulation and ablation. Charred forests reduce snow surface albedo through deposition of light absorbing impurities (LAI) on the snowpack surface from standing burned trees. Also, the more open burned forest canopy increases the transmittance of solar radiation to the snowpack surface. As a result, forest fires accelerate snowmelt rates and advance the timing of snowpack disappearance across burned areas for many years following fire. LAI in snow perpetuate powerful albedo feedbacks in burned forests, however no study has characterized the light absorbing impurities in snow following forest fire, or quantified the resulting effects to snow surface albedo across space and time.
The overarching goal of this proposed research is to develop a much needed observational and predictive capacity of hydrologically relevant snow properties in burned forested watersheds. To achieve this goal, we will address the following specific objective:

1. Characterize the spatio-temporal distributions of LAI in seasonal snowpack, and the resulting multi-scale effects to snow albedo in burned and unburned forests.
2. Improve the representation of snow albedo in burned and unburned forests in land surface models (LSMs) by incorporating a forest fire effects on snow albedo (FFESA) algorithm.
3. Develop and assess a hybrid remote sensing-modeling method for characterizing snow albedo in burned forested watersheds.

Our approach combines remote sensing and snow modeling with field observations in the Triple Divide region, an area with extensive burned forests in mountainous headwaters of the three major river systems in the western US. The field measurement plan includes a consistent stratified set of snow and forest measurements to fully characterize snow albedo-burned forest interactions during accumulation and ablation periods. These findings will be used to improve representations of snow albedo-burned forest interactions in LSMs and to assess model performance. Remote sensing data, from a range of instruments, will provide multi-scale measurements of snow covered area, albedo, melt onset, and snow disappearance. Our integrated approach will use remote sensing to inform the LSM of burned forest structure and snow conditions, and will use the model to evaluate hydrological impacts of forest fire effects on snow albedo. Modeling will also provide sub-pixel information at spatial and temporal scales beyond what is available with remote sensing alone. This innovative remote sensing-modeling approach can be applied to optical and microwave remote sensing of snow in burned forests.

This proposed investigation is relevant to the goals of NASA's Terrestrial Hydrology Program in that it will address a critical need to improve remote sensing of snow, enhance land-surface modeling, and provide expanded snow mapping capabilities that will benefit current and future missions.

Ronni Grapenthin/New Mexico Institute of Mining And Technology
Joining InSAR with GRACE: Geofluid Dynamics Analysis for New Mexico
17-NIP17-0119

Sustainable use of groundwater resources and a detailed understanding of aquifer structure, dynamics and long-term evolution are of importance to all aspects of human life, particularly in arid regions with limited recharge. Aquifers are generally monitored via hydraulic head changes in monitoring wells. Similarly, hydrocarbon production and reinjection of brine byproducts are often reported and monitored but, just like groundwater estimates, they are limited to point observations, limiting insight into reservoir dynamics. Assessments of geofluid storage capacities, heterogeneities in their structure and composition, and evolution necessarily involve a large degree of
interpolation between observation points based on often uncertain geologic data; frequently requiring extrapolation.

Space geodetic measurements have long been used to study magma transport and motion induced by effects in the hydrosphere such as groundwater pumping and aquifer recovery. The most commonly used tools in such studies are navigation satellite systems (GNSS), radar interferometry (InSAR), and satellite gravimetry (GRACE). The measurements quantify elastic and permanent deformation due to pore pressure changes and mass redistributions. The most promising strategy for future basin and sub-basin scale geofluid studies is a combination of InSAR and GRACE time series due to freely available data and global coverage. I propose to use time-dependent surface displacements measured with InSAR combined with well data to refocus GRACE-measured gravity changes to track geofluid dynamics and map subsurface storage regions over time.

To consolidate InSAR with GRACE's large footprint, I will develop and apply formal methods for their integration on the scale of the entire state of New Mexico and bordering regions. NM provides a rich menu of geofluid activity such as irrigation pumping, hydrocarbon production, brine reinjection and magma transport. The central objectives of this project are:

1) Comprehensive mapping of surface deformation in New Mexico through InSAR and GNSS time-series analysis.
2) Refocusing GRACE mass changes with spatio-temporal constraints from deformation and hydrocarbon well data.
3) Development of formal inversion methods to jointly use deformation and mass change to infer time-dependent source characteristics.

This project can transform the point and process-driven approach Earth Science traditionally takes as it embraces a systematic, time-dependent deformation analysis on state-scale, which has thus far not been attempted. This has the potential to reveal processes and structure that have gone unnoticed and succeed in the notoriously difficult task of groundwater tracking.

This work leverages openly available data from ESA and NASA and will incorporate NASA data that will become available near the start of the performance period (GRACE Follow-On) and potentially during the second half of the project (NASA and ISRO's NiSAR). The PI will reach out to New Mexico state water management agencies to utilize the new products in water management efforts, which increases accessibility of NASA products for users of state and local government agencies in the US and beyond.

The results from this project will directly contribute to goals identified in NASA’s 2016 CORE report. We will perform consistent analysis and modeling at state-scale using continuous high-density data to improve hazard mitigation and benefit society through precise water resource assessment. Human activities are leveraged to understand solid Earth structure and processes. The proposal captures 3 of the research and analysis focus
areas in the NIP solicitation: The primary focus is the water and energy cycle, but
temporal evolution of water recharge naturally provides information on climate
variability. Aquifer and structural mapping and methods combining remote sensing
techniques advance our understanding of Earth’s surface and upper crustal properties.

Kevin Hammonds/Montana State University, Bozeman
Bridging the Gap Between the Micro-Scale Processes and Macro-Scale Properties of Terrestrial Snowcovers: A Laboratory Study Combining Advanced Materials Characterization Techniques With Differential Synthetic Aperture Radar Interferometry
17-NIP17-0045

Although terrestrial snowcovers contribute to the global water supply of nearly one-sixth of the world’s population, most of the world’s snow cover is located in remote and isolated terrain. To monitor the state of both seasonal and perennial snow covers, several snow monitoring systems based on microwave remote sensing techniques have been deployed, but a remote sensing product that derives the snow water equivalent over various types of terrain and on a global scale, has yet to be developed. Currently, there are several international space-borne, aerial, and ground-based remote sensing missions taking place that offer snow monitoring products from both passive and active microwave remote sensors, but many opportunities still exist for further exploring and better interpreting these datasets. For instance, it is known that shifts in the microstructural properties of a snowpack can directly impact radar amplitude, coherence, and the microwave brightness temperature when measured remotely. Many of these approaches require a priori information about snow microstructure, which is measured extremely sparsely in space and time, and for which model uncertainties are very large. Similarly, if analyzing polarimetric radar data, observed shifts in the polarization state of a snowpack are clearly indicative of a shift in the dominant snow grain shape profile, isotropy, and/or preferential crystallographic orientation of the snow grains, but little is known about how these physical properties are correlated to the raw radar data. Furthermore, and perhaps most importantly, very little field research and virtually no laboratory research has been conducted to link these and other remote sensing observables with not only the microstructural state of the snowpack, but also the driving micro-scale physics responsible for these changes. If the microscale physics of snow can be correlated with its macro-scale remote sensing observables, however, a much clearer understanding of the Earth's global water cycle and energy budget will be achieved.

In the research proposed here, the microstructural properties of snow that modify the radar reflectivity, polarimetric signature, and image coherence of multi-frequency and synthetic aperture radar systems will be investigated. From within the Sub-Zero Science and Engineering Research Facility at Montana State University, a series of controlled laboratory experiments will be performed in which artificially created snowpacks are perturbed to mimic natural-like conditions while being monitored with a full suite of remote sensing instrumentation, including multi-frequency polarimetric radar and broadband radiometry systems. To compliment these observations, advanced materials characterization techniques will also be employed, where X-ray computed
microtomography, scanning electron microscopy, and electron backscatter diffraction will be used to elucidate micron and sub-micron scale snow properties such as the crystallographic orientation and the degree of anisotropy of the snow grains. With this unique combination of remote sensing and in-situ observations from within a controlled laboratory environment, new insight into the micro-scale physics of snow that drive macro-scale radar- and radiometric-observables will be derived, microwave remote sensing retrieval algorithms will be improved, and several novel approaches to the remote sensing of snow will be applied and tested including circular synthetic aperture radar and differential synthetic aperture radar interferometry. Given NASA’s ongoing field campaigns focused on the cryosphere, such as SnowEx and IceBridge, combined with NASA’s planned spaceborne missions of NISAR and IceSat-2, a remarkable opportunity now exists to link many of the desired yet still fundamentally unknown characteristics of snow with these and other remote sensing platforms through this detailed laboratory study. Lastly, no field work will be required for this research.

Laura Holt/NorthWest Research Associates, Inc.
Southern Hemisphere Gravity Wave Sources and Effects on Circulation, Transport, and Ozone
17-NIP17-0087

The proposed research will combine NASA satellite data and model output from the Chemistry-Climate Modeling Initiative (CCMI) to investigate atmospheric gravity waves and their effects on circulation and atmospheric composition in the Southern Hemisphere. Recent research suggests that large-amplitude gravity waves generated by convection are important drivers of circulation, temperatures, and transport in the lower stratosphere, which influence atmospheric constituents such as ozone and water vapor. However most atmospheric models have biases in temperatures and winds because of deficiencies in the way that gravity waves and their effects on circulation are represented. This problem is especially pronounced in the Southern Hemisphere stratosphere, where winds are generally too strong and temperatures too cold in most chemistry-climate models. Additionally, the stratospheric final warming in the Southern Hemisphere is typically one or two weeks late in models compared to observations. This leads to major temperature biases in the lower stratosphere and associated effects on ozone chemistry. The reasons for these biases are not well understood, although it has been suggested that missing Southern Hemisphere gravity wave drag in models is a major culprit. Possible sources of the missing gravity wave drag include inadequate continental orographic gravity wave drag, orographic gravity wave drag from small, unresolved islands, lateral propagation of gravity waves generated at other latitudes, and nonorographic gravity waves generated by fronts and convection. Deficiencies in modeled gravity wave effects and the resulting model biases in wind and temperature in the Southern Hemisphere hinder our ability to accurately model the ozone hole and its recovery, which also has implications for our ability to model surface climate change. This project will identify the important sources of the missing gravity wave drag in the Southern Hemisphere and improve our understanding of gravity wave sources and gravity wave impacts on circulation, transport, and composition.
The methods will focus on data from NASA satellite instruments, including precipitation and latent heating from the Global Precipitation Measurement (GPM) mission, infrared brightness temperatures from the Atmospheric Infrared Sounder (AIRS), and temperatures from the High Resolution Dynamics Limb Sounder (HIRDLS). For example, at the extremes of the HIRDLS measurement latitudes (near 63 degrees in the Southern Hemisphere), the zonal sampling is very dense and provides an abundance of information on waves spanning many spatial scales. This information has not yet been exploited to investigate the missing Southern Hemisphere drag. The gravity wave information obtained from the satellite instruments will be used to evaluate the sources of missing drag in the CCMI models. This will result in recommendations for improved gravity wave parameterizations, which will ultimately improve our ability to simulate the ozone hole and its recovery in a changing climate.

Cameron Homeyer/University of Oklahoma, Norman
Analyses of Convective Influence on Upper Troposphere Lower Stratosphere Composition Using Aura MLS, Ground-Based Radar, and MERRA-2
17-NIP17-0018

Deep moist convection can affect the concentration and distribution of trace gases in the upper troposphere and lower stratosphere (UTLS), which is important for atmospheric chemistry, Earth’s radiation budget, and climate. For example, the radiative forcing of climate by greenhouse gases such as ozone and water vapor has been shown to vary significantly with changes in their distribution and concentration near the tropopause. Due primarily to the contrast in the composition of the troposphere and stratosphere, processes leading to stratosphere-troposphere exchange (STE) often result in the largest and most rapid changes in UTLS composition. However, the global impact of small-scale processes such as convection on UTLS composition is unknown, due to a limited understanding of their geographic distribution, frequency, and additional characteristics. This study seeks to improve our understanding of convective influence using a unique combination of ground-based radar observations, trace gas profiles from the Microwave Limb Sounder (MLS) aboard the NASA Aura satellite, and assimilated atmospheric states from the NASA Modern Era Retrospective Analysis for Research and Applications version 2 (MERRA-2).

The efforts in this proposal will test a key hypothesis: convection is a significant contributor to changes in the composition of the UTLS over large spatial scales (i.e., regionally and/or globally). Through examining the validity of this hypothesis, we seek to determine: (1) the relationship between the physical characteristics of convection, the thermodynamic characteristics of its environment, and its impact on the composition of the UTLS, (2) the seasonality of the location, frequency, magnitude, and depth of convective influence over the contiguous United States and its implications for radiation and climate, and (3) the relative roles of tropospheric transport, STE, and chemical processes such as stratospheric ozone depletion in establishing the observed UTLS composition linked with convection. The key hypothesis and related objectives will be
addressed using trajectory mapping techniques driven by MERRA-2 winds. In particular, trajectories will be used to link convection and cloud-free regions over the United States identified in a new, high-resolution, high-frequency database of observations from the U.S. NEXRAD WSR-88D ground-based precipitation radar network with downstream Aura MLS profiles. The two populations of MLS profiles will then be compared to determine the influence of convection on the composition of the UTLS. These analyses will advance our understanding of convective influence and its impact on chemistry and climate.

The proposed effort will support NASA’s international leadership as a discovery organization by using and promoting the use of unique NASA datasets and by building off of previous NASA accomplishments. In addition, by increasing our understanding of convective influence on UTLS composition, this study will support two primary objectives of NASA’s mission in Earth system science: (1) to advance the understanding of changes in the Earth's radiation budget that result from changes in atmospheric composition, and (2) to improve the ability to predict climate changes by better understanding the role of the atmosphere in the climate system.

Alexandra Konings/Stanford University
Using Model-Data Fusion to Determine Plant Hydraulic Traits and Transpiration 17-NIP17-0014

Transpiration comprises about 65% of global evapotranspiration (ET) and by influencing the partitioning of water at the surface, has a first-order effect on how precipitation variability is translated to downstream water resources and ecosystem services. Most land surface models treat (evapo-)transpiration as a function of soil moisture. Instead, transpiration physiologically depends on leaf water potential, and is thus influenced by plant water storage and the movement of water through the plants as well as by soil moisture. Because of the myriad feedbacks between plant water stress, stomatal closure leaf area index, and atmospheric CO2 and VPD conditions, capturing these plant hydraulic effects is critical for correctly capturing the response of transpiration to water stress and predicting future fluxes of ET. However, while including the equations necessary to account for plant hydraulics in land surface models is straightforward, parameterizing them is a key difficulty. Hydraulic traits are generally more variable within plant functional types than across them, so standard methods of parameterization based on plant functional types are not reliable nor informative. Here, we will use remote sensing observations to infer such parameters at model-informative scales, building a stepping stone for the next generation of evapotranspiration approaches for land surface and earth system models.

In this project, we will build a Plant Hydraulic mODel-Data fusion System (PHODDS) to simulate transpiration and determine spatially variable, effective plant-scale hydraulic traits. The PHODDS simulates the land surface water balance as constrained by uncertain, remote-sensing based observations. It updates model parameters to match these observations, rather than merely updating the model state, as in data assimilation. The
proposed system is enabled by the use of two (uncertain) observational constraints: total ET from ALEXI and microwave vegetation optical depth, which my group has recently shown carries information about leaf water potential. We will also assimilate surface soil moisture.

PHODDS will be used to investigate for what climates and plant traits conventional methods of modeling transpiration as a function of soil moisture lead to the greatest error during drought. By investigating this question with parameters that are locally optimized by the model-data fusion system, we will be able to isolate the role of model structure from the role of parameterization errors in determining transpiration model quality. We will further use PHODDS to investigate the controls on the buffering effects of transpiration: we will determine what hydraulic traits are linked to sensitivity to different types of drought (e.g. vapor pressure deficit or soil moisture-driven effects), enabling improved understanding of hydrologic resilience to future drought occurrence.

Differences in model tuning and resolution may prevent parameters from PHODDS to be directly useable in the next generation of land surface or earth system models. However, because of the limited information of plant functional types about hydraulic traits, an alternative way of determining likely trait values is necessary for model parameterizations. In the last component of this proposal, we will build a predictive system that can classify ecosystems into alternative clusters with similar traits values. This system will be optimized to maximize predictability of the traits, and will depend on ecosystem properties that have previously been shown to influence hydraulic traits: canopy height, topography, mean climate, etc. This predictive system should dramatically increase the usability of PHODDS results across a variety of models.

Isaac Larsen/University of Massachusetts, Amherst
Quantifying the Magnitude of Agriculturally-Induced Soil Erosion by Integrating Satellite Observations, Airborne Lidar, and Laboratory Data
17-NIP17-0041

Soils support terrestrial life and are the medium that grows the vast majority of the food consumed world-wide. Soil erosion reduces soil fertility, resulting in diminished agricultural production that ultimately threatens food security. Soils contain twice as much carbon as Earth's atmosphere, hence understanding the magnitude of soil carbon erosion has key implications for global climate. Ecosystem services are adversely impacted by soil erosion and the combined on- and off-site costs of soil erosion in the U.S. reaches tens of billions of dollars annually. Despite recognition of the need to conserve soil and the implementation of soil conservation efforts, there are still major uncertainties regarding the magnitude of soil erosion in the U.S. The large uncertainties in the magnitude of soil loss hinder the ability to design effective soil conservation measures and soil erosion policy, and hence undermine food security, ecosystem health, and human prosperity.

The central objective of the proposed work is to use satellite-based spectral data to determine the proportion of the landscape which has completely lost carbon-rich topsoil
in the Midwestern U.S. The proposed research will test hypotheses focused on three themes: 1) developing and implementing spectral methods to quantify the spatial magnitude of carbon-rich soil loss and topographic controls on soil erosion; 2) calibration of numerical soil erosion models with remotely sensed data; and 3) regional upscaling of soil carbon loss and predictions of the associated agricultural productivity and economic declines. By integrating a variety of spectral and remote sensed data, including an iron index calculated from high-resolution WorldView-2 imagery, a carbon index calculated from Landsat 8 imagery, high-resolution aerial LiDAR topographic data, and soil carbon, horizon, and laboratory spectral data from hundreds of samples analyzed by the USDA Rapid Carbon Assessment project, the proposed work develops a multi-scale framework for assessing the magnitude of soil loss and determining the underlying physical drivers of soil erosion in one of Earth's most important agricultural regions.

Proof-of-concept results from a test area indicate the WorldView-2 iron index can be calibrated with laboratory soil spectra to identify areas where carbon-rich A-horizon soils have been completely eroded, exposing pedogenic iron-rich B-horizon subsoils. LiDAR topographic data indicate hilltops with convex topography have the highest iron index values, and hence soil loss. Preliminary numerical modelling indicates trends in iron exposure track those in erosion and deposition predicted by numerical simulations of topographic diffusion, suggesting soil transport by plowing is the dominant process driving soil loss from hilltops. Upscaling with LiDAR and Landsat 8 data in the test area independently indicate extensive erosion of carbon-rich topsoil, with soil B-horizon exposure on over half of the agricultural land area. The preliminary results indicate remotely-sensed data can be used to inform land management practices to enhance preservation of carbon-rich A-horizon soils, and also suggest there is a potential to store large quantities of carbon in degraded Midwest soil via farming practices that restore soil carbon.

The proposed research activities advance the goals of NASA's Earth Science Program through development of innovative methods for detecting the spatial distribution of land cover changes and the influence of those changes on the carbon cycle. NASA and other satellite-based products will be utilized to promote and increase the use of space-based remote sensing while generating products that provide science-based guidance to inform societally-relevant decisions regarding soil erosion and agricultural sustainability.

Xinfeng Liang/University of South Florida, Tampa
Using Satellite and Deep Ocean Measurements to Investigate the Influence of Mesoscale Eddies on Deep Ocean Internal Waves
17-NIP17-0002

Mesoscale eddies are ubiquitous in the World Ocean. A considerable amount of knowledge about mesoscale eddies has been gained, especially since the advent of satellite altimetry in the 1980s. However, most previous work has focused on signals near the sea-surface and, more recently, down to about 2000 m (thanks to Argo). The signals of mesoscale eddies in the deep ocean and their influence on the deep-ocean dynamics have not yet been intensively studied. Recently, a few regional studies found that
mesoscale eddies can significantly influence a variety of deep ocean processes, including subinertial flows, internal waves, and diapycnal mixing. Considering the ubiquitouosity of mesoscale eddies in the global ocean, it is expected that deep-ocean currents are commonly affected by mesoscale variability, particularly near large topography. These eddy-influenced deep ocean currents, mainly subinertial, likely contribute to driving, dissipating and modulating internal waves, and consequently are expected to affect turbulence and mixing as well.

The primary aim of this proposed project is to explore to what extend mesoscale eddies, which can be identified with satellite measurements, affect the deep-ocean currents around the global ocean, and how the eddy-related deep-ocean currents modulate and/or generate deep-ocean internal waves. To achieve this goal, we propose to combine the altimeter data and an archive of deep-ocean measurements to investigate the connections between surface-observed mesoscale eddies and deep-ocean dynamical processes, such as subinertial flows and internal waves, over the global ocean. We will first obtain subinertial currents in the less-studied deep ocean (below 2000 m) and examine under what circumstances these currents are associated with mesoscale eddies revealed in the altimeter data. Then we will investigate the relationships between subinertial currents and near-inertial/tidal currents in the deep ocean, in relationships also to other factors (e.g., topography, latitude and regional circulation).

The proposed studies are closely relevant to NASA. One of the two primary data sources is the altimeter data from various NASA missions. Moreover, the proposed analyses will extend the use of satellite measurements to the study of the deep ocean, which is still poorly understood. Also, since frequency and intensity of mesoscale eddies depend on the state of the climate, the eddy modulation of deep-ocean currents, internal waves, and mixing, connects climate change and climate variability to physical and biogeochemical processes in the deep ocean, allowing for unexplored climate feedback mechanisms. Thus, the proposed analyses will also contribute to one of the major focus areas of the NASA's mission in Earth system science --- Climate Variability and Change.
assumptions and algorithms. This proposal presents a first-of-its-kind remotely sensed ensemble of the water cycle called REESEN that both explicitly closes the water balance and characterizes natural and human processes through a diverse combination of remote sensing observations. REESEN will comprise roughly 50 unique and fully constrained water balance estimates for major global river basins. Two additional benefits include, first, an application within the NASA Land Information System (LIS) data assimilation system to improve water cycle simulations of major international droughts from recent decades. Second, a measure of the impact of human activities on the water cycle using REESEN to discover what is missing and needed from state-of-the-art LSMs. This research will make a significant update to long-standing estimates of global freshwater availability that have largely overlooked human activities.

This proposal addresses the NASA Science Plan Outcome: "Progress in quantifying the key reservoirs and fluxes in the global water cycle and in improving models of water cycle change and fresh water availability".

The major objectives of this work are to:

1. Develop an ensemble of the terrestrial water balance from unique combinations of remote sensing (RS) products. A procedure will be applied to constrain multiple combinations of satellite products towards overall water balance closure at a monthly time step over major global river basins. Residual errors are redistributed among water balance components. An experiment to attribute residual errors to observable geophysical and climatic features will explore transferability of water balance closure to ungauged areas in a spatially distributed manner. This global, satellite-based ensemble will be a first-of-its-kind estimate of the water cycle, useful to update previous estimates of global freshwater availability.

2. Evaluate improvements in performance in NASA LIS data assimilation when assimilating REESEN. Assimilating the constrained water balance components from REESEN is expected to overcome errors from the previous assimilation of raw, unconstrained water balance components and provide key improvements through inter-component water balance consistency. Estimates of streamflow and evapotranspiration will be evaluated against reference data sets to quantify potential improvements and the system will be applied to simulate a set of recent international droughts as case studies.

3. Create probabilistic expressions of the fluctuations in the water cycle and quantify the signature of human activities. REESEN provides a novel and implicit observation of the impact of human activities on water cycle variability. Since existing estimates of global freshwater are based on models that lack accurate representation of human activities, differencing REESEN with these, as well as with reference 'unmanaged' observational datasets will offer new insights into the role of human activities on the water cycle. These comparisons will further provide quality-control/quality-assurance for REESEN, as well as to identify the most important areas where models may be improved.
Composed of a complex network of wetland ecosystems that vary in their sensitivity to disturbances, the Everglades provides a unique opportunity to develop an extensive monitoring system that is capable of detecting disturbances, measuring disturbance impacts, and estimating ecosystem recovery rates. One of the most important disturbances that occur across this landscape is fire. A critical determinant of ecosystem structure and function, fire is necessary to maintain the mosaic of Everglades ecotypes. Currently, Everglades ecotypes are at great risk to shifts in fire regimes with climate change. These risks are further exacerbated by anthropogenic impacts on the quantity, quality, and timing of freshwater discharge into these ecosystems, which drives vegetation abundance and species composition. Although fire plays a critical role in the restoration and maintenance of many ecosystems, it is unclear how hydrology, climate, and land management interact in the Everglades to influence subsequent ecosystem recovery.

When and how often to apply fire continues to be controversial, and fire management has been identified as a critical area of research for the preservation of ecosystems. The restoration and management of fire dependent ecosystems requires ecologically appropriate fire management that, ideally, should be based on the climatically driven natural fire regimes that are necessary to support these fire-adapted ecosystems. Climate change is making it increasingly difficult to determine when and how frequent fires should occur across fire dependent systems. To improve our understanding of the fire regimes required to sustain fire dependent communities, we propose to study the links between fire regimes, hydrology, climate, and ecosystem recovery. Our proposed research will deliver tools for monitoring changes in ecosystem function and evaluate ecosystem recovery by measuring fire induced shifts in NDVI trajectories in Everglades ecosystems. This research will allow us to evaluate how and why ecosystem recovery rates vary in time and in space, which will provide the information that is necessary to determine the fire regimes required to maintain fire dependent ecosystems. This work is essential to improve our understanding of the variation in ecosystem recovery that exists on the landscape and drivers of these patterns.

The proposed work leverages prior National Park Service (NPS), National Science Foundation (NSF), and Department of Energy (DOE) funded projects to improve our ability to monitor and detect important changes in ecosystem function. This research will make a significant contribution to NASA’s Earth System Science Division by quantifying and predicting the effects of major disturbance events on ecosystem health and productivity. Quantifying fire effects on productivity and the fate of disturbed biomass with variation in climate dynamics will improve carbon budget estimates and lead to better initialization, parameterization, and/or testing of ecosystem carbon cycle models.
Autonomous Scheduling of Agile Spacecraft Constellations for Rapid Response Imaging
17-NIP17-0107

Distributed Space Missions (DSMs), such as formation flight and constellations, are being recognized as important Earth Observation solutions to increase measurement samples over multiple spatio-temporal-angular vantage points. Larger numbers of smaller spacecraft also minimize launch and operational risks, and maximize evolution with time and technology. Small spacecraft (Cubesats up to 27U, ~40 kg in development) have the capability to host imager payloads and can slew to capture images within short notice, given the precise attitude control systems emerging in the commercial market. When combined with appropriate software, this can significantly increase response rate, revisit time and coverage. In prior work, we have demonstrated an algorithmic framework that combines orbital mechanics, attitude control and scheduling optimization to plan the time-varying, full-body orientation of agile, small spacecraft in a constellation, such that they maximize observations for given imaging requirements and spacecraft specifications. The proposed schedule optimization would run at the ground station autonomously, and the resultant schedules uplinked to the spacecraft for execution. The algorithm is generalizable over small steerable spacecraft, control capability, sensor specs and regions of interest.

In this project, we will modify the algorithm to run onboard small spacecraft, such that the constellation can make time-sensitive decisions to slew and capture images autonomously, without ground control. Upcoming technologies such as inter-satellite links, onboard processing of images for intelligent decision making and onboard orbit prediction will be leveraged for reaching consensus and coordinated execution among multiple spacecraft. Specifically, we will develop a communication module based on Delay/Disruption Tolerant Networking for onboard data management and routing among the satellites, which will work in conjunction with the other modules to optimize the schedule of agile communication and steering. We will then apply the developed software (for both, ground-based and onboard autonomy) on representative constellations to simulate targeted measurements of multiple phenomena, organized by relevancy scenarios: (1) episodic precipitation events and subsequent floods, with varying requirements for data latency and reaction time; (2) cloud property assessment by tracking specific multi-angular geometries; and (3) Monitoring the spread of wildfires. The autonomous command and control efficiency of our agile algorithm, compared to static sensors, will be quantified with a very simplified observing system simulation per use case.

The proposed algorithms, partially tested on simulation software, will be integrated with University of Hawaii’s COSMOS ground operations tool for software-in-the-loop verification. The onboard version of the algorithms will be integrated with NASA’s Core Flight Software - open source, project-independent framework, used on flight missions such as MMS and GPM. It is expected to plan agile constellation operations, in terms of inter-satellite coordination and control, with minimum latency in a simulated environment, as verified on the cases above. This project will serve NASA’s technical
and scientific areas of emphasis by delivering an Algorithm driven Information System (ADIS) capable of optimizing agile spacecraft constellation operations, which enables new types of measurements, is validated on flight software and applied to relevancy scenarios of recognized importance in Earth Science. This project addresses the NRC recommendations for low-cost, small satellites, miniaturized instruments, and robust constellations for meeting Decadal Survey goals. The chosen relevancy scenarios address SMD’s research and analysis areas: Water and Energy Cycle (precipitation, floods), Climate Variability and Change (clouds), Carbon Cycle and Ecosystems (fire) and the Applied Science program (flood, fire).

David Peterson/Naval Research Laboratory
Quantifying the Impact of Intense Pyroconvection on Stratospheric Aerosol Loading
17-NIP17-0009

Fire-triggered thunderstorms, or pyrocumulonimbus (pyroCb), are an extreme weather phenomenon associated with large wildfires at temperate and boreal latitudes. PyroCb can cause a significant release of smoke particles into the upper troposphere and lower stratosphere (UTLS). Recent meteorological investigations have shown that pyroCb, far from the niche phenomenon they initially appeared to be, are in fact a significant and endemic feature of the regional summer climate in several highly fire-prone regions of the world. The impact of pyroCb on stratospheric aerosol loading is almost completely unconstrained, apart from a handful of case studies.

The proposed study will integrate satellite observations with meteorological data and atmospheric modeling to provide the first ever constraint on the seasonal effects of pyroCb on the stratosphere. This study is organized around the following hypothesis: PyroCb injections of biomass burning smoke particles into the lower stratosphere are a fundamental warm season meteorological process in temperate and boreal regions that significantly influence lower stratospheric aerosol composition on hemispheric scales. By combining a systematic inventory of pyroCb activity with detailed examination of pyroCb properties using CALIOP, OMI, and OMPS, as well as a state-of-the-art atmospheric model, this study will address the following questions:

1. What is the total aerosol mass injected into the lower stratosphere by pyroCb at regional, hemispheric, and global scales?

2. How well does the spatial and temporal variation in the pyroCb source correlate with total wildfire activity, and how is it influenced by regional meteorology?

3. What is the contribution of regional pyroCb activity to the total aerosol load in the UTLS, and how does it modify local radiation balance?

The Naval Research Laboratory has developed tools for the systematic detection and monitoring of pyroCb. By combining an inventory of pyroCb events over multiple fire
seasons in North America, eastern Asia, and Australia with satellite observations from OMI and OMPS that can constrain absorbing aerosol content, and height-resolved information on smoke injection from CALIOP, this study will build a robust seasonal inventory of pyroCb events including estimates of mass injection profile for absorbing and non-absorbing aerosol particles. These data are essential inputs for atmospheric modeling applications that will provide the first simulations of pyroCb impacts on the UTLS.

The active and well-studied North American fire season of 2013 will be employed to build a focused simulation with the NASA Goddard Earth Observing System, Version 5 (GEOS-5) chemistry-climate model to quantify the contribution of pyroCb to stratospheric aerosol mass and radiative forcing, with respect to other tropospheric emissions and volcanic eruptions. Comparisons between this simulation and CALIOP, OMI, and OMPS observations will provide the first ever temporally and spatially resolved constraint on the contribution of regional pyroCb activity to stratospheric aerosol loadings. The proposed work will therefore establish a foundation for understanding the relative contribution of pyroCb activity to seasonal and inter-annual variation in stratospheric composition, and their corresponding effects on radiative forcing and circulation.

Kaylan Randolph/University of Connecticut, Storrs
A Measurement-Based Characterization of the Hyperspectral Reflectance of Breaking Waves, Subsurface Turbulent Kinetic Energy Dissipation Rates, and Air Entrainment as a Function of Physical Forcing
17-NIP17-0127

Present and planned satellite missions seek to monitor biogeochemical processes under a changing climate. Seas with a roughened-surface and breaking waves markedly change the reflectance of the surface ocean and enhance air-sea gas exchange. Correction approaches for ocean color imagery are based on a universal effective reflectance value determined from a small dataset of whitecaps under a narrow range of wind-wave conditions and fractional whitecap coverage modeled as a function of wind speed. Under any given wind speed, however, a spread of two or more orders of magnitude exists between the minimum and maximum measurements of whitecap coverage. Currently, no comprehensive datasets of naturally breaking waves exist to adequately assess the contribution of foam and bubbles to ocean color imagery.

Here, we propose to deploy field radiometers, high resolution cameras, optical and acoustical instrumentation at the Air-sea Interaction Tower (ASIT) at the Martha's Vineyard Coastal Observatory (MVCO) to evaluate the hyperspectral reflectance of natural breaking waves with concurrently measured physical air-sea interaction parameters. This investigation seeks to elucidate the relationship between ocean color and wave breaking, including air entrainment (i.e. the void fraction) and breaking intensity, with the goal of 1) improving the quality of ocean color products by quantifying the contribution of breaking waves to hyperspectral reflectance (i.e. the spectral effective
reflectance of whitecaps) under a wide range of well-characterized physical forcing conditions and over a large footprint and 2) supporting the development of algorithms to retrieve wave breaking metrics from ocean color measurements. The contribution of surface gravity waves to reflectance (i.e. radiance of the roughened sea surface) will also be explored statistically (e.g. the frequency distribution of total upwelling radiance under growing seas). These measurements support efforts to quantify near-surface physical processes including mixing, the exchange of momentum and heat, and the production of sea salt aerosols.

The proposed study site, the Air-Sea Interaction Tower (ASIT) at Martha's Vineyard Coastal Observatory (3 km South of Martha's Vineyard, MA), is the ideal platform for obtaining an accurate, robust dataset of the spectral reflectance of breaking waves. The tower is engineered to facilitate investigations into ocean-atmosphere interactions and is instrumented to answer questions about gas exchange and ocean mixing. Approximately 44% of the wave age record collected ASIT in the fall and winter represents the ideal conditions for wind-wave generation and actively breaking seas. The proposed long-term deployment during ideal conditions from the fixed, ASIT platform will facilitate the retrieval of the statistically robust whitecap dataset that the ocean color community has been lacking.

In addition, we seek to investigate the relationships between the above surface hyperspectral ocean color measurements, whitecap statistics, subsurface bubble size distribution, and subsurface turbulent kinetic energy (TKE) dissipation rate measurements of breaking waves. Such relationships will be useful in potentially expanding the role of ocean color into assessments of the air-sea flux and the role of surface gravity waves in kinetic energy exchange.

Mary Elise Rumpf/US Geological Survey Flagstaff
A Synergistic Approach Toward Remote Sensing of Effusive Volcanic Eruptions
17-NIP17-0141

Effusive lava flows pose a significant but under-studied hazard to human life and property. The most important parameter for forecasting lava flow hazards is the flux of lava at the vent (effusion rate). Thermal infrared satellite observations are excellent for calculating effusion rate but are frequently compromised by clouds. Radar is the orbital remote sensing method of choice for monitoring the surface when it is cloudy but the primary radar imaging technique, synthetic aperture radar (SAR), is confounded when the surface is moving as in an active lava flow.

The primary objective of this project is to derive a methodology to estimate effusion rate from a synergistic combination of orbital infrared and radar observations. This is achieved by deriving a common product, a map of the "activity state" of the lava flow, from either data set. This is done by taking advantage of the fact that the activity on lava flows follows patterns that are predictable over at least modest temporal and spatial scales. For example, if the flow front surges forward, a period of inflation should follow ‘
during which the lava flow builds up stores of liquid for the next advance. As another example, over a period of weeks, lava ponds can be expected to remain largely stable while open channels will become covered by an insulating crust. Being able to teach an algorithm to take advantage of this kind of knowledge is the key innovation in this project. Having the more frequent radar-based effusion rate estimates blended with the more reliable but less frequent infrared-based estimates will keep the effusion rate values from gradually diverging from reality.

These methods will be developed using historical data from the ongoing eruption on Kilauea Volcano, leveraging the vast monitoring infrastructure of the USGS Hawaiian Volcanoes Observatory. To test the new method, we will collect new data because (a) it is bad practice to test this kind of algorithm with the training data and (b) the "truth" data needs to be of significantly higher precision and accuracy to quantitatively assess the new method's errors and uncertainties. This study will lay the groundwork for other future advances in monitoring lava flows, including the use of Unmanned Aircraft Systems (UASs) and creation of tools that integrate data from the full spectrum of sensor types.

This project takes full advantage of the world renowned volcano hazard monitoring capability of the US Geological Survey. The PI's ample expertise in volcanology and remote sensing is supported by her Mendenhall Postdoctoral Fellow mentors at the USGS Astrogeology Science Center, the Hawaiian Volcanoes Observatory, the Cascades Volcano Observatory, and the Volcano Disaster Hazards Assistance Program. This provides the best possible environment for a young volcanologist to develop new skills. UAS operations will be conducted by the USGS National UAS Project office with policies and procedures that align with NASA expectations.

This 3-year proposed project is fully responsive to ROSES 2017, Section A.36, New (Early Career) Investigator Program in Earth Science (NNH17ZDA001N-NIP). The project will provide new methods useful for monitoring and mitigating volcanic hazards across the globe. This aligns with a priority of NASA's Earth Science Division's Earth Surface and Interior focus group: improving our understanding of lava flow evolution and scientists' capabilities in monitoring ongoing effusive eruptions. In addition, the PI is a female, early-career researcher in the first five years of receiving her Ph.D. The costs are kept modest by as the PI is a postdoctoral researcher and by including an undergraduate student to complete tasks related to data organization and analysis.

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Rashmi Shah/Jet Propulsion Laboratory
Coherence Properties Characterization of Signals of Opportunity Over Land Surface for Snow Retrieval
17-NIP17-0058

Snow water storage on land is a critical state variable in the terrestrial water cycle. Snow-derived water supply is a vital component of the global water budget since about one-sixth of world's population relies on snowmelt water for agriculture and human consumption. Therefore, quantifying available water supplies for human activities, how
they vary in space and time, and how they are changing are critical questions for the scientific community. The current methods for measuring snow have limitations with sampling to sample data globally as well as sample data accurately under vegetation canopy. The proposed signals of opportunity (SoOp) method will complement or even become a cost-effective alternative to existing active technologies.

SoOp is a microwave remote sensing technique that uses communication and navigation signals as transmitters in bistatic radar configuration to remotely sense the earth's surface in the forward scattering geometry using passive receivers. We propose to characterize key properties of reflected P/L-frequency bands SoOp for remote sensing of Snow Water Equivalent (SWE). The proposed research addresses following focus areas in New Investigator program solicitation: (1) Water and Energy Cycle, (2) Climate Variability and Change, and (3) Carbon Cycle and Ecosystems.

The proposed remote sensing method is based on the coherent reflection of P-band radio signals from geostationary communication satellites, which operate in two-frequency ranges at P-band (360-380 MHz and 240-270 MHz). The advantage of P-band signals is that the signals are capable of penetrating through some vegetation (a confounding factor in SWE retrievals), and could offer unprecedented capability to sense snowpack under forest canopy.

SoOp measurement principle requires reflected signal to be phase coherent over the measurement space. But the question still remains unanswered on whether or not signal return will be phase coherent from heavily vegetated areas and/or areas with big topographic change. This topic is being addressed in this research through analysis of available P-band airborne reflection data and L-band spaceborne reflection data. It is hypothesized that if L-band is coherent, then P-band will be as well because of higher wavelength of P-band signals.

The goal of this research is to advance the P-band SoOp technique for satellite remote sensing of SWE. The specific objectives of the proposed research are:

1. Develop the empirical relationship between tree heights and phase change in the measurement by conducting a tower-based experiment to collect P-band reflection data and measure the phase change in the signal through different heights of deciduous trees. In addition, ground-based experiment's data will be analyzed to determine the maximum tree height where phase coherency.

2. Analyze existing datasets from unmanned air vehicle (UAV)-borne and airborne experiments to quantify the phase coherence of P-band SoOp reflection with key emphasis on SWE measurements under dense vegetation canopy, slow platform movement, and small topographical change.

3. Data from the spaceborne L-band reflection mission Cyclone Global Navigation Satellite System (CYGNSS) will be evaluated to measure the degree of phase coherency of earth surface reflections data from spaceborne receivers. This, along with results from objective 1 and 2, will then be used for simulation of data in L/P-bands to evaluate the suitability of using phase coherence of P/L bands SoOp under various land terrain types. The proposed approach seeks to characterize properties from various sets of ground, airborne, and spaceborne data sets. The effort builds upon the success of a proof-of-concept experiment for SWE remote sensing based on P-band SoOp (in 2016), in which SWE was retrieved from tower-based receiver using reflections data from snow on ground with no vegetation.
This project will assess the impact of time-varying algorithm artifacts on cloud property trend detection by evaluating the multi-decadal stability of the 3D optical depth bias. The bias is caused by the 1D radiative transfer assumption often made in radiative transfer modeling of cloudy atmospheres. This assumption renders clouds, which realistically exhibit 3D structure, to horizontally homogeneous scenes, substantially simplifying the radiative transfer modeling problem. Many studies have evaluated the resulting bias on instantaneous scales; however, the stability of this bias on scales relevant to studying climate trends has not be studied. If this large bias changes over time, potentially due to a change in the distribution of different cloud types, it may distort the true cloud optical depth trend.

To evaluate if the 3D optical depth bias is stable between two climate states, we will need 1) large-scale distributions of the 3D optical depth bias for different cloud types and 2) projections of how the frequency of occurrence of different cloud types may change between two climate states. To achieve the second main part of this effort, we will use the output from select CFMIP2/CMIP5 models that correctly implement the International Satellite Cloud Climatology Project (ISCCP) instrument simulator. Determining large-scale distributions of the 3D cloud optical depth bias, however, requires a novel approach.

For the first task, a "brute-force" method for calculating global distributions of the 3D cloud optical depth bias would involve a staggering number of 3D radiative transfer modeling simulations, rendering such a task computationally intractable. We propose a method to overcome this challenge by limiting the number of 3D simulations to only the number needed to establish a statistical relationship between the 3D optical depth bias and an existing proxy of this bias.

The proxy is a 3D cloud anisotropy metric that was developed using fused Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR) measurements. This metric quantifies the departure of marine water clouds from satisfying the 1D radiative transfer assumption and can therefore be considered a proxy of the 3D cloud optical depth bias.

If we determine that the bias is sufficiently stable, then we will have a higher confidence in using existing cloud optical depth retrievals to detect secular optical depth trends. However, if this bias is not sufficiently stable, observed trends in cloud optical depth may be a combination of the actual trend and the changing bias (assuming a perfectly stable instrument). To assess "sufficient stability," we will compare any found bias "trends" to
optical depth trends computed from CFMIP2 output instrument simulators, and we will evaluate these changing bias trends in terms of the equivalent impact on constraining SW cloud feedback and climate sensitivity uncertainty.

Either of these results will provide essential information about the validity of using existing NASA cloud retrieval products for detecting and attributing changes in Earth's climate, which is a key goal of NASA's Earth Science Division. This project will spearhead this series of studies, which also need to be extended to other cloud properties and geophysical variables retrieved from satellite.

Hao Tang/University of Maryland, College Park

Integrating Space-Borne Lidar Observations to Characterize Vegetation Structure Dynamics Across Tropical Forests

17-NIP17-0098

Tropical forests exhibit dynamic responses to changes of natural environmental conditions and influences of anthropogenic activities. Direct and accurate measurements of vegetation structure and its dynamics across tropical forests yet are largely missing, preventing a more comprehensive evaluation of their roles in ecosystem services such as environmental protection and biodiversity conservation. Spaceborne light detection and ranging (lidar) technology can potentially fill this observational gap and advance our understanding of tropical forest ecology, as demonstrated by the success of NASA's Ice, Cloud, and land Elevation Satellite (ICESat) mission deployed between 2003 and 2009. To continue the global observation of vegetation structure, two following spaceborne lidar missions, ICESat-2 and Global Ecosystem Dynamics Investigation (GEDI), are scheduled for launch in 2018. Similarities of these lidar missions form the basis for complementary observations that can explore vegetation structure dynamics at time scales ranging from seasonal to decadal. Here, we propose to explore the spatial and temporal dynamics of vertical vegetation structure across tropical forests and investigate major drivers and impacts of these dynamics, primarily using data from the aforementioned three space lidar missions. The proposed work is centered on multi-platform lidar data integration though processes of pre-launch simulation and post-launch calibration, and incorporates four major categories of activities:

1) Integrate vertical vegetation structure observations from GEDI and ICESat series using existing and future airborne and field measurements.
2) Analyze seasonal and decadal changes of vegetation structure across tropical forests using the integrated data set.
3) Assess potential drivers of vegetation structure dynamics, from perspectives of plant physiology, natural environmental change and anthropogenic impact.
4) Explore the role of vegetation structure dynamics on carbon uptake capacity of tropical forests and habitat quality for biodiversity.

This proposal echoes the call from this solicitation to promote and increase the use of space-based remote sensing to discover and demonstrate ecological and biodiversity
hypothesis. Its anticipated results can greatly advance the capacity of NASA's lidar satellites in monitoring 3D structure dynamics of dense tropical forests, a recommendation from the latest NRC Earth Science Decadal Survey.

Christopher Terai/University of California, Irvine
Understanding Processes Constraining the Present-Day, Global Mean Precipitation Rate
17-NIP17-0068

The proposed research aims to increase our understanding of what drives the global water cycle in climate models and observations. The work has two specific aims: a) to identify likely leading mechanisms behind the spread in global mean precipitation across climate models, and b) to determine why many climate models appear to overestimate the present-day global mean precipitation rate. The study will employ output from current state-of-the-art climate models, NASA satellite retrievals of atmospheric variables, and NASA's Goddard Institute of Space Studies E3 (GISS-E3) climate model.

Two separate frameworks help us understand how heavily it precipitates: cloud-scale processes drive local-scale precipitation and an atmospheric energetic constraint helps explain global-mean precipitation rates by tying precipitation rates to latent heat fluxes. Despite their separate contributions to our understanding of the global water cycle, they have rarely been combined in previous studies. The proposed study attempts to bridge these two different frameworks to understand what determines the global mean precipitation rate in current state-of-the-art climate models.

When we examine the present-day global mean precipitation rates as simulated by climate models participating in the Fifth Coupled Model Intercomparison Project (CMIP5), we find a 14% spread in global mean precipitation rate across models, even when the models are all forced with the same sea surface temperature and atmospheric forcing agents. Based on preliminary analyses, we find that variations in the longwave cooling and sensible heat flux into the atmosphere explain a majority of the variance, and we hypothesize that a substantial amount of the intermodel spread in global mean precipitation can be explained by differences in model physics that determine two mechanisms: the precipitation efficiency and vertical mixing strength. Metrics will be constructed to quantify the strength of these two mechanisms to test this hypothesis.

We also hypothesize that the strength of the two mechanisms explains the bias that many models have in overestimating the global mean precipitation. We will test this hypothesis by comparing the metrics of the two mechanisms, which we calculate from the CMIP5 models and from NASA satellite and reanalysis products. This will guide experiments with NASA's GISS E3 climate model.

Using the metrics, various configurations of NASA's GISS E3 model will be used to conclusively test whether the hypothesized mechanisms can explain differences in precipitation rates at least within the confines of a single-model framework. Finally, we
will test whether the model biases in the global mean precipitation rate are improved if we configure the local-scale process parameterizations to match the observed strength of the metrics.

The findings from this investigation will advance our understanding of the relationship between local-scale physics and global-scale energy constraints and help provide a large-scale mechanistic understanding of what drives the observable water cycle. The results will also identify what mechanisms need to be better understood, represented in climate models, and observed, if we wish to gain a fundamental understanding of what drives the global water cycle in the future.

Thomas Wahl/University of Central Florida
Modelling Global Storm Surges in the Past, Present and Future and the Associated Socio-Economic Impacts
17-NIP17-0003

Substantial research efforts have been directed towards improved estimates of past and future global mean sea level rise (SLR). At the same time, changes in storm surges and associated socio-economic impacts have not been assessed at global scale and remain poorly understood.

Various types of data have become available that can be brought together to develop new models for global storm surge analyzes. A new database of high-frequency water levels from tide gauges (GESLA-2) consists of 1355 individual records, but there are still long coastline stretches where no data exist or records are too short to be useful. To overcome this limitation, the first numerical global storm surge model was recently developed and used to generate a 35-year hindcast of hourly water levels. Because they are computationally expensive, broad-scale numerical models are limited in their applicability to explore long-term changes in storm surges.

Statistical models have proven to be a powerful alternative/addition to numerical models because they can efficiently simulate storm surges over long time periods for locations where some data exist, either from observations or numerical models. Links are established between water levels and their drivers, such as surface winds and sea-level pressure. Previously, these predictors were typically derived from atmospheric reanalysis products with spatially varying quality and course resolution. Here, we propose to use remote sensing data instead to develop a new set of (near-) global models to analyze storm surges in the past, present, and future. In a multiple regression approach, we will use water levels as predict and include various types of remote sensing data, or products that have been directly derived from them, to represent the predictors. Most notably, we will use the Cross-Calibrated Multi-Platform (CCMP) Wind Vector Analysis Product Version 2, which combines wind speeds from microwave radiometers (e.g., SMI/I, SSMIS, TMI), wind vectors from polarimetric radiometers (e.g., WindSat) and scatterometers (QuikSCAT and ASCAT), moored buoy wind data, and ERA-Interim model output for the background wind field. Other variables can also affect storm surges
and will be included as additional predictors, for example precipitation and sea surface temperature. Again, we will use (merged) satellite observations where available.

Once calibrated and validated, we will use the models for various applications: (i) we will apply the improved regression coefficients to long reanalysis products to reconstruct storm surges over the last century globally. This will allow us to calculate more accurate return water levels and assess trends (being careful in our interpretation, noting that centennial reanalyses are prone to spurious trends). (ii) We will use climate model output to simulate storm surges into the future, where still water levels will be derived by including tidal predictions from the FES2014 tide model (which is based on extended altimetry records) and SLR projections. Because the statistical models are computationally cheap, we can consider an ensemble of multiple climate models and provide extended projections (until 2300). Socio-economic impacts will be assessed with the Dynamic Interactive Vulnerability Assessment (DIVA) model, an integrated state-of-the-art research model of coastal systems that uses elevation data from NASA's Shuttle Radar Topography Mission (SRTM) and population data from the Global Rural-Urban Mapping Project (GRUMP).

The project focuses on the areas "Climate Variability and Change" and "Weather". It integrates and analyses various types of NASA Earth Science data "to advance knowledge of Earth as a system to meet the challenges of environmental change and to improve life on our planet", one of NASA SMD's strategic objectives.

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**Chenxi Wang/University of Maryland, College Park**  
**Developing an Advanced Algorithm to Retrieve Ice Water Path and Cloud-top Height for Ice Cloud Using Combined Passive Infrared and Microwave Observations**  
**17-NIP17-0114**

The objective of this investigation is to develop an advanced cloud ice water path (IWP) and cloud-top height (CTH) retrieval algorithm from combined satellite passive infrared (IR) and microwave (MW) observations, so as to overcome sensitivity limitations in each individual technique. A generalized algorithm will be delivered to NASA data center as needed, to be applied to the platforms where both IR and MW observations are acquired simultaneously. We will also apply the new algorithm to VIIRS+ATMS (2012-present) data.

Current IWP retrievals from satellite-based instruments can vary by a factor of 10. Because of the large (four orders of magnitude) dynamic range in ice cloud variability, limitations of individual instruments (with sensitivity in a spectral region) are inevitable. The new effort in this work will make use of complementary information from passive IR and MW observations, to derive long-term, consistent, and comprehensive records for global ice clouds.

The new retrieval algorithm is built upon successful algorithms for individual sensors and takes advantage of the cloud properties that are common in both IR and MW. Advantages of the proposed algorithm include:
1. Passive IR and MW observations are independent of solar illumination, allowing a joint, uniform ice cloud retrieval at different local times and locations.
2. Cloud retrievals will be carried out over a wide dynamic range from optically thin to thick ice clouds.
3. Retrievals at hybrid spatial resolutions will be implemented to minimize impacts of ice cloud inhomogeneity effects.
4. Comprehensive error analysis will be performed to characterize and quantify uncertainties from different sources.
5. Can be applied to platforms with simultaneous IR and MW observations.

The new effort will provide the scientific communities with unprecedented coverage and accuracy for IWP and CTH. The proposed joint retrieval algorithm can be easily applied to other existing platforms with similar IR and MW channels, e.g., the AVHRR+MHS onboard NOAA 5th generation Polar Operational Environmental Satellites, and platforms in the near future, e.g., the Joint Polar Satellite System (JPSS). The long-term and consistent cloud records will directly benefit the NASA's Earth Science research communities, improve our understanding of uncertainties in current cloud records, and serve as unique and valuable observational constraints for reproducing cloud microphysical processes and improving ice cloud parameterizations in climate and weather models.

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Lei Wang/Ohio State University  
Making the Most of the Geodetic Observations Over Greenland: Enhanced Modeling of the Spatiotemporal Complexities of the Present-Day Greenland Ice Sheet Evolution and GIA through Rigorous Integration of Multiple Geodetic Data Types  
17-NIP17-0128  

Better understanding of climate-driven ice mass changes and their impact on solid Earth is of extreme interest since it helps unravel the puzzle of why and how the melting might evolve in the future. This is particularly true over Greenland where the ice sheet (GrIS) holds the equivalent of more than 7m of sea level rise, and is extremely sensitive to climate change. However, the disagreement among the estimated present-day GrIS mass changes are significant, especially at regional scale where GIA effect may represent a significant portion of the geodetic measurements (e.g. GRACE). Thus, self-consistent estimation of GIA and present-day GrIS mass change is crucial to improve the understanding of the spatial and temporal complexities of the coupled processes.

Near two-decades long continuous geodetic observations for the GrIS have been available from various space- and ground-based geodetic techniques. Moreover, the coming four years will be a period of growth for other new observations (GRACE follow-on, ICESat-II and the continuous operation of GNET) over Greenland. It thus provides an unprecedented opportunity to understand the complex couplings between past- and present-climate driven ice mass changes and solid Earth deformation over Greenland. The proposed research utilizes an innovative, state-of-the-art approach for Bayesian assimilation/integration of multiple types of geodetic data sets, to deliver
simultaneous, integrated and self-consistent data-driven estimates of present-day GrIS mass change and GIA. The modeling of the spatiotemporal evolutions of the present-day GrIS mass changes will be free from the assumption of constant rate and seasonal amplitudes, and emphasizes the temporal and spatial variabilities of the GrIS changes reflecting the complexities in the ice sheets-climate system. This approach naturally accommodates data gaps and thus rigorously bridges the breaks between two missions, such as GRACE and its follow-on, ICESat and ICESat-II. The estimated data-driven GIA fields will be insensitive to Earth and ice deglaciation history models. Statistically rigorous uncertainties will be produced for both the present-day GrIS mass changes and the GIA estimates. The estimated time-variable GrIS mass variations will provide further insight into the impact of the GrIS on the observed sea level rise.

Jennifer Watts/Woods Hole Research Center Inc.
Reconciling Carbon Flux Budgets in Alaska and Northwest Canada through Integrated Satellite, Airborne, and Field Measurements
17-NIP17-0010

This project will apply an innovative satellite data driven terrestrial carbon flux (TCF) model framework supported by detailed biophysical process measurements, in conjunction with atmospheric inverse modeling, to improve understanding of carbon (CO2 and CH4) dynamics and the environmental controls on northern ecosystem carbon budgets. At present, it remains highly uncertain if lengthening growing seasons and increases in vegetation productivity will offset heightened plant and soil respiration occurring with high latitude warming. Also uncertain is the impact of autumn and winter CO2 release, and wetland CH4 emissions, on annual carbon budgets. This study will explore and quantify linkages between changing terrestrial carbon fluxes, landscape thermal and moisture conditions, and disturbance events over Arctic-boreal ecosystems in Alaska and northwest Canada. This will be made possible through a suite of observations from tower eddy covariance sites, new measurements of winter soil CO2 respiration, atmospheric CO2 and CH4 measurements from the NASA Carbon in the Arctic Reservoirs Vulnerability Experiment (CARVE), satellite optical-infrared and microwave remote sensing retrievals, and improved resolution reanalysis products.

The TCF model will be enhanced for northern tundra and boreal regions to improve ecosystem respiration response under autumn and winter cold temperature conditions. The algorithm improvements will be informed using a new NASA Arctic Boreal Vulnerability Experiment (ABoVE) network of winter soil CO2 flux observations. The updated TCF model will be used to generate a 16-yr (2003-2018) baseline record of daily vegetation gross primary productivity (GPP), ecosystem respiration (Reco), net ecosystem CO2 exchange (NEE), and wetland CH4 emissions at a 1-km resolution. A series of alternative 500-m flux simulations will also be provided using 3-km fields from the Polar Weather Research and Forecasting (Polar-WRF) model and improved resolution microwave surface freeze/thaw, soil moisture and inundation retrievals.
The bottom-up 1-km and 500-m ecosystem carbon fluxes will be used as priors in regional atmosphere model inversions to assess terrestrial carbon source and sink activity across the ABoVE domain. This will be achieved using the Weather Research and Forecasting-Stochastic Time-Inverted Lagrangian Transport (WRF-STILT) and Geostatistical Inverse Modeling (GIM) framework, in conjunction with CO2 and CH4 concentration measurements obtained from CARVE flights and tall towers. The STILT/GIM analyses will be used as prognostic and corrective tools to evaluate the ability of model flux maps to represent spatial patterns observed in regional atmospheric concentrations.

Products resulting from this study will include a 16-year record of carbon fluxes and budgets for the NASA ABoVE domain at a 1-km resolution, and alternative 500-m records for Alaska over the 2013-2015 Polar-WRF observation period. Trend maps and analysis of underlying environmental conditions driving shifts in carbon flux patterns and budgets will also be provided for Alaska and the ABoVE domain. Resulting data will be made available from the Woods Hole Research Center and archived at the Oak Ridge National Lab (ORNL) Distributed Active Archive Center in accordance with NASA guidelines. This study targets the Carbon Cycle and Ecosystem focus area in this solicitation by improving understanding of carbon budgets, carbon cycle processes and ecosystem vulnerability to changing water and energy cycles occurring in Arctic-boreal systems. This study will contribute to model benchmarking activities that inform science research needs for NASA including the ABoVE, Soil Moisture Active Passive (SMAP), and Surface Water & Ocean Topography (SWOT) missions.

Melinda Webster/Goddard Space Flight Center
Assessing and Improving the Seasonal Capability of ICESat-2 Data for Sea Ice Research
17-NIP17-0093

Over the last several decades, Arctic sea ice has undergone profound changes that affect Earth’s climate. Arctic sea ice is younger and less extensive. In particular, dramatic losses in sea ice thickness and volume have occurred, which global climate models project will continue. A thinner, less extensive sea ice cover enhances the Earth’s ice-albedo feedback, allowing polar oceans to absorb more solar radiation and warm, which delays sea ice growth and warms the atmosphere. Thus, several remote sensing efforts are devoted to routine monitoring of sea ice thickness to document and better understand the ongoing changes, and to improve weather forecasts and climate projections [National Research Council, 2012].

of these remote sensing efforts is NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2), a laser altimeter mission dedicated to measuring surface elevations of sea ice, ice sheets, and vegetation. The launch of ICESat-2 in 2018 will be the first time that a space-borne, photon-counting lidar instrument will have been used for sea ice observations. Thus, the interpretation of the photon returns is fraught with perplexing ambiguities, especially when the sea ice surface transforms from snow-covered in spring
to meltwater-covered in summer. Altimetry theory and previous missions (e.g., ICESat) have established a strong framework for deriving sea ice thickness from altimetry data, but critical knowledge gaps remain. Ground-based efforts are needed to improve and extract sea ice information from photon-counting lidar data when surface processes, like melt pond evolution, alter the photon returns in irregular ways.

Coincident, year-round field observations are fundamental to addressing these challenges in interpreting ICESat-2 data and extending the seasonal capability of retrieving sea ice parameters. Such observations can be achieved through the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), a field program in which a research ship will be frozen into the Arctic ice pack year-round to gather continuous observations of sea ice, oceanic, and atmospheric conditions. MOSAiC serves as the ideal platform for capturing the seasonal changes in conditions that affect ICESat-2 data, and will provide a once-in-a-generation opportunity to deliver results with longevity. By taking advantage of the unique overlap between the ICESat-2 mission and MOSAiC field campaign, this project will open a pathway for an early career investigator to become engaged in a Decadal Survey mission and develop a strong foundation in advancing remote sensing observations for sea ice research.

I propose to collect and synthesize sea ice field observations with remotely sensed data to assess and improve the interpretation and year-round capability of extracting sea ice parameters from ICESat-2 data. This will be accomplished by assessing the seasonal realism of the snow depth product for ICESat-2, and investigating the effects of the seasonal evolution of the sea ice surface on ICESat-2 photon returns. The expected outcomes of the project will directly support NASA's 2014 Strategic Plan for Earth Science by:

- Improving the quality of observations from space for research and monitoring changes in the Earth system; sea ice thickness retrievals will be improved via more accurate snow depth information and open water detection.
- Making effective use of observations for evaluating and improving models; sea ice thickness uncertainties will be constrained and used to test the predictive skill of a global climate model.
- Driving advances in the observational capability of a Decadal Survey mission for science research; the seasonal capability of extracting sea ice parameters from ICESat-2 will be assessed and extended.