NASA Science Mission Directorate
Research Opportunities in Space and Earth Sciences – 2019 NNH19ZDA001N-SLCST
A.11 Sea Level Change Science Team

This program element selected members for the NASA Sea Level Change Science Team (N-SLCT). The goals of N-SLCT is to integrate research results, data sets, and model outputs to improve the accuracy of sea level estimates and its components, to integrate results into better projections of sea level rise, and to communicate the results of NASA's sea level research in a simplified manner to the science community and the public. NASA received 15 proposals and selected 7 with funding of ~$10M over four years.

Carmen Boening/Jet Propulsion Laboratory
A NASA Web Portal for Sea Level Change
19-SLCST19-0005

Executive Summary
This proposal addresses the Web Portal Element of the NASA Research Announcement for the NASA Sea Level Change Science Team. Building on the existing sea level change portal (SLCP) that has been developed and maintained by our team at JPL, ESDIS, and Moore Boeck, we will serve as the integral component for disseminating, highlighting, and integrating the interdisciplinary data and results produced by the NASA Sea Level Change Team (N-SLCT). The main focus for the continuation of the web portal is to facilitate the work of the N-SLCT by enabling easy integration of PI-generated data and tools into the website as well as maintain the stream of high-quality research highlights and up-to-date sea level research information.
In order to achieve these goals, we seek to address the following objectives:

- O-1: Provide an access point to relevant SLC datasets, especially N-SLCT-produced data
- O-2: Provide tools and support for SLC data visualization, download, comparison, and analysis
- O-3: Provide a platform for PI- and team generated tools
- O-4: Provide up-to-date SLC indicators
- O-5: Provide up-to-date information related to research, activities, and findings within the realm of SLC
- O-6: Provide background information and numbers on sea level past, present, and future
- O-7: Enable and facilitate N-SLC team communication

We are seeking to achieve these objectives in strong collaboration with the N-SLCT by frequently reaching out for new information (e.g. publication, data, tools), enabling team member ownership of website content (e.g. Understanding Sea Level, By The Numbers, Annual Report, data streams and requirements for team tools) as well as regular (e.g. annual) usability testing to advance and improve the website. Over the past 5 years and in particular since the launch of the portal at the end of 2015, we have started to establish a

stable stream of information and data between scientists, the data distributors (DAACs), and the general public. Based on this experience, in response to the NRA, we will lay out plans for maintaining high quality content and a strategy for continuing and improving the integration and exchange of data, tools, and research highlights.
For this purpose, we will elaborate in particular on our strategies for each component of the SLCP following the objectives outlined above. Components are:

- Content development
- Technical maintenance and development
- Data and tool integration
- Web design

We also describe the general workflow, management strategies, and communication stream with the N-SLCT. Examples include weekly content, technical development, and design meetings as well as bi-weekly group meetings to report on updates and plan for the next week. Task management follows a sprint model; tasks are tracked via JIRA. Regular communication with ESDIS ensures seamless integration of new components and updates into the system. Communication with the N-SLCT takes place on a regular basis by email and via telecons as well as in-person meetings to a) integrate new data and tools into the portal and DAACs, b) work with scientists to integrate new results from the N-SLCT into the content and design structure and c) get regular feedback on the current state of the portal in order to plan for improvements. In the following we will describe our plans on how to continue and improve these current practices and integrate new information into the site in the future.

Eric Larour/Jet Propulsion Laboratory
From Grounding Lines to Coastlines: An Integrated Approach to Barystatic Sea-Level Projections
19-SLCST19-0003

We propose to leverage our capability to model relative sea-level (RSL), GIA (Glacial-Isostatic Adjustment), ice-sheet dynamics, with rigorous uncertainty quantification (UQ), within our computational software Ice and Sea Level System Model (ISSM). Additionally, we will compute ocean circulation using the MIT General Circulation Model (MITgcm) and the Estimating the Circulation and Climate of the Ocean project (ECCO). Our goal is to deliver the following key scientific objectives:
1. Gain understanding of how current probabilistic regional sea-level projections can be improved by the use of time-correlated forward ice-sheet and GIA model projections.
2. Understand how ocean circulation around the Antarctic Ice Sheet (AIS) impacts grounding line (GL) retreat of ice streams and how this translates into specific patterns of predicted coastline migration around the world.
3. Understand the impact of a generalized representation of mantle creep (that allow for soft-mantle rheologies) on both the evolution of GL position in the West Antarctic Ice Sheet (WAIS) and coastal migration around the world.
4. Quantify the impact of the improvements in GL dynamics and understand the associated consequences for sea-level projections and coastline evolution around the world.

The framework we propose will allow us to perform highly flexible, NSLC-T interactive, and efficient updates to the probabilistic forecasting product during the course of the 4 year funding of the proposal.

Tong Lee/Jet Propulsion Laboratory
Attributions of Past Regional Sea Level Variations and Projection of Future Sea Level Changes
19-SLCST19-0007

Understanding the forcing mechanisms of regional dynamic sea level (SL) variations in the past and investigating the sources of uncertainties for regional SL projections are among the key objectives of the Sea Level Change Science Team (SLCST). Despite significant progress in the mechanistic understanding of past regional SL variations, important knowledge gaps remain in terms of attributions because of a lack of systematic quantification of the relative contributions of atmospheric, hydrologic, and cryospheric forcings across time scales and regions. Regional sea level projections for the 21st century have large uncertainties, with ocean dynamics contribution being one of the key sources of the uncertainties. However, little is known about the impacts of forcing uncertainties versus the uncertainties caused by SL response to the same forcing in different models. Recent advance of the Estimating the Circulation and Climate of the Ocean (ECCO) modeling and state estimation system, the associated sensitivity analysis tools, and the ongoing CMIP6 effort present a timely opportunity to narrow these knowledge gaps.

Fist, to reduce the knowledge gaps for attributions of past SL variations, we propose to decipher the relative contributions of atmospheric, hydrologic, and cryospheric forcings to regional SL variations from sub-seasonal to tri-decadal time scales during the altimeter era and to elucidate the salient ocean dynamic processes. This objective will be accomplished by a synergistic use of ECCO ocean state estimates, forcing sensitivity experiments using ECCO global and regional high-resolution forward models, and ECCO adjoint model. In particular, the adjoint model provides an efficient way to compute SL sensitivities at targeted locations to each of the forcings as a function of space and time. The adjoint sensitivities will be combined with the respective forcing variations to identify the dominant forcing(s) and key region(s) of forcing influence on SL variations for a list of coastal locations that are particularly vulnerable to sea level change. These efforts contribute to Objective 2.2 of this NRA.

Second, we propose to estimate the contributions of the 21st-century projected changes in atmospheric, hydrologic, and cryospheric forcings to regional SL projections and to quantify the effects of forcing ensemble spreads on regional SL projection uncertainties. This objective will be achieved by combining the sensitivities derived from the ECCO ocean model adjoint with the projected changes of atmospheric, hydrologic, and cryospheric forcings for the 21st-century from CMIP6. This novel method isolates the effect of forcing uncertainties on SL projections because the adjoint sensitivities reflect the dynamics of a single ocean model, thereby removing the effect of inter-model

differences in SL response to the same forcing. We will also examine the uncertainties of the adjoint sensitivities associated with model resolution, ocean mixing, and initial conditions, and assess their impacts on SL projection. Our efforts complement an ongoing CMIP6 activity that focuses on the effect of inter-model differences in SL response to the same forcing. Our efforts contribute to Objective 2.3 of this NRA.

Lastly, we will provide the regional SL projections and their uncertainties to NASA's Sea Level Portal, including those associated with individual forcings. We will work with other SLCST members to (1) compare these projections and uncertainties with those caused by non-ocean-dynamic processes developed by other SLCST members, and (2) combine the projections and uncertainties from ocean dynamics and other processes to develop synthesized team products. This contributes to Objective 2.4 of this NRA.

Robert Nerem/University of Colorado, Boulder
Using Satellite Observations to Improve Our Understanding of Future Regional Sea Level Change and Its Impacts
19-SLCST19-0011

Sea level change is an important indicator of how the Earth is responding to climate change, and it is also a key driver of associated socioeconomic impacts. Therefore, understanding how much sea level will rise in the future, and how it will impact coastal populations centers and infrastructure, is an objective of paramount importance. Satellite measurements, such as satellite altimetry, satellite gravity, and satellite photogrammetry, have the potential to revolutionize our understanding of sea level rise and its impacts. We propose to investigate several different topics important to understanding sea level change and its impacts:

(1) We propose to investigate the causes of regional sea level trends observed in 26 years of satellite altimeter data to better understand and predict future regional sea level patterns;

(2) We propose to develop methods to extrapolate observed sea level and ice mass changes decades into the future to provide short-term observationally-driven regional sea level rise projections;

(3) We propose to continue developing ICESat-2 constrained global coastal DEMs from NASAs commercial satellite imagery archive to assist in sea level impact studies and projections using results of (1) and (2);

(4) We propose to use satellite InSAR measurements to develop regional estimates of vertical land motion to supplement GNSS-determined land motion;

(5) We propose to use satellite altimeter and gravity measurements to evaluate the CMIP6 climate projections and investigate how the satellite measurements can assist the interpretation of those projections; and

(6) We plan to assist the broader NASA Sea Level Change Team (N-SLCT) in developing new science and related products. We plan to conduct this investigation in concert with the NASA Sea Level Change Team (N-SLCT) and make our results available through the NASA Sea Level Web Portal.

Sophie Nowicki/Goddard Space Flight Center
Combining Multi-Satellite Observations, Modeling and Earth System Data Assimilation for Understanding Observed and Projected
for Understanding observed and projected sea level change
19-SLCST19-0004

This proposal aims to contribute to the NASA Sea-Level Change Team (N-SLCT) through an interdisciplinary investigation that addresses the multi-faceted problem of current and future sea level rise. The goals of the proposed work are to 1) provide observation evidence of global and regional sea level change with improved spatio-temporal accuracy from multi-satellite observations of sea level and ice sheets (GRACE, GRACE-FO, Jason-1/2/3, IceSAT-2, OIB); 2) quantify the contribution of underlying physical mechanisms of sea level variability with atmospheric reanalysis and land hydrology data assimilation from the Goddard Earth Observing System (GEOS) and ice sheet studies, which we use in the Estimating the Circulation and Climate of the Ocean (ECCO) framework to understand the influences of near-coastal sea level changes; 3) project sea level change on near-term timescales using the seasonal forecasting system of GEOS and 21st century contribution of ice sheet mass using the ISSM; 4) contribute with our knowledge and expertise to the NASA Sea Level Change Team (N-SLCT), and deliver products on the N-SLCT portal that can be used towards a common product. Our work builds on previous research efforts sponsored by NASA (including past N-SLCTs) and are primarily based on NASA observations and models, yet our research will benefit the larger sea level and climate research communities. The work also addresses the broader needs of stakeholders and others affected by sea level by investigating prognostic forecasts for time periods of interest (seasonal, 21st Century).

Understanding and characterizing relevant mechanisms and underlying processes that are key in current sea level change necessitates an integrated approach which uses available remote sensing, data assimilation, and modeling resources. Our interdisciplinary team consists of modelers and remote sensing experts in the fields of ocean, atmosphere, hydrology and cryosphere sciences, that is uniquely suited to contribute to the four objectives of the solicitation. Many of our team members participated in the first two N-SLCT, and our work builds on these efforts. Our team provided datasets to the N-SLCT portal; for example, the global sea level dataset from altimetry, which we can immediately revise and update without waiting for external groups to address reprocessing issues on their time frame. This strength applies to all the observational or modeling datasets that we will share with the N-SLCT, and given the importance of these dataset or models for sea level research, it is important that the N-SLCT has members cognizant of any issues that require special attention when dataset are assimilated or

interpreted. Our team participated in team wide efforts (such as the current N-SLCT team paper), team telecoms and meetings; and will continue to be engaged with other teams as we work towards a common product.

Our integrated approach directly contributes to the goals of the solicitation, and also addresses the NASA Earth Science Division goal to "Improve the ability to predict climate changes by better understanding the roles and interactions of the ocean, atmosphere, land and ice in the climate system" (NASA 2014 Science Plan, https://science.nasa.gov/about-us/science-strategy, p.43), as well as NASA's focus area in Weather, Climate Variability & Change, Water & Energy Cycle, and Earth Surface & Interior (https://science.nasa.gov/earth-science/programs/research-analysis). Our work responds to the 2017-2027 Decadal Survey Science and Application Priorities on Sea Level Rise: "C1: How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets…" and "S3: How will local sea level change along coastlines around the world in the next decade to century?" (Table S.1, National Academies of Sciences, Engineering, and Medicine, 2018).

Christopher Piecuch/Woods Hole Oceanographic Institution
Contributions to Coastal Sea-Level Extremes: Understanding the Past and Projecting the Future
19-SLCST19-0010

Vulnerable coastal communities across the United States are experiencing the effects of sea level rise in the present day. Ongoing increases in the frequency and severity of coastal sea level extremes are producing tangible and disruptive consequences on a regular basis. Sea level rise will continue to increase the frequency and severity of such events. The impacts will manifest in new locations during coming decades. Sea level rise is therefore not a problem only for the distant future. Decision makers require cutting-edge science distilled for applied tasks such as establishing planning horizons, assessing design lifetimes of key infrastructure, and developing coastal management strategies.

We seek funding to improve both the scientific basis and utility of information available to decision makers regarding ongoing changes in the frequency and severity of coastal sea level extremes over the next ~30 years. Products resulting from the research will include:

(1.) Budgets quantifying the relative contributions of different physical processes, and covariation between those processes, to historical coastal sea level variability and extreme events observed in coastal data records as a function of space and time;
(2.) Projections of sea level variability and extreme events along the coastal US and US territories for the period 2020–2050 detailing how the various contributing processes, and correlations between them, will evolve into the future.

Our research efforts will address the specific objectives identified in the NASA-Sea Level Change Science Team (N-SLCST) solicitation related to providing evidence of sea

level change, quantifying contributions to sea level variability, developing projections of sea level changes, and synthesizing results enabling a team product.

David Rounce/University of Alaska, Fairbanks
Quantifying Contributions from Glaciers and Terrestrial Hydrology to Recent and Future Sea Level Change
19-SLCST19-0014

Glacier and land water storage changes are two of the largest contributors to global mean sea level. Understanding the timing and magnitude of sea level change is important for all coastal communities. In order to accurately project glacier and land water storage changes to sea level we need a clear picture of the link between glaciers and terrestrial hydrology, and must advance how process-based models account for key glacier processes and human intervention.

Our overarching goal is to understand and quantify the contribution of total water storage on land to global mean sea level change from 1950-2100, and distinguish its two most important components: glacier mass change and land water storage change. We hypothesize that integrating glacier and land water storage processes (through modeling) will reduce previous estimates of both glaciers and groundwater contributions to sea level rise due to a) interactions between the two water sources that have not yet been accounted for and b) the critical role of humans in altering the hydrological cycle.

Our objectives are to:

i) Quantify the effects of changing glaciers and land water storage on global mean sea level change by refining and integrating glacier and hydrologic models.

ii) Determine the underlying physical mechanisms affecting both glacier mass change, land water storage, and the linkage between the two.

We will produce and analyze new remote sensing measurements to advance our understanding of key glacier processes that affect global glacier mass change. We will use these observations to develop and integrate new approaches accounting for frontal ablation, debris cover, and glacier dynamics in our glacier evolution model (PyGEM), calibrate the model with an unprecedented amount of mass balance and frontal ablation measurements, and produce refined projections of glacier mass change to 2100. Glacier model output will be used in an integrated, process-based hydrologic modeling framework (WBM) that will use state-of-the-art global groundwater methods and gravimetric measurements to enhance our ability to estimate the contribution to sea level of the interconnected glacier-hydrological processes over the land surface. This novel, integrated view, that directly assesses the connections between glacier runoff and terrestrial hydrology, will produce more reliable projections of sea level change that will be fundamental for regional-scale decision making.