NASA's Science Mission Directorate, NASA Headquarters, Washington, DC, has selected proposals for the Modeling, Analysis and Prediction (MAP) Program in support of the Earth Science Division (ESD). The Modeling, Analysis, and Prediction (MAP) program seeks an understanding of the Earth as a complete, dynamic system, with particular emphasis on climate and weather. The MAP program supports observation driven modeling that integrates the research activities in NASA’s Earth Science Program. The research is distinguished by rigorous examination and incorporation of satellite-based observations, using models to bridge the spatial and temporal scales between satellite observations and observations from ground and air based campaigns. This contributes to the validation of the satellite observations and to observationally based improvements of Earth system model components. MAP strives to generate models and model components that are documented and validated. An overview of the current program may be found at http://map.nasa.gov. The research themes specific to this solicitation include investigations to improve the representation and prediction of regional sea level rise in Earth system models, the representation of the Cryosphere and its interaction with ocean, land, and atmosphere in ESMs, ocean modeling and data assimilation, particularly coupled data assimilation, and improvement of the Earth System Modeling Framework and its utilization in Earth system models. The ESD has selected 10 out of a total of 19 proposals received in response to this solicitation. The total funding for these investigations is approximately 13.5 million dollars.

Santha Akella/Goddard Space Flight Center
Effectively Constraining Both Atmosphere and Ocean Components in an Integrated Earth System Analysis Data Assimilation System
19-MAP19-0007

Background:
Satellite altimeters in conjunction with Argo in-situ measurements are revolutionizing oceanography. Data assimilation of sea level anomaly (SLA) from satellite altimeters and Argo temperatures and salinities effectively constrain important climate variables such as the ocean heat content. Therefore, these data are essential for improved ocean analyses and coupled predictions. The atmospheric water vapor, which is used to correct for path errors for altimetry, is important for accurate retrieval of SLA. Unfortunately, present state of the art data assimilation systems, that lack an Integrated Earth System Analysis (IESA) approach to obtain a best estimate of the state of the Earth System do not treat measurements of SLA, and atmospheric water vapor) in a consistent manner. For example, altimetry products rely upon ECMWF model data for atmospheric corrections.

Objectives:
One of the main goals of an IESA is to assimilate disparate observations of different components of the earth system into a unified modeling and data assimilation system. We
propose to develop an important aspect of the IESA that consistently combines observations of the atmosphere with the ocean, specifically focusing on atmospheric water vapor, ionospheric correction and satellite altimetry. Extending upon systems developed by Global Modeling and Assimilation Office (GMAO) and Geodesy and Geophysics Laboratory (GGL) at NASA GSFC, we propose following developments:

(i) Directly assimilate cross-calibrated foot-print level along-track sea level anomaly (SLA) from satellite altimeters (Topex/Poseidon, Jason series satellites), derived by the GGL into the ocean component of a prototype GMAO IESA.

(ii) Directly assimilate Atmospheric Microwave Radiometer (AMR) measured brightness temperatures, also onboard T/P and Jason series satellites into the atmospheric component of the GMAO IESA.

(iii) Develop data thinning and quality control procedures to consistently assimilate SLA and AMR measurements into the ocean and atmospheric components respectively (i.e. SLA improves ocean, AMR improves atmosphere and is used to further improve atmospheric correction to SLA and so forth).

These proposed cross-component developments would not only constrain the atmosphere and ocean components of the earth system, but also the air-sea feedbacks between them.

The above developments will be implemented and tested in the GMAO IESA. Our validation metrics will include comparison to withheld data, short- and longer-term forecasts to address impacts on numerical weather prediction and annual to inter-annual variability of sea level. Specific ocean metrics would consist of deep (mode) water transport at key locations such as at the RAPID array to measure the strength of the Atlantic Meridional Overturning Circulation (AMOC).

Broad Relevance:
We anticipate successful implementation of our IESA developments will lead to:

a) Better understanding of feedbacks and interactions between the oceans and atmosphere.

b) Production of internally self-consistent climate variables that have been constrained using a wide variety of dissimilar observations.

c) Improved uncertainty estimates that will have positive implications for sea level rise in global climate models (GCMs).

Team Consists of: (i) Dr. Santha Akella will lead the development of the GMAO IESA components to assimilate AMR and altimeter data, and study the impact on short time-scale predictions; (ii) Drs. Richard Ray and Brian Beckley will contribute to the satellite altimeter data, and aid in diagnosing and validating improvements to the predictions of sea level rise; (iii) Dr. Eric Hackert will refine the assimilation of Argo measurements and study the seasonal-scale oceanic impacts.
The Earth System Modeling Framework is a high-performance modeling infrastructure package used in multiple modeling systems at NASA including the Goddard Earth Observing System (GEOS), the Land Information System (LIS), and development branches of ModelE. ESMF provides a component construct, parallel data structures, efficient communication and remapping operations, and other utilities. Most modeling systems do not use ESMF components directly, but access ESMF functions through a “usability layer” that provides reusable component implementations, standardized coupling protocols, and consistent use of metadata. The two major usability layers are the Modeling, Analysis, and Prediction Layer (MAPL), developed at NASA GSFC in conjunction with the GEOS model, and the National Unified Operation Prediction Capability (NUOPC) Layer, developed under a multi-agency agreement including Navy, NOAA, and other operational centers. MAPL and NUOPC were designed independently, and the resulting layers initially provided limited interoperability. Under a 2015 MAP award, the ESMF team and NASA GSFC developers designed and implemented strategies to provide technical interoperability between MAPL and NUOPC and to unify overlapping parts of the two layers. The NUOPC layer was extended with missing functionality provided by MAPL so that NUOPC could replicate the same behaviors as found in a deep hierarchy of MAPL components, such as the GEOS atmospheric model. Previous work to unify MAPL and NUOPC has resulted in both increased use of ESMF functions within GEOS and multiple options for interoperability between MAPL and NUOPC.

Here we propose to build on these prior efforts to unify MAPL and NUOPC and ensure that ESMF core operations meet the computational performance requirements of GEOS in the next 5-8 years. The objectives of this proposal are to (1) increase the adoption of NUOPC in GEOS in the major top-level components ExtData, History, Atmosphere, and Ocean; (2) expand ESMF and the NUOPC Layer to support advanced data staging capabilities and integrate with GEOS asynchronous I/O capability; (3) optimize core ESMF operations at scales expected for GEOS operational runs in the next 5-8 years; and (4) align testing and code management practices between MAPL and the NUOPC Layer to ensure ongoing coordinated development and promote code unification and sharing.

The proposed work will increase the NUOPC-compliance of NASA models and will promote code sharing and scientific collaboration with the broader community. It will also further the MAPL/NUOPC interoperability and unification efforts prioritized by the NASA MAP program, leading to greater adoption of ESMF functions in NASA codes and overall reduced maintenance costs. The optimization tasks will ensure critical NASA infrastructure software is scalable and ready for efficient execution on next generation operational codes. Finally, the improved code management and testing practices will ensure infrastructure code robustness across platforms and provide mechanisms to encourage flow of infrastructure code into the base ESMF implementation.
Motivation: Simulating the complex interactions between surface and subsurface processes is important for capturing the influence of groundwater storage and flows on land surface processes and associated land-atmosphere fluxes. Most current land surface models, however, employ only simple formulations of shallow, unconfined groundwater storage changes and cannot represent deep aquifers or lateral flows. These shortcomings limit the physical realism of simulated land surface states and fluxes and the characterization of hydrologic extremes. Further, the lack of detailed subsurface process representation in land surface models has limited the utility of data assimilation systems that ingest observations from gravimetry missions such as GRACE and GRACE-FO. The proposed project will leverage the advanced land surface modeling and data assimilation features of the NASA Land Information System (LIS) and the sophisticated subsurface modeling features of ParFlow to develop a next-generation surface-subsurface terrestrial modeling environment that will overcome these limitations and enable new science.

Approach: The integration of LIS and ParFlow will be accomplished using standard software tools and paradigms of the National Unified Operational Prediction Capability (NUOPC) identified by the Earth System Modeling Framework (ESMF) effort. In addition to coupling the physical models within LIS and ParFlow, the proposed work will develop cross-model coupled data assimilation instances, including non-sequential, iterative, and irregular types of coupling instances. These efforts will also establish coupling paradigms and constructs within ESMF/NUOPC that will be relevant for the larger MAP-supported ESM community.

Relevance: The proposed system would combine the strengths of LIS and ParFlow and enable the interoperable use of physical models and data assimilation techniques in highly scalable environments. The detailed representation of subsurface processes within ParFlow will enable better simulation of processes such as groundwater recharge, discharge, withdrawals, lateral flows and vertical exchanges and the effects of human management on these processes. These enhancements will also improve the suitability of data assimilation environments employing observations from missions such as GRACE and GRACE-FO. By developing observation system simulation experiments with the LIS-ParFlow system, the proposed work will support the activities of NASA’s Mass Change designated observable study team. Finally, the proposed LIS-ParFlow system will be used to assess the impact of including detailed subsurface hydrology on coupled land-atmosphere prediction. The proposed work is thus directly relevant to the MAP program goals of enhanced observation-driven modeling and data assimilation for improving Earth system model components.
We propose to leverage sea-level, solid-Earth and ice-sheet modeling capabilities built into the Ice Sheet System Model (ISSM), ocean circulation capabilities built into MIT General Circulation Model (MITgcm), the Modern-Era Retrospective Analysis for Research and Applications version 2 (MERRA2) and a suite of satellite observations (IceSat, IceSat-2, GRACE, GRACE-FO, ERS-1/2, Envisat, Cryosat-2) in order to deliver:

1. a high-resolution spatio-temporal reconstruction of relative sea-level (RSL) evolution from 1980 to present-day contributed to by mass changes in the Cryosphere and Hydrosphere.

2. a quantitative assessment of the relative contribution of each water (river basins, lakes and dams) and ice (outlet glaciers in Greenland, ice streams in Antarctica, mountain glaciers among others) catchment to RSL everywhere in the world.

3. a 100-year projection of the impact of an evolving Cryosphere on tidal heights and storm surges as captured by MITgcm.

Our approach here is to better inform scenarios that can impact sea-level change at a specific location (for example port cities). These scenarios will involve changes in mass coming from an evolving Hydrosphere and Cryosphere. Such scenarios could be for example how: 1) the collapse of Thwaites Glacier (West Antarctica, Larour et al. 2019) or 2) the extremes in the water cycle of the Indian subcontinent or Amazon basin; will impact sea-level in New York, storm surges in Jakarta, Indonesia or tidal heights in Norfolk, Virginia.

We will rely on the following tools, methods and data:

1. the Ice and Sea level System Model (ISSM, Laroureetal.2012a; Adhikarietal.2016; Larour et al. 2016) to provide a forward capability for both ice sheet and sea-level models. In addition sensitivities of sea-level to total water mass changes will be recovered using the automatic adjoint capabilities of ISSM (Larour et al. 2016).

2. MERRA2 combined with GRACE data and ground water hydrological data to constrain changes in terrestrial water storage (TWS)

3. a combination of GRACE, GRACE-FO and elevation changes from 30 years of satellite altimetry (ERS-1/2, Envisat, Cryosat-2) to constrain past changes in land ice mass (including both ice sheets and mountain glaciers)

4. MITgcm to compute changes in tidal heights and storm surges as coastlines migrate inland and wet new areas and sea-surface heights increase. We will rely on the Estimating the Circulation and Climate of the Ocean project (ECCO, Menemenlis et al. 2005; Forget et al. 2015) used by MITgcm to provide forcings that are dynamically consistent with time evolving observations (TOPEX/Poseidon-to-Jason satellite altimetry period).

The tradition of our research with ISSM, ECCO and MERRA2 is to emphasize data assimilation and development of model adjoints. The two processes mean that the three models rather naturally mature in strength, as ever greater data is absorbed and informs the sensitivity analyses. In this way, the models achieve a robust capability to attribute model predictions to the individual sources of environmental changes that are causal. Such predictions can rigorously respect probabilities and quantify uncertainties. The expected significance of this effort is therefore to improve on the state estimation of non-
steric sea-level, through separation of its components, projection in the next 100 years and impact on ocean tidal heights and storm surges.

John Marshall/Massachusetts Institute of Technology
Assessing the Impact of Glacial Melt on the Coupled Climate
19-MAP19-0011

This is a proposal to contribute to the development of a fully coupled cryosphere-climate model capability in ModelE and science applications thereof. We will leverage on-going and align with future model development at GISS to facilitate a model that incorporates an improved representation of polar glacial melt, especially presently missing ice shelf basal melting. This will allow us to estimate and put constraints on, the melt components of polar ice (Antarctica and Greenland) and its effect on the adjacent sea-ice, ocean and global climate, including sea-level, sea-surface temperature and salinity and sea-ice extent.

We propose a 'Response Function' analysis of the resulting model in which step perturbations are introduced and the sensitivity of the coupled climate to those perturbations explored and compared to other drivers. We will focus on evaluating the new modeling capability in terms of observations, both remotely-sensed NASA products and in-situ observations of the interior ocean.

The proposed work addresses core research questions that are central to NASA such as "How is the Earth system changing?", "What are the sources of change in the Earth system and their magnitudes and trends?", "How will the Earth system change in the future?".

Dimitris Menemenlis/Jet Propulsion Laboratory
Toward Seamless Simulation, Estimation, and Prediction of Weather and Climate with the GEOS/ECCO Coupled Model and Data Assimilation System
19-MAP19-0018

There is growing interest in long-range prediction from the agriculture, energy, defense, and maritime sectors of the government and the economy. Many of these interests involve the need to plan for infrastructure. An example of this is the design of ports for Arctic shipping in a coming decade with ice-free summer conditions. The societal need for predictions on interannual-to-decadal time scales motivates the proposed work.

The proposed study aims to make incremental but significant advances in NASA's interannual-to-decadal prediction capability by combining expertise from two flagship NASA modeling and data assimilation efforts, the Goddard Earth Observing System (GEOS) and the Estimating the Circulation and Climate of the Ocean (ECCO). One set of breakthroughs will be spurred by a fully coupled atmosphere-ocean-ice simulation, where all three fluids are integrated globally with km-scale horizontal grid spacing. Both GEOS
and ECCO have been run, separately, at groundbreaking resolutions, providing valuable
scientific insights and guidance for subgrid-scale parameterizations in the two fluids.
The ultra-high resolution run that we propose to carry out will illuminate coupled air-sea
exchange mechanisms that cannot be resolved by current-generation coupled simulations.
A second set of breakthroughs will be spurred by the incorporation of certain aspects of
ECCO data assimilation tools into GEOS toward improved interannual-to-decadal
prediction capability.

The specific technical and scientific objectives of this study are divided in three
categories:
I. Coupled GEOS/ECCO modeling tasks:
   Development and integration of a km-scale GEOS/ECCO simulation
   Process studies with this simulation relevant for long-term prediction
   Adjustment of a moderate-resolution GEOS/ECCO simulation
II. Coupled atmosphere-ocean-ice data assimilation tasks:
   GEOS/ECCO weakly coupled data assimilation system development
   Ensembles of long-term prediction experiments
   Code refactoring in preparation for future versions of GEOS
III. NASA data exploration and utilization tasks:
   Observations currently assimilated in GEOS and ECCO
   Arctic sea ice thickness initialization and prediction
   Contributions to upcoming and under-development missions

This proposal responds to this Research Announcement’s theme of "Ocean Modeling
and Data Assimilation including the Cryosphere". The objectives of the proposed
research are directly relevant to the goal of "furthering NASA's capabilities in the area of
ocean modeling and data assimilation". The proposed works builds on existing
capabilities separately developed by the GEOS and ECCO modeling and data
assimilation teams and aims to combine them in a single modeling and data estimation
framework that is greater than the sum of its individual components. The proposed
objectives also directly address the call to develop an "improved understanding and
representation of oceans and their interactions in the Earth system, consistent with the
goal of developing an up-to-decadal Earth system prediction capability". The key science
question that focuses all of the specific proposal objectives is the relevance of the newly-
combined GEOS/ECCO system to study and assess multi-year to decadal prediction and
predictability.

Eric Rignot/University Of California, Irvine
Southern Ocean State Estimate with ce-Shelf Cavities Evaluated with Remote
Sensing Observations to Improve Projections
19-MAP19-0019

The Antarctic Ice Sheet is a significant contributor to sea level rise at present and has the
largest potential for future sea level rise in the coming centuries. Most of the mass loss is
governed by the acceleration of its glaciers, not by changes in surface mass balance, and
the glacier acceleration is caused by the enhanced advection of subsurface, warm, salty
water of Antarctic Circumpolar Current origin, or CDW, onto the continental shelf,
beneath the ice shelf cavities, and reaching the glacier grounding lines. As more warm
CDW reaches the grounding lines, the glaciers retreat and speed up, which is conducive
to more retreat, especially if the glaciers are resting on retrograde bed slopes, i.e. bed
elevation drops in the inland direction. IPPC-class models and Earth system models fail
to reproduce this evolution of Antarctic ice for two major reasons: 1) The shapes of the
sub-ice-shelf cavities that potentially host CDW and the presence of troughs on the
continental shelf that control the advection of CDW are not well known and ice shelves
are not well represented in Earth system models; 2) Ocean models need to be run at a
high spatial resolution on the continental shelf to model off-the-shelf to on-the-shelf
ocean heat transport, but this is not the focus of ocean models in ESMs. Here, we will
map the shape of nearly all sub-ice-shelf cavities using a new compilation of airborne
gravity data, including Operation IceBridge (OIB) data from 2009-2019, combined with a
new compilation of magnetic anomalies, a new bed topography on land named
BedMachine Antarctica, multi-beam echo-sounding data at sea from the International
Bathymetry Chart of the Southern Ocean, existing pan-Antarctica seismic data on the
continental shelf and on ice shelves, and novel seal mammal diving depth data from
Marine Mammals Exploring the Oceans Pole to Pole near ice shelf fronts. The
bathymetry will be delivered as a level 4 product to NSIDC for ice sheet/ocean modelers
to use in Antarctica. Secondly, we will run a 1 km resolution eddy-resolving, cavity-
inclusive model of the Southern Ocean forced by re-analysis using the MITgcm ocean
model. At the northern boundary, the model will be constrained by an extension of the
Southern Ocean State Estimate to 2003-2021 via massive data assimilation. To evaluate
the 1-km model results, we will compare the modeled ice shelf melt rates with pan-
Antarctic ice shelf melt rates calculated from remote sensing data: time series of ice
velocity from MeASUREs-3, ice elevation from ICESAT-1, OIB, ICESat-2,
WorldView/GeoEye and TanDEM-X, and ice thickness from BedMachine. The results
will provide bathymetry, ice shelf melt rates, and guidelines to improve the representation
of ice shelves in ESM, e.g. GEOS-5 which uses MITgcm. As part of the ocean analysis,
we will investigate the relationship between climate variables and ice shelf melt rates
using the adjoint method to reduce uncertainties in projections. We will combine the
derived ice shelf melt rate sensitivities with climate projections from CMIP6 and
CMIP6/ScenarioMIP ensemble members to project ice shelf melt under different
emission scenarios. Overall, the results of this project will be a major step forward in the
modeling of Antarctic ice/ocean evolution in a warming climate, with ocean state around
Antarctica, ice-shelf melt rates, reliable bathymetry with ice shelf cavities, and
constraints to better project the coming decades of Antarctic evolution with lower
uncertainties. This work will enhance our current modeling capabilities in Antarctica,
capitalize on NASA and non-NASA space and airborne observations, data assimilation
techniques, and ESM development to pave the way for more realistic projections of
Antarctic Ice Sheet evolution and its impact on sea level rise. This work will contribute to
NASA overall research objective to better understand the role of oceans, atmosphere and
ice in the climate system and its impact on global sea level rise.
Understanding the distribution of surface meltwater on Antarctica’s floating ice shelves is essential in making predictions of their stability and the ice sheet contribution to future sea level rise. In addition, meltwater processes are key in accurate representations of ice shelf surface melt and heat exchange with the atmosphere in ice sheet and Earth System Models (ESMs), which do not currently account for surface melt distribution. Here we propose to build the first three-dimensional surface hydrology model for Antarctic ice shelves, which we call MONARCHS (MOdel of aNtARctic iCe shelf surface Hydrology and Stability).

Technical and Science Objectives:
1. We will build the first comprehensive three-dimensional surface hydrology model for Antarctic ice shelves, MONARCHS. The model will include key processes such as lateral flow of water, ponding, ice erosion by flow, and ice shelf flexure.
2. We will incorporate a maximum entropy production (MEP) scheme for calculating surface heat fluxes, with unique advantages in modeling surface heat exchange over data sparse regions, into MONARCHS.
3. We will perform extensive calibration and validation using data products derived from NASA airborne and satellite platforms, in addition to existing ground-based field measurements.
4. We will identify key processes driving recent surface melting and water distribution over Antarctic ice shelves through comprehensive sensitivity studies.
5. We will assess future Antarctic ice shelf hydrology and stability using CMIP6 climate model output, including the NASA GISS ModelE.
6. We will couple MONARCHS to NASA’s Ice Sheet System Model (ISSM) in order to improve the parameterization of surface hydrology in ice shelf models.
7. We will use results to inform new development of surface heat flux schemes over polar regions in NASA ESMs.

Deliverables:
• A novel, comprehensive surface hydrology model for Antarctic ice shelves openly available to the climate and glaciology communities;
• Modeled surface melt distribution for all Antarctic ice shelves, including high-resolution lake location and depth information;
• A new, fully validated surface heat balance scheme for snow/ice surfaces suitable for inclusion in earth system models;
• Projections of ice shelf vulnerability to breakup due to surface melting for all Antarctic ice shelves.
Anastasia Romanou/Goddard Space Flight Center
Transient Climate Response to Emissions (TCRE): Combined Heat and Carbon Feedbacks Under Different Emission Scenarios
19-MAP19-0010

The question ``how much will surface temperatures rise with increased emissions of greenhouse gases into the atmosphere'' is central to climate science, climate change mitigation and adaptation strategies. An appropriate metric for this question is the `Transient Climate Response under Emissions' (TCRE) which is the ratio of surface warming to cumulative emissions: it represents how much CO2 (or other greenhouse gasses) can be emitted to the atmosphere before a warming target, say 2\degg C or 1.5\degg C is reached.

Our best estimates of TCRE are based on climate model simulations but the range of model responses is very large both globally and even more so on regional scales.

We propose to use the NASA Goddard Institute for Space Studies (GISS) - General Circulation ModelE GCM, coupled to an ocean carbon cycle and prescribed land carbon, to describe, understand and quantify ocean heat and carbon uptake feedbacks under a broad variety of climate change scenarios, how the TCRE depends on model physics vs. model ocean biogeochemistry, and highlight the pathways and processes that control heat and carbon feedbacks in the ocean. We aim to provide analytic and empirical relationships between the TCRE and the carbon cycle feedbacks.

To address these objectives we will analyze results from a range of modeling capabilities and we will exploit the large number of simulations already produced at GISS for the purposes of the Climate Model Intercomparison Project 6 (CMIP6).

A key element of the proposed work is that model assessment and parameter choice in the sensitivity runs will be observationally constrained and based on NASA products such as: sea ice from NSIDC, SST from AVHRR and MODIS, SSS from Aquarius and the newly launched SMAP, chlorophyll from SeaWiFS and MODIS, column integrated CO2 from OCO2, subsurface carbon components from EXPORTS (when available) and Argo and bio-Argo, SOCCOM, SOCAT for pCO2 and other biogeochemical parameters, CFC from WOA database.

The proposed work addresses core research question "How will the Earth system change in the future?" and is directly aiming to Theme 3.3 "Improved understanding and representation in global models of atmosphere/ocean/ocean biosphere interactions, including heat, momentum and carbon dioxide".
The increasing number and spatial variation of coastal flooding events around the world has led to a developing awareness of the importance of regional sea level rise (SLR). This awareness drives a clear need to better understand regional vulnerability, risks, and to aid in adaptation efforts. With the successful closure of the global sea level rise budget from 1993 to the present (WCRP Global Sea Level Budget Group, 2018) and further integration of key components of that budget into Earth System models, it is now possible (and vital) to develop better integrated assessments of regional SLR using state-of-the-art observational data and modeling.

We propose to build on existing integrated assessments of the major factors that affect regional sea level rise with increased emphasis on self-consistent calculations of key terms. The factors include: 1) steric effects in the ocean, 2) addition of mass to the ocean from a) mountain glaciers, b) ice sheets, c) net groundwater removal/retention, 3) ocean/atmospheric circulation impacts on sea surface height, 4) gravitational, rotational and deformation (GRD) changes associated with past and present-day ice and ocean change, 5) local vertical land movement (due to compaction, groundwater removal, or neo-tectonics etc.).

Many of these effects can now be calculated directly in Earth System Models (ESMs) (including GISS ModelE), for instance, steric effects, ocean/atmospheric circulation changes and ice sheet mass balance, and some can be integrated directly from other sources (e.g. mountain glacier loss from GRACE, long-term glacial isostatic adjustment from ICE-6G and updates), and local assessments of vertical land movement (at selected locations) and extrapolated forward). New capabilities from both remote sensing (GRACE, GRACE-FO) and modeling within the ESM will allow estimates of net groundwater change to be included in both hindcasts and projections. Fast response GRD effects can be calculated from first principles from the changes in mass distributions in the more complete ESMs. These integrated regional SLR projections can be then converted into changes in local storm surge and flood risk using explicit calculations of changes in extratropical storms, observation-based statistical emulations of tropical storm characteristics and tracks, combined with as much local information (such as tides, local vertical land movement) as is available.

The proposal will focus on a) improving the capacity for end-to-end capability for assessing risk that can integrate these diverse sources of information under past historical forcings and for multiple future scenarios, b) integrating these results with local heterogeneous factors and existing methodologies that are essential for producing actionable information, and c) assessing the changing risks of coastal flooding using tidal
information and both modeled and emulated storm statistics (and any plausible changes to them).

The proposed work is relevant to the “Representation and Prediction of Sea Level Rise” element in the solicitation and will serve NASA SMD’s goals to understand how the earth system is changing and will change in the future, characterize the uncertainties in predictions, and help improve the mitigation and adaptation to global change.