Grand Challenge:

A framework for addressing
The coevolution of physical, ecological and human systems in coastal environments

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1. Motivation: Disruptions Do Not Recognize Spatial or Temporal Boundaries.

Coastal environments support a wide range of ecosystem services, human infrastructure and activity, and a rich benthic environment. Geophysical processes that occur at many different time scales impact wellbeing and threaten habitats for human and natural populations. As human activity and responses to these threats in turn affect geophysical and ecological processes, the coastal environment evolves through interactions between coastline dynamics, ecological dynamics and socioeconomic processes. Ecological, hydrodynamic, and morphological processes occur at timescales ranging from hours to centuries over fine spatial scales (meters) to hundreds of kilometers. Human activity ranges from daily activity to policy responses that occur at decadal scales. To better understand the coevolution of complex dynamic systems, we need to examine interactions and feedbacks across many processes and over multiple spatial and temporal scales.

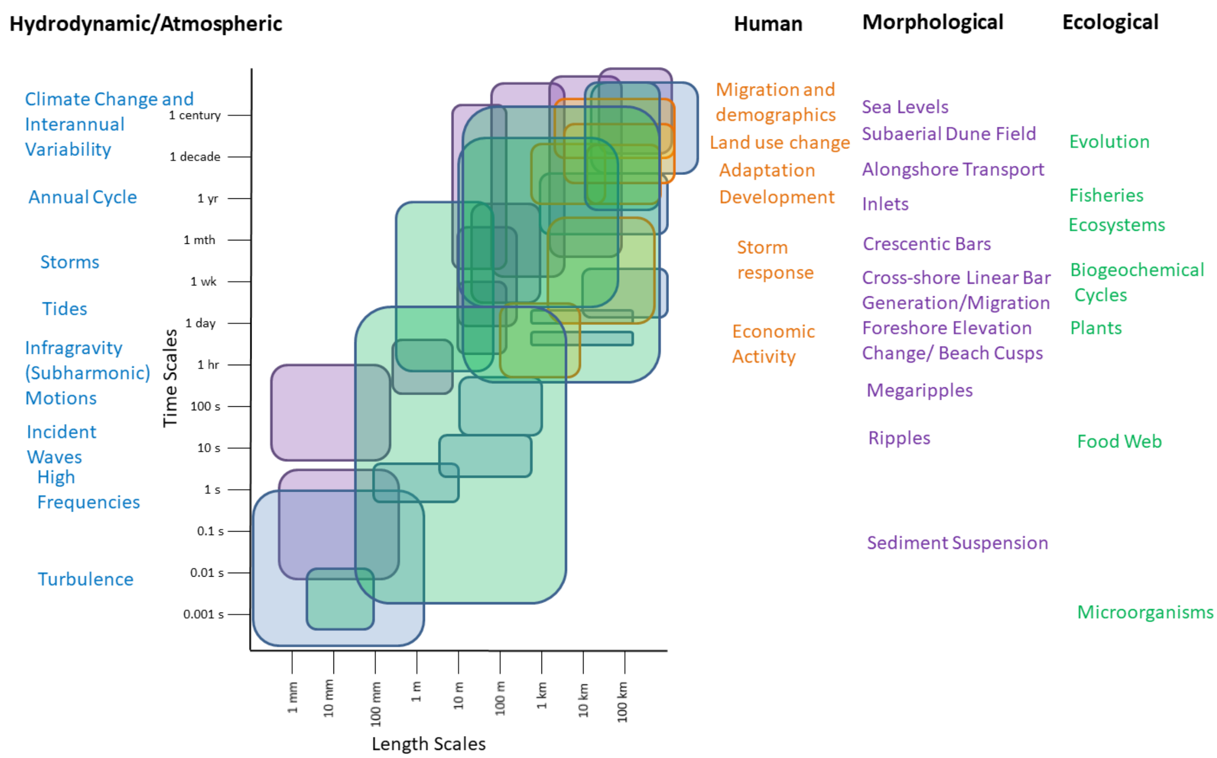

Figure 1. Overlapping spatial and temporal scales of atmospheric/hydrodynamic, geomorphological, ecological, and human processes in coastal systems. The recommended framework will focus on scales from hours to century, and meters to 100's of km.

2. Specific Recommendations

- Develop a framework to allow researchers to **address basic science questions involving natural-human coastal systems**. Possible examples include:
    - o How does hazard mitigation affect future habitability of coastal environments?
    - o What thresholds trigger retreat (of coastlines and people)?
    - o Does the feedback to develop coastlines, protect the development, and then further develop the protected area affect inequalities in coastal wealth, and social justice?
    - o How fast will coastlines and wetlands retreat in the future under different scenarios of climate change, sea level rise, and shoreline stabilization?
    - o How do human adaptation and mitigation measures at local scales affect coastal evolution at regional scales over longer time scales?
    - o Deltas support dense human habitation and economic activity, necessitating a range of manipulations of environmental processes, including flood control measures. How do such manipulations change the trajectory of landscape and ecosystem evolution—and therefore future land use and protection measures?

- To identify and quantify key interactions, occurring across a range of scales, and how they may be represented in a hierarchy of models, **collaborations need to be facilitated across disciplines** including: geomorphology, economics, political science, sociology, psychology, computer science, engineering, atmospheric science, oceanography, and planning.

- **Develop flexible model frameworks**. The models needed to make useful predictions will need to integrate different approaches. No single model or type of model will be able to answer all questions related to the coupled natural-human coastal dynamics. For example, high resolution and high details models for event scale simulations (e.g., storms), will need to be coupled with models for coastal evolution that synthesize and parameterize the effects of faster-scale processes; and models for physical/geological processes will need to be coupled with socio-economic models that have different resolutions. Particular effort should be made to facilitate the integration of physical/geological/ecological models with socio/economic models. Simulation of a range of spatio-temporal scales at multiple resolution (detail) will require the development of methods that can seamlessly integrate the disparate scales, and efficiently utilize cutting-edge high performance computing (HPC) paradigms. Model development and coupling should leverage and contribute to existing resources, especially the Community Surface Dynamics Modeling System (CSDMS, featuring a Coastal Working Group and Coastal Vulnerability Initiative), which offers expertise and software infrastructure for model-coupling, and which models freely available to other researchers.

- **Develop empirical analysis and data integration to inform model development and testing.** Empirical analyses and the integration of databases that measure changes in geophysical outcomes, ecological conditions and socio-economic indicators are critical to develop empirically grounded models with coupled interactions at different spatial and temporal scales. Empirical analysis is needed to understand the impact of episodic events (hazards) on socio-economic outcomes, distribution of human populations and to inform policy responses. Whereas static benefit-cost analysis and quasi-experimental approaches to identify the impact of a natural event on human activity are well developed, empirical identification of causal pathways in dynamic coupled systems remains largely unexplored. The development of databases and methods that go beyond cross-sectional analysis are needed to inform the wide range of models at different timescales.

3. *Impact and Values: Advances Basic Science and Informed Decision Making*

- The recommended framework will facilitate research addressing societally relevant and compelling basic science questions, including those related to:
    - How adaptations and mitigations lead to cascading impacts across jurisdictional and spatio-temporal scales. We are challenged to improve forecasts of these cascades. Robust vulnerability assessments should combine multiple spatial and temporal scales spanning from presses (i.e., gradual change) to pulse events (i.e., low frequency high impact events).
    - Assessing alternative pathways of adaptation, mitigation, and co-evolution of landscapes and habitats (human and ecological)

- The recommended framework will also support informed decision making. Disasters like hurricanes present challenges for decision makers, especially in the context of changing climate and increasing rates of sea-level rise. On an event-time scale, extreme storms (e.g., hurricane, Nor'easter's) often embody multiple hazards. After events, decisions made for reconstruction have long-term impacts on how the coastal system evolves, and therefore what the risks in the future. Recovery, adaptation and mitigation decisions made with the long-term spill-over effects in mind could be more effective for long-term sustainability of human habitation of coastal systems.

- The research made possible by the recommended framework will involve training a new generation of researchers in interdisciplinary science. An important component of research is the training of undergraduate, graduate students and postdoctoral scholars in methods that cut across multiple disciplines. Research that links human, geophysical, and ecological processes will inherently develop researchers who are able to communicate across disciplinary divides and share methods and data in a new collaborative capacity. This training of a generation of interdisciplinary scientists will also improve science communication and skills to share research with a broader public audience. Interactions with other disciplinary perspectives will also likely inform research within their own fields in new and innovative ways.

4. *Reasoning*

Actions humans take to mitigate coastal hazards, or to recover after disasters, alter how coastal landscapes and ecosystems change. How the landscapes and ecosystems change influence future risks and hazards. Altered future risks and hazards, in turn, drive future mitigation and future disasters and recoveries. Given the tight coupling between human dynamics and natural dynamics in coastal environments, we need to study coastal systems holistically to be able to understand or forecast how they evolve. As one example, the elevation and topographic shape of barrier islands, including sand dunes that tend to block moderate storm surges, help determine the range of storm impacts a barrier community is exposed to. Humans often augment coastal dunes, to enhance the storm protection they provide—which prevents moderate 'overwash' events in which storm waves wash sediment on top of the barrier. In addition, after severe storms that destroy the dunes and spread sand across a barrier, the recovery process typically involves bulldozing the deposited sand off developed areas. In the absence of these mitigation and recovery processes, sand deposited on a barrier tends to maintain the barrier's elevation relative to a rising sea level (i.e. a stabilizing feedback tends to maintain a barrier's elevation above sea level). The mitigation and recovery decisions humans make—for reasons that are very reasonable from a short-term perspective—have the unintended effect of lowering the barrier's elevation relative to a rising sea level. Lower elevations tend to amplify the future risks of 'nuisance' flooding and of severe overwash events. Thus, we need to address couplings between human and natural processes, and between processes occurring over different time scales (from event to decadal), to both understand how the system works and to inform decision making that could balance short term needs and longer-term sustainability.