University-Government Collaboration to Enhance Coastal Resilience: The Rationale for a Trans-disciplinary Community Initiative

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Abstract
A community science program is needed to facilitate the collaborative development of models for forecasting the key factors that will impact coastal systems and the resilience of coastal communities over the next few decades. The program should enable innovative enhancements of decision-making utilizing model results. It must integrate natural and social sciences and involve academia, federal agencies, local and state officials and nongovernmental organizations. The scientific community at large can initiate and evolve a network of interdisciplinary scientists and supporting cyber-infrastructure with emphasis on complex coastal systems. Model projections can support local government officials in making resilience assessments to plan for more effective humanitarian assistance by interagency partners and help to identify the most vulnerable communities, environments, and facilities. The integrative methodologies for planning should utilize expert advice, field data and a range of computer models, including probabilistic analyses, physics-based numerical models, socioeconomic models and complex systems models. Science-based and scenario-driven workshops enable scientists and stakeholders with diverse backgrounds to collaborate effectively. The most important outcome of this initiative must be: viable long-range resilience programs that enable continually evolving adaptive management strategies underpinned by advanced numerical modeling.

1. Introduction

The academic community, collaborating with federal agencies and state and local entities, can play a pivotal role in facilitating the integration of natural and social sciences in order to better assess the vulnerability and resilience of coastal systems subject to changing threats from rising seas, increased storm frequency and intensity, evolving societal pressures and demographics, land loss, altered river discharge and water quality degradation. Haidvogel et al. (2013) among others have emphasized the need for integrating social and natural sciences in environmental forecasting programs. Dearing et al. (2014) articulate regional-scale social-ecological interdependence. The overall goal of the envisioned community effort should be to integrate social and natural sciences to assist planning and risk assessment of coastal communities threatened by both long-term and event-driven (e.g., by severe storms) inundation, land loss, water quality degradation and resulting risks to human health and safety as well as declines in industries such as tourism, fisheries, agriculture and shipping. A long-range vision of such a program is centered on the creation of a virtual cyber domain that enables multi-institutional teams of numerical modelers from National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers, Navy, Department of
Homeland Security, Bureau of Safety and Environmental Enforcement, and U.S. and foreign Universities to work together to model coastal threats and community, ecosystem and infrastructural responses to future scenarios of environmental and socioeconomic change.

A community science program is needed to guide development of models for forecasting the key factors that will impact coastal systems and the resilience of coastal communities over the next few decades and to assess how model results can improve decision-making. Once models have proven their reliability over and over in real-world events and have undergone rigorous testing, inter comparisons and refinements by way of collaborative testbed and proving-ground programs, they can no longer be ignored by governmental leaders and emergency managers, as they were in the days and hours before Hurricane Katrina made landfall in coastal Louisiana in 2005. But the scientific community at large must nurture the essential enlightenment of leaders via careful and straightforward articulation of scientific evidence and predictions.

As a first step and to identify the priorities, science requirements, and long-term goals, the Southeastern Universities Research Association (SURA) Coastal and Environmental Research Committee (CERC), brought together a diverse community of natural and social scientists from academia, government and Non-Governmental Organizations (NGOs) in a workshop on Understanding and Modeling Risk and Resilience in Complex Coastal Systems held in Washington, D.C. on October 29 & 30, 2014 (SURA-CERC, 2014). SURA is a consortium of 63 universities with several standing committees. The consensus from the workshop was that a consortium to facilitate collaborations among an extended and distributed community of interdisciplinary modelers and researchers concerned with coastal resilience representing numerous universities, federal, state and local agencies and non-governmental organizations is urgently needed. The envisioned consortium could be modified from the examples of the University Corporation for Atmospheric Research (UCAR), the International Geosphere-Biosphere Program (IGBP) or other non-profit consortia. A rationale for the creation of such a consortium is set out in what follows.

2. Resilience

“Resilience is the capacity of a system, be it an individual, a forest, a city or an economy to deal with change and continue to develop” (Stockholm Resilience Centre, 2015). According to a recent National Academies report on disaster resilience, (National Academies 2012. Disaster Resilience – A National Imperative ) “Resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.” Resilience involves the ability to adapt to constantly changing environmental, economic, and social stressors. It does not imply constancy, stasis or resistance to change. It is the capacity to continually change and adapt yet remain viable. Humans and nature are interdependent. According to the Stockholm Resilience Centre: “Resilience thinking embraces learning, diversity and above all the belief that humans and nature are strongly coupled to the point that they should be conceived as one social-ecological system”. Low risk is not necessarily requisite for
high resilience but risk and resilience should both be considered in planning future mitigation strategies. Coastal risk assessment is considered in detail in a recent NRC report (National Research Council, 2014a). Considering the complex interdependence of many factors, community resilience and ecosystem resilience must be considered together, not as separate problems. Furthermore, since the built infrastructure and related services are integral components of communities, infrastructure resilience must be considered in relation to both communities and ecosystems.

For natural ecosystems, such as wetlands, biodiversity is a source of enhanced resilience. Similarly, economic diversity probably results in increased community diversity. One well-known vulnerability index considers vulnerability to environmental hazards (Cutter, 1996). The U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC) is developing a tiered set of coastal resilience metrics that integrate engineering, environmental and community resilience (Rosati, 2014; Rosati et al., 2015). Rosati et al., (2015) describe expert elicitation, data driven, and tiered methods to quantify resilience. Expert elicitation is somewhat subjective while the data-driven methods rely on a combination of historical data and numerical modeling. The USACE’s approach considers preparation, resistance, recovery, and adaptation depending on factors such as need, time, space, and available funding. The three-tiered approach includes expert elicitation, field data and simple models, and rigorous assessment based on probabilistic analyses (Schultz et al. 2012). An important aspect of any viable long-range resilience program is that it must enable continually evolving adaptive management strategies underpinned by advanced numerical modeling. The USACE has provided extensive guidance for engineering responses to sea level rise including regionally specific estimates of change (USACE, 2014).

3. Initial Steps Toward Launching a Collaborative Program

Formulating a comprehensive plan for an enduring coastal resilience program can begin with determining areas where interdisciplinary synergies can be most readily applied, facilitating the infrastructural advances that are needed to accommodate future modeling and preparing a research plan for moving forward as a community. The scientific community at large can initiate and evolve a network of interdisciplinary scientists and supporting cyber-infrastructure with emphasis on complex coastal systems. Three crucial steps in this process include the following:

Step 1: Articulating the interconnections of socio-ecological systems and identifying the societal, legal, biophysical and biogeochemical criteria needed to model resilience in specific coastal regions.

- Refine understanding of interconnections of human and natural coastal processes.
- Advance understanding of the linkages between regional and ocean systems and scale-dependent inter-connections among societal, biophysical and biogeochemical factors.
• Develop criteria for assessing changes in ecosystem services and the impacts that these changes may have on rural and urban socioeconomic systems.
• Following the IGBP example, develop an analytical framework that is relevant to policy and decision-making at different levels and takes account of legal issues and constraints.

**Step 2: Identifying the systems science requirements for future coastal risk and resilience programs.**

• Catalyze interdisciplinary collaborations.
• Prioritize coastal threats (by region).
• Identify well-defined, integrated research questions and the required modeling, analysis and visualization products to address these questions.
• Identify and prioritize legal factors that may impact community resilience or vulnerability.
• Assess and refine social resilience indices as they pertain to both urban and rural coastal communities.
• Develop feasible data management structures for trans-disciplinary integration and communication.

**Step 3: Creating an accessible and extensible cyber infrastructure for cross-disciplinary communication and collaboration**

• Identify design criteria for a collaborative web portal for cross-disciplinary communication.
• Identify the search tools needed to effectively access existing data sets and model outputs.
• Develop a cyber template(s) to enable social and natural scientists, managers and legal scholars to share information in mutually understandable formats.
• Define the needs for more effective data and model output visualization.

4. **Modeling Storms, Chronic Changes and Alternative Futures**

Predictive models will necessarily underpin our ability to plan future adaptive strategies on decadal time scales. Event-scale forecasts will likely continue to depend on operational agencies such as National Weather Service (NWS) and National Hurricane Center (NHC) but improved tools from the appropriate collaboration-facilitating consortium can help to make those forecasts more reliable and relevant. At both long-range and event time scales, we should expect advances to be made progressively not only in modeling specific phenomena such as storm surges and demographic shifts but also in linking models and model outputs in ways that highlight feedbacks and non-linear connections. These will be complex systems
models and the modelers will very likely need access to high performance computing resources. For all of the modeling activities, agreed upon sets of standards for the models as well as the observational data used to assess the models will be essential. A key role for the facilitating “Enterprise” or Consortium will not be to execute models but to provide the virtual environment within which modelers and non-modeling scholars from different disciplines can interconnect. Quite simply, coastal systems science must involve bringing together different components of the system and integrating them.

Recent collaborative research projects conducted by investigators from different disciplines in the natural sciences have successfully created new conceptual, theoretical, methodological, and translational innovations that address complex coastal problems by integration. With funding from NOAA’s U.S. Integrated Ocean Observing System Program (IOOS®), SURA has facilitated strategic collaborations to build and guide the Coastal and Ocean Modeling Testbed (COMT; Luetich et al. 2013). The resulting COMT is now one of 11 official NOAA testbeds. The overarching goal of the COMT is to accelerate the transfer of research results to improve operational coastal ocean modeling and forecasting skill. SURA has advanced the COMT to evaluate the readiness of coastal and marine forecasts of low dissolved oxygen, flooding from storm surge and wave conditions. The models tested, compared and refined during the first three years of COMT are summarized as follows:

a. Inundation, Surge and Waves- ADCIRC (Luetich et al. 1992; Dietrich et al. 2010); FVCOM (Chen et al., 2003); SELFE (Zhang and Baptista, 2008); SLOSH (Jelesnianski et al. 1992); SWAN (Booij et al. 1999; Zijlema, 2010); WWMII (Roland et al., 2009); WAVEWATCHIII (Tolman, 2009).

b. Shelf Hypoxia- ROMS (Haidvogel et al. 2008; Fennel et al. 2011); FVCOM (Chen et al. 2003); NCOM (Ko et al. 2008); HYCOM (Prasad and Hogan, 2007); NGOM-POM (Oey, 1996; Lanerole and Patchen, 2011).

c. Estuarine Hypoxia-Chesapeake Bay ROMS (Xu et al. 2011; Scully, 2013); Chesapeake Bay Operational Forecast System (Lanerolle et al. 2011); EFDC (Hong and Shen, 2012); CH3D-ICM (Cerco et al. 2010); 1-term DO model (Scully, 2013).

However, the COMT has not yet been extended to include social science or economic models.

Beyond obvious organizational and governance challenges, effective interdisciplinary integration of models will require the convergence of an extensive and uncommonly diverse suite of scientific, demographic, economic, legal and cultural data and information. As the program matures, the challenges of “big data” and its management will necessitate the provision of sophisticated cyber services to ensure that the information is accessible and understandable to users with a wide range of backgrounds. Existing models of inundation, water quality, coastal erosion, ecosystem dynamics and related impacts will be needed in future assessments of resilience. However, while physical and ecosystem modelers are predicting natural threats, the affected communities are also changing. The ways their economies evolve changes the community’s risk. Changes in the age of the population and in its cultural heritage also
change the risk factors. One challenge to social scientists: help predict what socio-economic changes are coming in the next 10-20 years. Questions such as: “How will the risk of flooding during an extreme event be exacerbated in various sea level rise scenarios?” will depend on where people with different vulnerabilities are living in the future. Recent advances in detailed modeling of “street-level” flooding in well-mapped neighborhoods (Blumberg et al., 2015) can contribute to answering such questions as can similar advances in modeling the timing of storm surges in relation to tides (Georgas et al., 2014).

The International Geosphere Biosphere Programme (IGBP) has articulated the importance of intersecting social and natural sciences and has evolved a new paradigm that considers human and natural earth processes to be interdependent and to function and change as a complex system (see www.IGBP.net). The idea of complexity is now widely accepted by modelers of dynamic systems involving the non-linear interdependence of multiple processes. The coupling of societal, biogeophysical, biogeochemical and ecological processes constitutes a prominent example of complexity. Over the next few years, advances in our ability to anticipate, plan for and mitigate the impacts of adverse changes in coastal processes and coastal communities will increasingly require not only continued refinements of natural science and social science models but also on development and application of complex systems models (e.g. Janssen, 1998) that account for a hierarchy of interconnections and non-linear feedbacks. To enable such transformational advances, the scientific community should begin by assessing:

• Existing knowledge of human-environment complex system dynamics;
• The ability to model socio-ecological interactions at different scales;
• Relevance of existing models and analyses to policies and management practices;
• The potential impact of legal structures on community resilience to hazards;
• Development and assessment of “social vulnerability indices;”
• The applicability of complexity theories to analyzing interconnectedness of socio-ecological systems and addressing coastal sustainability.

5. A Cyber Infrastructure to Support a Virtual Modeling Community

During the October 29 & 30, 2014 coastal resilience workshop in Washington, D.C., Hans-Peter Plag (Old Dominion University) pointed out the need for Virtual Research Environments to Enable Knowledge Creation in Response to Societal Needs. He advocated the creation of cyber-supported “playing fields” where it is easier to work with others. The infrastructure should be able to help link societal benefits to essential variables. There are numerous cyber tools and toolkits available to help make linkages, provide visualization, archive and retrieve data etc. However, the community needs a tech support network and training in how to utilize the tools. The envisioned coastal resilience consortium (or “collaboratorium”) should help with these technical services. A cyber-infrastructure supported by an independent consortium can provide the playing field for developing, validating, communicating, and generally advancing the
interdisciplinary collaboration between natural and social sciences for modeling risk and resilience in complex coastal systems. The supporting cyber services should include High Performance Computing (HPC) resources for running models, a platform for accessing, sharing and archiving data and model outputs as well as for accessing and sharing open-source model codes, and a catalogue of and access to analysis routines and visualization tools.

An independent community-shared consortium can help the community to take a first step in addressing questions of risk and resilience by facilitating the creation of an open-source base of empirical and numerical model data along with a rigorous set of data standards and an extensible cyber infrastructure for managing, and accessing the necessary information. This will support a combination of discipline-specific and cross-disciplinary numerical modeling, coupling the outputs from physical process models with ecosystem and socioeconomic models, and statistical analyses of socioeconomic factors that might ultimately determine the resilience of communities to expected stressors. In addition, modeling protocols could be extended to enable the potential impacts (positive or negative) of engineering approaches or management decisions to be assessed. Over the course of the next few years, it is possible to accommodate most or all of the cyber needs.

As an example, the ongoing COMT, has had significant success in evolving an appropriate supporting cyber infrastructure. The primary purpose of the COMT cyber infrastructure has been to develop a unified search, access, analysis and visualization environment that allows scientists to run and compare different models with each other and with observational data (Luetich et al. 2013). Among other things, this has involved maintaining a web site, a data archive, providing high-performance computing resources, and custom code to perform tasks such as skill assessment and format conversions.

6. The Challenges of Engaging Academia in Multi-institutional Collaboration

Participants at the SURA coastal resilience workshop in October 2014, agreed with the urgency of adopting far-reaching interdisciplinary approaches to modeling future risks and resilience of socio-eco-techno-logical systems, as articulated by the IGBP and the Stockholm Resilience Centre. The complex interdependence among human communities, coastal ecosystems, climate and ocean physics is accepted as axiomatic by the vast majority of the scientific community. However, many universities are not up to the task of true interdisciplinary research. Part of the problem relates to the accreditation system and its discipline-specific standards. This impedes interdisciplinary work at many traditional universities. Multi-discipline papers with many authors are not really valued and young untenured faculty who engage in too much interdisciplinary work may be denied tenure. The discipline-based distribution of faculty on campuses is also a discouraging factor: social scientists and natural scientists may be based on opposite sides of large campuses or even on different campuses of multi campus state universities. The need for new approaches to facilitating interdisciplinary research and education was highlighted in a recent National Research Council (NRC) report on “Convergence”
As emphasized in this NRC report, “Convergence” is intended to imply integration of knowledge, tools and ways of thinking from several disciplines. It is not simply the “patching together” of results from one single discipline as an input to another discipline.

Centers and institutes are one way to promote the melding of disciplines and are not as constrained as traditional departments. “Enterprise” entities that promote interdisciplinary synergies but also are designed to evolve as science and needs change may be better models. In a keynote presentation at the SURA Board of Trustees meeting in Washington DC on November 7, 2014, Ed Seidel, Director, National Center for Supercomputing Applications, proposed the notion of a Center for Research, Education and Innovation (CREI). The “CREI” or “enterprise” can facilitate the inclusion of industry and governmental entities along with academics. These Enterprises would be theme based and may be virtual as opposed to centrally located. Climate change is an example of a focus as is coastal resilience. The enterprise themes can change or adapt as new needs and understandings unfold. The world is likely to be very different in 2050, as will the missions of universities that remain relevant.

7. Enhancing the Resilience of Vulnerable Communities

One urgent aspect of effectively intersecting social and natural science in this program is to anticipate and better plan for the future impacts of climate change on low-income communities living in flood-prone areas. The tragedy that unfolded in 2005 when Hurricane Katrina made landfall along the Louisiana and Mississippi Gulf Coast, was most acute in the flooded low lying and low-income neighborhoods of New Orleans, particularly the Ninth Ward (Fig. 1). Nearly 2,000 people died and hundreds of thousands were displaced. The most severely affected African-American population has still not fully recovered ten years later. Notably, President Barack Obama marked the 10th anniversary of Hurricane Katrina on August 27, 2015 with a speech in the Lower Ninth Ward that commended work that residents, local, state, and the federal government have done to help New Orleans rebound.

As sea levels rise, low-lying vulnerable urban areas throughout the world will be more frequently flooded by storms. Wealthy populations will migrate to higher ground and the value of these higher elevation properties will escalate. Low-income families will be forced to move into higher density areas or to low-lying, flood-prone areas. Frequent street flooding of low-lying neighborhoods can paralyze traffic, sewers can be flooded, drinking water may be contaminated and water-borne pathogens may be spread throughout neighborhoods. And, as was the case in New Orleans in the days following Katrina, extensive inundation of neighborhoods can impede rescue operations following disasters.

Model projections can support local government officials in making resilience assessments to plan for more effective humanitarian assistance by interagency partners and help to identify the most vulnerable communities, environments, and facilities. The coastal scientific community must consider what kinds of data, model predictions,
management policies and governmental investment strategies might prevent future dire circumstances similar to those faced by low income residents of New Orleans in 2005. It is now possible to predict “street by street” flooding probabilities utilizing detailed topographic data and projected sea level rise as well model predictions of future demographics. Human health must also be considered such as the feasibility of immunizations against water-borne diseases. What kind of protective structures such as sea walls or dikes might help protect low-lying neighborhoods if the “triaged” allocation of limited resources is more favorable to low income communities? What are some of the ways that the academic community can assist governmental agencies at local, state and federal levels in making long-range plans that serve all residents?

Figure 1. The Lower Ninth Ward gained national attention owing to the magnitude of destruction from Hurricane Katrina. Bounded on the south by the Mississippi River, the Ninth Ward is geographically the largest of the seventeen Wards of New Orleans. It consists of the entire area within New Orleans downriver of the Industrial Canal.

Today, the NHC grades hurricanes on a scale of 1 to 5 (the Saffir-Simpson scale, which indexes relative wind stress and the potential wind damage to structures). But these levels apply only to wind intensity and likely impacts on structures and do not distinguish among the contrasting impacts that these storms may have on human communities, ecosystems, water quality or infrastructure other than buildings. For example, a Category 3 hurricane can be devastating to a low lying coastal city subject to widespread inundation by storm surge, with a fragile transportation infrastructure, a delicate coastal ecosystem and a poor community with low societal and economic resilience. The same storm may be but a short-lived nuisance to a more affluent community on high ground, surrounded by robust infrastructure and a healthy, resilient coastal ecosystem. In these two cases, the impacts of that Category 3 storm will be dramatically different. Similarly, the decadal impacts of the alternative climate change scenarios will vary with regional and local circumstances. If community impacts were to be gaged on the levels of 1 (low impact) to 5 (severe impact) the storm impact in the first case might be level 5 but in the second case the impact might be a modest level 2 or 3.
Future decisions as to how to triage the distribution of limited mitigation resources, post-storm recovery assets and disaster relief should be prioritized on the basis of total predicted storm impact, not simply storm intensity and stress on structures. At present, the impacts are assessed after the fact but are not rigorously anticipated in advance. Defining objective and meaningful indices of such impacts must precede the eventual application to real time or foreshadowed events. The Hazus Program of the Federal Emergency Management Agency (FEMA) represents the present “state of the art” in meeting these needs and allows emergency managers, insurers and the public to estimate the economic and social losses from hurricanes and floods (www.fema.gov/HAZUS). However, many aspects of this program are regionally specific and have not been implemented for many coastal communities. Hopefully, in the future, the academic community will be able to contribute to Hazus in meaningful ways via the envisioned coastal resilience consortium.

8. Outreach to Policy Makers and Politicians

As Hurricane Katrina bore down on New Orleans in 2005, numerical models, were predicting high storm surges and waves for Coastal Louisiana. Data buoys and integrated observing systems such as Wave-Current-Surge Information System for Coastal Louisiana in the Gulf of Mexico verified wave predictions. Those predictions were readily accessible in real time on the Internet in the form of color-coded animations and numerical data, but they were largely ignored by local, State and Federal leaders as well as by many emergency managers. In 2015, long-range scientific projections of climate-related phenomena and their impacts continue to be widely denied by many politicians and decision makers. Fortunately, in 2012, short-term wind, storm surge and wave forecasts were heeded as Super Storm Sandy moved up the U.S. East Coast and approached New York Bight and this undoubtedly saved many lives. But substantial improvements in communication and trust are still needed.

The scientific community at large must nurture the enlightenment of politicians and decision makers. This may be the largest challenge of all, but it is imperative that the scientific community work diligently to persuade emergency managers and leaders at all governmental levels to trust science-based model predictions. This will require careful and well-articulated, non-jargonized communication over a prolonged period combined with clear demonstrations - over and over and over - that numerical models really work and are not a hoax. So the question is: How do we do that? One obvious way is to get to know the leaders and gain their trust through regular one on one visits, open forums involving bi-directional exchanges but not “lectures”, and clear demonstrations of mutual respect among academics, local, state and federal government officials and politicians. And, of course, patience and persistence are essential. The envisioned “Coastal Resilience Consortium” should be able to greatly broaden the scope of outreach to officials by developing an accessible and extensible web site that serves clear graphical and textual explanations of long-and short-term model results.
9. Potential Beneficiaries of the Initiative

This initiative will directly contribute to NOAA’s stated goal of Resilient Coastal Communities and Economies, but will require a thoughtful, and possibly lengthy, process involving an uncommonly diverse community of social and natural scientists, engineers, legal scholars, health scientists, stakeholders and decision makers. For the ongoing COMT program, the target beneficiaries have been operational agencies (particularly NOAA) and the main product has been the transfer of methodologies and models from research to operations. For the proposed consortium, the potential stakeholders may include the State Sea Grant Programs, re-insurers, county governments, state governments, health workers, emergency managers, resource managers, FEMA, NGOs such as Nature Conservancy and the Sierra Club; educators, the general public-and operational agencies (particularly NOAA and U.S. Army Corps of Engineers). Although the specific needs of each of these stakeholders differ, the universal nature of the most urgent questions should enable the facilitating consortium to focus firstly on problems that are important to a broad range of beneficiaries. In some cases, however, it may be necessary to concentrate on a subset of stakeholders who have a narrow definition of “acceptable benefits” that communities actually value. Risk reduction is one such benefit.

10. The Next Steps

a. Workshops

As the coastal science community goes forward toward the creation of a Consortium for Coastal Resilience (or similar entity), there needs to be a clear focus on the nature of the connections and methods we hope to foster. At least in the beginning, we should not dwell too deeply on the generalities and generic scenarios. Instead, more progress will probably be made if we identify a few geographically specific cases and explore ways that we might collaborate to address, or anticipate, future system responses to plausible scenarios of future changes in natural and social conditions at the selected location. The scenario might be driven in part by climate change predictions (e.g., from National Center for Atmospheric Research) and in part by statistical projections of future demographics and economics. The aim would not be to actually solve a problem but rather to explore how to collaborate and what methodologies and processes would be needed.

At the invitation of the Environmental Planning and Community Resilience Division, Broward County, Florida, the second workshop will be held in Broward County during a time of “King Tides” (October 26, 27 & 28, 2015) beginning with visits to several sites subject to frequent inundation (e.g., Fig. 2). The mean range of the mixed, mainly diurnal tide for Broward County is 0.62 m and increases to approximately 1.2 m during “King Tides”(NOAA, 2015). Several other non-tidal effects contribute to the coastal flooding. For Florida as a whole, the rise in mean sea level over the past century has been around 21 cm (Maul, 2015), but this rate is likely accelerating due the steric effects of warming seas. The USACE (2011, 2013) estimates that by 2030 sea level will be roughly 18 cm higher than at present while Boon and Mitchell (2015) conclude that by 2050 mean sea level in South Florida could be on the order of 50 cm higher. These
estimates do not take account of any unexpected glacial melting or calving in Antarctica or Greenland. Regional contributions to non-tidal water levels include long-term changes in global mean sea level, atmospheric-pressure and wind induced changes, fluctuations in offshore Ekman transport caused by fluctuations in Gulf Stream transport intensity, storm surge, wave-induced set up, and land sinking.

Figure 2. The historic Stranahan House in Fort Lauderdale is sited along the New River, which originates in the Everglades and flows east (Credit Environmental Protection and Growth Management Department, Broward County).

The workshop plan is to create a step-by-step process to help workshop attendees visualize the issues and then define courses of action for challenging topics addressed by Broward County government personnel. Collaborative teams will be multidisciplinary and have appropriate sets of cyber tools to develop courses of action. During the scenario, participants will apply research, communication and advocacy skills to improve Broward County’s approach to coastal resilience. The scenario, challenge questions, background information, and several applicable extended abstracts and technical posters are available online at http://scholarworks.uno.edu/resilience/2015/. The scenario-based analysis allows participants to estimate the impact of different factors, with the intent of getting an objective sense of resilience. Follow-up workshops through 2018 are planned to focus on the following coastal regions:

Middle Atlantic Bight and Chesapeake Bay – Scenarios include environmental conditions represented by low-lying barrier islands, low-lying coastal plains, estuaries, and cuspatte forelands fronted by wide, low gradient continental shelf and subject to rising sea levels, tropical and extra-tropical storms, high storm surges and frequent beach erosion. Water quality is also an important issue to be characterized. Among the societal factors for scenario development are coastal urban and rural communities with a mix of affluent and low-income populations. A diverse economic base includes military bases, tourism, commercial fisheries, aquaculture, agriculture, universities, technology and business.

Northern Gulf of Mexico and Mississippi Delta – Representative environmental conditions for scenario development include a major deltaic coast which experiences
a diurnal microtidal regime and relatively low wave energy except during episodic storms and hurricanes. Environmental characterizations include natural deltaic processes of growth and retreat as a result of sediment deposition from the Mississippi river change rapidly in response to hurricanes, sea level rise, and reduction of new river sediment supply by levees and river mouth jetties. Sea level rise and engineering works combine to reduce the Mississippi river’s flow into certain areas impacting the natural land-building power of the river. Increased salt-water intrusion from the Gulf of Mexico into freshwater wetlands has negative impacts on freshwater ecosystems. Societal factors for scenario development include coastal urban and rural communities with a mix of affluent and low-income populations. Louisiana’s economy relies heavily on tourism, recreational activities, and the oil and gas industry. A diverse economic base includes military installations, tourism, commercial fisheries, aquaculture, agriculture, universities, shipping and ports, technology and business.

South Atlantic Bight – Natural environmental conditions for a science-based scenario include low-lying barrier islands, low-lying coastal plains, estuaries, and tidal marshlands subject to a mesotidal regime, rising sea levels, tropical and extratropical storms, high storm surges and frequent beach erosion. Water quality is also an important issue. Coastal urban and rural communities are represented by a mix of affluent and low-income populations. The scenario distinguishes among a variety of regional socioeconomic characteristics where a strong economy relies heavily on tourism, recreational activities, and commercial fishing. A diverse economic base includes military training facilities and ports, tourism, commercial fisheries, aquaculture, agriculture, universities, shipping and ports, technology and business.

The future workshops are intended to help make the regional coastal communities safer and more resilient to hazards. The workshops will bring together organizations from all sectors and foster partnerships for community collaboration. The scenario-driven workshops enable natural and social scientists to collaborate across disciplinary “boundaries”, share best practices, and adopt resilience measurements that are appropriate to their specific coastal realms. The major goals and objectives are to:

- Reduce the impact of coastal hazards to coastal communities, ecosystems and economies.
- Improve the regional capacity to identify, plan, and respond to natural hazards.
- Develop better communication, awareness, and understanding of coastal hazards.
- Foster community resilience through outreach, education and innovative product development.
- Allow stakeholders to develop a common understanding and best practices to identify resilience metrics appropriate for their region.

b. Creating an Advisory Committee

Over the long term, the coastal research community should be encouraged (and supported) to work together with agencies toward the development of plans or actions that improve preparedness, and/or promote recovery and/or adaptation within multiple
coastal jurisdictions or locations throughout the United States coastal zones. As one forthcoming example of such preparedness plans, The National Institute of Standards and Technology (NIST, 2015) is expected to issue its *Community Resilience Planning Guide for Buildings and Infrastructure Systems* sometime in the fall of 2015. To ensure that the proposed consortium is well-informed, rigorous and objective, a Science and Requirements Advisory Committee (SRAC), composed of well-established and non-conflicted experts, should be established to provide advisory opinions, analyses, data standards and collaborative integration of coastal resilience science and technology in different regions of the U.S. The SRAC can lead the evolution of a research plan focused on how science could enable the United States' to anticipate and address the consequences of changing climates, environments, sea levels and coastal demographics and on how separate research teams can strengthen each other through independently-facilitated collaboration. The trans-disciplinary nature of the SRAC can benefit three important issues common to existing resilience programs: (1) prioritizing funding; (2) highlighting new approaches to stimulating science, technology, and innovation; and (3) communication of data, model output and methodologies among diverse disciplines and between academia and operational agencies. This approach also highlights how federal, state, and local governments can draw on university resources to prepare, resist, recover, and adapt to natural and man-made disturbances.

**c. Defining Metrics for Success**

An initial task of the SRAC should be to work with the scientific community and stakeholders to define an appropriate and realistic set of performance metrics by which to gage the progress and success of the Consortium and of the workshop series. These metrics, and the associated sets of data and model standards, will be critical to the acceptance of future model predictions by government officials and the general public and will guide the progressive evolution of the Consortium. An important initial metric may be to quantify the degree to which a consensus is achieved among participating scientists and stakeholders with regard to strategies for moving forward on the decadal time scale and how best to integrate across disciplines. Measures of effective collaboration may include the production of interdisciplinary, multi-authored white papers, publications, proposals and disaster response plans. The extent to which the collaborative products are adopted by, or influence, operational agencies is another important metric as are improvements in the ability of the community to gain the trust of politicians and officials. As the Consortium matures and supports innovative modeling and testbed activities, skill assessments of new integrative complexity and social science models may be added to the list of metrics.

**11. Conclusions**

Impermanence and dynamic change have always characterized coastal environments and efforts by engineers, managers or officials to enforce stasis are destined to fail over the long term. Adaptive strategies are preferable. Climate change, sea level rise, ecosystem evolution, hydrologic changes in river discharge to the coasts and changes in the intensity and duration of storms and attendant coastal erosion are likely to accelerate the alteration of natural coastal realms over the decades ahead. In
concert with these natural changes, the socioeconomic environment that underpins human coastal communities is also impermanent and dynamic. The interplay between natural and socioeconomic processes in the “Anthropocene” (e.g. www.IGBP.net) is already giving rise to suites of highly complex and non-linear feedbacks, many of which are counter intuitive. In some cases, the outcomes of these feedbacks may be beneficial, but, for the most part, they are detrimental and, sometimes, have the potential for catastrophe as we saw in New Orleans when hurricane Katrina made landfall.

Improved abilities to predict, communicate, mitigate and respond to the outcomes of future coastal processes, gradual as well as abrupt, on both long-term and event time scales are essential to the welfare of coastal communities and to the sustainability of coastal ecosystems and built infrastructures. The distributed virtual world of “big data” and high performance computing resources offers the potential for the scientific community to make giant strides in developing these essential abilities. But only as a community that embraces the extended brain trust of all relevant disciplines and draws from many universities, federal agencies, NGOs and industry. Ideally, this distributed “Collaboratorium” should not be confined to U.S. institutions but may include international talent willing to participate in an “open source” and “open access” activity governed by a rigorous set of data and coding standards and rules of engagement. No single agency, university or organization will ever have the breadth or depth of capability that exists within the globally distributed scientific community at large. Similarly, no single agency, foundation or industry should be expected to fund the consortium. Instead, a competitive, multi-agency model, such as the National Ocean Partnership Program (NOPP) should be explored initially but with the hope of growing the effort over time through foundation and private sector support. The future must involve the broadest and most extensive collaboration possible. The consortium envisioned here should enable, encourage and guide the needed collaboration.

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13. Further Reading


