Understanding and Modeling Risk and Resilience in Complex Coastal Systems (final workshop report)

Coastal and Environmental Research Committee (CERC), Southeastern Universities Research Association, Washington, D.C.

Understanding and Modeling Risk and Resilience in Complex Coastal Systems

Final Report
from a SURA-led Workshop held October 29 & 30, 2014
at SURA Headquarters, 1201 New York Ave. NW. Washington, DC

Sponsored by the
SURA Coastal and Environmental Research Committee (CERC)
Chris D'Elia, Chair

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Preface

At its Fall Meeting in November 2013, SURA's Coastal and Environmental Research Committee (CERC) identified a need for a new initiative focused on 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. The overall ***goal*** of the proposed program is ***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 economic declines in industries such as tourism, fisheries and shipping.*** At subsequent CERC meetings in February and March 2014 it was concluded that, as a first step in launching this initiative, SURA should bring together a diverse community of natural and social scientists from academia, government and NGOs to identify the priorities, science requirements, cyber support needs and long term goals of such an initiative. To that end, a workshop was held in Washington, D.C. on October 29 & 30, 2014. The immediate goals of the workshop were ***to identify the most critical issues in assessing future risks, vulnerabilities and resilience of complex coastal systems that involve interdependent social, legal, biogeophysical and biogeochemical factors.*** The desired outcomes included:

1. **Creation of** a ***SURA Consortium for Coastal and Environmental Resilience***.
2. **Establishment of a major new multiinstitutional program.**
3. **A competitive funding proposal by a multi- institutional team.**
4. **Defining and establishing a user group base that will benefit from products.**

The workshop agenda can be found in Appendix 1. Appendix 2 lists the workshop attendees along with their affiliations and areas of expertise. Some unedited summary notes from the workshop are in Appendix 3. Appendix 4 lists the responses of workshop participants to the question: "What is one thing SURA should do next?" In what follows in this report, we attempt to synthesize the discussions that took place and present the conceptual foundation and tentative next steps for the new SURA initiative.

1. Introduction

The importance of including the social sciences in future environmental forecasting programs was recently emphasized in a special issue of *Oceanography* synthesizing the U.S. Globec Program (Haidvogel *et al.*, 2013). The International Geosphere Biosphere Programme (IGBP)[1] has recently emphasized the mutual interdependence of human (i.e., socioeconomic) and natural systems (e.g., ecosystems, biophysical and biogeochemical systems). Social-ecological interdependence, particularly at regional scales, is articulated by Dearing et al., (2014). In mid January 2014, the

[1] IGBP, Available online. URL: http://www.igbp.net/. Accessed February 9, 2015.

IGBP, in collaboration with the International Human Dimensions Program (IHDP), held a workshop in Washington, DC focused on the global dynamics of the human-natural complex system. Within its definition of "resilience" the Stockholm Resilience Centre emphasizes the co-dependence of natural and social systems as follows: "**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"** (see http://www.stockholmresilience.org/21/research/what-is-resilience.html)**.**

Rigorous study of coastal and environmental phenomena has been instrumental in expanding the understanding of coastal and atmospheric processes leading to better predictive tools and has also informed the development of techniques for resilient engineering and public policies. Generally, research to develop better understandings of physical and ecological processes has been conducted with little regard to the social, behavioral, and economic connections. These connections are bidirectional and must be treated accordingly. Socioeconomic research has traditionally been performed separately by an entirely different community. Such reductionist practices are inefficient in identifying practical solutions to real problems and diminish the relevance of research in this important area. The need for cross-fertilization and real collaboration among scientific communities is urgent and essential.

Social science research contributes to understanding the impact of weather and climate events on individuals, communities and society through the study of social vulnerability. The integration of social science knowledge further enhances natural science models aimed at mitigating the effects of atmospheric phenomena and promoting the adaptive capacity of human and social systems to rebound. An important goal of this interdisciplinary collaboration is the development of strategies to enhance ecosystems without exacerbating social vulnerability.

Considering the earth system as a whole, the 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.*** The idea of complexity is now widely accepted by modelers of dynamic systems involving the non-linear interdependence of multiple processes (e.g., Nicolis and Prigogine, 1989). The mathematician Jules Henri Poincaré (1854-1912), in 1899, originally articulated the concept of dynamical systems as systems that can be described by coupled non-linear equations. The global coupling of societal, biogeophysical, biogeochemical and ecological processes constitutes a prominent example of complexity. During his keynote remarks at the SURA workshop, James Syvitski, Chair of the IGBP, pointed out their concern with how the earth operates as a system and how humans are changing it. The IGBP's *Future Earth* project is facilitating research for global sustainability.

2. What is Resilience and What are its Metrics?

There was considerable discussion about how resilience is defined and measured. With respect to the definition, there was a general consensus that we should adopt the definition of the Stockholm Resilience Centre (SRC), which is stated as follows: ***"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).** In adopting this definition, it was acknowledged that there are many other, but closely related, definitions. For example, the American Society of Civil Engineers defines resilience as "*the capability to mitigate against significant all-hazards risks and incidents and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security."* Or, 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."*

Consistent with the SRC definition, the consensus of workshop discussants was that 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**. According to the Stockholm Resilience Centre, "-- there are virtually no ecosystems that are not shaped by people and no people without the need for ecosystems and the services they provide." With that in mind, community resilience and ecosystem resilience should probably 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. There was considerable discussion during breakouts and plenary sessions contrasting risk vs. resilience. It was generally agreed that low risk is not necessarily requisite for high resilience but that 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)

Resilience and stability are closely related. Dynamic stability does not imply stasis. A system can be dynamically stable but we as communities often inhibit the natural stabilizing processes and this can create vulnerability to sudden perturbations. Humans create a dis-equilibrium, which can result in the failure of their infrastructure. This does not result in a resilient community. Louisiana is an example of societal enforcement of disequilibrium. For example, natural resilience of the Mississippi Delta in the geological past involved the annual supply and re-distribution of river sediment. But today, the impoundment of river flow by dams and the confinement of flow by levees and jetties have substantially limited the amount of sediment that is able to nourish the wetlands of coastal Louisiana. In New Orleans the levees have enabled land to be developed but have also put New Orleans in an unnatural and, in the long term, unsustainable- situation: the city is below sea level and sinking as sea level rises. The time scale is crucial in assessing resilience. For example, strategies for increasing

resilience at short-term or event scales (i.e., as in the case of New Orleans) can have deleterious consequences for long-term resilience.

Agreeing on acceptable quantitative metrics of resilience proved more problematic and remains a challenge for future deliberations. It was noted that some metrics already exist for specific subsystems. 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). Dr. Julie Rosati of The U.S. Army Corps of Engineers, Engineer Research and Development Center (ERDC) has recently been working on the development of a coastal resilience metric that includes engineering, environmental, and community resilience. The ERDC approach considers resilience to involve four basic stages: preparation, resistance, recovery, and adaptation.

Some skepticism was expressed at the SURA workshop about the reliability or relevance of some of the composite indices that attempt to combine multiple factors into a "single number" metric of resilience. Since many of these factors are co-dependent and the interconnections are sometimes non-linear, metrics involving simple additive contributions are likely to be inadequate. For the future, a better approach may be to utilize complex systems models that take account of interactions among multiple factors. SURA can help to facilitate such an approach.

3. What are the Challenges to and Science Requirements for Advancing Interdisciplinary Assessments of Coastal Risk and Resilience?

Workshop participants 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 SRC. 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 holds universities back from interdisciplinary work. 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 keynote presentation at the SURA Board of Trustees meeting in Washington D.C. on November 7, 2014 by Ed Seidel, Director, National Center for Supercomputing Applications[2]. Seidel referred to a recent NRC report on "Convergence" (National Research Council, 2014b). As emphasized in this

[2] National Center for Supercomputer Application, Available online. URL: http://www.ncsa.illinois.edu/. Accessed February 9, 2015.

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. They may form "tribes" of like-minded individuals. "Enterprise" entities that promote interdisciplinary synergies but also are designed to evolve as science and needs change may be better models. Alternatively, the enterprise may be a ***Center for Research, Education and Innovation (CREI)*** a term proposed by Ed Seidel in his presentation to the SURA Board of Trustees. 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 an enterprise focus as is coastal resilience. What disciplines do you need, and what state partners and local municipalities and politicians? There would not be faculty spots in the enterprise. Faculty could stay in their home departments but they could come and go and the Enterprise could "buy out" portions of their time. The enterprise themes can change; as new needs and understandings unfold, they would adapt. The world is likely to be very different in 2050, as will the missions of universities that remain relevant**. SURA can be the "Coastal Resilience Enterprise" and SURA institutions as well as other institutions could become a part of this "Enterprise". As we explain in the next subsection, SURA proposes the creation of a *Consortium (or* Collaboratorium) *for Coastal and Environmental Resilience*.**

Beyond obvious organizational and governance challenges, effective interdisciplinary integration 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. SURA's existing Coastal Ocean Modeling Testbed (COMT) has been successful in bringing together modelers of physical processes such as coastal inundation and continental shelf and estuarine hypoxia. These same models 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. Answers to 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.

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 the National Weather Service and National Hurricane Center but improved tools from the non-governmental "Enterprise" can help to make those

forecasts more reliable and relevant. At both 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, systems science must involve bringing together different components of the system and integrating them and SURA can help do this.***

4. What Roles Can SURA Play in Facilitating Integration and Supporting the Science Needs for Coastal Resilience?

During her lunchtime remarks at the workshop, Margaret Davidson (NOAA) highlighted some key roles that only a multi-institutional entity like SURA can play. A prominent organizational example for climate modeling is that of the National Center for Atmospheric Research and the Universities Consortium for Atmospheric Research (NCAR/UCAR). Her assessment was that we don't really need an "NCAR" but we need a hub for intellectual awareness; a think tank, an intellectual community of practice. SURA can develop standards and frameworks and enable multiple models, outputs and visualizations. She advocated that SURA could serve as a "Collaboratorium" for Coastal Resilience. This notion is consistent with the idea of the *Coastal Resilience Enterprise* (or *Coastal CREI*) as articulated in breakout discussions the previous day. SURA can and should do this. SURA's overarching hallmark is the ***Science of Collaboration.*** In all of the disciplines which SURA has been and expects to be involved, its prime role has been to facilitate collaborations among numerous, geographically distributed institutions. But SURA could do this best in partnership with other organizations such as the Consortium for Ocean Leadership, the National Sea Grant Program, and/or local government entities.

The overall ***function*** of the proposed "Collaboratorium" would not necessarily be to produce final answers but to provide an interdisciplinary virtual environment and set of services to enable a broad interdisciplinary community to address a shared long-term goal. This ***goal*** will likely evolve with time but may initially 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 economic declines in industries such as tourism, fisheries and shipping.*** The SURA-based enterprise would help to determine areas where interdisciplinary synergies can be most readily applied, facilitate the infrastructural advances that are needed to accommodate future modeling and prepare a research plan for moving forward as a community. The resulting research plan should guide a community science program aimed at developing models for forecasting the key factors that will impact coastal systems and the resilience of coastal communities over the

next few decades and assessing how model results can improve decision-making. Some specific target activities of the "Collaboratorium" may the foci of future workshops.

5. What Cyber Support Services Will be Needed and How can SURA Help to Provide or Facilitate Those Services?

On the second day of the workshop, Hans-Peter Plag and Gary R. Crane facilitated an extensive discussion focused on ideas and concepts leading to the development of a shared information technology cyber infrastructure for distributed data-management and community modeling. Plag 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. SURA could help with these technical services. There seemed to be a general consensus (not unanimous) that a SURA supported cyber-infrastructure to develop 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 would be welcome. SURA's 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.

SURA can help the community to take a first step in addressing questions of risk and resilience by facilitating the creation of a 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 for SURA to accommodate most or all of the cyber needs identified at the workshop. By way of the ongoing COMT, SURA has had significant success in evolving an appropriate supporting cyber infrastructure. While many of the existing cyber services will continue to assist the physical scientists within the proposed interdisciplinary consortium, services will need to be extended significantly to support the social scientists and especially to support an anticipated new generation of complex systems models and their outputs. Complexity science is highly interdisciplinary, and addresses fundamental questions about living, adaptable, changeable systems (Janssen, 1998).

6. Who Would be the Target Beneficiaries of a SURA Consortium for Coastal Resilience?

Throughout the two-day workshop, a frequently repeated question was: ***who are we doing this for?*** We must consider who will be the stakeholders and clients. There was a broad consensus that we could not justify this undertaking just for the benefit of university scientists. 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; educators, the general public- and operational agencies. Although the specific needs of each of these stakeholders differ, the universal nature of the most urgent questions should enable the 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. All agreed that decision makers must have timely and actionable information to guide their response to emergency situations.

7. The Next Steps? A Second Workshop to define a scenario and potential region to test

As we go forward toward the creation of a *Consortium for Coastal Resilience* (or similar entity) we need to have a clear focus on the nature of the connections and methods we hope to foster. It was generally felt that, at least in the beginning, we should not dwell too deeply on the generalities and generic scenarios. Instead, more progress will be made if we identify one or two 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 NCAR) 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 would be needed.

In this exercise, we will attempt to devise problem-focused strategies and innovative solutions that require an integrative approach. We want the outcome to be bigger than the sum of the parts. Innovation should be driven by integration. Ideally, we should strive to carry out this pilot exercise in collaboration with the municipality or county of the selected site, with representatives from the appropriate federal agencies such as FEMA and USACOE, the state Sea Grant program, the insurance industry as well the natural and social scientists who will be building the methodologies. Hence, it would probably be preferable to hold the workshop at the chosen case study site. At the invitation of Dr. Samantha Danchuk of the Environmental Planning & Community

Resilience Division, Broward County, Florida, we are considering holding this follow up workshop in Broward County during October, 2015. The workshop is being planned to occur during the Spring tides following full moon on or about October 27th beginning with a full-day field excursion to visit sites subject to frequent inundation. A preliminary assessment will gage the level of collaboration among social and physical scientists.

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Appendix 1. Workshop Agenda

October 28, 2014

Late Afternoon/Early Evening Arrival Dinner (no host) for those in town

October 29, 2014 (full day)

08:00 **Registration and Breakfast**

08:30 **Welcome:** *Chris D'Elia, SURA Trustee & Chair, SURA Coastal and Environmental Research Committee*

08:45 **Workshop Goals and Background; Introductions**
Don Wright, SURA Director of Coastal and Environmental Research

09:30 **Keynote Presentation – *The Anthropocene and the Birth of Future Earth***
*James Syvitski, Chair, **International Geosphere Biosphere Programme*** **and**
Executive Director, Community Surface Dynamics Modeling System, University of Colorado at Boulder

10:15 Break

10:30 Open Discussion**: Assessing the Vulnerability of Coastal Communities to Climate and Societal Changes. Where are we?** *Moderator: Nancy Targett, Dean and Professor, College of Earth, Ocean and Environment, University of Delaware*

11:30 **Charge to Breakout Groups,** *Don Wright, SURA*
Identifying model criteria, science requirements and Cyber-infrastructure priorities

12:00 Lunch **w/Speaker** – ***Science Under Siege*** *Bob Gagosian, Director, Consortium for Ocean Leadership*

13:00 **Breakout Session: Identifying model criteria, science requirements and cyber-infrastructure priorities**

- Theme 1-- Articulating the interconnections of socio-ecological systems and identifying the societal, legal, biophysical and biogeochemical criteria needed to model resilience in the four specific coastal regions. – Robert Twilley, LA Sea Grant- Leader
- Theme 2 -- Identifying the systems science requirements for future coastal risk and resilience programs. – Bob Gagosian, COL -Leader
- Theme 3 -- Creating an accessible and extensible collaborative cyber infrastructure for cross-disciplinary communication. - Rick Devoe, South Carolina Sea Grant Consortium -Leader

15:30 Break

15:45 **Plenary to review outcomes of Breakout 1; open discussion**

17:30 Wrap up for Day 1

18:30 No-host dinner at local restaurant

October 30, 2014 (adjourn at 3 PM)

07:30 **Breakfast**

08:30 **Motivating the Theme**: *Hans-Peter Plag (invited), ODU's Mitigation and Adaptation Research Institute*

08:50 Open Discussion**: Ideas and concepts leading to the development of a shared information technology cyber infrastructure for distributed data-management and community modeling**
Moderator: Gary Crane, SURA Director of Information Technology Programs

09:30 **Charge to Breakout Groups,** *Don Wright, SURA*
Defining indices of resilience

09:45 Break

10:00 **Breakout Session : Defining indices of resilience**

- Theme 1 -- Community resilience – Tom Birkland, NCSU-Leader
- Theme 2 -- Ecosystem resilience – Jim Morris, USC -Leader
- Theme 3 -- Infrastructure resilience –Samantha Danchuk, Environmental Planning & Community Resilience Division, Broward County, Florida- (Invited Leader)

12:00 Lunch **w/Speaker** – *Margaret Davidson (invited), Acting Director of NOAA Office of Ocean and Coastal Resource Management*

13:00 Plenary to review outcomes of each breakout group; open discussion

14:30 Summary of main points and next steps

15:00 Wrap up and Adjourn

Appendix 2. **Workshop Attendees and Their Interests**

First Name	Last Name	Organization/Institute	Please describe your expertise and interest in the topic of this workshop.
Thomas	Birkland	North Carolina State University	Expertise in the public policies made at the national and sub-national level related to natural hazards, including hazard mitigation. Developing expertise in infrastructure and resilience issues. Promoting interdisciplinary research that draws upon the physical, natural, and social and behavioral sciences, as well as engineering and the design disciplines as associate dean for research in the College of Humanities and Social Sciences at NC State. Focused on conducting research that will have a positive influence on policies that seek to promote hazard resilience, promote ecosystem function along the coastline, and that are based in the best science.
Arthur	Cosby	Mississippi State University - Social Science Research Center	Applies social science knowledge to such real-world problems as health, poverty, career development, racial disparities, tobacco control, families/children and policy studies.
Gary	Crane	SURA	Director of Information Technology Initiatives for the Southeastern Universities Research Association (SURA). Provides leadership and management for information technology projects and programs.
Gwynn	Crichton	The Nature Conservancy	Leads a coastal resilience/climate adaptation initiative for The Nature Conservancy's Virginia Coast Reserve program on the Eastern Shore of Virginia. Works as the Principal Investigator on a National Fish and Wildlife Foundation Hurricane Sandy Coastal Resiliency Fund grant to engage and equip local stakeholders on the Eastern Shore with tangible science-based tools for developing more effective climate-hazard mitigation and risk reduction strategies. Have made progress in incorporating social benefits of various natural infrastructure strategies modeled to enhance coastal resilience for The Nature Conservancy. Am focused on learning more about how to bolster approaches to incorporating socio-economic considerations.
Christopher	D'Elia	Louisiana State University	Chair of SURA Coastal and Environmental Research Committee. Nutrient Dynamics in aquatic Systems; Estuarine Ecology; Coral Reef Ecology; Algal/Invertebrate Symbiosis; Science History and Policy; Math and Science Education; Analytical Chemistry; Climate Dynamics; Environmental Science; Pollution
Samantha	Danchuk	Environmental Planning & Community Resilience Division, Broward County, Florida	Expertise/ experience: computational fluid dynamics, oil spill modeling in rivers/ coastal areas, coastal modeling, resilient redesign, local/ state government comprehensive planning. Interest: Miami/ Dade, infrastructure/ transportation system risk and resilience, implementation strategies for phased climate change adaptation
Margaret	Davidson	NOAA	Principal scientific advisor on coastal inundation science, resilience, development, and policy at NOAA.
Denise	DeLorme	University of Central Florida	Environmental communication through the application of qualitative research methods
Rick	DeVoe	S.C. Sea Grant Consortium	Research focuses on relationships between land use and land use change and ecosystem condition (including work with local governments and planning entities); coastal stormwater pond function, performance, and management; coastal ocean policy and governance at the state and regional levels, including marine planning; coastal and offshore aquaculture policy, management, and regulatory environment; and offshore energy development policy and management.
David	Eggleston	NC State University/CMAST	Interested in metrics for coastal resilience. Teaching and research focuses on experimental marine benthic ecology, detecting ecological impacts, fisheries and behavioral ecology, population dynamics and modeling, estuarine and coastal habitat restoration, marine conservation biology, marine science education.
Robin	Ersing	University of South Florida	Research interests focus on social vulnerability and disasters with an emphasis on community resilience. Projects include local, state and international research on the disaster experiences of impoverished communities, female headed households, and limited English proficiency groups such as migrant farm laborers.

Robert	Gagosian	Consortium for Ocean Leadership	Strong interest in research relevant to sea level rise, resilience and new model predicative capabilities.
Scott	Hagen	University of Central Florida	Member of the Steering Group. Research is focused on massively parallel, high performance computational modeling of ocean, coastal, and inland shallow water flows from tides, wind waves and storm surge. Recent efforts expand into transport and ecological modeling, particularly with respect to the coastal dynamics of sea level rise, and are aiding coastal planners around Florida and in the northern Gulf of Mexico.
Troy	Hartlely	Virginia Sea Grant/Virginia Institute of Marine Science	Social science; governance and communication networks; state Sea Grant programs.
Rodger	Harvey	Old Dominion University/ Ocean, Earth and Atmospheric Sciences	Research focused on Arctic and polar ocean organic geochemistry and climate, particularly the exchange of materials across the lad-sea interface and carbon sequestration. A pressing research topic and region is rising sea level as observed in the Hampton roads region of Virginia. This coastal site sits at the forefront of rising sea level and there is a pressing need for science based strategies to mitigate its impact. There are multiple stakeholders with varied goals who need science based strategies to set priorities.
Shana	Jones	University of Georgia, Carl Vinson Institute of Government	Assisting communities with managing legal and policy issues related to land use, environmental quality, and coastal flooding. Currently involved on several projects that involve modeling sea level rise projections, coastal flooding, etc. at the Vinson Institute of Government at the University of Georgia. Prior to UGA, founded and directed the Virginia Coastal Policy Clinic at William & Mary Law School. Collaborate with VIMS and William & Mary on a variety of environmental projects. Partnering with North Carolina Sea Grant on a project related to legal issues that could arise out of incorporating social vulnerability data such as race into geo-spatial mapping. Some of the legal and policy questions needing further research as coastal and climate change risks are modeled include: • Are there legal issues arising out of utilizing social vulnerability indices – particularly with respect to race as a "suspect classification" subject to "strict scrutiny"– in adaptation planning that government officials should be aware of before relying on such information as part of their decision-making? What about privacy? The Americans with Disabilities Act? HIIPA? • What set of principles should guide legal and/or policy reforms designed to guide adaptation planning that incorporates social vulnerability data? • What should the selection criteria for identifying a rural and urban areas of mapping and study? Does risk modeling treat these areas equally? • Is it possible to model the impact of proposed or enacted land use law and adaptation policies?
Andrew	Keeler	UNC Coastal Studies Institute	Projects that bring individual and institutional choice behavior more explicitly into modeling and policy analysis of coastal adaptation policy. Research that helps the community to understand incentives and economic optimization behavior is an important complement to planning and vulnerability-based approaches, and failure to account for reactive behavior is problematic for both political and policy approaches to coastal adaptation actions. Time is given short shrift on the economic side -- discussion sometimes proceeds as if the probability of non-viability at some future point somehow diminishes the value of continued coastal occupancy until non-viability occurs. This factor should enter more directly into the analysis of adaptation policy broadly considered.
Nina	Lam	Louisiana State University	Research focused on GIS, remote sensing, spatial analysis, environmental health, and resilience. Participating on several projects related to business resilience in New Orleans after Katrina, community resilience assessment, and coastal vulnerability modeling using a coupled natural-human system approach.
Karen	McGlathery	University of Virginia	Resilience of seagrass and salt marsh ecosystems in Mid-Atlantic (Virginia Eastern Shore). Lead Virginia Coast Reserve LTER project on climate and land-use change effects on coastal barrier

			systems, and NSF-funded coastal sustainability grant on a cross-site comparison (Virginia, Massachusetts, Georgia) of marsh vulnerability to scenarios of sea-level rise and feasible social adaptations. Partner with The Nature Conservancy on developing coastal resilience tool for Eastern Shore with long-term data, experiments and models from VCR LTER research.
James	Morris	University of South Carolina	Sea level rise, coastal responses, modeling, ecosystem ecology
Fredrika	Moser	Maryland Sea Grant	Engaging coastal communities in the discussions of uses and development of tools and technologies by the research community so as to inform their decisions about management and adaptation to flood waters and changing landscapes associated with sea level rise. Modeling projects involving risk and resilience with a human dimension component should include inputs from the communities that the research is ultimately likely to affect.
Brad	Murray	Duke University	Collaborative research with coastal geomorphologists and economists on modeling the coupled dynamics of human/coastline change, including plan-view and profile modeling of evolution over decadal to century timescales (using complex systems approaches). Research that considers how short term storm impacts and associated human protection measures translate into long-term coastal/human change.
Tonya	Neaves	George Mason University / School of Policy, Government, and International Affairs	Research during the past several years has focused on four streams: 1) the social capital and political trust of communities in the aftermath of disasters, and 2) the effectiveness of disaster warning technologies, 3) the perception of disaster risk, resiliency, and responsibility, and 4) developing sound traffic safety measures. This portfolio has included securing contracts from the Mississippi Office of Highway Safety/National Highway Safety Transportation Administration, American Transportation Research Institute, Mississippi-Alabama Sea Grant Consortium/National Oceanic and Atmospheric Administration, Mississippi Department of Marine Resources, American Trucking Association/Transportation Security Administration, and Oak Ridge National Laboratory/Federal Emergency Management Agency. I have also published such findings in a number of journals, including Journal of Emergency Management, Review of Public Personnel Management, Natural Hazards Review, Public Integrity, and Journal of Health and Human Services Administration. In terms of the workshop theme, risk and resiliency are key behavioral factors that should be examined by demographic, temporal, and spatial elements. This has become most evident when examining recovery efforts between Exxon-Valdez Oil Spill and the Deepwater Horizon Oil Spill. One of the impacted communities was very homogeneous whereas the other being very heterogeneous (i.e. similar to coastal regions where varying population groups tend to live). This difference in planning and response efforts should be highly tailored at the local level by utilizing a set of social and political climate analysis measures that utilize a number of surveying methodologies.
Jayantha	Obeysekera	South Florida Water Management District	Sea Level Rise, Climate Change, Regional water management, and Adaptation
Emily	Pidgeon	Conservation International	Leading the coastal climate change program for a large environmental NGO. Developing innovative ecosystem-based approaches to climate change adaptation. Coordinating the International Blue Carbon Scientific Working Group and developing projects globally which utilize the carbon storage and sequestration capacity of coastal wetlands to motivate conservation and restoration of these ecosystems.
Hans-Peter	Plag	Old Dominion University	Sustainability, global and climate change, local to global sea level changes, Earth system dynamics, solid Earth geophysics, the rheology of the Earth's mantle and continuum mechanics, deformation of the solid Earth, space geodesy and geodetic reference frames.
Liesel	Ritchie	Natural Hazards Center	Research on the social impacts of disasters with an emphasis on technological disasters, social capital, and renewable resource communities. Candidate to be one of NIST's Disaster Resilience Fellows (in the Sociology of Disasters domain area). Serves as the

			Assistant Director for research at the NHC and a research professor the University of Colorado–Boulder.Conducts research on how measures of "community capitals" are related to disaster resilience. Developed and conducted a workshop on "Natural Hazards and Community Resilience" for FEMA's Emergency Management Institute during 2011 and has participated in numerous such workshops in the last few years. Has studied disaster events such as the Exxon Valdez and BP Deepwater Horizon oil spills; Hurricane Katrina; and earthquakes in Haiti and New Zealand. Planning and conducting field work in rural and urban settings, small and large communities, as well as with tribal/First Nations populations. Leads evaluation efforts for the USGS's SAFRR Tsunami Scenario Project for coastal California, and is co-PI on both a NOAA-funded project to incorporate social science into its tsunami program and on a new NSF project which focuses on the dynamic economic resilience of businesses and regional economies following Superstorm Sandy.
James	Sanders	Skidaway Institute of Oceanography, UGA	Interests in coastal resiliency, member of SURA's "Understanding and Modeling Risk and Resilience in Complex Coastal Systems" workshop steering group.
Stephanie	Shipp	Virginia Tech	Deputy Director of the Social and Decision Analytics Laboratory. Research activities are focused on statistical analysis for public policy; data infrastructure; survey management; longitudinal analysis; confidentiality; science of science policy; smart and resilient cities; and big data. The Lab has projects that study social cohesion and what that looks like in terms of short term disasters and longer run more subtle shocks to a city or metropolitan area. Lab researchers are building a data infrastructure based on multiple sources of data at the local, county, state, and federal level that would allow researchers to comprehensively map networks. The data sources will include administrative, survey, and organic flows such as social media, community flyers and local newspapers.
Liz	Smith	Old Dominion University	Physical oceanographer, climate change.
James	Syvitski	Community Surface Dynamics Modeling Systems	Keynote speaker, Chair, International Geosphere Biosphere Programme (IGBP). IGBP was launched in 1987 to coordinate international research on global-scale and regional-scale interactions between Earth's biological, chemical and physical processes and their interactions with human systems. IGBP views the Earth system as the Earth's natural physical, chemical and biological cycles and processes and the social and economic dimensions.
Nancy	Targett	University of Delaware	Dean of the College of Earth, Ocean, and Environment at the University of Delaware, and Director of the Delaware Sea Grant College Program.
Robert	Weisberg	University of South Florida	SURA Fellow and co-organizer. Research interests include coastal ocean circulation: coordinating observing and modeling toward describing and understanding continental shelf and estuary phenomenology of ecological and societal relevance; for instance, harmful algae blooms, fisheries, coastal inundation by storm surge and waves, harmful substance transport, safe navigation.
Susan	White	NC Sea Grant	Critical need to engage community level leaders, planners and local constituents to ensure applications and practical tools/models and information are developed and able to be applied at a local level. Research priorities are aligned with user needs as identified through assessments, etc early on in research development process. Community understanding of "risk" and "resilience" is variable and needs to be addressed/corporately bought into prior to research investments at the local level to ensure best application/long-term engagement. Communication of risk continues to be a priority, including multiple venues and audiences (e.g., English as a Second Language population).
Don	Wright	SURA	SURA Director for Coastal and Environmental Research
Reid	Nichols	SURA	SURA Coastal and Environmental Research Program Manager
Rick	Luettich	University of North Carolina	Coastal hazards; Principal Investigator for SURA's Coastal and Ocean Modeling Testbed (COMT)
Jerry	Miller	Science for Decisions	Science and Technology policy. Ensuring good science to support good decisions.

Appendix 3. Some Notes from the Workshop

- The science of the 21st Century looks very different to the science of the Enlightenment or even to the science of the 20th Century.
- The lone scientist, immersed in his laboratory, is an anachronism.
- Today's scientists are collaborators, where large, multidisciplinary teams focus on complex, applied and translational problems. In this realm, SURA is an integrator.
- SURA fills a matchmaker roll. In addition, SURA can link active researchers to support teams that may be working to resolve global and national problems. SURA might provide models and rapid response personnel for humanitarian assistance/disaster response missions (e.g., USN Rapid Environmental Assessment).
- Integration involves innovation and acceleration – SURA might accelerate innovation with respect to coastal resiliency by facilitating collaboration among multi-disciplinary collaborators.
- Convergence is an approach to problem solving that integrates the knowledge, tools, and ways of thinking from multiple disciplines, including physical, economic, social, and behavioral sciences. Innovations through convergence may improve our understanding of coastal resilience.
- Challenge of water: Is clean water located in the right places? Lack of clean water is responsible for many deaths in the world. Humanity is building approximately one large dam every day.
- Requirements (needs) approach might address risk (where are people and environment at risk), restoration (identify ecological and socio-economic factors that determine the success of restoring coastal habitats), and resiliency (community options, adaptation solutions, and lessons learned). Communities transition from recovery to planning and redevelopment. Local governance supports programs (e.g., Broward County) that make communities more resilient to coastal hazards by providing them the appropriate tools, information, guidance, and technical assistance needed to make informed decisions on mitigation and adaption measures.
- Research results to policy changes to implementation…
- NGO Perspective – Simple solutions are more important (applicable, error bars, stakeholders, answers need to be in context)
- Cyber Infrastructure is science driven with both research and service components.
- Virtual community discussions led to the idea of a "Collaboratorium". Maybe a Collaboratorium is an advanced analysis (information management), visualization (similar to large disaster control center screen), and presentation space for

government, university, and industry experts. It provides a site for the exploitation of "Big Data," which can be viewed from the "Big Board." SURA might develop such a project to facilitate technology transfer among science, government and business partners. It seems that ODU is moving in this direction with MARI, the Mitigation and Adaptation Research Institute.

- Various people discussed topics best described as information management. Management ensures that information supports all aspects of planning, decision making, execution, and assessment.
- Communication systems facilitate positive interaction in the "resiliency" domain – technical (people in critical facility), organizational (first responders), social (communities), and economic (e.g., industry).
- How do you sustain cyber infrastructure? Collaboration and co-production, memberships or commercial partnerships.
- All agreed that decision makers must have timely and actionable information to guide their response to emergency situations. Actionable information might be produced by decision support systems. Some information is derived from models. Data assimilation, which certainly supports geophysical modeling, was discussed by the multidisciplinary group. The actual types of disparate data were not really identified. Very few people acknowledged the requirement to actually merge historic information, in-situ date, imagery, and numerical model output in order to get the best "picture."
- Resilience is a characteristic of sustainability.
- Vignettes or scenarios are core to problem-based learning and the development of concepts of operations.
- GIS technologies can be used to integrate and update disparate data. Jack Dangermond, the founder of ESRI, might be interested in becoming an industry partner.
- How can the COMT archive and model viewer be used to support contingency plans? Could a demonstration be planned with the ODU MARI, possibly one focused on short term hazards (erosion/accretion) to long-term phenomena (climate change/sea level rise).
- COMT provides thresholds that could be used in contingency planning and exercises (e.g., oil spill).
- Focus is almost solely on the hazards and the potential disasters we might be facing.
- Economic input/output models are very limited. Research thrust to improve social and economic models. Missing data to develop models that address social and economic aspects. Define loss and recovery. Link physical damage and social impacts.

Appendix 4. What is one thing SURA should do next? (individual responses from workshop participants)

- Develop proto framework for collaboration with governance, membership and goals/outcomes + 4-5 teams then convene highly structured workshop to focus on the 4-5 objectives drawing upon solid scientists with strong social inclination

- Pursue the financial support of a cyber-infrastructure to develop 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

- Periodic modeling forum (or Fora) focused on specific modeling issues

- Official organizational framework (as a first step) and Research Coordination Network (NSF) Proposal

- Partnering with local government to help them simulate/visualize their future risks in response to their specific concerns

- Library of vignettes "science based scenarios" with rapid response links

- Workshop- in person or virtual to list research topics & questions by location. Also, an online list of contacts by region as resource for local communities.

- Change the Miami/Dade site location to Southeast Florida (SMILE)

- Work with Federal agencies to identify/clarify research opportunities & "match make" researches to facilitate competitive proposal development.

- Act as a think tank for follow up on integrating natural and Social Science collaborations

- Act as a clearinghouse (?) on grant funded opportunities on Natural and Social science collaborations

- Help set up "incubator" sites across the universities on this work

- Be more transparent and visible with its efforts to the broader community so we can plug in where opportunity arises

- Take the discussions on the road (real or virtual) to more broadly engage resilience/risk scientists on this topic and future scoping

- Help with developing proposals in response to design competition and other coastal initiatives in private sector and government funding opportunities

- SURA oceans group should transition to a think tank

- Work with universities to establish "enterprise centers" virtual collaborations with cyber-knowledge collections and visualization tools that connect equally with knowledge providers from all involved in a specific coastal resilience problem

- Coordinate interdisciplinary and multiple institution research grant proposals and projects

- Develop a program on coastal resilience and utilize the expertise on social, ecological, engineering resilience; start with submitting a white paper to "Science" or similar

- Develop research service environment to support stakeholder driven research projects focusing on societal problems in the coastal zone

- Use the report from this meeting as the basis for discussions with a variety of federal agencies to inspire them to create programs to which proposals can be submitted. If SURA succeeds in inspiring a new paradigm as indicated yesterday, then such new programmatic homes will be needed

- Identify a sub task team(s) to inventory existing expertise, resources etc. and prioritize with the goals of grant proposals

Workshop Quote

"Techniques and technologies already exist to facilitate collaboration, so no huge investments in new cyber infrastructure are necessary. What is needed is institutional support and commitments to build, maintain, and curate these systems and the information they provide in a way that is broadly useful to all scholars."

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