Final Project Memorandum: Sea-Level Rise Modeling Handbook: Resource Guide for Resource Managers, Engineers, and Scientists

USGS Mission Area
Climate and Land-use Change

USGS Program
NCCWSC/DOI Climate Science Centers

Product Type
Extended Abstract

Final Project Memorandum
Southeast Climate Science Center Project

1. ADMINISTRATIVE

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Project Title:
Sea-Level Rise Modeling Handbook: Resource Guide for Resource Managers, Engineers, and Scientists

Project Number:
05

Date of Report:
20 November, 2014

Period of Performance:
September 2012 - September 2014

Total Cost:
$50,000.00

2. PUBLIC SUMMARY

A handbook for resource managers was produced to describe the science and simulation models for understanding the dynamics and impacts of sea-level rise on our coastal ecosystems. The focus of this guide was to categorize and describe the suite of data, methods, and models, their design, structure, and application, for hindcasting and forecasting the potential impacts of sea-level rise in coastal environments. Basic illustrations of the components of the Earth's hydrosphere and effects of plate tectonics, planetary orbits, and glaciation are explained to understand the long-term cycles of historical sea-level rise and fall. Discussion of proper interpretation of contemporary sea-level rates and trends from tide gauge stations and satellite altimetry missions are presented to show their complementary aspects and value for understanding variability in eustasy and land motion for different coastal reaches of the U.S. Examples of the different types and classes of hydrology and ecosystem models used to predict potential effects of future sea-level rise at local and regional scale applications are presented. Coastal land managers, engineers, and scientists will benefit from this synthesis of tools and models that have been developed for projecting causes and consequences of sea-level change on the landscape and seascape.

TECHNICAL SUMMARY

Global sea-level is rising and may accelerate with continued fossil fuel consumption from industrial and population growth. In 2012, the U.S. Geological Survey in cooperation with the Southeast Climate Science Center conducted more than 30 training and feedback sessions with Federal, State, and nongovernmental organization (NGO) coastal managers and planners across the northern Gulf of Mexico coast to evaluate current scientific understanding and utilization of resource aids and modeling tools for sea-level rise assessment and planning purposes. In response to the findings from the sessions, this sea-level rise modeling handbook has been designed as a natural resource manager's guide of the science and simulation models for understanding the dynamics and impacts of sea-level rise on our coastal ecosystems. The review herein of decision-support tools and predictive models was compiled from the training sessions, from online research, and from science publications. The purpose of this guide is to describe and categorize the suite of data, methods, and models and their design, structure, and application for hindcasting and forecasting the potential impacts of sea-level rise in coastal ecosystems. The data and models cover a broad spectrum of disciplines involving different designs and scales of spatial and temporal complexity for predicting environmental change and ecosystem response. These data and models have not heretofore been synthesized, nor have appraisals been made of their utility or limitations. Some models are more accessible as publicly available online demonstration tools for non-experts, whereas others require more expert capacity to apply them to for any given park, refuge, or regional application. A simplified tabular context has been developed to list and contrast a host of decision-support tools and models from the ecological, geological, and hydrological perspectives. Criteria were established to distinguish the source, scale, and quality of information input and geographic datasets; physical and biological constraints and relations; datum characteristics of water and land components; utility options for setting sea-level rise and climate change scenarios; and ease or difficulty of storing, displaying, or interpreting model output. Coastal land managers, engineers, and scientists

can benefit from this synthesis of tools and models that have been developed for projecting causes and consequences of sea-level change on the landscape and seascape.

3. PURPOSE AND OBJECTIVES

Coastal wetlands of the Southeastern United States are undergoing retreat and migration from increasing tidal inundation and saltwater intrusion attributed to climate variability and sea-level rise. Much of the literature describing potential sea-level rise projections and modeling predictions are found in peer-reviewed academic journals or government technical reports largely suited to reading by other Ph.D. scientists who are more familiar or engaged in the climate change debate. Various sea-level rise and coastal wetland models have been developed and applied of different designs and scales of spatial and temporal complexity for predicting habitat and environmental change that have not heretofore been synthesized to aid natural resource managers of their utility and limitations. Training sessions were conducted with Federal land managers with U.S. Fish and Wildlife Service, National Park Service, and NOAA National Estuarine Research Reserves as well as state partners and nongovernmental organizations across the northern Gulf Coast from Florida to Texas to educate and to evaluate user needs and understanding of concepts, data, and modeling tools for projecting sea-level rise and its impact on coastal habitats and wildlife. As a result, this handbook was constructed from these training and feedback sessions with coastal managers and biologists of published decision-support tools and simulation models for sea-level rise and climate change assessments. A simplified tabular context was developed listing the various kinds of decision-support tools and ecological models along with criteria to distinguish the source, scale, and quality of information input and geographic data sets, physical and biological constraints and relationships, datum characteristics of water and land elevation components, utility options for setting sea-level rise and climate change scenarios, and ease or difficulty of storing, displaying, or interpreting model output. The handbook is designed to be a primer to understanding sea-level rise and a practical synthesis of the current state of knowledge and modeling tools as a resource guide for DOl land management needs and facilitating Landscape Conservation Cooperative (LCC) research and conservation initiatives.

4. ORGANIZATION AND APPROACH

This work was conducted by a team of scientists from the U.S. Geological Survey National Wetland Research Center and the University of Louisiana at Lafayette. The paragraphs below identify the research methods utilized and activities performed.

In 2012, the U.S. Geological Survey in cooperation with the Southeast Climate Science Center conducted more than 30 training and feedback sessions with Federal, State, and nongovernmental organization (NGO) coastal managers and planners across the northern Gulf of Mexico coast to evaluate current scientific understanding and utilization of resource aids and modeling tools for sea-level rise assessment and planning purposes. Information gathered from these interactive feedback sessions helped determine the level and breadth of understanding of factors and forces controlling sea-level rise and the knowledge and use of simulation models for predicting future habitat change and impact to wildlife. In response to the findings from the sessions, this sea-level rise modeling handbook has been designed as a natural resource manager's guide of the science and simulation models for understanding the dynamics and impacts of sea-level rise on our coastal ecosystems. A literature review was conducted of the various decision-support tools and predictive models from resource material gathered from the training sessions, from online research, and from science publications. The structure and outline of this handbook focused on the science behind sea-level change, past and present, and the simulation models and projection of sea-level rise under climate change for assessing potential impacts to the landbase, habitat, and associated wildlife. The purpose of this guide was to describe and categorize the suite of data, methods, and models and their design, structure, and application for hindcasting and forecasting the potential impacts of sea-level rise in coastal ecosystems. The data and models cover a broad spectrum of disciplines involving different designs and scales of spatial and temporal complexity for predicting environmental change and ecosystem response. These data and models have not heretofore been synthesized, nor have appraisals been made of their utility or limitations. Some models are more accessible as publicly available online demonstration tools for non-experts, whereas others require more expert capacity to apply them to for any given park, refuge, or regional application. A simplified tabular context has been developed to list and contrast a host of decision-support tools and models from the ecological, geological, and hydrological perspectives. Criteria were established to distinguish the source, scale, and quality of information input and geographic datasets; physical and biological constraints and relations; datum characteristics of water and land components; utility options for setting sea-level rise and climate change scenarios; and ease or difficulty of storing, displaying, or interpreting model output. Coastal land managers, engineers, and scientists can benefit from this synthesis of tools and models that have been developed for projecting causes and consequences of sea-level change on the landscape and seascape.

5. PROJECT RESULTS

The primary project results are numerous presentations to resource staff of coastal refuges, parks, and reserves from federal and state agencies across the northern Gulf Coast from Florida to Texas.

A nationally advertised Webinar entitled "Sea-level Rise Modeling Handbook: Resource Guide for Coastal Land Managers, Engineers, and Scientists" was presented on July 1, 2014 as a part of the National Climate Change and Wildlife Science Center's Climate Change Science and Management Webinar Series. Over 300 participants from government, academic, and corporate entities registered for this presentation making it the most widely attended webinar to date. The video presentation was given by Dr. Thomas Doyle (USGS National Wetlands Research Center) and was posted at the following URL links:
https://nccwsc.usgs.gov/webinar/332

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http://gallery.usgs.gov/videos/825

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6. ANALYSIS AND FINDINGS

The primary project analyses and findings are summarized as follows:

Changes in climate during past ice ages and warming periods have affected sea levels and coastal extent as evidenced from ice, sediment, peat, and fossil records. Ancient sea-level reconstructions from multiple disciplines and techniques demonstrate worldwide consistency of high and low sea-level cycles of 120 meters (m) or more for long glaciation periods and higher and lower rates during the rise and fall segments. Current eustatic sea-level rates of more than 3 millimeters per year (mm/yr) in global ocean volume (eustasy) are moderate by historical calculations but when amplified by high rates of land subsidence may prove consequential to wetland stability and persistence on a local or regional basis. Tide gage records show that some coastal reaches are undergoing uplift from glacial rebound that accounts for an effective sea-level fall counter to the prevailing global rise of sea level elsewhere. Satellite altimetry provides a more accurate rate of global ocean volume (eustasy) exceeding 3 mm/yr for the most recent tidal epoch (1994–2012). Tide gages for the same time period generally show higher sea-level rise rates where there is active subsidence or crustal tilt. Sea-level rise rates for U.S. tide gages along the Gulf of Mexico coastline exhibit comparatively lower and higher rates in earlier tidal epochs of the 20th century, confounding any certainty of short- or long-term acceleration based on satellite observations.

In this handbook, we explain and illustrate proper evaluation of sea-level rates between satellite observations and tide gages, which requires observed records that are longer than a tidal epoch (greater than 19 years), have the same start and end dates, are seasonally balanced, have equal frequency modulation, and are complete (without data gaps). Otherwise, it is improper and problematic to contrast a sea-level rate from long-term tide gage trends with short-term satellite observations, as has been done in media and scientific reports. In effect, tide gage records and satellite observations are compatible and complementary, and there is value and need for both. Satellites account solely for the change in eustasy, whereas tide gages also capture the rate and direction of land motion (rise or fall). No matter the degree of human or natural consequence, rising sea level is already affecting our coastal ecosystems and infrastructure to an extent that society must deal with the problems and setbacks of coastal flooding. Various Earth-climate and coastal wetland models have been developed to address the interaction and impact of changing climate and land-use from a sea-level rise perspective. Simple models utilizing coarse datasets and constructs of the behavior of natural systems may only provide limited utility and certainty suitable for instructional or educational purposes, whereas more complex models require expert development and more site-specific parameterization and validation for aiding management decisions. The dynamic nature of the components of the Earth's hydrosphere and climate that account for the net balance of ocean volumes combined with the interactive effects of rebound and tilting of continental plates, as well as differential local and regional subsidence, presents a complicated process to model easily or with certainty. Models help our understanding of these interacting processes and provide the basis for forecasting potential change useful for land management and conservation planning.

In 2012, the U.S. Geological Survey in cooperation with the Southeast Climate Science Center conducted more than 30 training and feedback sessions with Federal, State, and nongovernmental organization (NGO) coastal managers and planners across the northern Gulf of Mexico coast to educate and to evaluate user needs and understanding of concepts, data, and modeling tools for projecting sea-level rise and its impact on coastal habitats and wildlife. It was our goal to introduce the non-expert to the broad spectrum of models and applications that have been used to predict or forecast environmental change and ecosystem response for sea-level rise assessments. We have compiled a rather comprehensive treatise of the data, models, and methods from various related disciplines to offer a condensed synthesis of the science and simulation models of sea-level rise, past, present, and future. As demonstrated, the models vary greatly in design and detail, functionally and structurally, spatially and temporally, physical to biological, from leaf to landscape, and so on. It is our hope that coastal managers, engineers, and scientists will benefit from a greater understanding of the dynamics and models that have been developed for projecting causes and consequences of sea-level change on the landscape and seascape.

7. CONCLUSIONS AND RECOMMENDATIONS

Primary Conclusions:

- Ancient sea-level reconstructions from multiple disciplines and techniques demonstrate worldwide consistency of high and low sea-level cycles of 120 meters (m) or more for long glaciation periods and higher and lower rates during the rise and fall segments. Current eustatic sea-level rates of more than 3 millimeters per year (mm/yr) in global ocean volume (eustasy) are moderate by historical calculations but when amplified by high rates of land subsidence may prove consequential to wetland stability and persistence on a local or regional basis.
- Tide gage records show that some coastal reaches are undergoing uplift from glacial rebound that accounts for an effective sea-level fall counter to the prevailing global rise of sea level elsewhere. Satellite altimetry provides a more accurate rate of global ocean volume (eustasy) exceeding 3 mm/yr for the most recent tidal epoch (1994–2012). Tide gages for the same time period generally show higher sea-level rise rates where there is active subsidence or crustal tilt. Sea-level rise rates for U.S. tide gages along the Gulf of Mexico coastline exhibit comparatively lower and higher rates in earlier tidal epochs of the 20th century, confounding any certainty of short- or long-term acceleration based on satellite observations.
- In this handbook, we explain and illustrate proper evaluation of sea-level rates between satellite observations and tide gages, which requires observed records that are longer than a tidal epoch (greater than 19 years), have the same start and end dates, are seasonally balanced, have equal frequency modulation, and are complete (without data gaps). Otherwise, it is improper and problematic to contrast a sea-level

rate from long-term tide gage trends with short-term satellite observations, as has been done in media and scientific reports. In effect, tide gage records and satellite observations are compatible and complementary, and there is value and need for both. Satellites account solely for the change in eustasy, whereas tide gages also capture the rate and direction of land motion (rise or fall).

- Various Earth-climate and coastal wetland models have been developed to address the interaction and impact of changing climate and land-use from a sea-level rise perspective. Simple models utilizing coarse datasets and constructs of the behavior of natural systems may only provide limited utility and certainty suitable for instructional or educational purposes, whereas more complex models require expert development and more site-specific parameterization and validation for aiding management decisions. Models help our understanding of these interacting processes and provide the basis for forecasting potential change useful for land management and conservation planning.

Primary Recommendations

- This handbook is a primer for the benefit of education of non-experts about the various kinds and utility of physical and ecological models used for conducting sea-level rise assessments. Many of the participants in our training and feedback sessions asked for our judgment of model quality to know which are best and most trusted. Independent tests of model functionality and performance were beyond the scope of funding and project objectives. Because most models are not rigorously validated, additional research is needed to provide benchmark testing of model robustness and fit.
- Nearly all of the modeling applications for sea-level rise are limited in a one dimensional approach of water over land from a coastal perspective and do not consider the freshwater dimension of runoff and inflow. New modeling paradigms are needed to generate the next-generation model at the watershed scale to consider the consequences of freshwater drainage, delivery, and quality from an ecological flows perspective. Water availability is a major concern and in many cases surface waters are reduced for municipal and industrial needs and allowances never reaching the estuarine zone of river outlets. In many instances, inter-basin transfers and flow controls are in place to route or hold freshwater which is exacerbating saltwater intrusion and salinity pulses in the estuarine zone. In general, the existing landscape models for sea-level rise assessments are fairly rudimentary and dependent on datasets of vegetative cover or surface elevation that are coarse, unrectified, or dated to provide a proper resolution for intended applications. New and improved modeling paradigms with greater integration and hierarchy are needed to consider the multi-scalar aspects of coastal systems and issues.

8. MANAGEMENT APPLICATIONS AND PRODUCTS

Models help our understanding of the interacting processes of climate and ecosystems and provide the basis for forecasting potential change useful for land management and conservation planning. This handbook will provide a condensed but comprehensive read of the science and simulation models used currently to conduct sea-level rise assessments for their education and informed decisions. Coastal land managers, engineers, and scientists can benefit from this synthesis of tools and models that have been developed for projecting causes and consequences of sea-level change on the landscape and seascape as a resource primer and reference guide.

9. OUTREACH

The outreach products included below are separated into the following two categories: (1) Publications; and (2) Presentations. The presentations category includes webinars, conference presentations, workshop presentations, and seminars.

Publications

Doyle, T.W., Chivoiu, Bogdan, and Enwright, Nicholas M., 2015, Sea-level rise modeling handbook—Resource guide for coastal land managers, engineers, and scientists: U.S. Geological Survey Professional Paper XXXX, 100 p.

Presentations

Webinar entitled "Sea-level Rise Modeling Handbook: Resource Guide for Coastal Land Managers, Engineers, and Scientists" was presented on July 1, 2014 as a part of the National Climate Change and Wildlife Science Center's Climate Change Science and Management Webinar Series. Over 300 participants from government, academic, and corporate entities registered for this presentation making it the most widely attended webinar to date. The video presentation was given by Dr. Thomas Doyle (USGS National Wetlands Research Center) and was posted at the following URL links:

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http://gallery.usgs.gov/videos/825

10. LITERATURE CITED