Chapter 15
Simulation Management Systems Developed by the Northern Gulf Coastal Hazards Collaboratory (NG-CHC): An Overview of Cyberinfrastructure to Support the Coastal Modeling Community in the Gulf of Mexico

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Abstract Given the significance of natural and built assets of the Gulf of Mexico region, the three states of Alabama, Louisiana, and Mississippi, leveraged their unique partnerships, proximity, and significant prior investments in cyberinfrastructure (CI) to develop the Northern Gulf Coastal Hazards Collaboratory (NG-CHC). This collaboratory was established to catalyze collaborative research

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via enhanced CI to reduce the regions vulnerability to natural and human disasters by facilitating high performance modeling to test hypotheses focused on engineering design, coastal system response, and risk management of coastal hazards. The objective of the NG-CHC is to advance research and inspire collaboration through highly available innovation-enabling CI, with a particular focus on geosciences and engineering from the watershed to the coast. An integrated CI capable of simulating all relevant interacting processes is needed to implement a system that captures the

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dynamic nature of coastal surface processes. The NG-CHC has implemented CI to locate appropriate data and computational resources, create necessary workflows associated with different simulation demands, and provide visualization tools for analysis of results. Three simulation management systems, SIMULOCEAN, SULIS, and ASGS, were implemented, each with a defined suite of hypotheses and institutional participants to run collaborator experiments. The NG-CHC focused on developing suites of CI tools centered on handling the functional needs of each simulation management system in a collaborative environment. The NG-CHC also developed curriculum units, computer games and simulations to extend the knowledge of coastal hazards to students from middle school to college. Education and outreach activities were developed to increase public understanding and support for sustainable coastal practices. The elements of the CI tool box within NG-CHC describe generic tools needed to promote a 'collaborative modeling environment' in other coastal systems.

15.1 Introduction

Coastal margins are important to the sustainability of economically important coastal fisheries, to strategic and economically important energy activities around the world, and as critical transportation centers associated with port activities (Adger et al. 2005; Crossett 2004; Day et al. 2007). They are regions of increased risks to human and natural resource infrastructure due to environmental drivers associated with climate change, sea level rise, hurricane frequency, and land-surface dynamics (Crossett 2004; Crowell et al. 2013; Cutter et al. 2008). These risks are amplified by significant human populations living in coastal regions, where approximately 8.5 million people live in census blocks that border ocean or are contained within the 1 % annual chance of a coastal flood (Crossett 2004; Crowell et al. 2013). Eight of the ten largest cities in the world and 44 % of the world's seven billion population are located within 150 km of the ocean (Vörösmarty et al. 2009). As a result, coastal hazards and public health are major concerns to agencies responsible for the safety of coastal regions (Adger et al. 2005; Hallegatte et al. 2013; Laska et al. 2005; Norris et al. 2008; Syvitski and Saito 2007). Coastal floodplains and rivers, the coastal ocean, and the underlying geology form a complex hydrodynamic, geomorphic, and ecological system that substantially impacts coastal inhabitants and natural resources (NSF 2009; Norris et al. 2008; Opperman et al. 2009; Pinter 2005). Understanding and predicting the behavior of coastal systems, under prevailing and extreme environmental conditions, is an important problem in many countries around the world, particularly those with deltaic coasts (Nicholls et al. 2011; Sherrieb et al. 2010; Vörösmarty et al. 2009).

The northern coast of the Gulf of Mexico is a region where weather and storm disturbance plays a significant role in public safety (Lin et al. 2012; NRC 2006), and are expensive entities to the Gulf of Mexico's offshore energy industry (Fischetti 2001). Every day, the Gulf of Mexico production facilities extract, process, and transport approximately three million equivalent barrels of oil (27 % of U.S. production) and natural gas (25 % of U.S. production), with at least 12.5 % going to state and federal royalties (NRC 2006). The oil and gas infrastructure in the Gulf of Mexico is substantial, with 6,400 producing wells, 4,000 active platforms, and 29,000 miles of pipelines. Hurricanes pose a considerable threat to production operations, forcing evacuation of offshore drilling rigs and temporarily ceasing production. For example, during hurricane Katrina more than 700 platforms were evacuated reducing the oil production to less than 10 % (Feltus cited by Cruz and Krausmann 2008). The Northern Gulf Coast also constitutes one of the most culturally and ecologically rich coastal ecosystems in the world (Laska et al. 2005). Within this region are found 25 % of the nation's coastal wetlands and 40 % of all salt marshes in the contiguous 48 states (Day et al. 2007). These ecosystems are a buffer against storm damage and a nursery and foraging area for fish and crustaceans. Louisiana ranks first among all states in the commercial harvest of menhaden, oysters, and crabs and is a major producer of shrimp (NRC 2006). Overall commercial fisheries in the Northern Gulf Coast states account for over 50 % of the nation's total fish catch. Long-term trends in the estuarine fish community in the northern Gulf of Mexico indicate that during the period 1992–2004 fish communities increased in abundance, species richness, and trophic balance. However, it has been considered that moderate increases in nutrient loads, habitat loss, and climate change could cause a "tipping point" with a rapid decay in fish community structures, number of species, and abundance (Jordan et al. 2010; Rabalais et al. 2002).

The Northern Gulf Coast provides an ideal setting for developing new insights into modeling coastal environmental responses to dynamic external forcings associated with sea level and watershed processes (Dietrich et al. 2010; Galloway et al. 2009; Twilley 2007; Westerink et al. 2008). Thus, the Northern Gulf Coast is a region of dynamic land-water interfaces – with extensive coastal wetlands, barrier islands and river networks that challenge a static approach to modeling and analytical approaches used to design scenarios commonly employed by regional planning and risk management (Paola et al. 2011; Twilley et al. 2008). Finally, coastal regions around the world will experience increased risks from climate change and sea level rise (Day et al. 2008; Vörösmarty et al. 2009). These processes and human development scenarios of the Northern Gulf Coast represent research opportunities to develop solutions to living and working in healthy coastal landscapes nation- and worldwide.

Given the significance of natural and built assets of the Gulf Coast region, and their vulnerability to natural and human disasters, the Northern Gulf Coastal Hazards Collaboratory (NG-CHC) was established to accomplish the following goals: (1) enhance the research competitiveness of the region, (2) advance economic opportunities by reducing risks to coastal communities, and (3) catalyze collaborative research via enhanced cyberinfrastructure (CI) that facilitates high-performance modeling to test hypotheses focused on engineering design, coastal system response, and risk management of coastal hazards. The three states in the consortium, Alabama, Louisiana, and Mississippi, leveraged their unique partnerships, proximity, and significant prior investments in CI to advance science and engineering of coastal hazards across the region (Fig. 15.1). One of the grand

Fig. 15.1 Description of the Northern Gulf Coastal Hazards Collaboratory showing the location of universities involved and some of the topics of the simulation management systems developed by the consortium

challenges for earth system science is to characterize dynamic environmental processes at appropriate space and time scales with integrated observation networks and simulation models (NSF 2009). Such capabilities are critical to societal needs for reduction of risks to built, human and natural environments (Galloway et al. 2009). The observational and data storage systems located at university, government and private industry in the Northern Gulf Coast have increased capacity due to recent major investments in CI. However, this region lacks the necessary regional scale CI to integrate these data inventories into information and knowledge to improve our ability to simulate and forecast dynamics of water-land interactions in coastal and watershed environments. The strategic plan of NG-CHC was to develop integrated CI for a research and education environment to promote regional capability in simulating coastal hazards by enhancing the linkages between modeling and data sources in a multidisciplinary environment that couples geoscience, engineering, geoinformatics, computational science, and STEM education (Fig. 15.2). Coastal hazards represent generic environmental, engineering and social problems worldwide in which human and natural dynamics are strongly and inherently coupled (Galloway et al. 2009). Thus CI developed in the NG-CHC has national and international implications to living and working in coastal environments. This overview describes the strategies developed within the NG-CHC to

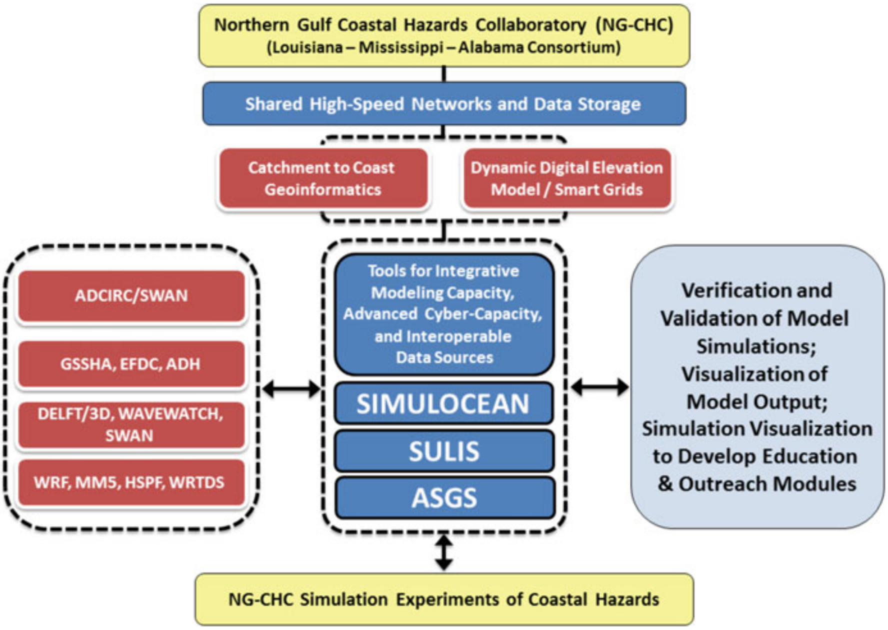


Fig. 15.2 Conceptual diagram of the simulation management systems in the Northern Gulf Coastal Hazard Collaboratory including geoinformatics with vision of developing specific cyberinfrastructure to evaluate coastal risks

define a more integrated research environment by interpreting landscape patterns, forecasting hydrodynamics, and applying critical thinking and problem solving techniques in 'simulation system designs'.

15.2 Simulation Management Systems

There are three types of simulation management systems developed to drive the NG-CHC CI development (Fig. 15.2). The strategy in selecting these three systems was to include: (1) modeling systems that are defined for one geographic region that can be expanded to other areas of need in the northern Gulf, as noted in the Introduction; (2) modeling platforms that capture the diversity of processes from the catchment to the coast for more robust simulations of ecosystem and geosciences processes related to coastal hazards specific to the northern Gulf; (3) simulations that couple hazard mitigation using ecosystem restoration with estimates of risk reduction. These simulation management systems were also designed to provide guidance to coastal hazard preparedness and response (disaster science and management), and economic development. The scientific goal of these simulation management systems was to develop the mathematical, computational, and engineering framework for modeling the geosciences, including watershed science, oceanography, meteorology, ecology, and geomorphology under a changing climate. The need for such a framework was driven by numerous applications that will be considered by each of the simulation experiments on coastal hazard planning, preparedness, and response. By pursuing each approach, and linking these collective efforts within the NG-CHC, our strategy was to build incremental capacity with strategic CI to promote discovery in coastal hazards using the Northern Gulf Coast landscape as a laboratory.

There is no single model that addresses all the coastal hazards described in the Introduction, so a collection or a "community" of models connected by cyberinfrastructure is a basic requirement of the Collaboratory. Further, the diversity of hazard management needs makes single management system far too ambitious for a single project and much too limiting for the Collaboratory. The NG-CHC focus was to produce three simulation management systems including the following: SIMULOCEAN, SULIS, and ASGS (Fig. 15.2) that connect with each other and with other systems (e.g., the Corps of Engineers eCoastal system, USACE 2013). These interconnected 'systems of systems' represents the major accomplishments of the NG-CHC in providing a modeling framework whereby scientists and engineers from across the institutions of the northern Gulf of Mexico Coast could participate in discovery on critical issues of coastal hazards.

SIMULOCEAN is a web-based deployment and visualization framework for coastal modeling (Fig. 15.3), available at http://simulocean.org. SIMULOCEAN collects observational data, schedules modeling codes for execution, manages data transfer, and visualizes both observational and numerical results. SIMULOCEAN can also provide direct validation and verification for models, and automatically generate high quality technical reports. The SIMULOCEAN framework leverages the Advanced Message Queuing Protocol (AMQP) in the background to collect and dispatch various tasks necessary for simulation and data management. The backend of SIMUOCEAN is written with the Python scripting language and built on top of a MySQL database. The front end is written in HTML, CSS and JavaScript (Table 15.1).

There are five components of SIMULOCEAN to achieve the functionality described above. (1) A module is implemented in SIMULOCEAN to support job management and data transfer (system workflow implementation). A user can create, control, and manage simulations running on remote supercomputers via a web-based interface (Fig. 15.3). (2) A GIS-based interface was implemented to support observational data retrieval and archiving in SIMULOCEAN. (3) FVCOM, ADCIRC, and Delft3D have been compiled, tested and implemented in SIMULOCEAN, in addition to SWAN and CaFunwave (Table 15.2 identifies all model acronyms used in this review). Users in the NG-CHC can now configure and run simulations using those three additional models and retrieve the output data following the simulations. (4) A user's manual and step-by-step tutorial were added to make it easy for users to get started with SIMULOCEAN. Online documents were also developed to provide guidance. A video tutorial of how to use SIMULOCEAN to run Delft3D models is available at http://www.youtube.com/watch?v=LfwaYjDbjWE. (5) Collaborating with the University of Alabama in Huntsville (UAH) the metadata for each simulation executed on SIMULOCEAN is now automatically injected into the NG-CHC metadata server to facilitate searching and analysis of simulation output data.

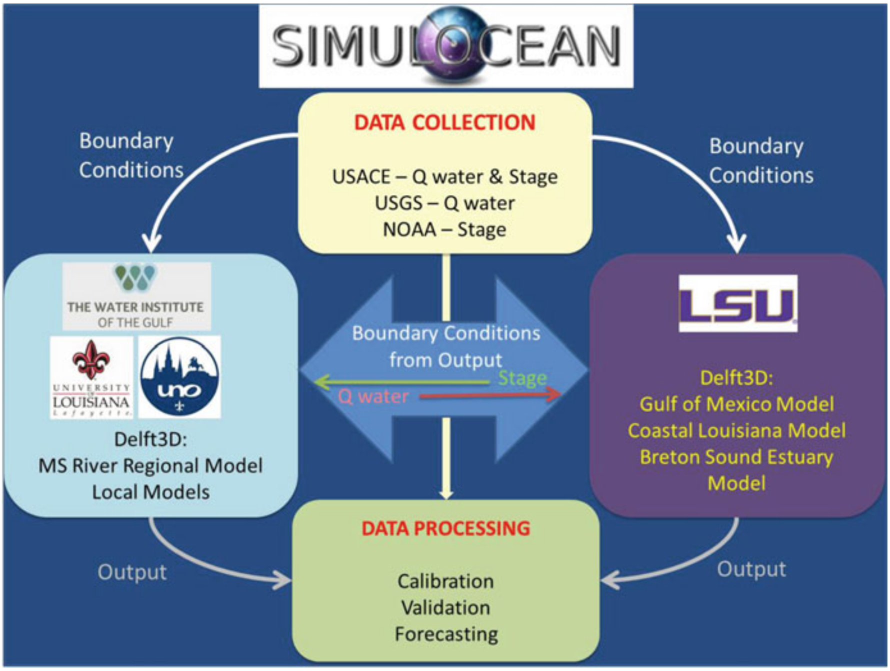


Fig. 15.3 Example of how a SIMULOCEAN user can create, control, and manage simulations running on remote supercomputers with ease using the web-based interface. *Upper panel* describes the basic flow of information; *lower panel* shows the web-based interface that the user utilizes to submit jobs for simulation

Table 15.1 Data sources used to develop merged product and test extraction toolset

Data source	Name	Date completed	Spatial resolution	Horizontal datum	Vertical datum
USGS NED	NED 1/9	N/A	1/9 arc-second	NAD83	NAVD88
USGS NED	NED 1/3	N/A	1/3 arc-second	NAD83	NAVD88
USGS NED	NED 1	N/A	1 arc-second	NAD83	NAVD88
NOAA VDatum	Mobile	11/30/2009	1/3 arc-second	NAD83	NAVD88
NOAA VDatum	New Orleans	04/30/2010	1/3 arc-second	NAD83	NAVD88
NOAA VDatum	Northern Gulf Coast	12/31/2010	1 arc-second	NAD83	NAVD88

SULIS is a manager's assessment system with a public interface and supports two functioning sub-sections of NG-CHC: a section utilizing models to simulate water, sediment, and constituent flow from watershed to coastal bay to Gulf, and an informatics services section that translates model results for use by resource managers (Fig. 15.4). The modeling section simulates river, watershed and gulf

Table 15.2 Acronyms of the models used by the Northern Gulf Coastal Hazards Collaboratory

Model	Name
ADCIRC	Advanced circulation model for oceanic, coastal and estuarine waters
SWAN	Simulating waves nearshore
GSSHA	Gridded surface/subsurface hydrologic analysis
EFDC	Environmental fluid dynamics code
ADH	Adaptive hydraulics modeling
DELFT3D	3D modeling suite to investigate hydrodynamics, sediment transport and morphology
WRF	Weather research and forecasting model
MM5	PSU/NCAR Mesoscale model
HSPF	Hydrological simulation program fortran
WRTDS	Weighted regressions in time, discharge, and season
FVCOM	The unstructured grid finite volume coastal ocean model

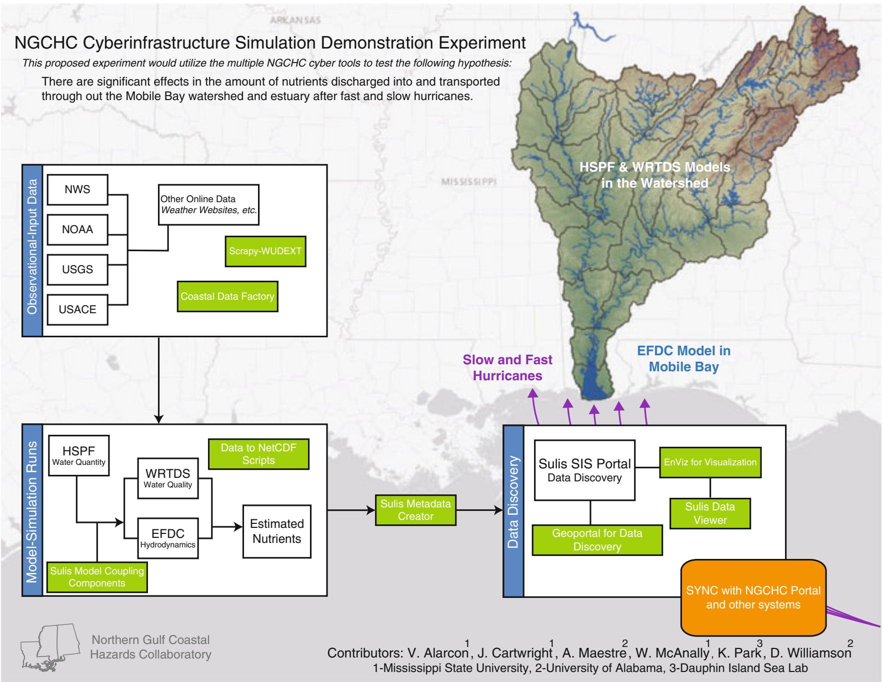


Fig. 15.4 SULIS is a simulation management system with public interface, developed by MSU that functions in two groups: the modeling group and the informatics services (SIS) group

processes based upon hurricane surge data, constituent loads in the watershed and basin, and rainfall. For example, the coupled EFDC model is able to simultaneously run multiple modeled systems, exchanging inflow, water surface, and salinity data among all model instances in the coupled system. This approach was used to allow surge from an ADCIRC model operated within SIMULOCEAN to drive a Mobile

Bay surge model, which propagated the surge into a smaller embayment, Week's Bay. The data transfer system allows data to be passed among models instantly, to achieve more complex model goals such as storm-induced hypoxia.

An open source metadata and data discovery system (built on the Esri Geoportal) serves as the foundation for SULIS Informatics Services (SIS). The SIS capability provides tools for managers to use in assessing environmental hazard risks. The custom install can handle complex model data for exploration, visualization and analysis. The data within the Geoportal can be associated with specific projects (NG-CHC, Mobile Bay RSM, etc.) and their component products, model data, and observed data can be tied to a specific sub-project, allowing easier exploration and discovery of data. The Inference Engine is an analysis component of SULIS, which includes a form of Reduced Order Modeling (ROM) that uses complex, physics-based (high-fidelity) computational model outputs to predict new results with substantially less computational effort than additional model simulations. Support vector regression and spline regression techniques allow predictions to be made in a fraction of the time needed by the original models. Tests using EFDC and ADCIRC model simulations involving several different variables show that the Inference Engine ROM represents an effective method of extending model results.

The ADCIRC Surge Guidance System (ASGS) is a real time software automation system for coastal ocean modeling that uses the ADCIRC coastal circulation model with optional coupling to the SWAN wave model (Fig. 15.5). The open source ASGS project was initially conceived in 2006 in the immediate aftermath of Hurricane Katrina. It is a self-contained package of software modules that operate on any size platform, from a desktop PC to HPC platforms with tens of thousands of cores. Its purpose is to reliably automate the execution of ADCIRC in real time, regularly consuming meteorology data and formulating it for ADCIRC in order to provide a comprehensive, integrated, high resolution modeling system for wind and storm surge conditions associated with specific advisories of hurricane events. The guidance produced by the ASGS has been actively used and relied upon by agencies at the state and federal levels, including the US Army Corps of Engineers, the US Coast Guard, the Louisiana Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP), as well as emergency managers and weather forecasters at the state and local levels in Louisiana, Mississippi, Alabama, North Carolina and Texas.

Storm forecasts demand accuracy to build user confidence, timeliness to be relevant, and robustness to be a stable and reliable product. Predictions also require modeling results to be effective and user-friendly to emergency managers, using visually appealing products that convey detailed results sufficient to evaluate flooding risks. The NG-CHC simulation research environment developed an interactive website known as Coastal Emergency Risks Assessment (CERA), available at http://coastalemergency.org, which presents ADCIRC (and SWAN) results in an environment to serve disaster management needs (Fig. 15.5). CERA has been designed to be an intuitive and easy to understand tool for the scientific community, emergency managers, and decision makers. The CERA website generates data

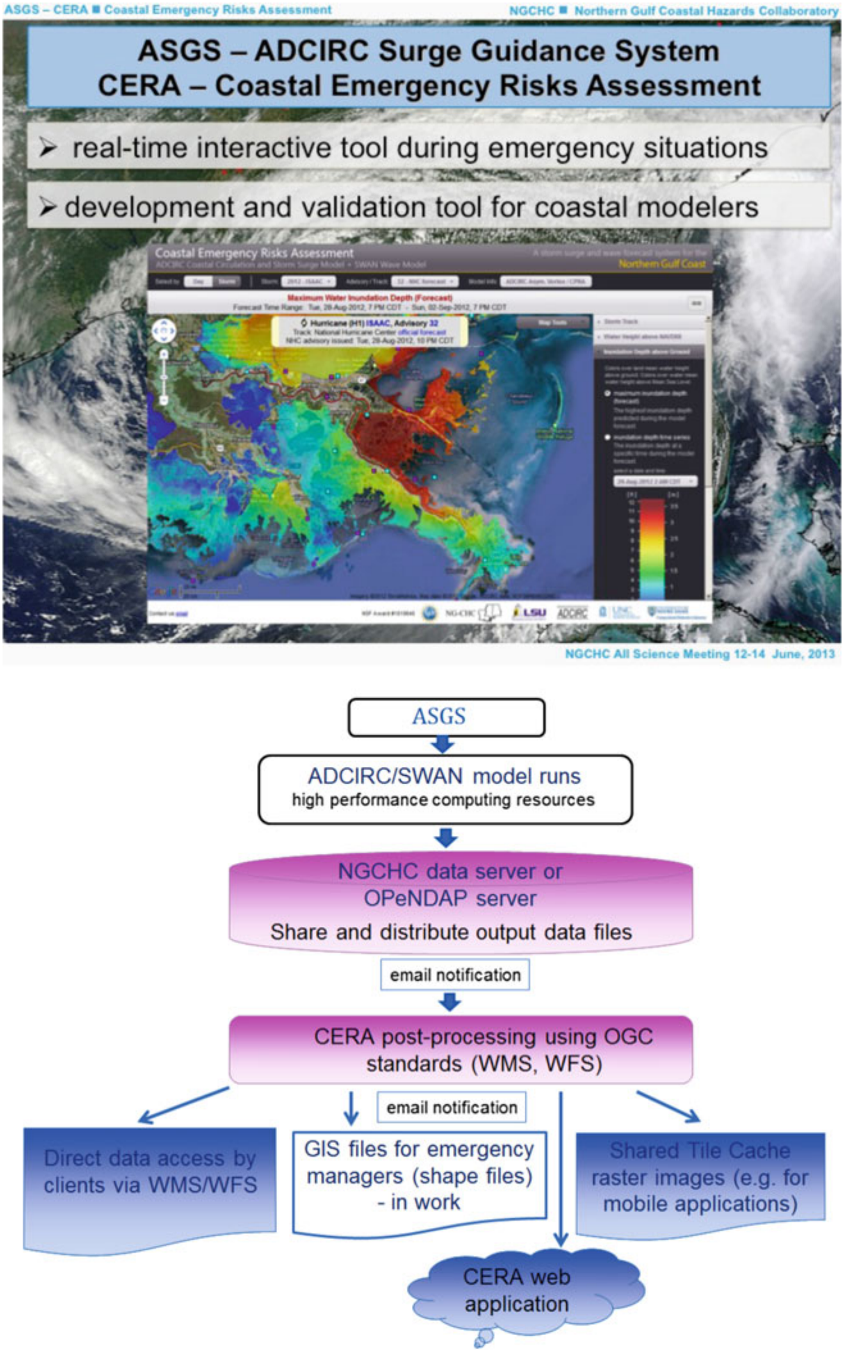


Fig. 15.5 Coastal Emergency Risks Assessment (CERA) has provided operational advisory services related to impending hurricane events (**a**), including a diverse group of clients during Hurricane Isaac during 2012. ASGS system was modified to compare ISAAC hindcasts with different grid, wind speed, and speed conditions tested to evaluate the effects on maximum water inundation

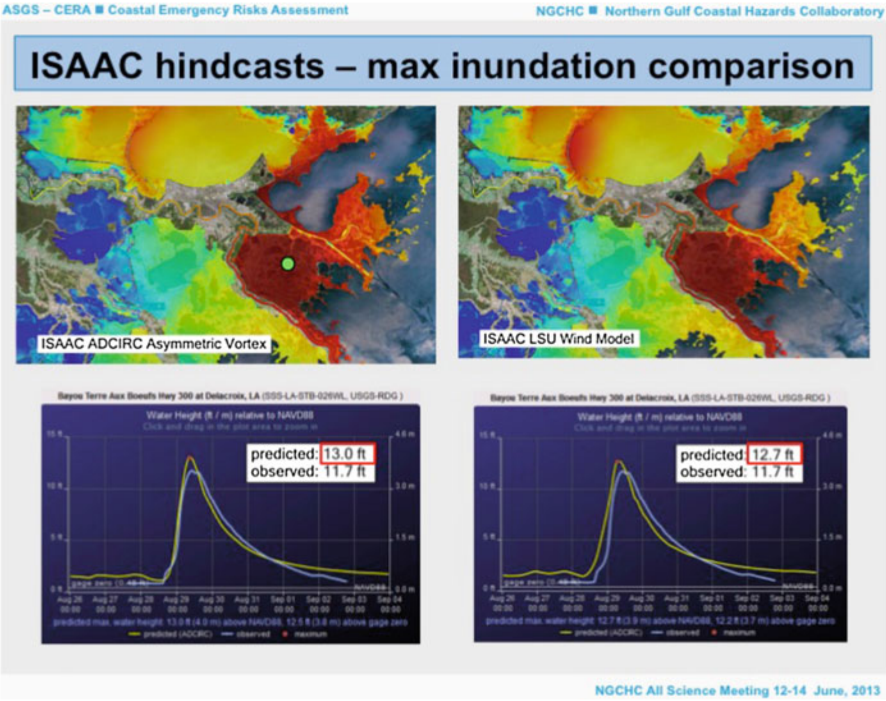


Fig. 15.6 Example of the capability of CERA web site to compare simulated water levels using ASGS compared to actual observations in the field. The ASGS system was modified to compare ISAAC hindcasts with different grid, wind speed, and speed conditions tested to evaluate the effects on maximum water inundation

visualization products directly from ASGS using a stable, reliable, and robust workflow implemented by an effective post-processing system. This workflow delivers huge data sets to hundreds of users via a web mapping application and enables timely and accurate data distribution to the wider disaster management community. CERA has been extensively developed using feedback from emergency managers and federal agencies over the last 8 years taking advantage of real-time hurricane events such as Hurricanes Rita, Gustav, Ike, and Isaac in the Gulf of Mexico. It was also used as an effective real-time tool during the Deepwater Horizon event in 2010 where the ASGS provided daily forecasts of nearshore and inshore penetration of surface oil along the northern Gulf Coast (Dietrich et al. 2012).

The CERA visualization sub-system overlays the simulation results with consolidated real-time data, which is automatically collected from various sensors distributed along the Northern Gulf Coast such as NOAA, U.S. Geological Survey (USGS), US Army Corp of Engineers, and National Hurricane Center (NHC) (Fig. 15.6). The ASGS/CERA simulation management system uses several standards and technologies like the usage of Open Geospatial Consortium (OGC) standards to ensure interoperable data exchange. The interface also allows visualization of multiple runs based on different track and wind projections, facilitating probability projections and sensitivity studies. For example, CERA presented results of different ADCIRC forecasts for Hurricane Isaac (2012) from Louisiana State University and Mississippi State University, based on simulation runs supported on each institution's high-performance computing systems.

15.3 Geoinformatics

To support the application of these three simulation management systems, NG-CHC also invested in CI systems that could enhance the geoinformatics used in each of the modeling grids. A key objective of the Dynamic Digital Elevation Models (DDEM) was to form digital grids that capture the elevation of natural and built infrastructure of the region and change the way the diverse environmental systems interact (Fig. 15.2). Dynamics in both elevation models and models of environmental systems (e.g. sea level rise, subsidence, and construction of civil infrastructure) produces complex behavior of water distribution in the northern Gulf Coast. The majority of digital elevation and bathymetry data are created and housed by federal and state agencies in the northern Gulf Coast. Limited, specialized data are available from selected county governments in the region and is usually the result of flood mapping and other countywide (parish) projects. Primary sources of data are the U.S. Geological Survey (USGS) and the National Geophysical Data Center (NGDC) for land surface and bathymetry, respectively.

The Coastal Relief Model (CRM, V. 4) released by the NGDC in 2001 was chosen as the basis for the DDEM. The CRM encompasses the Northern Gulf of Mexico (NGOM) from Pensacola, FL to Sabine Pass, TX with a three-arc second resolution. The comprehensive documentation that accompanies the CRM provides transparent understanding of the bathymetric surveys that have been included. Another appealing aspect of the CRM that led to its adoption as initial framework is that it represents the first high-quality, high-resolution DEM covering the U.S. coastal zone.

The bathymetric component of the merged DDEM (BDDEM) consists of two stages (Fig. 15.7). The first stage incorporated five NGDC-produced digital elevation models into the original CRM consisting of one arcsec resolution image from Northern Gulf Coast and one-third arcsec resolution images from Biloxi, Mobile, SE Louisiana and New Orleans (Table 15.3). These datasets were incorporated into the merged DDEM, with vertical datum established as NAVD88 and one-third arcsec resolution with bathymetric data sources current through 2001. The second stage BDDEMs were systematically updated by incorporating bathymetric survey data released by NOAA-NOS (National Ocean Service) over the period 2002–2011. The 2002 BDDEM used the first stage product as its basis, and subsequent years used the previous year as its basis (i.e., BDDEM 2003 uses BDDEM 2002 etc.). For the three member states of the NG-CHC, the unincorporated single beam and multi-beam bathymetric surveys through 2011 included 19 surveys for Alabama, 12 for Mississippi, and 80 for Louisiana, as well as three surveys from western Florida (Fig. 15.7).

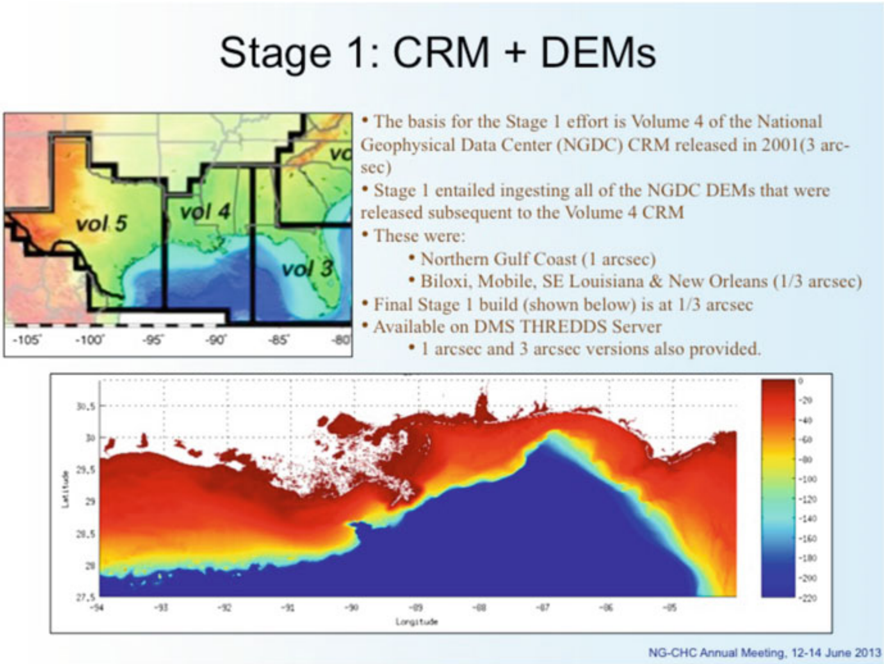


Fig. 15.7 Example of the first stage in adding bathymetric data to the dynamic digital elevation model (DDEM) strategy of NG-CHC

Table 15.3 Specifications for the NGDC high resolution DEM in the northern Gulf of Mexico

Name	Date completed	Spatial resolution	Horizontal datum	Vertical datum
Biloxi	03/29/2007	1/3 arc-second	WGS84	MHW
Mobile	11/30/2009	1/3 arc-second	NAD83	NAVD88 and MHW
Northern Gulf Coast	12/31/2010	1 arc-second	WGS84	NAVD88 and MHW
New Orleans	04/30/2010	1/3 arc-second	NAD83	NAVD88, MHW and MLLW
Southern Louisiana	12/31/2010	1/3 arc-second	WGS84	NAVD88 and MHW

The workflow applied for incorporating these NOS surveys by year employed open source software tools consisting of the Generic Mapping Tools (GMT, Wessel and Smith 1998), MB-System (Caress and Chayes 1996) and NOAA's Vertical Datum Transformation Tool (VDatum, http://vdatum.noaa.gov/welcome.html). The workflow consisted of: (1) translating the NOS survey to NAVD88 and gridding them to a resolution of one-third arcsec; (2) merging and annealing the gridded NOS survey within a surrounding subset extracted from the BDDEM basis; and (3) placing the updated bathymetry field subset back into the basis BDDEM at one-third arcsec. These software tools and workflow were streamlined to produce an open source toolkit that will allow either further updating of the BDDEM, or application of these tools to researchers in other coastal regions.

In addition to developing the first two stages of BDDEM products on the University of Southern Mississippi THREDDS server, NG-CHC developed a web-based Graphical User Interface (GUI) extraction module that facilitates extraction of bathymetry, using the second stage updates (2011) of three-arcsec resolution as the prototype. A BDDEM website was established (http://bddem.ngchc.org) that leverages the data identification and extraction capabilities developed for SIMULOCEAN. The BDDEM website is currently under active development as a resource designed to facilitate extraction of BDDEM fields to match a user's specific interest.

15.4 Collaborative Environment

From the above descriptions it can be seen that each of the three simulation management systems serves a somewhat different constituency ranging from science to engineering to management and functions from hazard prevention planning to emergency operations to ecosystem restoration. They share a common toolkit (Table 15.4) and the "connective tissue" of the cyberinfrastructure.

15.4.1 Cybertools of NG-CHC

The NG-CHC focused on developing a suite of CI tools (Table 15.4) centered on handling the needs of the simulation management systems in an integrated view (Nicolson et al. 2002). CI tools were used as a method for rapid prototyping all NG-CHC modeling efforts. These tools assisted researchers in identifying critical limitation that each simulation management system will face during its refinement and generation of future prototypes. Conducting the three collaboratory experiments in parallel, facilitated conditions where tools developed by one team enhanced the capabilities of the other NG-CHC teams, thus fostering collaboration. In addition, the group found that it was critical to engage a combination of modelers and non-modelers in the process of developing CI tools as well as educational aids/tools. This was in part accomplished by regularly scheduled discussions during bi-weekly teleconferences. The CI tools and services developed by the NG-CHC collaborators focused on functional attributes and services as follows: metadata extraction; cataloging and discovery; large file data transfers; workflow services; data access, formatting, processing, storage and visualization; and educational tools (Table 15.4). These CI tools provided scientists and educators with a reusable suite of standards-based tools and services to enable effective science collaboration, as well as improved access to high-performance computing (HPC) systems. Applications of the cybertools listed in Table 15.4 are described in the "Collaboratory Experiments" Sect. 15.5 below.

Table 15.4 Description of the various tools developed to support simulation management systems in NG-CHC

Tool title	Descriptions
Metadata extractions, cataloging, and discovery	
Sulis metadata creator <beta>	Web-based metadata template and creator that generates xml metadata records
NG-CHC Metadata driven visualization	Metadata driven visualization capability has been integrated into the NGCHC metadata catalog so that users can visualize distributed data within the portal
NG-CHC Metadata catalog	Developed a highly adaptable information catalog that is also deployable within collaborative environments. The catalog provides users with the ability to search, browse, and discover the information at different levels of granularity (Collection and Data Granule). Also developed a deployable visualization tool that consumes the catalog information. Packaged together, the catalog and the supporting visualization tool provide a suite of solutions to distributed coastal data management
Large files data transfer	
Globus online	Installed GlobusOnline server to facilitate staging and transfer of large data files during simulation experiments using the GridFTP protocol to facilitate data transfers. The team is working on automatically capturing the metadata for the transferred data and publishing it to the metadata catalog, allowing researchers to discover the large simulation experiment data via the portal or other tools and use Globus Connect to download
Workflow services	
Visual workflow system	A visual workflow system to assist the DDEM group with streamlining bathymetry data generation. The workflow will be triggered when new NOAA survey files become available
Science workflow deployment suite	Developed an apache airavata based science workflow management tool that can be used for constructing, deploying and executing workflows. This tool allows any application to be wrapped as a service. These services are deployed in cloud or computing clusters. Deployed mining workflows at the NSF XSEDE resources successfully. This tool abstracts various XSEDE job related functionalities, hence submitting and monitoring such jobs via workflow composer (XBaya) are seamless

(continued)

Table 15.4 (continued)

Tool title	Descriptions
Data access, formatting, processing, storage and visualization services	
GeoTIFF to NetCDF4 tool	MATLAB based scripts to extract header information from GeoTIFF, input GeoTIFF, transpose, and write NetCDF4 using low-level NetCDF MATLAB functions
ADCIRC to ESRI shape file scripts	C++ programs that take ADCIRC model data as an input and allows either the entire data or a selected geographic region of the data to be converted to an ESRI shape file
SULIS portal viewer	Custom viewer based on the Esri javascript API for searching and visualizing data from the Sulis Informatics Services Portal
SULIS severe weather viewer	Custom viewer based on Esri javascript API for viewing and comparing model forecast data for specific storms. Different forecasts can be compared side by side. Additional layers can be loaded to show additional data such as contextual information
Weather Underground Web Data Extraction Tool (WUDEXT)	This new tool extracts information stored in tables located at the bottom of any weather underground webpage. Such data, when used with caution, can be a useful supplement to traditional stations. The tool is able to extract the climate data from multiple days, months, and even years. All the extracted information is stored in a single text file
Coastal datafactory	The Coastal Data Factory (CDF) is a web-based data grabbing and preprocessing toolkit for gathering, refining, storing and plotting coastal data. CDF provides a data warehouse with an on-demand data grabbing engine that allows users to easily fetch data from multiple data sources or/and local data center and check data availability via web-based graphical user interface
Data to NetCDF scripts	C++ programs take ADCIRC, ADH, or EFDC model data and converts the data to a NetCDF format to be processed by the Sulis viewer. This provides a global maximum layer that will show the highest predicted values at each location of the ADCIRC grid
ASGS -NHC text advisories to ATCF format	Perl script to parse text advisories (shtml) from the National Hurricane Center. Converts them to ATCF format for use within ADCIRC. Writes a forecast track (fst) file by default
ASGS -ADCIRC ASCII to NetCDF script	A windows executable that allows the conversion of ADCIRC ascii files to NetCdf as used for the ASGS workflow

(continued)

Table 15.4 (continued)

Tool title	Descriptions
EnVis	Enhancements to scientific visualization package for complex model data. Envis can handle both unstructured and structured data. It can also handle rendering using level-of-detail and tiling which makes it appropriate to use within Esri map layers. It is used in the Sulis Geoportal to handle interactive visualizations
Coastal events driven data delivery and visualization	Event-Driven Data Delivery (ED3), aggregation and processing automates the access and processing of data for situational awareness in a hazardous event that could potentially become a disaster. ED3 is being integrated with decision support systems to state agencies in Alabama, and others to help define the capabilities that will best suit the end users for a variety of events. In NG-CHC, ED3 can be used to trigger data collection and subsequent workflow during tropical storm events
FloodViz	Visualization tool that calculates the inundation of land based on the river levels over time provided from HEC-RAS over the DEM, geo-referenced imagery, and ESRI shape files. The batch mode capability of this tool will be used to output contour lines, which can be used by the Sulis viewer. Once this is in place, FloodViz may also be expanded to handle other model data as inputs
Educational tools	
Research-based interactive computer simulation to model response of floodplains to precipitation events	An interactive research-based computer simulation and educational tool for floodplain analysis
Online storm surge game	An interactive web-based user interface for a simple one dimensional storm surge model

15.4.2 NG-CHC Portal

The NG-CHC collaborative environment enables close interaction among coastal scientists, educators and computer scientists. Minimizing the complexities of sharing, discovering and using data and information can enable the scientific process and stimulate discovery, by allowing users to concentrate on science. Based on a freely available Content Management System (CMS), the extensible environment provides a portal with modules specifically developed to support science research, analysis, and visualization for distributed coastal data management. Users can organize, discover, share, and use information about data, models, tools and other

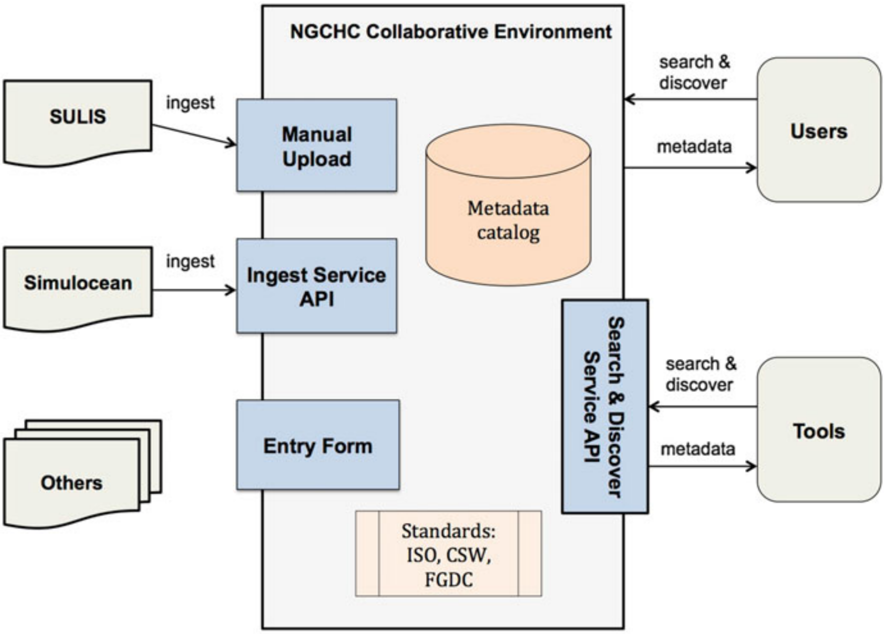


Fig. 15.8 The information architecture of the NG-CHC Collaborative Environment Metadata Catalog shows how the standards-based catalog can be updated manually with ingest scripts, via an automatic ingest service, or with a simple user entry form. The catalog can be searched and accessed by either users or tools to discover and consume data of interest

resources; discuss project activities and results; view publications, presentations and other documents; and track the history of project activities. Information can be categorized and aggregated by content type and group audience. Integrated tools and services include collaboration support; standards-based metadata extraction, cataloging and discovery; large file data transfers; workflow services; data access, formatting, processing, storage and visualization. The NG-CHC portal includes both public and private areas, as well as an education and outreach area with project information, educational tools and learning modules, to increase public knowledge and understanding.

The NG-CHC collaborative environment hosts a Federal Geographic Data Committee (FGDC)-based metadata catalog, providing users with a central location to search, browse, and discover information at different levels of granularity. A variety of metadata ingestion tools are supported, including ingest scripts that plug into a modeling workflow, a file upload interface, a manual form-based interface, and a THREDDS metadata harvester, to aggregate information and catalogs from a variety of coastal information systems. Both SULIS and SIMULOCEAN publish metadata to the NG-CHC metadata catalog in support of simulation experiments, as depicted in the information architecture (Fig. 15.8). Standards-based publication of catalog entries allows for existing tools to search, discover, and consume the information.

An integrated metadata-driven visualization tool provides custom mapping capabilities for a variety of data. Any geo-located data (image) can be displayed as a layer. Users can select from a list of available data layers or add their own data layers and overlay on various maps, including 2D and 3D maps. Analytic capabilities (such as feature queries) are available over displayed layers. Both the catalog and related tools are compliant with geospatial metadata and visualization standards, making this cyberinfrastructure interoperable with other standards-compliant geospatial tools and systems.

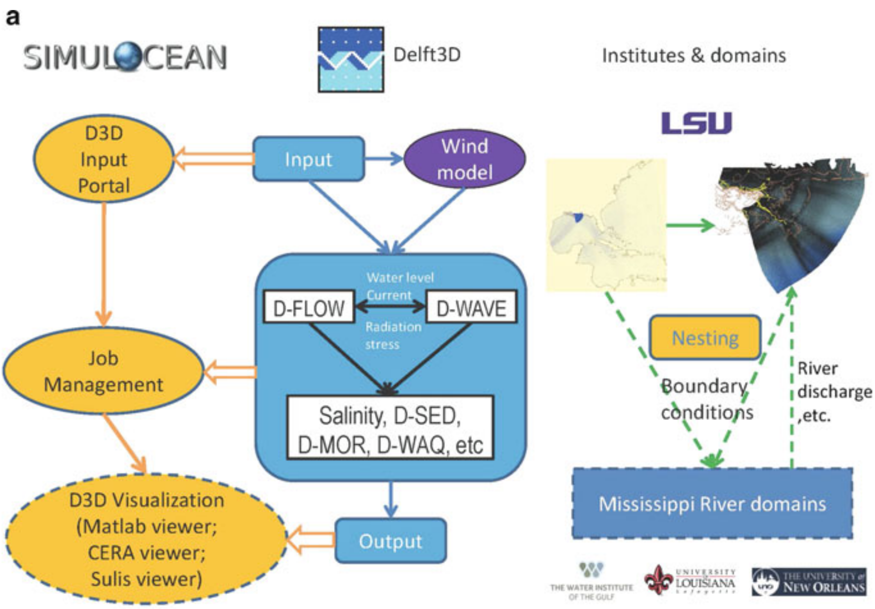
An event-driven data delivery (ED3), aggregation, and processing tool can be used to automate the access and processing of data for situational awareness in coastal hazard events that could potentially become disasters. For instance, a tropical storm event could trigger data collection and subsequent workflows that process and prepare the data for more rapid decisions to help mitigate the effects of coastal hazards. Together, these tools and services provide a suite of solutions for NG-CHC project activities, model development and simulation experiments.

15.5 Collaboratory Experiments

The following three experiments were developed during the 3-year NG-CHC project. These experiments were contributions from the group to develop interdisciplinary models that inform coastal and inland water resources planners and managers. This exercise initiated an open, highly participatory, and coordinated collaboration among the universities involved, and it is in line with the goal of developing tools that promote general agreements and a shared vision of future users (Loucks 2012).

15.5.1 River Management and Ecosystem Restoration

Ecosystem restoration of the northern Gulf coast requires an accurate prediction of sediment transport and landscape changes caused by tropical cyclones and winter storms (Chen et al. 2007, 2008; Zhao and Chen 2008). To meet the needs, NG-CHC adopted the open-source software package Delft3D as a key component of SIMULOCEAN (Figs. 15.3 and 15.9). Nested, curvilinear grids ranging from basin-scale domains similar to the ADCIRC mesh to local-scale domains that cover Breton Sound and Terrebonne Bay, coastal basins of Mississippi River delta, have been developed. Simulations of Hurricanes Katrina (2005) and Gustav (2008) as well as Tropical Storm Lee (2011) using the nested Delft3D model, and comparisons with field observations have been carried out. It is found that the domain decomposition function (nesting with different resolution) in Delft3D is particular useful to capture storm surge in this complex coastal region.



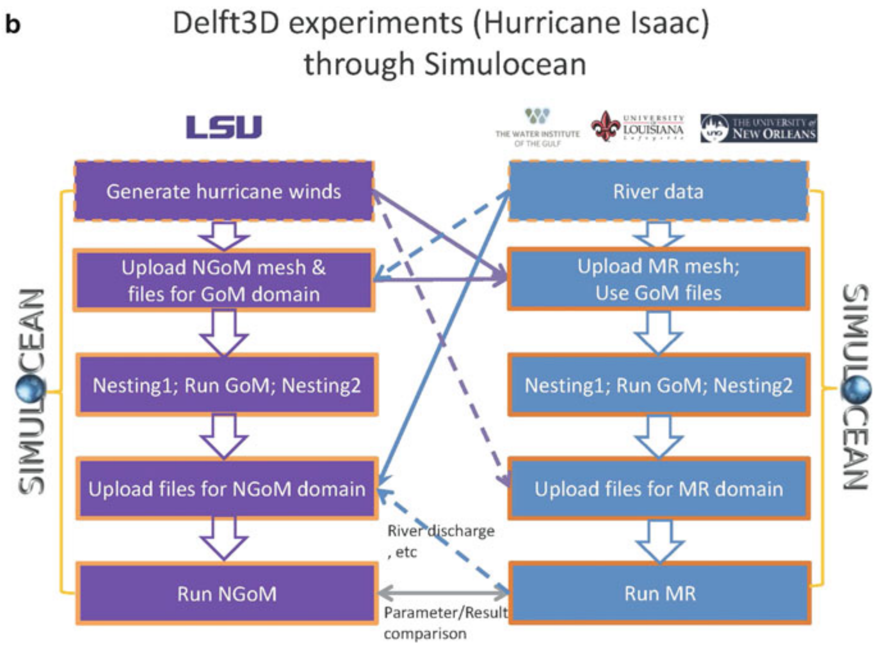


Fig. 15.9 SIMULOCEAN was used to perform a suite of experiments on Lower Mississippi River using following models: (**a**) a regional Delft3-d model for the Lower Mississippi River; (**b**) a 3-d FVCOM surge model for the Pontchartrain Estuary

SIMULOCEAN was also used as a management system to simulate storm surge movement up the Mississippi River during extreme events (Fig. 15.9). The following models were validated and applied to evaluate interaction of coastal restoration features along the Mississippi River. A regional Delft3D model for the Lower Mississippi River captures storm surge and sediment transport from the mouth of the river upstream to one of the largest flood control structures just north of New Orleans, the Bonnet Carré Spillway. At a finer scale resolution of river dynamics, two Delft3D models were used to simulate sediment transport in segments of the river upstream and downstream of the Bonnet Carré Spillway. The validation of these finer scale models during operation of this flood control structure, during high flood events, were used to simulate anticipated sediment dynamics for a proposed river diversion structure planned for location in the vicinity of Myrtle Grove, Louisiana. Along with these river models based on Delft3D, is another simulation approach of estuarine processes using a 3-D FVCOM surge model for the Pontchartrain Estuary. This model was also operated within the SIMULOCEAN management system to test model behavior as validation technique using results from Hurricane Isaac (2011). The estuary model showed that, for the same storm category, the maximum surge heights are very sensitive to storm duration, as controlled by the storm's forward speed. Finally, a rapid response dynamic 1-D (HECRAS) was designed to compute storm surges as far upstream as Old River Control Structure, nearly 485 km upstream from mouth of Mississippi River. These numerical experiments were conducted using validated models as described, using the simulation management systems to compare model results with field observations. The local high-resolution models have been used to develop sediment water delivery ratios (SWR) for river diversion structures with deep and shallow sill designs. The SWRs are important in assessing the efficiency of a diversion in building land (Meselhe et al. 2012).

15.5.2 Mobile Bay Experiment: Processes from Catchment to the Coast

A simulation experiment was conducted using SULIS to develop a protocol for integrating four models for the Mobile Bay system (Figs. 15.4 and 15.10), including HSPF to simulate flow discharge (Alarcon et al. 2009), WRTDS to calculate nutrient loads (Maestre et al. 2012; Hirsch et al. 2010), ADCIRC to simulate storm surges on the shelf, and EFDC to forecast circulation and nutrient transport in Mobile Bay (Kim and Park 2012), using the cybertools of Table 15.4. For example, the Watershed model HSPF imported landscape data from elevation database using the metadata catalog, computed rainfall runoff which was converted to a common format by the GeoTiff tool. Those results were picked up by the WRTDS model to calculate nutrient loads to the bay. All simulations during the experiment were logged into the database by the Metadata Creator. Surge data

Fig. 15.10 Joint effort from NG-CHC universities to estimate nutrient transport in Mobile Bay and its watershed as part of the loose coupling experiments

from ADCIRC were supplied the same way and all inputs merged for use in the water quality simulation of Mobile Bay and subsequent visualization and analysis by the cybertools. The impact of the protocol is to allow coastal scientists and engineers to model the interactive effects of hurricane storm surge and watershed processes in Mobile Bay and resource managers to examine the results for planning and operations requirements. This is a new capability provided from the collaboratory to the principal disciplines of coastal engineering and science along with resource management across the spectrum of physical, biological and human systems. This capability can be used by practitioners to investigate a number of environmental phenomena that may have significant social and economic impacts (e.g., hypoxia in coastal areas directly affects fisheries, recreation, and land values).

While much research exists in freshwater studies regarding transport of nutrients through watersheds, efforts to investigate the dynamic role of the watershed on the receiving bay during and after a hurricane, as well as testing hurricanes with different intensity, are lacking. The protocol developed in the Mobile Bay Simulation Experiment provided an avenue for evaluating watershed impacts on coastal ecosystems during these events. For example with this protocol one can ask how different characteristics of storms would affect nutrient transport mechanisms and thus impact the distribution of land-derived materials along a coastal area. The Environmental Protection Agency (EPA), The National Marine Fisheries Service (NMFS), and other state and federal organizations can use this protocol to better manage coastal resources.

15.5.3 Forecasting Hurricane Storm Surge

ASGS and CERA software facilitates hindcasting exercises by providing the following capabilities in testing how different storms interact with coastal environments: (1) storm surge model validation; (2) model result comparisons; and (3) real-time comparisons of model results with observational data collected during a hurricane. For example, during Hurricane Isaac (2012) operational runs were provided using different grid configurations and wind forcing algorithms by LSU and MSU to test sensitivity of these parameters to forecasts of coastal inundation. LSU used a high-resolution grid configured for the Louisiana coast including updated elevations for improved levee systems following Hurricane Katrina (produced by Coastal Protection and Restoration Authority for the 2012 Coastal Master Plan, known as the CPRA grid). While this grid contains updated information for Louisiana coast, it has lower resolution for the eastern Northern Gulf in Mississippi and Alabama. In contrast, MSU used the S08 grid for simulations of ADCIRC during Hurricane Issac, which more accurately represents elevations of the Mississippi and Alabama coastlines, but does not capture the detail of coastal Louisiana. Developing software that can quickly visualize simulation results from different grid systems is advantageous since even small errors in hurricane track forecasts can result in large surge differences along the coast of these three states. In addition, MSU and LSU could focus their supercomputing capability to local impacts, but at the same time emergency managers could compare relative estimates for respective coasts in the northern Gulf region. Both institutions used shell scripts for preprocessing and post-processing data. LSU used ASGS for preprocessing while MSU's was in-house. Both relied on software tools such as Google Earth, OpenDAP, GIS Shapefile generation, perl, netcdf, FORTRAN, and

GMT. This helped to improve forecasting methods, validate ADCIRC model grids, and enhance modeling research by the ADCIRC community.

Both LSU and MSU downloaded intensity, track, and storm size parameters in the National Hurricane Center forecast statements, but incorporated these parameters in different wind forcing schemes to generate a forecast ensemble. LSU used the "asymmetric vortex" method discussed by Mattocks and Forbes (2008), while MSU used a variant of the Holland scheme, which included storm translation and radius of 34-knot winds implicitly in the wind shape parameter. CERA provided graphics for both simulations comparing results to real-time observations and hindcast analysis for Isaac. For instance, different wind models were compared to the official wind model (asymmetric vortex). Maps were created to identify locations of significant differences in coastal inundation predicted between the two simulation efforts. In addition, USGS rapid deployment stations were posted on the CERA website to compare observed and predicted values of the two grids and to compare the different wind models (Figs. 15.5 and 15.6).

15.6 Education and Outreach

The focus of the NG-CHC has been to create a collaborative environment that allows the integration of models from the catchment to the coast. While products have included tools that facilitate this integration, the output of these efforts has been focused on scientific visualizations. Thus, the focus of the education effort has been to introduce students to scientific visualizations, models and modeling through a lens of coastal hazards.

The NG-CHC developed a Coastal Hazard Curriculum Unit for middle and high school students consisting of four lesson modules (Fig. 15.11). The curriculum unit is currently based on visualizations of hurricane storm surge using the REAL tool. The REAL (Rapid Estimates of Approaching Landfall) tool uses pre-computed, high resolution model data to generate fast, accurate, time dependent and operation estimates of local storm surge. As a unit, these modules help students learn about accessing data online, the use of visualizations in scientific research, how to use Google Earth (GE), hurricanes and the importance of storm surge as a coastal hazard. While initially available only in paper and electronic form (during testing), this unit has being converted to an online tool. The curriculum unit is openly available at http://stormsurge.disl.org.

Formative assessments of curriculum unit (Fig. 15.11, upper panel) were conducted on the coastal hazard curriculum unit at 3 K-12 educator workshops (n = 58 participants total: Teachers Exploring Coastal Hazards, MSU, 6/2012; Climate Change in the Gulf of Mexico, DISL, 7/2012; iSTEM meeting, Huntsville, AL 2/2013; Climate Change in the Gulf of Mexico, DISL 6/2013). The GE module was added as a result of need indicated by formative evaluations.

Student evaluations of the curriculum unit were conducted in the spring and summer of 2013 (n = 110; 70 % 11th graders; Auburn High School marine science

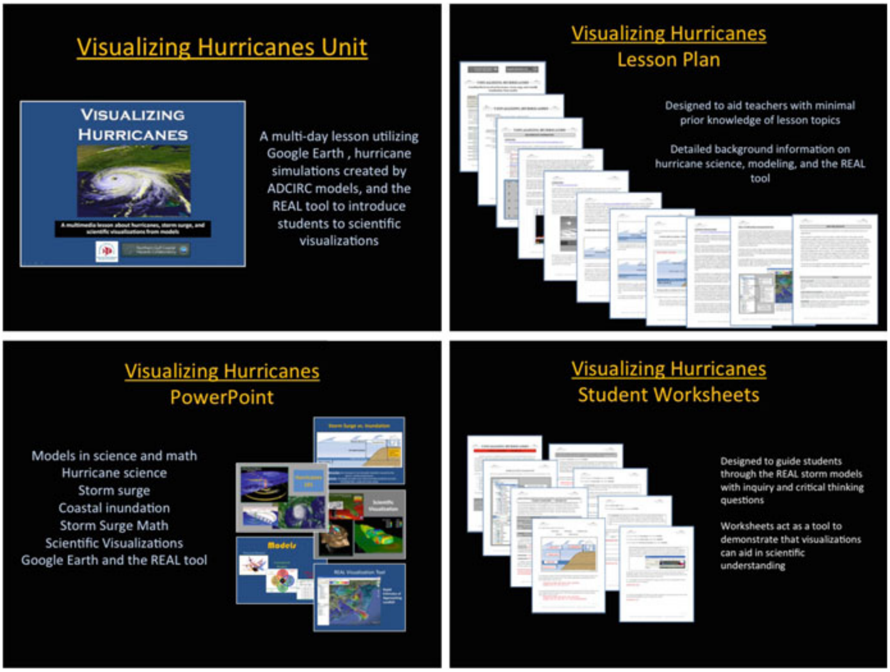


Fig. 15.11 Coastal Hazard Curriculum Unit for middle and high school students entitled 'Visualizing Hurricanes'. The *upper left panel* and *bottom two panels* define some of the materials developed as part of the curriculum unit including lesson plans, power point presentations, and student worksheets

club; Baker High School marine biology classes; Discovery Hall Programs Summer High School program) (Fig. 15.11, lower panel). Student evaluations indicated that the lesson plans were interesting (75 %), clear and easy to understand (75 %) and resulted in "improved knowledge of storm surge and inundation" (92 %). Interestingly, 72 % indicated they would be more likely to pay attention to evacuation notices about storm surge as a result of these lessons. Lastly, 81 % agreed or strongly agreed with the statement "using visualizations helps me to better understand scientific information".

This interactive simulation approach to the exploration of hurricanes and associated storm surge has been developed into a storm surge 'game' suitable for K-12 students and the public. The 'game' allows the user to explore the impacts of storm surge at the local scale by selecting both storm intensity and storm landfall location along the northern gulf coast. Model simulations then display maximum surge elevation or maximum surge inundation as color superimposed on a map or satellite view. Included is the ability to display hydrographs showing water levels at tide gauge locations over time. Users can zoom in and out displaying a smaller or larger geographic area. The 'game' can be accessed at http://stormsurge.disl.org.

An interactive research-based computer simulation and educational tool for floodplain analysis (Fig. 15.12, lower panel) simulated the response of upland

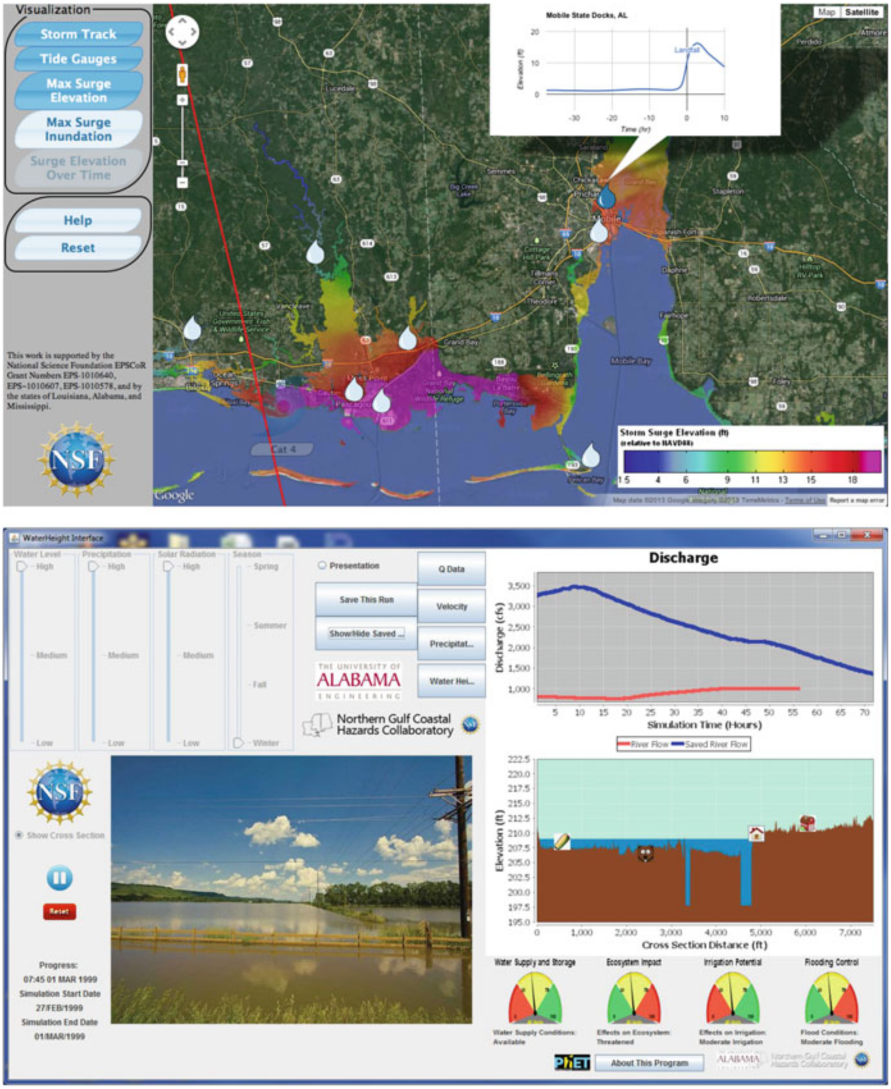


Fig. 15.12 Screen clips of interactive educational tools developed by NG-CHC. The online storm surge 'game' (*upper panel*) allows users to explore the impacts of storm intensity and landfall location on surge elevations and inundations on specific geographic locations using a Google Earth interface. The tool allows the simulation of hypothetical storm tracks (*red line*), the display of location-specific hydrograph plots, and the ability to zoom in geographically. The floodplain computer simulation and educational tool (*lower panel*) allows users to set initial conditions of water elevation, precipitation, and solar radiation in specific seasons, and observe the changes in discharge, velocity, and water stage in a floodplain located in the Sipsey River (Alabama) (color figure online)

flood plains to extreme event precipitation. The simulation is based on similar efforts developed by the PhET project of the University of Colorado to model real-life science and engineering phenomena. Variables including water level, solar radiation, season, and storm intensity can be adjusted by the user to assess the relative impacts of different scenarios. Target audiences for the educational tool are K-12 to college students. The simulation allows students to choose the initial conditions of a section of the Sipsey River (located near Tuscaloosa, Alabama) and observe the potential impacts in the floodplain. The simulation is initiated from historical records, while the user observes how the discharge, stage, and velocity of the river changes. The simulations are based on hourly records collected at the Elrod station managed by the USGS. The first draft version of the simulation has been posted as an executable Java executable file in the NG-CHC portal. An initial testing of the tool was conducted by students at the University of Alabama.

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