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Development of the Coupled HYCOM and ADCIRC Models with an Application in the Northern Gulf of Mexico

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Current applications require the ability to resolve complex fluid dynamics in shallow straits and near-coastal zones; however, this level of resolution is not possible with structured grid regional/global ocean models, such as HYCOM. Thus, development efforts have centered around enhancing the 3D baroclinic dynamics of an unstructured coastal model, ADCIRC, which has been successfully validated against process-oriented tests on simplified domains and against laboratory data. The advantage of utilizing ADCIRC is its ability to map intricate shoreline and the corresponding topography needed to resolve the complex fluid dynamics. In two-dimensional barotropic applications, such as hurricane storm surge, the model domain encompasses large portions of an ocean basin in order to simplify the open boundary conditions; however, in the high-resolution, 3D, baroclinic simulations there is an order of magnitude increase in the computational demands. Thus, the model domain for baroclinic applications is restricted to the shallow water region of interest. Consequentially, this places the open boundary in a zone dominated by complex, nonlinear processes, so proper specification of the open boundary conditions is difficult. Hence, one solution is to couple the offshore (downscaled) conditions provided from HYCOM to the nearshore (coastal) circulation model of ADCIRC. This presentation will incorporate the model development needed to achieve the ADCIRC/HYCOM coupling along with an application in the northern Gulf of Mexico utilized to preliminary evaluate the coupled model.

Modeling the Turkish Straits System with 3D Baroclinic ADCIRC

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In this study, we utilize a coupled model system to model the entire Turkish Strait System. Two narrow, shallow straits, i.e. the Dardanelles and the Bosphorus, form a physical connection between the Marmara Sea and its adjacent water bodies, the Aegean Sea to the southwest and the Black Sea to the northeast. This collection of seas and straits is known as the Turkish Strait System (TSS). Saline, dense water from the Aegean flows in a deep, lower layer through the Marmara Sea to the Black Sea while fresher and lighter Black Sea water flows in a surface layer to the Aegean Sea; forming a two-layer estuarine flow. Though the TSS dynamics are the result of interconnections between the straits and the ocean basins, earlier modeling efforts have focused dynamical studies on individual straits or seas.

3D Baroclinic version of ADCIRC is utilized to capture the range of spatial scales, geometric complexity and interconnected dynamics of the TSS. The unstructured ADCIRC mesh has the resolution, using a minimum element edge length of 7 m, necessary to model flow in the narrow straits whose minimum width is approximately 600 m. Flexibility of the finite element mesh not only captures the fine scales within the straits but is also able to represent mesoscale variability in the Marmara Sea while coupling to a basin scale model in the Aegean and Black Seas. Basin-wide dynamics are captured by the HYbrid Coordinate Ocean Model, HYCOM, which applies the finite difference method over a structured grid to solve the primitive mass and momentum balance equations. HYCOM's hybrid vertical coordinate allows the use of three vertical coordinate types (depth, terrain-following and isopycnal) which better represents thermohaline dynamics in waters of rapidly varying bathymetric change. Within the HYCOM Aegean-Marmara-Black Sea model (HYCOM-AMB), both straits are represented as idealized channels since the current resolution (~1.3 km) is not sufficient to resolve the geometry of the straits.

Model experiments presented focus on the time period of the sea trials (a joint project between the NATO Undersea Research Center and the U.S. Naval Research Laboratory), starting in late August and extending through November 2008. ADCIRC is initialized by temperature, salinity, velocity and water surface elevation fields from HYCOM-AMB solutions over the same region. At the open ocean boundaries, HYCOM-AMB values for elevation, temperature and salinity are updated daily throughout the ADCIRC model simulation. Surface forcing for both models is derived from the Navy's Coupled Ocean-Atmospheric Mesoscale Prediction System (COAMPS). The capability of ADCIRC to represent two-layer stratified flow dynamics both in the straits and in the Marmara Sea is examined. The results show many of the significant flow features of the TSS system. The model is shown to capture both the Dardanelles dense flow and the Bosphorus jet flowing into the Marmara Sea through the straits. Moreover, the flow of the dense Mediterranean water beyond the Black Sea shelf as well as the spread of the Dardanelles plume into the Aegean Sea is observed in the model results. Finally, the response of the currents and density structure over the water column to atmospheric forcing will also be examined.

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2D & 3D Studies with ADCIRC in a Long Narrow Channel

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To better understand the differences between 2D and 3D model behavior, several tests are run on an idealized domain. Previous studies simulating Hurricane Isabel and forcing an idealized wind over a uniform channel have shown that the differences in 2D and 3D simulations are on the order of 5%. Those tests varied the turbulent eddy viscosity and the bottom roughness in the 3D model, while using a constant Manning's n in the 2D model. Subsequent model runs for Hurricane Charley resulted in a larger difference between the two constructs, ~15-20%. Our work here is an attempt to dig deeper and resolve the discrepancy. We perform a preliminary suite of simulations forcing a long narrow channel with winds that vary from a constant 10m/s, 30m/s and 50m/s to a time varying 50m/s max wind pulse. Three bathymetries are used, constant depth 2m and 5m, and a sloped bathymetry starting at 156.5 and ending at 2m. For each 3D simulation 3 bottom roughness values, 0.001, 0.005, 0.01, and 3 surface roughness values, 0.03, 0.3, 3.0 are tested. These 3D simulations are compared to 2D simulations where the bottom friction is varied from 0.002, 0.0025, and 0.003. These preliminary tests confirm the previous results, that difference between 2D and 3D model results, when forced with a steady wind, is less than 5%. In most cases the difference is less than 3%. For the preliminary test cases, the largest differences occur when forced with the time varying wind pulse. A follow–up suite of simulations is performed, focusing on a time varying forcing, and four new domains which range from a plane slope 1:2000, to a 1:1000 profile that ends with a 200km long 2m deep shelf. Both 2D and 3D model simulations are performed. Examining the force balance, we draw conclusions about the relative importance of the total acceleration and bottom stress terms compared to the wind stress. These results will help us to better understand the differences in the results obtained using a 2D and 3D model construct.

Modeling a Tidal River in ADCIRC: The Importance of the Flood Plains

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Many coastal rivers are bordered by extensive areas of marshes, swamps and intertidal flats which exert a distorting effect on the tidal wave as it travels along the river axis. This distortion is important to upstream transport through tidal pumping. As models such as ADCIRC are increasingly being applied in rivers, and are called upon to make high resolution predictions of the tidal and river currents, it becomes important to accurately model these channel edge effects. A model is presented of the lower Pearl River in Louisiana and Mississippi incorporating the neighboring flood plains and accounting for the effects both of topography and vegetation. Computed currents and elevations are compared to measurements in the tidal reach of the river. A detailed look is taken at the modeled tidal wave distortion and this is compared to theory.

Aspects of Coupled Hydrologic – Hydrodynamic Modeling for Coupled Flood Inundation

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The hydrodynamic model ADCIRC has been used extensively to model inundation due to hurricane storm surge. Work funded by the National Oceanic and Atmospheric Administration and Department of Homeland Security seeks to produce a more complete coastal flood inundation modeling system by creating a total water level product that incorporates rainfall-runoff along with the tide, wind and wave induced coastal flooding currently used for predictions. Coupling of a hydrologic model to ADCIRC will allow predicted river boundary conditions out of the hydrologic model to be used in ADCIRC. A number of issues exist in coupling the models, including which hydrologic model to use, where the boundary will be located and the boundary conditions used to exchange information between the models. The initial target area for this study is the Pamlico Sound region of coastal North Carolina. The Tar and Neuse Rivers both feed the Pamlico Sound and the area was impacted by Hurricanes Floyd (1999) and Isabel (2003) in the last decade. The hydrologic models that have been set-up and calibrated for the Tar and Neuse Rivers to provide results for the coupled modeling are a physics-based distributed hydrologic model, V_{flo}, and the National Weather Service Hydrology Lab distributed model, HL-RDHM, which is a distributed model using SAC-SMA and kinematic routing. Methods to modify the ADCIRC grid and initialize the rivers will be presented. Additionally, results from studies of various methods of specifying discharges at the upstream river boundary will be discussed. Select coupled model results will be shown for tropical systems that have impacted the target area.

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A Tool for Rapid Configuration of a River Model

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A software tool has been developed, the River Simulation Tool (RST), that allows the configuration of a two-dimensional hydrodynamic river model based on imagery-extracted information that defines model geometry and water depth, as available. The RST contains automated shoreline processing and mesh generation capabilities for unstructured grids and accommodates user-specified forcing and parameter values. Alternatively, the RST provides synthetic bathymetry and default forcing and parameter values for those situations in which observational data or information describing the river environment is unavailable. Implementation of the RST's ensemble creation feature allows an assessment of the sensitivity of river predictions to the specification of water depth, bottom type, and upstream discharge conditions. This presentation describes the components of the RST in detail and its application to the upper East Pearl River, MS. Solutions for water level and currents from the RST-generated river model are intercompared to examine different approaches for model application in the same region.

The ADCIRC Surge Guidance System (ASGS) - Pushing Surge Calculations into Quasi-Operational Forecast Mode

Rick Luettich, UNC Chapel Hill

An overview will be presented of experience gained in the first year (2009) of the ADCIRC Surge Guidance System (ASGS). This program was develolped to provide coordinated, quasi-operational, semi-automated storm surge/inundation/wave guidance for US East and Gulf Coasts. Specific aspects of ASGS include consistent and tested codes, grids, and methodology to provide consistency of message and complementary, prioritized runs and results, including redundancy. ASGS seeks to leverage and help improve regional computing resources, scientific/engineering expertise and established clients. ASGS takes advantage of multiple HPC facilities to provide 5 day forecasts within 2-3 hrs; seeks to develop, train and expand an expert base; develop communications with regional NWS WFOs, state emergency management offices; and provide targeted release of guidance (e.g., results not released publicly).

Real Time Surge Guidance under Antecedent Conditions: Analysis of ASGS Results for Hurricane Ida

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Hurricane Ida of 2009 represented a smaller and therefore more typical hurricane threat for the northern Gulf Coast than the major storms that are often re-analyzed and reviewed by storm surge researchers. Although the analysis of severe hurricanes is useful for design calculations, storms like Ida actually present more ambiguity to decision makers during their approach. This ambiguity magnifies the need for accurate storm surge guidance. The achievement of accurate storm surge guidance in a real time system requires an understanding of the relative importance of the sources of physical forcing such as direct wind stress, barometric pressure, wave radiation stress, astronomical tides, riverine flow, antecedant background meteorological forcing, and sea level residual on the total setup of the water surface elevation. The contributions of each of these types of physical forcing to the total water level setup was therefore quantified, using Hurricane Ida as a case study, to determine which forcing types were dominant in various locations, and to ensure that all the significant physical drivers of storm surge were included in the ASGS formulation. Results and conclusions about the upcoming 2010 hurricane season will be presented.

Development, Implementation and Validation of an ADCIRC-based Operational Coast Forecast System

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Abstract – An automated coastal forecast system has been developed and implemented for the Korean Coast region. The core coastal circulation model embedded in this system is a three-dimensional, finite-element based hydrodynamic model, the Advanced Circulation Model for Shelves, Coastal Seas, and Estuaries (ADCIRC). Its unstructured grid allows modeling complex coastal regions at fine spatial scale. The West Korea Coast is a highly dynamic, tidally-driven region with complex coastlines and tidal flat zones; it is therefore requires a high resolution system that has the capability to represent and model complex geometry and wet/dry situations. Various scripts, programs and toolkits are developed to automate major tasks of the forecast run stream such as initial setup, forcing data acquisition, model configuration and post-processing. The grid bathymetry was derived from the Naval Research Laboratory global Digital Bathymetry Data Base (DBDB2) 2-minute resolution database. This dataset also incorporates the high resolution Yellow Sea/Korean Coast data from Choi. The model grid domain encompasses Yellow Sea, Bohai Sea and part of the East China Sea where the open ocean boundary follows the 200 m isobaths between Taiwan and Japan. The tidal potential and tidal constituents are extracted from the FES2004 global tidal database and the present setup includes eight main tidal constituents. For the surface forcing, meteorological wind and atmospheric pressure fields are provided by the Navy Coupled Ocean Atmospheric Mesoscale Prediction System (COAMPS).

The Korean Coast forecast system has been running daily on NRL's Linux cluster since September 1st, 2009. The current configuration is to make 48-hour forecasts valid at 0Z everyday. A typical 48-hour forecast run cycle takes approximately 4 minutes wall clock time on a 16-processor Linux cluster. Current system products include hourly 2-dimensional water level and current plots for the Korean Coast region and time series of water levels at specified locations. Although this system is fully automated, this system does provide additional flexibility to support manual override and modification. Preliminary model validation and issues in implementing such a system will be presented at the workshop.

ADCIRC's Role in NOAA's Storm Surge Roadmap

J. Feyen (NOAA/NOS/OCS/CSDL)

NOAA has a storm surge mission that covers a large range of customer requirements, offices, and expertise. In order to leverage resources to best meet the needs of its customers, NOAA has developed a Storm Surge Roadmap that describes an agency-wide strategy for improving its storm surge enterprise. The vision, which reflects NOAA's many missions, is to clearly communicate the total water inundation risk above ground level for decision-making across multiple time scales such that the U.S. is optimally resistant and resilient to inundation impacts. The Roadmap provides a systematic approach to growth by coordinating and leveraging research, development, and operations across NOAA and its partners. It enables NOAA to move beyond incremental improvements in capability toward a long term, multi-disciplinary strategy based on a customer-focused approach. Presently in Phase 1, the Roadmap is focused on maximizing the best of current techniques while promoting research into new tools and capabilities that will transition to operations down the road.

The presentation will describe the Roadmap, how it functions, outcomes, and what lies ahead. It will highlight the role community-based models such as ADCIRC play within NOAA's storm surge enterprise for the future by describing a modeling framework, ways to streamline the transition of research to operational facilities including important principles to consider, and some recent development work.

Development of an Extratropical Surge plus Tide Operational Forecast System (ESTOFS)

Yuji Funakoshi, Jesse Feyen, and Frank Aikman III (NOAA/NOS/OCS/CSDL)
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Joe Sienkiewicz (NOAA/NWS/NCEP/OPC)
Hugh Cobb and Jessica Schauer (NOAA/NWS/TPC/TAFB)

The objective of this project is to develop an ADCIRC-based operational extratropical surge and tide forecast system (ESTOFS), predicting water levels and currents for the Western North Atlantic basin. A high resolution unstructured mesh is used to describe the complex geometry over the shelf and near the coast. The Global tidal model harmonic constituent database is applied for open ocean boundary conditions. The Global Forecast System (GFS) is used to provide atmospheric forcing. The operational model will provide water level over the entire domain and point predictions at Center for Operational Oceanographic Products and Services (CO-OPS) stations.

The following three candidate grids are used to evaluate the accuracy and robustness of the ADCRIC-based model for the Western North Atlantic domain:

1. East Coast 1995 tidal database grid (EC95): EC95 was completed in 1995 on a grid consisting of 31,435 nodes. Coastal resolution generally averages about 6 km. The model performance was verified using tidal elevation data from over 65 observation stations throughout the domain.
2. East Cost 2001 tidal database grid (EC2001) version 2e: EC2001 was completed in 2001 on a grid consisting 254,565 nodes. Coastal resolution generally averages about 3 km. The model performance was verified using tidal elevation data from over 100 observational stations throughout the domain.
3. University of Central Florida (UCF) grid: UCF grid, containing 52,774 nodes, was generated based on localized truncation error analysis. Coastal resolution generally averages about 5 km. Qualitative and quantitative comparisons of model performance were made at 150 historical tidal stations throughout the domain.

These grids were applied to the November 2009 "Veteran's Day Nor'easter" to validate the model performance. Input variables and parameters were consistent in all models and referred from Delaware Bay Model Evaluation Environment, which was verified by tidal simulation. Water levels were compared with observed and predicted water levels at CO-OPS National Water Level Observation Network stations. A standard suit of National Ocean Service skill assessment statistics which includes Series Mean, Root Mean Square Error, and Central Frequency were computed for these models.

The ESTOFS will be implemented within National Centers for Environmental Prediction (NCEP) Central Operations (NCO) to predict surge and tides. It is designed to provide surge and tide levels to WaveWatch III (WWIII) for coupling and to provide boundary conditions for higher resolution coastal models of water levels and waves. Therefore, its set-up is designed to mimic WWIII: it will use the same GFS forcing, and have the same forecast cycle and length, and will even run concurrently at NCO. Second, it will also provide NWS with a second extratropical surge model in addition to the Extra Tropical Storm Surge system (ETSS) that currently is based on the Sea Lake and Overland Surge from Hurricanes (SLOSH) model. ESTOFS combines tides with surge and utilizes unstructured grids which can provide higher resolution at the coast. This capability serves the needs of NCEP's Ocean Prediction Center and the National Hurricane Center's Tropical Analysis and Forecast Branch, who are responsible for providing marine forecasts.

Convergence of Storm Surge Forecasts for Hurricanes Gustav and Ike

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Forecast simulations of Hurricane Gustav and Hurricane Ike were carried out using winds generated by an asymmetric wind model directly coupled to ADCIRC at every time step and grid node. The wind model was forced by parameters provided in the National Hurricane Center's forecast advisories. The variability of water elevations produced by different advisories was analyzed for the two storms.

Several measures were used to study the evolution and convergence of the predicted surge. Comparisons between the storm surge magnitude and the areal extent of the inundation generated by individual advisories and best track data were used to determine the variability in the predicted storm surge during the final 5 days of the storms.

Differences in maximum surge elevations for ensembles comprised of the final 20, 15, 10 and 5 advisories plus the best track were employed to evaluate the evolution and convergence of the storm surge forecasts. The timing and spread of the convergence of storm surge forecasts computed in this study provide useful measurements for supporting decision-making during threats of tropical cyclone landfall.

Coupled Waves and Storm Surge during Hurricane Gustav

JC Dietrich, JJ Westerink, AB Kennedy, M Zijlema, LH Holthuijsen, C Dawson, RA Luettich

Recent modeling of hurricane storm surge has coupled circulation and waves models so that they run on the same unstructured meshes and by the same computational processors. This method improves both the efficiency and accuracy of the computed solution. The coupled SWAN+ADCIRC model is well-positioned to generate waves and surge in deep water, propagate them onto the continental shelf, and dissipate them in complex nearshore systems. Gustav impacted southern Louisiana in 2008, during the same intense hurricane season as Ike. Gustav made landfall in south-central Louisiana, but its winds forced waves and surge against the levees and infrastructure near New Orleans. It is a good validation hurricane because of the wealth of measured time series, which show how the hurricane evolved as it moved through the system. Validation results show that SWAN+ADCIRC simulates accurately the waves and storm surge during this hurricane event.

Implementation of the Unstructured PADCSWAN Coupled Model for the Puerto Rico Region

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The unstructured PADCSWAN coupled model is implemented for the Puerto Rico region to simulate storm surge inundation. In order to calibrate the model a number of numerical experiments are conducted to explore the effect of unstructured mesh resolution, tropical cyclone wind profile and wind stress parameterization on the wind setup, wave setup and storm surge. Various studies have shown the importance of tropical cyclone wind profile and wind stress parameterization in simulating storm surge inundation, but not for the Caribbean region. With this study we seek to test the applicability of current parametrization schemes to the Caribbean region as a ground for possible new developments in the future. Hindcasts for Hurricane Georges and Hurricane Omar are made to asses the validity of the various studied parameterizations and results for the parameterization schemes are presented. The effects of using a single unstructured mesh for both circulation and wave models in an island with steep bathymetric gradients such as Puerto Rico will also be explored.

Hindcasting Waves and Surge for Hurricane Ike on the Texas Gulf Coast

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The Texas Gulf Coast is a geometrically complex system of narrow inlets, broad back bays, coastal ridges, rivers, and intricate topology adjacent to the particularly broad continental shelf making the region especially susceptible to highly localized water level and current gradients associated with the flooding that occurs during tropical storms. Most population centers lie on bays and rivers that are hydraulically connected to the Gulf, allowing for water driven by storms to penetrate far inland and onto the wide coastal plain. Hurricane Ike struck the Gulf Coast near Galveston, Texas as a strong category 2 hurricane on September 13, 2008, creating significant storm surge and inland flooding. This study applies the high resolution, unstructured, parallel, tightly coupled ADCIRC+SWAN (ADvanced CIRCulation+Simulating WAves Nearshore) hydrodynamic and wave models for the Texas Gulf Coast on a computational grid of over three million nodes resolving coastal features as small as fifty meters. The grid domain extends from the Texas coastal flood plain to the Atlantic Ocean including the entire Gulf of Mexico and Caribbean Sea. The model is used to validate the inland flooding and wave action that occurred during Hurricane Ike and to investigate the resolution requirements to properly resolve coastal features that have significant effects on near-shore flooding. Additionally a sensitivity study of near shore frictional parameters and the resulting effects of coastal and inland water levels will be presented. In this study, the coupled ADCIRC+SWAN model results will be validated using extensive wave and surge data collected by NOAA, USGS, US Army Corps of Engineers, and other federal and local authorities. Included in this study is an investigation into the previously undocumented forerunner surge which inundated the Texas coast with up to 2 meters of water 12 hours prior to landfall.

High resolution numerical modeling of tides in the Western Atlantic, Gulf of Mexico, and Caribbean during the Holocene

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High quality relative sea-level (RSL) data help to quantify variations in crustal movements since the last glacial maximum (LGM). These data are useful for calibrating models of earth rheology and for the development of coastal lowlands, among other uses. Changes in RSL originate from many sources, including glacial rebound, tectonic effects, and local processes. One component of the local processes is the change, over time, in tidal range.

To investigate the contribution of tidal range changes to RSL changes, high-resolution tidal simulations of the Western Atlantic, Gulf of Mexico, and Caribbean during the Holocene (present day to 10,000 years before present; 10kybp) have been carried out. The simulations were done using the ADCIRC model and the unstructured finite-element model grid had a shoreline resolution of *O*(1km). Paleobathymetry data were obtained using the ICE-5G (e.g., Peltier, 2004, Ann. Rev. Earth Planet Sci.) model. The open boundary forcing (along the 60th meridian) was obtained (Griffiths and Peltier, 2009, Journal of Climate) from a global ocean model.

Harmonic analysis was performed on the results of the ADCIRC simulations and the derived tidal amplitudes and phases were used to calculate tidal datums such as mean higher high water (MHHW) and tidal range in 1000 year increments from present day to 10kybp. The results demonstrate a very marked amplification of the tides at 9kybp throughout the domain and a strong reduction of the tides at around 5kybp in the Bay of Fundy region.

Tidal Energy Potential in UK Waters

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The paper presents findings from a 2-year Joule Centre study, ‘Tapping the Tidal Power Potential of the Eastern Irish Sea’ funded by the UK's Northwest Development Agency (and subsequent developments). This evaluated the scope for reliable electricity generation from a combination of estuary barrages/lagoons and tidal-stream energy devices using 0-D and 2-D computer modeling (using ADCIRC). The emphasis was towards conjunctive operation incorporating allowances for other schemes outside the region, including a ‘Severn’ barrage, an integral part of the study being potential impacts of the energy removal on the overall tidal dynamics of the Irish Sea and environmental issues arising.

Estimates arising suggest that the estuarial waters of the North West of England, stretching from the Dee & Mersey, to Morecambe Bay and the Solway Firth are capable of meeting about 5% of UK national electricity demand. This places it on a par with the ‘Severn’ Esutary, which is currently of significant public interest due to the ongoing UK Department of Energy and Climate Change Severn Tidal Power Consultation. In addition, by including barrages down the UK's eastern coast, smaller estuary barrages, and Tidal Stream devices, the UK could realistically achieve 20% of its current electricity demand from Tidal Energy.

Multi-Scale and Multi-Physics Integrated Hurricane, Water Surge, and Overland Flow Modeling in Parallel Platform

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Abstract

An integrated modeling scheme of a hurricane from its incipience to landfall, associated water surge in ocean and flooding in the coastal region is developed. There are three primary models in this multi-scale and multi-physics integrated scheme. Using the latest meteorological data 2-3 days before a hurricane strikes the ground track path, wind speed, pressure, rain, etc are predicted using an open source parallel code Weather Research and Forecasting (WRF). The hurricane wind speed and pressure obtained from WRF are used as input in another open source parallel code ADvanced CIRCulation (ADCIRC) to model the water surge in the ocean. The shoreline water elevation data obtained from ADCIRC are used in a diffusive overland flow parallel (OpenMP) code developed in Northrop Grumman Center for HPC at Jackson State University to model the flood in the coastal region.

In an actual hurricane event WRF, ADCIRC, and overland codes must be executed in sequence, preferably every 6 hrs before its landfall. The meteorological data are updated every 6 hrs, and the latest data are needed to get the most accurate hurricane track and strength from WRF simulation. WRF accuracy is propagated to ADCIRC and overland codes. Parallel implementation of the codes is necessary to ensure a speedy and viable forecasting.

Results from three primary models stated above are used in two secondary models to address the evacuation strategy and the evaluation of the hurricane / flood damage on the coastal infrastructure, including the transportation systems in the Mississippi coast. The evacuation strategy includes planning and timing the whole procedure, dynamic evacuation paths, and priority-based traffic routing. All results must be made available for both management and evacuees in Google Earth for visualization, analysis, and decision-making. All the models are synchronized and fully automated for ease of the end users. All the images and KMZs are created within the automation code without the need of any external visualization software.

As a case study for the present research, hurricane Katrina (2005) and its impact on the Mississippi coastal region is chosen.

This study is the major part of an on-going project in Northrop Grumman Center for HPC at Jackson State University regarding the homeland security in the state of Mississippi, funded by Department of Homeland Security.

A Study on Performances of Nodal Discontinuous Galerkin Methods on Quadrilaterals and Triangles

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In this work, we present a study on the performance comparison of nodal bases on triangles and on quadrilaterals for Discontinuous Galerkin (DG) solutions of hyperbolic conservation laws. DG methods based on a nodal basis on triangles and two tensor product nodal bases on quadrilaterals are considered. Settings of interest involve the situation in which a mesh of quadrilateral elements is constructed from merging two adjacent triangular elements or vice versa. To assess performance, a linear advecting rotating plume transport problem is used as a test case. The numerical results indicate that, for cases where the order of the basis is low to moderate, the computing time required to reach a given final time for the quadrilateral elements is shorter than that for the triangular elements. The results also show that the quadrilateral elements yield higher computationally efficiency in terms of cost to achieve similar accuracy.

Engineering Hurricane Model

Chris Massey and Ty Wamsley
USACE-ERDC-CHL

Realistic coastal storm modeling requires the integration of several complex and sophisticated numerical modeling systems. In particular, the following systems are currently being used by the US Army Corps of Engineers, a tropical planetary boundary layer model, MORPHOS-PBL, to generate the cyclone wind and pressure fields, an ocean hydrodynamic model, ADCIRC, to generate the surge field, and both regional and nearshore ocean wave models, WAM and STWAVE, to generate the wave fields. In addition to these models that simulate the oceans response to a storm in the form of waves and surge, a bed morphology model, such as C2SHORE, is needed to simulate landscape changes due to the surge and wave effects.

In order to gain a more complete representation of the response to the storm, these systems need to be tightly coupled. Currently these modeling systems are present in a scripted work flow where individual models are loosely coupled via file input/output only. This work flow system has been successfully applied to many Corps projects. However, the entire system remains cumbersome to configure and costly to compute due to the loose coupling methodology which requires multiple applications of some models in order to get feed back response from other models.

We will present a new work flow that is easier to configure with the aid of graphical user interfaces in the Surface Modeling System (SMS). The new work flow also has tightly coupled models, where appropriate, using the Earth System Modeling Framework (ESMF). The tight coupling of models enabled by ESMF, allows for timely feedback responses into each model for improved physical responses. These tightly coupled feedback responses come without the need to re-run a model which reduces the over all cost of execution of the work flow. For our purposes the cost of the work flow is measured by both the computational effort and the required time to solution. In addition to improved physical responses, using ESMF allows for an almost plug-n-play capability for models so that different models can be used within the present system and the system can be expanded to include new capabilities, such as environmental models, for future applications. This new work flow system with GUI’s and tightly coupled models represents an enabling technology for more comprehensive studies on flood and shore protection and sediment management.

Sensitivity of Storm Surge to Coastal Dune Erosion in Northeastern Texas

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As hurricane storm events make landfall, coastal dune features may be significantly eroded by the combined action of wind, waves, and storm surge. These storm induced topographic changes have the potential to influence the surge depth and the extent of inundation for regions of the coastal zone behind the dune features. It has been suggested that dune erosion should be included in the surge modeling so that the 100yr levels more accurately reflect likely topographic scenario. As a first step in assessing the need for including dune morphology, it is desired to estimate the potential impact of dune erosion. This study compares storm surge simulations on two geometries; an eroded topography and a non-eroded geometry. The results show that erosion of coastal dunes can increase surge by several feet compared to the surge if dune erosion is not included. The magnitude of the surge varies throughout the coastal region and depends upon storm parameters such as landfall location and storm size.

ADCIRC Applications to Hurricane Ike Simulations

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Predicting and studying coastal inundation due to hurricanes and tropical storms is a problem of critical importance to the United States, as decisions will be made in the next several years on how to design better protection systems and improve emergency management practices in the event of future storms. In this collaborative project, the investigators are developing an accurate numerical model of storm surge to explore the ramifications of simulated hurricane landfall locations on the Texas Gulf coast region. UT Austin and SSPEED researchers are studying the effects of proposed man-made and natural protection systems for vulnerable coastal areas, specifically the proposed "Ike Dike" in the Galveston Bay region. The project investigates the use of petascale computing to significantly advance the state-of-the-art in storm surge simulation, to accurately model flows at multiply interacting, high resolution scales, and to demonstrate that results from these simulations can be directly applicable to emergency management planning.

Our investigation focuses on the ADCIRC hydrodynamic model simulating Hurricane Ike which struck the Gulf Coast near Galveston, Texas as a strong category 2 hurricane on September 13, 2008, creating significant storm surge and inland flooding. This study investigates the results of varying Hurricane Ike parameters on the Texas Gulf Coast region both with and without the Ike Dike. By varying storm impact location, wind intensity, and finite element approximation technique, we present several results utilizing the ADCRIC model and FigureGen visualization tool. We also focus on the hydrograph analysis of several locations in the Galveston bay region that are of critical importance to local industry.

An Assessment of Anthropogenic Effects on Southern Louisiana Hurricane Storm Surge

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Anthropogenic changes of hydrologic significance to southern Louisiana have stemmed from amongst others the dual need to: (1) create and stabilize navigable waterways and (2) protect life and property against flooding. The anthropogenic changes associated with flood protection works can be described as the fortification, expansion, and systemization of naturally occurring levees along river banks as well the creation of new levees and flood control structures. Flood protection and navigation policies have been a source of controversy for well over a century, but have recently been thrust into the national spotlight as a result of the devastation to New Orleans inflicted by Hurricane Katrina. A significant effort has been made to address the geomorphic and biological consequences resulting from the current flood protection policy. The objective of this study was to address the effect that anthropogenic features have on flooding from hurricanes.

Anthropogenic effects were evaluated by considering the specific components of the following flood protection conditions: (1) Raised Levees, (2) Existing, and (3) Removed Features. Since the SL15 regional application of the ADCIRC storm surge model has proven to be a valid predictor of storm surge as shown by case studies for hurricanes Katrina and Rita, it served as the existing model. Four historical hurricanes (Gustav, Ike, Katrina, and Rita) and several hypothetical storms of greater magnitude were modeled so as to evaluate the roles of path and severity. Results from the study suggests that while the levee system can decrease the overall land area inundated by storms it can also result in higher water levels in the Mississippi River and Lake Pontchartrain, thus leading to a greater potential for overtopping and levee failure for the metropolis of New Orleans.

High Resolution Modeling of Flow, Tides and Hurricane Storm Surge in the Lower Mississippi River

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The Mississippi River is the largest conduit for riverine flow and sediment in the contiguous United States. Previous studies of the discharge-stage relationship of this river, as well as keen interest in potentially high riverine stages during low-frequency storm events, provided impetus to drastically improve the spatial resolution of bathymetry, topography and frictional resistance of Southern Louisiana, and particularly along the Lower Mississippi River, within the Southern Louisiana (SL) computational meshes. Hurricane Katrina brought to the fore the ability of hurricane surge to propagate up-river at low riverine discharges. Improvements in bathymetric and friction resolution in the lower Mississippi River provide the opportunity for potentially improved tidal and surge signal dynamics within the sub-region. The recent development of a more highly-resolved unstructured computational mesh of the region, SL16, will be discussed, and will be compared to the previous unstructured mesh, SL15. SL16 maintains the paradigm of large domains, and has increased resolution in the Gulf of Mexico; along the Florida continental shelf and Gulf coast; in the Mississippi River and its delta; and along the western Louisiana and eastern Texas coasts. Recent bathymetric surveys of the Mississippi River obtained from the U.S. Army Corps of Engineers were used to assign the bathymetry in the Mississippi River and to its distributaries in the delta. Traditional riverine manning n values have been reviewed in the new computational mesh, particularly within the Mississippi River channel, its distributaries, and the surrounding coastal marshes. Manning n values were determined through land-use maps for various topographic features, including coastal marshes and low-lying coastal floodplains. Riverine frictional resistance is improved through the adoption of a base riverine manning n value, with an additional increase in regions of large meandering. A study of the relationship between riverine stages and increasing discharges will be conducted through the simulation of the Mississippi River, with the application of this new high resolution computational mesh. This will be compared to the previous unstructured SL15 grid model, as well as measured riverine constituents at various stations along the river. In addition, discharges at various distributaries in the Mississippi River delta were computed at specific locations in the distributaries. These simulated discharges are expressed as percentages of the discharges simulated at the Tarbert Landing and Venice recording stations. These percentages will be compared to measured discharge information at the same locations, as well as previous simulations with the SL15 computational mesh.

South Carolina/North Carolina Storm Surge Model Comparison

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The South Carolina Storm Surge Study Group (SC Group) analyzed multiple tests to compare the ADCIRC model results of the North Carolina Storm Surge Study Group (NC Group) model (NC model) and the SC Group model (SC model). Specifically, the comparison sought to determine how closely the maximum water surface elevations (MAXE) produced by simulations with the different models compared near the South Carolina-North Carolina border (the area of interest).

The tests compared simulations conducted with the same wind fields and all model parameters matched as closely as possible (bottom roughness, eddy viscosity, tau0, etc). Initially, model simulations applied the Hurricane Hugo wind field. However, Hurricane Hugo made landfall too far south of the South Carolina-North Carolina border to cause appreciable surge in the area of interest. The SC Group modified the wind field and shifted the storm track northward to make landfall at the South Carolina-North Carolina border. The Groups designated this storm “North Hugo” or Nugo.

For Hurricanes Hugo and Nugo, the MAXE of the two models agreed within inches in the area of interest, with a slight bias towards higher levels in the NC model. The SC group investigated localized differences of up to 2 feet and concluded that they derive from resolution differences. Additionally, the SC Group observed a globalized difference in MAXE of 5-6 inches (in areas away from the area of interest), with the NC model producing higher MAXE. Subsequent sensitivity checks adjusting eddy viscosity, timestep, and wet/dry parameters did not reduce the global difference.

Hurricane Track Definition and Interface to ADCIRC Wind Modeling

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The ADCIRC engine is capable of modeling a wide variety of wind conditions. The system supports many different file formats to allow users to obtain wind data from a variety of sources. The interface in the Surface-water Modeling System (SMS) has traditionally included options to specify the format being used, but very little support has been included to assist with the generation of the wind data. Recent enhancements, developed in conjunction with the staff of the Coastal and Hydraulics Laboratory at the Engineering Research and development center have resulted in a set of tools for simplifying the modeling of tropical storms. The interface includes a new storm coverage that contains the definition of the defined storm track as well as other storm parameters. The system is also capable of generating various permutations of the storm characteristics. With this GIS data, the SMS creates input files for either the PBL wind model or the parameters needed for the Holland wind model incorporated into the ADCIRC system. Additional enhancements to facilitate the application of wind in the ADCIRC engine are anticipated.