National Center for Computational Hydroscience and Engineering
The University of Mississippi

Assessment of Impact of Sea Level Rise on Coastal and Estuarine Infrastructure Using Numerical Simulation Model

Yan Ding, Ph.D.

Research Assistant Professor
National Center for Computational Hydroscience and Engingeering
The University of Mississippi, University, MS 38677

ENGR 597 (Session 10) Global Warming - Causes, Impacts and Solutions

February 16, 2009

Outline

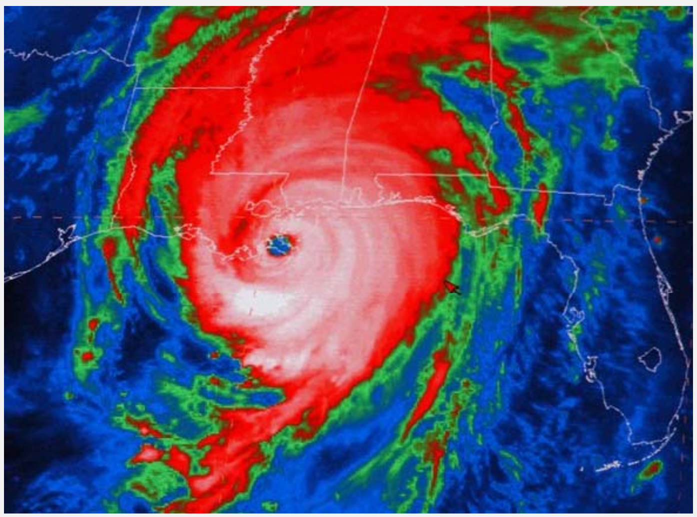
- Brief Introduction
  - Coastal Hazards due to Hurricane, Storm, and Tides
  - Instrumental Records for Climate Change
  - Analysis of Climate Change
  - Impacts of Sea Level Rise (SLR)
  - Coastal Zones
  - Coastal Flood Hazard Zones
- Coastal and Estuarine Hydrodynamic and Morphodynamic Processes
- Analysis of Dynamic Impact of SLR by A Coastal/Estuarine Process Model: CCHE2D-COAST
- A Numerical Case Study: Assessment of Sea Level Rise in an Estuary

Objectives

- Understanding the impacts of SLR on coastal areas under the storm/hurricane conditions
- Test the CCHE2D-Coast model's capabilities to assess the impacts in various SLR scenarios.
- Demonstrate the analysis method for evaluation of the impacts in an estuary by means of sensitivity studies
- Discussion of some issues related to the future studies

Vulnerable Coasts

Storm Surge, Hurricane Katrina



Wave crashed against a boat that washed into Highway 90 in Gulfport, MS, AP Photo

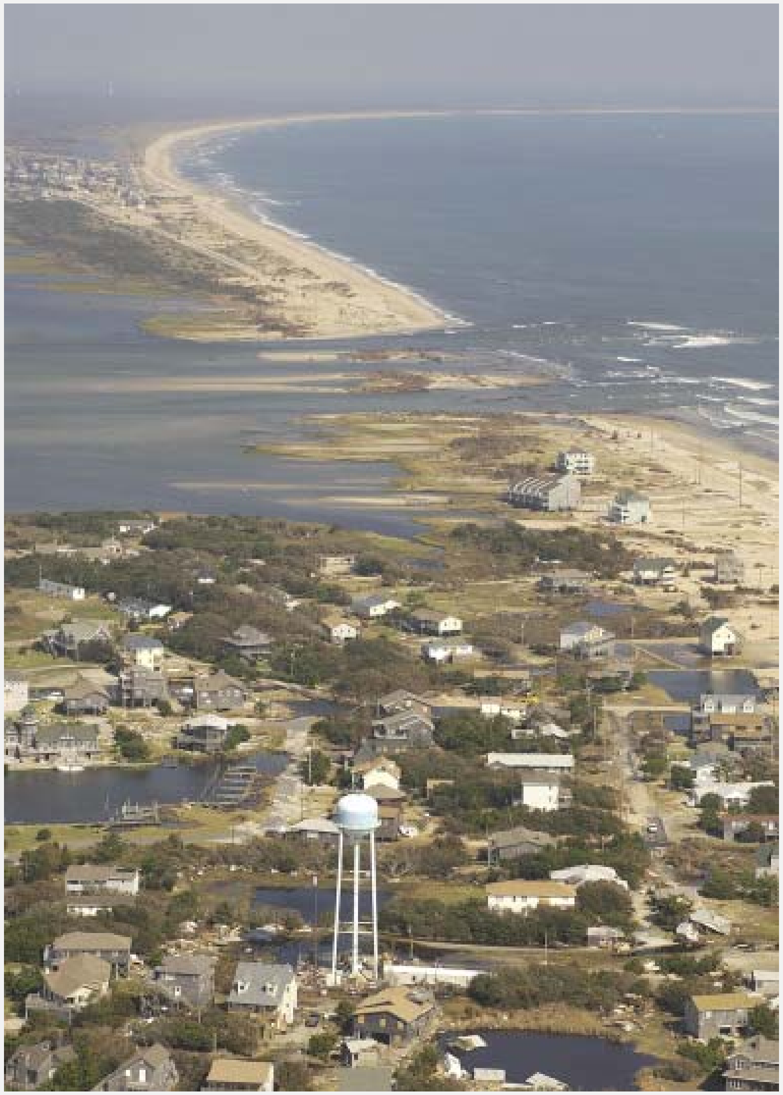
Water spilled over a collapsed levee in New Orleans on Tuesday (8/30/2005)

Beach Erosion and Shoreline Retreat

A beautiful beach before 13 years

Embankment and groin for shore protection

Barrier Breaching

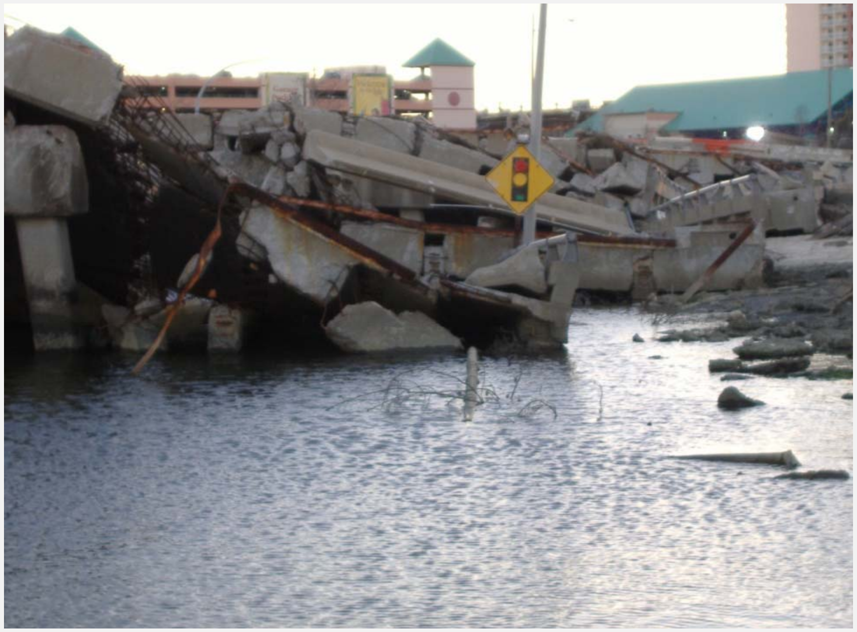


Hurricane Isabel
Hatteras Island Breach,
21 Sep 03

(Breached ~ 18 Sep 03)

Structure Failure

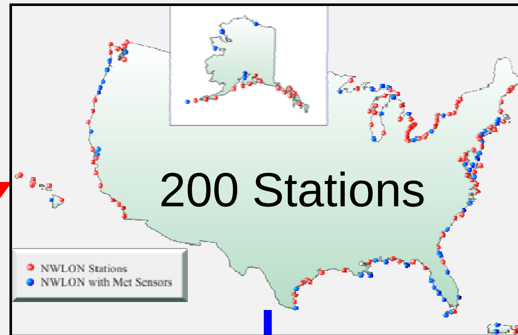
Structure Failure by Hurricane Katrina



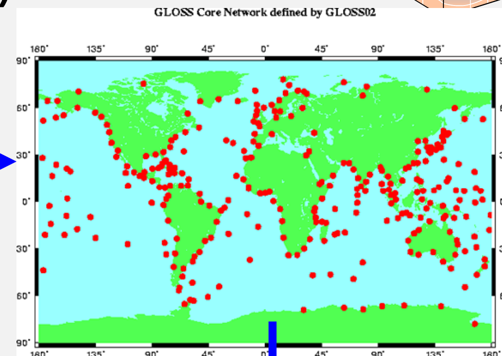
US 90, Bilox, MS, Feb 26, 2006

Contributions to Instrumental Records for Climate Change

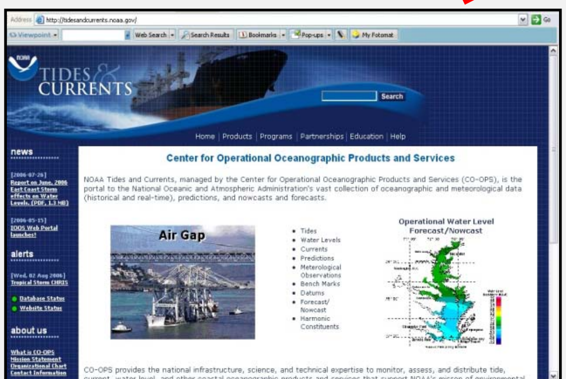
National Water Level Observation Network (NWLON)



Global Sea Level Network

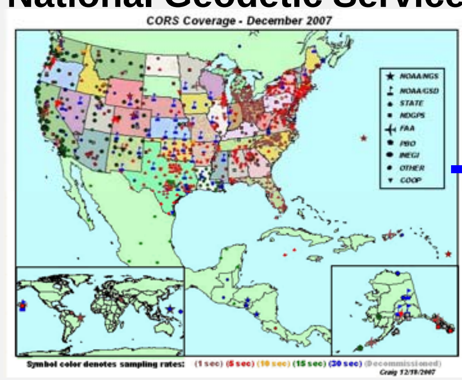


CO-OPS

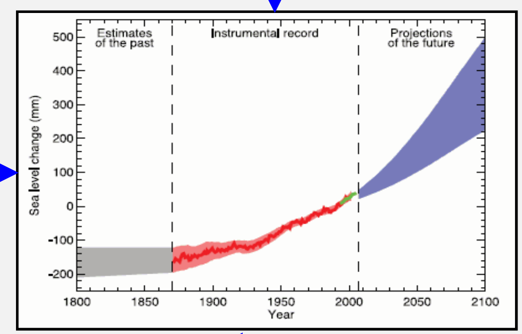


TidesandCurrents.noaa.gov

National Geodetic Service

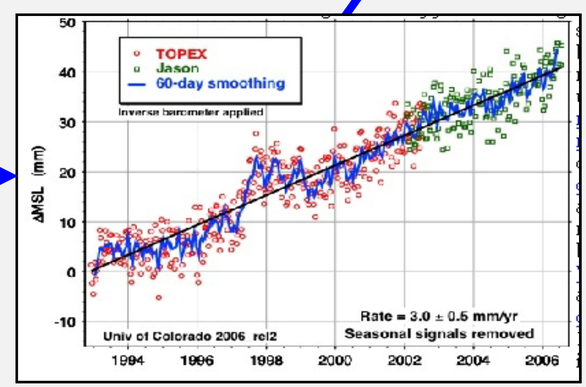


Continuously Operating Reference Stations (CORS)
http://www.ngs.noaa.gov/CORS/



Global Sea Level Rise Estimates

NWLON Platform Harvest Station is used for Satellite Altimetry Calibration

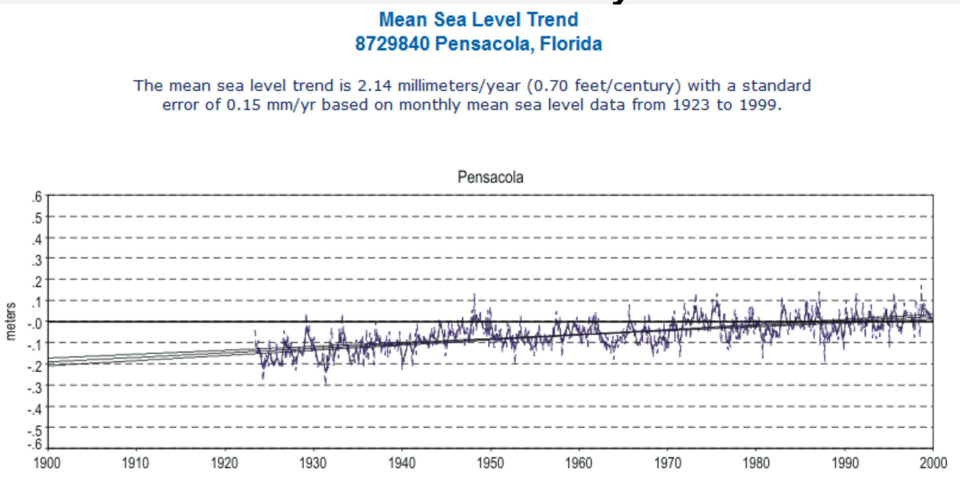


Analysis of Climate Change

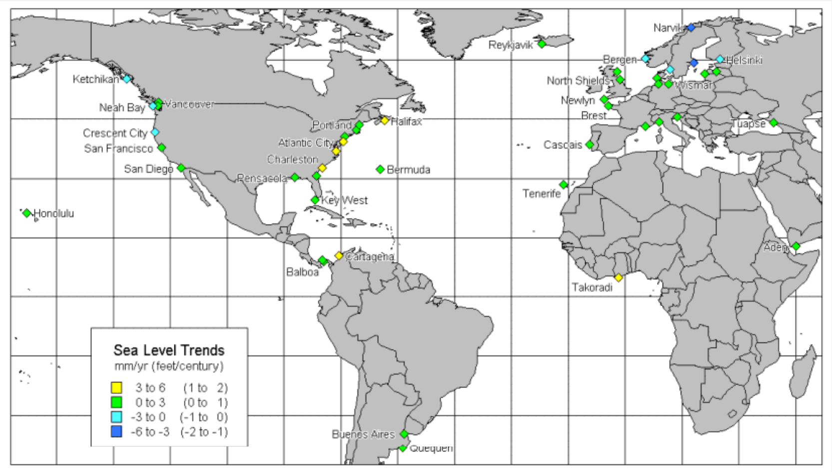
http://www.tidesandcurrents.noaa.gov/sltrends.html

Long-term Variations in Sea Level and Analysis of Trends:

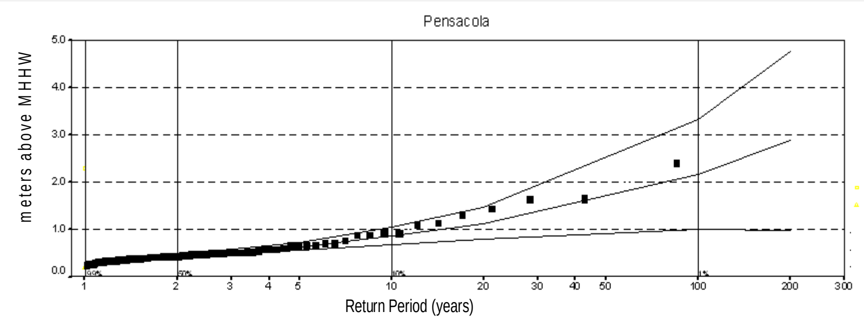
NWLON Station Analyses



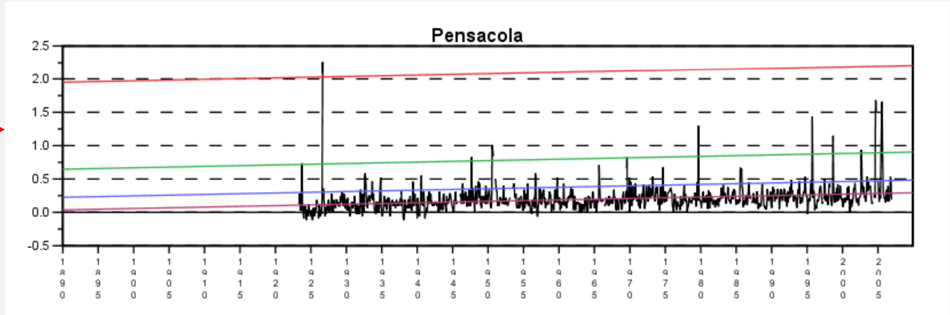
New Global Station Analyses



Exceedance Probability Analyses and the 100-year Event :*



Annual Exceedance Probability Curves

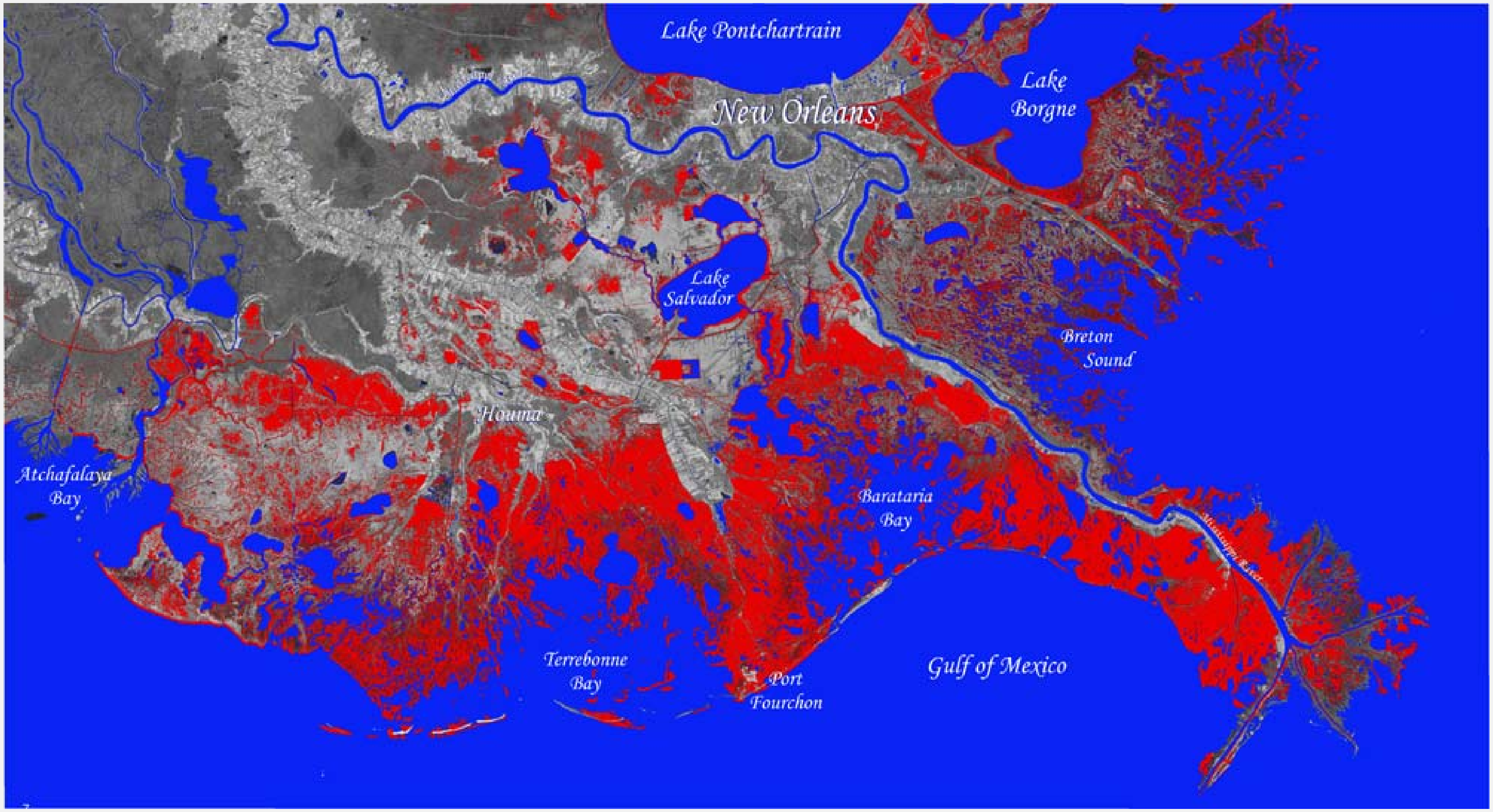


1%, 10%, 50%, 99% Exceedance Probability Levels

* In development 2008

Landscape Change: Predicted Landloss in Louisiana

USGS Published Landloss Since 1932 and Projected For the Next 45 Years



1932 1956 1978 1988 2000 2050

USGS

NWRC

Impact of SLR

In General, Four Primary Impacts of SLR:

- Permanent Inundation and displacement of coastal lowlands;
- Increased flood and storm damage;
- Increased erosion;
- Salinization of surface and increased waters.

Impacts of SLR on Particular Coastal Regions:

- Higher and more frequent flooding of wetlands and adjacent shores.
- Expanded flooding during high tides and severe storms.
- Increased wave energy in the near-shore area (shoreline erosion and land erosion).
- Upward and land-ward migration of beaches (shoreline changes).
- Accelerated coastal retreat and erosion.
- Saltwater intrusion into coastal freshwater aquifers.
- Damage to coastal infrastructure.
- Broad impacts on coastal economy of coastal communities (coastal resilience).

Potential Socio-Economic Impacts of SLR

- Increased loss of property and coastal habitats
- Increased flood risk and potential loss of life
- Damage to coastal protection works and other infrastructure
- Loss of renewable and subsistence resources
- Loss of tourism, recreation, and transportation functions
- Loss of non-monetary cultural resources and values
- Impacts on agriculture and aquaculture through decline in soil and water quality

National-Scale Assessments (by Inventory-Based Approach)

Potential Impacts to a 1-m Rise in Sea Level,

Country	People Affected		Capital Value at Loss		Land At Loss		Wetland At Loss	Adaptation/ Protection Costs	
	#People (1000s)	% Total	Mil US$	% GNP	Km^2	% Total	Km^2	Mil US$	% GNP
Argentina	-	-	5000	>5	3400	0.1	1100	>1800	>0.02
Bangladesh	71000	60	-	-	25000	17.5	5800	>1000	>0.06
China	72000	7	-	-	35000	-	-	-	-
Egypt	4700	9	59000	204	5800	1.0	-	13100	0.45
Japan	15400	15	849000	72	2300	2.4	-	>156000	>0.12
Netherlands	10000	67	186000	69	2165	5.9	642	12300	0.05
Nigeria	3200	4	17000	52	18600	2.0	16000	>1400	>0.04
Tonga	30	47	-	-	7	2.9	-	-	-
Uruguay	13	<1	1700	26	96	0.1	23	>1000	>0.12
U.S.A.	-	-	-	-	31600	0.3	17000	>156000[8]	>0.03
Venezuela	56	<1	330	1	5700	0.6	5600	>1600	>0.03
TOTAL	178834		1146310		149022		58790	27124	

Notes: Assuming Existing Development and a 1-m Rise in Sea level. All impacts assumed no adaptation, while adaptation assumes protection, except in areas of low population density. Costs are 1990 US$. Source: Bijlsma et al. (1996)

Challenges to Planning and Management of Coastal Zone

- Find new design criteria of coastal infrastructure:
  →Storm, Wave, Surge, Tide
- Redefine extreme storm events (the 1% annual chance storm (i.e.100-year storms) will be quite different due to global climate change).
- Update out-of-date flooding/inundation maps for most of coastal communities
- Redefine storm surge zones, evacuation route and evacuation zones, emergency shelter, etc.
- Re-evaluate coastal resiliency, hazard preparedness, coastal emergency management, first responding planning, coastal infrastructure planning, etc.
- Establish and maintain a premier data collection and delivery system such as a GIS- and Internet- based system.

FEMA: Map Modernization Program

- FEMA National Flood Insurance Program (NFIP)

  Under the National Flood Insurance Act of 1968, as amended, property owners whose properties are within the designated floodplain and have a mortgage from a federally regulated financial institution are required to purchase federal flood insurance.

- Map Modernization Program

  In fiscal year 2003, Congress appropriated $150 million, allowing FEMA to initiate a full-scale update of the nation's flood maps called the <u>Multi-Hazard Flood Map Modernization Program</u>, an effort FEMA expects to take about 5 years and cost about $1 billion. In fiscal year 2004, Congress appropriated an additional $200 million for map modernization, and the administration has requested an additional $200 million for fiscal year 2005 to continue the program.

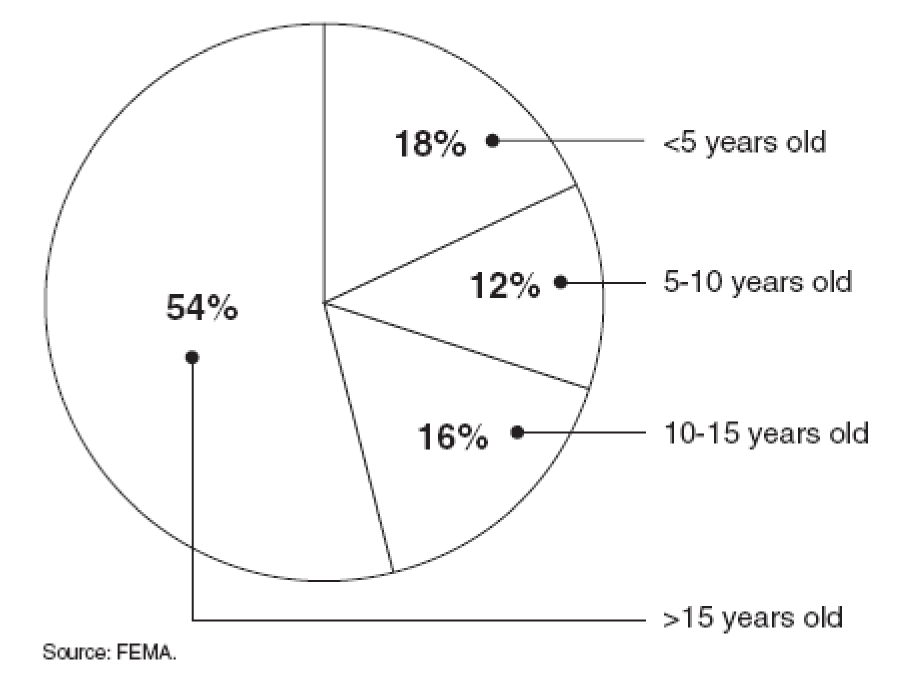
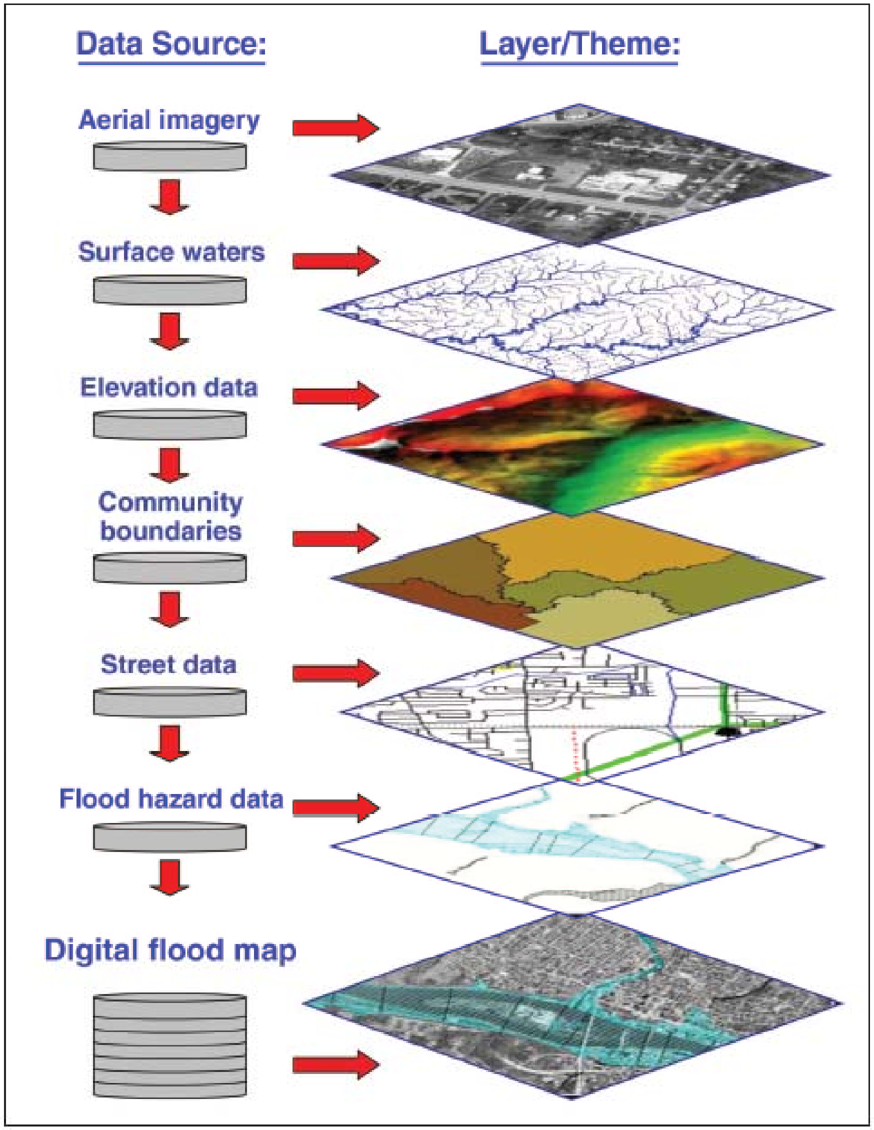


Fig. Age of the Nation's Current Flood Map Inventory

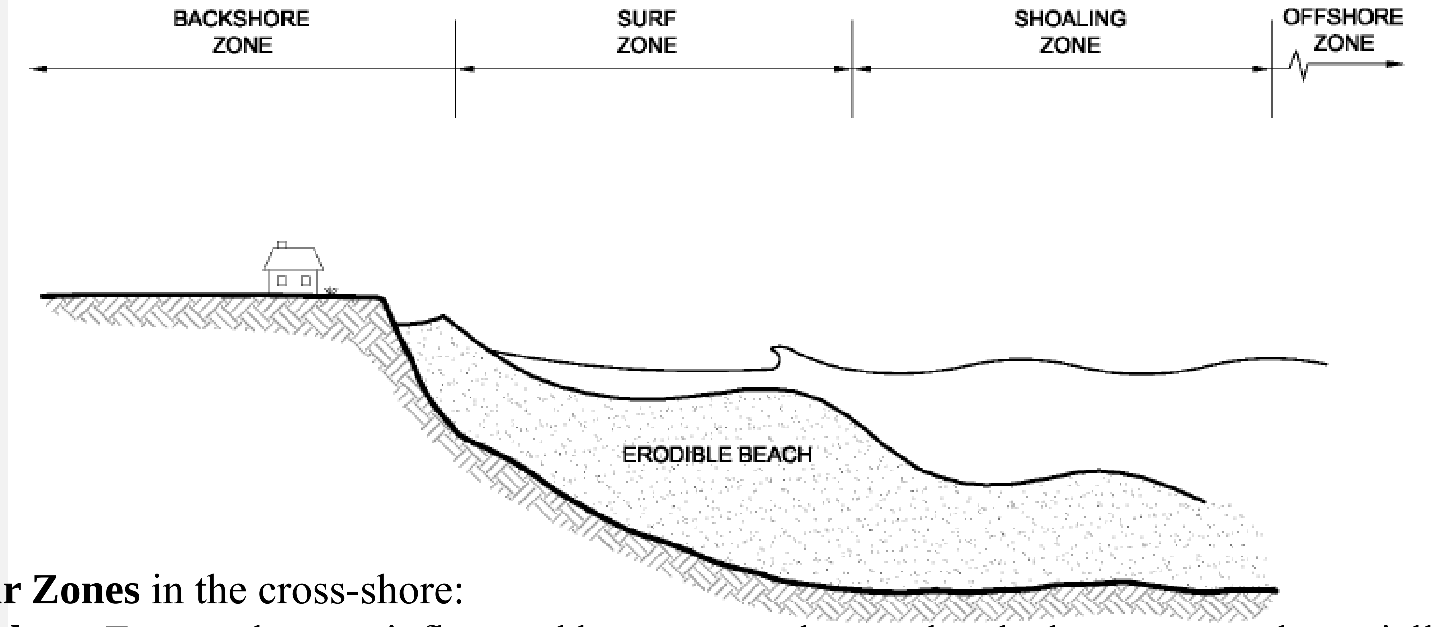
Key GIS Layers or Themes for Digital Flood Maps

Through map modernization, FEMA intends to produce more accurate and accessible flood maps by using advanced technology to gather accurate data and make the resulting information available on the Internet. Currently, many of the flood maps in FEMA's inventory do not accurately reflect the true flood hazard risks because over time, new development and other factors altered watersheds and floodplains faster than the maps could be updated.



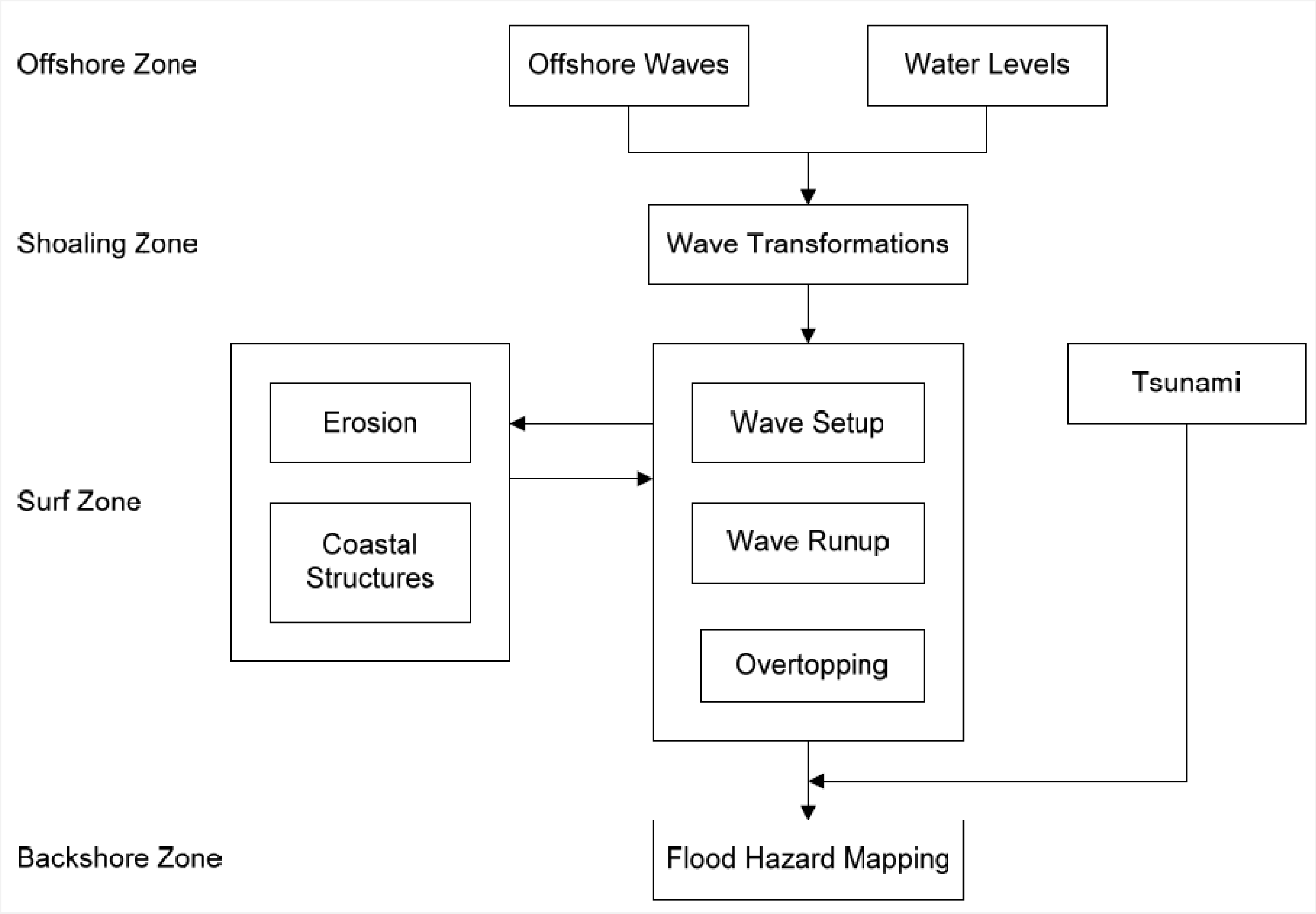
Source: FEMA.

Coastal Zones

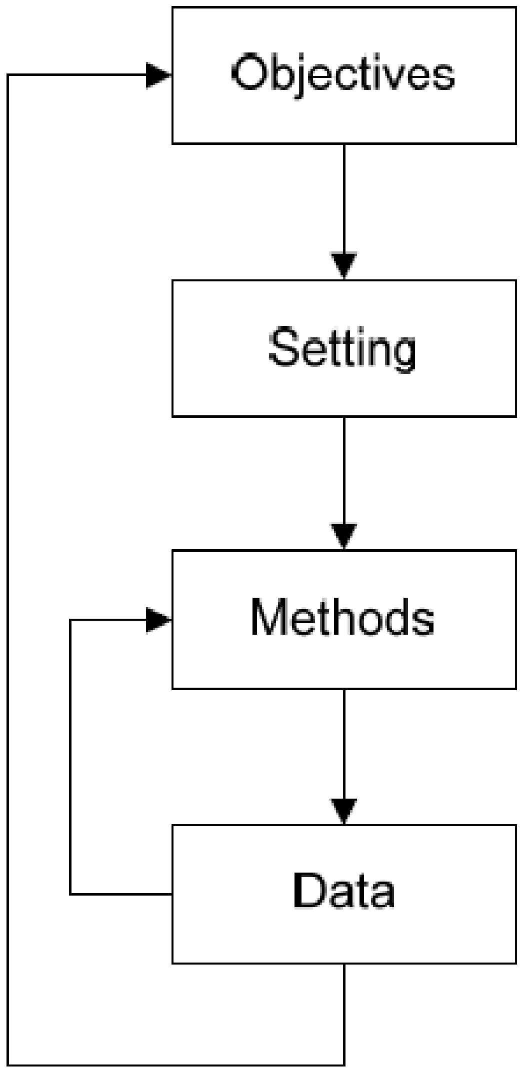


Four Zones in the cross-shore:
Offshore Zone = the area influenced by waves and water levels that are not substantially influence by bathymetry or topography. Dominant processes in this zone include swell, seas, astronomical tides, storm surge, and large-scale climate perturbations such as El Niňo.
Shoaling Zone = the area outside the surf zone where offshore conditions are transformed by interaction with bathymetry or topography. This includes refraction, diffraction, dissipation, and generation of waves.
Surf Zone = where waves break as they interact with the bottom. Dominant processes include wave setup, runup, overtopping, erosion, and interaction with structures.
Backshore Zone = the area that is outside the normal surf zone, but may be subject to inundation during coastal flooding events. This area is subject to development and is the critical area for determination of flood hazards.

Coastal Zones and Processes



Coastal Flood Hazard and Mapping



Hazard Map

Exposure, Morphology, Hazard History, Structures

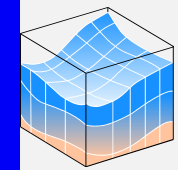
Waves, Runup, Overtopping, etc.

Numerical models play a key role in computing water elevations, velocities, coastal erosions/depositions under the selected hydrological conditions (1% annual chance storm/flood)

GROW, NOAA, LIDAR, etc.

Study Methodology and Development Considerations

Numerical Modeling for Predicting/Planning Coastal Hazards and SLR



- Numerical modeling is to use a mathematical model and a computer (or a supercomputer) to simulate/predict physical processes under a set of given conditions.
- Coastal/estuarine numerical models are to compute the coastal/estuarine processes such as wave transformation, storm surge, tide, sediment movement, erosion/deposition, etc. so as to predict hydrological variables, e.g. water levels, velocities, bed changes, bio-mass properties, etc.
- Numerical model can predict complex unsteady physical processes to provide a set of dynamic results for engineering assessment.
- Numerical models need data: hydrological data (wave, wind, tide, runoff, river inflow, storm track, etc), bathymetry/topography (e.g. DEM data from GIS application), boundary condition data, etc.
- Numerical models have to be verified and validated for any site-specific studies.
- So far, coastal/estuarine numerical modeling are the most accurate methodology to predict/plan coastal hazards and sea level rise impacts. They have been extensively adopted in coastal storm water management.

Coastal Flood Hazard Zones

FEMA generally divided coastal flood hazard zones into three categories:

1) **VE zone** (the coastal high hazard area where wave action and or high-velocity water can cause structural damage during the 1% annual chance flood: Wave runup zone, wave overtopping splash zone, high-velocity flow zone, breaking wave height zone, and primary frontal dune zone)

2) **AE zone** (and other A zones, where flood hazards are not as severe as VE zones

3) **X zone** (which is only subject to flooding by flood more severe that the 1% annual chance flood)

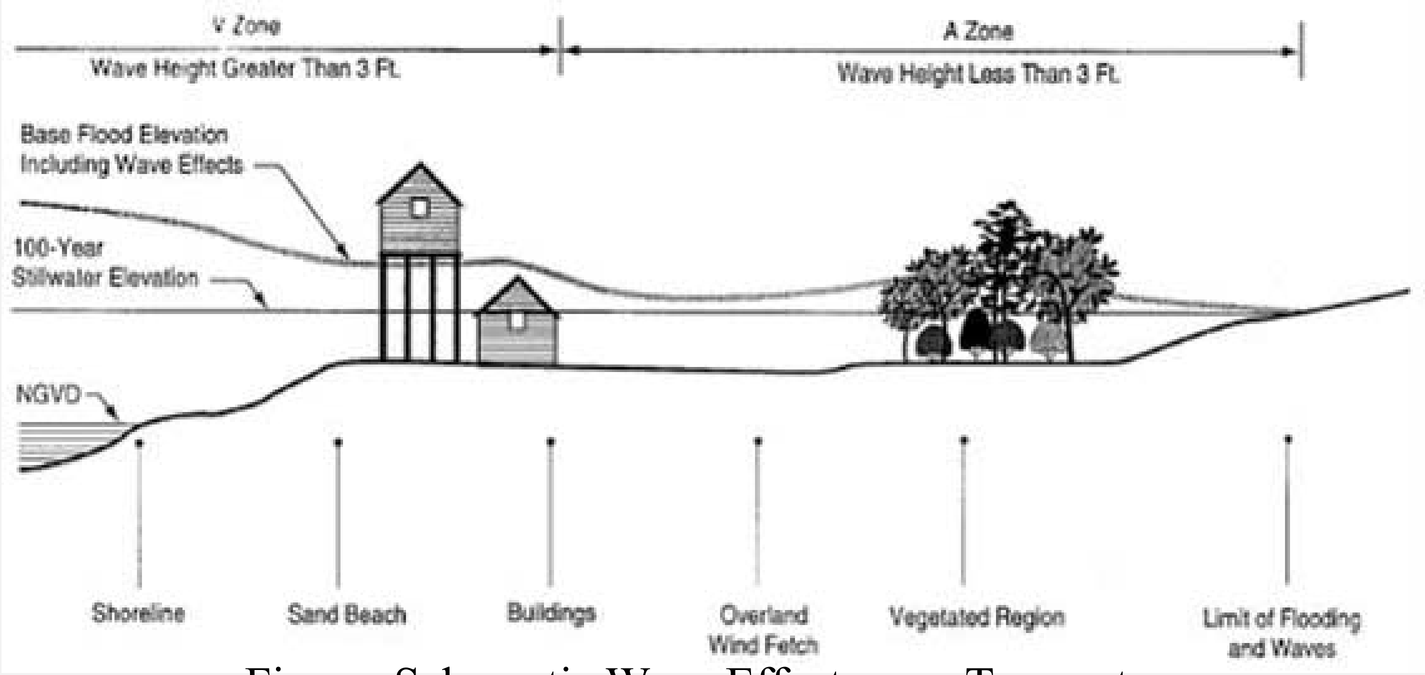
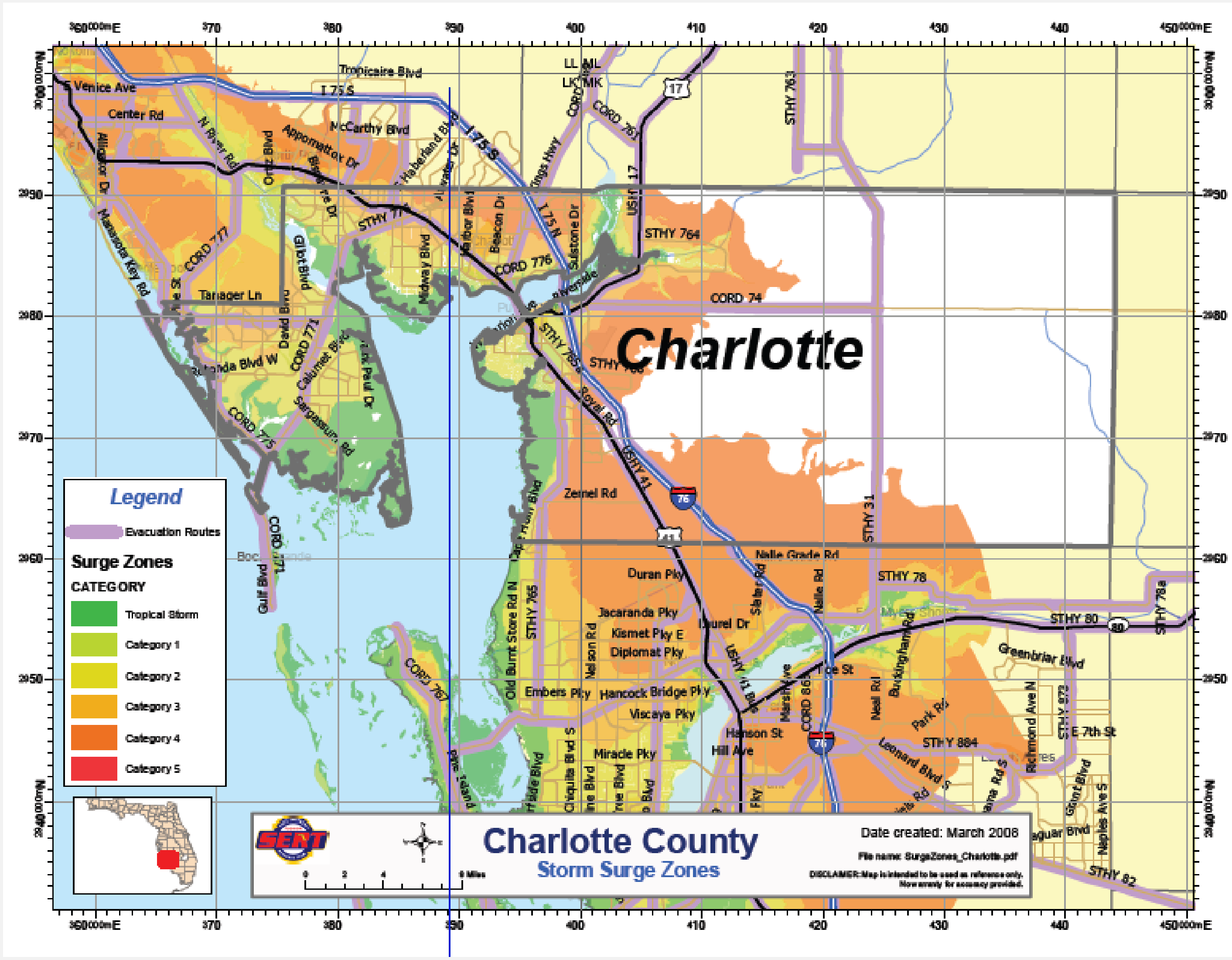


Figure. Schematic Wave Effects on a Transect

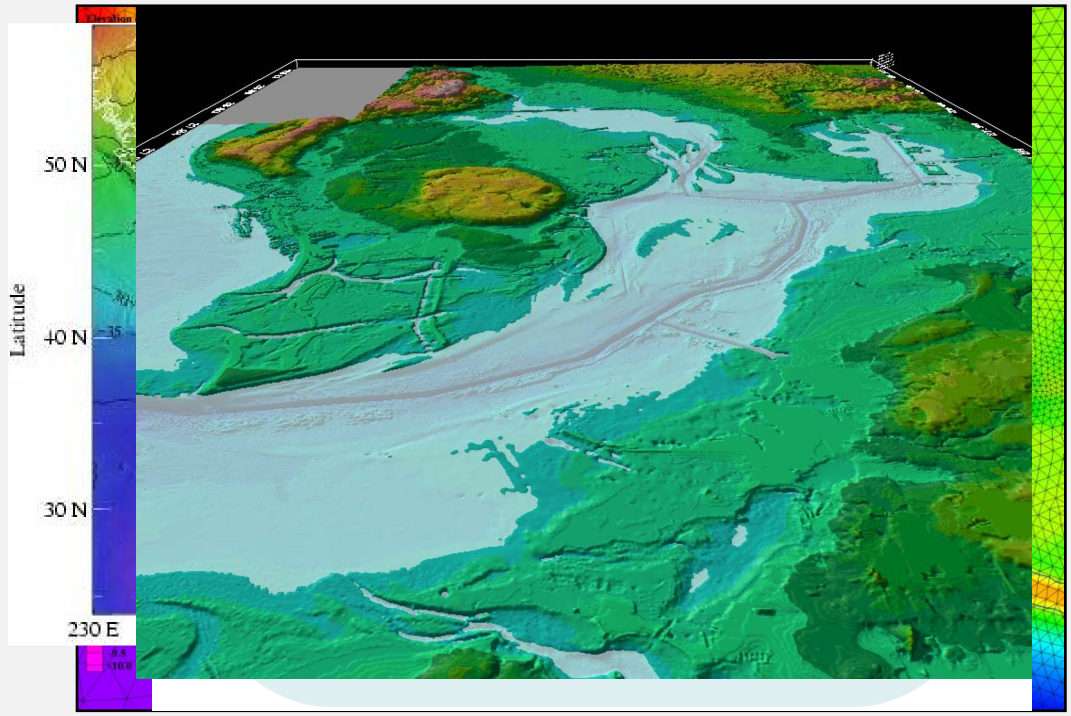
Coastal Flooding: A Coastal Disaster Preparedness Map

Charlotte County, FL

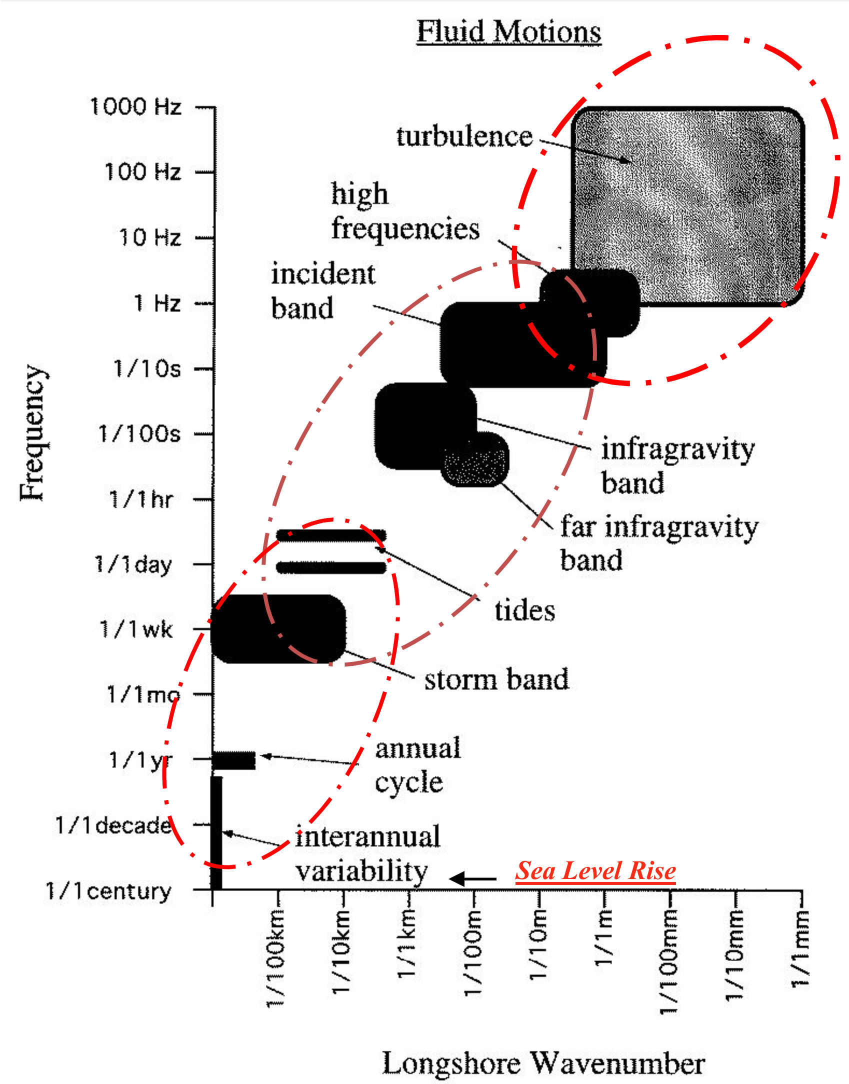


What do you need to develop geospatial tools for addressing SLR?

- Water level data
- Geodetic Data
- Geophysical data
- Models
- Transformation programs
- GIS applications



Spatial and Temporal Multi-Scales of Hydrodynamics and Morphology in Coasts and Estuaries



See http://www.coastal.udel.edu/coastal/

•***Small-Scale Processes*** *(0.1mm-10m; 0.1s-1day)*

Fluid and sediment motions in turbulent wave-current bottom boundary layer

•***Intermediate-Scale Processes*** *(1-10km; 1s-1yr)*

Wave breaking across surf zone, wave-induced nearshore current, lower frequency infragravity wave motions by storm surges, sediment transport alongshore and crossshore, fresh water and sediment from rivers during floods, and tidal motions

•***Large-Scale Processes*** *(1-100km; months-decades)*

Ocean circulations, sea-level rising, global scale weather change, long-term shoreline change, etc.

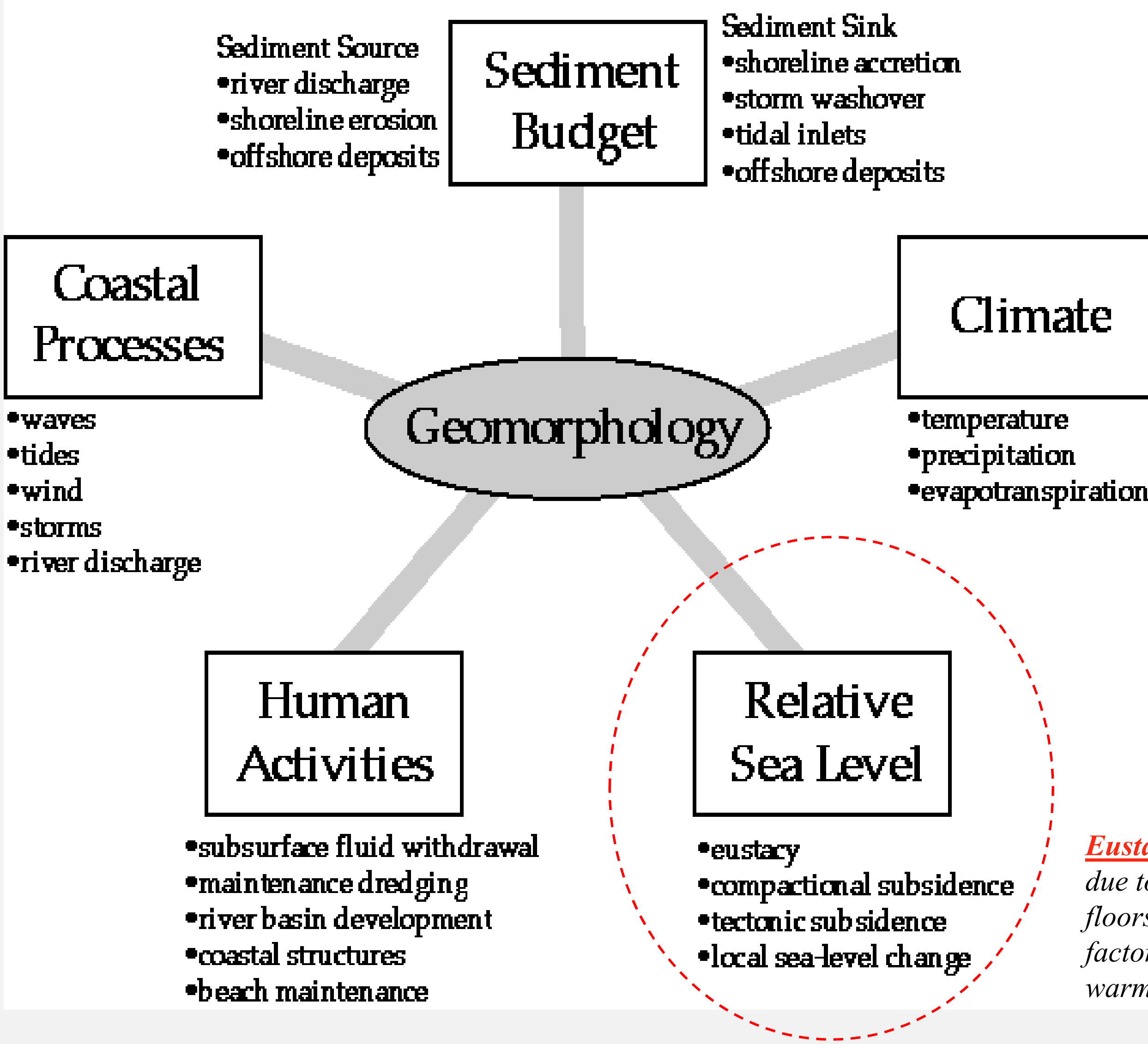
A challenging goal:

a realistic coupled waves-currents-morphologic-ecological evolution model

Scales of Sea Level Rise due to Climate Change?

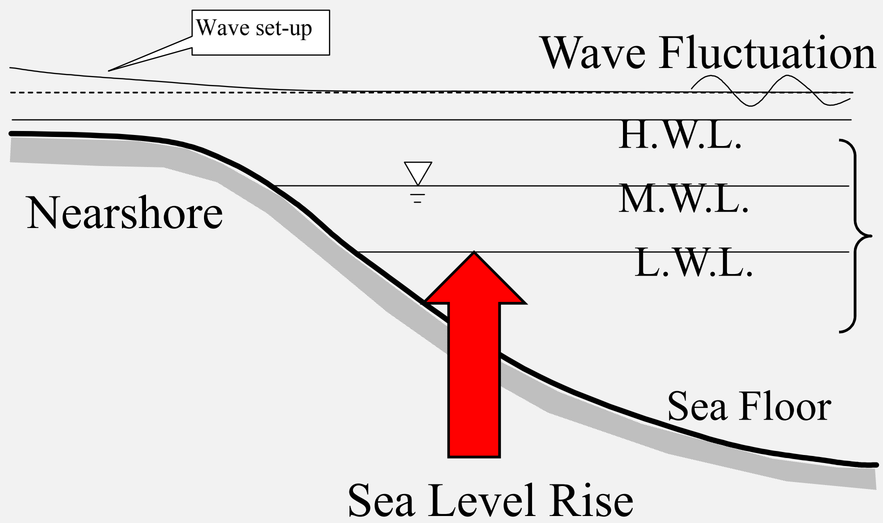
- Global Scale, varying yearly to century

Shoreline Change Variables



Eustacy: *Changes in sea level due to subsidence of the ocean floors, ocean volume and/or factors relating to global warming*

Water Level (Vertical Datums)



H.W.L. = High Water Level
M.W.L. = Mean Water Level → Mean Sea Level
L.W.L. = Low Water Level

Tidal datums at Los Angels, Outer Harbor

Tidal datums at LOS ANGELES, OUTER HARBOR based on:

LENGTH OF SERIES:	19 Years
TIME PERIOD:	January 1983 - December 2001
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	

Elevations of tidal datums referred to Mean Lower Low Water

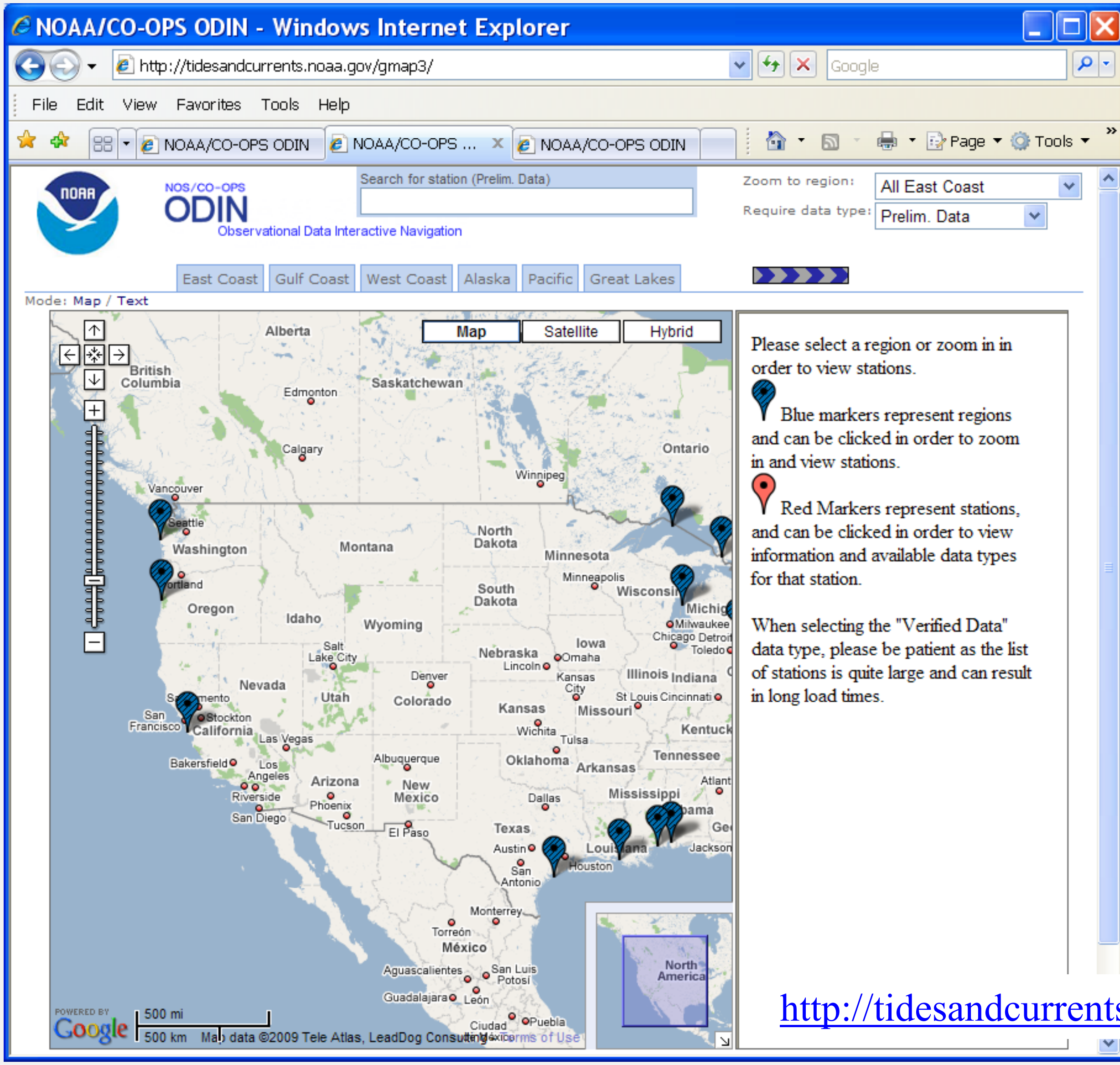
HIGHEST OBSERVED WATER LEVEL (01/27/1983)	= 2.384
MEAN HIGHER HIGH WATER (MHHW)	= 1.674
MEAN HIGH WATER (MHW)	= 1.449
MEAN TIDE LEVEL (MTL)	= 0.868
MEAN SEA LEVEL (MSL)	= 0.861
MEAN LOW WATER (MLW)	= 0.287
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)	= 0.062
MEAN LOWER LOW WATER (MLLW)	= 0.000
LOWEST OBSERVED WATER LEVEL (12/17/1933)	= -0.832

http://tidesandcurrents.noaa.gov/benchmarks/9410660.html

Averages are taken over the entire tidal datum *epoch*, which is a particular 19-year period explicitly specified for the definition of the datums; a full astronomic tidal cycle covers a period of 18.6 years. The average of all hourly tides over the epoch is the **M.S.L**.

NAVD = North American Vertical Datum
NGVD = National Geodetic Vertical Datum

NOAA ODIN
(Observational Data Interactive Navigation)



http://tidesandcurrents.noaa.gov/gmap3/

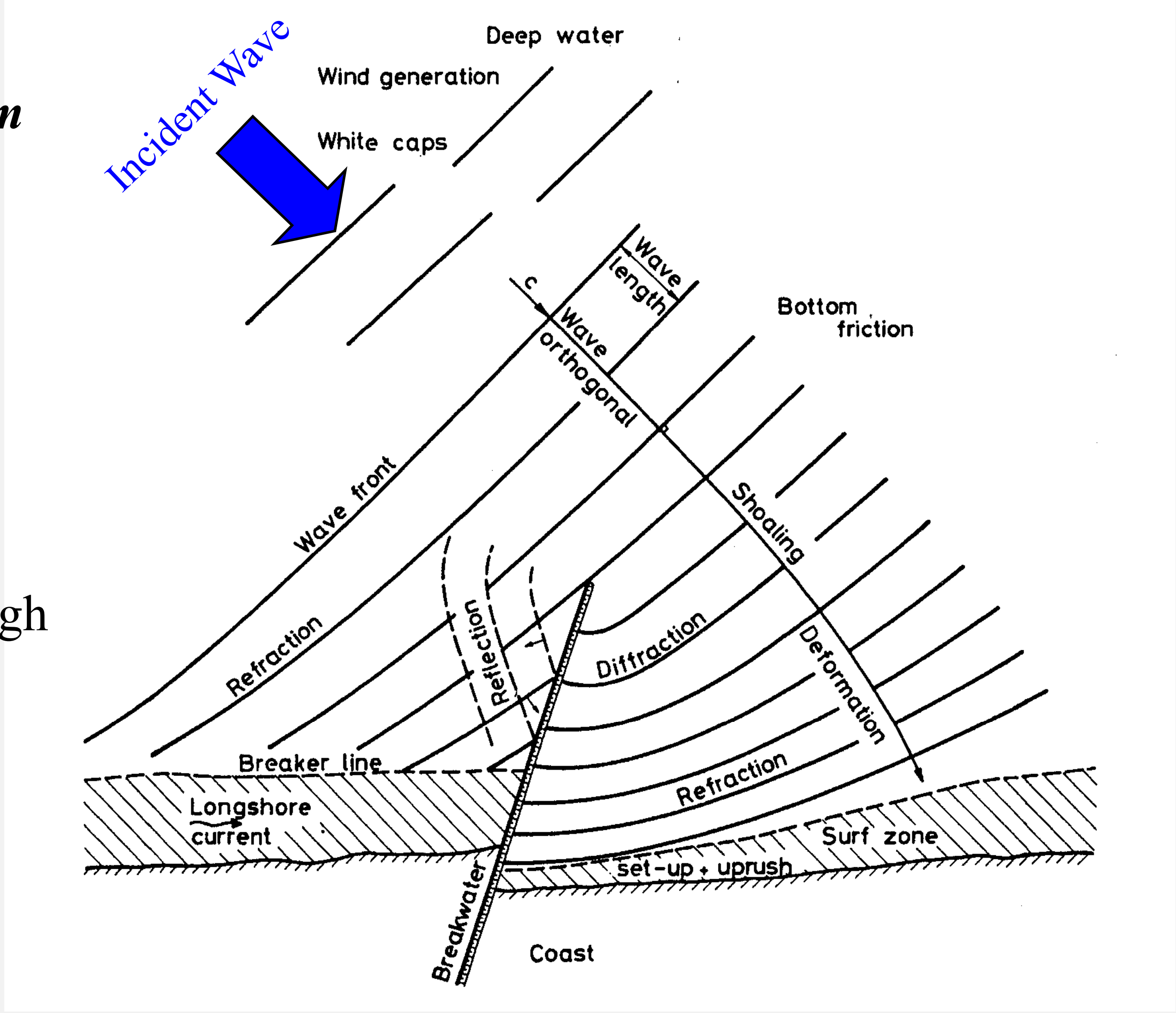
Wave Transformation and Deformation

Columbia River Entrance, WA/OR, 1966 *Smith & Cialone (2000)*

Deformation of Irregular Waves

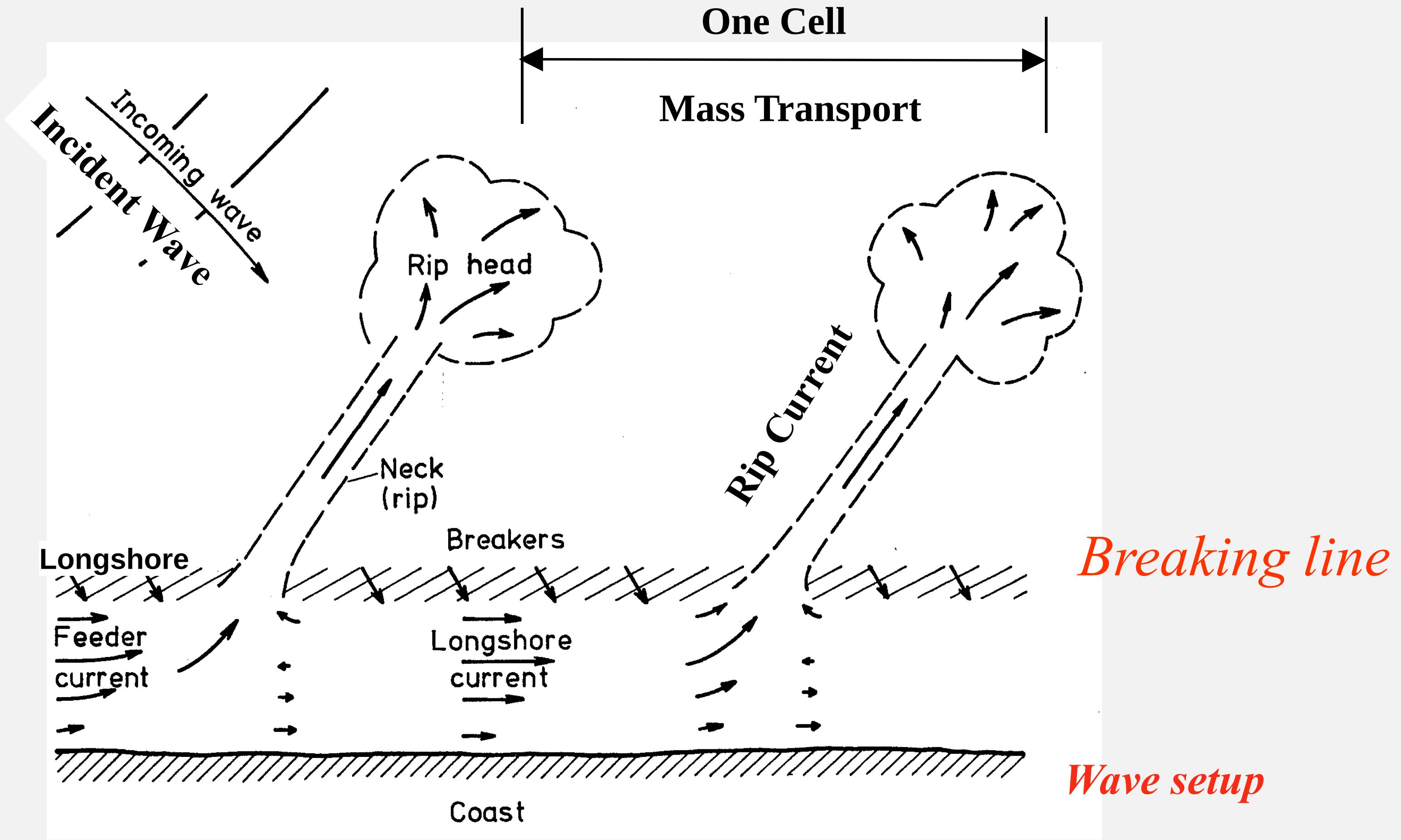
Deformation of waves from offshore to onshore

- Shoaling
- Refraction
- Diffraction
- Reflection
- Wave Breaking
- Wave Transmission through structure
- Bottom Friction
- Wave-Current Interaction
- ……



Longshore and Cross-shore Sediment Transport

(Locally Morphological Change due to Rip Current)



Currents generated by breaking wave

Longshore Sediment Transport in Coasts

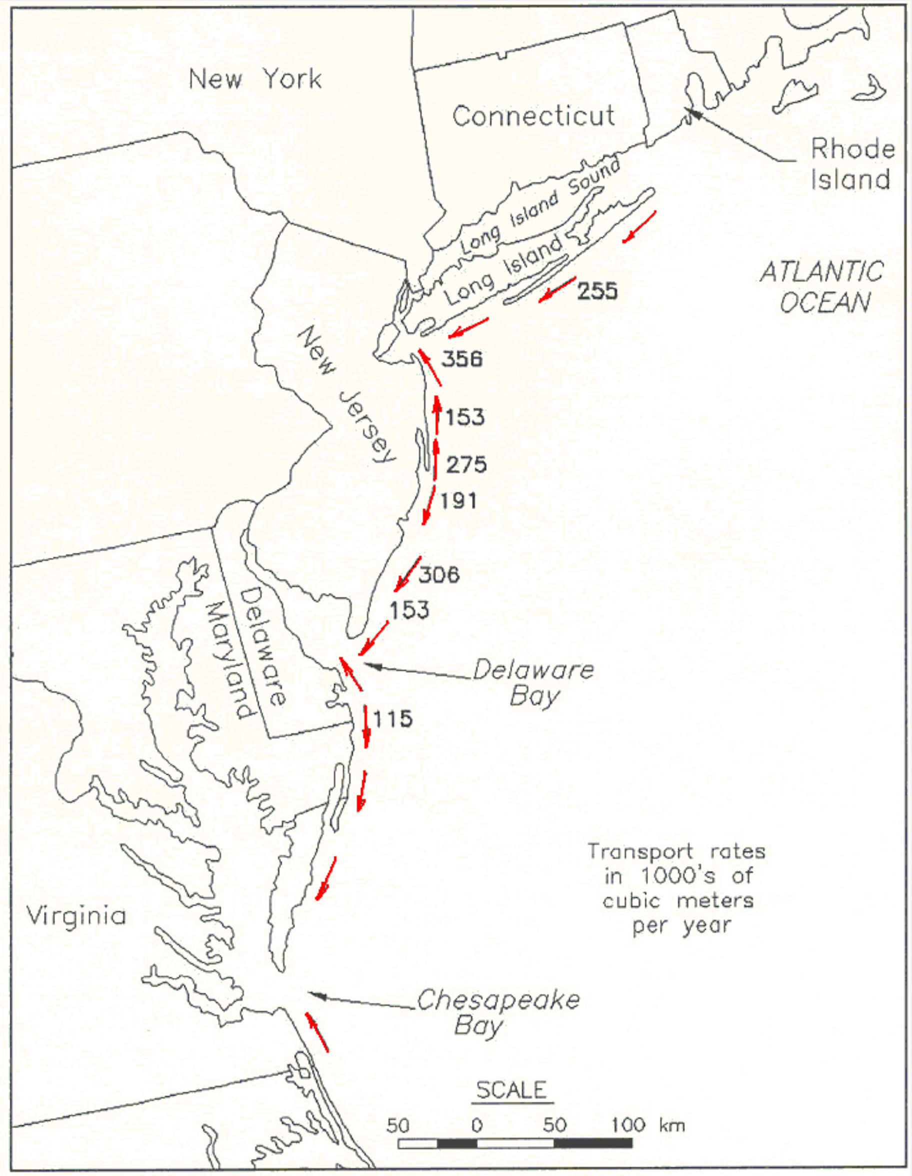
Ocean City Beach looking north, Maryland
Downloaded from: http://images.usace.army.mil/main.html

Observations on natural beaches as well as in laboratory wave basins have confirmed that the longshore current is largely confined to the surf zone. This longshore current drives the shoreward movement of longshore sediment transport.

Longshore Sediment Transport

Estimated Annual Net Longshore Transport Rates and Direction along the East Coast of the United States Based on Data from Johnson(1956, 1957) and Komar (1979)

— *COASTAL ENGINEERING MANNUAL, 2000*



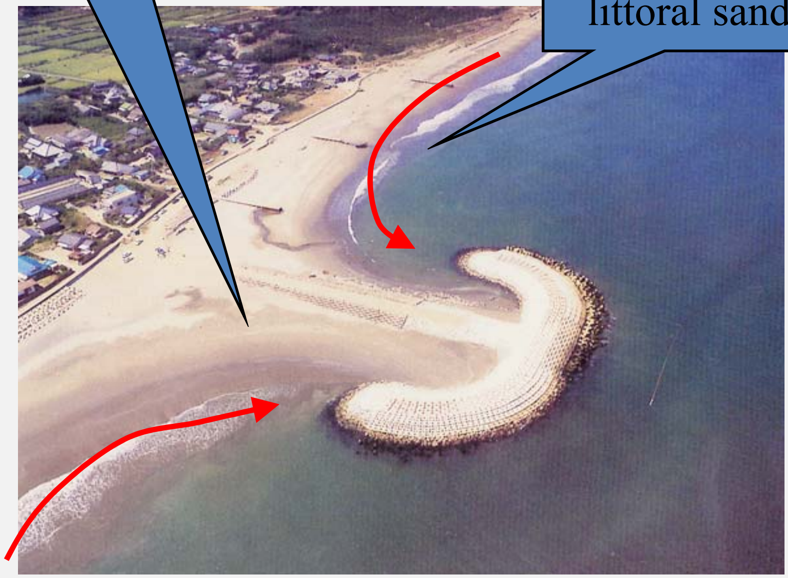
Longshore and Cross-shore Sediment Transport in Local Scale

(2D Morphological Change in River Mouth)

Sediment alongshore q_l=?
Sediment cross-shore q_c=?

Deposition of littoral sand

Movement of littoral sand



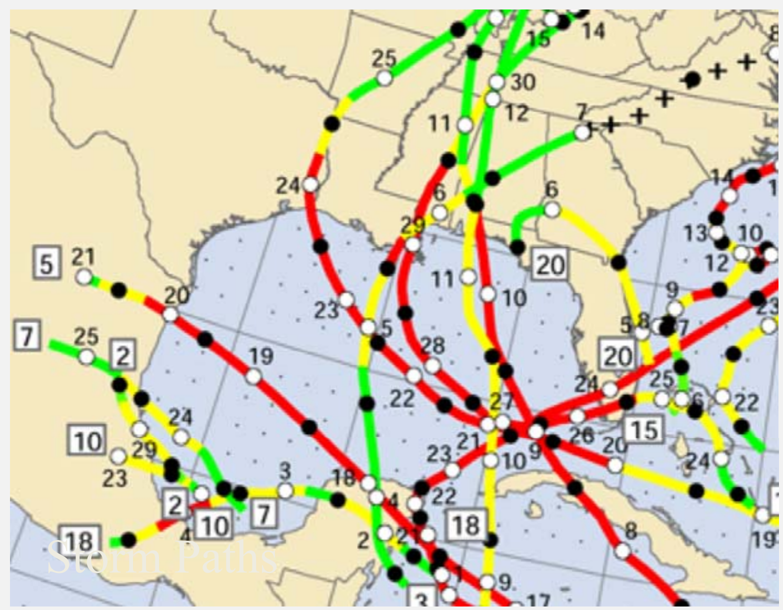
Erosion Protection (Artificial Headland)

River Mouth

The total longshore sediment transport model is not useful for this case.

Challenges to Complex Problems

- Complicated natural phenomena varying in regional and global scales
- Constantly update bathymetry and topography by monitoring and predicting bathymetric changes in coasts and estuaries
- Tremendous impacts on local and regional communities
- Multidisciplinary research efforts by universities, institutes, government agencies, local disaster managers, etc
- Multiple data resources existing in different locations (offshore, onshore, inland, research institutes, Internet)
- Lack of a integrated application system to handle all the physical processes and instrumental observations to predict impacts of storms/hurricanes, surges, tides, river floods, geomorphologic changes on the Gulf Coast regional community.

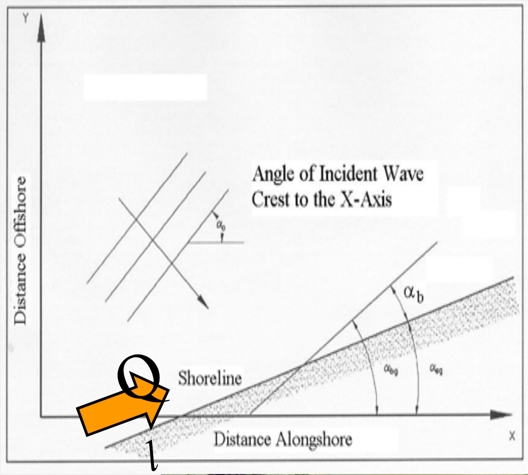


Traditional Problem Solving by Numerical Model

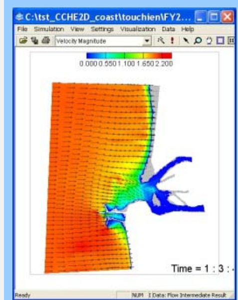
- Mathematical models for single or simplified physical process in a small local scale
- Simple model input data (e.g. boundary conditions) and small output data
- Offline simulations (no direct connection with real-time field measurements)
- Research work done by individual scientist or group
- Poor accuracy of model results
- Poor predictability
- Lack of capabilities for solving large-scale and long-term problems

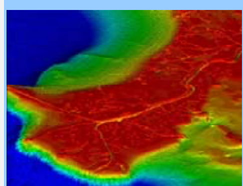
$$Q_l = \frac{K}{(\rho_s - \rho)g(1-\lambda)}(EC_g)_b \sin\alpha_b \cos\alpha_b$$

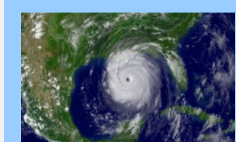
$$E_b = \frac{\rho g H_b^2}{8}$$

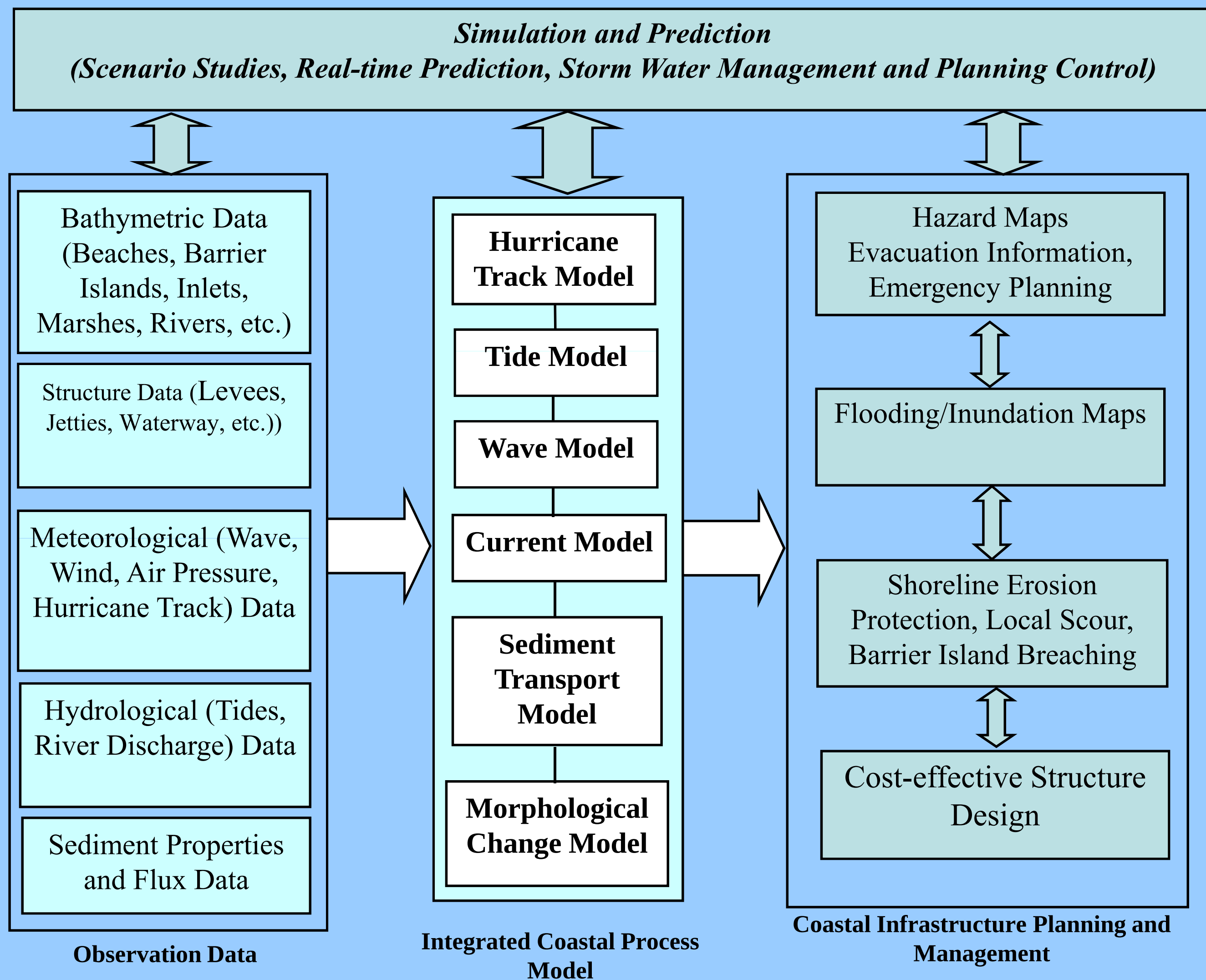


NCCHE's Coastal/Estuarine Modeling Development (CCHE2D-Coast)









CCHE2D-Coast is a fully-integrated numerical model system for simulating waves, current, morphological changes in one mesh

Capabilities of CCHE2D-COAST

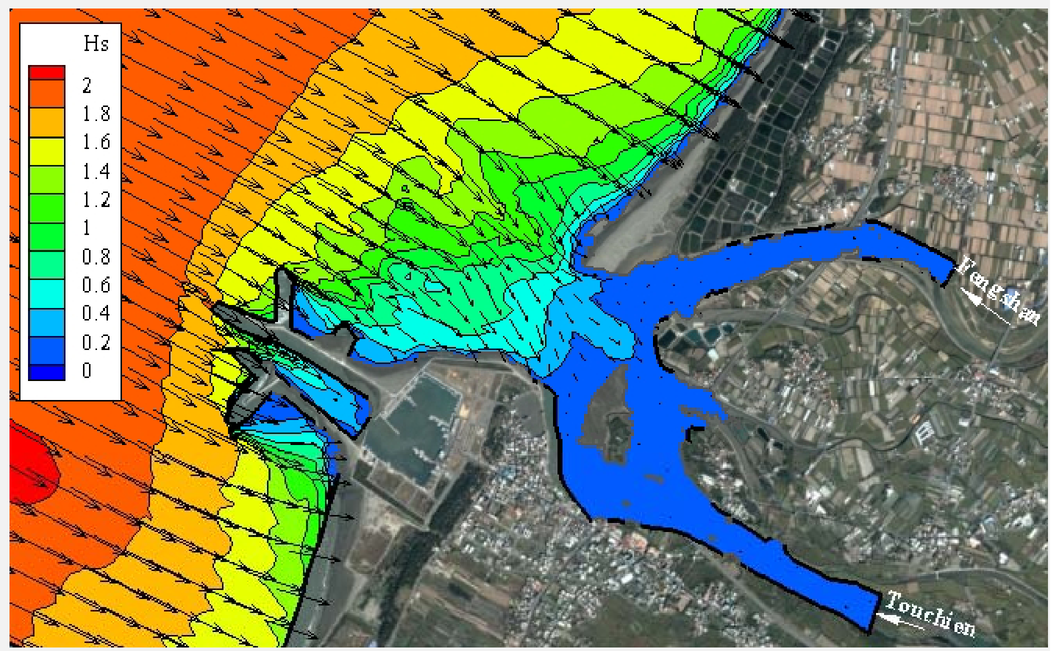
- Irregular Wave Deformations: Refraction, Diffraction, Wave-Current Interaction, Transmission through Obstacles, Wave Breaking, etc.
- Nearshore Currents Including the Surface Roller Effect in the Surf Zone due to Wave Breaking,
- Sediment Transport due to Combination of Wave and Current,
- Morphological Change,
- A Variety of Coastal Structures and Sand Nourishment, e.g., Groin, Offshore Breakwater, Artifical Headland, Jetty, Artifical Reef (Submerged Dike);
- Flexible non-orthogonal available for simulating complex coastlines

Multidirectional Wave Action Model in CCHE2D-Coast

- Short-wave-averaged models dealing with irregular and multidirectional waves developed on a statistical basis;
- Spectral Wave Action Equation;
- The models can predict irregular wave transformation in a large-scale region (1-100km)
- The model supports non-orthogonal mesh grids

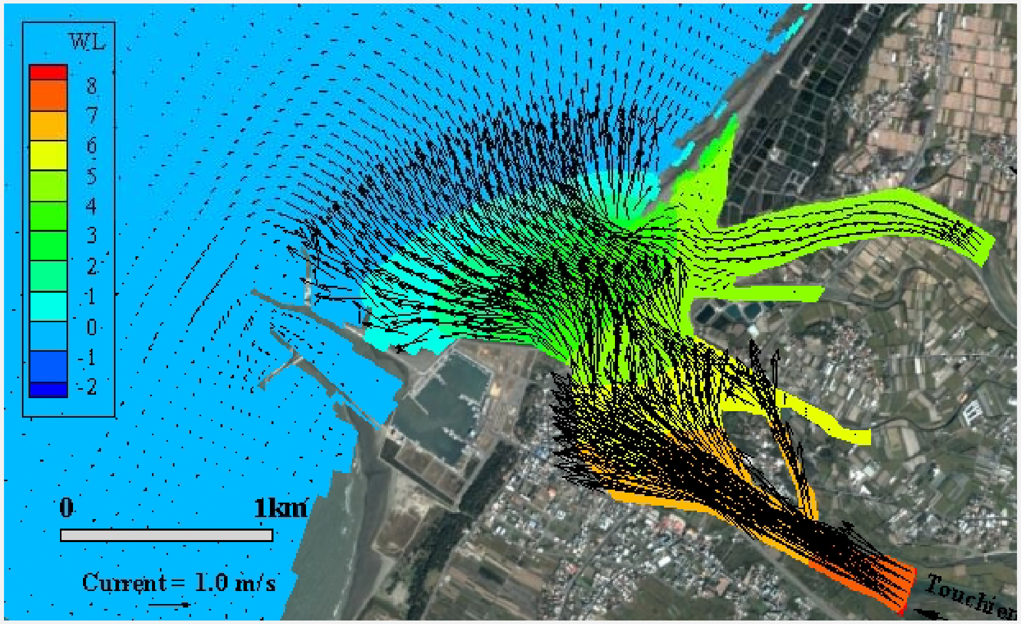
<u>Wave Deformation Processes in CCHE2D-Coast</u>

- Refraction
- Diffraction
- Shoaling
- Wave Breaking
- Wave Transmission through structure
- Bottom Friction
- Wave-Current Interaction
- Wind-induced waves



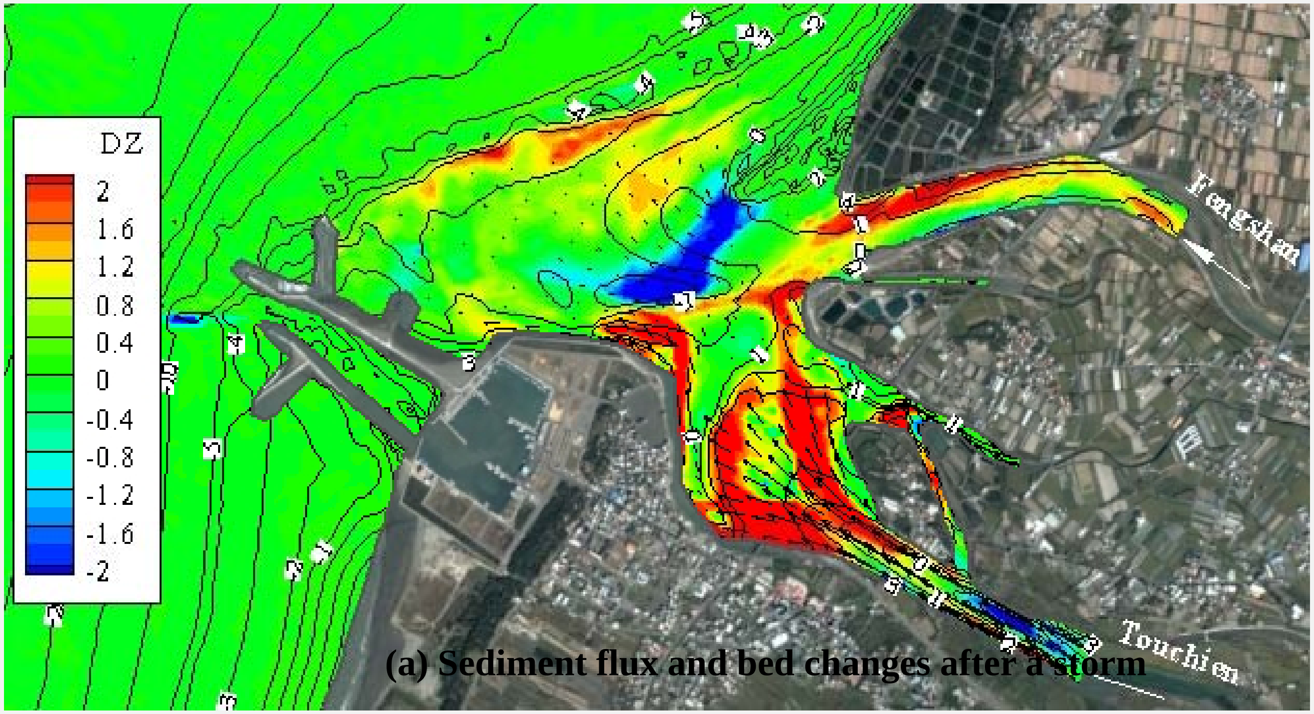
CCHE2D Coastal/Estuarine Hydrodynamic Model

- Tidal currents: ebb and flood tides
- River Inflows: hydrographs at upstream of estuary
- Wave-driven currents: longshore /cross-shore currents
- Coriolis force
- Wave breaking in the surf zone: surface rolling effect, 3D undertow flow
- Pressure gradients due to mean water level variations (set-up, setdown)
- Bottom friction due to waves and mean currents
- Turbulence: turbulent shear stress, turbulence mixing
- Wind friction
- Inertia of the currents due to irregular waves and long-waves
- Simulation of drying and flooding of inter-tidal flats (moving boundaries)



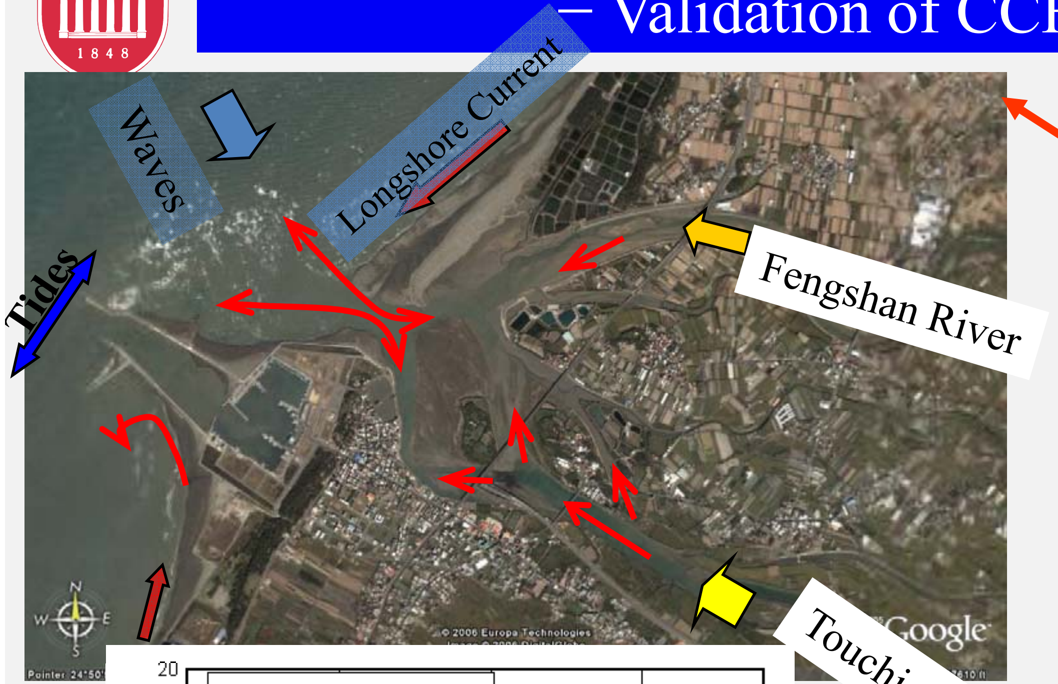
Sediment Transport and Morphodynamic Modeling in CCHE2D-Coast

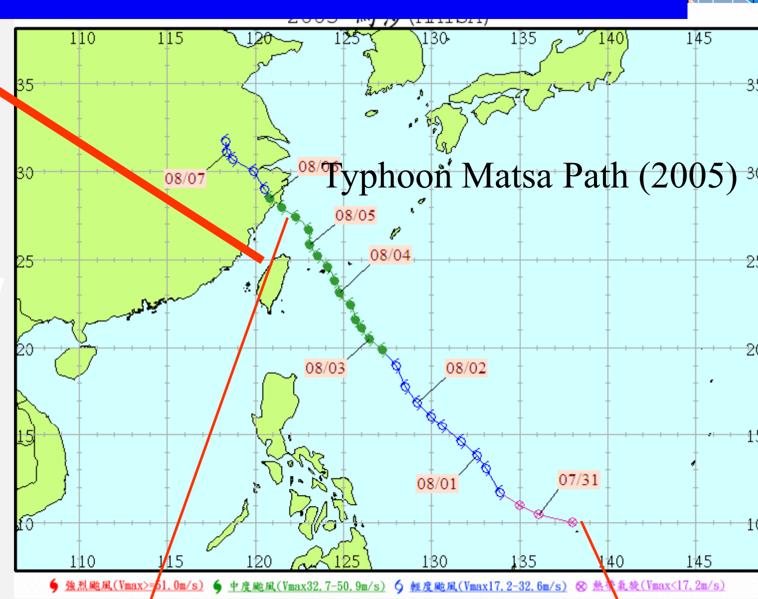
- Sediment transport modeling: Total sediment transport load includes bed load and suspended load
- Sediment transport due to wave-current interaction
- Integrated sediment transport models to calculate the sediment transport rate from upstream river to estuary and coast
- Morphodynamic changes should be fed back to simulations of waves and currents
- Wetting/drying process for bed changes

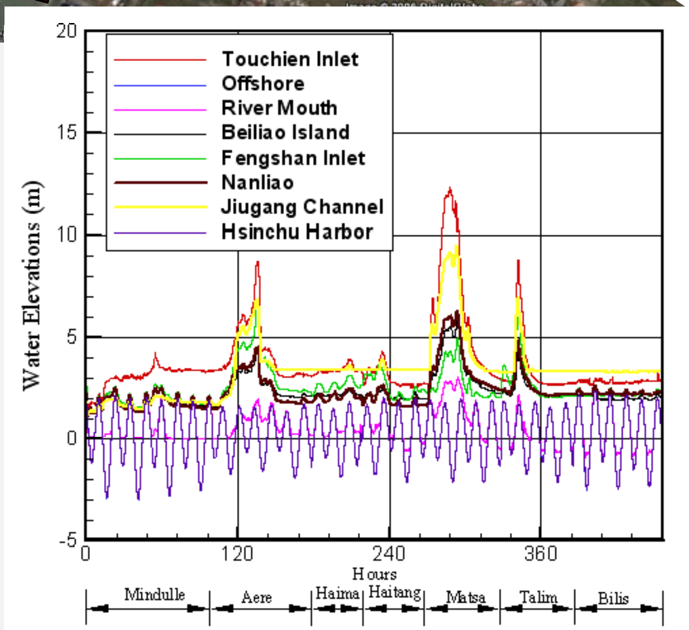


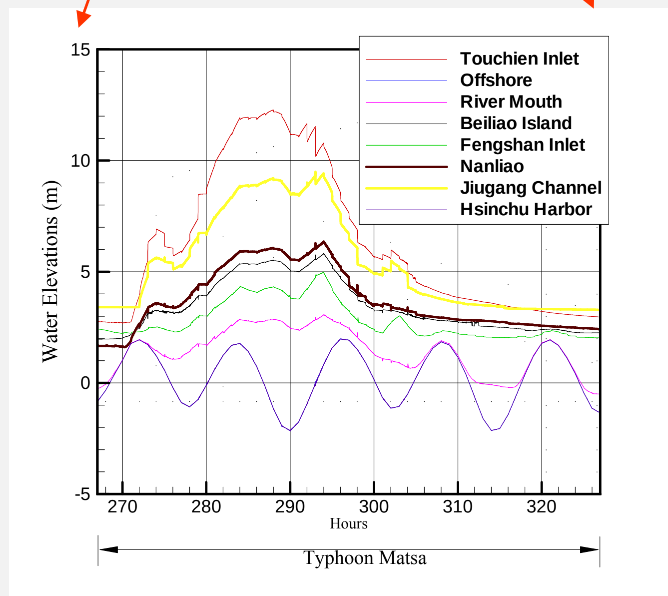
(a) Sediment flux and bed changes after a storm

CCHE2D-Coast Response to Storms at an Estuary – Validation of CCHE2D-Coast

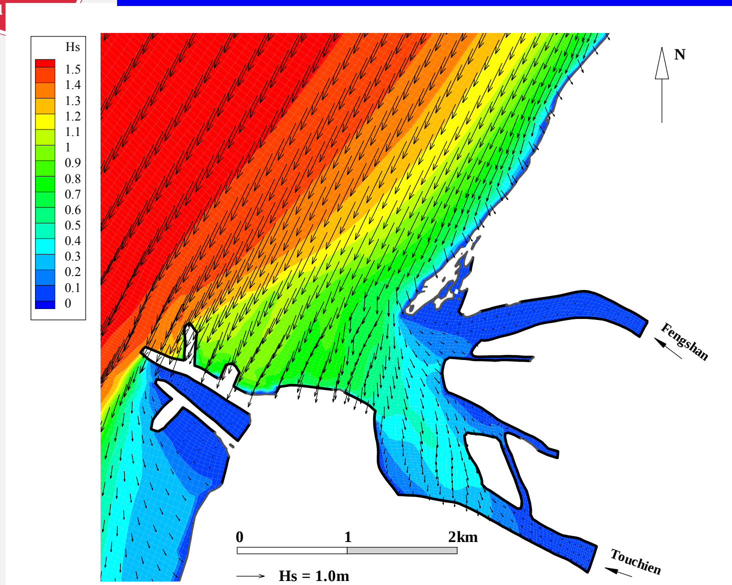




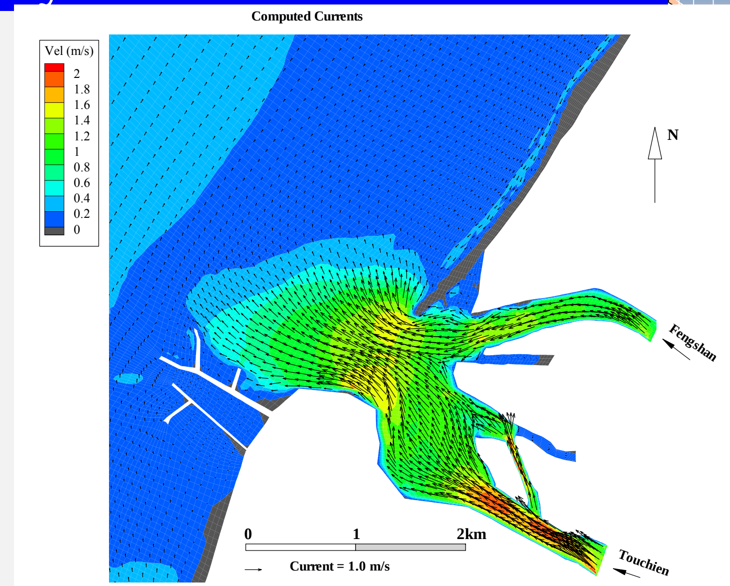




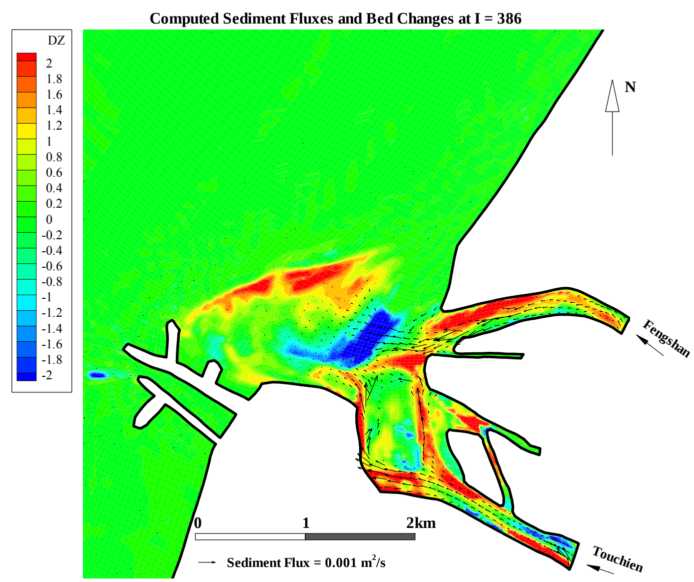
Computed Waves, Currents, and Morphological Changes in an Estuary



Waves at Typhoon Talim,

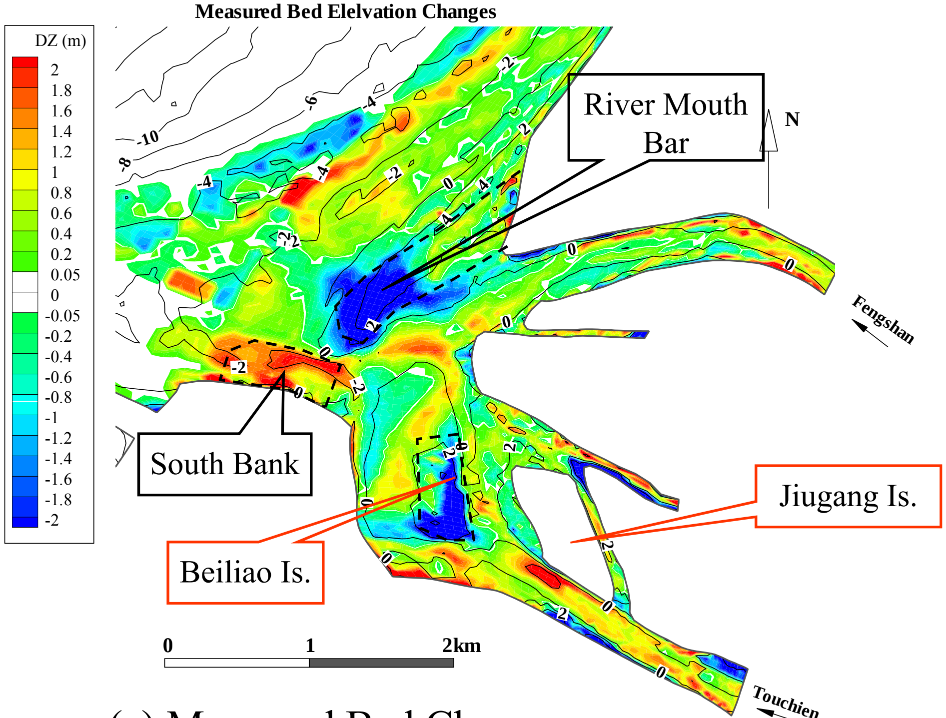


od current at Typhoon Talim, 09/01/2005 1:00

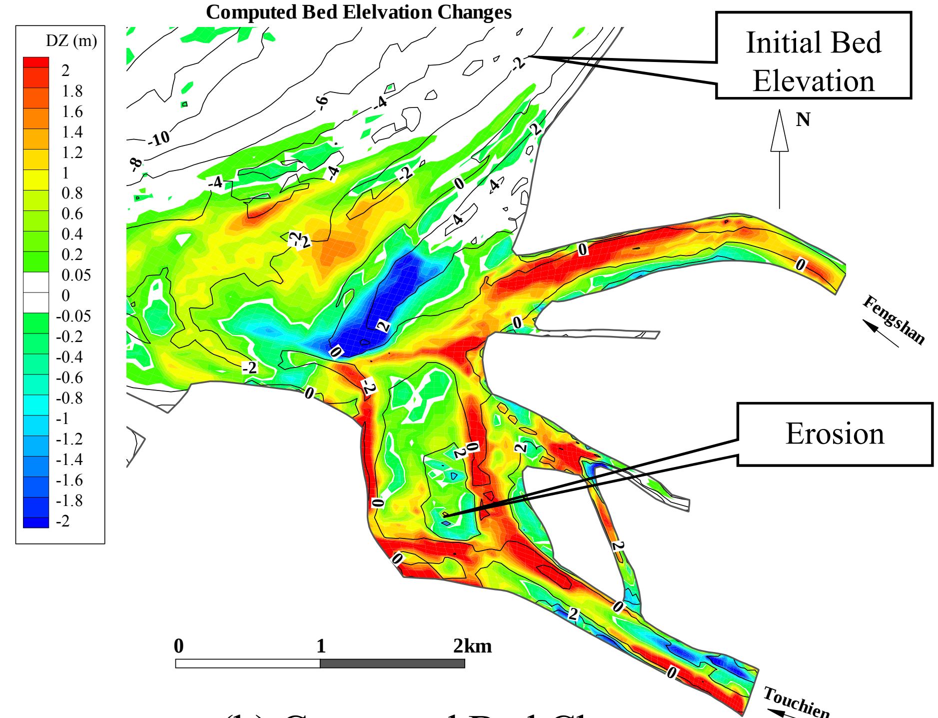


Bed Changes after Typhoon Talim

Comparison of Bed Changes from 2004 to 2006



(a) Measured Bed Changes



(b) Computed Bed Changes

(1) The long-term morphodynamic simulations correctly reproduced the erosion and breaching occurred in the river mouth;

(2) The simulations give a similar erosion pattern at the head of the Beiliao Island, but underestimated erosion;

(3) The simulated depositions in the south bank of the river mouth show the consistent pattern with the observations.

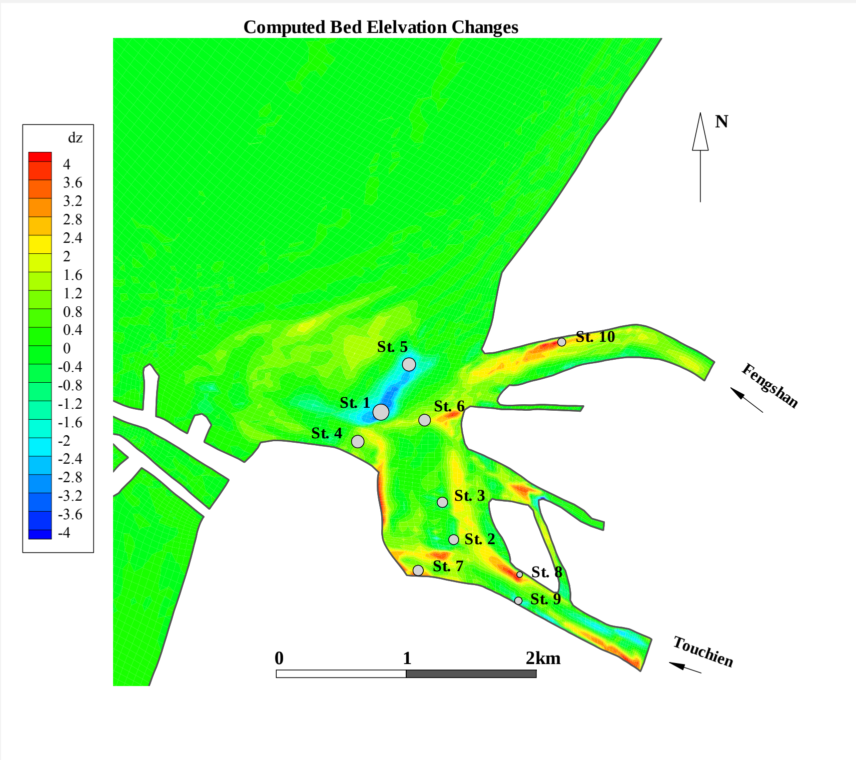
(4) The morphodynamic simulations produced a similar offshore bar development; the size of the offshore bar simulated by the model is larger than the measurements. Further detailed measurements at the offshore may be needed.

(5) The simulated morphological changes in the Touchien River show almost the same size and locations of deposition and erosion, e.g. the erosion at the left bank, the deposition at the right bank near the Jiugang Island.

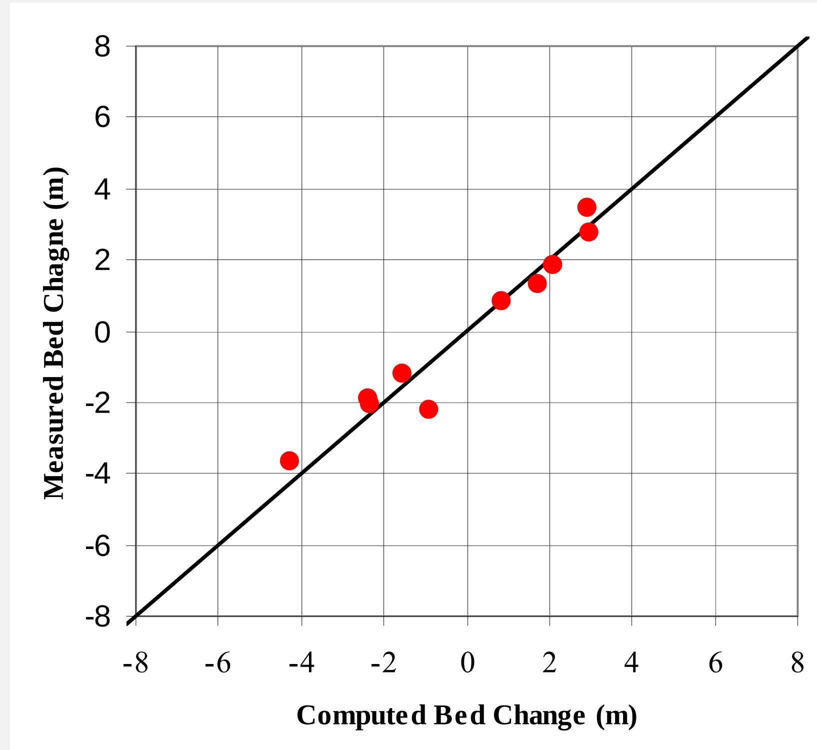
(6) The simulations in the Fengshan River show overestimated deposition by comparing with the observation.

Calibration of Morphodynamic Model

(Comparison of Bed Elevations at Selected Stations)



(a) Stations for Model Calibration

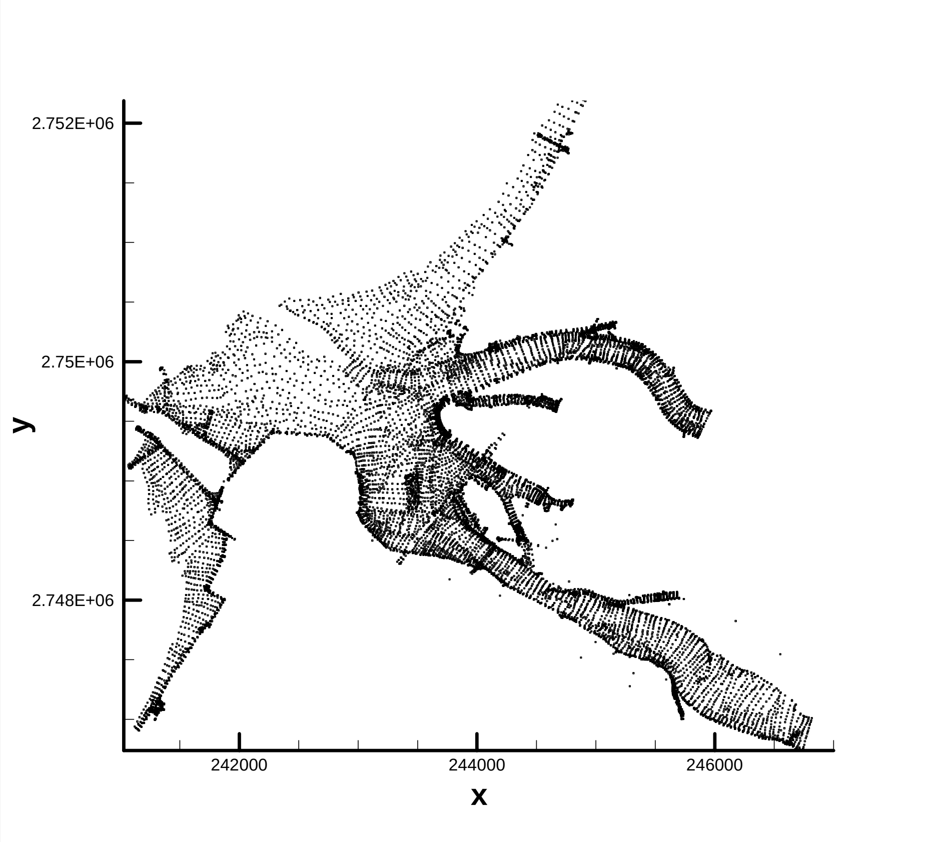


(b) Calibration performance of the final case

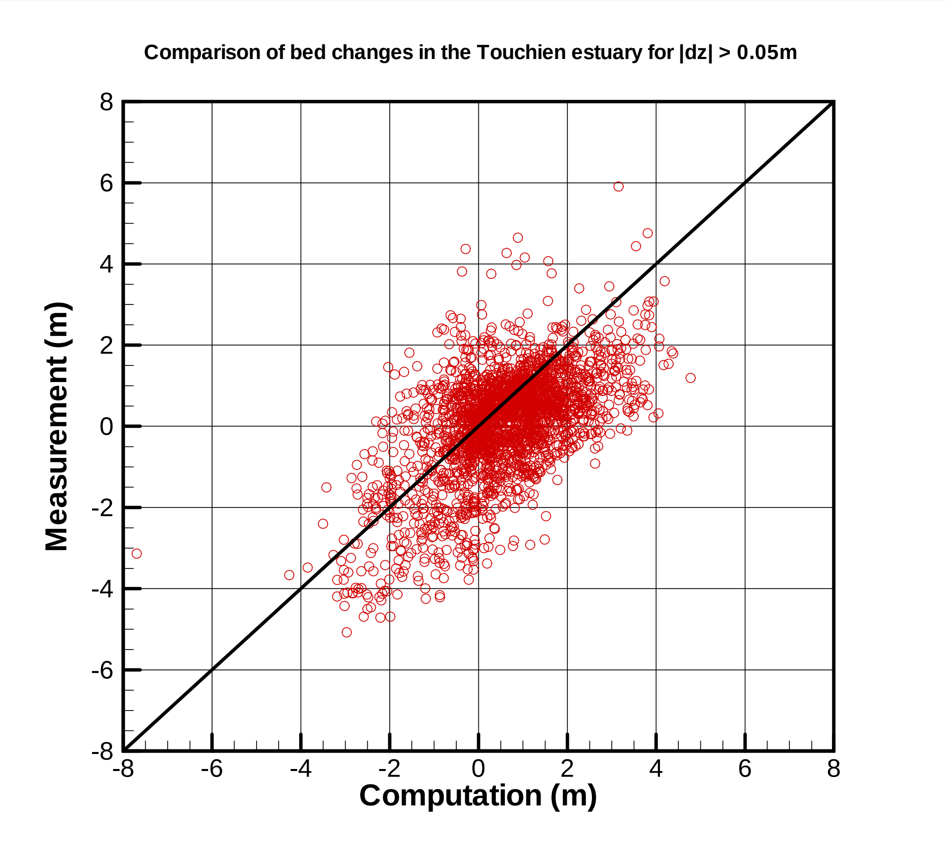
By testing the morphodynamic simulations for more than 12 runs and calibrating only two parameters in the Watanabe's total load formulation, the site-specific validated model show the calibrated parameters are:

Empirical coefficient of the sediment transport rate $\boldsymbol{B_w = 3.0}$ (usually 2.0 – 7.0)
Empirical coefficient of downslope gravitational effect $\boldsymbol{\varepsilon = 10.0}$ (which is the suggested value)

Validation of Morphodynamic Model (Comparisons of Bed Elevations of All Measured Data)



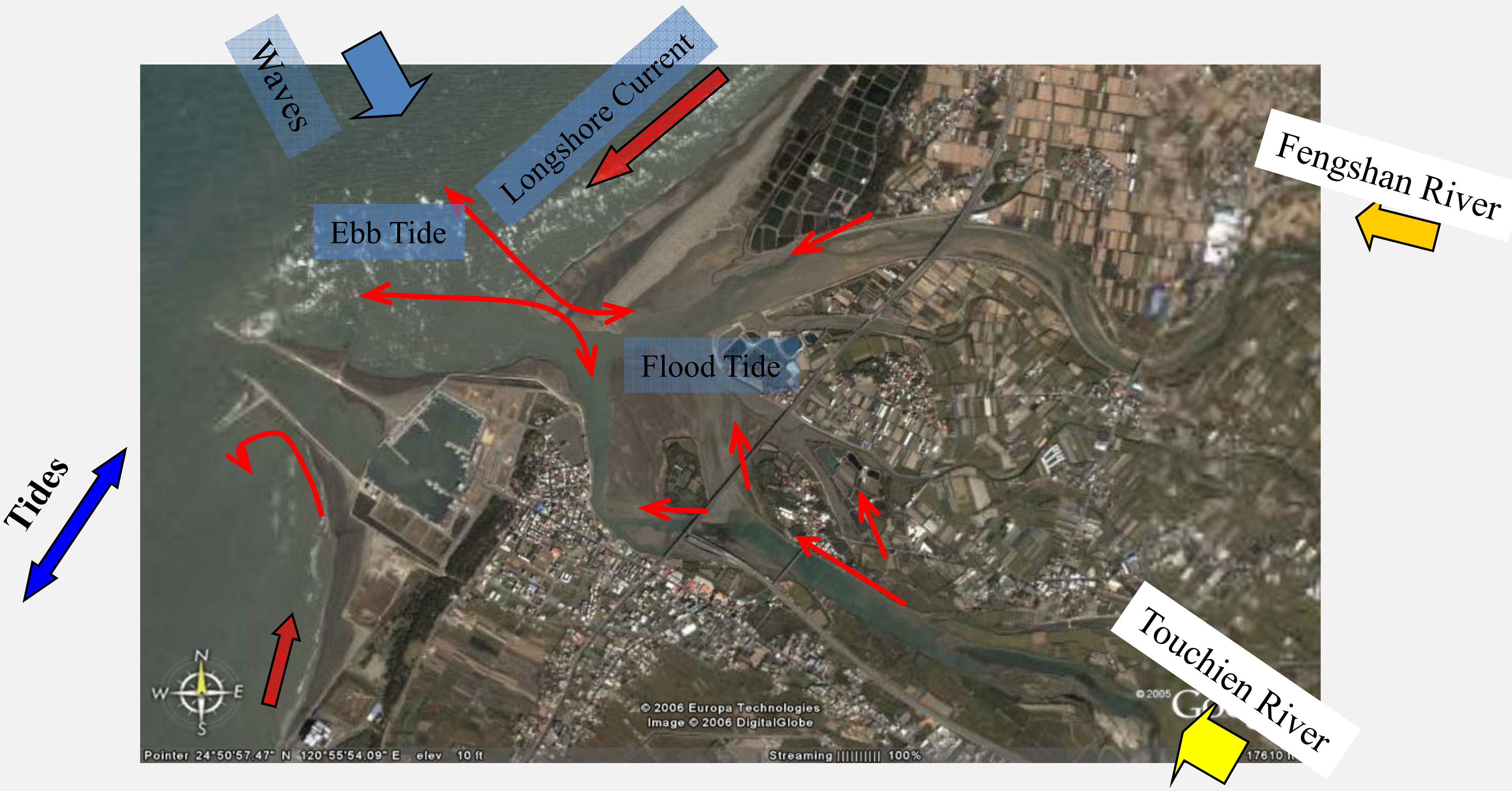
(a) Bed elevation measurement points



(b) bed changes at all the mesh nodes in the estuary in which the bed changes are not less than 5 cm

Through the comprehensive comparisons in all the nodes, the averaged absolute error of bed change, $\sum(\Delta Z_1 - \Delta Z_2)/n$, is **±37.0** cm, where ΔZ_1 and ΔZ_2 are computed and measured bed changes, respectively; n is the total nodes in the estuary (approximately 6500 nodes).

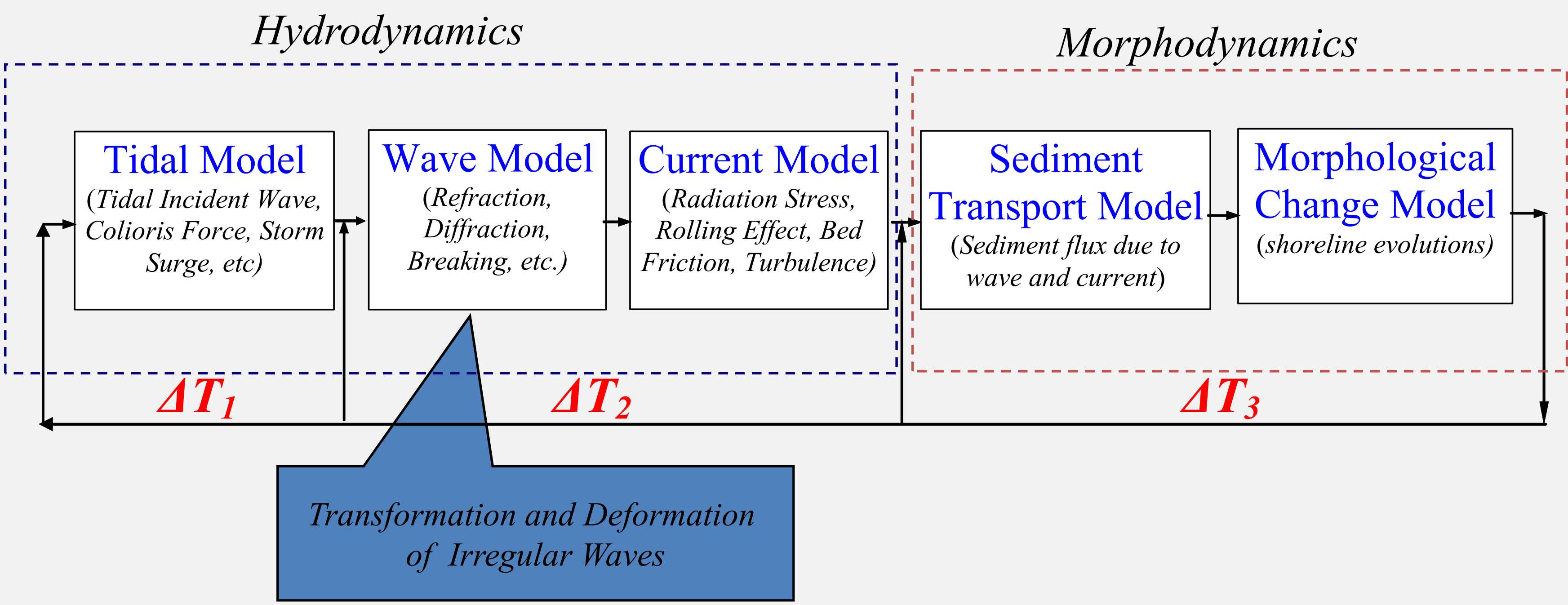
Morphological and Coastal Flood Simulations in Estuary



Objectives: figure out hydrodynamic and morphological responses to the combined forcings of tides, waves, typhoons, river floods, and winds; Find a better engineering plan to prevent coastal inundations due to flooding and sediment transport.

Sponsors: Water Resources Planning Institute, Water Resources Agency, MOEA, Taichung, Taiwan (2006-2007), collaborated with National Chiao Tung University, Hsinchu, Taiwan

A Coastal/Estuarine Process Model: CCHE2D-COAST



- *Integrated Modules and Feed back System*
- *ΔT: Feedback Interval*

Wave Action Model (1)

- Energy Balance Equation + ***Diffraction***

The variations of wave energy density ***S(x,y,θ,f)*** under the attack of irregular/multi-directional incident waves, can be represented as follows, *(Mase, 2001)*

Diffraction Term

$$\frac{\partial S v_x}{\partial x}+\frac{\partial S v_y}{\partial y}+\frac{\partial S v_\theta}{\partial \theta}=Q+\frac{\kappa}{2\omega}\left(\frac{\partial}{\partial y}\left(CC_g\cos^2\theta\frac{\partial S}{\partial y}\right)-\frac{1}{2}CC_g\cos^2\theta\frac{\partial^2 S}{\partial y^2}\right)$$

where θ = wave direction (-0.5π – 0.5π), v = energy transport velocity, Q = source term arisen from energy dissipation, e.g., wave breaking and bottom friction. κ = empirical coefficient (=2.0-3.0). C=wave celerity, Cg=wave group celerity

$$v_x = C_g\cos\theta,\quad v_y = C_g\sin\theta\quad v_\theta=\frac{C_g}{C}\left(\sin\theta\frac{\partial C}{\partial x}-\cos\theta\frac{\partial C}{\partial y}\right)$$

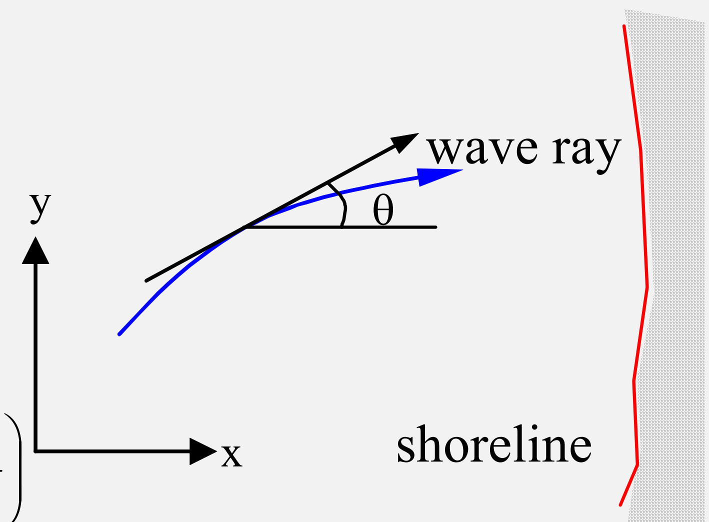


Fig. Coordinate System

Governing Equations (2DH) for Nearshore Current

- Shallow Water Equations + Radiation Stress

(*Ding et al., 2000*)

$$\frac{\partial \eta}{\partial t} + \frac{\partial h u_i}{\partial x_i} = 0$$

$$\frac{\partial h u_i}{\partial t} + \frac{\partial h u_j u_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left(h \nu_e \frac{\partial u_i}{\partial x_j} \right) - g h \frac{\partial \eta}{\partial x_i} - \frac{\partial R_{ij}}{\partial x_j} + \frac{\tau_i^s - \tau_i^b}{\rho}$$

u_i = the depth averaged velocity vector; η = water elevation; *h* = water depth,; R_{ij} = wave-induced radiation stress; τ^s=*surface wind stress* τ^b = bottom friction stress; ν_e=eddy viscosity.

Morphodynamic Changes

- Slope-related Transport Equation

Change rate of seabed level

Mass balance

Downslope gravitational transport (H.J.de Vriend, 1993)

$$\frac{\partial Z_b}{\partial t} = -\frac{\partial q_j}{\partial x_j} + \frac{\partial}{\partial x_j}\left(\varepsilon \left| q_j \right| \frac{\partial Z_b}{\partial x_j} \right)$$

Where Z_b is the seabed level, q_j is the totally local sediment transport rate, ε is an empirical constant.

Total Sediment Transport Rate (2D)

- Time-averaged Total Sediment Transport Rate

Energetic Method（Watanabe, 1984）

$$q = q_C + q_W \qquad (m^2/s)$$

Sediment transport due to mean current

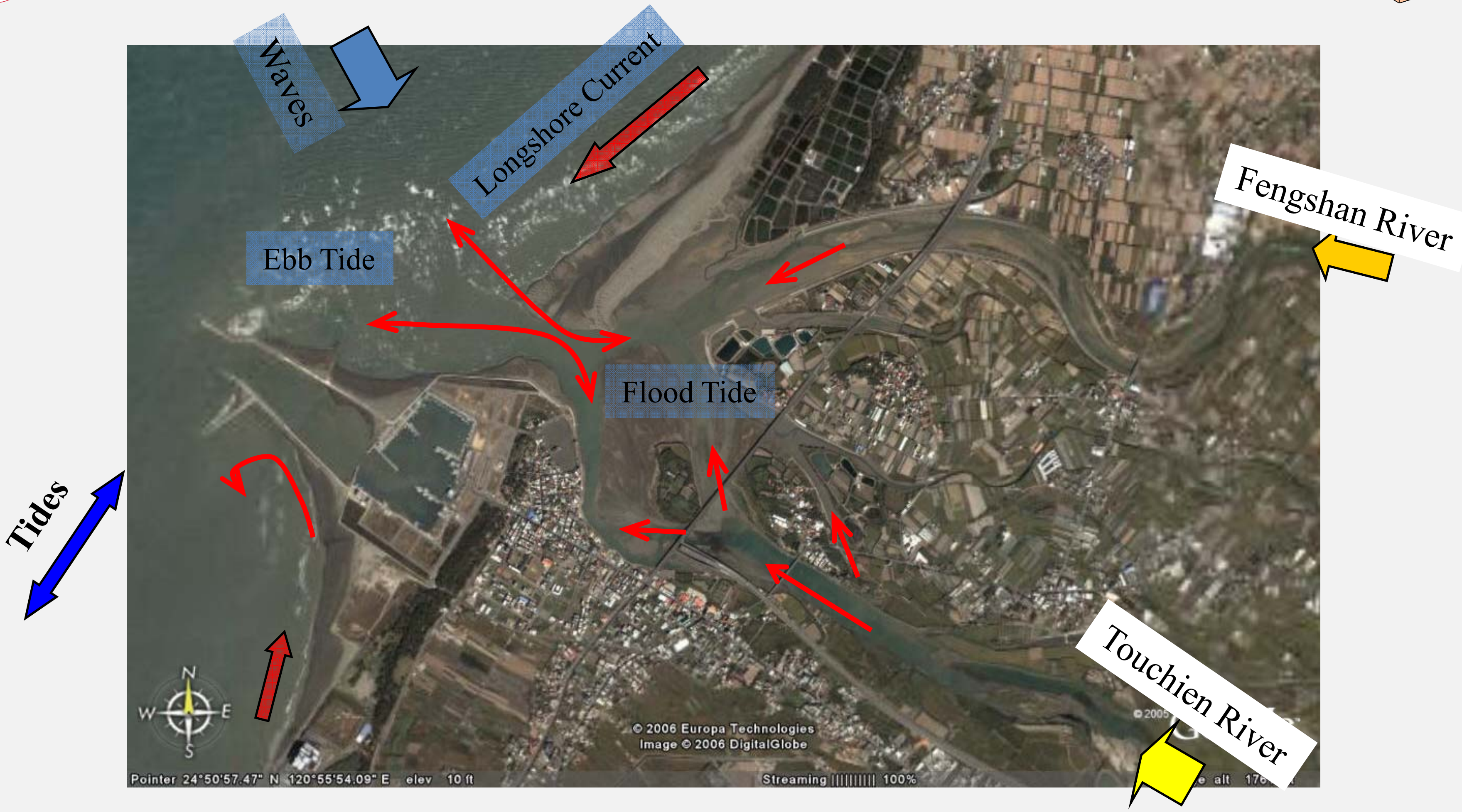
$$q_C = A_C(\tau_m - \tau_c)U / \rho g$$

Sediment due to wave motion

$$q_w = A_W F_D(\tau_m - \tau_c)U_b / \rho g$$

τ_m: The maximum bed-shear stress under wave and current
τ_c: The critical bed-shear stress
U: Depth-averaged velocity
U_b: Bottom orbital velocity
Ac, Aw: Empirical coefficients

Assessment of Impact of SLR in an Estuary during Storm and Flood Season

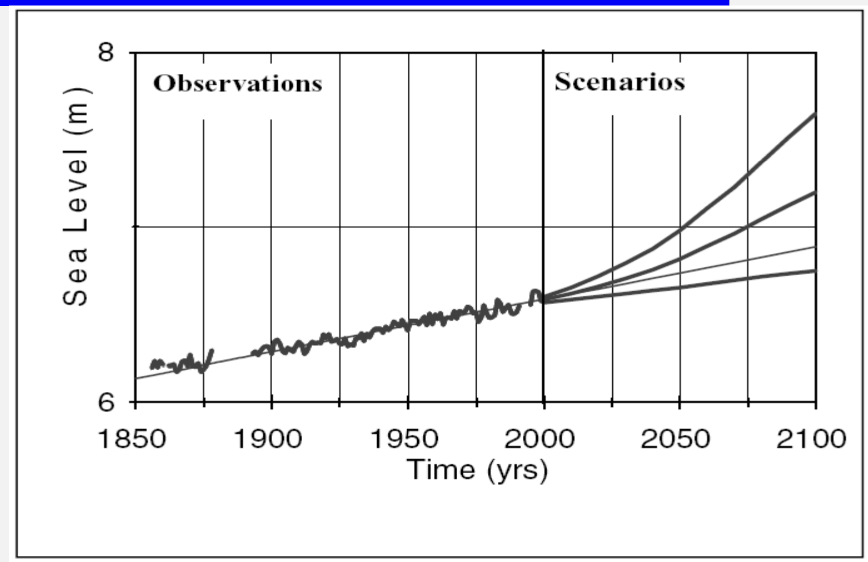


A medium-sized estuary has equally important physical processes, or external forcings, e.g., tides, waves, river inflows, winds. The modeling work for this kind of estuaries is a challenge

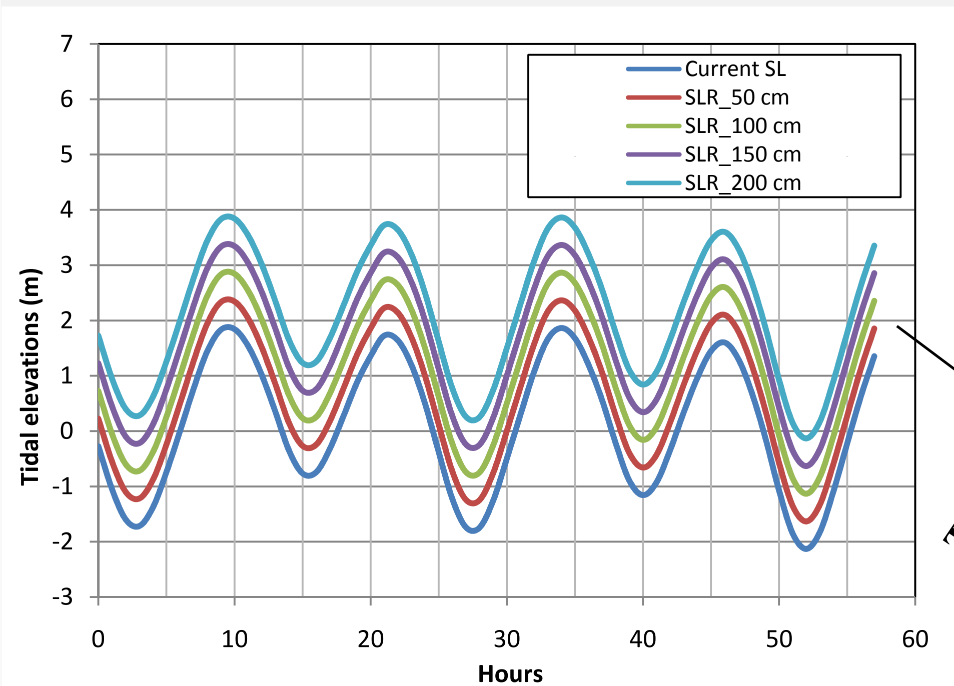
Hydrological Conditions for SLR Scenarios at an Estuary: Tides

Five Scenarios for Demonstration

Case 1	0.0 m (status quo)	
Case 2	0.5 m	+ 100-year Flood
Case 3	1.0 m	Waves
Case 4	1.5 m	Winds
Case 5	2.0 m	

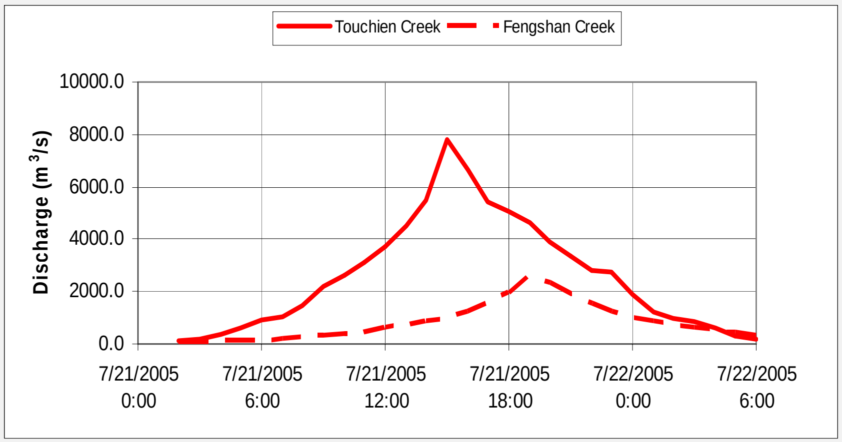


An example to project the SLR at New York City

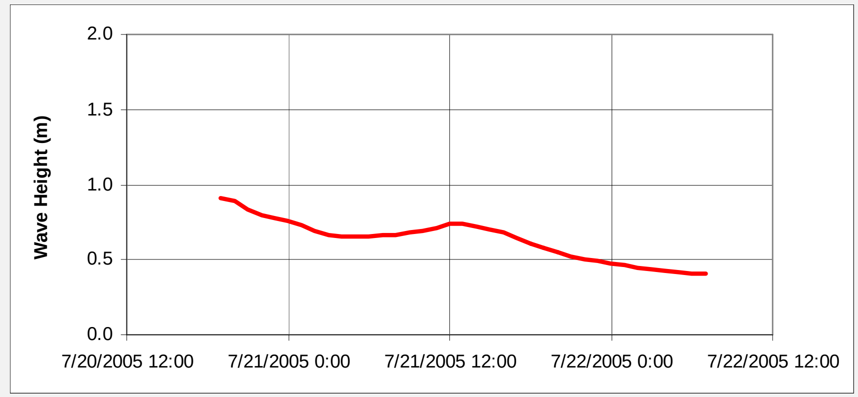


Tidal Elevations Boundary Conditions at offshore

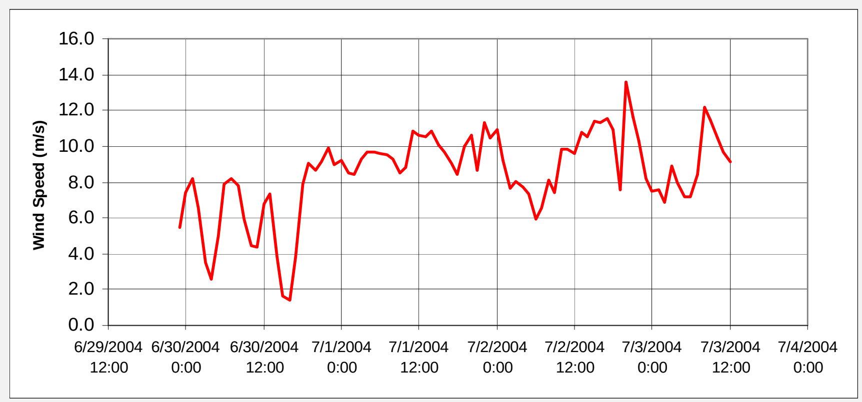
Hydrological Conditions for an Extreme Storm Event (100-year flood): Floods, Waves, Winds



(a) Hydrographs at river upstream

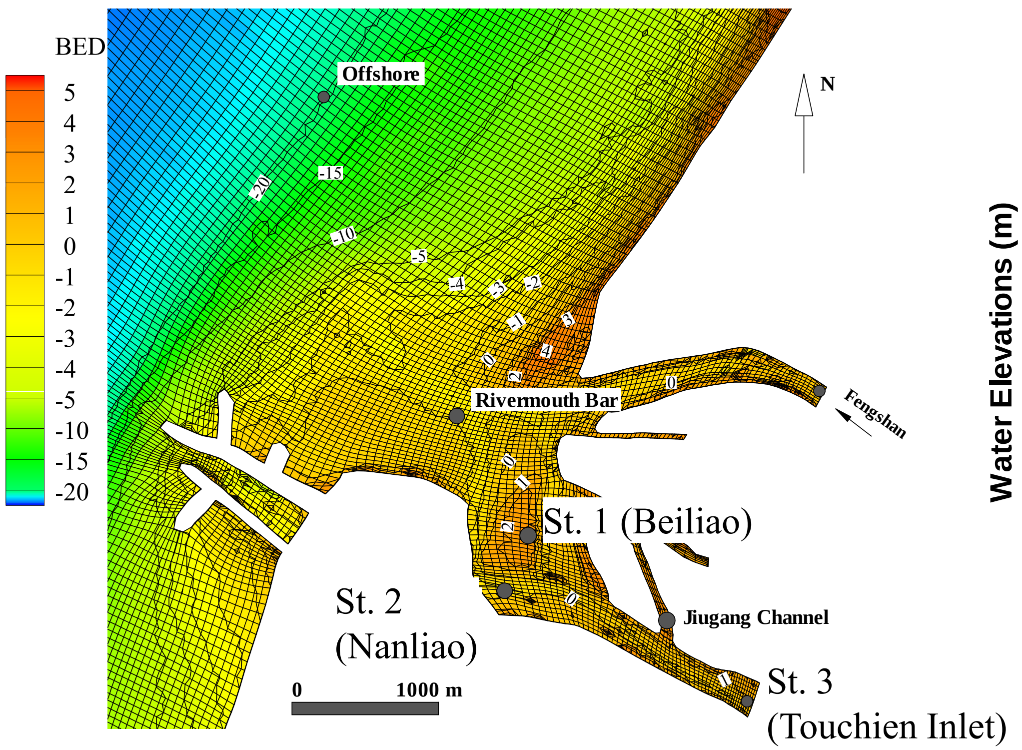


(b) Significant wave height at offshore

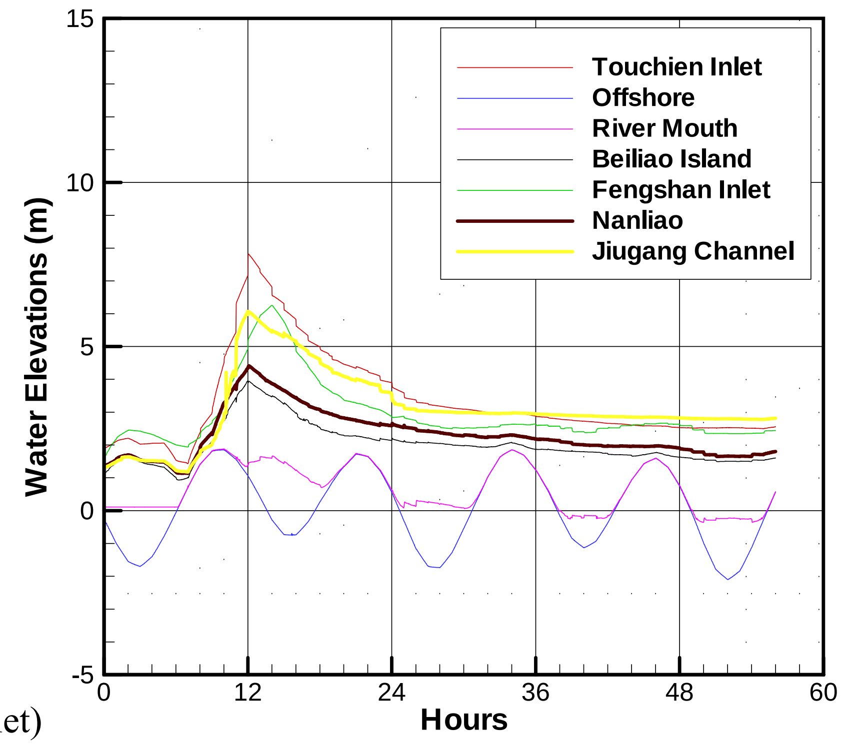


(c) Wind speed over the estuary

Monitoring Stations

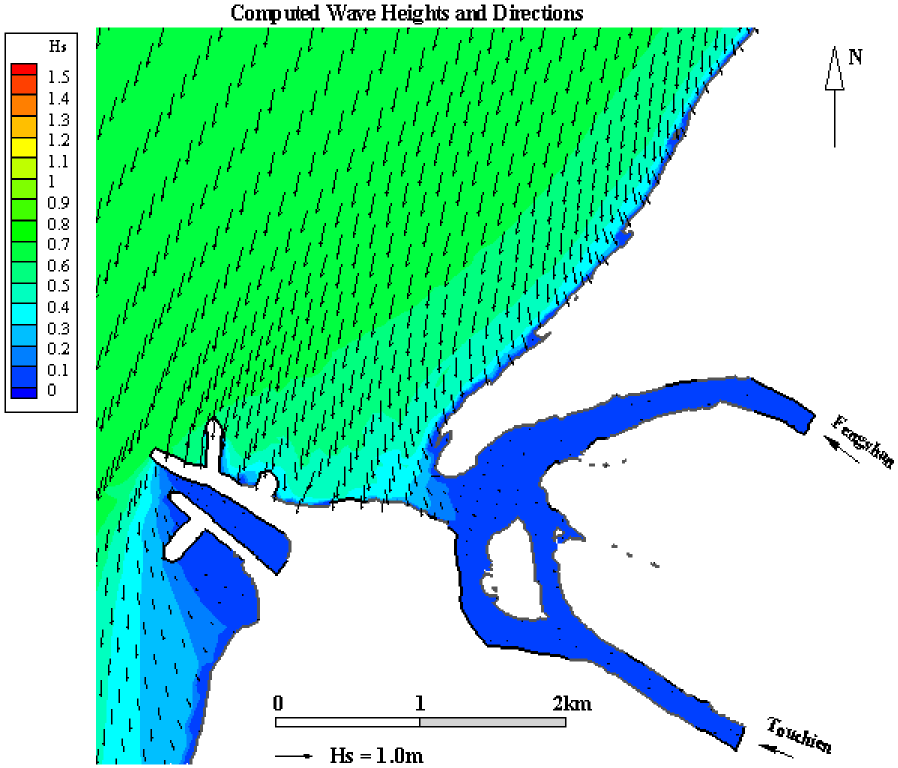


(a) Grid and bathymetry in an estuary

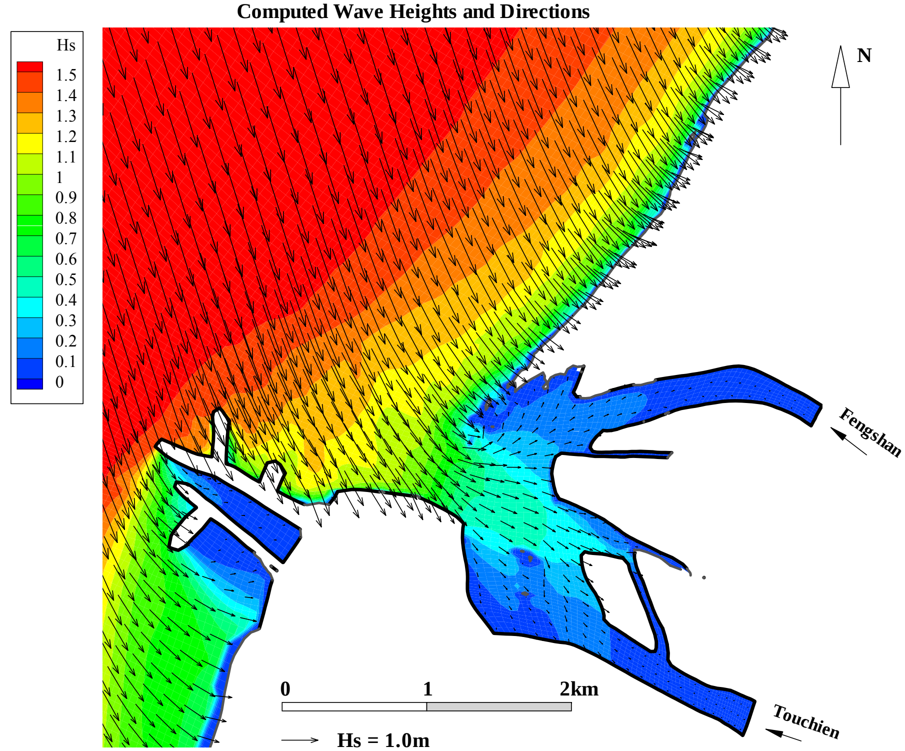


(b) Water Elevations at Seven Stations (Current SL)

Wave Heights and Directions (Current SL)

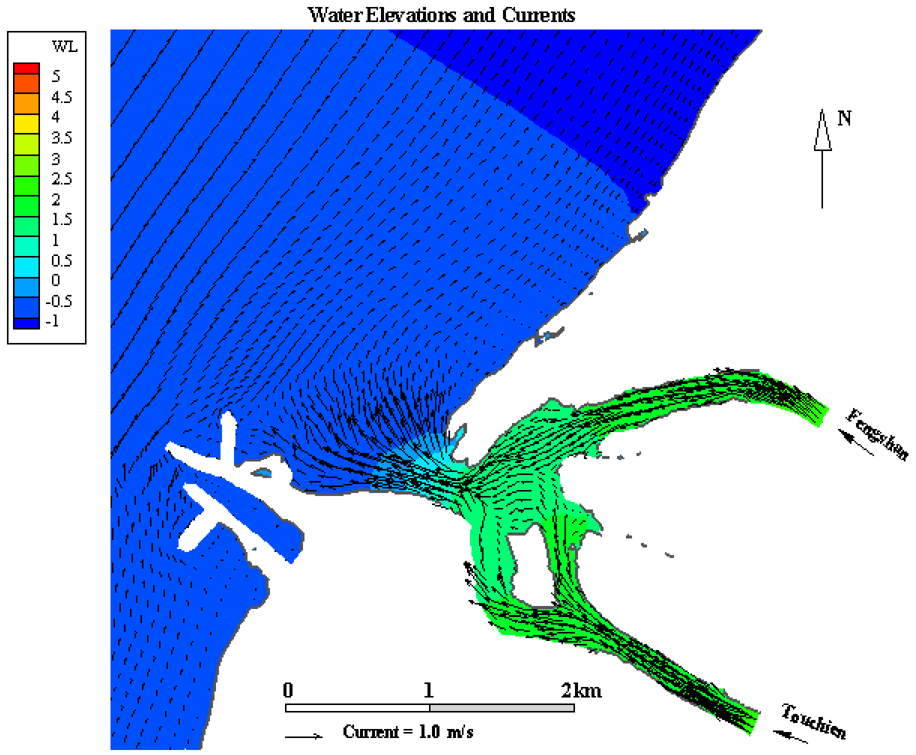


(a) Wave Heights and Directions over the entire period

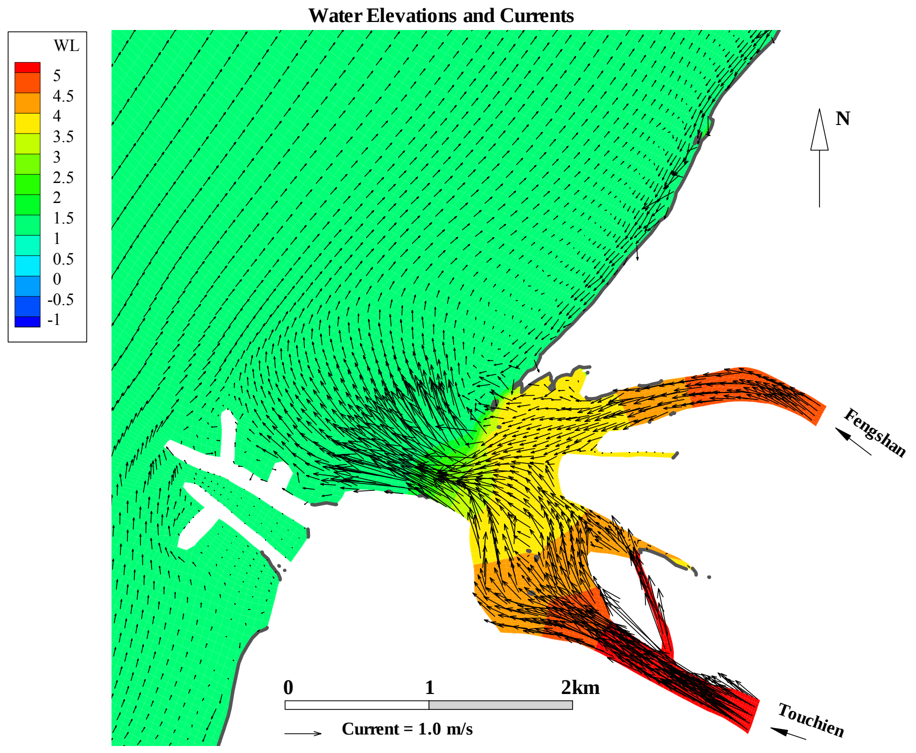


(b) Wave Heights and Directions at Peak Stage

Water Elevations and Currents (Current SL)

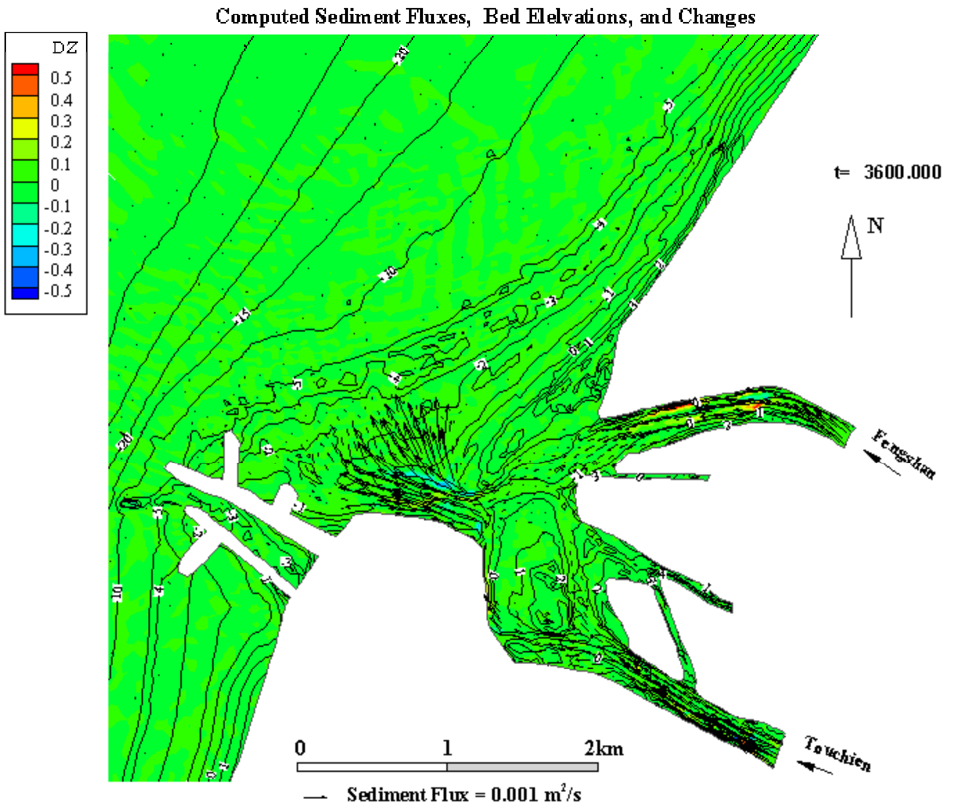


(a) Computed Currents over the entire period

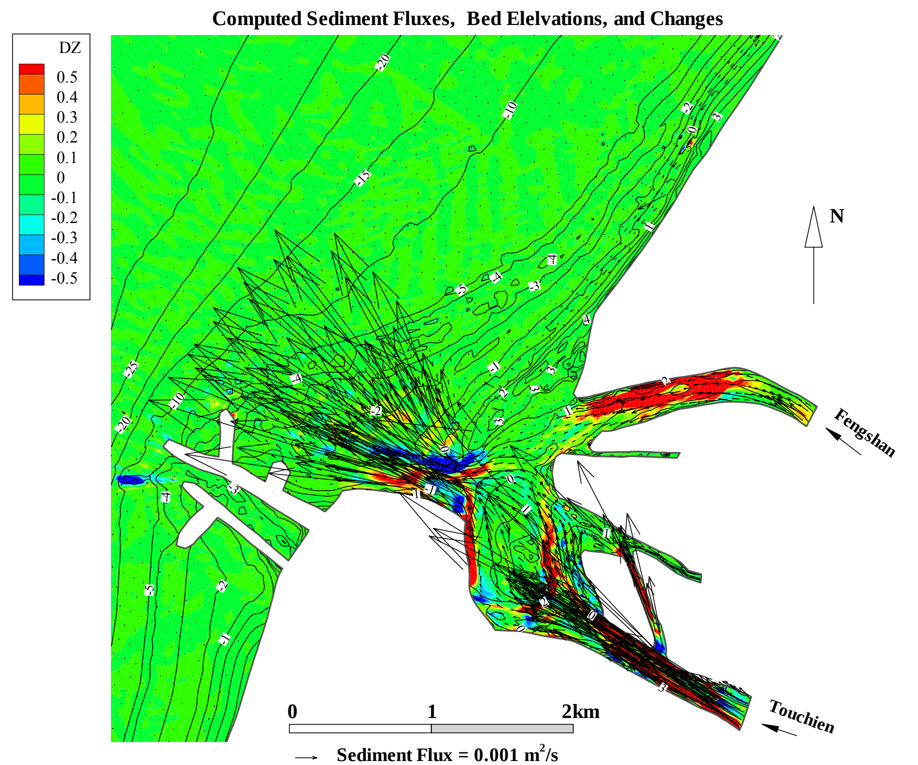


(b) Computed Currents at Flood Peak

Morphodynamic Changes (Current SL)

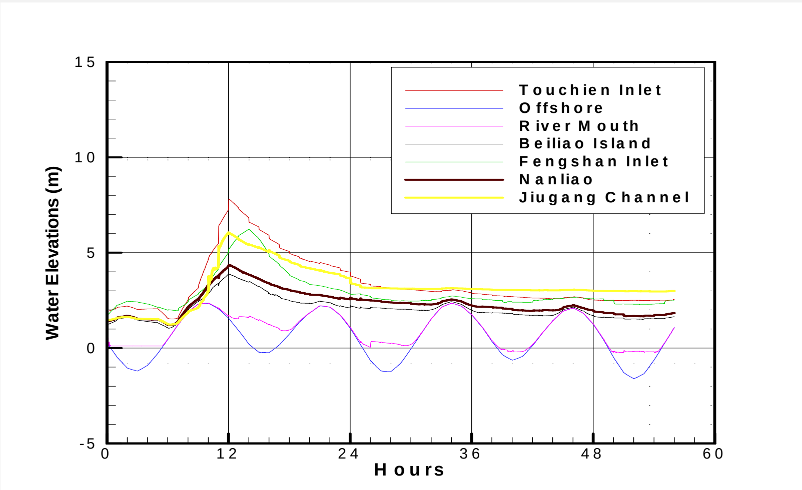


(a) Sediment Fluxes and Bed Elevations Changes Over the Entire Period

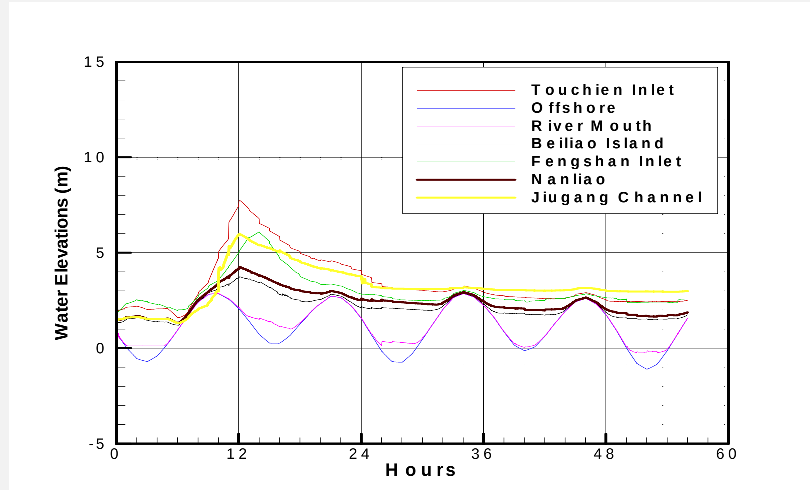


(b) Sediment Fluxes and Bed Elevations Changes at Peak Stage

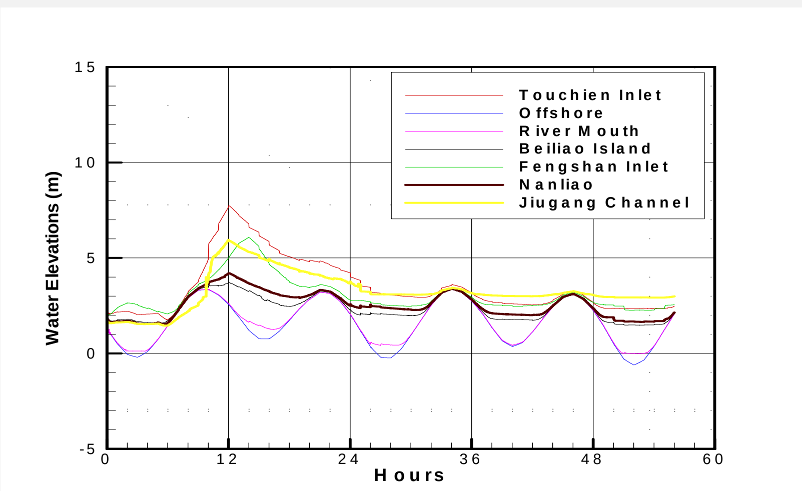
Water Elevations at Seven Stations due to SLR



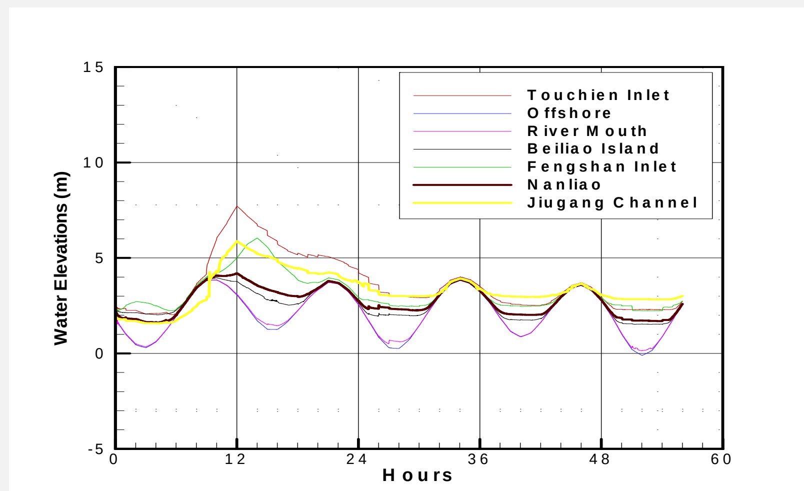
(a) SLR = 50 cm



(b) SLR = 100 cm

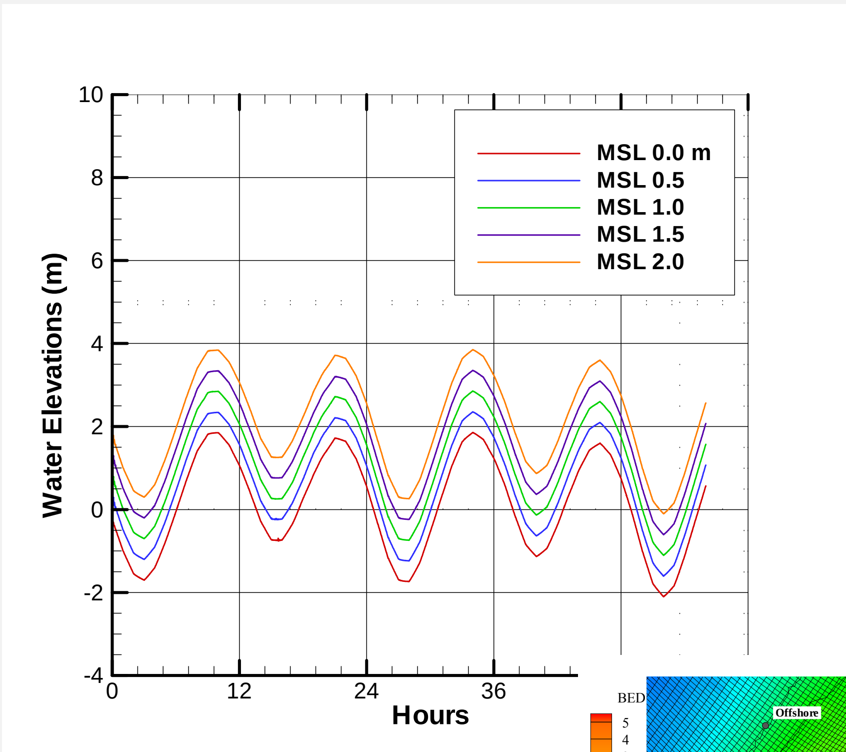


(c) SLR = 150 cm

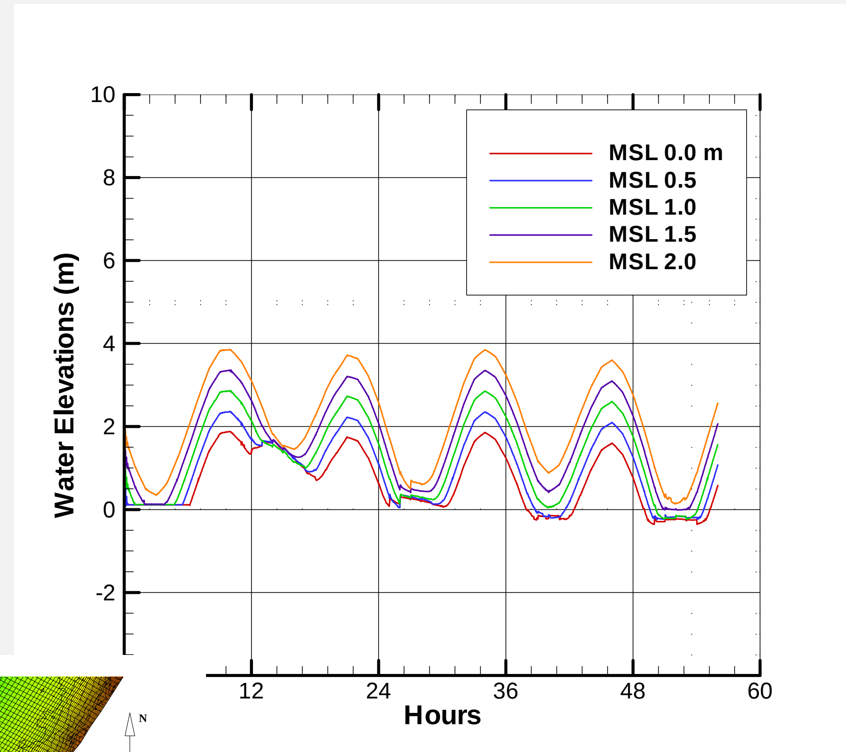


(d) SLR = 200 cm

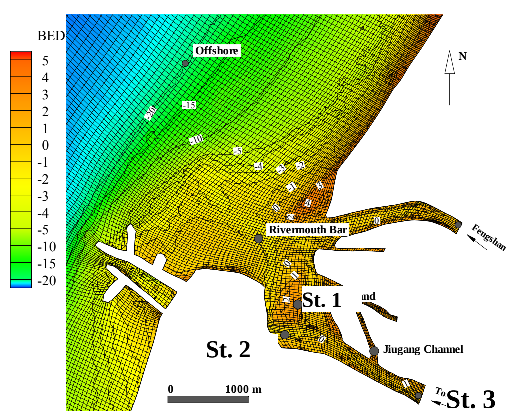
Water Elevations at Different Stations due to Different SLR



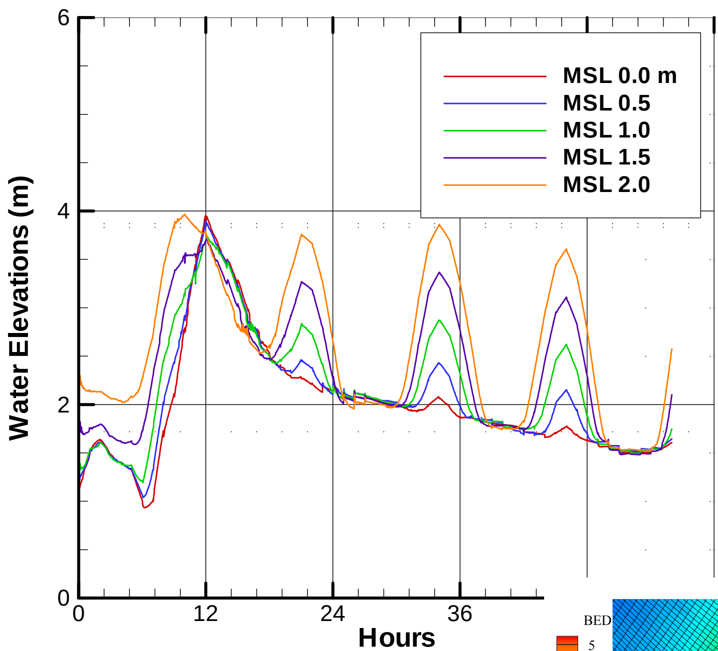
(a) Offshore



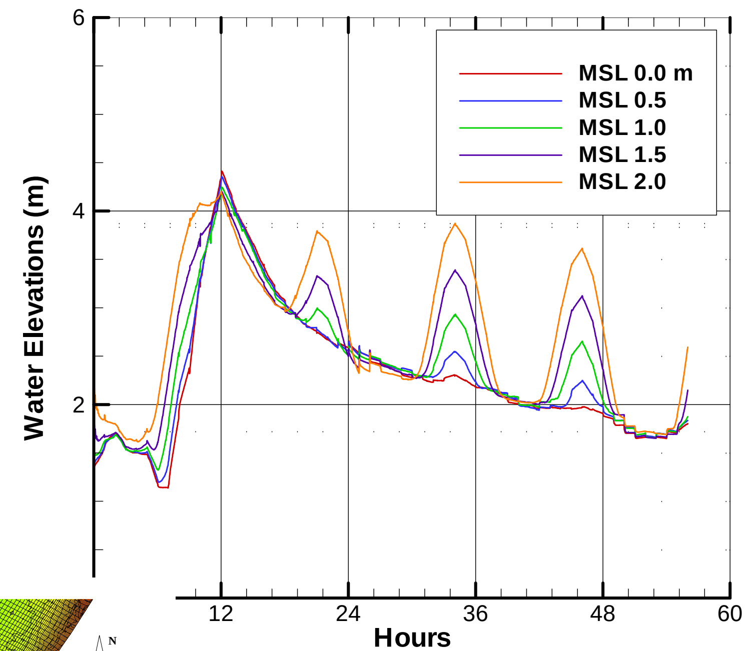
(b) River Mouth



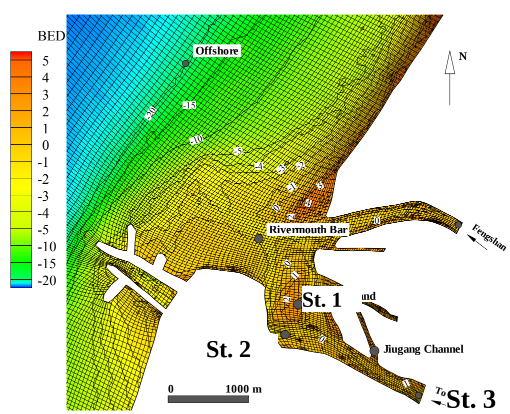
Water Elevations at Different Stations due to Different SLR



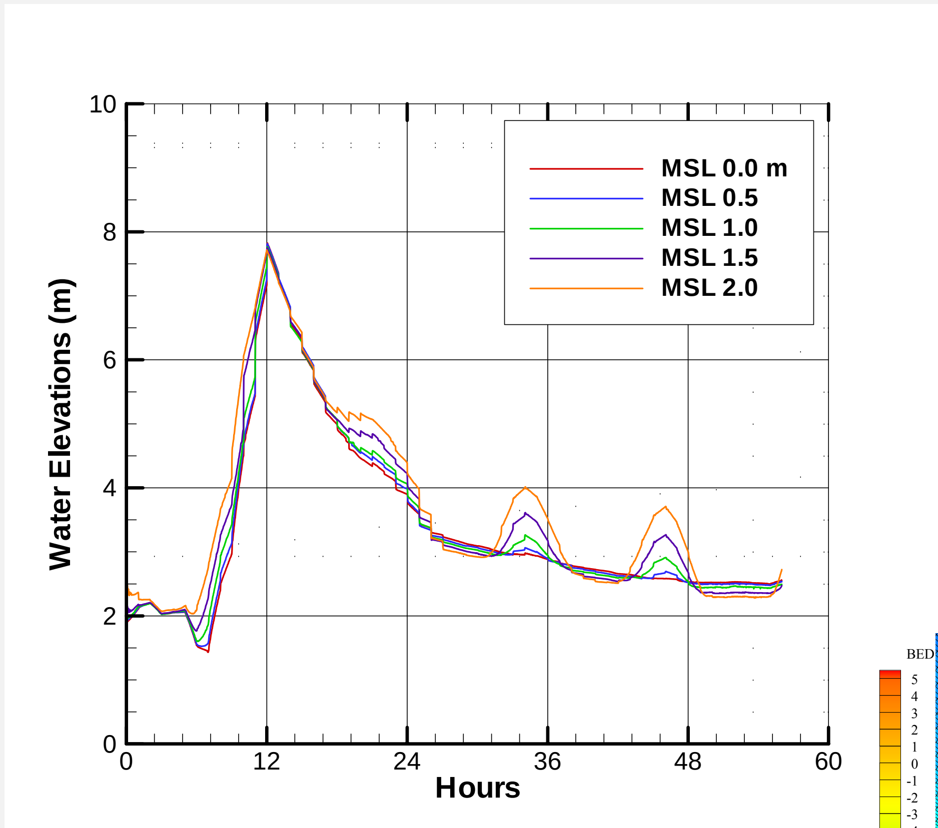
(c) St. 1 (Beiliao Island)



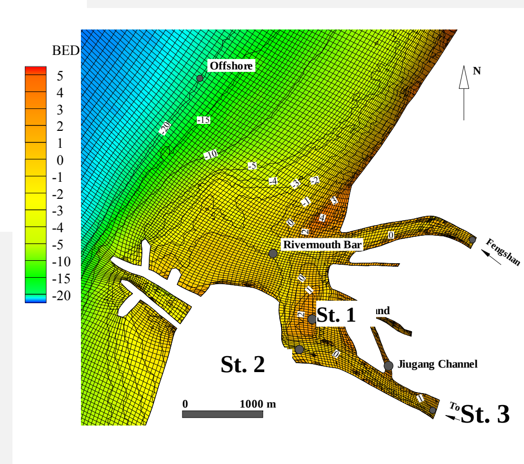
(d) St. 2 (Nanliao)



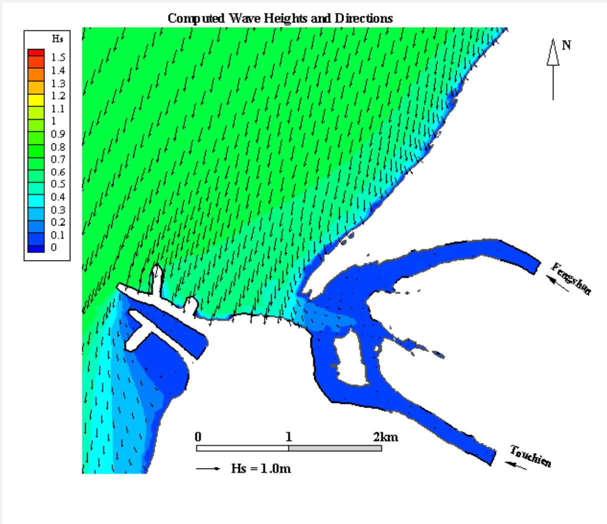
Water Elevations at Different Stations due to Different SLR



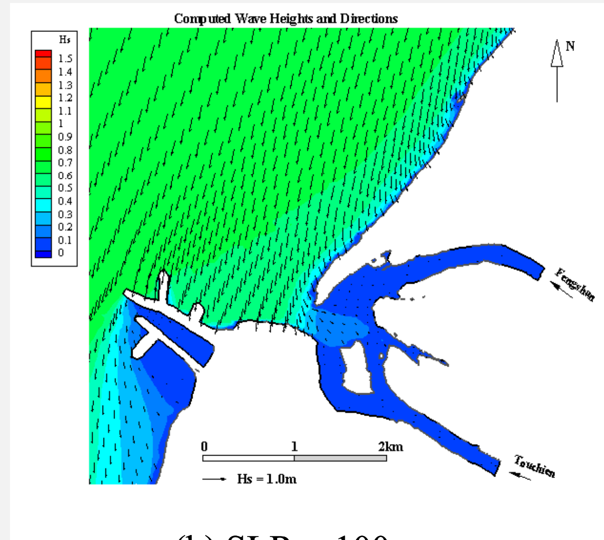
(e) St. 3 (Touchien Inlet)



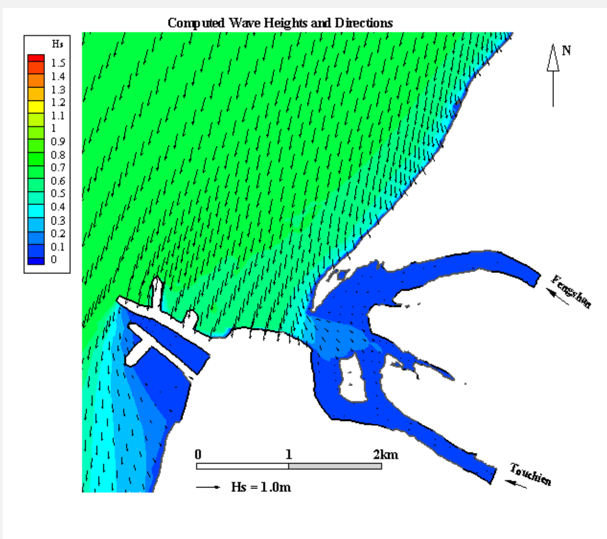
Wave Heights and Directions due to SLR



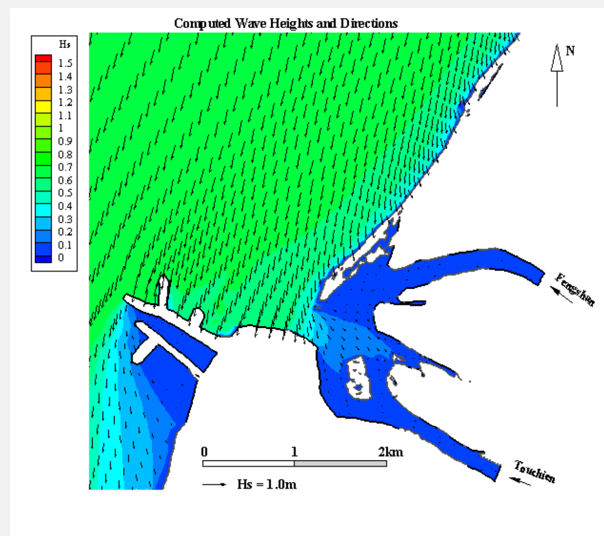
(a) SLR = 50 cm



(b) SLR = 100 cm

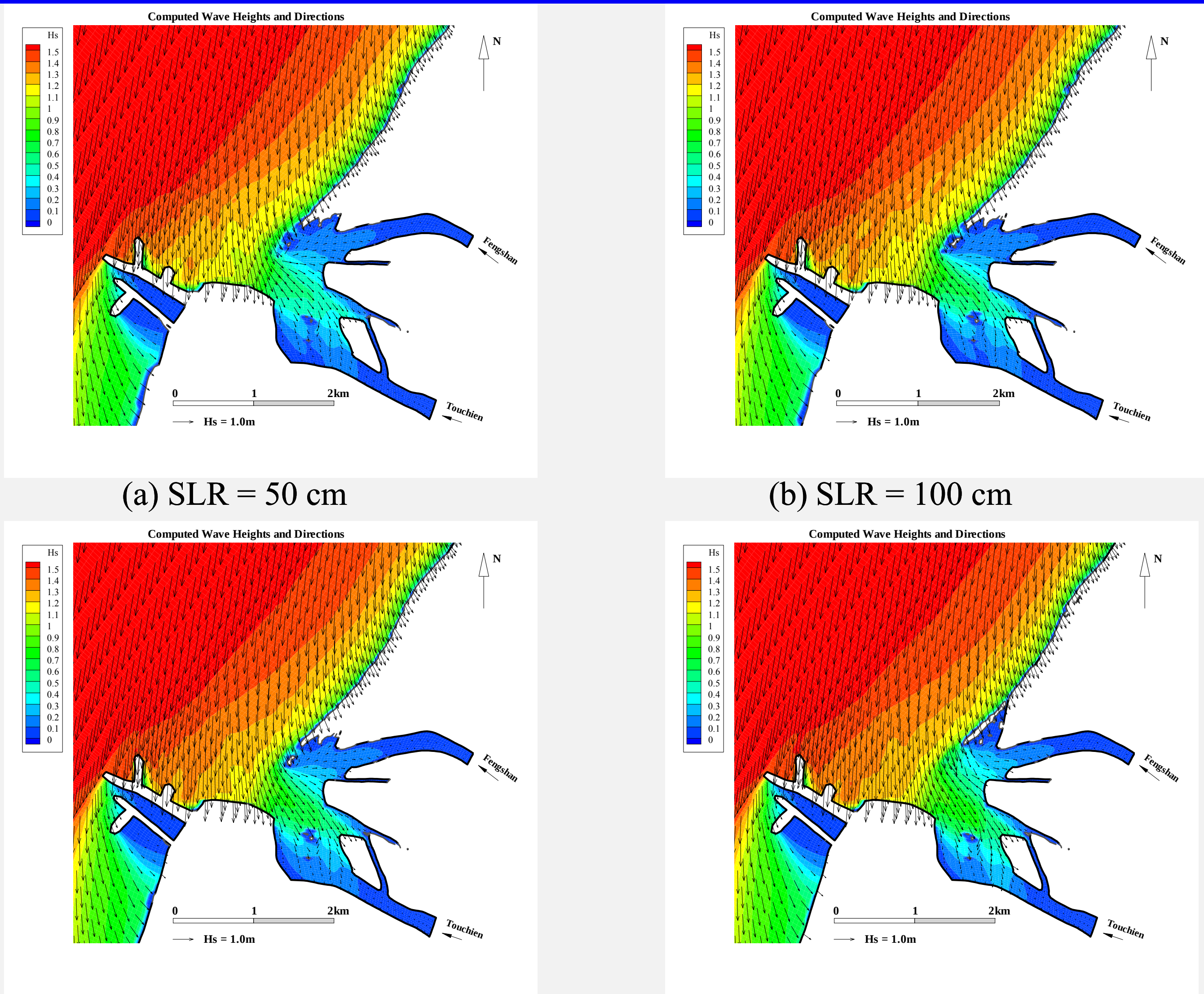


(c) SLR = 150 cm



(d) SLR = 200 cm

Wave Heights and Directions at Peak Stage due to SLR



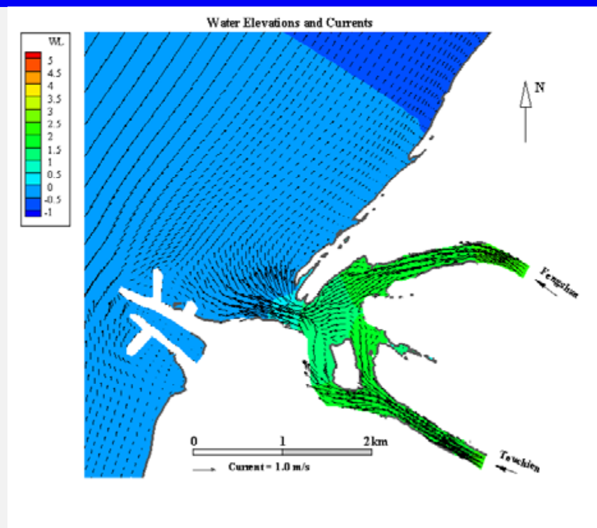
(a) SLR = 50 cm

(b) SLR = 100 cm

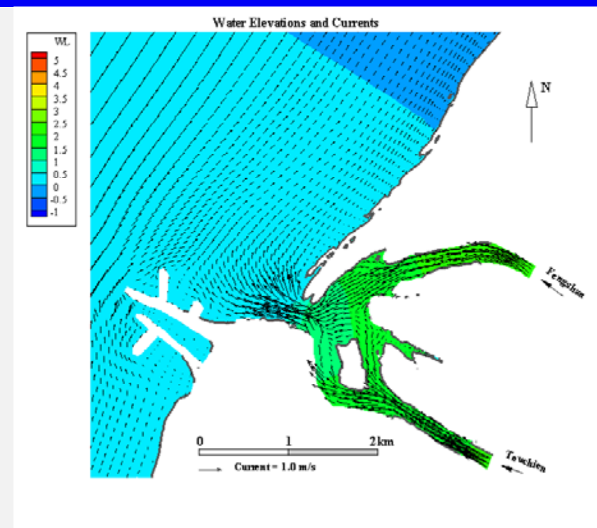
(c) SLR = 150 cm

(d) SLR = 200 cm

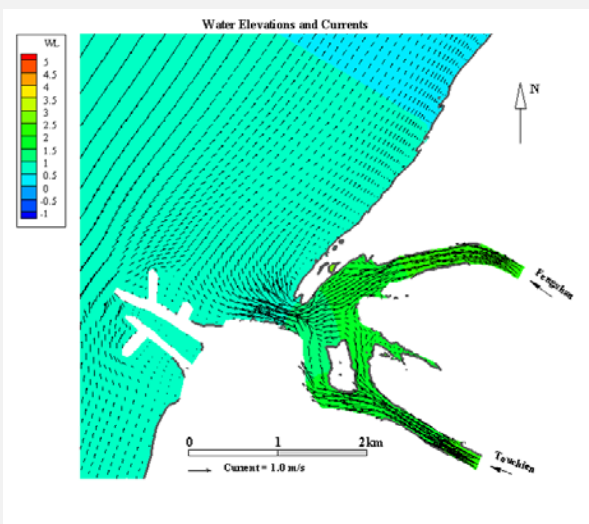
Water Elevations and Currents due to SLR



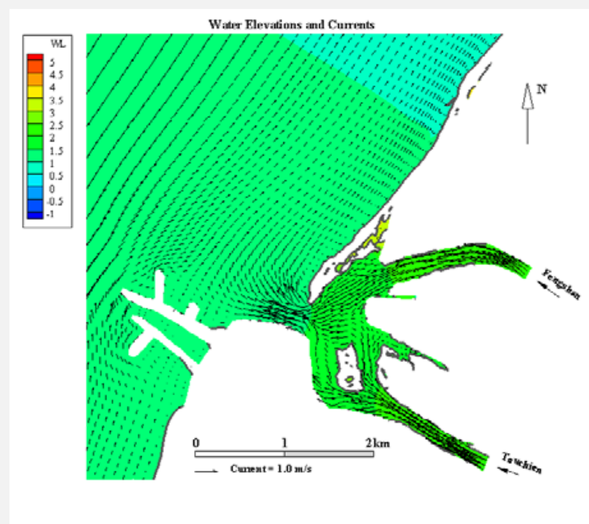
(a) SLR = 50 cm



(b) SLR = 100 cm

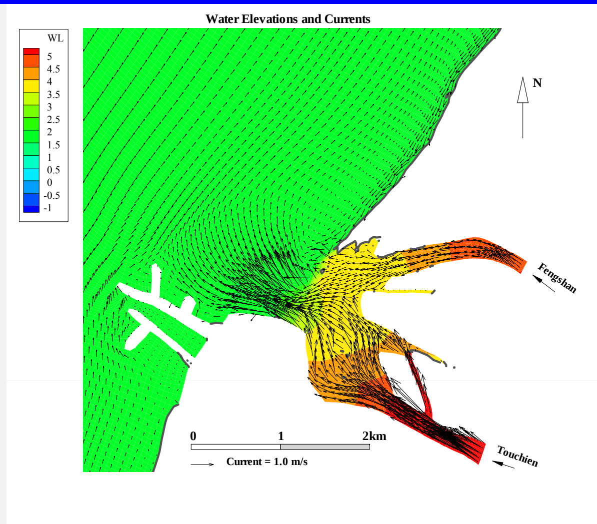


(c) SLR = 150 cm

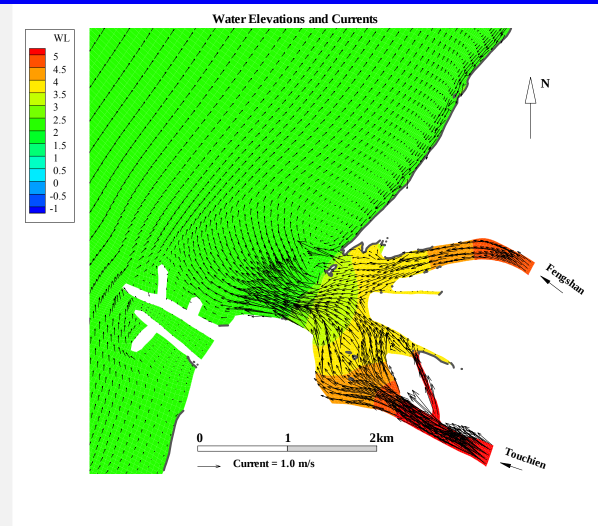


(d) SLR = 200 cm

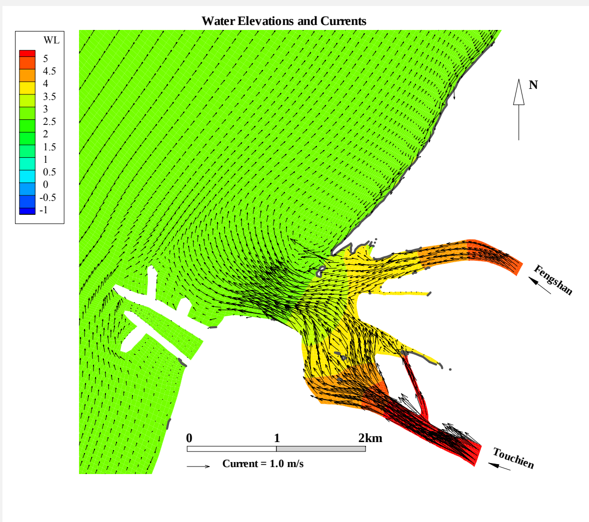
Water Elevations and Currents at Peak Stage due to SLR



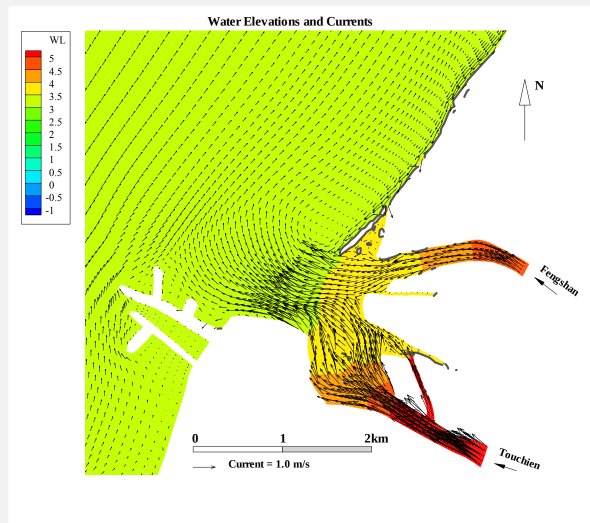
(a) SLR = 50 cm



(b) SLR = 100 cm

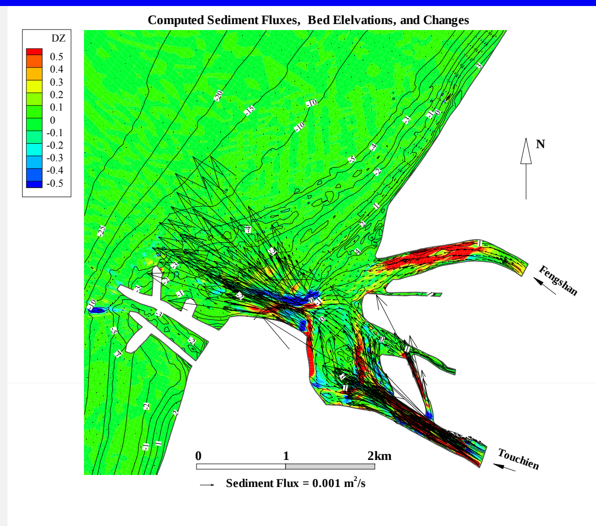


(c) SLR = 150 cm

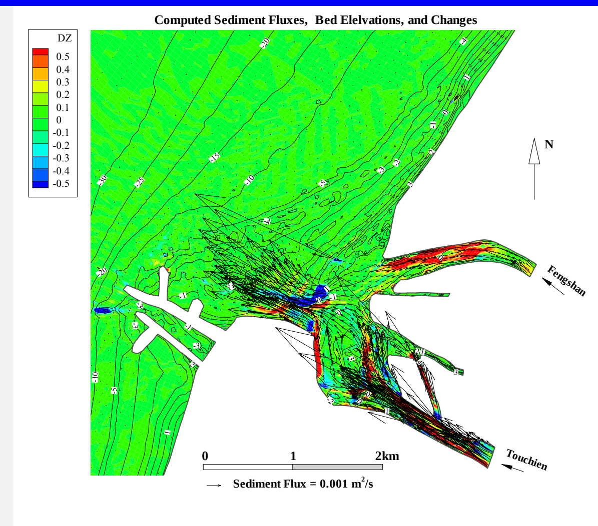


(d) SLR = 200 cm

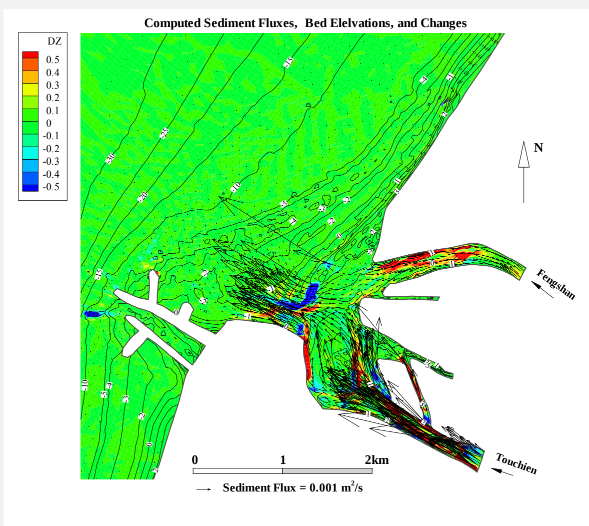
Morphodynamic Changes at Peak Stage due to SLR



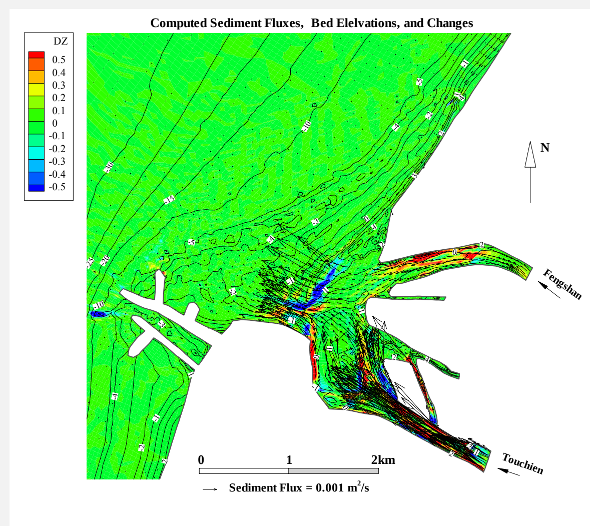
(a) SLR = 50 cm



(b) SLR = 100 cm

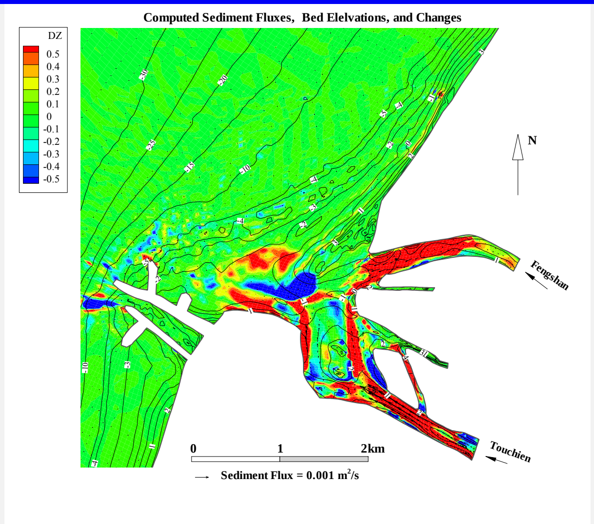


(c) SLR = 150 cm

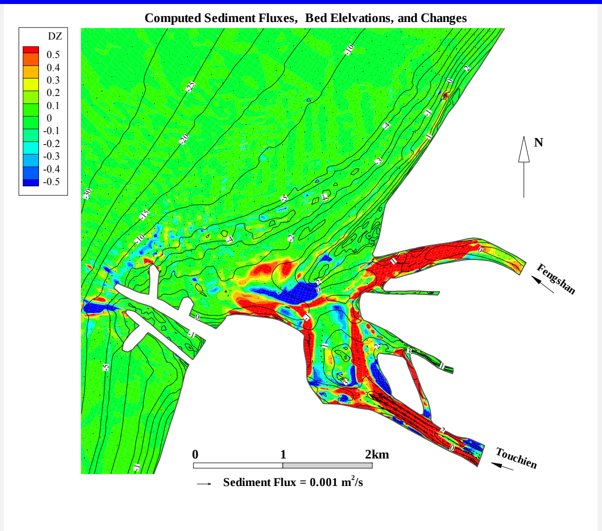


(d) SLR = 200 cm

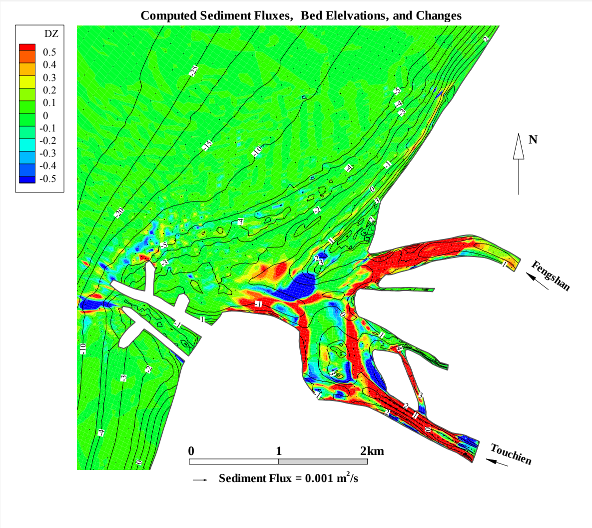
Morphodynamic Changes at End Stage due to SLR



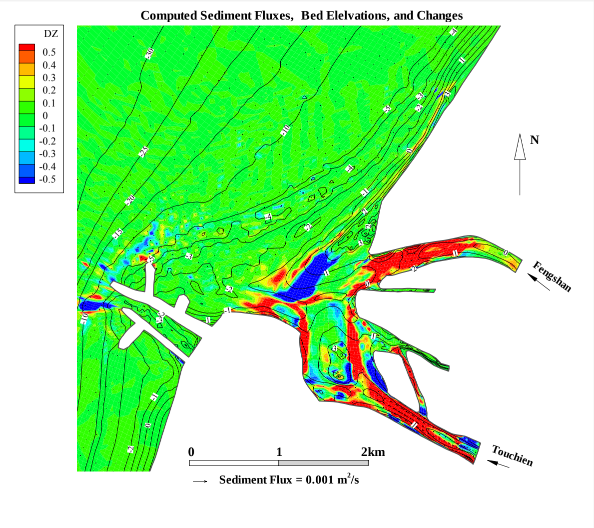
(a) SLR = 50 cm



(b) SLR = 100 cm



(c) SLR = 150 cm



(d) SLR = 200 cm

Summary

- An integrated coastal/estuarine process model (CCHE2D-COAST) was applied to investigate the hydrodynamics and morphodynamics changes due to the SLR in a typical medium-size estuary.
- Five different scenarios have been simulated to record the hydrodynamics and morphodynamics changes under different SLRs (0, 50, 100, 150 and 200 cm).
- The hydrodynamic results show that there is obvious wet/dry cycle change at all upstream monitoring stations. Further, there is significant inundation effect at the river mouth bar due to SLR 1.5m. In addition, the river area is more susceptible to the tidal effect at SLR 0.5 m.
- The morphodynamics results show that the there is apparent change in erosion/deposition areas due to SLR. Further, the rivermouth bar is more exposed to erosion effect, which consequently will cause a significant change in the shoreline.
- The preliminary results of the tests show that CCHE2D-COAST model is able to effectively simulate the hydrodynamics and morphodynamics in coasts and estuaries under different SLRs scenarios and the results are promising for future more detailed analysis.

Some Questions for Triggering Discussions

- Can we validate the models by reproducing the historical SLR processes? Or is it necessary?
- For the short-term assessment of SLR, it is relatively ease to make scenarios for representing SLRs. But how about the bathymetry? because you may not assume the current bathymetry as the one for all the short-term scenarios.
- How to assess the impacts on wetland and saltwater intrusion (surface water and ground water in coastal aquifers),
- How to assess the impacts on coastal infrastructure such as seawalls, breakwaters, harbors ?
- How to estimate the influence of SLR on current engineering measures in coastal projects , e.g. beach nourishment ?
- Others ?

Take-Home Assignments

1. Find tidal datums in the Bench Mark Sheets of Gulfport Harbor, MS on the website of NOAA Observational Data Interactive Navigation at http://tidesandcurrents.noaa.gov/gmap3/. Draw a figure to display the MSL, NGVD, and NAVD. Then, retrieve tidal datums in the Bench Mark Sheets of the USCG New Canal Station, Lake Pontchartrain, LA. Find the differences of the tidal datums between the two locations. Explain why they are different.

2. What are the impacts of sea level rise on coasts and coastal communities?

3. What are coastal zones? What are coastal flood hazard zones defined by FEMA?

4. What is the CCHE2D-Coast model? What are the model's capabilities to simulate coastal processes related to assessment of impacts of SLR.

References

- Bode, L., and Hardy T.A. (1997). "Progress and recent development in storm surge modeling", *Journal of Hydraulic Engineering*, ASCE, 123(4), 315-331.
- CCHE2D (2008). http://www.ncche.olemiss.edu/software/cche2d, Accessed on February 15, 2009.
- Cooper, M. J. P., Beevers, M.D., and Oppenheimer M. (2005). Furture sea level rise and the New Jersey coast – Assessing potential impacts and opportunities, Science, Technology and Environmental Policy Program, Woodrow Wilson School of Public and International Affairs, Princeton University, Available at http://www.princeton.edu/~cmi/news/Future%20of%20Sea%20Level%20Rise%20and %20 the%20New %20Jersey%20Coast.pdf.
- Ding, Y., Wang, S. S. Y., and Jia, Y. (2006b), Development and validation of a quasi three-dimensional coastal area morphological model, *Journal of Waterway, Port, Coastal, and Ocean Engineering*, ASCE, Vol.132, No.6, pp. 462-476, November, 2006.
- Mclean, R.F. et al. (2001). Coastal Zones and Marine Ecosystems, in: McCarthy, J.J. et al. (eds.), Climate Change 2001: Impacts, Adaptation, and Vulnerability, Cambridge University Press, Cambridge, pp 343-379.
- Nicholls, R.J. and J.A. Lowe. 2004. Benefits of Mitigation of Climate Change for Coastal Areas. Global Environmental Change 14: 229-244
- Titus, J.G. and Richman, C. (2000), 'Maps of Lands Vulnerable to Sea Level Rise, Modeled Elevations along the U.S. Atlantic and Gulf Coasts', *Climate Research* 18, 205-228.

Further Information

- Coastal and Estuarine Processes Research in NCCHE
  → http://www.ncche.olemiss.edu/index.php?page=tidal
- ENGR 693-73, Research Topics in Engineering Science I, Basic Wave Mechanics for Coastal and Ocean Engineers
- Contact Dr. Yan Ding at ding@ncche.olemiss.edu