Coastal Hydraulics and Downstream Boundary Conditions

COMET Advanced Hydrologic Sciences
Virtual Course, Part 2

August 16, 2011

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NOAA's National Weather Service (NWS)

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The overall purpose is to show that there are currently available applications for operational forecasting with HECRAS in CHPS with a coastal boundary condition.

Acknowledgements

- NOAA Office of Hydrologic Development
  (Hassan Mashriqui, Seann Reed)
- NOAA Meteorological Development Laboratory (MDL) - Extra-tropical Storm Surge
  (Will Shaffer, Arthur Taylor, Anne Kramer, Amy Haase)
- NOAA National Ocean Service (CBOFS/COOPS/CSDL/NOS)
  (Frank Aikman, Jesse Feyen, Lyon Lanerolle)
- FEMA Region 3
  (Jon Janowicz)
- Virginia Institute of Marine Science
  Chesapeake Inundation Prediction System
  (Harry Wang)
- University of North Carolina at Chapel Hill
  (Rick Luettich)

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… And thanks to you for listening!

Objective

By the time we are finished (35 minutes) you should be able to answer the following:

- Why do we need improved coastal river forecasts?
- What are dominant processes in coastal models?
- What are current NWS/NOAA operational capabilities for modeling in coastal areas?
- How can a 1-d HECRAS model be used with a coastal boundary condition in CHPS?

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Forecast Responsibility

Poll Question

Who is responsible for water level forecasts on the nation's coast?

A) NWS (National Weather Service)

B) NOS (National Ocean Service)

C) U.S. Coast Guard

D) Professional Beach Lifeguard Association of North America

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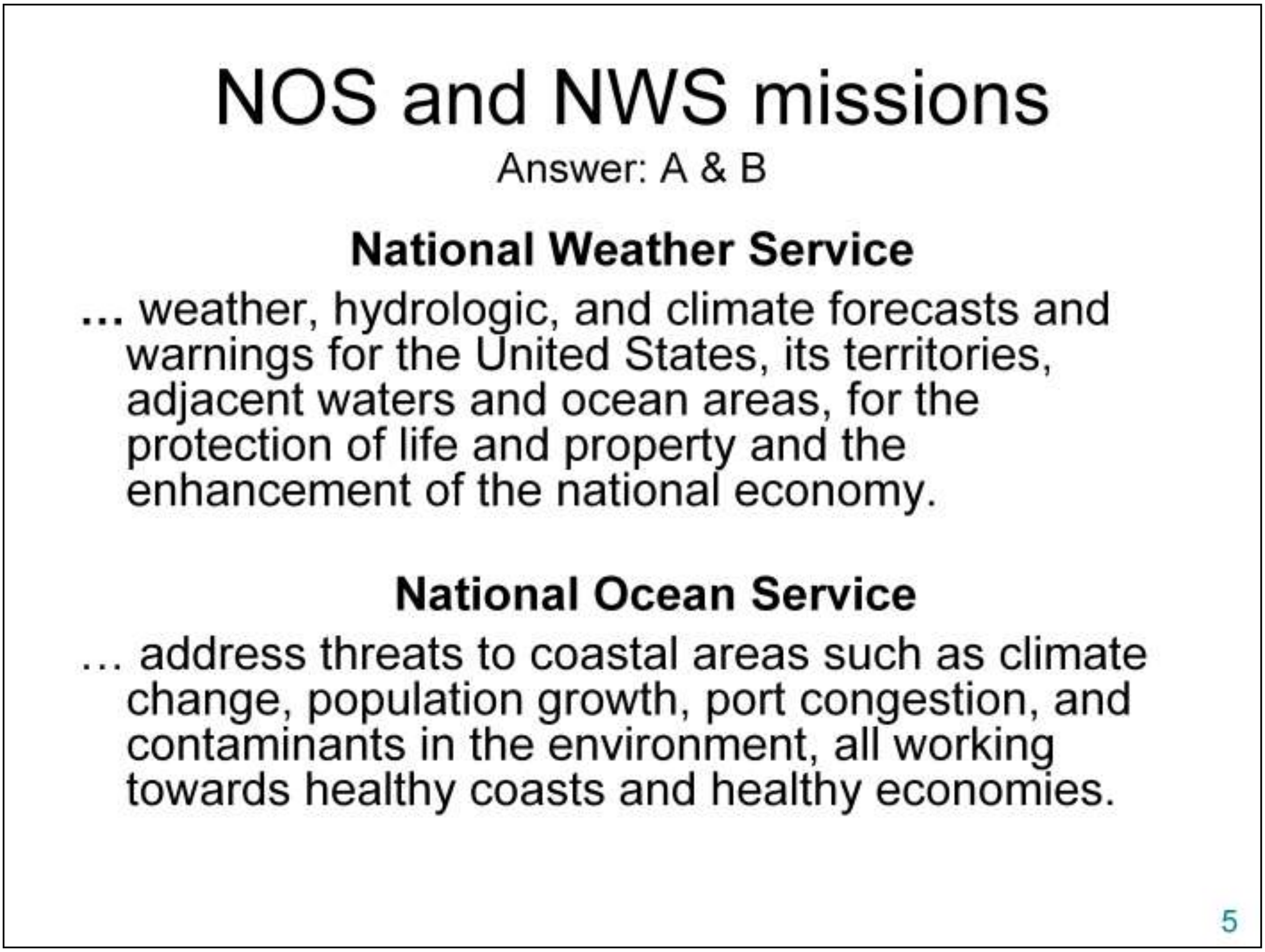
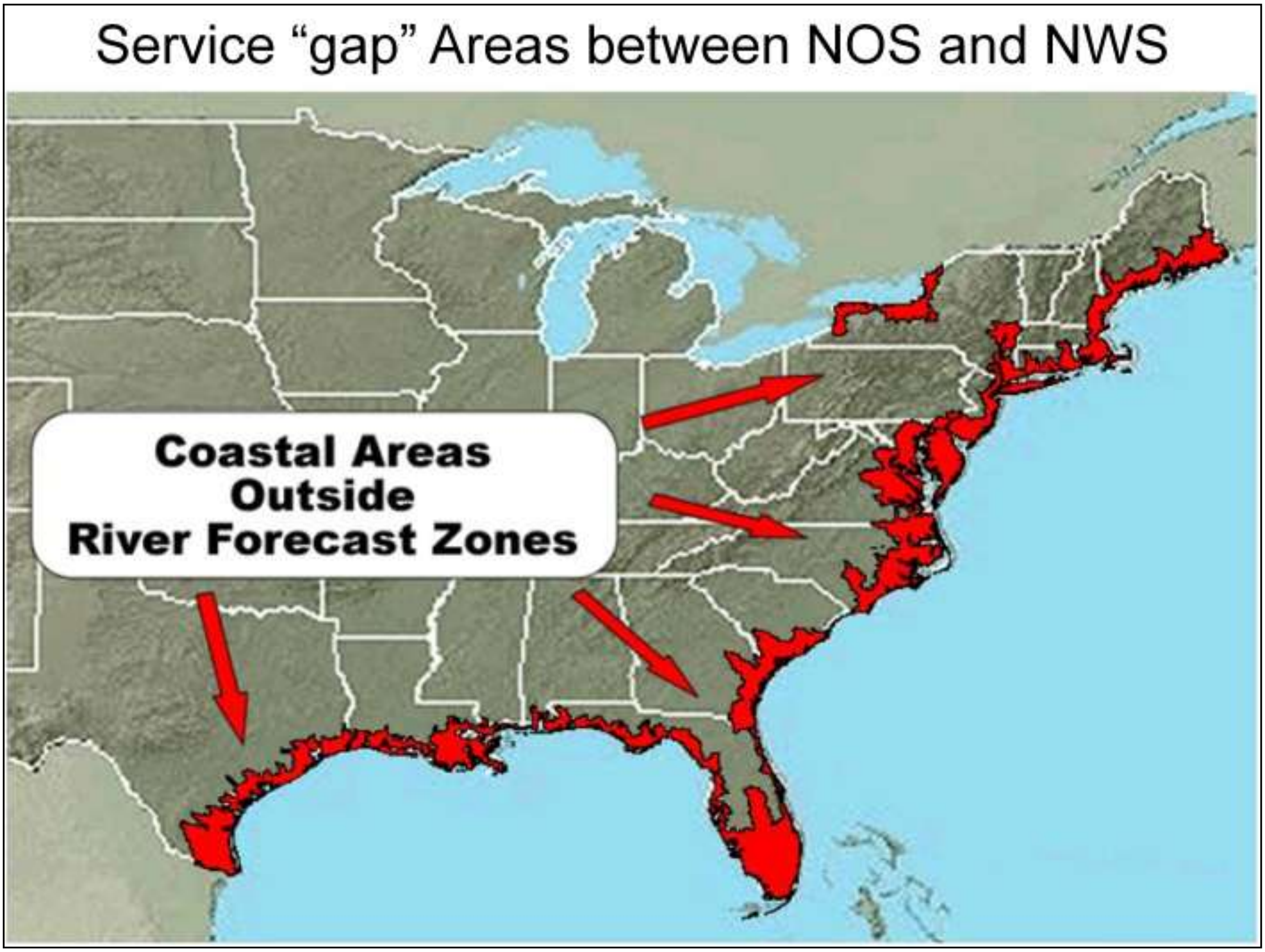


The weather service is responsible to issue warnings for hazardous water levels. The responsibility for modeling water level is shared between NWS and NOS.



This graphic focuses on the East Coast.

NOAA's National Weather Service (NWS) uses hydrologic models and one-dimensional (1D) hydraulic routing models to forecast river flows and stages at over 4,000 locations in the United States (http://www.nws.noaa.gov/ahps/). Despite these extensive services, coastal areas without existing freshwater forecasts still exist. New and enhanced water information will be valuable for decision makers in these areas. This slide shows the approximate extent of gap areas along the Atlantic and Gulf Coasts. Note that tidal Potomac River (case Study later in presentation) is in the Chesapeake Bay.

Tidal Harmonics

Poll Question:

True/False: Tide is caused by direct gravitational effects of the moon and sun i.e. when the moon is directly overhead, we expect to see the highest tide.

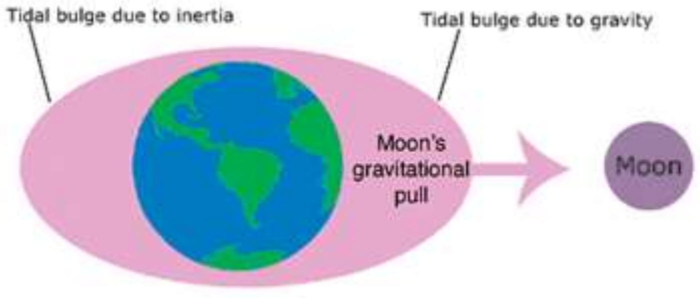
A. True

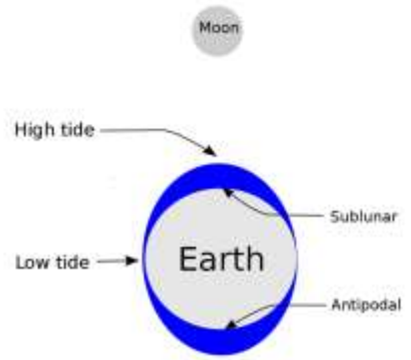
B. False

Tidal Harmonics

Answer/Discussion:

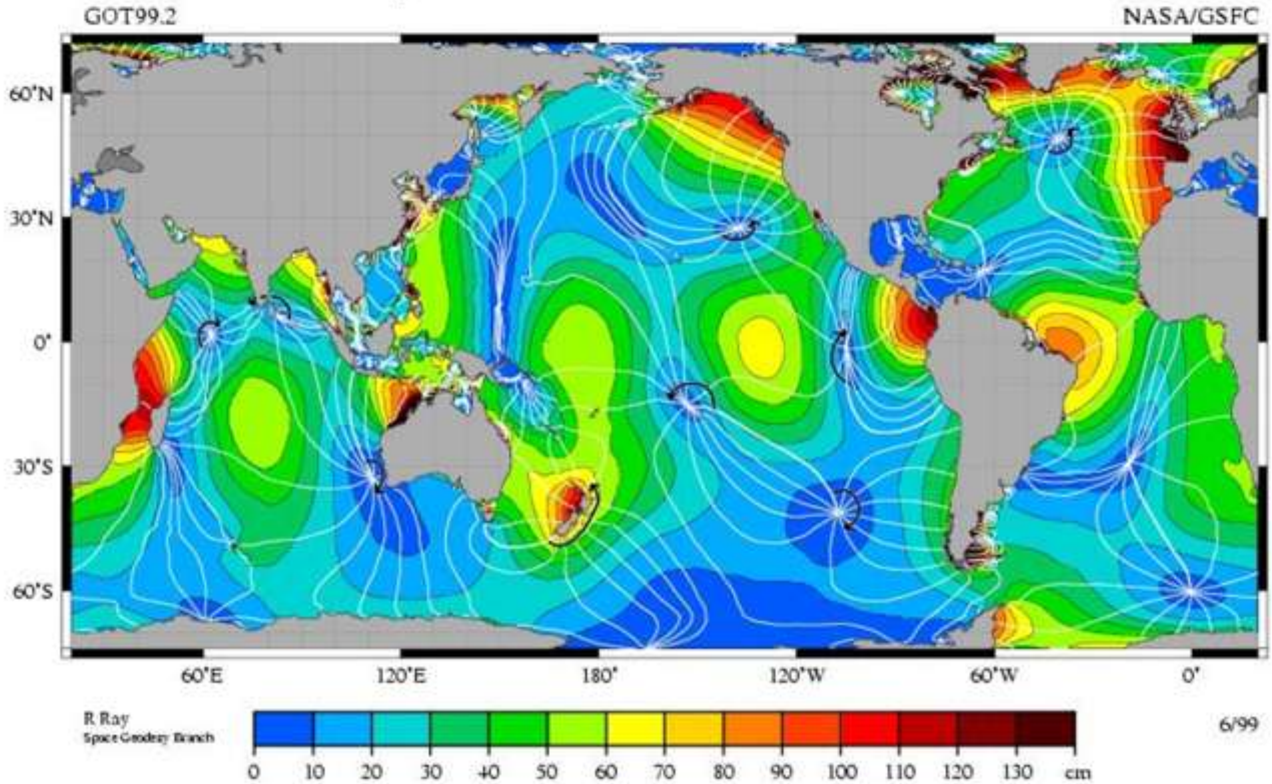
While it is true that the primary gravitational driver for tide is the moon, it is more correct to say that tides are **very long-period harmonic waves** that move through the oceans in response to the forces exerted by the moon and sun and constrained by the continental boundaries.





The diagrams are a helpful but simplified representation.

Amphidromic Points



Credit: R. Ray, NASA - Goddard Space Flight Center; NASA - Jet Propulsion Laboratory; Scientific Visualization Studio; Television Production NASA-TV/GSFC

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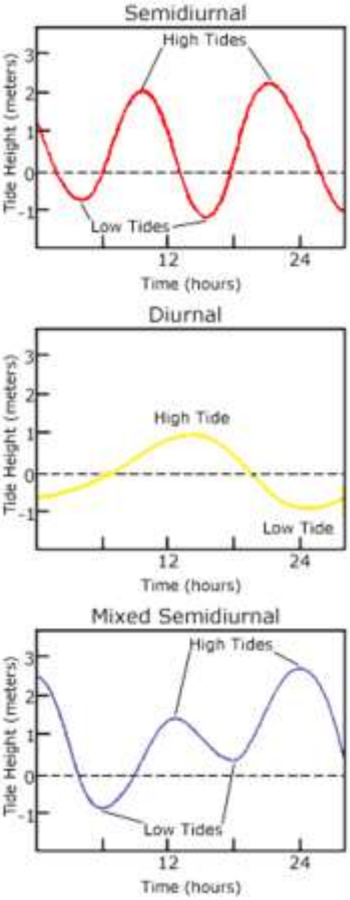
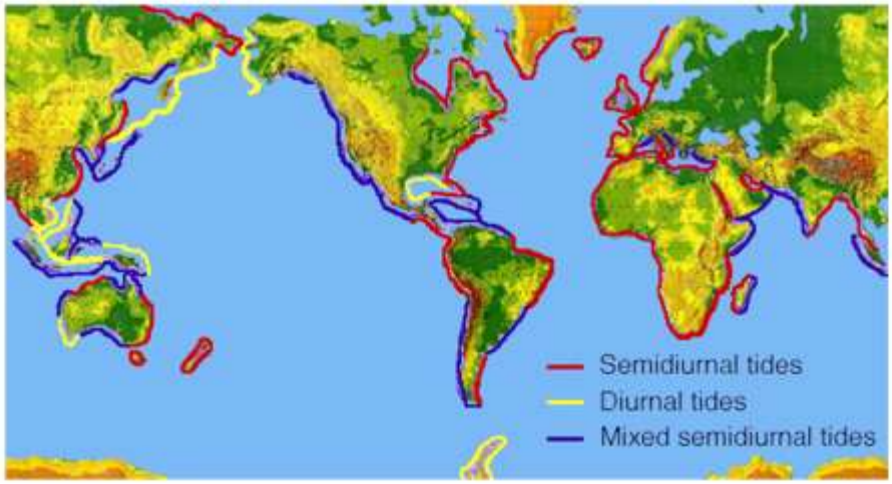
This graphic shows the amplitude of the M2 tidal constituent. Amplitude is indicated by color, and the white lines are cotidal differing by 1 hr. The curved arcs around the amphidromic points show the direction of the tides, each indicating a synchronized 6 hour period.

Coriolis forces play a role in the direction of rotation.



Types and Causes of Tidal Cycles – Semidiurnal, Diurnal, Mixed Semidiurnal; Semidiurnal Forcing + Continental Interference



Semidiurnal - two high and two low tides of approximately equal size every lunar day.

Diurnal - one high and one low tide every lunar day.

Mixed Semidiurnal - two high and two low tides of different size every lunar day

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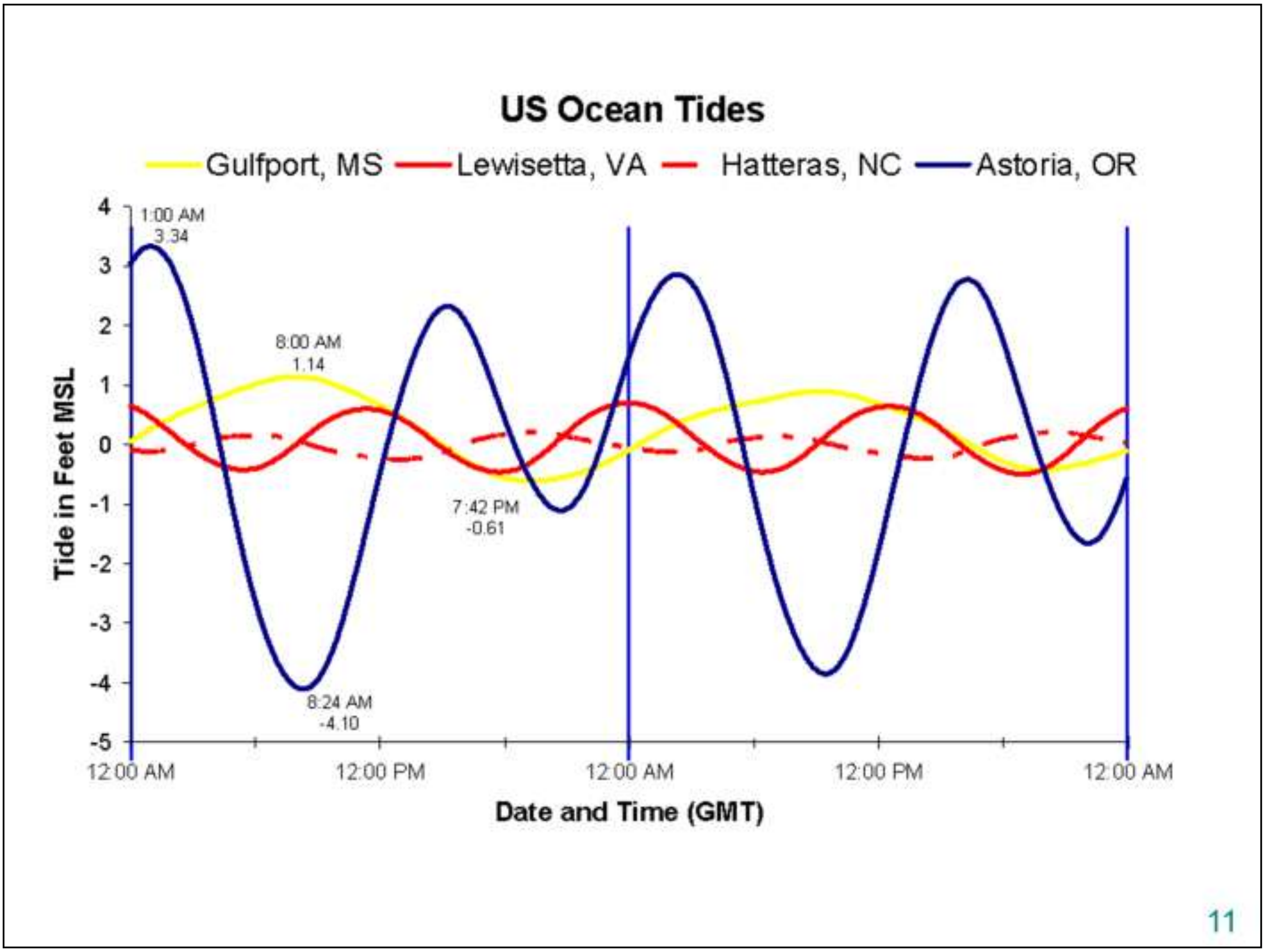
Diurnal tide cycle (upper left). An area has a diurnal tidal cycle if it experiences one high and one low tide every lunar day. Many areas in the Gulf of Mexico experience these types of tides.

Semidiurnal tide cycle (upper right). An area has a semidiurnal tidal cycle if it experiences two high and two low tides of approximately equal size every lunar day. Many areas on the eastern coast of North America experience these tidal cycles.

Mixed Semidiurnal tide cycle (lower middle). An area has a mixed semidiurnal tidal cycle if it experiences two high and two low tides of different size every lunar day. Many areas on the western coast of North America experience these tidal cycles.

Tides establish complex patterns within each ocean basin that often differ greatly from tidal patterns of adjacent ocean basins or other regions of the same ocean basin (Sumich, J.L., 1996). This map shows the geographic distribution of different tidal cycles along the earth's coastlines. Areas experiencing diurnal tides are marked in yellow, areas experiencing semidiurnal tides are drawn in red and regions with mixed semidiurnal tides are outlined in blue.



Various locations in the US with different tidal ranges and cycle types.

Storm Surge

Poll Question:

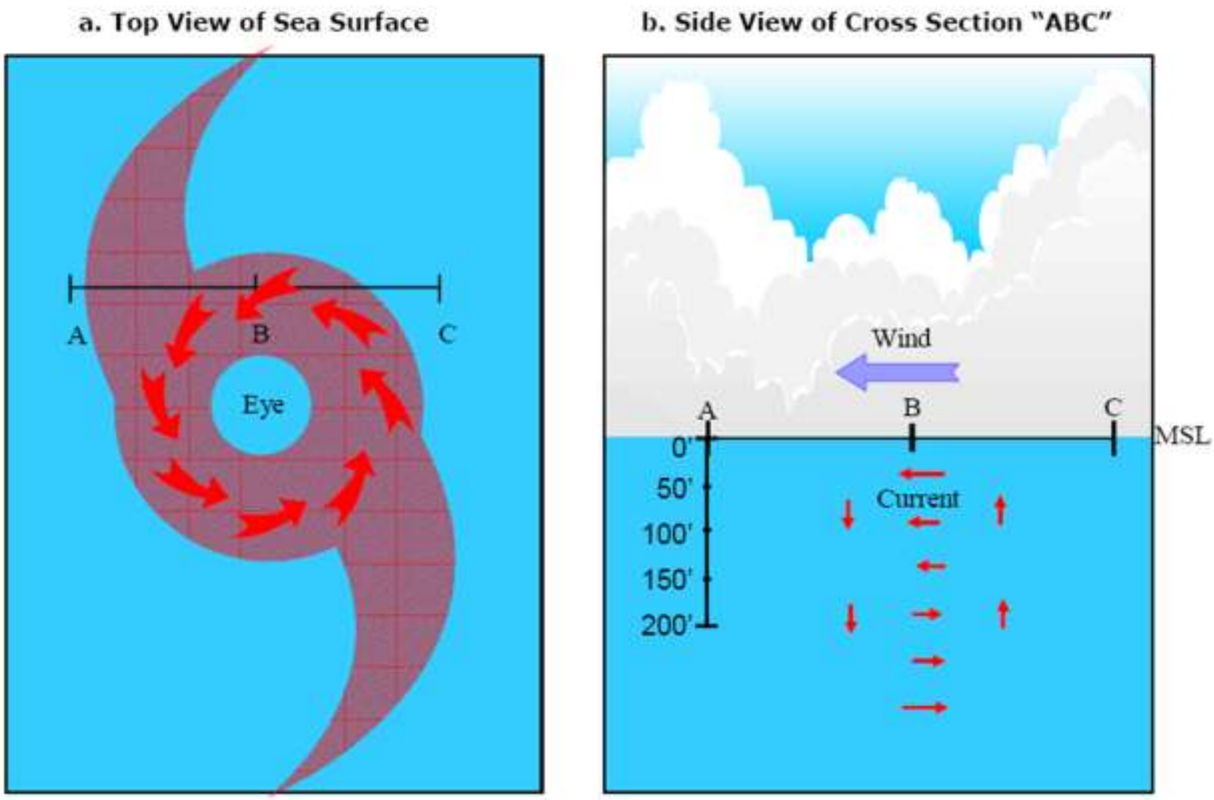
Storm surge effects are most severe in coastal areas

A: … with **gently** sloping continental shelf?

Or

B: … with **steeply** sloping continental shelf?

Deep Water



FEMA SLOSH Display Training
http://www.fema.gov/pdf/plan/prevent/nhp/slosh_display_training.pdf

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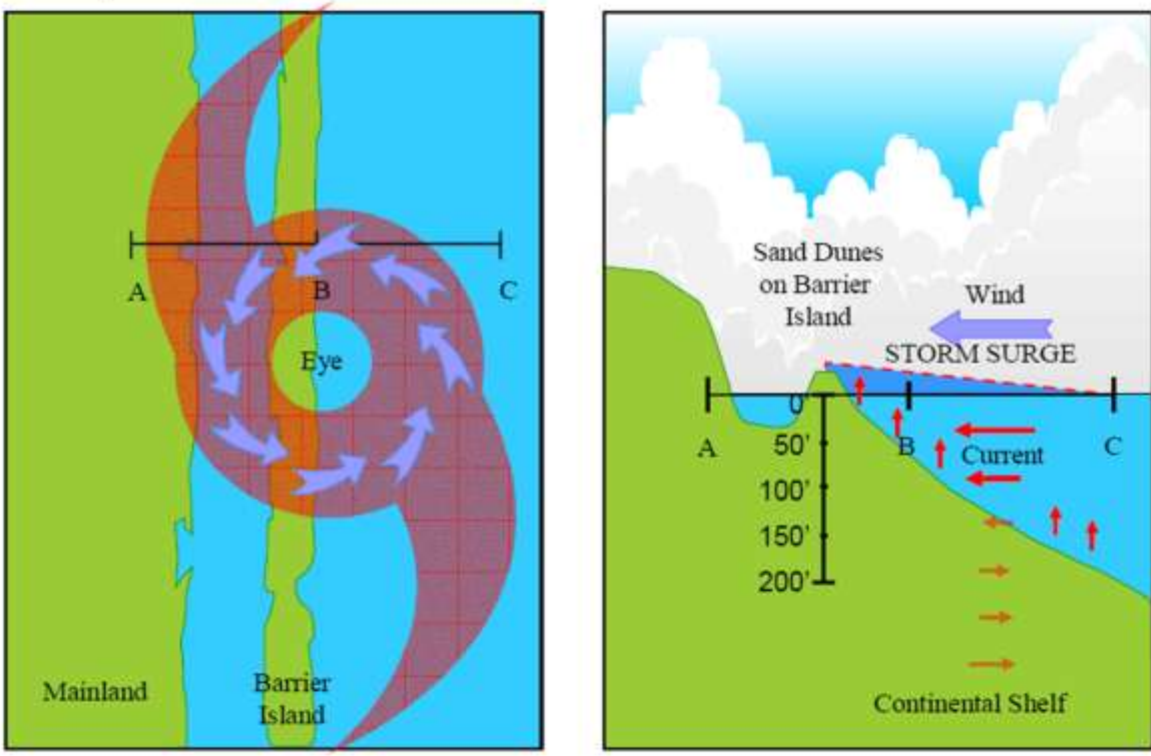
The deep water allows a recirculating current to form which prevent formation of a surge bulge.

Landfall

a. Top View of Sea Surface and Land

b. Side View of Cross Section "ABC"



FEMA SLOSH Display Training
http://www.fema.gov/pdf/plan/prevent/nhp/slosh_display_training.pdf

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In shallow water, the recirculation is cut short and a surge forms and the net flow of water is inland.

Storm Surge

Answer/Discussion: A

Storm surge is caused by the landward flow of water driven by surface friction from winds.

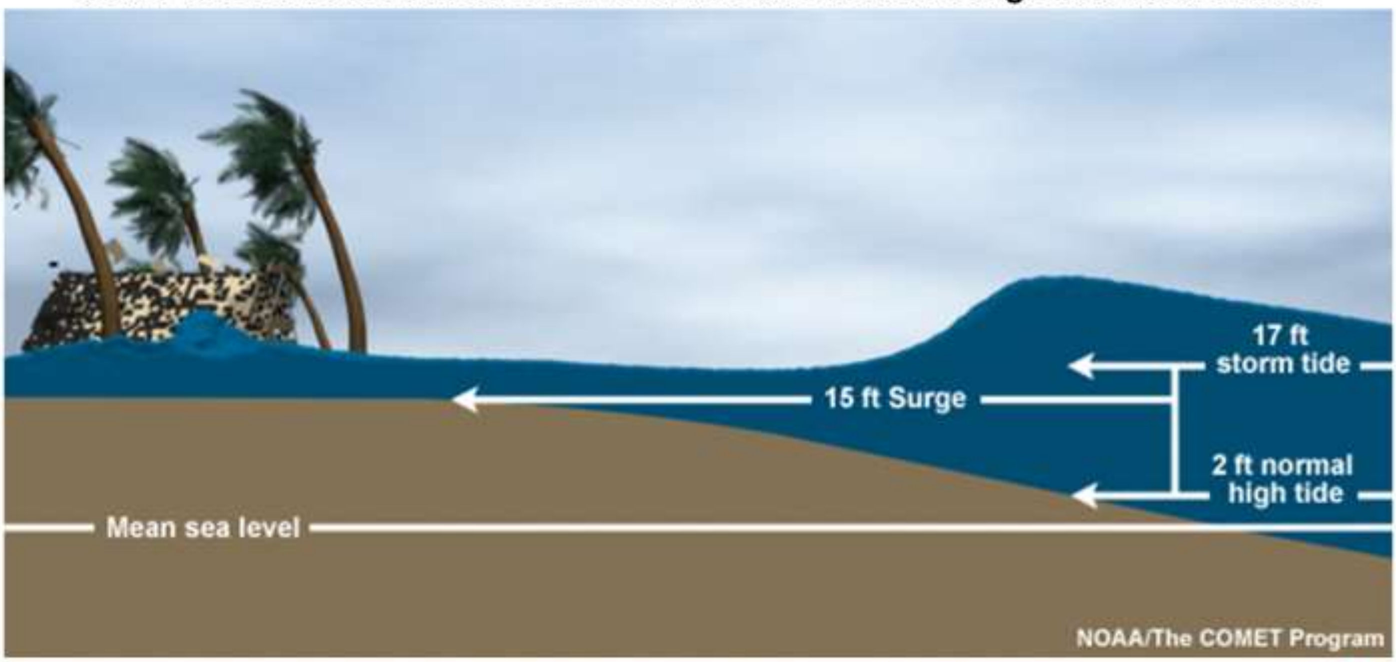
In coastal areas with a gently sloping shelf, the water tends to ‘pile up’. Over a deep or steeply sloping shelf, the wind energy may escape more easily downward or to the sides.

This is why a larger diameter hurricane generates a larger surge – the water cannot flow away to the sides as easily.

Storm Surge

Storm **surge** is an abnormal rise of water generated by a storm, **over and above the predicted astronomical tides** and should not be confused with storm tide.

Storm **tide** is the combined water level rise due to **both surge and tidal** effects.



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For downstream boundary conditions, we need the total water level referenced to the same datum as the cross section geometry.

Modeling

Model types (What equations, how are they solved?)

Dimension ● 1-d useful in coastally bounded channels ● depth averaged 2d good for sediment transport, level forecast only in deep ocean ● full 3d good for sediment transport and water quality

Frame of reference Lagrangian ● Eulerian

Solution domain Regular grid ● flexible mesh/grid

Solution technique finite difference ● finite element ● finite volume

Modeled processes surface waves ● salinity ● temperature ● tide ● surge ● boundary deformation

Model codes ROMS ● FVCOM ● ADCIRC ● ELCIRC/SELFE ...

Specific Model implementations

NOCMPS (CBOFS, DBOFS, etc.)
http://tidesandcurrents.noaa.gov/nocmp.html

CIPS – ELCIRC/SELFE
http://www.noblis.org/MissionAreas/oas/ThoughtLeadership/RecentPapersandPresentations/Documents/CIPS_Sea_Technology.pdf
http://www.vims.edu/~drf/chesapeake.html

CIFlow – Ensemble Approach
http://www.nssl.noaa.gov/projects/ciflow/sea.php

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When someone says "I have a model", it is important to determine what they are using to define their model.

NOAA Operational Ocean Forecast Products

1. MDL/NWS Extratropical Storm Surge Forecast (ET Surge)
   http://www.weather.gov/mdl/etsurge/
   http://weather.noaa.gov/pub/SL.us008001/ST.expr/DF.gr2/DC.ndgd/GT.slosh/AR.conus/
2. COOPS/CSDL/NOS National Operational Coastal Modeling Program Chesapeake Bay Operational Forecast System (CBOFS)
   http://co-ops.nos.noaa.gov/models.html
3. COOPS/CSDL/NOS Extratropical Surge and Tide Operational Forecast System (ESTOFS)
   http://www.emc.ncep.noaa.gov/FCCS_Science/F7_CSDL_ESTOFS_Status_16May2011.ppt

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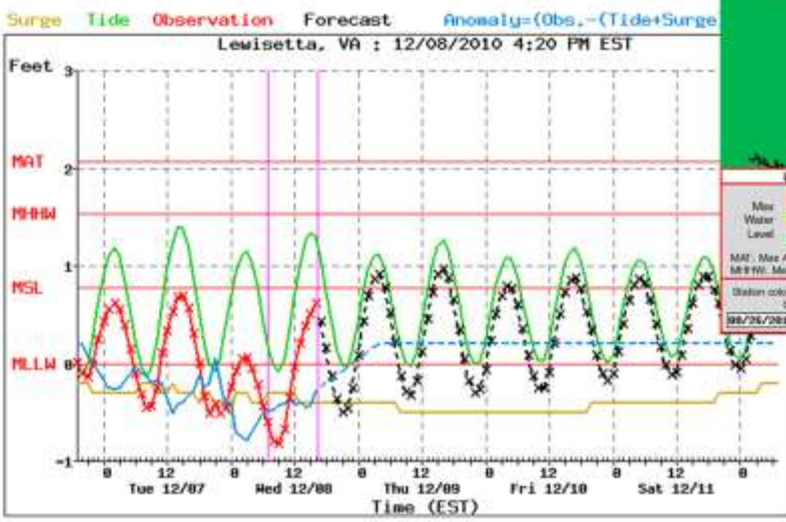
All three of these products give surge. CBOFS and ESTOFS give total water level while ET Surge requires a second data source giving tide. CBOFS also models water quality. ESTOFS is designed to allow coupling with a wave forecast engine.

Extra Tropical Storm Surge Point Forecast

AWIPS text database contains current "official" SLOSH-based surge water level forecasts at more than 100 U.S. tide stations.



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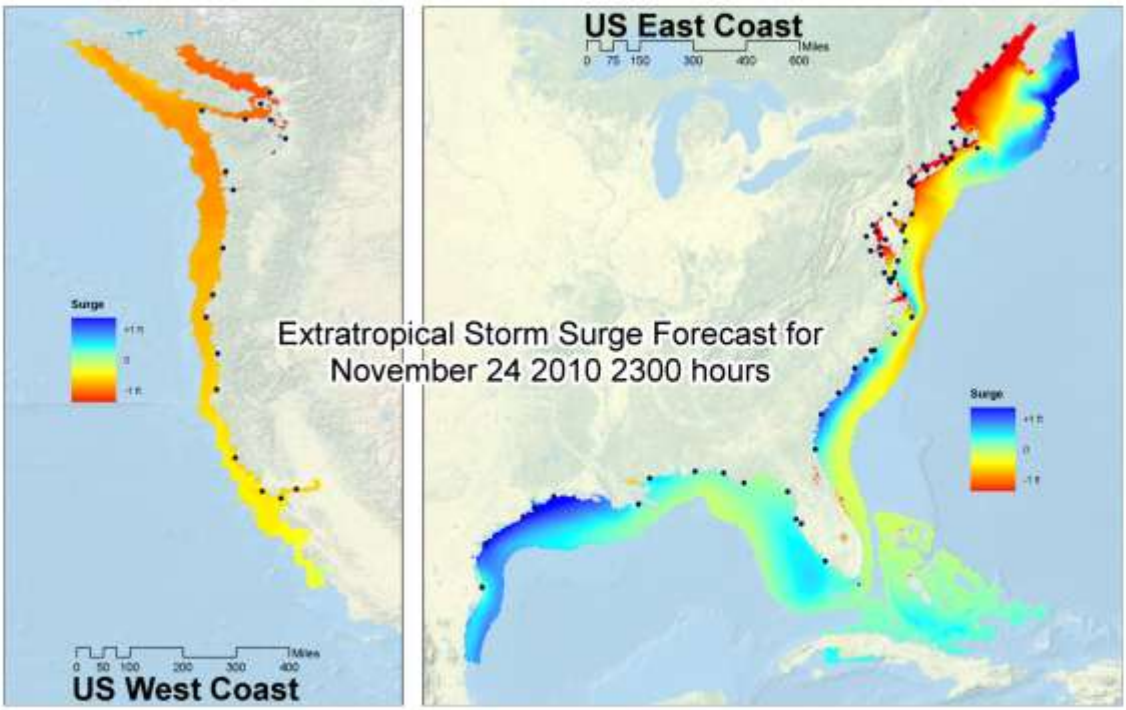
The extratropical water level forecasts product as captured as a screen shot from the web on 08 December 2010 at 09:00 EDT.

Available in AWIPS Text Database

OHD has template CHPS config and scripts for using this data in CHPS

Extra Tropical Storm Surge Gridded Forecast



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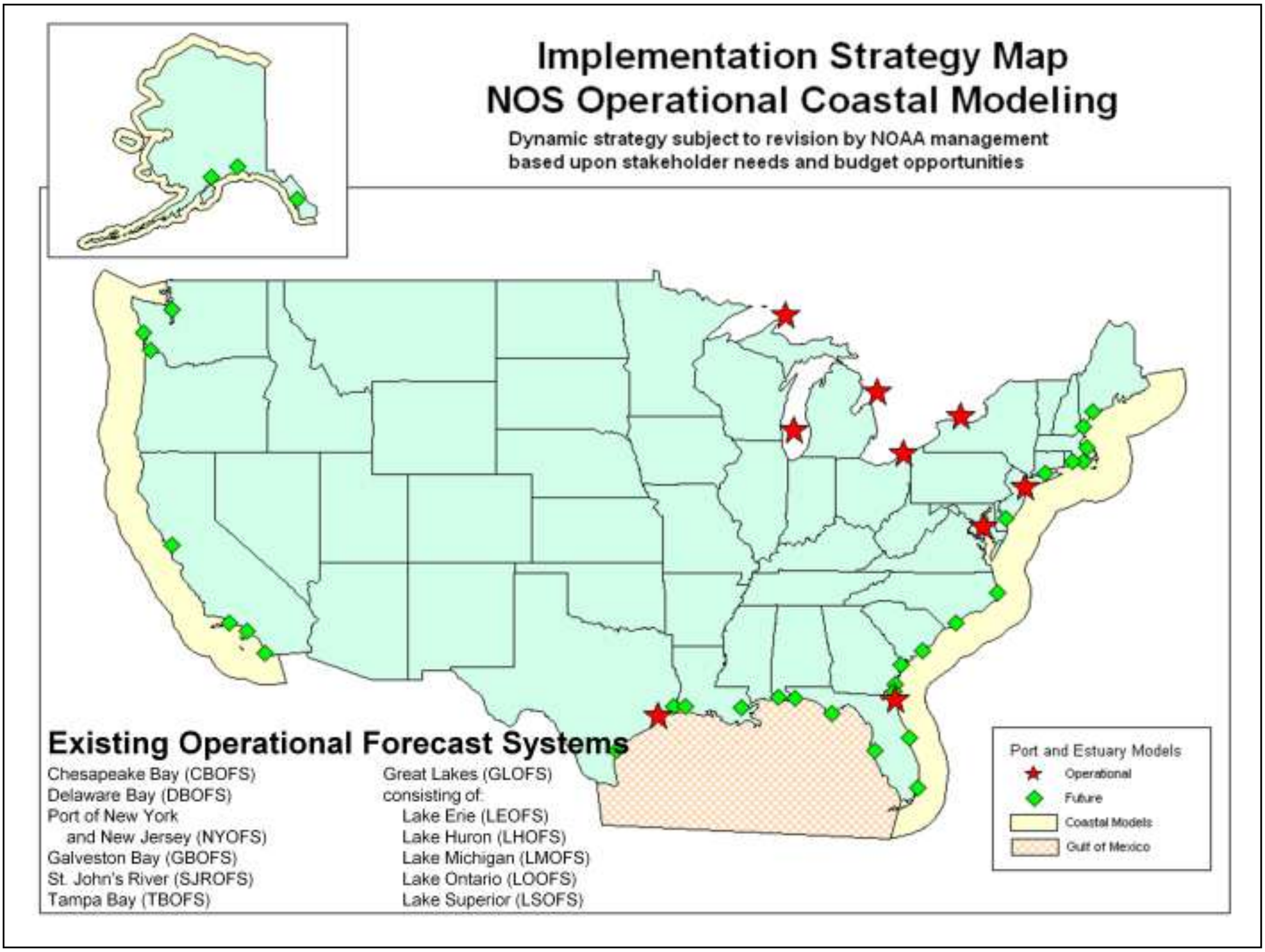
MDL gridded product has gridded format surge forecast with continuous US coastal coverage. These maps show the extent of coverage from an example dataset.

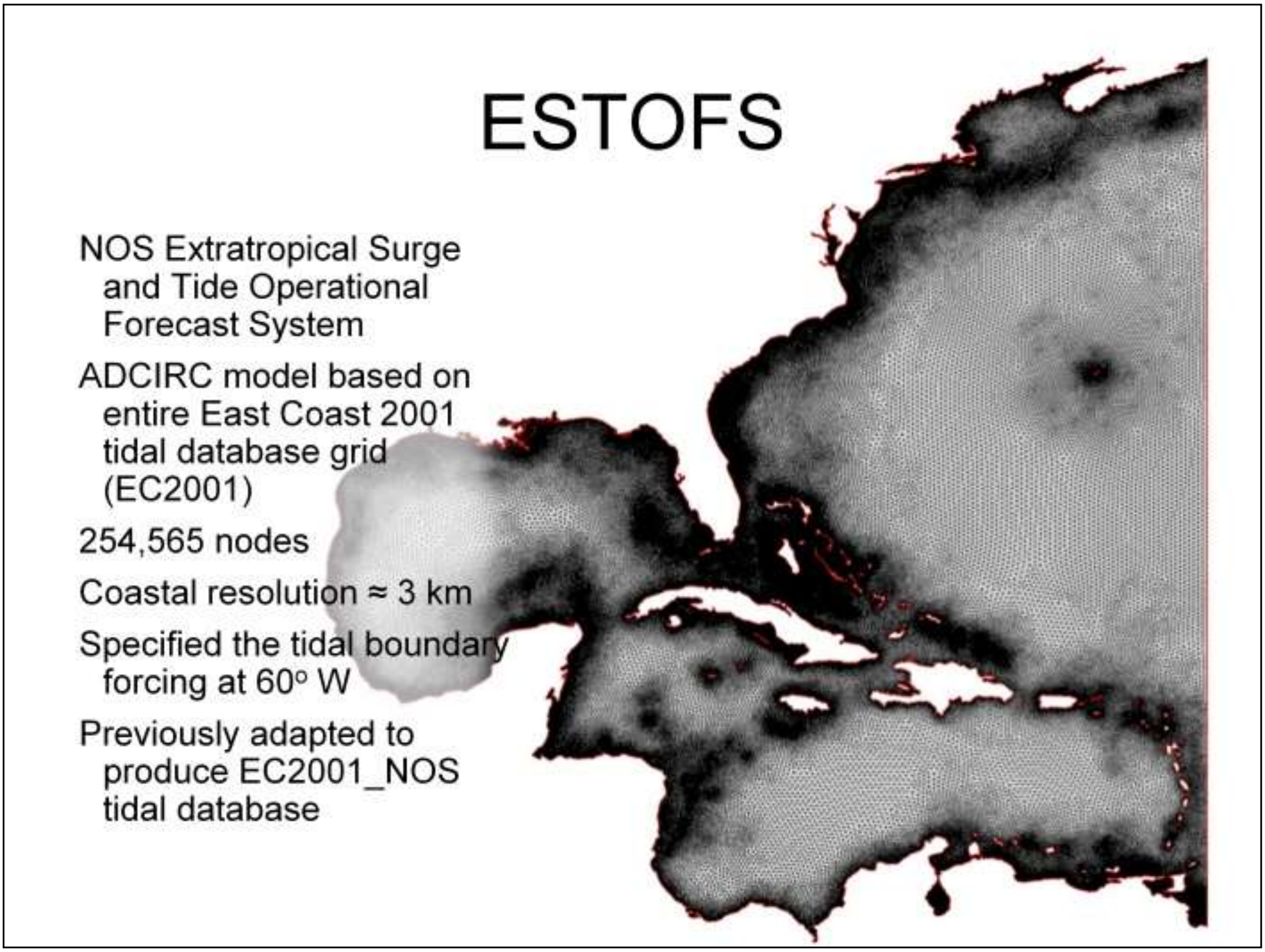
Ingesting into CHPS requires first downloading gridded dataset from http:// site

CHPS natively reads grib2 NDFD grid.



The 11 operation OFS systems provide forecasts using multiple different model technologies. Output is generally available as a NetCDF grid which may be accessed using the OpenDAP protocol.

CHPS has an OpenDAP method but it uses the http:// protocol which is not available on AWIPS forecasting workstations. OHD is investigating methods to allow AWIPS CHPS configurations to use the method.



ESTOFS is the latest (operational June 2011) modeling product from NOS and is continuous across the entire US East Coast.

A method for ingesting this data into CHPS has not been investigated.

Tidal Potomac River at Washington, D.C.

Combining HECRAS model with coastal boundary condition in a live, operational CHPS configuration at MARFC

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MARFC Study

Link unsteady HEC-RAS to operational NOAA (NWS/NOS) estuary-ocean models

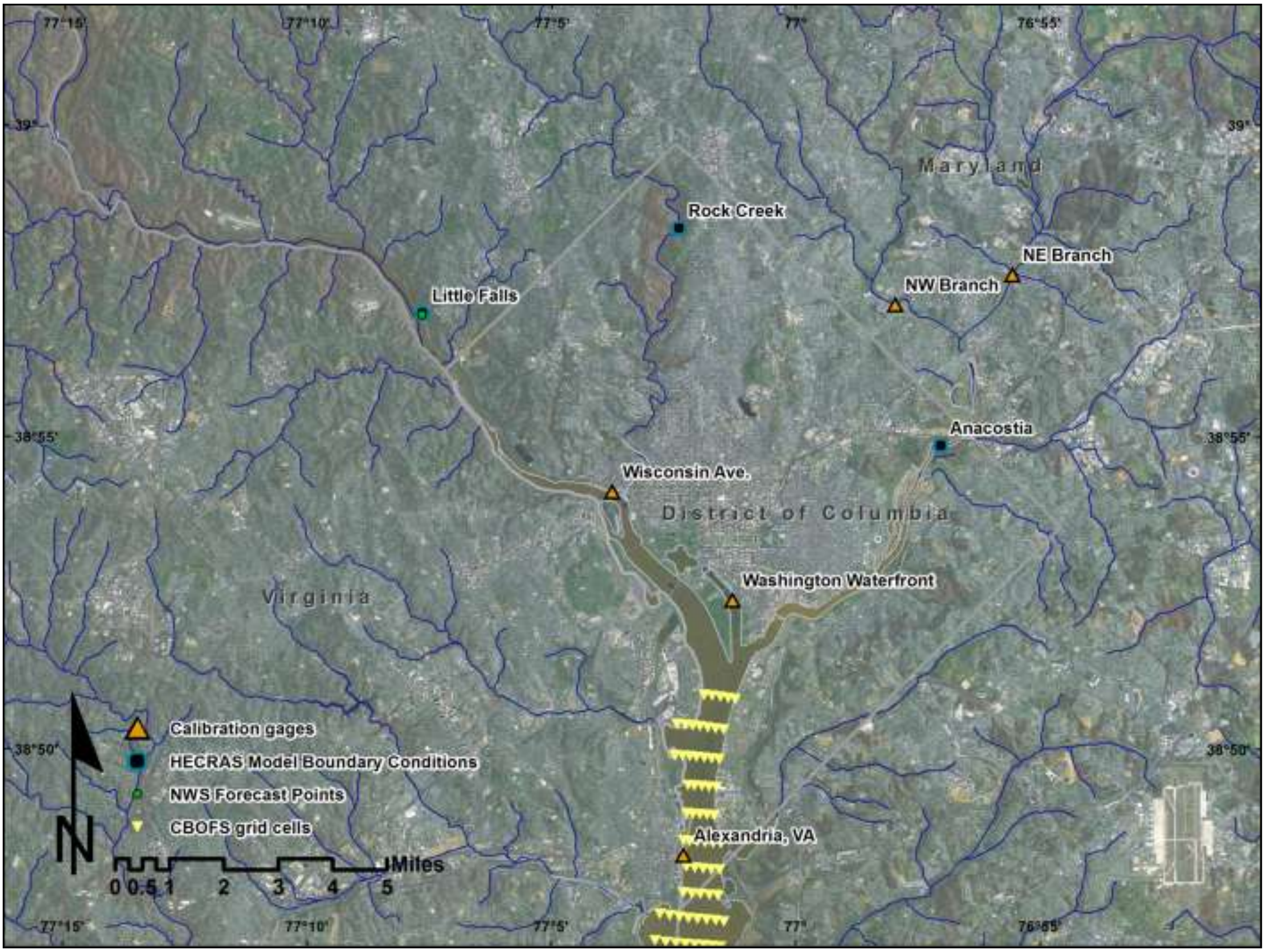
- Build and calibrate a HEC-RAS model that can be run operationally at the Mid-atlantic River Forecast Center
- Assess HEC-RAS accuracy in propagating tide/surge boundary forcings upstream
- Use HEC-RAS to better understand the impacts of estuary-ocean boundary condition on river stage forecast accuracy

Other RFCS who are using coastal boundary conditions in CHPS:

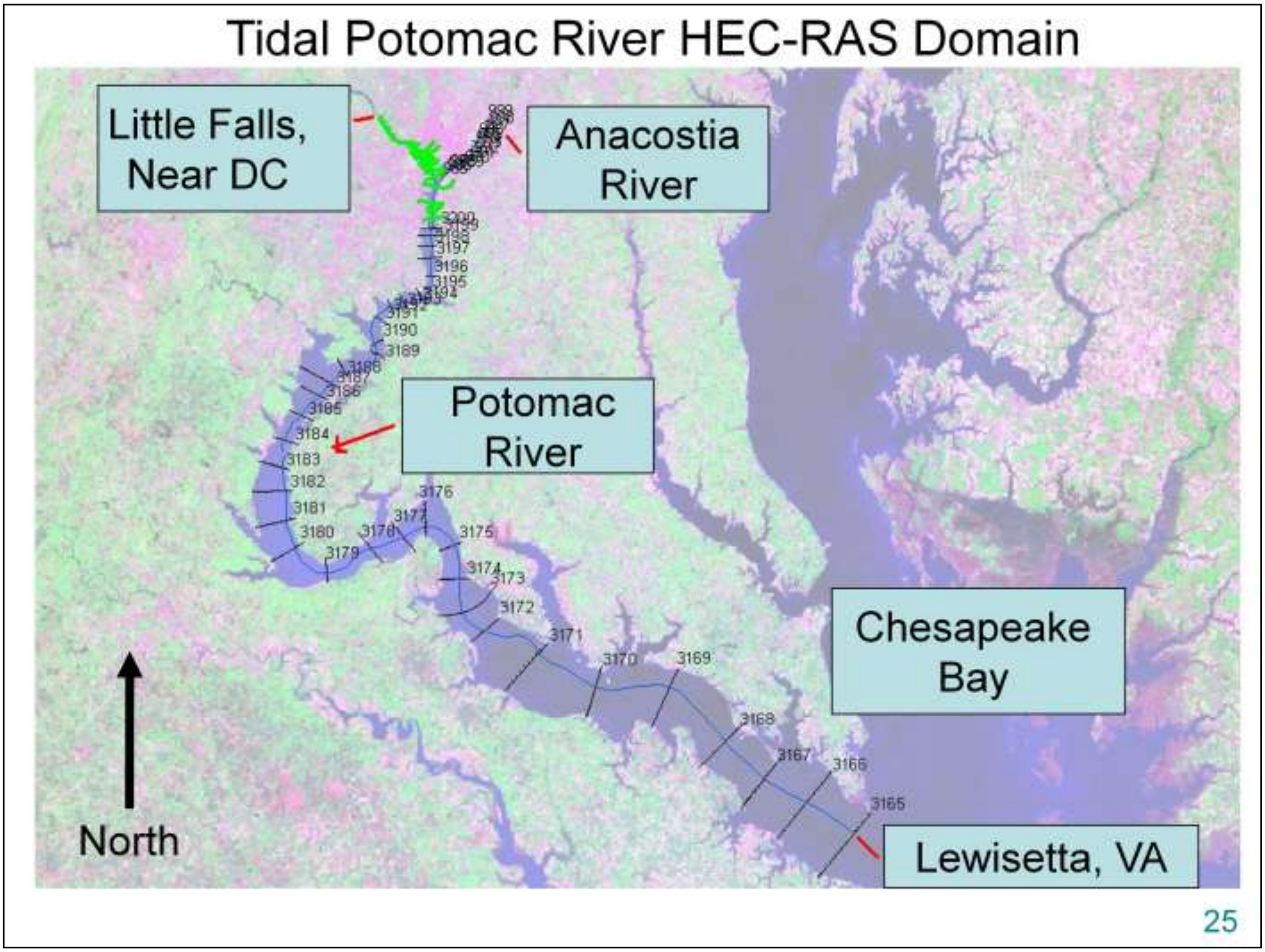
NWRFC Columbia Model uses astronomical tide predictions, observed water level, and a blending routine which projects anomalies into the future – no physical surge modeling.

NERFC uses water level observations and astronomical tide forecasts but no storm tide data yet.

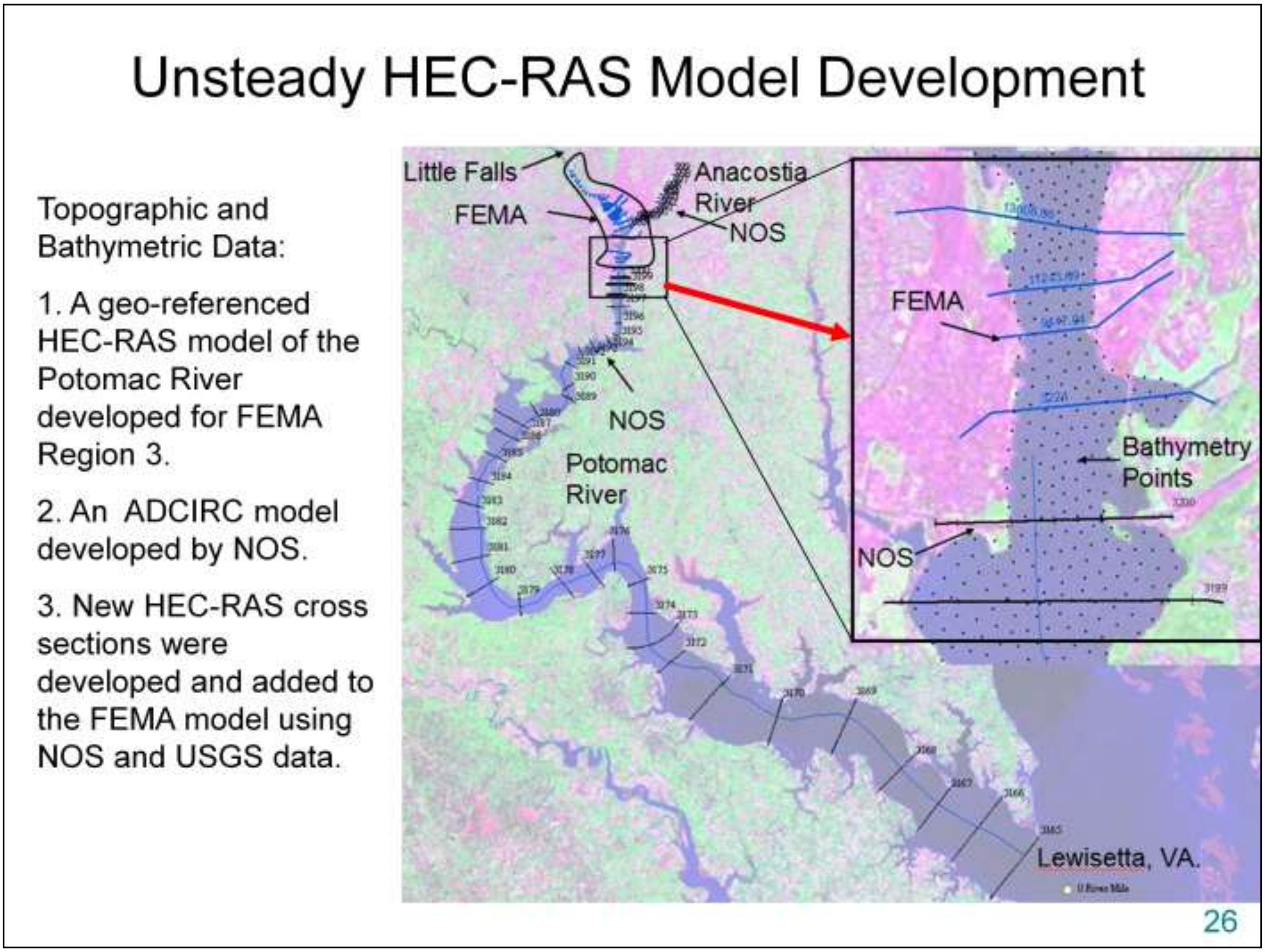
LMRFC has ingested gridded ETSurge into CHPS for for boundary condition adjustment.



There is a 10 mile (15km) gap between the last NWS RFC forecast point at Little Falls and the upstream-most forecast from the CBOFS model.



The tidal Potomac River unsteady HEC-RAS Model domain consists of the Potomac River from Little Falls, near Washington, D.C. to its mouth at the Chesapeake Bay near Lewisetta, Virginia. The main stem model covers about 114 miles (from River mile 4.42 to 118.25) and contains 89 cross-sections.

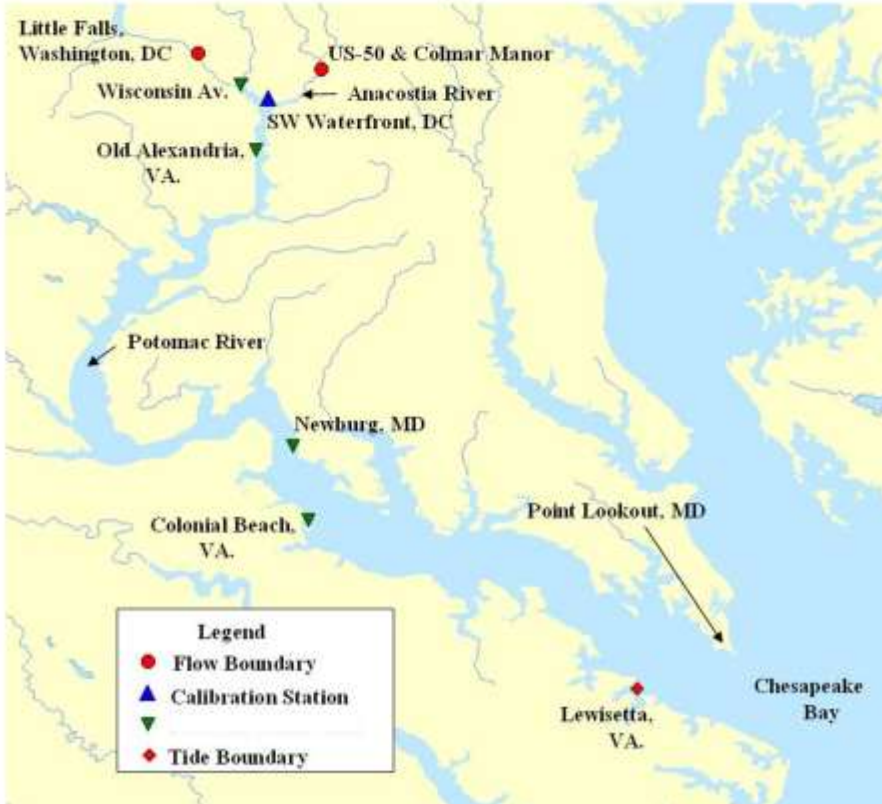


The unsteady HEC-RAS model described in this paper has been developed based on the bathymetry data provided by NOS-CSDL and a geo-referenced HEC-RAS model of the Potomac River from Little Falls to Haines Point Gage developed for FEMA Region 3. The geo-referenced HEC-RAS cross-sections were imported into ArcGIS along with the geo-referenced NOS-CSDL bathymetry data and satellite imagery. New HEC-RAS cross sections were developed from the downstream section of the FEMA model based on NOS-CSDL data. FEMA and NOS-CSDL data boundary locations are shown in Fig. 4. The inset of Fig. 4 shows the border location between FEMA and NOS-CSDL data and the density of the bathymetry points.

Model Calibration and Validation

Calibration for:

1. Harmonic Tide
2. Observed Stage and Discharge Time Series
3. Historic Flood Events
4. Hurricane Surge



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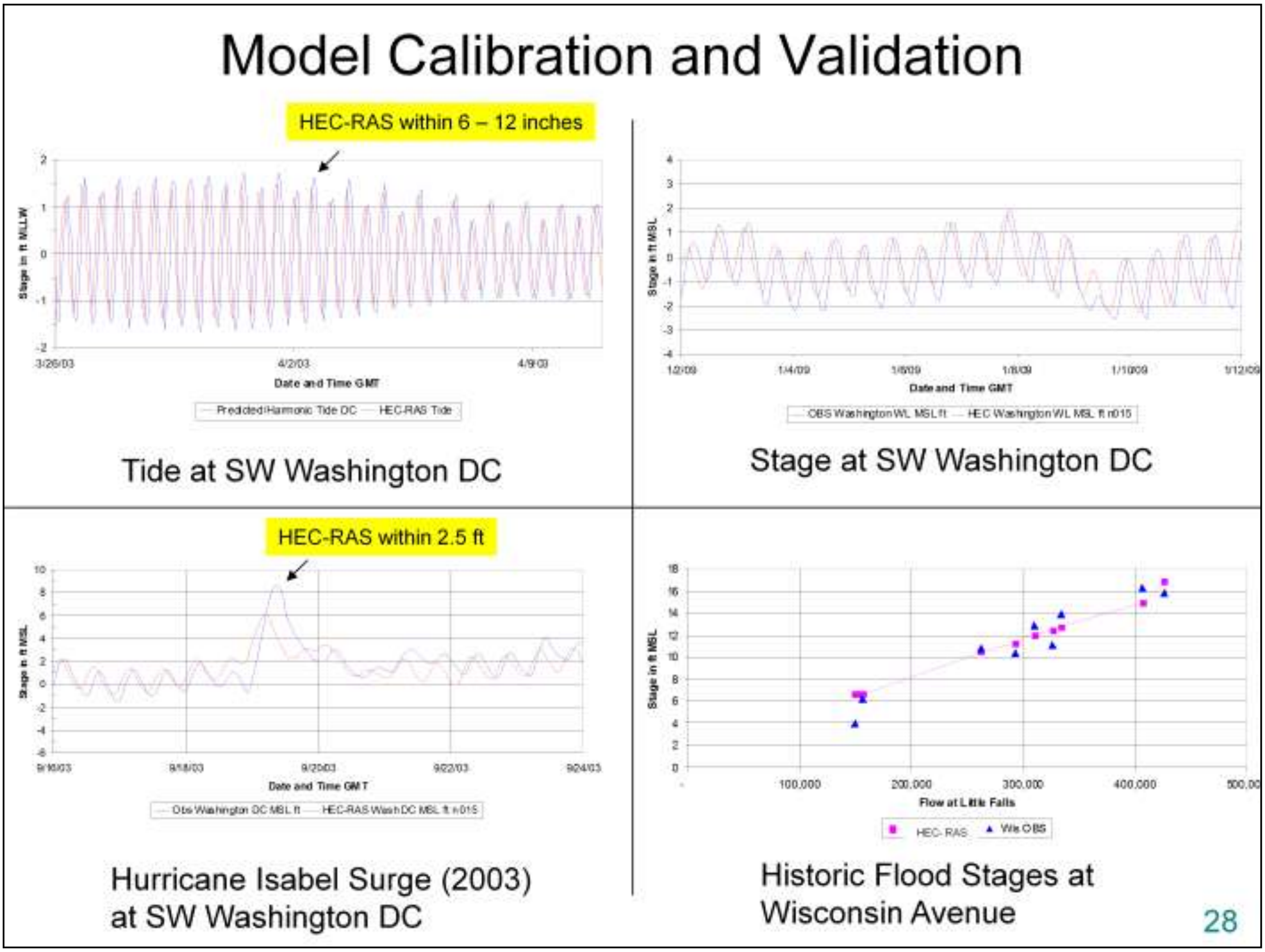
Tidal simulation was performed to evaluate the model's capability to reproduce the tides using harmonic constituents for the Lewisetta, Virginia and the SW Waterfront in Washington, D.C. stations. The Lewisetta water level time series was used as the downstream boundary condition to run the HEC-RAS model and the simulated water level near Washington, D.C. was compared to the time series generated by harmonic constituents for the same location.

Following the tidal simulations, we calibrated the model using inflow and tidal boundary conditions from 01 June 2003 to 30 May 2004. This period includes storm surge and subsequent high river discharge through the Potomac River. Initial Manning's n roughness values were assigned based on information from the FEMA HEC-RAS model for the upper portion of the model. For the lower portion, we started with a Manning's n from the literature (0.025) and then made adjustments to match the tidal amplitude.

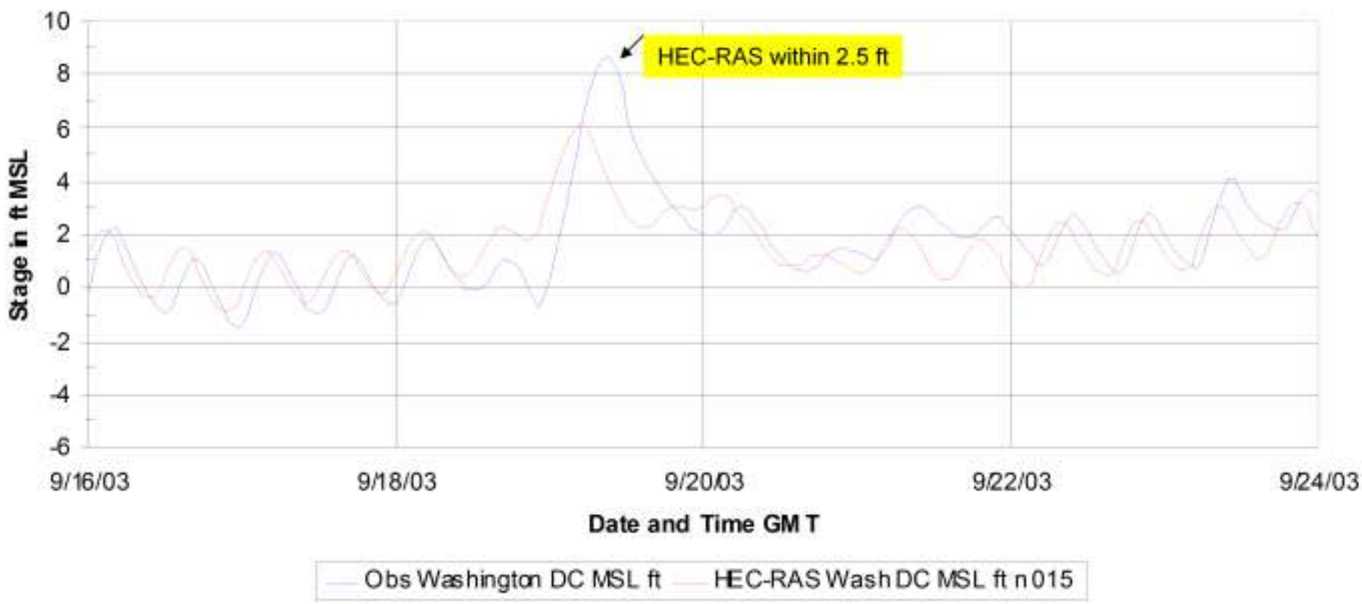
Two validation periods were selected: 1) 01 Jan 2009 to 13 Jan 2009 and 2) 07 Feb 2009 to 28 Feb 2009. Recent 2009 data were selected so that parallel analyses requiring additional forcing data (e.g. observed and modeled wind forcings) can be run for the same period.



Tide and stage are within in 6-12 inch and hurricane Isabel (2003) surge is within 2.5 ft of the observed stage. Historic flood elevations are with 1-2 ft range.

2003 Hurricane Isabel Surge Simulation using HEC-RAS without Wind Forcing - Simulated Surge at Washington DC

Manning's n calibration does not improve water level to match surges



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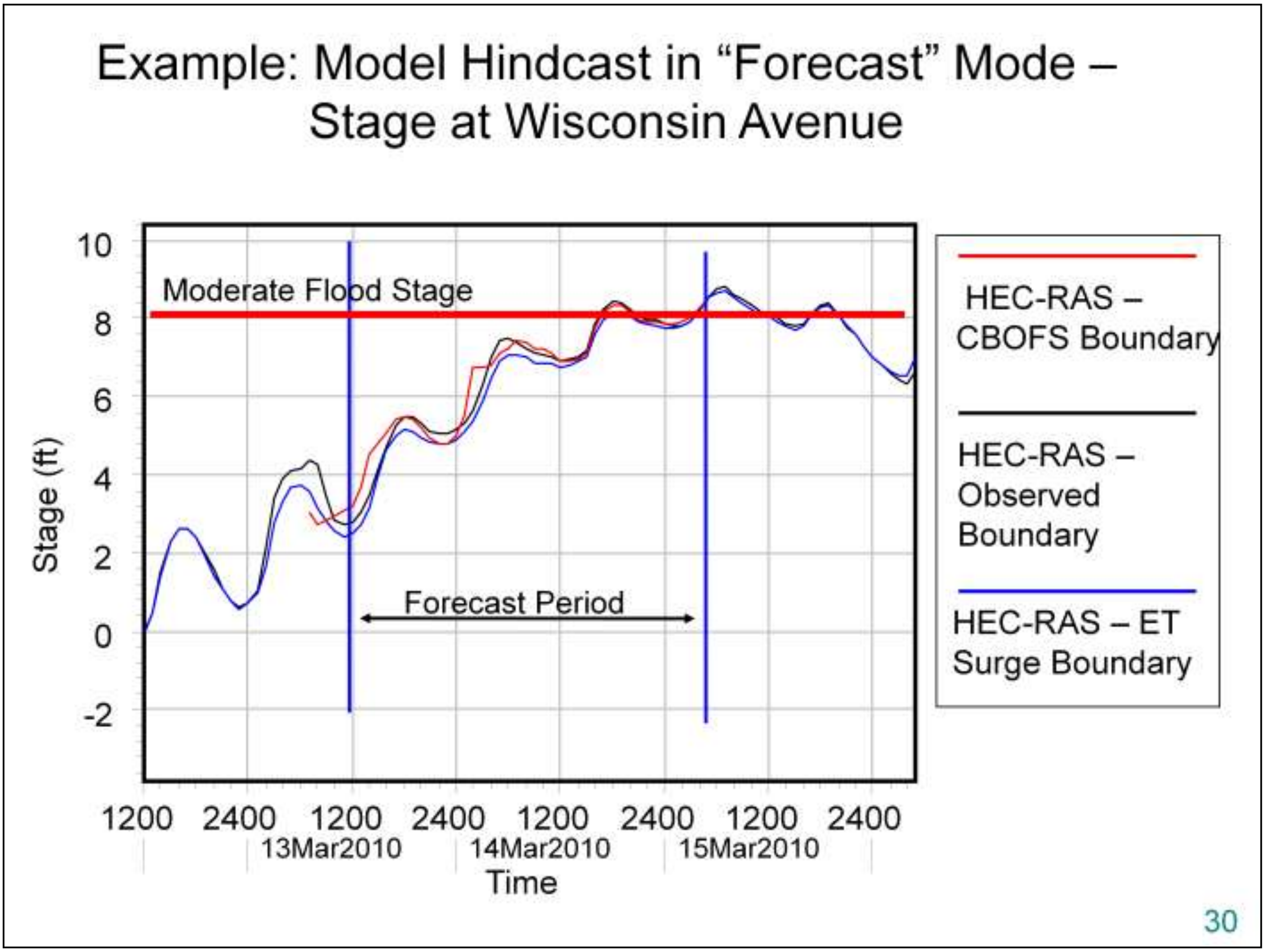
Tide and stage are within in 6-12 inch and hurricane Isabel (2003) surge is within 2.5 ft of the observed stage. Historic flood elevations are with 1-2 ft range.



HEC-RAS: CBOFS Boundary

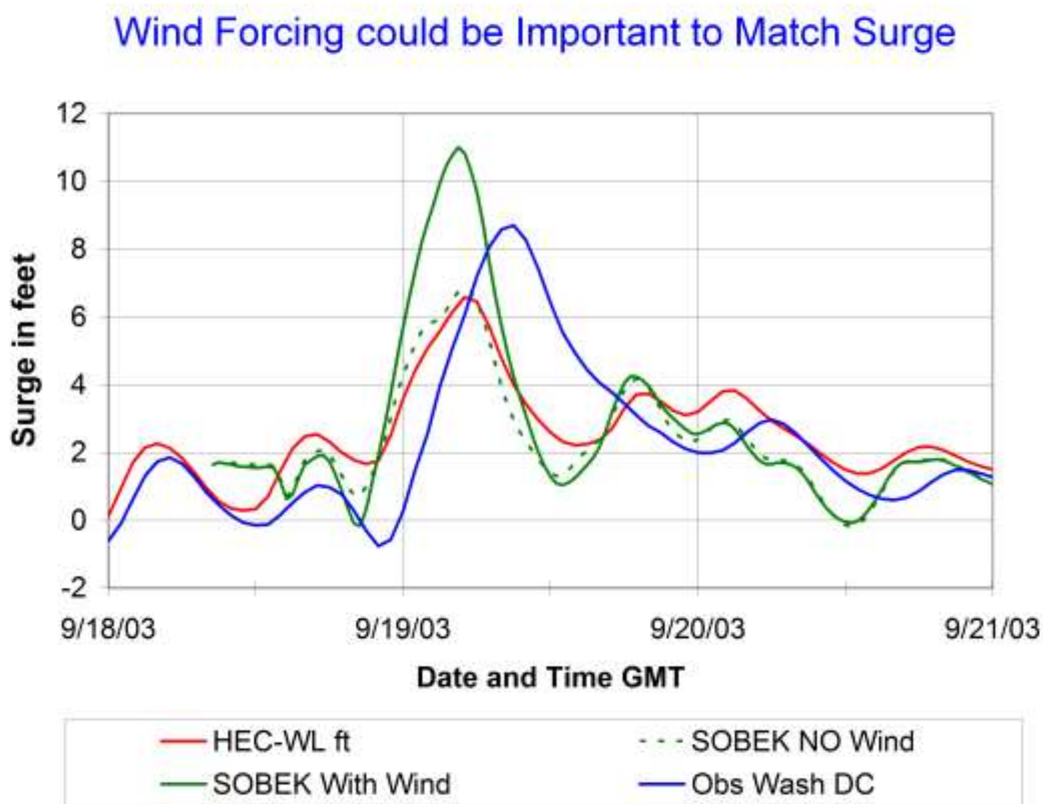
HEC-RAS: Observed Stage at Boundary

HEC-RAS: ETSurge Boundary

HEC-RAS model was run in forecast mode for the March 2010 event. Boundary forecast tide at Lewisetta, Va. was obtained from -

1) NOS’ Chesapeake Bay Operational Forecast System (CBOFS) and
2) NWS/MDL’s Extratropical Water Level Forecast (ET Surge)

2003 Hurricane Isabel Surge Simulation using SOBEK with and without Wind Forcing - Simulated Surge at Washington DC



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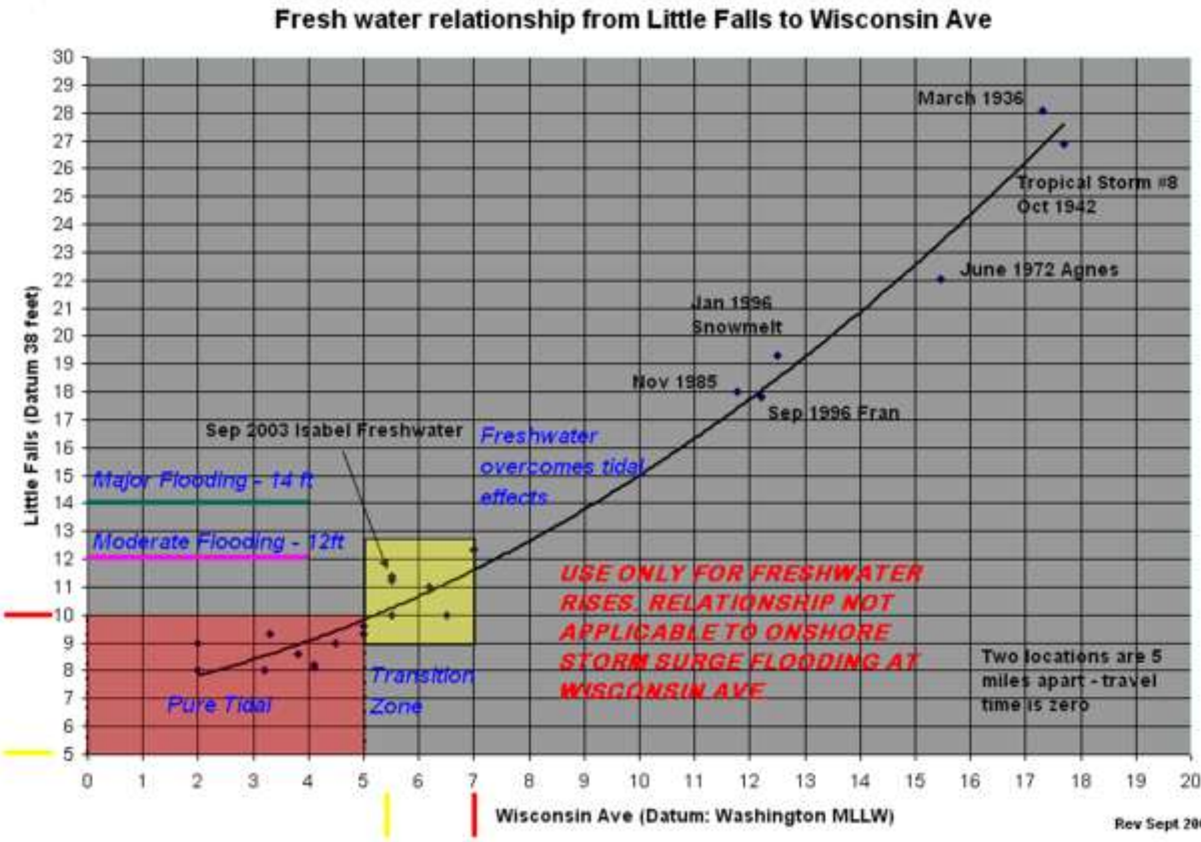
Wind clearly has the capability to make a difference (note change between SOBEK runs with and without wind.) The effect is large enough that is must be calibrated simultaneous with roughness.

Graph Currently Used to Predict Stages at Wisconsin Avenue

Cannot account for 2 – 5 ft tidal variations; HEC-RAS can



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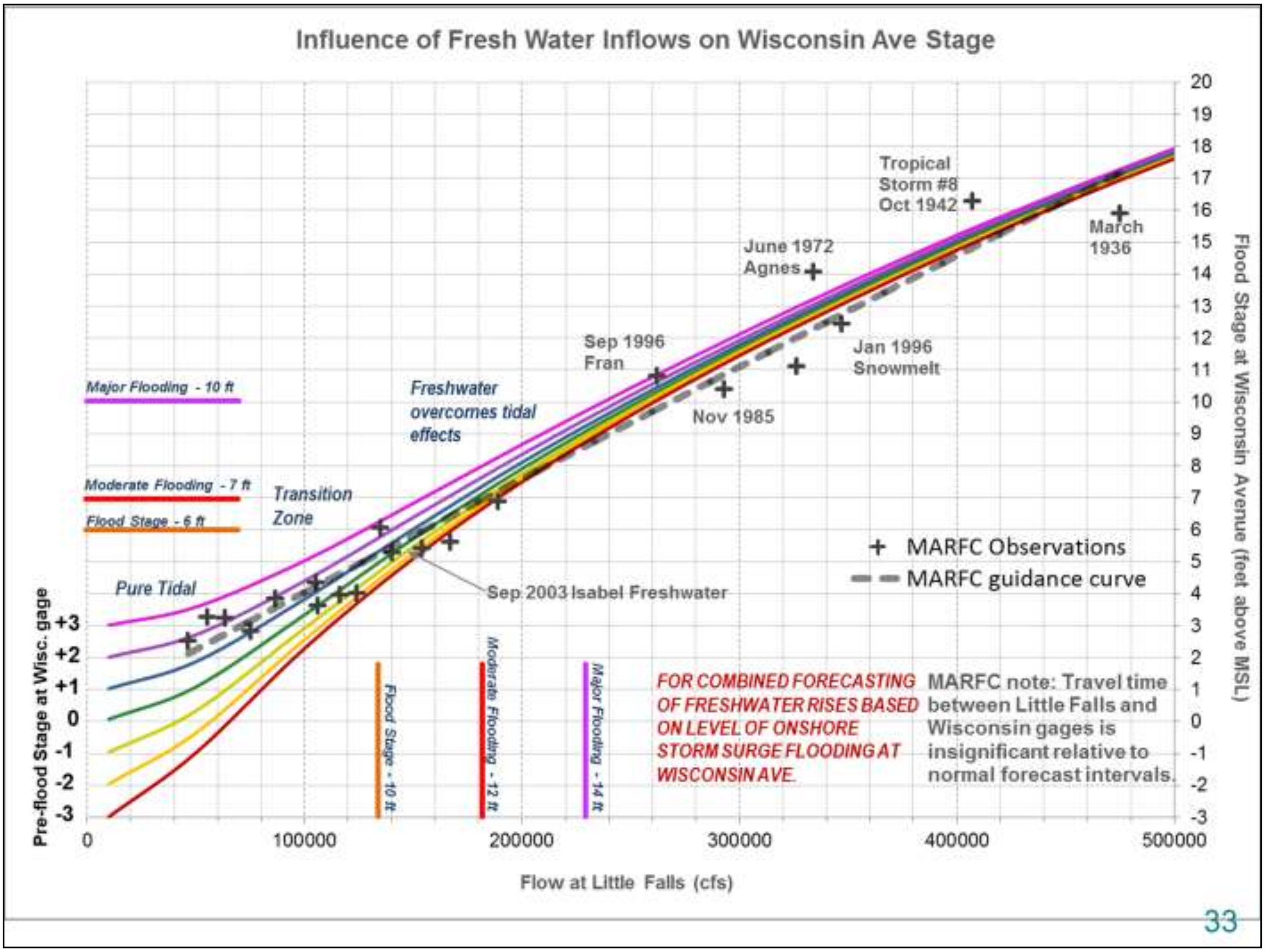
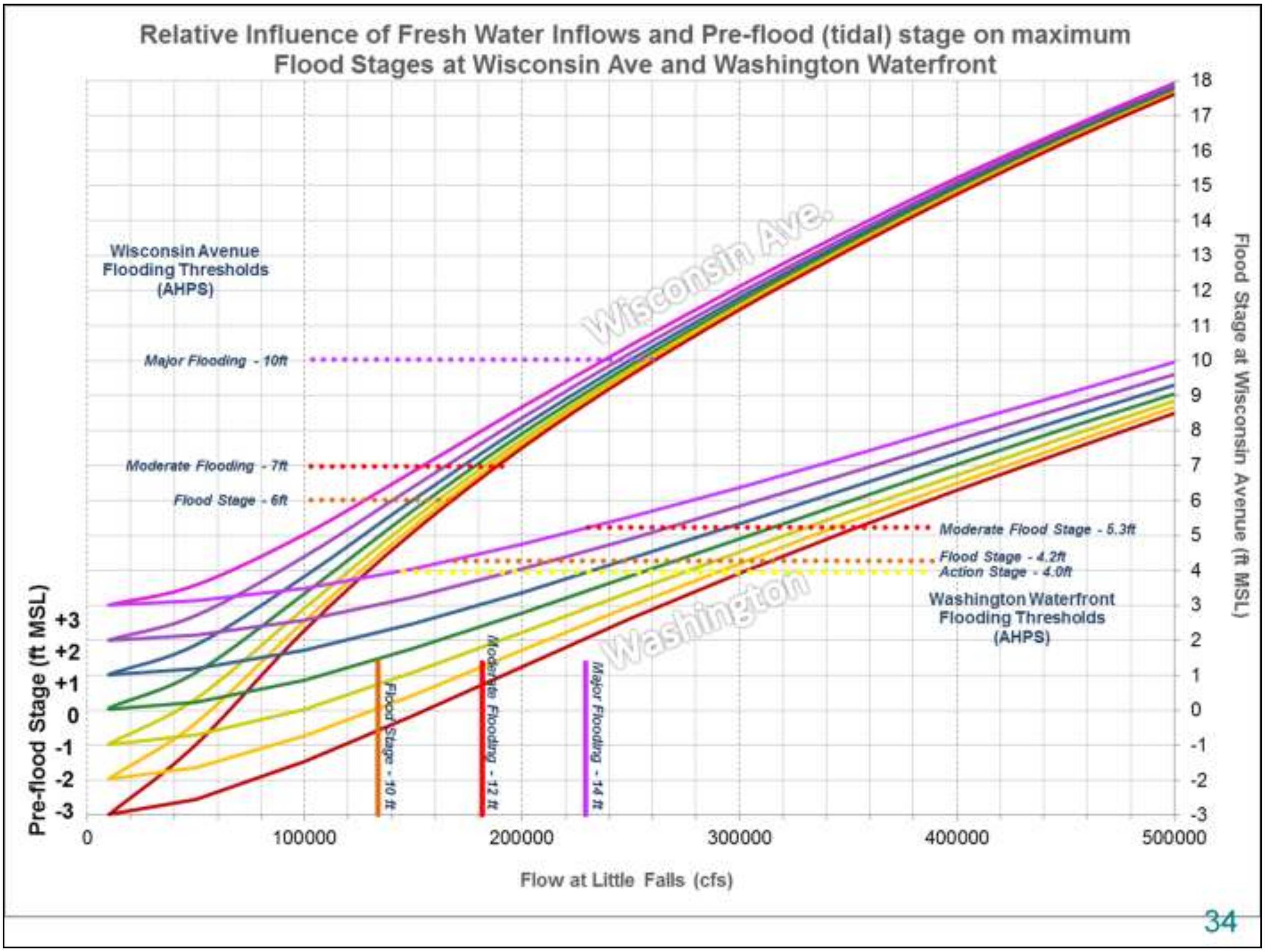
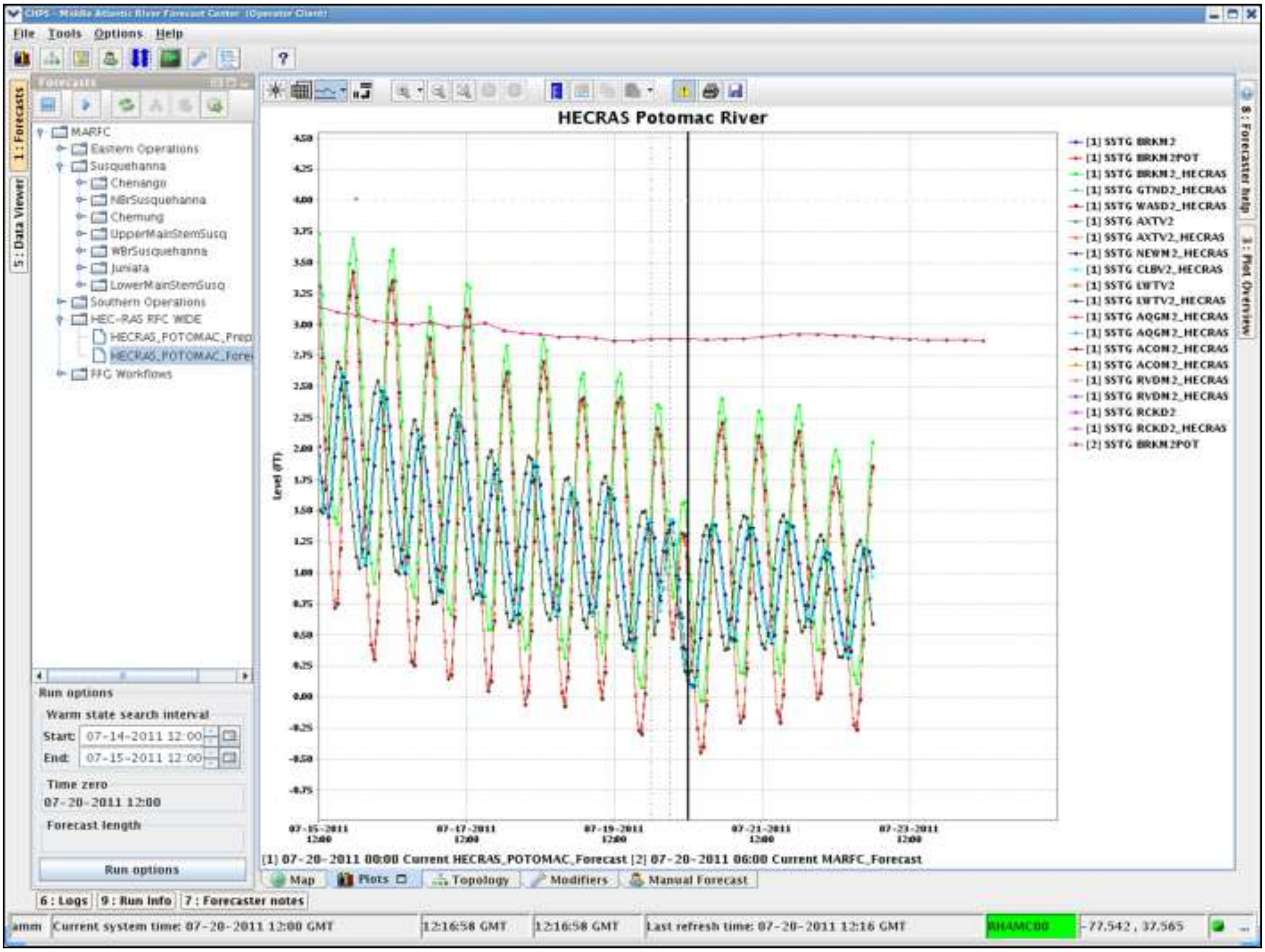
Importance of tide simulation in the Tidal Potomac River. Freshwater stage relationship currently in use in MARFC for guidance purposes



Updated MARFC guidance graphic including the results from hypothetical flows on the Potomac with vary downstream boundary elevations. The HECRAS model results capture well the variation in the observed data providing confidence for using the model as a forecast tool.

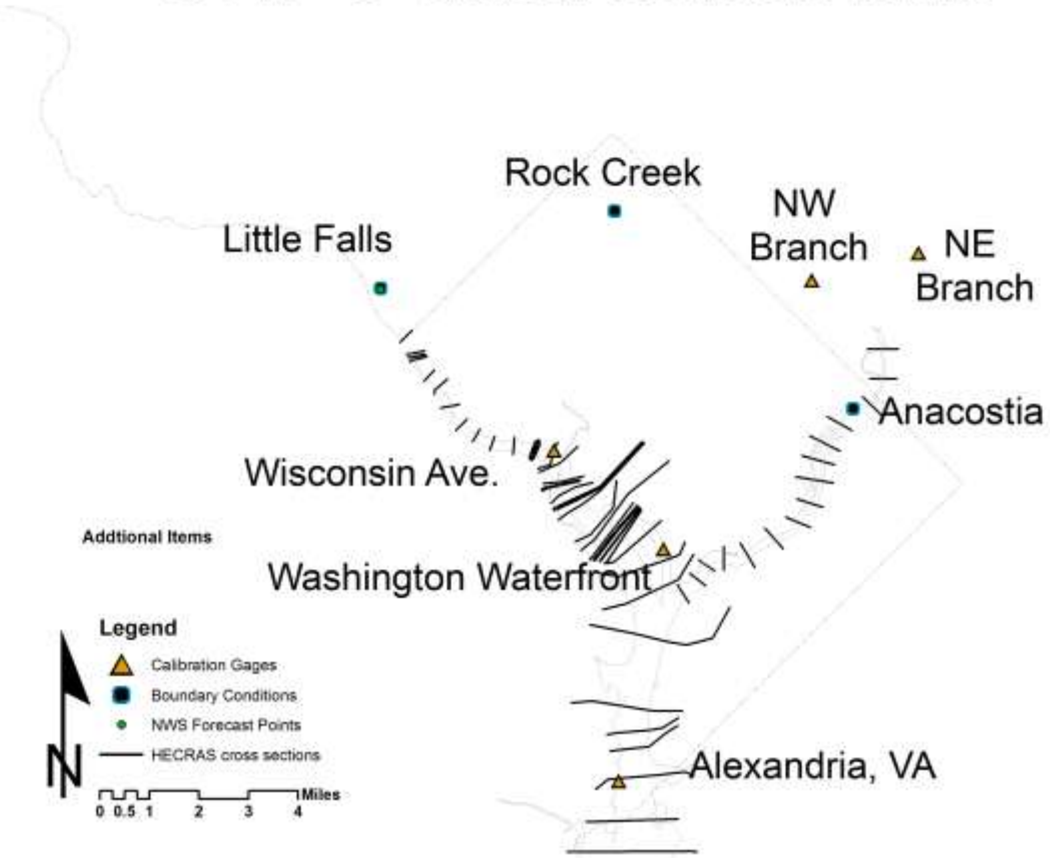


Further downstream at the Washington Waterfront, the pre-flood stage is a more significant factor and the Potomac inflow becomes less significant a factor in peak flood level.



Screenshot from the MARFC CHPS operational Client showing the forecasts for a number of tidally influenced areas on the Potomac

CHPS data schematic



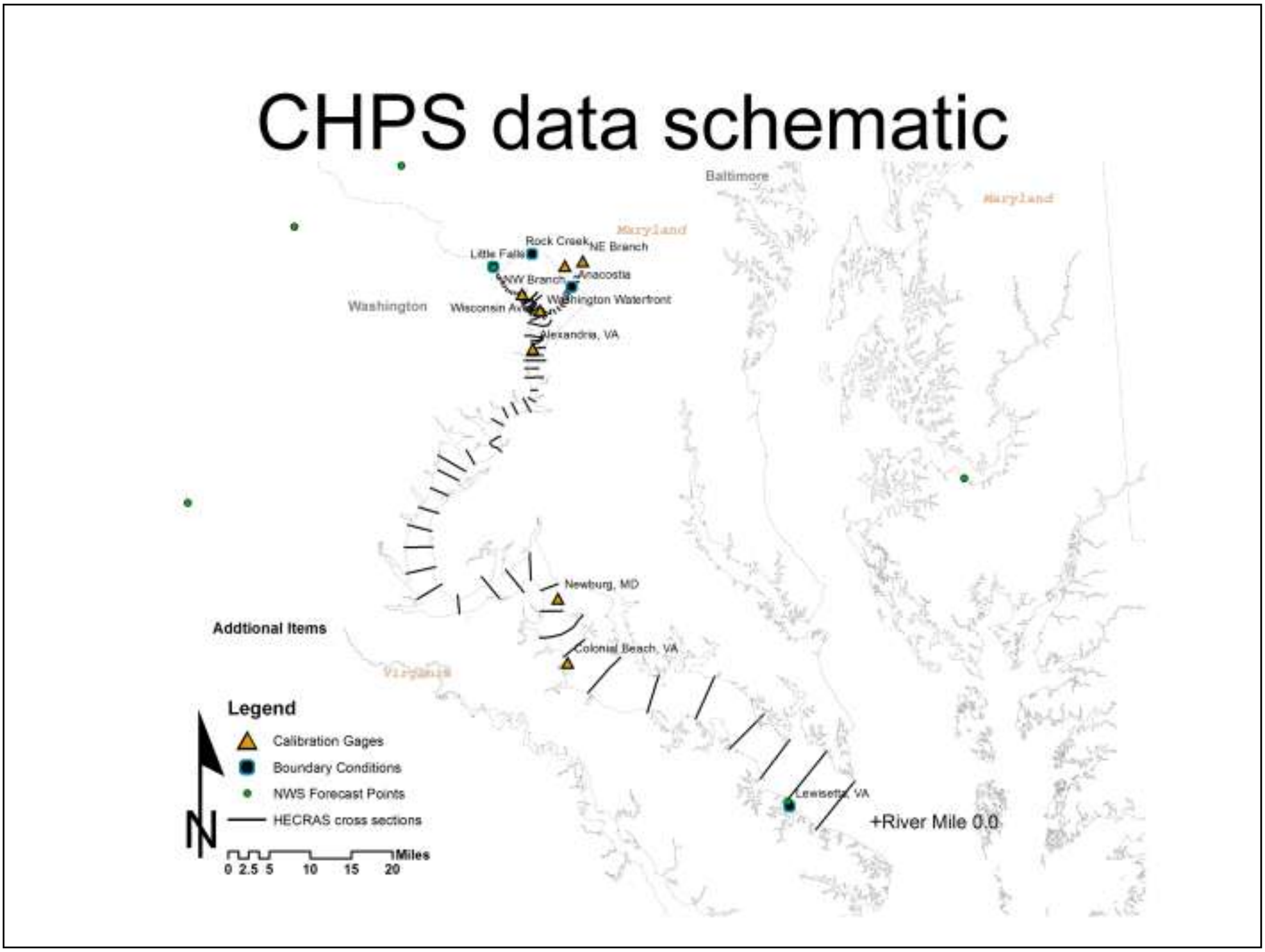
Use whiteboard to draw sources of data:
LWTV2 – Forecast point

RCKD2 – FFG forecast point

ACOM2 – USGS Gage flow – persisted

RVDM2 – USGS Gage flow – persisted

ACQM2 – sum of upstream flows



Use whiteboard to draw data sources:

Repeat upstream sources and add LWTV2 Observed NOS waterlevel + Water level forecast from any of the coastal datasets.

Summary

- Data and methods are currently available to perform tide+surge bounded river forecasts
- HEC-RAS model accuracy becomes more dependent on estuary-ocean model boundary accuracy at points farther downstream and for events with lower freshwater flows
- Amplitude and phase of the tide vary significantly along the US coast
- Next Steps
  1. Widespread implementation of current method (HECRAS + Point ET Surge)
  2. Operational ingest of gridded datasets (NOCMP OFS models, ESTOFS, and gridded ET Surge)
  3. Wind forcing along HEC RAS channel
  4. Inundation extent …

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1D unsteady HEC-RAS – fast, ready for operational use.

Future work will involve comparisons to 2D/3D models with more complete physics.

Also we will consider developing recommendations for which gridded coastal model to use as a boundary.

Inundation Mapping

Poll Question:

If OHD generates an operational method to produce on-the-fly inundation extents using a DEM and a HECRAS model, how often would this be useful to our office?

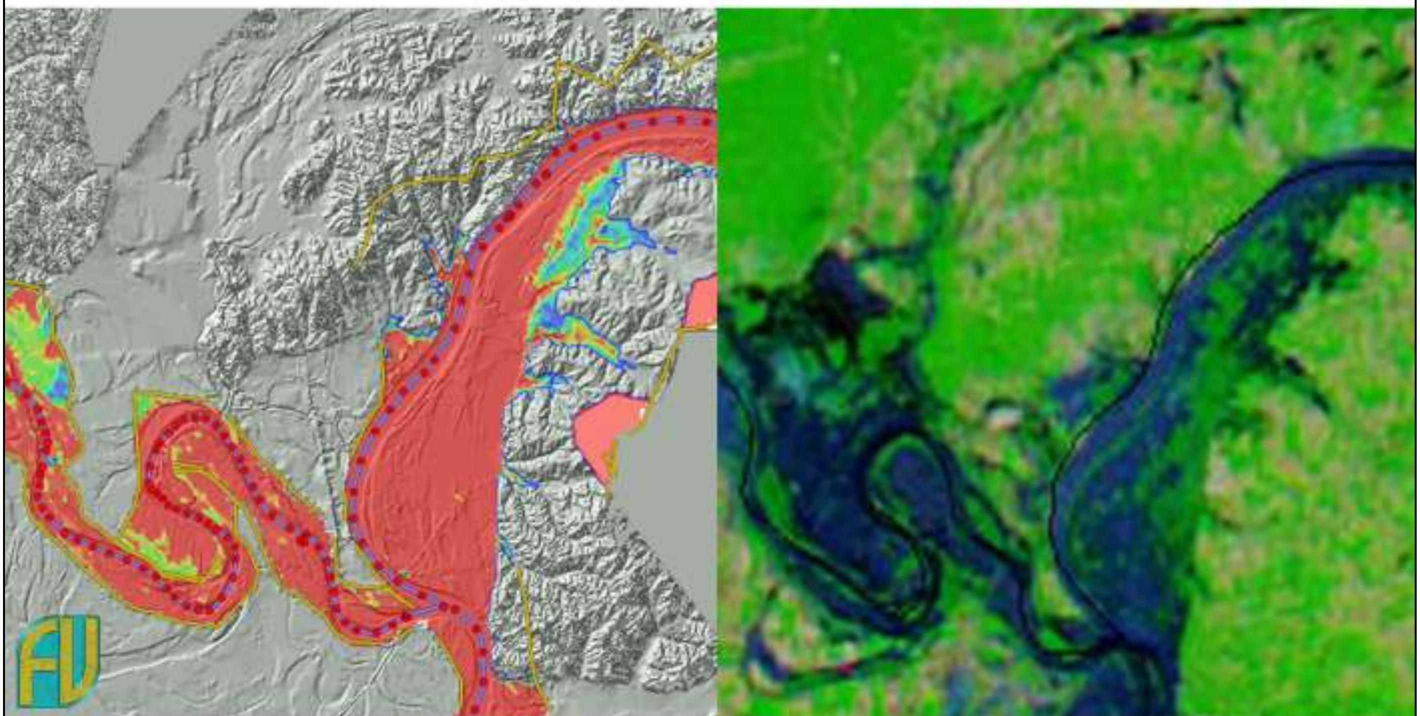
A. Never

B. Infrequently - One or two times per year

C. Often - Several or many times per year

D. Constantly

FloodViz Visualization of HEC-RAS output vs. MODIS image
Pascagoula River - May 6, 2011



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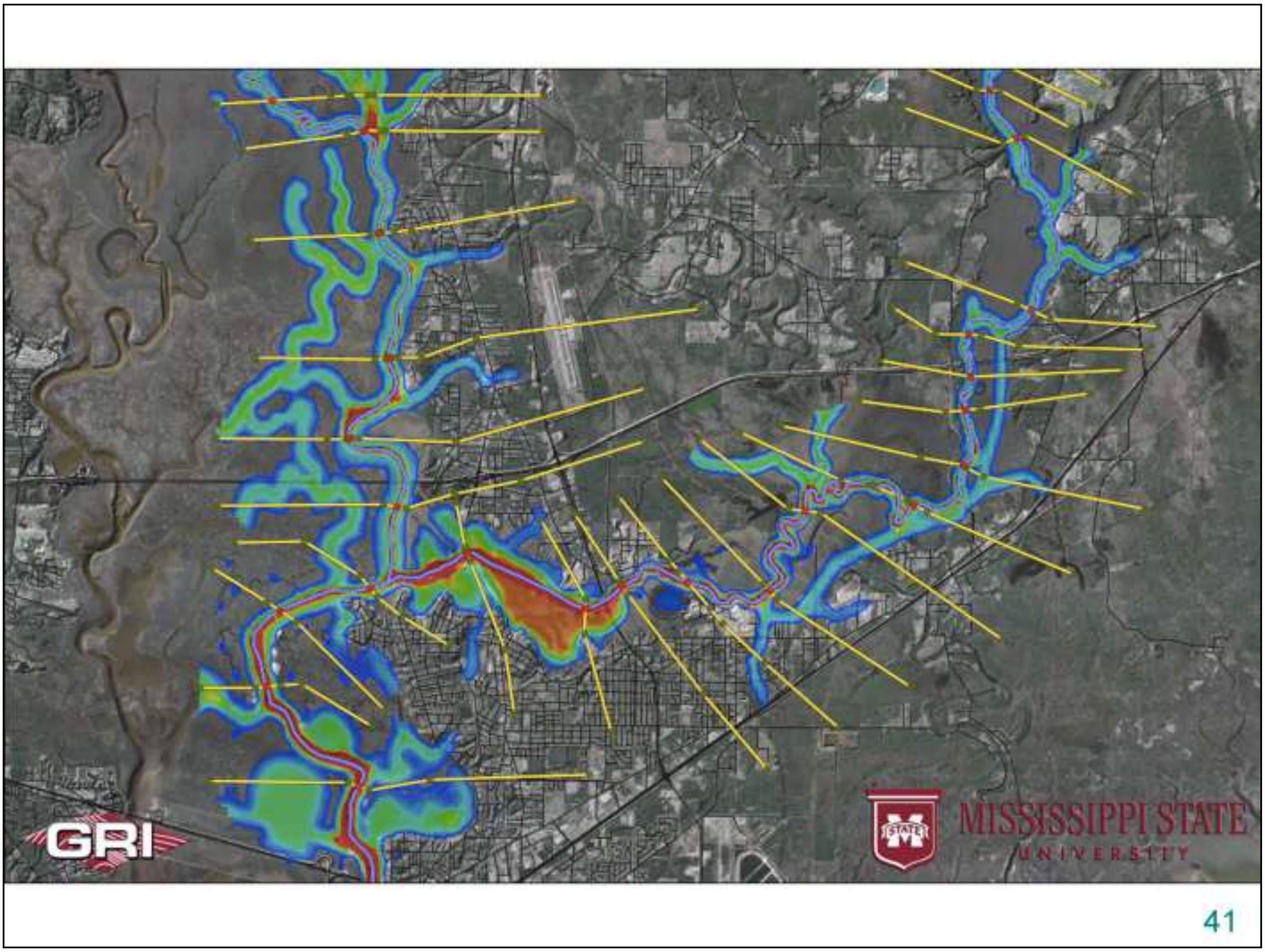
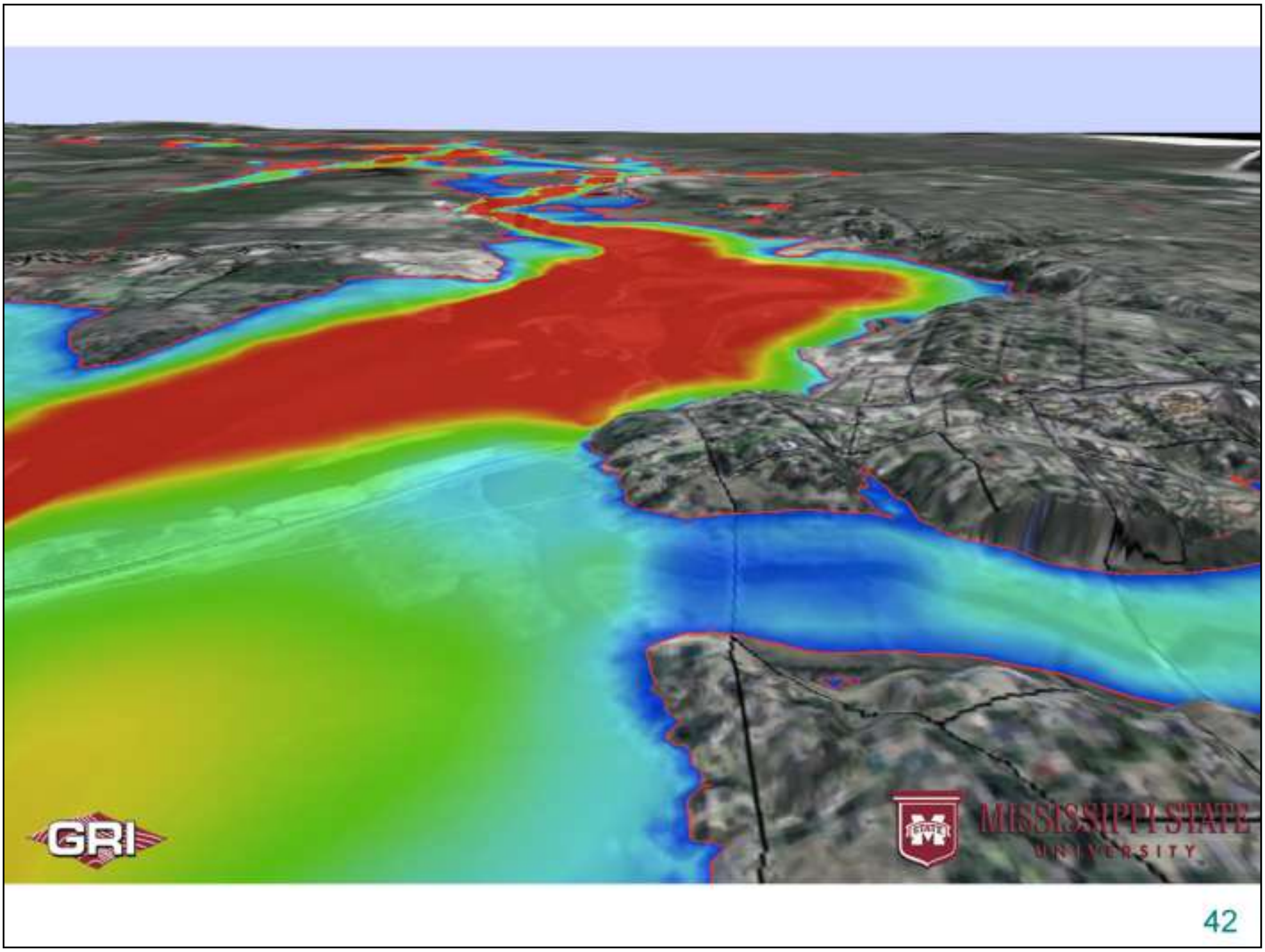
FloodViz is a visual analytic software package to enable scientists and forecasters to better interpret and distribute hydrologic information. FloodViz will serves as a useful platform for NWS forecasters to more quickly and accurately forecast extent of flooding. Additionally, these tools will allow forecasters to relay more meaningful information to the emergency management community while issuing forecasts to help protect lives, property and the nation.

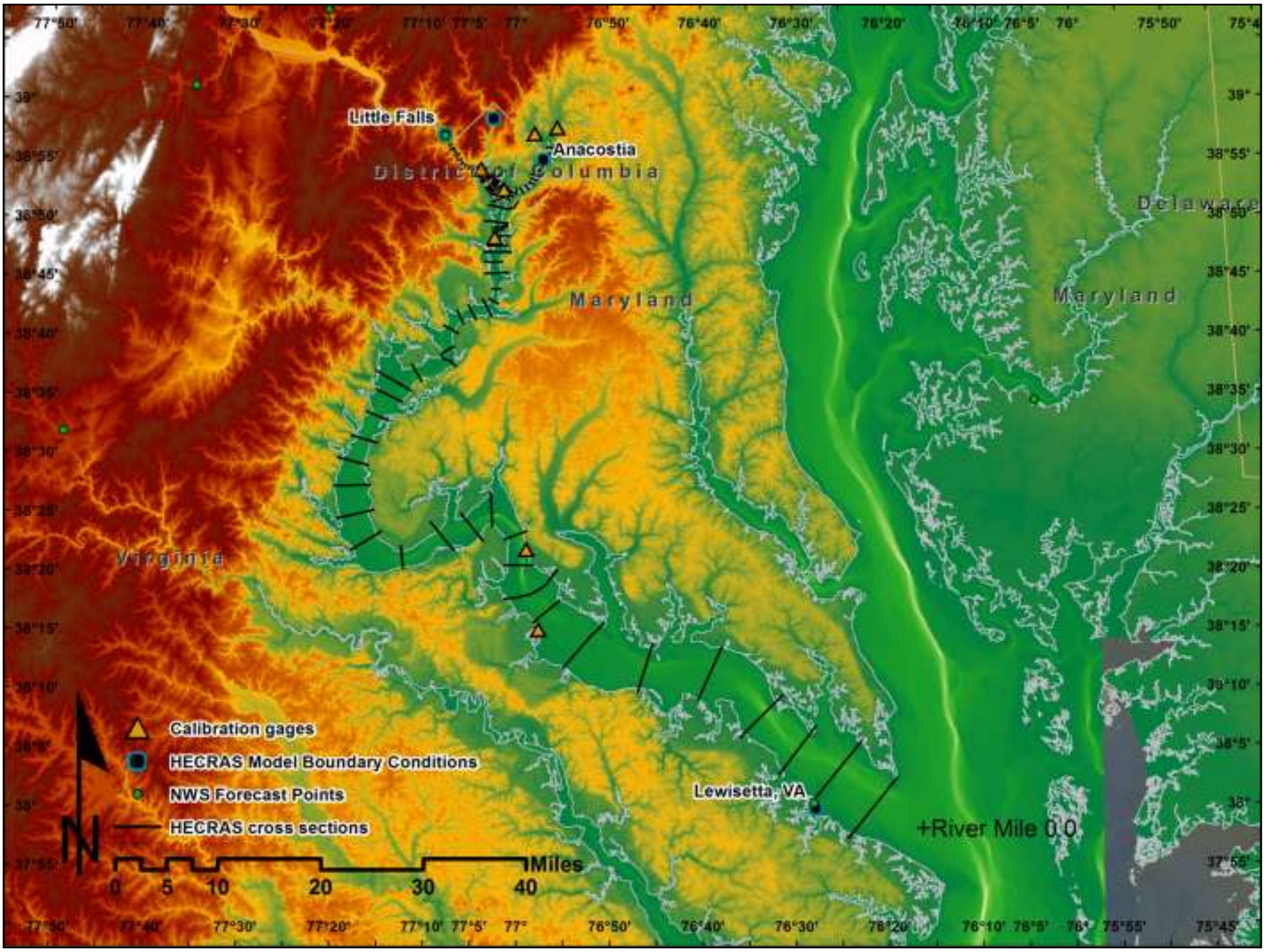
This FloodViz software is being developed by visualization researchers at Mississippi State University in partnership with the Lower Mississippi River Forecast Center.



2-D plan view visualization of flood inundation for the Pascagoula River in 2011. Yellow lines indicate the cross sections and extent of the HEC-RAS model. Water surface is colored by water surface depth (water surface elevation - terrain elevation).



3-D oblique visualization of flood inundation for the Pascagoula River in 2011. Yellow lines indicate the cross sections and extent of the HEC-RAS model. Water surface is colored by water surface depth (water surface elevation - terrain elevation).



Future Work:

HECRAS has several features to allow mapping of inundation extent but these are not available to the operational forecaster within AWIPS.

As noted, we have recently started experimenting with a technology developed at LMRFC and Mississippi State University to allow mapping of the extent of inundation within AWIPS using HECRAS model outputs from CHPS. Hopefully, this will be widely available soon.

End of Slides

(questions?)