U.S. Army Corps
of Engineers

Louisiana Coastal Protection and Restoration

ENCLOSURE E

Wind, Waves, and Water Workshop Report

Preliminary Technical Report to Congress

June 2006

SUMMARY REPORT

Louisiana Coastal Protection and Restoration Project (LACPR)
"Wind, Waves, and Water" Hurricane Protection Design Workshop
December 20-21, 2005
Vicksburg, MS

US Army Corps of Engineers®

CONTENTS

BACKGROUND .....Page 2

PURPOSE AND STRUCTURE 2

DISCUSSIONS.....4

DESIGN TEAMS 5

POST-WORKSHOP DESIGN IDEAS 6

WORKSHOP ATTENDEE LIST 8

WORKSHOP AGENDA 10

BACKGROUND

The December 2005 Hurricane Protection Design Workshop, also referred to as the "Wind, Waves, and Water Workshop" was the first of three technical workshops conducted during the six-month development of the Preliminary Technical Report, which will be submitted to Congress on June 30, 2006. The Preliminary Technical Report will contain approximately 25% of the assessment and design contained in the Final Technical Report that is being conducted over the two-year period from December 2005 to December 2007. The Wind, Waves, and Water Workshop was followed by a Plan Formulation Workshop on February 13 –14, 2006 in Lafayette, LA and an Engineering Technical Approaches and Innovations Workshop on March 2 – 3, 2006 in Vicksburg, MS.

PURPOSE AND STRUCTURE

The Wind, Waves, and Water Workshop was held to establish design teams and to discuss issues related to estimating the maximum hurricane for design comparison and analysis. Participants included the U.S. Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), several domestic and foreign universities, including Delft University in the Netherlands.

The first day of the workshop consisted of presentations on topics such as the existing New Orleans flood protection system, impacts of Hurricane Katrina, enhancement of the protection plan, the Dutch sea defense system, hurricane modeling, windfield measurement, wave and storm surge forecasting, estimating storm frequency, etc. The second day was an open discussion on selecting design storms, estimating frequency of occurrence, and predicting hurricane parameters, such as wind, pressure, wave, storm surge, runup and overtopping. The overall goal of the workshop was to discuss possible design approaches for an enhanced level of hurricane protection focusing on wind and surge and to communicate plans for the technical report.

DISCUSSIONS

A large part of the freeform discussion was on how to define the design hurricane. Draft legislation from Congress refers to designing for a hurricane "equivalent to Category 5." The intent of the legislation has been interpreted as the desire to protect against a storm "worse than Katrina." The definition of "equivalent to Category 5" is open to interpretation from a modeling standpoint. General consensus was to follow the Netherlands approach and start by designing for 1/10,000 year storm (vs. 1/1,000 year or 1/100 year storm), with the realization that it will probably be too expensive politically. Other issues related to the design storm include the following:

- Keep in mind that there isn't one storm that is the worst case scenario for all parts of the system.

- Consider stalled storms (i.e. rainfall effects) as well as severe storms. (Note that in some NOAA publications 'stalled' is defined as a forward speed of 5 knots or less.)
- Consider sequential storms with little recovery time in between.
- Consider rapidly developing storms with little warning.
- Look at different landfall locations.
- Consider disappearing coastline/subsidence.
- Consider changing climate (i.e. global warming effects).
- Relate the design storm to something citizens can understand, i.e. as compared to past hurricane occurrences and Categories 1 - 5.

A summary of other issues brought up during the discussion follows.

Legislation Clarification

- Determine how to define "worst possible" and "worst probable" storms.
- Define what is meant by "protection," i.e., does flood protection mean completely dry or does it allow 1% overtopping, etc.
- Recommend changes to draft language in legislation, i.e. strike "equivalent to CAT 5" and change it to "design storm causing Category 5-type storm surge of between - to - feet"

Communication Issues

- Engage State and levee districts in the process.
- Develop central location for data/information; public web site is available.
- Public outreach needed to seek outside thoughts/ideas.
- Anything built in the long-term will require the EIS process.

Economic Considerations

- Will science or cost determine the design? Rank alternatives in terms of economic efficiency and respond in a quantitative, defensible manner.
- Politicians in Washington, D.C. will want to see more than just economics considered.
- If the new levees cost $100 billion and they protect 1 million people that equals $100,000/person which may be considered excessive in political sense.

Configuration/Construction of Levees

- Define alignment of levee systems.
- Develop redundancies in the levee system—a large portion of the city could have been protected from flooding after Katrina with an interior flood wall as low as 5 ft.
- Consider partition levees so that if a levee fails, it will only affect a small area.
- Allow for some exceedances (overtopping) so you don't have catastrophic failure.
- Consider using ring levees.
- Phase in construction since it takes time to build structures.
- Provide a higher level of protection in some areas.

- Use Lake Pontchartrain as a buffer—moveable gates in the canals might be helpful to close off the canals to stop inundation from Lake Pontchartrain.
- Consider altering MRGO.
- Keep in mind that diversions will cause flooding in alternate areas.
- Use spillways in the river levees to relieve some of the pressure.

Modeling Issues

- Start by running a parametric representation of Camille, Betsy, and Katrina.
- Take a hard look at wave runup, which is underrepresented in present approaches.
- Develop a plan to get better data in the future for validating the models.
- Consider tweaking models, but may need to run them the way they are because of time constraints.
- Use meteorological physical bounds on the most extreme event (170 knots) in decision making; reduce number of model runs by starting with the max.
- Use the map of the 2050 coastline for modeling.
- Run many storm combinations through SLOSH right away and look at the water levels to get an idea of which storms would be of most interest.
- Expect characteristic error in models, both in terms of bias and random error. Evaluate the error characteristics of the model when driven in a parametric sense.
- MORPHOS is looking at wave effects on currents and comparing DELFT3D to ADCIRC. It was suggested that what is learned in MORPHOS could help; however, MORPHOS is a long-term project and may not be ready in time for this project.
- Address the process as a dynamic system—the science today is not the same as it will be in 10 years, nor will this problem be completely solved in 10 years.

Non-Structural Alternatives

- Consider evacuation plans.
- Create a plan for protecting structures and reconstruction of selected areas based on new science and technology and criteria evolving from man-made and environmental changes. Expect that some areas will still get flooded, so flood-proof houses and raise house elevations.

Risk Analysis

- Are we going to include in the risk analysis, the possibility of increasing the structure elevation?
- To keep equal risk everywhere, you need a much greater factor of safety.
- What you are designing influences the risk—considering this would help decrease cost/decrease loss of life/flooding.
- Consider ecosystem restoration in the risk assessment.
- The definition/plan should define protection as the amount of flooding that it will protect against, amount of overtopping allowed etc. Better to refer to it as flood damage control “reduction” since you can’t provide 100% guarantee. Should recognize concerns/evacuation education, building codes/ etc.
-

DESIGN TEAMS

At the end of the workshop, the following three preliminary teams were formed:
1. Design of Levee Protection Schemes
2. Statistics/Risk/Defining Max. Hurricane
3. Modeling.

Members were assigned to each team for design as well as for independent technical review.

POST-WORKSHOP DESIGN IDEAS

The following design concepts were submitted after the workshop by attendees Paul Kemp and Joseph Suhayda:

(1) Shorten levee runs to the greatest extent practicable. If this means enclosing wetlands, then integrate them into the protection system by prohibiting development and using them to accommodate waters that overtop, thereby allowing a somewhat lower but more robust levee.

(2) Use floodgates at key tidal passes to limit heights to which interior levees must be built and to allow for controlled set-down.

(3) Develop a ring-levee strategy for smaller towns that encourages safe but concentrated development and is attractive to residents and businesses, with a local tax structure that reflects the local flood protection priorities.

(4) Wetland and barrier islands, coastal forests, swamps whether existing now or to be created should be integral to overall design (i.e. marsh aprons, interior barrier islands, etc.). Learn what wetlands and natural systems can do to protect against waves and storm surge, then incorporate these lessons into the coastal restoration program. We should not be arguing in a year about whether wetlands, coastal forests and barrier islands work at this point, because we know that they have some influence (+ and -) under some conditions. We have enough information after hurricanes Katrina and Rita and after the south Asian tsunami to nail some things down and that should be an important intermediate goal. Don't be afraid to modify and expand upon the near-term LAR plan as it is clearly unresponsive to the new priorities. Developing river spillways to dump surge waters propagating upstream can also be used as downstream restoration diversion structures, for example. We will get more support from the nation if we can show that our reconstruction program is ecologically sound and innovative.

(5) Avoid creating leveed peninsulas, particularly if they create the potential in combination for amplifying storm surge. The initial plan proposed by the District appears to suffer from this problem because it is a combination of elements that were proposed separately in the past without consideration of the regional effects. Parallel or sub-parallel peninsulas follow the historic deltaic development patterns but are a problematic template for Cat 5 storm protection.

(6) Model regional effects carefully and modify design to reduce amplification of surge in adjacent unleveed areas like Mississippi.

(7) Commit now to a detailed model-based risk assessment of the type discussed by Peter Vickery. It will take some time to carry out and will need much interpretation by experts and policy-makers at the end, so don't crowd him any more than you have to. Give him all the resources and help he needs. At the same time, the design effort should follow several parallel courses so that we have some options at the end to create an integrated design that is clearly responsive to the risk assessment.

(8) Visual MEOWs shown by Westerink pertaining to Cat 4 and 5 should define the threat and can be used to communicate the geographic variation in the threat.

(9) Investigate possible advantages of treating wave and surge components with separate design structures. For example, use of wave break or attenuators or sacrificial structures in front of levees.

(10) Investigate designs that allow for some overtopping of floodwalls and levees without running risk of breach. Manage overtopping water with elements like retention basins, interior barriers and a collection, drainage and pumping system.

(11) Building enhanced flood protection must be coordinated with locals throughout design process rather than just getting comments via NEPA process.

(12) Recognize that dangerous storms can form quickly and compromise any evacuation plans. Therefore, saving lives in such a worst-case situation must be a priority. Flood protection system design must be coordinated with other policy elements such as building codes, FEMA flood insurance elevation requirements and evacuation. It is not true that the flood protection system only protects property and not people. The notion that evacuation is sufficient to take care of people is incorrect and does not take into consideration emergency personnel and the reality that not everyone can leave.

WORKSHOP ATTENDEE LIST

Attendee	Organization	Attendee	Organization
Anderson, Carl	USACE-MVN	Kemp, Paul	LSU
Axtman, Tim	USACE-MVN	Kenny, Maureen	NOAA-CSDL
Banks, Larry	MVD	Kiser, Scott	NOAA
Bass, Robert	USACE- MVN	Kobayashi, Nobuhisa	Center for Applied Coastal Research University of Delaware
Beven, John	NOAA -National Hurricane Center	Koziara, Mike	NOAA
Bivona, John	USACE - MVN	Lavelle, Frank	Applied Research Associates
Boc, Stan	USACE, ERDC	Luettich, Rick	University of North Carolina - Chapel Hill
Bolourchi, Zahir "Bo"	Louisiana Department of Transportation & Development	Mark, David	USACE, ERDC
Brooks, Eddie	MVD	McAdory, Robert	USACE, ERDC
Brown, Patricia	NOAA	Melby, Jeff	ERDC
Cialone, Mary	USACE, ERDC	Mislan, Angel	USACE- MVN
Constance, Troy	USACE-MVN	Morehiser, Mervin	USACE-MVN
Davis, Jack	USACE-ERDC	Mosher, Reed	ERDC
Dean, Robert	University Of Florida	Naomi, Alfred	USACE
Dokka, Roy	LSU	Pfeifer, Thomas E	U.S. Army Engineer District--New York
Ebersole, Bruce	ERDC	Pope, Joan	USACE
Eslinger, David	NOS/NOAA	Powell, Mark	NOAA -Hurricane Research Division
Foster, Jerry	USACE- HQ	Powell, Nancy	USACE- MVN
Green, Stan	USACE-MVN	Ratcliff, Jay	USACE
Grieshaber, John	USACE	Resio, Donald	ERDC
Hote, Janis	USACE	Revitte, Frank	NOAA
Hovis, Gerald	NOAA	Rinard, Steve	NOAA
Hughes, Steve	USACE	Riordan, Denis	LSU
Irish, Jennifer	U.S. Army Engineer District--New York	Roelvink, Dano	UNESCO-IHE Institute of Water Education
Jaeger, John	USACE Huntington District	Ruppert, Tim	USACE- MVN
Jensen, Robert	USACE, ERDC	Russo, Edmond	USACE-ERDC
Jolissaint, Donald	USACE- MVN	Saia, John	HDR Inc.
Shadie, Charles	MVD	Trotter, Paul	NOAA
Shaffer, Wilson	NWS HQTR	Twilley, Robert	LSU

Attendee	Organization	Attendee	Organization
Shinkle, Kurt	NOAA/NGS	Veneziano, Daniele	Massachusetts Institute of Technology
Smith, Jane	USACE, ERDC	Vickery, Peter	Applied Research Associates- IntraRisk Division
Stelling, G.S.	Delft University	Weber, Larry	IIHR Hydroscience and Engineering
Stutts, D Van	USACE	Westerink, Joannes	University of Notre Dame
Suhayda, Joseph		Winer, Harley	MVD
Thibodeaux, Burnell	USACE		

WORKSHOP AGENDA

Hurricane Protection Design Workshop
Engineer Research & Development Center
Vicksburg, MS
20-21 December 2005

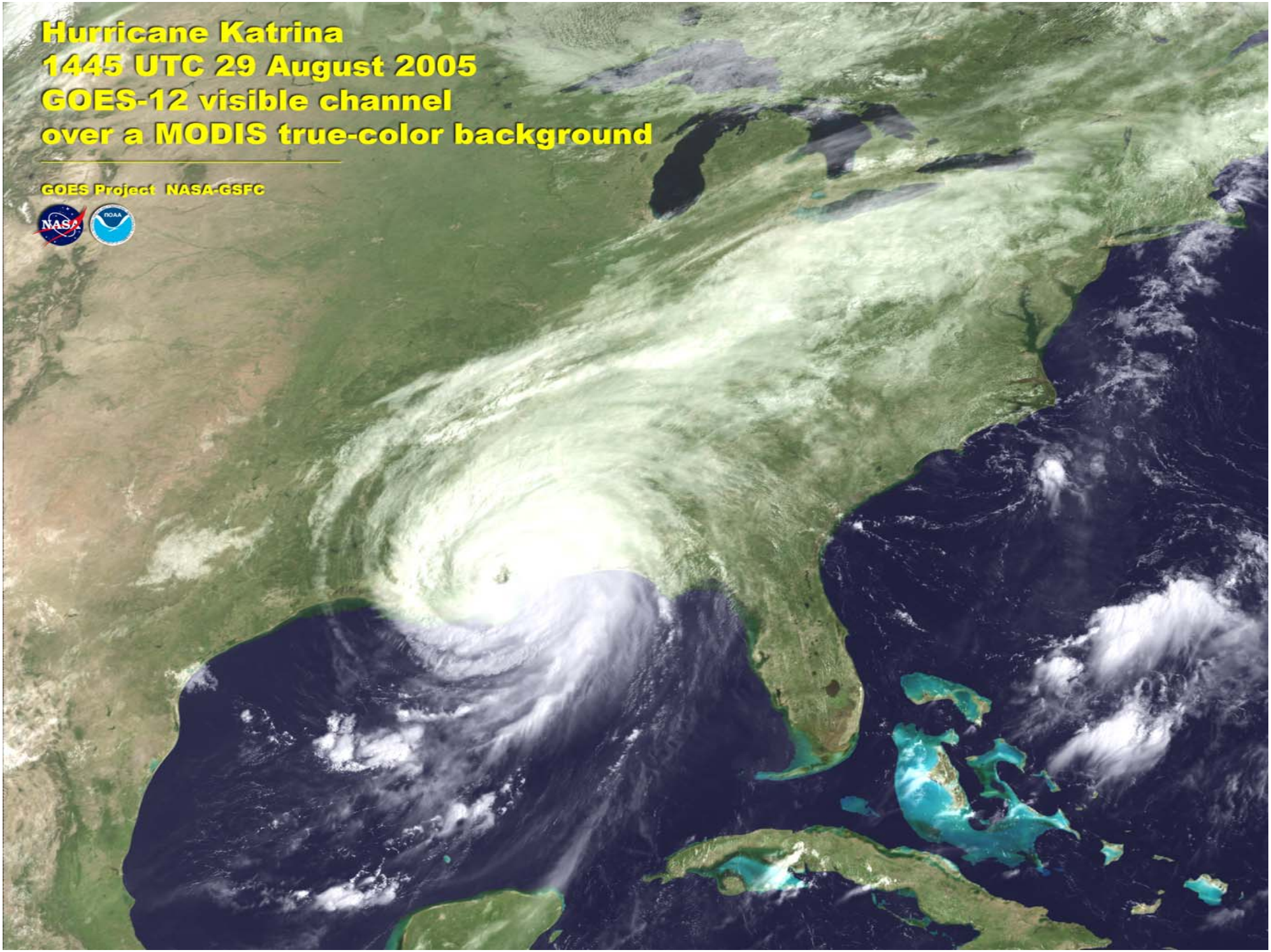
Tuesday, December 20, 2005		
Time	**Subject**	**Presenter**
07:30 – 08:00	***Sign In and Administration***	
08:00 – 08:10	Welcome	Thomas Richardson – USACE-ERDC
08:10 – 08:20	Introductions	Bruce Ebersole – USACE-ERDC
08:20 – 08:30	Agenda & Meeting Objectives	Van Stutts – USACE-MVN
08:30 – 09:00	New Orleans Flood Protection System & Design	Carl Anderson – USACE-MVN Janis Hote – USACE-MVN
09:00 – 09:30	Impact of Katrina	Nancy Powell – USACE-MVN
09:30 – 09:45	***BREAK***	
09:45 – 10:15	Enhanced Protection Plan	Tim Axtman – USACE-MVN Carl Anderson – USACE-MVN
10:15 – 11:00	Dutch Sea Defense & The Role of Models	G.S. Stelling – DELFT
11:00 – 11:45	Climatology of Hurricane Landfalls & Analysis Forecasting Hurricane Structure	John Beven – NOAA
11:45 – 12:35	***LUNCH***	
12:35 – 13:05	Experienced Hurricane Windfields	Mark Powell – NOAA
13:05 – 13:35	Wave Prediction in SE Louisiana	Jane Smith – USACE-ERDC
13:35 – 14:05	Storm Surge Prediction in SE Louisiana	Joannes Westerink – University of Notre Dame
14:05 – 14:35	Storm Surge Prediction (SLOSH)	Wilson Shafffer – National Weather Service
14:35 – 14:50	***BREAK***	
14:50 – 15:20	Nearshore Waves and Wave Effects on Storm Impact	J.A. (Dano) Roelvink UNESCO-IHE
15:20 – 15:50	Estimating Storm Frequency	Don Resio – USACE-ERDC Peter Vickery – Applied Research Associates
15:50 – 17:00	Comments on Proposed Plans / Other Ideas	Bruce Ebersole – USACE-ERDC
17:00	***ADJOURN***	

Hurricane Protection Design Workshop
Engineer Research & Development Center
Vicksburg, MS
20-21 December 2005

Wednesday, December 21, 2005

Time	Subject	Presenter
07:30 – 08:00	***Sign In and Administration***	
08:00 – 08:15	Review Workshop Objectives	Van Stutts – USACE-MVN
08:15 – 08:45	Selecting Storms / Estimating Frequency of Occurrence	Bruce Ebersole – USACE-ERDC
08:45 – 9:15		
09:15 – 09:45		
09:45 – 10:15	Wind and Pressure Prediction	
10:15 – 10:30	***BREAK***	
10:30 – 11:00	Wave Prediction	Bruce Ebersole – USACE-ERDC
11:00 – 11:30	Storm Surge Prediction	
11:30 – 12:00	Runup and Overtopping Prediction	
12:00 – 12:30	Summarize Approach for Waves and Water Levels	
12:30	**ADJOURN**	

US Army Corps of Engineers®


Hurricane Katrina
1445 UTC 29 August 2005
GOES-12 visible channel
over a MODIS true-color background
GOES Project NASA-GSFC

Public Law 109-103

Energy and Water Development Appropriations Act, 2006

DEPARTMENT OF THE ARMY

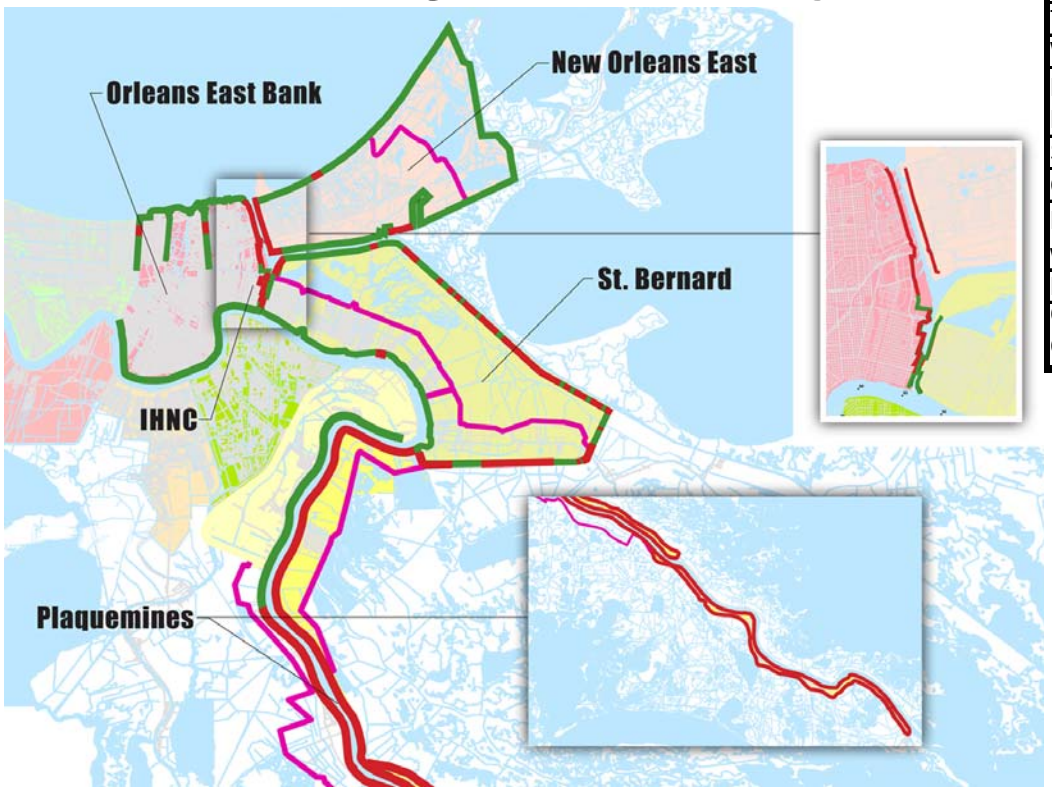
Corps of Engineers--Civil

The following appropriations shall be expended under the direction of the Secretary of the Army and the supervision of the Chief of Engineers for authorized civil functions of the Department of the Army pertaining to rivers and harbors, flood control, shore protection and storm damage reduction, aquatic ecosystem restoration, and related purposes.

INVESTIGATIONS

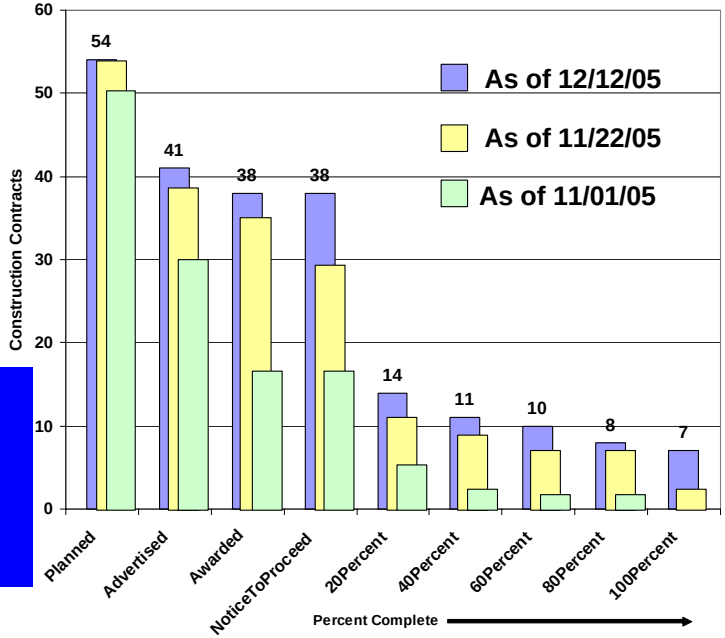
....That using $8,000,000 of the funds provided herein, the Secretary of the Army, acting through the Chief of Engineers, is directed to conduct a comprehensive hurricane protection study at full Federal expense to develop and present a full range of flood, coastal and hurricane protection measures exclusive of normal policy considerations for south Louisiana and the Secretary shall submit a feasibility report for short-term protection within 6 months of enactment of this Act, interim protection within 12 months of enactment of this Act and long-term comprehensive protection within 24 months of enactment of this Act: *Provided further*, That the Secretary shall consider providing protection for a storm surge equivalent to a Category 5 hurricane within the project area and may submit reports on component areas of the larger protection program for authorization as soon as practicable: *Provided further*, That the analysis shall be conducted in close coordination with the State of Louisiana and its appropriate agencies.

Hurricane Protection System Restoration – Program Summary



Construction Progress

Feature of Work	Quantity	Scheduled Total	Total To Date	Percent Complete
Temporary Prot.	Lineal Feet	17,300	13,600	78.6%
Wall Demolition	Lineal Feet	8,805	4,665	53.0%
Major Levee Repair	Cubic Yards	4,030,348	293,700	7.3%
Sheetpile	Lineal Feet	18,250	870	4.8%
Concrete Wall	Lineal Feet	15,005	0	0.0%
Misc.Levee/Flood-wall Scour Repair	Miles	181.0	67	37.0%
Rip Rap	Tons	162,800	12,000	7.4%
Control/Flood Gate Structures	Each	13	0	0.0%



Reconstruction Schedule
- Restore to pre-Katrina conditions
  - •Federal system by 1 Jun 06
- Assess non-Federal systems: by 15 Dec 05

Estimated Program Costs - $1.3B

Hurricane Protection System
- 284 miles: Federal levees/floodwalls
- 71 pump stations

Damage
- 169 miles: Federal levees/floodwalls
- 34 pump stations

12/13/05

.....long-term comprehensive protection within 24 months of enactment of this Act: *Provided further*, That the Secretary shall consider providing protection for a storm surge equivalent to a Category 5 hurricane within the project area and may submit reports on component areas of the larger protection program for authorization as soon as practicable.....

Saffir-Simpson Scale

Category 1	74 – 95	mph winds
Category 2	96 – 110	mph winds
Category 3	111 – 130	mph winds
Category 4	131 – 155	mph winds
Category 5	155+	mph winds

The obvious question that we need to address here is what do we mean by Category 5 protection?

It seems clear that the intent of the language contained in P.L. 109-103 is that we are to insure that the degree of Protection afforded by a "comprehensive protection plan" must be capable of protecting against at least a minimum Category 5 event.

Lessons learned from Hurricane Katrina tell us that there will be larger events that will occur and we must insure that Protective works will not fail when these events occur.

24 Months to Develop Comprehensive Plan!

That Means!

We have at most 6 Months

- Define the Design Storm or Storms
- Run Critical Tracks
- Establish Design Water Levels
- Design Waves

How do we establish the design storm or storms?

It is perhaps assumed in the language of P.L. 109-103 that Cat 5 storms produce greater surges than Cat 4 storms and to say that you have Cat 5 protection implies that you are protected against all meteorological events having a Saffir Simpson rating less than 5.

We will have to insure that the design Storm does in fact produce such a surge.

Hurricane Workshop
ERDC Vicksburg, MS
Agenda for 20-21 Dec 2005

Day 1

0800 Welcome - ERDC
0810 Introductions – All
0820 Agenda and Meeting Objectives – MVN Stutts
0830 New Orleans Flood Protection System and it's design – MVN Anderson and Hote
0900 Impact of Katrina - MVN N. Powell
0930 Break
0945 Enhanced Protection Plan – MVN Anderson and Axtman
1015 Dutch Sea Defense and the Role of Models – DELFT Stelling
1100 Climatology of Hurricane Landfalls and Analysis & Forecasting Hurricane Structure - NOAA Beven
1145 Lunch
1235 Experienced Hurricane Windfields - NOAA M. Powell
1305 Wave Prediction in SE Louisiana - ERDC Smith
1335 Storm Surge Prediction in SE Louisiana – UND Westerink
1405 Storm Surge Prediction (SLOSH) – NWS Shaffer
1435 Break
1450 Nearshore Waves and Wave Effects on Storm Impact – UNESCO-IHE Roelvink
1520 Estimating Storm Frequency - ERDC Resio and Vickery
1550 Comments on proposed plan concepts and ideas for providing protection plans to be examined Part 1
1700 End day 1

Hurricane Workshop

ERDC Vicksburg, MS

Agenda for 20-21 Dec 2005

Day 2

0800 Review Workshop Objectives - MVN Stutts

Rest of Workshop Facilitated by Ebersole

0815 Level of Protection and Proposed Plan
0845 Recommendations for design approach
0915 Hurricane Intensity and Frequency Estimating
0945 Wind and Pressure Prediction

1015 Break

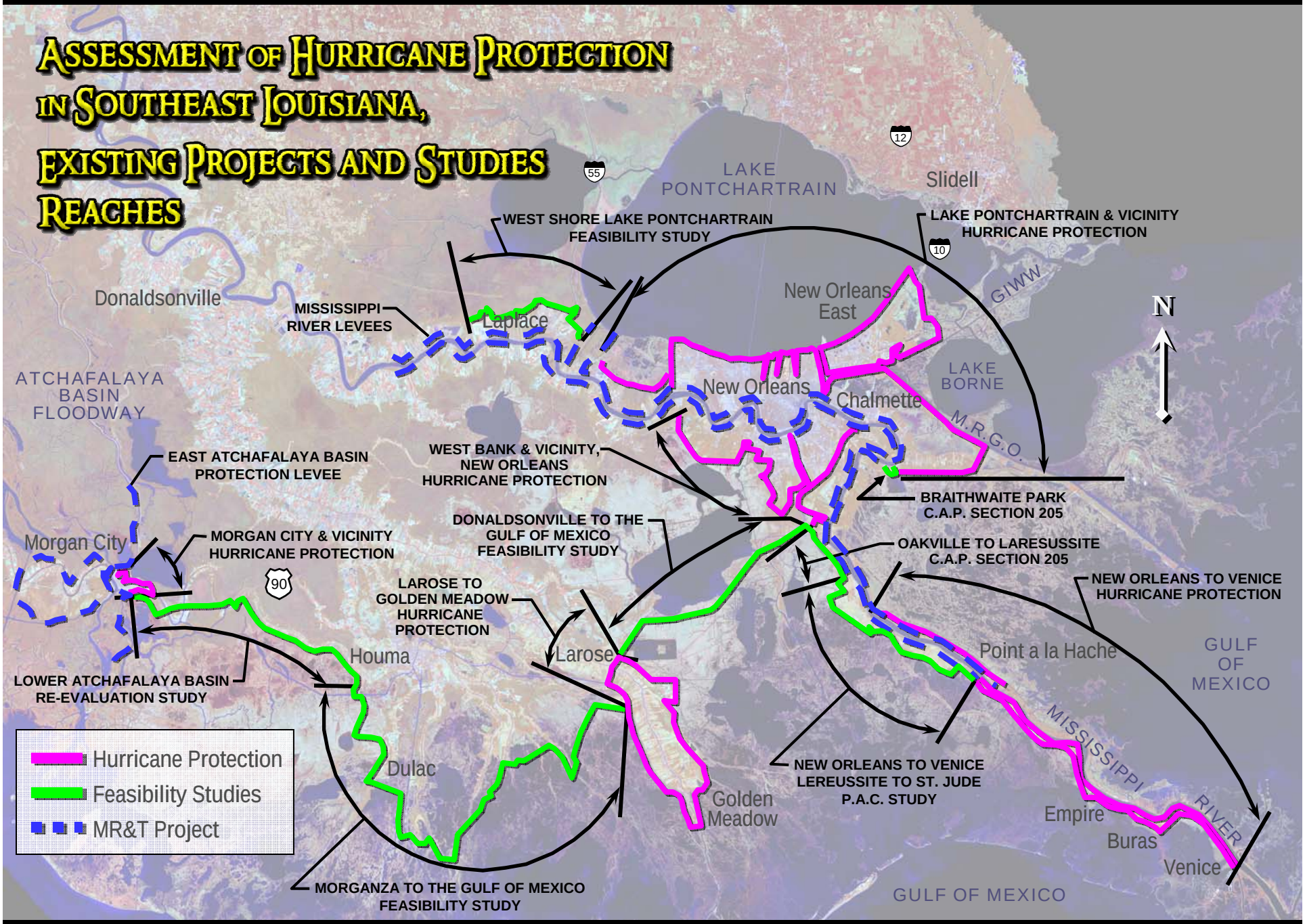
TITLE: New Orleans Flood Protection System & Design

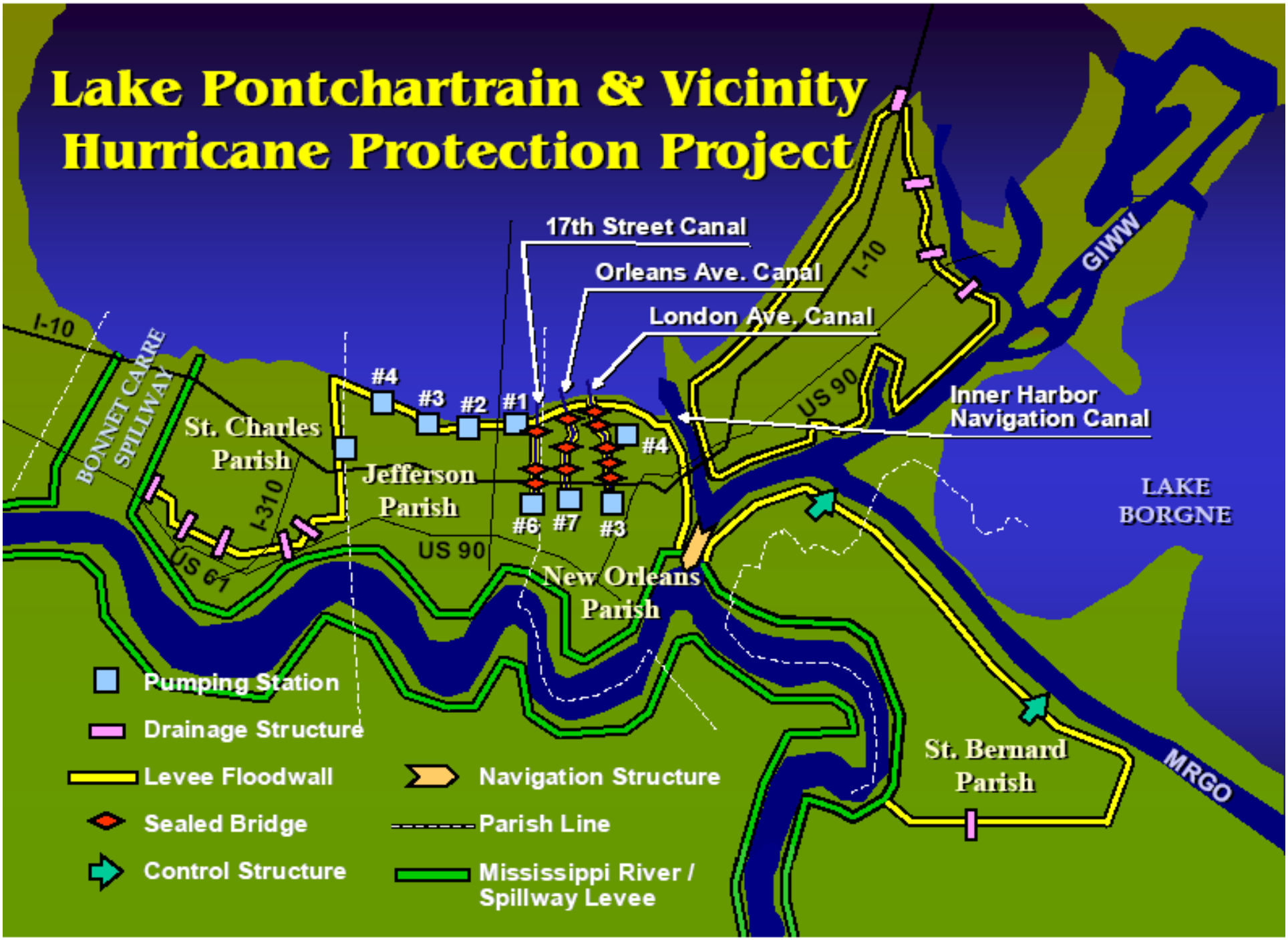
PRESENTED BY: Carl Anderson, USACE-MVN

SUMMARY: The presentation provided a brief assessment of existing hurricane protection for South Louisiana. In southeast Louisiana, there are five authorized projects that provide different levels of hurricane protection. Four of these projects are either completed or are under construction. There are also seven ongoing flood or hurricane protection studies. Two flood control projects provide protection from flooding along the Mississippi River and its tributaries. There are no hurricane protection studies or projects for the southwest coast of Louisiana.

Assessment of Hurricane Protection in Southeast Louisiana, Existing Projects and Studies Reaches

Assessment of Hurricane Protection in Southeast Louisiana, Existing Projects and Studies Reaches

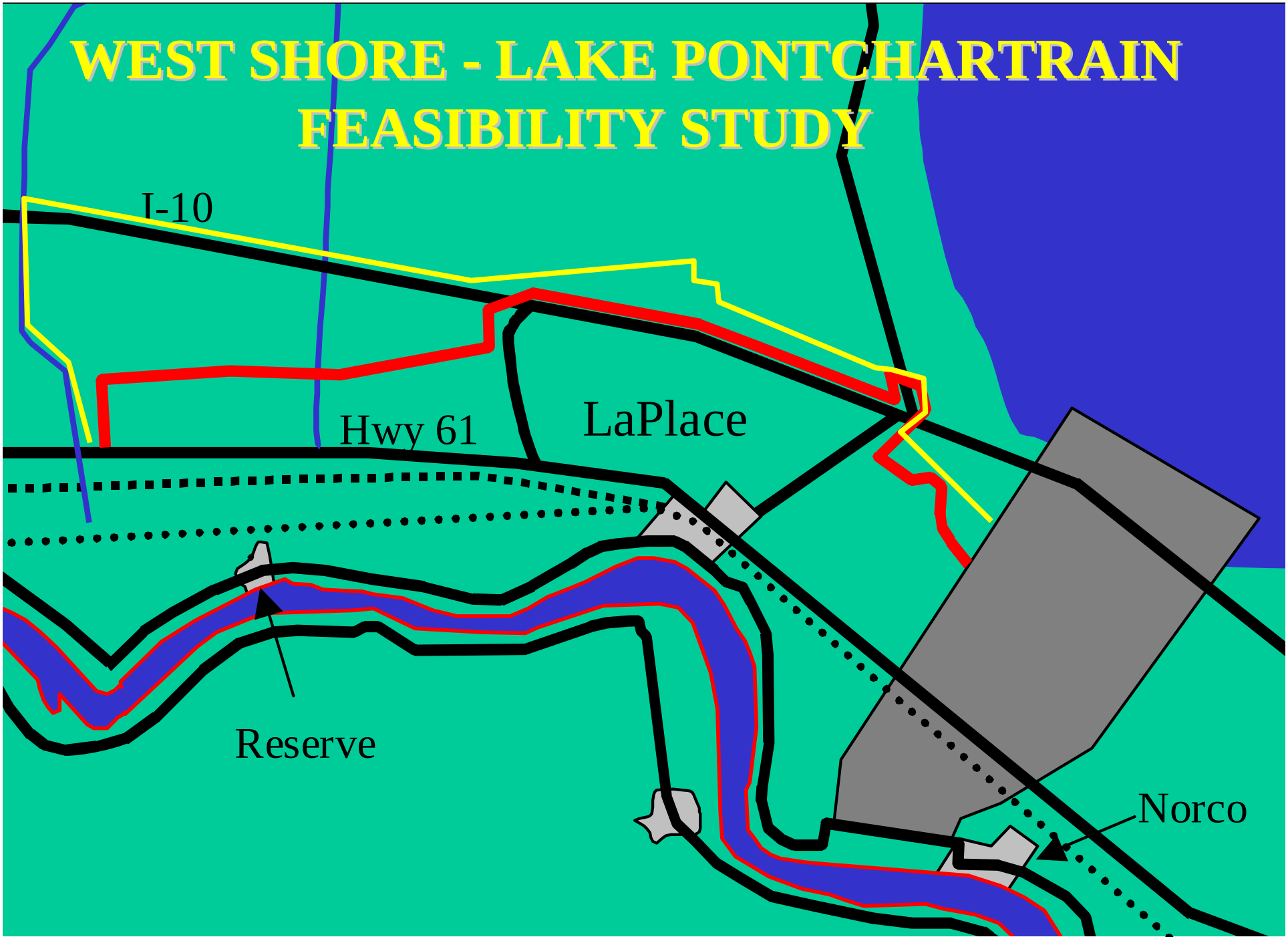



Lake Pontchartrain & Vicinity
Hurricane Protection Project
17th Street Canal
Orleans Ave. Canal
London Ave. Canal
Inner Harbor
Navigation Canal
GIWW
I-10
I-10
US 90
US 90
BONNET CARRE
SPILLWAY
St. Charles
Parish
Jefferson
Parish
New Orleans
Parish
St. Bernard
Parish
LAKE
BORGNE
MRGO
I-310
US 61
#1
#2
#3
#4
#4
#3
#6
#7
Pumping Station
Drainage Structure
Levee Floodwall
Sealed Bridge
Control Structure
Navigation Structure
Parish Line
Mississippi River /
Spillway Levee

Lake Pontchartrain,LA and Vicinity Hurricane Protection Project

- The project was originally authorized in 1965.
- The project is located in St. Bernard, Orleans, Jefferson and St. Charles Parishes on the East Bank of the Mississippi River.
- The project was designed to protect against the Standard Project Hurricane (SPH)
- The project consists of over 120 miles of levees, floodwalls and floodgates.

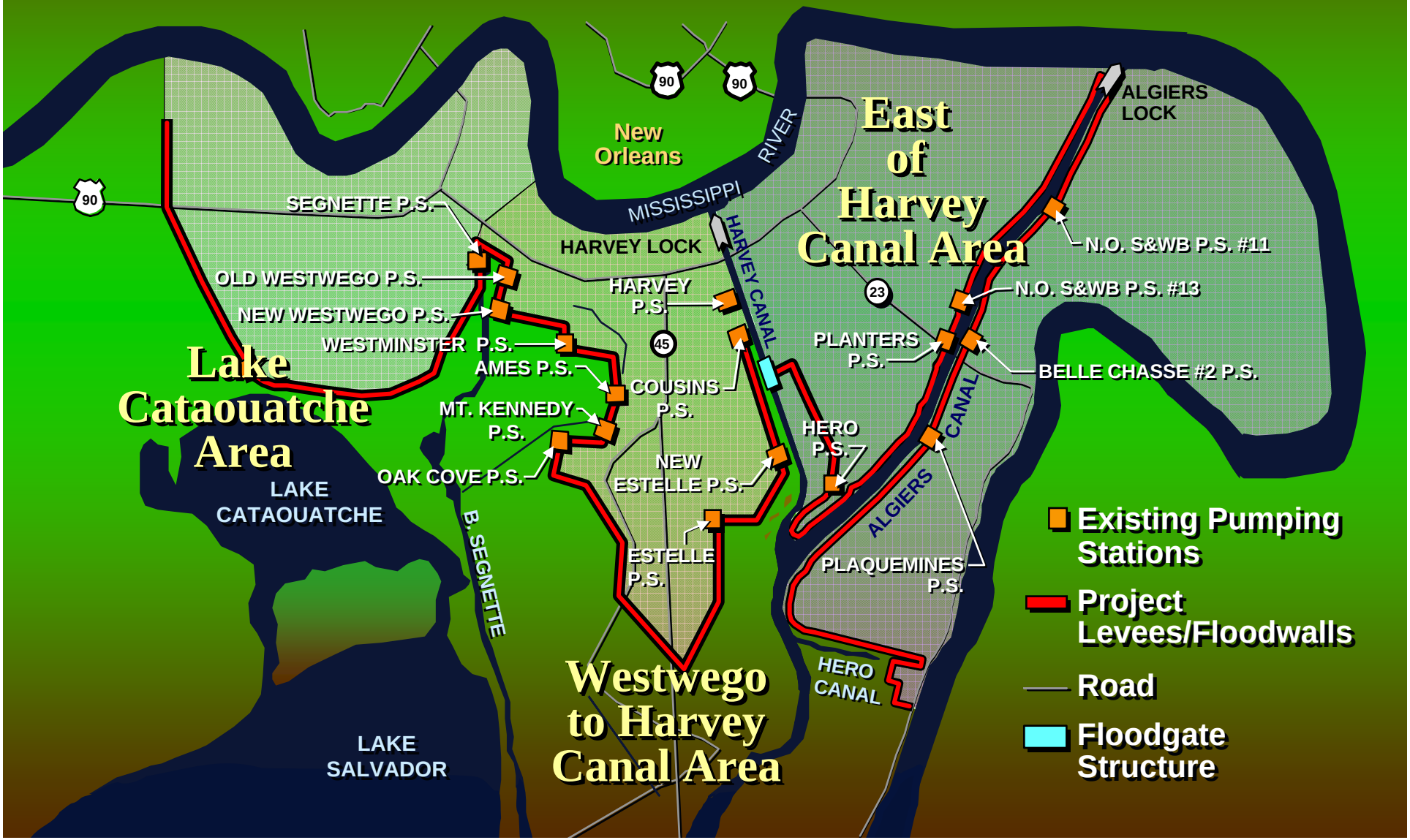
WEST SHORE - LAKE PONTCHARTRAIN FEASIBILITY STUDY



WEST SHORE - LAKE PONTCHARTRAIN FEASIBILITY STUDY

- The study was authorized in 1974 but a cost share agreement was not signed until 1998.
- The study area is located in St. Charles, St. John the Baptist and St. James Parishes on the East Bank of the Mississippi River.
- The study's purpose is to investigate increased levels of hurricane protection.
- The proposed plan is approx. 18 miles of levees and floodwalls and 4 pump stations.

West Bank & Vicinity, New Orleans, LA, Hurricane Protection Project



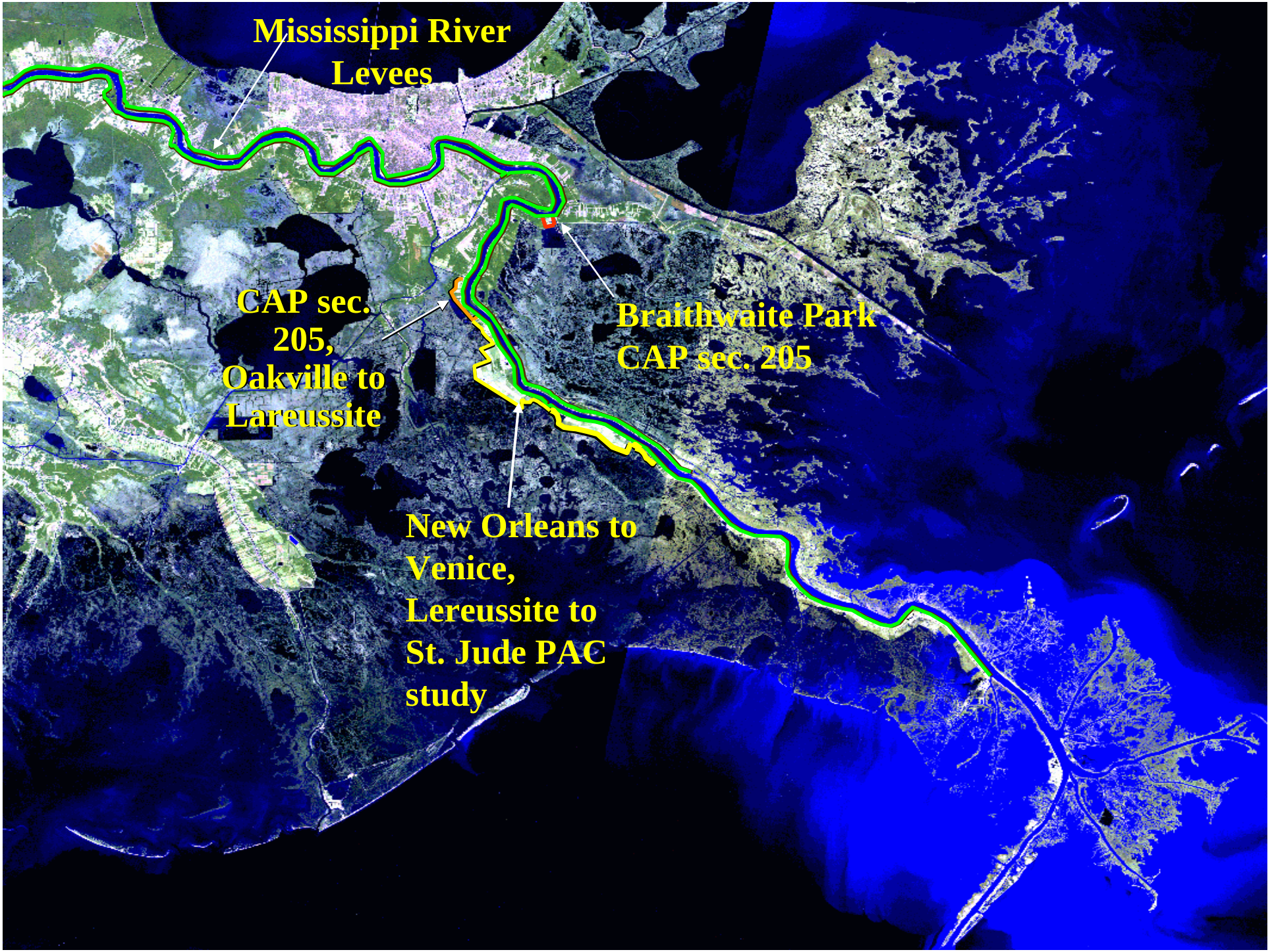
West Bank & Vicinity, New Orleans, LA, Hurricane Protection Project

- The project was originally authorized in 1986.
- The project is located in Jefferson, Orleans and Plaquemines Parishes on the West Bank of the Mississippi River.
- The project was designed to protect against the Standard Project Hurricane (SPH).
- The project consists of approx. 66 miles of levees, floodwalls and floodgates.

New Orleans to Venice Hurricane Protection Project

New Orleans to Venice Hurricane Protection Project

- The project was authorized in 1962.
- The project is located in Plaquemines Parish on both the East and West Banks of the Mississippi River.
- The project was designed to protect against the 100-yr frequency storm.
- The project consists of 87 miles of levees, floodwalls and floodgates.


Mississippi River Levees
CAP sec. 205, Oakville to Lareussite
Braithwaite Park CAP sec. 205
New Orleans to Venice, Lereussite to St. Jude PAC study

Mississippi River Levees

- The project was originally authorized in 1928.
- The project extends along the river on the West Bank from Black Hawk, La. to Venice and the East Bank from Baton rouge La. to Bohemia, La.
- The project was designed to protect against a Project Flood.
- The project consists of over 450 miles of levees, floodwalls and floodgates and 3 major flood diversion structures.

CAP Section 205, Oakville to Lareussite

- The study was authorized in 2000.
- The study is located in Plaquemines Parish on the West bank of the Mississippi River.
- The study purpose is to investigate increased levels of hurricane protection.
- The proposed plan consists of approx. 8 miles of levees and floodwalls.

Braithwaite Park CAP Section 205

- The Feasibility Study was submitted in 2004.
- The study area is located in Plaquemines Parish on the East bank of the Mississippi River.
- The project is designed to protect against a 50-yr frequency design storm.
- The proposed plan consists of 13,570 feet of levees and Floodwalls and floodgates.

New Orleans to Venice, Lereussite to St. Jude PAC study

- The Post Authorization Change Study was authorized in 2004.
- The study is located in Plaquemines Parish on the West bank of the Mississippi River.
- The study purpose is to investigate increased levels of hurricane protection to 100-yr frequency storm.
- The proposed plan consists of approx. 26 miles of levees and floodwalls.

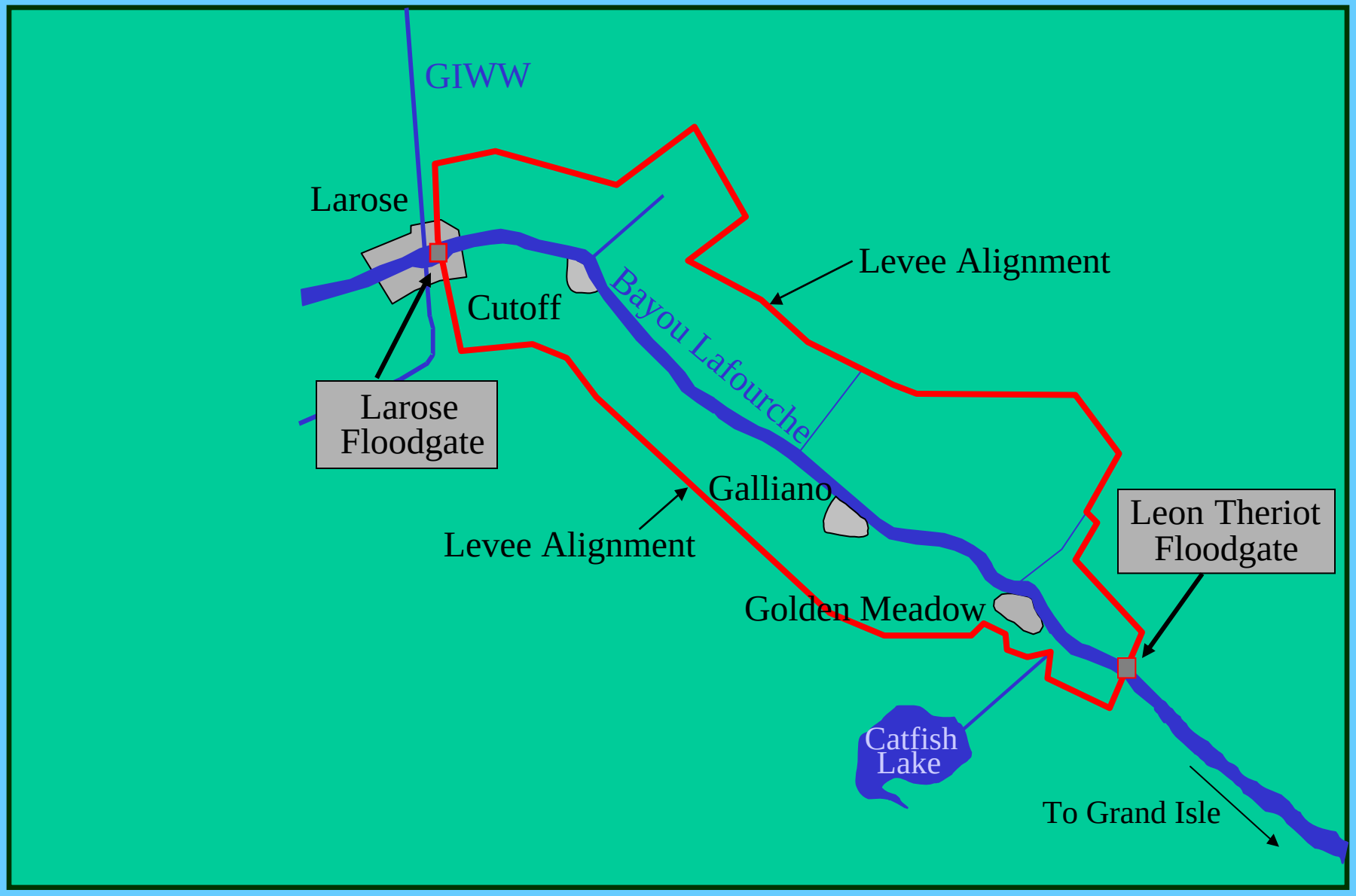
Donaldsonville, LA to the Gulf of Mexico

Possible Hurricane Levee Alignments

Donaldsonville, La. to the Gulf of Mexico

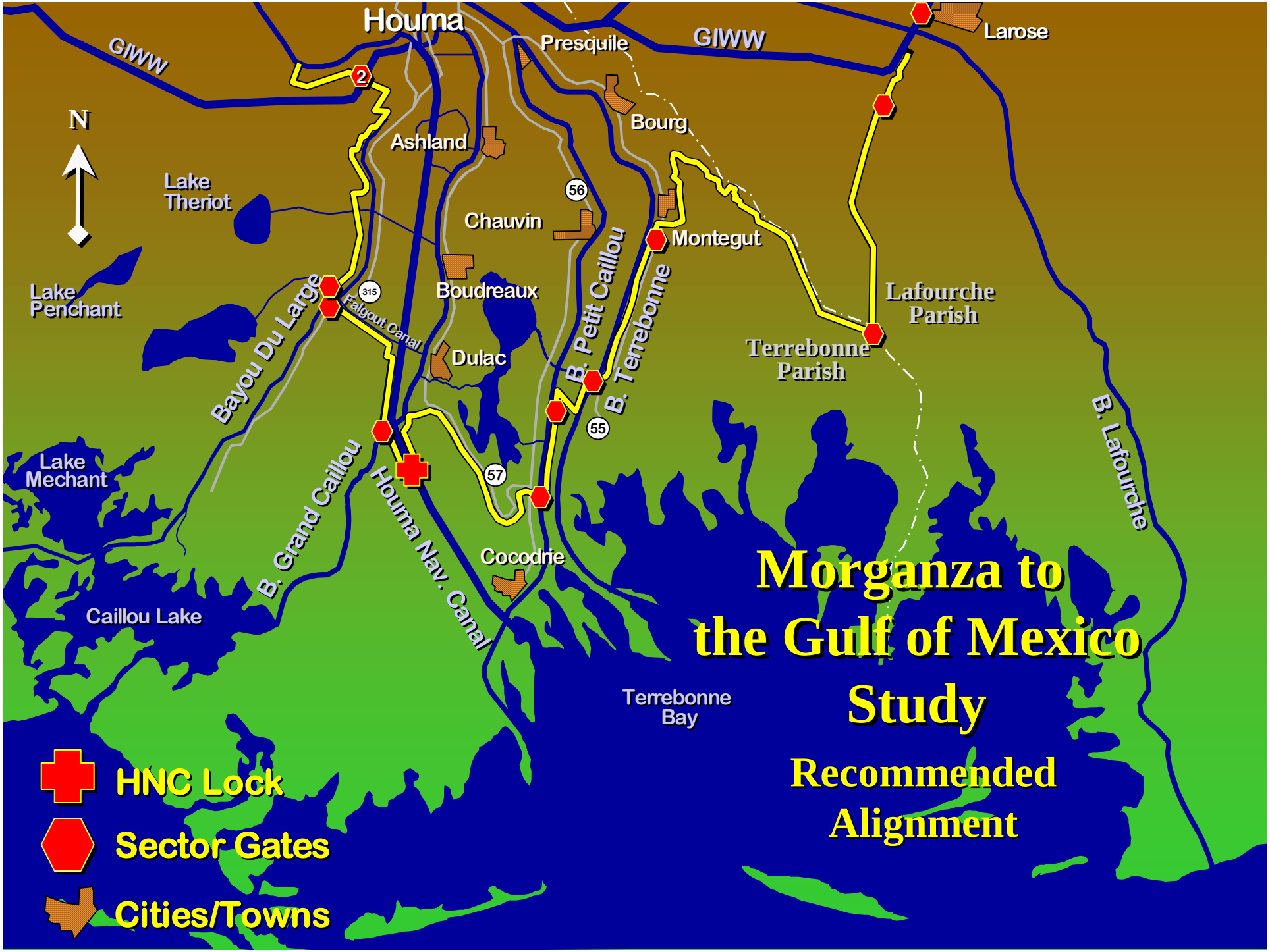
- The study was authorized in 1998.
- The study area is located in Ascension, Assumption, St. James, St. James, St. John the Baptist, Lafourche, St. Chares and Jefferson Parishes west of the Mississippi River.
- The study purpose is to investigate increased levels of hurricane protection.
- Currently 4 alignments are being considered ranging from 130 miles to 27 miles long.

LAROSE TO GOLDEN MEADOW, HURRICANE PROTECTION PROJECT



LAROSE TO GOLDEN MEADOW, HURRICANE PROTECTION PROJECT

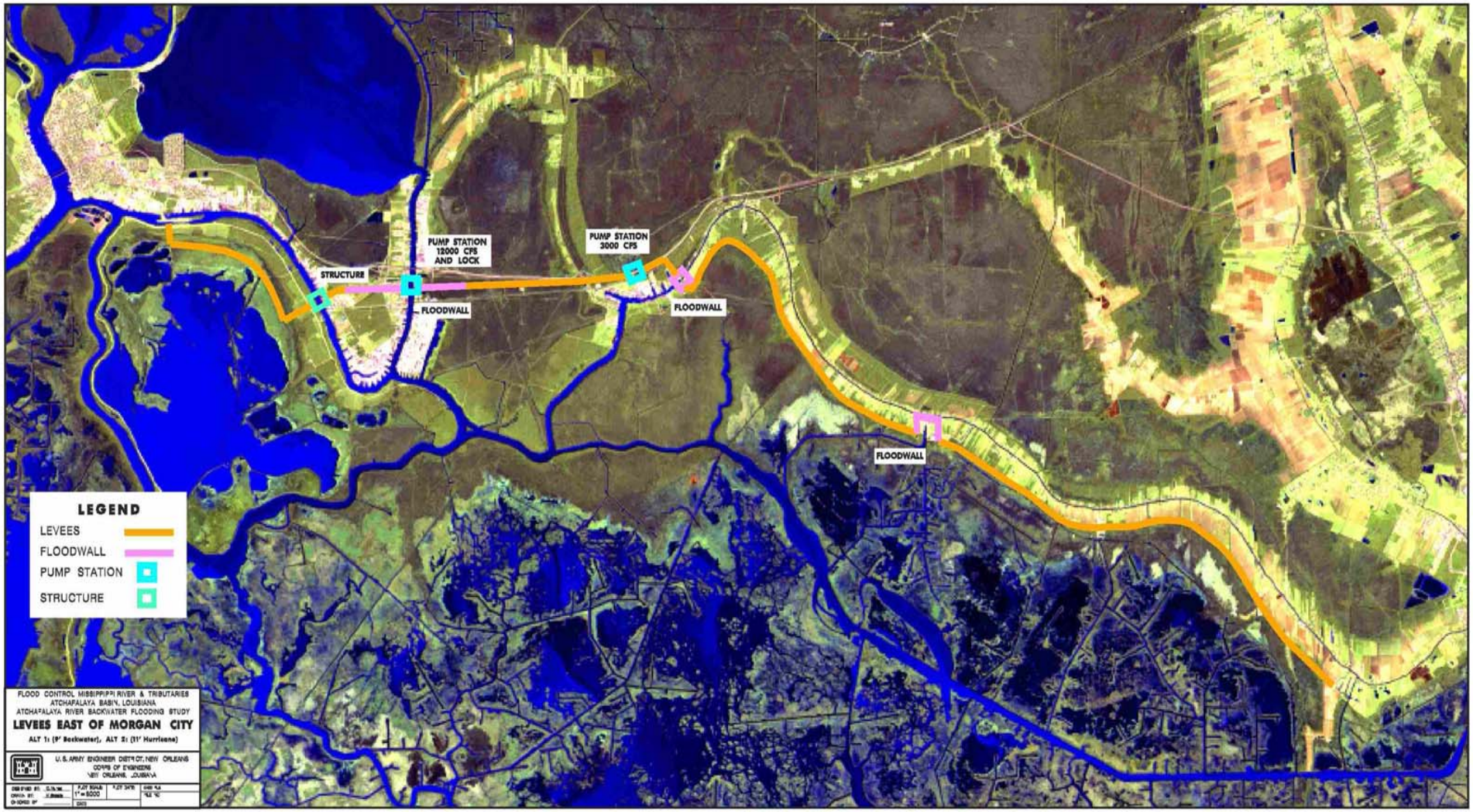
- The project was authorized in 1965.
- The project is located in Lafourche Parish along Bayou Lafourche.
- The project was designed to protect against the 100-yr frequency storm.
- The project consists of approx. 40 miles of levees and floodwalls with a navigable floodgate at each end of the Bayou.


Houma
GIWW
GIWW
Presquile
Larose
N
Ashland
Bourg
Lake Theriot
Chauvin
Montegut
Lake Penchant
Boudreaux
Lafourche Parish
Falgout Canal
Bayou Du Large
Dulac
B. Petit Caillou
B. Terrebonne
Terrebonne Parish
B. Lafourche
Lake Mechant
B. Grand Caillou
Houma Nav. Canal
Cocodrie
Caillou Lake
Terrebonne Bay
2
56
315
55
57
Morganza to the Gulf of Mexico Study
Recommended Alignment
HNC Lock
Sector Gates
Cities/Towns

Morganza, La. To the Gulf of Mexico, Hurricane Protection Project

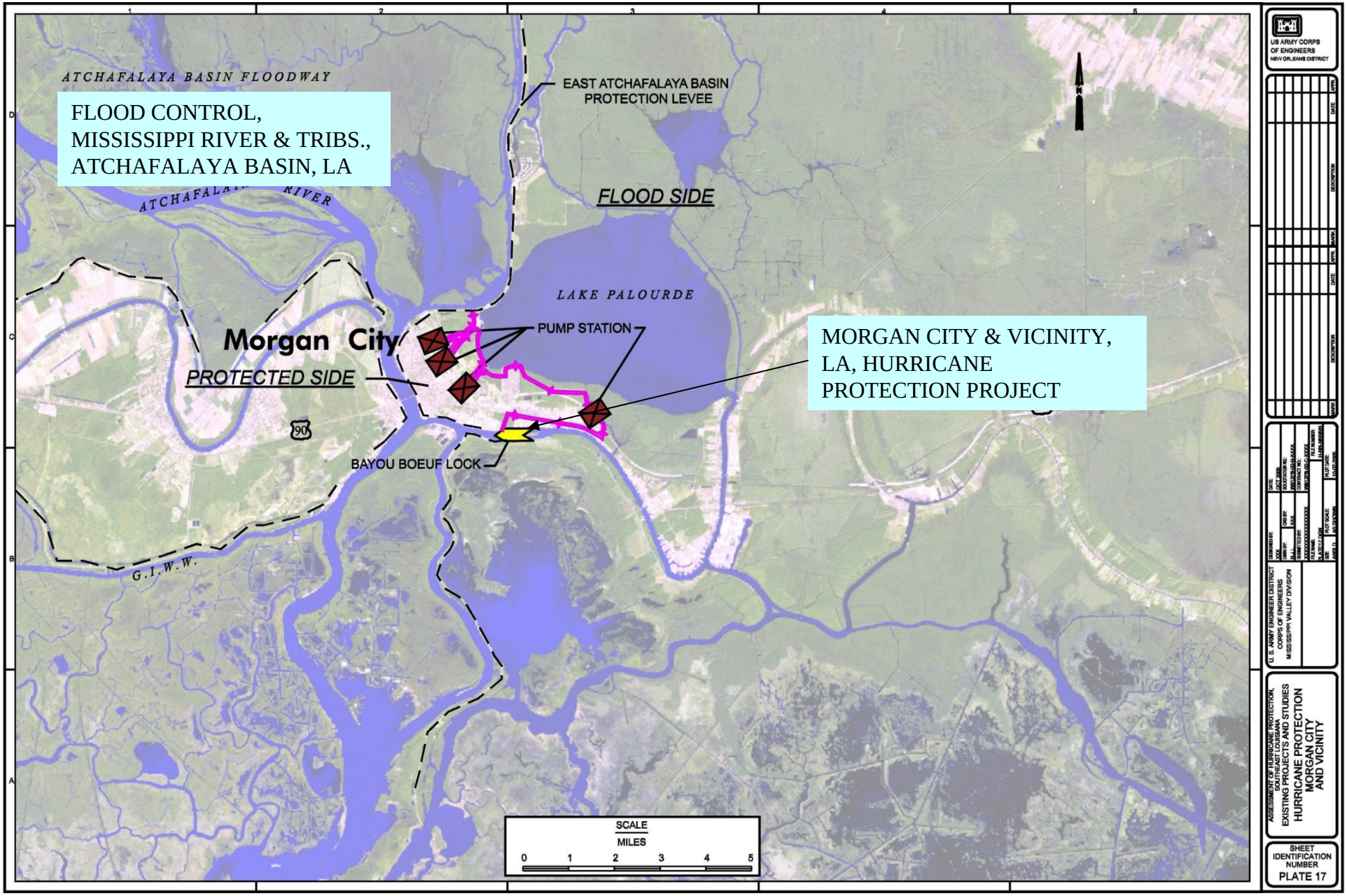
- The Feasibility Report was submitted in 2002.
- The project is located in Terrebonne and Lafourche Parishes South of Houma, La.
- The project was designed to protect against the 100-yr frequency storm.
- The project consists of approx. 72 miles of levees and floodwalls with numerous navigable floodgates and water control structures. A lock in the Houma Navigation Channel is also part of the project.

Lower Atchafalaya Basin Reevaluation Study



Lower Atchafalaya Basin Reevaluation Study

- The study was authorized in 1994.
- The study area is located in Iberville, West Baton Rouge, St. Martin, Ascension, Iberia, Assumption, St. Mary, Terrebonne and Lafourche Parishes west of the Atchafalaya River.
- The study is to investigate providing protection against backwater flooding from the Atchafalaya River.
- The proposed plan consists of approx. 30 miles of levees and floodwalls with several navigable floodgates, pumping stations and a lock/pump station complex.

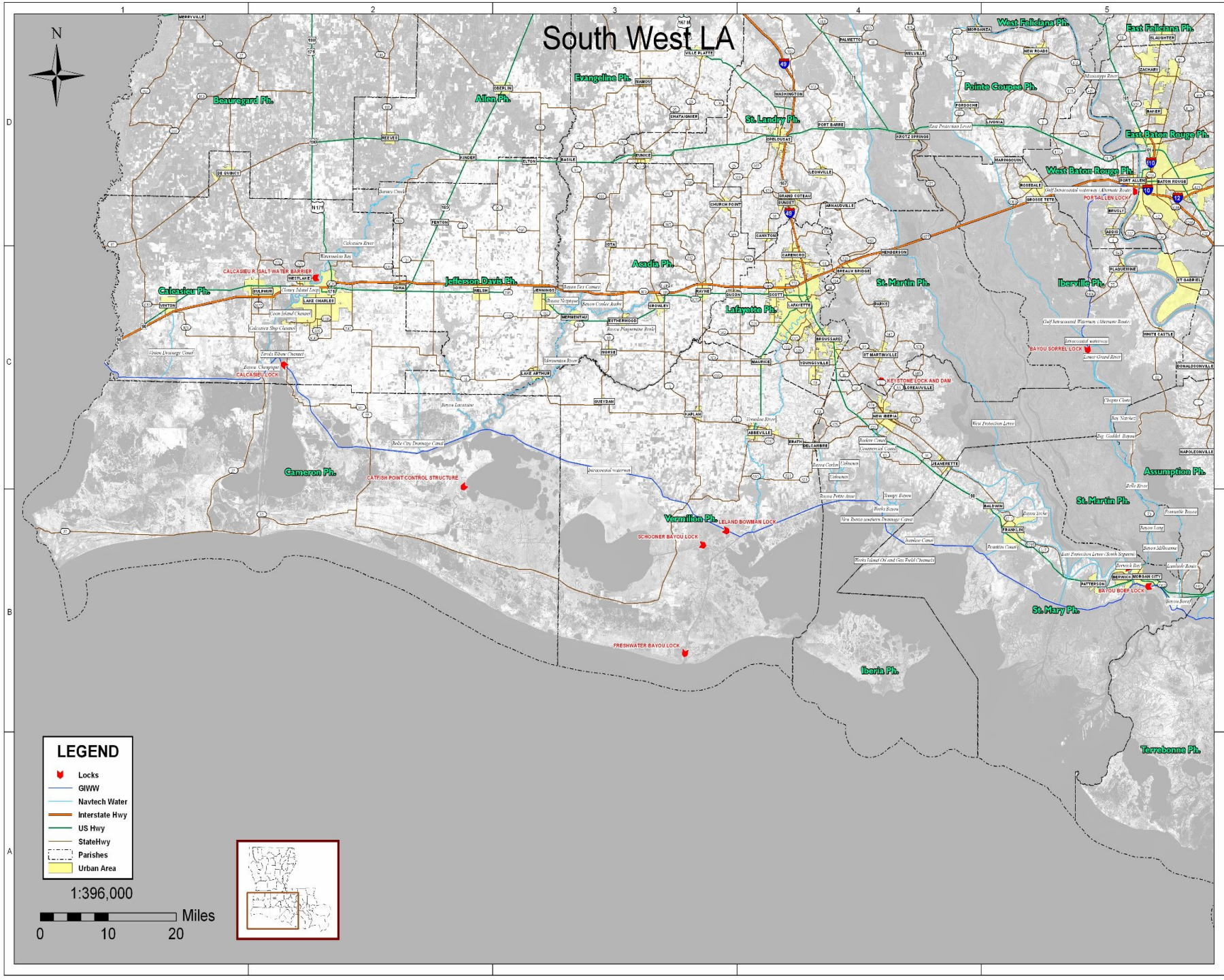

FLOOD CONTROL,
MISSISSIPPI RIVER & TRIBS.,
ATCHAFALAYA BASIN, LA
ATCHAFALAYA BASIN FLOODWAY
EAST ATCHAFALAYA BASIN
PROTECTION LEVEE
FLOOD SIDE
LAKE PALOURDE
PUMP STATION
Morgan City
PROTECTED SIDE
MORGAN CITY & VICINITY,
LA, HURRICANE
PROTECTION PROJECT
90
BAYOU BOEUF LOCK
G.I.W.W.
SCALE
MILES
0 1 2 3 4 5
US ARMY CORPS
OF ENGINEERS
NEW ORLEANS DISTRICT
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION
ASSESSMENT OF HURRICANE PROTECTION, FLOOD CONTROL AND RELATED PROJECTS
EXISTING PROJECTS AND STUDIES
HURRICANE PROTECTION
MORGAN CITY
AND VICINITY
SHEET
IDENTIFICATION
NUMBER
PLATE 17

Morgan City and Vicinity, La., Hurricane Protection Project

- The project was authorized in 1965.
- The project is located in St. Mary Parish west of the Atchafalaya River.
- The project was designed to protect against the 100-yr frequency storm.
- The proposed plan consists of approx. 10 miles of levees and floodwalls

Flood Control, Mississippi River & Tribs., Atchafalaya Basin, La.

- The project was originally authorized in 1928.
- The project is located in south-central Louisiana with the Atchafalaya River flowing through the middle of the basin.
- The purpose of the project is to carry half of the Project Flood from the Mississippi River.
- The project consists of a leveed/flood walled floodway about 15 miles wide and 110 miles long from Old River to the Gulf of Mexico. There are numerous drainage structures, pump stations floodgates and locks.



U.S. ARMY CORPS OF ENGINEERS
NEW ORLEANS DISTRICT

MARK	DESCRIPTION	DATE	APPR.	MARK	DESCRIPTION	DATE	APPR.

DESIGNED BY: M. Shields
DWN BY: M. Shields
CKD BY: xxx
SUBMITTED BY: Project Manager
FILE NAME: South West LA.mxd
SIZE: ANSI X
SCALE: 1:NOT TO SCALE
DATE: MM/DD/YYYY
SOLICITATION NO.: W912P8-00-B-XXXX
CONTRACT NO.: W912P8-00-C-XXXX
FILE NO.: H-N-H-NNNN
PLOT DATE: MM/DD/YYYY

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION

South West Louisiana

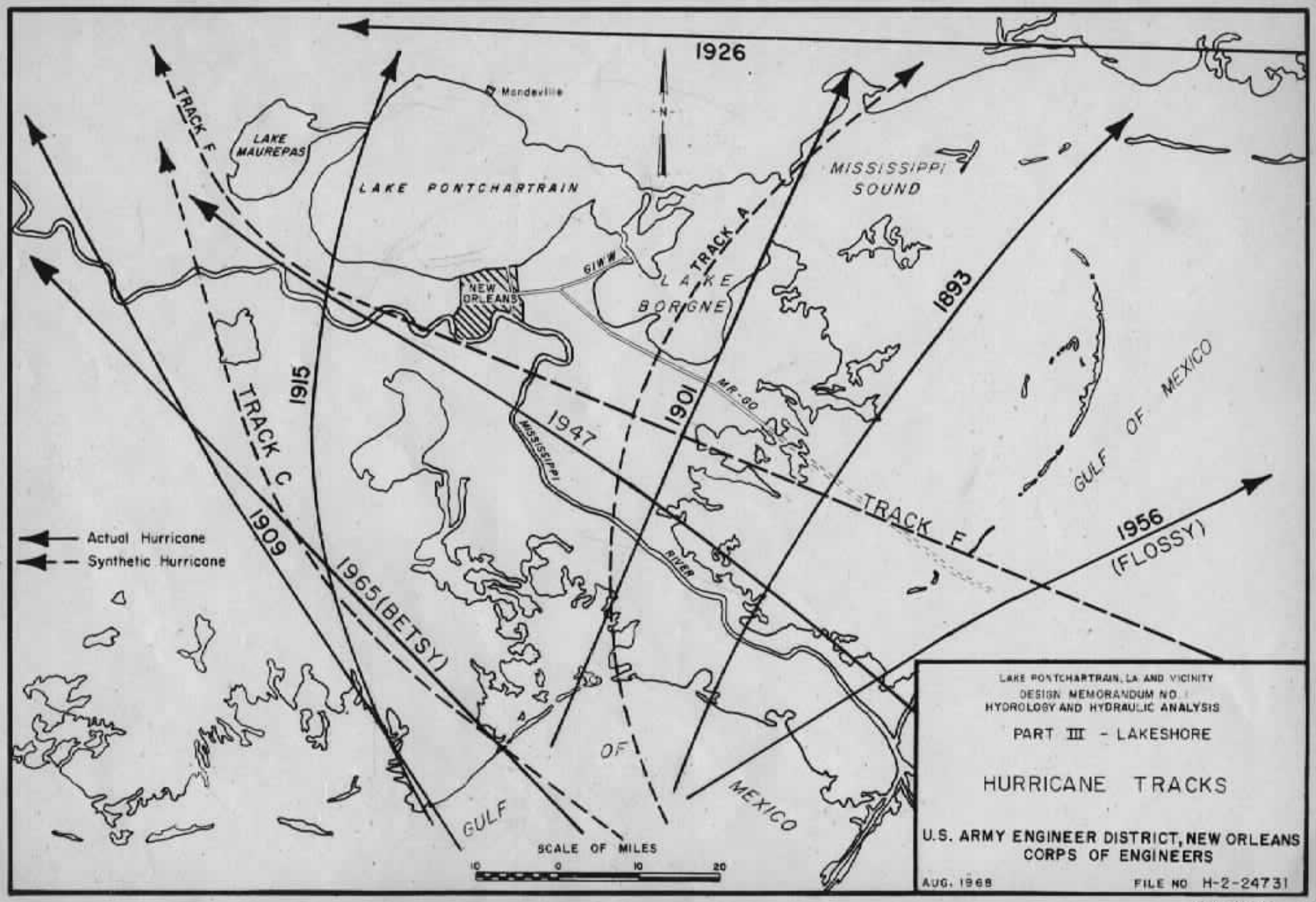
SHEET IDENTIFICATION NUMBER
C-XX

TITLE: New Orleans Flood Protection System & Design

PRESENTED BY: Janis Hote, USACE-MVN

SUMMARY: This presentation describes the development of the Standard Project Hurricane (SPH) and its characteristics and how the effects of the SPH were used to engineer hurricane protection projects. The U.S. Weather Service's "NHRP Report No. 33, Meteorological Considerations Pertinent to Standard Project Hurricane, Atlantic and Gulf Coasts of the United States, November 1959," provided baseline design parameters for the SPH. Subsequently, the wind parameters were later updated with information gathered from Hurricane Betsy in 1965. The resulting SPH parameters were the design basis for the Lake Pontchartrain Lake and Vicinity Project. Two historical hurricanes from 1915 and 1947 and their associated tracks, stages, and other parameters were used to establish relationships and verify procedures for storm surge routing between Lakes Pontchartrain and Borgne. The resulting stage in the Lake Pontchartrain was used to determine the design stages for the south shore. Wave runup was computed using the computed significant wave; runup was added to the design water surface elevation to arrive at the required height of each protective structure.

The SPH has a frequency of once in 100 years in Zone B, a 400-mile reach from Cameron, LA, to Pensacola, FL. Critical tracks and forward speeds of historical storms were used to compute a frequency for each portion of the levee. Stages were computed for each of these tracks for several CPIs and forward speeds. In 1966, an analysis was performed on the 42 historic hurricane tracks which crossed into Zone B. The probabilities of the hurricane tracks were applied to stages computed for the SPH and several lesser CPIs of the critical track for Lakes Pontchartrain and Borgne. The probabilities of equal stages for both groups of tracks were then added arithmetically to develop wind tide levels for all directions. Using this method and a simple frequency of historical stages, a frequency of the SPH for both Lakes can be developed.



LAKE PONTCHARTRAIN, LA AND VICINITY
DESIGN MEMORANDUM NO.
HYDROLOGY AND HYDRAULIC ANALYSIS

PART III - LAKESHORE

HURRICANE TRACKS

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

AUG. 1968 FILE NO H-2-24731

PLATE 3

PLATE 3

STANDARD PROJECT HURRICANE

Standard Project Hurricane (SPH) is a hypothetical hurricane intended to represent the most severe combination of hurricane parameters that is reasonably characteristic of a specified region, excluding extremely rare combinations. It is assumed that the SPH would approach a given project site from such direction, and at such rate of movement, to produce the highest hurricane surge hydrograph, considering pertinent hydraulic characteristics of the area.

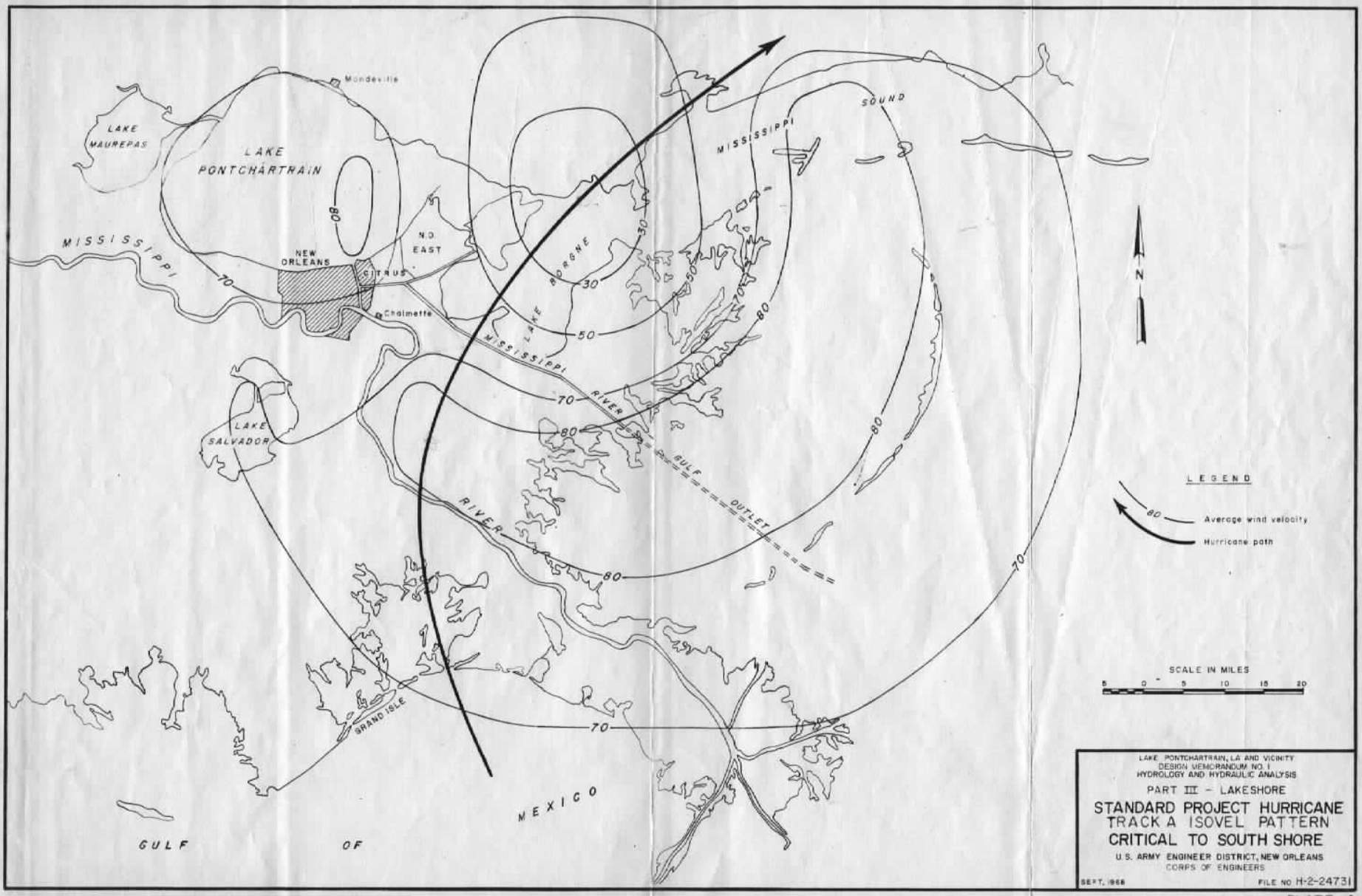


PLATE 4

Track A

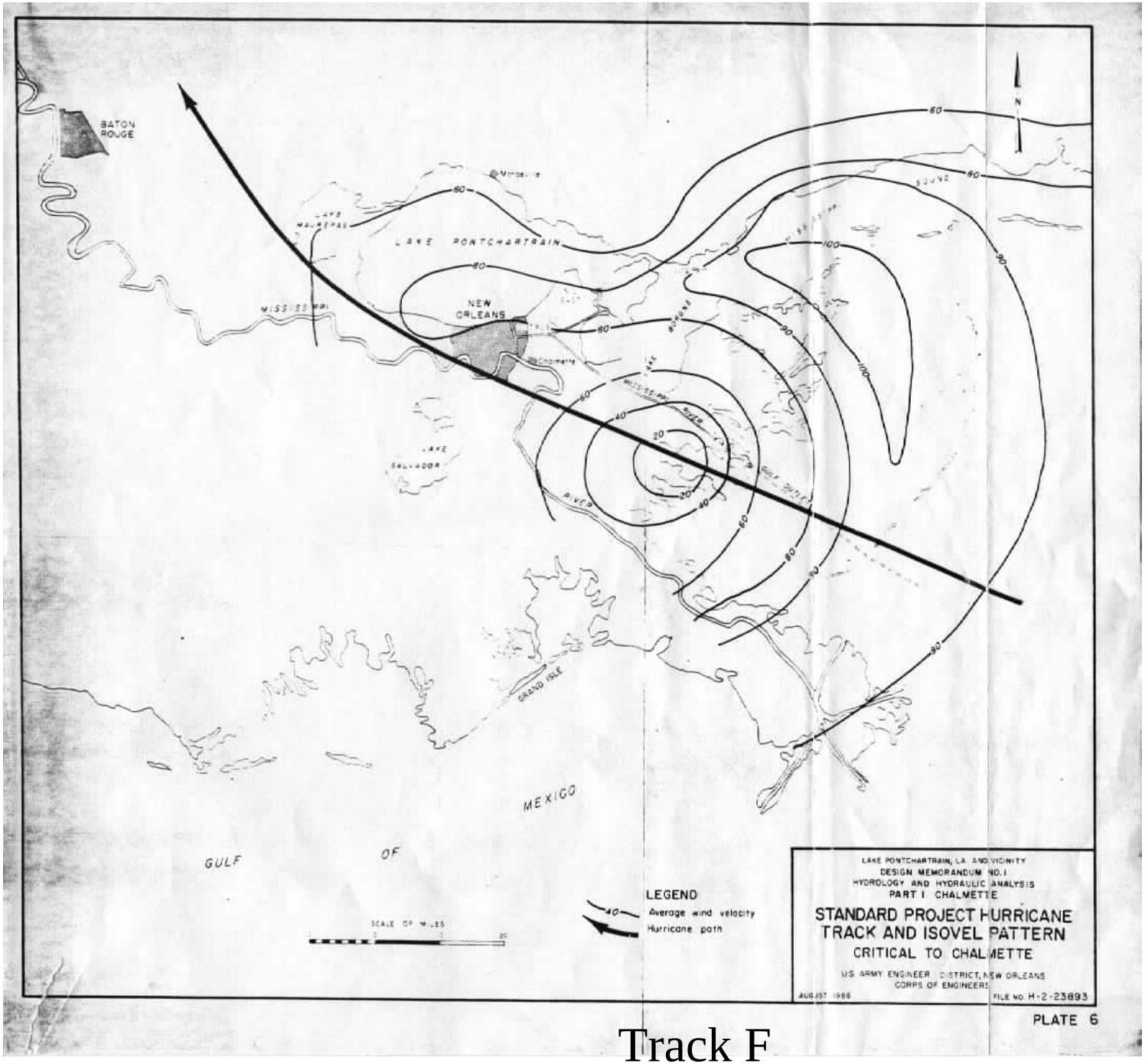


PLATE 6

Track F

For the Open coast……

The General Equation for Steady State Surge Calculations, in its modified form, is as follows:

$$S = 1.165 \times 10^{-3} \frac{V^2 F}{D} N Z \cos \theta$$

where S = wind setup in feet

V= windspeed in statute miles per hour

F = fetch length in statute miles

D = average depth of fetch in feet

θ = angle between direction of wind and the fetch

N = planform factor, generally equal to unity

Z = surge adjustment factor

HOURS REFERENCED TO LANDFALL	EL. IN LAKE BORGNE		EL. IN LAKE PONTCHARTRAIN			FLOW INTO LAKE PONTCHARTRAIN						L. PONT. STORAGE		OVERFLOW	FLOW INTO L. MAUREPAS	EL. IN LAKE MAUREPAS	
	EL. IN L. BORGNE	AV. OF (2)	AV. EL. IN L. PONT.	EL. AT HWY. 11	AV. OF (5)	HEAD BETWEEN L. BORGNE & L. PONT.	FLOW INTO L. PONT.	VOLUME OF FLOW FOR 2 HOURS	RAIN IN L. PONT.	VOLUME OF RAIN FOR 2 HOURS	TOTAL INFLOW INTO L. PONT.	STORAGE IN L. PONT. FOR EL. IN (4)	Δ STORAGE IN L. PONT.	FLOW OVER L. PONT. LEVEES FOR 2 HOURS	(12)-(14)-(15)	STORAGE IN L. MAUREPAS	AV. EL. IN L. MAUREPAS
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	FEET M.S.L.	FEET M.S.L.	FEET M.S.L.	FEET M.S.L.	FEET M.S.L.	FEET	1000 C.F.S.	1000 D.S.F.	FEET	1000 D.S.F.	1000 D.S.F.	1000 D.S.F.	1000 D.S.F.	1000 D.S.F.	1000 D.S.F.	1000 D.S.F.	FEET M.S.L.
2	9.44		3.94	2.33					0.115			1970.4				225.1	1.12
		9.84			1.21	8.65	4214.0	351.2		13.7	364.9		346.5	2.3	16.1		
4	10.25		5.26	0.09					0.052			2317.1				241.2	1.27
		9.91			1.62	8.29	4043.2	336.9		48.0	378.9		351.7	11.6	15.6		
6	9.56		4.55	3.14					0.155			2668.8				256.8	1.41
		9.11			4.55	4.56	2510.6	192.6		49.6	242.2		202.5	25.8	15.9		
8	8.66		7.28	5.96					0.180			2871.3				270.7	1.58
		7.43			7.43	0.00	0.0	0.0		21.0	21.0		-47.7	54.9	15.8		
10	6.19		7.11	8.90					0.075			2823.6				284.5	1.65

HOURS REFERENCED TO LANDFALL	VERIFICATION: STAGES IN PASS MANCHAC — L. PONT. SIDE		LAKE MAUREPAS SIDE					FLOW INTO LAKE MAUREPAS			STAGE IN LAKE MAUREPAS	
	EL. IN PASS MANCHAC	AV. OF (19)	TILT IN L. PONT.	TILT IN L. MAUREPAS	EL. IN PASS MANCHAC	AV. OF (23)	HEAD BETWEEN L. PONT. & L. MAUREPAS	FLOW INTO L. MAUREPAS	VOLUME OF FLOW FOR 2 HOURS	STORAGE IN L. MAUREPAS	EL. IN L. MAUREPAS
(1)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
	FEET M.S.L.	FEET M.S.L.	FEET	FEET	FEET M.S.L.	FEET M.S.L.	FEET	1000 C.F.S.	1000 D.S.F.	1000 D.S.F.	FEET M.S.L.
2	3.54		1.21	0.24	1.00					226.2	1.13
		4.52				0.86	3.66	165.8	13.8		
4	5.50		5.41	1.08	0.73					240.0	1.24
		6.02				0.90	5.12	189.6	15.1		
6	6.53		3.41	0.68	1.07					255.4	1.40
		6.08				1.52	4.76	180.5	15.0		
8	5.61		-0.36	-0.07	1.57					270.4	1.53
		5.11				1.82	3.29	140.2	13.4		
10	4.61		-4.29	-0.86	2.08					283.8	1.64

SAMPLE ROUTING

EXPLANATION:

COLUMN (2) FROM LAKE BORGNE HYDROGRAPH DERIVED BY THE METHOD DESCRIBED IN PARAGRAPH A-36(1) AND SHOWN ON PLATE A-14

(4) ASSUMED

(5) OBTAINED FROM WATER SURFACE CONTOURS DERIVED FROM WIND SETUP COMPUTATIONS FOR LAKE PONT., SAMPLE SHOWN ON PLATE A-16

(7) (5) - (2)

(8) FROM CHEF MENTEUR PASS AND RIGOLETS RATING CURVE SHOWN BELOW

(9) FROM RAINFALL ESTIMATES DESCRIBED IN PARAGRAPH A-31 AND MASS RAINFALL CURVES SHOWN ON PLATE A-24

(12) (9) + (11)

(13) FROM LAKE PONT. STORAGE CURVE SHOWN BELOW FOR THE ELEVATION IN (4)

COLUMN (14) (13) - (13)

(15) BY THE PROCEDURES DESCRIBED IN PARAGRAPH A-33

(17) (14) + (17)

(18) CORRESPONDING ELEVATION FOR VOLUME IN (17) FROM LAKE MAUREPAS STORAGE CURVE SHOWN BELOW

(19) SAME AS EXPLANATION FOR (5)

(20) (19) - (5)

(22) 1/8 OF (21), AS DESCRIBED IN PARAGRAPH A-36(3)

(23) (19) - (22)/2

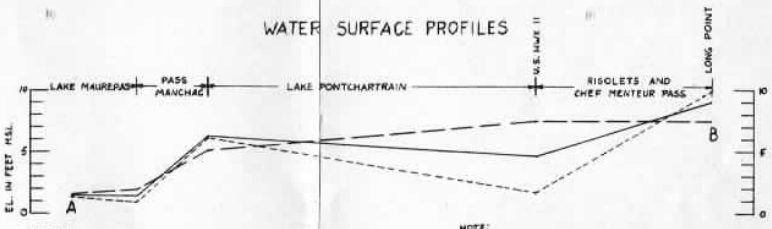
(23) (20) - (23)

(26) FROM PASS MANCHAC RATING CURVE SHOWN BELOW

(28) (27) + (26)

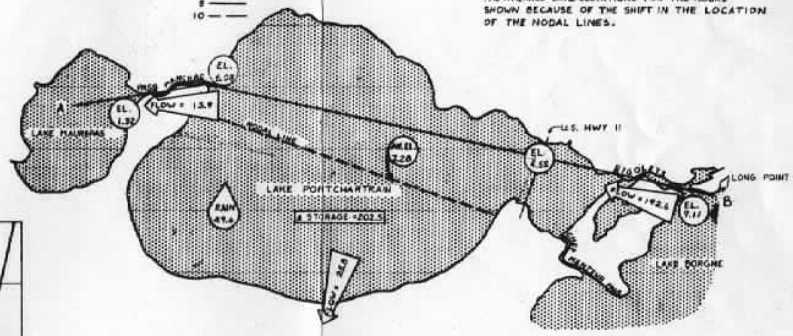
(29) CORRESPONDING ELEVATION FOR VOLUME IN (28) FROM LAKE MAUREPAS STORAGE CURVE SHOWN BELOW

WATER SURFACE PROFILES



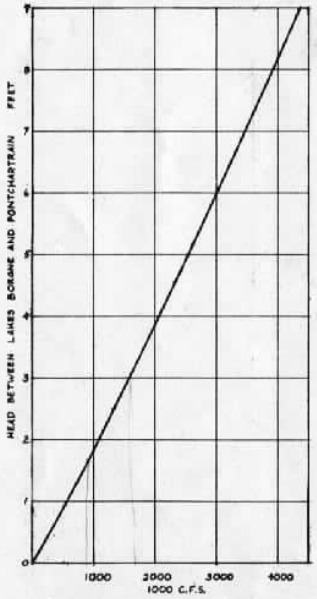
LEGEND:
HOURS AFTER LANDFALL 6 - - - - - 8 —— 10 — —

NOTE:
THE LAKE PONTCHARTRAIN PROFILES DO NOT REFLECT THE AVERAGE LAKE ELEVATIONS FOR THE HOURS SHOWN BECAUSE OF THE SHIFT IN THE LOCATION OF THE NODAL LINES.

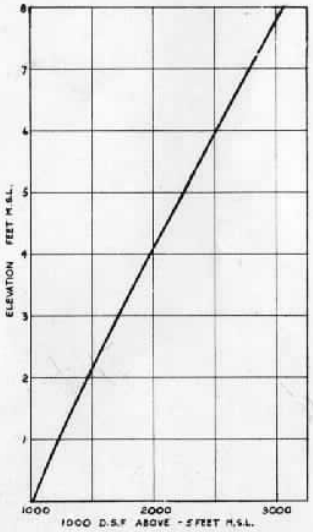


ROUTING DIAGRAM
6 TO 8 HOURS AFTER LANDFALL

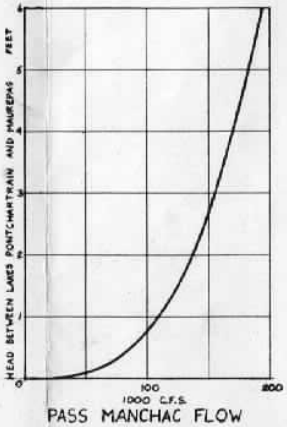
NOTE:
FLOW AND RAIN IN 1000 D.S.F.
ELEVATIONS IN FEET M.S.L.



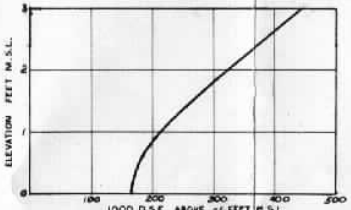
CHEF MENTEUR PASS & RIGOLETS FLOW



LAKE PONTCHARTRAIN STORAGE



PASS MANCHAC FLOW

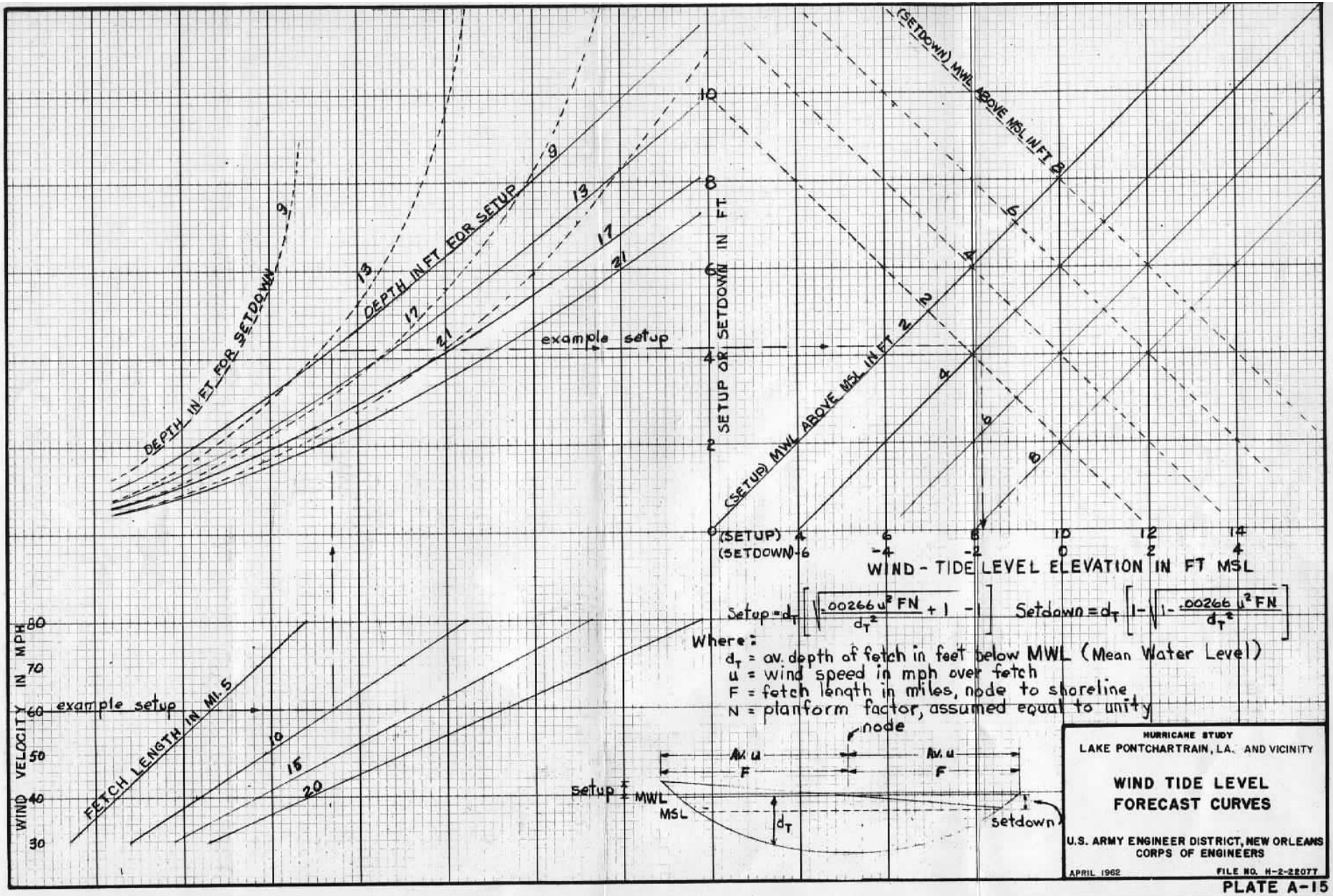


LAKE MAUREPAS STORAGE

HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY

LAKE PONTCHARTRAIN ROUTING

SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS, LA.
CORPS OF ENGINEERS
DATE: JUNE 1962 FILE NO. H-2-22077



$$\text{Setup} = d_T\left[\sqrt{\frac{.00266\,u^2 FN}{d_T^2}+1}-1\right] \qquad \text{Setdown} = d_T\left[1-\sqrt{1-\frac{.00266\,u^2 FN}{d_T^2}}\right]$$

Where:

d_T = av. depth of fetch in feet below MWL (Mean Water Level)
u = wind speed in mph over fetch
F = fetch length in miles, node to shoreline
N = planform factor, assumed equal to unity

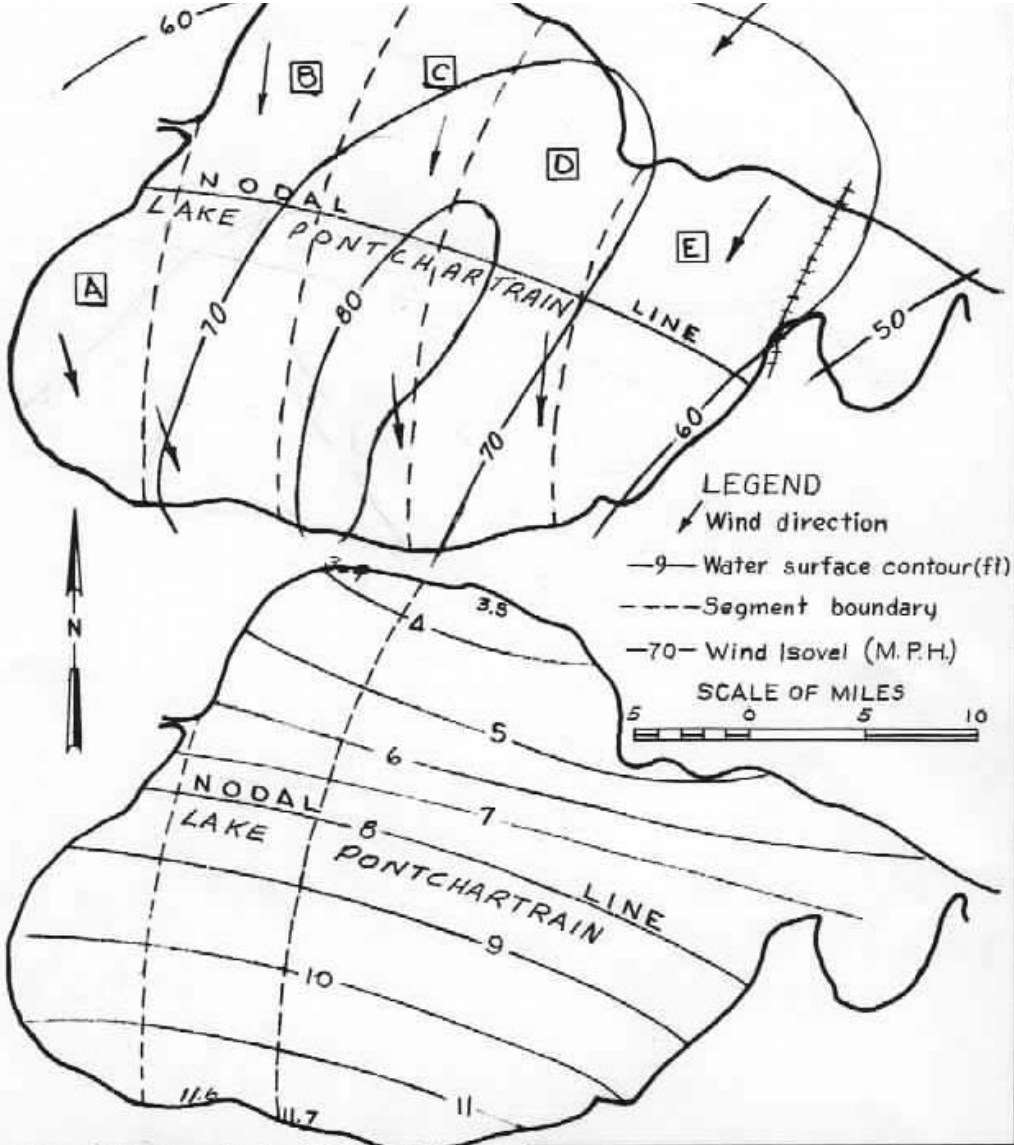
HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY

WIND TIDE LEVEL FORECAST CURVES

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962 FILE NO. H-2-22077

PLATE A-15



Sample: 8 hours after landfall-Track A-SPH

Setdown:

$$S = 19.2\left[1-\sqrt{1-\frac{0.00266(66)^2(12.5)(1.0)}{(19.2)^2}}\right] = \begin{array}{r} +8.0\text{-MWL} \\ -4.1 \\ \hline +3.9\text{-WTL} \end{array}$$

Setup:

$$S = 20.5\left[\left(\sqrt{\frac{0.00266(70)^2(12.5)(1.0)}{(20.5)^2}+1}\right)-1\right] = +3.6'$$

$$\begin{array}{r} 8.0\text{-MWL} \\ +3.6' \\ \hline +11.6'\text{-WTL} \end{array}$$

Interpolate with data for MWL=+6.0' to obtain WTL's for routed MWL=+7.28'.

HURRICANE STUDY

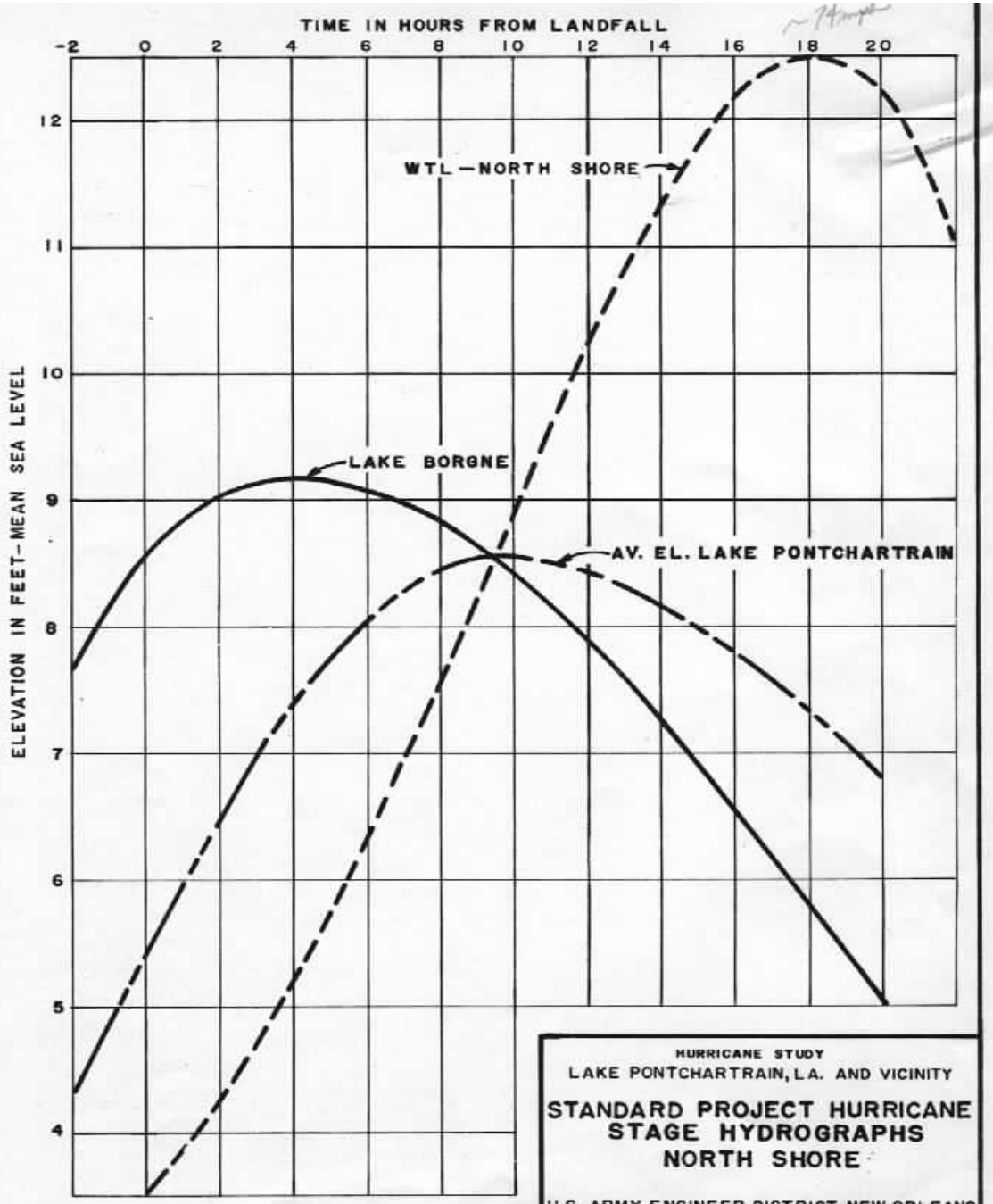
LAKE PONTCHARTRAIN, LA. AND VICINITY

LAKE PONTCHARTRAIN ISOVELS – SETUP ZONES WIND TIDE CONTOURS

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962

FILE NO. H-2-22077



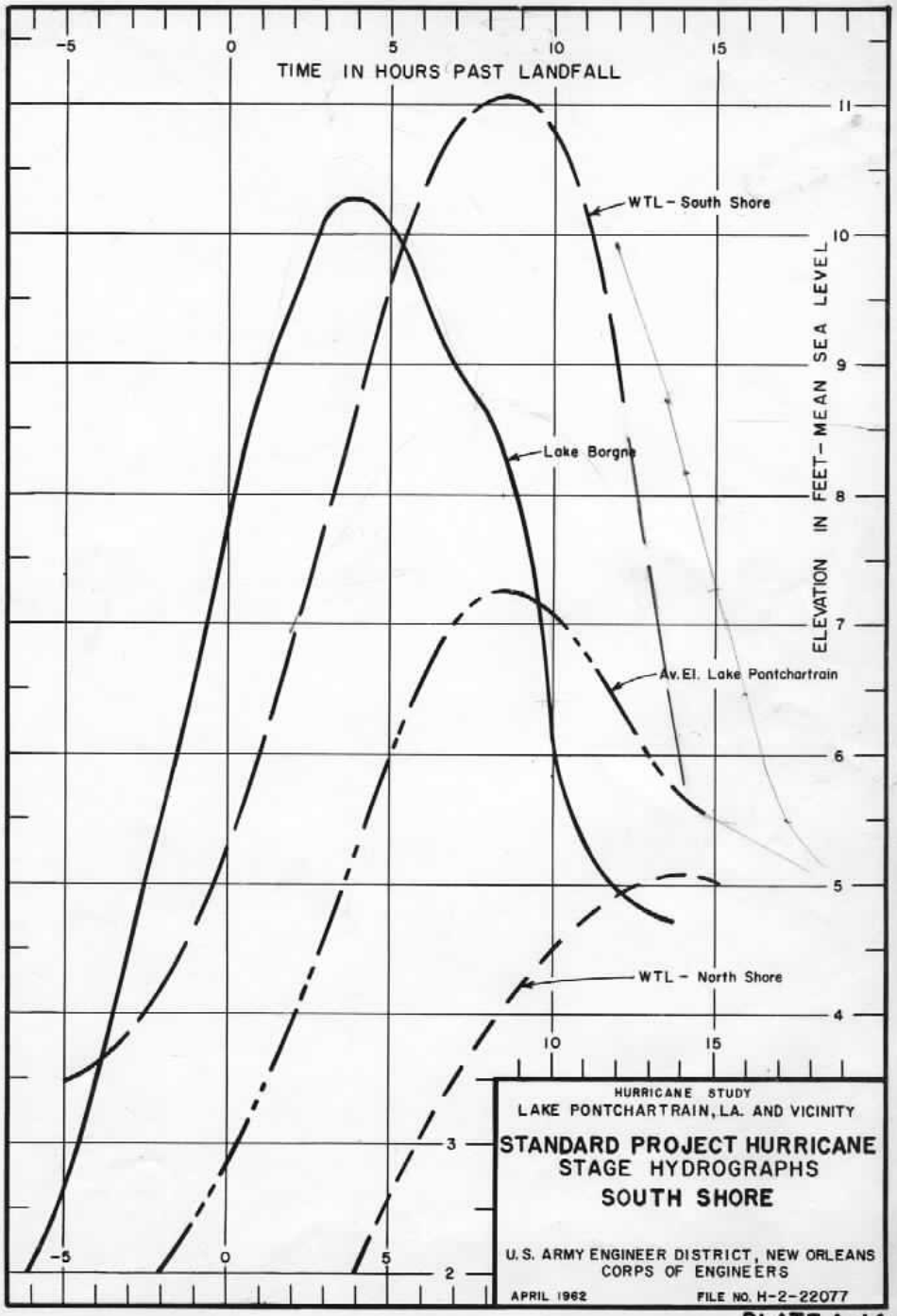
HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY

STANDARD PROJECT HURRICANE STAGE HYDROGRAPHS NORTH SHORE

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962 FILE NO. H-2-22077

PLATE A-13



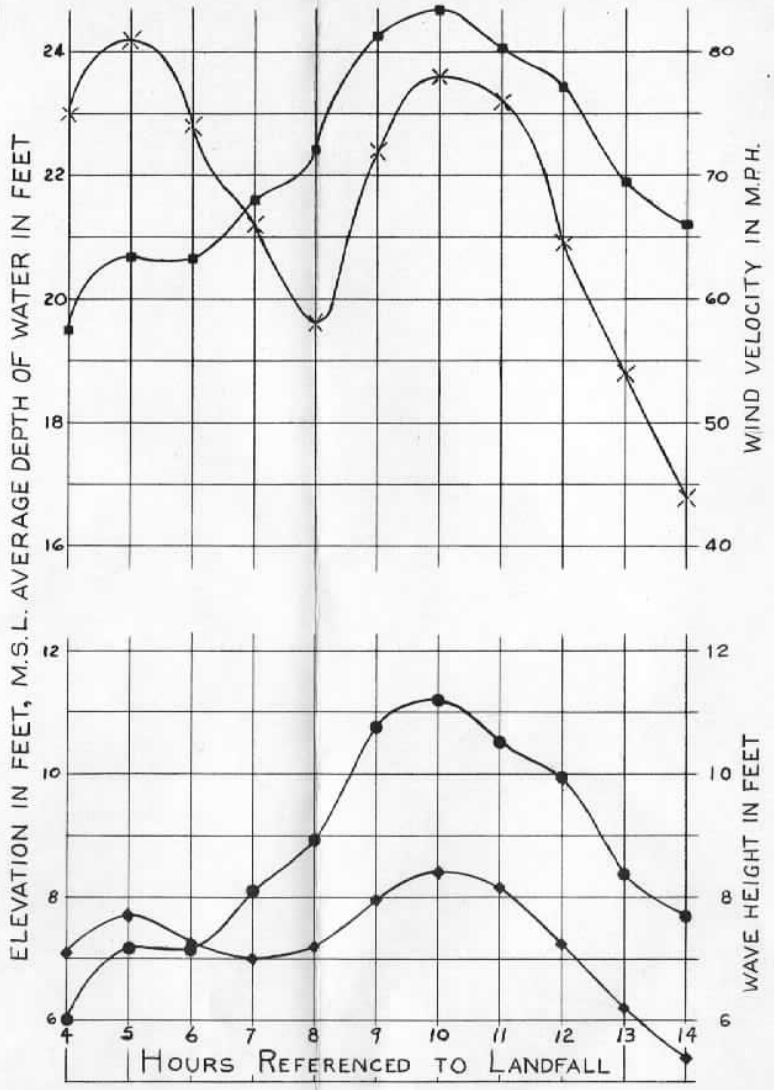
HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY

STANDARD PROJECT HURRICANE
STAGE HYDROGRAPHS
SOUTH SHORE

U. S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962 FILE NO. H-2-22077

PLATE A-14

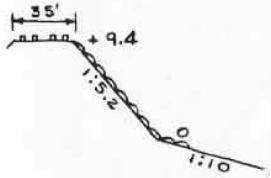


× = AVERAGE WIND VELOCITY.

■ = AVERAGE DEPTH OF WATER (d) ALONG 5 MILE FETCH. Average bottom surface equals -13.5 feet (m.s.l.)

● = WIND TIDE LEVEL.

◆ = SIGNIFICANT WAVE (H_3) AT TOE OF LEVEE.



EXISTING SECTION

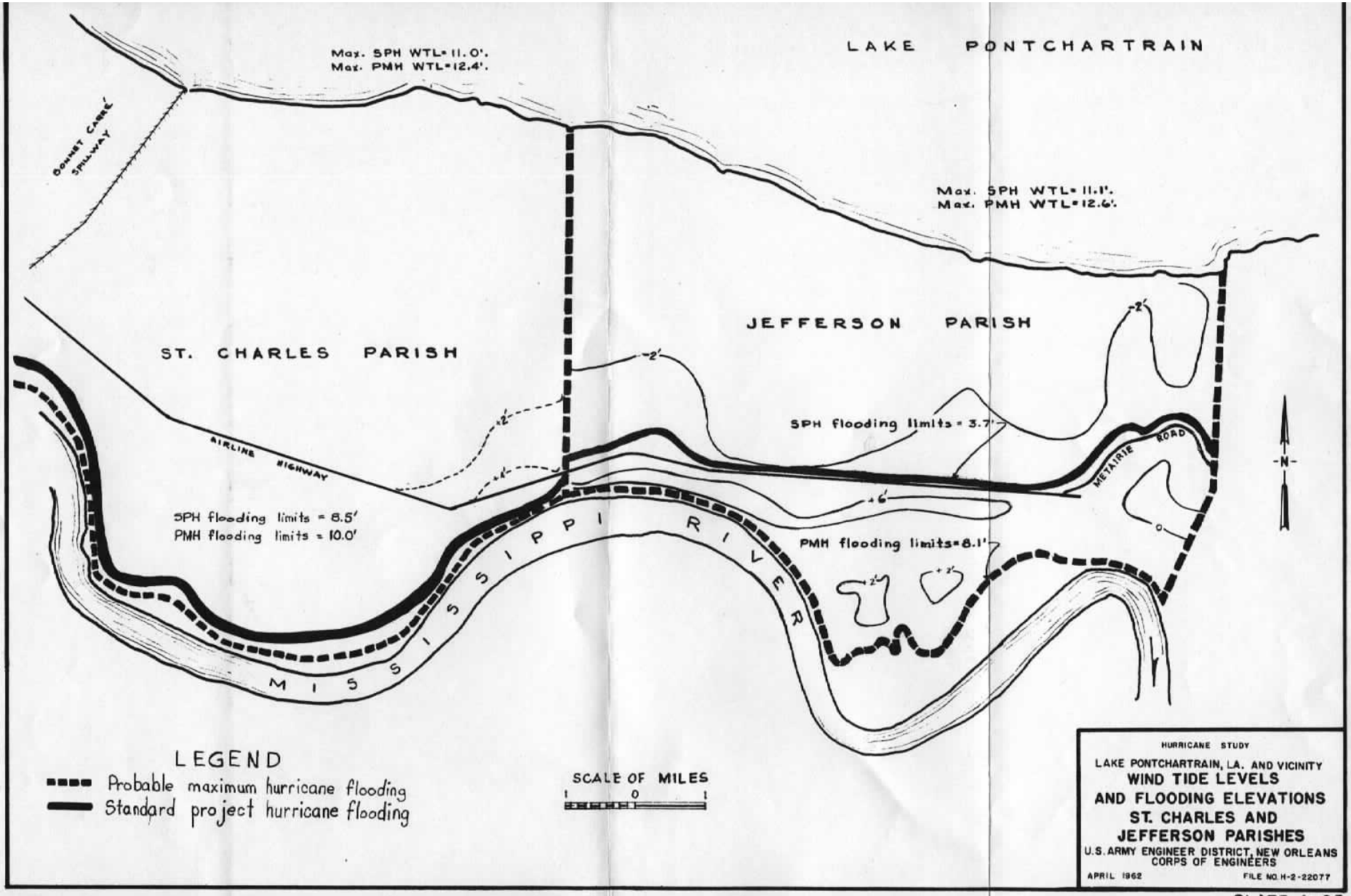
HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY

CITRUS LAKEFRONT
SPH WAVE FACTORS
EXISTING CONDITIONS

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962 FILE NO. H-2-22077

PLATE A-22



HURRICANE STUDY

LAKE PONTCHARTRAIN, LA. AND VICINITY

WIND TIDE LEVELS AND FLOODING ELEVATIONS ST. CHARLES AND JEFFERSON PARISHES

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962 FILE NO. H-2-22077

PLATE A-25

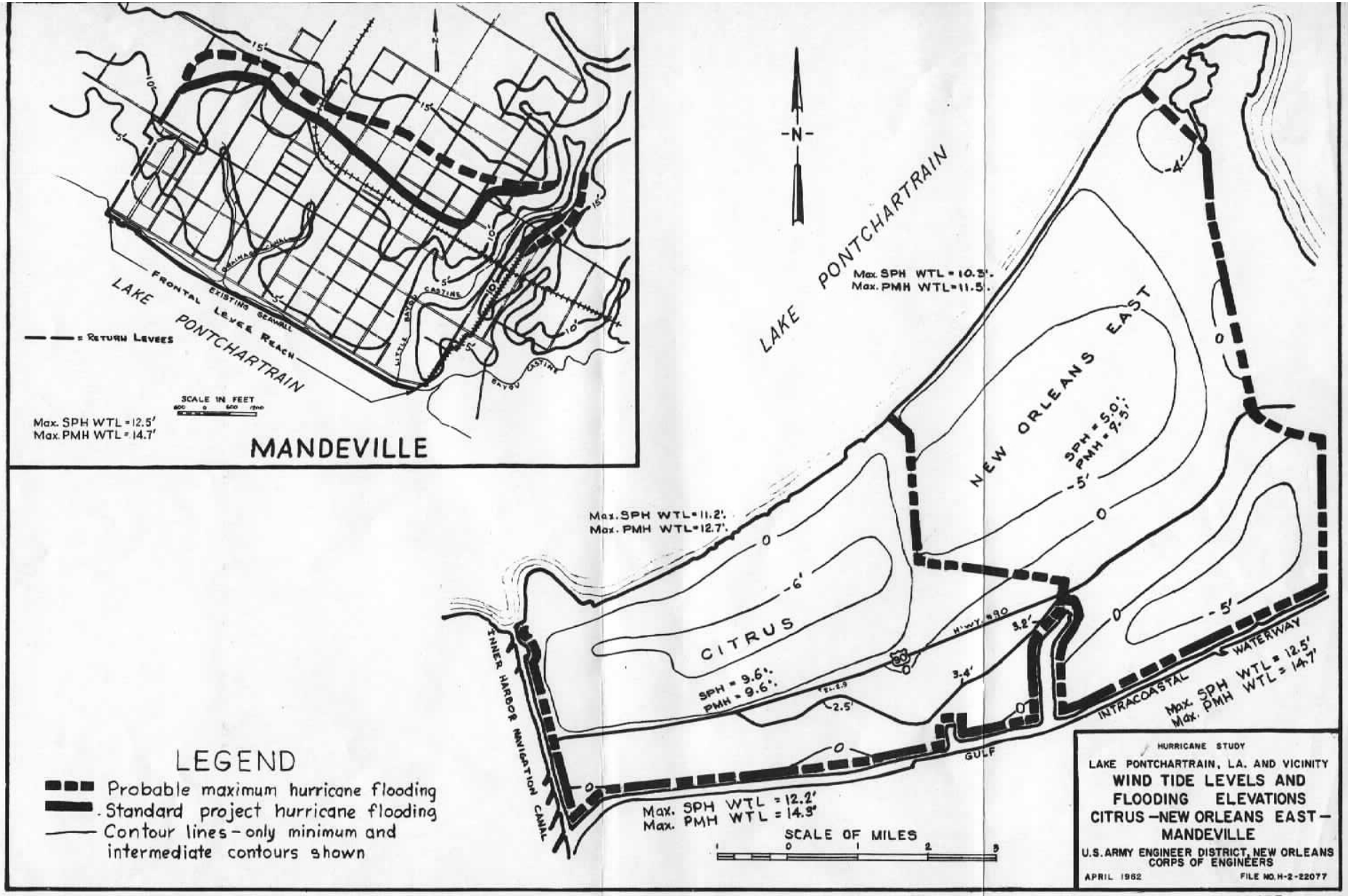
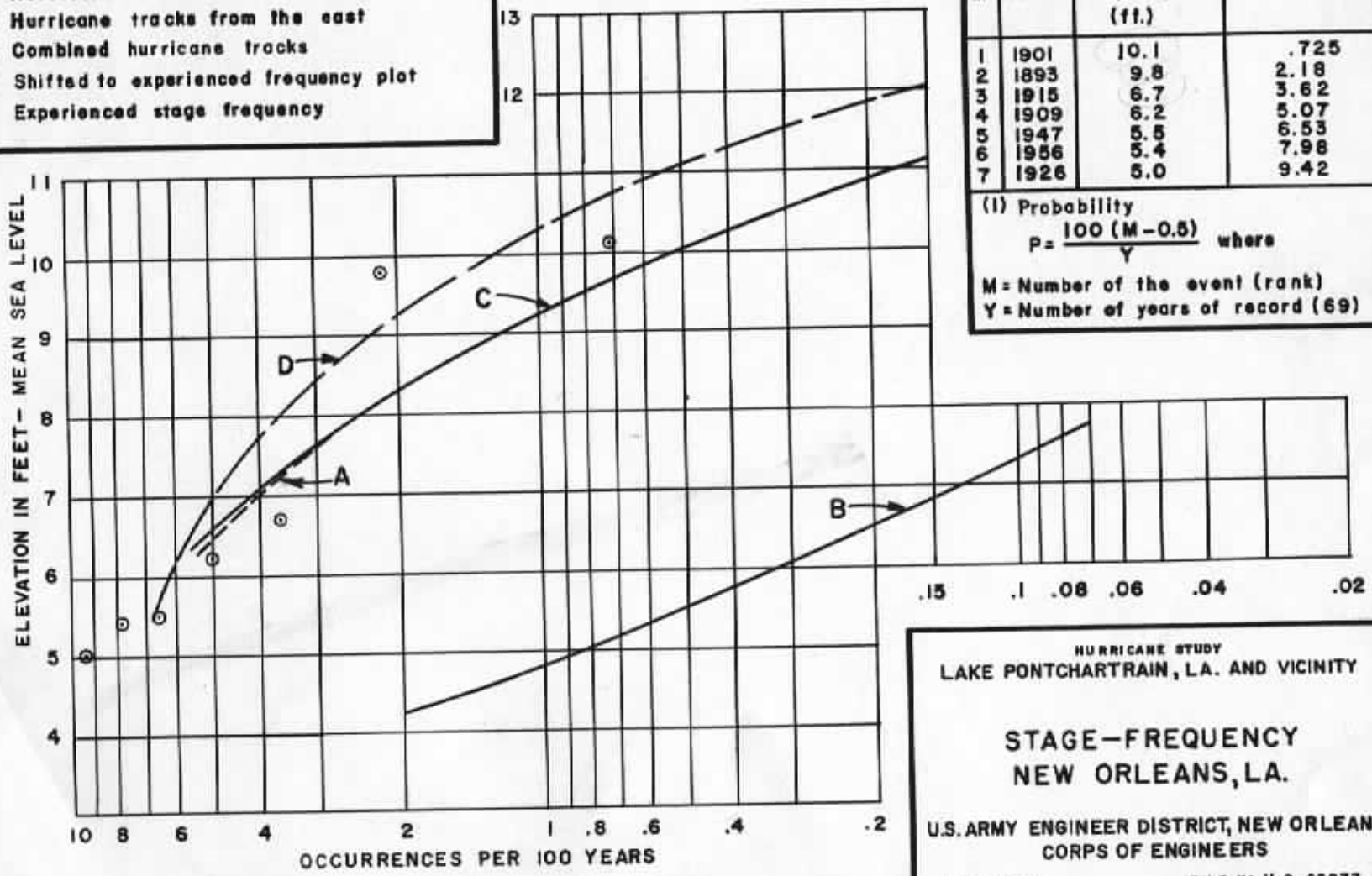

MANDEVILLE
LAKE PONTCHARTRAIN
FRONTAL LEVEE REACH
EXISTING SEAWALL
LITTLE BAYOU CASTINE
BAYOU CASTINE
= RETURN LEVEES
SCALE IN FEET
Max. SPH WTL = 12.5'
Max. PMH WTL = 14.7'
-N-
LAKE PONTCHARTRAIN
Max. SPH WTL = 10.5'.
Max. PMH WTL = 11.5'.
NEW ORLEANS EAST
SPH = 5.0'.
PMH = 7.5'
Max. SPH WTL = 11.2'.
Max. PMH WTL = 12.7'.
CITRUS
SPH = 9.6'.
PMH = 9.6'.
INNER HARBOR NAVIGATION CANAL
HIWY 90
INTRACOASTAL WATERWAY
GULF
Max. SPH WTL = 12.5'
Max. PMH WTL = 14.7'
Max. SPH WTL = 12.2'
Max. PMH WTL = 14.3'
SCALE OF MILES
LEGEND
Probable maximum hurricane flooding
Standard project hurricane flooding
Contour lines - only minimum and intermediate contours shown
HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY
WIND TIDE LEVELS AND FLOODING ELEVATIONS
CITRUS - NEW ORLEANS EAST - MANDEVILLE
U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS
APRIL 1962
FILE NO. H-2-22077

PLATE A-27



FREQUENCY ANALYSIS

M	Years	Wind tide level (ft.)	(1) Probability
1	1901	10.1	.725
2	1893	9.8	2.18
3	1915	6.7	3.62
4	1909	6.2	5.07
5	1947	5.5	6.53
6	1956	5.4	7.98
7	1926	5.0	9.42

(1) Probability

$$P = \frac{100\,(M-0.5)}{Y} \quad \text{where}$$

M = Number of the event (rank)
Y = Number of years of record (69)

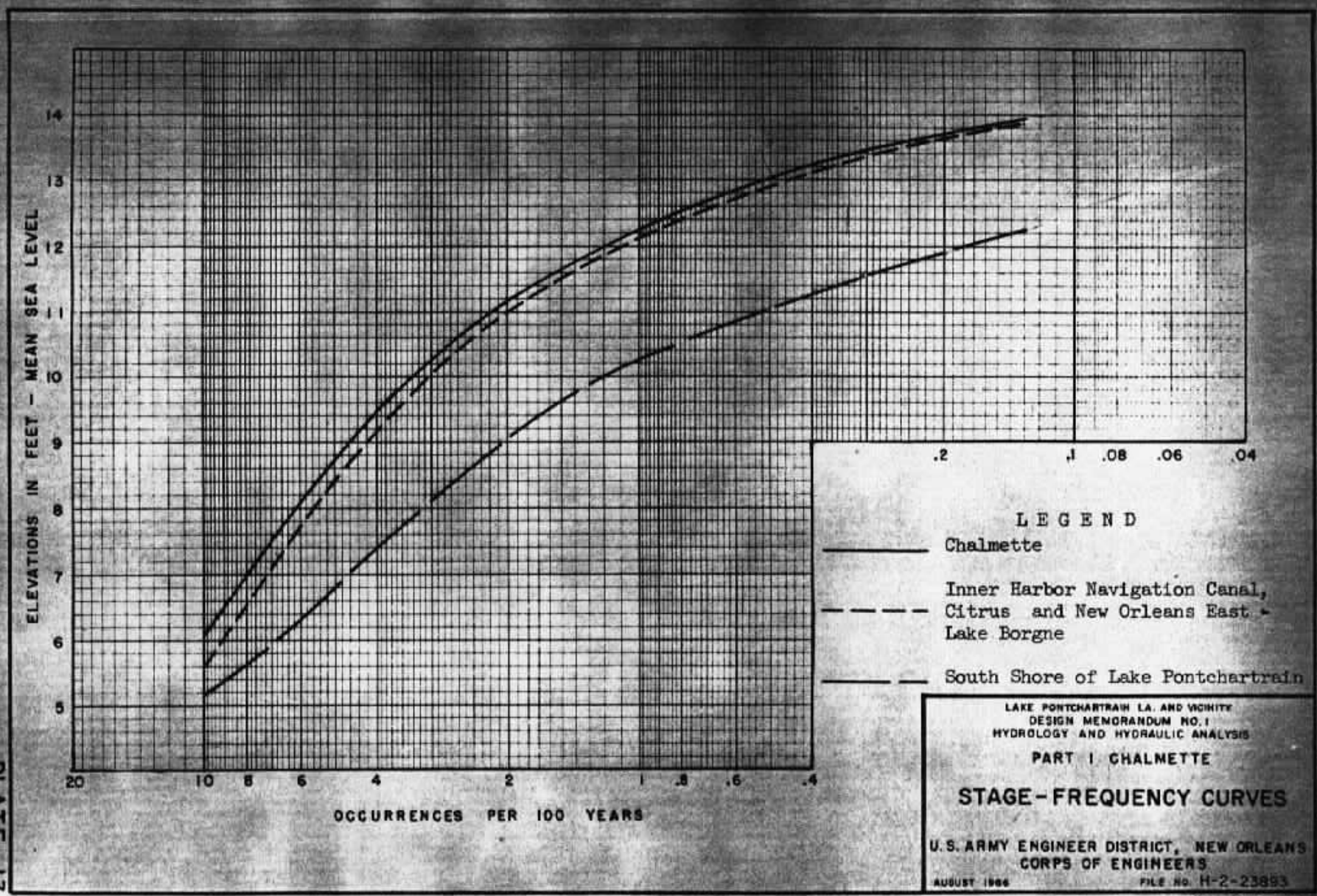
HURRICANE STUDY
LAKE PONTCHARTRAIN, LA. AND VICINITY

STAGE-FREQUENCY
NEW ORLEANS, LA.

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

APRIL 1962 FILE No. H-2-22077

PLATE A-28



LAKE PONTCHARTRAIN LA. AND VICINITY
DESIGN MEMORANDUM NO. 1
HYDROLOGY AND HYDRAULIC ANALYSIS

PART I CHALMETTE

STAGE-FREQUENCY CURVES

U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS

AUGUST 1966 FILE No. H-2-23893

PLATE 13

PLATE 13

TITLE: Impact of Katrina

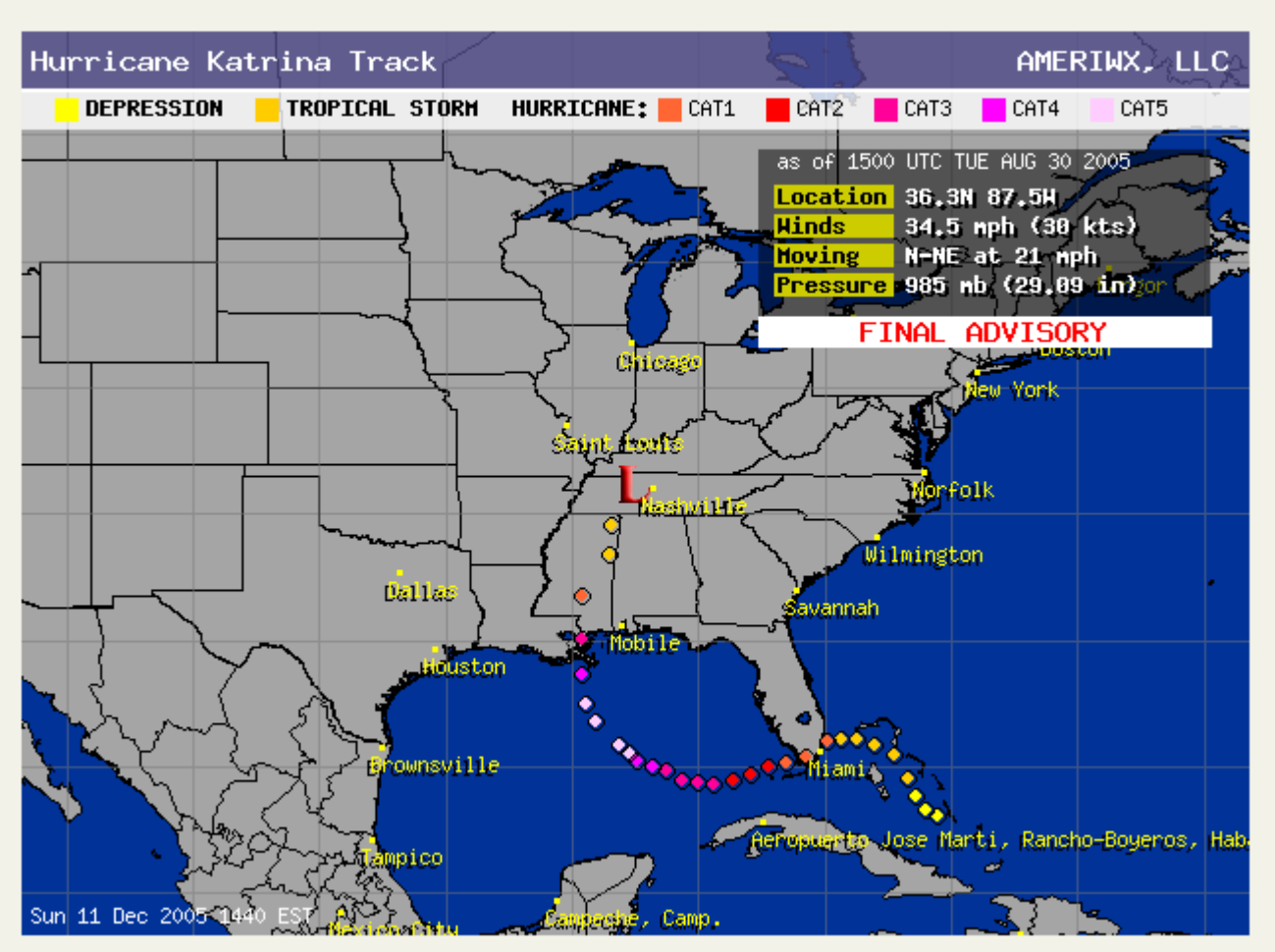
PRESENTED BY: Nancy Powell, USACE-MVN

SUMMARY: The presentation provided an overview of the damages to New Orleans and southeastern Louisiana caused by Hurricane Katrina in 2005. Summaries of the number of levee and floodwall failures, the volume of floodwaters removed, the number of inoperable pump stations, and other damages were presented by parish. Also, the preliminary high water marks produced by the hurricane surge and levee and floodwall failures were presented. The Louisiana Division of Environmental Quality and EPA Region 6 analyzed sediments deposited by Katrina floodwaters, and concluded that Katrina caused oil and chemical spills.

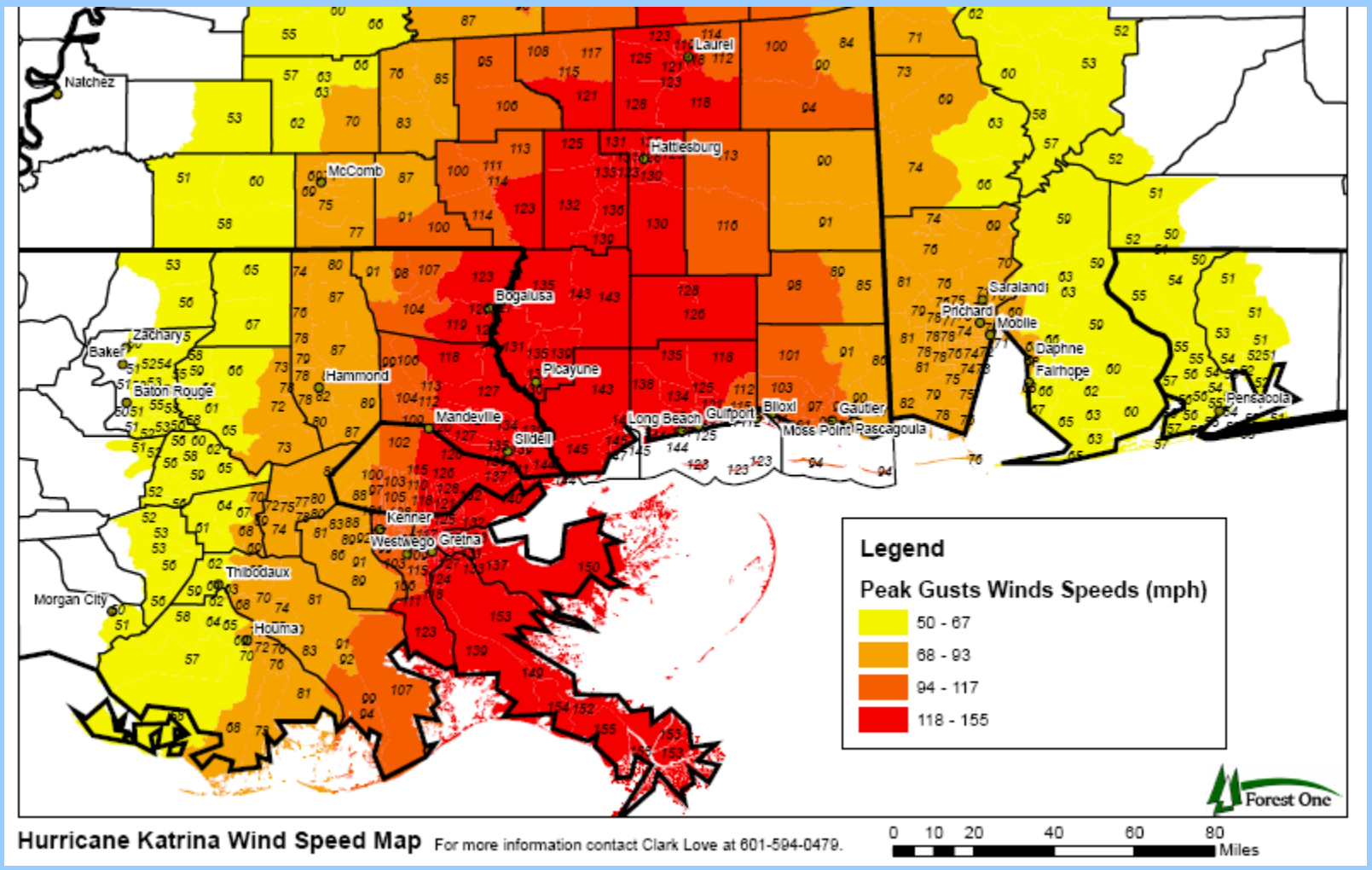
Impact of Katrina

Nancy J. Powell, PE
Chief, Hydrologic Engineering Section
New Orleans District

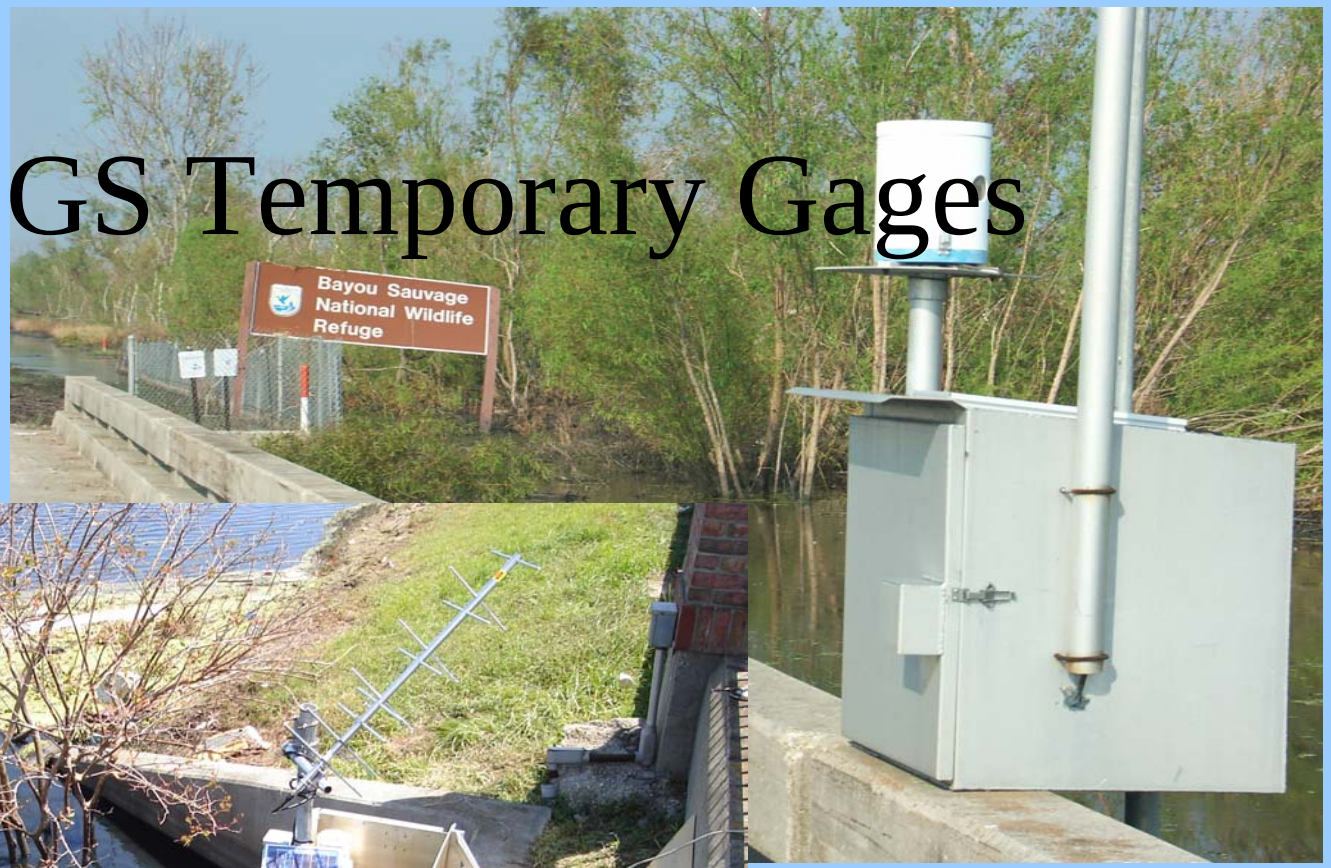
Hurricane Katrina



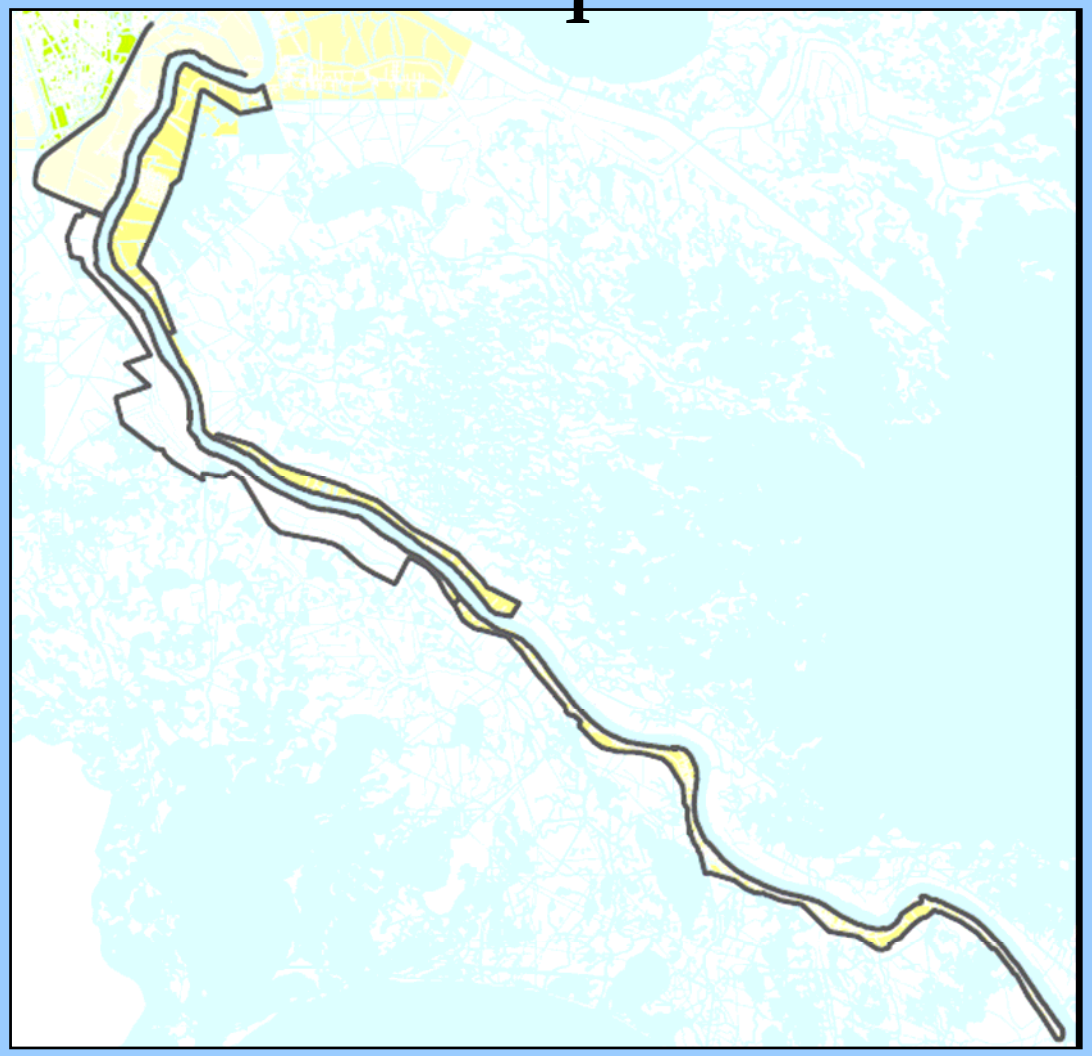
Peak Gusts, mph



USGS Temporary Gages



Plaquemines Parish



344,000 acre-ft of Hurricane Katrina and Rita floodwaters removed.

Damage in Plaquemines Parish

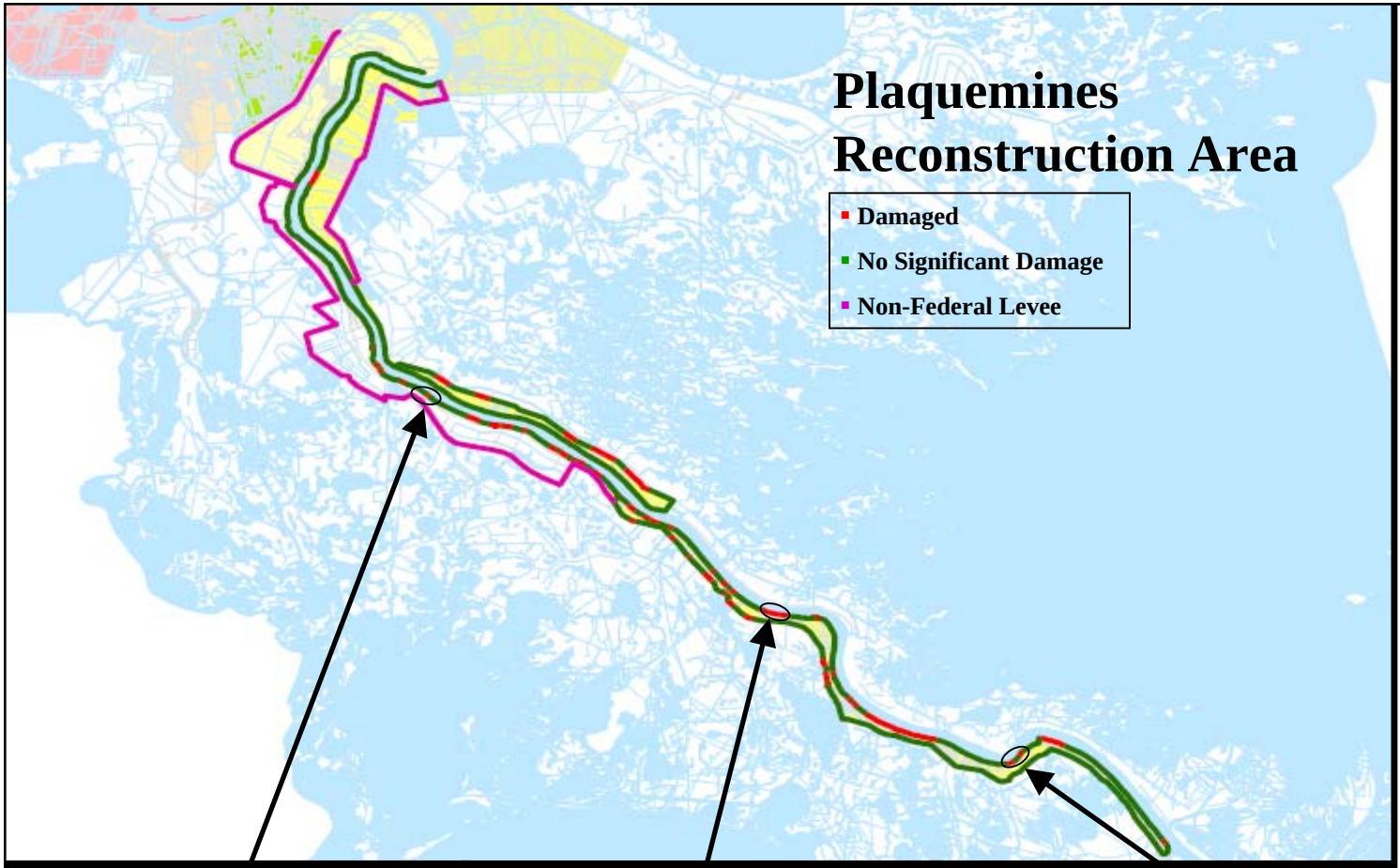
Damage in Plaquemines Parish

Damage in Plaquemines Parish

Damage in Plaquemines Parish

Damage in Plaquemines Parish

Damage in Plaquemines Parish



Breach at Pointe A La Hache

Breach at Nairn

Failed Floodwall at Triumph

Local Authorities

- Plaquemines Parish Government (Buras, Grand Prairie, and Plaquemines Parish West Bank Levee Districts)
- Louisiana DOTD

Hurricane Protection System

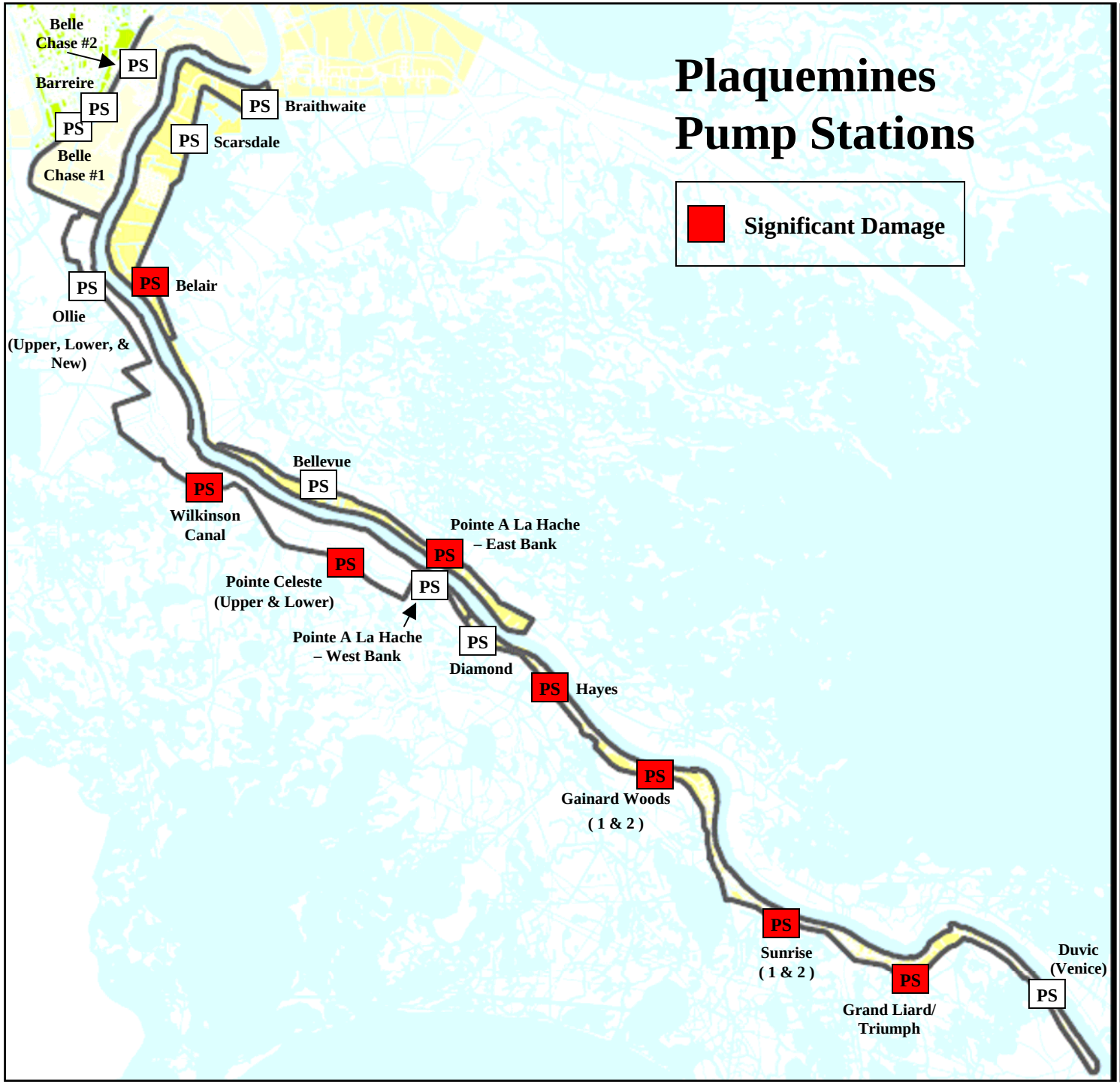
- 109 miles of Mississippi River levee and floodwall (34 miles part of NoV)
- 53 miles of Hurricane Protection back levee
- 6.5 miles of floodwall
- One marine floodgate
- Non-Federal/Private: 19 pump stations

Damage

- 20 miles of Mississippi River and Hurricane Protection levee
- 2 miles of floodwall
- Non-Federal/Private levees and pump stations – continuing to evaluate

US Army Corps of Engineers

As of 24 2200 OCT 05



Local Authorities

- Plaquemines Parish Government
- Citrus Lands

Drainage System

- 16 Parish owned and operated
- Pump Stations (45 pumps)
- Pump Capacity = 12,000 cfs
- 2 Privately owned and operated pump stations (8 pumps)
- Pump Capacity = 840 cfs

Damage

- 7 pump stations significantly damaged (partial pumping capacity)
- 1 pump stations completely damaged (no pumping capacity)
- 9 pump stations – minor damage
- 1 pump station – not damaged

Mississippi River Levees

- 4360 ft below flowline out of original 5600 ft that had been deficient
  - Average Deficiency 0.8 Feet
  - Completion Expected by January 1, 2006

- 5.2 miles do not have 4-ft freeboard out of original 6.7 miles deficient
  - Average Deficiency 2.1 Feet
  - Completion Expected by January 1, 2006

VESSELS REMOVAL STATUS

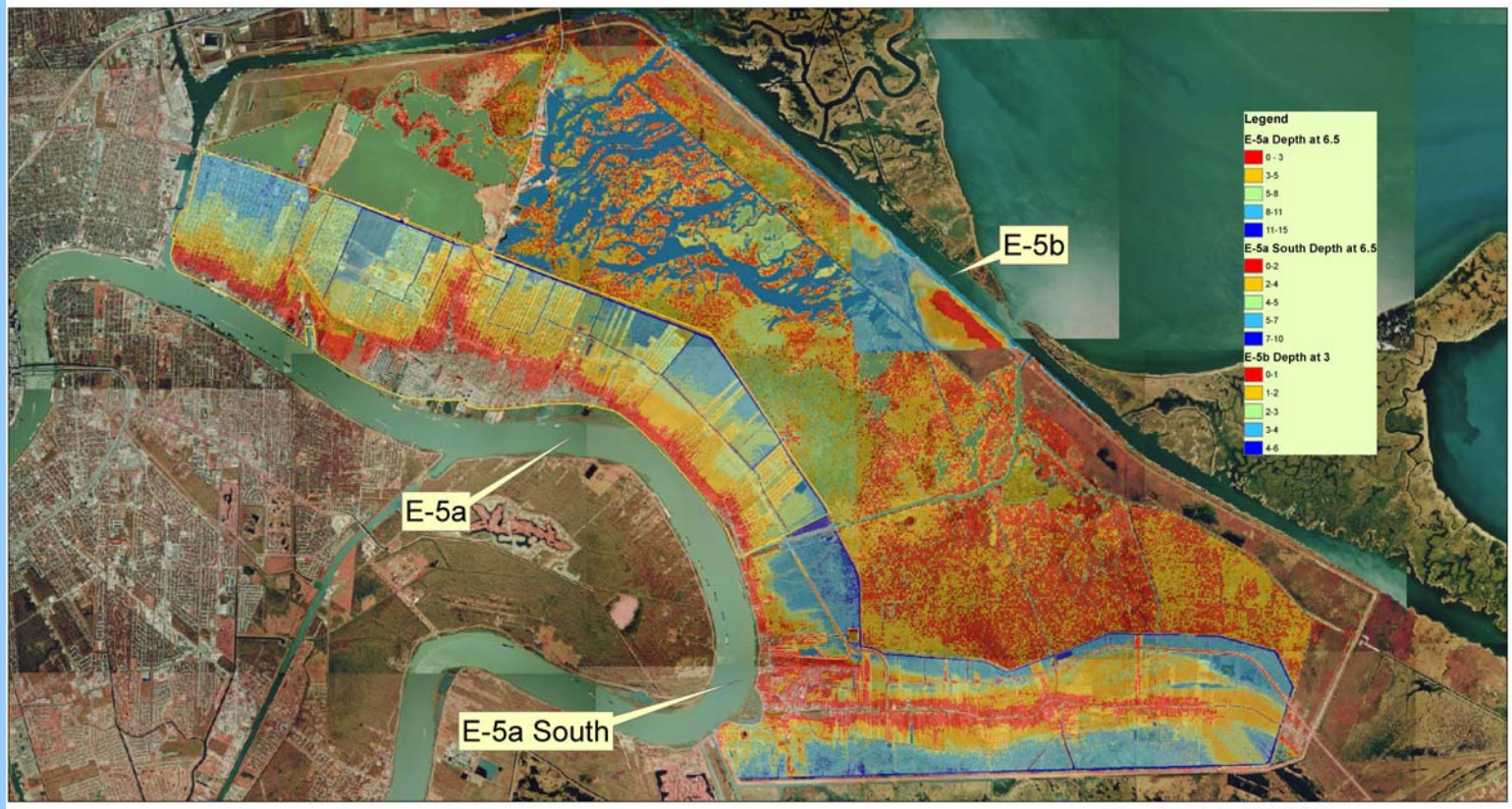
Type	Removed	Owner Removing	Requires Removal	$ Required To Remove Remaining
Boats	10	0	55	$3,300,000
Barges	34	14	8	$640,000
House Boats	1	1	0	$0
Marina Work for Boat Storage				$400,000
Total	45	15	63	$4,340,000

Current Funds of $2,000,000 To Start Vessel Removal Work

Requesting Additional Funds $2,400,000 for Estimated Completion Cost

St Bernard

Saint Bernard



Flood Depths 9/3/2005

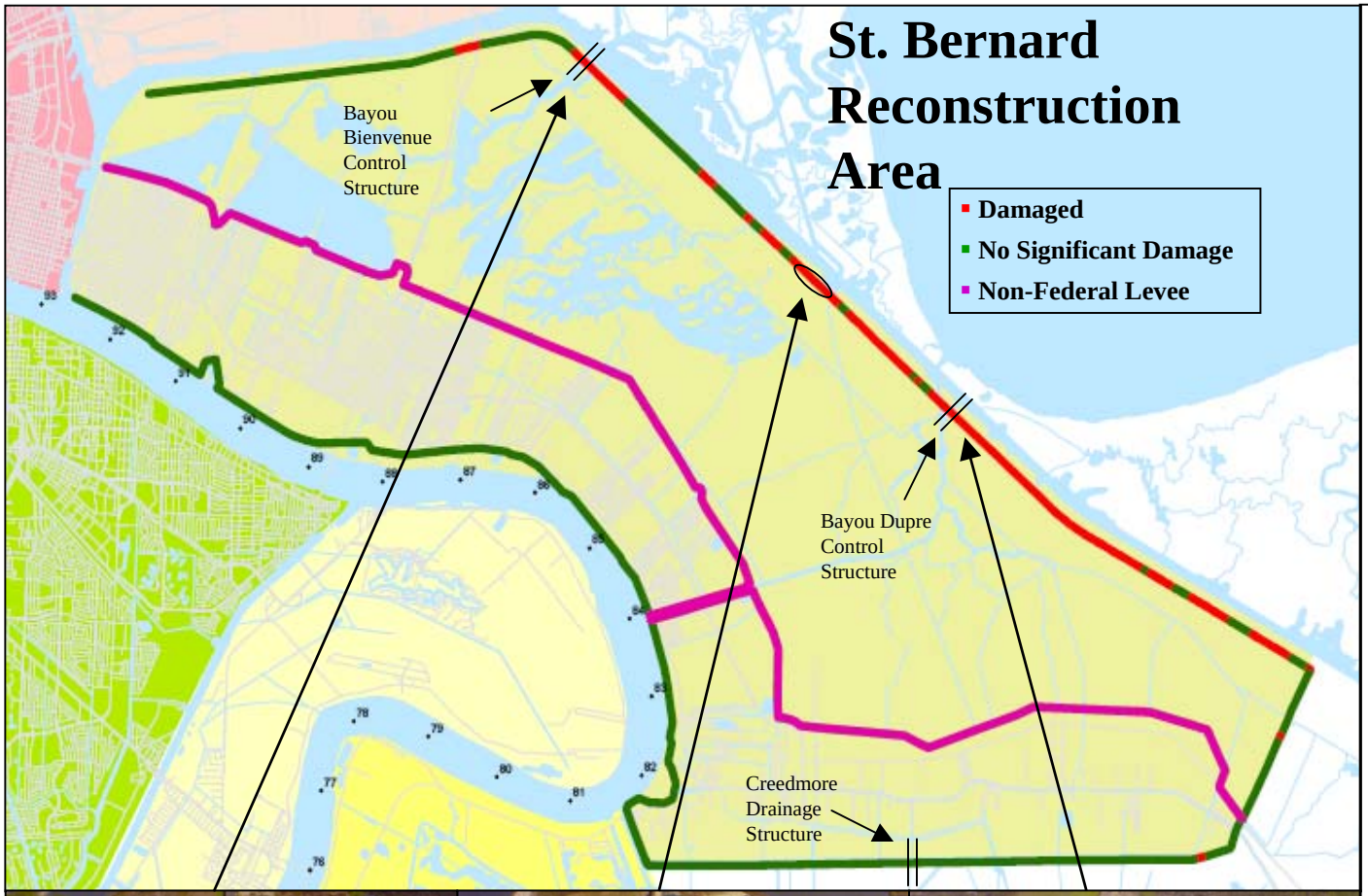
158,000 acre-ft of Hurricane Katrina and Rita floodwaters removed.

Includes Lower 9th Ward

Damage in St Bernard Parish

Damage in St Bernard Parish

St. Bernard Reconstruction Area



Bayou Bienvenue Control Structure

Breach near Pipeline Canal

Bayou Dupre Control Structure

Local Authorities

- Lake Borgne Basin Levee District / Orleans Levee District
- St. Bernard Parish Government
- Louisiana DOTD

Hurricane Protection System

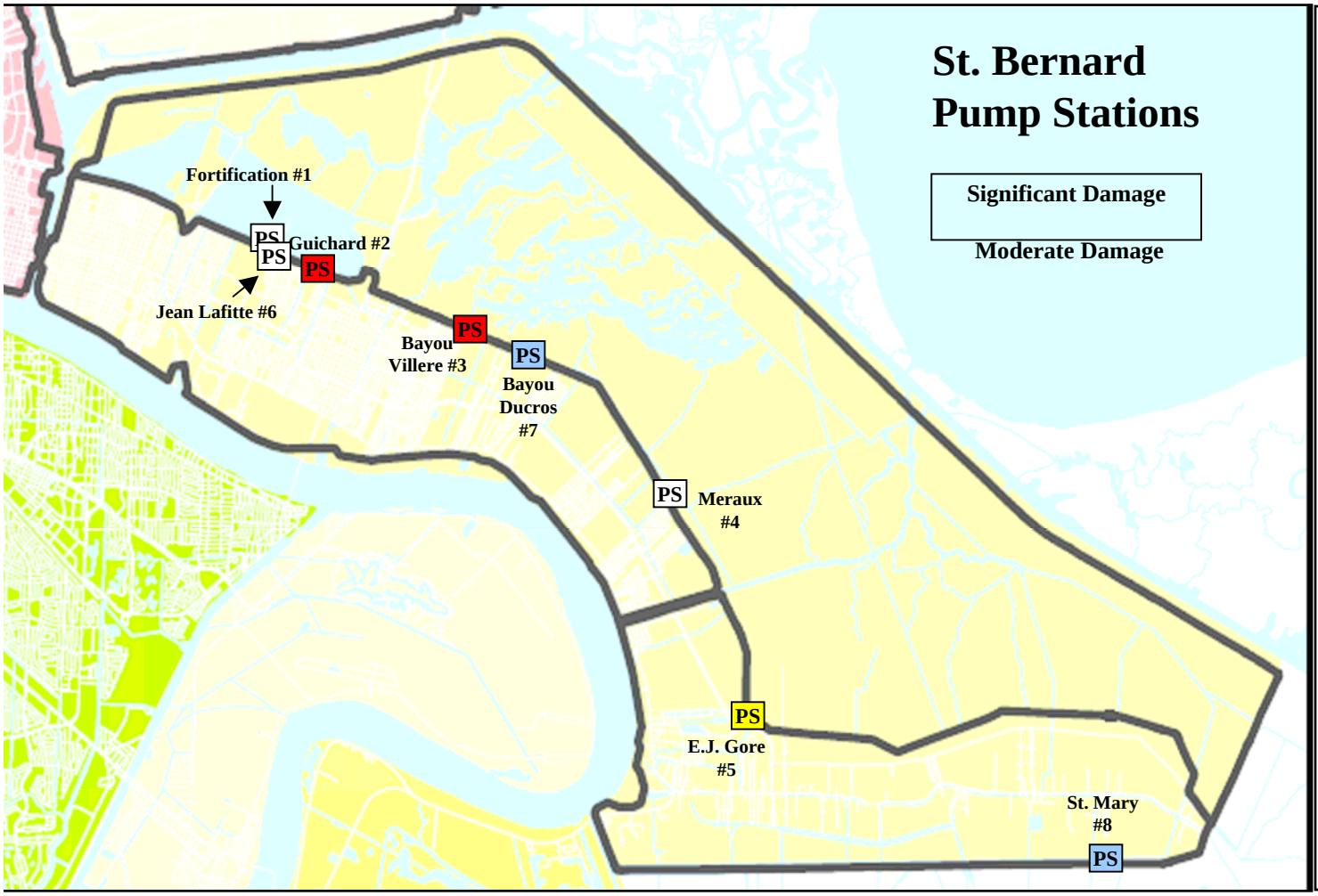
- 30 miles of exterior levee and floodwall
- 22 miles of non-federal interior levee
- 8 pump stations
- 2 control structures
- 6 floodgates

Damage

- 8 miles of exterior levee and floodwall (I-wall)
- 1.4 miles of non-federal interior levee
- 8 pump stations
- 2 control structures
- 4 floodgates

US Army Corps of Engineers

As of 24 2200 OCT 05



Local Authorities

St. Bernard Parish Government

Lake Borgne Levee District

Drainage System

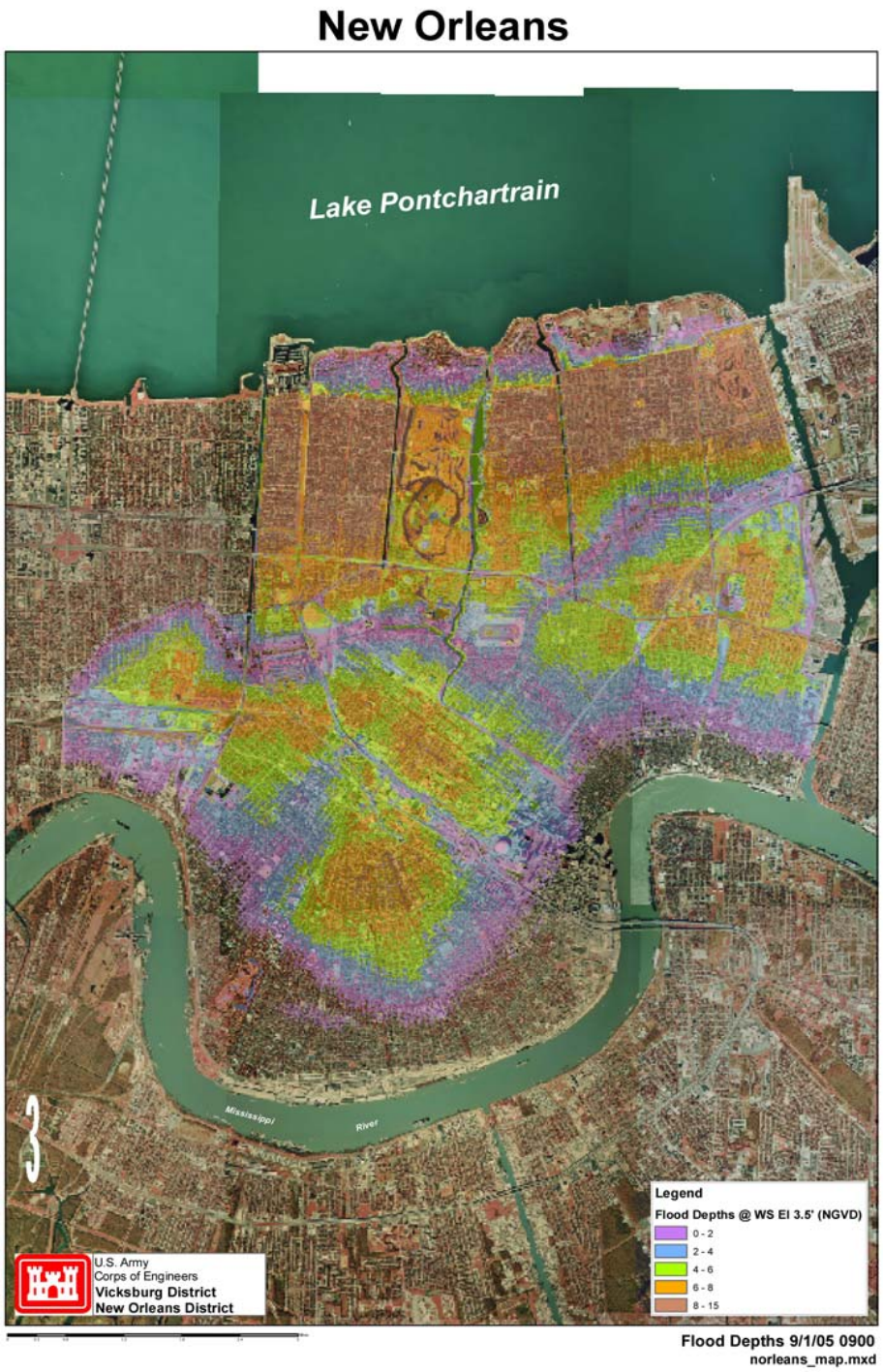
8 Parish owned and operated pump stations (23 pumps)
Pump Capacity = 4,800 cfs

Damage

1 pump station moderately damaged (partial pumping capacity)

2 pump stations severely damaged

5 pump stations minor damage (full capacity)



New Orleans Metro

110,000 acre-ft of Hurricane Katrina and Rita floodwaters removed.

includes Hoey Basin in Jefferson Parish

New Orleans East

120,000 acre-ft of Hurricane Katrina and Rita floodwaters removed.

Damage in New Orleans

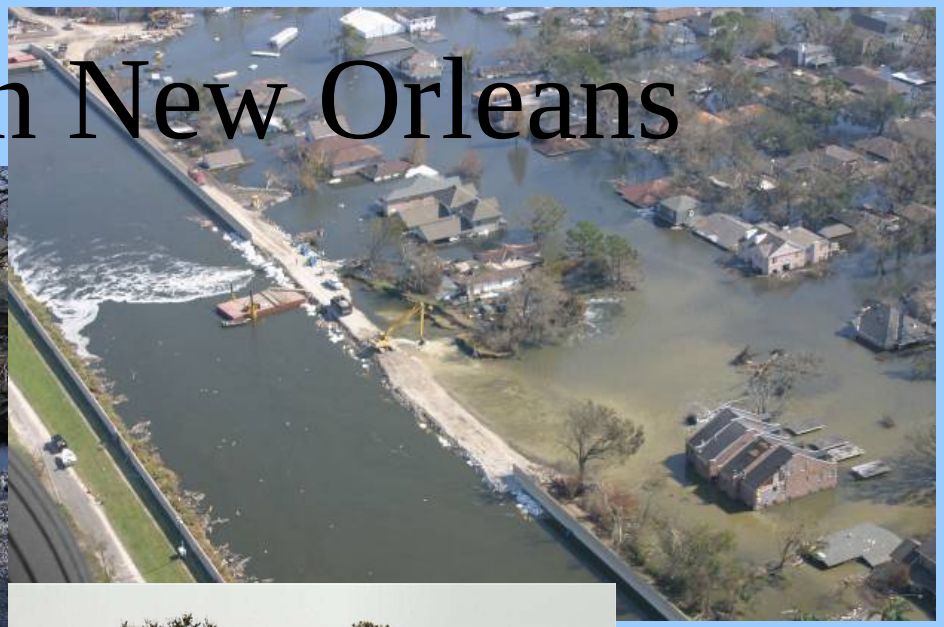
Damage in New Orleans

Damage in New Orleans

Damage in New Orleans

Damage in New Orleans

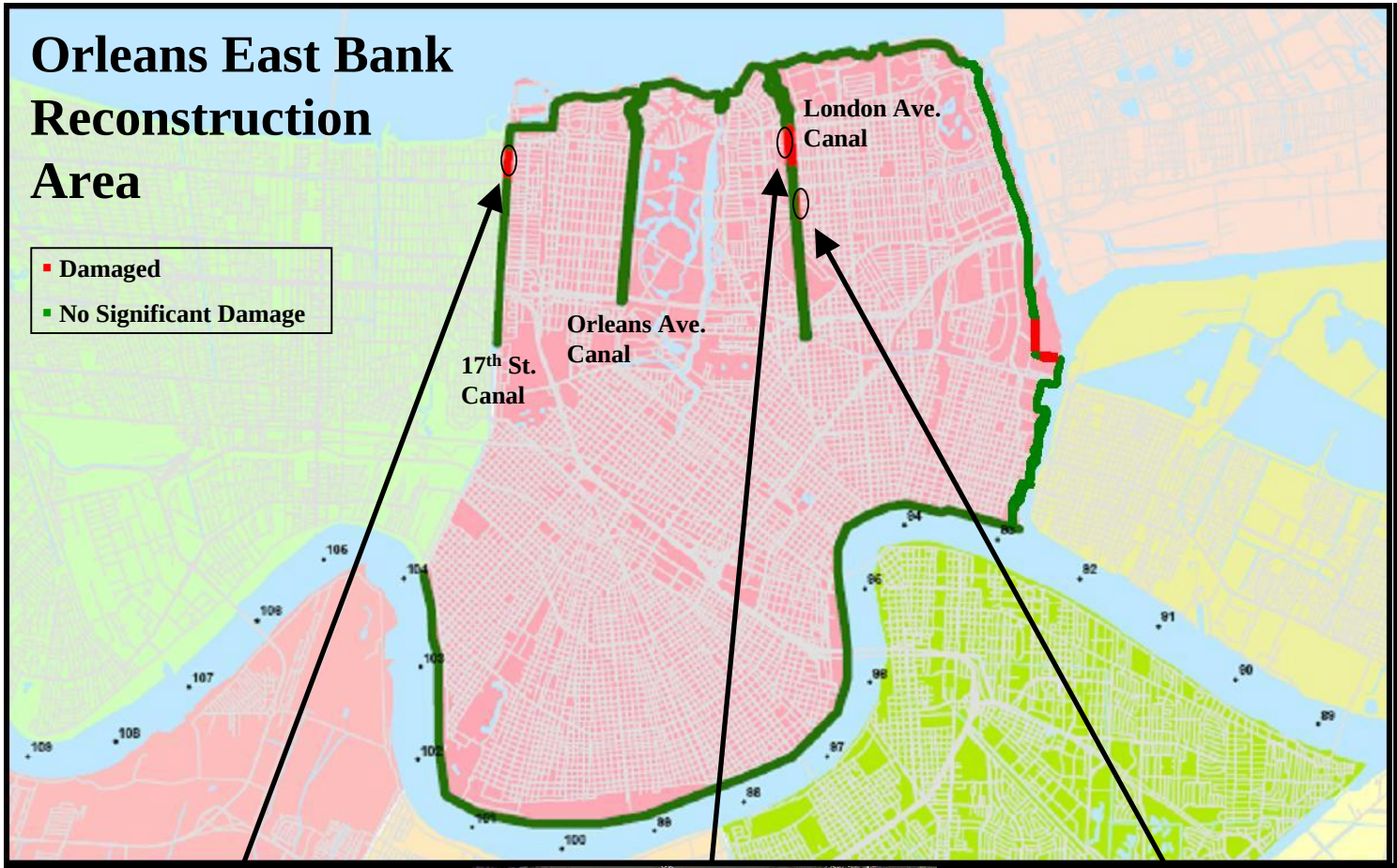
Damage in New Orleans



Damage in New Orleans

Damage in New Orleans East

Orleans East Bank Reconstruction Area



17th St. Canal I-wall Breach

London Ave. Canal Breach

Canal Breach at Mirabeau

Local Authorities

- Orleans Levee District
- Orleans Parish Government
- N.O. Sewerage and Water Board
- Louisiana DOTD

Hurricane Protection System

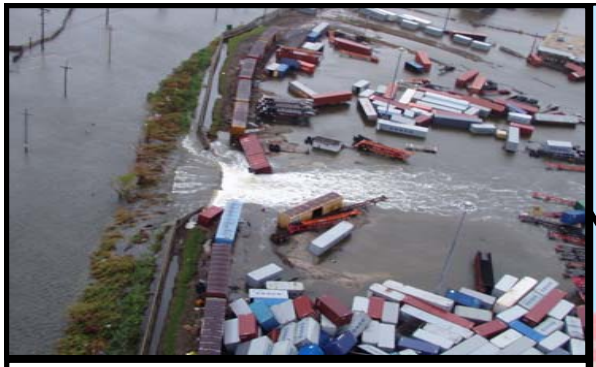
- 19.2 miles of levee and floodwall
- 13 pump stations
- 15 roadway floodgates

Damage

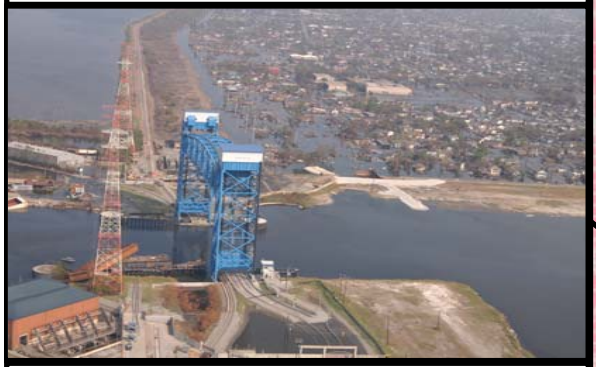
- 1.1 miles of levee and floodwall
- 13 pump stations

US Army Corps of Engineers

As of 24 2200 OCT 05



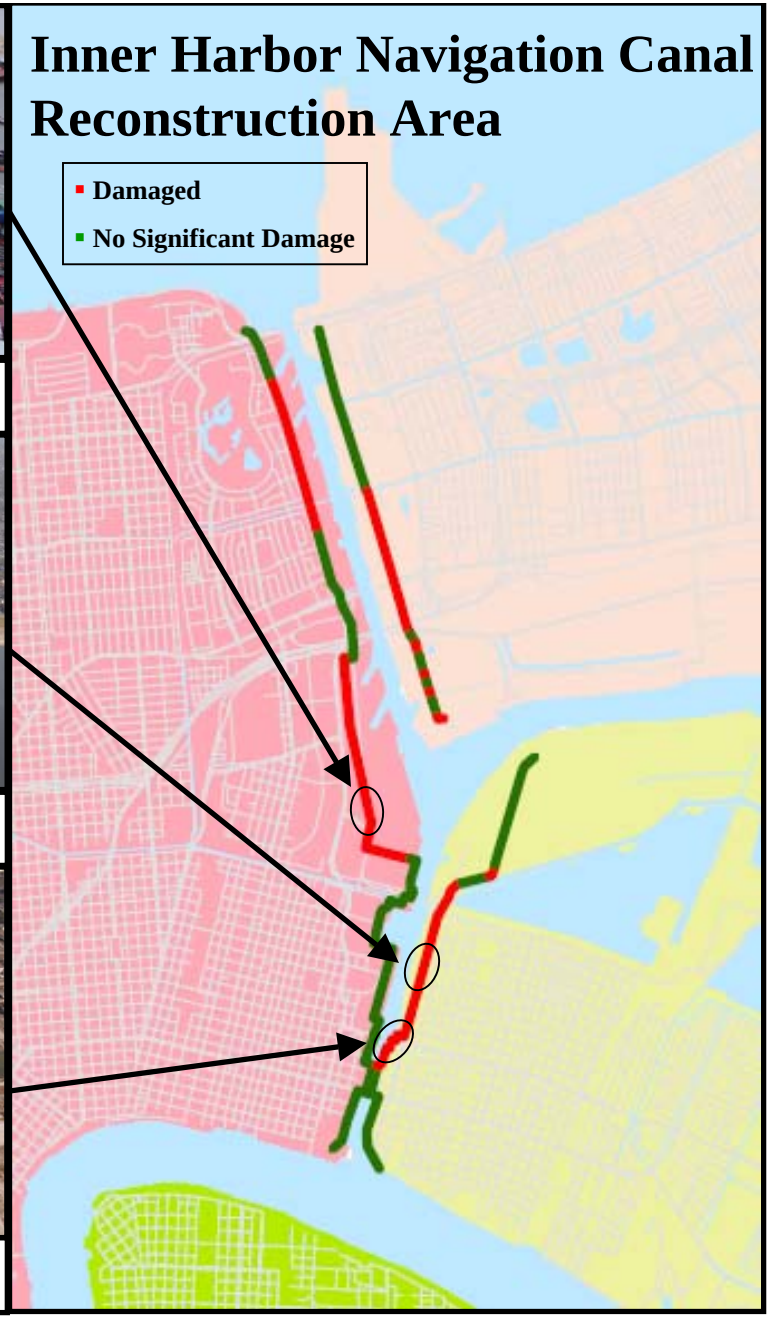
Flooding of Container Storage Yard



Northern 9th Ward Breach

Sheetpile Floodwall Collapse

Inner Harbor Navigation Canal Reconstruction Area



Local Authorities

- Orleans Levee District
- Port of New Orleans
- Louisiana DOTD

Hurricane Protection System

- 12.3 miles of floodwall and levee

Damage

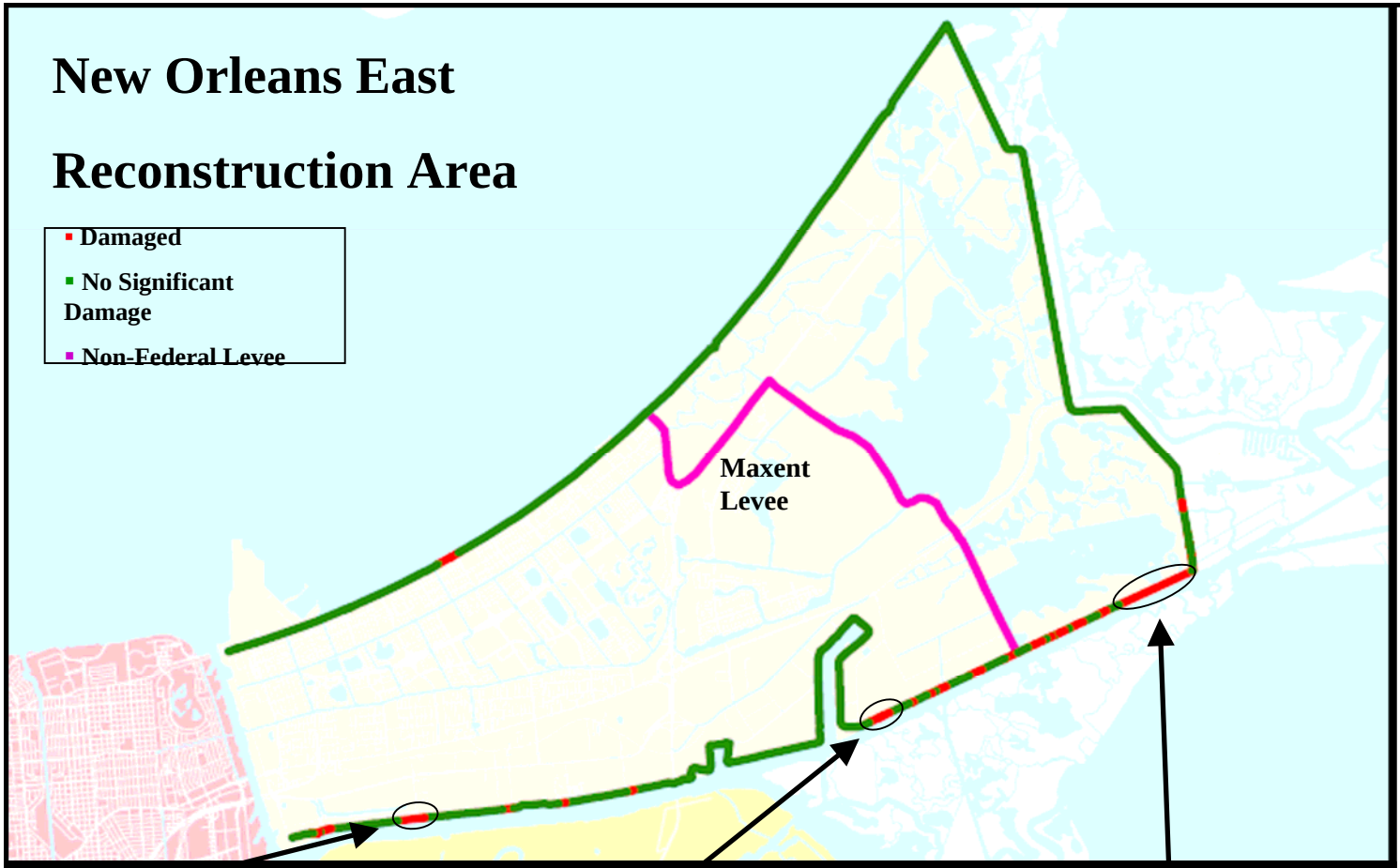
- 5 miles of floodwall and levee

US Army Corps of Engineers

As of 24 2200 OCT 05

New Orleans East

Reconstruction Area



Citrus Back Levee

Air Products Breach

Intracoastal Waterway Breach

Local Authorities

- Orleans Levee District
- Orleans Parish Government
- N.O. Sewerage and Water Board
- Louisiana DOTD

Hurricane Protection System

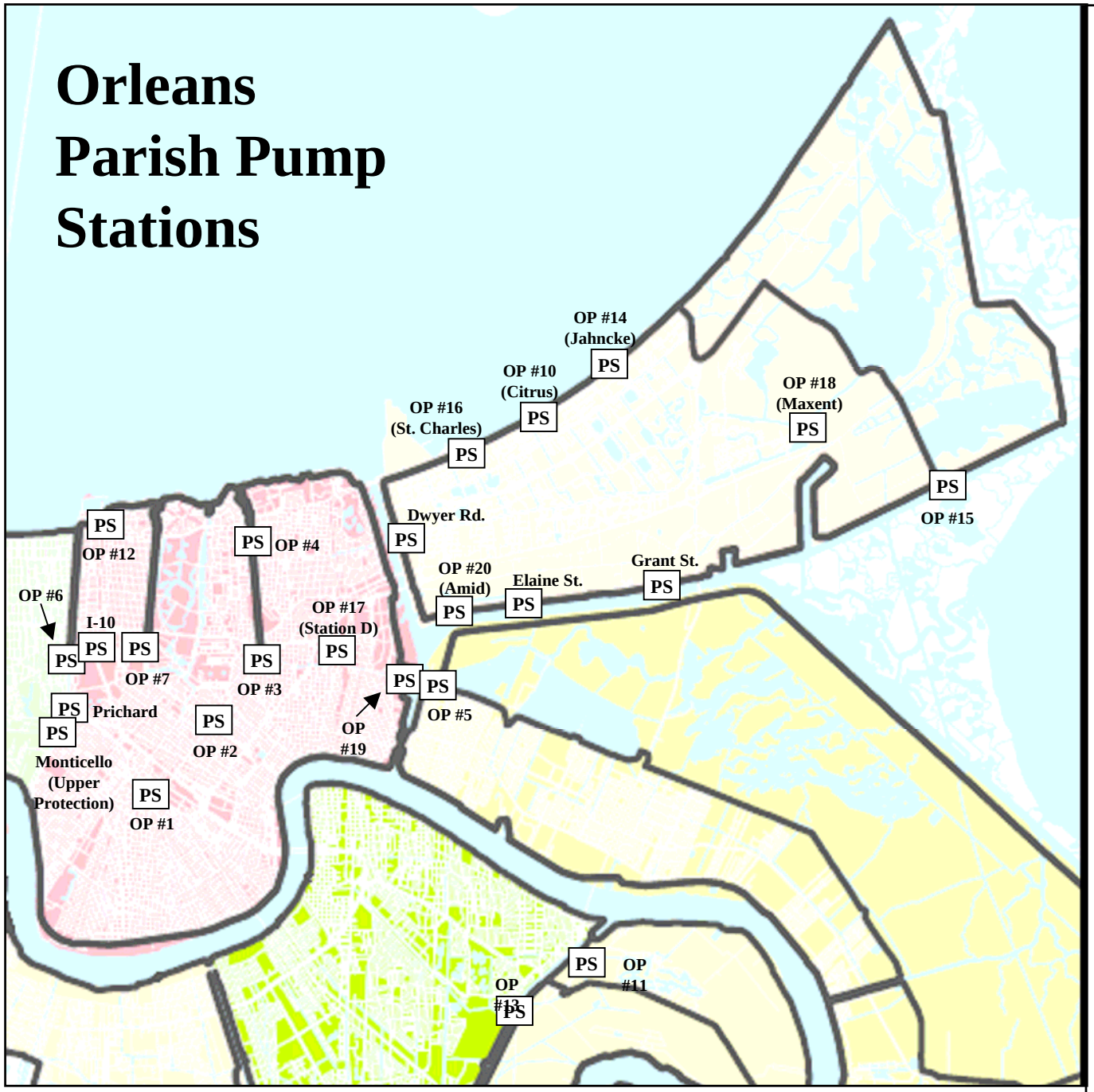
- 39 miles of exterior levee and floodwall (I-wall)
- 8 miles of interior levee
- 8 pump stations
- 2 highway floodgates
- 1 railroad floodgate

Damage

- 4.6 miles of exterior levee and floodwall
- 8 pump stations

US Army Corps of Engineers

As of 24 2200 OCT 05



Local Authorities

- New Orleans Sewerage & Water Board

Drainage System

- 23 Parish owned and operated pump stations (108 pumps)

  Pump Capacity = 44,000 cfs

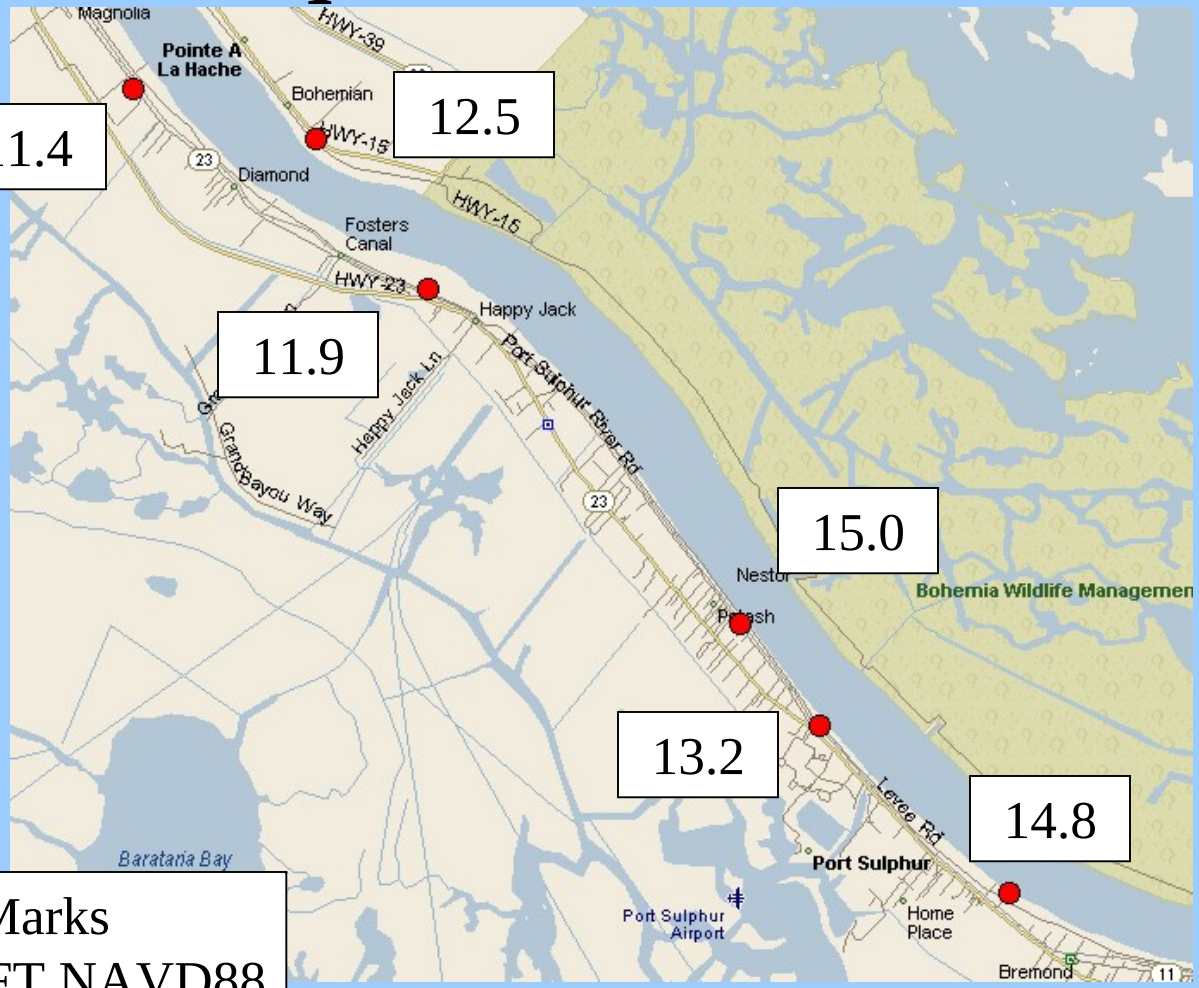
Damage

- Assessment Pending

- SWB through FEMA repairing electric motors & switch gear

Damage in St Tammany Parish

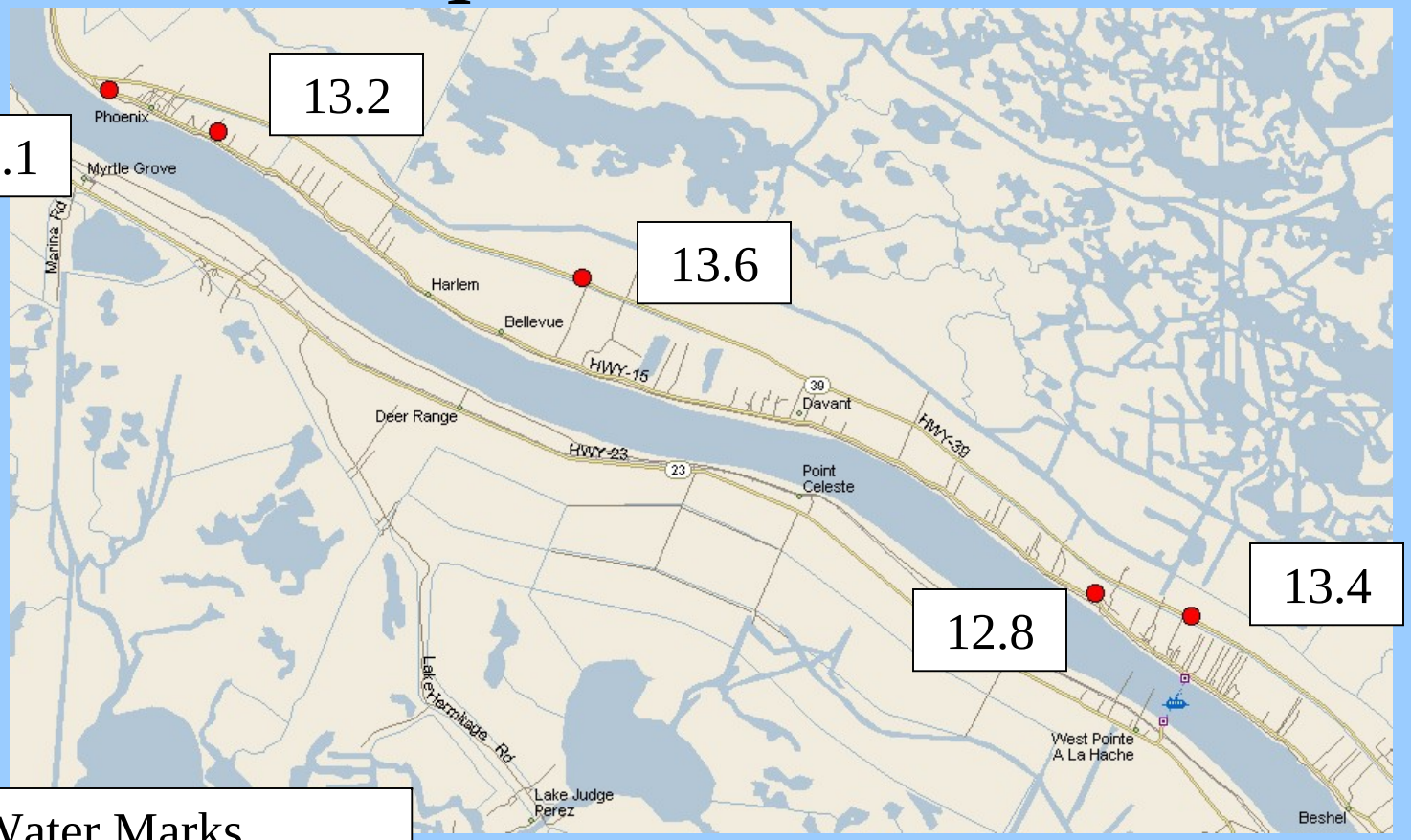
Plaquemines Parish



High Water Marks
Elevation in FT NAVD88

Preliminary

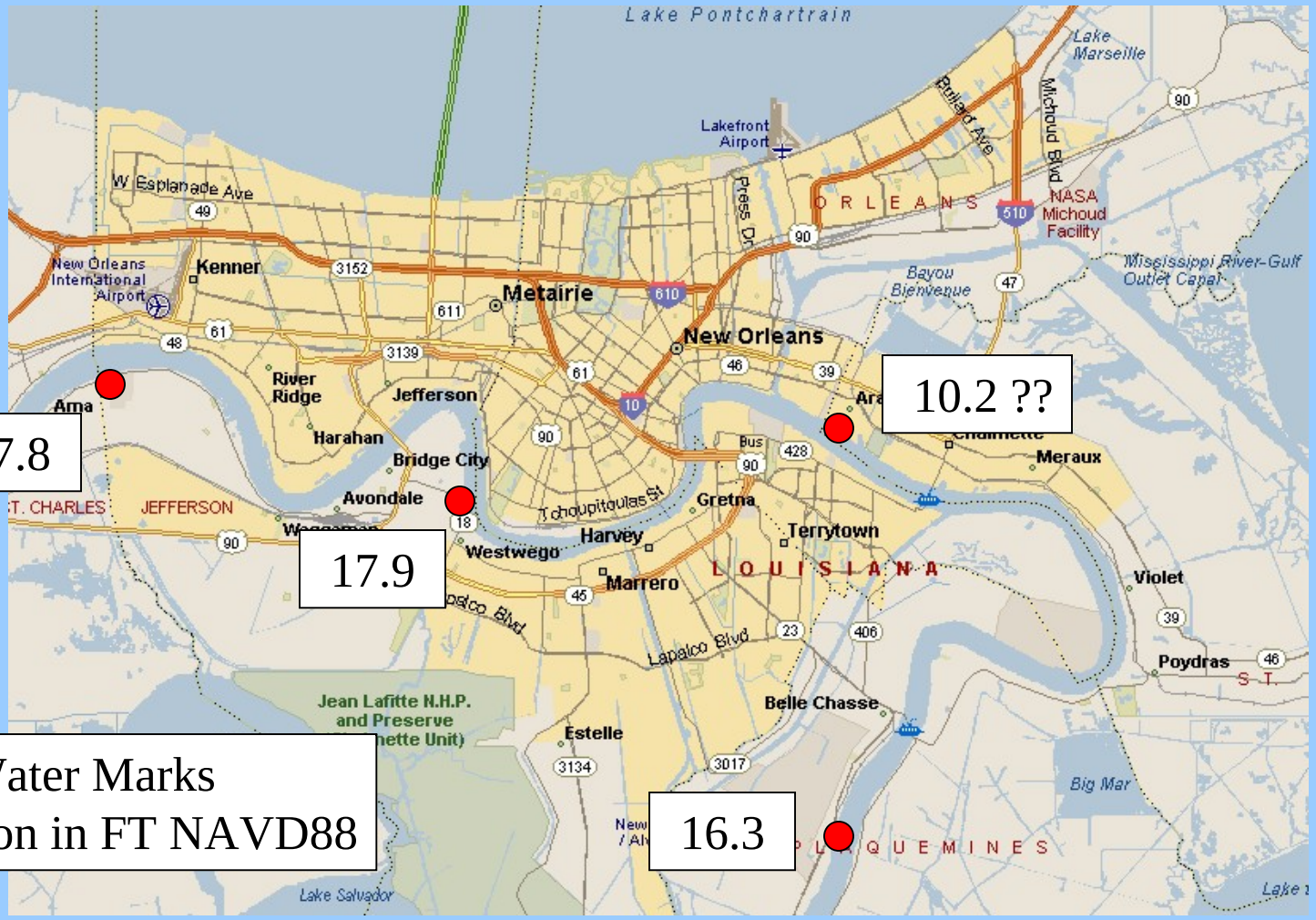
Plaquemines Parish



High Water Marks
Elevation in FT NAVD88

Preliminary

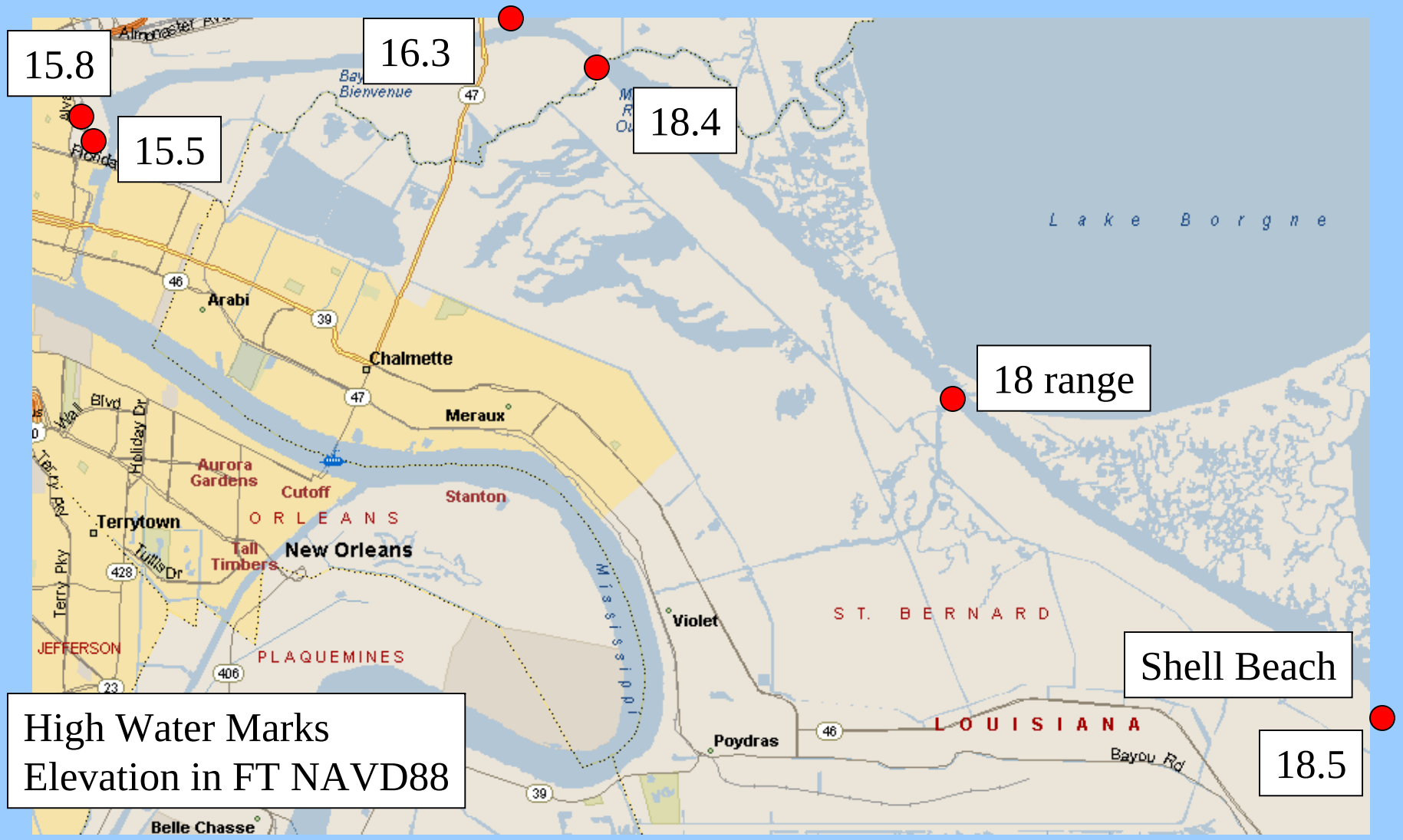
Mississippi River Levee



High Water Marks
Elevation in FT NAVD88

Preliminary

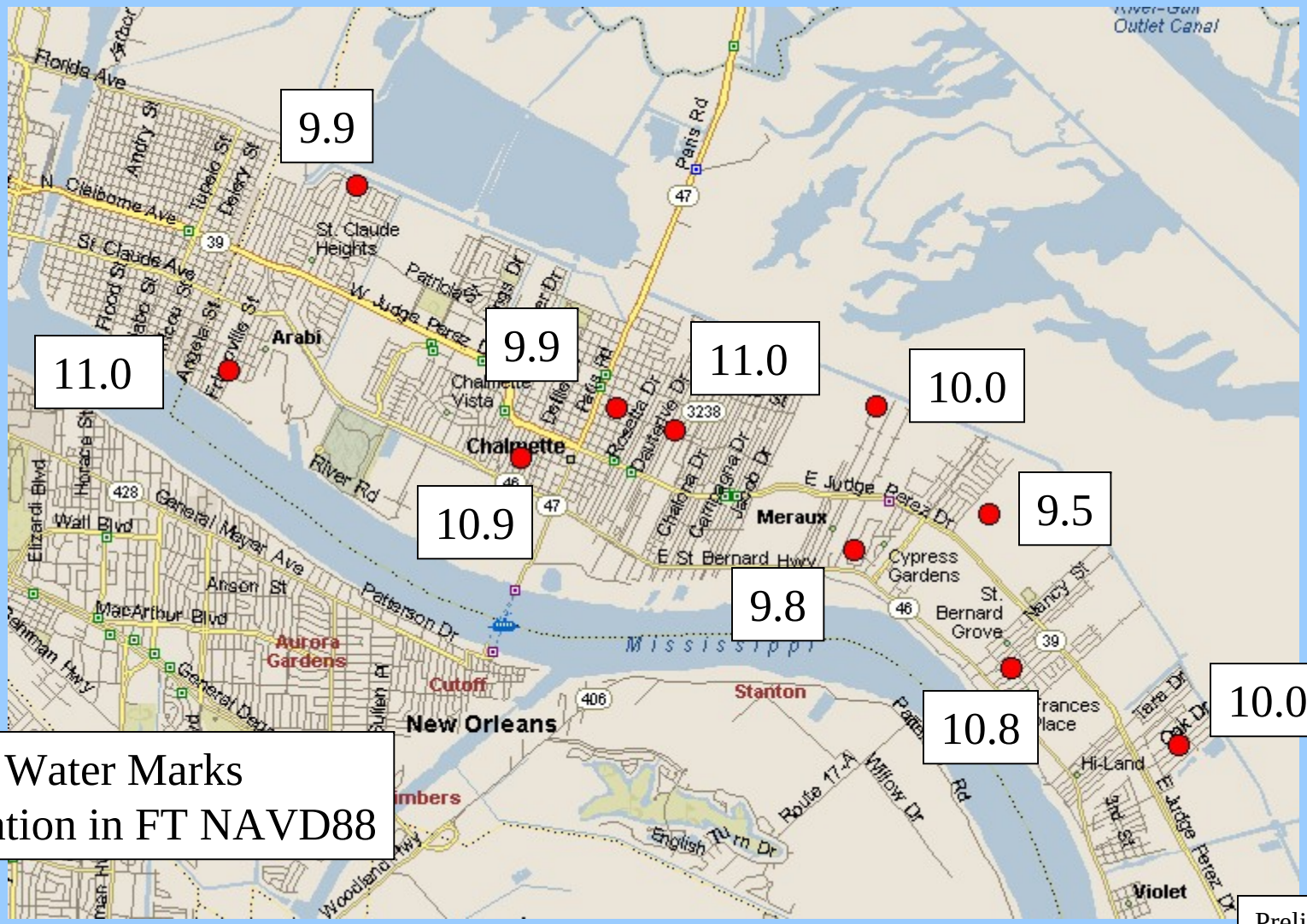
St Bernard and 9th Ward



High Water Marks
Elevation in FT NAVD88

Preliminary

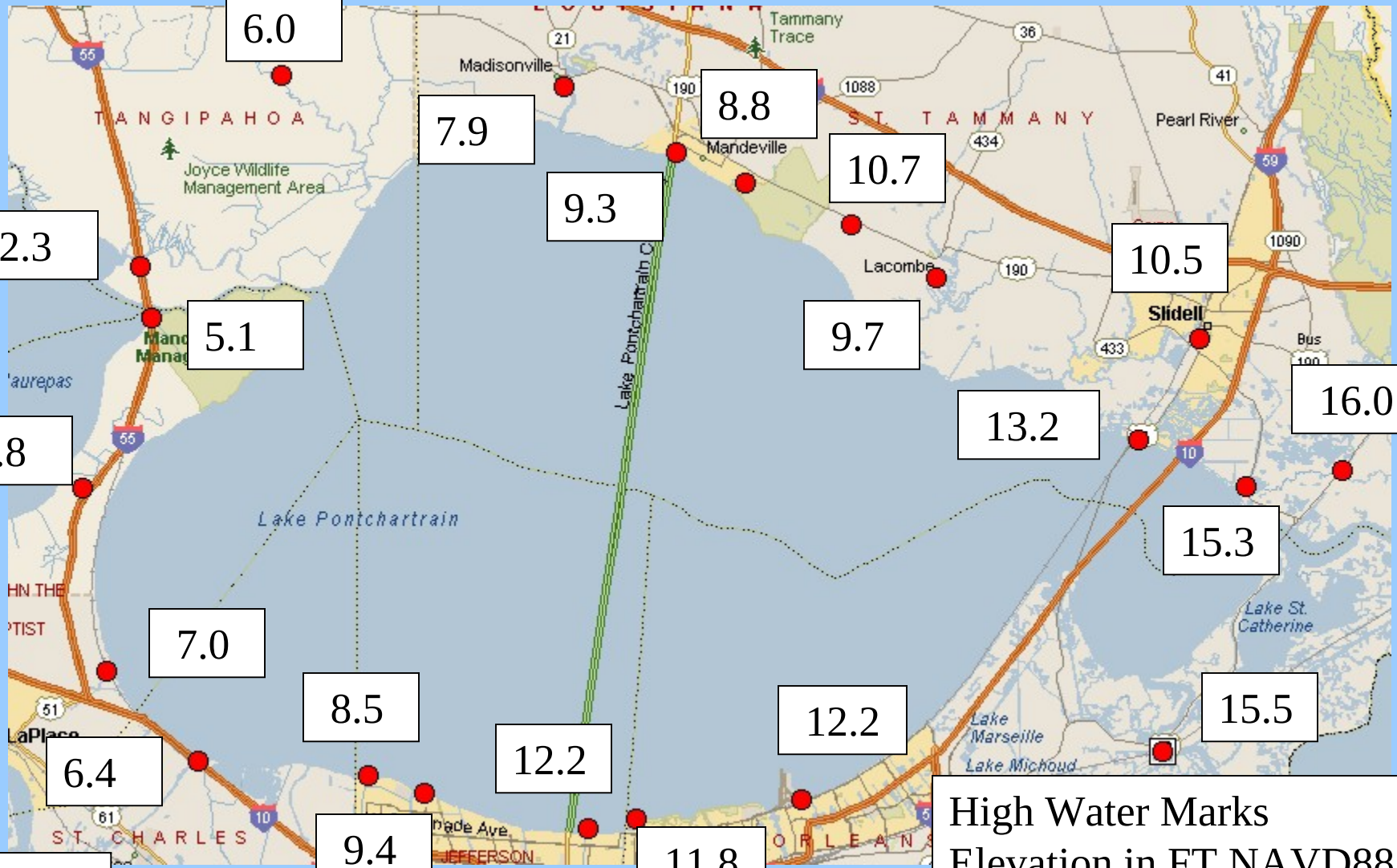
St Bernard and 9th Ward, Interior



High Water Marks
Elevation in FT NAVD88

Preliminary

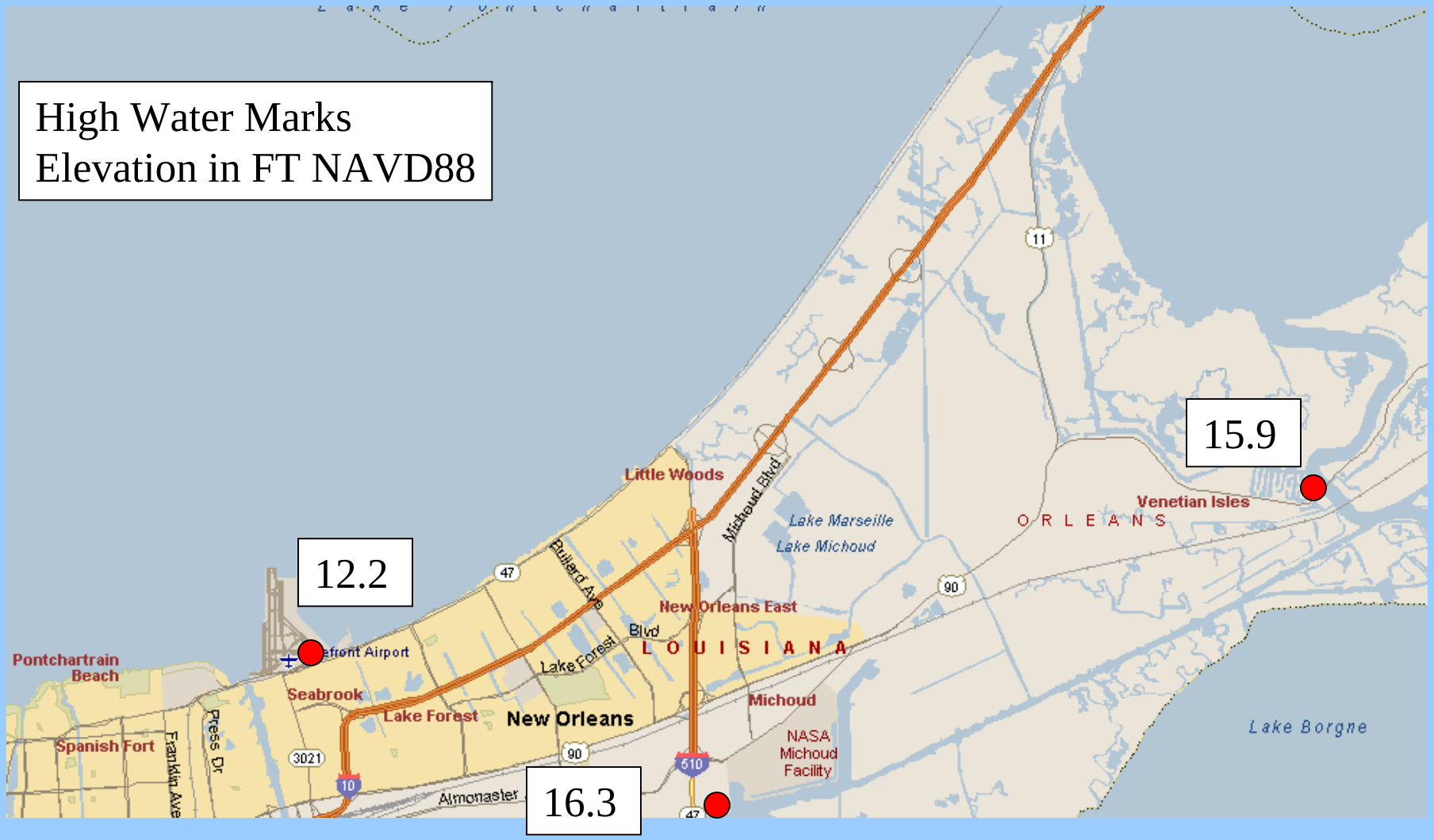
Lake Pontchartrain



High Water Marks
Elevation in FT NAVD88

Preliminary

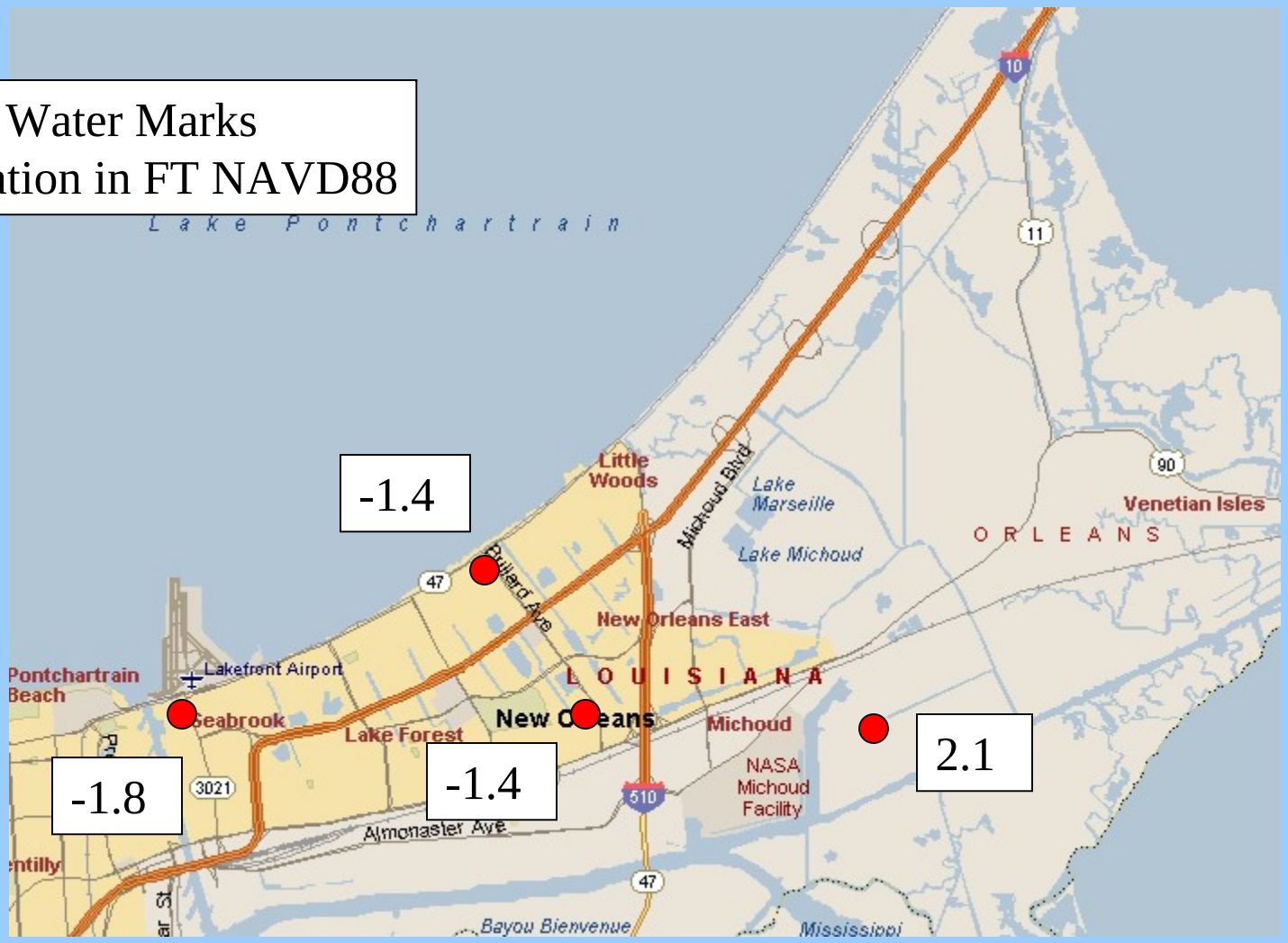
New Orleans East



Preliminary

New Orleans East, Interior

High Water Marks
Elevation in FT NAVD88



Preliminary

IHNC

High Water Marks
Elevation in FT NAVD88

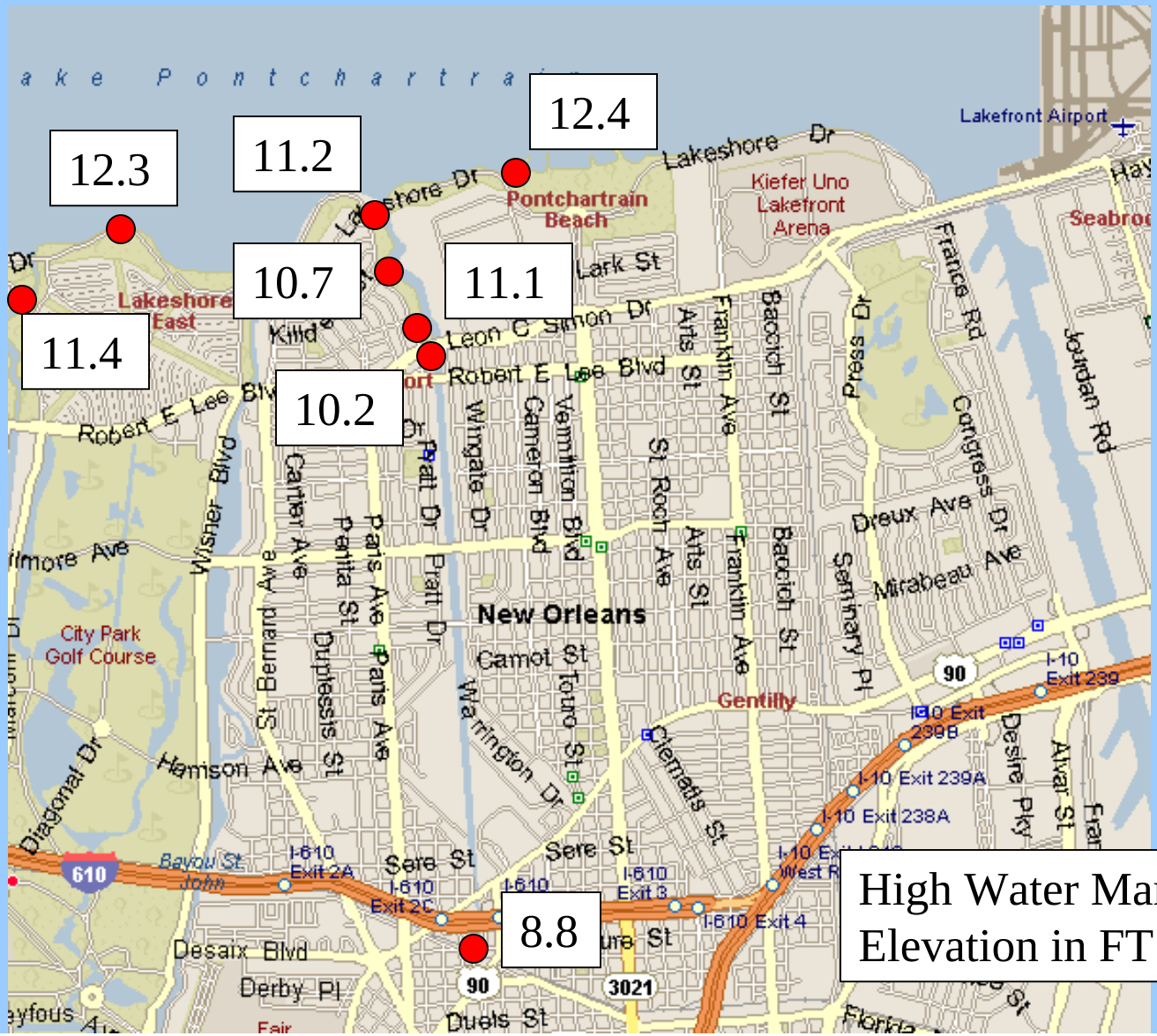
Preliminary

17th St Canal

High Water Marks
Elevation in FT NAVD88

Preliminary

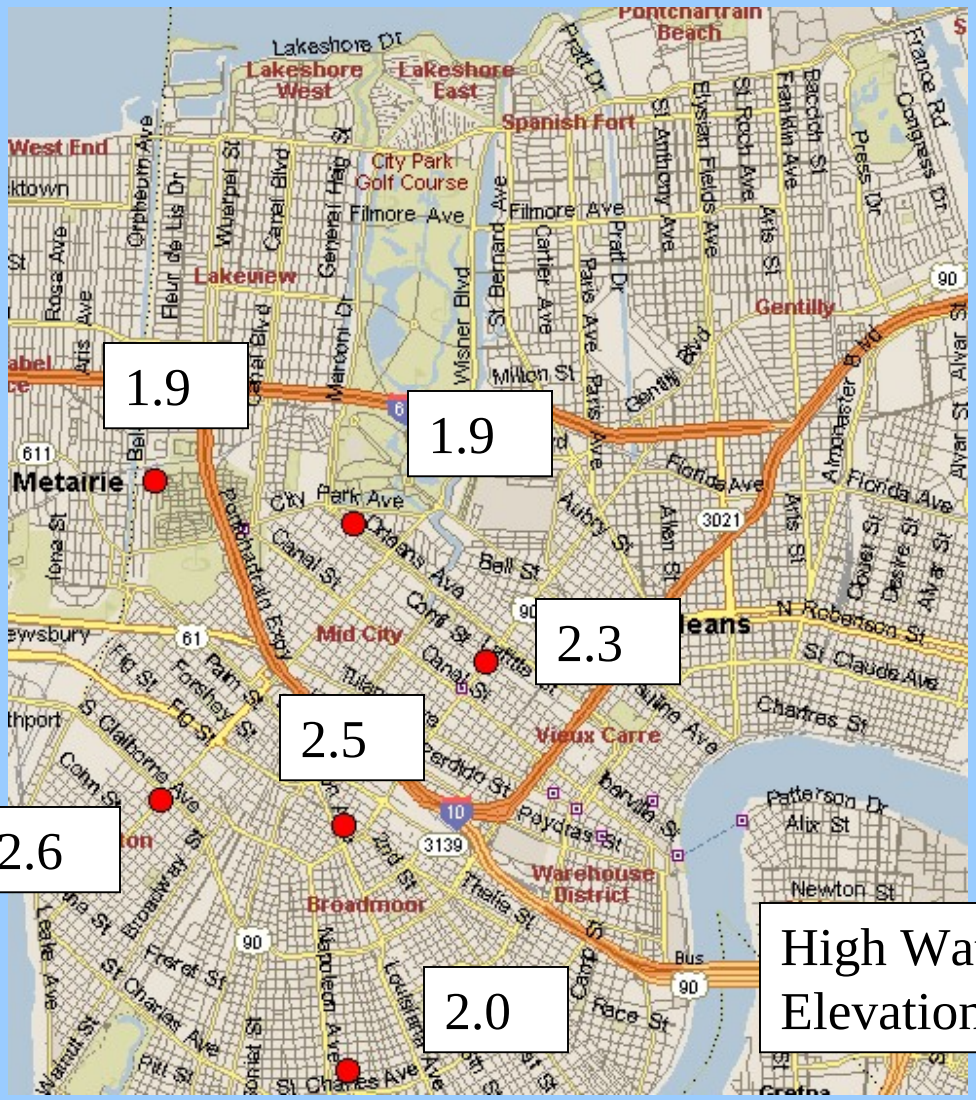
London Ave Canal



High Water Marks
Elevation in FT NAVD88

Preliminary

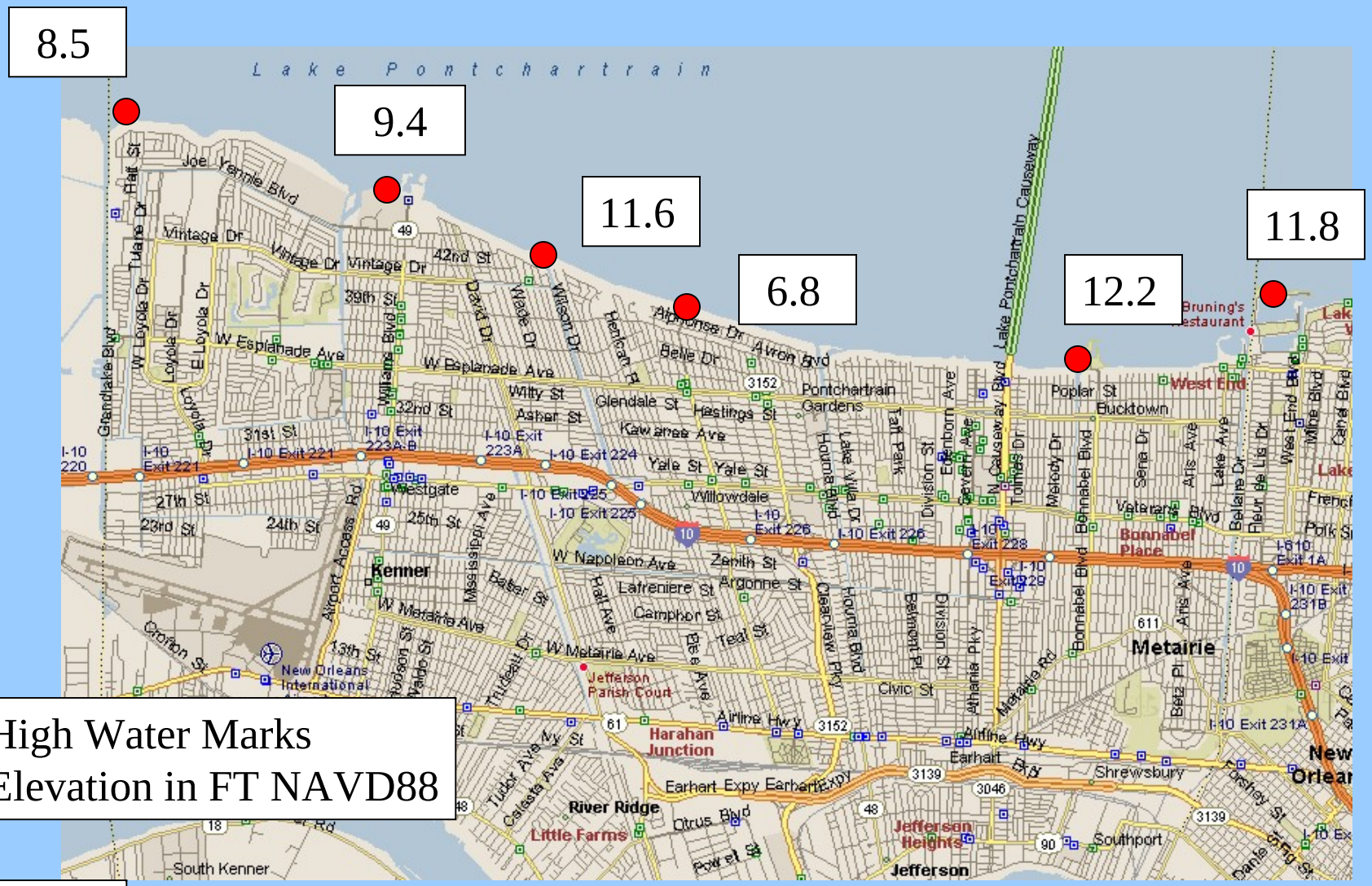
New Orleans, Interior



High Water Marks
Elevation in FT NAVD88

Preliminary

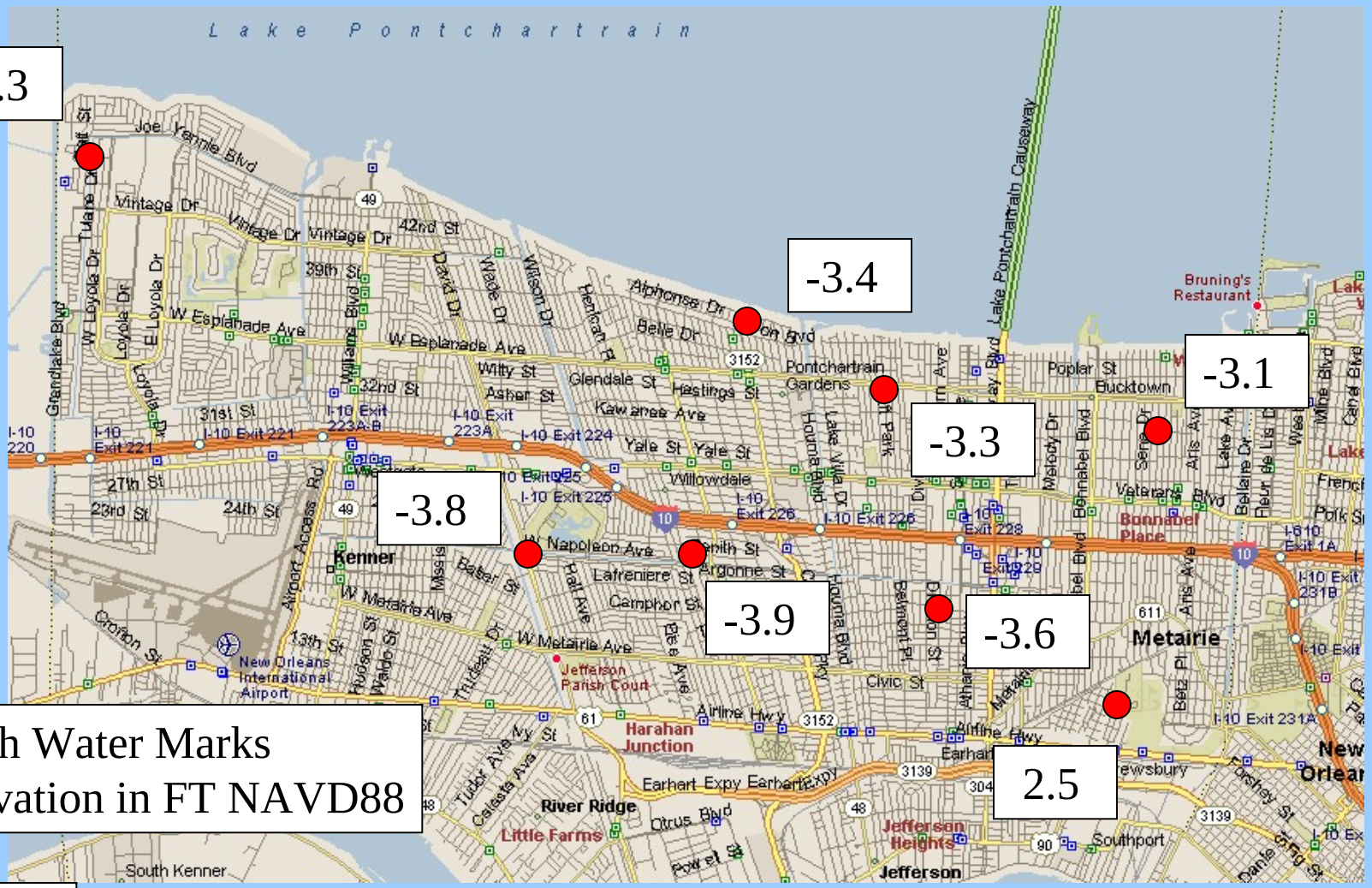
East Bank Jefferson Lakefront



High Water Marks
Elevation in FT NAVD88

Preliminary

East Bank Jefferson, Interior

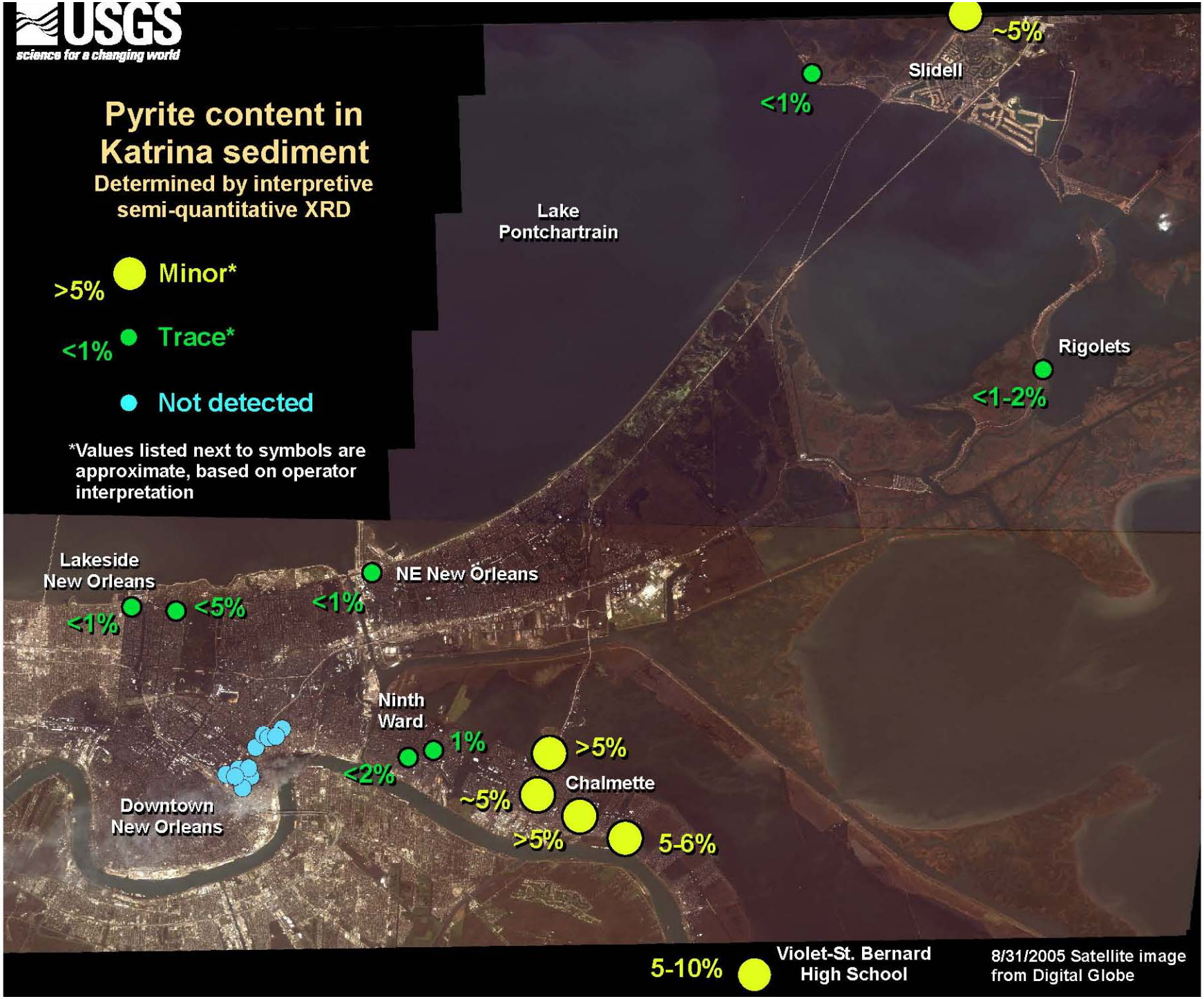


High Water Marks
Elevation in FT NAVD88

Preliminary

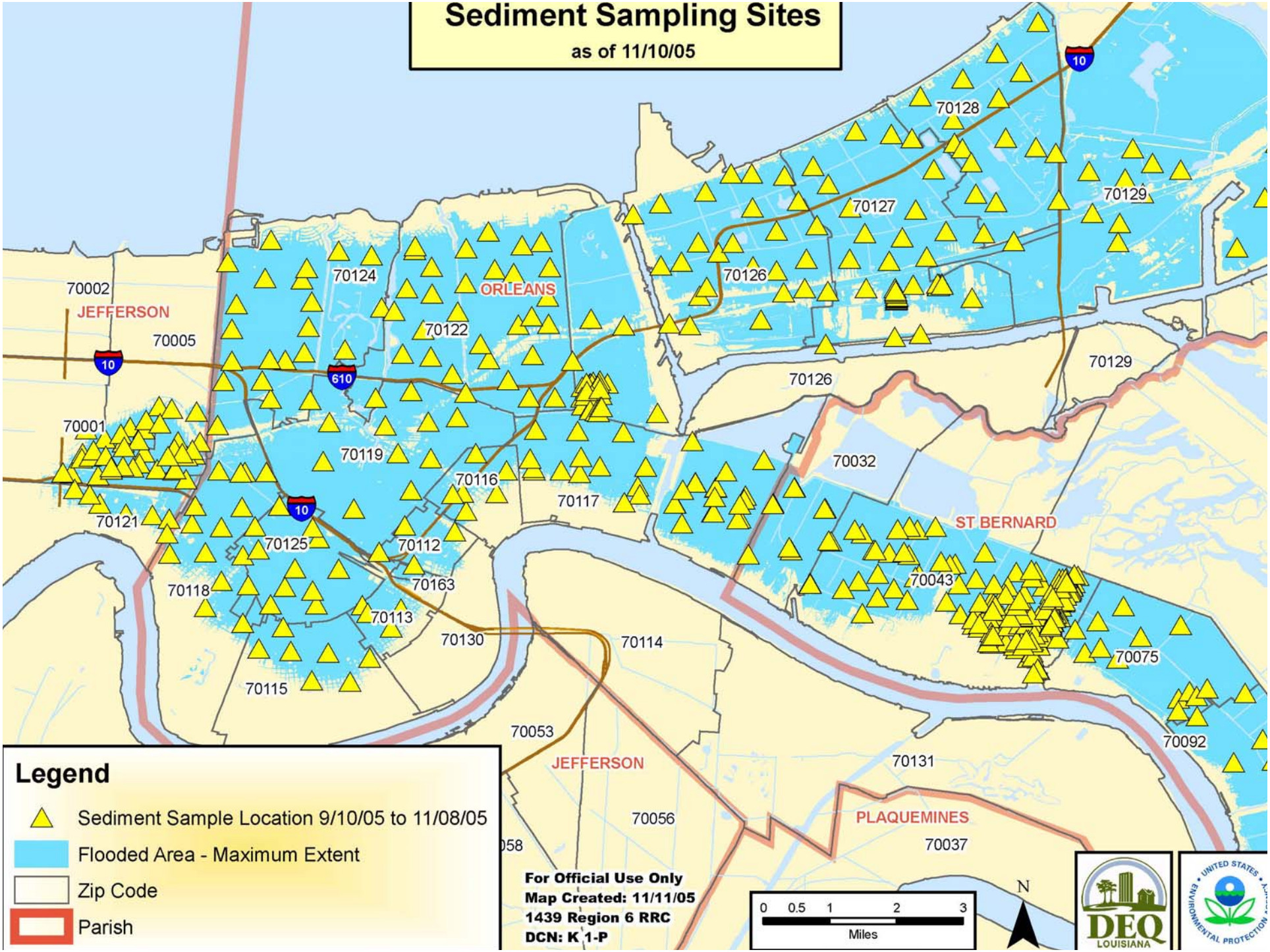
Sediment Monitoring

Sediment Monitoring


USGS
science for a changing world
Pyrite content in Katrina sediment
Determined by interpretive semi-quantitative XRD
>5% Minor*
<1% Trace*
Not detected
*Values listed next to symbols are approximate, based on operator interpretation
~5%
Slidell
<1%
Lake Pontchartrain
Rigolets
<1-2%
Lakeside New Orleans
<1%
<5%
<1%
NE New Orleans
Ninth Ward
1%
<2%
>5%
Chalmette
~5%
>5%
5-6%
Downtown New Orleans
5-10%
Violet-St. Bernard High School
8/31/2005 Satellite image from Digital Globe

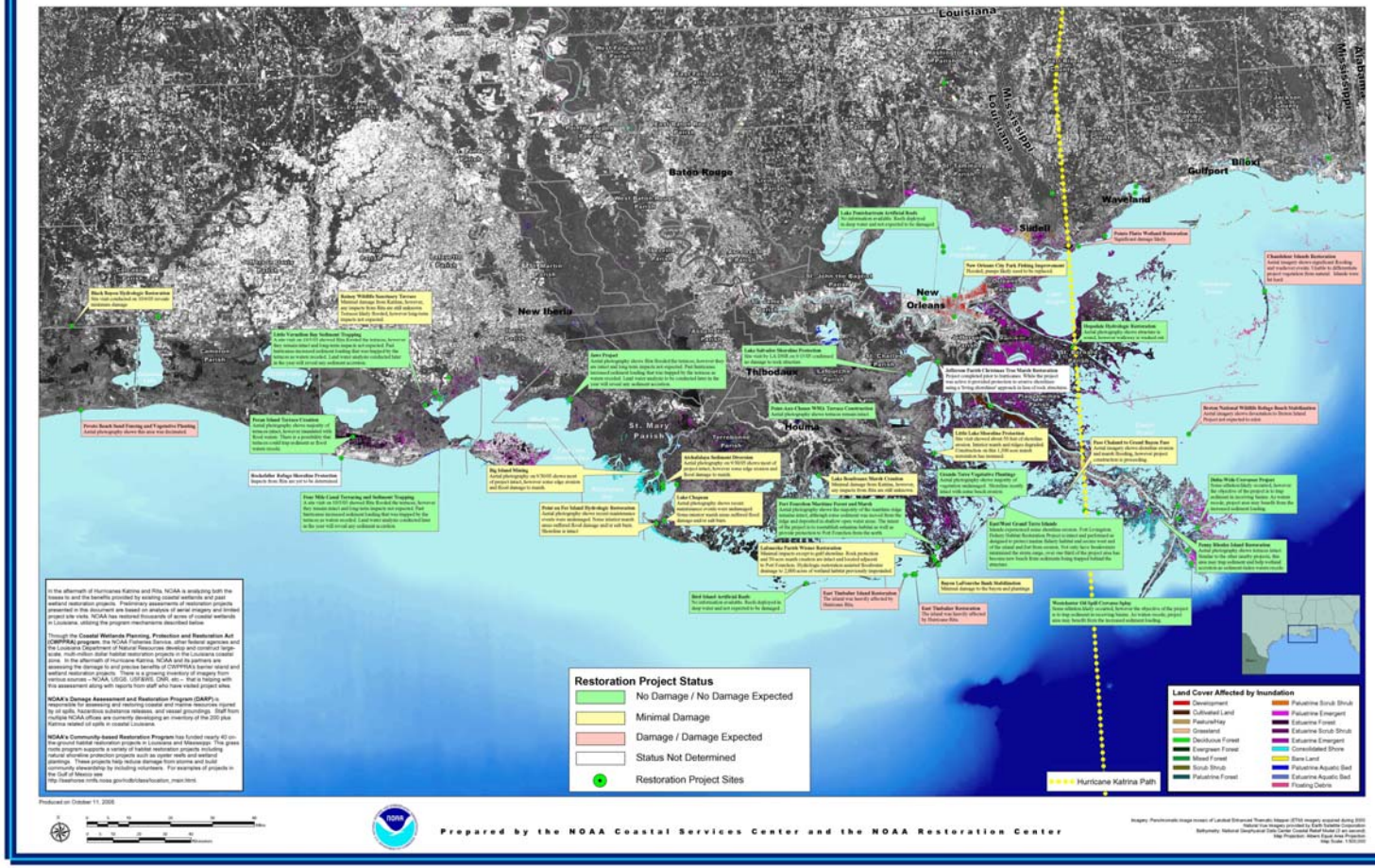
Sediment Resampling Levels

Nov. 19 - 20, 2005

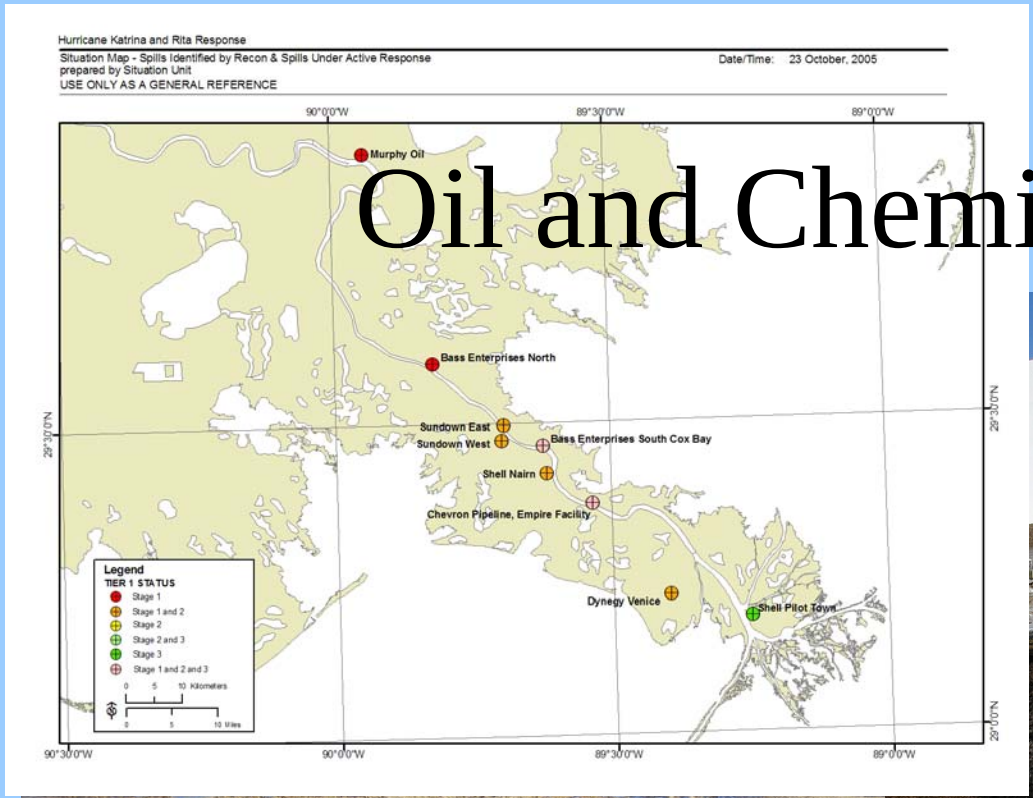

Sediment Sampling Sites
as of 11/10/05
70002
JEFFERSON
70005
70001
70121
70124
ORLEANS
70122
70119
70116
70117
70125
70112
70163
70118
70113
70130
70115
70114
70053
JEFFERSON
70056
70128
70127
70126
70126
70129
70129
70032
ST BERNARD
70043
70075
70092
70131
PLAQUEMINES
70037
10
610
10
10
Legend
Sediment Sample Location 9/10/05 to 11/08/05
Flooded Area - Maximum Extent
Zip Code
Parish
For Official Use Only
Map Created: 11/11/05
1439 Region 6 RRC
DCN: K 1-P
0 0.5 1 2 3
Miles
N
DEQ
LOUISIANA
UNITED STATES ENVIRONMENTAL PROTECTION

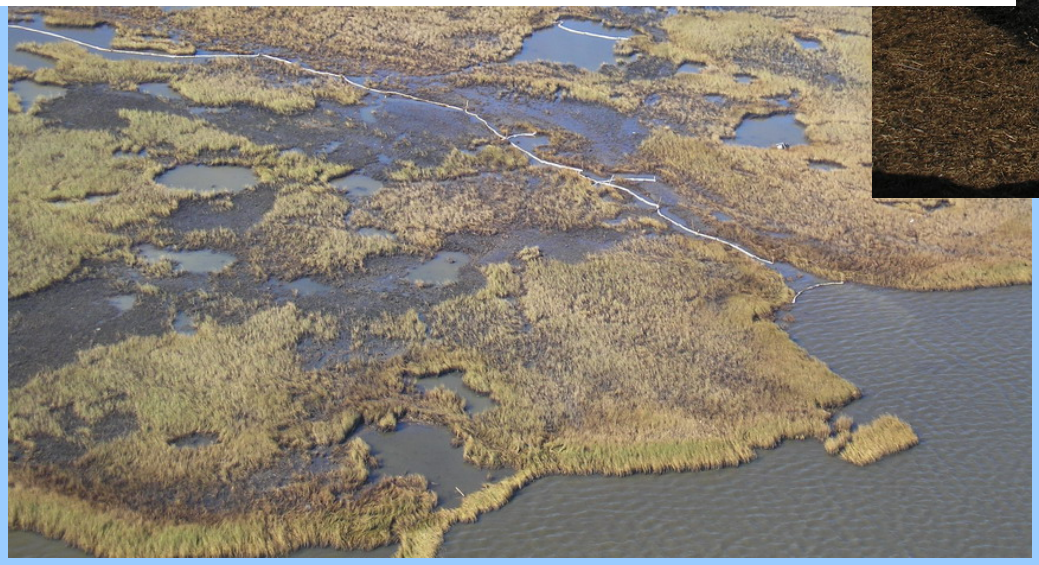
NOAA Habitat Restoration Projects

Hurricane Katrina/Rita Impacts



Oil and Chemical Spills





Impact of Katrina

Nancy J. Powell, PE
Chief, Hydrologic Engineering Section
New Orleans District

TITLE: Enhance Protection Plan

PRESENTED BY: Tim Axtman and Carl Anderson, USACE-MVN

SUMMARY: This presentation described the synergies between structural hurricane protection and the restoration of coastal wetlands. The basis for this comparison was the Louisiana Coastal Area (LCA) Ecosystem Restoration Study and the Category 5 hurricane protection assessment made by the New Orleans District following Hurricane Katrina. The process of forecasting loss trends and developing appropriate coastal restoration measures was explained. The relationship between pre- and post-storm coastal features and landscapes and their effect on storm surge was described. The second portion of the presentation discussed the potential structural alignments and features that could provide Category 5 hurricane protection across coastal Louisiana. Many of these structural features and alignments incorporate existing hurricane protection projects. Other proposed protection projects were identified that could be capitalized on. Those coastal areas with no current projects or plans were identified. In summary, the hydrologic impacts of both environmental restoration measures and structural hurricane protection features should be considered.

Integrating Storm Protection and Coastal Restoration for Louisiana

Hydraulic Design Conference

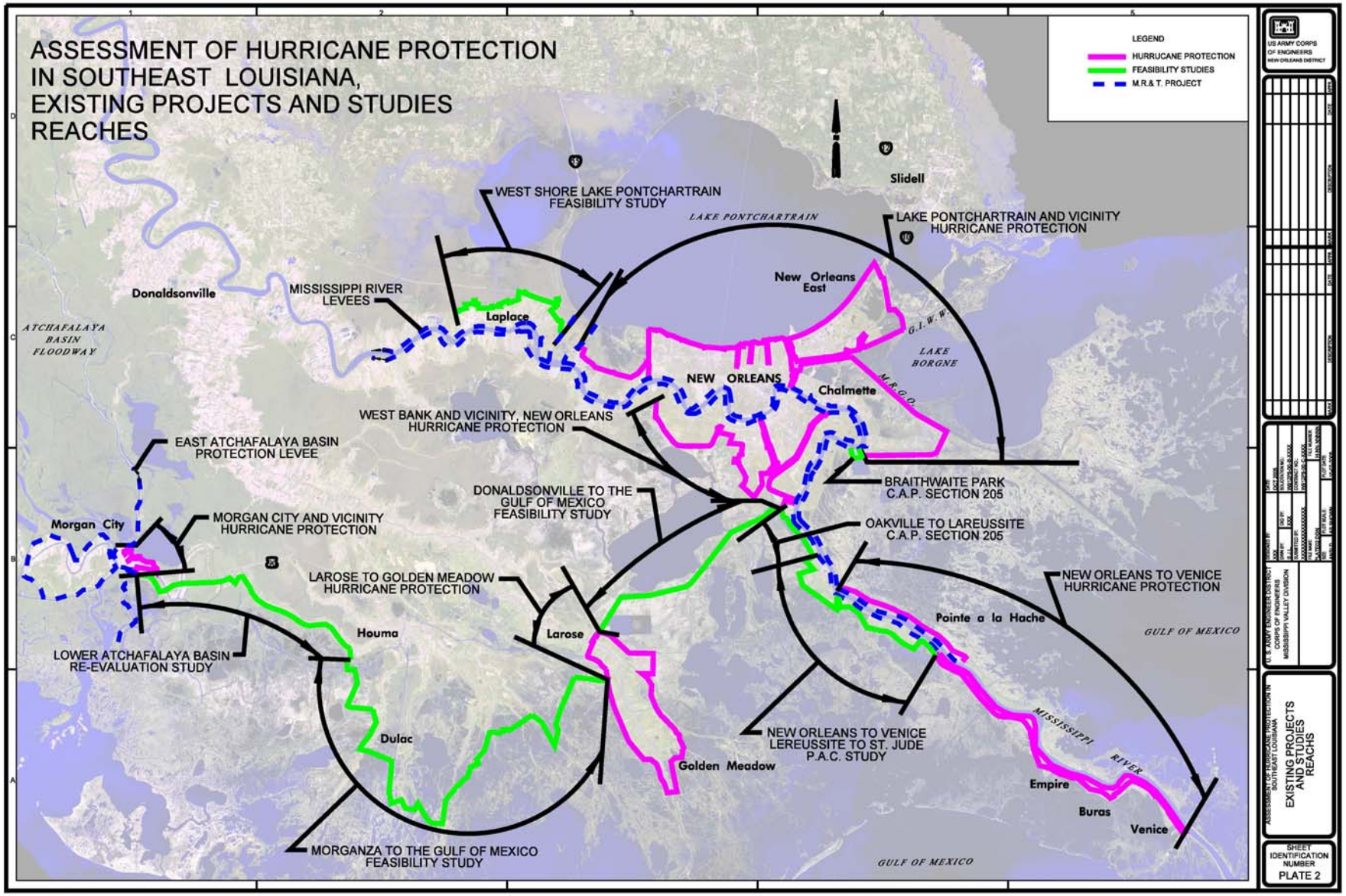
December 2005

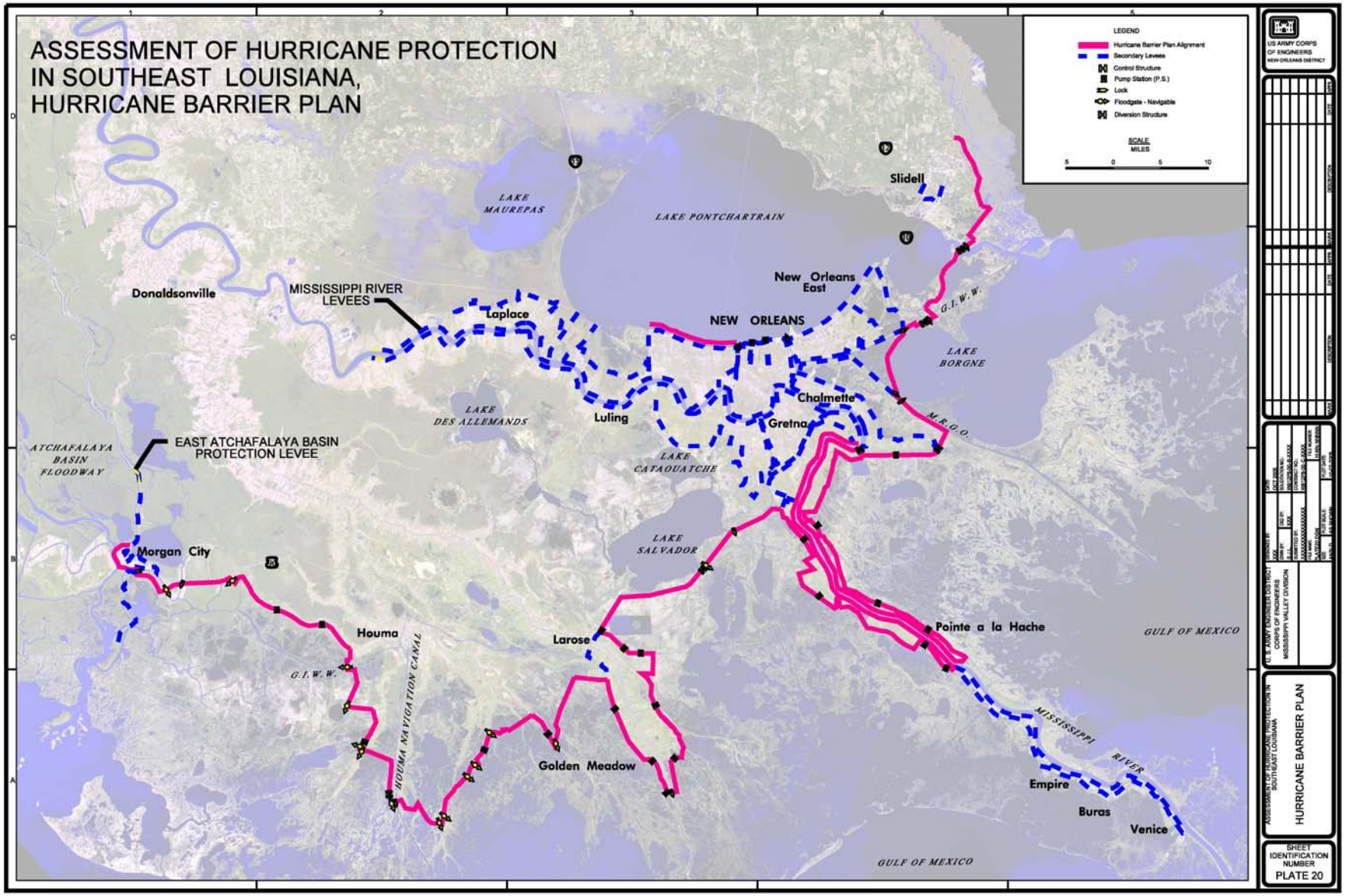
US Army Corps of Engineers®
New Orleans District

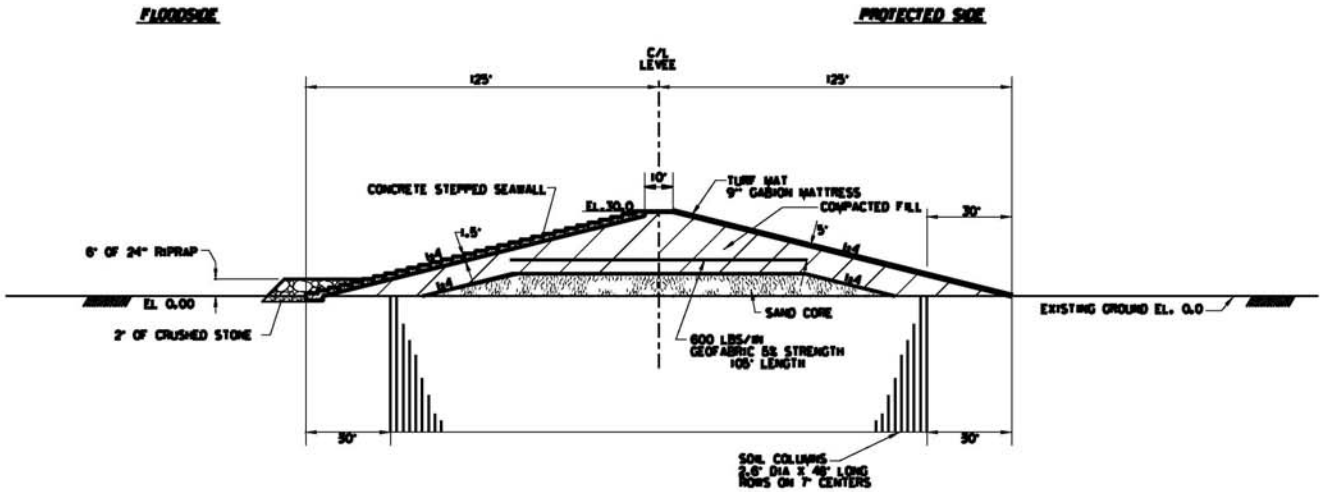
Overview

- Increasing hurricane protection in southern LA
- Hurricane impacts to the coast
- Storm surge reduction
- Coordination
- Integrating coastal restoration plans

Increasing Hurricane Protection in Southern LA


ASSESSMENT OF HURRICANE PROTECTION
IN SOUTHEAST LOUISIANA,
EXISTING PROJECTS AND STUDIES
REACHES
LEGEND
HURRUCANE PROTECTION
FEASIBILITY STUDIES
M.R.& T. PROJECT
WEST SHORE LAKE PONTCHARTRAIN
FEASIBILITY STUDY
LAKE PONTCHARTRAIN
LAKE PONTCHARTRAIN AND VICINITY
HURRICANE PROTECTION
Slidell
New Orleans
East
Donaldsonville
MISSISSIPPI RIVER
LEVEES
Laplace
ATCHAFALAYA
BASIN
FLOODWAY
G.I.W.W.
LAKE
BORGNE
NEW ORLEANS
Chalmette
M.R.G.O.
WEST BANK AND VICINITY, NEW ORLEANS
HURRICANE PROTECTION
EAST ATCHAFALAYA BASIN
PROTECTION LEVEE
BRAITHWAITE PARK
C.A.P. SECTION 205
DONALDSONVILLE TO THE
GULF OF MEXICO
FEASIBILITY STUDY
Morgan City
MORGAN CITY AND VICINITY
HURRICANE PROTECTION
OAKVILLE TO LAREUSSITE
C.A.P. SECTION 205
LAROSE TO GOLDEN MEADOW
HURRICANE PROTECTION
NEW ORLEANS TO VENICE
HURRICANE PROTECTION
Pointe a la Hache
GULF OF MEXICO
Houma
Larose
LOWER ATCHAFALAYA BASIN
RE-EVALUATION STUDY
MISSISSIPPI
RIVER
NEW ORLEANS TO VENICE
LEREUSSITE TO ST. JUDE
P.A.C. STUDY
Dulac
Golden Meadow
Empire
Buras
Venice
MORGANZA TO THE GULF OF MEXICO
FEASIBILITY STUDY
GULF OF MEXICO
US ARMY CORPS
OF ENGINEERS
NEW ORLEANS DISTRICT
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION
ASSESSMENT OF HURRICANE PROTECTION IN
SOUTHEAST LOUISIANA
EXISTING PROJECTS
AND STUDIES
REACHS
SHEET
IDENTIFICATION
NUMBER
PLATE 2


ASSESSMENT OF HURRICANE PROTECTION
IN SOUTHEAST LOUISIANA,
HURRICANE BARRIER PLAN
LEGEND
Hurricane Barrier Plan Alignment
Secondary Levees
Control Structure
Pump Station (P.S.)
Lock
Floodgate - Navigable
Diversion Structure
SCALE
MILES
5 0 5 10
US ARMY CORPS
OF ENGINEERS
NEW ORLEANS DISTRICT
LAKE MAUREPAS
LAKE PONTCHARTRAIN
Slidell
New Orleans East
NEW ORLEANS
G.I.W.W.
LAKE BORGNE
Donaldsonville
MISSISSIPPI RIVER LEVEES
Laplace
Chalmette
Gretna
M.R.G.O.
LAKE DES ALLEMANDS
Luling
LAKE CATAOUATCHE
ATCHAFALAYA BASIN FLOODWAY
EAST ATCHAFALAYA BASIN PROTECTION LEVEE
LAKE SALVADOR
Morgan City
Houma
Larose
Pointe a la Hache
GULF OF MEXICO
G.I.W.W.
HOUMA NAVIGATION CANAL
Golden Meadow
MISSISSIPPI RIVER
Empire
Buras
Venice
GULF OF MEXICO
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION
ASSESSMENT OF HURRICANE PROTECTION IN SOUTHEAST LOUISIANA
HURRICANE BARRIER PLAN
SHEET IDENTIFICATION NUMBER
PLATE 20



CONCRETE STEPPED SEAWALL ON SOIL-CEMENT FOUNDED LEVEE WITH SAND CORE

NOT TO SCALE

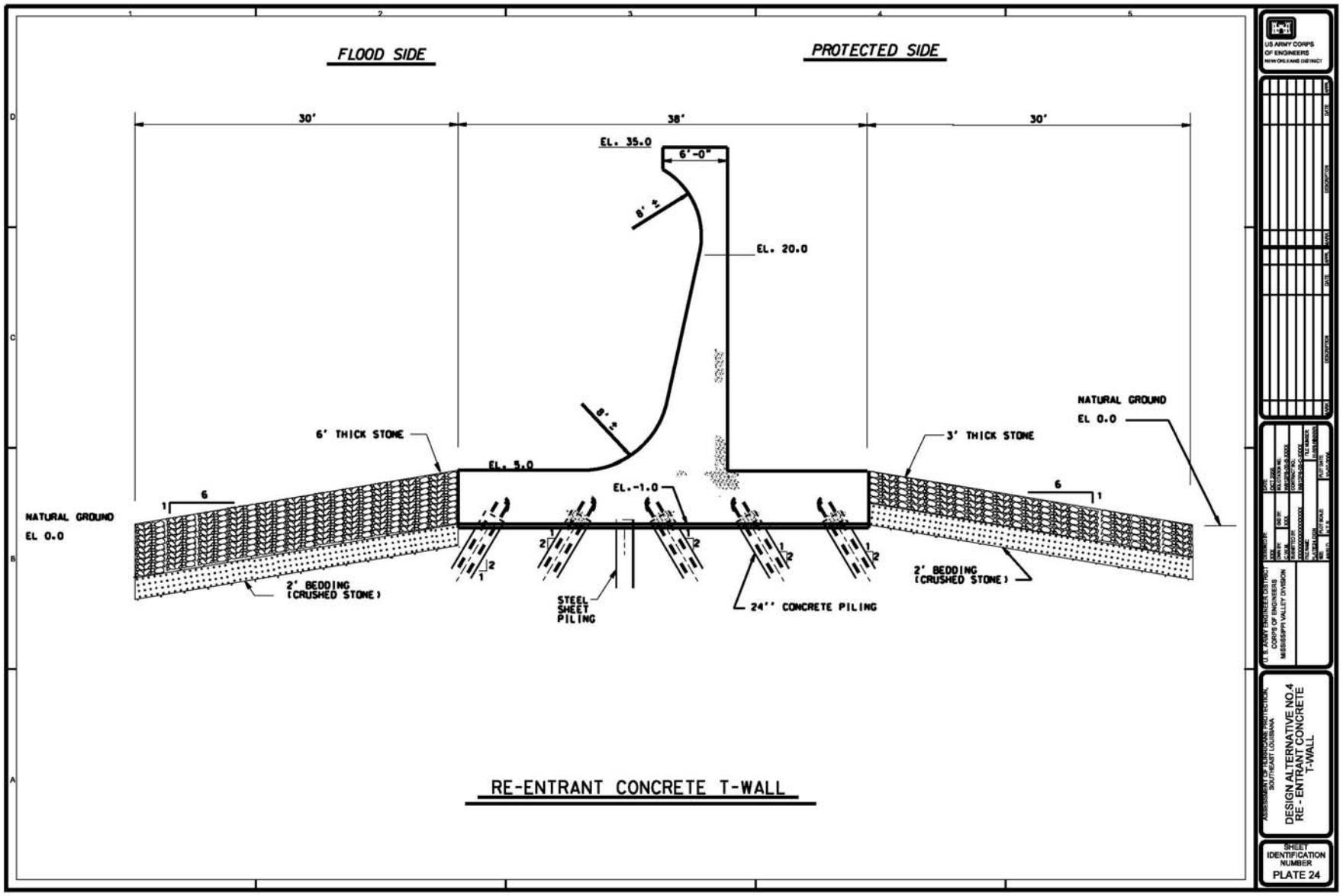
US ARMY CORPS OF ENGINEERS
NEW ORLEANS DISTRICT

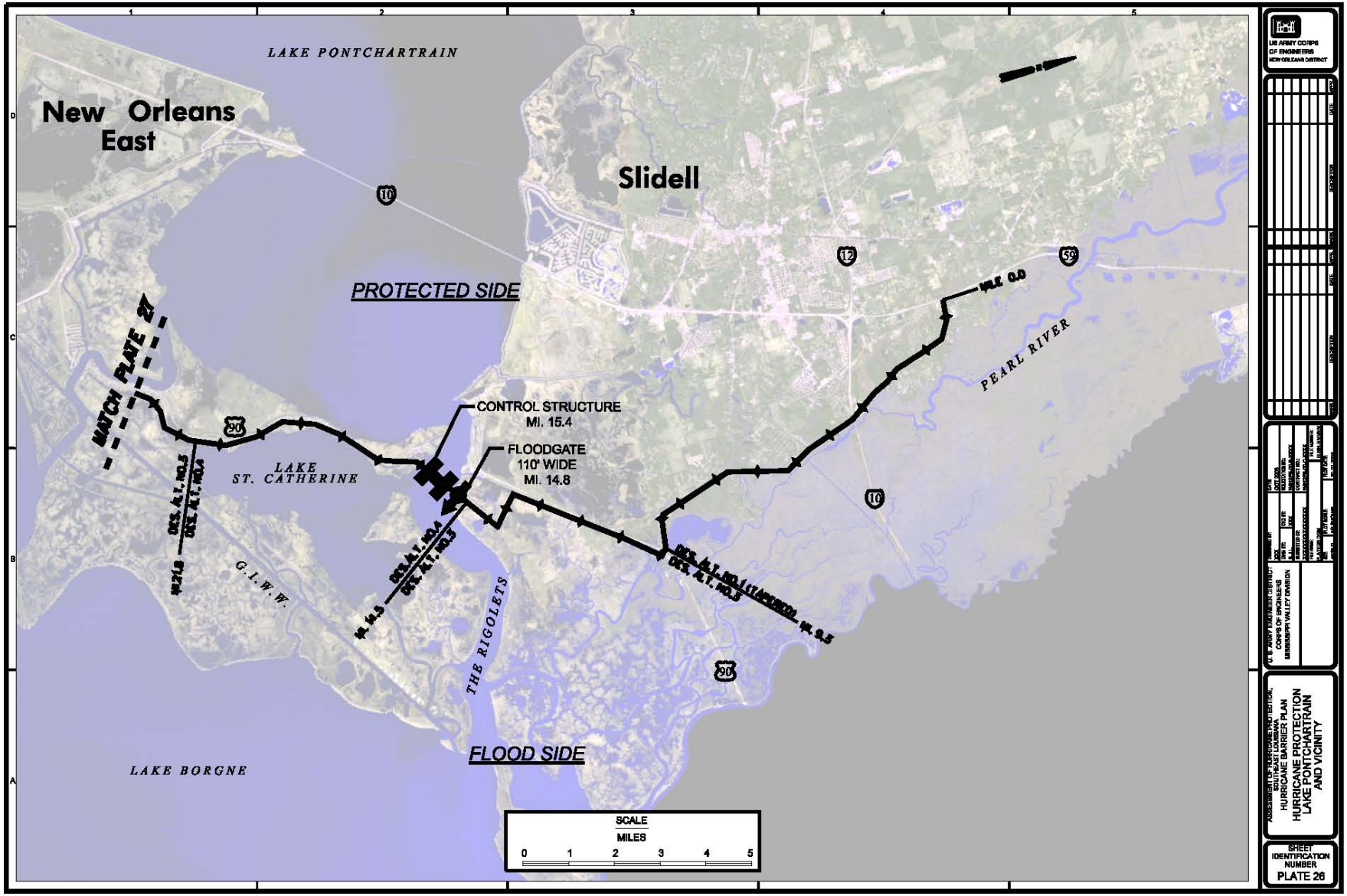
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION

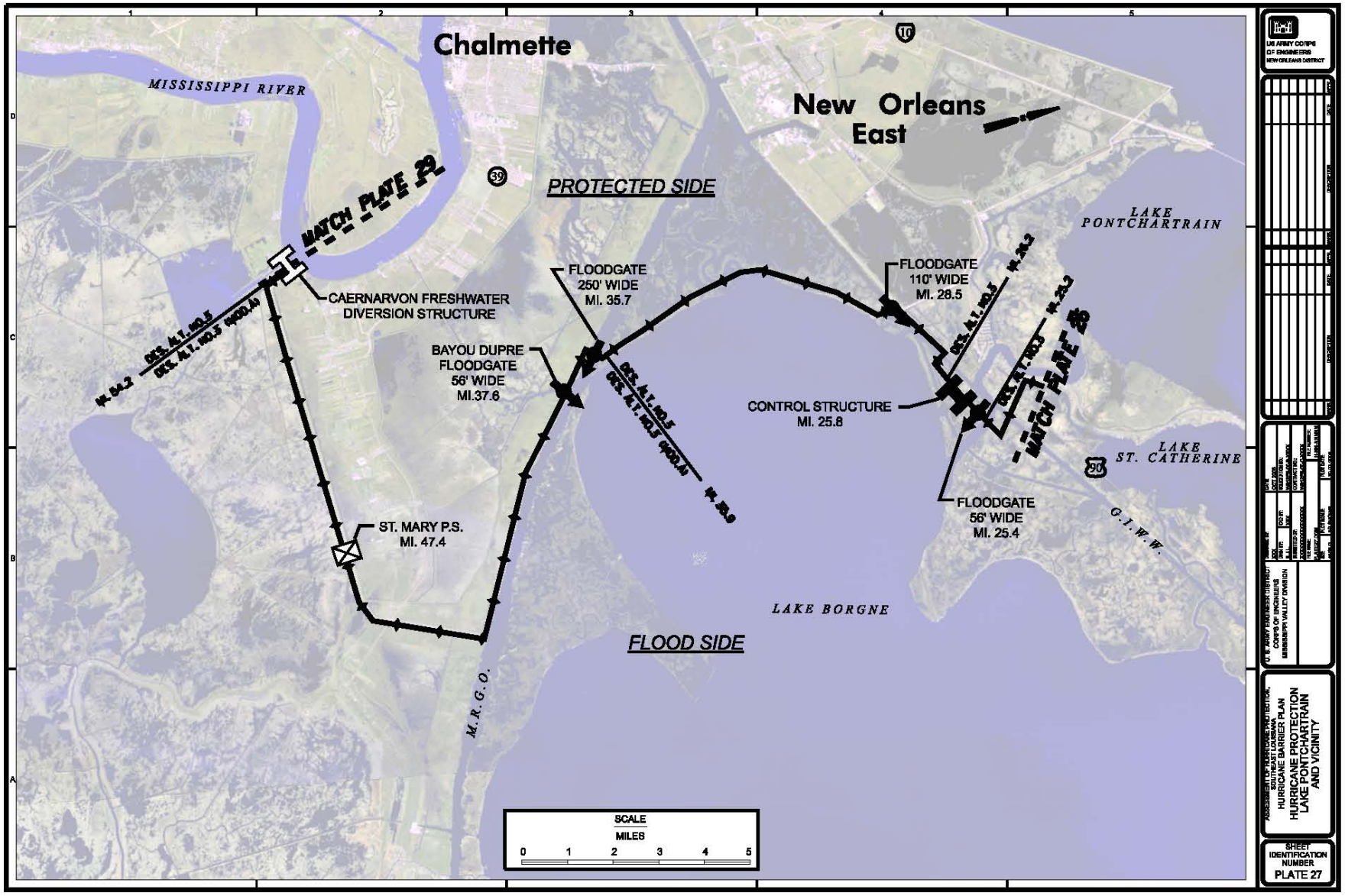
ASSESSMENT OF ALTERNATIVE RIGHT-OF-WAY,
SOUTHEAST LOUISIANA

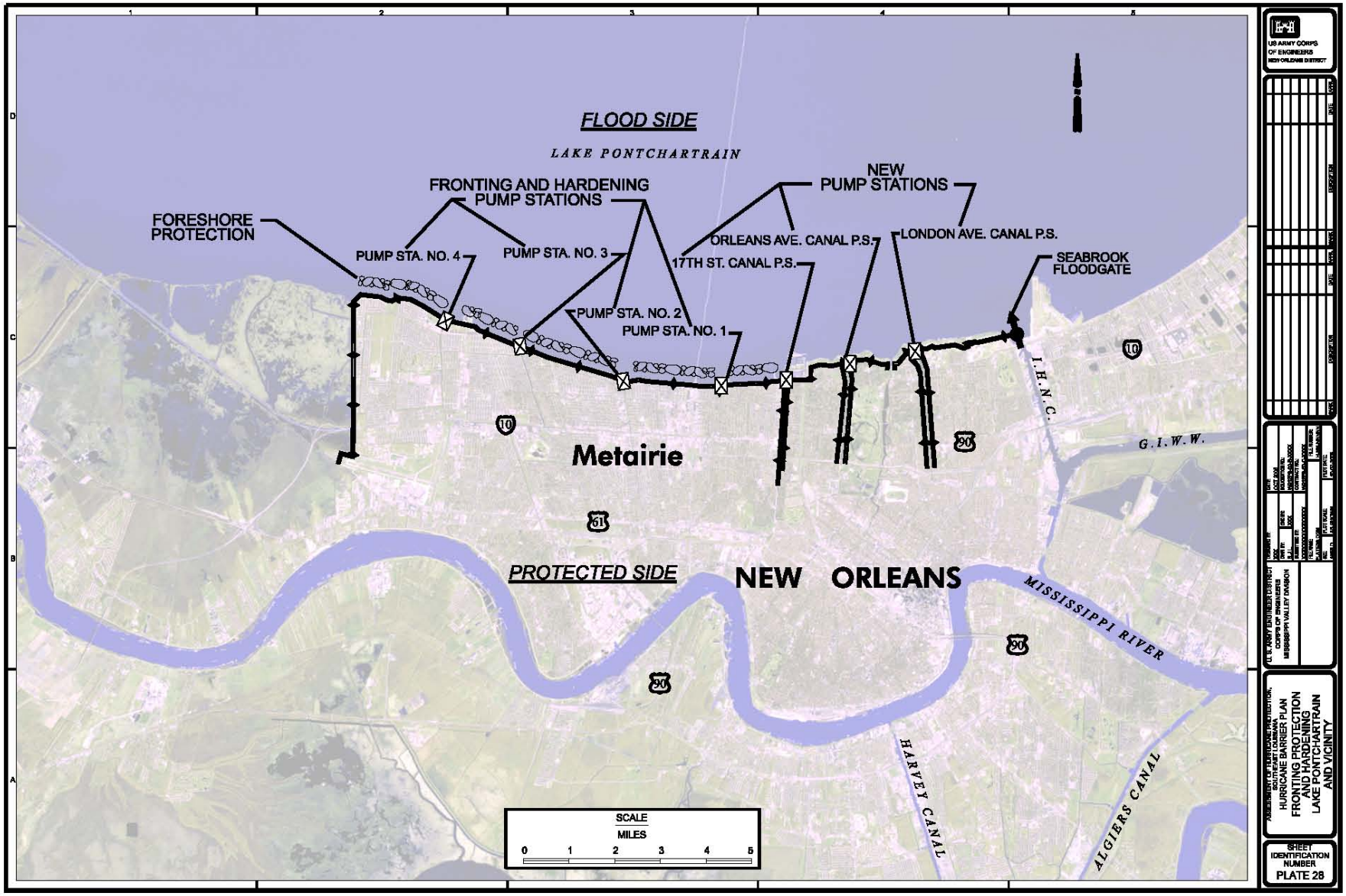
DESIGN ALTERNATIVE NO.3
CONCRETE STEPPED SEAWALL
ON SOIL CEMENT FOUNDED
LEVEE WITH SAND CORE

SHEET IDENTIFICATION NUMBER
PLATE 23


FLOOD SIDE
PROTECTED SIDE
30'
38'
30'
EL. 35.0
6'-0"
8'-2"
EL. 20.0
8'-2"
6' THICK STONE
3' THICK STONE
NATURAL GROUND
EL 0.0
NATURAL GROUND
EL 0.0
EL. 5.0
EL.-1.0
6
1
6
1
2' BEDDING
(CRUSHED STONE)
2' BEDDING
(CRUSHED STONE)
STEEL
SHEET
PILING
24" CONCRETE PILING
RE-ENTRANT CONCRETE T-WALL
US ARMY CORPS
OF ENGINEERS
NEW ORLEANS DISTRICT
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION
DESIGN ALTERNATIVE NO.4
RE - ENTRANT CONCRETE
T-WALL
SHEET
IDENTIFICATION
NUMBER
PLATE 24


LAKE PONTCHARTRAIN
New Orleans East
Slidell
PROTECTED SIDE
MATCH PLATE 27
LAKE ST. CATHERINE
G.I.W.W.
CONTROL STRUCTURE
MI. 15.4
FLOODGATE
110' WIDE
MI. 14.8
THE RIGOLETS
FLOOD SIDE
LAKE BORGNE
PEARL RIVER
SCALE
MILES
0 1 2 3 4 5
US ARMY CORPS OF ENGINEERS
NEW ORLEANS DISTRICT
HURRICANE PROTECTION
LAKE PONTCHARTRAIN
AND VICINITY
SHEET IDENTIFICATION NUMBER
PLATE 26


Chalmette
MISSISSIPPI RIVER
New Orleans East
PROTECTED SIDE
MATCH PLATE 29
CAERNARVON FRESHWATER DIVERSION STRUCTURE
FLOODGATE 250' WIDE MI. 35.7
BAYOU DUPRE FLOODGATE 56' WIDE MI.37.6
ST. MARY P.S. MI. 47.4
FLOODGATE 110' WIDE MI. 28.5
CONTROL STRUCTURE MI. 25.8
FLOODGATE 56' WIDE MI. 25.4
MATCH PLATE 26
LAKE PONTCHARTRAIN
LAKE ST. CATHERINE
G.I.W.W.
LAKE BORGNE
FLOOD SIDE
M.R.G.O.
SCALE
MILES
0 1 2 3 4 5
US ARMY CORPS OF ENGINEERS
NEW ORLEANS DISTRICT
HURRICANE PROTECTION LAKE PONTCHARTRAIN AND VICINITY
SHEET IDENTIFICATION NUMBER
PLATE 27



US ARMY CORPS OF ENGINEERS
NEW ORLEANS DISTRICT

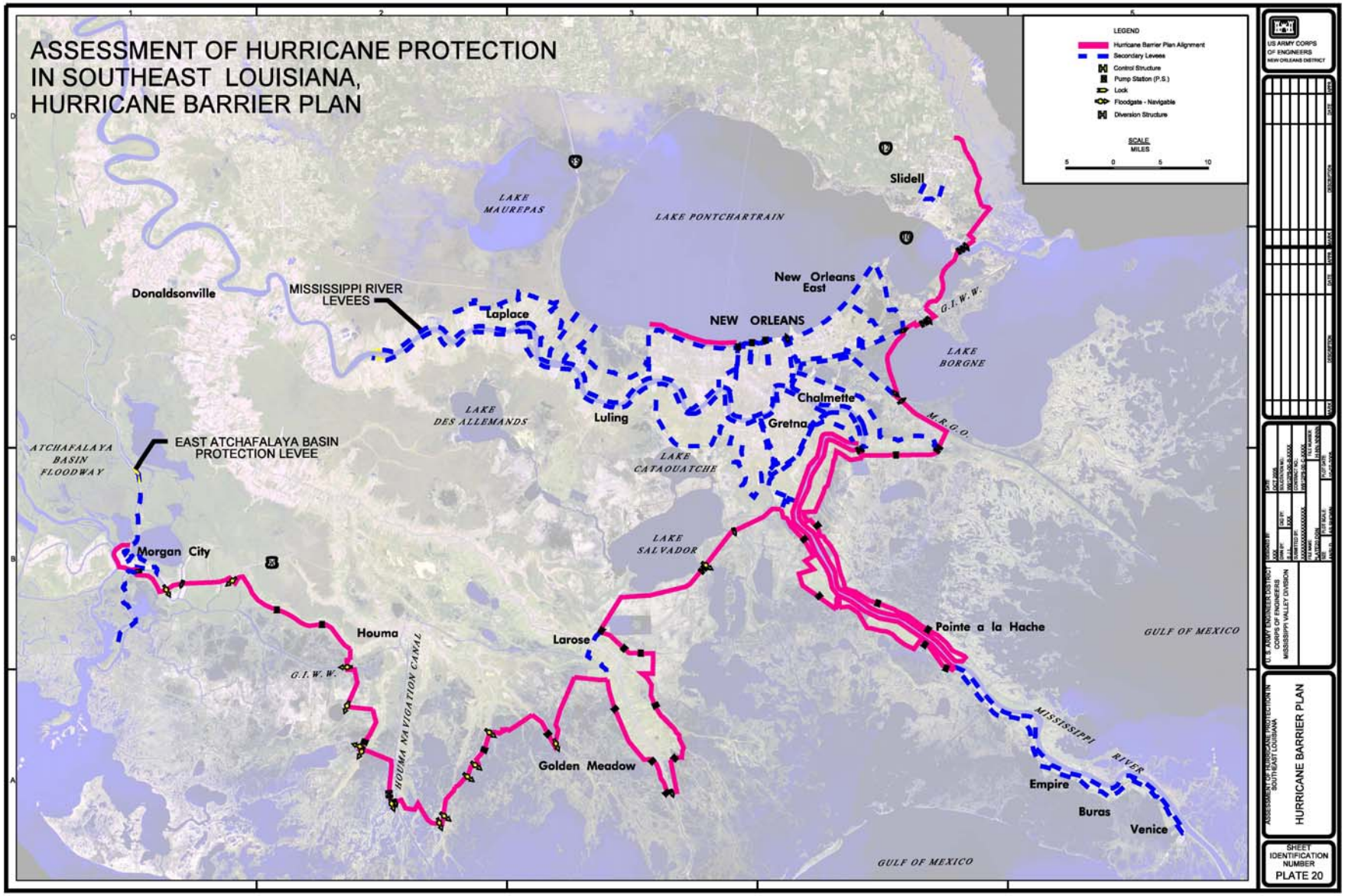
NO.	DESCRIPTION	DATE

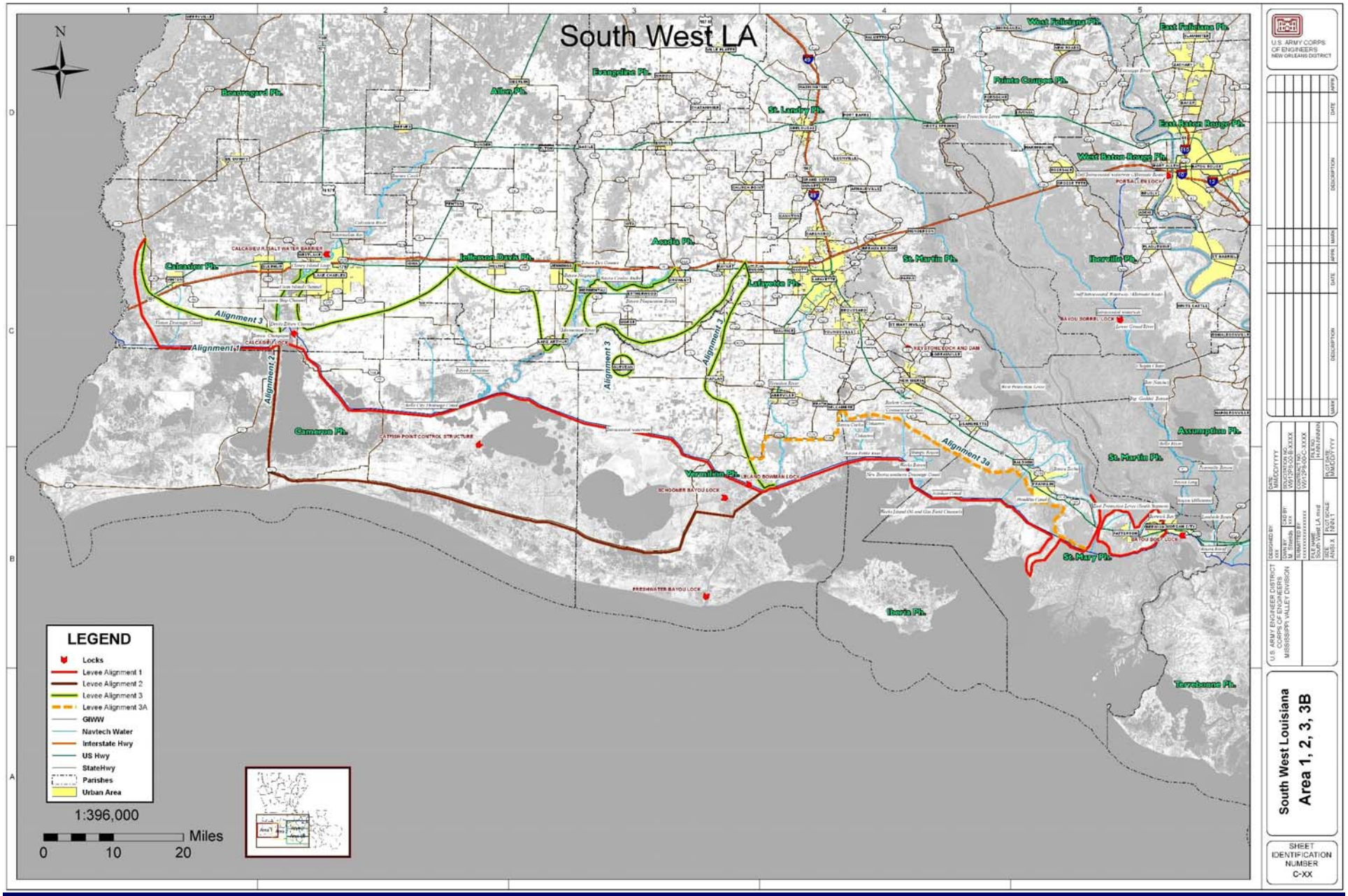
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION

DATE
CAD BOOK
DESIGNED BY
DRAWN BY
CHECKED BY
SUBMITTED BY
CONTRACT NO.
DRAWING NUMBER
FILE NUMBER
LAFMN-N/A
FILE NAME
PLATE NAME
PLATE NAME
SCALE: 1:250
PLATE NO.
LAFMN-N/A

ASSESSMENT OF HURRICANE PROTECTION, SOUTHEAST LOUISIANA
HURRICANE BARRIER PLAN
FRONTING PROTECTION AND HARDENING LAKE PONTCHARTRAIN AND VICINITY

SHEET IDENTIFICATION NUMBER
PLATE 28


ASSESSMENT OF HURRICANE PROTECTION
IN SOUTHEAST LOUISIANA,
HURRICANE BARRIER PLAN
LEGEND
Hurricane Barrier Plan Alignment
Secondary Levees
Control Structure
Pump Station (P.S.)
Lock
Floodgate - Navigable
Diversion Structure
SCALE
MILES
5 0 5 10
US ARMY CORPS
OF ENGINEERS
NEW ORLEANS DISTRICT
LAKE MAUREPAS
LAKE PONTCHARTRAIN
Slidell
New Orleans East
NEW ORLEANS
G.I.W.W.
LAKE BORGNE
Donaldsonville
MISSISSIPPI RIVER LEVEES
Laplace
Chalmette
Gretna
M.R.G.O.
LAKE DES ALLEMANDS
Luling
LAKE CATAOUATCHE
ATCHAFALAYA BASIN FLOODWAY
EAST ATCHAFALAYA BASIN PROTECTION LEVEE
LAKE SALVADOR
Morgan City
Houma
Larose
Pointe a la Hache
GULF OF MEXICO
G.I.W.W.
HOUMA NAVIGATION CANAL
Golden Meadow
MISSISSIPPI RIVER
Empire
Buras
Venice
GULF OF MEXICO
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
MISSISSIPPI VALLEY DIVISION
ASSESSMENT OF HURRICANE PROTECTION IN SOUTHEAST LOUISIANA
HURRICANE BARRIER PLAN
SHEET IDENTIFICATION NUMBER
PLATE 20


South West LA
N
Beauregard Pa.
Allen Pa.
Evangeline Pa.
St. Landry Pa.
Pointe Coupee Pa.
West Feliciana Pa.
East Feliciana Pa.
East Baton Rouge Pa.
West Baton Rouge Pa.
Calcasieu Pa.
Jefferson Davis Pa.
Acadia Pa.
Lafayette Pa.
St. Martin Pa.
Iberville Pa.
Cameron Pa.
Vermilion Pa.
Iberia Pa.
Assumption Pa.
St. Mary Pa.
Terrebonne Pa.
Alignment 1
Alignment 2
Alignment 3
Alignment 3a
CALCASIEU RIVER SALT WATER BARRIER
CALCASIEU LOCK
CATFISH POINT CONTROL STRUCTURE
SCHOONER BAYOU LOCK
FRESHWATER BAYOU LOCK
ORLANDO BOWMAN LOCK
PORTAGE LOCK
BAYOU SORREL LOCK
KEYSTONE LOCK AND DAM
BAYOU BOEUF LOCK
LEGEND
Locks
Levee Alignment 1
Levee Alignment 2
Levee Alignment 3
Levee Alignment 3A
GIWW
Navtech Water
Interstate Hwy
US Hwy
StateHwy
Parishes
Urban Area
1:396,000
Miles
0
10
20
U.S. ARMY CORPS OF ENGINEERS
NEW ORLEANS DISTRICT
U.S. ARMY ENGINEER DISTRICT CORPS OF ENGINEERS MISSISSIPPI VALLEY DIVISION
South West Louisiana
Area 1, 2, 3, 3B
SHEET IDENTIFICATION NUMBER
C-XX

Hurricane Impacts to the Coast

Direct Wetland Losses

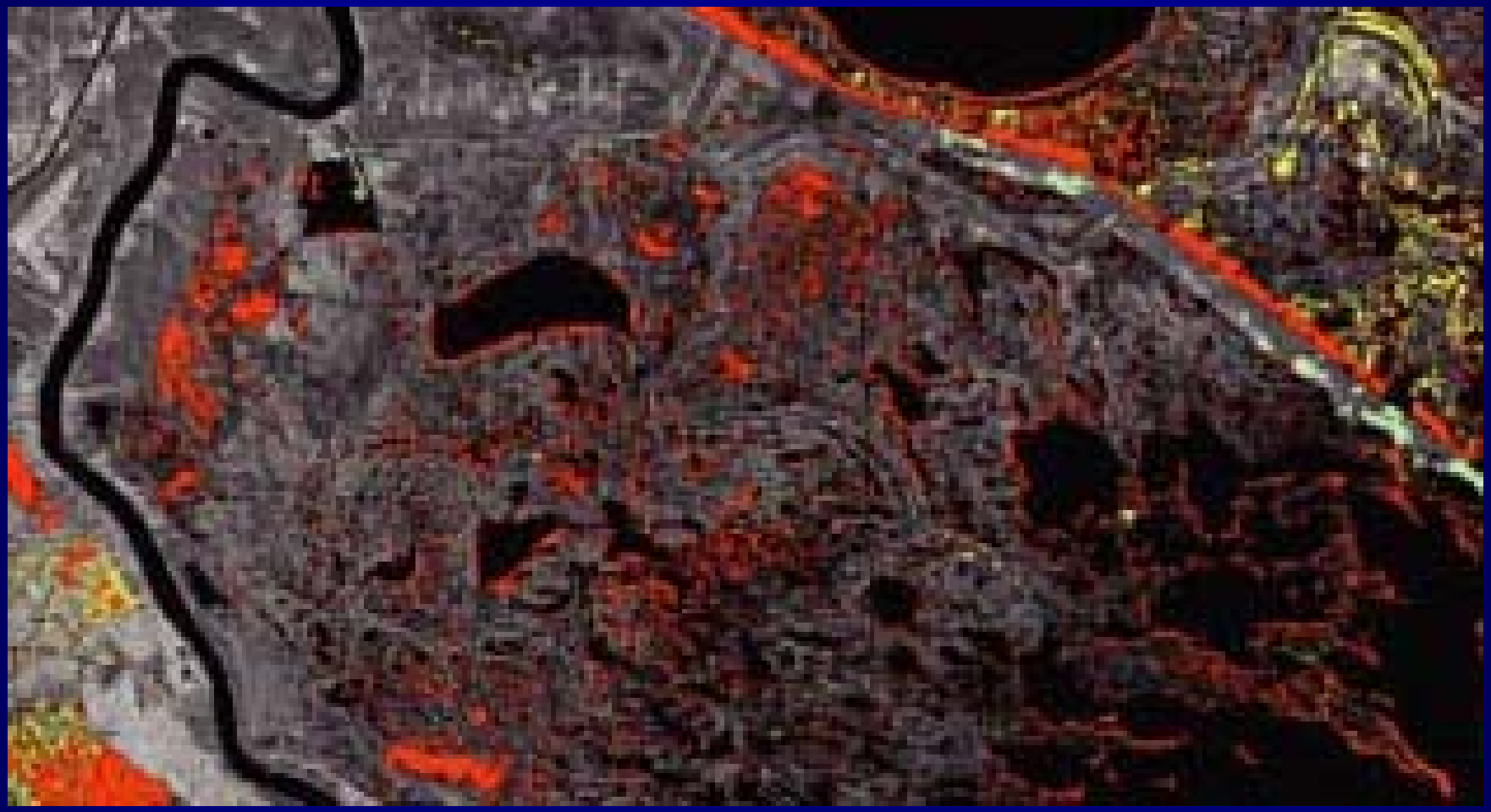
- Caernarvon: Mississippi River diversion to create new wetlands (Multimillion dollar investment; 1991)

- Breton Sound Region (133 mi^2) Preliminary Estimate ~ 26 % loss

  - Initial: wind & wave

  - Secondary: saltwater intrusion, increased susceptibility to storms

Historic and Projected Landloss in the Vicinity of the Caernarvon Diversion

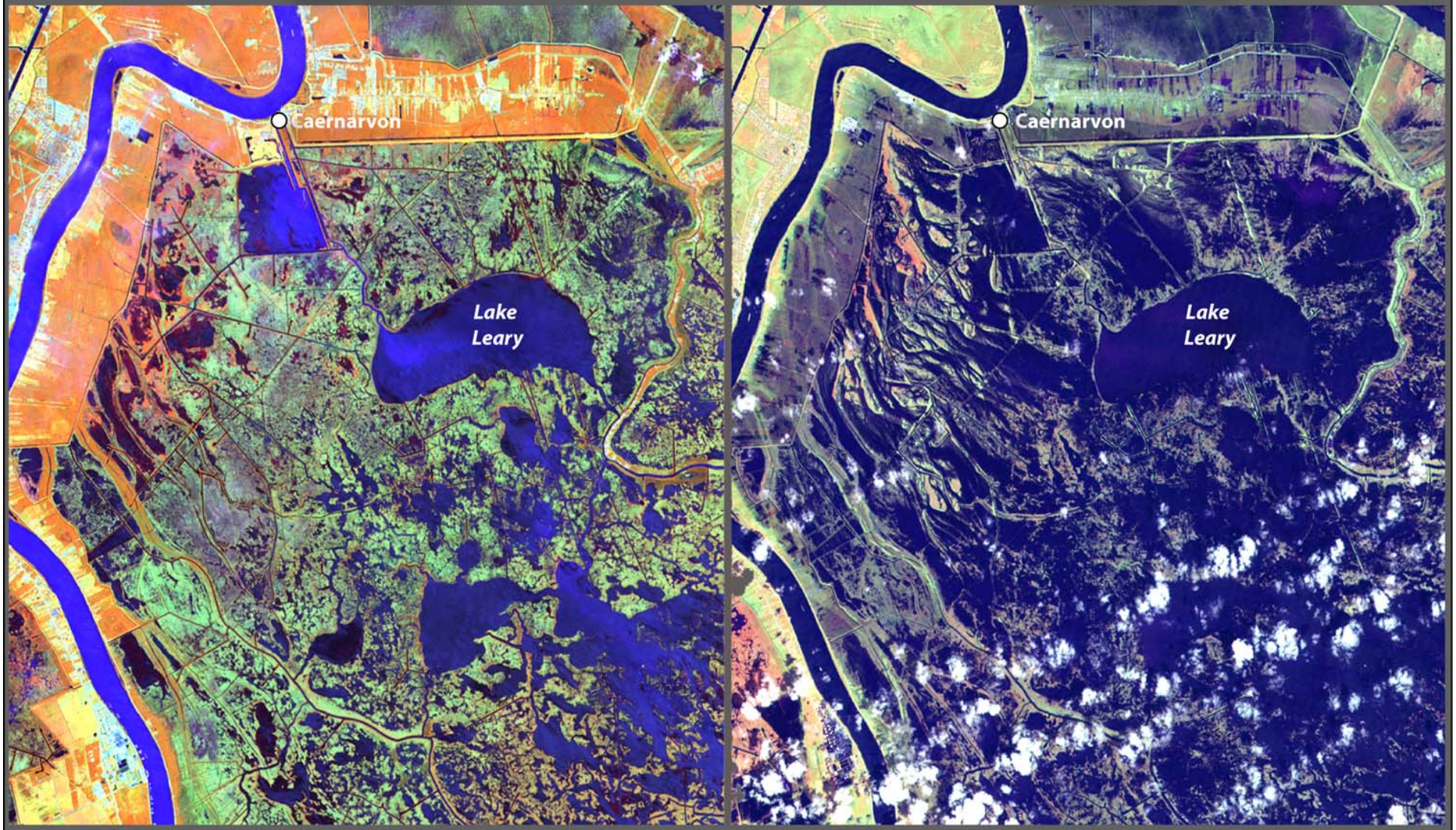


From USGS landloss map

- Historic loss (1932-2000)
- Projected loss (2000-2050)

Landsat Thematic Mapper 5 Hurricane Katrina Comparison Images
Upper Breton Sound Area

April 16, 2004 | **September 7, 2005**



Source: USGS NWRC
Landsat Thematic Mapper Satellite Imagery provided by EROS Data Center
Bands 4 (near-ir), 5 (mid-ir), and 3 (visible red) displayed

Draft: Sept. 28, 2005

USGS
science for a changing world

Storm Surge Reduction

Strategic Natural Lines of Defense

Coastal Lines of Defense

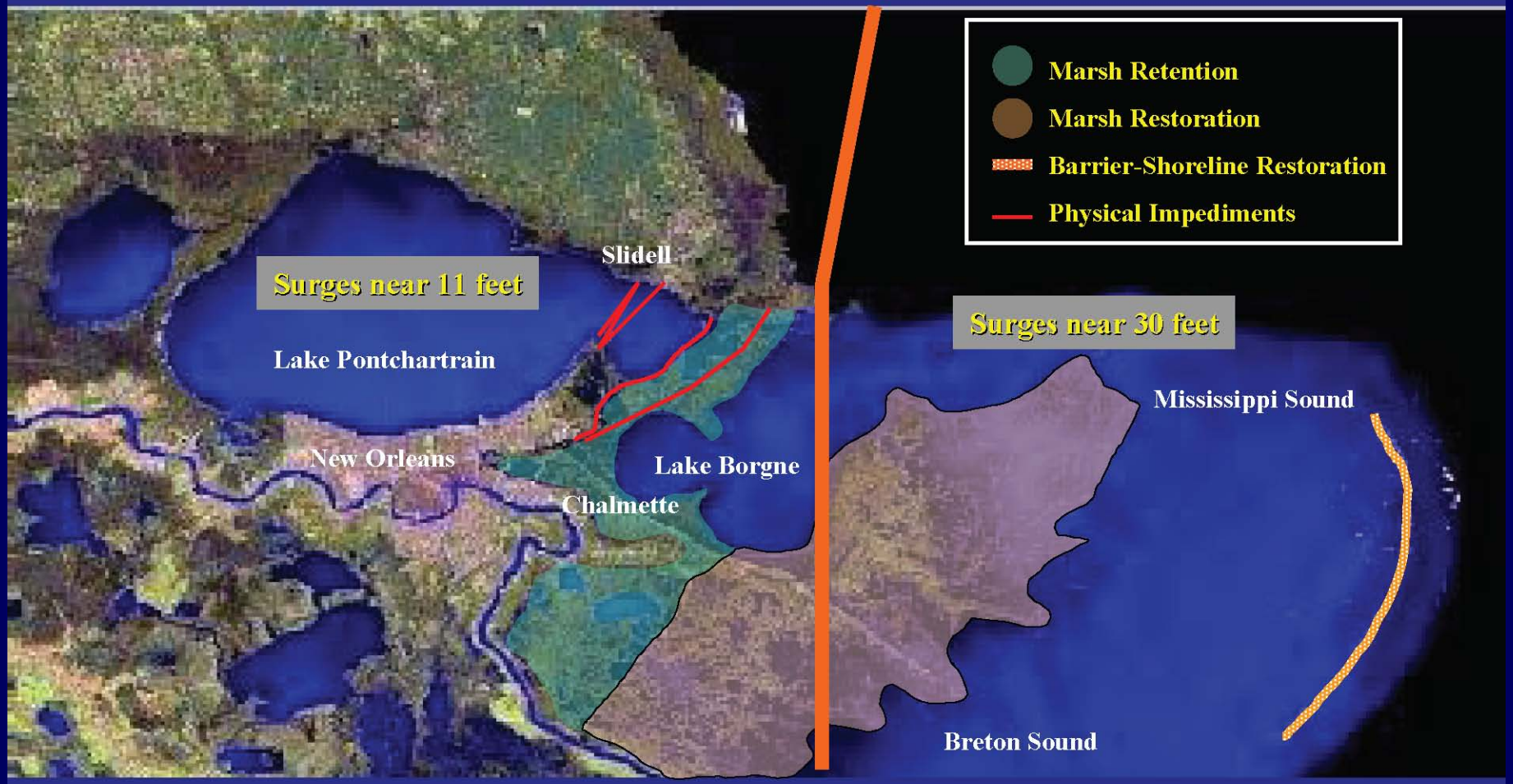
- Wetlands provide flood water storage
- Natural habitat features (forested ridges, marsh and islands) buffer the coastal area from storms and provide other ecosystem benefits
- LA coast wetlands restoration supports coastal protection and recovery
- Surge reduction benefits more important in lower intensity storm events with more frequent return intervals

Storm Surge Reduction

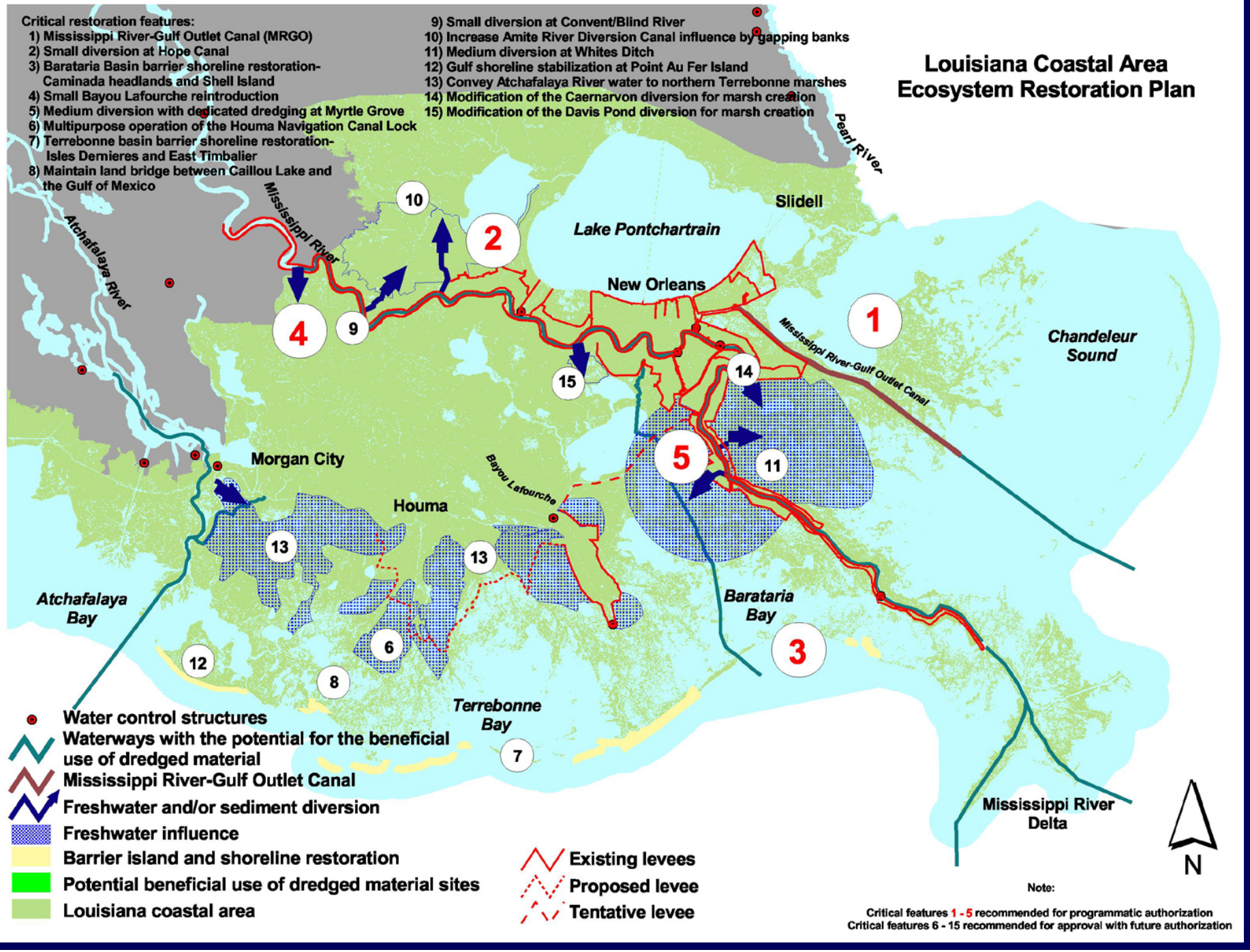
- The concept of natural lines of storm surge defense is based on the hydraulic principle that surge elevation is effectively reduced by the friction of flowing over a vegetated land mass.

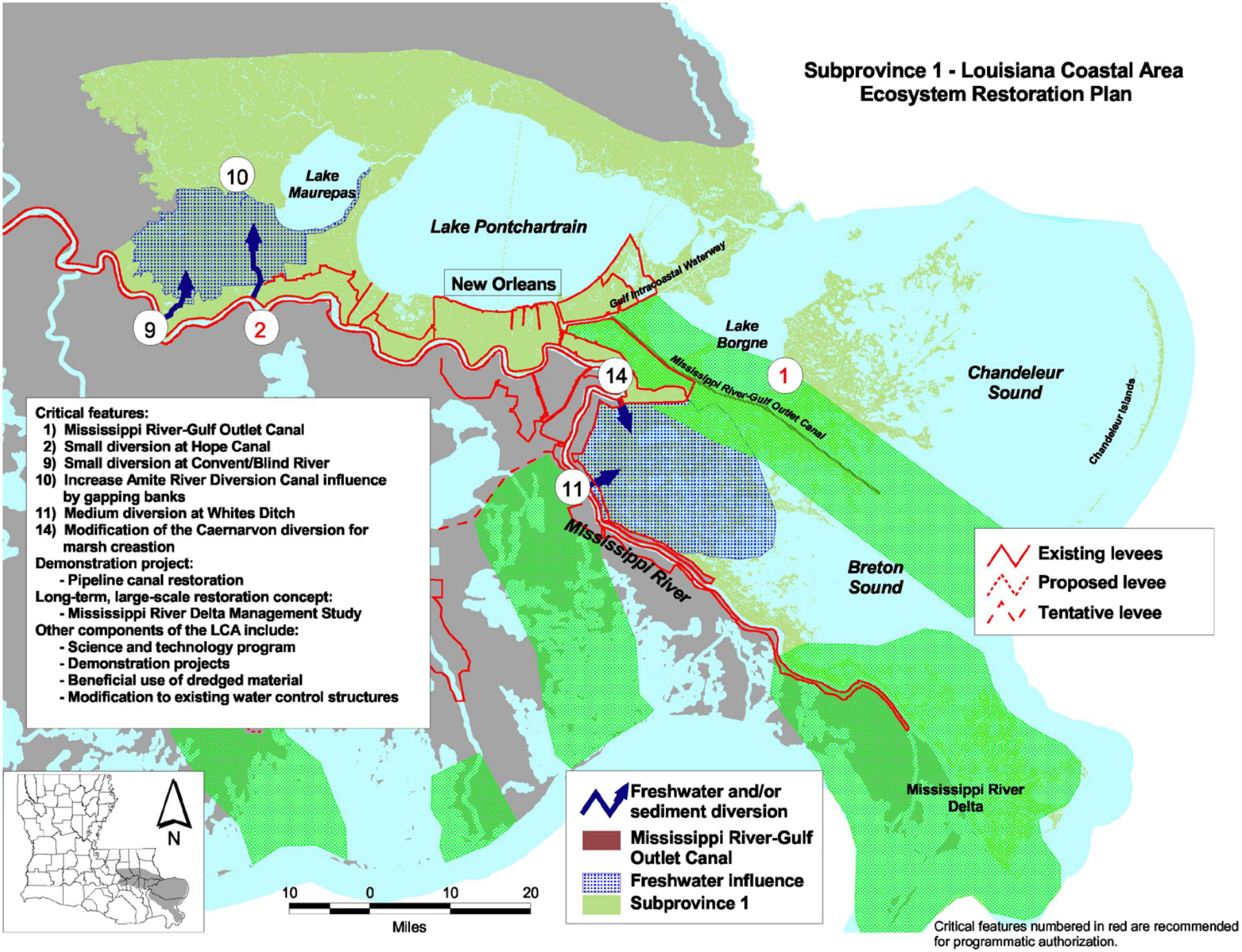
- Historically an engineering “rule of thumb” has been used for estimating potential storm surge reduction in LA.

- The engineering “rule of thumb” for the effect of coastal wetlands in reducing storm surge elevation provides for an estimated one foot of surge reduction for each 2.7 miles of wetlands over which the surge must flow.


Marsh Retention
Marsh Restoration
Barrier-Shoreline Restoration
Physical Impediments
Surges near 11 feet
Slidell
Lake Pontchartrain
New Orleans
Lake Borgne
Chalmette
Surges near 30 feet
Mississippi Sound
Breton Sound

LA Coastal Restoration Plan

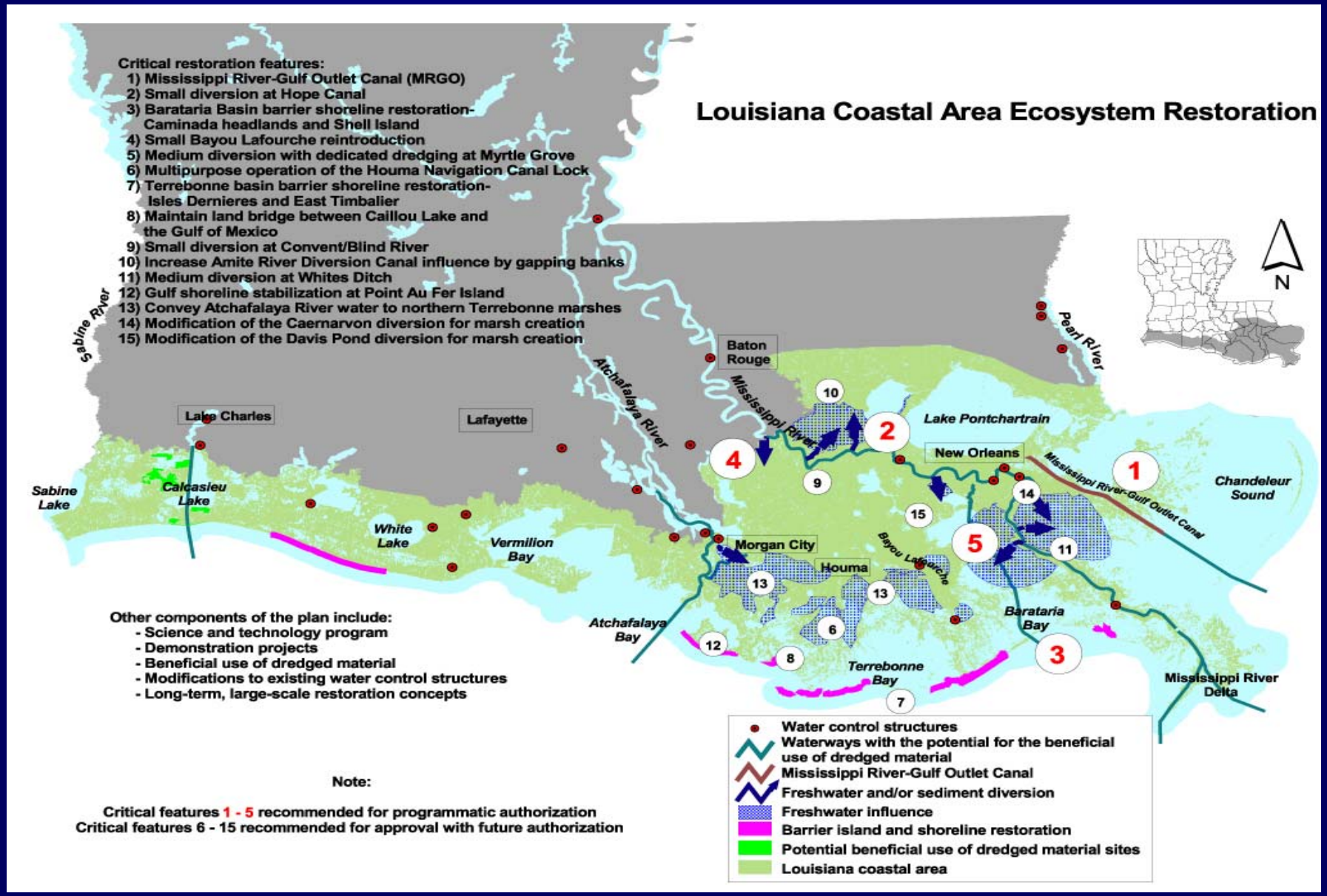

Louisiana Coastal Area
Ecosystem Restoration Plan
Critical restoration features:
1) Mississippi River-Gulf Outlet Canal (MRGO)
2) Small diversion at Hope Canal
3) Barataria Basin barrier shoreline restoration-Caminada headlands and Shell Island
4) Small Bayou Lafourche reintroduction
5) Medium diversion with dedicated dredging at Myrtle Grove
6) Multipurpose operation of the Houma Navigation Canal Lock
7) Terrebonne basin barrier shoreline restoration-Isles Dernieres and East Timbalier
8) Maintain land bridge between Caillou Lake and the Gulf of Mexico
9) Small diversion at Convent/Blind River
10) Increase Amite River Diversion Canal influence by gapping banks
11) Medium diversion at Whites Ditch
12) Gulf shoreline stabilization at Point Au Fer Island
13) Convey Atchafalaya River water to northern Terrebonne marshes
14) Modification of the Caernarvon diversion for marsh creation
15) Modification of the Davis Pond diversion for marsh creation
Pearl River
Slidell
Lake Pontchartrain
New Orleans
Mississippi River
Atchafalaya River
Mississippi River-Gulf Outlet Canal
Chandeleur Sound
Morgan City
Bayou Lafourche
Houma
Atchafalaya Bay
Barataria Bay
Terrebonne Bay
Mississippi River Delta
N
Water control structures
Waterways with the potential for the beneficial use of dredged material
Mississippi River-Gulf Outlet Canal
Freshwater and/or sediment diversion
Freshwater influence
Barrier island and shoreline restoration
Potential beneficial use of dredged material sites
Louisiana coastal area
Existing levees
Proposed levee
Tentative levee
Note:
Critical features 1 - 5 recommended for programmatic authorization
Critical features 6 - 15 recommended for approval with future authorization


Subprovince 1 - Louisiana Coastal Area
Ecosystem Restoration Plan
Lake Maurepas
Lake Pontchartrain
New Orleans
Gulf Intracoastal Waterway
Lake Borgne
Mississippi River-Gulf Outlet Canal
Chandeleur Sound
Chandeleur Islands
Mississippi River
Breton Sound
Mississippi River Delta
10
9
2
14
1
11
Critical features:
1) Mississippi River-Gulf Outlet Canal
2) Small diversion at Hope Canal
9) Small diversion at Convent/Blind River
10) Increase Amite River Diversion Canal influence by gapping banks
11) Medium diversion at Whites Ditch
14) Modification of the Caernarvon diversion for marsh creastion
Demonstration project:
- Pipeline canal restoration
Long-term, large-scale restoration concept:
- Mississippi River Delta Management Study
Other components of the LCA include:
- Science and technology program
- Demonstration projects
- Beneficial use of dredged material
- Modification to existing water control structures
Existing levees
Proposed levee
Tentative levee
Freshwater and/or sediment diversion
Mississippi River-Gulf Outlet Canal
Freshwater influence
Subprovince 1
N
10 0 10 20
Miles
Critical features numbered in red are recommended for programmatic authorization.

Prioritization

- The N-T Plan and all larger plans provide restoration below the existing or proposed storm protection
- The critical features provide benefit to lines of defense
- Requires increased priority and development:
  - Beneficial Use of Dredged Material
  - Modifications to Existing Structures
  - Restoration of historic hydrology and geomorphic-structure

LCA Recommended Plan



TITLE: Dutch Sea Defense and The Role of Models

PRESENTED BY: G.S. Stelling, TU Delft

SUMMARY: The people of The Netherlands are continually challenged with the storm impacts of the North Sea coupled with their desire to live and prosper in a sub-sea level landscape. Following the disastrous flood of 1953, the Dutch made a bold commitment to protection from storm surges and flooding. This commitment is evidenced by the creation of the Delta Works project, a comprehensive project of barriers, gates, sluices, dikes, pumps, and other structural measures necessary for protecting The Netherlands from the surges of the open North Sea and interior flooding complicated by poor drainage issues. This presentation reviews this history and highlights several key structures like the Eastern Scheldt barrier and the sector gates for the Rotterdam harbor. The presentation further provides how the Dutch are continually evaluating the effects and operations of these structures through the use of various computer models, such as the multi-dimensional SOBEK model. Other modeling approaches involving computational fluid dynamics for evaluating the natural drainage systems and the effect of flood/surge control structures are also reviewed.

The use of computational models in water control of The Netherlands

Guus Stelling,Vicksburg, December 2005

TU Delft

The Netherlands

Afsluitdijk, 1931

Lorentz

Maeslandt barrier, 1996

Haringvliet sluices, 1968

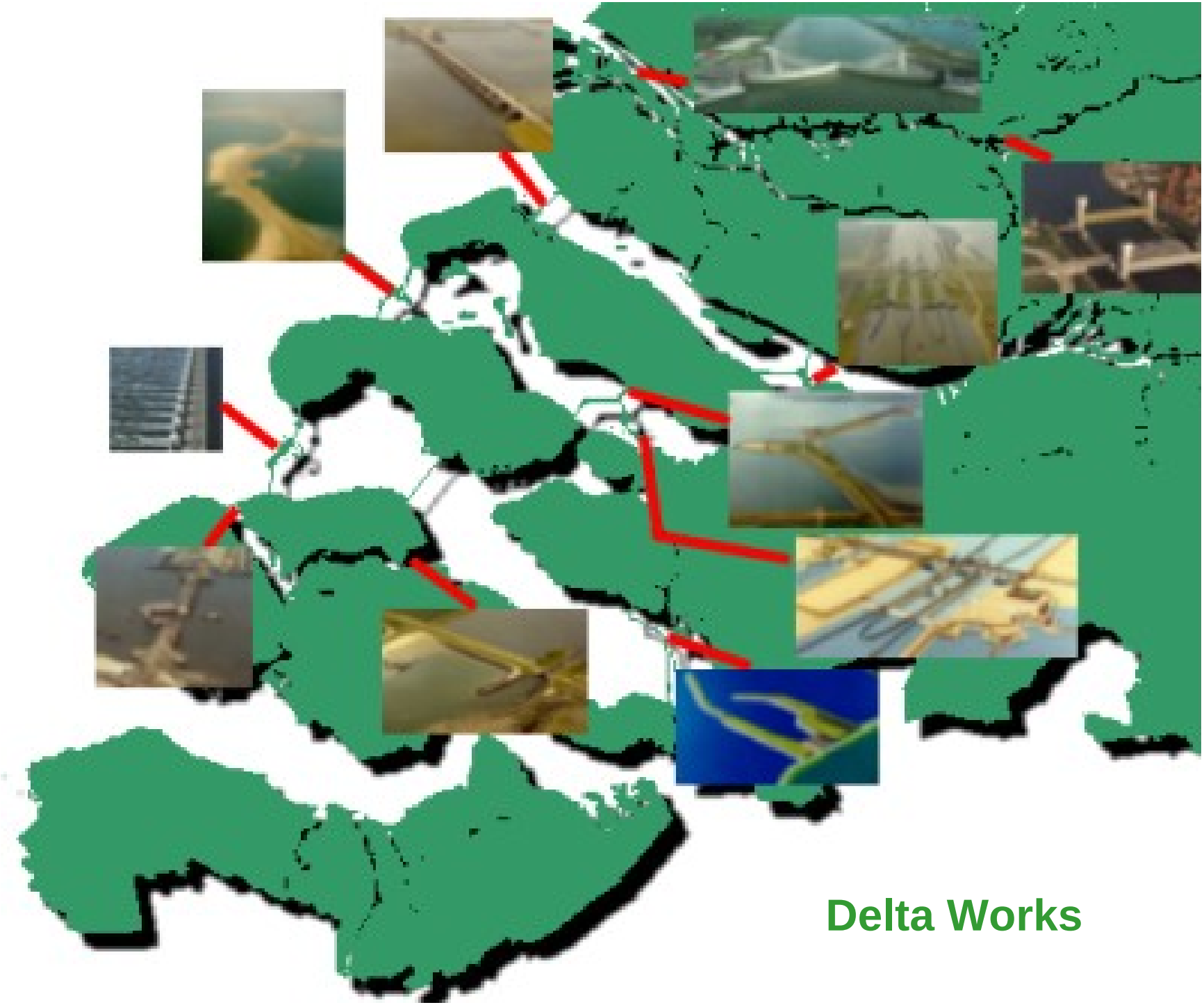
(J.J. Dronkers, 1D network)

Eastern Scheldt,

Storm surge barrier, 1986

(J.J. Leendertse, simsys2d or Waqua)

Afsluitdijk



Delta Works

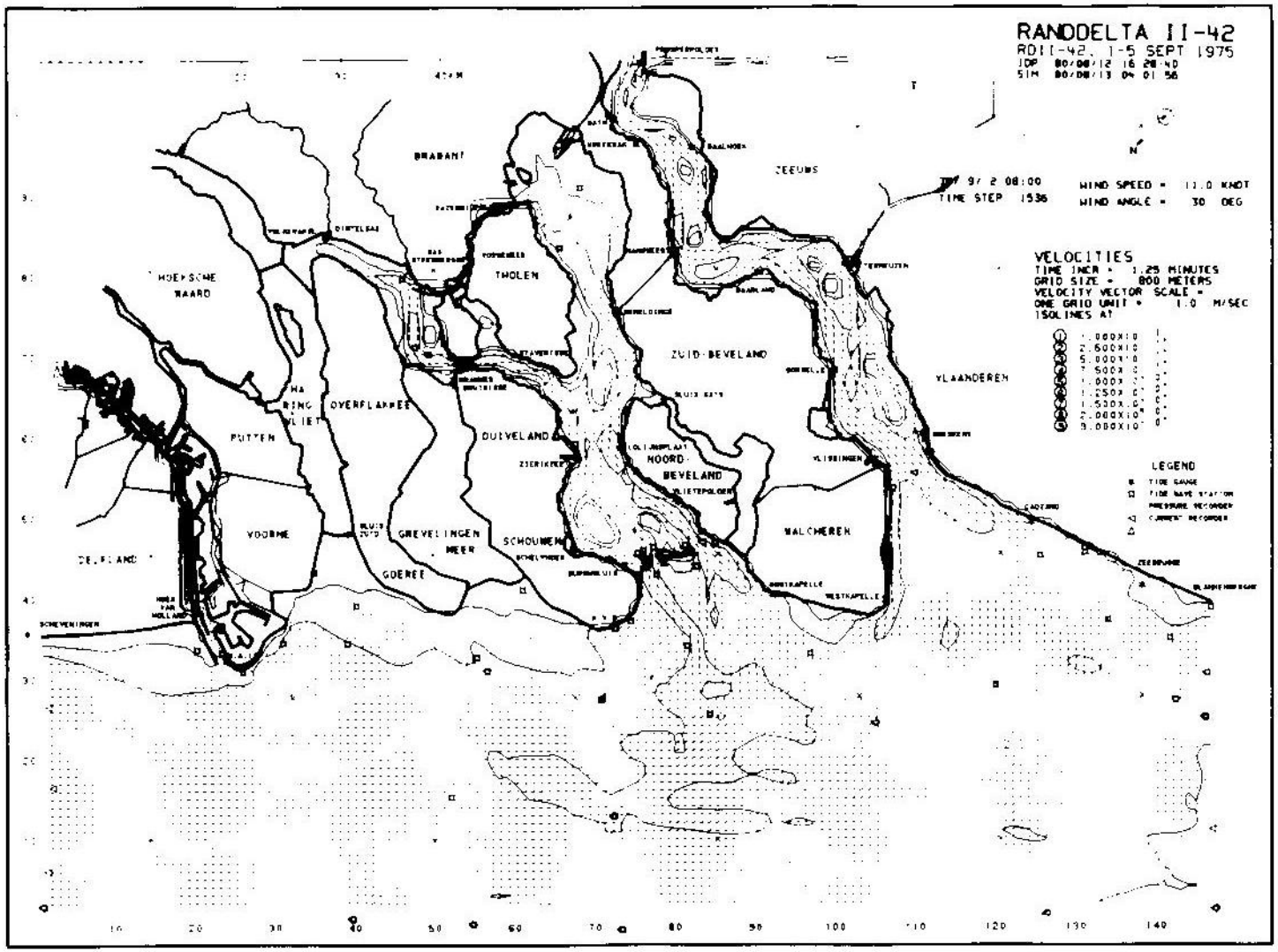


Fig. 2—Computed flow field of the RANDDELTA model simulating conditions during flood on 2 September 1975 at 8:00 hours

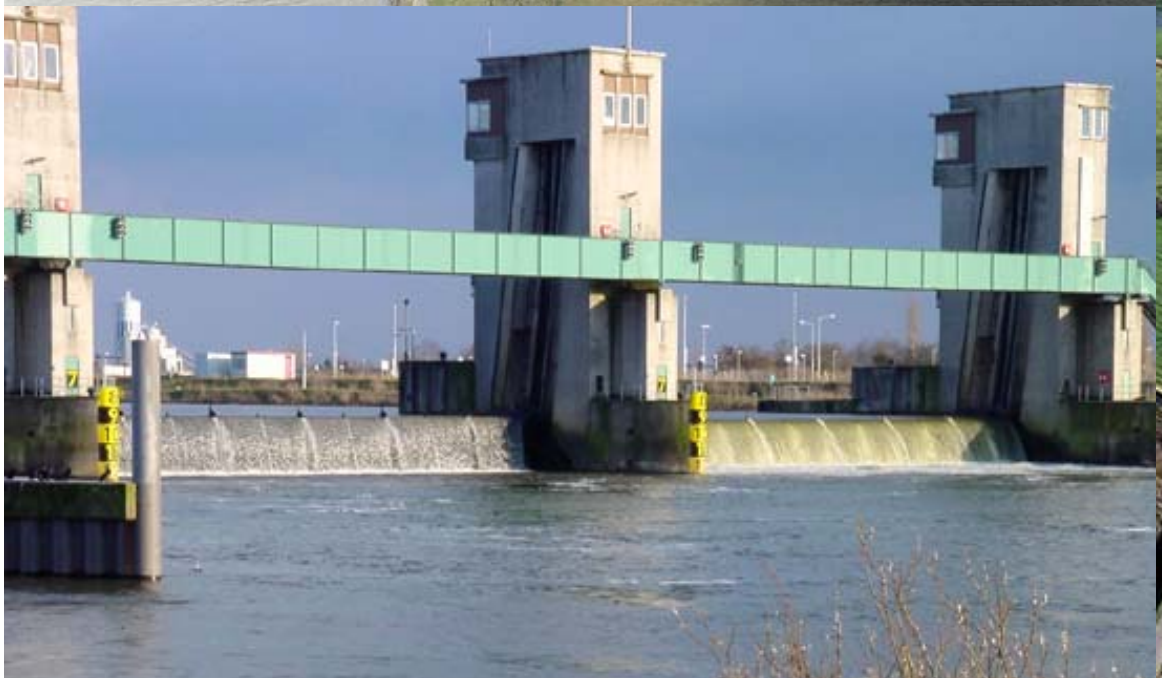
Storm surge barrier

Storm surge barrier at the Rotterdam harbour entrance (Rhine outlet in the North Sea)

More than 50% of the Netherlands is below sea level

The safety is enabled by a flood protection system with dikes, sluices, barriers, pumps, etc.

Pannerdensche Kop

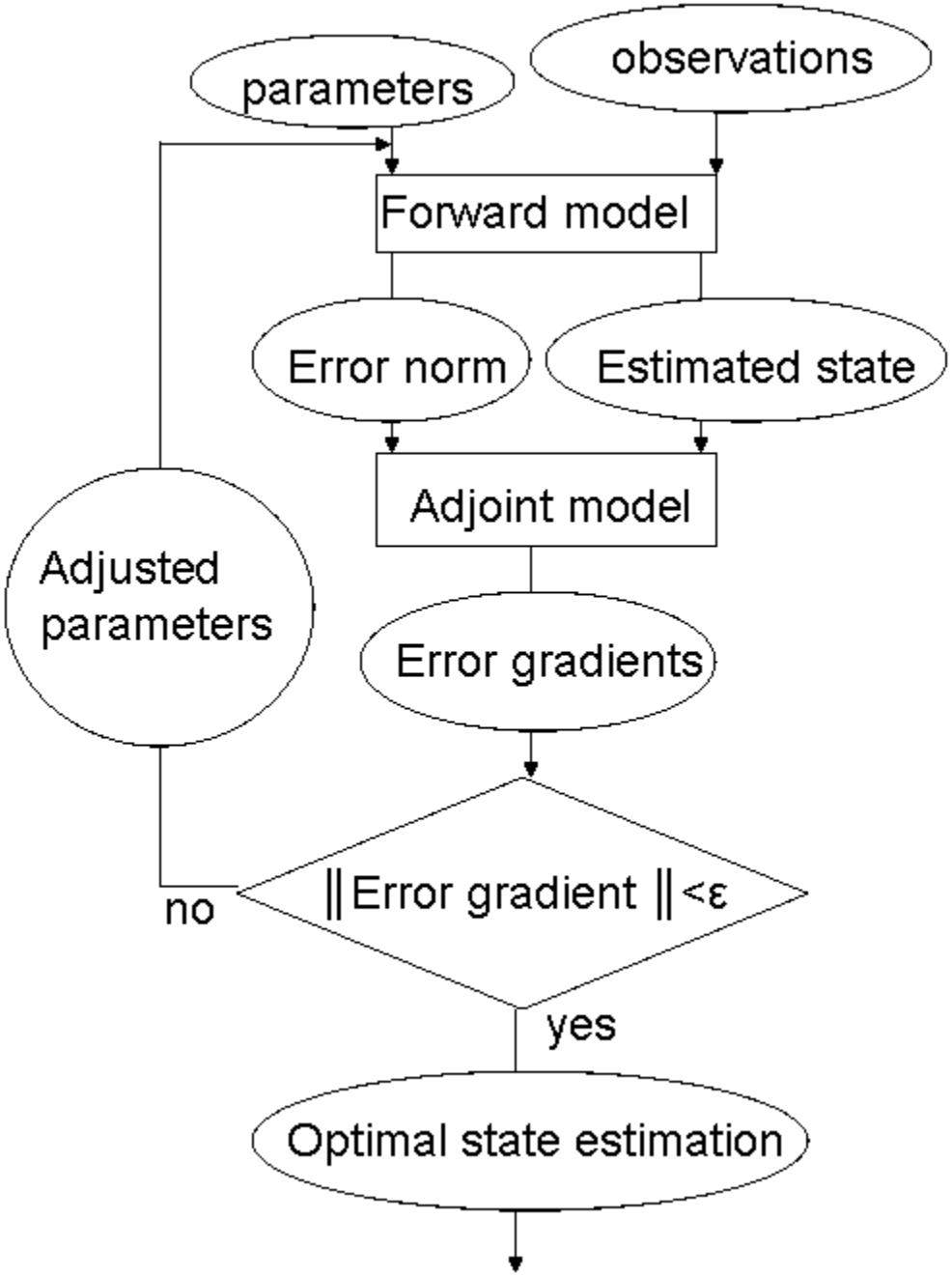


Water wave/flow modelling

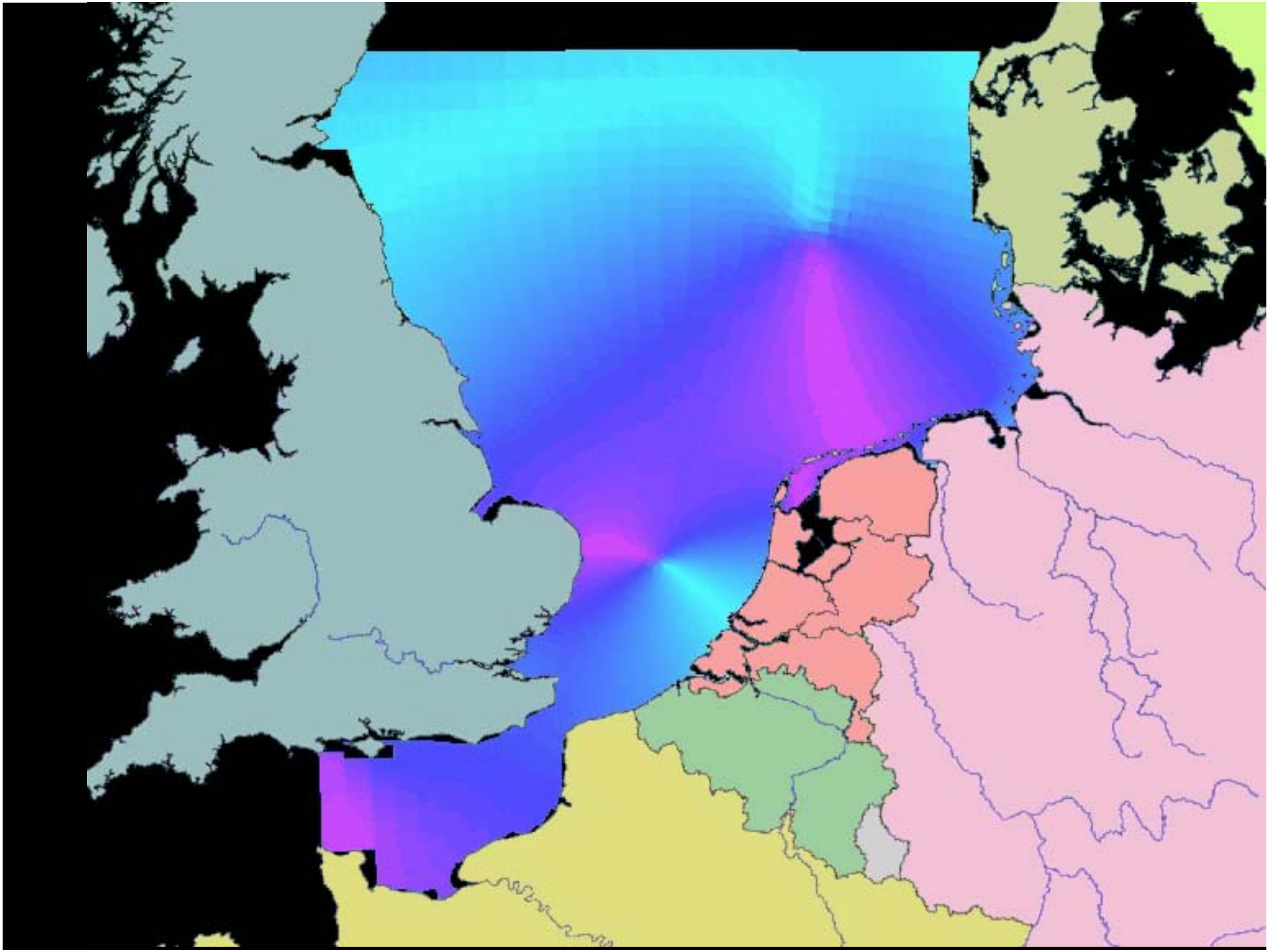
- long wave equations ($kh << 1$, $a/h = O(1)$)
- mild-slope equations ($kh = O(1)$, $a/h << 1$)
- Boussinesq equations ($O((kh)^2) = O(a/h) << 1$)
- Navier-Stokes equations (no restriction on kh and a/h)
  - MAC
  - VOF
  - non-hydrostatic free-surface flow modelling

Modelling goals:

- Understanding
- Designing
- Controlling

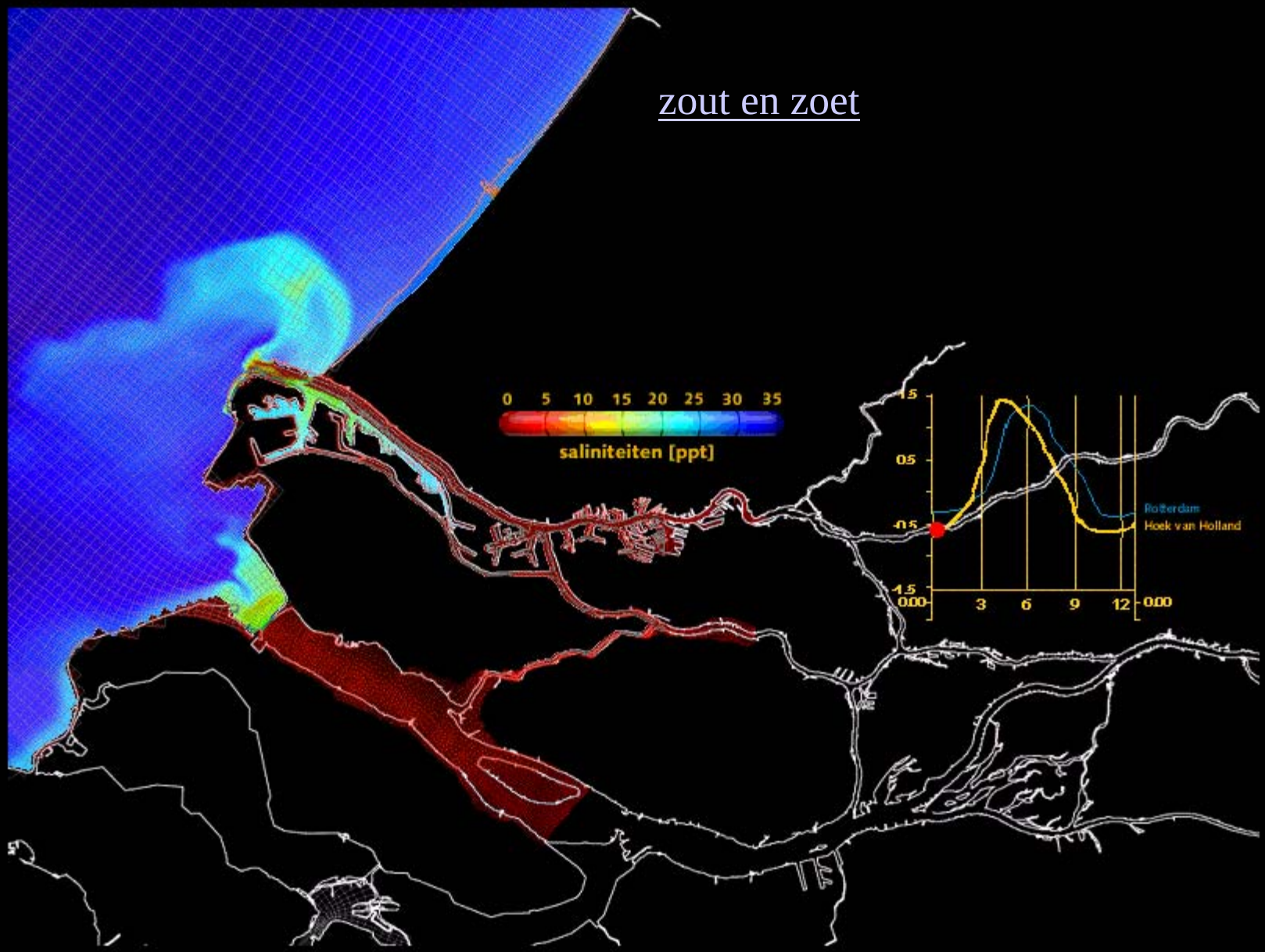


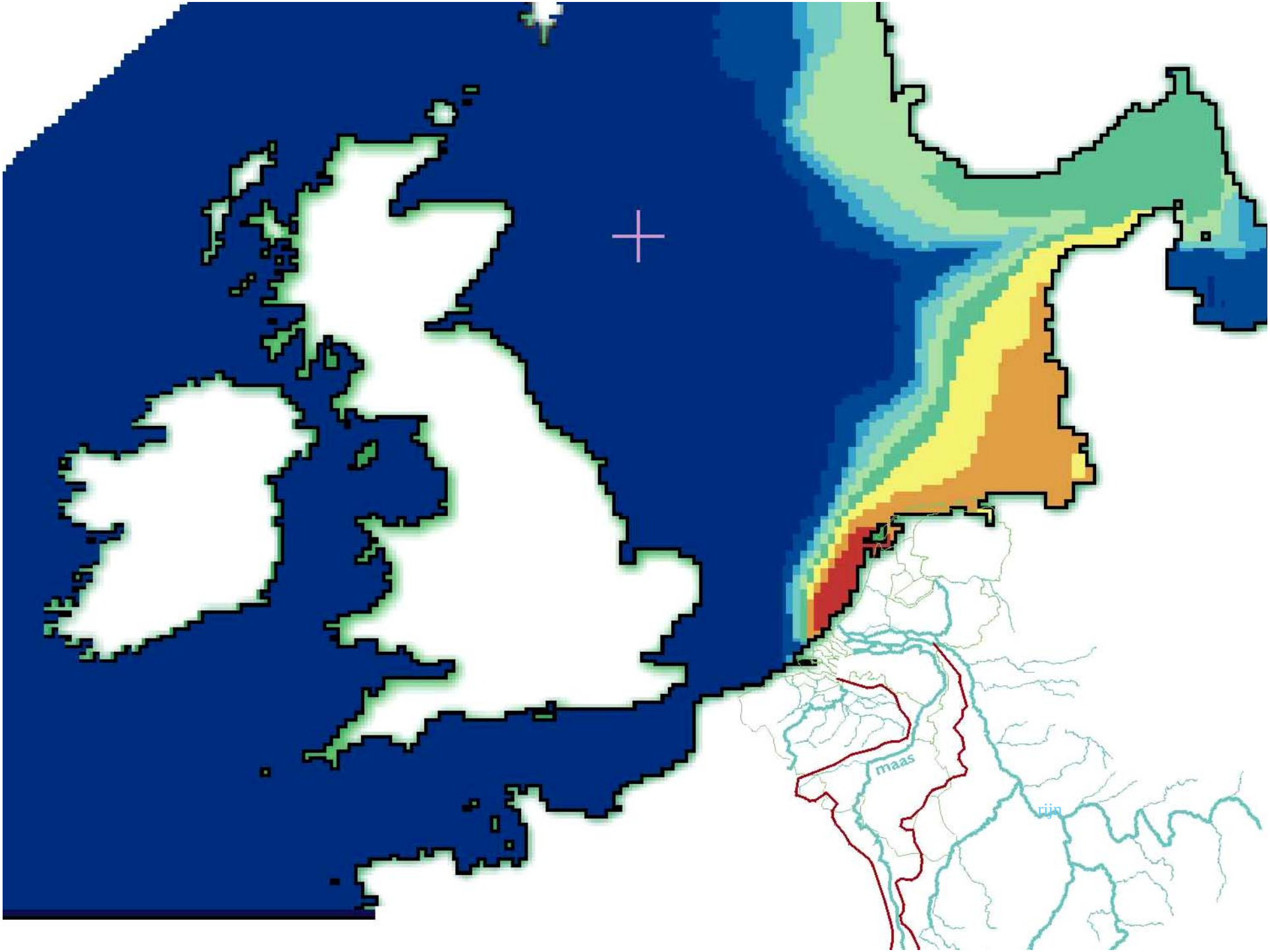
"Nowcast system"

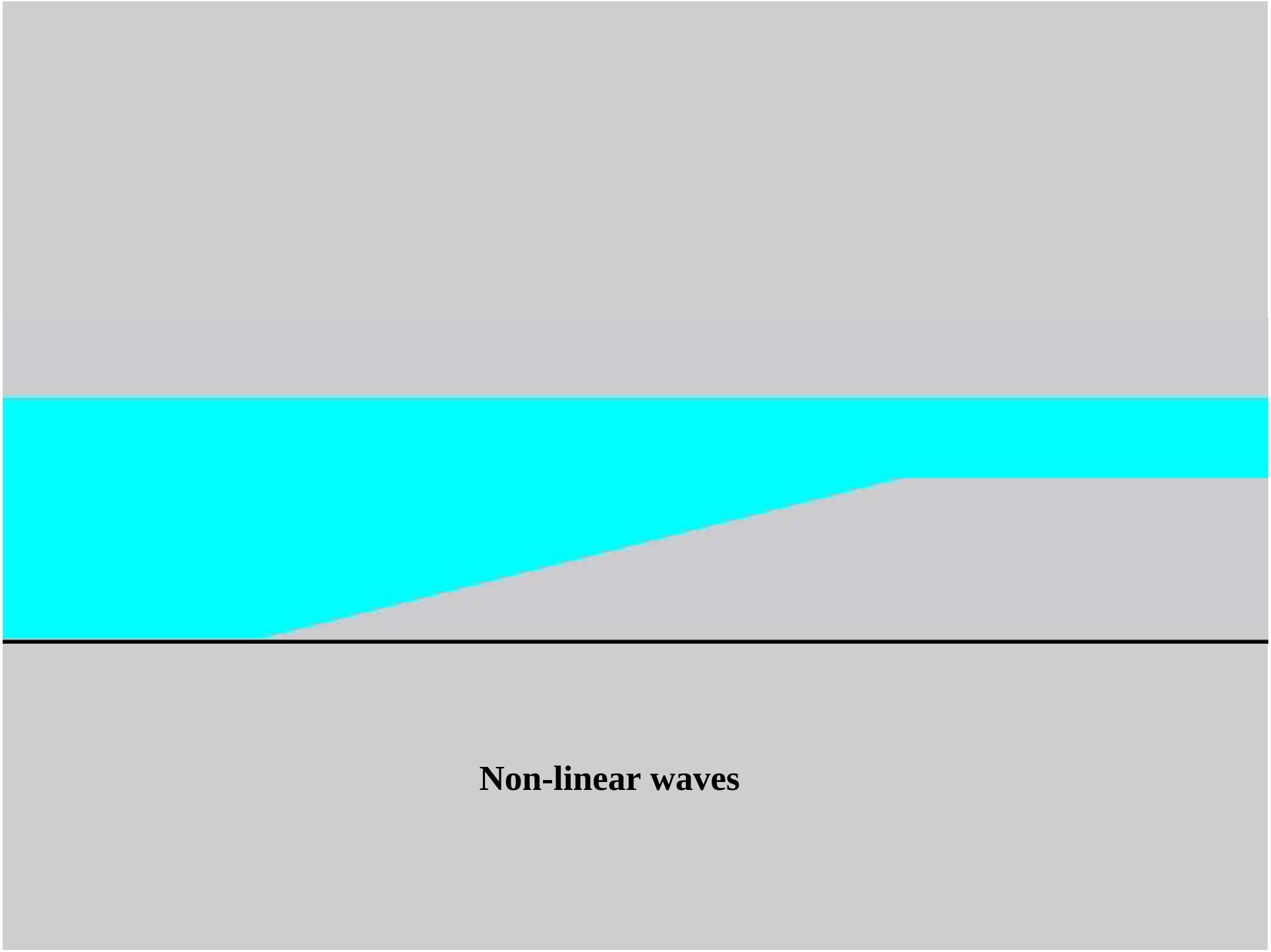


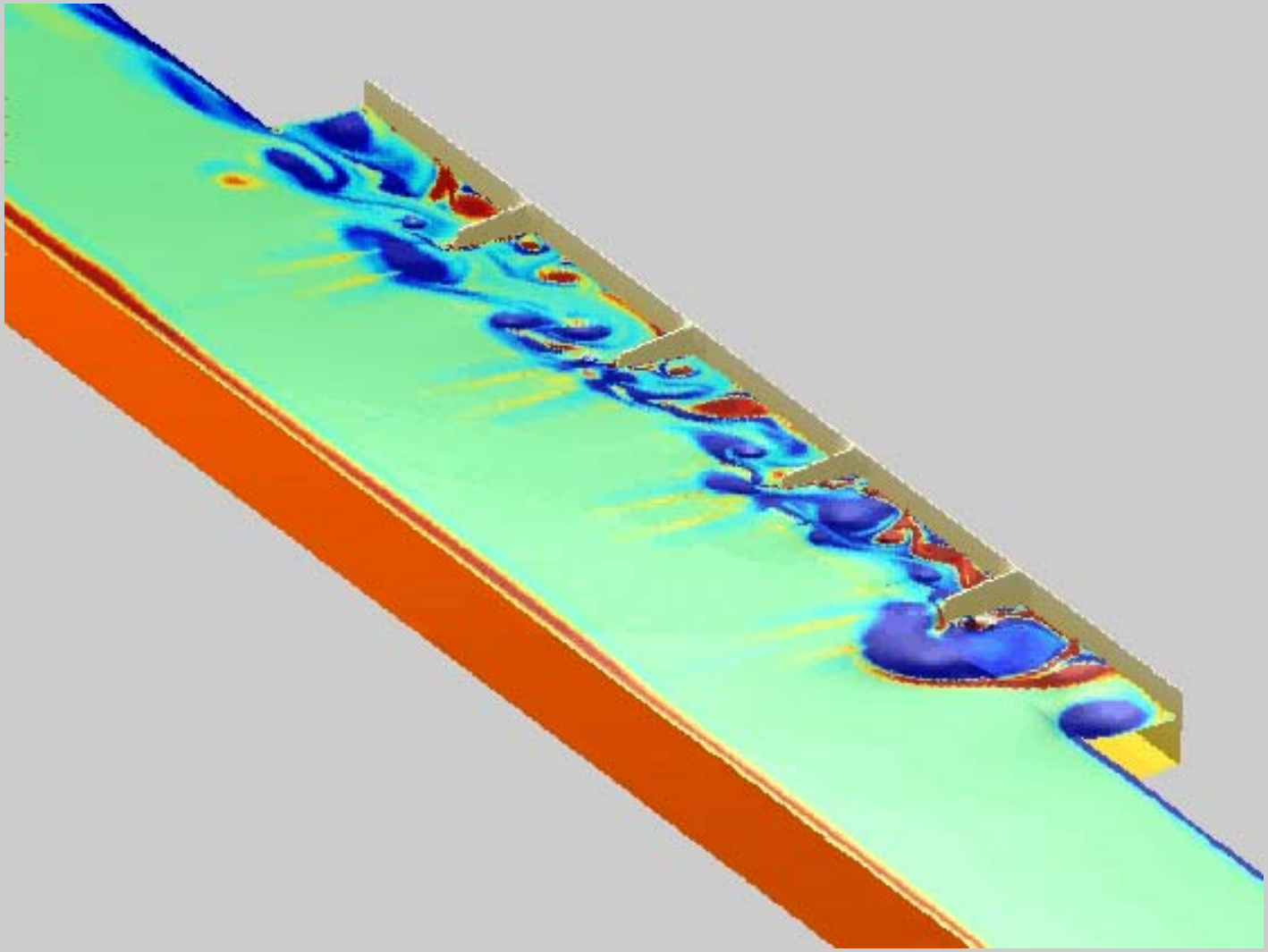
3D

zout en zoet




maas
rijn

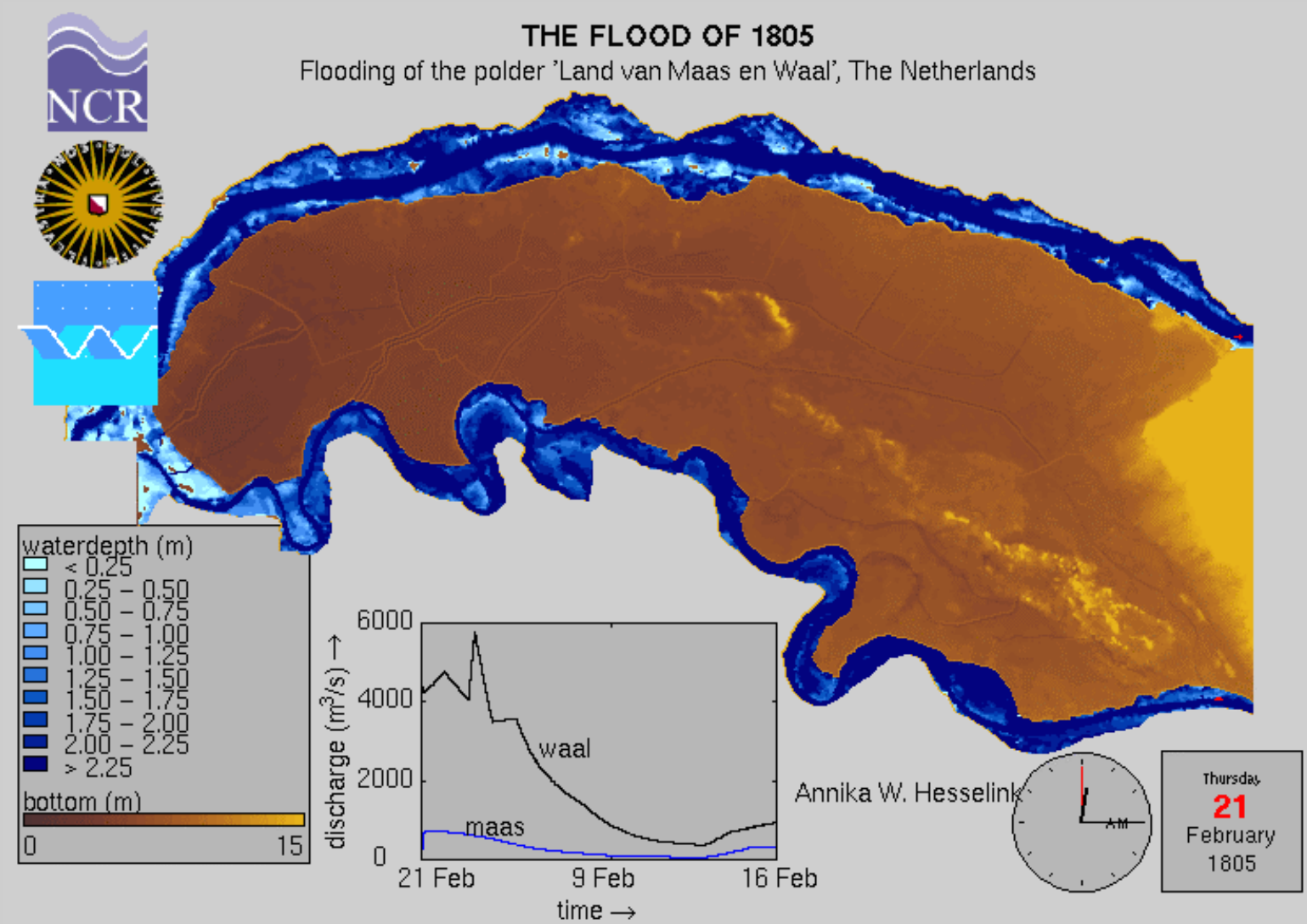

Non-linear waves

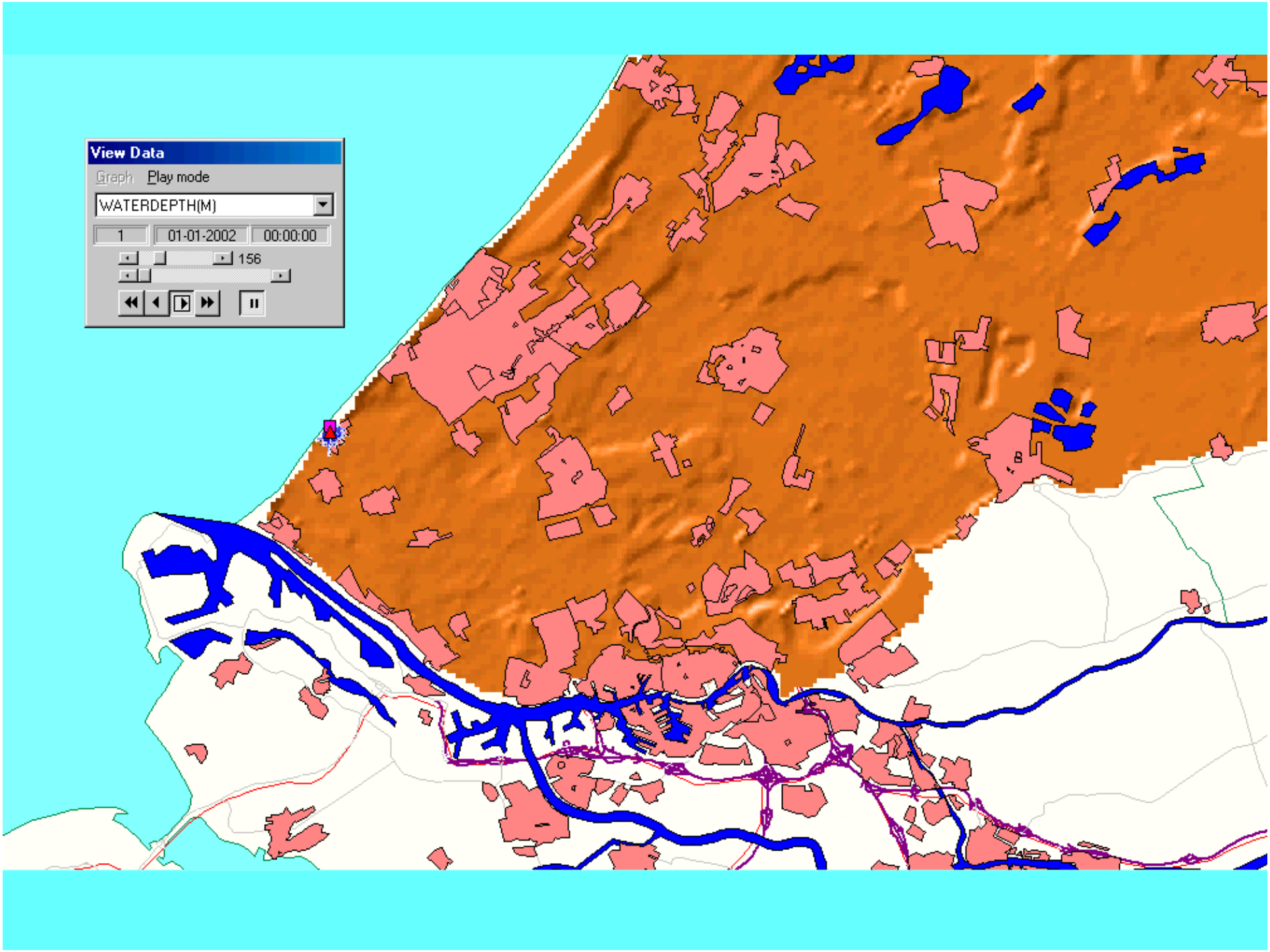


Dam break

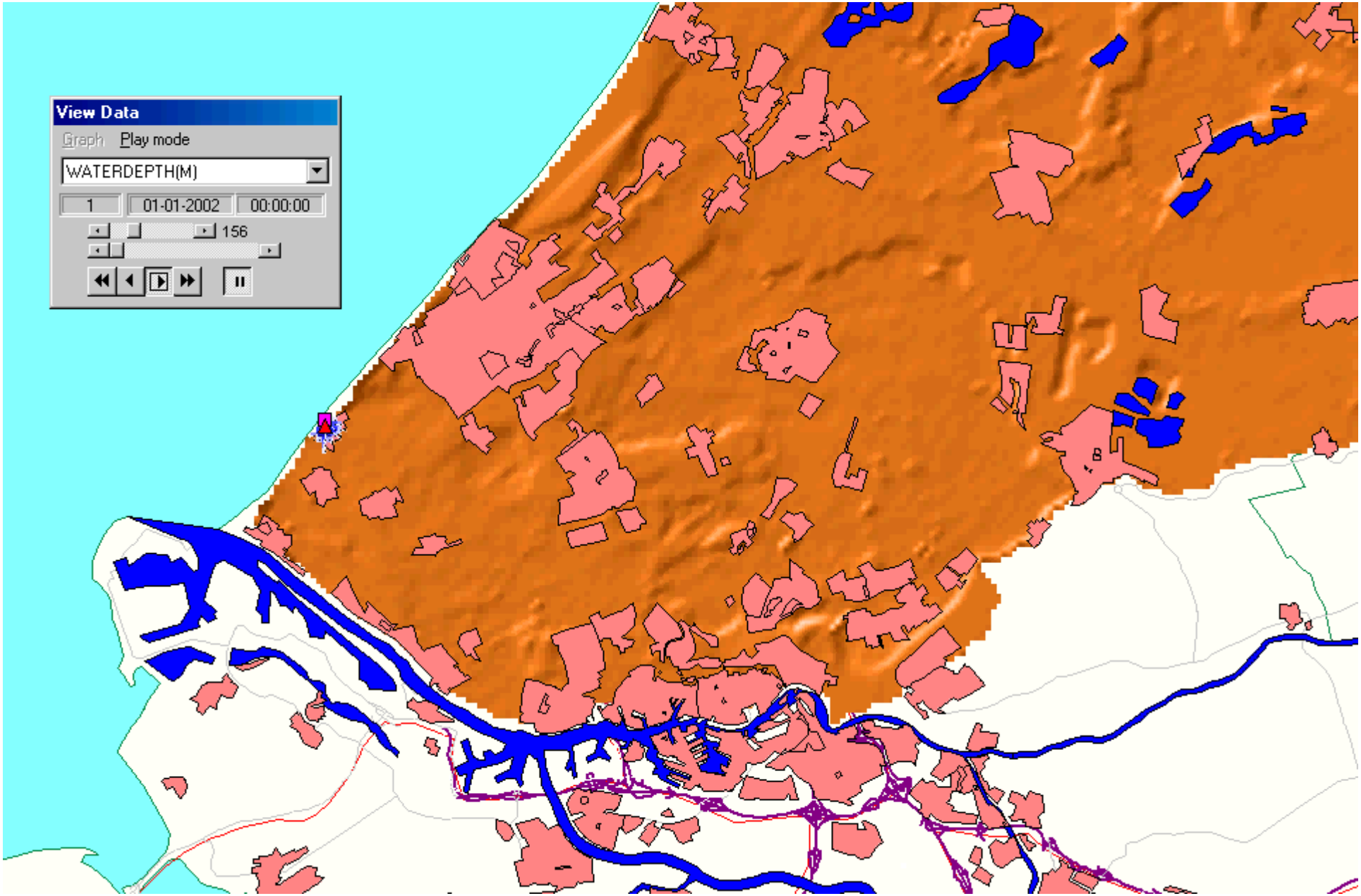
The Netherlands, 17th century

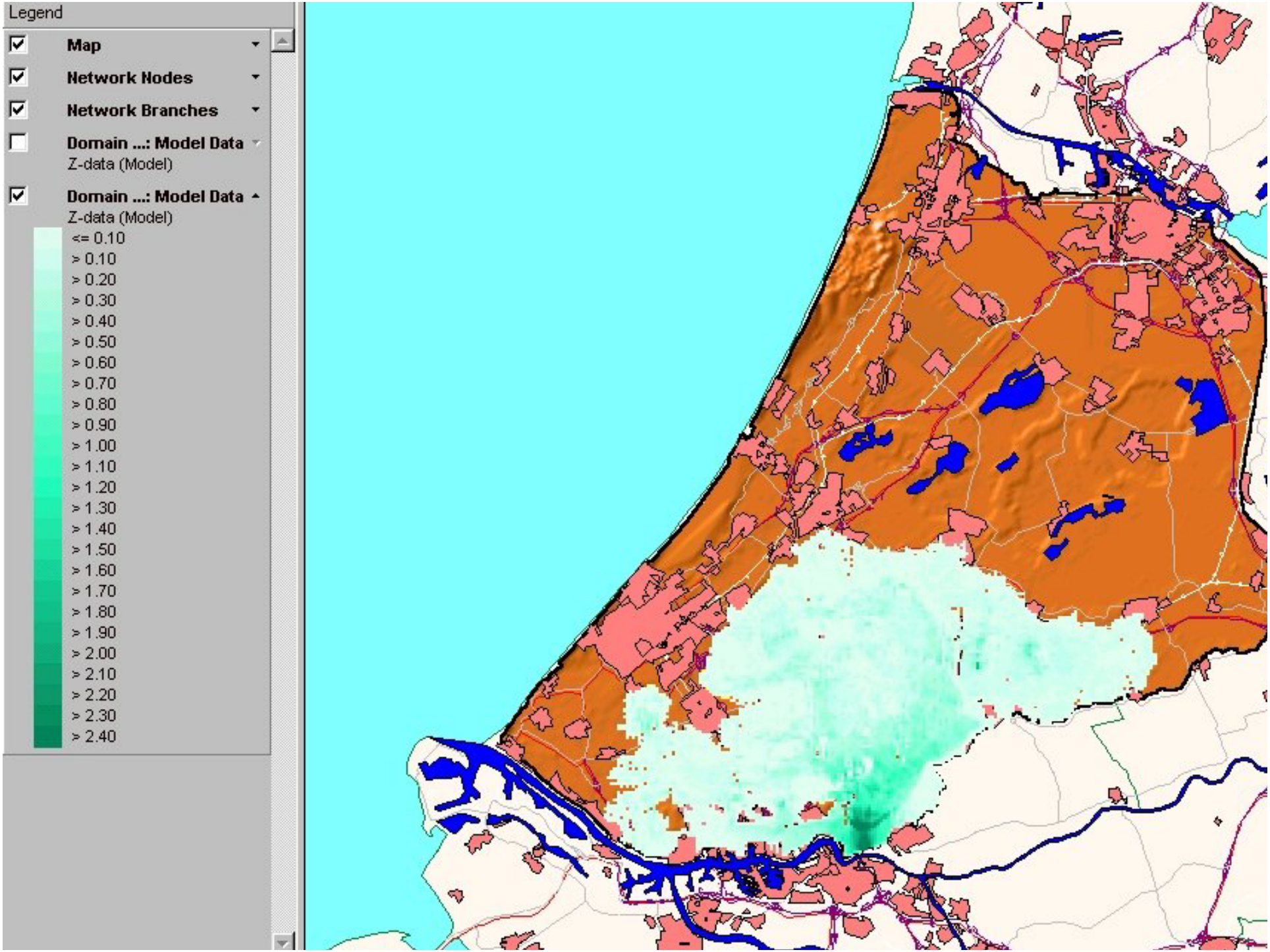
Active protection against water, The Netherlands 1953


THE FLOOD OF 1805
Flooding of the polder 'Land van Maas en Waal', The Netherlands
NCR
waterdepth (m)
< 0.25
0.25 – 0.50
0.50 – 0.75
0.75 – 1.00
1.00 – 1.25
1.25 – 1.50
1.50 – 1.75
1.75 – 2.00
2.00 – 2.25
> 2.25
bottom (m)
0
15
6000
4000
2000
0
discharge (m³/s) →
waal
maas
21 Feb
9 Feb
16 Feb
time →
Annika W. Hesselink
Thursday
21
February
1805

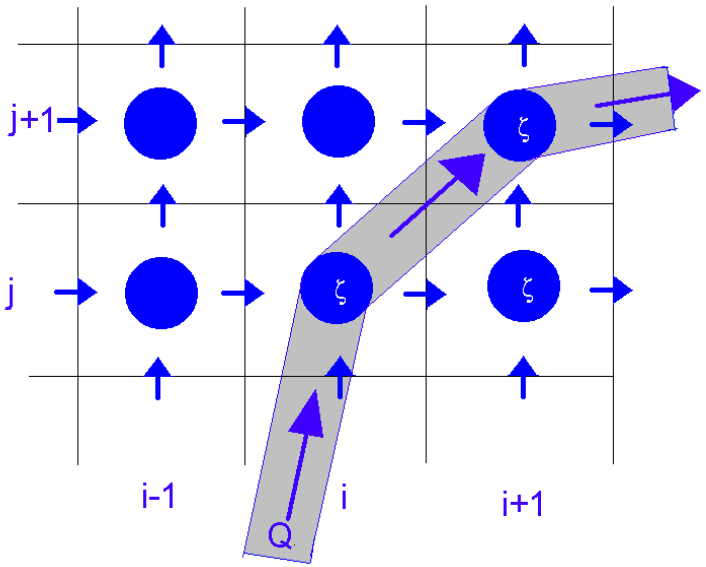

View Data
Graph
Play mode
WATERDEPTH(M)
1
01-01-2002
00:00:00
156

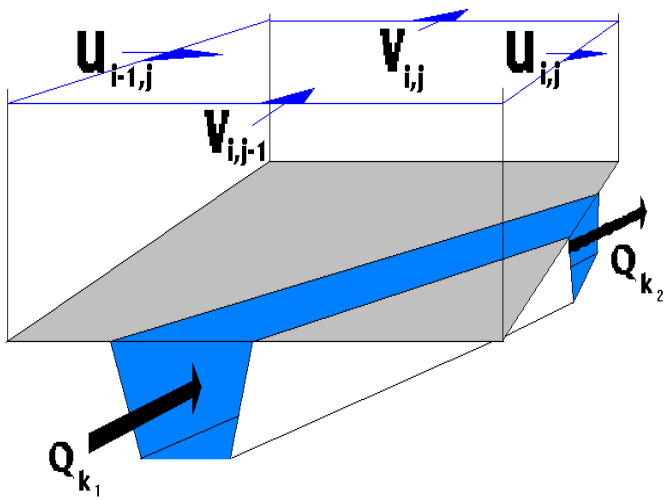
Offline impact assessment

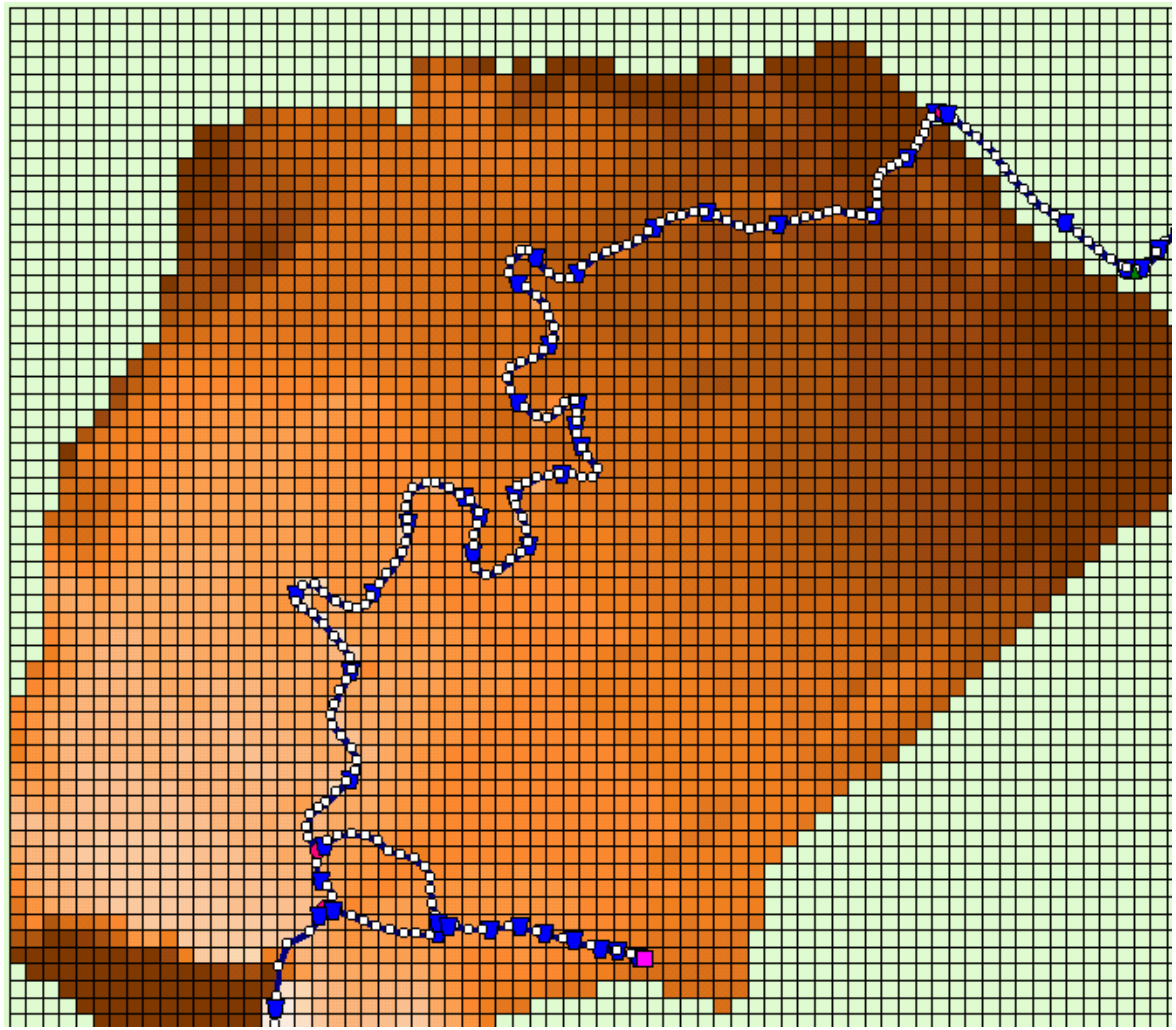


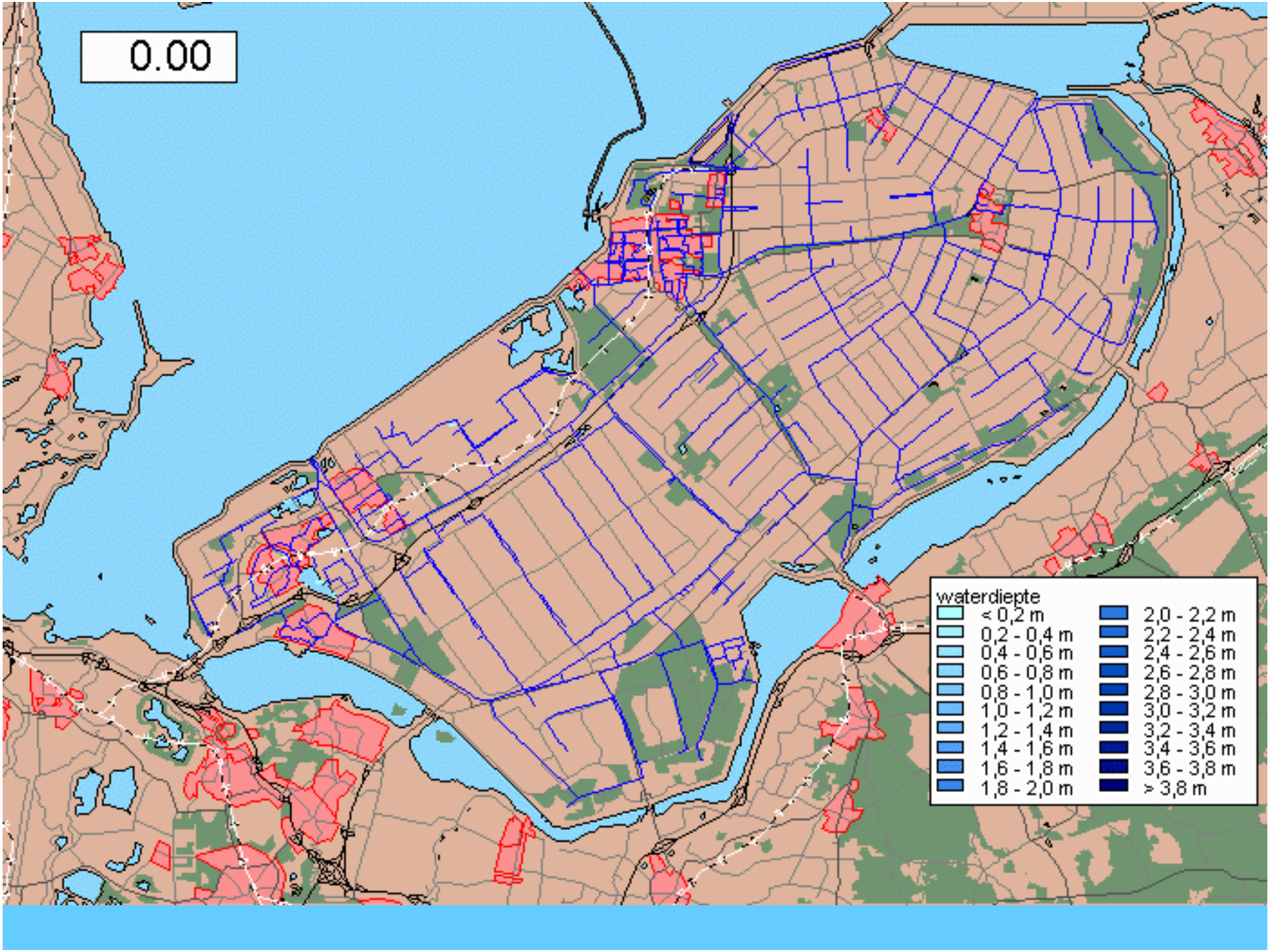

Legend
Map
Network Nodes
Network Branches
Domain ...: Model Data
Z-data (Model)
Domain ...: Model Data
Z-data (Model)
<= 0.10
> 0.10
> 0.20
> 0.30
> 0.40
> 0.50
> 0.60
> 0.70
> 0.80
> 0.90
> 1.00
> 1.10
> 1.20
> 1.30
> 1.40
> 1.50
> 1.60
> 1.70
> 1.80
> 1.90
> 2.00
> 2.10
> 2.20
> 2.30
> 2.40

1D/2D flow model SOBEK, for water management in rural and Urban areas

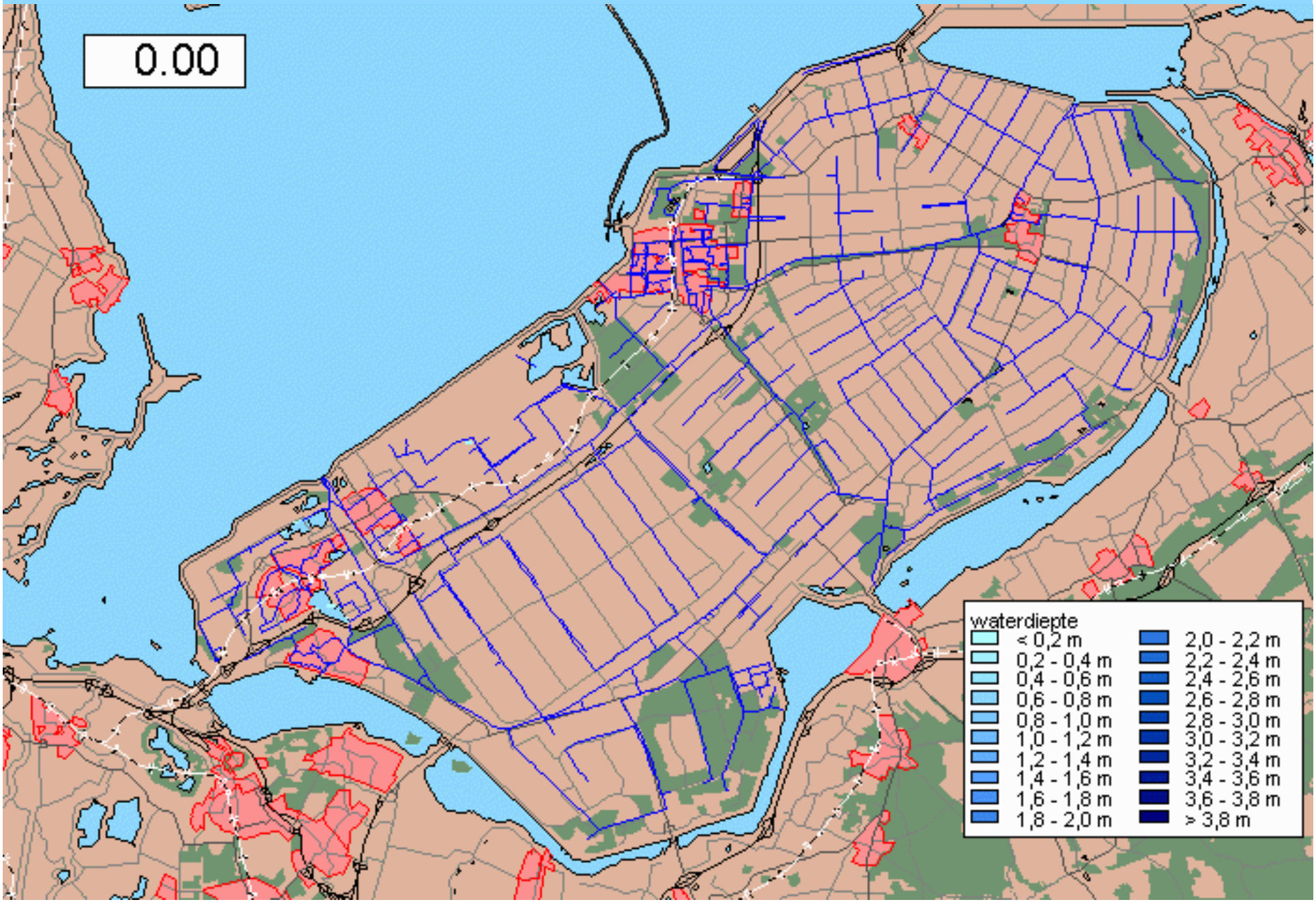







0.00
waterdiepte
< 0,2 m
0,2 - 0,4 m
0,4 - 0,6 m
0,6 - 0,8 m
0,8 - 1,0 m
1,0 - 1,2 m
1,2 - 1,4 m
1,4 - 1,6 m
1,6 - 1,8 m
1,8 - 2,0 m
2,0 - 2,2 m
2,2 - 2,4 m
2,4 - 2,6 m
2,6 - 2,8 m
2,8 - 3,0 m
3,0 - 3,2 m
3,2 - 3,4 m
3,4 - 3,6 m
3,6 - 3,8 m
> 3,8 m

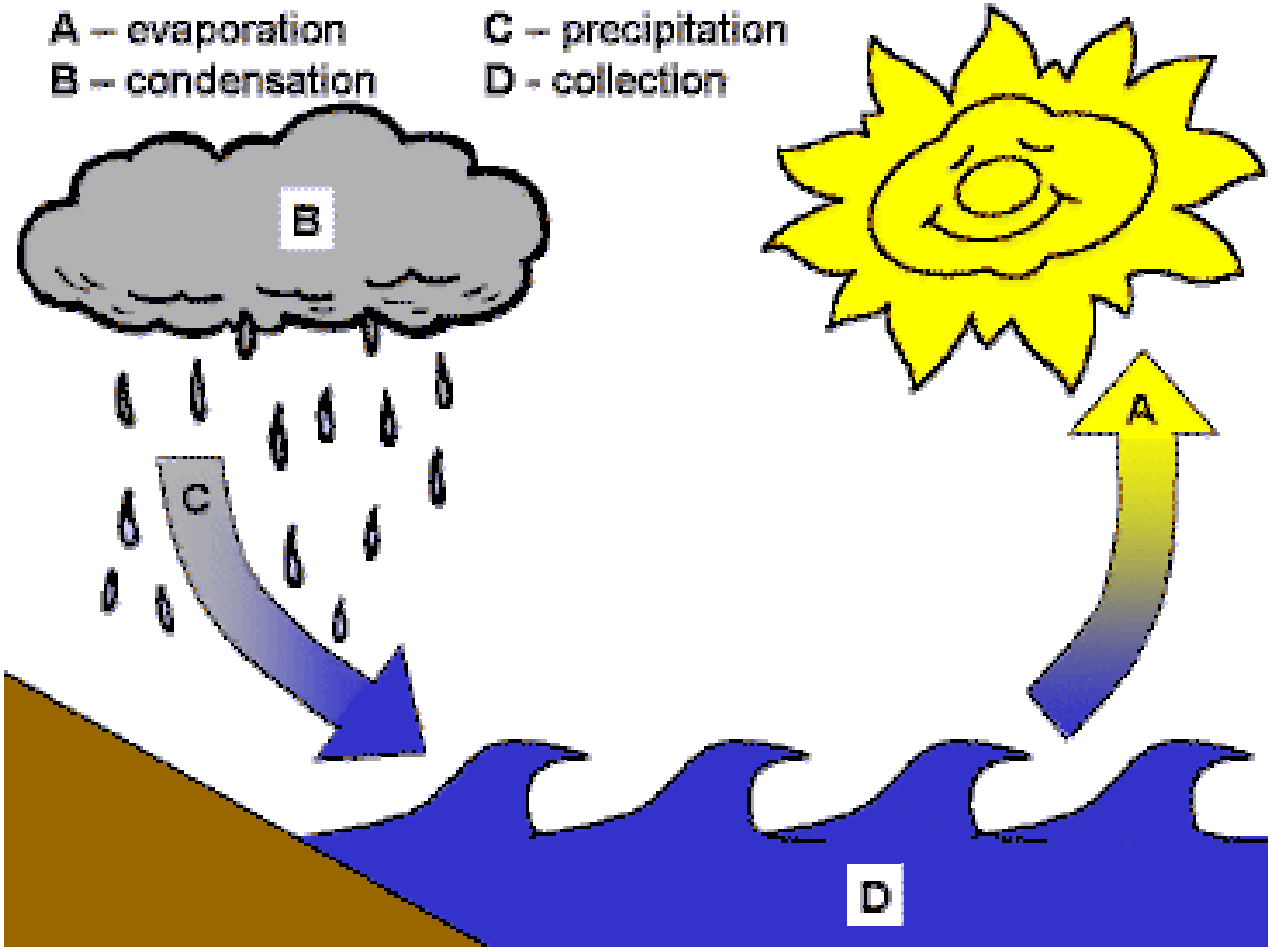
Inundation of a Dutch polder simulated with 1D/2D SOBEK



The water system is an integrated whole,

therefore models for the design of control, evacuation etc.,

must be as integrated as possible!



TITLE: Climatology of Hurricane Landfalls & Analysis Forecasting Hurricane Structure

PRESENTED BY: Jack Beven, Tropical Prediction Center/National Hurricane Center

SUMMARY: The first part of the presentation dealt with the climatology of hurricanes along the northern coast of the Gulf of Mexico with emphasis on how often Category 5 hurricanes recurs - about once every 50-55 years in the New Orleans area. The second part discussed tropical cyclone intensity and size, the difficulties of forecasting hurricane intensity, the variety of hurricane shapes and sizes, and the impact of these aspects on the expected storm surge.

Hurricane Risk for the Northern Gulf Coast

JACK BEVEN
TROPICAL PREDICTION CENTER

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

The TPC HURRISK Program

- Employs climatology derived from observed tropical cyclone tracks
- Does not take storm size parameters into account

Tropical Storms and Hurricanes Near New Orleans 1886-2003

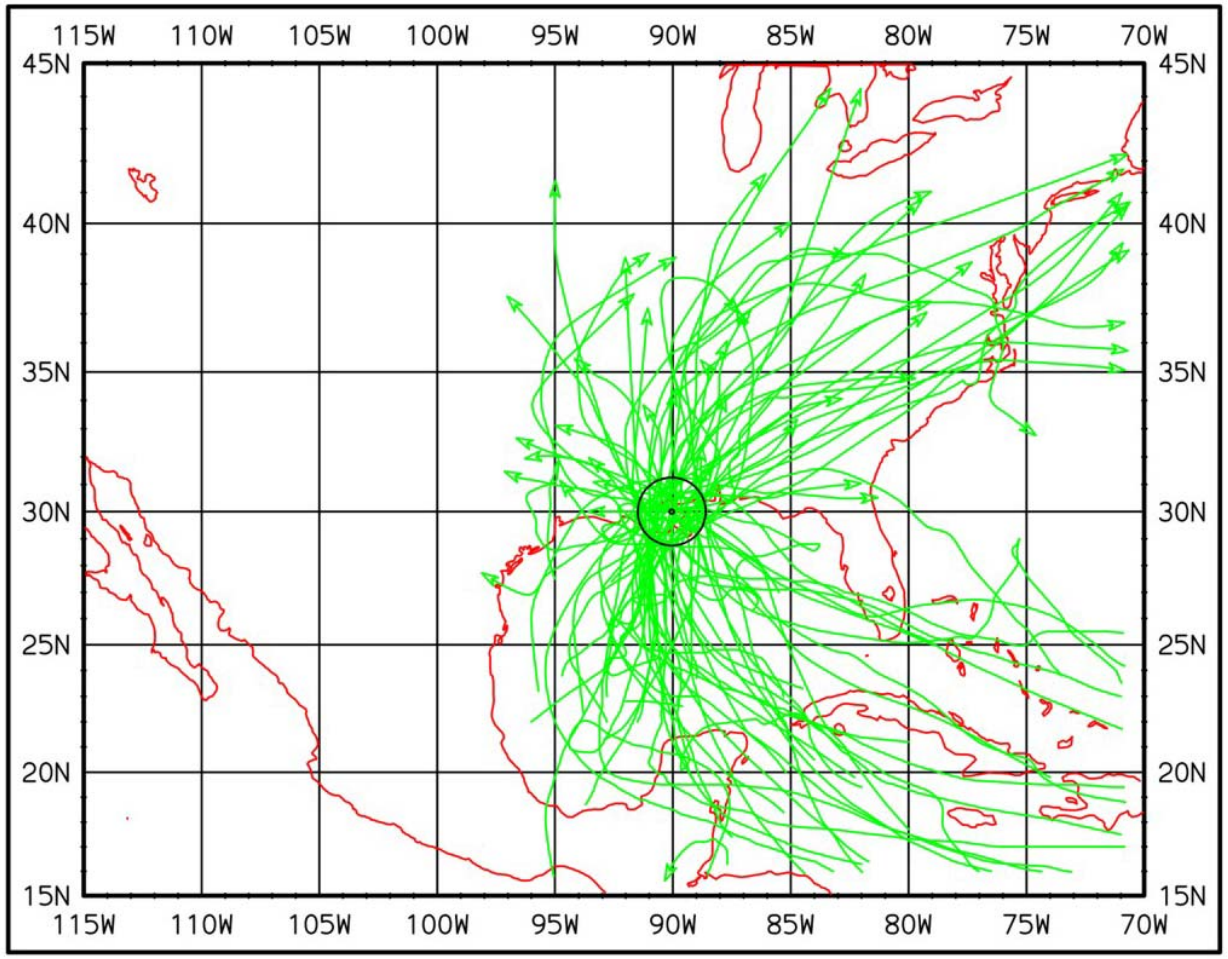
TROPICAL STORMS AND HURRICANES PASSING WITHIN 75 NMi OF NEW ORLEANS, 1886-2003

1 STORM INDEX NUMBER	2 STORM NAME	3 YEAR	4 MONTH	5 DAY	6 STORM NUMBER FOR YEAR	7 MAX WIND AT STORM CENTER (SEE NOTES)	8 CPA (CLOSEST POINT OF APPROACH)	9 DDD/SS.S DDD=HEADING SS.S=FORWARD SPEED AT CPA
1	NOT NAMED	1886	JUN	15	1	35(34)	73 (N)	087/12.0
2	NOT NAMED	1887	JUN	14	3	35(35)	69 (E)	352/10.0
3	NOT NAMED	1887	OCT	19	13	75(62)	24 (SE)	048/10.5
4	NOT NAMED	1888	AUG	20	3	95(75)	45 (W)	353/ 7.1
5	NOT NAMED	1889	SEP	23	6	70(65)	54 (SSE)	057/13.6
6	NOT NAMED	1890	AUG	27	2	50(38)	35 (W)	007/20.2
7	NOT NAMED	1892	SEP	12	4	50(44)	9 (SE)	039/15.9
8	NOT NAMED	1893	SEP	7	8	85(65)	15 (WNW)	025/10.0
9	NOT NAMED	1893	OCT	2	10	115(105)	34 (SE)	038/10.0
10	NOT NAMED	1895	AUG	16	1	50(50)	41 (SE)	039/ 4.3
11	NOT NAMED	1900	SEP	13	4	41(37)	48 (ESE)	027/10.0
12	NOT NAMED	1901	AUG	15	4	80(80)	45 (SE)	041/ 4.0
13	NOT NAMED	1905	OCT	9	5	40(37)	42 (WNW)	032/13.0
14	NOT NAMED	1906	SEP	27	6	95(95)	74 (ENE)	345/10.3
15	NOT NAMED	1907	SEP	21	2	40(40)	55 (E)	005/ 5.4
16	NOT NAMED	1909	SEP	21	8	105(100)	71 (WSW)	345/19.5
17	NOT NAMED	1912	JUN	13	1	43(39)	47 (NW)	054/20.6
18	NOT NAMED	1914	SEP	18	1	35(35)	6 (N)	265/11.2
19	NOT NAMED	1915	SEP	30	5	115(75)	3 (E)	004/11.6
20	NOT NAMED	1920	SEP	22	2	85(82)	46 (WSW)	332/17.4
21	NOT NAMED	1923	OCT	16	3	85(60)	59 (W)	352/21.7
22	NOT NAMED	1923	OCT	17	6	43(41)	57 (E)	357/24.0
23	NOT NAMED	1926	AUG	26	3	110(80)	50 (WSW)	336/ 7.0
24	NOT NAMED	1926	SEP	21	6	62(48)	31 (N)	275/ 7.8
25	NOT NAMED	1931	JUL	15	2	45(40)	66 (WSW)	347/ 8.3
26	NOT NAMED	1932	OCT	16	8	40(40)	15 (NW)	053/14.4
27	NOT NAMED	1934	JUN	16	2	105(68)	49 (W)	360/11.0
28	NOT NAMED	1936	JUL	27	4	40(33)	9 (ESE)	015/18.3
29	NOT NAMED	1939	SEP	26	3	37(30)	18 (SW)	028/ 6.5
30	NOT NAMED	1944	SEP	10	6	40(36)	19 (SE)	037/15.6
31	NOT NAMED	1946	JUN	15	1	35(35)	74 (S)	279/ 7.1
32	NOT NAMED	1947	SEP	19	4	100(96)	7 (NNE)	292/12.0
33	NOT NAMED	1948	SEP	4	5	70(55)	4 (ESE)	019/12.2
34	NOT NAMED	1949	SEP	4	5	40(40)	37 (W)	352/10.2
35	BRENDA	1955	AUG	1	1	60(52)	17 (NE)	315/10.6
36	NOT NAMED	1955	AUG	27	5	40(40)	9 (N)	280/12.3
37	NOT NAMED	1956	JUN	13	1	50(44)	26 (W)	010/16.2
38	FLOSSY	1956	SEP	24	7	79(77)	62 (SSE)	056/11.4
39	ESTHER	1957	SEP	18	6	45(45)	26 (WNW)	008/12.5
40	ETHEL	1960	SEP	15	6	73(60)	55 (E)	360/ 8.0
41	HILDA	1964	OCT	4	10	78(60)	42 (N)	082/11.3
42	BETSY	1965	SEP	10	3	135(90)	41 (SW)	315/16.9
43	CAMILLE	1969	AUG	18	3	165(165)	35 (ENE)	341/13.7
44	CARMEN	1974	SEP	8	6	130(130)	73 (SW)	322/ 8.1
45	BABE	1977	SEP	6	2	65(30)	49 (NW)	051/ 7.2
46	BOB	1979	JUL	11	2	65(53)	18 (W)	010/19.3
47	ELENA	1985	SEP	2	5	100(84)	41 (NNE)	300/16.0
48	JUAN	1985	OCT	31	10	70(58)	61 (SSE)	061/11.8
49	BERYL	1988	AUG	8	2	45(28)	1 (NE)	147/ 8.9
50	FLORENCE	1988	SEP	10	7	70(50)	3 (NE)	318/13.2
51	DANNY	1997	JUL	18	5	70(68)	44 (SE)	056/ 5.3
52	GEORGES	1998	SEP	29	7	91(48)	64 (NE)	090/ .6
53	HERMINE	1998	SEP	20	8	40(32)	31 (WNW)	018/13.5
54	ALLISON	2001	JUN	11	1	40(36)	14 (NW)	051/12.0
55	BERTHA	2002	AUG	5	2	35(30)	7 (ENE)	347/10.2
56	HANNA	2002	SEP	14	9	50(50)	63 (ESE)	015/13.2
57	ISIDORE	2002	SEP	26	10	55(55)	7 (ESE)	010/15.8
58	BILL	2003	JUN	30	3	50(46)	23 (WNW)	027/14.3

NOTES:
Datetimes are UTC, winds are in knots and distances are in nautical miles (nmi). Directions in column 8 refer to bearing of storm from site at the closest point of approach (CPA). Two winds are listed in column 7. First is the maximum wind anywhere within the 75 nmi scan radius. Second (in parenthesis) is the maximum wind at CPA. If this is <34 kts, it is treated as a weak tropical storm (34kts) in tables and charts. Site location (degs and degs/100) is 30.00N 90.05W.

CHART 1A

Tropical Storms and Hurricanes Near New Orleans 1886-2003

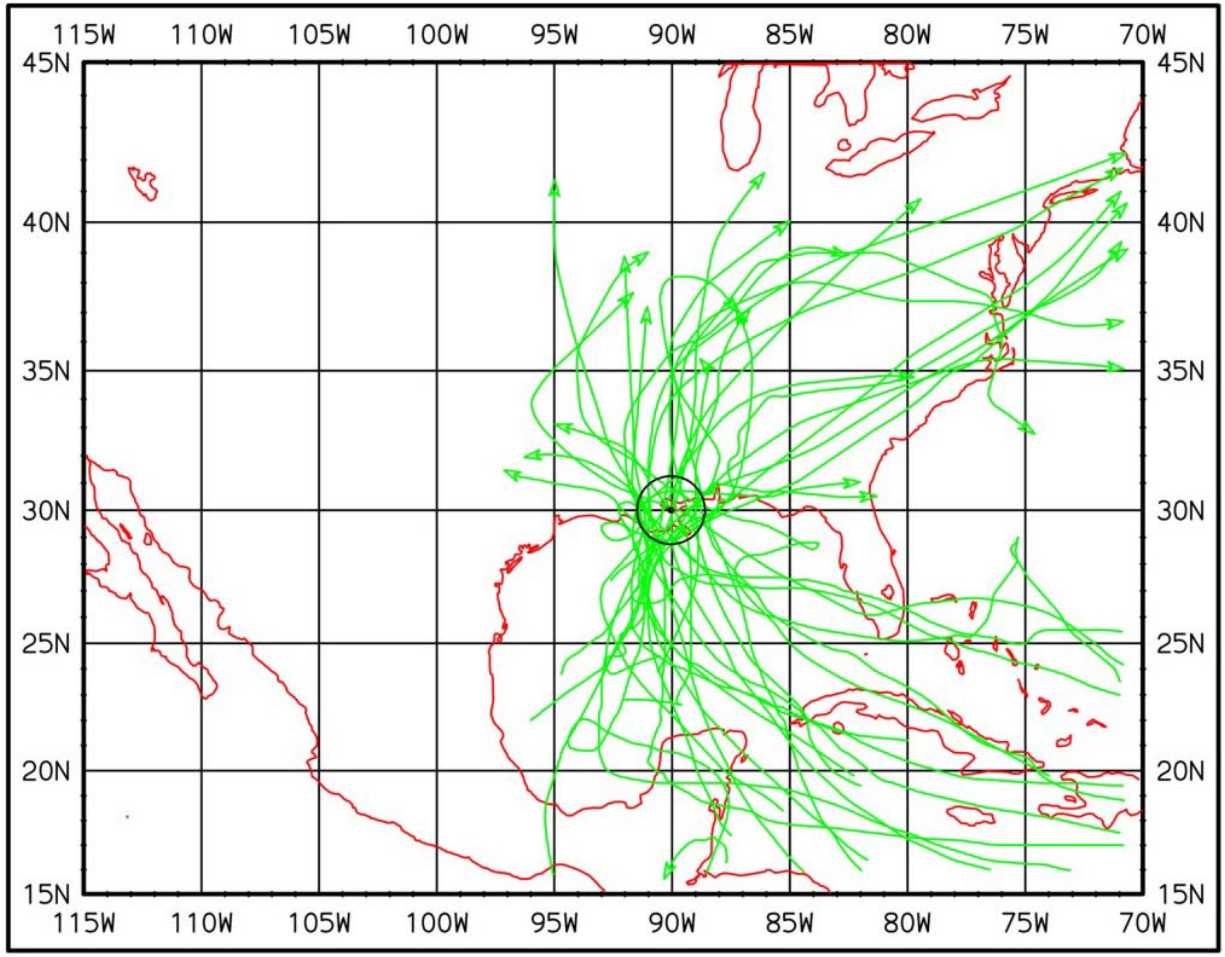


TROPICAL STORMS AND HURRICANES PASSING WITHIN 75 NMi OF NEW ORLEANS, 1886-2003

NUMBER OF STORMS IS 58

CHART 2

Hurricanes
Near New Orleans 1886-2003

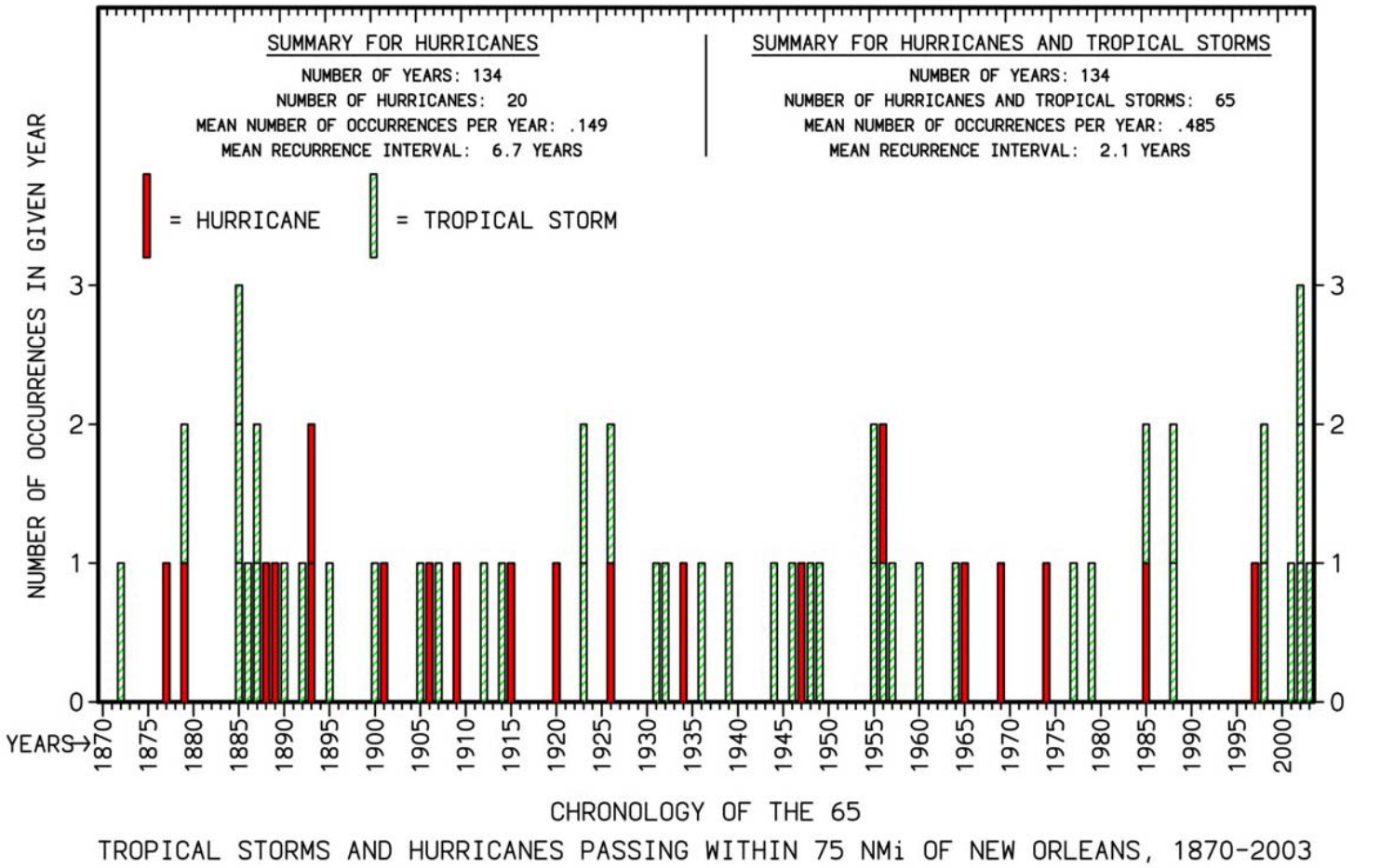


HURRICANES PASSING WITHIN 75 NMi OF NEW ORLEANS, 1886-2003

NUMBER OF STORMS IS 28

CHART 3

Tropical Storms and Hurricanes Near New Orleans 1886-2003

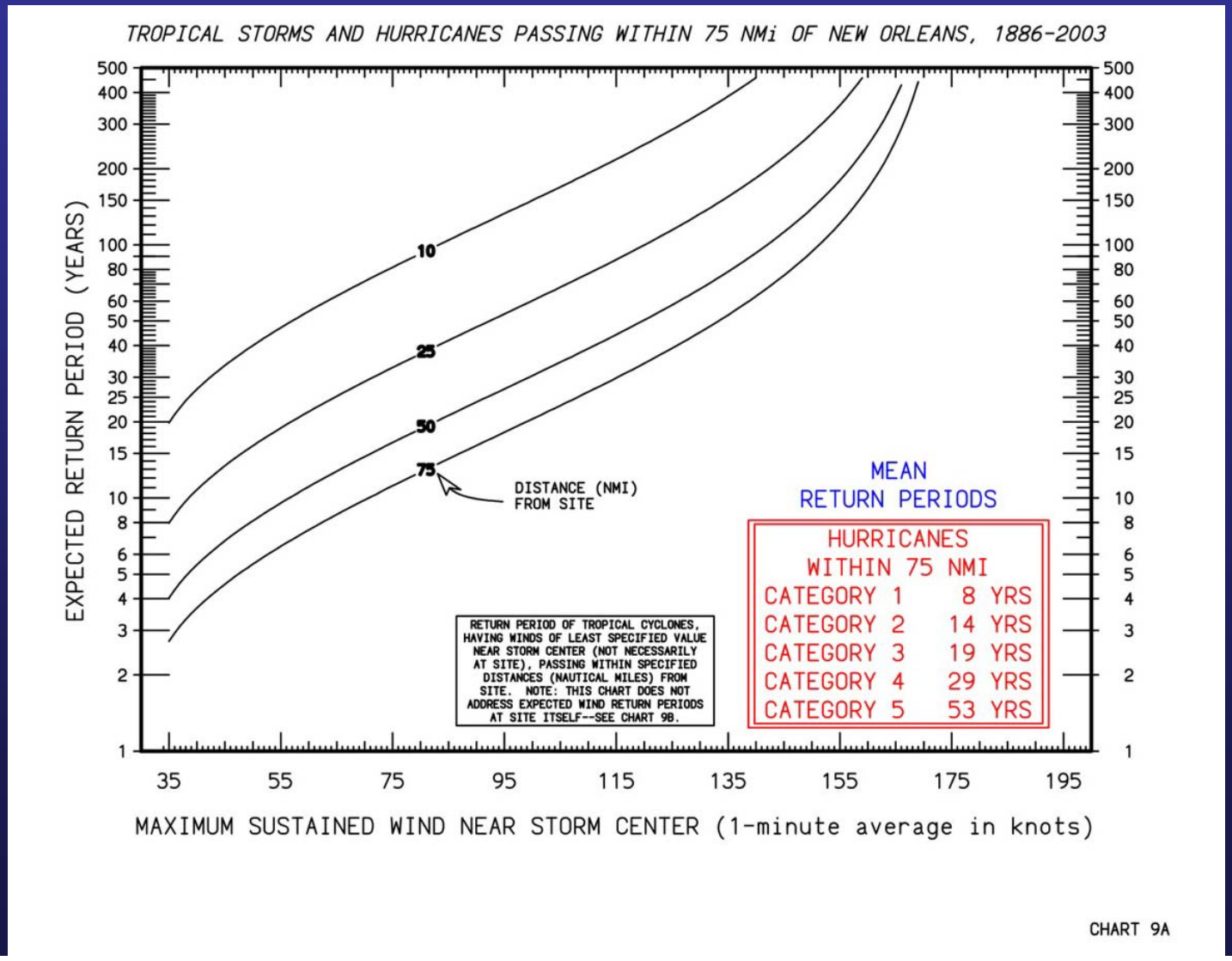


CHRONOLOGY OF THE 65
TROPICAL STORMS AND HURRICANES PASSING WITHIN 75 NMi OF NEW ORLEANS, 1870-2003

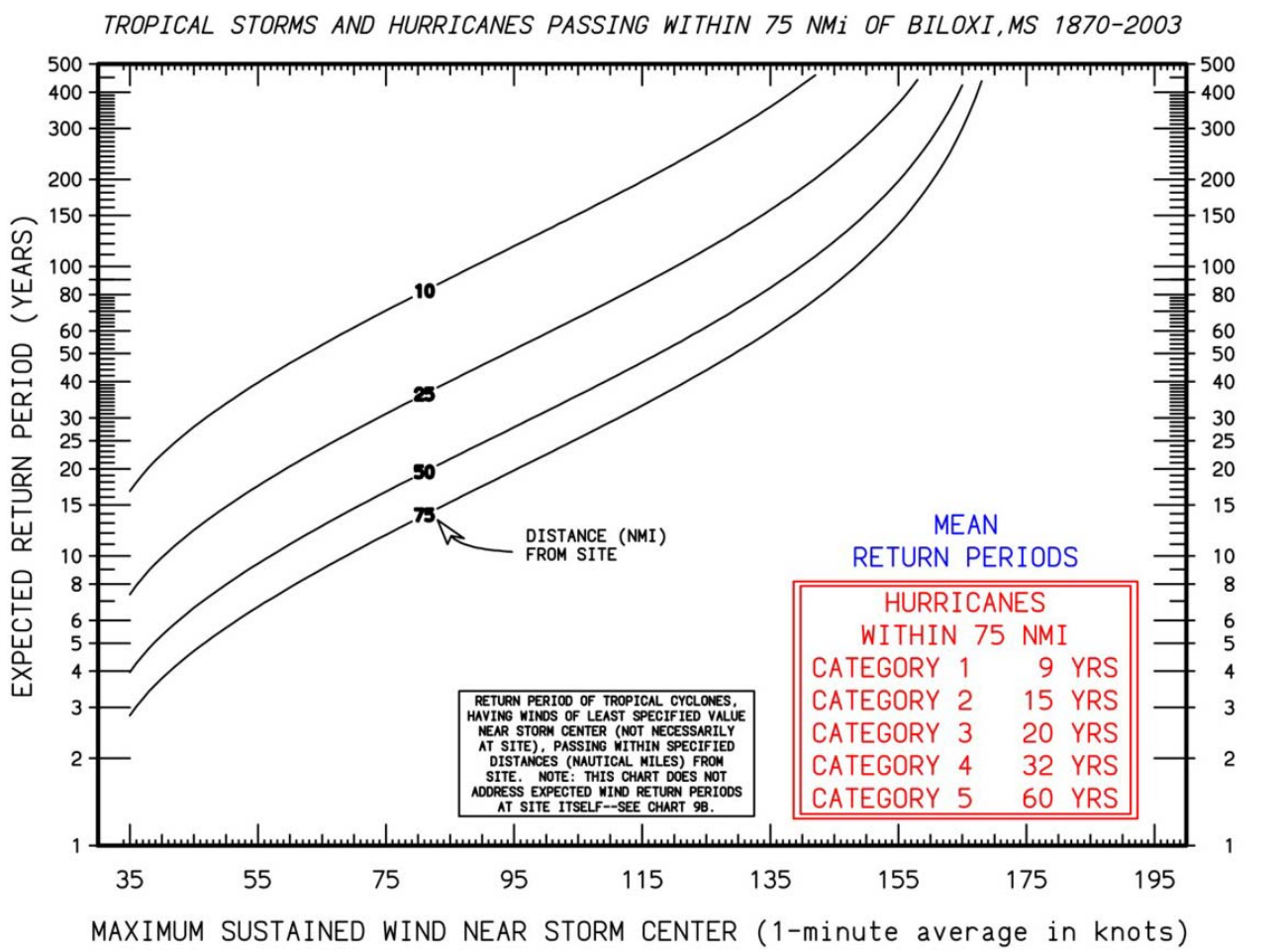
(Note: Designation as tropical storm or hurricane is at time of closest point of approach to site.)

CHART 4

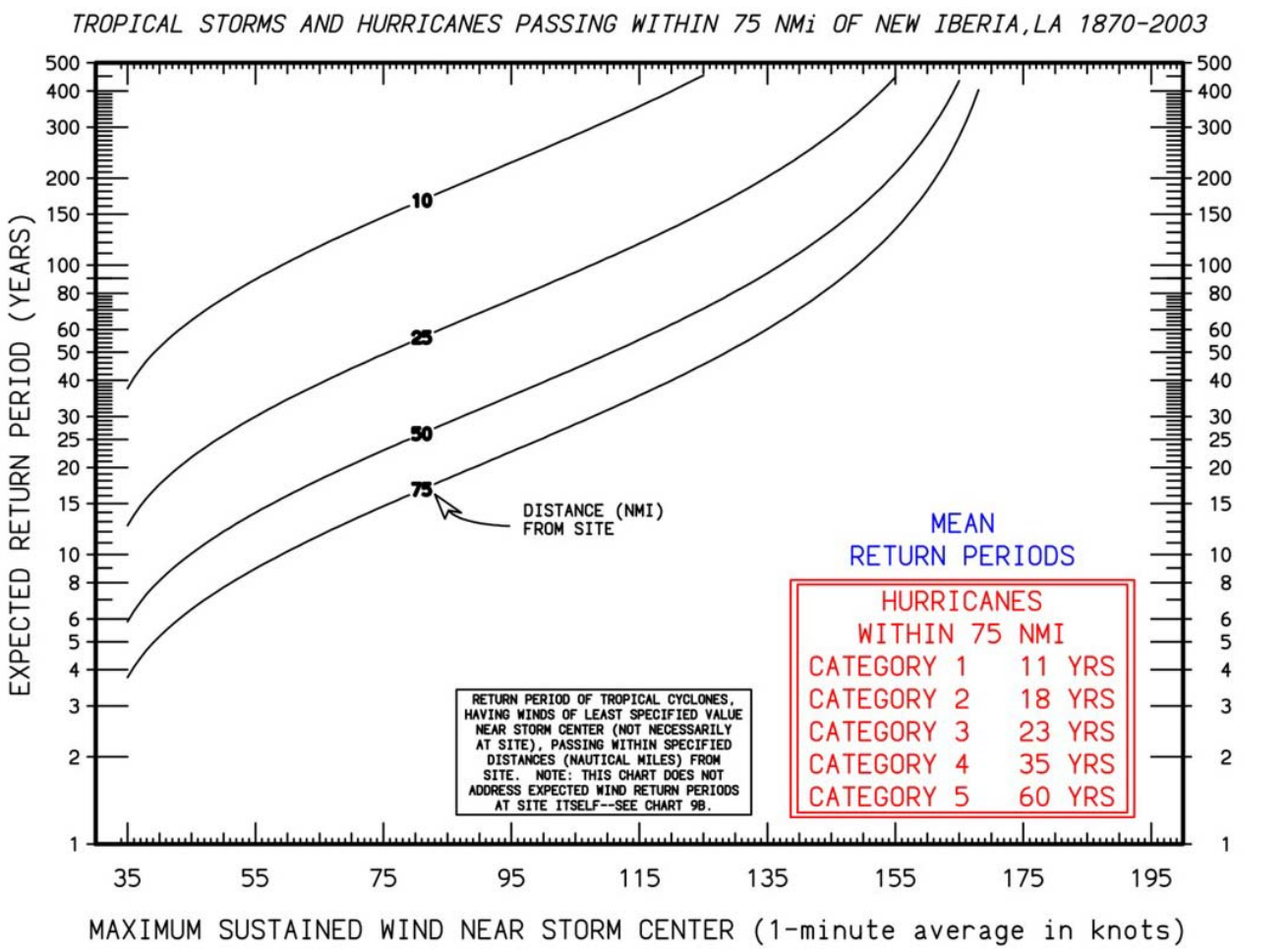
Tropical Storms and Hurricanes Near New Orleans 1886-2003



Tropical Storms and Hurricanes Near Biloxi 1886-2003



Tropical Storms and Hurricanes Near New Iberia 1886-2003

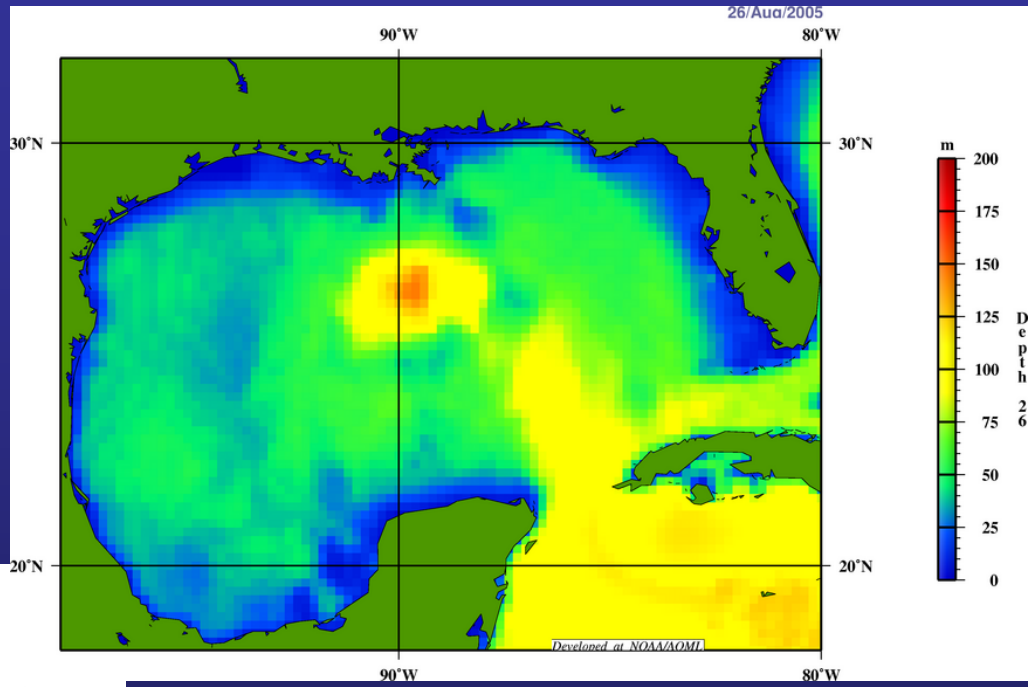


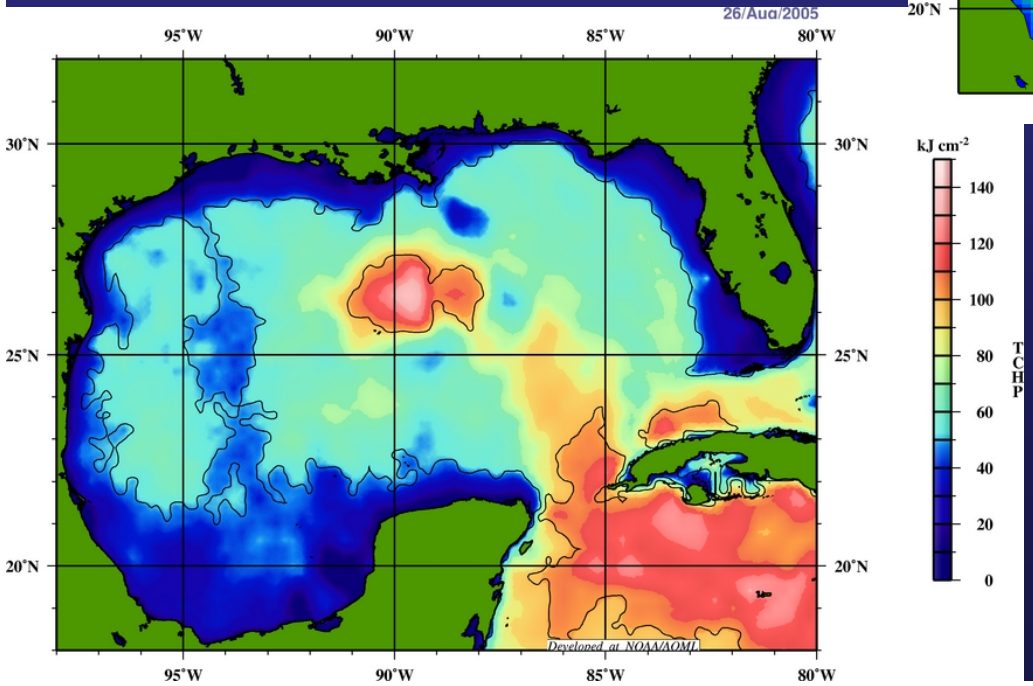
Role of The Loop Current

- The Loop Current is a normally-occurring deep warm water eddy in the central Gulf of Mexico
- This feature has a large resovoir of oceanic energy to supply to hurricanes
- Hurricanes Camille, Katrina, and Rita had significant portions of their tracks over the Loop Current

Role of The Loop Current

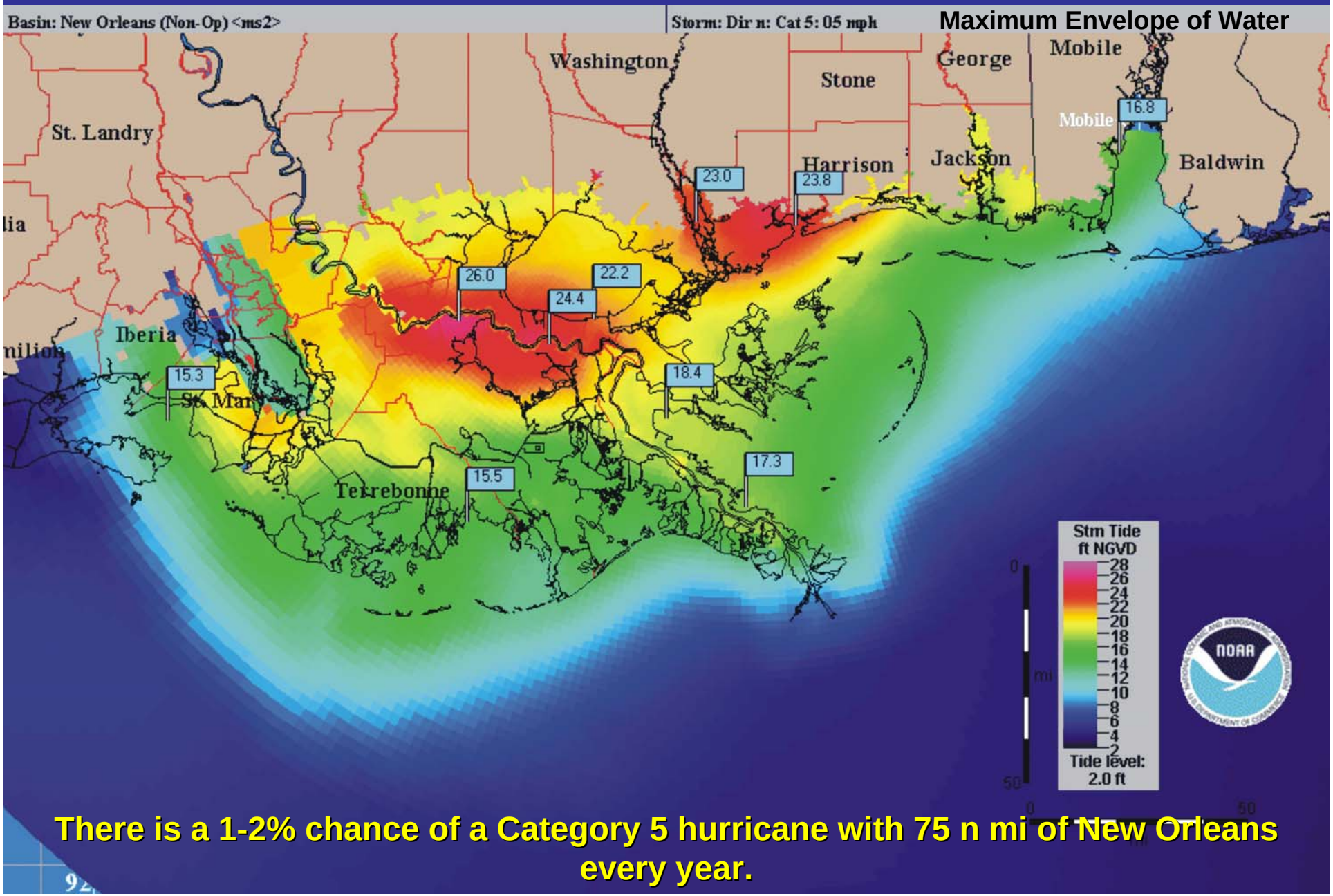
Depth of 26C Isotherm





Oceanic Heat Content

What Could This Mean?



There is a 1-2% chance of a Category 5 hurricane with 75 n mi of New Orleans every year.

Possible Issues

- Are the recurrence periods correct? The best track data base has uncertainties and errors, especially in the pre-air reconnaissance era.
- Could global warming cause a higher frequency of stronger hurricanes? Studies of this suffer from the uncertainties of the best track data base.
- Could coastal erosion and subsidence allow a greater ‘inland’ penetration of wave energy during storm surge events?

Hurricane Intensity and Structure - Prediction and Importance

JACK BEVEN
TROPICAL PREDICTION CENTER

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

Generalities on Intensity and Structure

- Tropical cyclones (including tropical storms and hurricanes) feature a large range of intensities and come in a variety of structures and shapes
- The intensity and size of a tropical cyclone are often not directly related
- Both intensity and size play a role in the generation of storm surge and the amount of impact on land

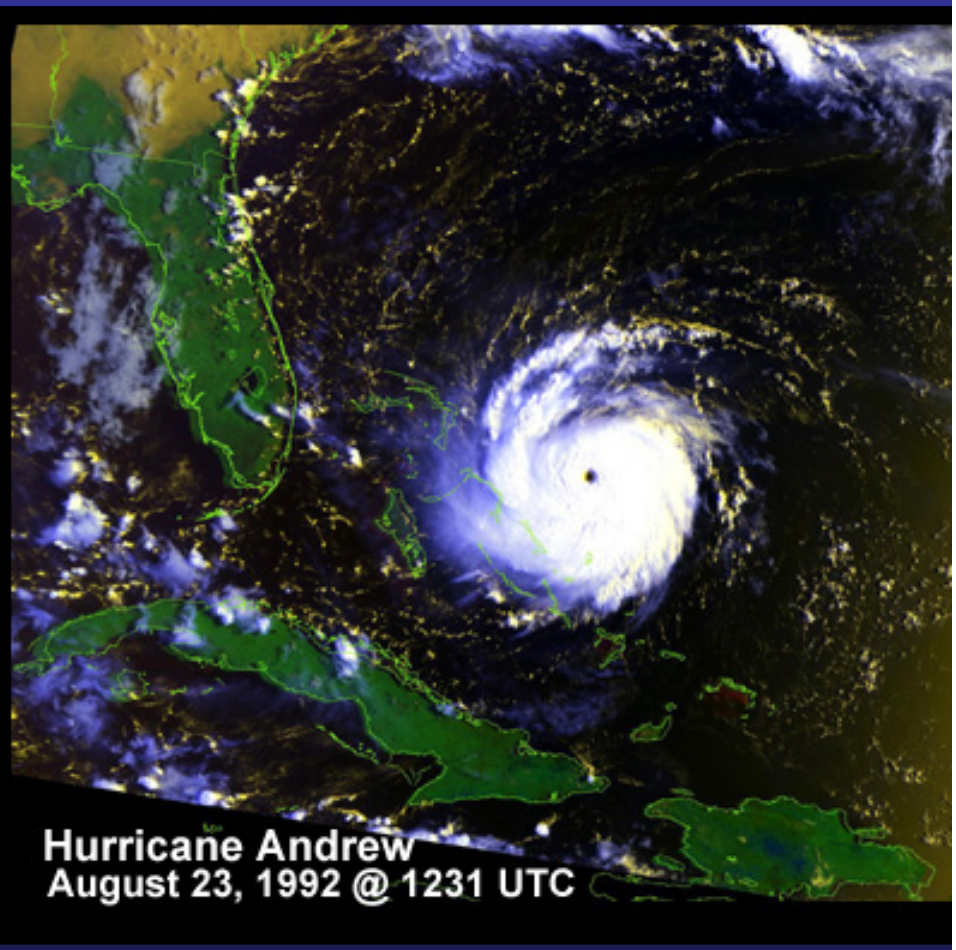
Structure and Intensity Variability

930 mb

Maximum winds: 105 kt

TS Force winds: 250 n mi

933 mb



Maximum winds: 145 kt

TS Force winds: 75 n mi

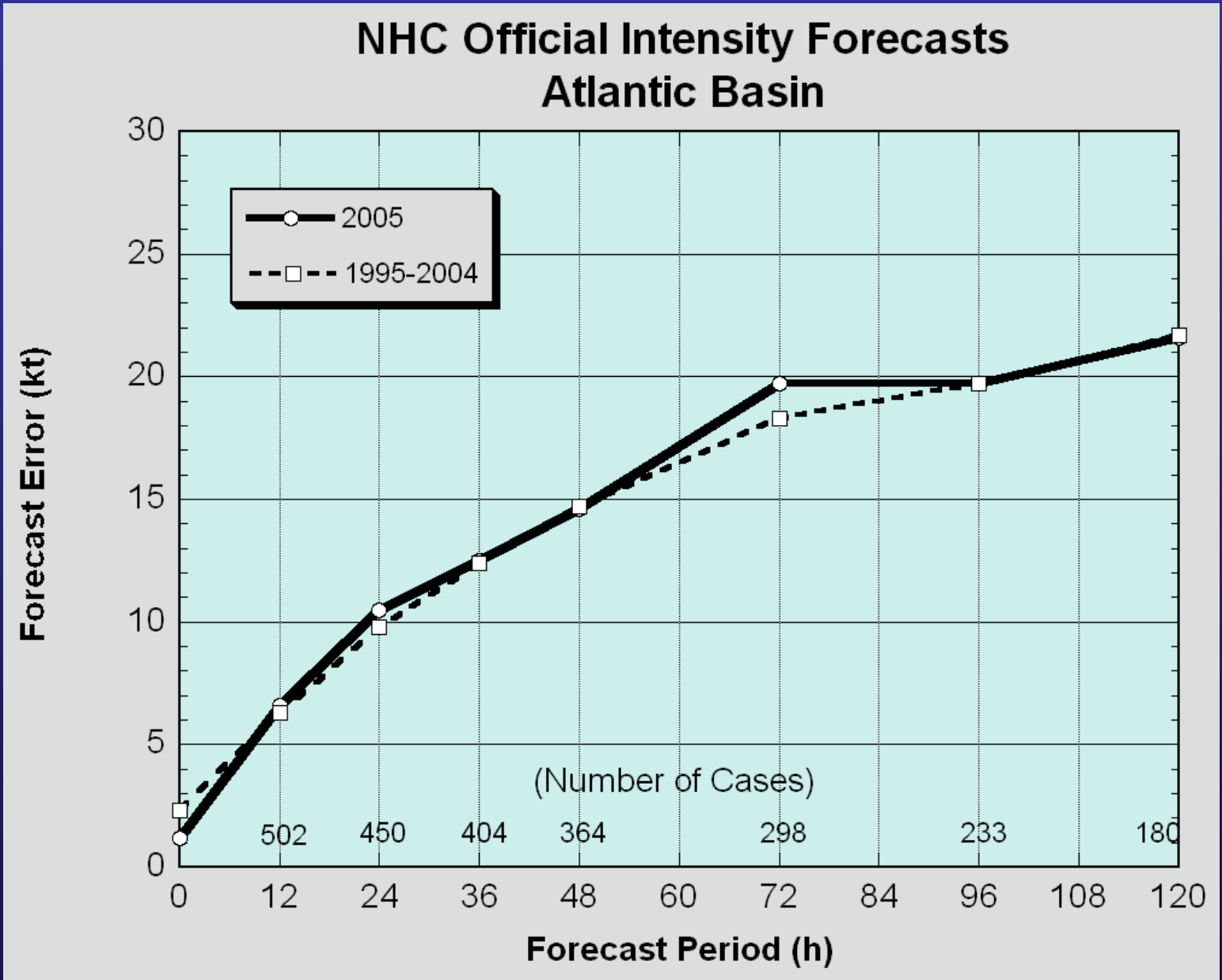
Tropical Cyclone Intensity

- The intensity is the maximum sustained wind anywhere in the cyclone
- These maximum sustained winds normally cover only a <u>limited</u> area near the center of the cyclone
- Generally, the stronger the cyclone, the closer the maximum winds are to the center

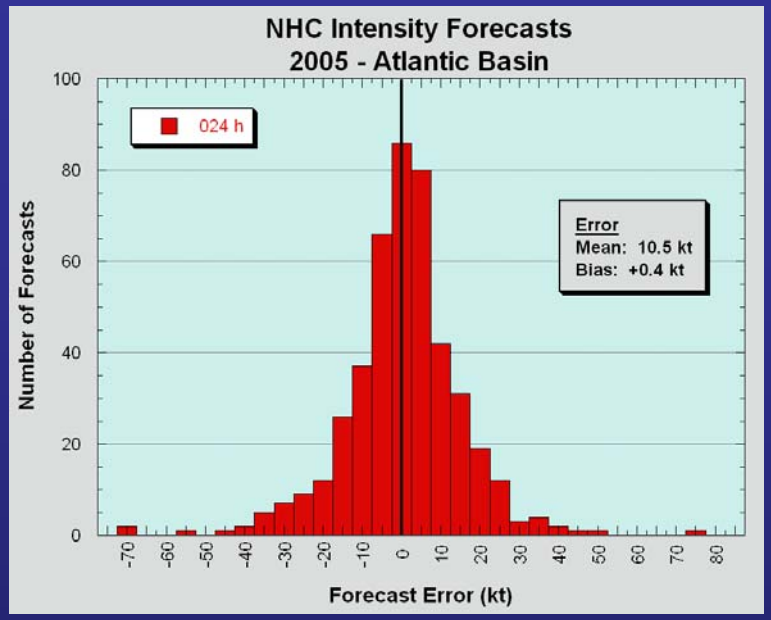
Tropical Cyclone Intensity Forecasting

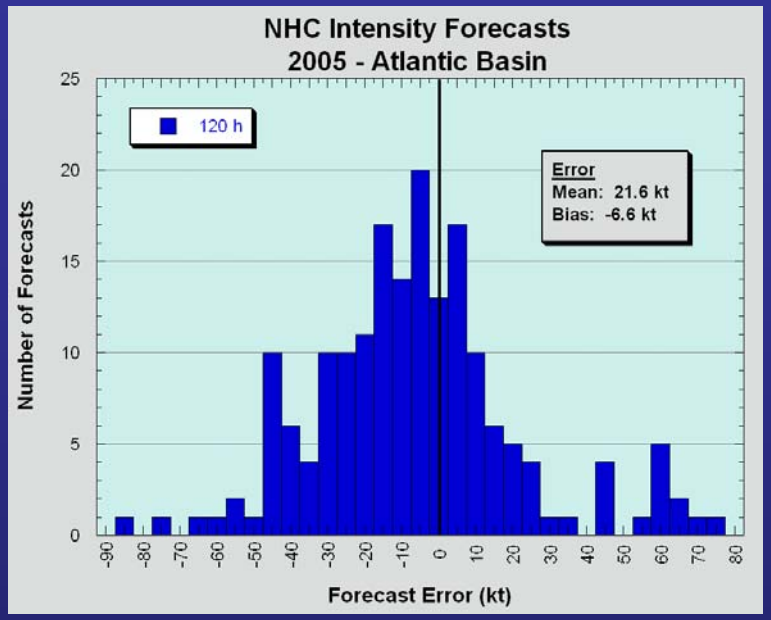
- Based on dynamical meteorological models, statistical methods, and forecaster experience
- Intensity forecasts generally less skillful than track forecasts
- Extremes of intensification (Wilma 2005) or weakening (Lili 2002) tend to be underforecast

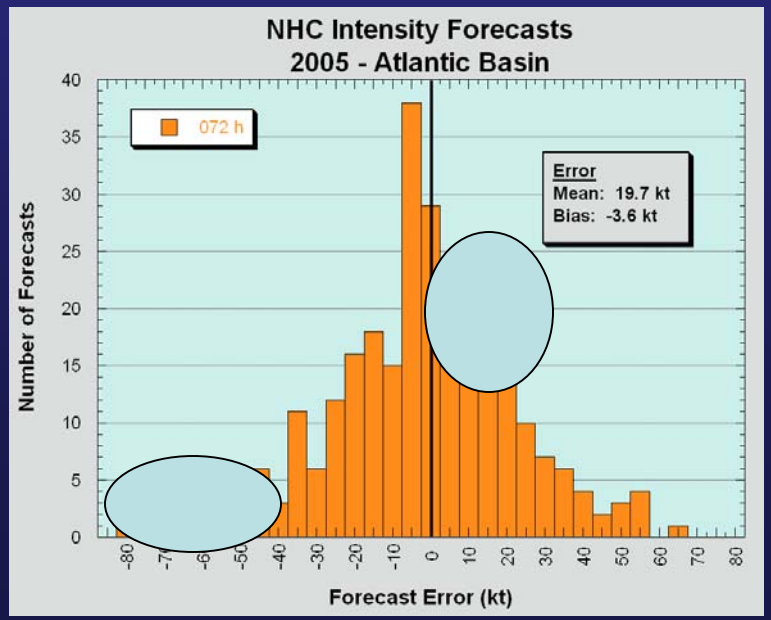
Intensity Forecast Verification



Intensity Error Distributions







Negative biases at longer forecast intervals. Extreme intensification continues to be a problem - generally well underforecast.

Tropical Cyclone Structure

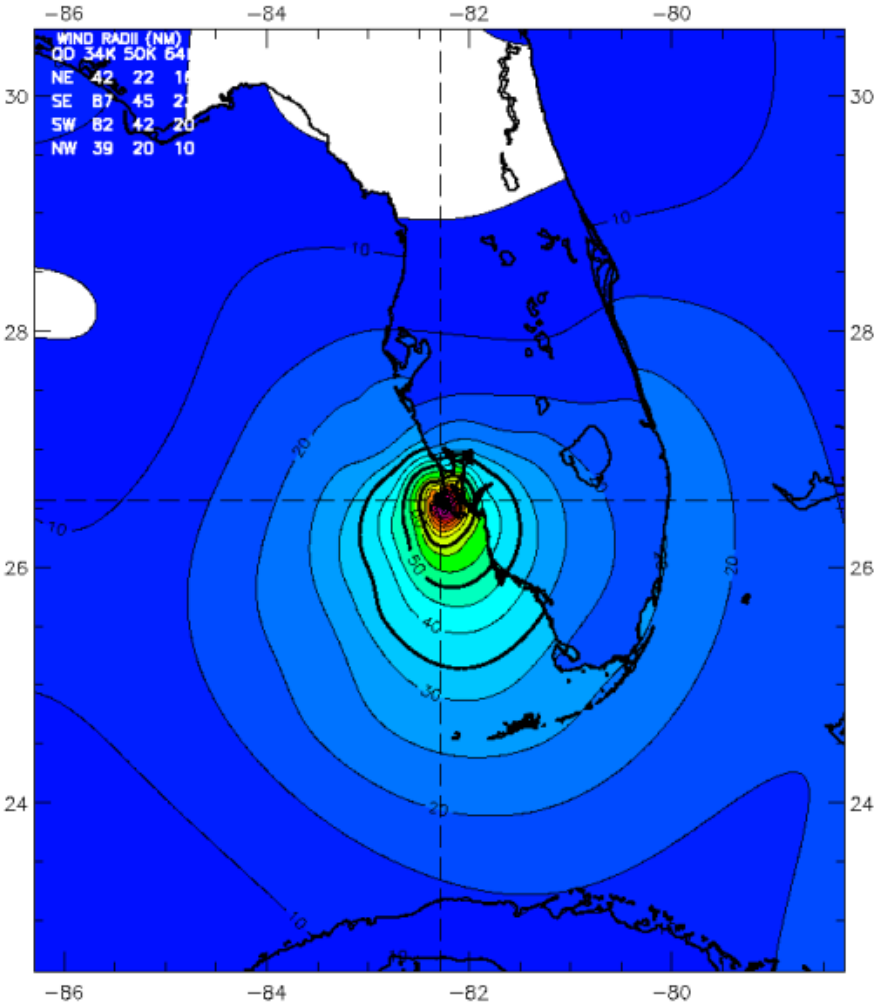
- Shows tremendous storm-to-storm variability
- Can also show tremendous variability in any given storm
- As a generality, tropical cyclones get larger with time, increasing intensity, and increasing latitude
- Two important elements are the overall size of the wind field and the radius of maximum winds (RMW)

Hurricane Charley 1930 UTC 13 Aug 2004

Max 1–min sustained surface winds (kt) for marine exposure

Analysis based on ASOS_LD_TO from 1522 – 2010 z; SHIP from 1750 – 1810 z; GPSSONDE_MBL from 1907 – 1958 z; GOES from 1602 – 1902 z; TOWER_LD_TO from 1523 – 2003 z; AFRES_FLT adj. to surface from mean height 3113 m from 1523 – 1957 z; MOORED_BUOY from 1550 – 2020 z; GPSSONDE_SFC from 0000 – 0000 z; CMAN from 1528 – 2000 z;

1930 z User fix; mslp = 946.0 mb



Observed Max. Surface Wind: 123 kts, 4 nm SE of center based on 1955 z AFRES_FLT sfc measurement
Analyzed Max. Wind: 123 kts, 5 nm SE of center

Experimental research product of:

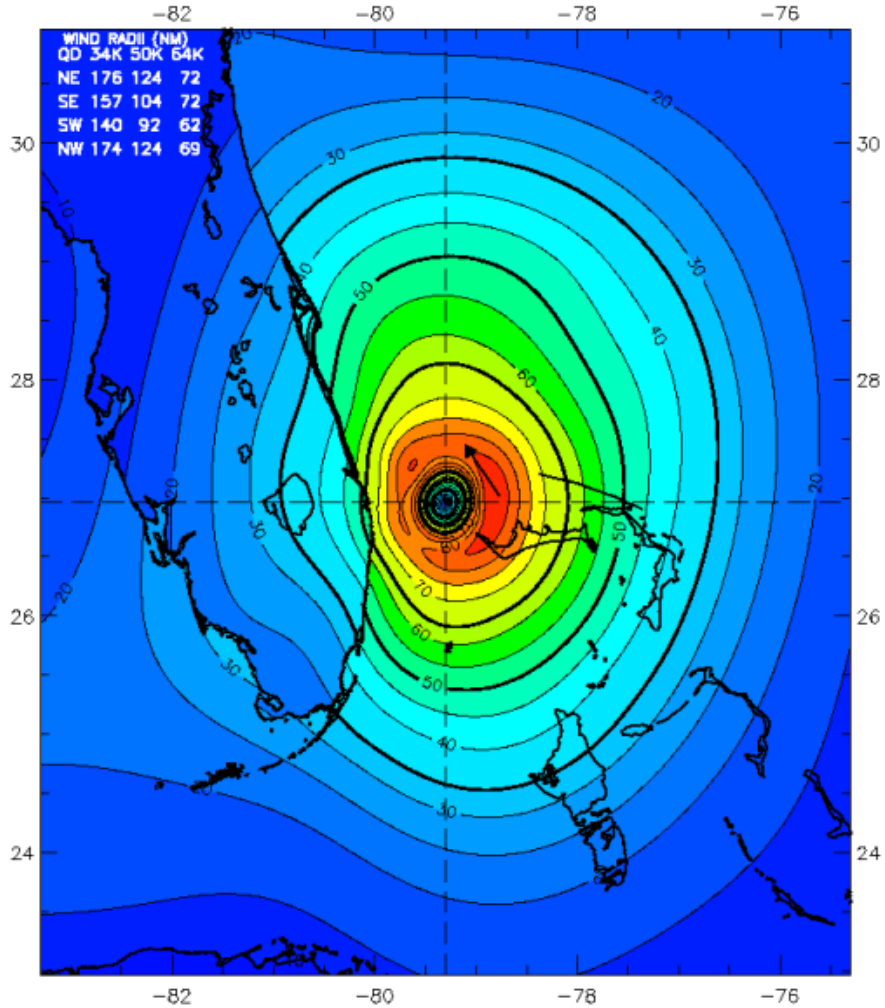
NOAA / AOML / Hurricane Research Division

Hurricane Frances 2230 UTC 04 Sep 2004

Max 1–min sustained surface winds (kt) for marine exposure

Analysis based on GPSSONDE_SFC from 2336 – 2336 z; MOORED_BUOY from 1759 – 1759 z; SFMR43 from 2230 – 2230 z; DRIFTING_BUOY from 2000 – 2000 z; GPSSONDE_WL150 from 2225 – 2225 z; TOWER_LD_TO from 2220 – 2220 z; SHIP from 1810 – 1810 z; CMAN from 2309 – 2309 z; CREWS_BUOY from 2200 – 2200 z; GOES from 2202 – 2202 z; CMAN_LD_TO from 2309 – 2309 z; ASOS_LD_TO from 2215 – 2215 z; GPSSONDE_MBL from 2225 – 2225 z;

2230 z position extrapolated from 2041 z Vortex wind center using 285 deg @ 4 kts; mslp = 959.0 mb



Observed Max. Surface Wind: 90 kts, 29 nm NE of center based on 2044 z GPSSONDE_MBL sfc measurement
Analyzed Max. Wind: 90 kts, 29 nm NE of center

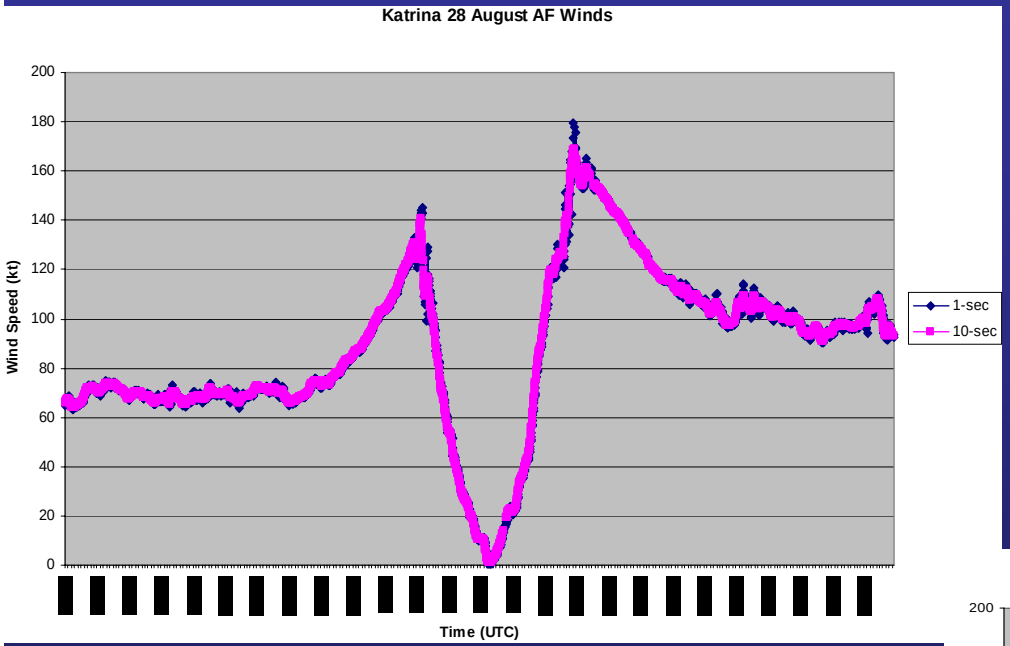
Experimental research product of:

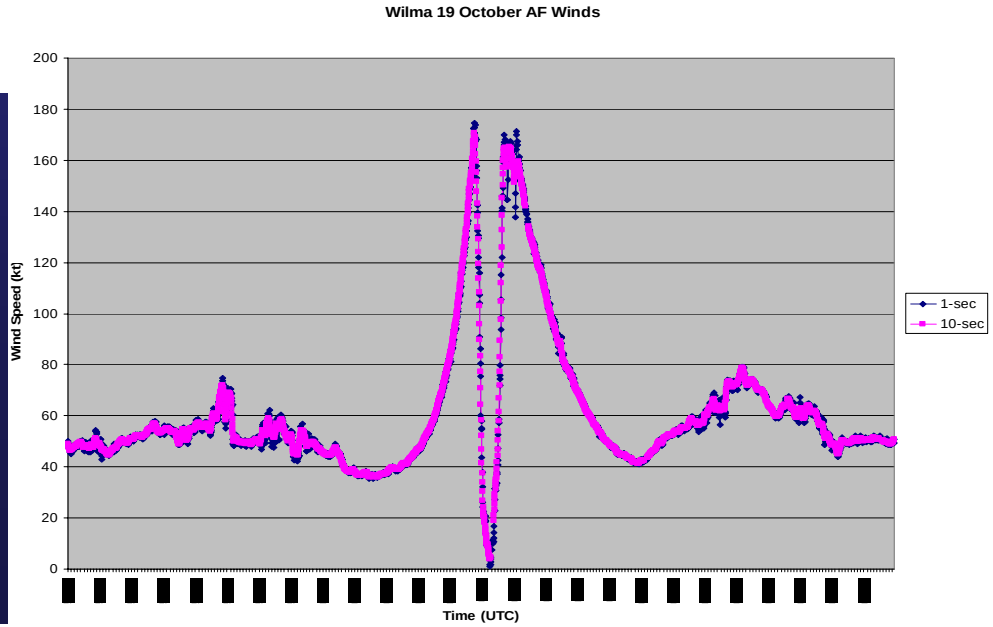
NOAA / AOML / Hurricane Research Division

Radius of Maximum Wind

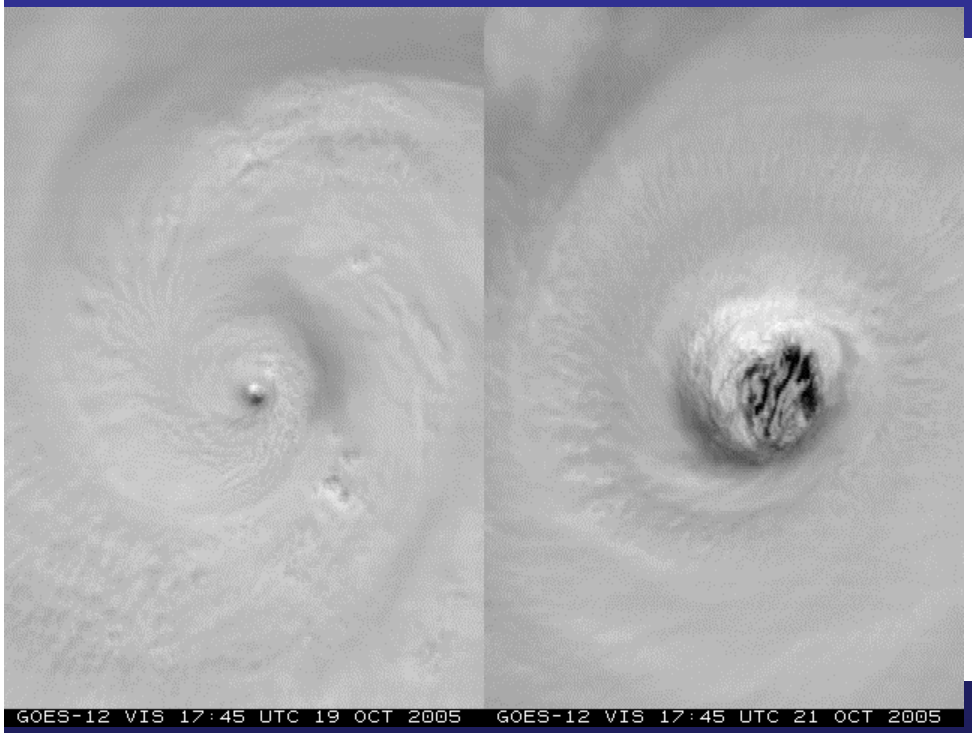
- The distance of the maximum sustained winds from the center of the cyclone - usually just outside the eye of a hurricane
- The TPC does not forecast the RMW quantitatively, and the qualitative forecast skill would be low
- The TPC Sea-Lake and Overland Surge from Hurricanes (SLOSH) model is very sensitive to this parameter
- While small storms will generally have relatively small RMW's, large storms can have a variety of RMW sizes ranging from very small to very large

Same Strength, Different Sizes



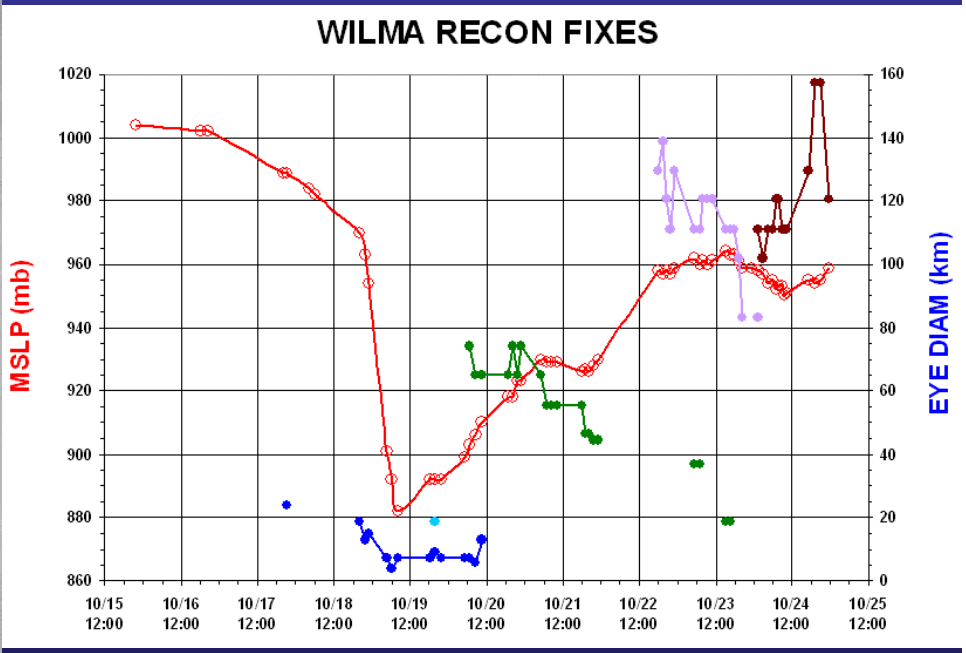


Changes In The Eye of Wilma



Pinhole eye on 19 October

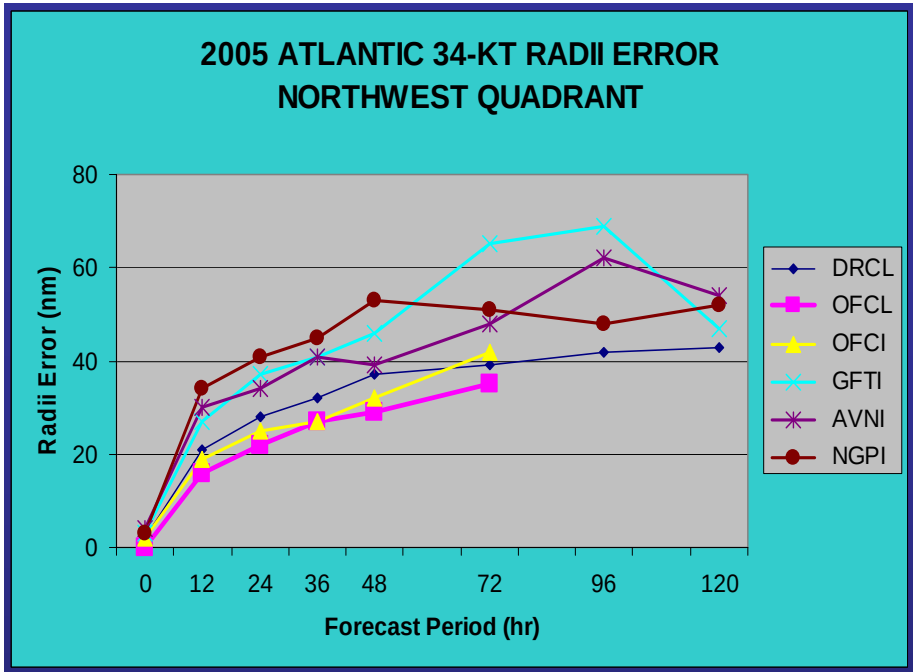
Larger eye after eyewall cycle

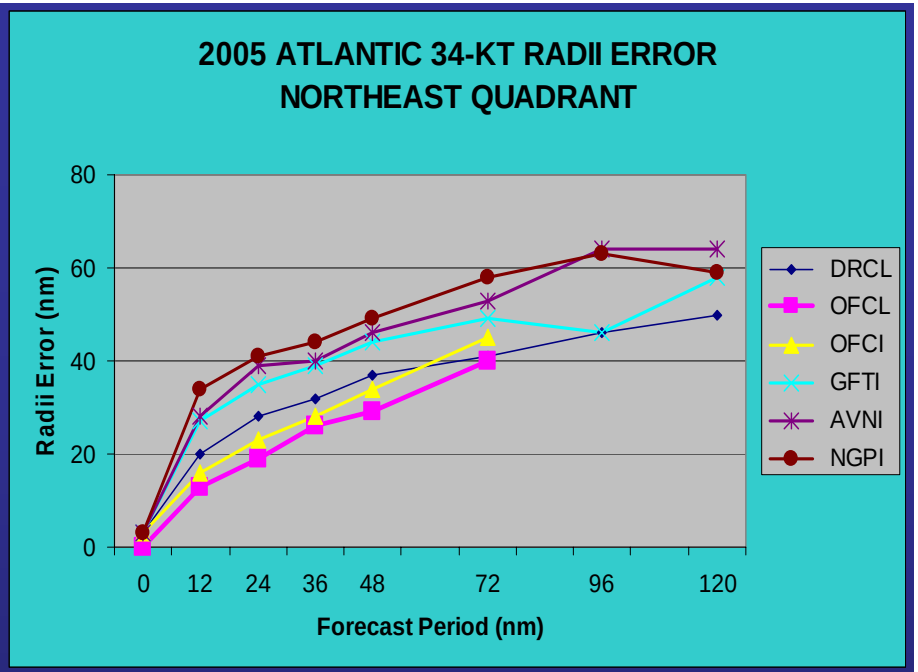


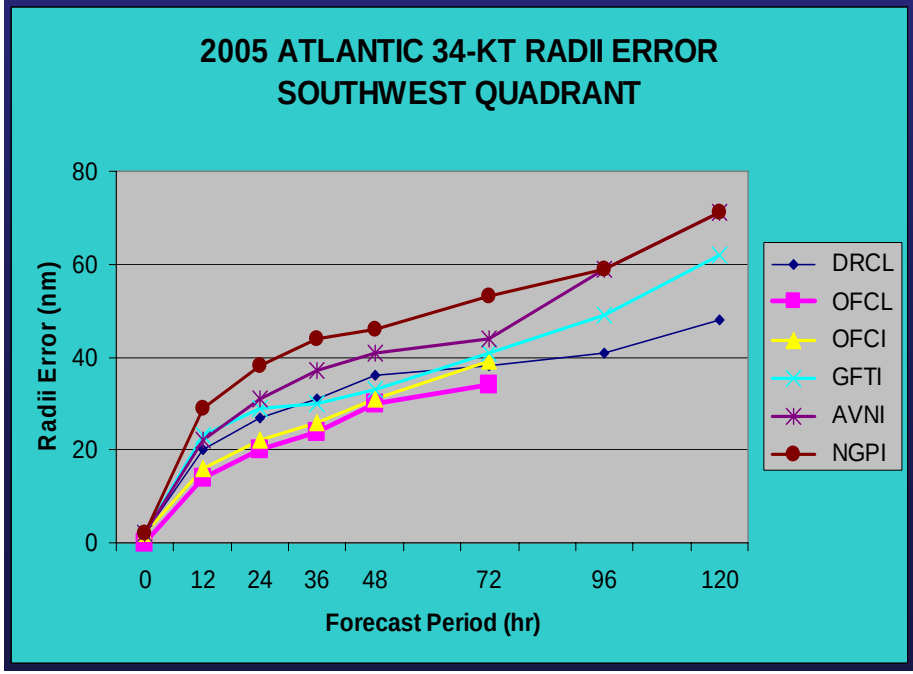
Pressure and eye size evolution

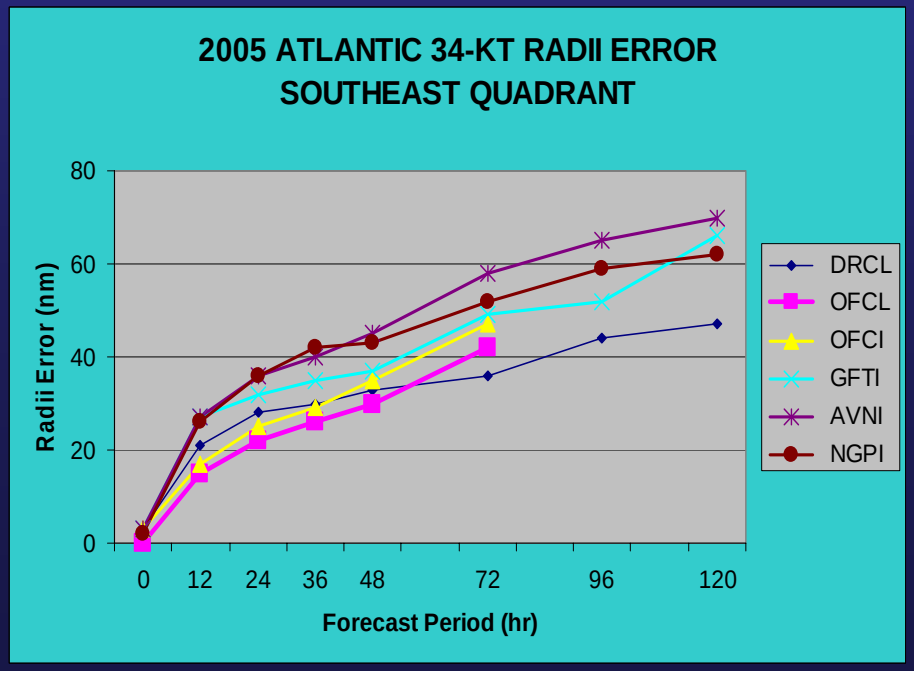
Cyclone Size

- The TPC defines cyclone size (in part) in terms of how far the 34-, 50-, and 64-kt winds extend from the center
- The TPC forecasts these radii quantitatively every six hours based on statistical and dynamical meteorological models
- Verification of these forecasts indicates they have some skill


2005 ATLANTIC 34-KT RADII ERROR
NORTHWEST QUADRANT
Radii Error (nm)
0
20
40
60
80
0
12
24
36
48
72
96
120
Forecast Period (hr)
DRCL
OFCL
OFCI
GFTI
AVNI
NGPI


2005 ATLANTIC 34-KT RADII ERROR
NORTHEAST QUADRANT
Radii Error (nm)
0
20
40
60
80
0
12
24
36
48
72
96
120
Forecast Period (nm)
DRCL
OFCL
OFCI
GFTI
AVNI
NGPI


2005 ATLANTIC 34-KT RADII ERROR
SOUTHWEST QUADRANT
Radii Error (nm)
0
20
40
60
80
0
12
24
36
48
72
96
120
Forecast Period (hr)
DRCL
OFCL
OFCI
GFTI
AVNI
NGPI


2005 ATLANTIC 34-KT RADII ERROR
SOUTHEAST QUADRANT
Radii Error (nm)
0
20
40
60
80
0
12
24
36
48
72
96
120
Forecast Period (hr)
DRCL
OFCL
OFCI
GFTI
AVNI
NGPI

Importance of Structure on Surge and Waves

- Generally, for storms of equal intensity the amount and aerial coverage of storm surge increases as the RMW gets larger
- Generally, for storms of equal intensity the amount and aerial coverage of storm surge increases as the overall size increases
- Larger RMW's and overall sizes generally mean larger fetch areas for wave generation

Full Gulf of Mexico SLOSH Basin for Dennis

Based on post-analysis wind data and the full Gulf Basin - definitely not S. O. P.!

TITLE: Hurricane Katrina Wind Fields

PRESENTED BY: Mark Powell, NOAA, Hurricane Research Division

SUMMARY: This presentation described the various satellite-, land-, sea-, and aircraft-based wind measurement platforms that operate in hurricanes and discussed their measurement accuracies, the errors in standardizing for height exposure, and averaging time, and presented a table showing a qualitative assessment of percentage accuracies. The Real-time Hurricane Wind Analysis System (H*Wind) was described and real-time analyses of Hurricane Katrina were shown.

HURRICANE KATRINA WIND FIELDS

Mark Powell
NOAA Hurricane Research Division, Miami FL

NOAA's Hurricane Research Division

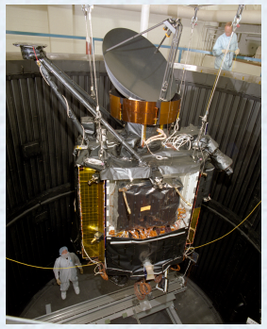
Photo: Brad Smull

part of the NOAA's Oceanic and Atmospheric Research
Atlantic Oceanographic and Meteorological Laboratories
Virginia Key, Miami FL (about 20 miles east of the Tropical Prediction Center)

Resources: 30 scientists and support staff from NOAA and University of Miami Cooperative Institute for Marine and Atmospheric Studies, regional lab with oceanographic expertise

- Outline
  - Measurement platforms in Katrina
  - Standardizing wind observations
  - H*Wind
  - Wind uncertainty
  - Status of project

Hurricane Katrina Data Sources



Aircraft: GPS sondes, SFMR (with calibration revision,
Airborne Doppler at 500 m adj. to sfc
AFRC Minobs adj. to sfc based on new SFMR-based adj.method

Satellites: GOES cloud drift, QuikScat, WindSat

Marine Platforms: Moored and drifting buoys, instrumented platforms:

C-MAN NDBC (4)
LUMCON (3)
WAVE CIS (5)
USM (1)
USAla Mobile Bay (1)
Slidell WFO Lake Ponchartrain
LAIS Port Sulphur
NOS (9)

Welcome to
Louisiana Universities Marine Consortium

Coastal Studies Institute, Louisiana State University
Program Director: Dr. Gregory W. Stone
WAVCIS Wave-Current-Surge Information System for Coastal Louisiana
218 Howe-Russell Geoscience Complex, Baton Rouge, Louisiana, 70803

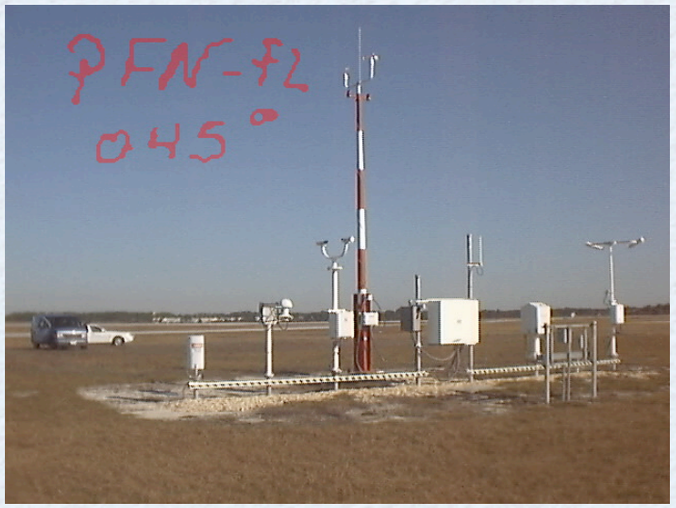
Hurricane Katrina Data Sources

TEXAS TECH ATMOSPHERIC SCIENCE GROUP

The University of Louisiana at Monroe

METEOROLOGY
University of South Alabama

LLWAS-RS Anemometer/Pole



Portable Mesonets:

3 TTU

5 FCMP

1 ULM

Mesonets:

U S AL (3)

LLWAS (3)

LA-MS LAIS (25)

EOCs (3)

ASOS (38)

Hurricane Katrina Data Sources
Land-based Doppler Radar

WSR 88D:

VAD at Slidell (250 m adj to sfc)

Dual Doppler (Slidell and Mobile)

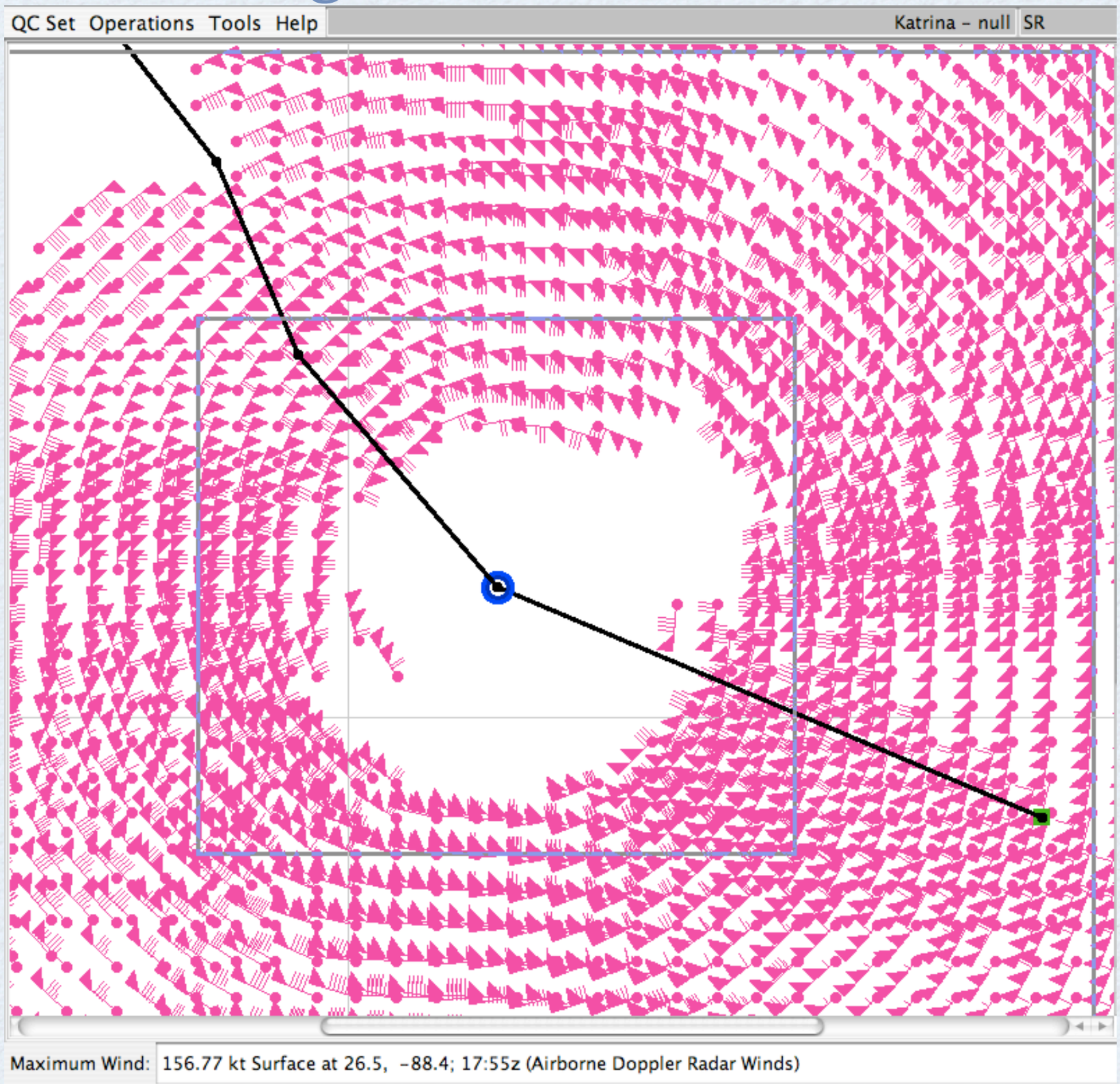
GBVTD Slidell

Unique Airborne Observations
NOAA P3
Flying Laboratory

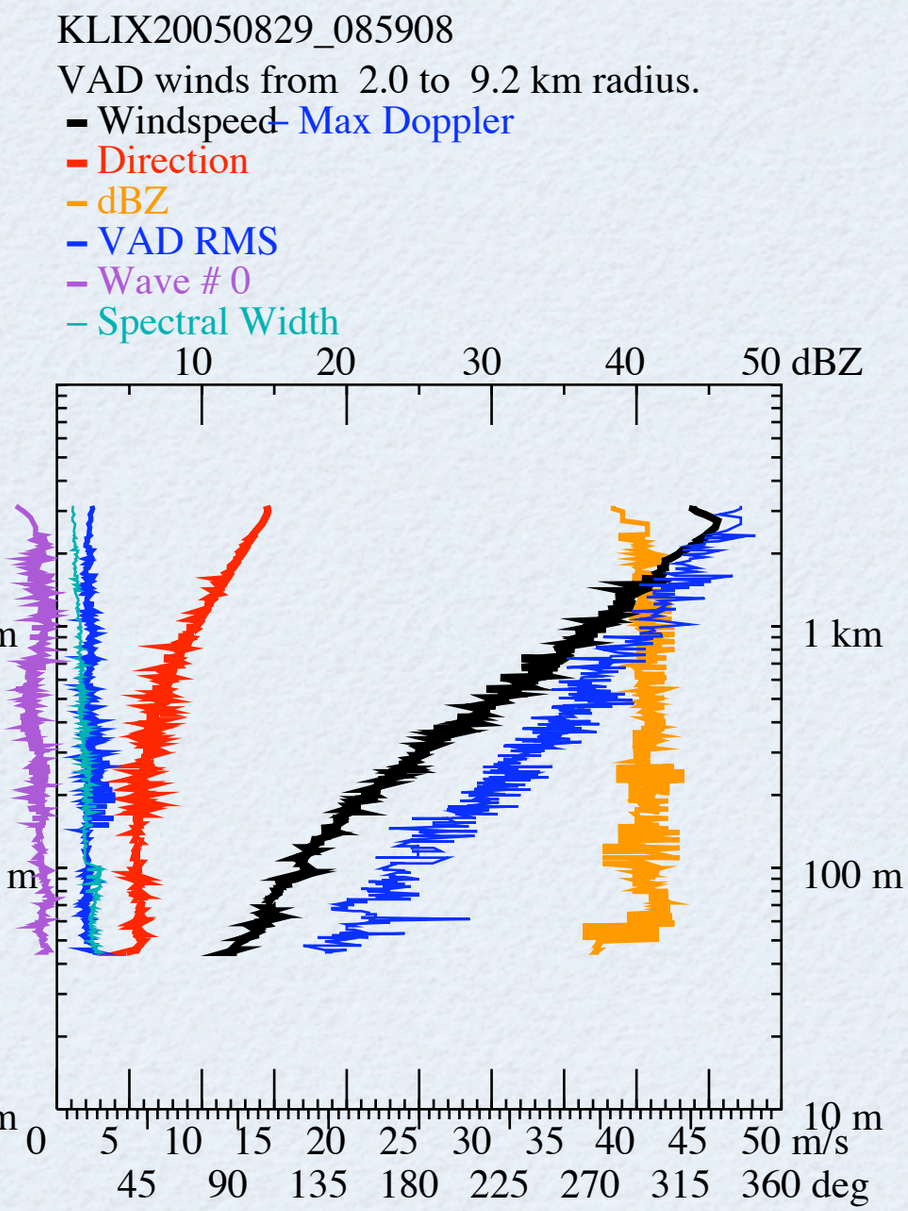
SFMR

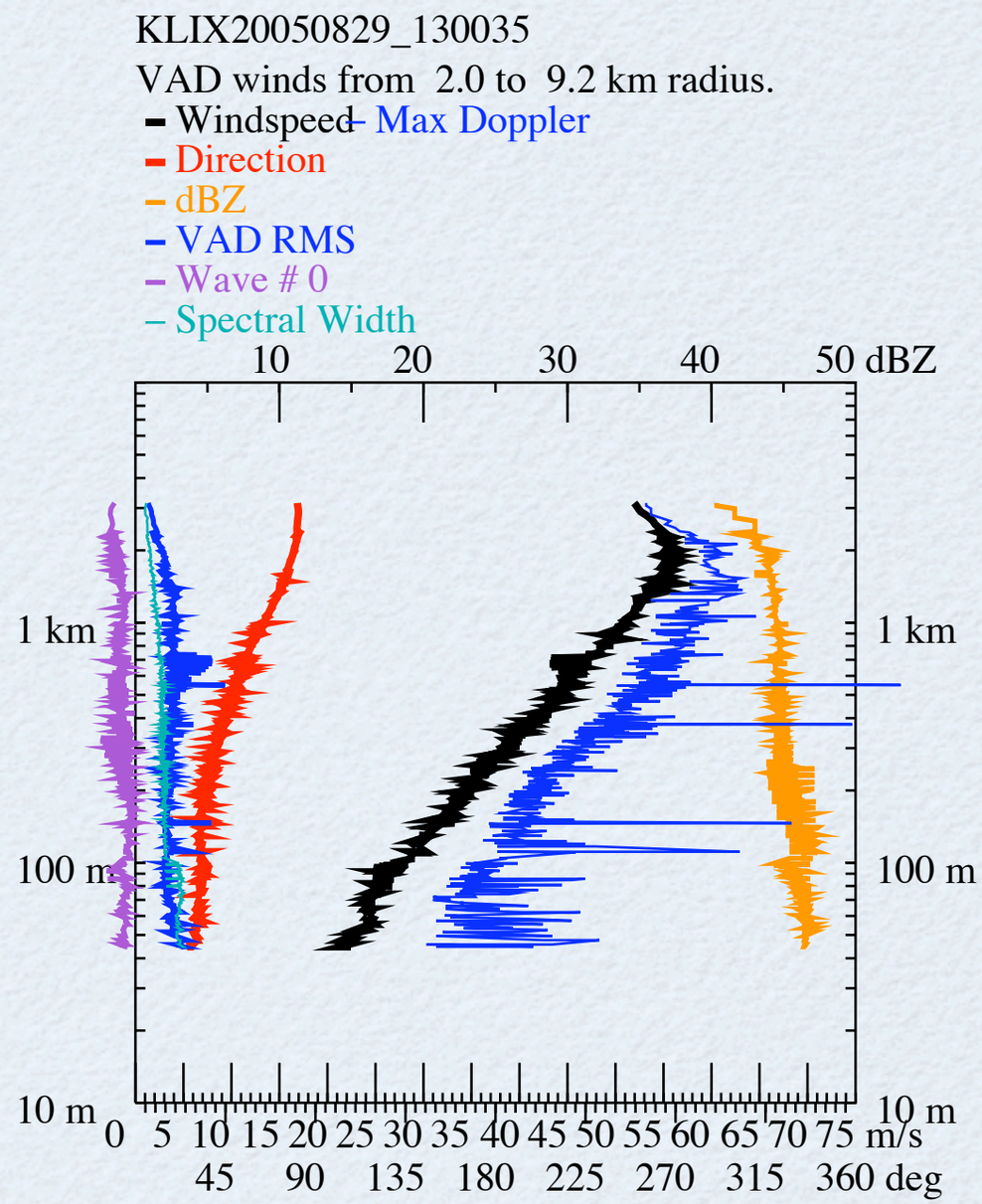
TAIL DOPPLER

Katrina Airborne Doppler Radar on 28 August 1755 (1255 CDT)



Single Doppler VTD Velocity Profiles from Slidell

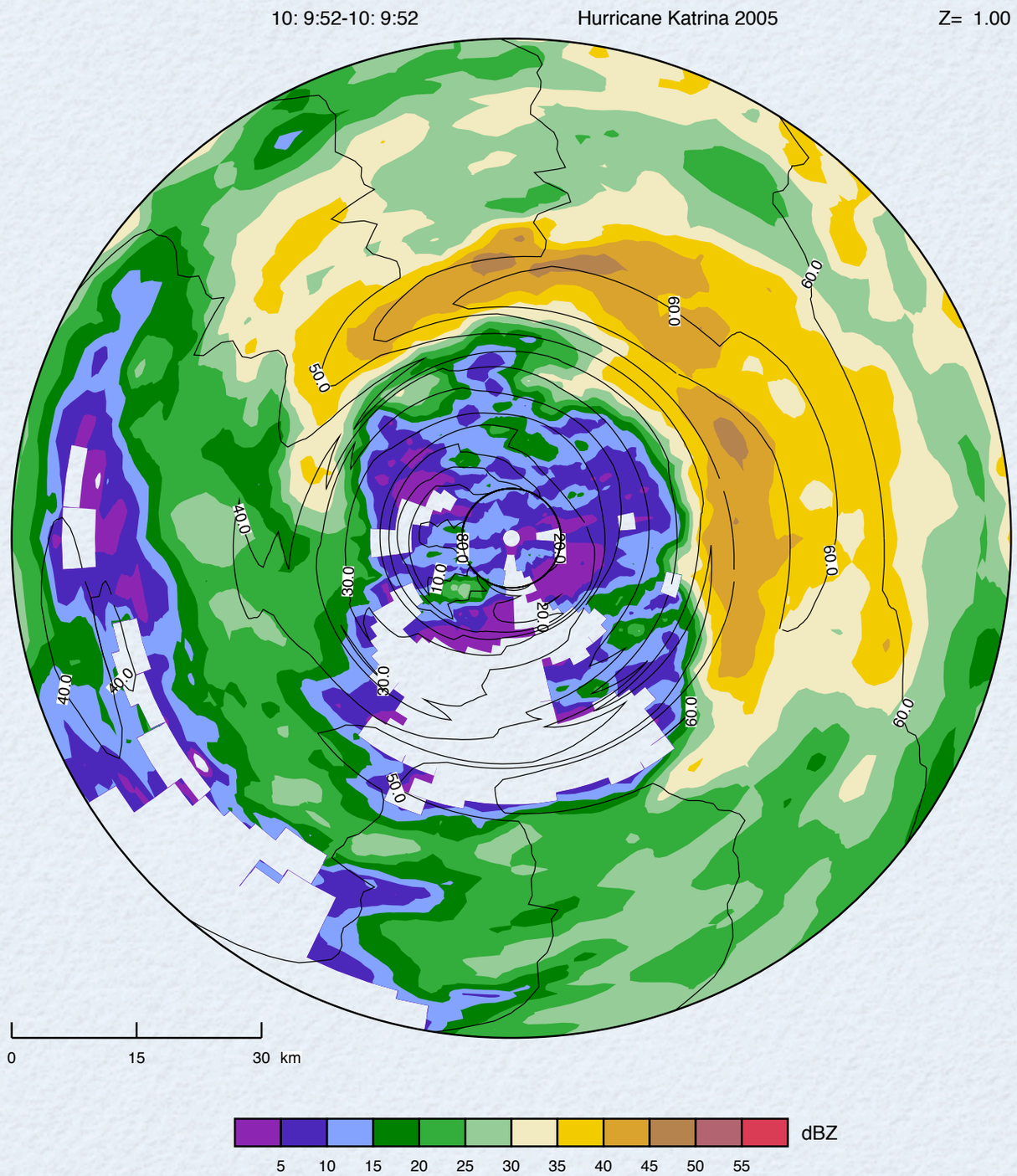




Single Doppler Radar
Ground-Based Velocity Track Display

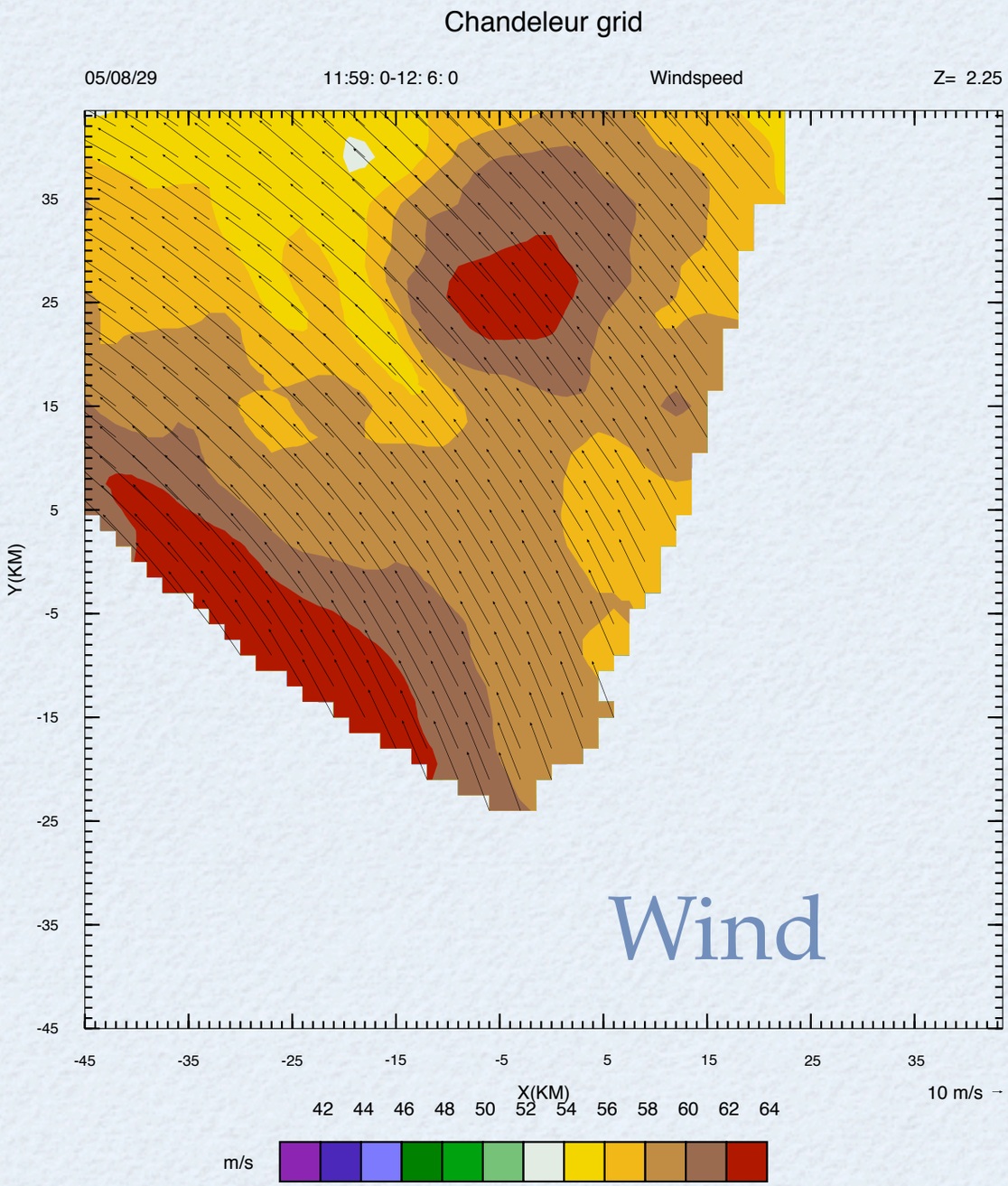
Hurricane Katrina 29 Aug 2005 KLIX

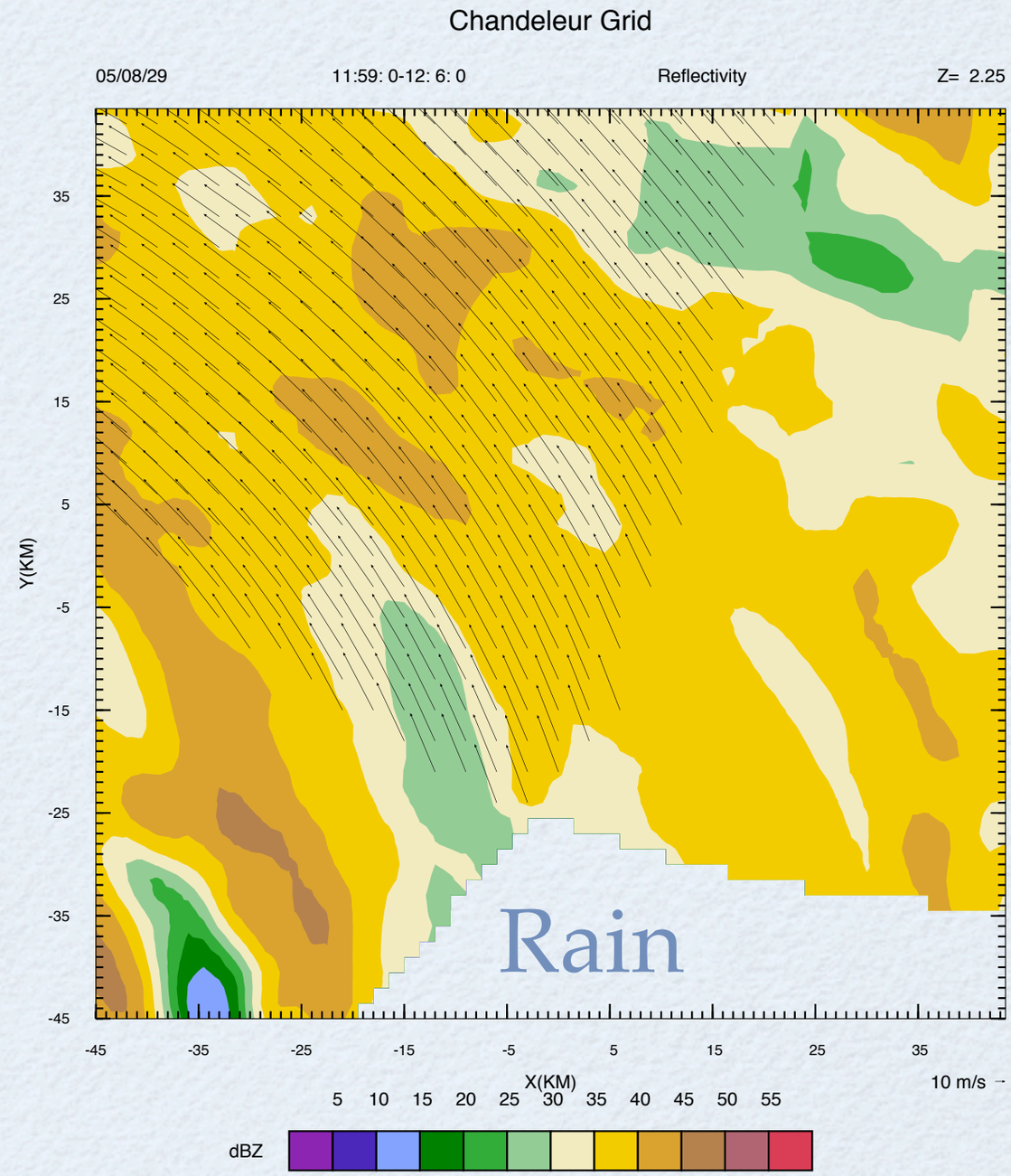
Wind, rain at 1000 m 0510 CDT



CONTOUR: DZ VA
LATITUDE: 30 DEG 20 MIN 11 SEC LONGITUDE: -89 DEG -49 MIN -31 SEC
ORIGIN: (*****,*****)

Dual Doppler Radar Analysis (LIX-MOB)





GPS SONDE

- 10-12 m/s fall speed
- 2 Hz Samples P, T, RH, Position
- Accuracy 0.5-2m/s, 2 m height
- Filtered to remove undersampled scales and noise from satellite switching
- Corrected for acceleration bias
- Wind errors large below 5-8 m

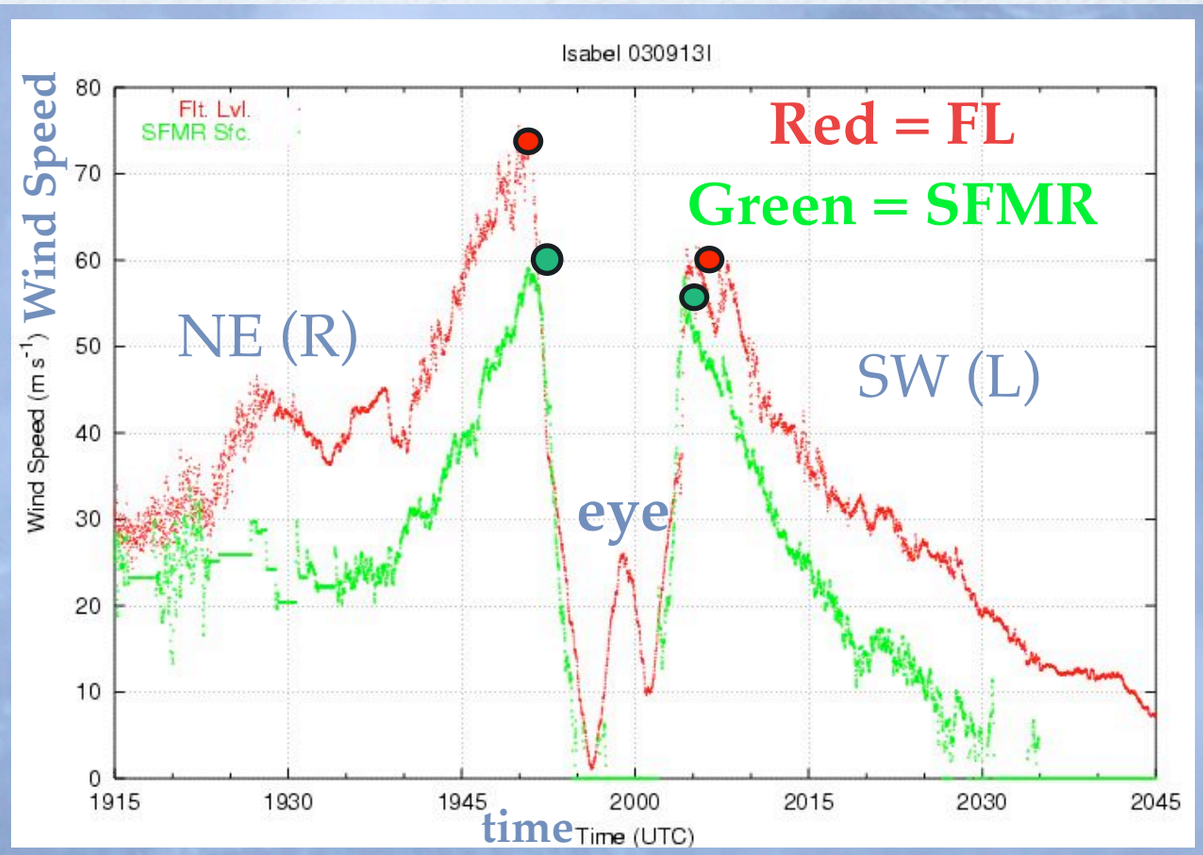
Stepped Frequency Microwave Radiometer

Microwave emission from foam on surface, intervening rain, at 8 frequencies

Sea State from ~ 2 km

(Photo: Paul Chang)

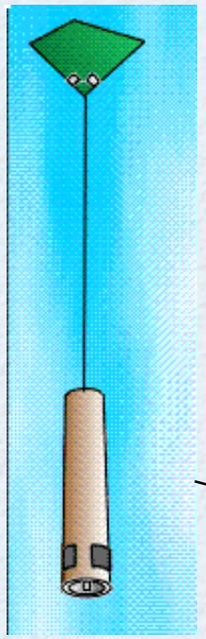
SFMR ↓



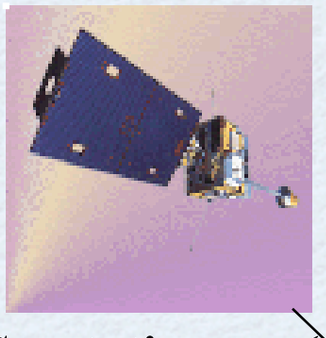
- Measures emissivity from the ocean surface-> wind speed, rain rate
- Can deduce the radial location of the peak surface wind relative to the peak flight-level wind
- Extensively validated against nearby GPS sonde surface measurements (Uhlhorn and Black 2003)
- Non-wind-related sea state effects must be corrected or removed

- **H*Wind**: A tool for interacting with observations
  - All observations standardized
  - Quality can be assessed graphically
  - Passed observations are objectively analyzed

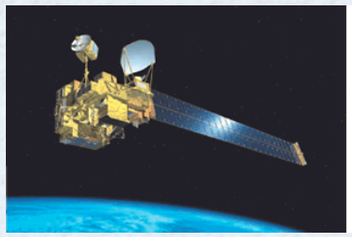
H*Wind Observing Platforms



GPS dropwindsondes



Geostationary (GOES) satellite data



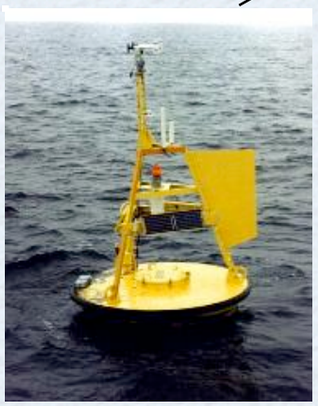
Polar Orbiting QSCAT, TM/I, and SSM/I satellites data

Air Force and NOAA Aircraft

Stepped Frequency Microwave Radiometer (SFMR)

Database

Coastal Marine Automated Network (CMAN)



NOAA Buoys

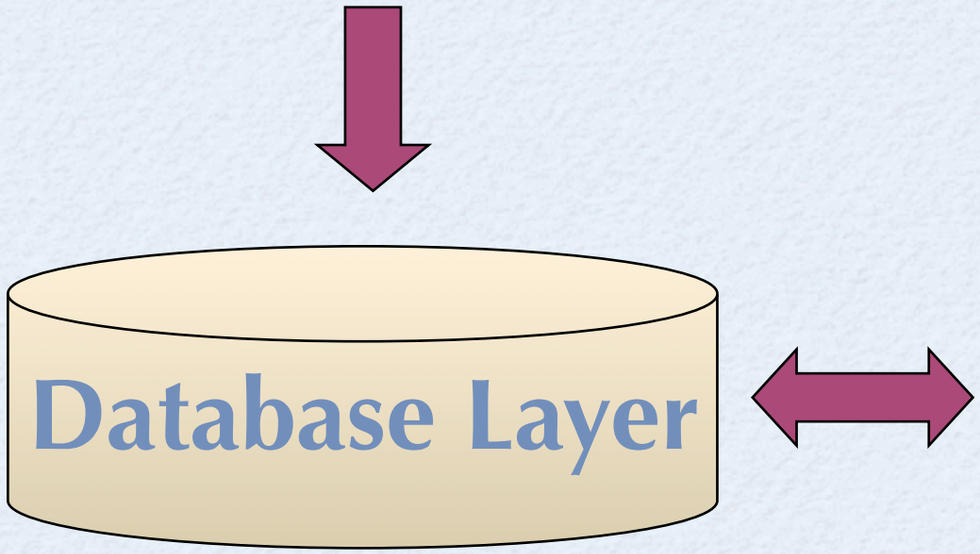
Drifting buoys

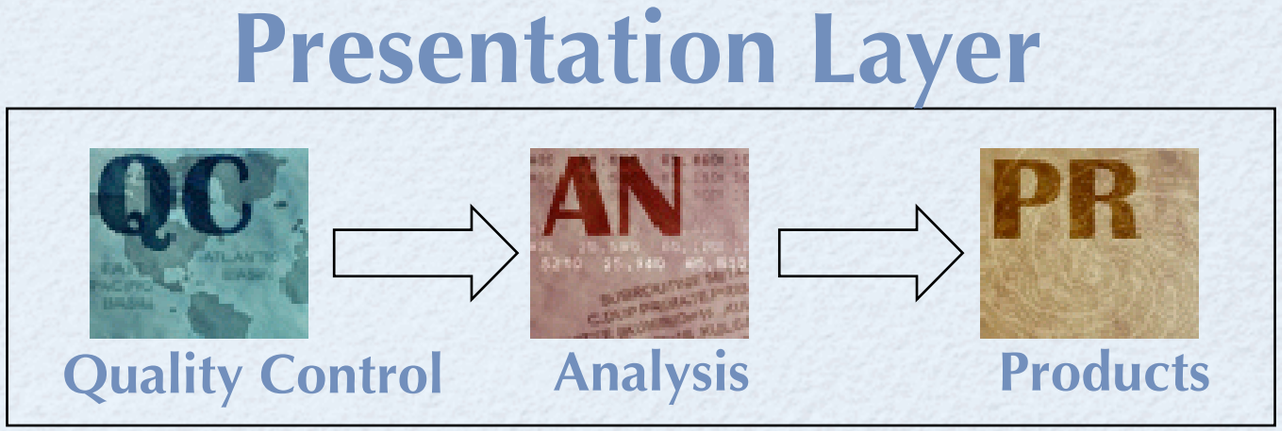
Ship reports

Automated Surface Observing System (ASOS)

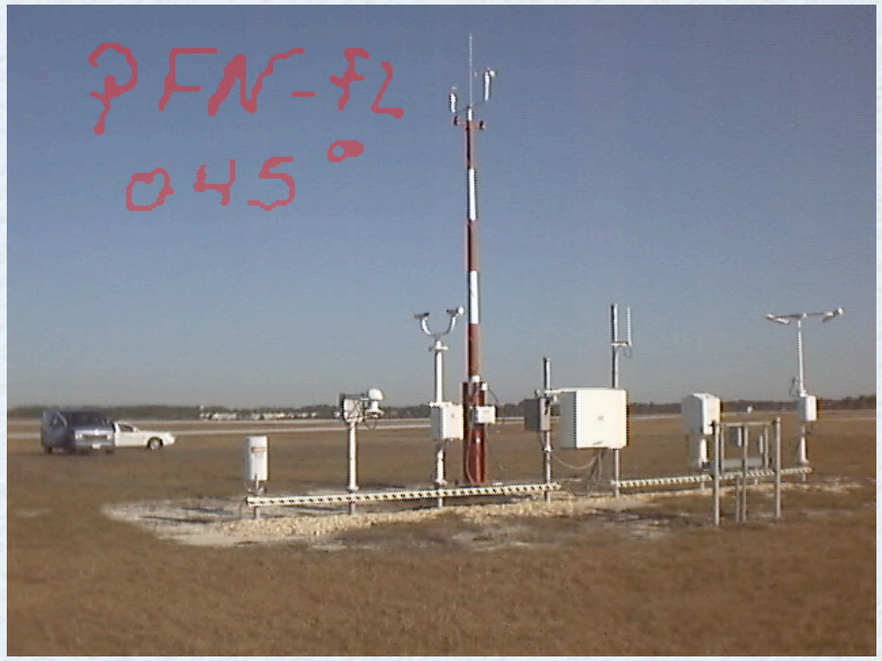
Mesonets

*H*WIND is an global, interactive, graphical, tropical cyclone observing system*





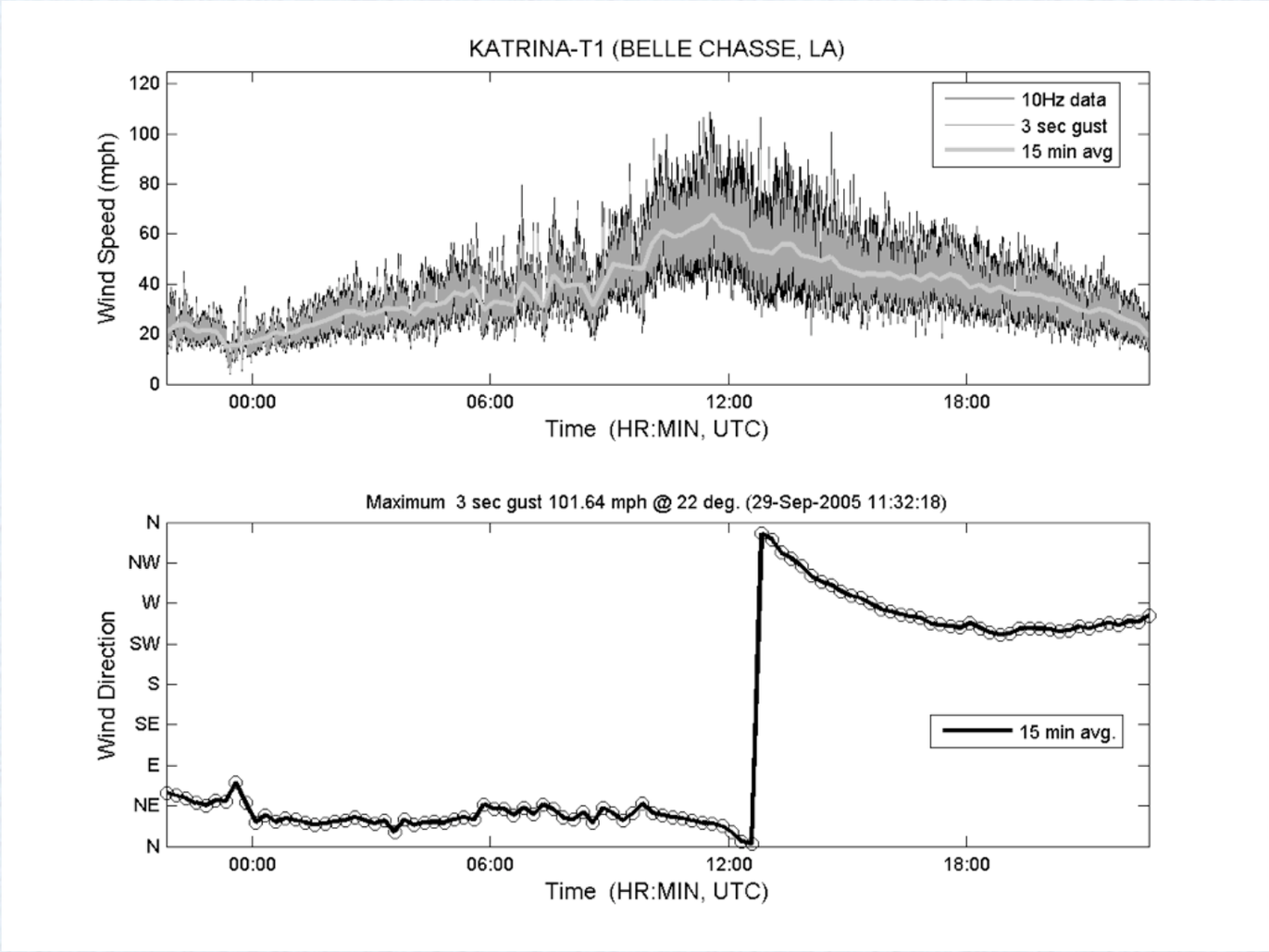
- **Standardizing Wind Observations**
  - Time
  - Exposure
  - Height 10 m



Ideal

not so much

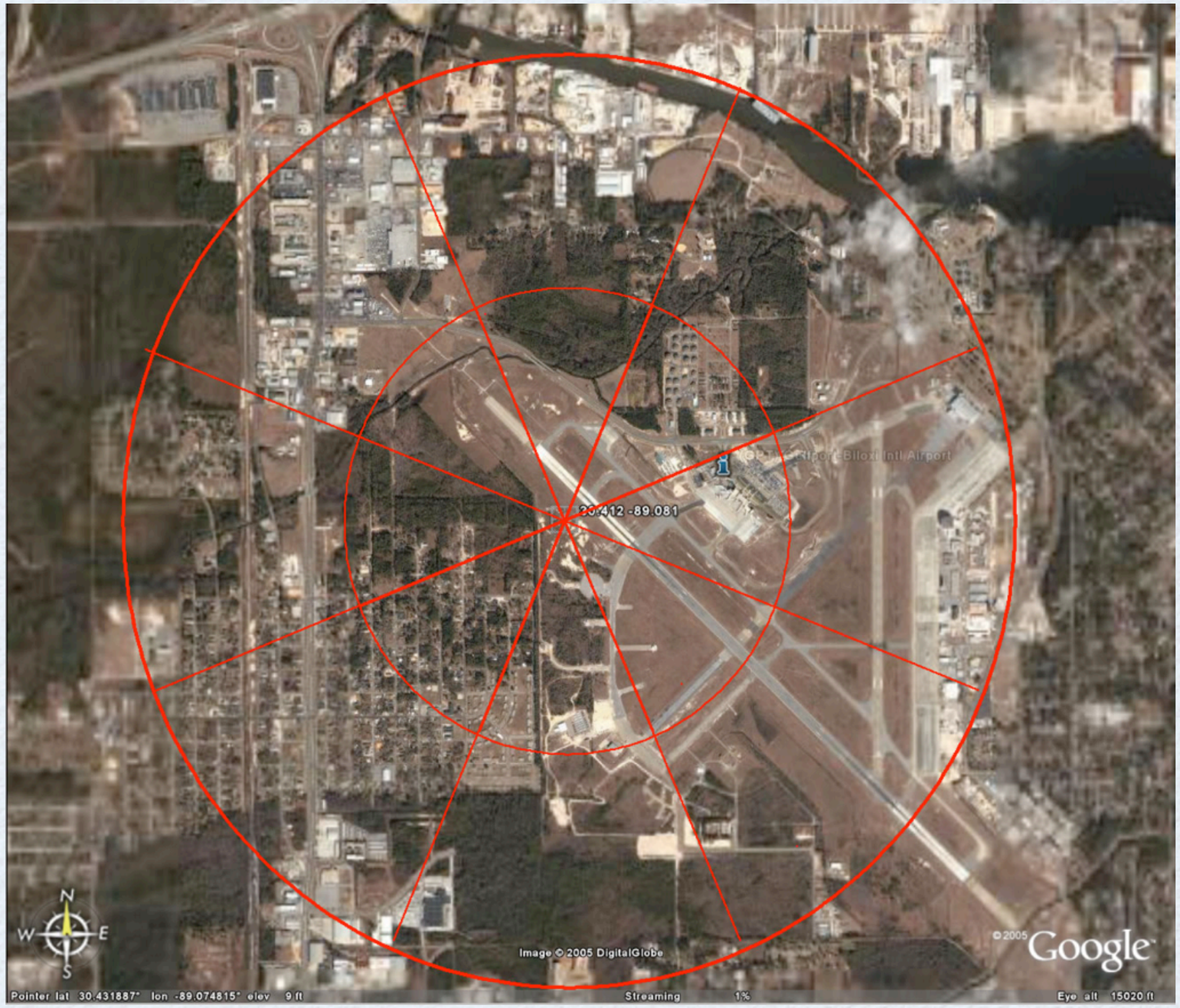
- **Standardizing Wind Observations: Time**
  - A mean wind (~ 10 min) is needed to do height corrections
  - If record continuous, use actual avg. period
  - If not, assume sample is an estimate of the mean wind



- **Standardizing Wind Observations: Height, Exposure**
  - Estimate upstream exposure (aerial and site photographs or compute marine based on wind speed)
  - Neutral stability log law to compute the mean wind at 250 m
  - Wind at 250 m is same over various terrain
  - Compute 10 m mean wind for open or marine exposure (log law)

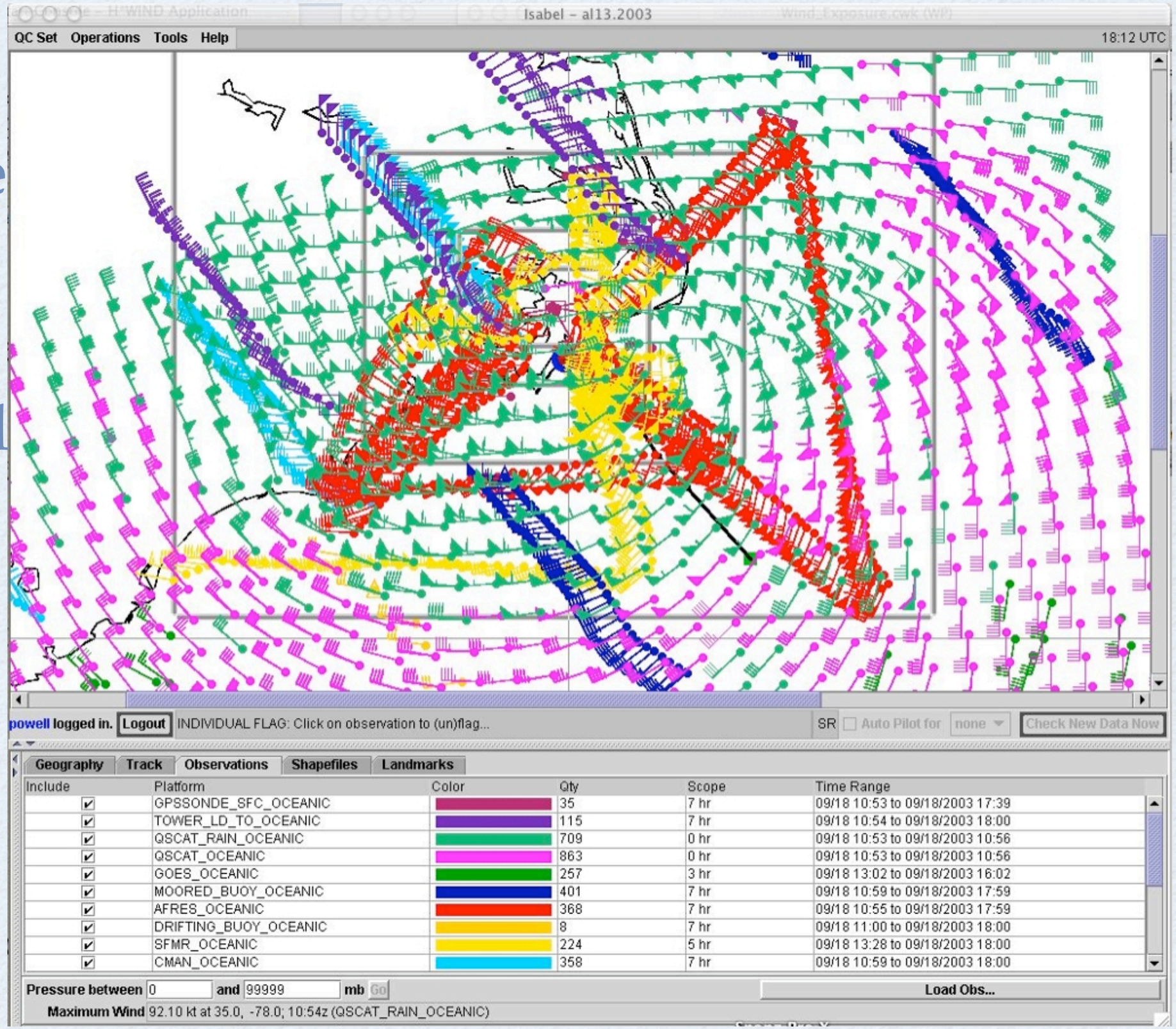
Exposure estimate for each 45 deg upstream wind direction sector

Gulfport ASOS



- **Standardizing Wind Observations: Time again**
  - Estimate the maximum sustained (1 min) wind
    - Use a gust factor (depends on avg. time, roughness)
    - Gust factor based on Vickery and Skerlj, J. Struct. Eng. 2005
  - Additional gust factors -> to 30 min or 10 min mean winds used by surge and wave models

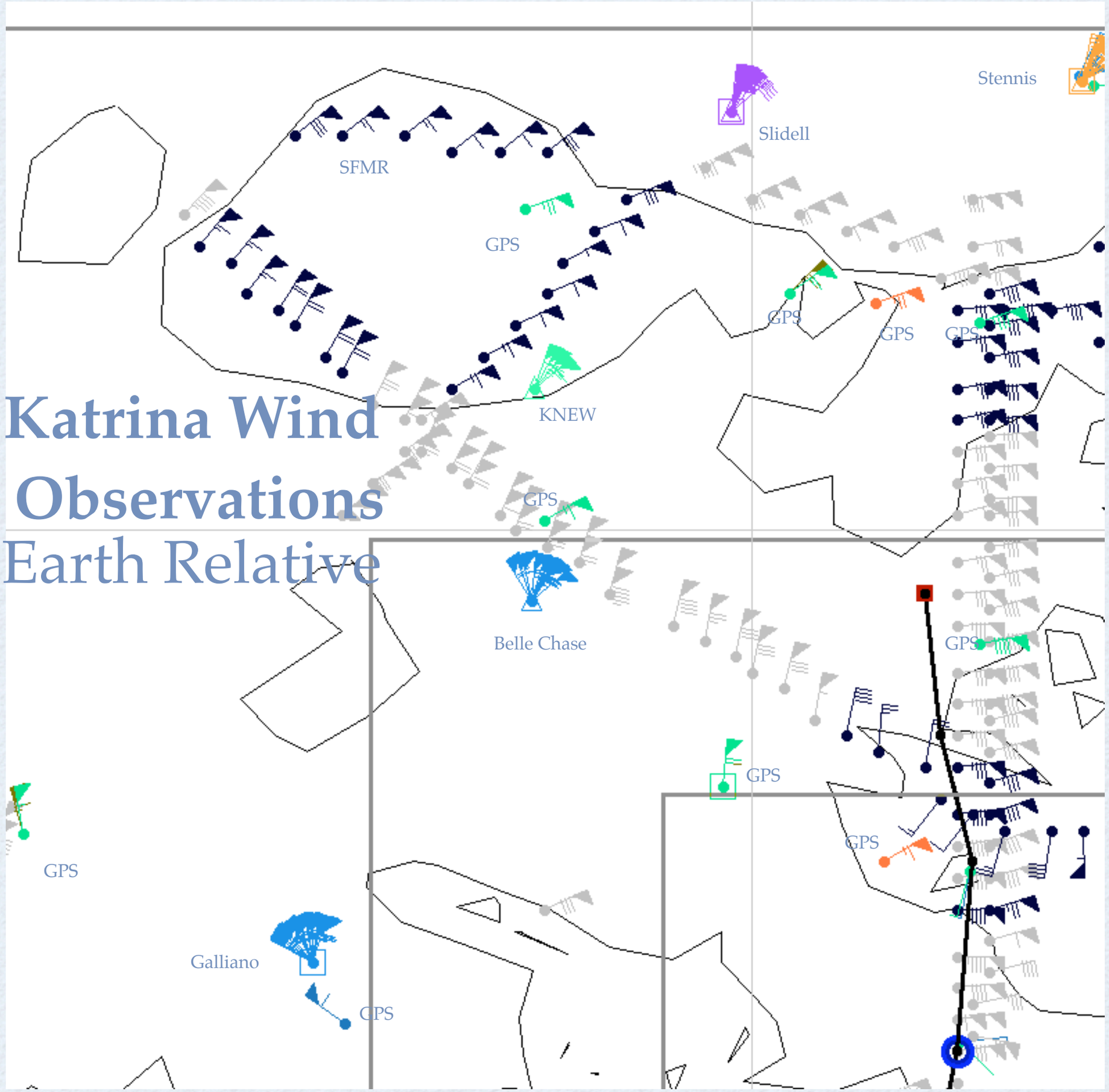
Hurricane Isabel 2003 at landfall



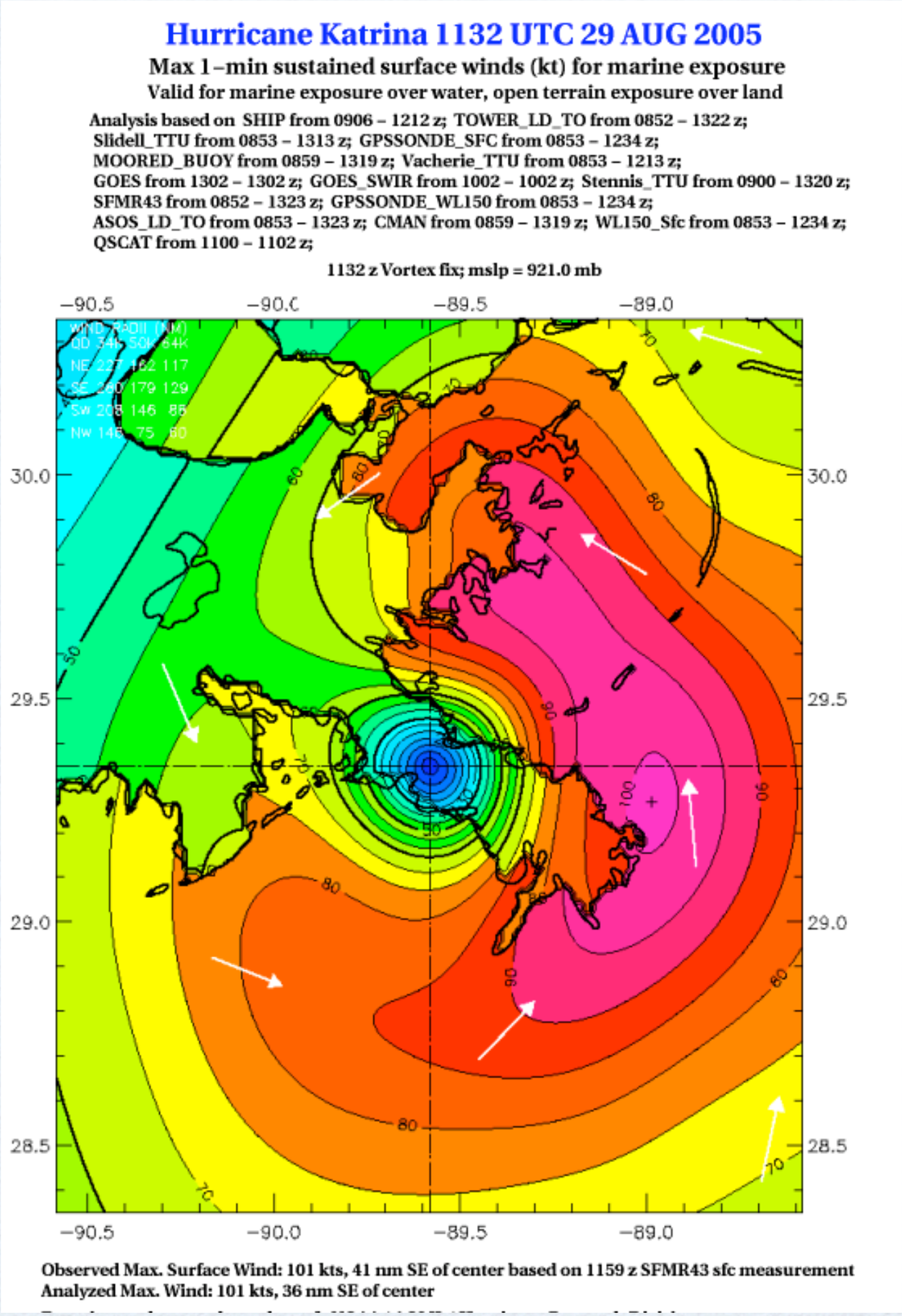
Include	Platform	Color	Qty	Scope	Time Range
✓	GPSSONDE_SFC_OCEANIC		35	7 hr	09/18 10:53 to 09/18/2003 17:39
✓	TOWER_LD_TO_OCEANIC		115	7 hr	09/18 10:54 to 09/18/2003 18:00
✓	QSCAT_RAIN_OCEANIC		709	0 hr	09/18 10:53 to 09/18/2003 10:56
✓	QSCAT_OCEANIC		863	0 hr	09/18 10:53 to 09/18/2003 10:56
✓	GOES_OCEANIC		257	3 hr	09/18 13:02 to 09/18/2003 16:02
✓	MOORED_BUOY_OCEANIC		401	7 hr	09/18 10:59 to 09/18/2003 17:59
✓	AFRES_OCEANIC		368	7 hr	09/18 10:55 to 09/18/2003 17:59
✓	DRIFTING_BUOY_OCEANIC		8	7 hr	09/18 11:00 to 09/18/2003 18:00
✓	SFMR_OCEANIC		224	5 hr	09/18 13:28 to 09/18/2003 18:00
✓	CMAN_OCEANIC		358	7 hr	09/18 10:59 to 09/18/2003 18:00

Katrina Wind Observations

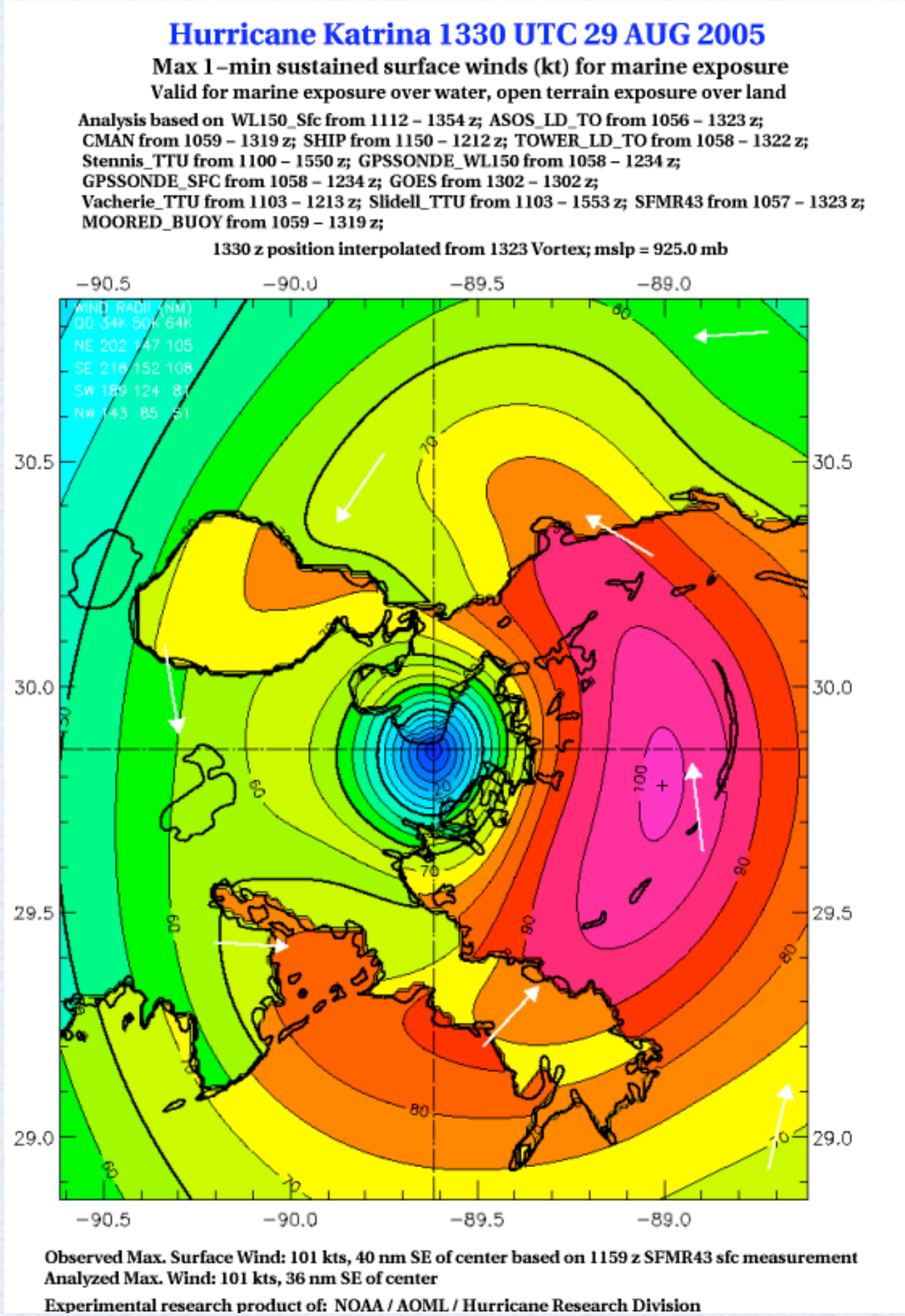
Earth Relative



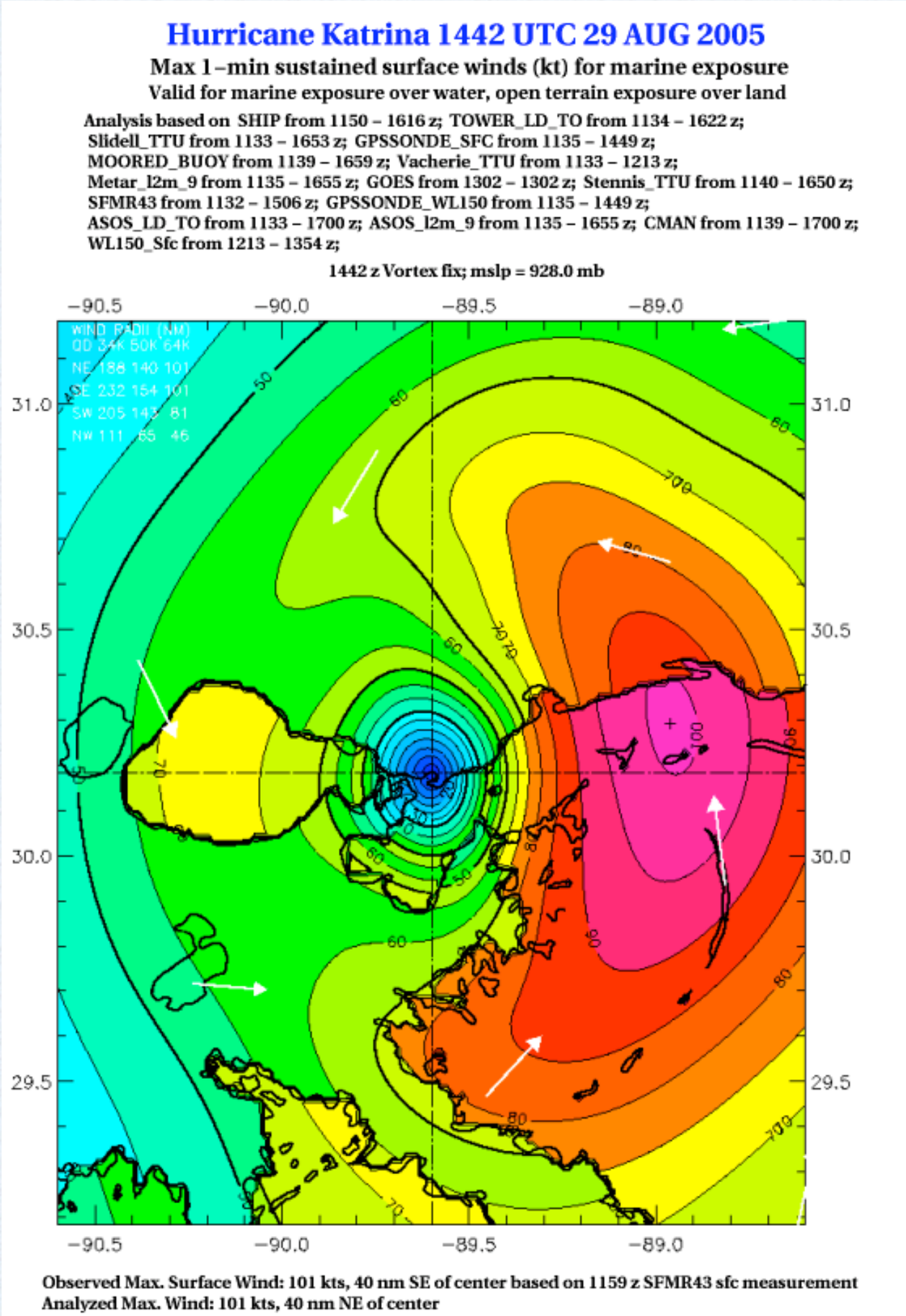
1132 UTC
(0632 CDT)



1330 UTC (0830 CDT)



1442 UTC
(0942 CDT)



- **Wind Uncertainty**
  - Instrument
  - Standardization
  - Representativeness (sampling in time and space)

Platform	Height (m)	Averaging time	Measurement Method	Instrument Uncertainty	Combined Uncertainty
FCMP, WEMITE Tower	5, 10	1-900 s	prop anemometer	1 m/s	5%
SFMR	10	6 km/WS	foam emissivity brightness temp.	0.5K	2 m/s , 10% WS > 55m/s
GPS from WL150	10	5 min	motion via GPS	3 m/s	10%
Moored Buoy	5, 10	10 min	prop anemometer	1 m/s or 10%	12%
GPS surface	8-12	0.5 with 10, 5s filter	motion via GPS	3 m/s	15%
C-MAN	10-40	10 min	prop anemometer	1 m/s or 10%	12%
ASOS	7, 10	2 min	cup anemometer	1 m/s or 5%	10% if record survives
Max Recon (GPS based)	10	5 min	GPS/Max Recon	13%	15%
Max Recon (sfmr-based)	10	2 min	SFMR/Max Recon	7%	10%
QSCAT	10	25 km/WS	Ku Backscatter	2 m/s until hvy. rain	10% until hvy. rain
GOES Cloud Drift	10	5 min	cloud motion-> Sfc wind	2.6 m/s	15% for WS<25 m/s
Ship	~ 20	10-30	anem or Beaufort	10%	20%

- **Major tasks:**
  - Master circulation center track based on all recon fixes, GPS sondes, WSR-88D Doppler radar fixes
  - SFMR calibration
  - SFMR-based flight-level wind -> sfc adjustment method
  - Roughness tables for all land stations based on aerial photos
  - Doppler VTD analysis for Slidell
  - Single Doppler GBVTD analysis, Dual Doppler (Mobile-Slidell)
  - Acquire and standardize all mesonet and supplemental data

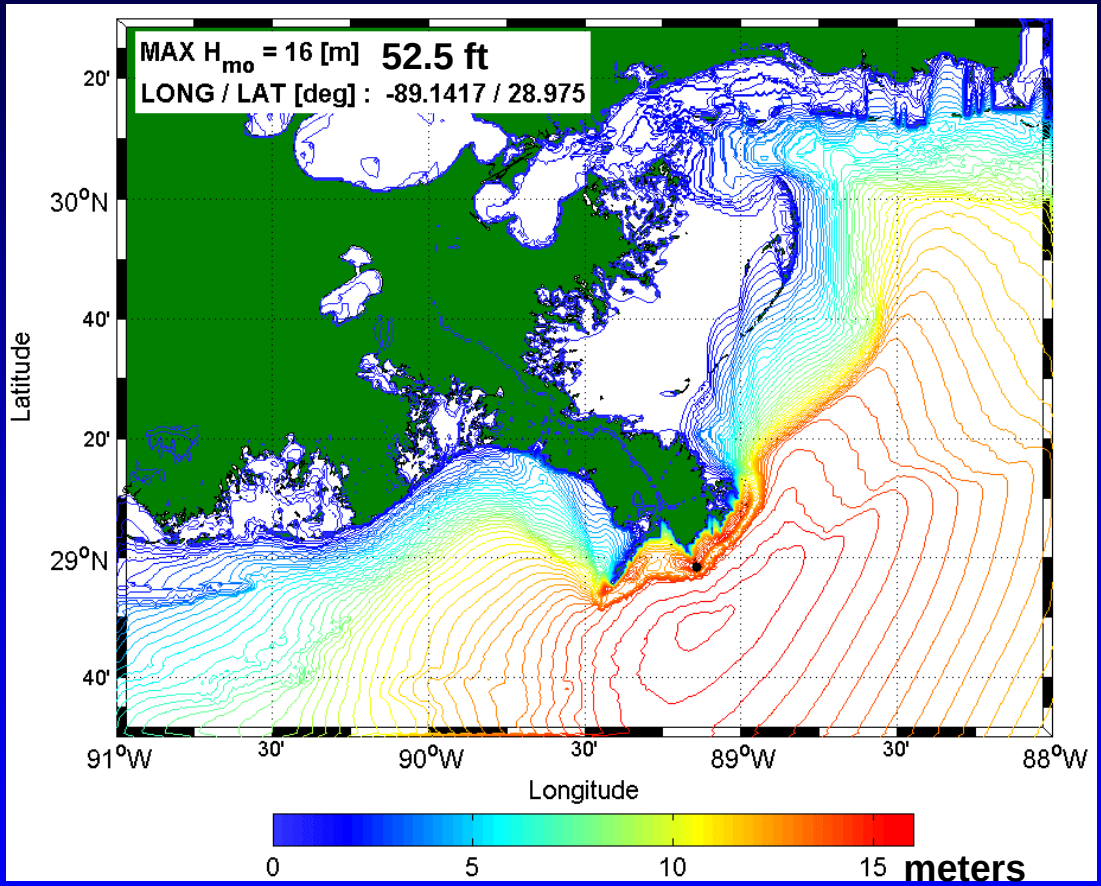
- **Tasks (continued)**
- New terrain adjustment methods based on aerial images, Powell et al., 2003
- New gust factor relationships based on Vickery and Skerlj 2005
- Incorporate new methods in H*Wind revision, include open database, new analysis server
- QC standardized data in H*Wind
  - Make on-the-fly changes based on iterating land-based roughness estimates
- 3 hourly wind analyses Gulf of Mexico until inland (26-29 August)
- Evaluate analysis uncertainty (pending funding, using bootstrap/Monte Carlo techniques)

TITLE: Wave Prediction in Southeast Louisiana

PRESENTED BY: Jane Smith, Robert Jensen, Ann Sherlock, USACE-ERDC

SUMMARY: This presentation summarized the wave modeling process used to analyze the impact of Hurricane Katrina in southeast Louisiana as part of the IPET study. Wave modeling used the wind field data generated from assembling and analyzing three data sources: (1) H*Wind snapshots developed by the Hurricane Research Division of NOAA provided the distribution of wind speeds within and around the hurricane based on a variety of observation platforms; (2) background wind fields produced by the NOAA National Centers for Environmental Prediction provided the large-scale wind fields, and (3) additional marine wind measurements. These data were integrated using an interaction optimum kinematic analysis system. Winds were produced on basin (Gulf of Mexico) and regional domains with spatial resolutions of 0.1 deg and 0.025 deg, respectively, and temporal resolution of 900 sec. The basin and regional waves were modeled with the time-dependent WAM model (cycle 4.5) using the same domains and resolutions as the wind fields. The maximum significant wave height hind cast was approximately 53 ft in deep water. Waves were modeled by nesting from basin to regional to near shore domains. The near shore wave model was nested into the regional WAM grid at a water depth of approximately 100 ft. Near shore waves were simulated on three grids at a spatial resolution of 200 m using the steady-state model STWAVE run at 30-min intervals. The near shore wave modeling includes local wind generation, spatially variable surge, and wave forcing on the boundary for the regional model. These simulations provide wave information used to estimate wave runup and overtopping at levees and structures and to estimate the wave momentum contribution to the surge (wave setup). Continuing work has included improved wind estimates, wave dissipation over marshes, and the addition of near shore grid for the Mississippi and Alabama coasts, and sensitivity analysis of model inputs.

Wave Prediction in Southeast Louisiana



J.M. Smith, R.E. Jensen, and A.R. Sherlock

US Army Corps of Engineers

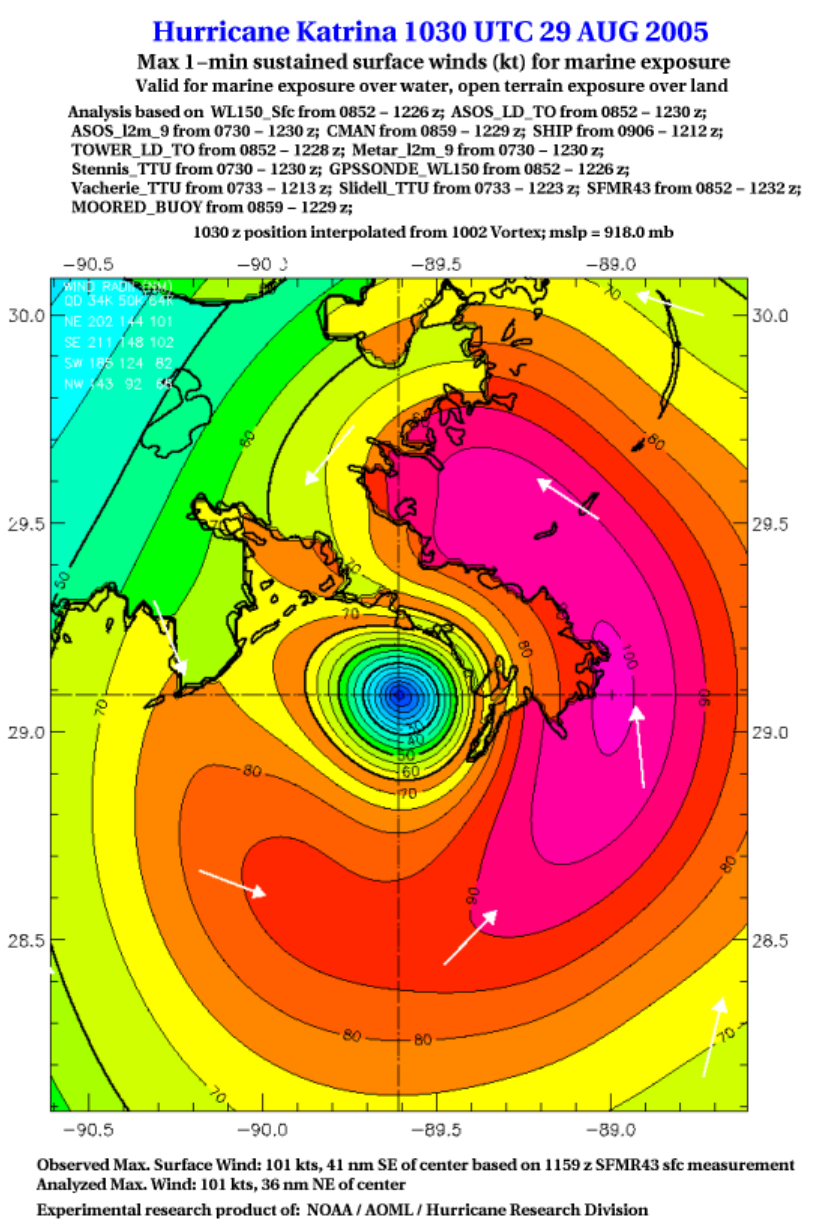
Coastal and Hydraulics Laboratory - ERDC

Outline

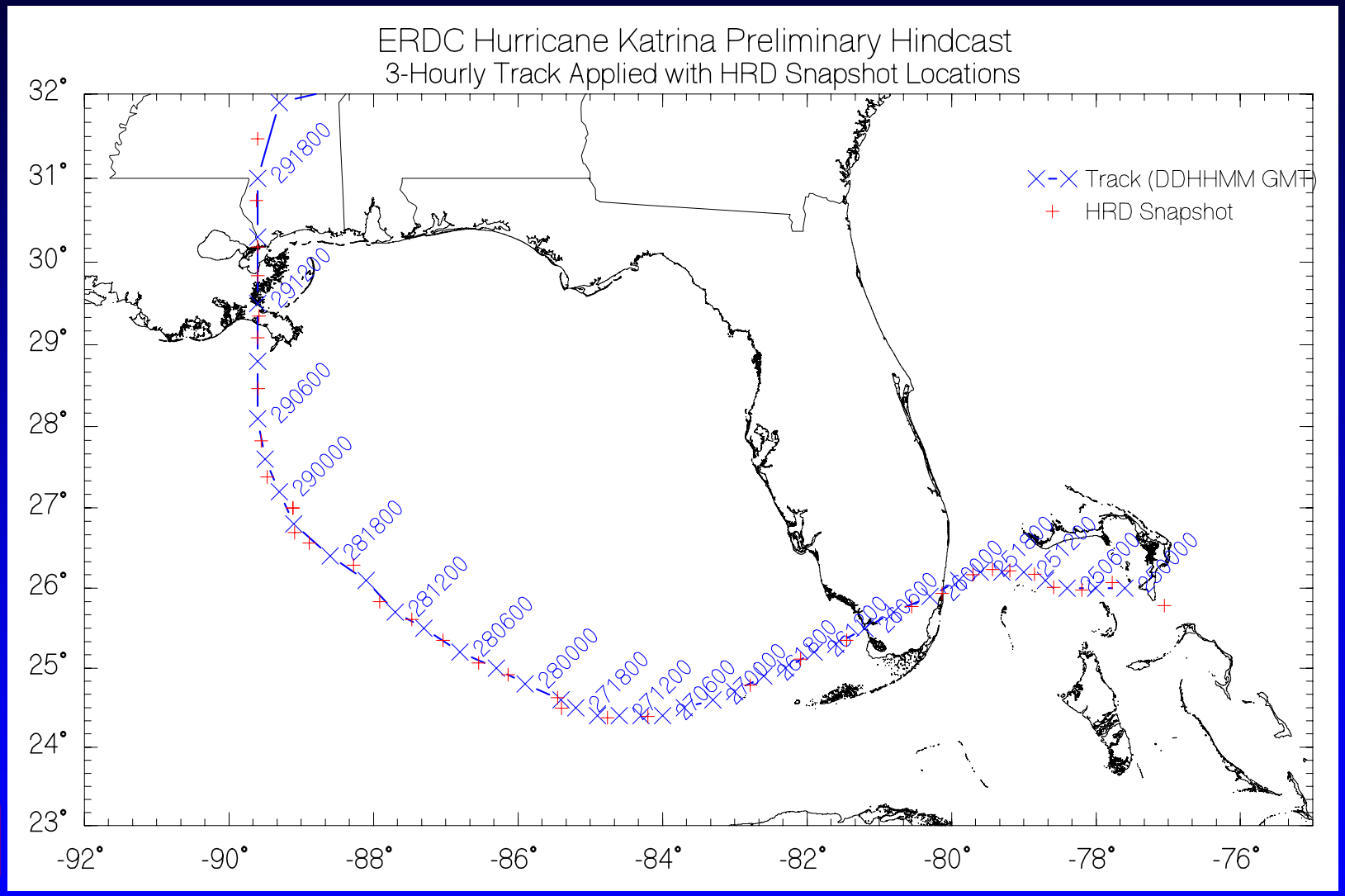
- Wind Input
- Basin and Regional Waves
- Nearshore Waves

Wind Input

- Wind Field Generation
  - H*Wind snapshots
  - Moving center interpolation
    - Continuity storm characteristics
    - No loss of information
  - Background fields NRA
  - Injection of marine data
  - Interactive Optimum Kinematic Analysis System IOKA
  - Winds Workstation

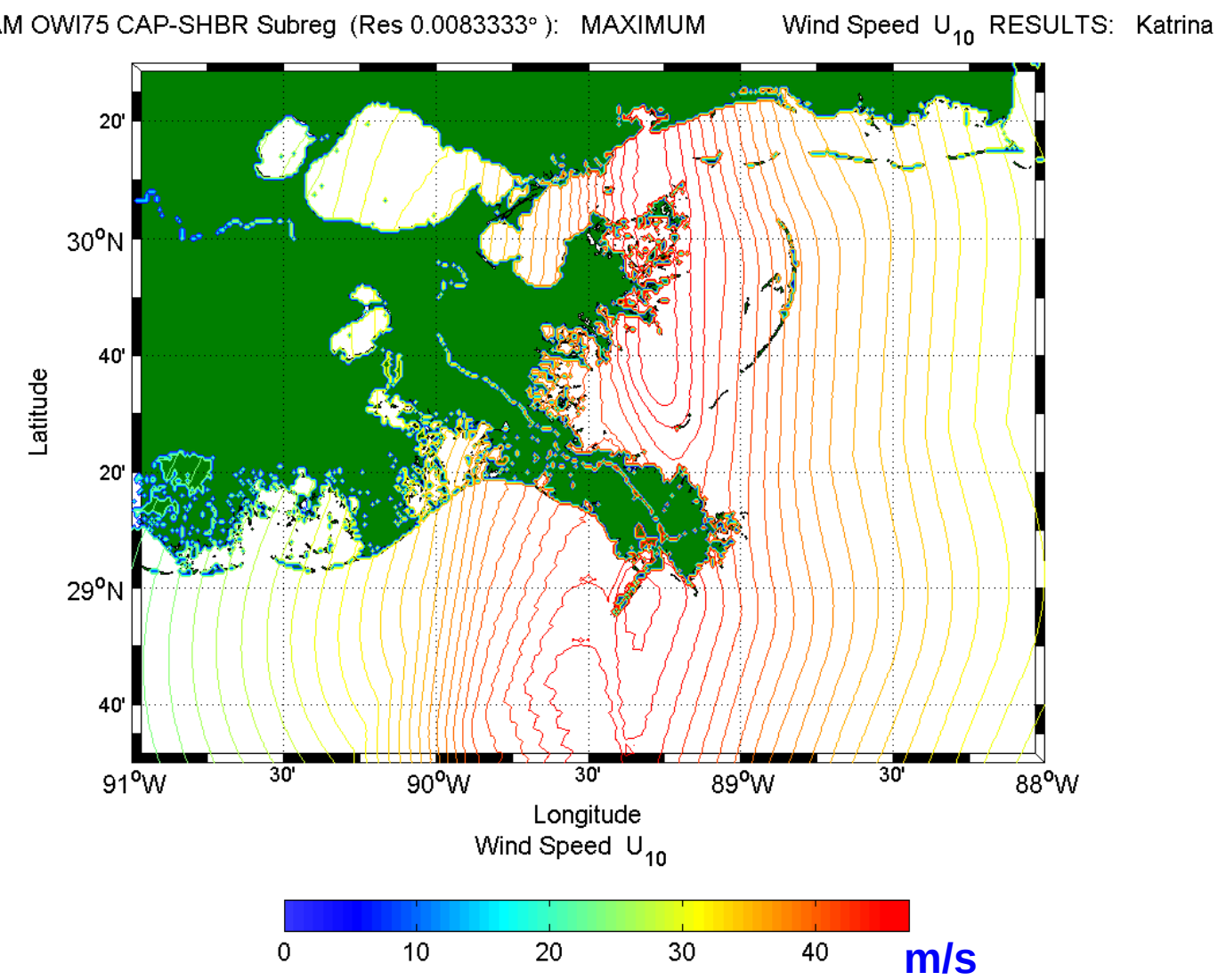


Wind Input


ERDC Hurricane Katrina Preliminary Hindcast
3-Hourly Track Applied with HRD Snapshot Locations
Track (DDHHMM GMT)
HRD Snapshot
32°
31°
30°
29°
28°
27°
26°
25°
24°
23°
-92°
-90°
-88°
-86°
-84°
-82°
-80°
-78°
-76°
291800
291200
290600
290000
281800
281200
280600
280000
271800
271200
270600
270000
261800
261200
260600
260000
251800
251200
250600
250000

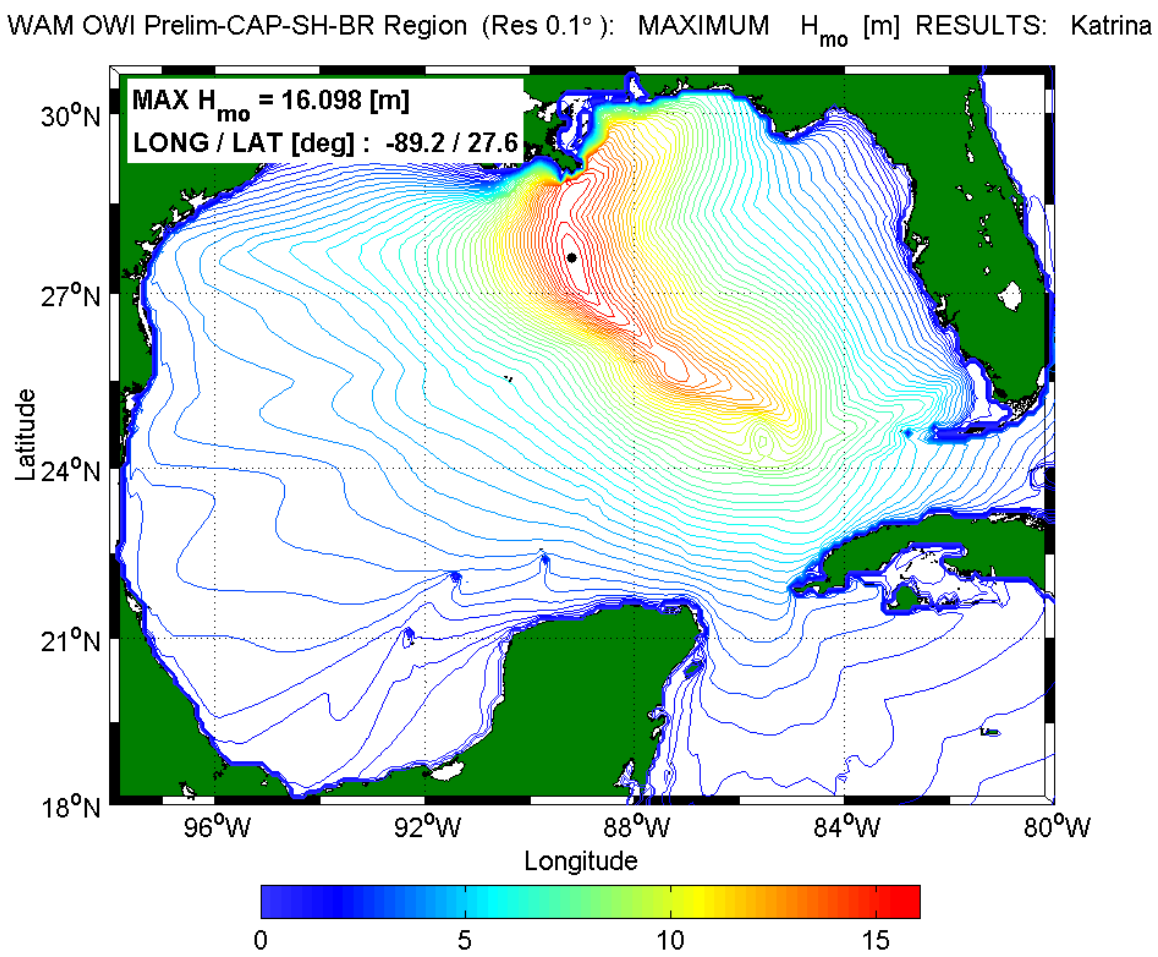
Wind Products

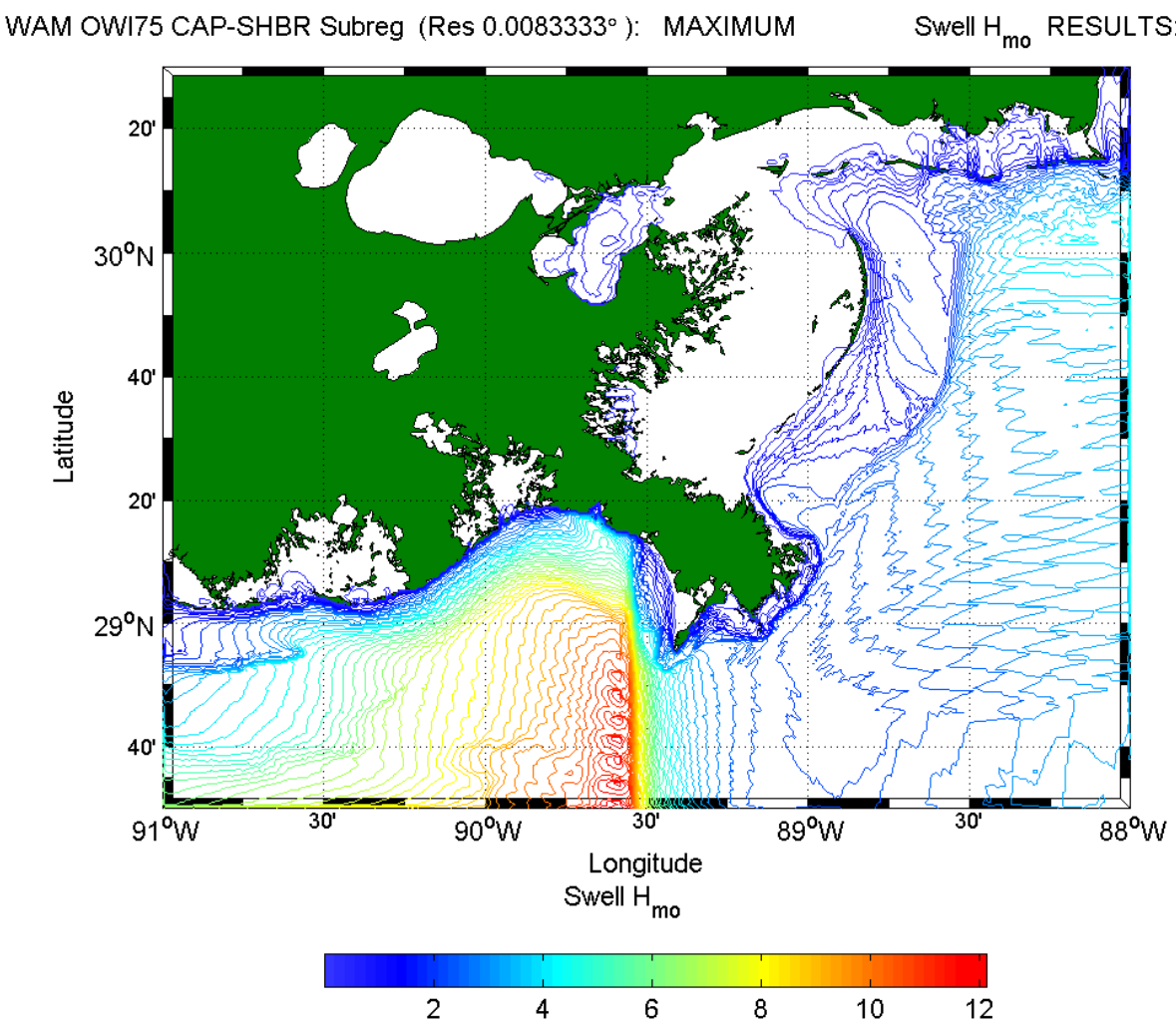
- Basin Scale
  - 98° to 80° W / 18° to 30.8° N
  - 0.1° spatial resolution
  - 900-s temporal resolution
  - 30-min ave
  - 2005082500 – 2005083100 UTC
- Regional Scale
  - 91° to 88° W / 28.5° to 30.8° N
  - 0.025° spatial resolution
  - 900-s temporal resolution
  - 30-min ave
  - 2005082906 – 2005082918 UTC

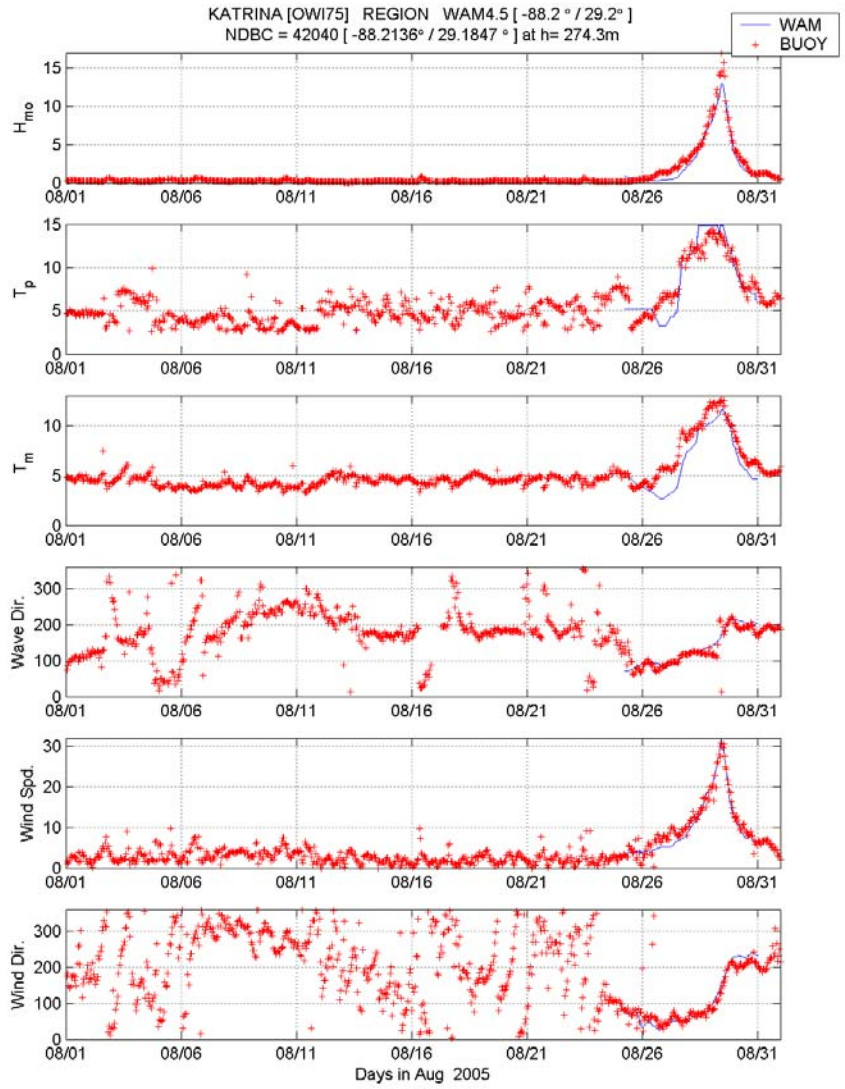

WAM OWI75 CAP-SHBR Subreg (Res 0.0083333°): MAXIMUM
Wind Speed U_{10} RESULTS: Katrina
20'
30°N
40'
20'
29°N
40'
Latitude
91°W
30'
90°W
30'
89°W
30'
88°W
Longitude
Wind Speed U_{10}
0
10
20
30
40
m/s

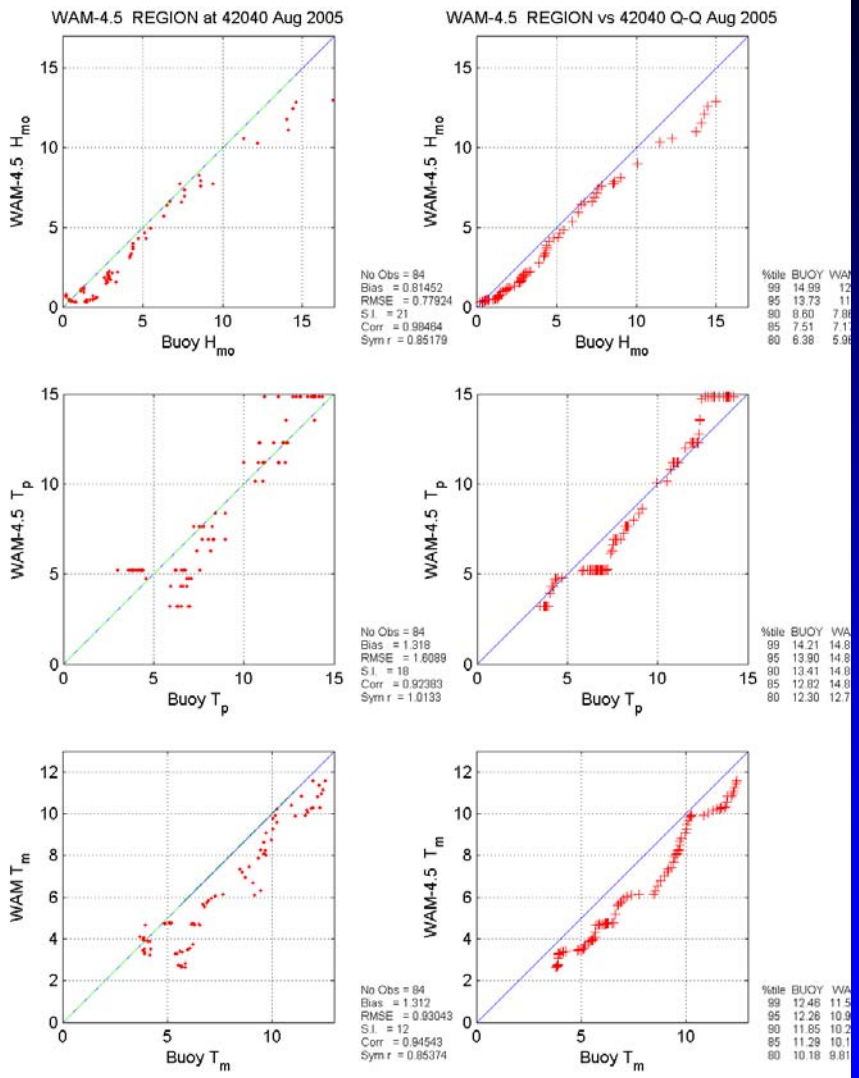
Basin and Regional Waves

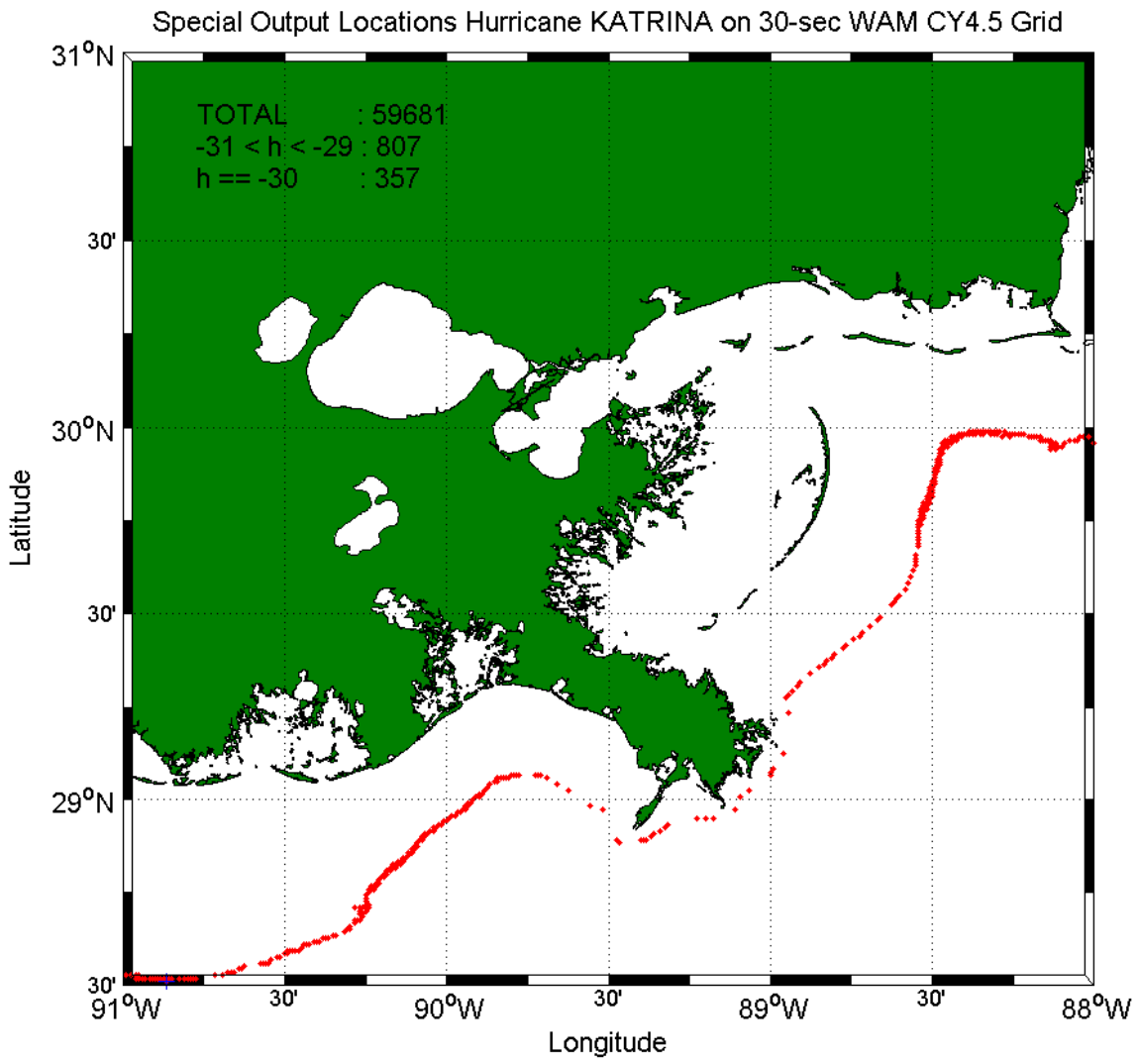
- WAM-CY4.5
  - Solves Action Balance
  - S_{in} , S_{nl} , S_{ds} , S_{w-b} S_{bk}
  - Includes: Shoaling / Refraction
  - Multi-Nested
    - Basin Scale
    - Regional Scale
  - Verified and Validated
  - Used in NOPP

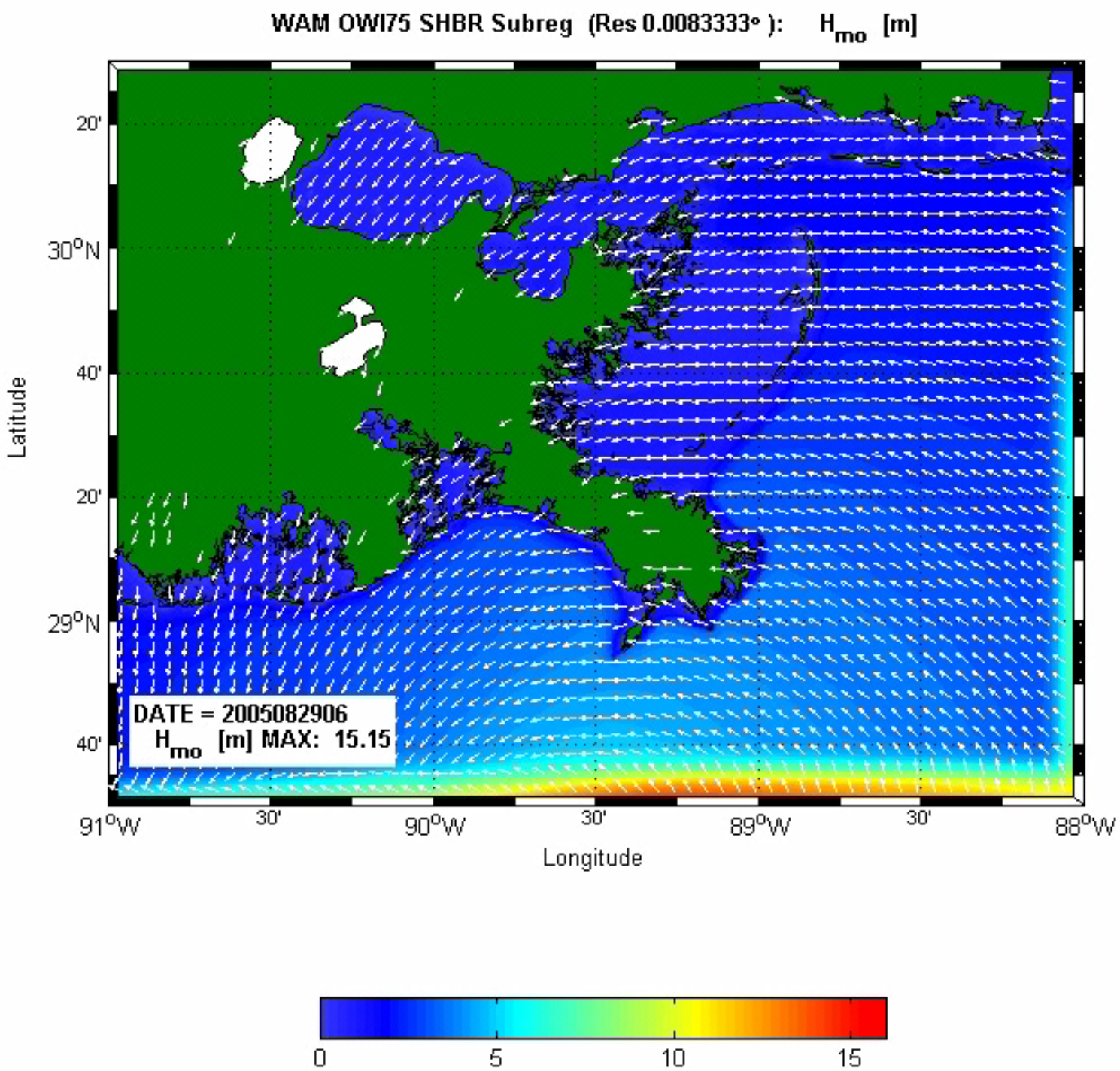

WAM OWI Prelim-CAP-SH-BR Region (Res 0.1°): MAXIMUM H_{mo} [m] RESULTS: Katrina
MAX H_{mo} = 16.098 [m]
LONG / LAT [deg] : -89.2 / 27.6
30°N
27°N
24°N
21°N
18°N
Latitude
96°W
92°W
88°W
84°W
80°W
Longitude
0
5
10
15


WAM OWI75 CAP-SHBR Subreg (Res 0.0083333°): MAXIMUM
Swell H_{mo} RESULTS: Katrina
20'
30°N
40'
20'
29°N
40'
Latitude
91°W
30'
90°W
30'
89°W
30'
88°W
Longitude
Swell H_{mo}
2
4
6
8
10
12


KATRINA [OWI75] REGION WAM4.5 [-88.2 ° / 29.2°]
NDBC = 42040 [-88.2136° / 29.1847 °] at h= 274.3m
WAM
BUOY
H_{mo}
T_p
T_m
Wave Dir.
Wind Spd.
Wind Dir.
08/01
08/06
08/11
08/16
08/21
08/26
08/31
Days in Aug 2005


WAM-4.5 REGION at 42040 Aug 2005
WAM-4.5 REGION vs 42040 Q-Q Aug 2005
WAM-4.5 H_{mo}
Buoy H_{mo}
No Obs = 84
Bias = 0.81452
RMSE = 0.77924
S.I. = 21
Corr = 0.98484
Sym r = 0.85179
%tile BUOY WAM
99 14.99
95 13.73
90 8.60
85 7.51
80 6.38
WAM-4.5 T_p
Buoy T_p
No Obs = 84
Bias = 1.318
RMSE = 1.6089
S.I. = 18
Corr = 0.92383
Sym r = 1.0133
%tile BUOY WAM
99 14.21
95 13.90
90 13.41
85 12.82
80 12.30
WAM T_m
WAM-4.5 T_m
Buoy T_m
No Obs = 84
Bias = 1.312
RMSE = 0.93043
S.I. = 12
Corr = 0.94543
Sym r = 0.85374
%tile BUOY WAM
99 12.46
95 12.26
90 11.85
85 11.29
80 10.18


Special Output Locations Hurricane KATRINA on 30-sec WAM CY4.5 Grid
TOTAL : 59681
-31 < h < -29 : 807
h == -30 : 357
31°N
30'
30°N
30'
29°N
30'
Latitude
91°W
30'
90°W
30'
89°W
30'
88°W
Longitude



US Army
of Engin

Nearshore Waves

- Requirements
- Methodology
- Preliminary Results
- Issues

Nearshore Wave Requirements

- Wave Runup and Overtopping on Structures
- Wave Momentum Contribution to Water Level (set up)
- Dynamic pressures
- Bottom velocities

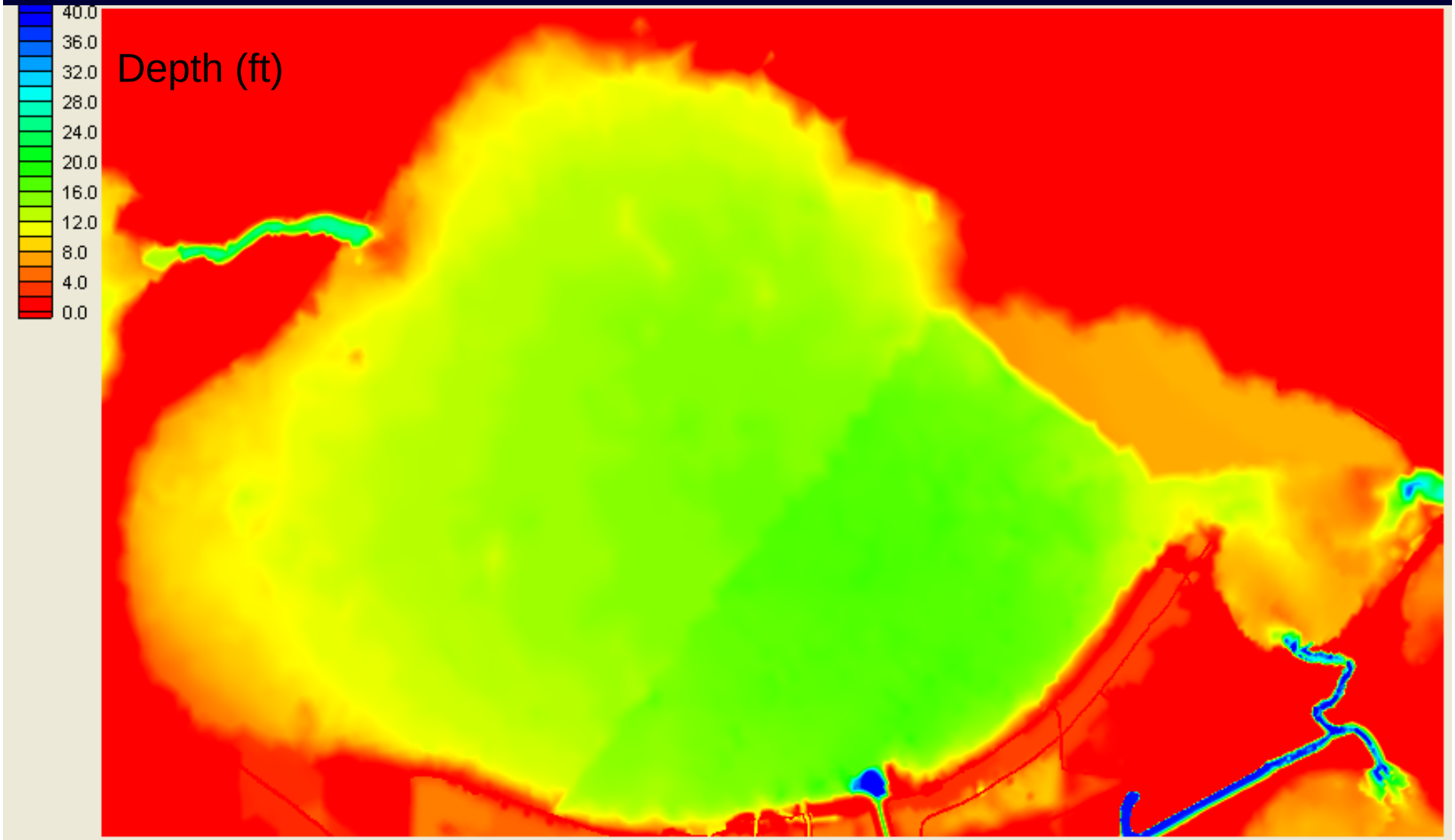
Nearshore Wave Modeling Methodology

- STWAVE
  - Wave generation and transformation model
  - Solves Action Balance
  - S_{in} , S_{nl} , S_{ds} , $S_{w\text{-}b}$ S_{bk}
  - Includes: shoaling / refraction / simplified diffraction
  - Spatially variable surge
  - Full- and half-plane versions
  - Steady state
  - Efficient
  - Nested from regional scale WAM
  - Standard Corps model

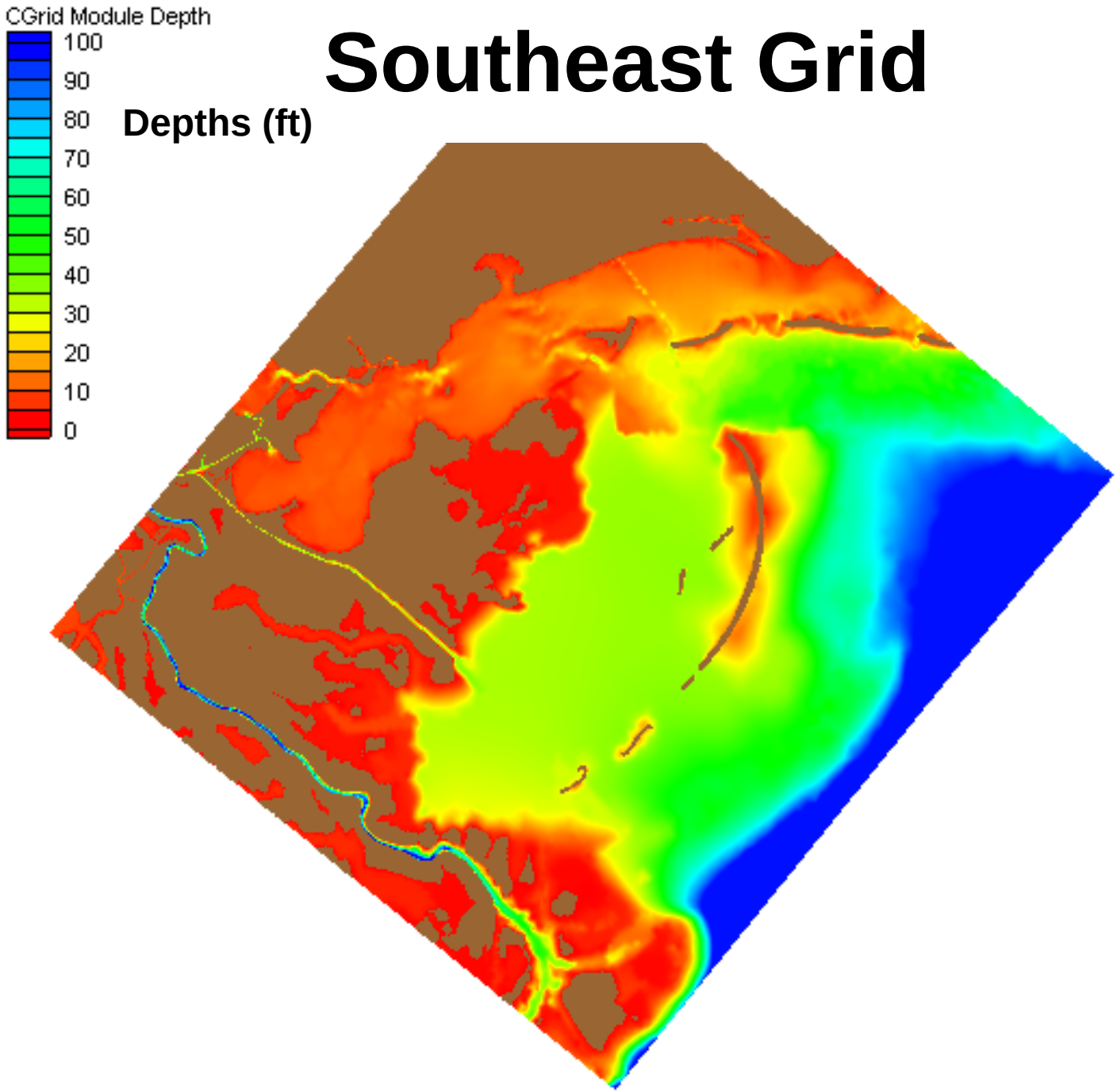
Nearshore Wave Modeling Methodology

- Southeast Louisiana Coast
  - Input: bathymetry, surge, wind and boundary regional wave spectra
  - Two grids: SW of Mississippi River, NE of Mississippi River (Lake Borgne)~ 100 mile domains, 200 m & 100 m resolution (~ 2 mill. cells)
  - Half-plane, steady-state STWAVE
  - 30-min intervals
- Lake Pontchartrain
  - Input: bathymetry, surge, and wind
  - One grid: ~ 25x40 mile domain (~ 600 k cells), 50X100 m resolution
  - Full-plane, steady-state STWAVE
  - 30-min intervals

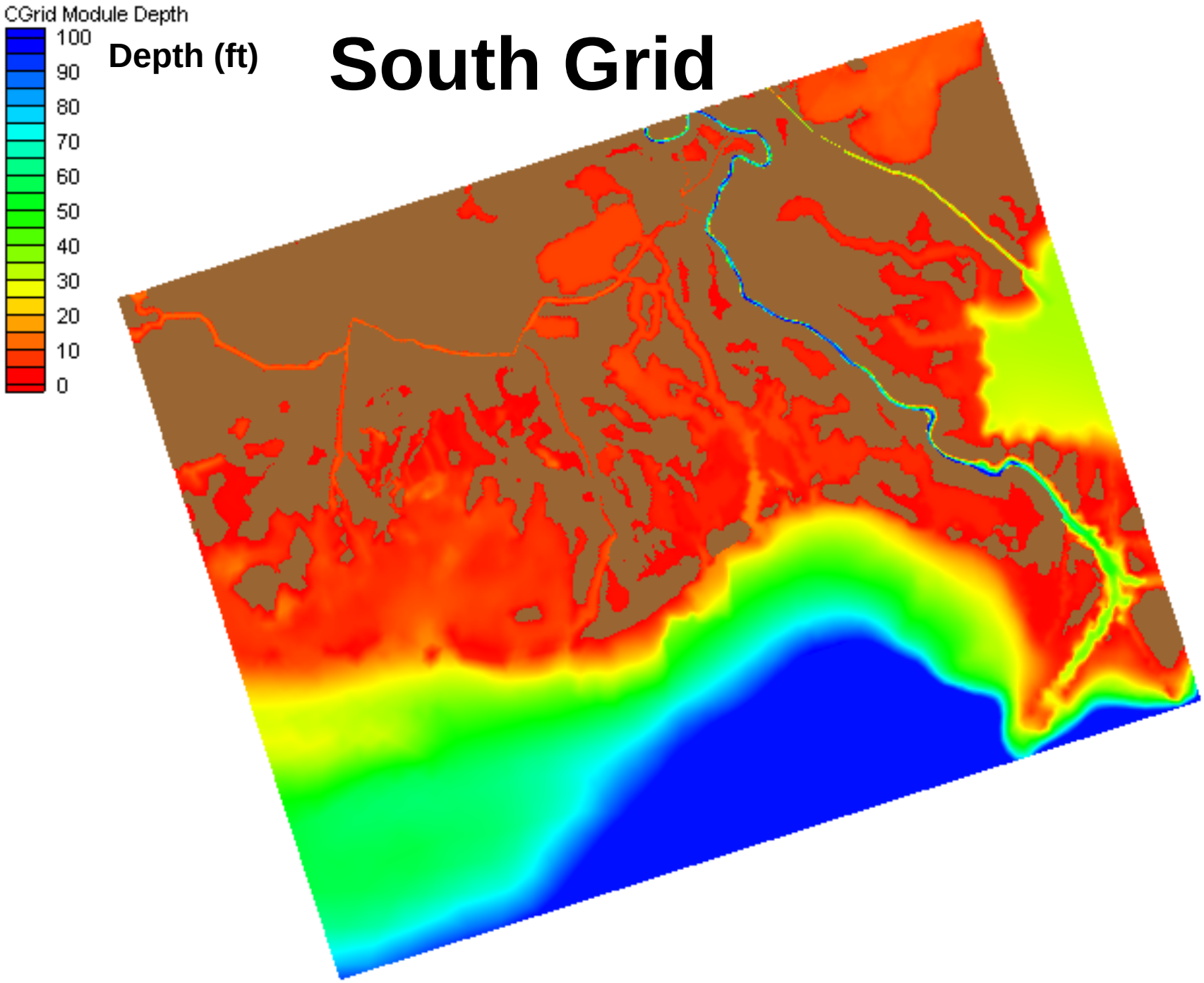
Pontchartrain Grid



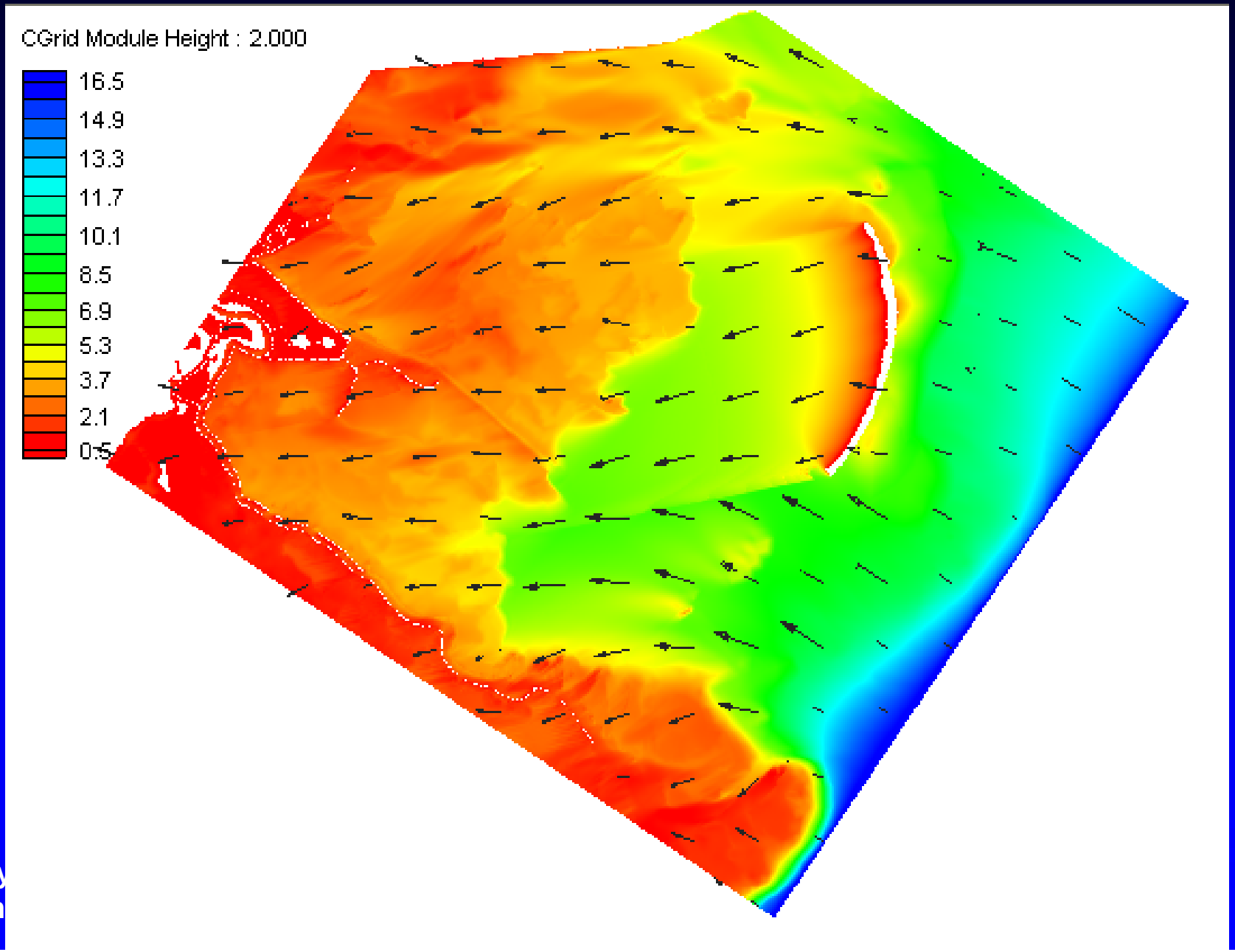
Southeast Grid



South Grid

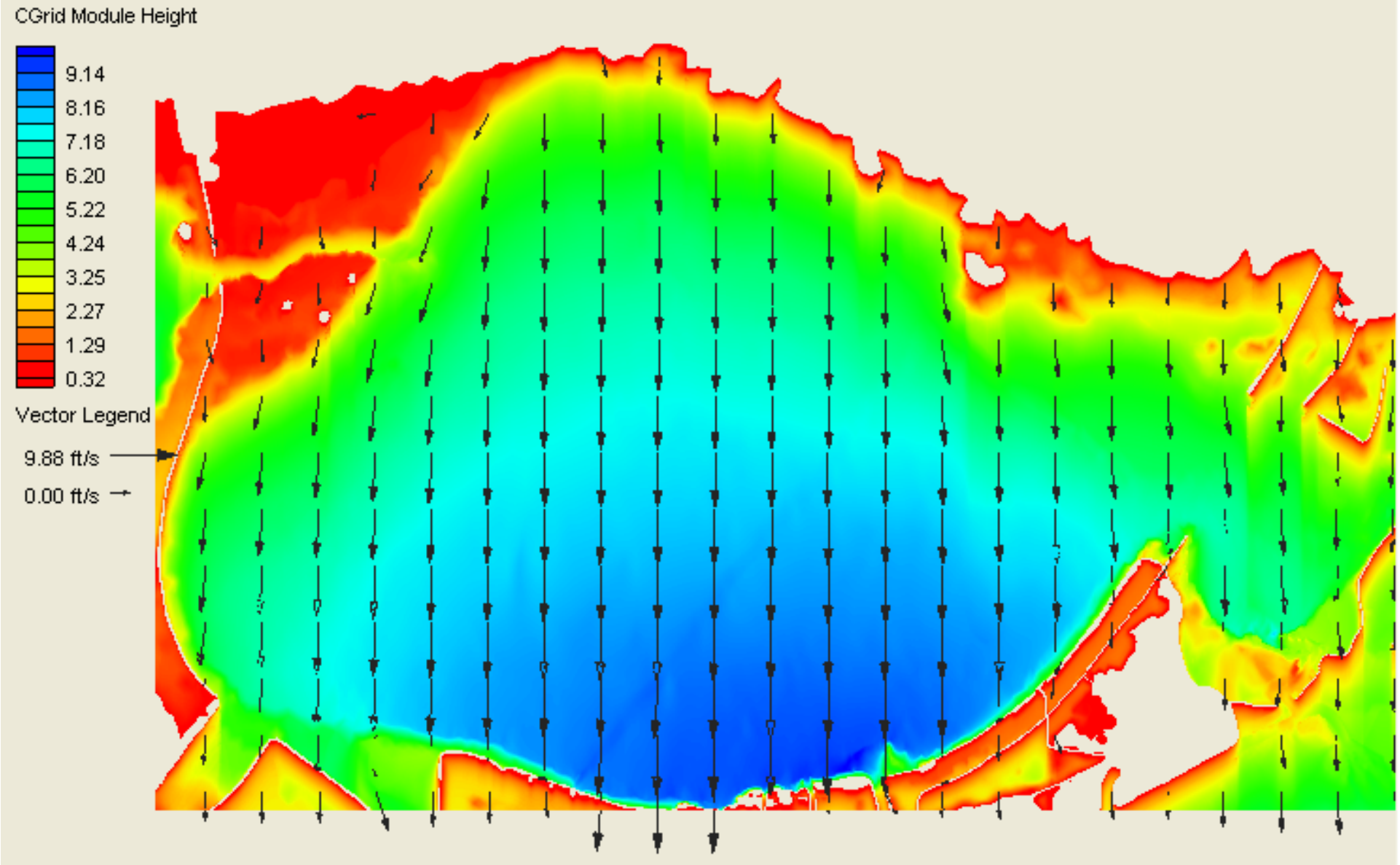


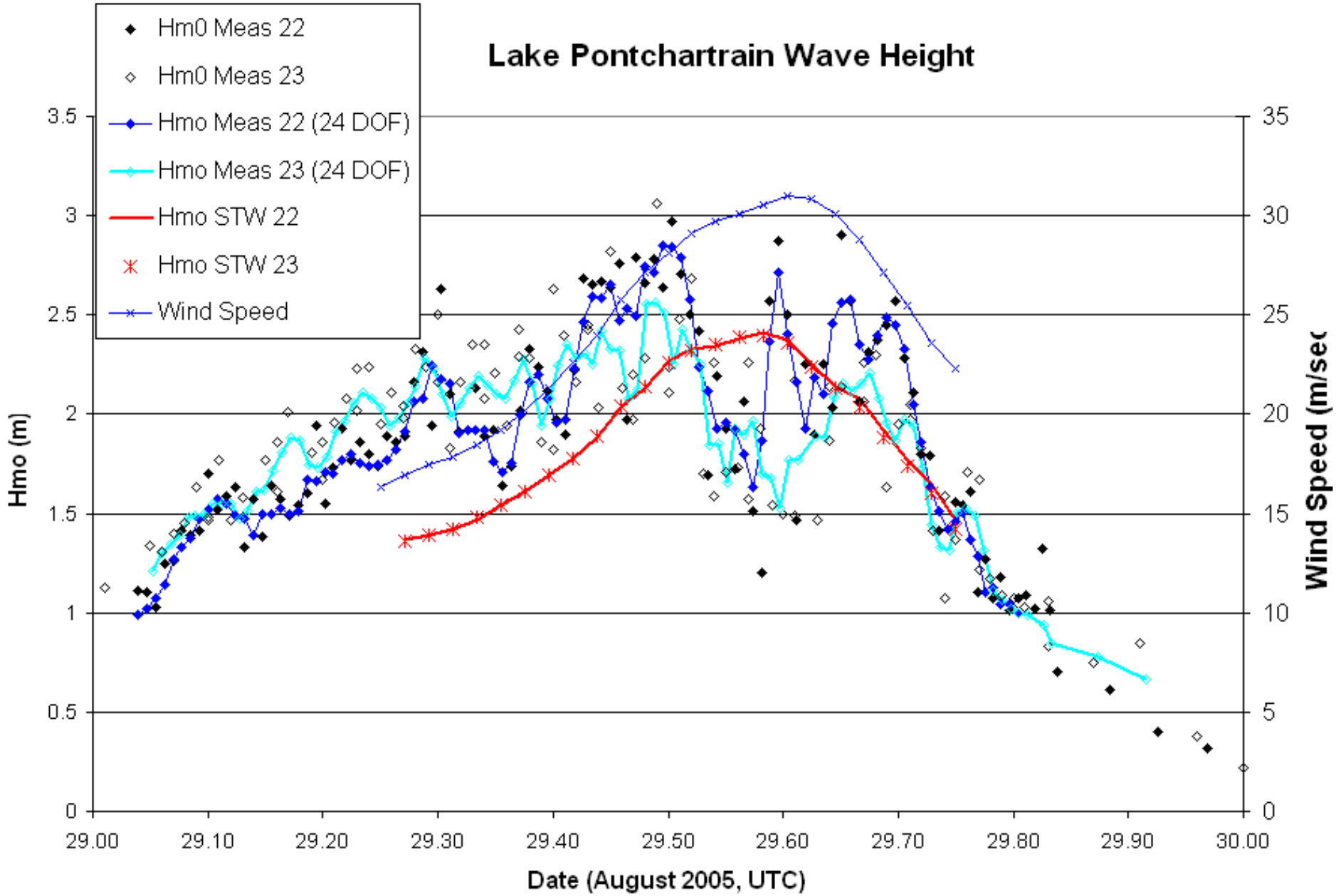
Southeast Grid

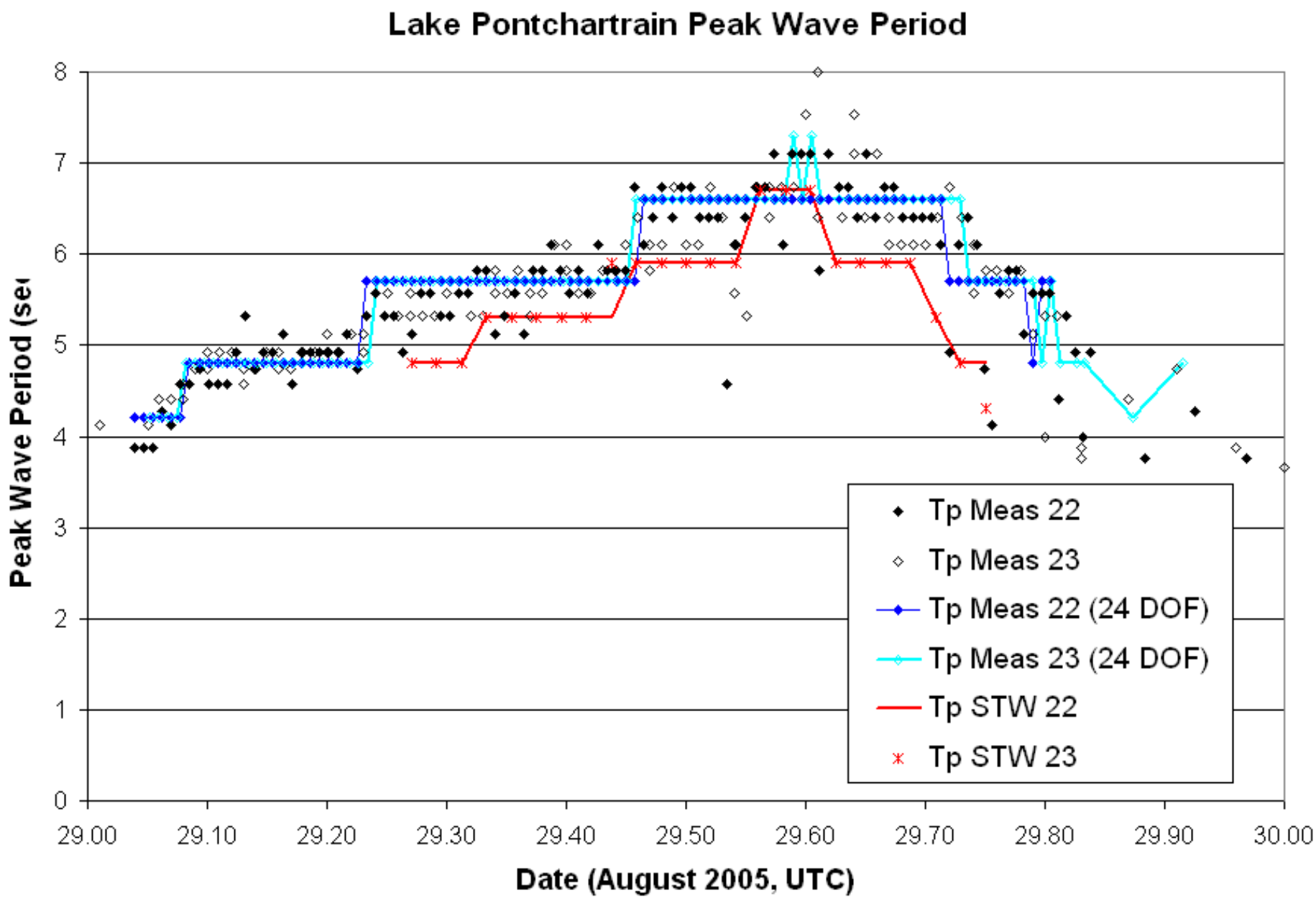


US Army
of Engin

Pontchartrain




Lake Pontchartrain Wave Height
Hm0 Meas 22
Hm0 Meas 23
Hmo Meas 22 (24 DOF)
Hmo Meas 23 (24 DOF)
Hmo STW 22
Hmo STW 23
Wind Speed
Hmo (m)
Wind Speed (m/sec
Date (August 2005, UTC)
0
0.5
1
1.5
2
2.5
3
3.5
0
5
10
15
20
25
30
35
29.00
29.10
29.20
29.30
29.40
29.50
29.60
29.70
29.80
29.90
30.00


Lake Pontchartrain Peak Wave Period
Peak Wave Period (se
Date (August 2005, UTC)
0
1
2
3
4
5
6
7
8
29.00
29.10
29.20
29.30
29.40
29.50
29.60
29.70
29.80
29.90
30.00
Tp Meas 22
Tp Meas 23
Tp Meas 22 (24 DOF)
Tp Meas 23 (24 DOF)
Tp STW 22
Tp STW 23

Continuing Work

- Basin & Regional Waves
  - Increase directional resolution
  - Isolate under estimate in H in RHQ of Katrina
    - Winds, air-sea temperatures, dissipation removing swell
  - Nearshore depths/depth gradients
  - Improve representation of Island
- Nearshore Waves
  - Spatially variable wind fields
  - Importance of temporal variation in the nearshore
  - Bottom dissipation over marshes
  - Inclusion of whitecapping dissipation in radiation stresses
  - Iteration between waves and surge
  - Add Mississippi/Alabama Coast grid

TITLE: Storm Surge Prediction in Southeast Louisiana

PRESENTED BY: Joannes Westerink, University of Notre Dame

SUMMARY: The presentation describes a basin to channel scale implementation of the ADCIRC unstructured grid hydrodynamic model that has been developed to accurately simulates hurricane storm surge, tides, and river flow in southern Louisiana. This model defines the domain and computational resolution appropriate for the relevant processes, specifies realistic boundary conditions, and implements accurate, robust, and highly parallel unstructured grid numerical algorithms.

The model domain incorporates the Western North Atlantic, the Gulf of Mexico, and the Caribbean Sea so that interactions between basins and the shelf are explicitly modeled and boundary condition specification of tidal and hurricane processes can be readily defined at the deep water open boundary. The unstructured grid enables highly refined resolution of the complex overland region for modeling localized scales of flow while minimizing computational cost. ADCIRC applies a finite element-based solution to the Generalized Wave-Continuity Equation form of the governing shallow water equations. Data assimilated or validated modeled wind fields provide hurricane wind and pressure field forcing. Wind fields are modified to incorporate directional boundary layer changes due to overland increases in surface roughness, reduction in effective land roughness due to inundation, and sheltering due to forested canopies. Validation of the model is achieved through hindcasts of historical Hurricanes Betsy and Andrew. Model hindcast results compare well with data from stations throughout South Louisiana. A model skill assessment indicates computed peak storm surge height has a mean absolute error of 0.30 meters.

The ADCIRC code and the hierarchy of South Louisiana models have been developed in partnership with the U.S. Army Research Development Center and the U.S. Army Corps of Engineers New Orleans District. Additional model funding has been provided by the Office of Naval Research, the National Science Foundation and other agencies. A hierarchy of higher resolution models is currently being developed for the IPET as well as FEMA flood mapping projects.

COMPUTATIONAL HYDRAULICS LABORATORY *at Notre Dame*

Storm Surge Prediction in Southern Louisiana

Joannes Westerink and Shintaro Bunya
University of Notre Dame

Rick Luettich
University of North Carolina – Chapel Hill

Clint Dawson
University of Texas - Austin

ERDC Category 5 Hurricane Workshop

December 20, 2005

ADCIRC Overview

- ADCIRC is an evolving framework to compute flow and transport in coastal oceans, shelves, estuaries, inlets, floodplains, rivers and beaches.
- ADCIRC solves
  - 2D shallow water equations (SWE)
  - 3D mass and momentum conservation subject to incompressibility, hydrostatic and Boussinesq approximations
  - 2D sediment continuity equation
  - 2D and 3D temperature and salinity transport equations

ADCIRC Features

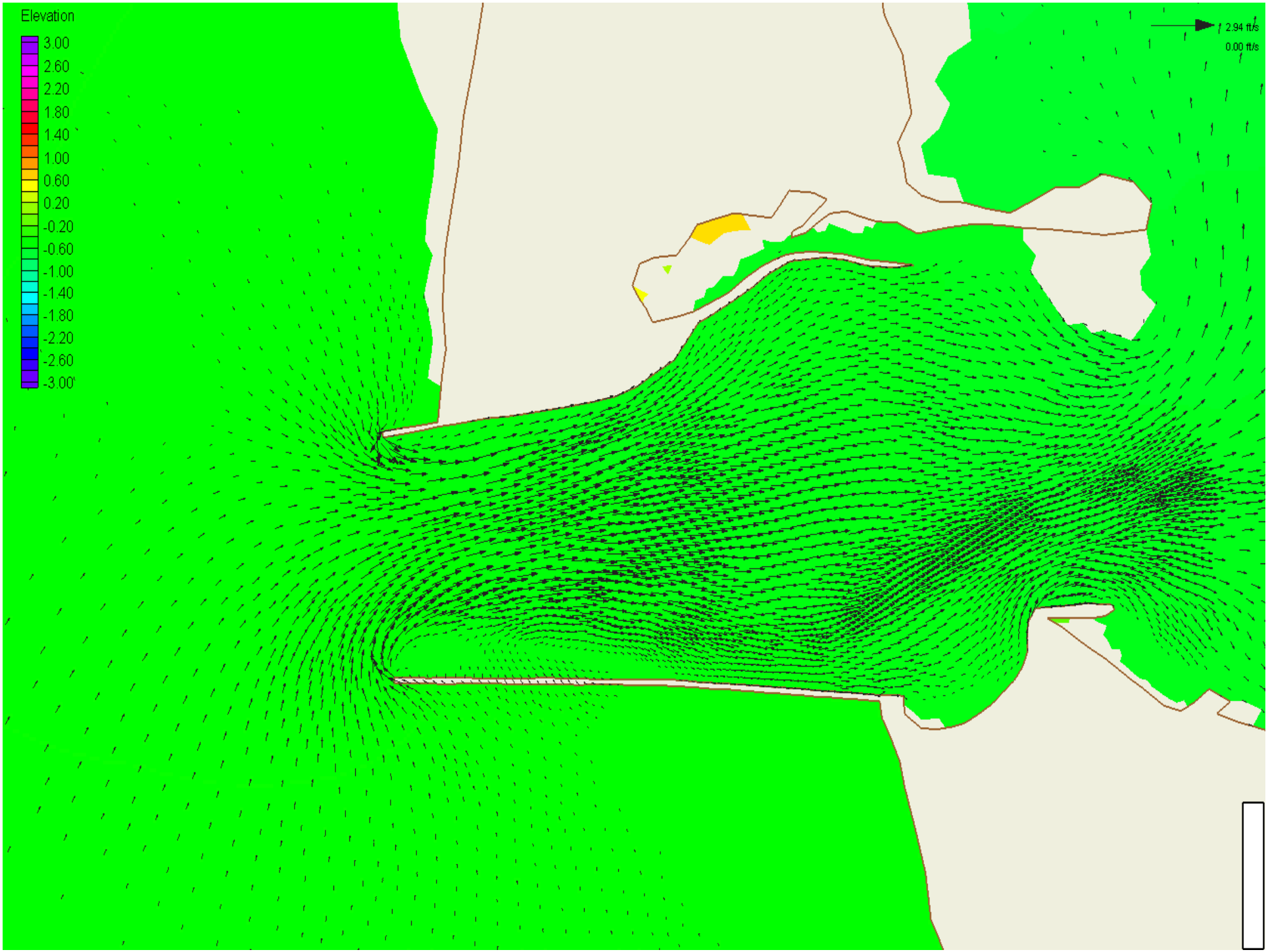
- ADCIRC accommodates the following forcing functions
  - Gravity
  - Tidal potential
  - Earth load/self attraction tide
  - Wind and atmospheric pressure
  - Elevation, flow and radiation boundary conditions
  - Dynamic coupling with wave and sediment models

ADCIRC Features

- Cartesian or spherical coordinates
- 2DDI and 3D
- Full wetting/drying elements (2D and 3D)
- Barrier elements (e.g. levees)
- Conduits and porous barriers
- Harmonic analysis (“on the fly”)
- Cold or hot starts
- Well Documented, Web Served, HTML Users Manual

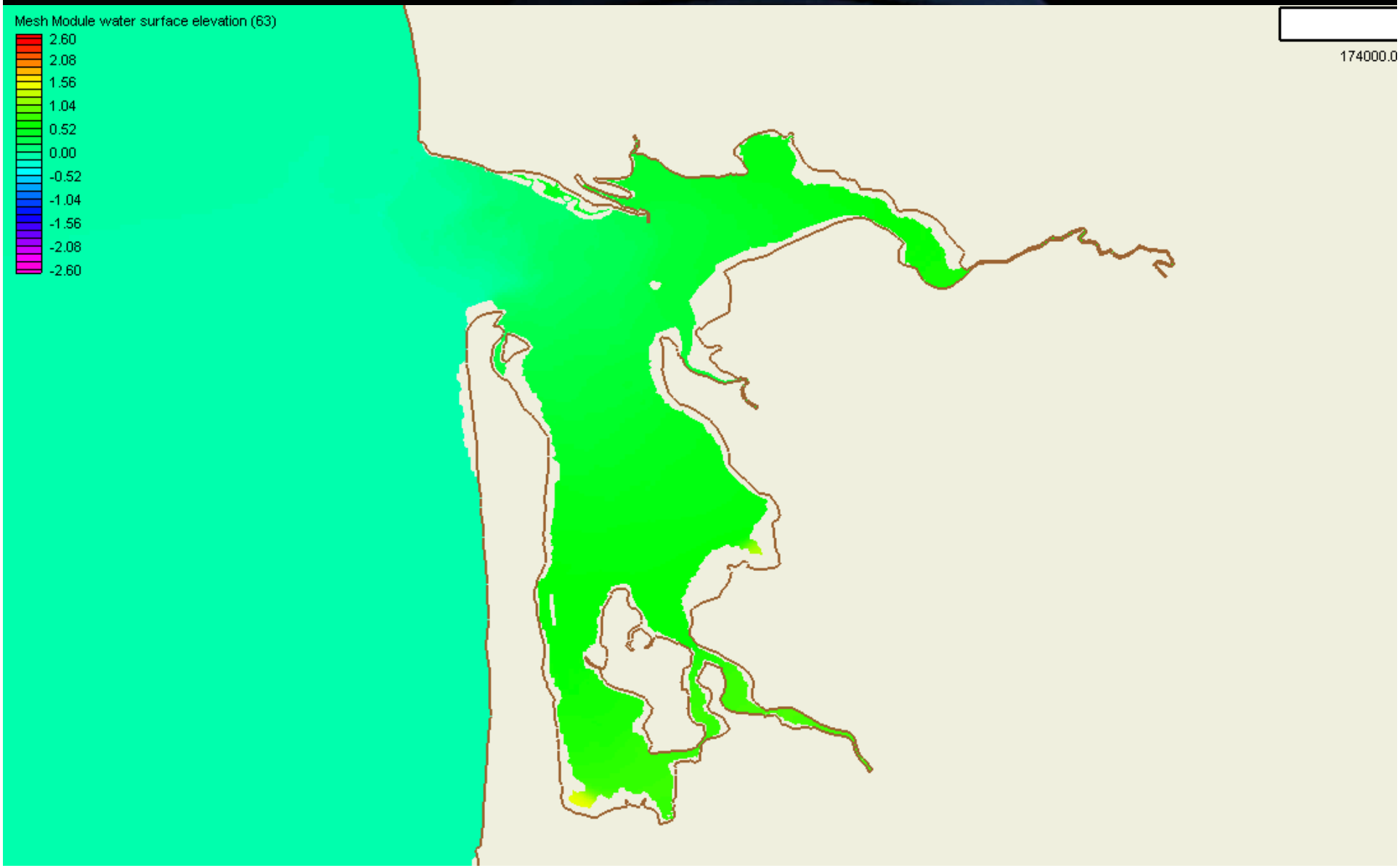
ADCIRC Overview

- Algorithmic design criteria
  - Very low numerical damping model allows model parameters to be based on physically relevant values
  - At least second order accurate
  - Robust
  - Operates efficiently in parallel to solve large unstructured grids (linear speed up or better on 256+ processors)
- ADCIRC has evolved into a multi-algorithmic code
  - Applies traditional Continuous Galerkin (CG) based algorithms
  - Applies new Discontinuous Galerkin (DG) based algorithms


Elevation
3.00
2.60
2.20
1.80
1.40
1.00
0.60
0.20
-0.20
-0.60
-1.00
-1.40
-1.80
-2.20
-2.60
-3.00
2.94 ft/s
0.00 ft/s

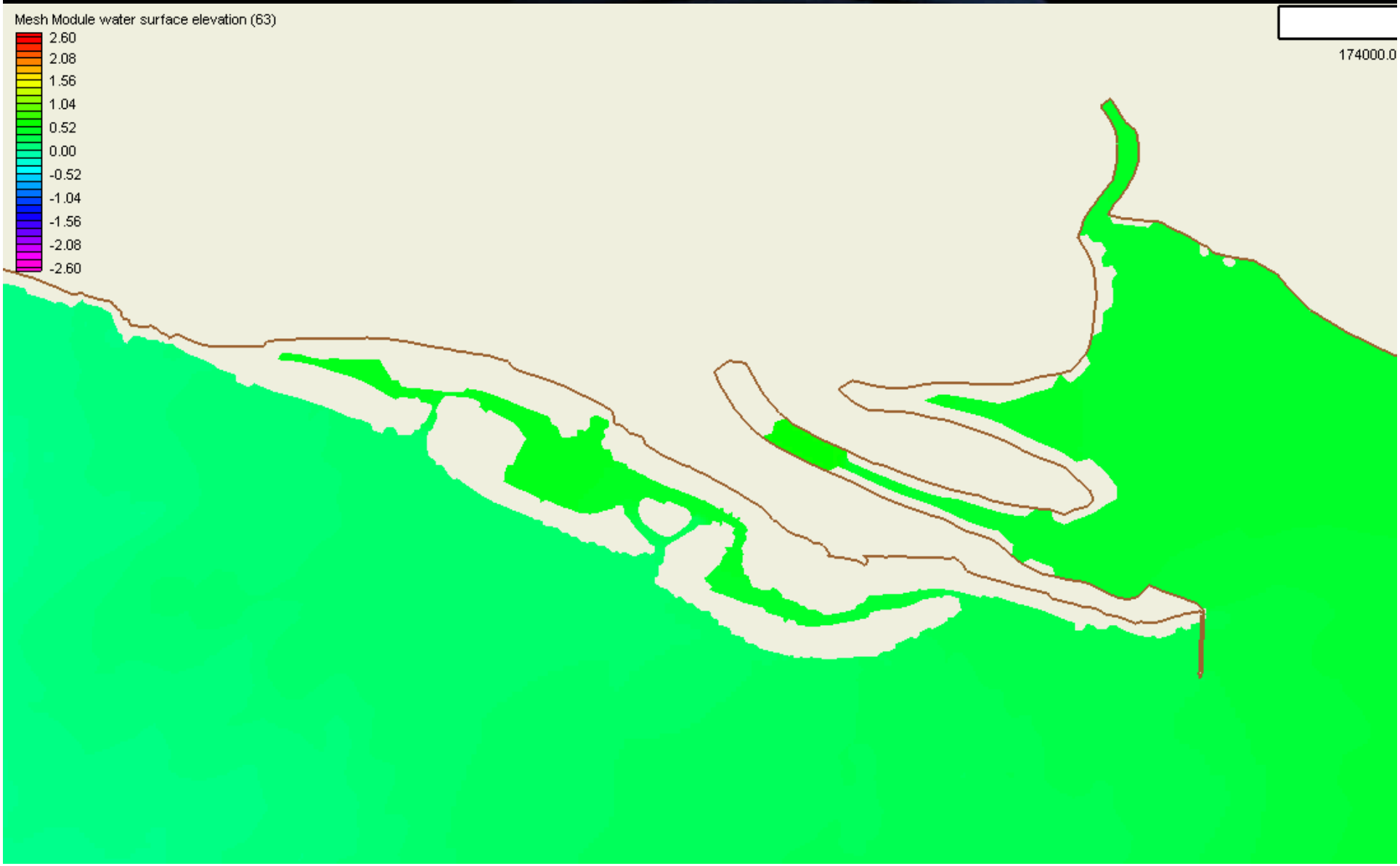
Courtesy D. Mark, USACE

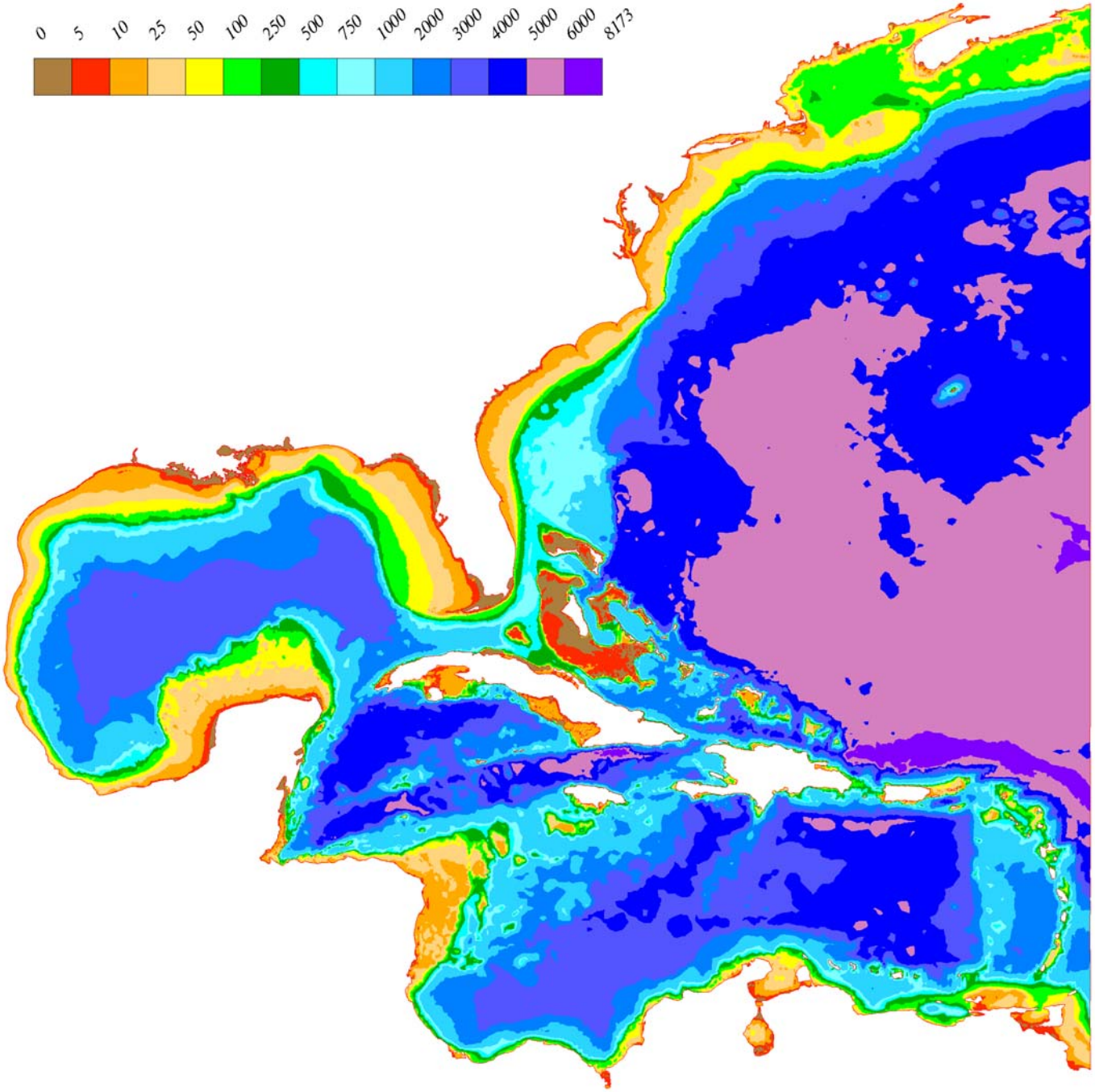
Willapa Bay – CG Solution

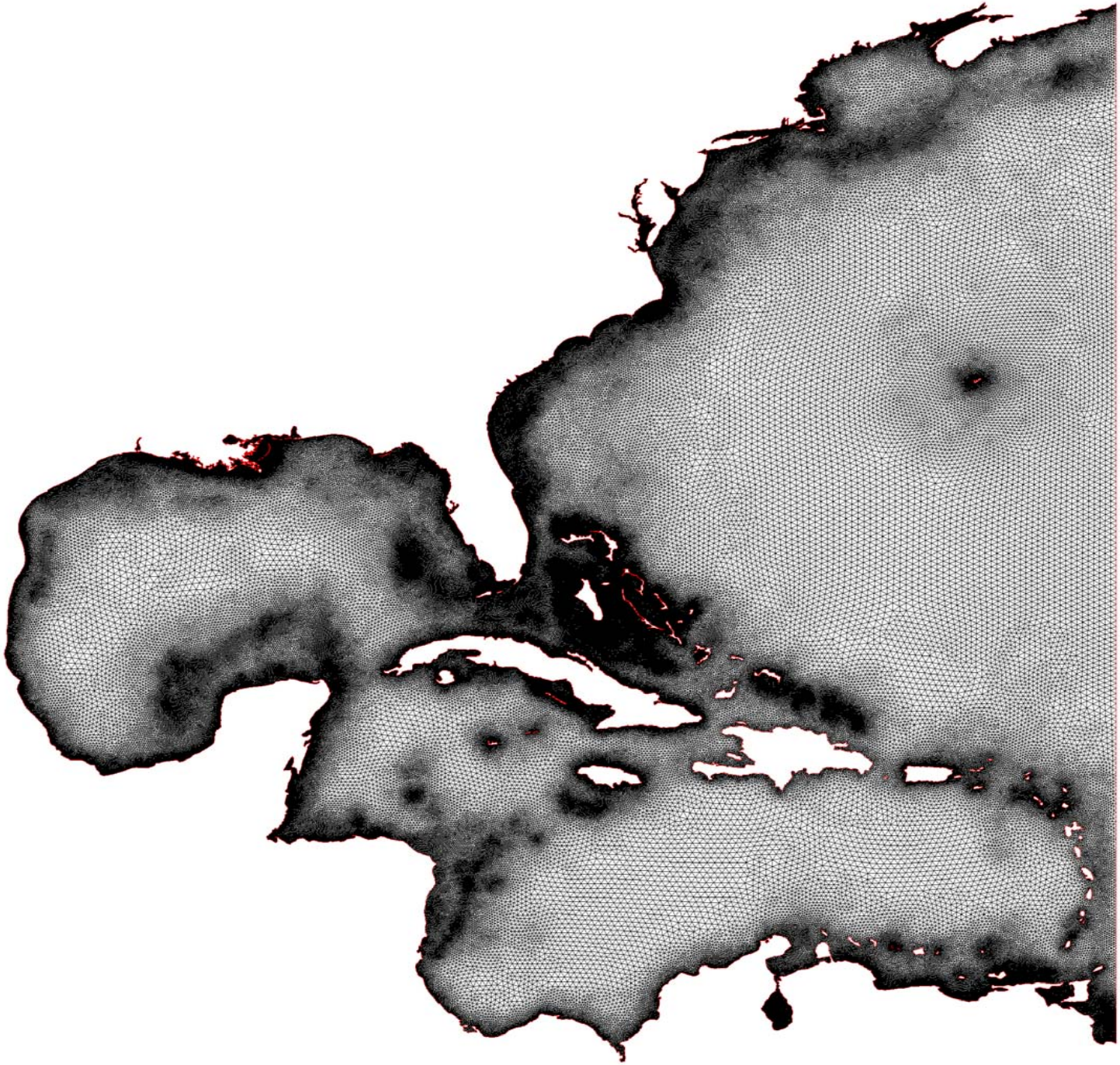


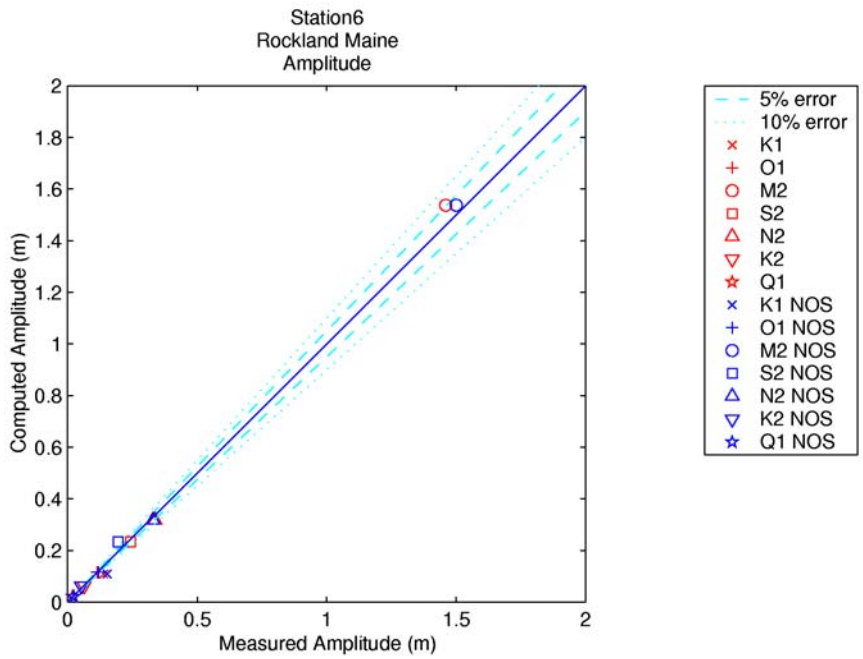
Courtesy D. Mark, USACE

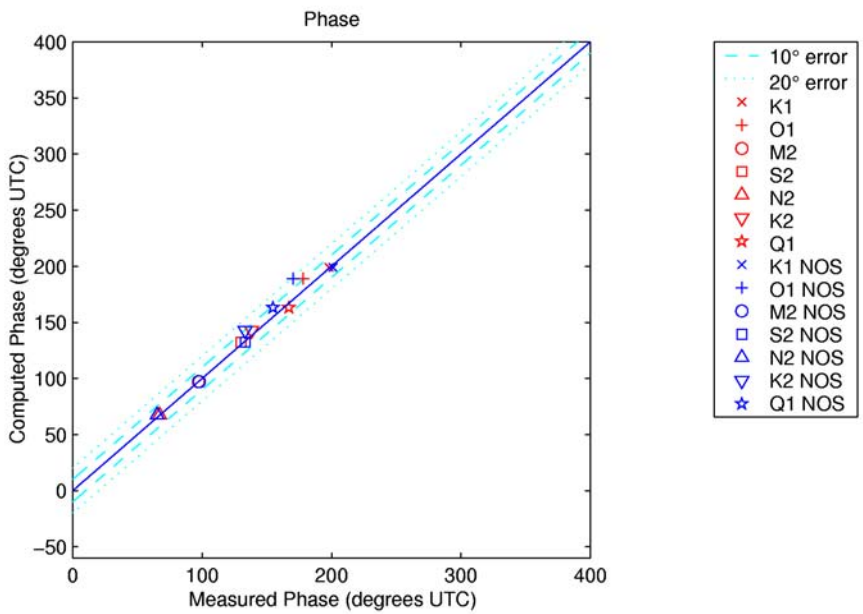
Willapa Bay – CG Solution

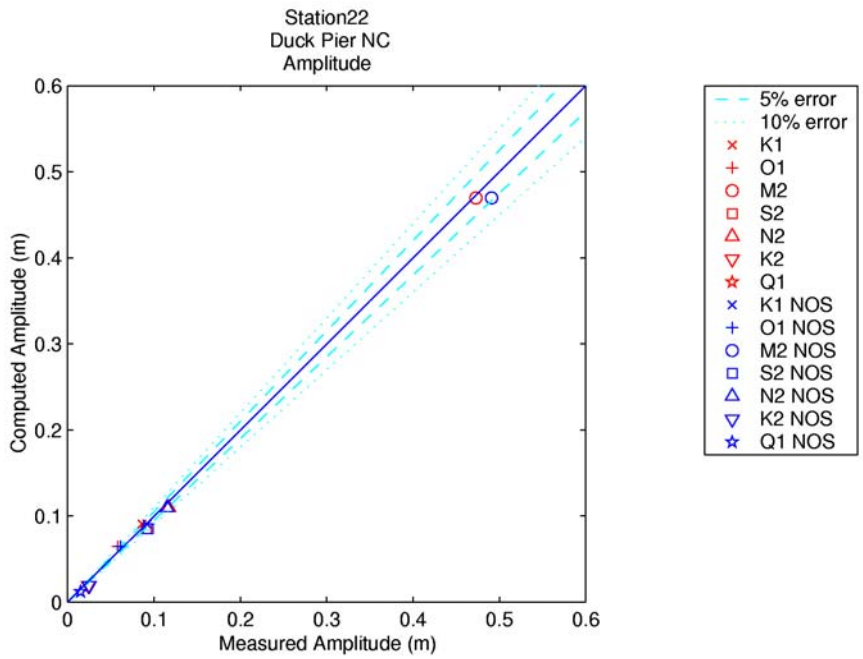


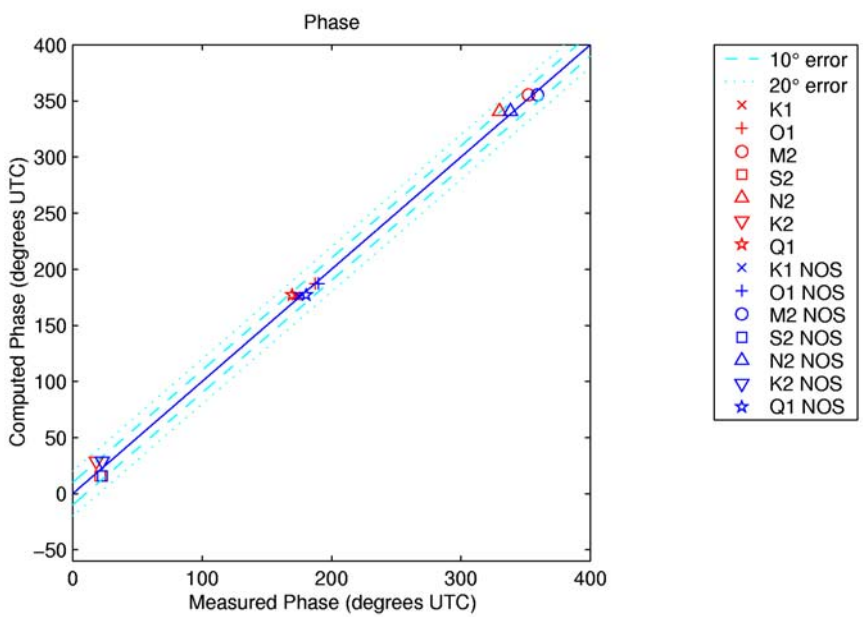

0
5
10
25
50
100
250
500
750
1000
2000
3000
4000
5000
6000
8173

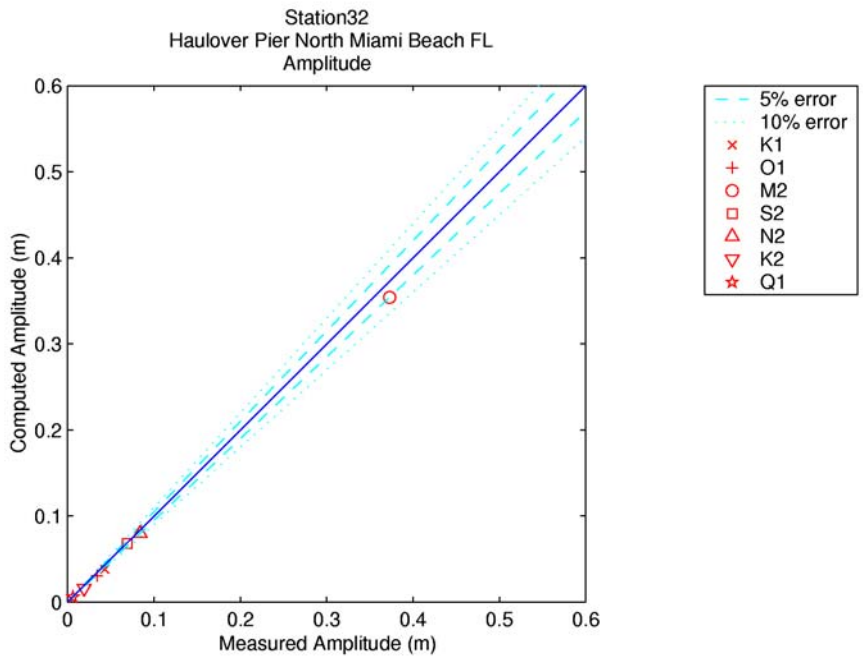


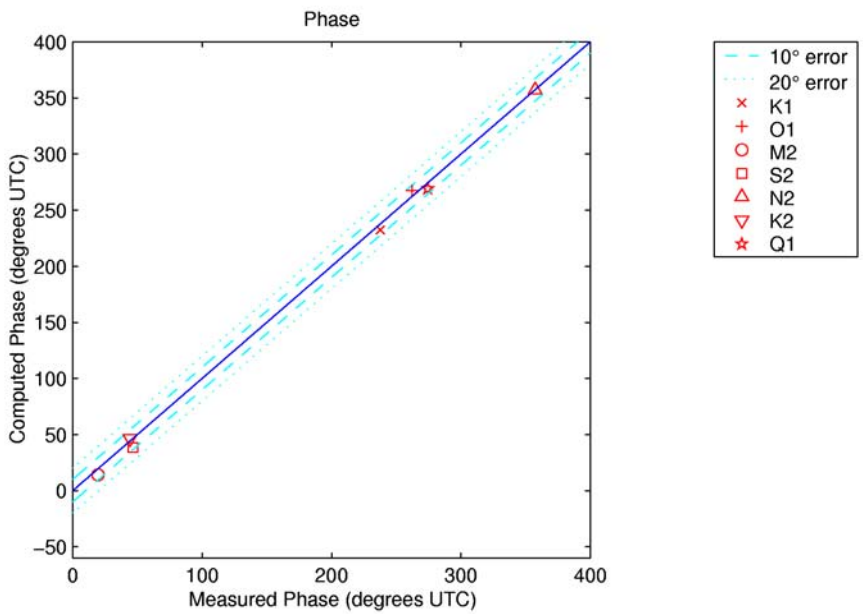

Station6
Rockland Maine
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
0.5
1
1.5
2
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1
K1 NOS
O1 NOS
M2 NOS
S2 NOS
N2 NOS
K2 NOS
Q1 NOS

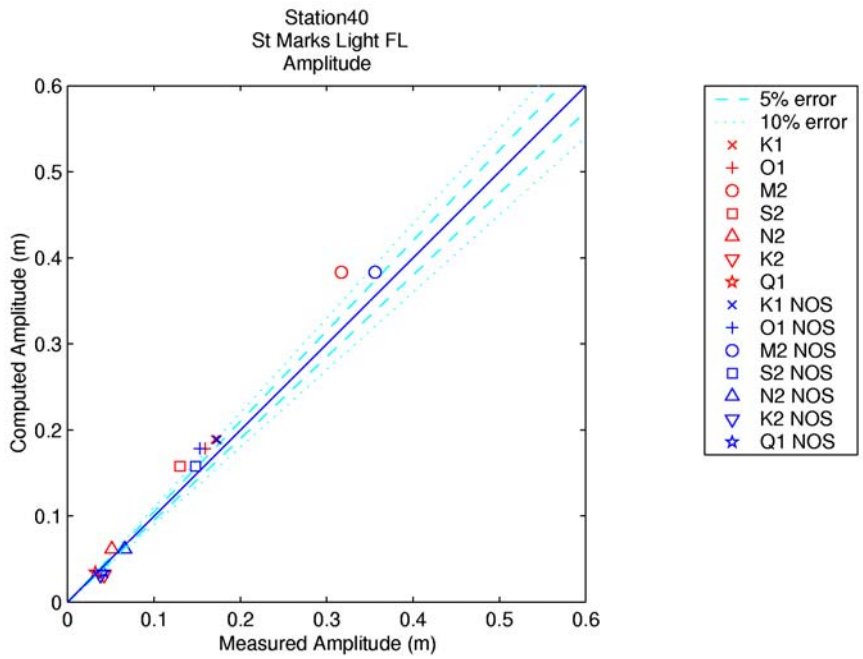

Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
0
100
200
300
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1
K1 NOS
O1 NOS
M2 NOS
S2 NOS
N2 NOS
K2 NOS
Q1 NOS

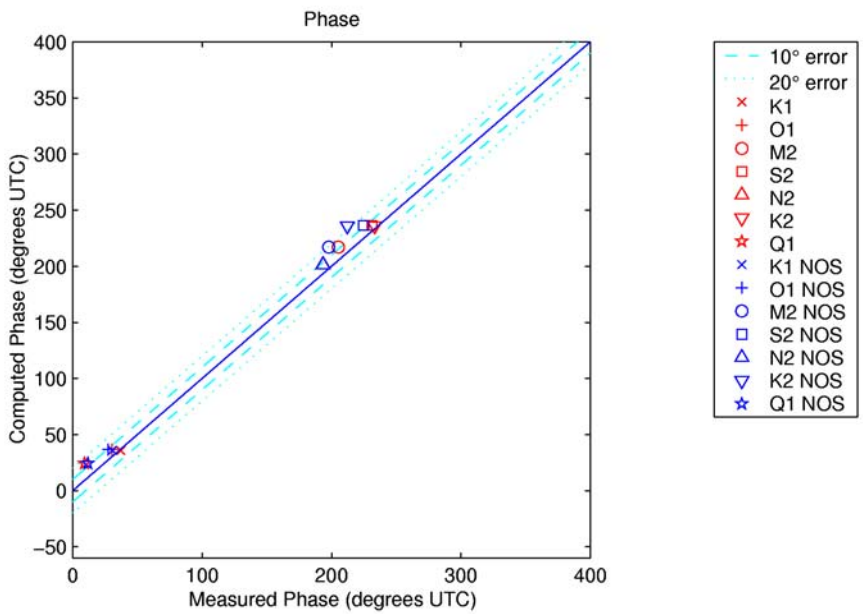

Station22
Duck Pier NC
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1
K1 NOS
O1 NOS
M2 NOS
S2 NOS
N2 NOS
K2 NOS
Q1 NOS

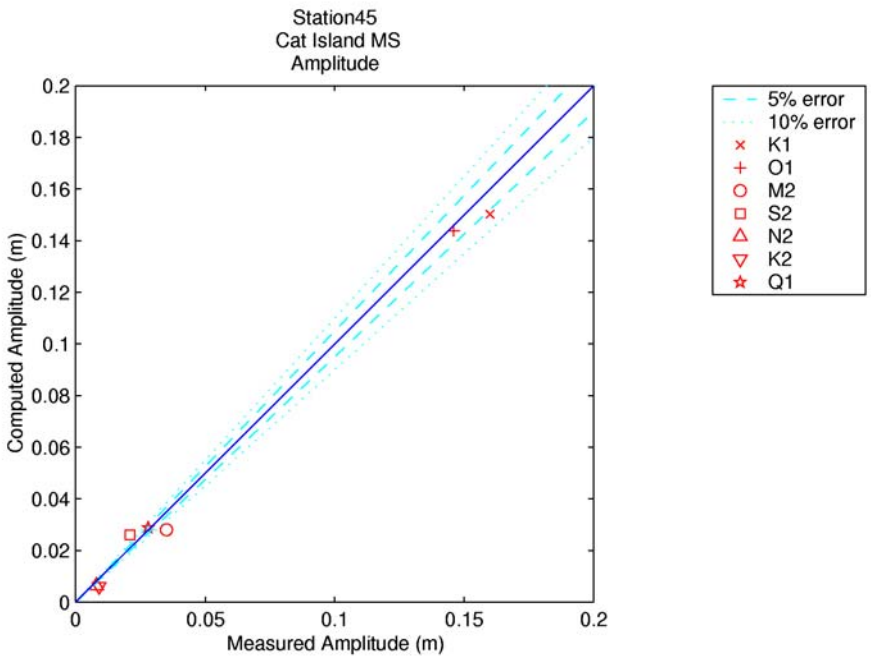

Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1
K1 NOS
O1 NOS
M2 NOS
S2 NOS
N2 NOS
K2 NOS
Q1 NOS

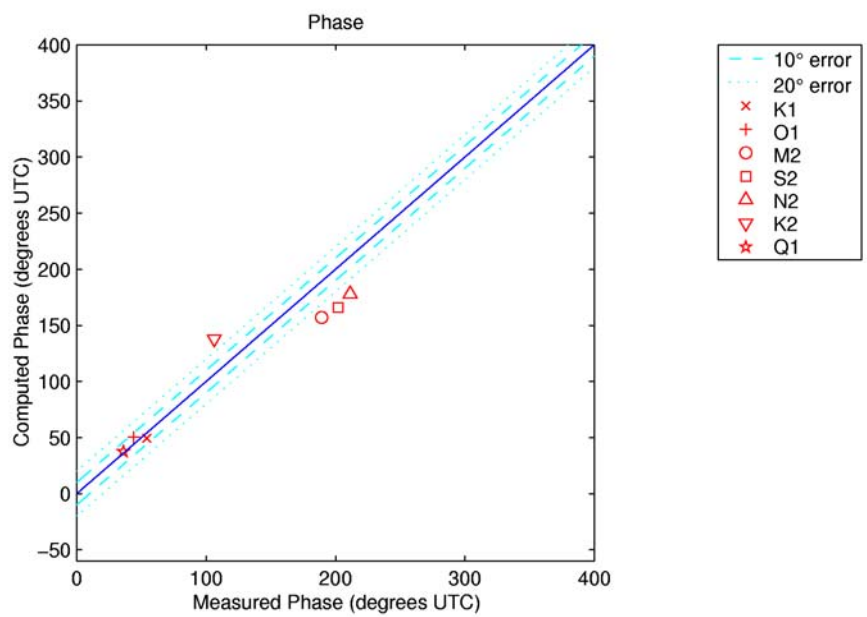

Station32
Haulover Pier North Miami Beach FL
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1

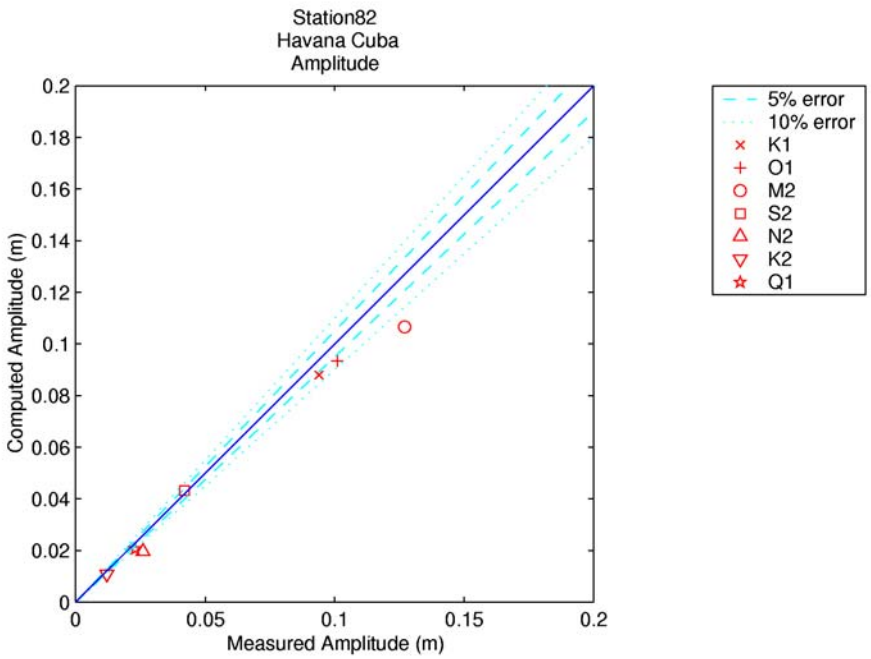

Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1

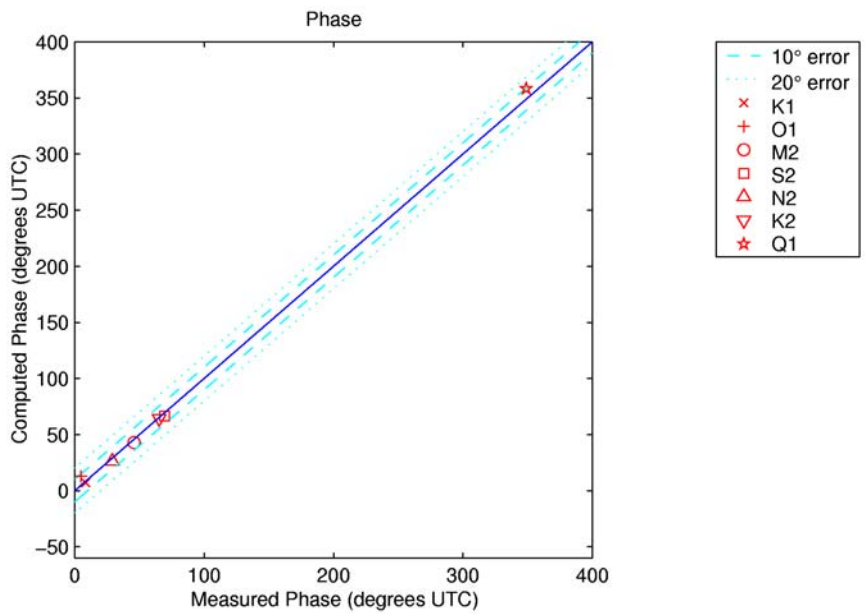

Station40
St Marks Light FL
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1
K1 NOS
O1 NOS
M2 NOS
S2 NOS
N2 NOS
K2 NOS
Q1 NOS

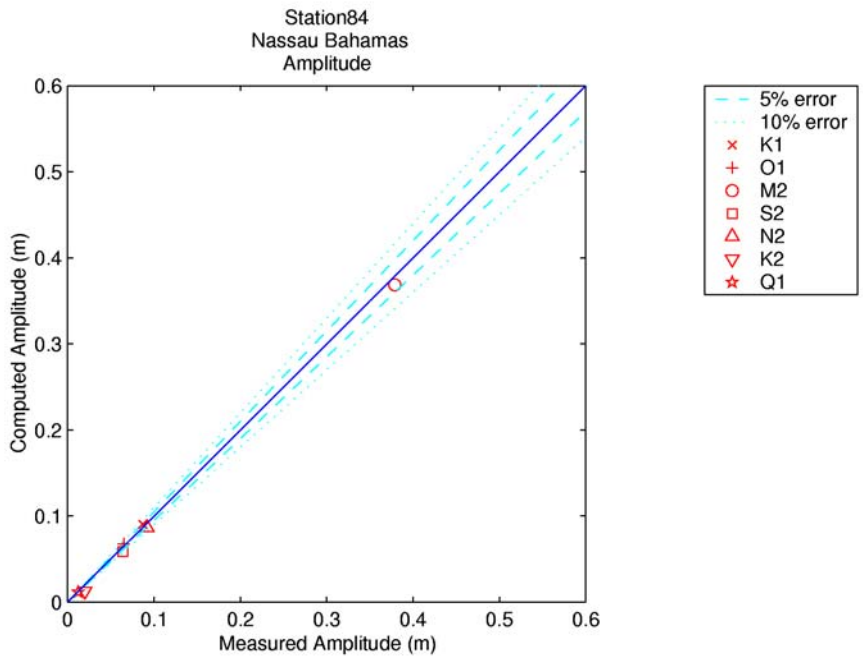

Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1
K1 NOS
O1 NOS
M2 NOS
S2 NOS
N2 NOS
K2 NOS
Q1 NOS

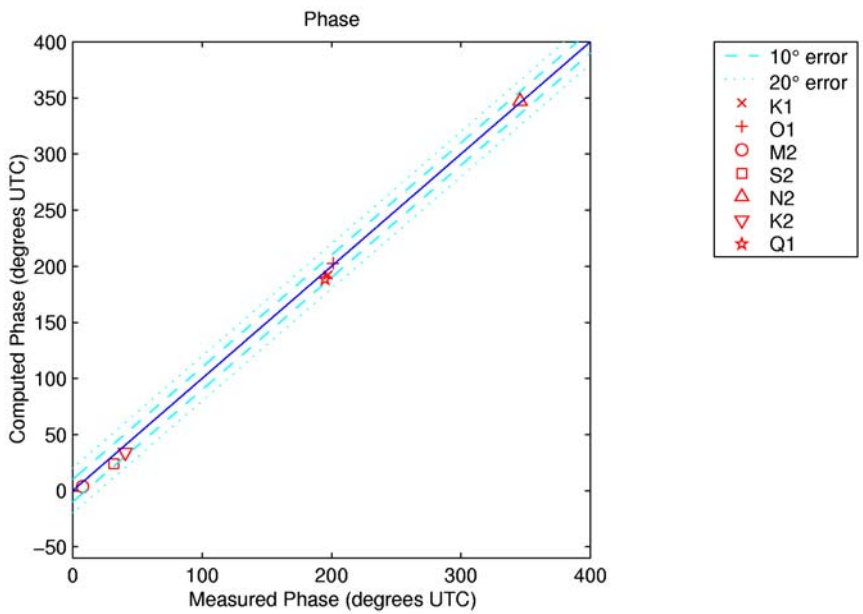

Station45
Cat Island MS
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
0.05
0.1
0.15
0.2
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1


Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
0
100
200
300
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1


Station82
Havana Cuba
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
0.05
0.1
0.15
0.2
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1

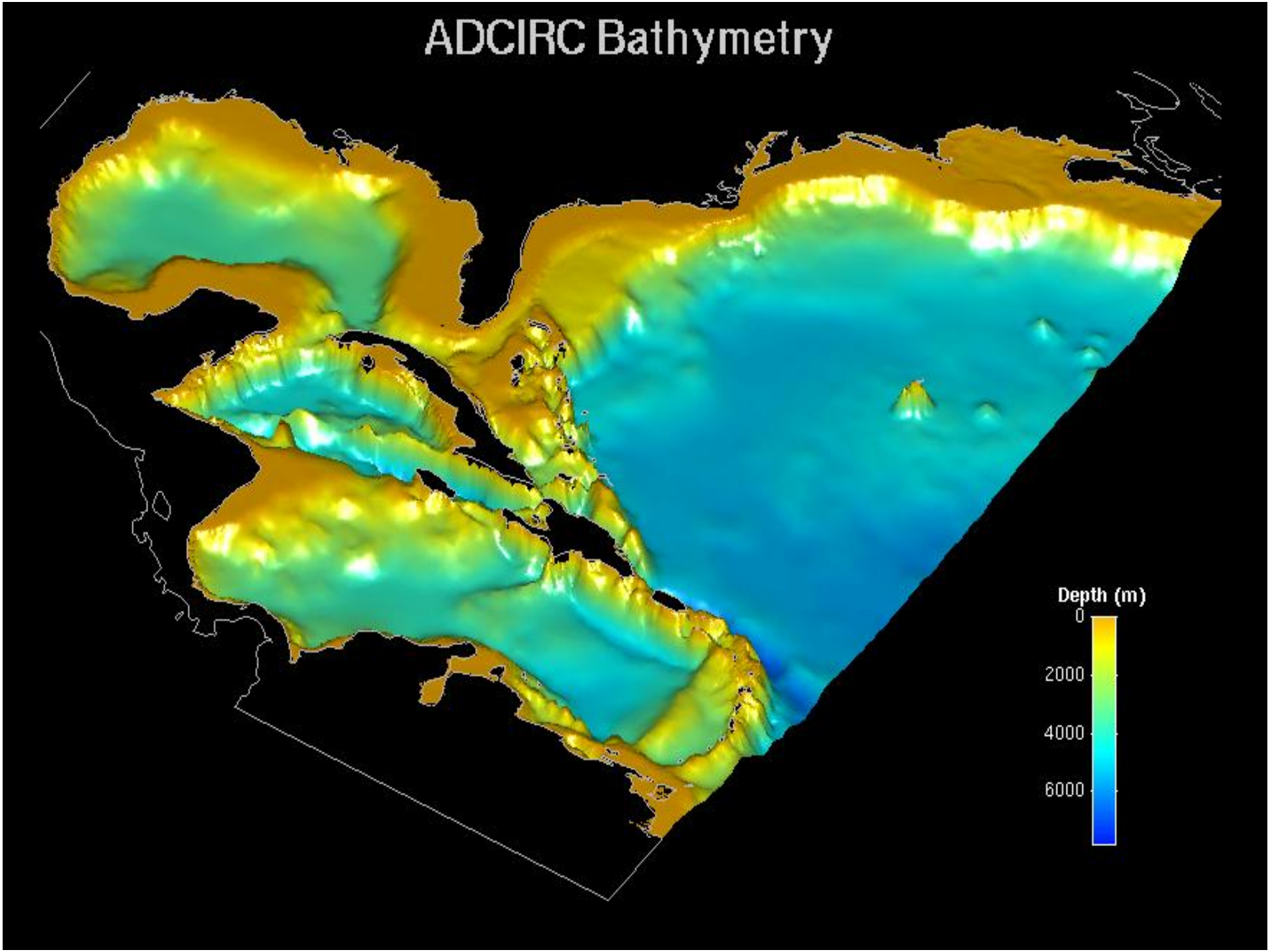

Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
0
100
200
300
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1

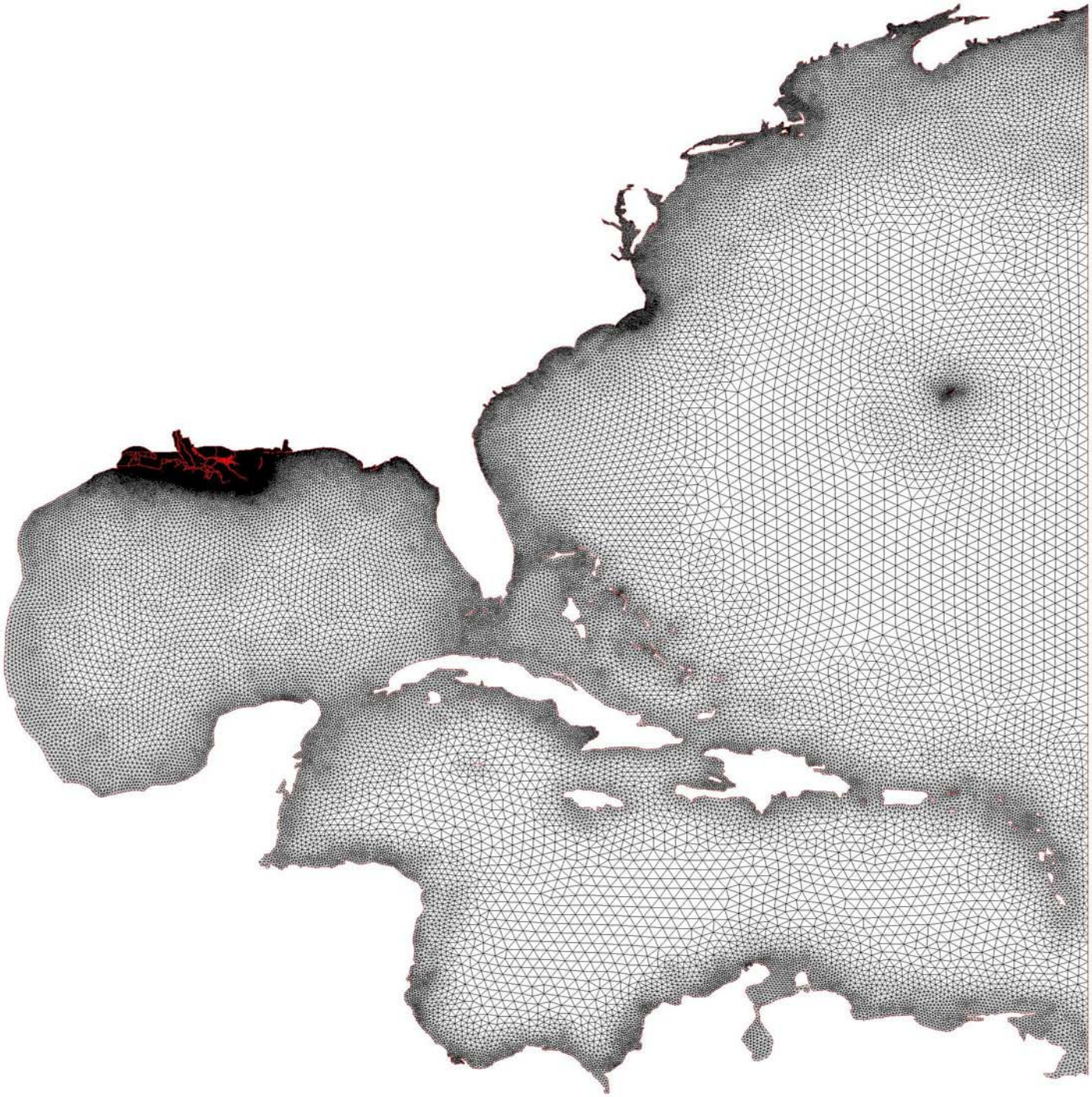

Station84
Nassau Bahamas
Amplitude
Computed Amplitude (m)
Measured Amplitude (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
5% error
10% error
K1
O1
M2
S2
N2
K2
Q1

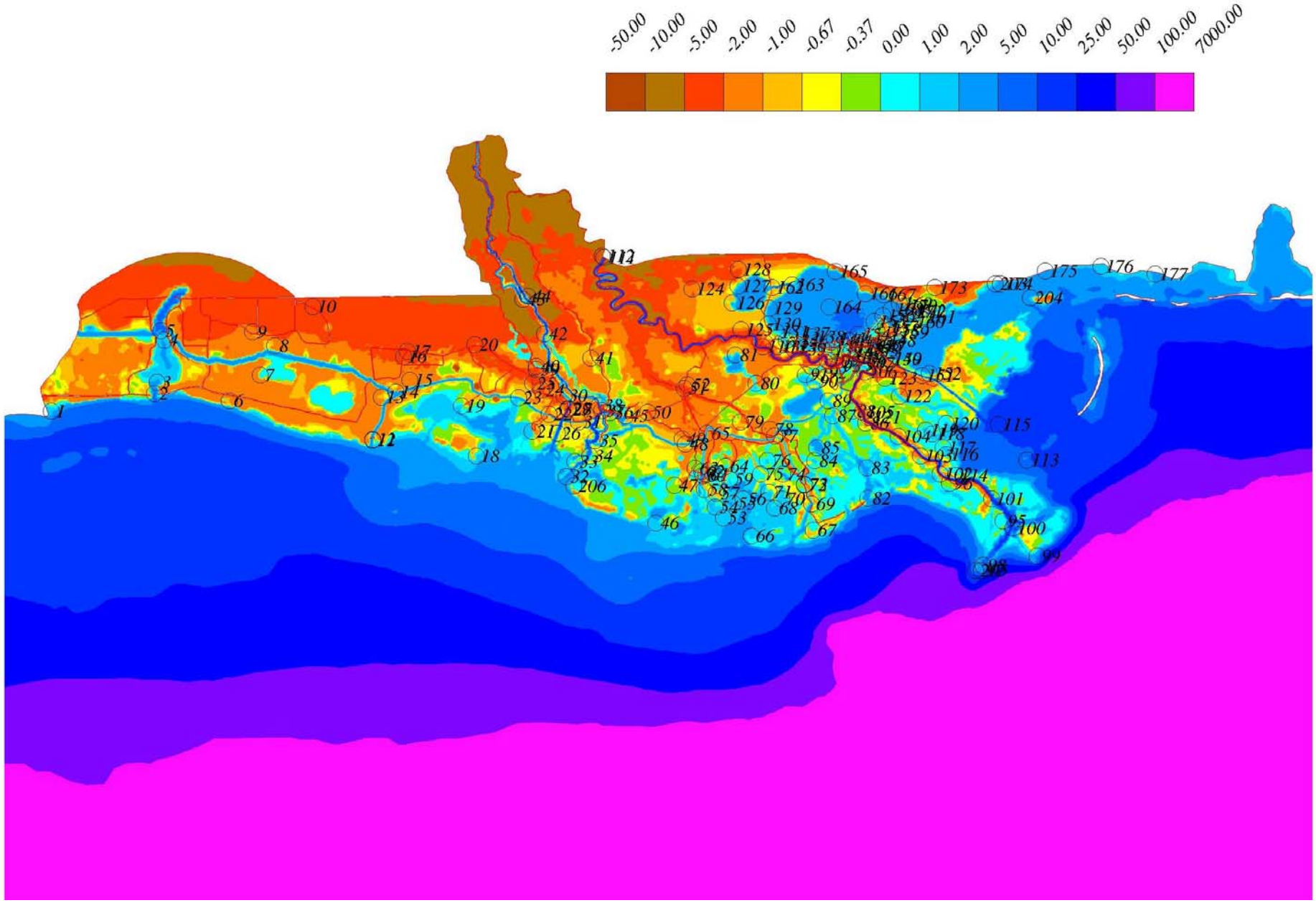

Phase
Computed Phase (degrees UTC)
Measured Phase (degrees UTC)
−50
0
50
100
150
200
250
300
350
400
10° error
20° error
K1
O1
M2
S2
N2
K2
Q1

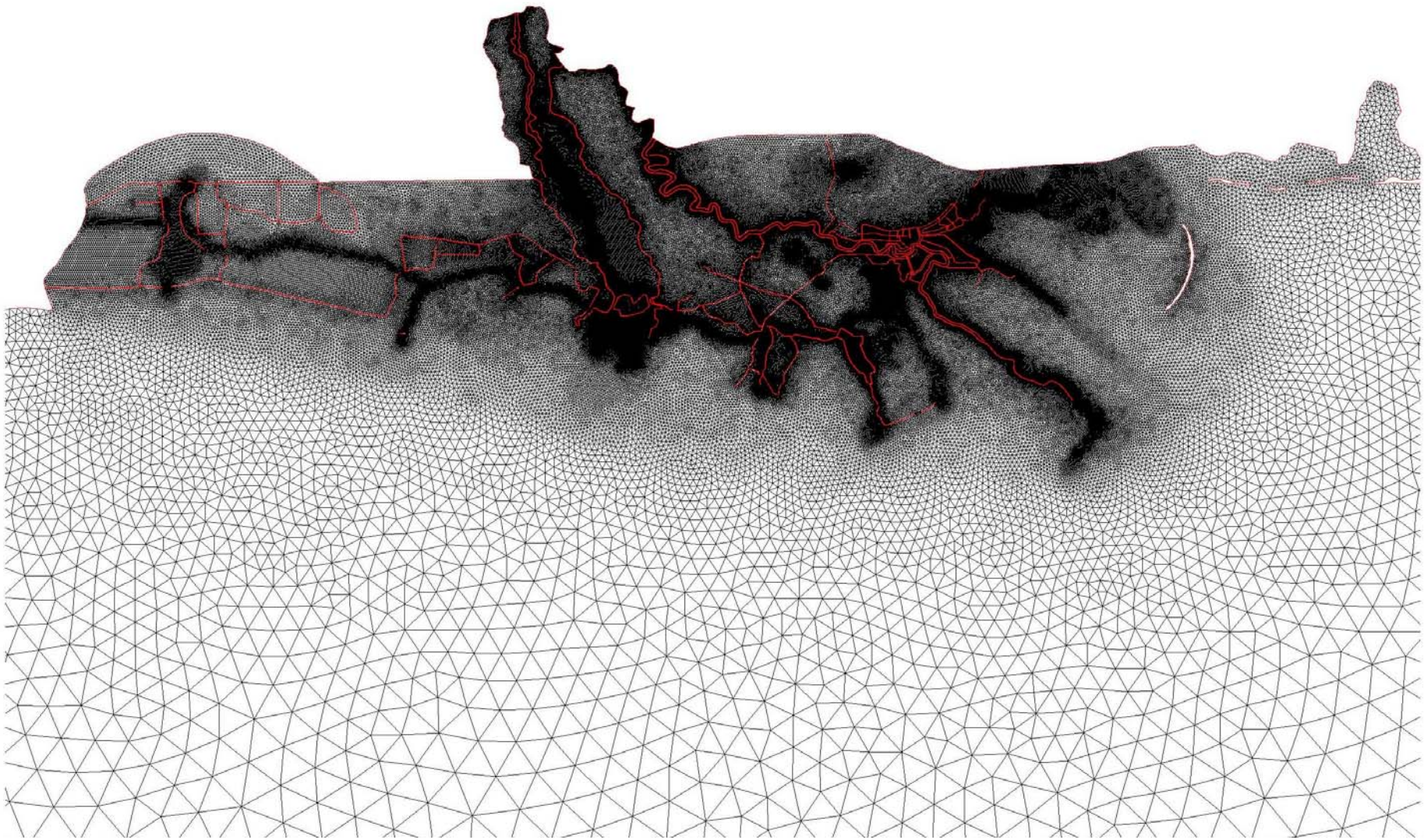
Hurricane Storm Surge Modeling in Southern Louisiana – S08 Model

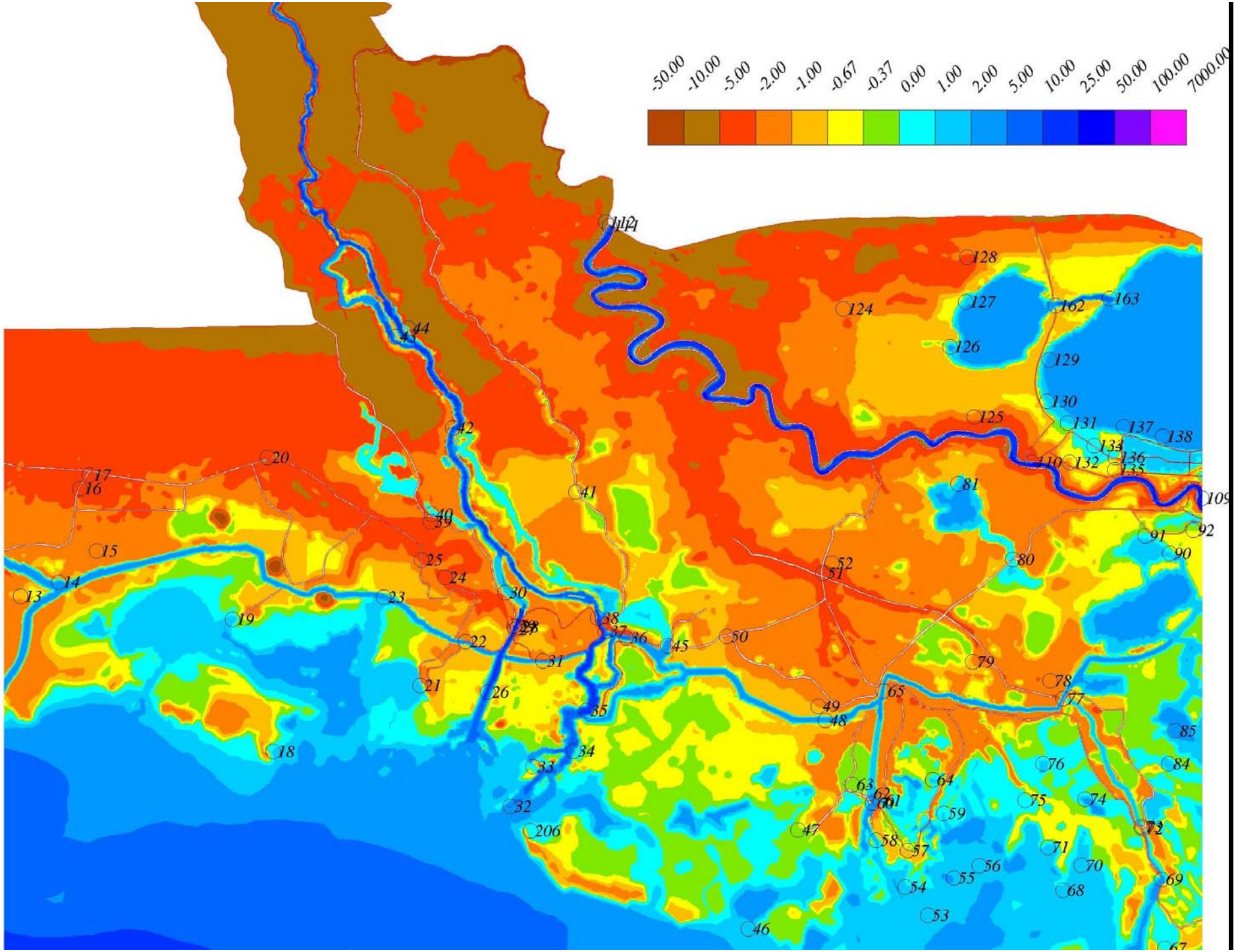
- Application of large computational domain
- Model domain incorporates the western North Atlantic, Gulf of Mexico and Caribbean Sea
- The large domain strategy correctly captures:
  - Basin to basin interactions
  - Basin to shelf dynamics
  - Shelf to adjacent coast/floodplain dynamics
  - Control structure and channel influence on flood propagation
- The large domain strategy significantly simplifies the specification of boundary conditions by selecting hydrodynamically simple boundaries and resolves the local scales of importance

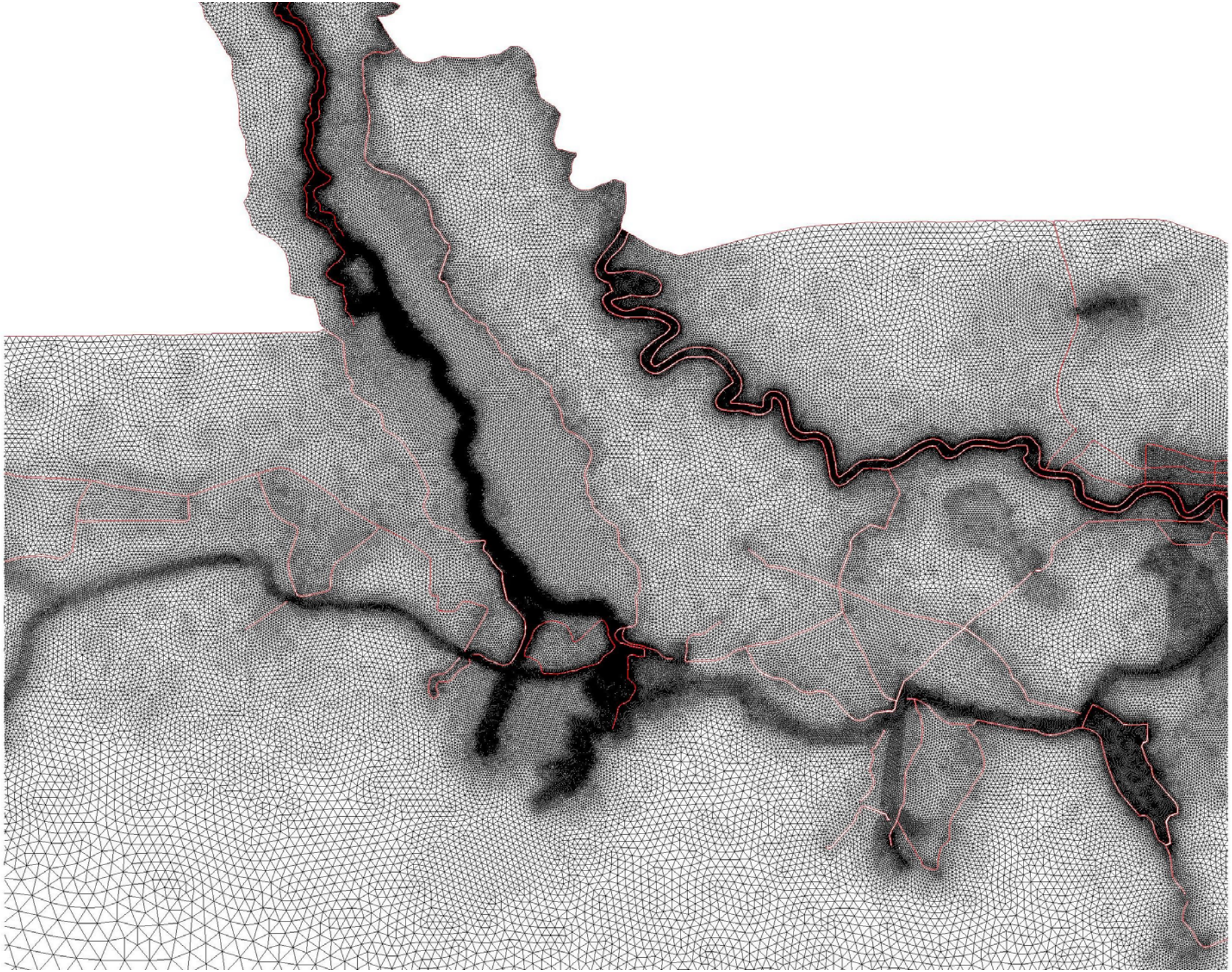

ADCIRC Bathymetry
Depth (m)
0
2000
4000
6000

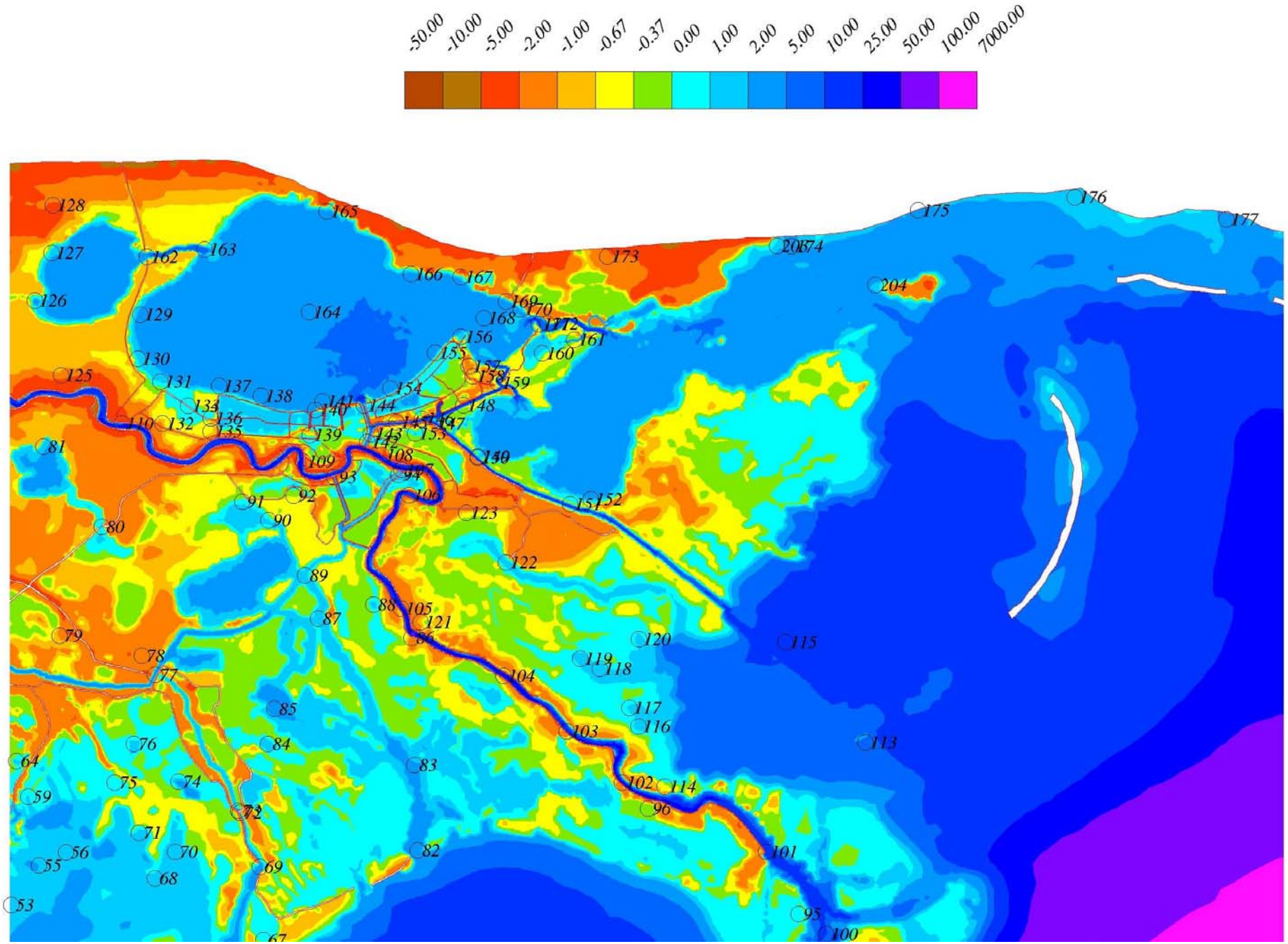


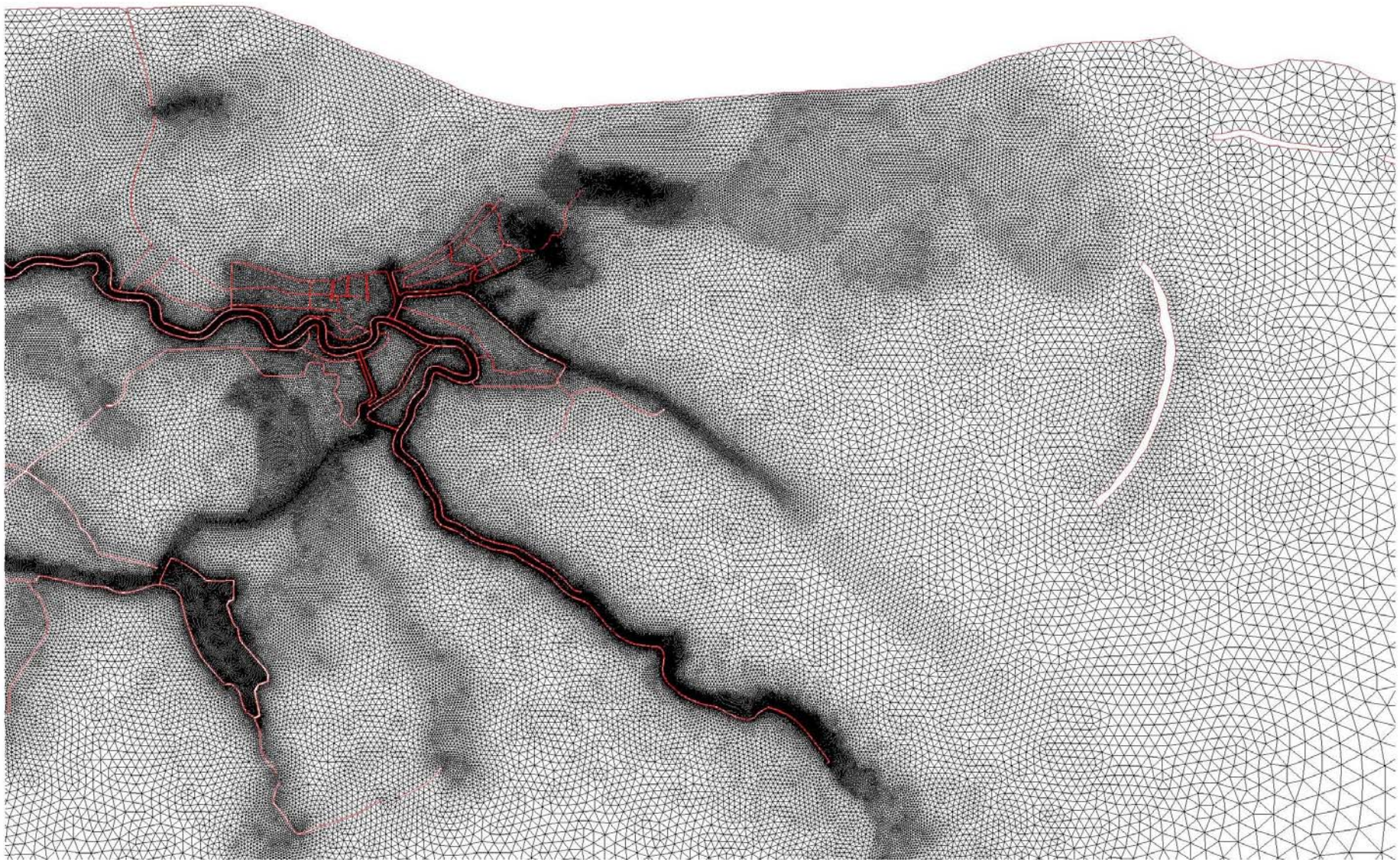

-50.00
-10.00
-5.00
-2.00
-1.00
-0.67
-0.37
0.00
1.00
2.00
5.00
10.00
25.00
50.00
100.00
7000.00

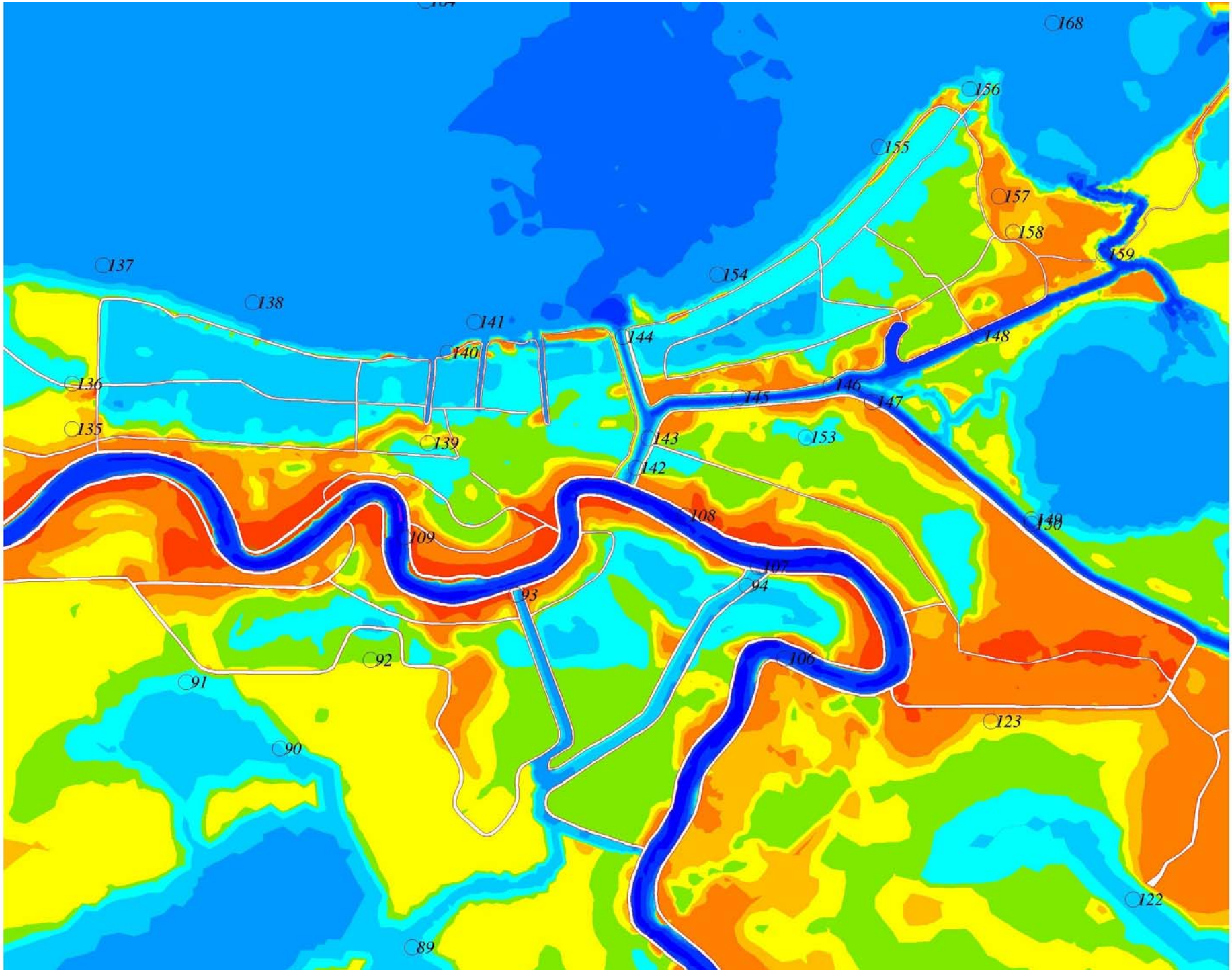


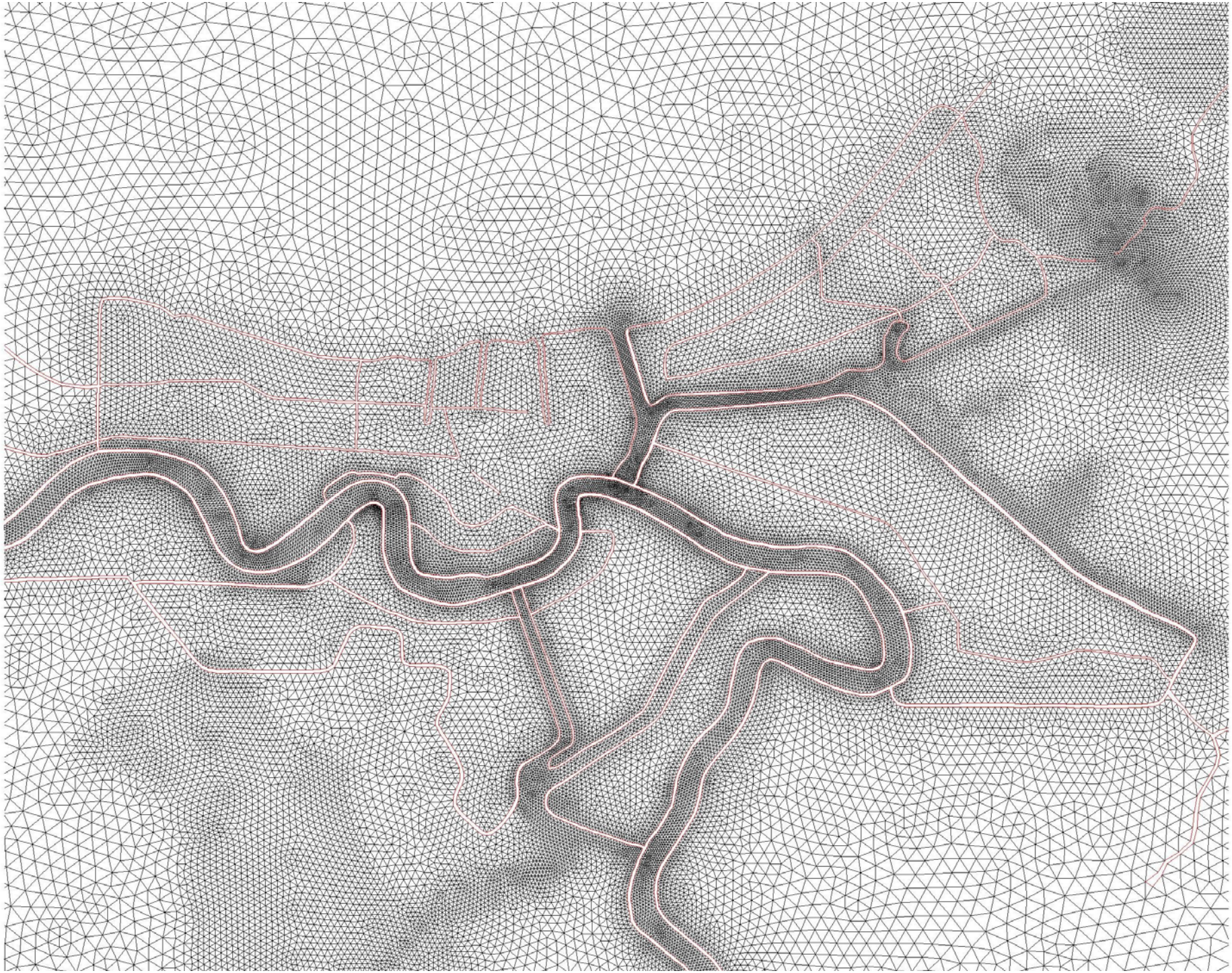

-50.00
-10.00
-5.00
-2.00
-1.00
-0.67
-0.37
0.00
1.00
2.00
5.00
10.00
25.00
50.00
100.00
7000.00




-50.00
-10.00
-5.00
-2.00
-1.00
-0.67
-0.37
0.00
1.00
2.00
5.00
10.00
25.00
50.00
100.00
7000.00

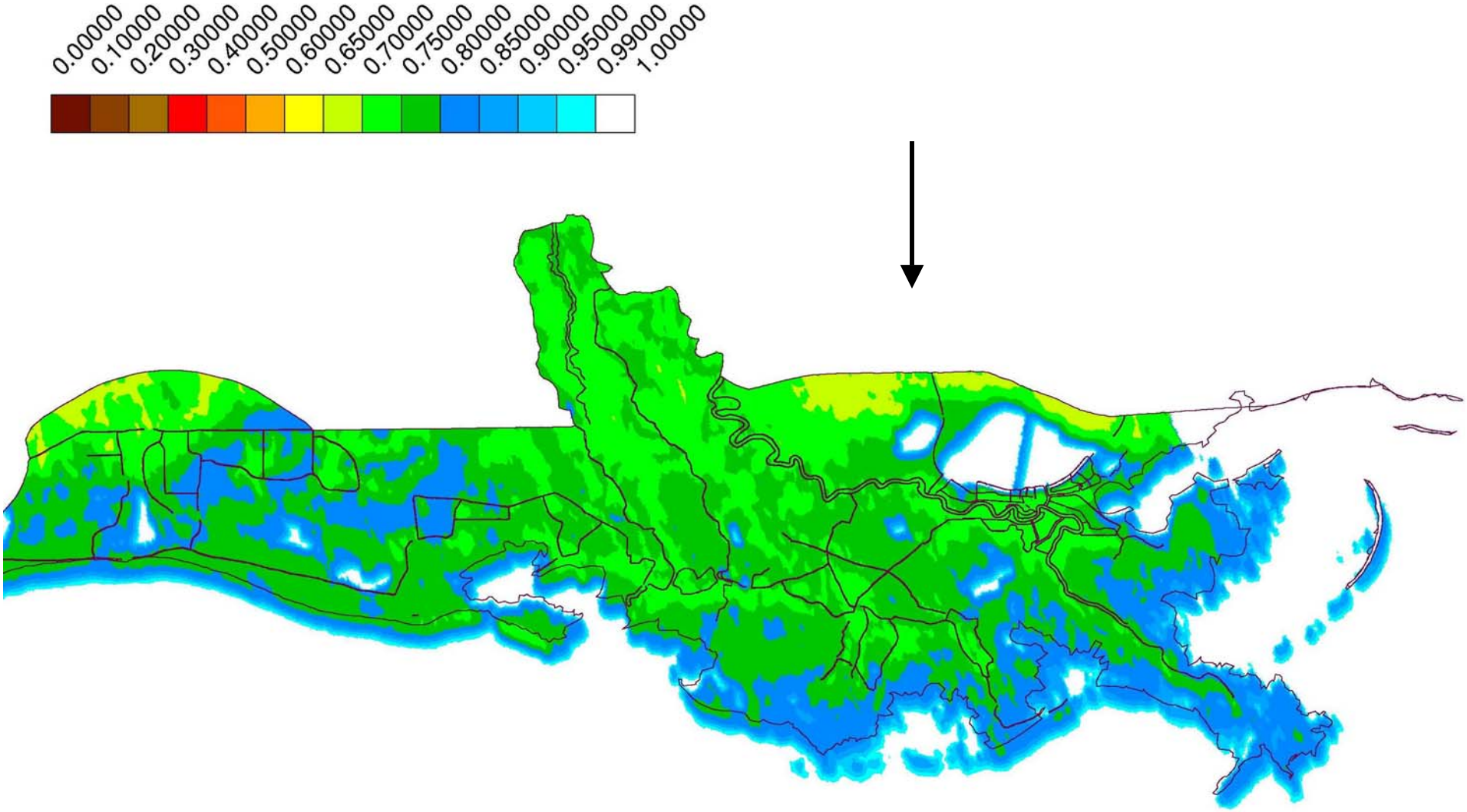


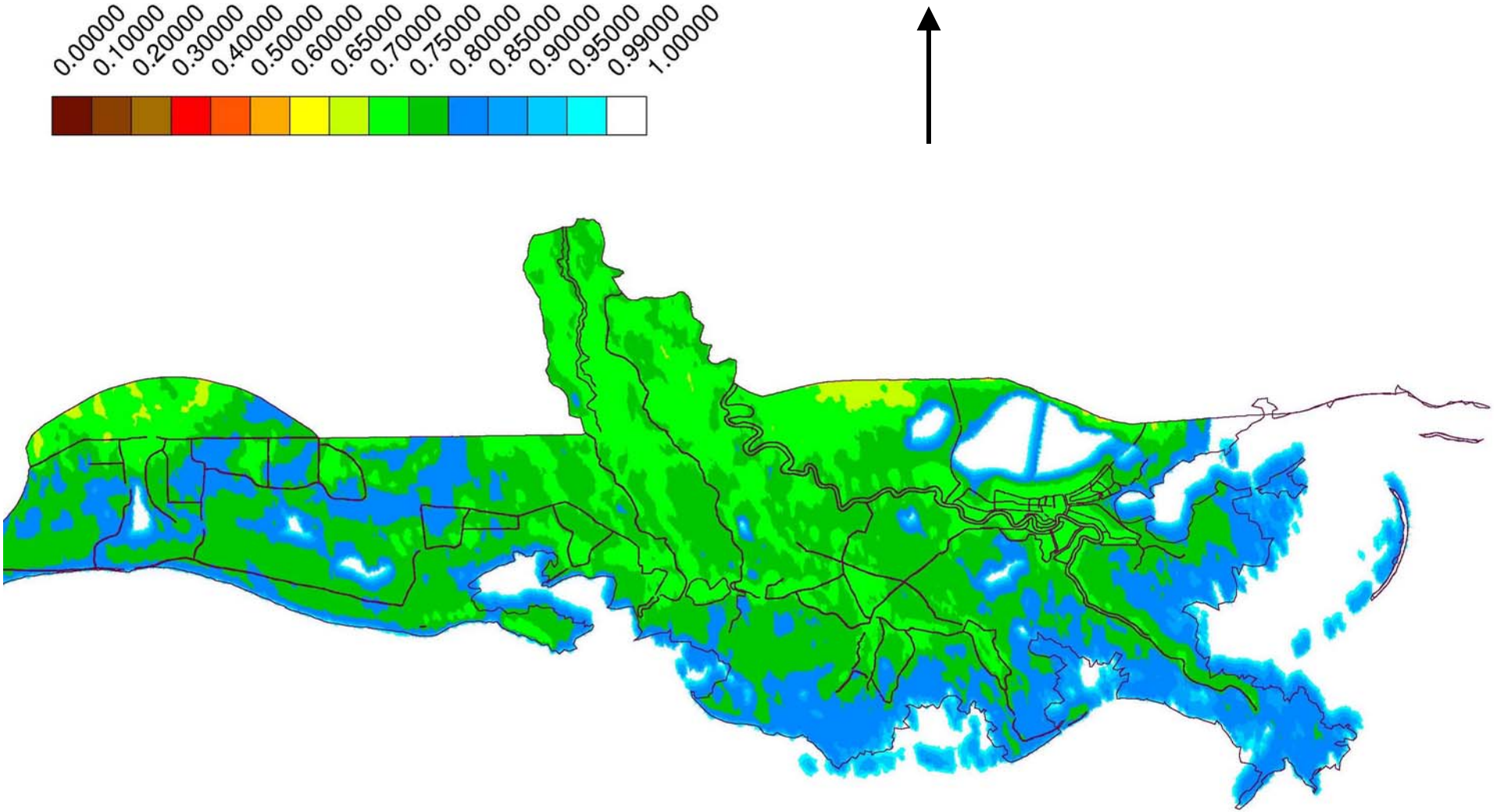

168
156
155
157
158
159
137
154
138
141
144
148
140
136
146
145
147
135
139
143
153
142
108
149
150
109
107
94
93
92
106
91
123
90
122
89



ADCIRC Physical Details

- Improvements in winds by incorporating directional land roughness to adjust the overland/near-shore wind boundary layer
- Incorporation of canopies where winds are zeroed due to loss of momentum propagating through the canopy.
- Dynamic wind drag coefficient variation between land and sea values as region becomes inundated.


0.00000
0.10000
0.20000
0.30000
0.40000
0.50000
0.60000
0.65000
0.70000
0.75000
0.80000
0.85000
0.90000
0.95000
0.99000
1.00000

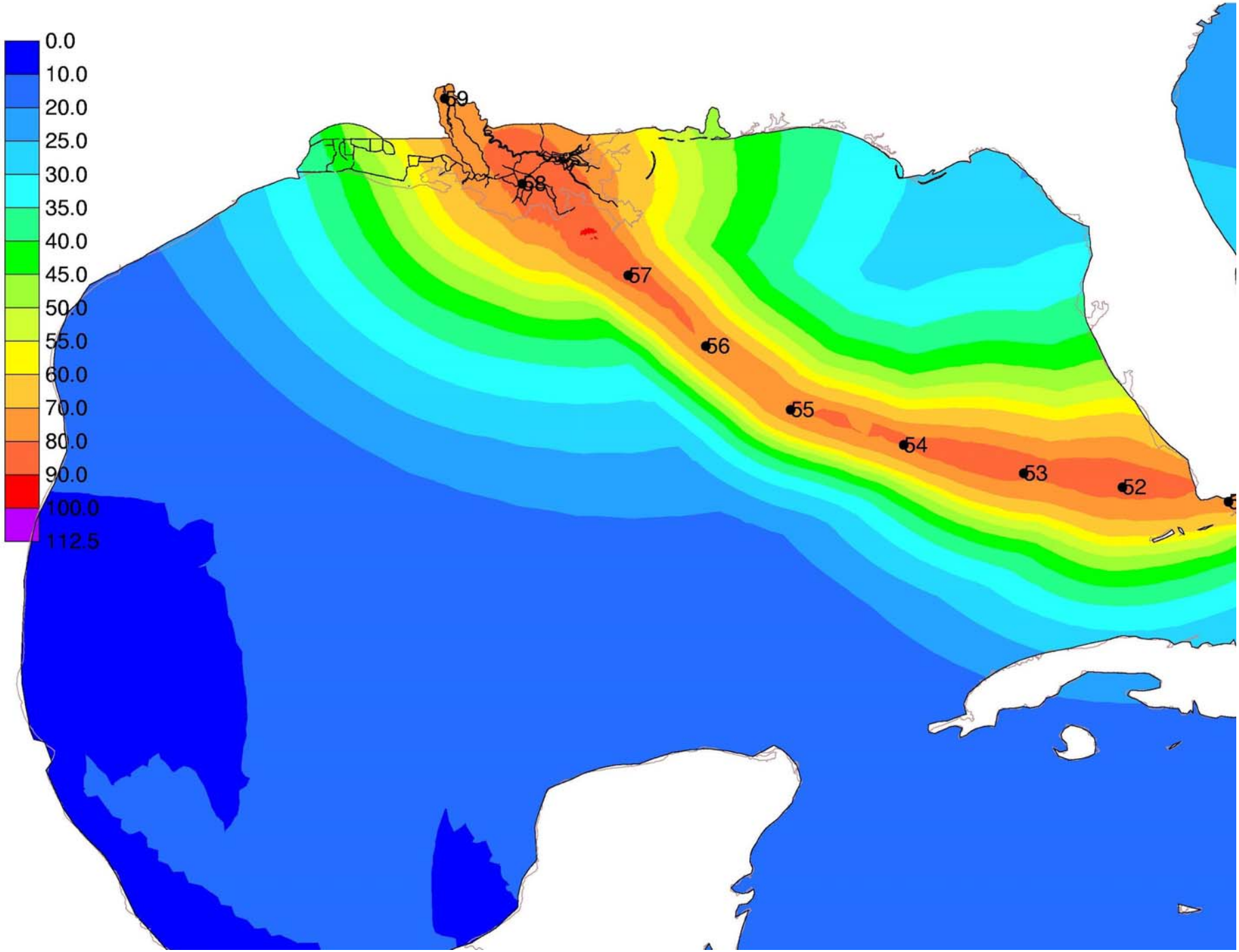

0.00000
0.10000
0.20000
0.30000
0.40000
0.50000
0.60000
0.65000
0.70000
0.75000
0.80000
0.85000
0.90000
0.95000
0.99000
1.00000

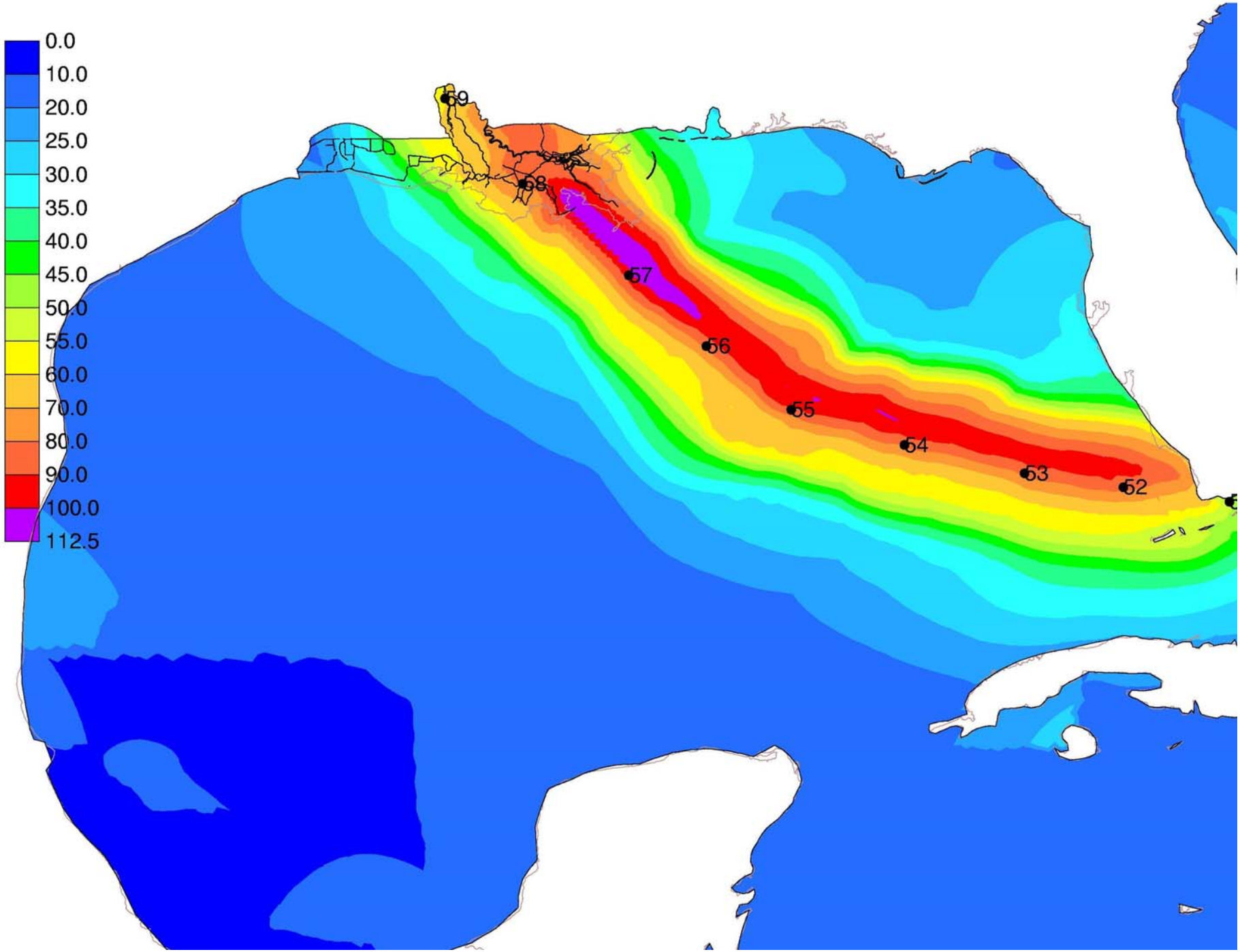
ADCIRC Physical Details

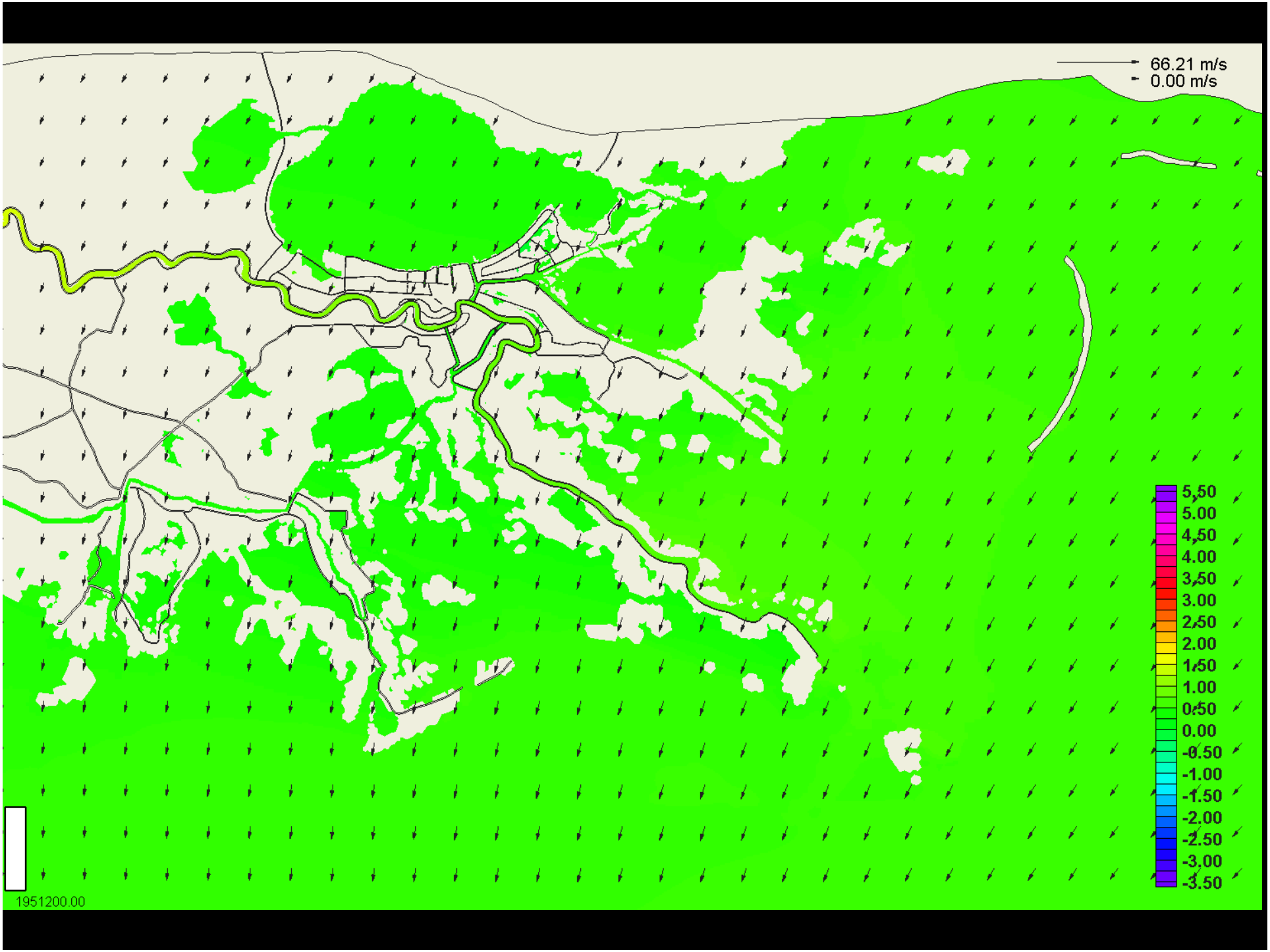
- Lagrangian tracking to ensure that no artificial weakening of the storm occurs.
  - This is especially important if the storm is fast moving or if there are large time periods between the wind snaps
- Applying both the PBL wind model and the HRD H*WIND data assimilation based Nowcast system
  - PBL winds are based on track, pressure deficit, forward speed and maximum wind speed. Many assumptions and average hurricane characteristics are used which may oversimplify a given storm. The PBL model can produce good results.
  - H*WIND data assimilation code incorporates hundreds of measurements and other indicators to simulate winds as they were.

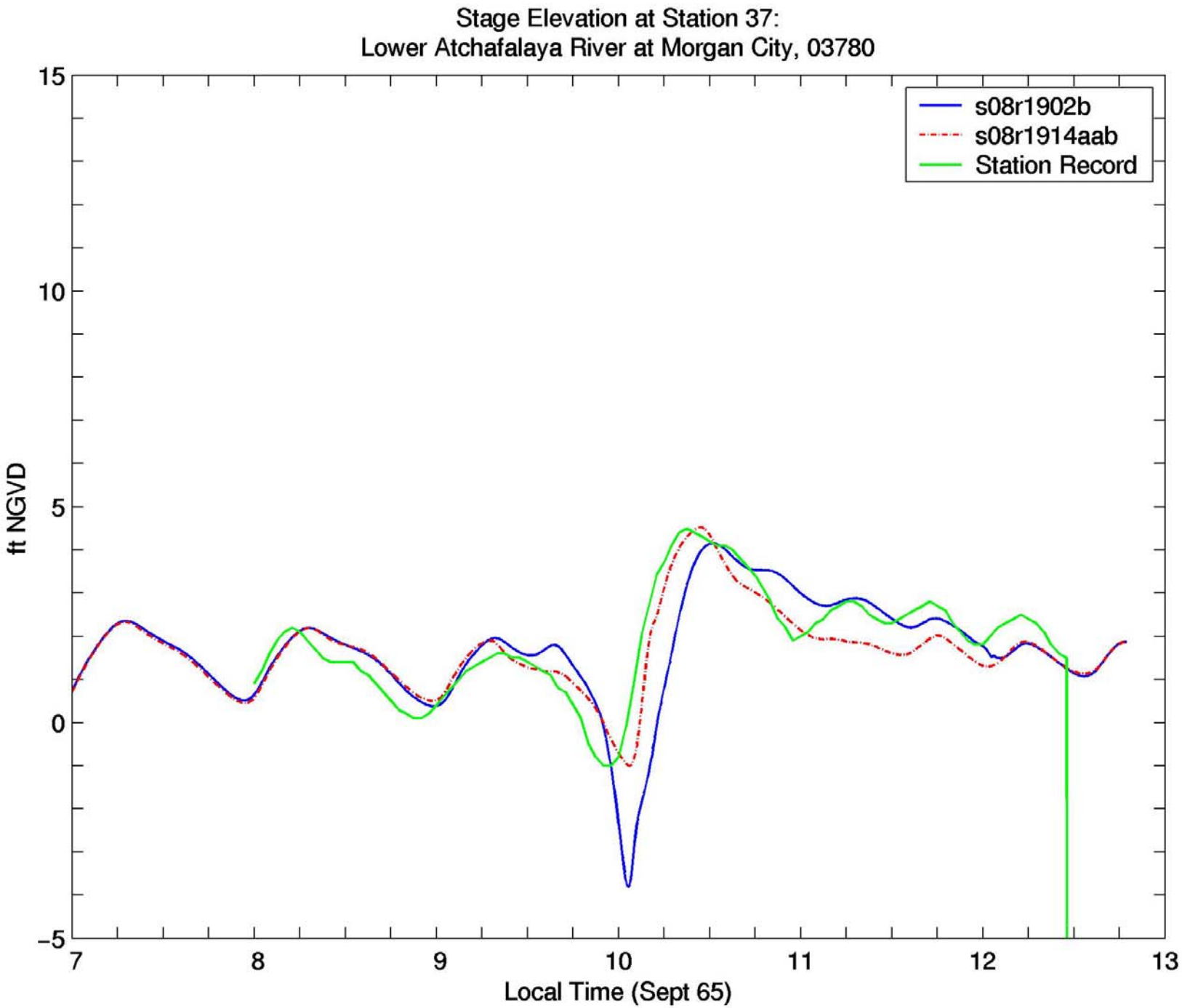
Hurricane Betsy

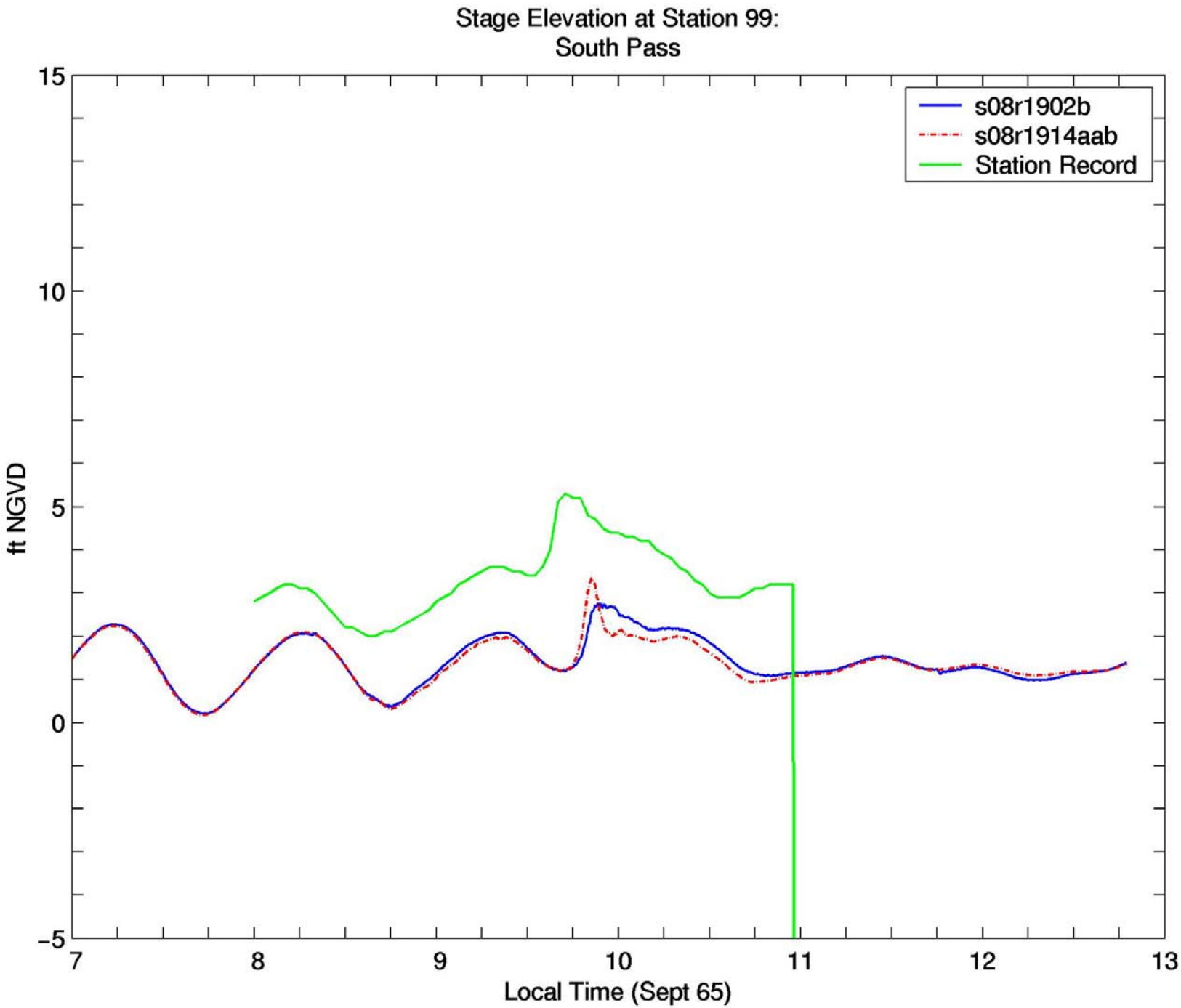
- 1965 Category 5
- Landfall near Grand Isle, LA
- Levees are included at 1965 heights
- Planetary Boundary Layer (PBL) model and HRD data assimilated wind model

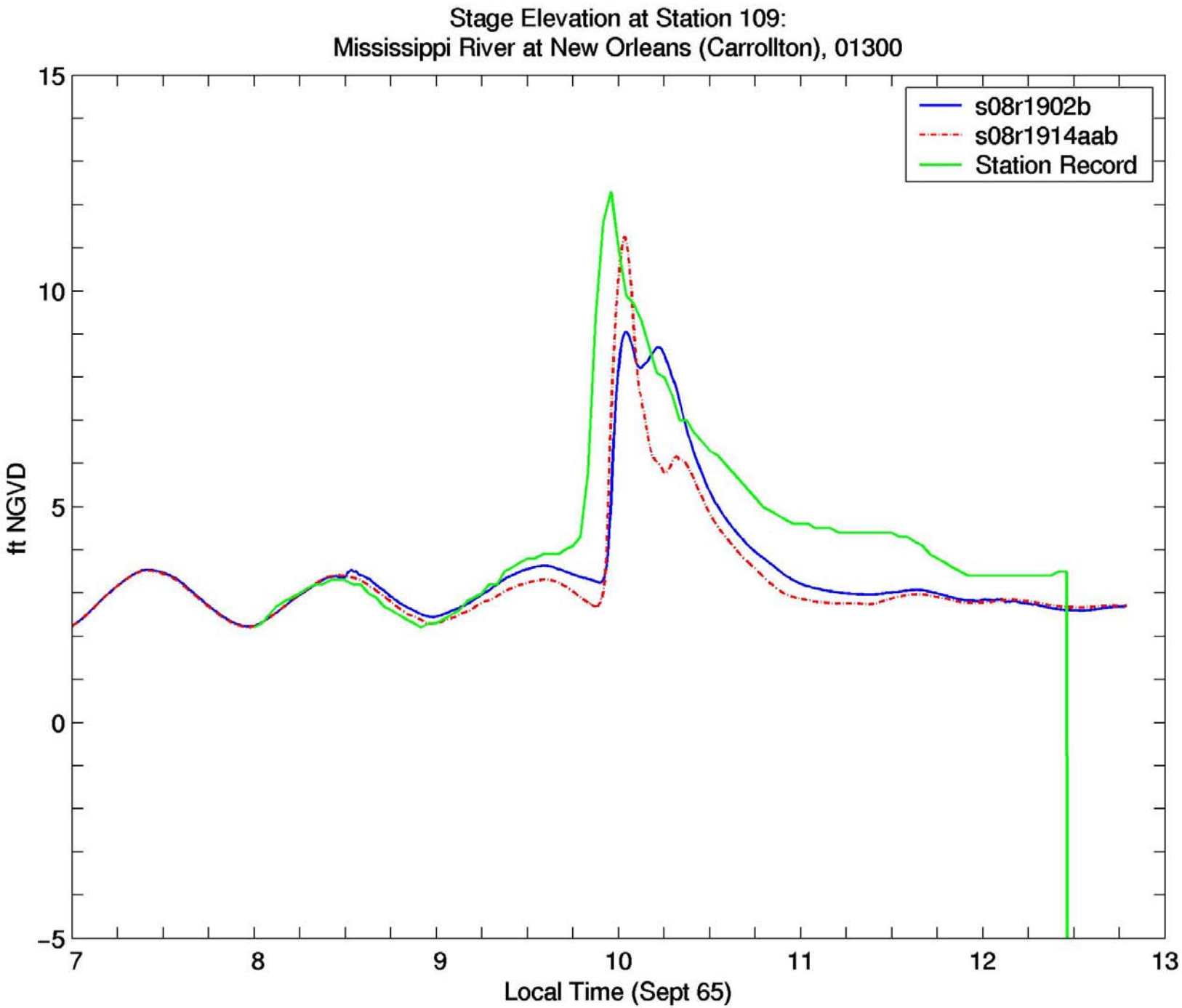

0.0
10.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
70.0
80.0
90.0
100.0
112.5
59
58
57
56
55
54
53
52

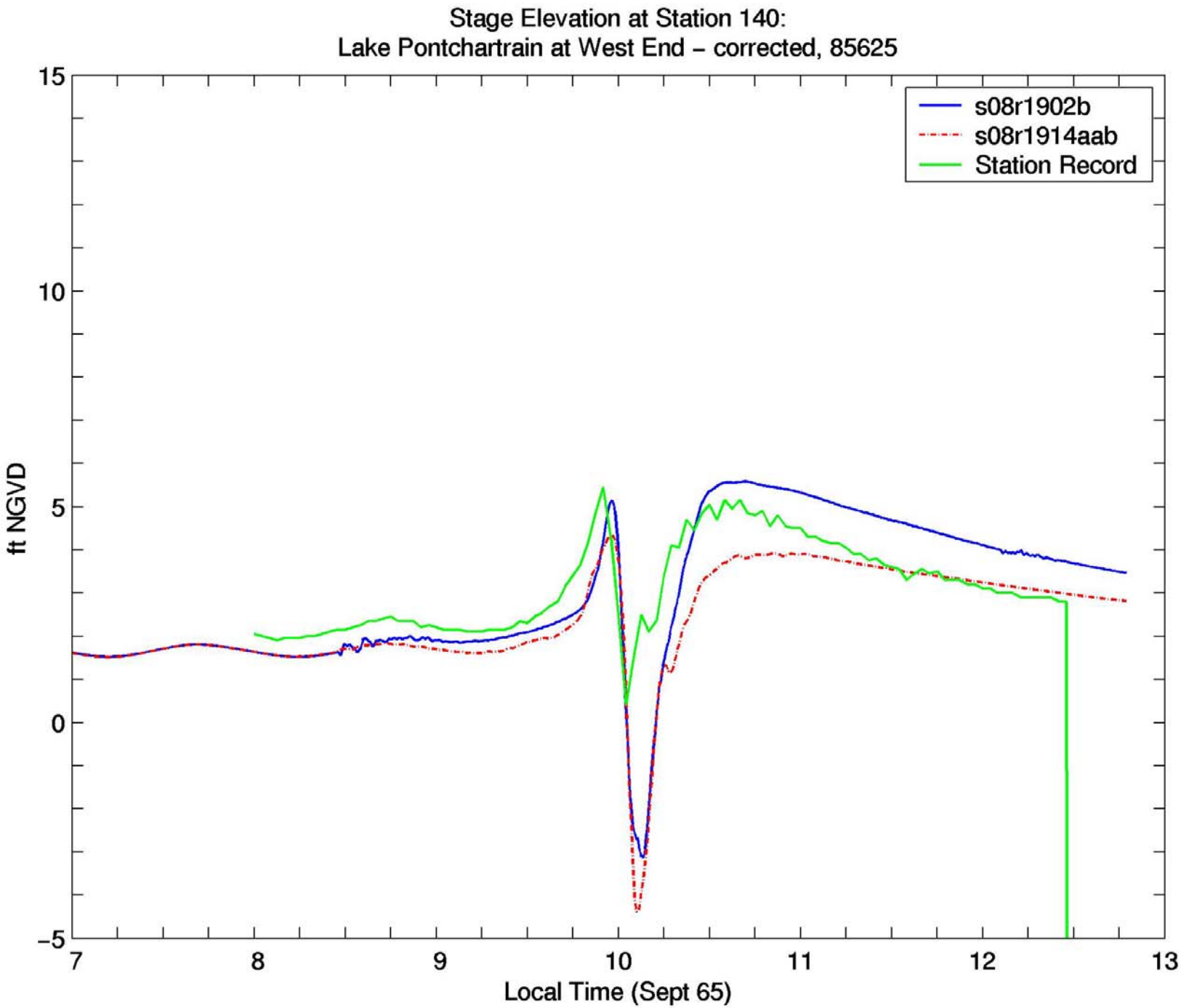

0.0
10.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
70.0
80.0
90.0
100.0
112.5
59
58
57
56
55
54
53
52

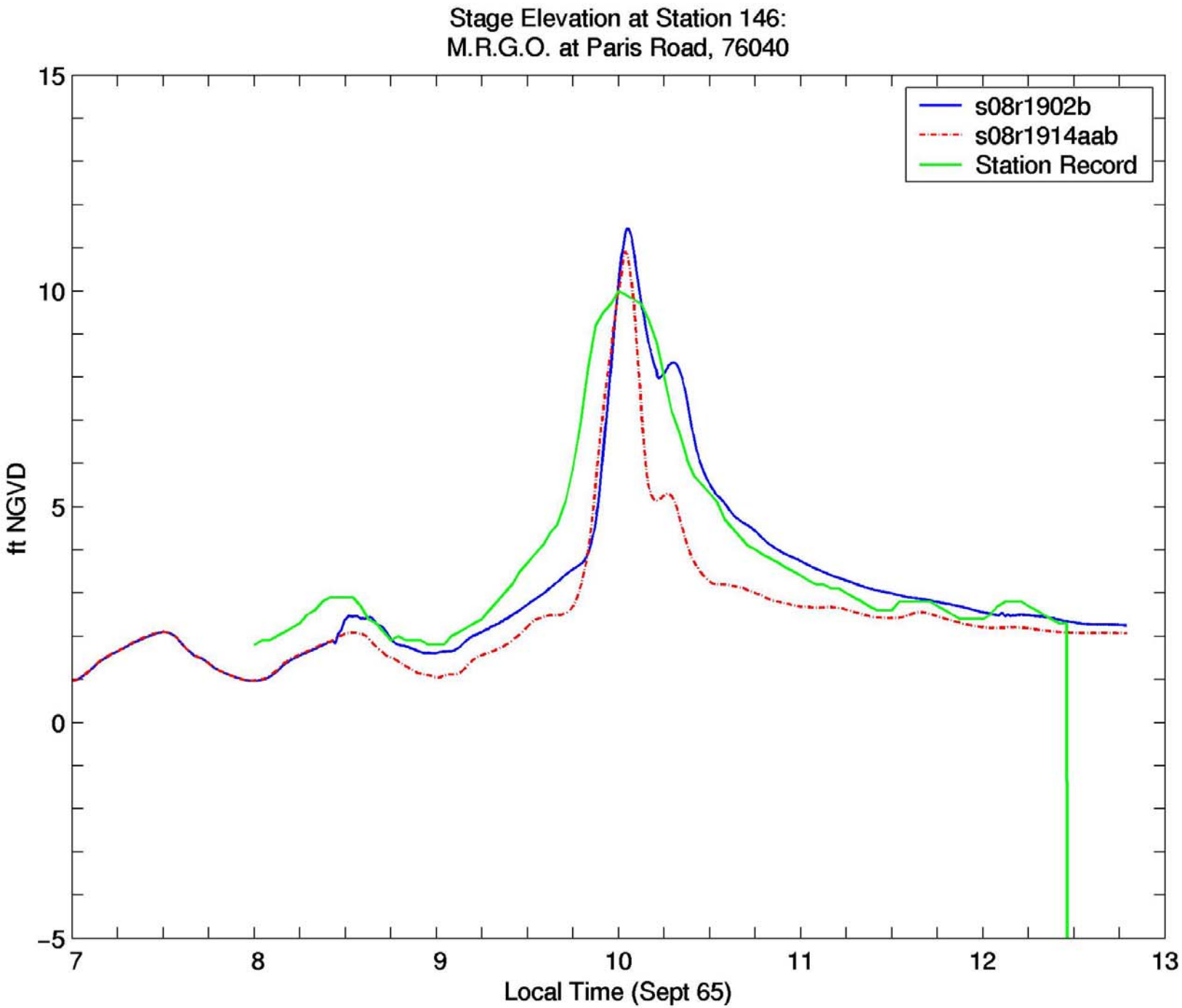

66.21 m/s
0.00 m/s
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
1951200.00

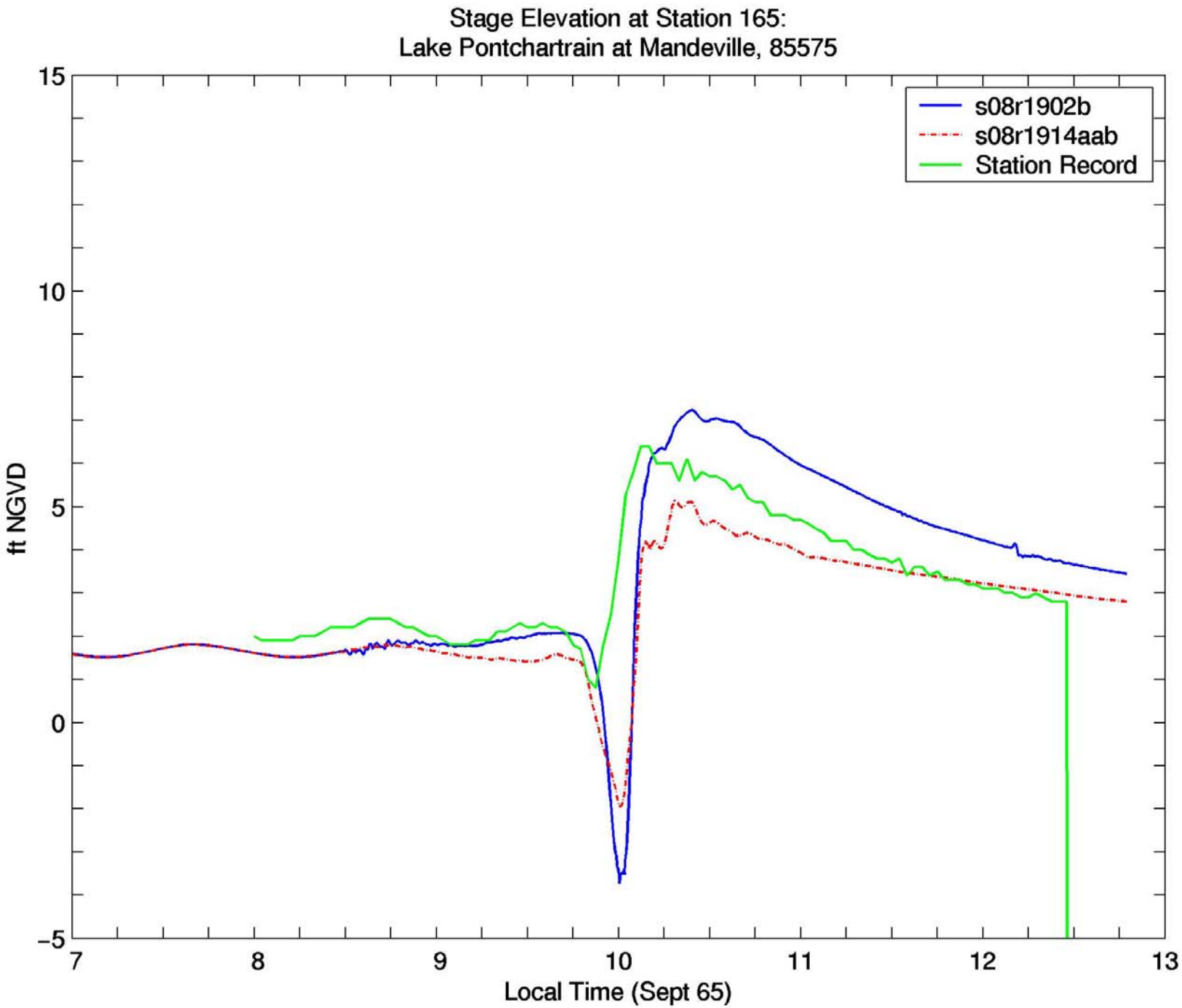

Stage Elevation at Station 37:
Lower Atchafalaya River at Morgan City, 03780
s08r1902b
s08r1914aab
Station Record
ft NGVD
15
10
5
0
−5
7
8
9
10
11
12
13
Local Time (Sept 65)


Stage Elevation at Station 99:
South Pass
s08r1902b
s08r1914aab
Station Record
ft NGVD
Local Time (Sept 65)
15
10
5
0
−5
7
8
9
10
11
12
13


Stage Elevation at Station 109:
Mississippi River at New Orleans (Carrollton), 01300
s08r1902b
s08r1914aab
Station Record
ft NGVD
Local Time (Sept 65)
15
10
5
0
−5
7
8
9
10
11
12
13

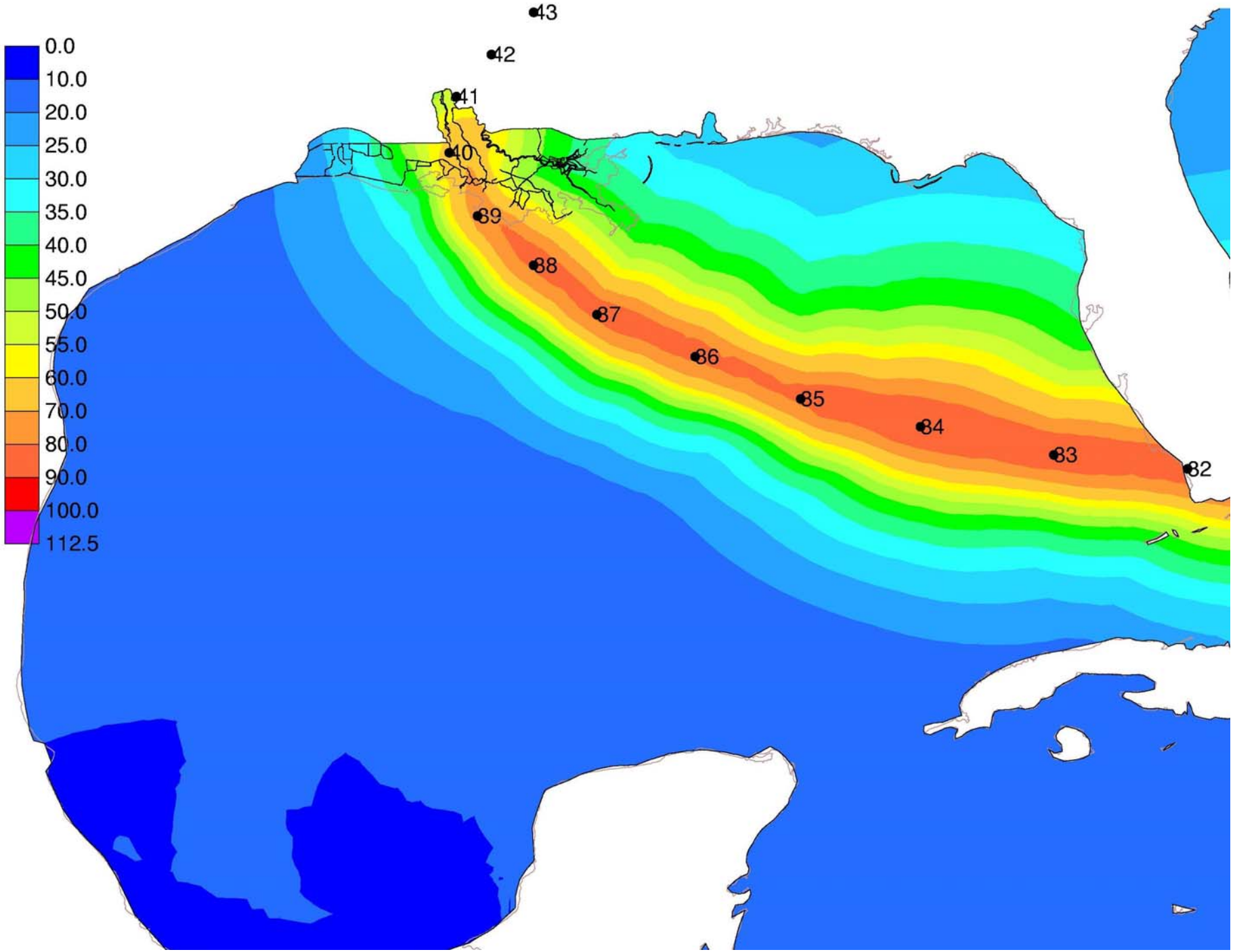

Stage Elevation at Station 140:
Lake Pontchartrain at West End – corrected, 85625
s08r1902b
s08r1914aab
Station Record
ft NGVD
Local Time (Sept 65)
15
10
5
0
−5
7
8
9
10
11
12
13

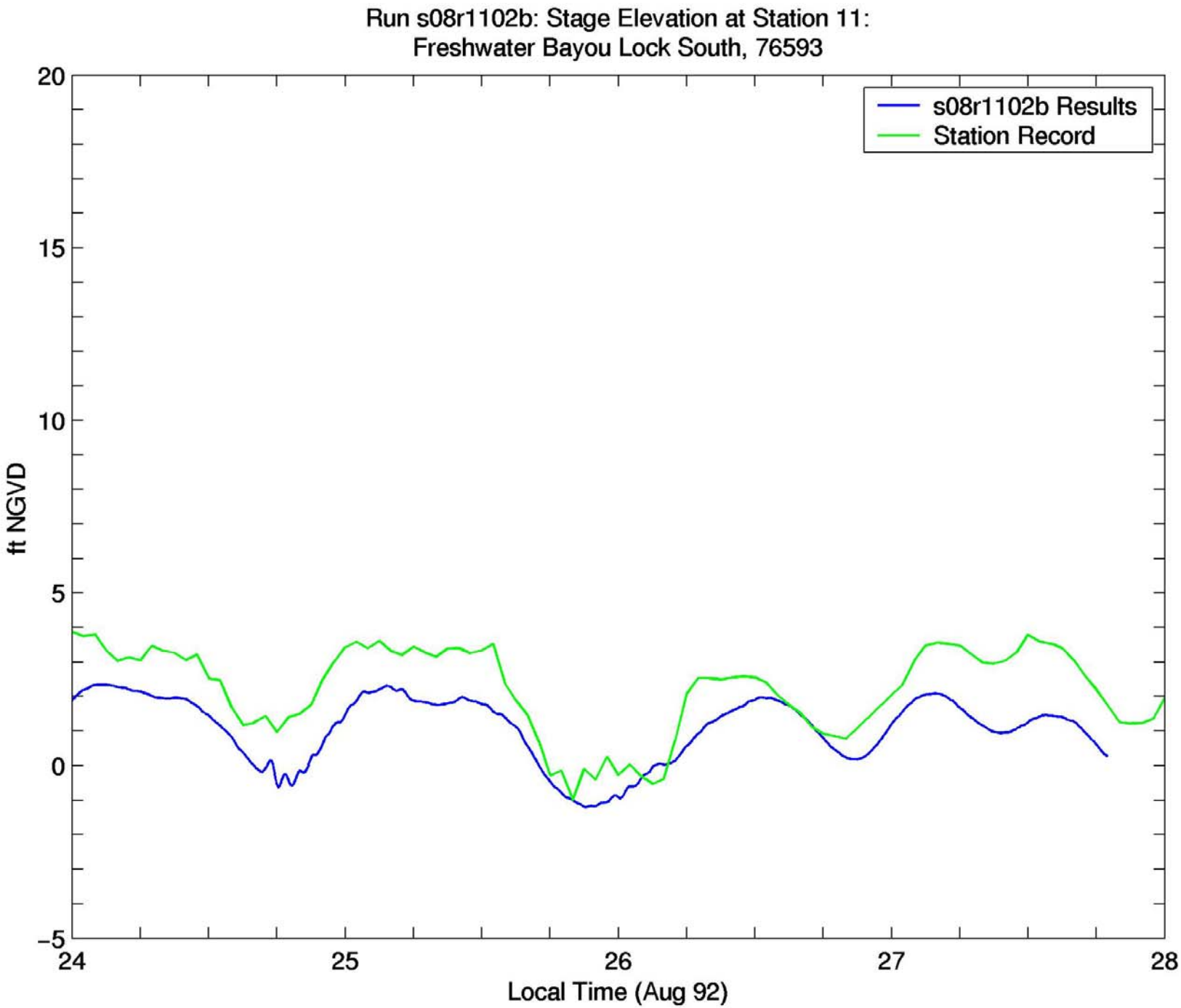

Stage Elevation at Station 146:
M.R.G.O. at Paris Road, 76040
s08r1902b
s08r1914aab
Station Record
ft NGVD
Local Time (Sept 65)
15
10
5
0
−5
7
8
9
10
11
12
13

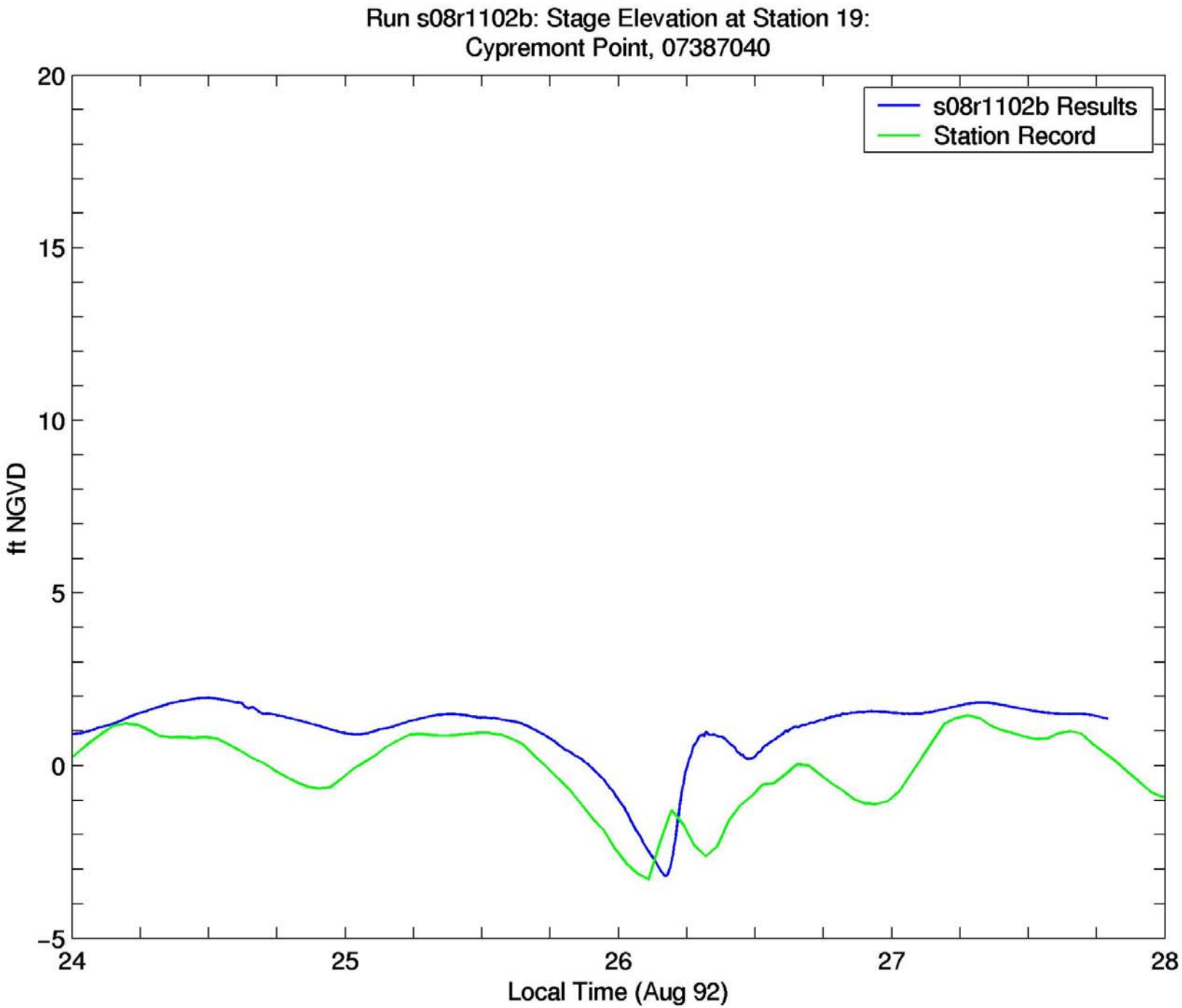

Stage Elevation at Station 165:
Lake Pontchartrain at Mandeville, 85575
s08r1902b
s08r1914aab
Station Record
ft NGVD
Local Time (Sept 65)
15
10
5
0
−5
7
8
9
10
11
12
13

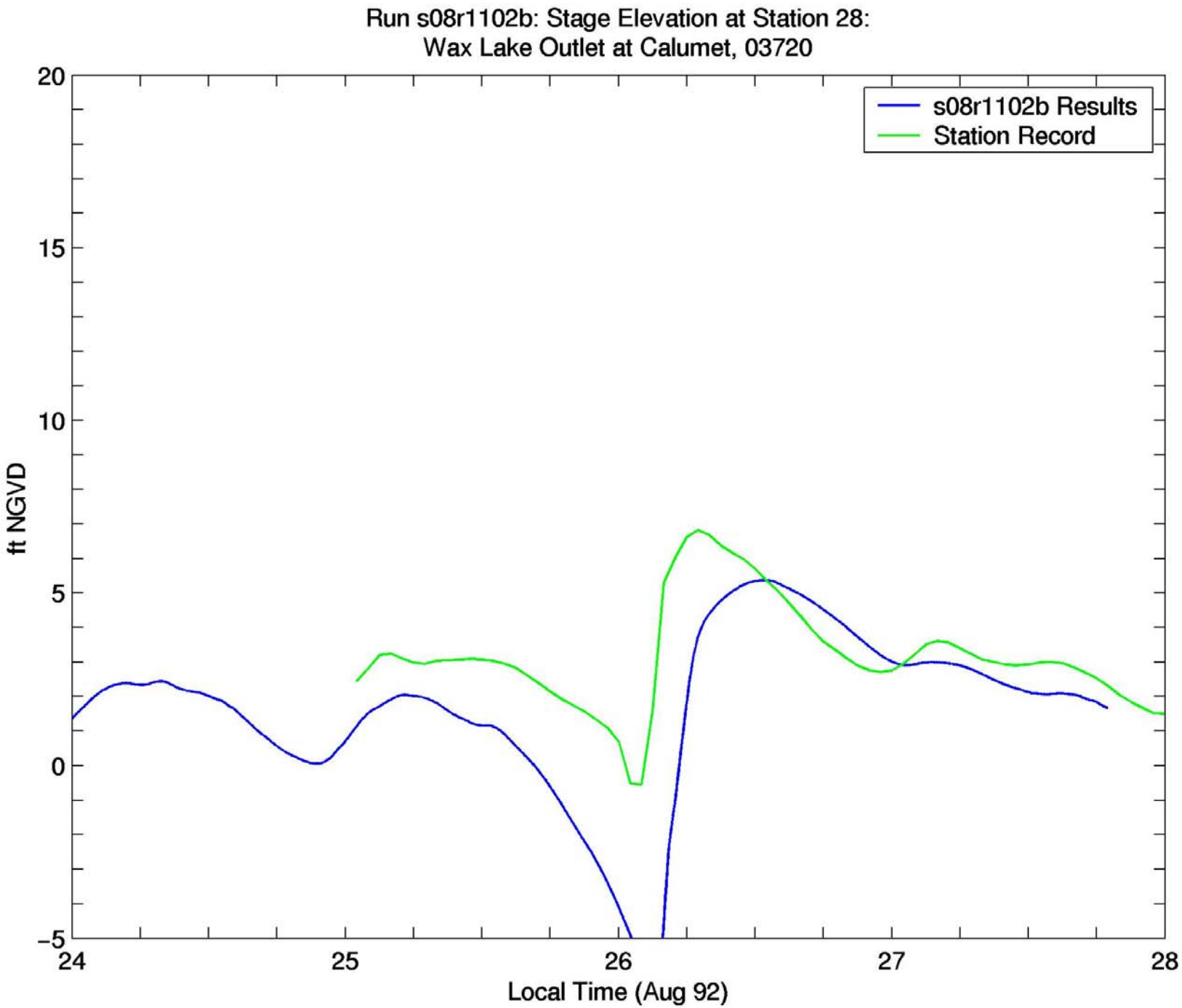
Hurricane Andrew

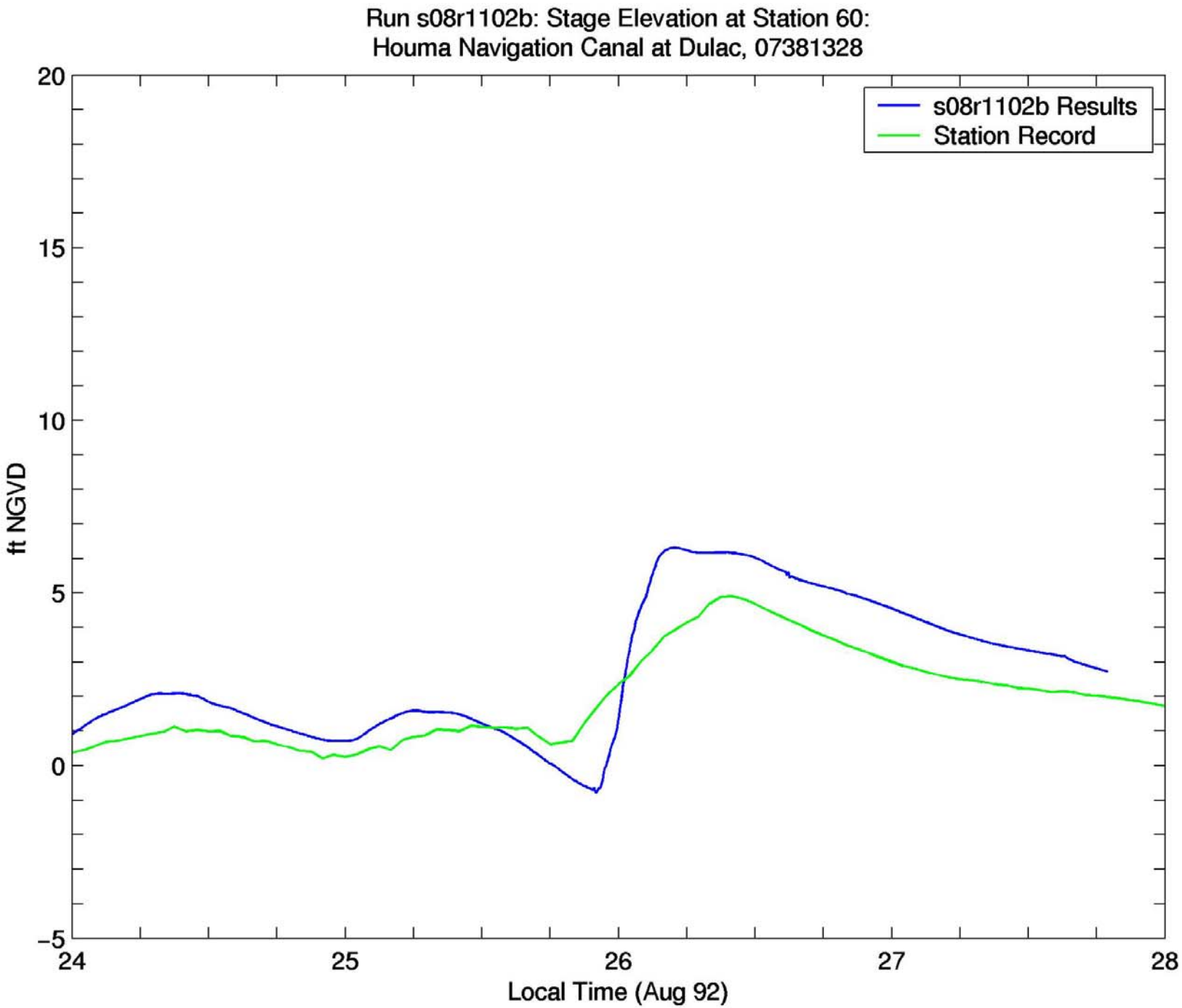
- 1992 Category 4
- Landfall near Point Chevreuil, LA
- Levees are included at 1992 heights
- Planetary Boundary Layer (PBL) model

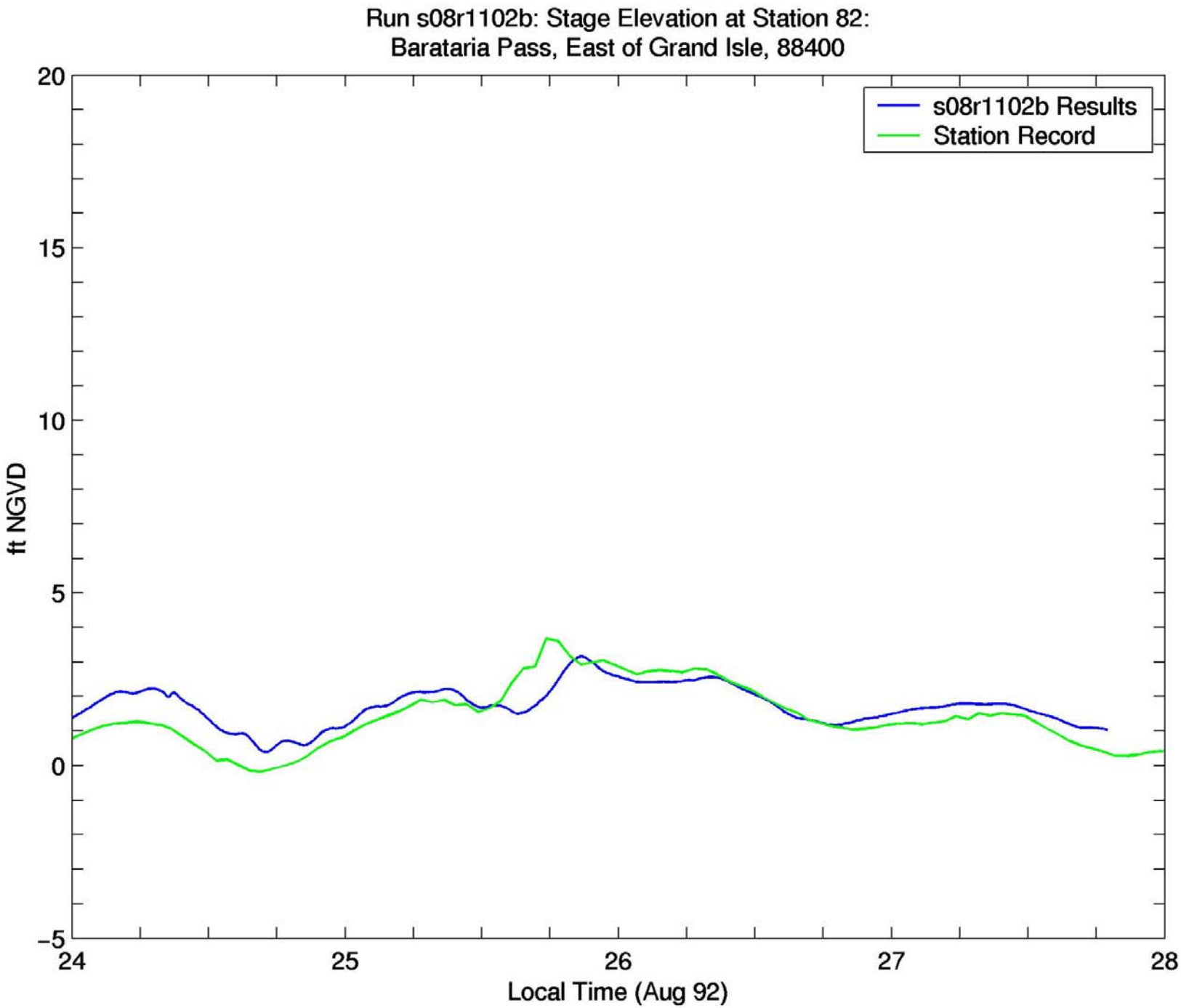

0.0
10.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
70.0
80.0
90.0
100.0
112.5
43
42
41
40
39
38
37
36
35
34
33
32

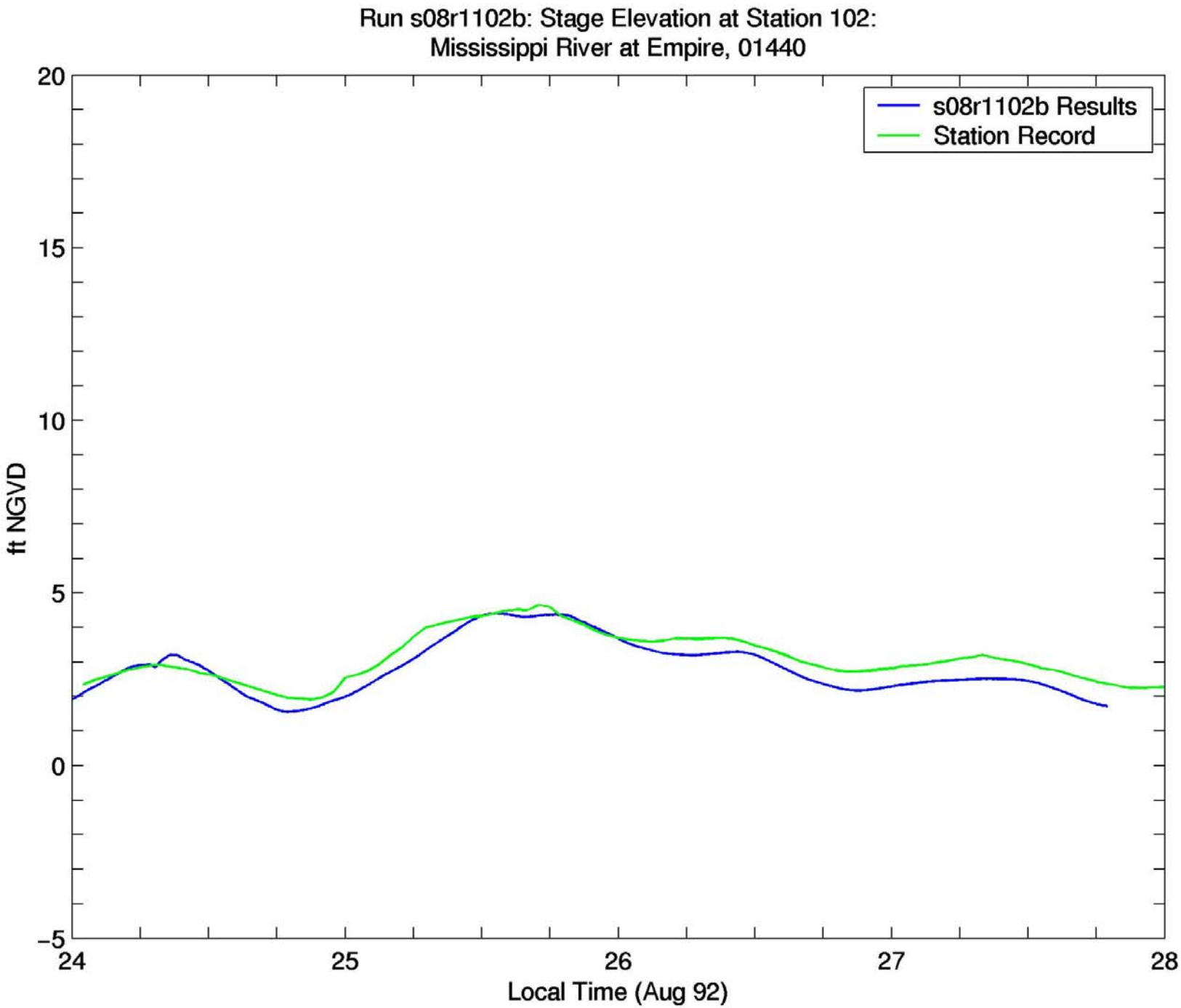

Run s08r1102b: Stage Elevation at Station 11:
Freshwater Bayou Lock South, 76593
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)

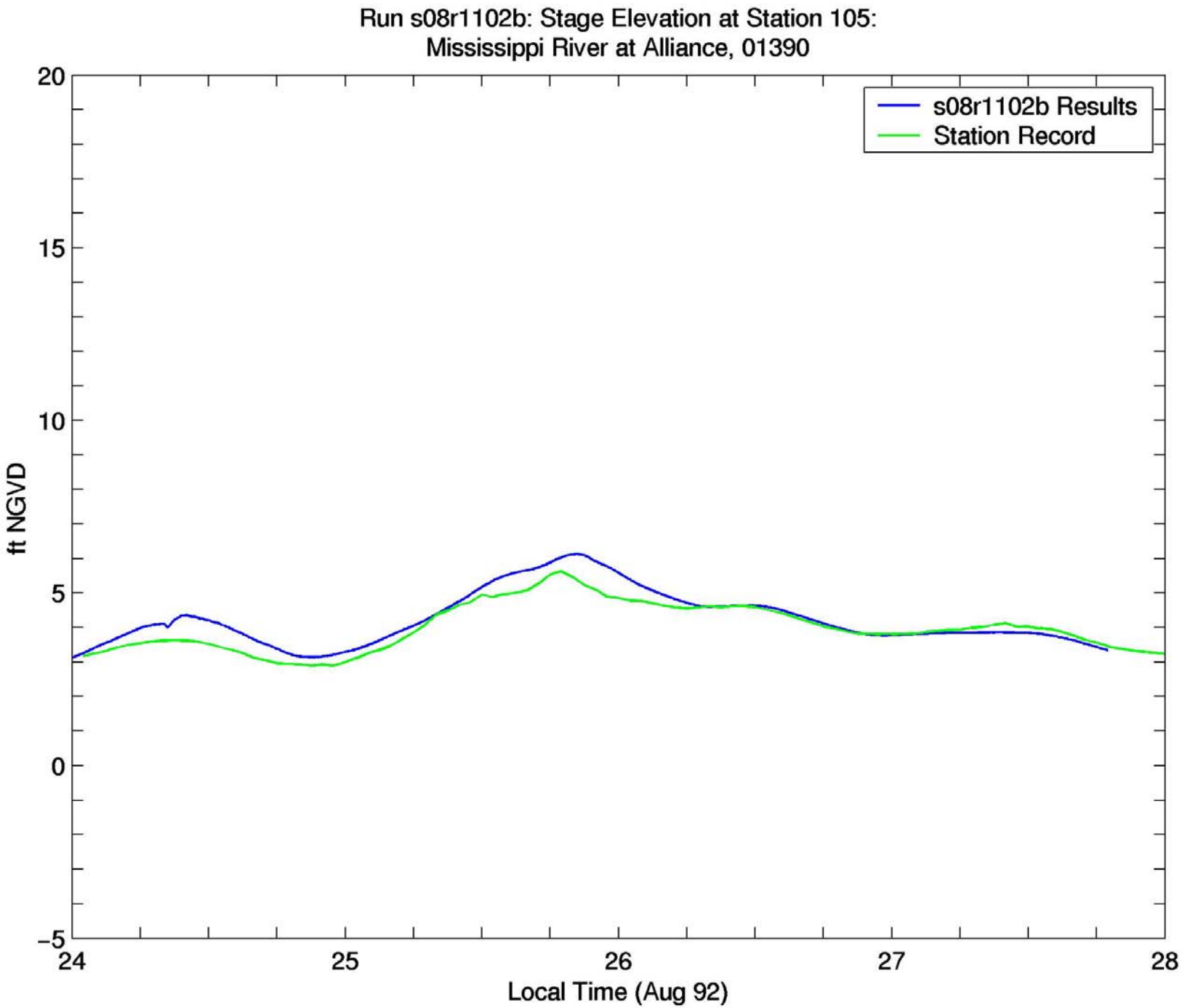

Run s08r1102b: Stage Elevation at Station 19:
Cypremont Point, 07387040
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)

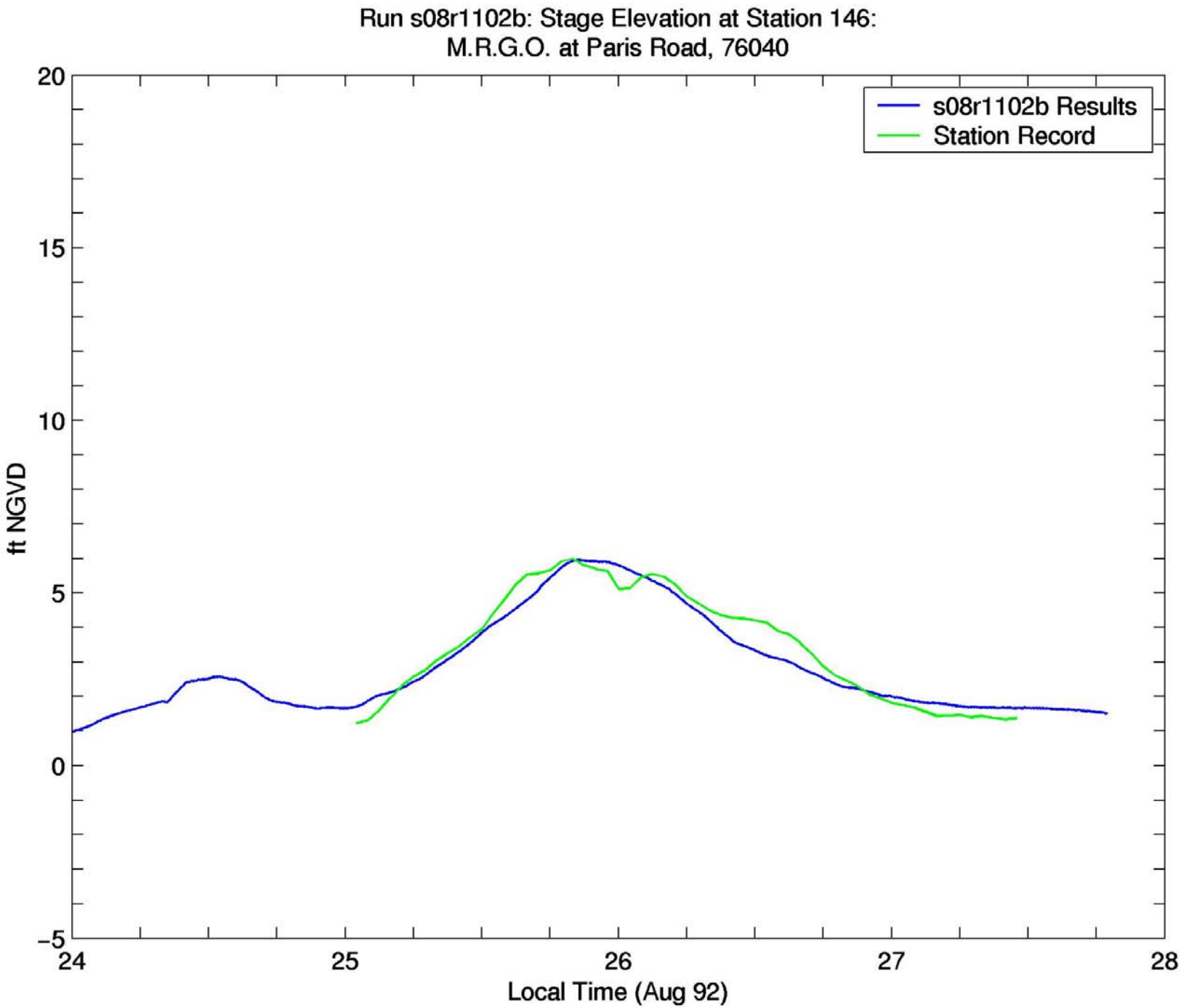

Run s08r1102b: Stage Elevation at Station 28:
Wax Lake Outlet at Calumet, 03720
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)

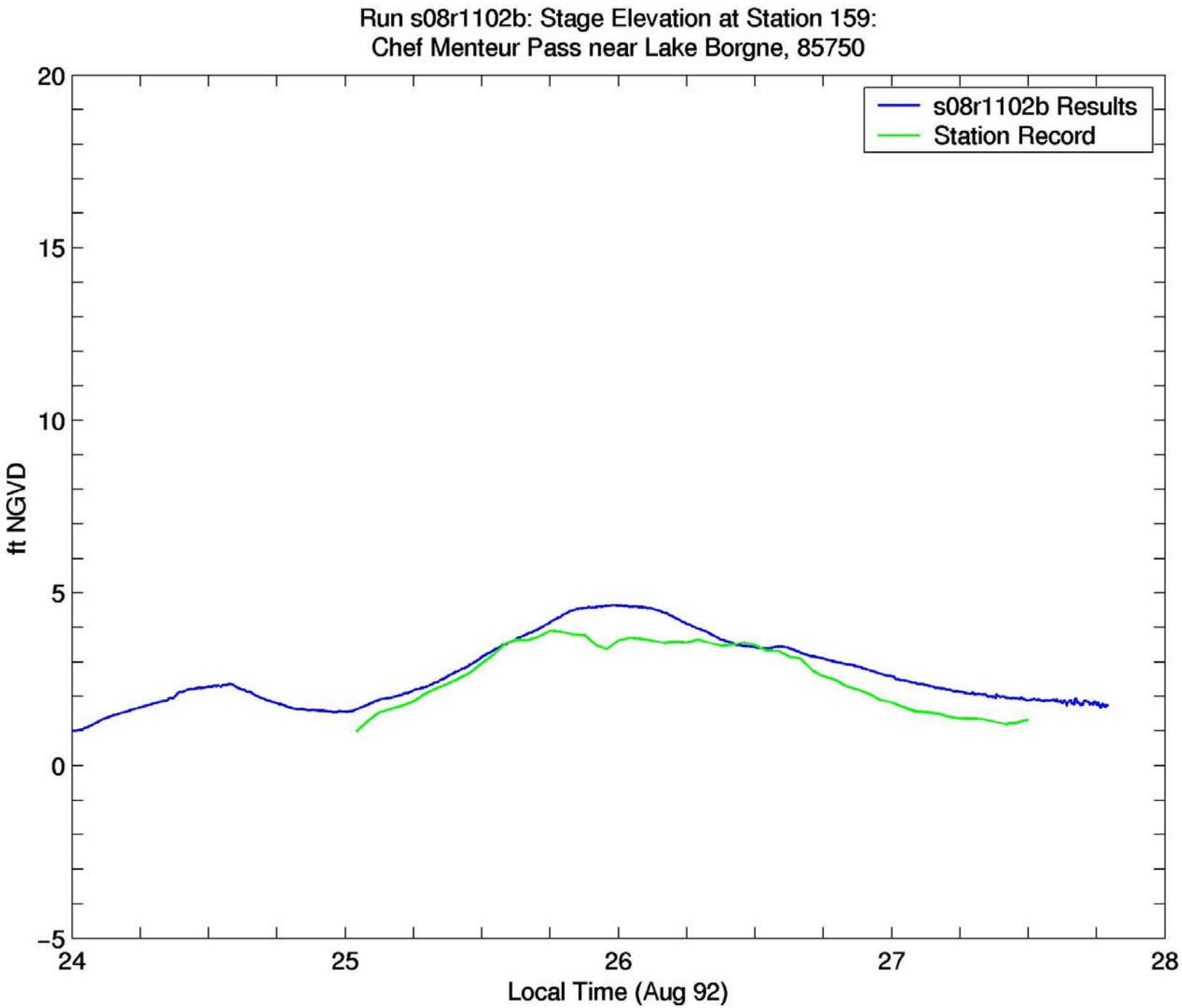

Run s08r1102b: Stage Elevation at Station 60:
Houma Navigation Canal at Dulac, 07381328
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)

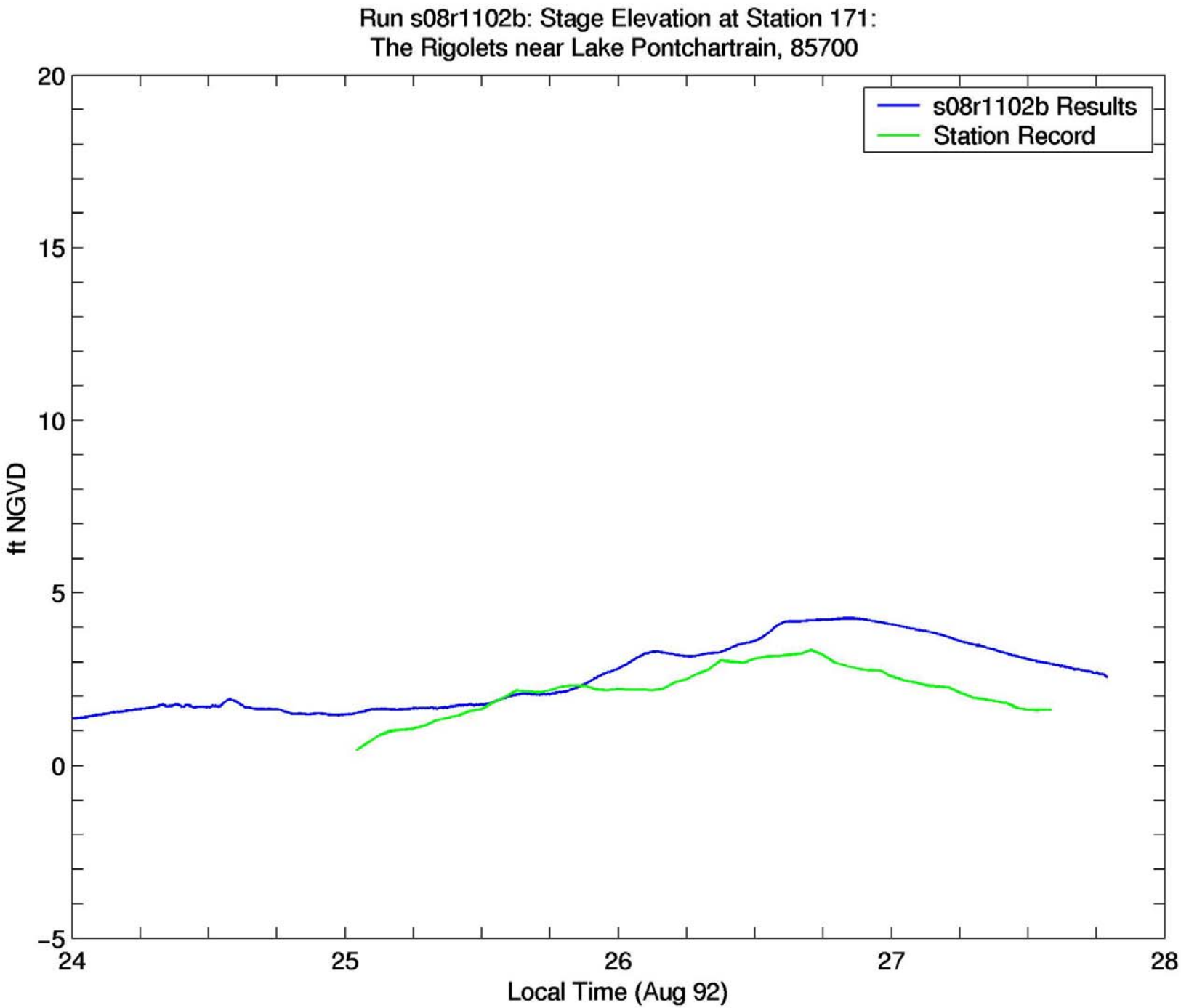

Run s08r1102b: Stage Elevation at Station 82:
Barataria Pass, East of Grand Isle, 88400
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)

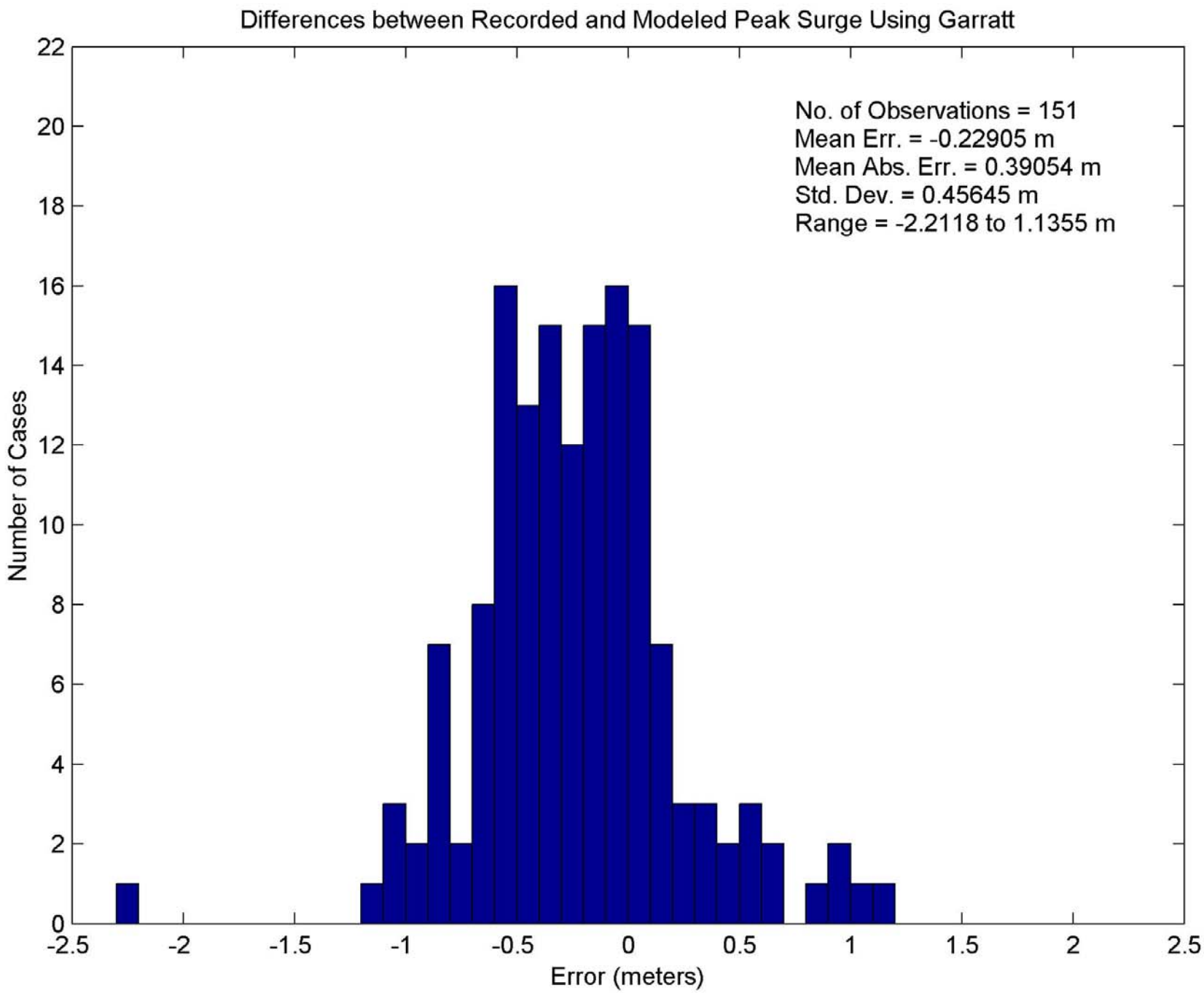

Run s08r1102b: Stage Elevation at Station 102:
Mississippi River at Empire, 01440
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)

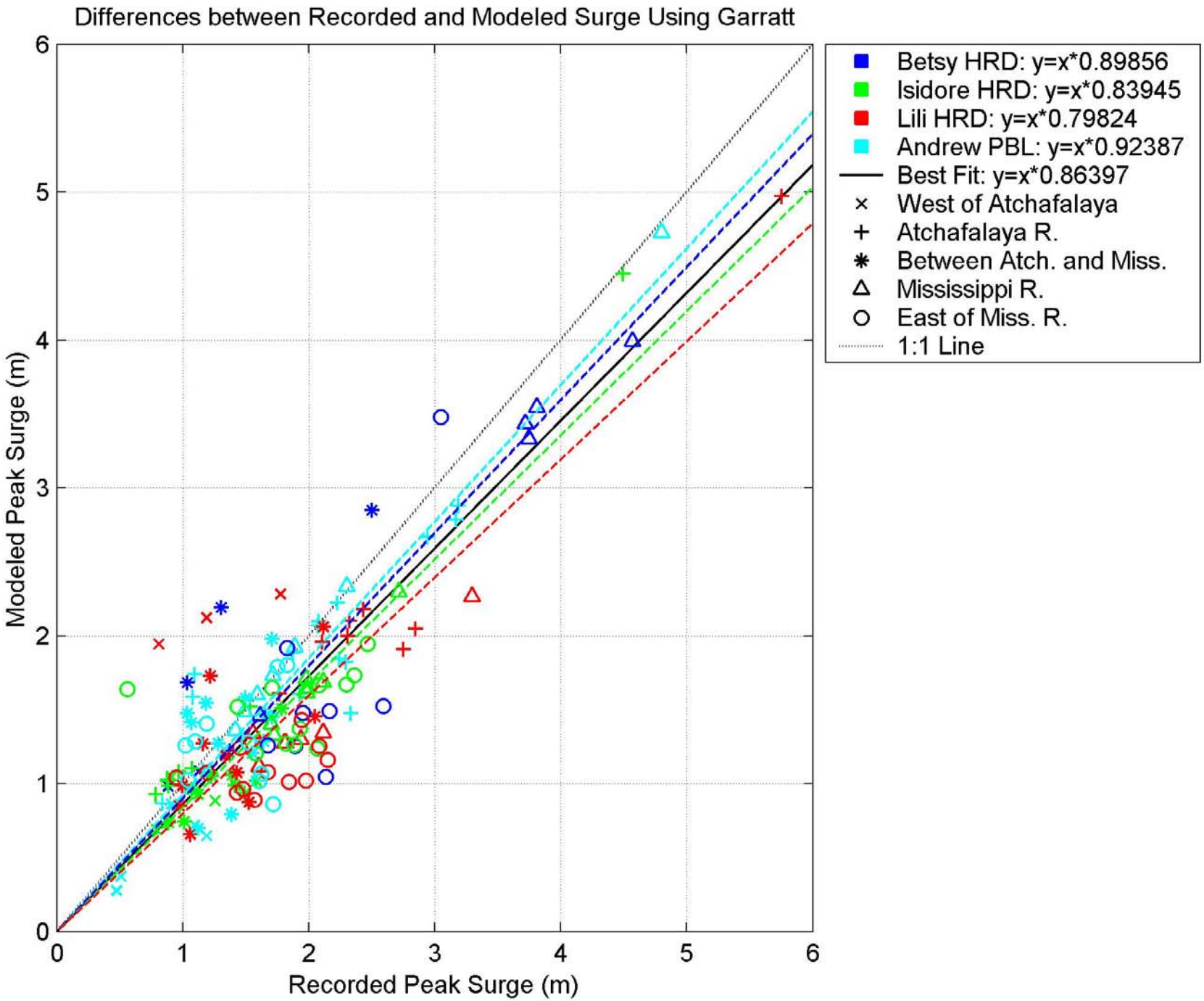

Run s08r1102b: Stage Elevation at Station 105:
Mississippi River at Alliance, 01390
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)


Run s08r1102b: Stage Elevation at Station 146:
M.R.G.O. at Paris Road, 76040
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)


Run s08r1102b: Stage Elevation at Station 159:
Chef Menteur Pass near Lake Borgne, 85750
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)


Run s08r1102b: Stage Elevation at Station 171:
The Rigolets near Lake Pontchartrain, 85700
s08r1102b Results
Station Record
ft NGVD
20
15
10
5
0
−5
24
25
26
27
28
Local Time (Aug 92)


Differences between Recorded and Modeled Peak Surge Using Garratt
No. of Observations = 151
Mean Err. = -0.22905 m
Mean Abs. Err. = 0.39054 m
Std. Dev. = 0.45645 m
Range = -2.2118 to 1.1355 m
Number of Cases
Error (meters)
0
2
4
6
8
10
12
14
16
18
20
22
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5

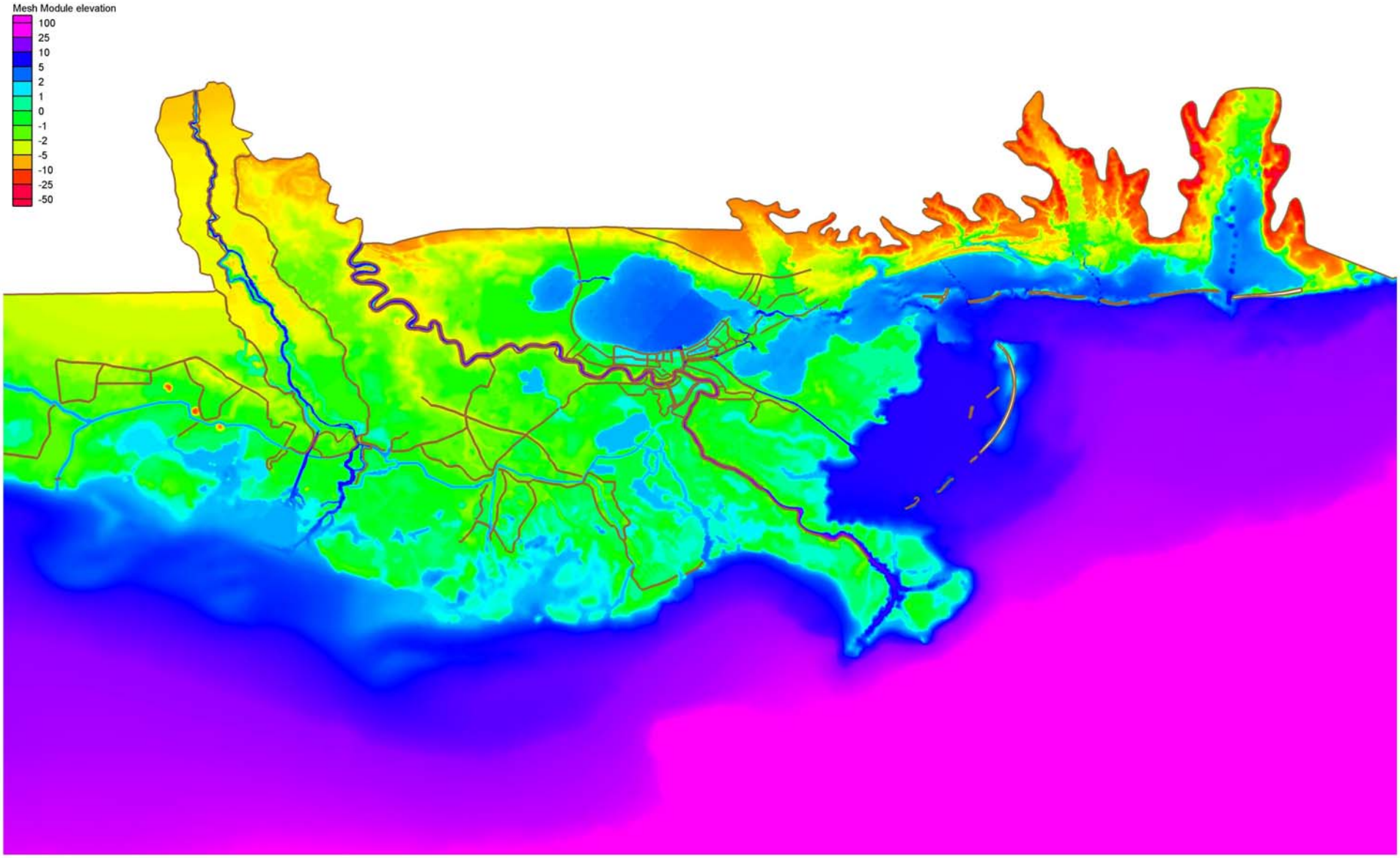

Differences between Recorded and Modeled Surge Using Garratt
Modeled Peak Surge (m)
Recorded Peak Surge (m)
0
1
2
3
4
5
6
Betsy HRD: y=x*0.89856
Isidore HRD: y=x*0.83945
Lili HRD: y=x*0.79824
Andrew PBL: y=x*0.92387
Best Fit: y=x*0.86397
West of Atchafalaya
Atchafalaya R.
Between Atch. and Miss.
Mississippi R.
East of Miss. R.
1:1 Line

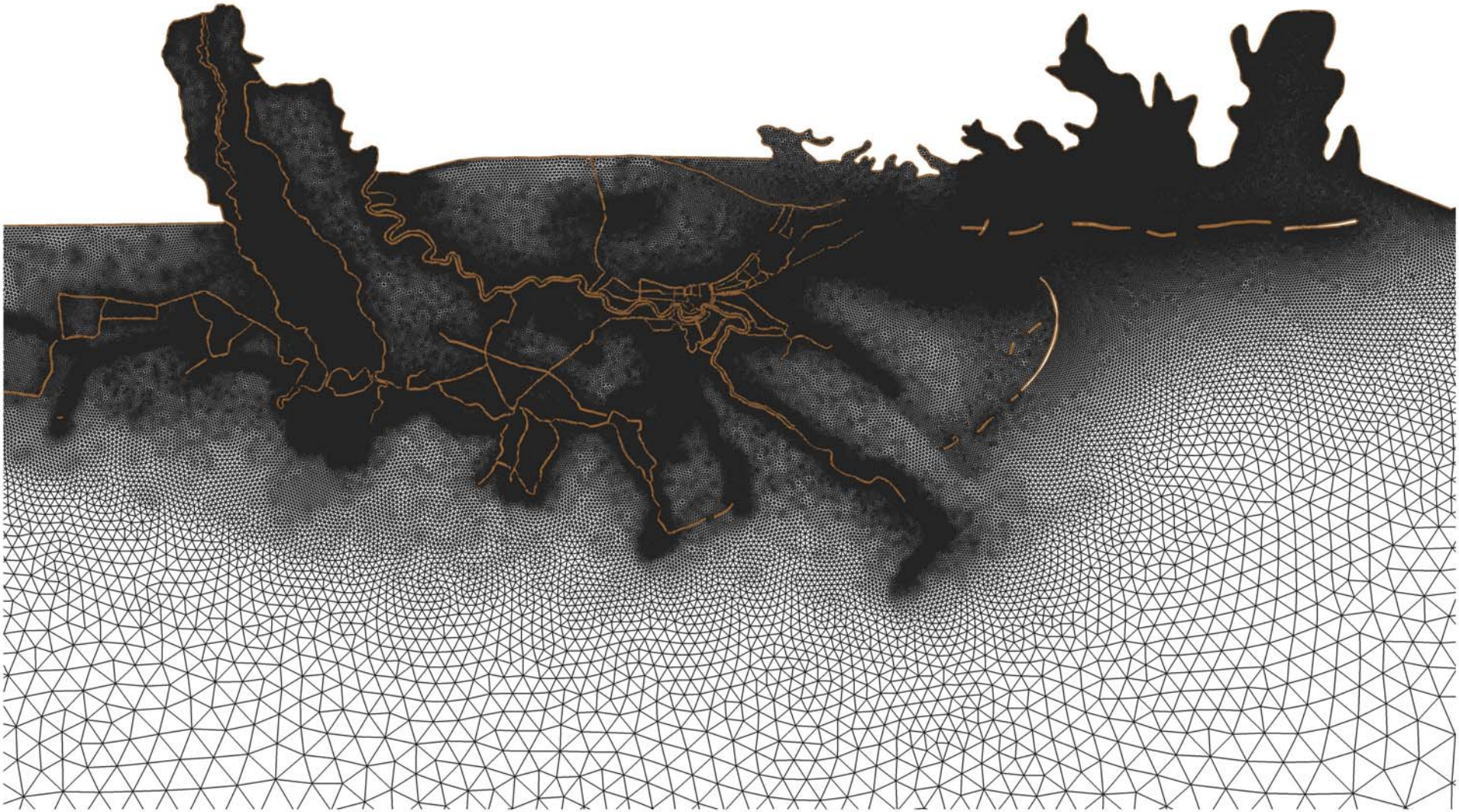
Model Refinements

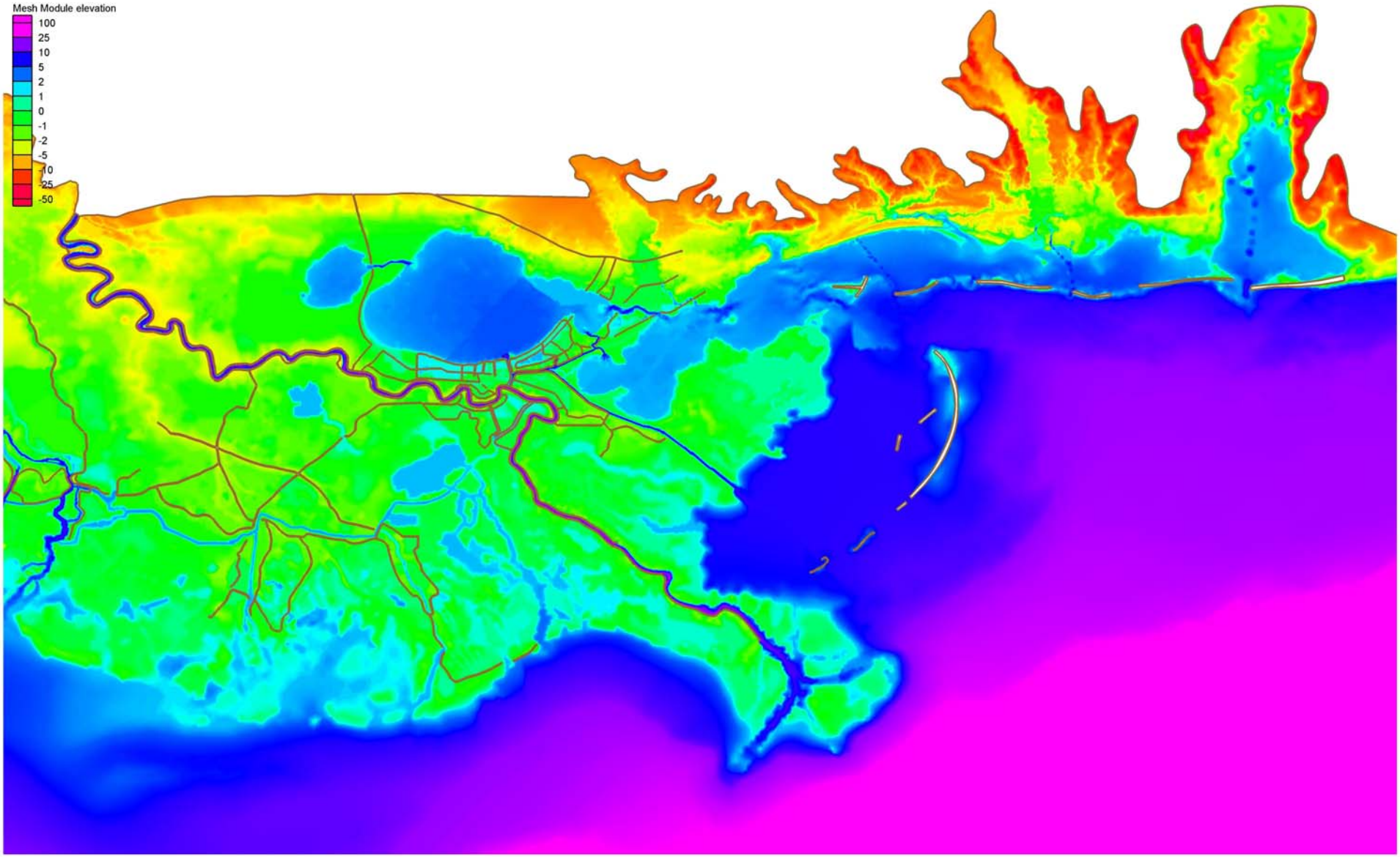
- Regions that are poorly resolved typically have the largest errors.
- Adding 2x to 8x local grid resolution to improve local detail and therefore response
  - Refine entrances, canals, waterways, and lakes
  - Add gates and more levees and roads
  - Possible due to improvements in computers and ADCIRC software advances
- Improve bathymetry and topography (Lidar)

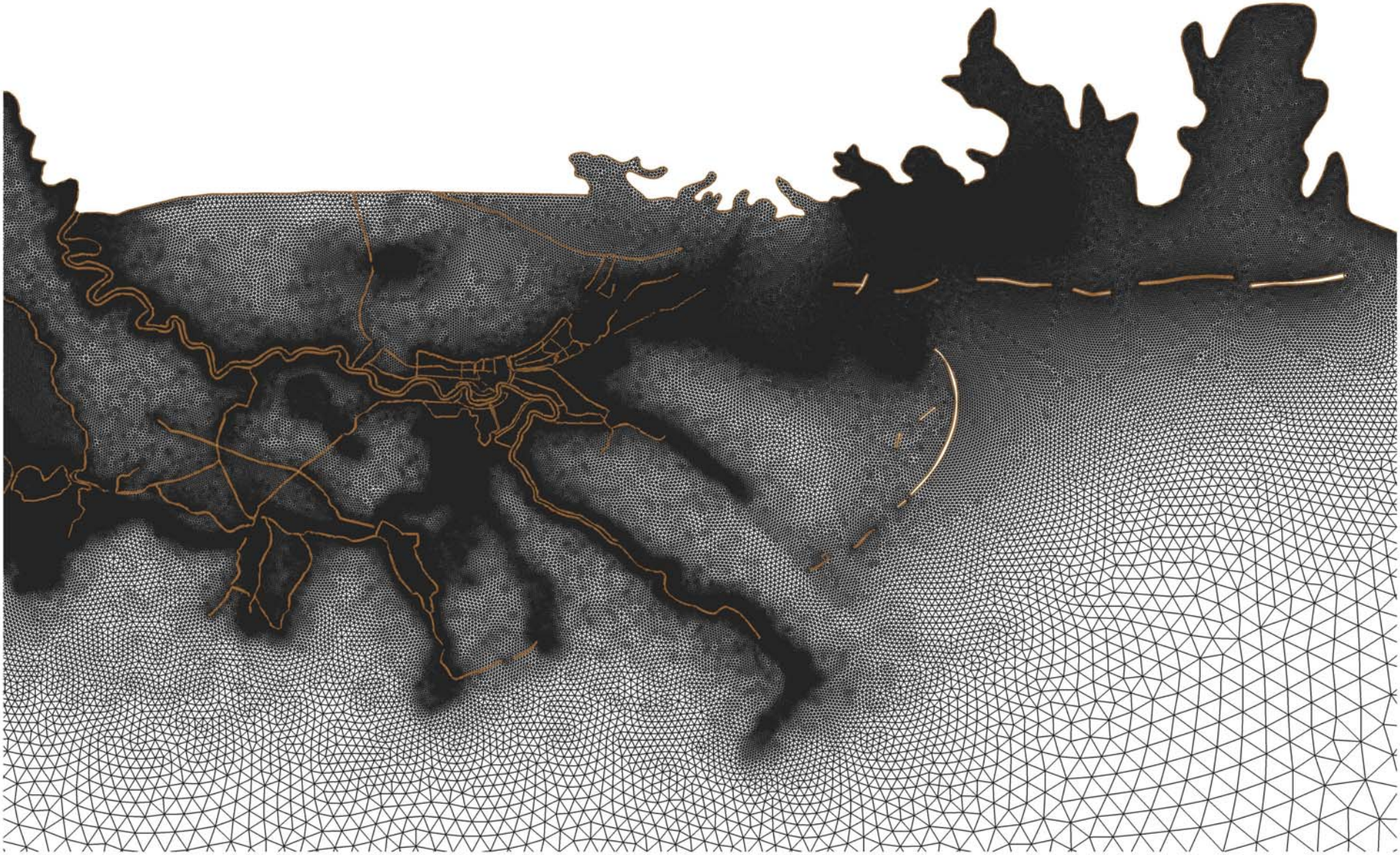
TF01 Grid

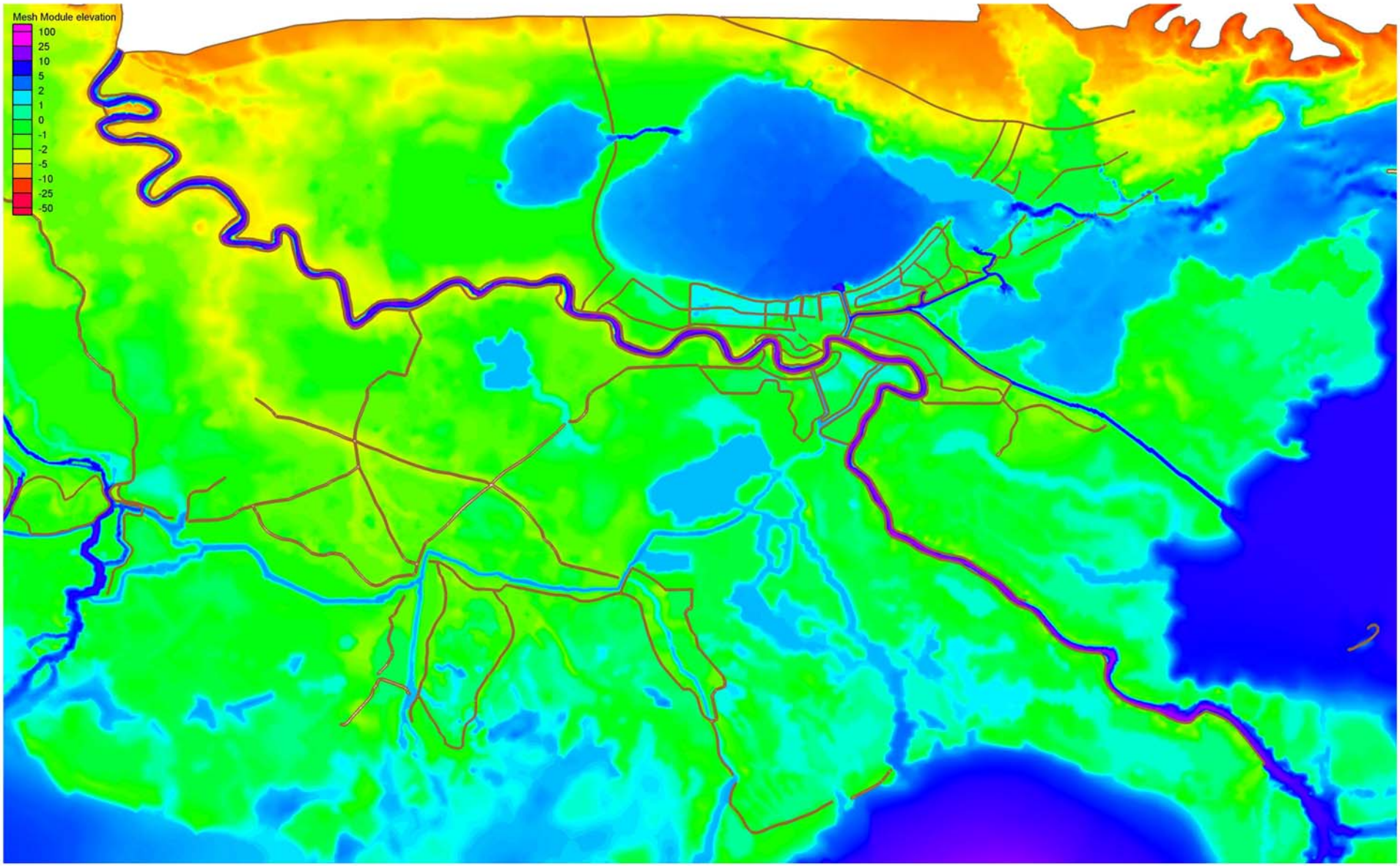
- Add north shore of Lake Pontchartrain, Mississippi coast and Alabama coast including Mobile Bay
- Generally extend floodplain up to the 18 m contour
- Resolution similar to S08 (down to 100m)
- Bathymetry is USGS DEM based
- This model is fully operational

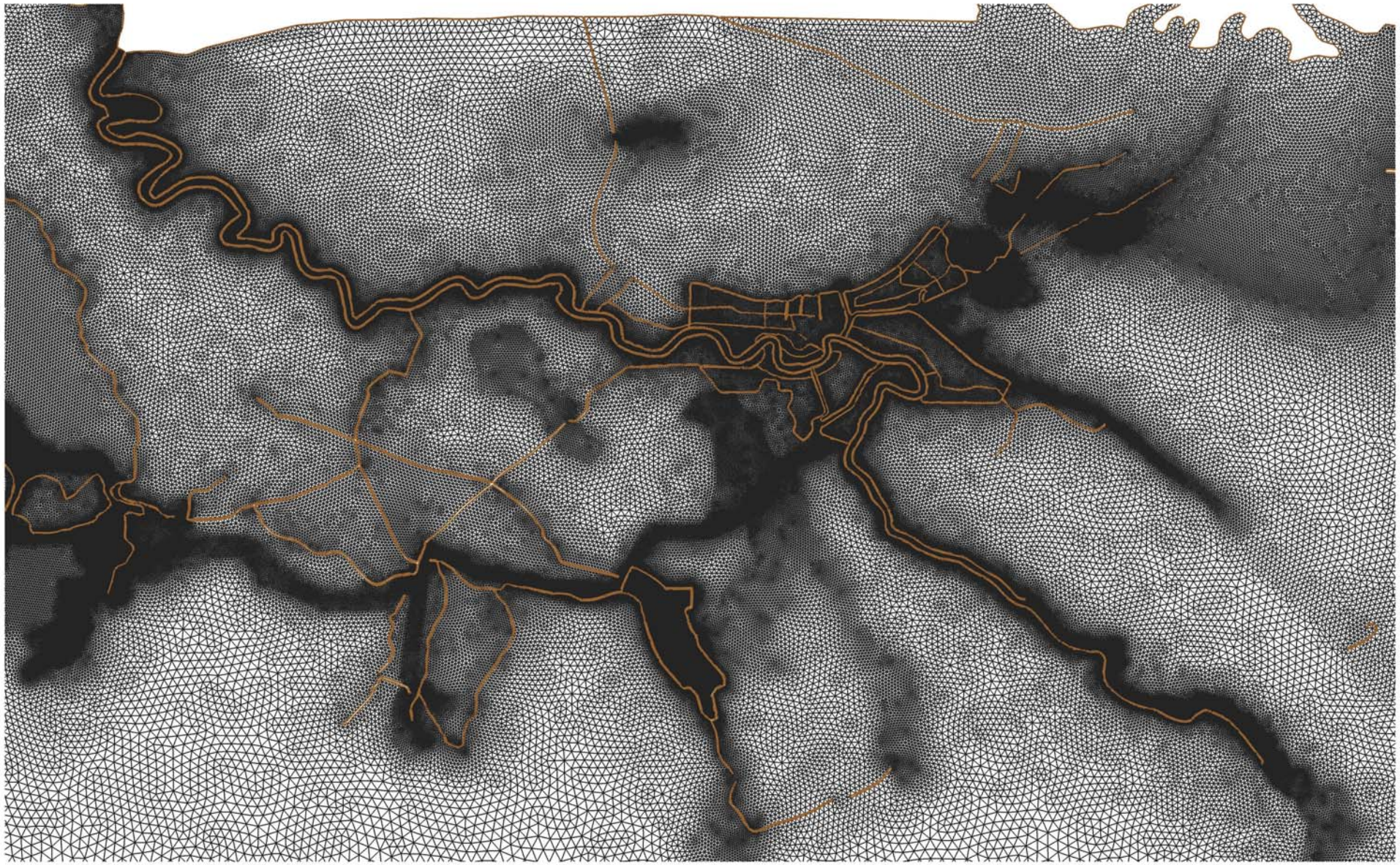

Mesh Module elevation
100
25
10
5
2
1
0
-1
-2
-5
-10
-25
-50




Mesh Module elevation
100
25
10
5
2
1
0
-1
-2
-5
-10
-25
-50

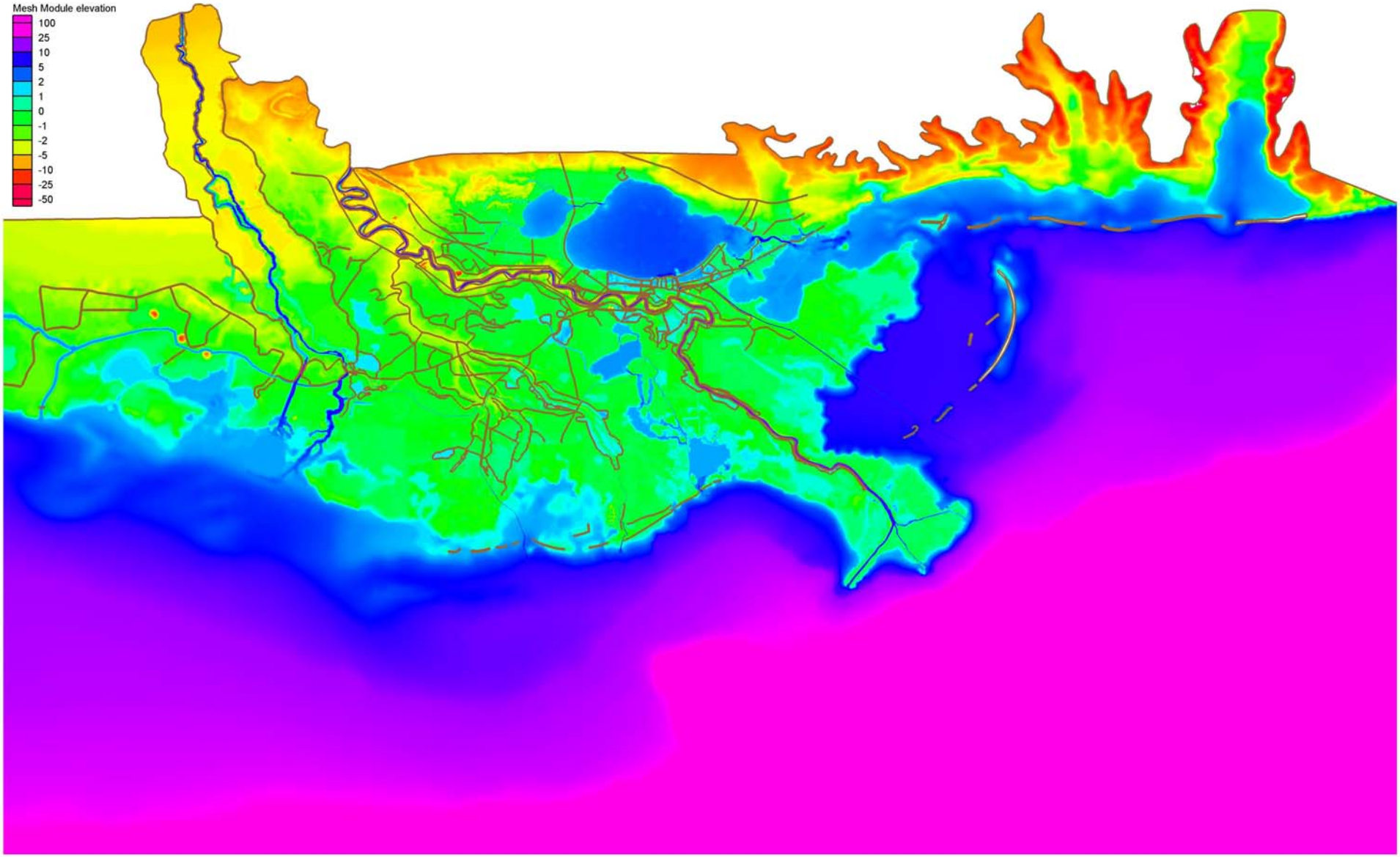


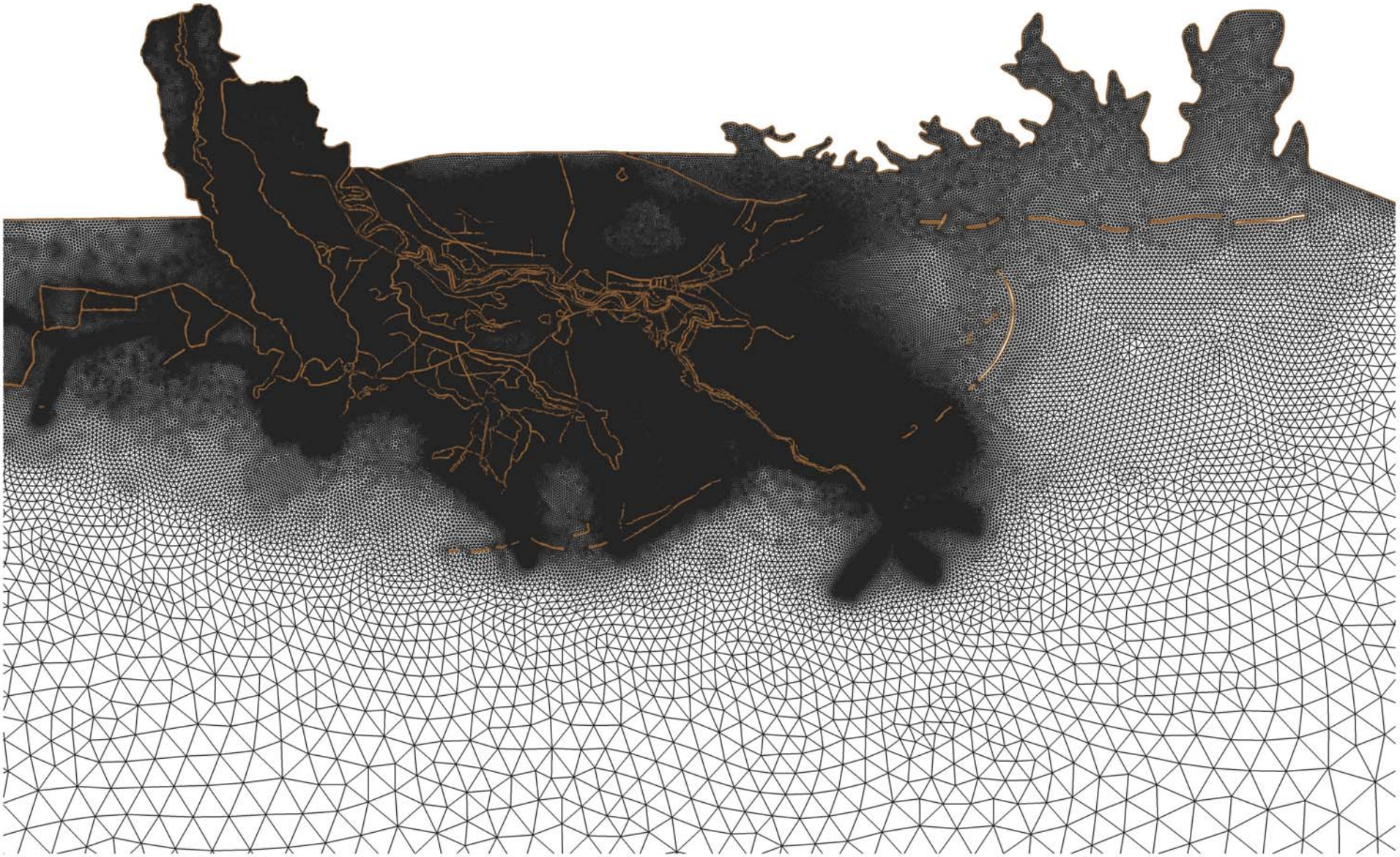

Mesh Module elevation
100
25
10
5
2
1
0
-1
-2
-5
-10
-25
-50

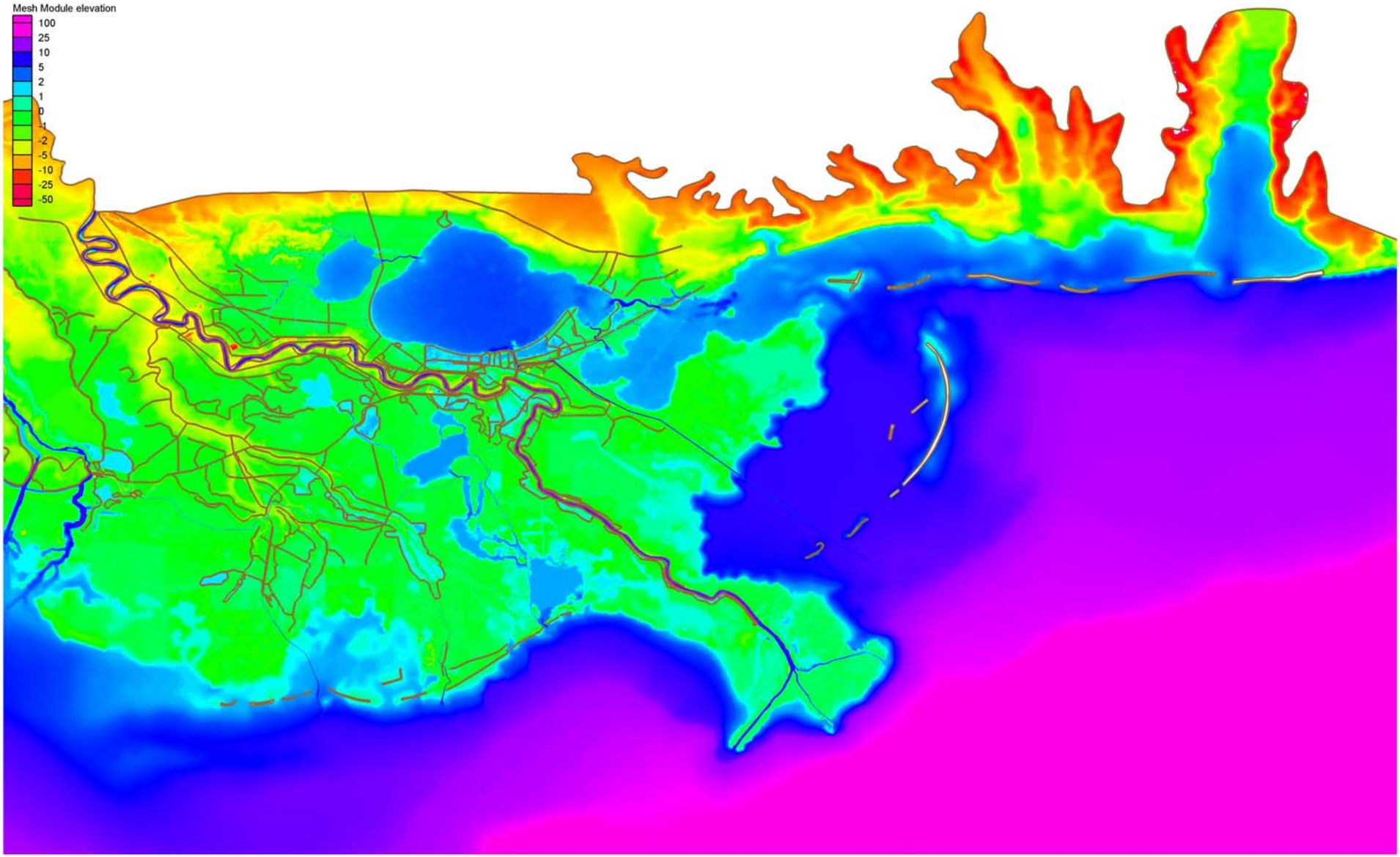


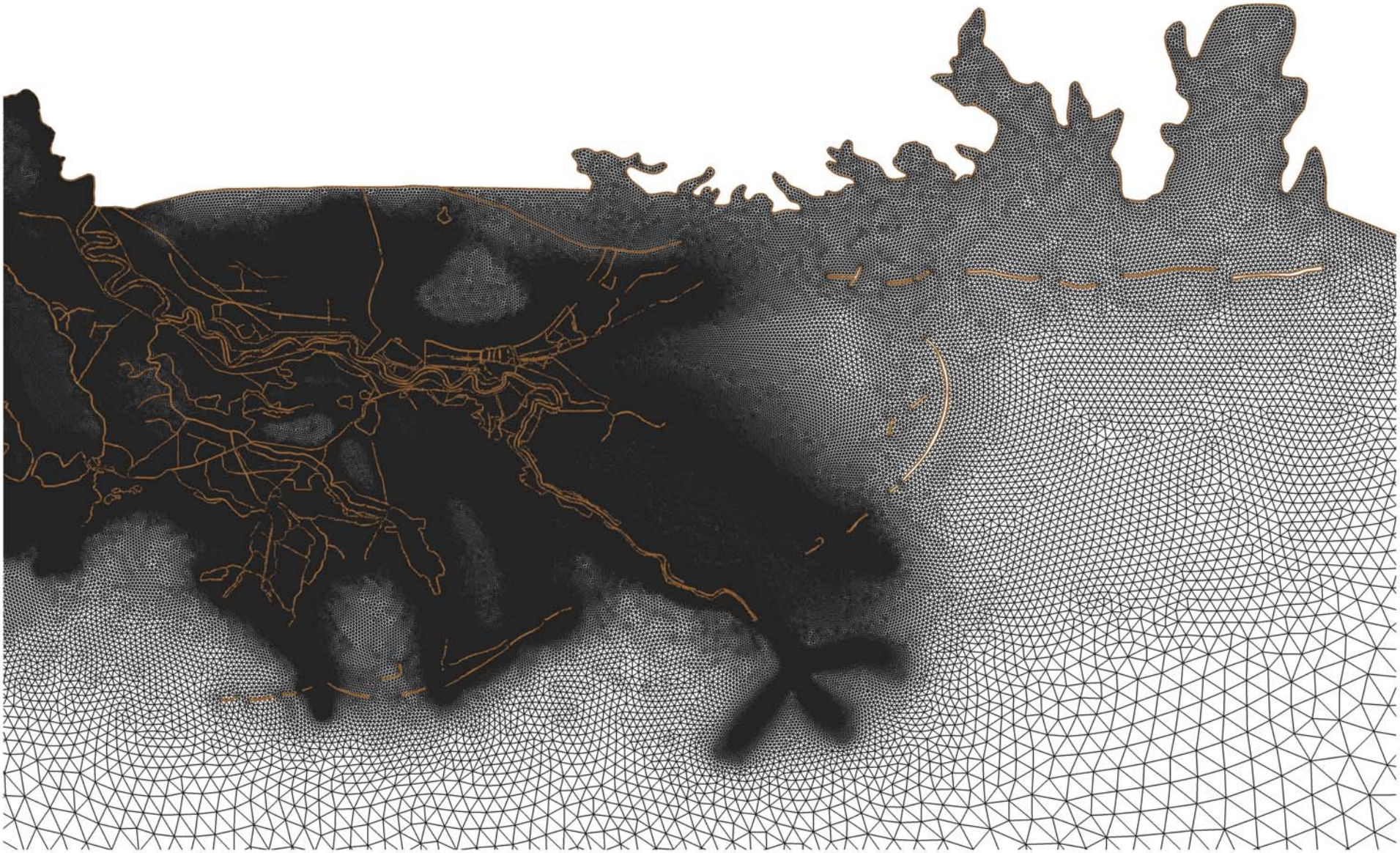
S12 Grid

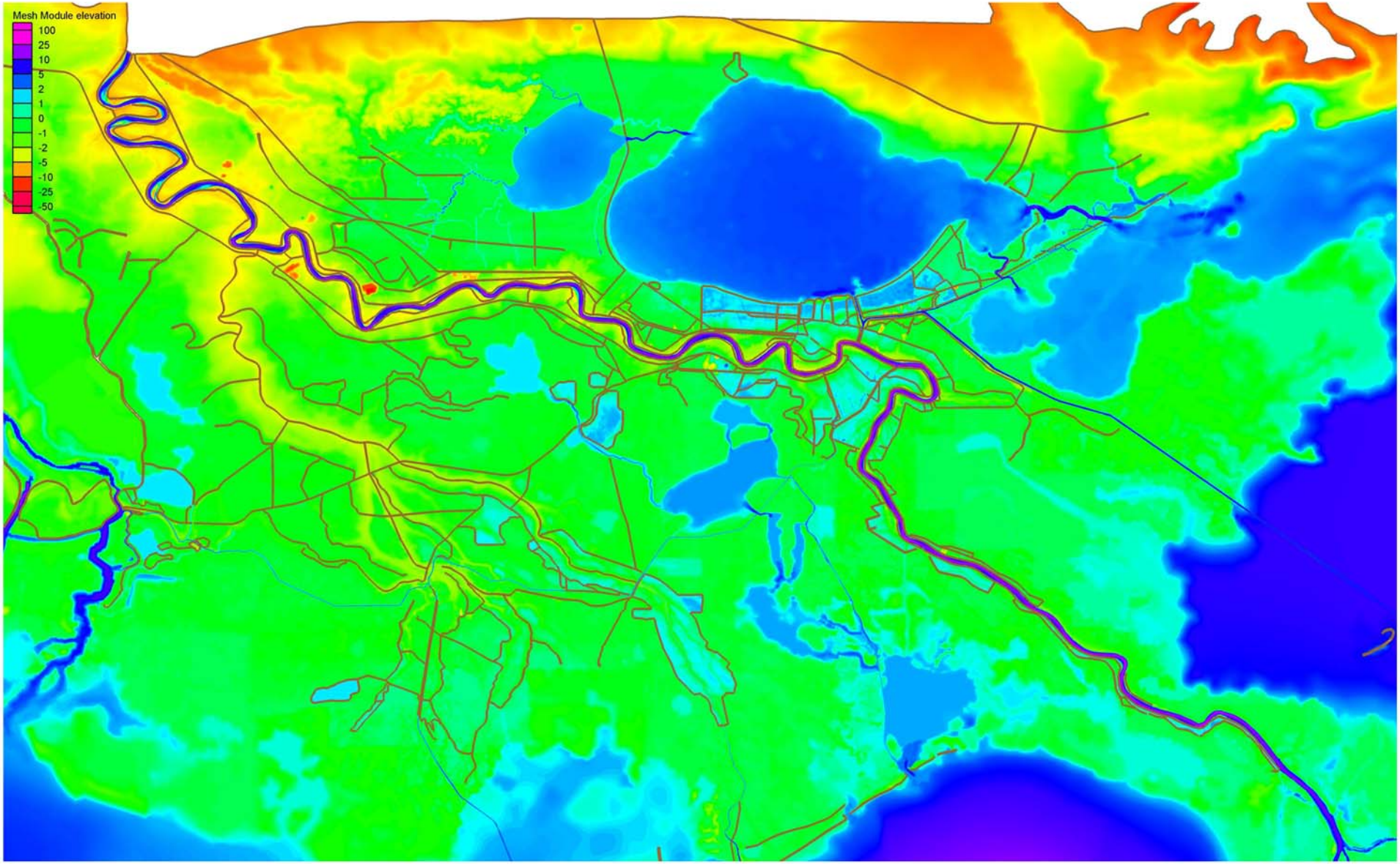
- Add north shore of Lake Pontchartrain, Mississippi coast and Alabama coast including Mobile Bay
- Add detail from area east of the Atchafalaya Basin to east of the Mississippi river
- Resolution down to 60 m
- Feature definition if significantly improved over S08
- Bathymetry is Lidar/USGS DEM based
- This model is running and undergoing final checks for levee crown heights

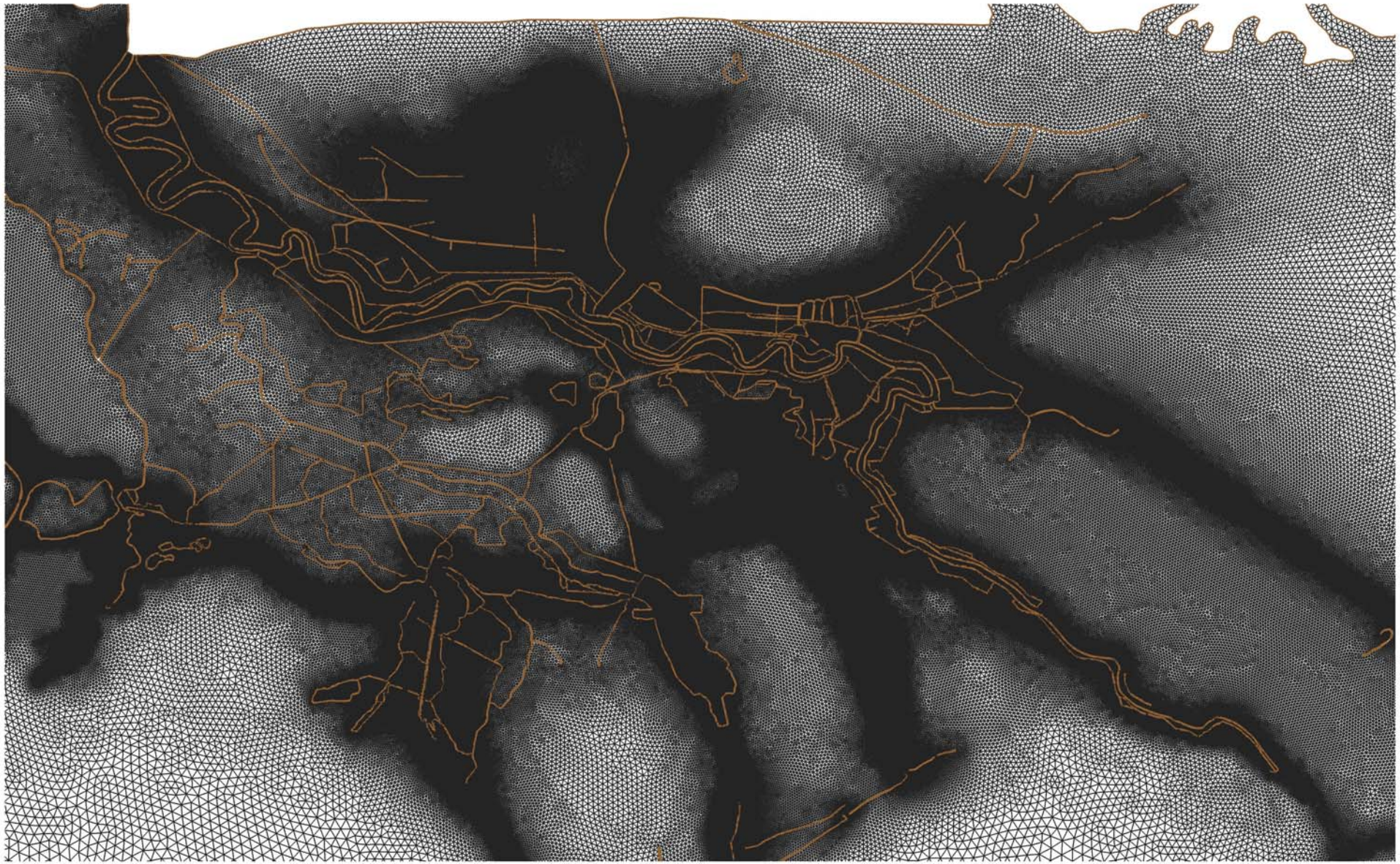

Mesh Module elevation
100
25
10
5
2
1
0
-1
-2
-5
-10
-25
-50




Mesh Module elevation
100
25
10
5
2
1
0
-1
-2
-5
-10
-25
-50




Mesh Module elevation
100
25
10
5
2
1
0
-1
-2
-5
-10
-25
-50

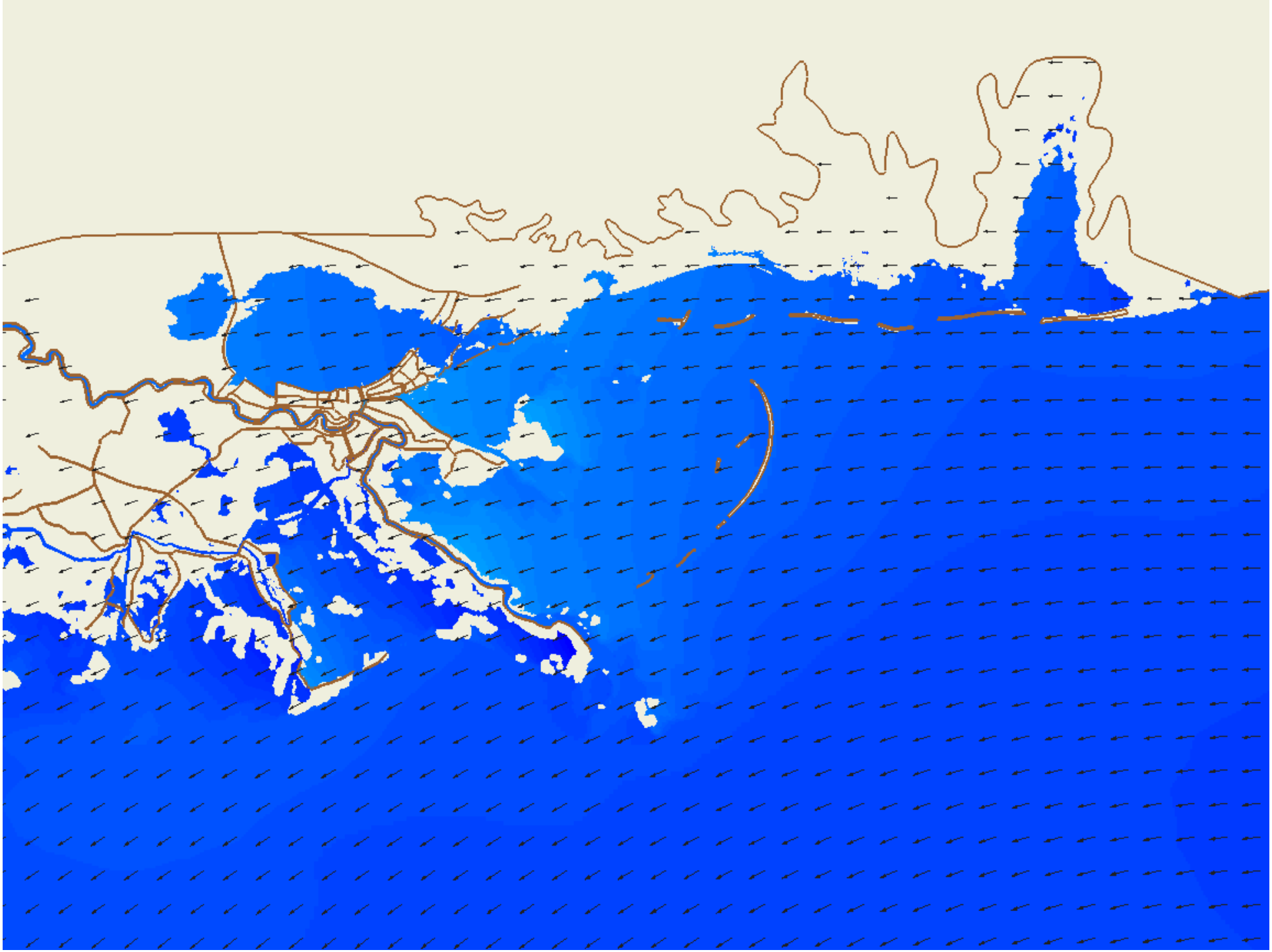


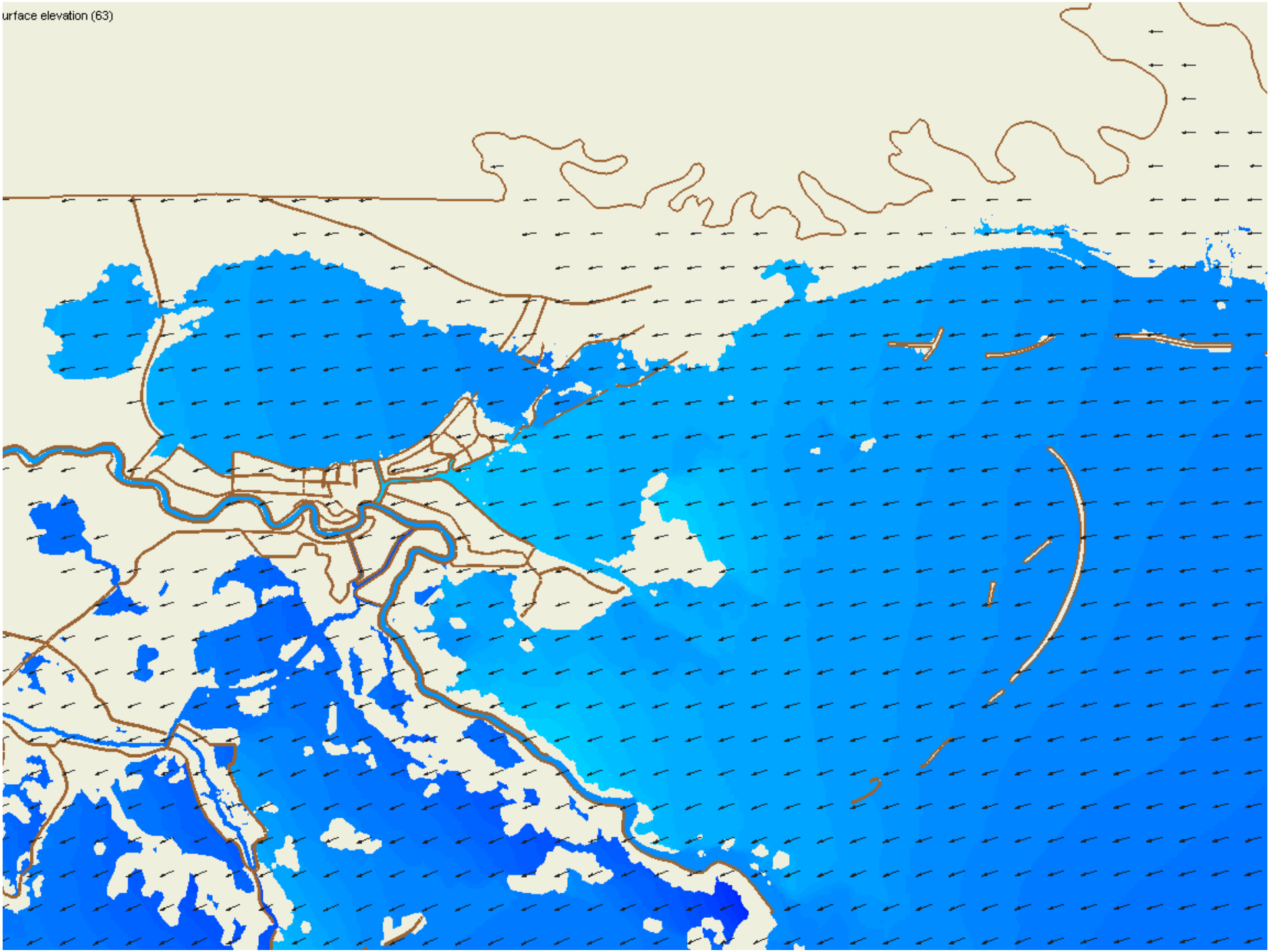
Model Refinements

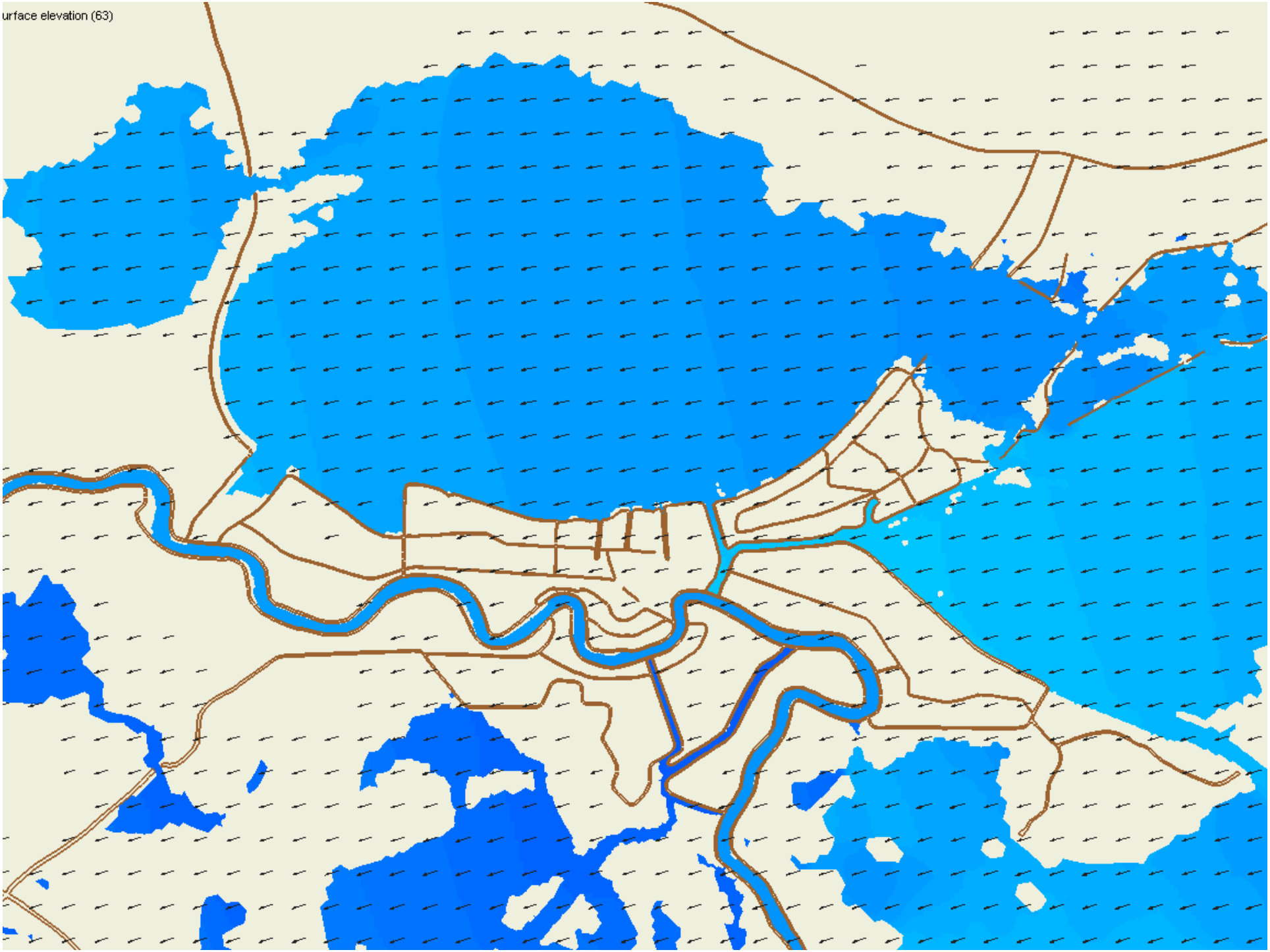
- Missing wave effects
- Couple to wave model
  - Wave radiation stress
  - Modify bottom stress
  - Compute air-sea drag coefficient using wave steepness

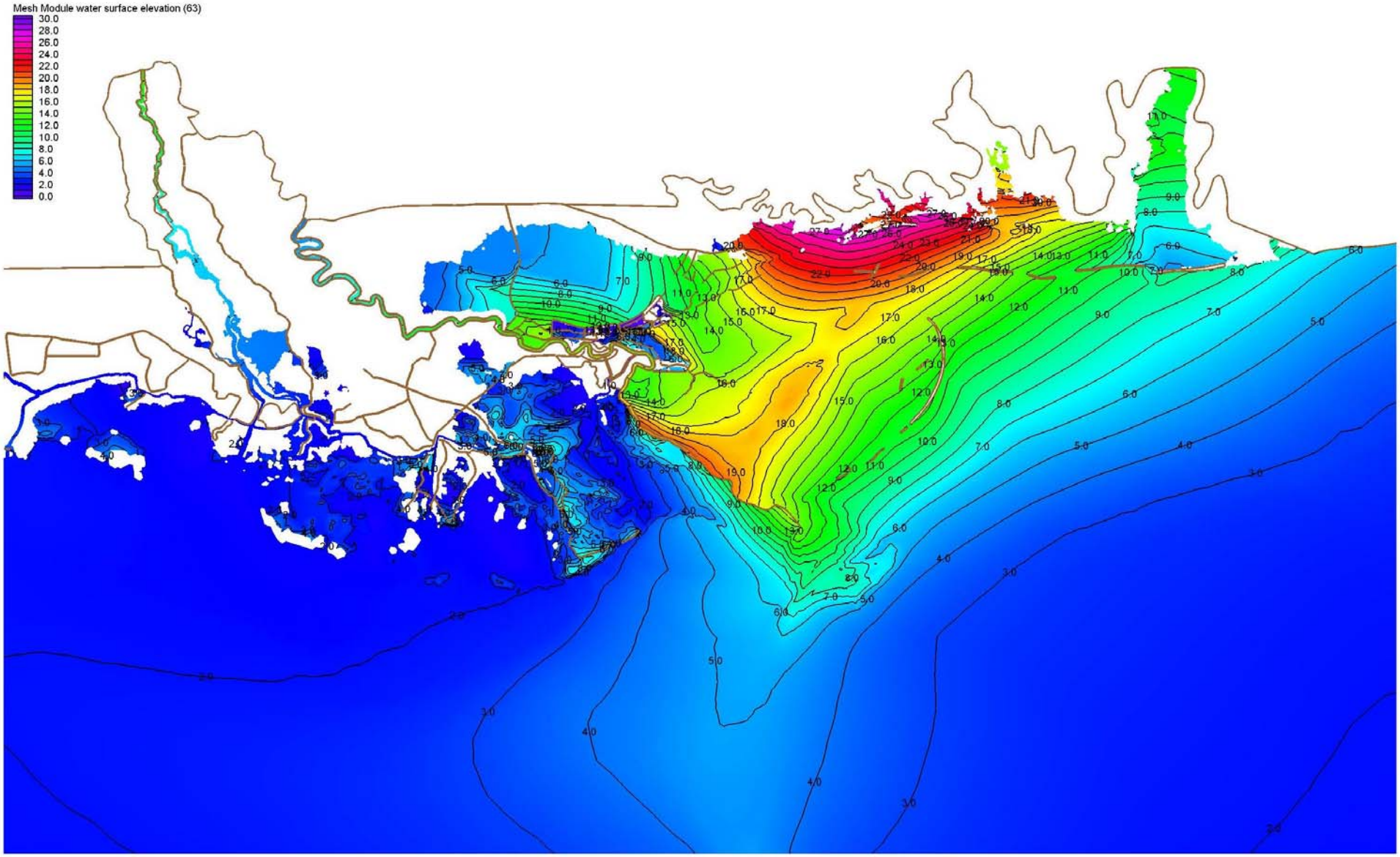
Hurricane Katrina Hindcasts

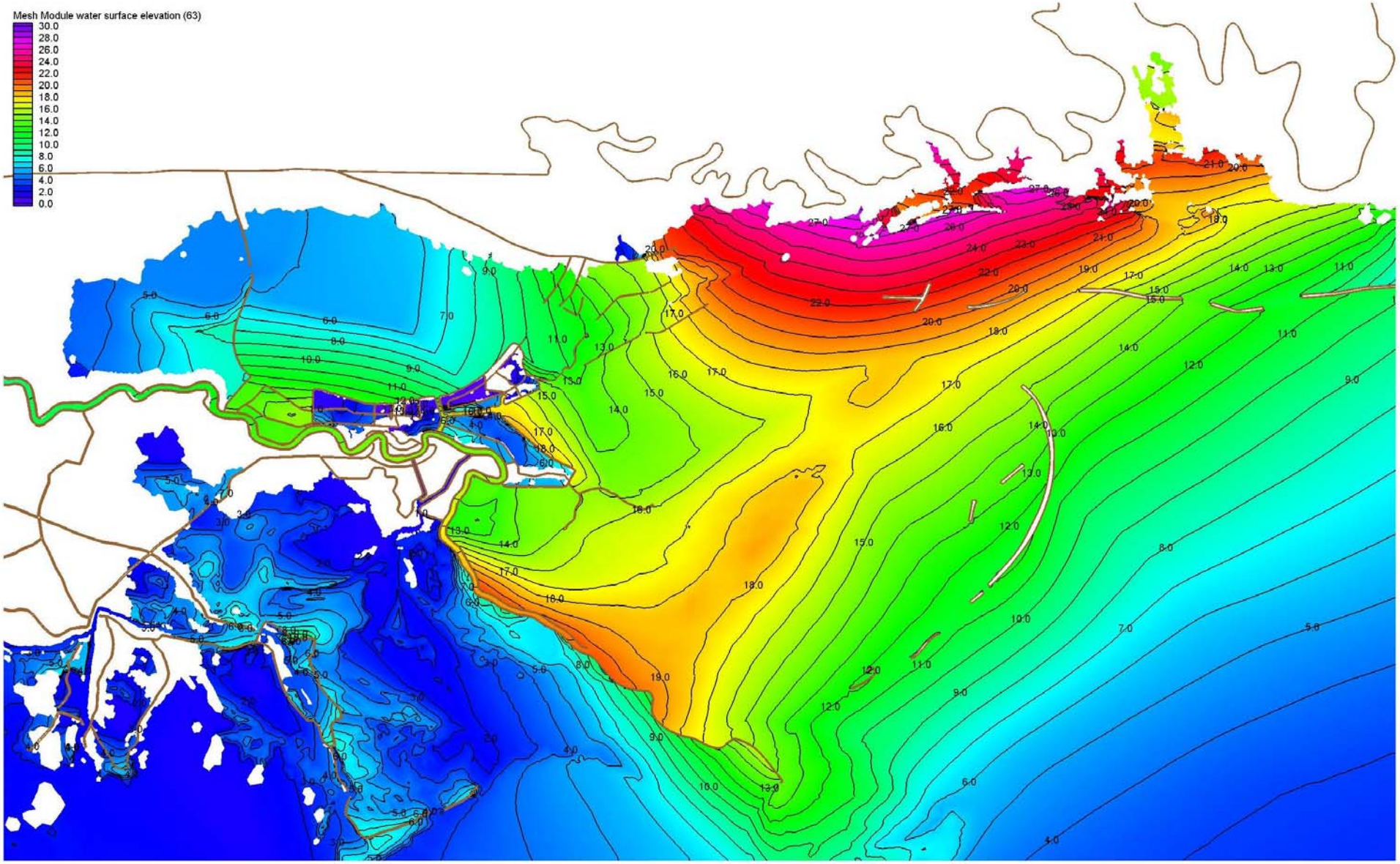
- TF01 grid is being used to hindcast Hurricane Katrina
  - PBL and NOAA-HRD H*Wind winds were applied
  - Currently obtaining preliminary estimates of wave radiation stresses

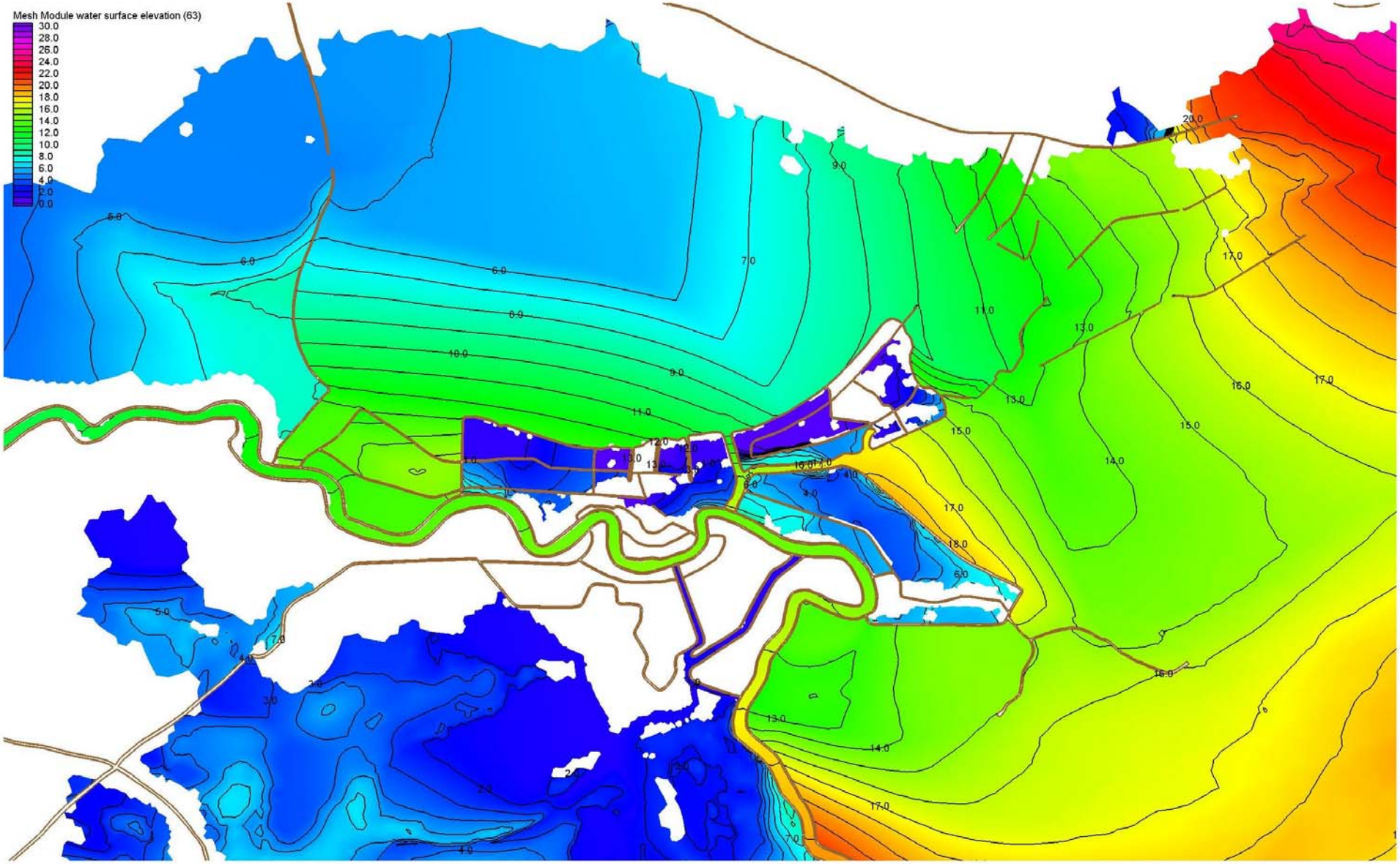


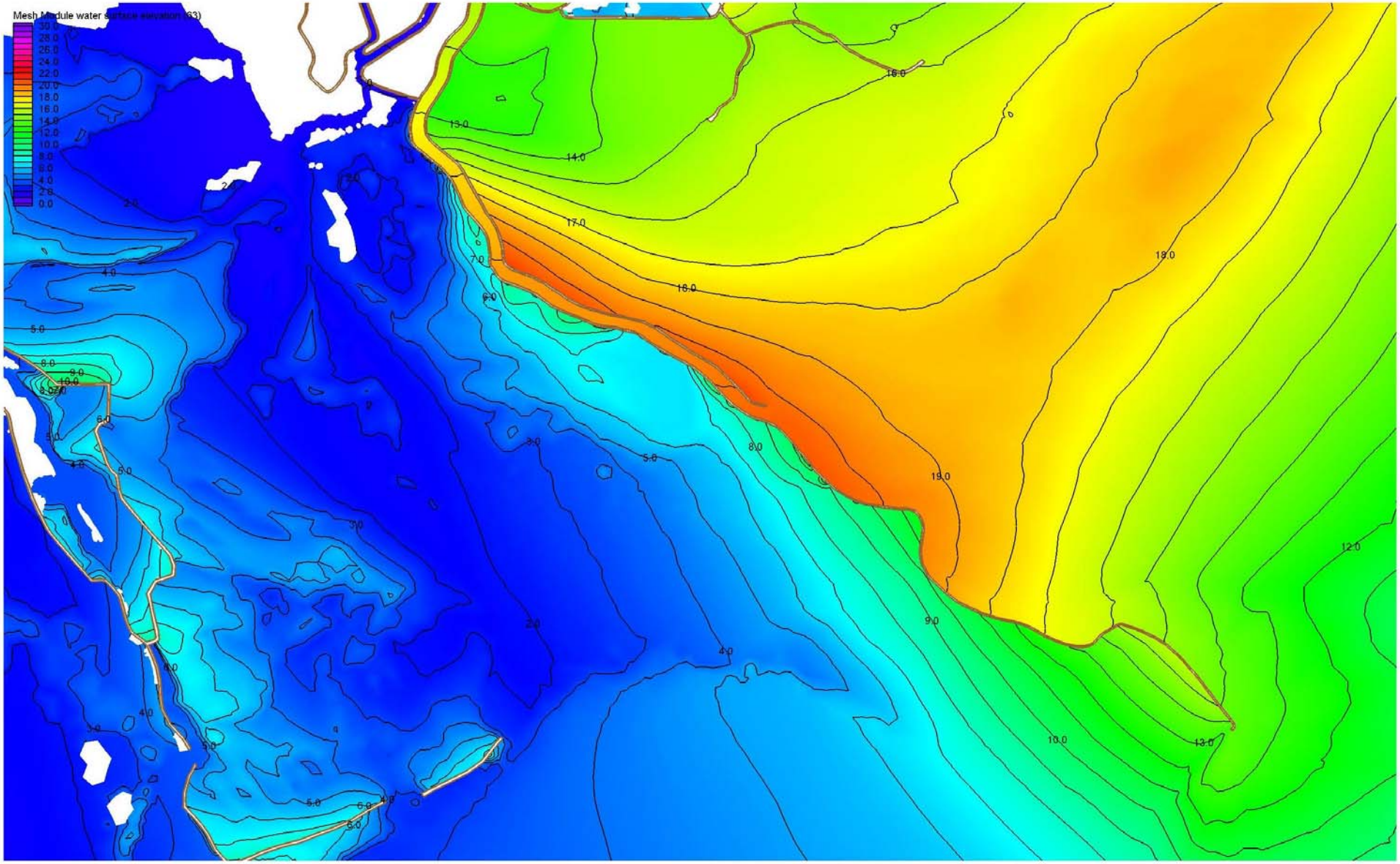

urface elevation (63)


urface elevation (63)


Mesh Module water surface elevation (63)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0

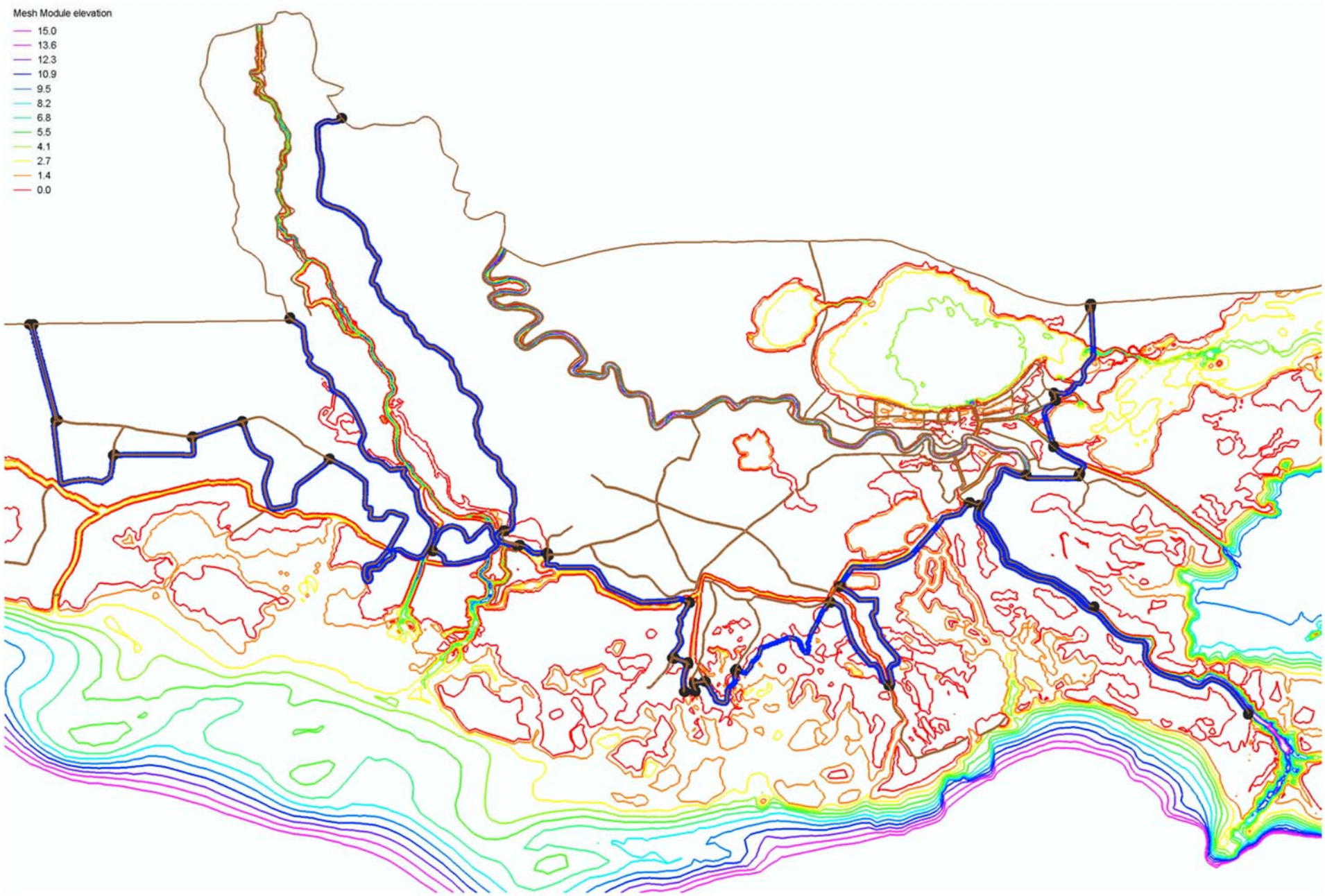

Mesh Module water surface elevation (63)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0

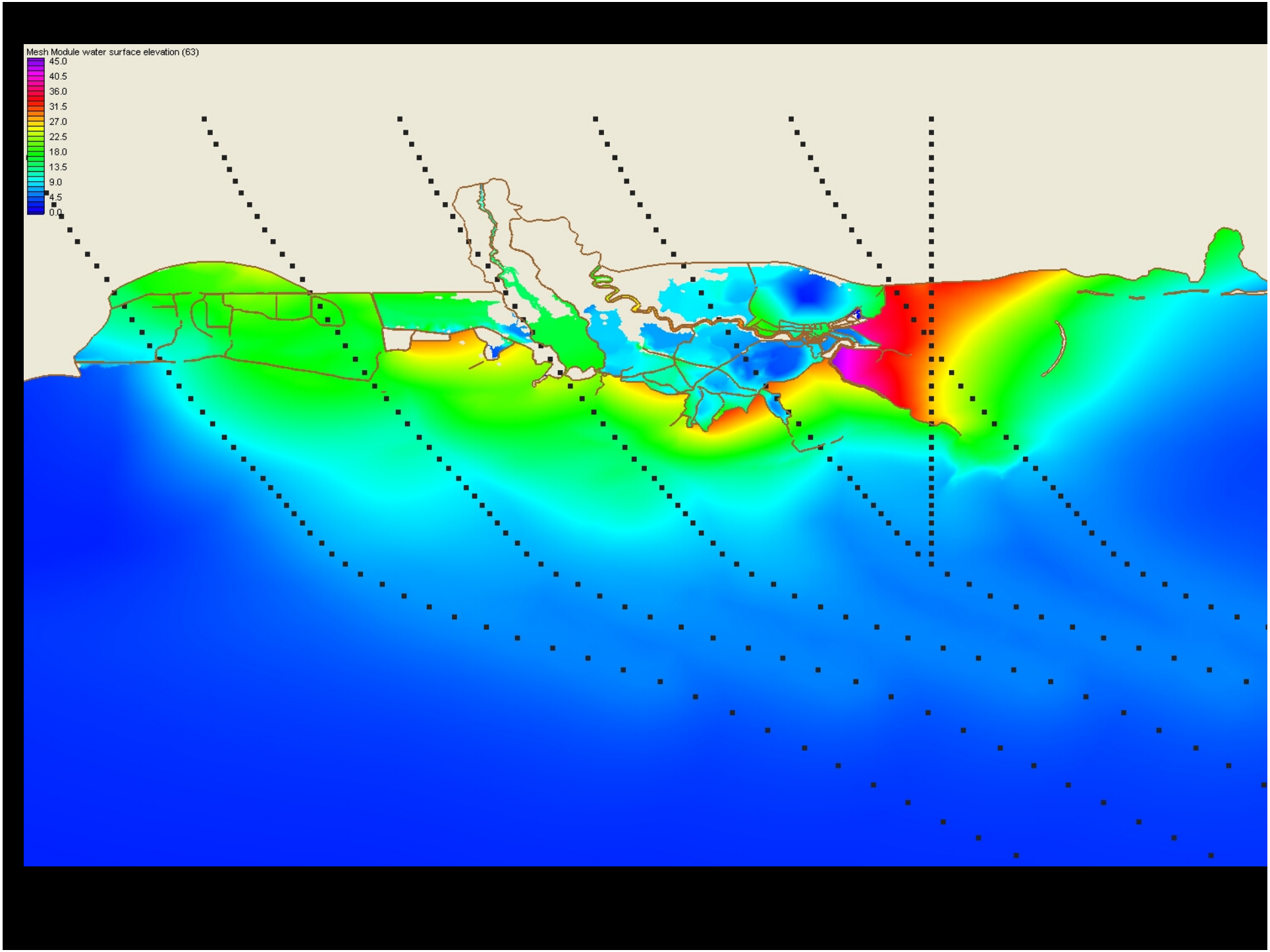

Mesh Module water surface elevation (63)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0

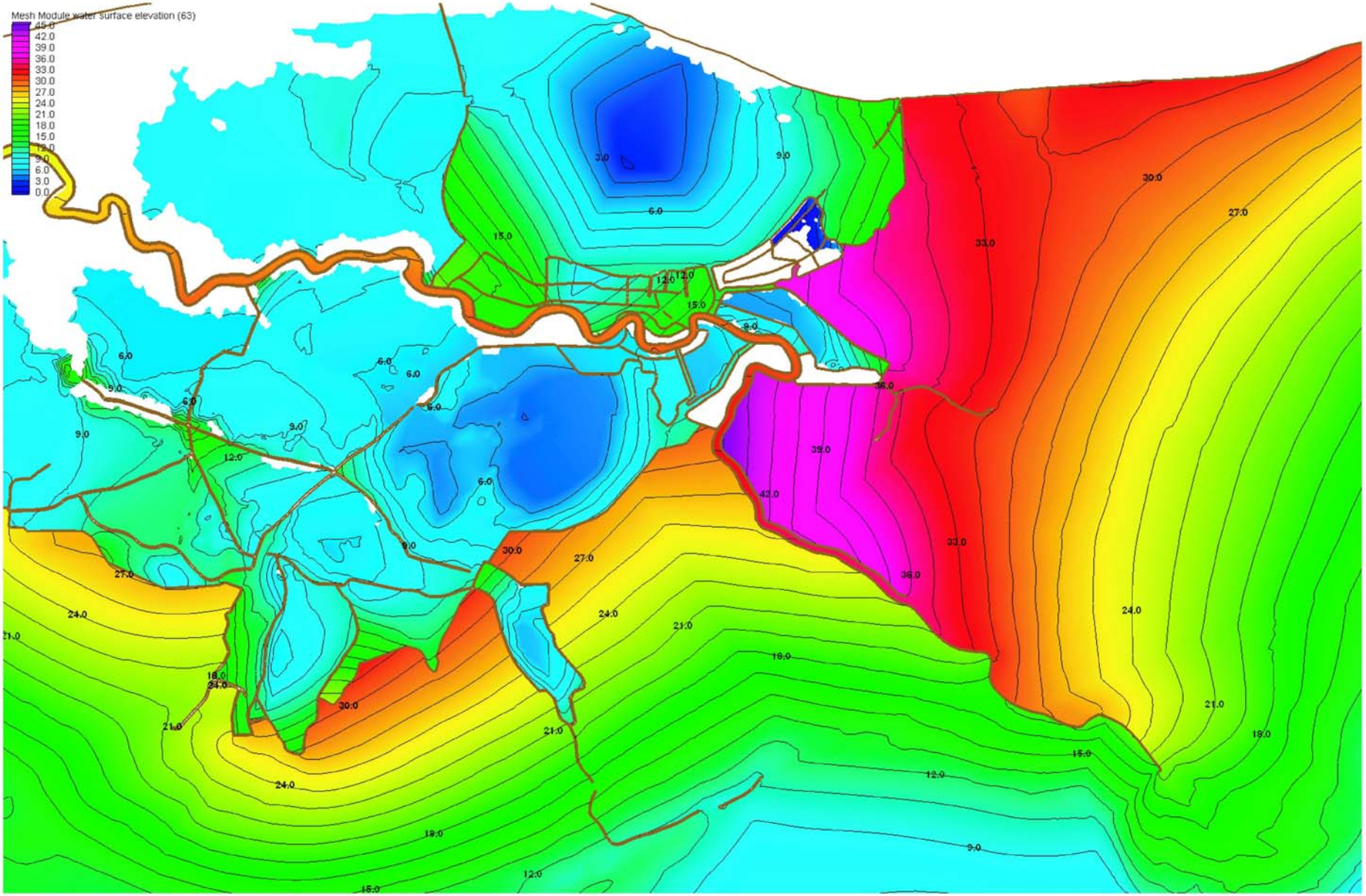

Mesh Module water surface elevation (63)
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0

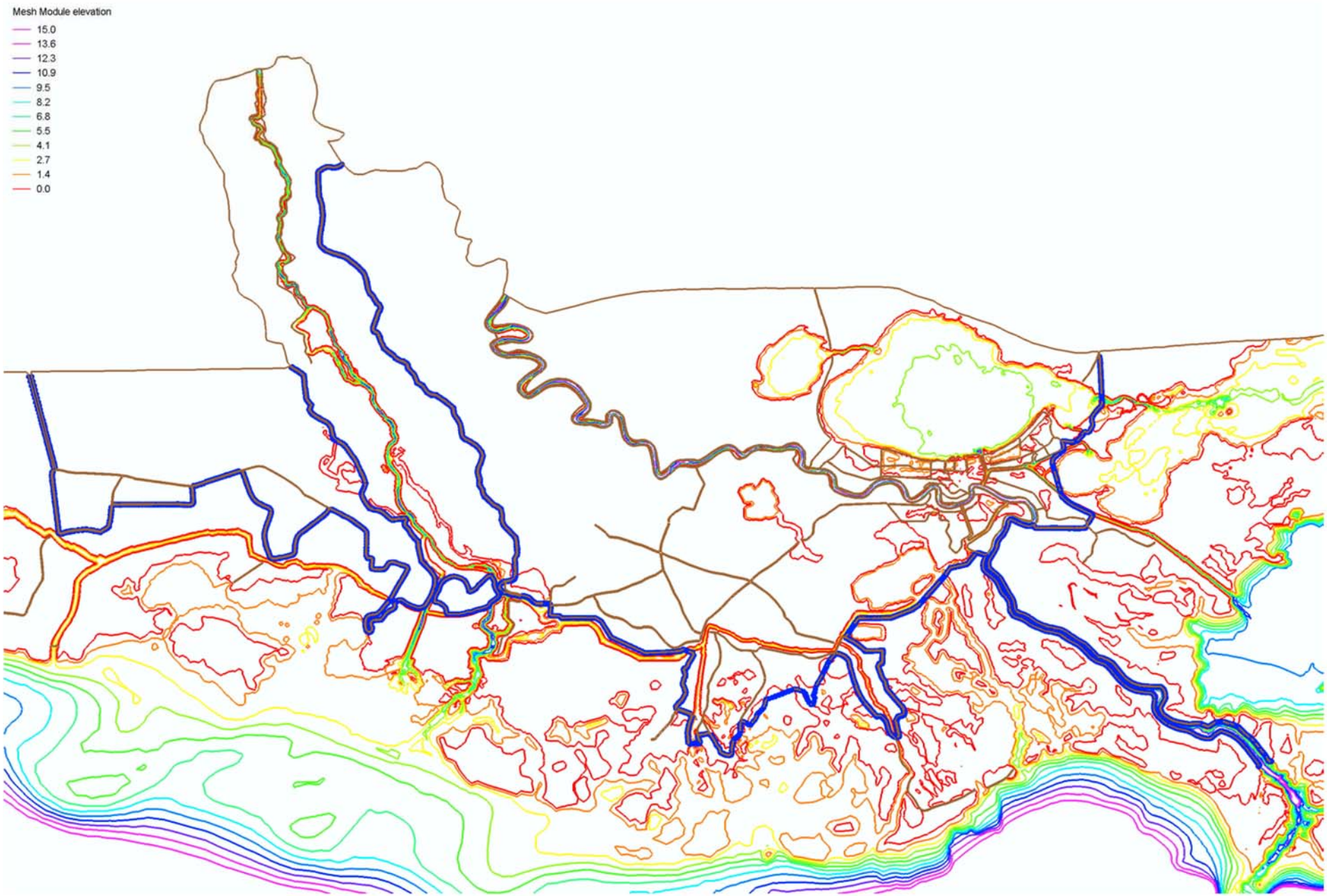
Category 5 Protection Systems

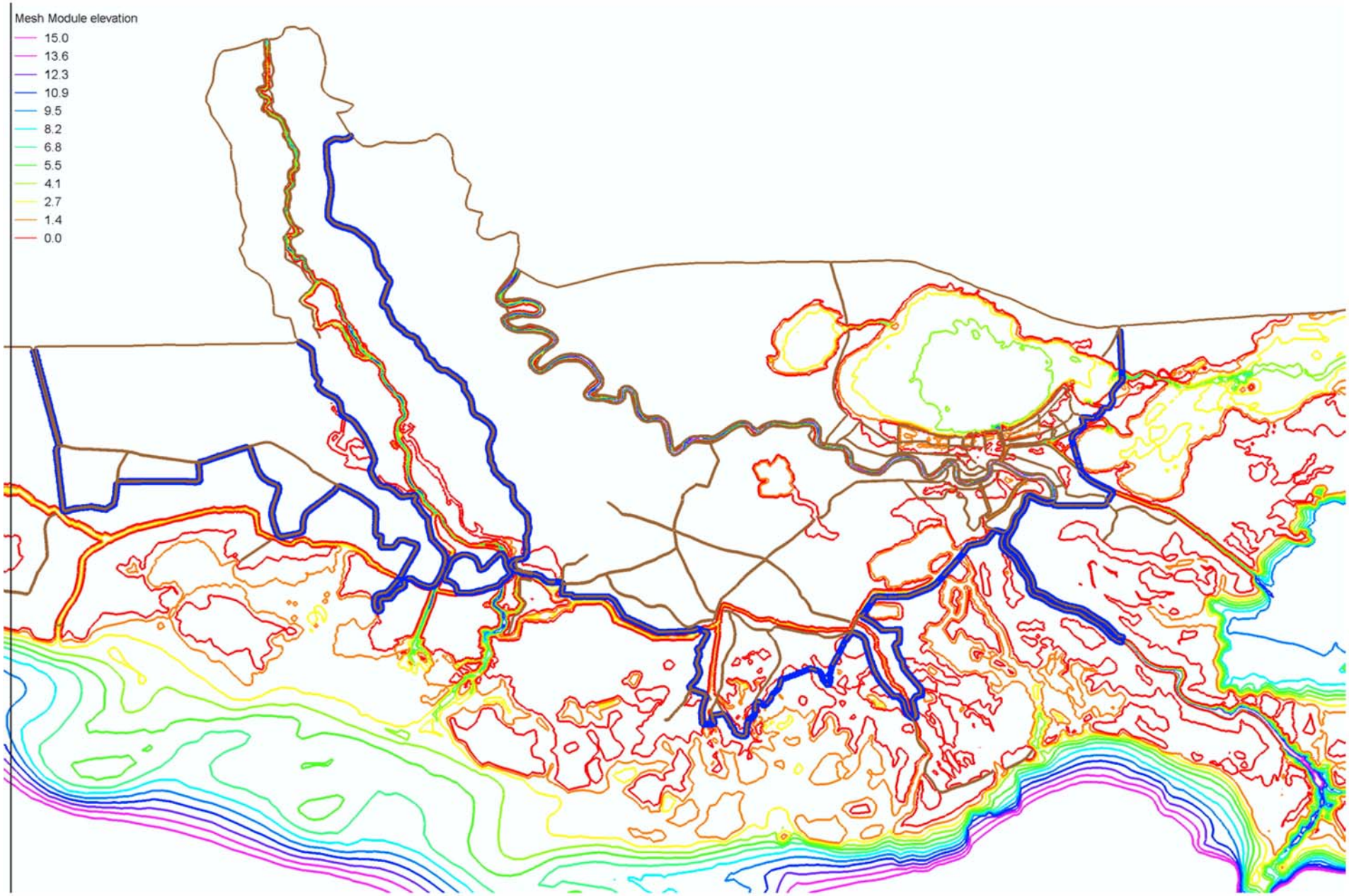
- System 1 is current design
- System 2 adds an east levee to the Mississippi River
- System 3 eliminates the west levee on the Mississippi River
- System 4 extends protection seaward and elliminates concavities
- System 5 exends protection further seaward towards deeper waters

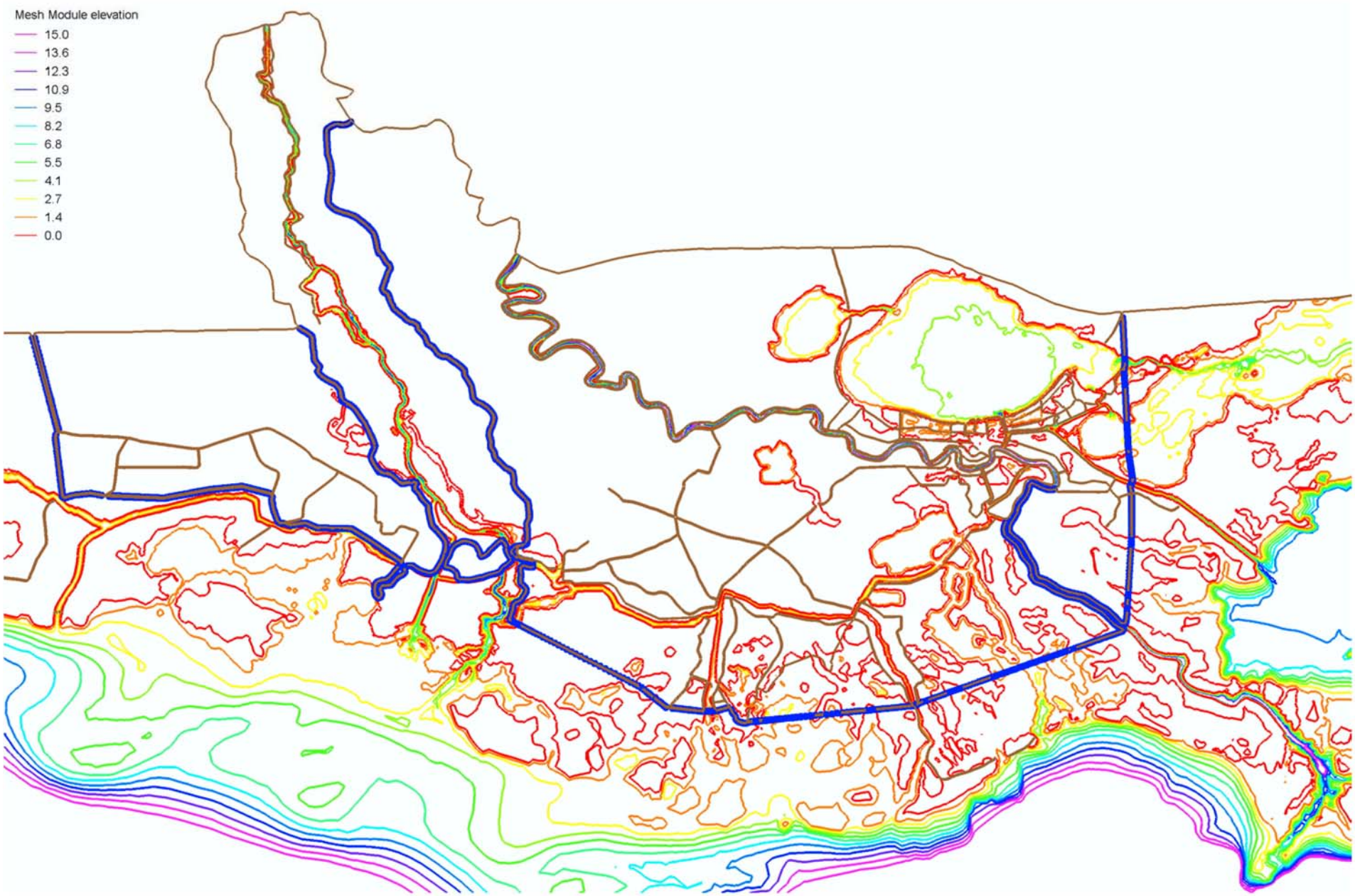

Mesh Module elevation
15.0
13.6
12.3
10.9
9.5
8.2
6.8
5.5
4.1
2.7
1.4
0.0

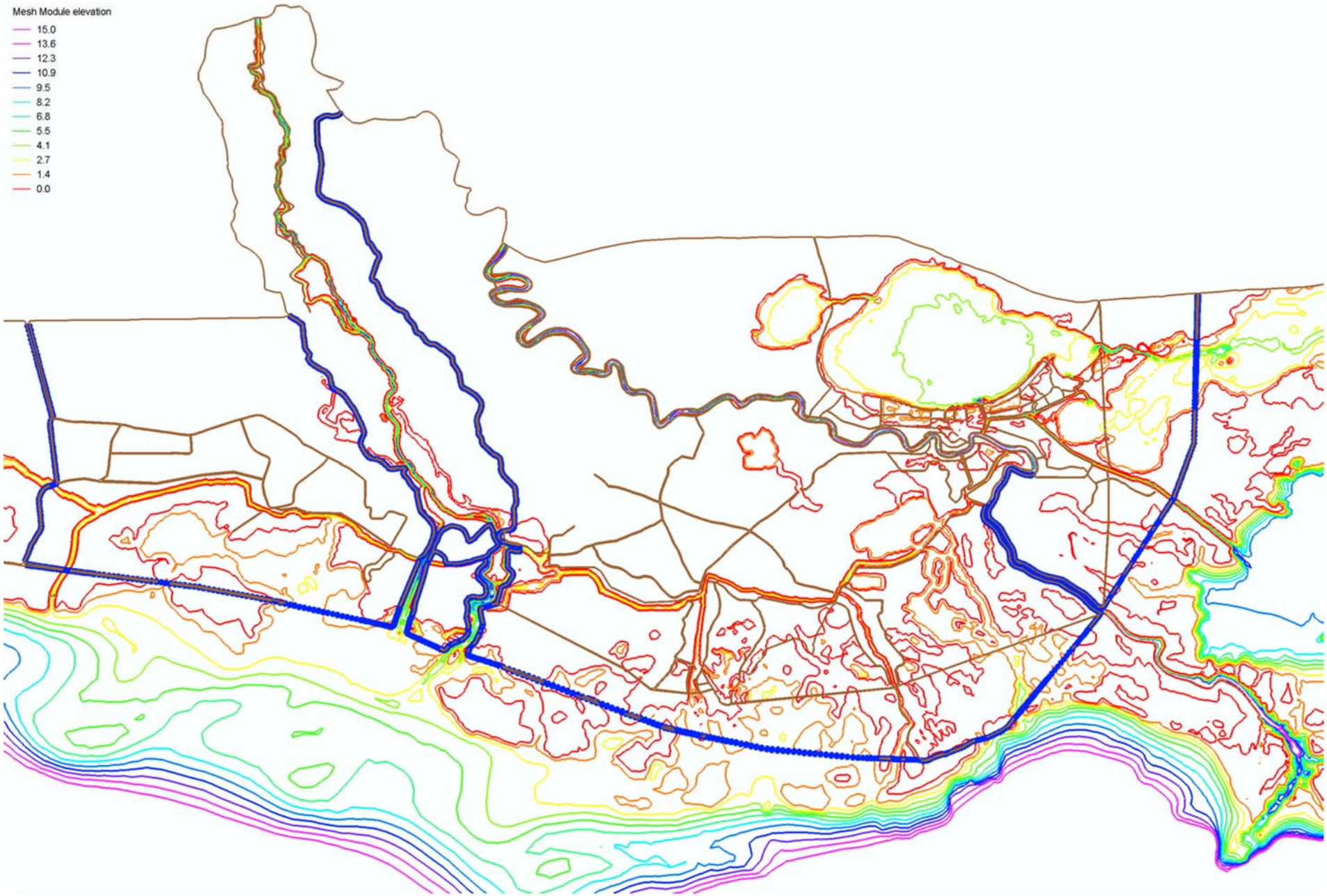

Mesh Module water surface elevation (63)
45.0
40.5
36.0
31.5
27.0
22.5
18.0
13.5
9.0
4.5
0.0


Mesh Module water surface elevation (63)
45.0
42.0
39.0
36.0
33.0
30.0
27.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0


Mesh Module elevation
15.0
13.6
12.3
10.9
9.5
8.2
6.8
5.5
4.1
2.7
1.4
0.0


Mesh Module elevation
15.0
13.6
12.3
10.9
9.5
8.2
6.8
5.5
4.1
2.7
1.4
0.0


Mesh Module elevation
15.0
13.6
12.3
10.9
9.5
8.2
6.8
5.5
4.1
2.7
1.4
0.0


Mesh Module elevation
15.0
13.6
12.3
10.9
9.5
8.2
6.8
5.5
4.1
2.7
1.4
0.0

ISS007E14745

TITLE: Storm Surge Prediction (SLOSH)

PRESENTED BY: Wilson Shaffer, National Weather Service

SUMMARY: When forecasting hurricane landfalls and storm surges, the margin of error in the National Hurricane Center's (NHC) forecasts must be incorporated in the predictions. For example, 12 hours before Hurricane Ivan was forecast to make landfall west of Mobile Bay. However, Ivan tracked about 30 miles to the east, and was larger than the size used in the National Hurricane Center's operational SLOSH model run. As a result, a completely different flooding pattern occurred.

For support comprehensive hurricane evacuation planning, the SLOSH model has been run for the New Orleans area in a simulation study mode, with surges computed for thousands of hypothetical hurricanes. From these studies, NHC generates composites referred to as MEOWs (Maximum Envelopes of Water) and MOMs (Maximum of the MEOWs). The MEOW gives the potential flooding for an approaching hurricane with a given category, forward speed, land falling direction, and tide level, combining hurricanes of various landfall locations. The MOM combines MEOWs to give the possible flooding for a given category of hurricane. The landfall direction dependence of the New Orleans area for Category 5 hurricanes using SLOSH MEOWs was also presented.

Hurricane Protection Design Workshop

Vicksburg, MS

Dec. 20-21, 2005

Dr. Wilson (Will) Shaffer

NATIONAL WEATHER SERVICE

DEFINITIONS:

STORM SURGE is the increase in water level due to a storm (hurricane/typhoon/extratropical)

STORM TIDE is the total water level *ABOVE A REFERENCE DATUM* during a storm

= Astro Tide + STORM SURGE +ANOMALY

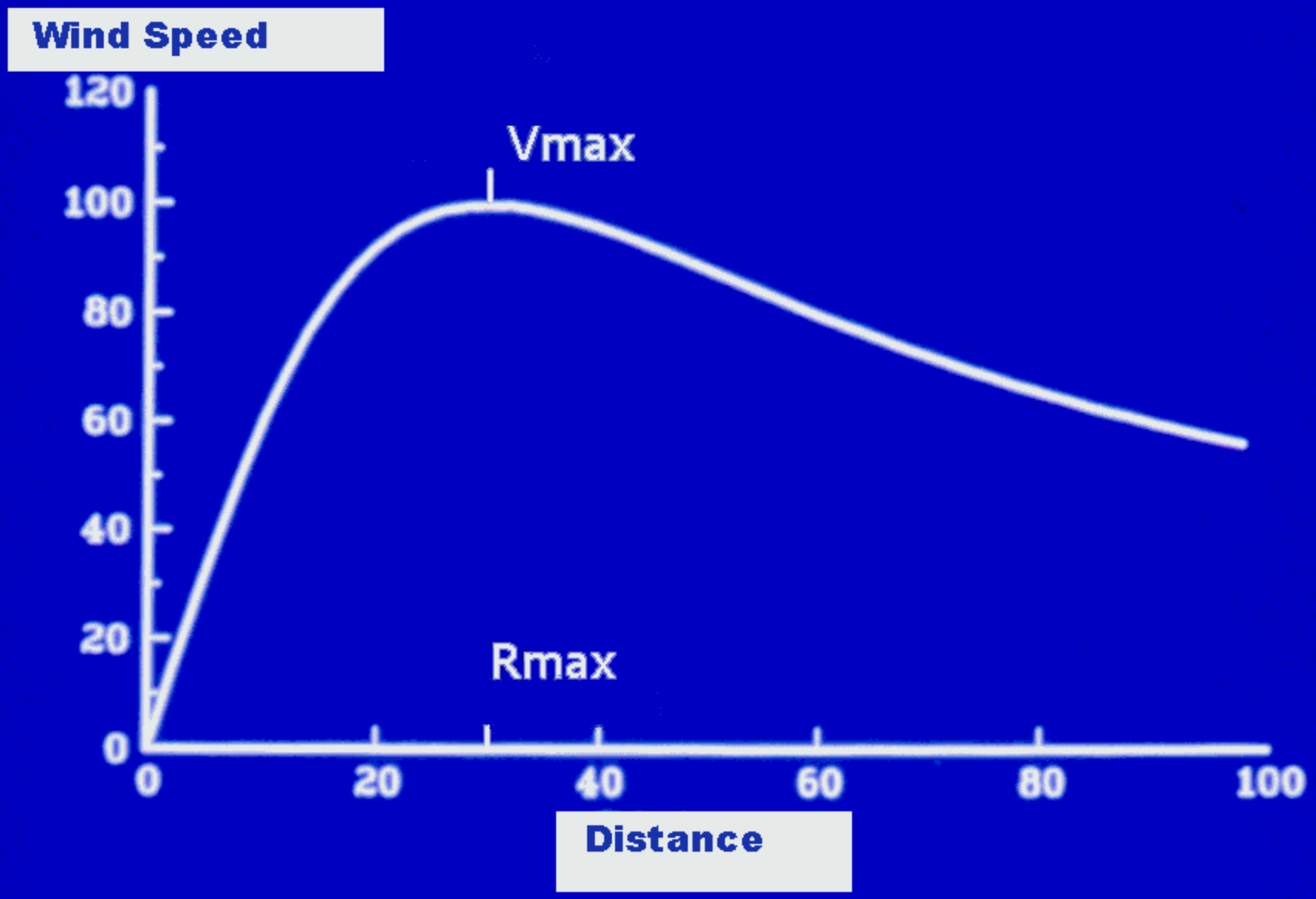
METEOROLOGICAL INPUT TO SLOSH

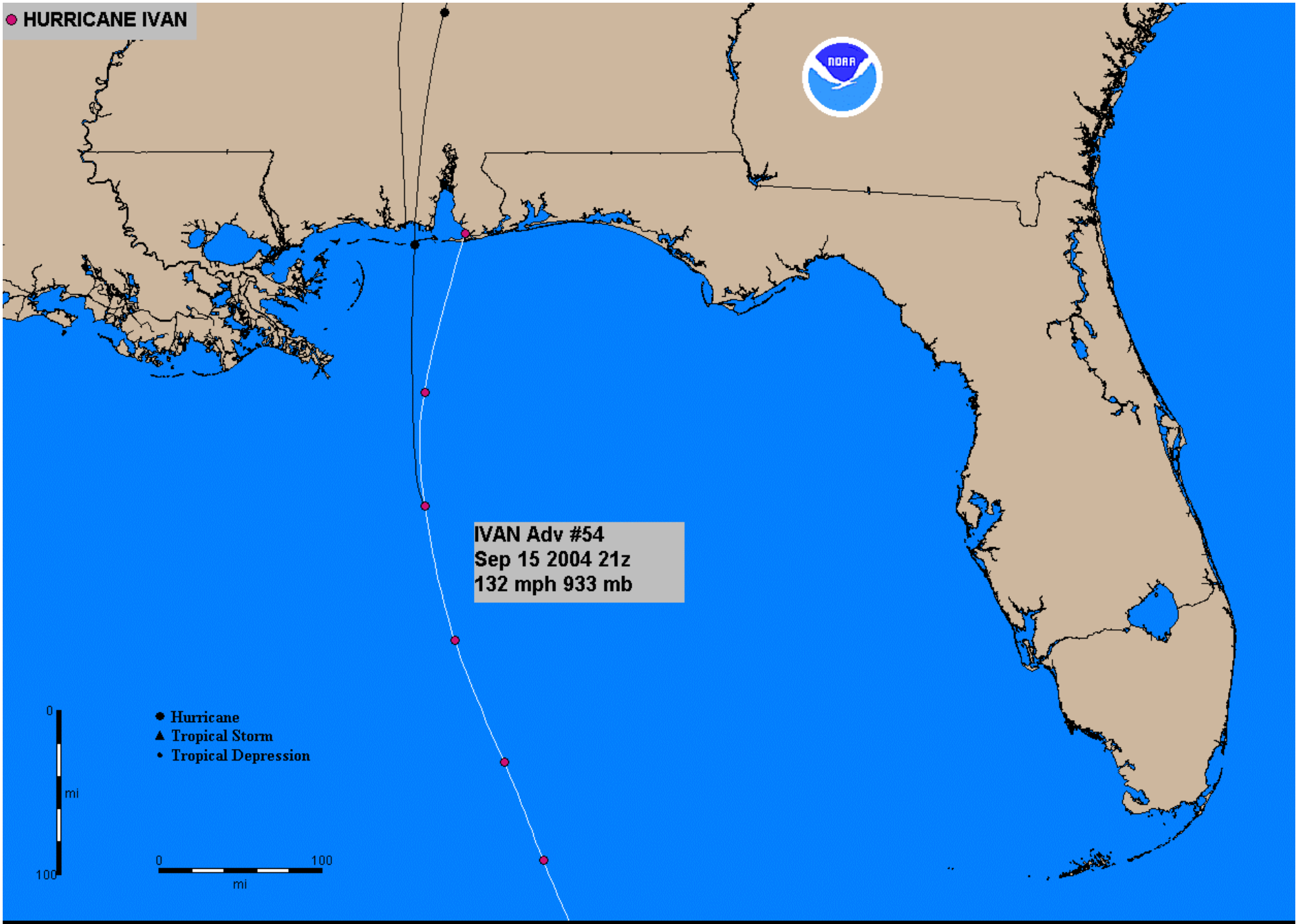
TRACK Positions - latitude & longitude

INTENSITY - (pressure drop)

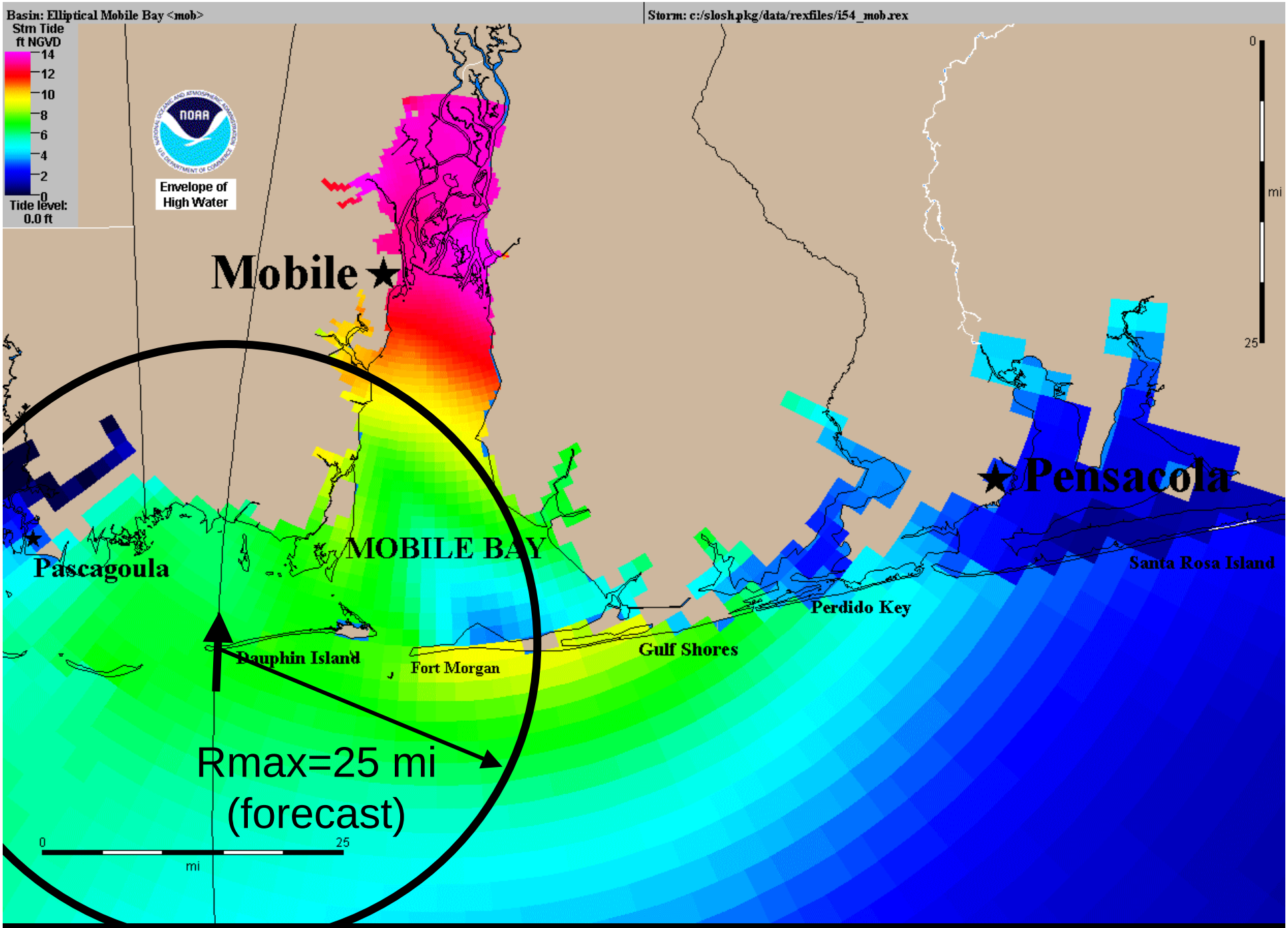
SIZE - Radius of maximum wind

SLOSH WIND PROFILE

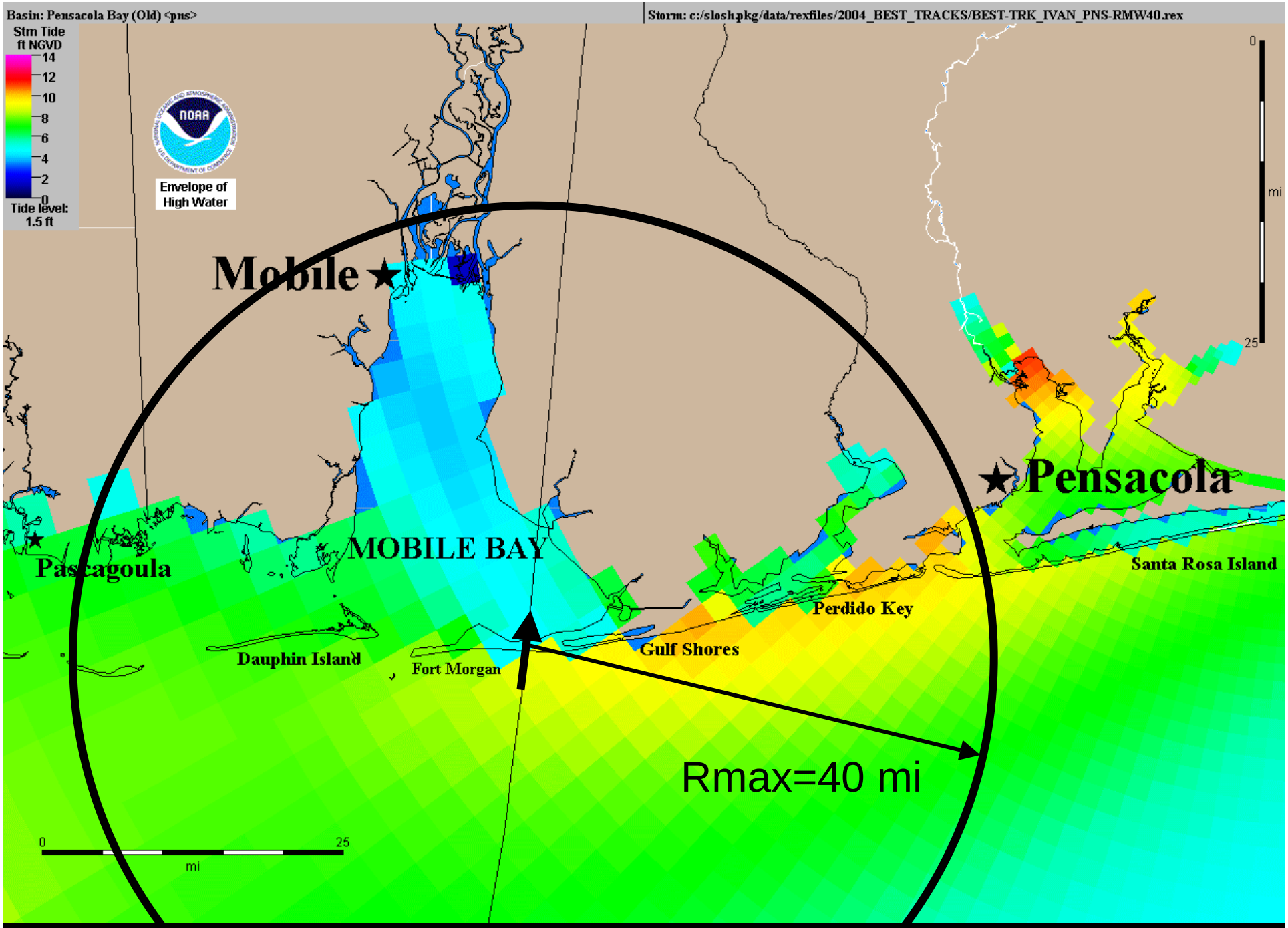




Hurricane Ivan – Actual Track 30 mi E of Adv 54 Forecast Track

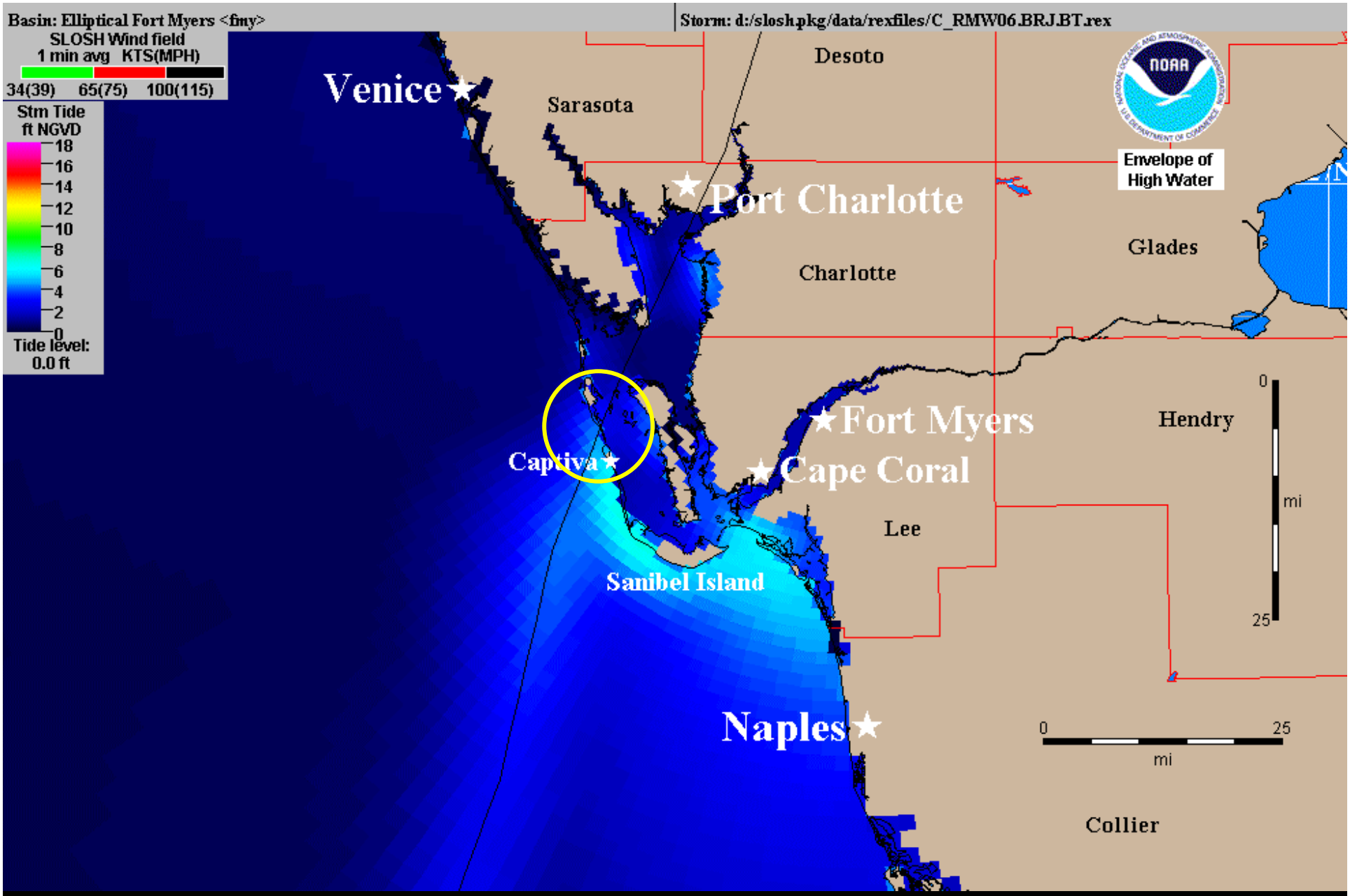


Surges based on NHC Advisory 54 for Ivan

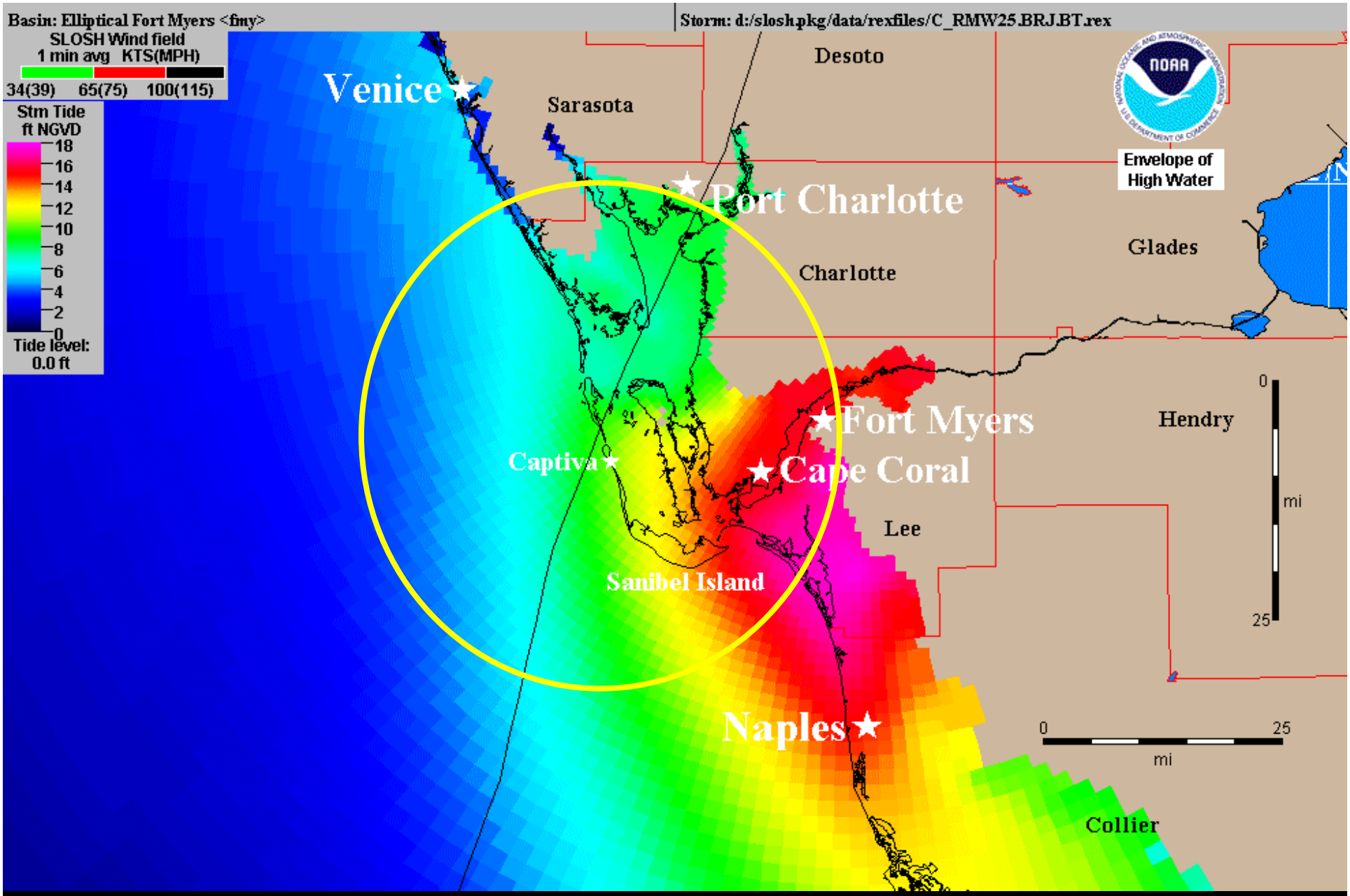


Surges based on NHC best track for Ivan

STORM SIZE MATTERS!

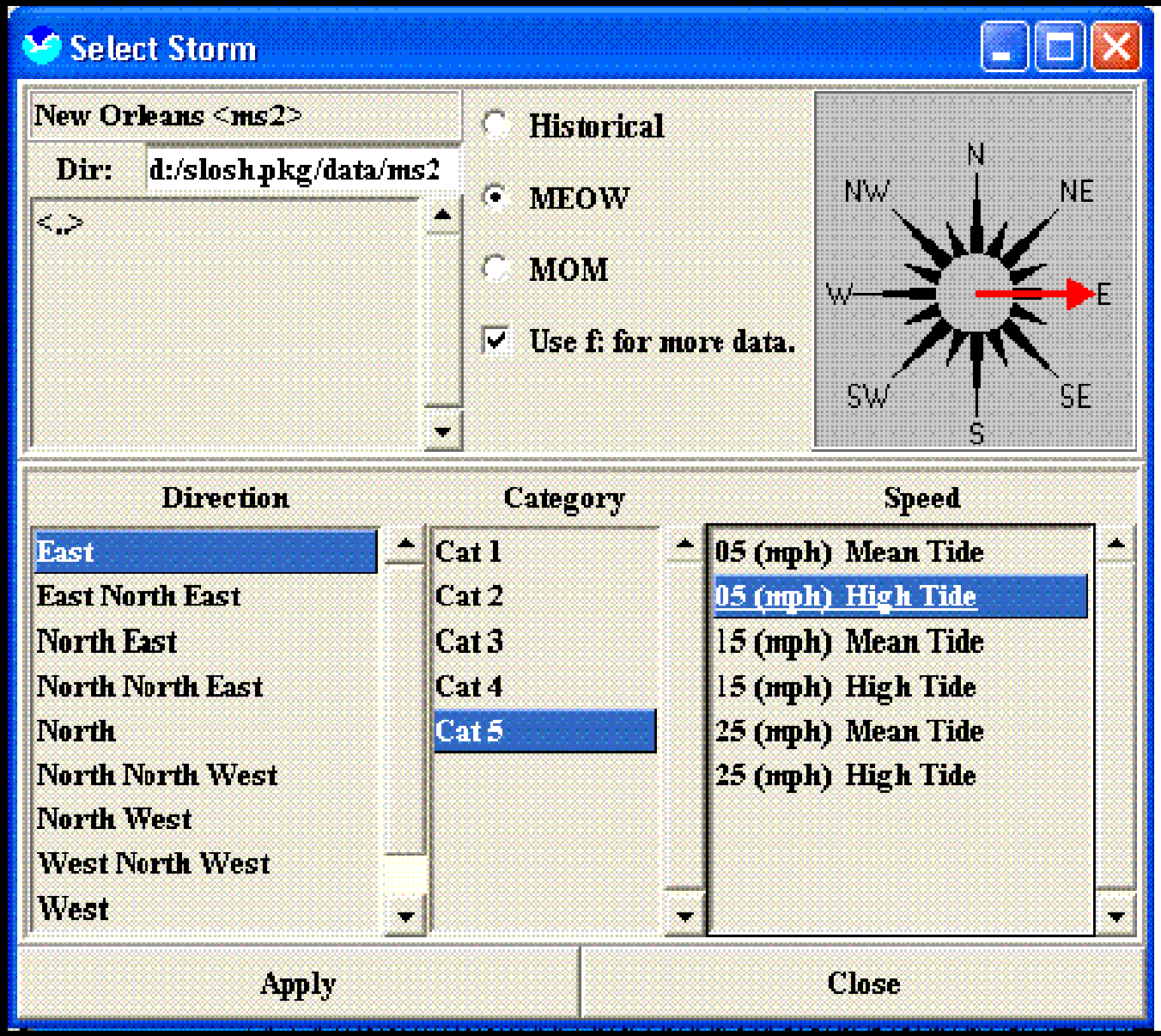

Basin: Elliptical Fort Myers <fmy>
Storm: d:/slosh.pkg/data/rexfiles/C_RMW06.BRJ.BT.rex
SLOSH Wind field
1 min avg KTS(MPH)
34(39) 65(75) 100(115)
Stm Tide
ft NGVD
18
16
14
12
10
8
6
4
2
0
Tide level:
0.0 ft
Venice
Sarasota
Desoto
Port Charlotte
Charlotte
Glades
Envelope of
High Water
Fort Myers
Cape Coral
Captiva
Sanibel Island
Lee
Hendry
Naples
Collier
0
25
mi

RMW=6

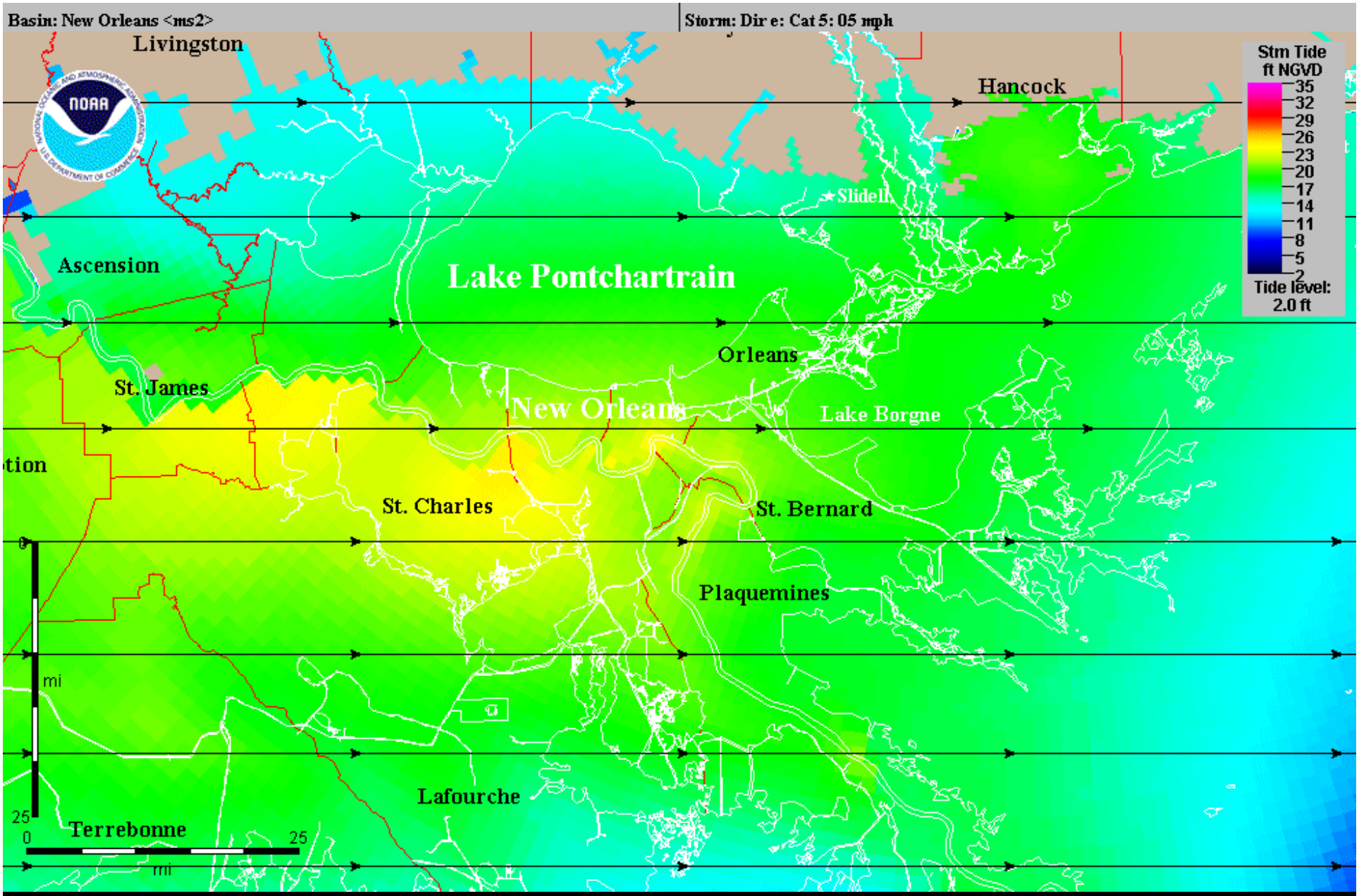


RMW=25 “Average” size

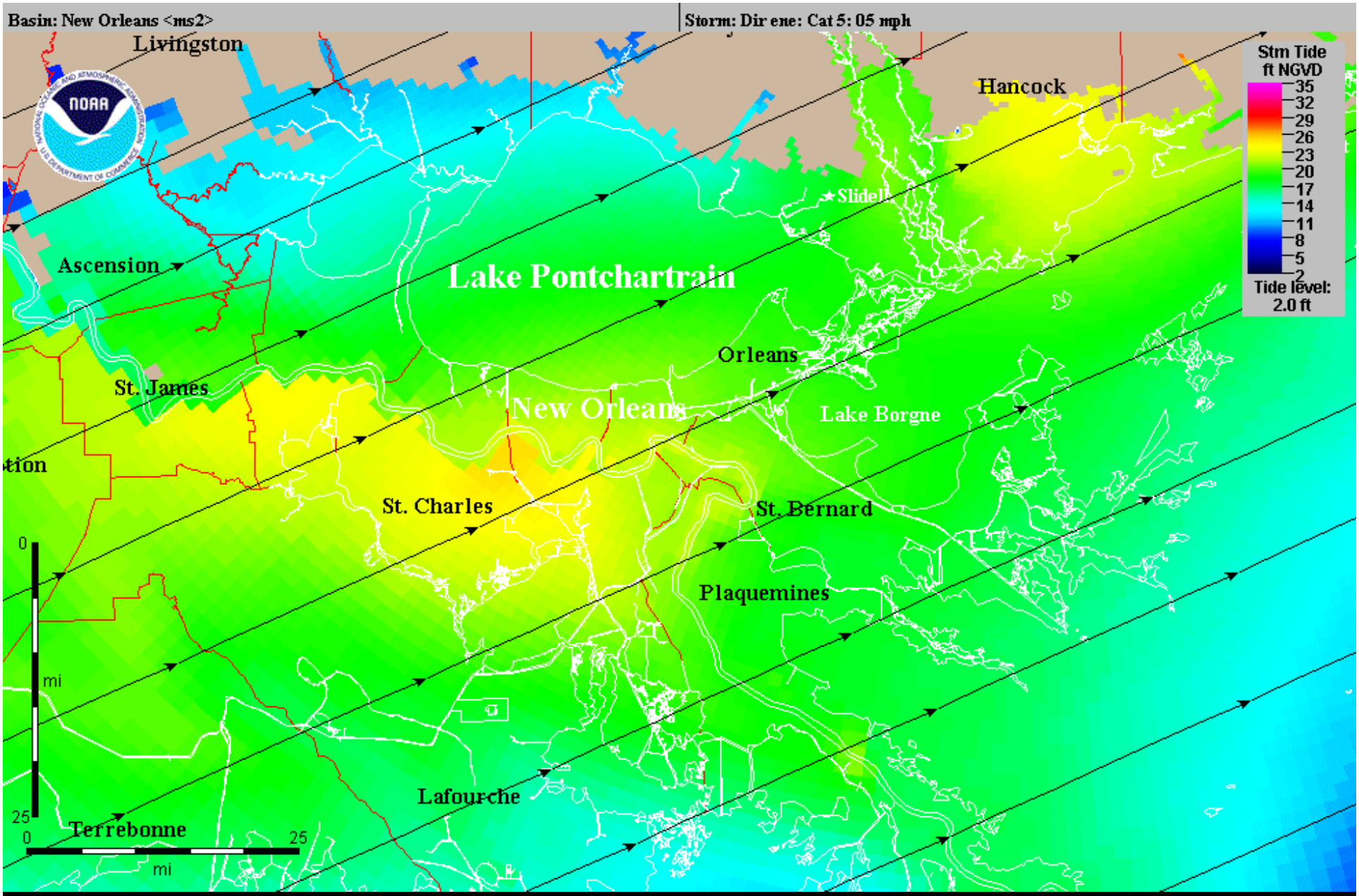
SLOSH Simulation Study for New Orleans


Select Storm
New Orleans <ms2>
Dir: d:/slosh.pkg/data/ms2
<..>
Historical
MEOW
MOM
Use f: for more data.
N
NW
NE
W
E
SW
SE
S
Direction
East
East North East
North East
North North East
North
North North West
North West
West North West
West
Category
Cat 1
Cat 2
Cat 3
Cat 4
Cat 5
Speed
05 (mph) Mean Tide
05 (mph) High Tide
15 (mph) Mean Tide
15 (mph) High Tide
25 (mph) Mean Tide
25 (mph) High Tide
Apply
Close

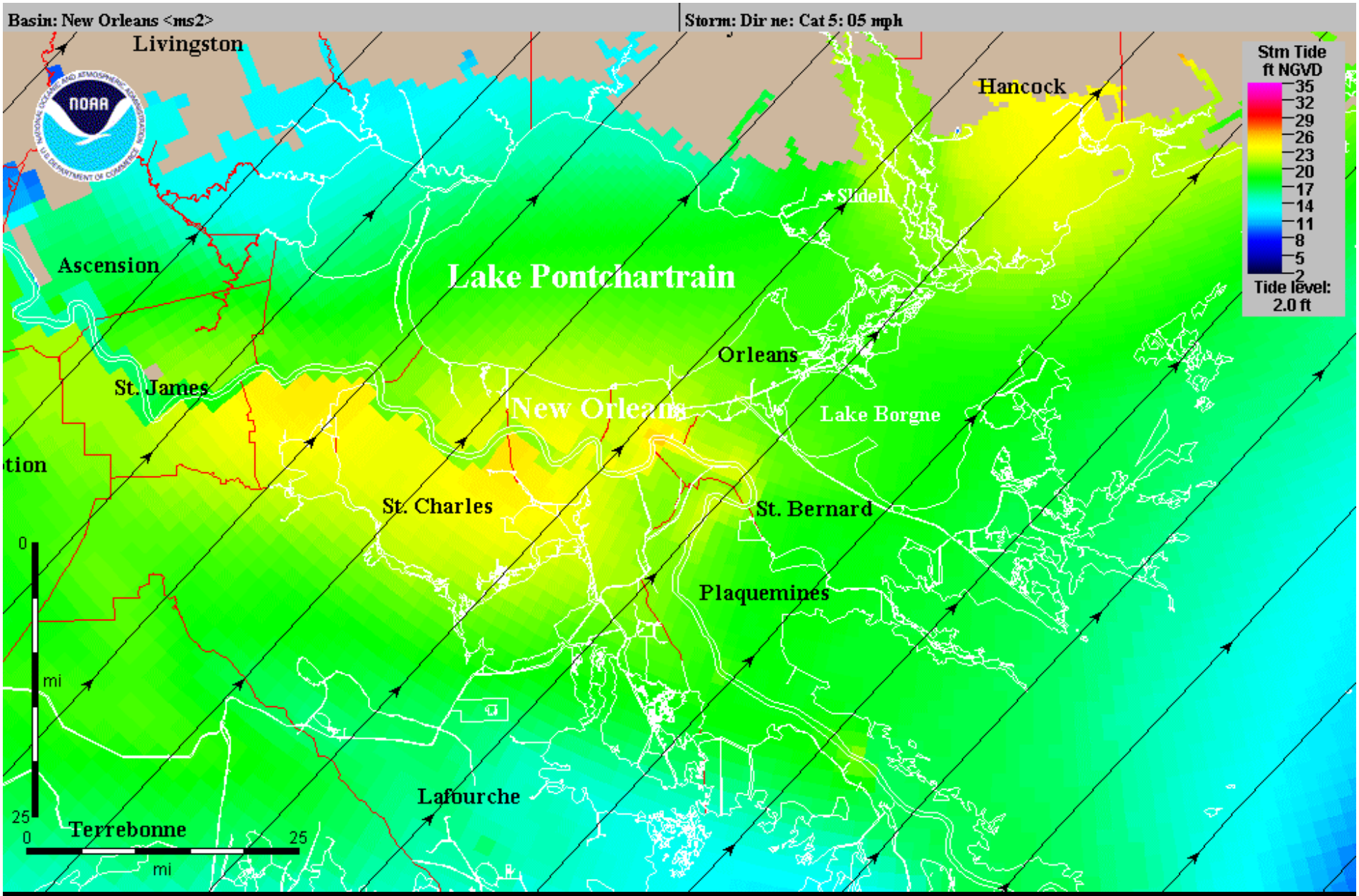
SLOSH Simulation Study: Cat 5 Hurricanes



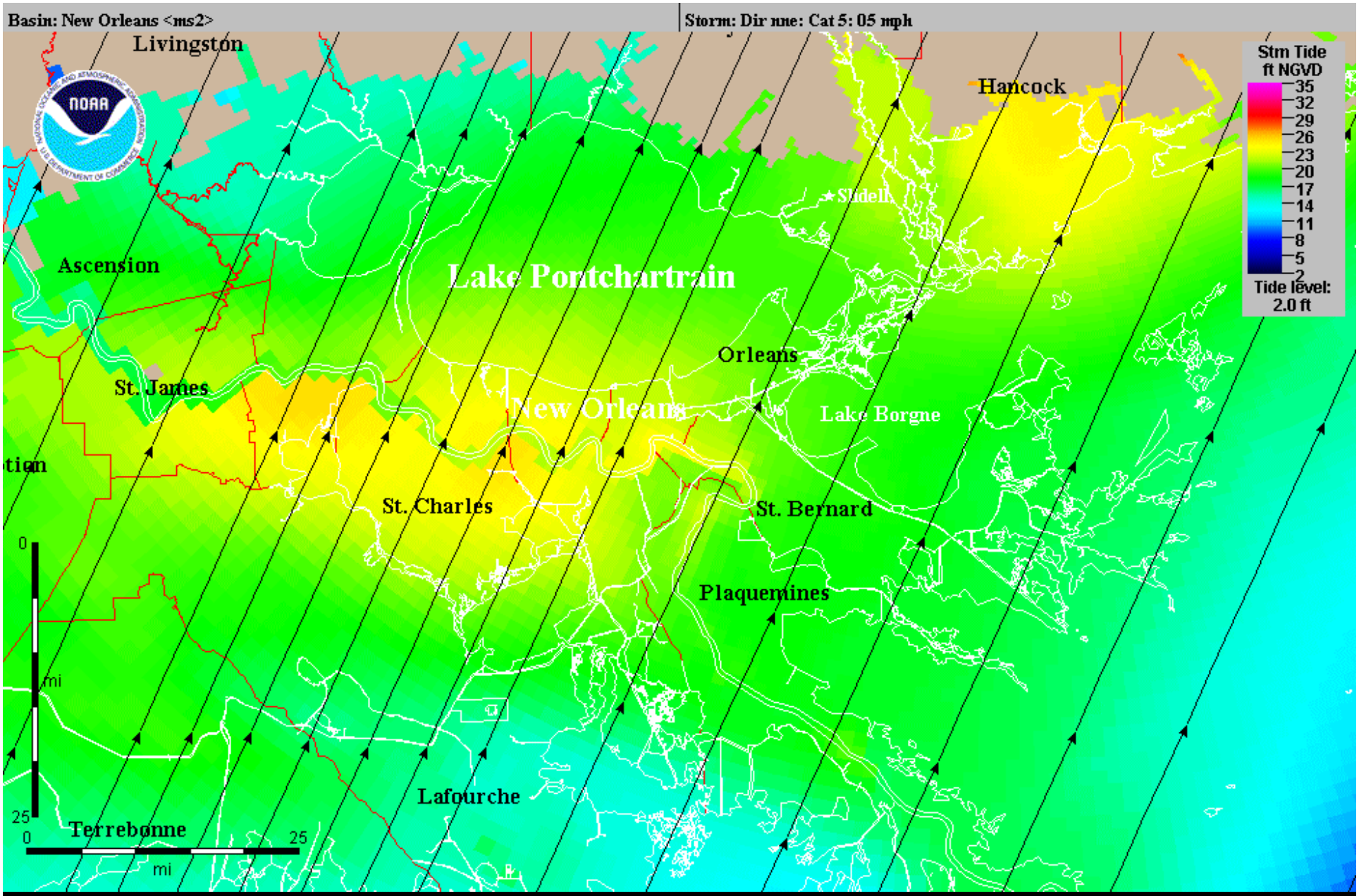
Cat 5, East, 5 mph, High Tide



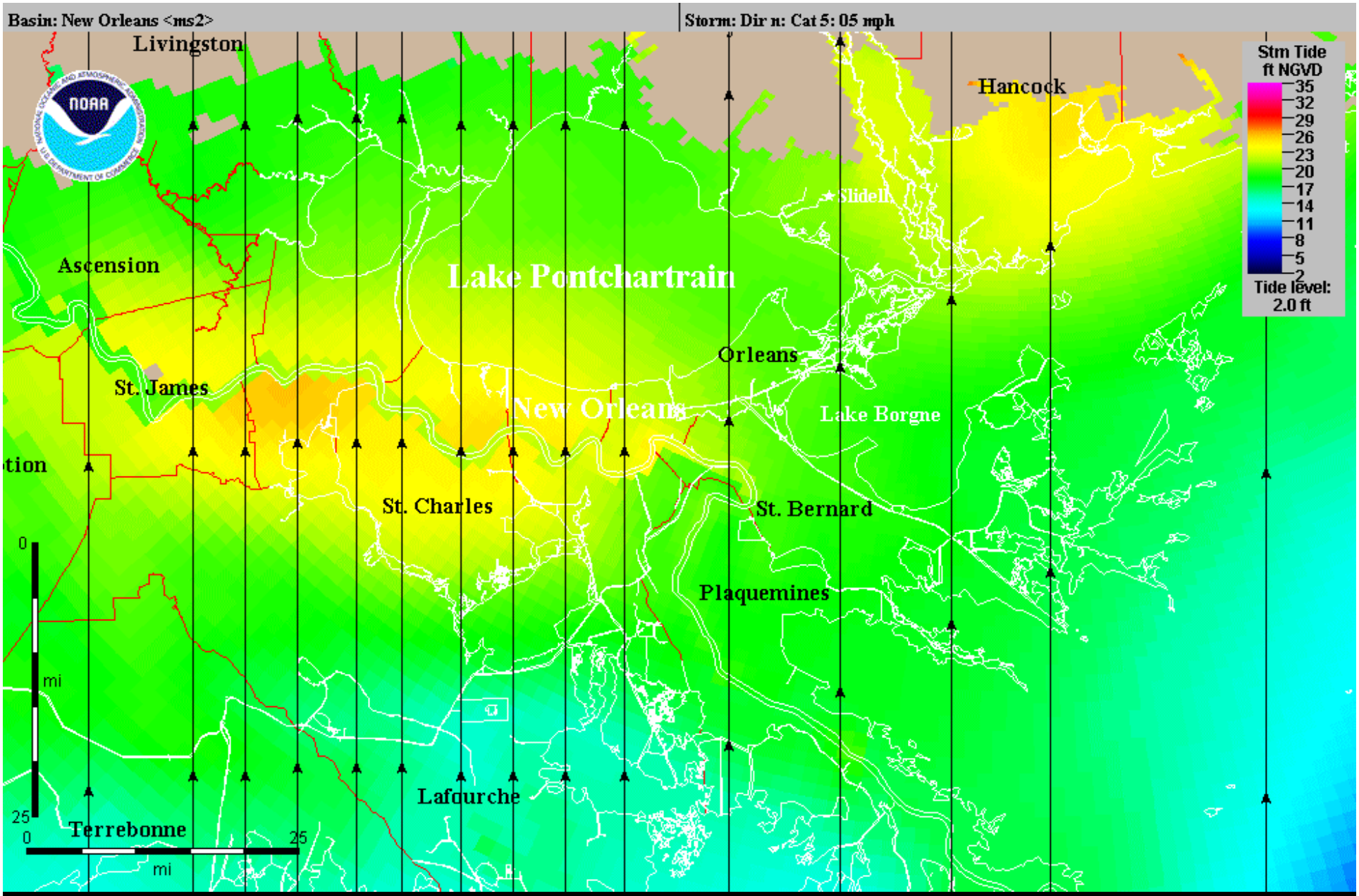
Cat 5, ENE, 5 mph, High Tide



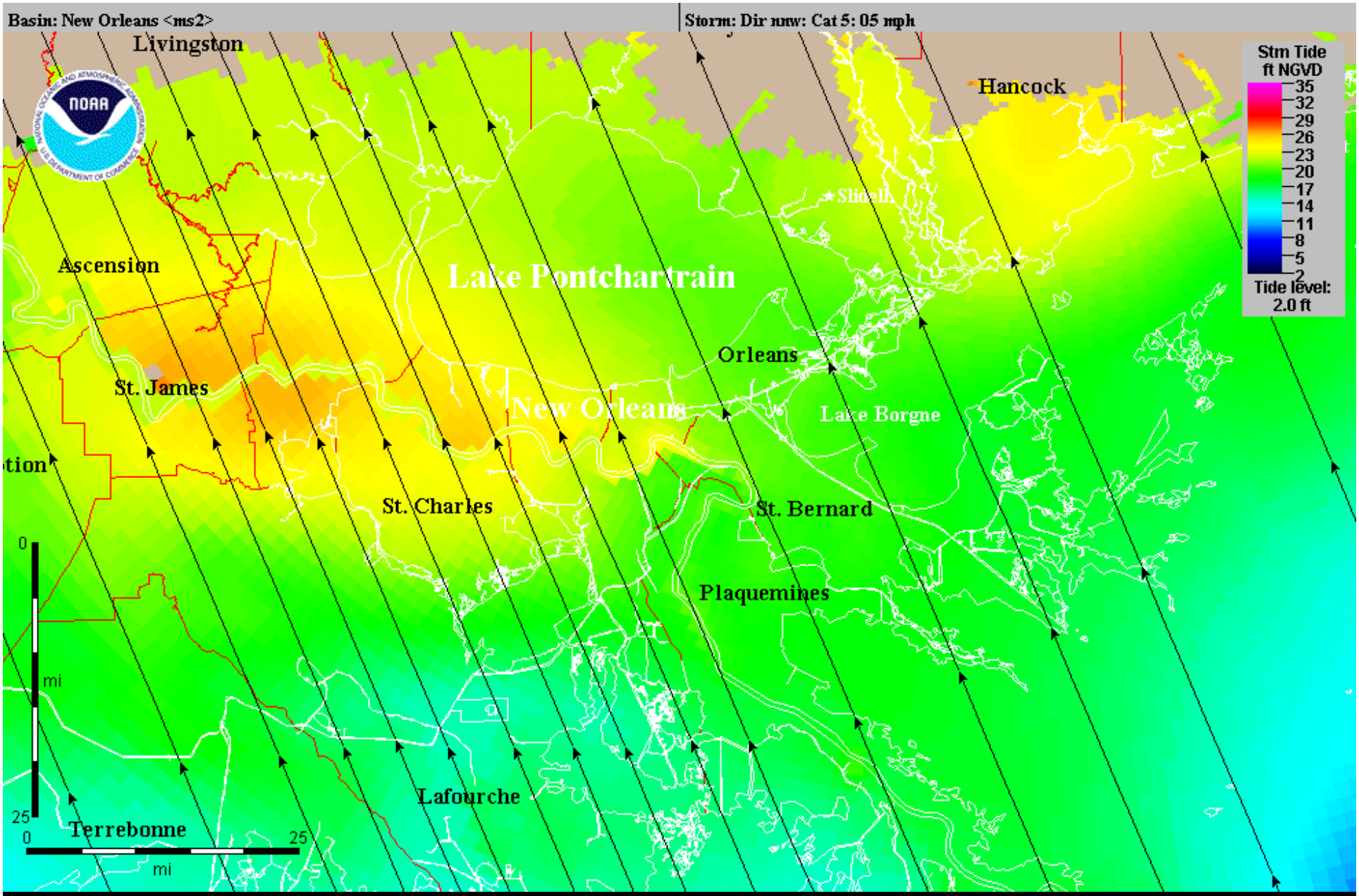
Cat 5, NE, 5 mph, High Tide



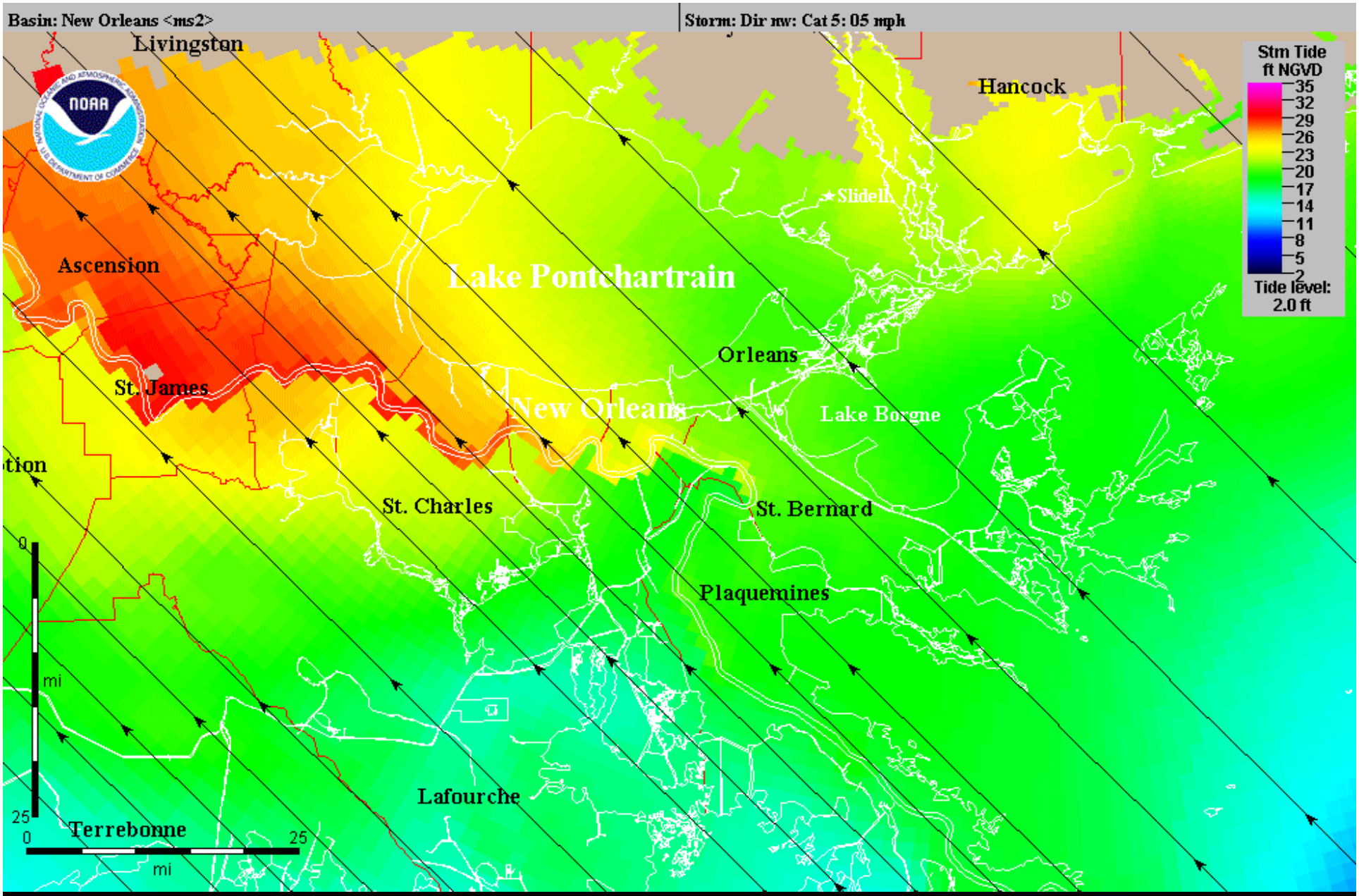
Cat 5, NNE, 5 mph, High Tide



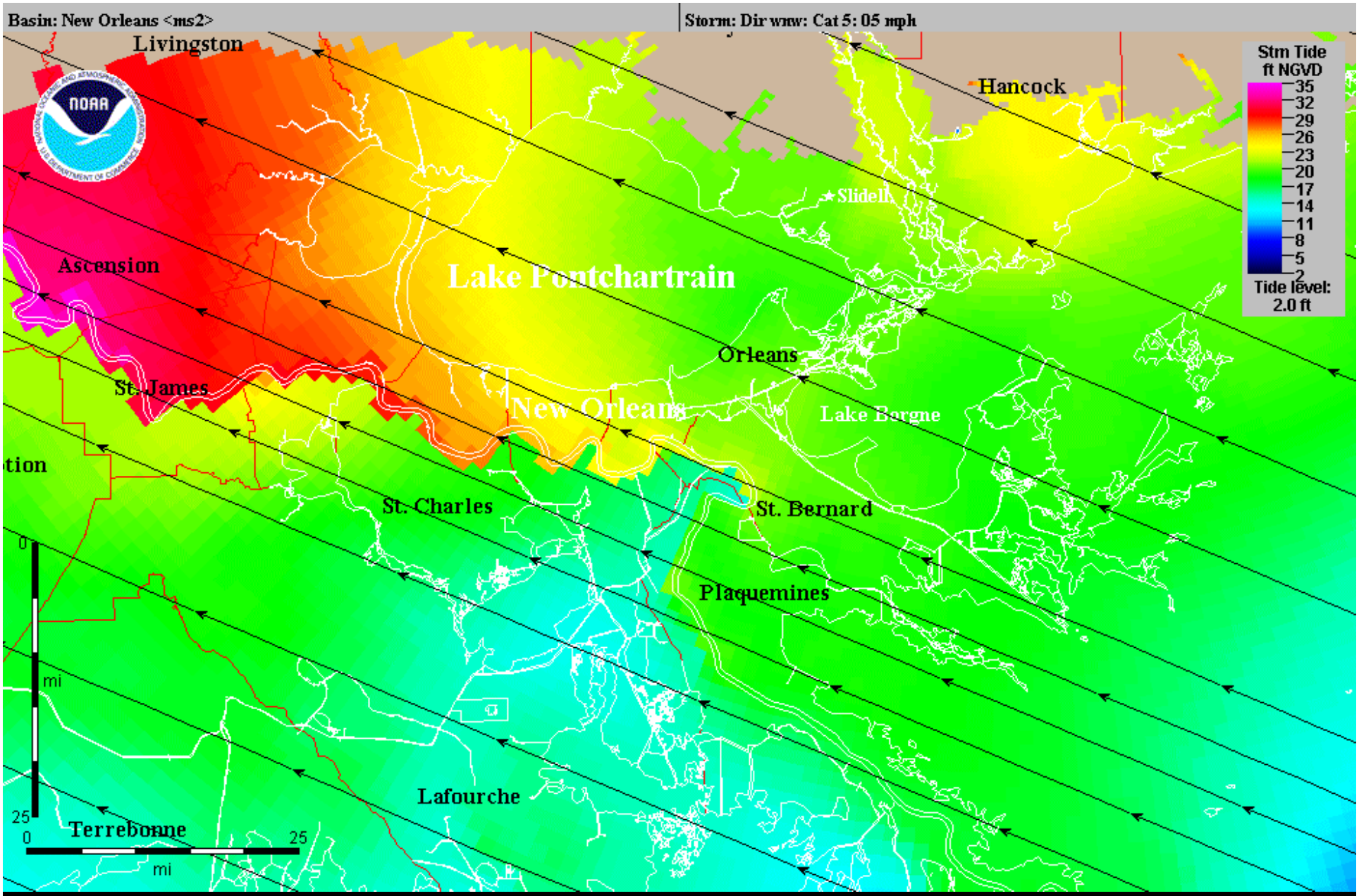
Cat 5, North, 5 mph, High Tide



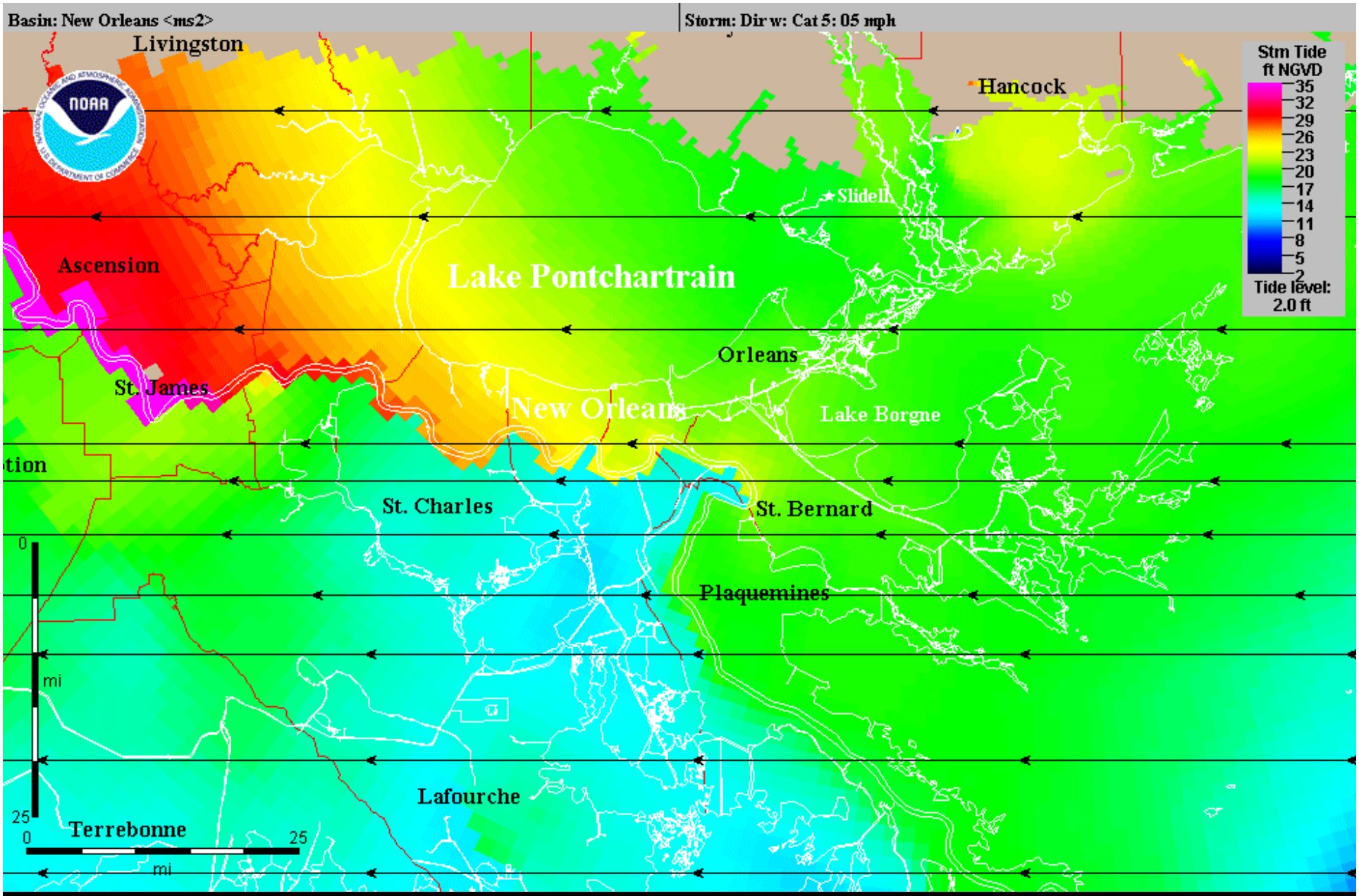
Cat 5, NNW, 5 mph, High Tide



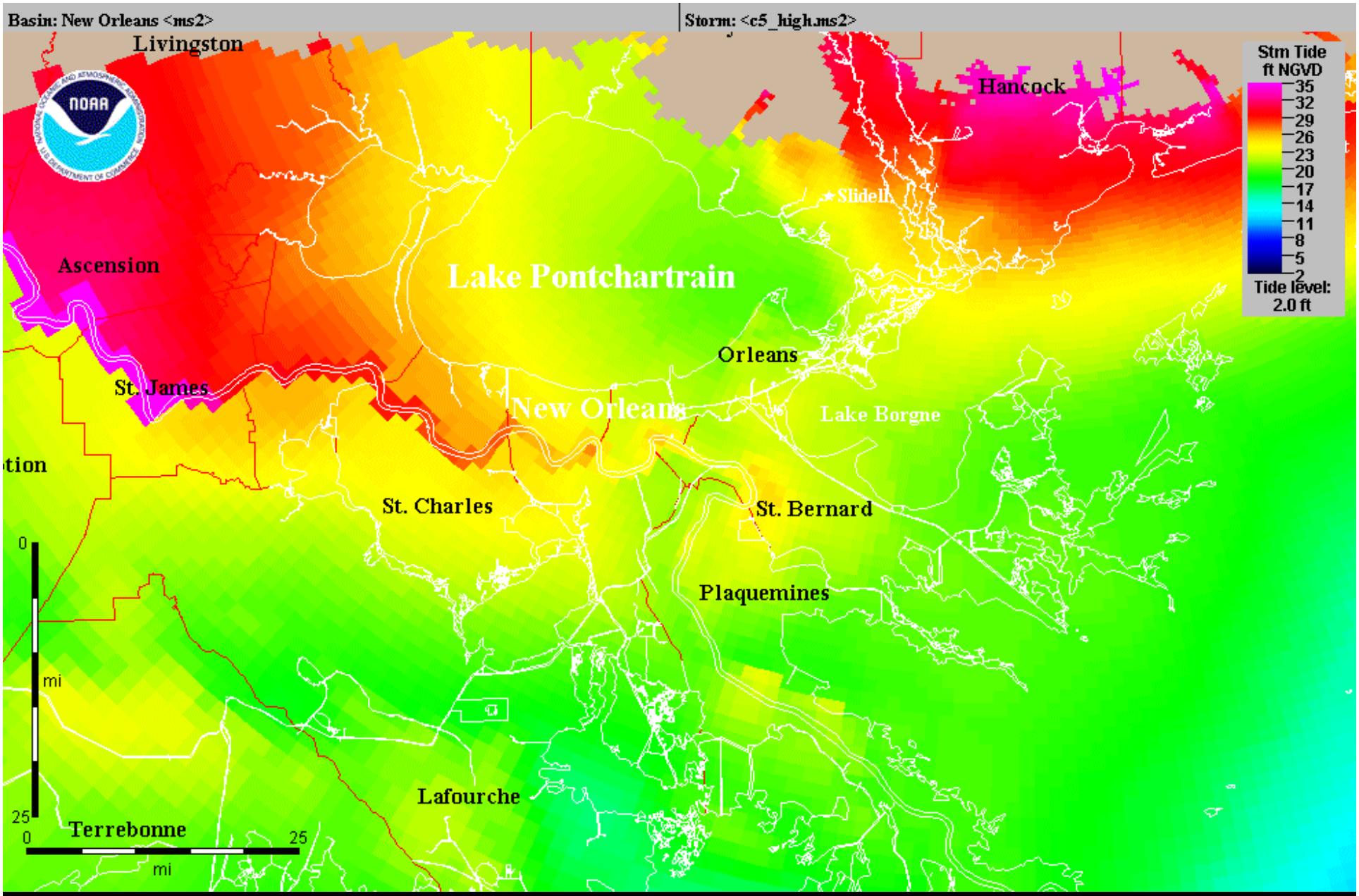
Cat 5, NW, 5 mph, High Tide



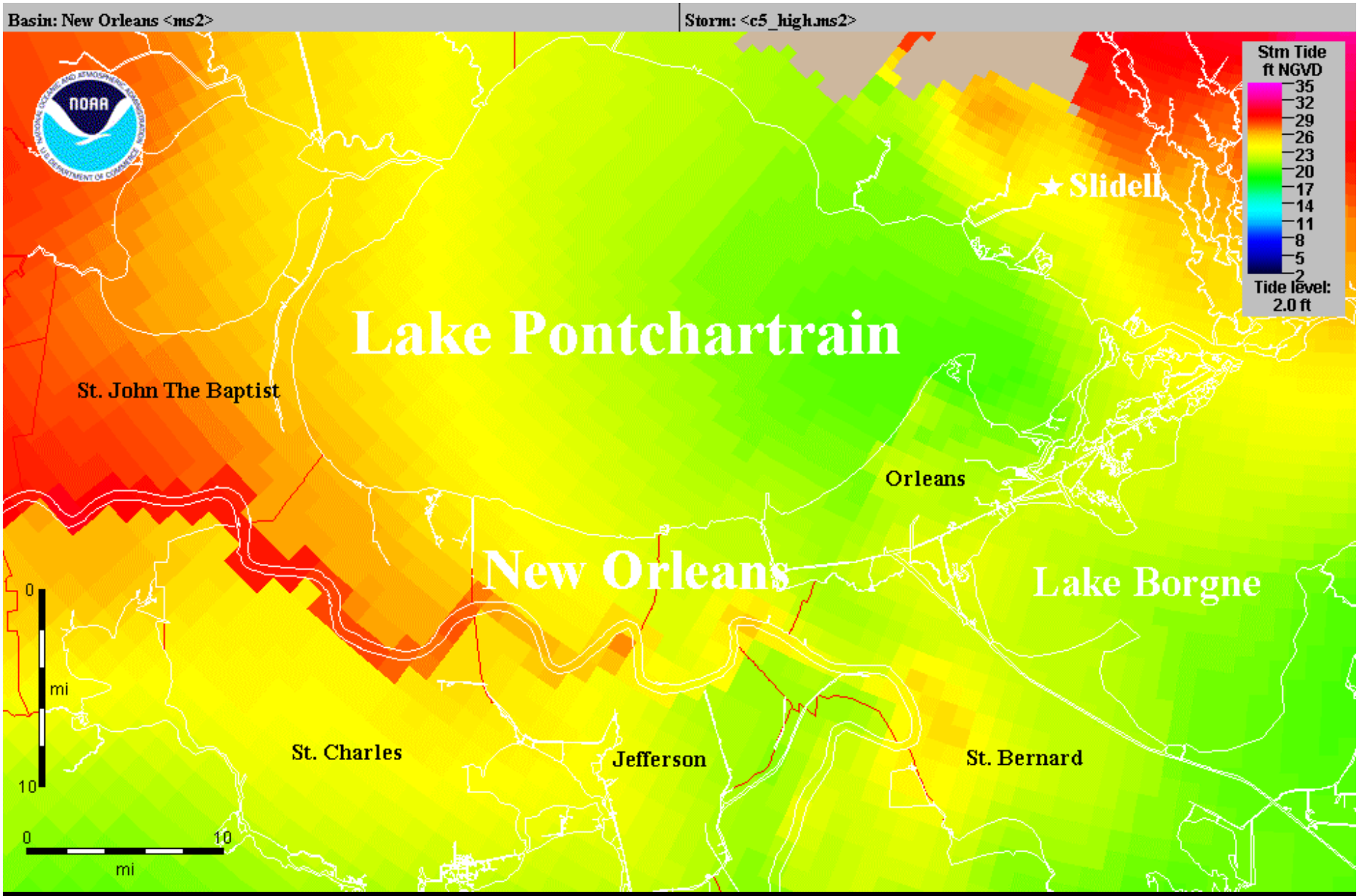
Cat 5, WNW, 5 mph, High Tide



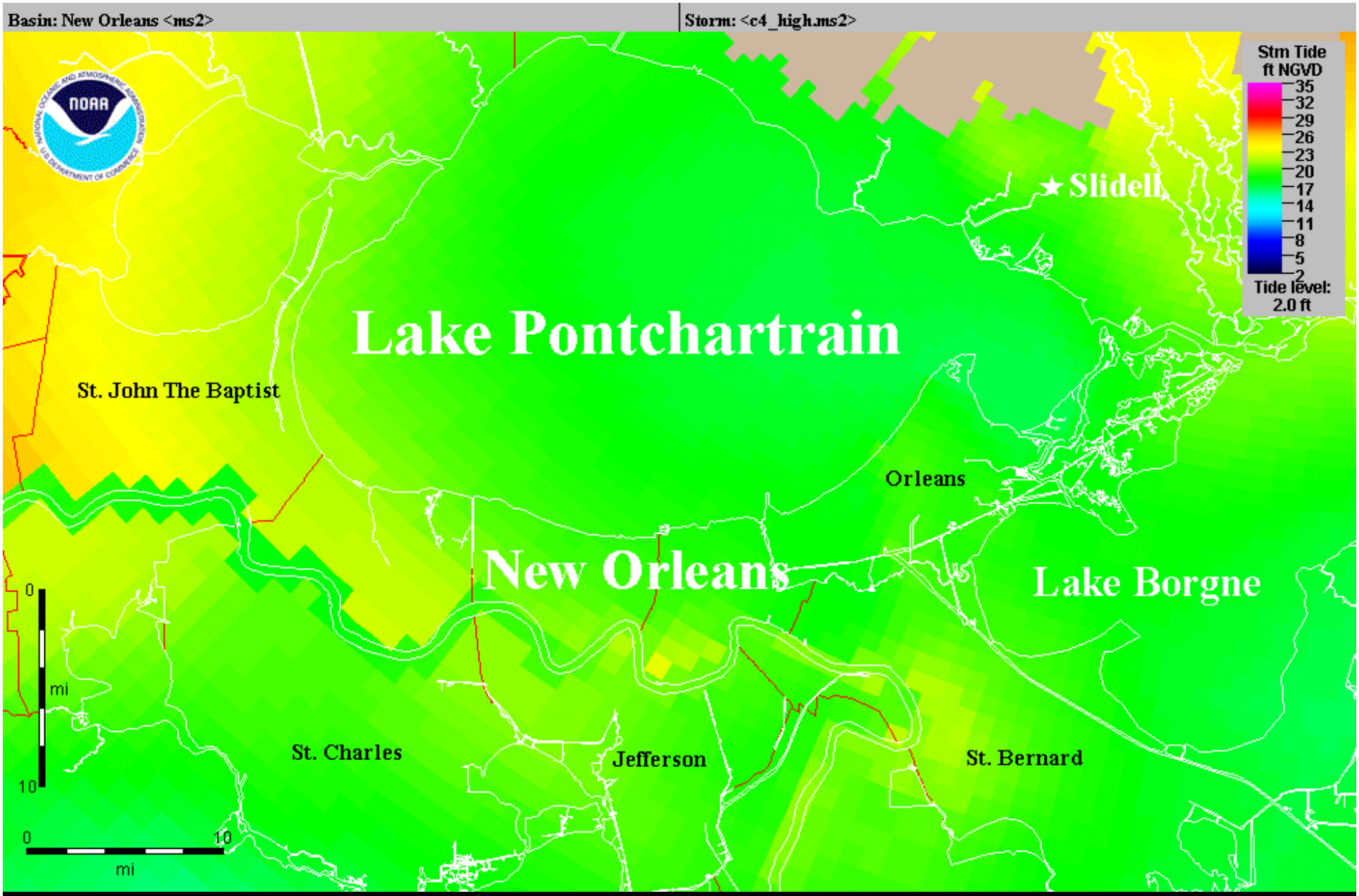
Cat 5, West, 5 mph, High Tide



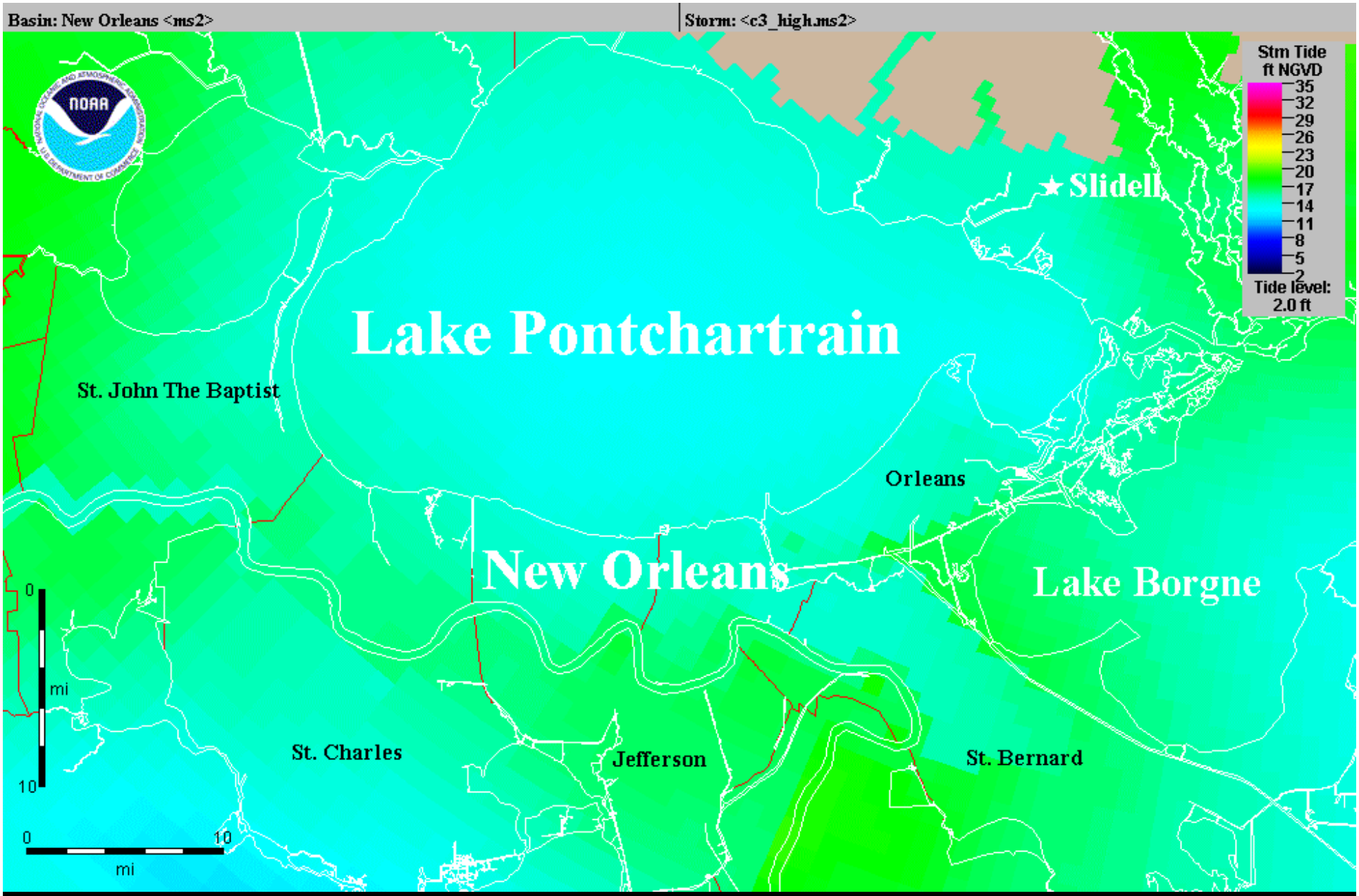
Cat 5 MOM – High Tide



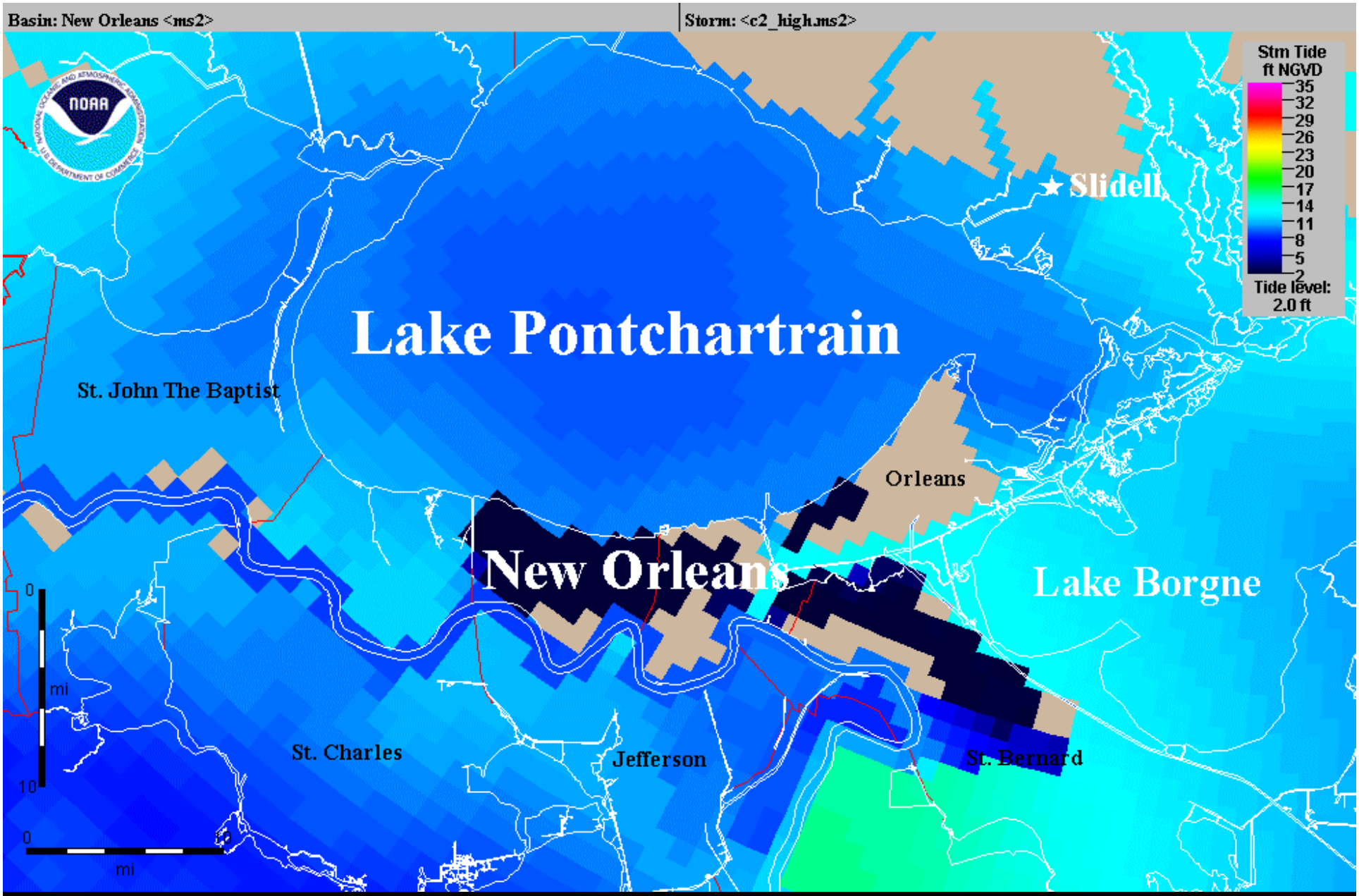
Cat 5 MOM – High Tide



Cat 4 MOM – High Tide

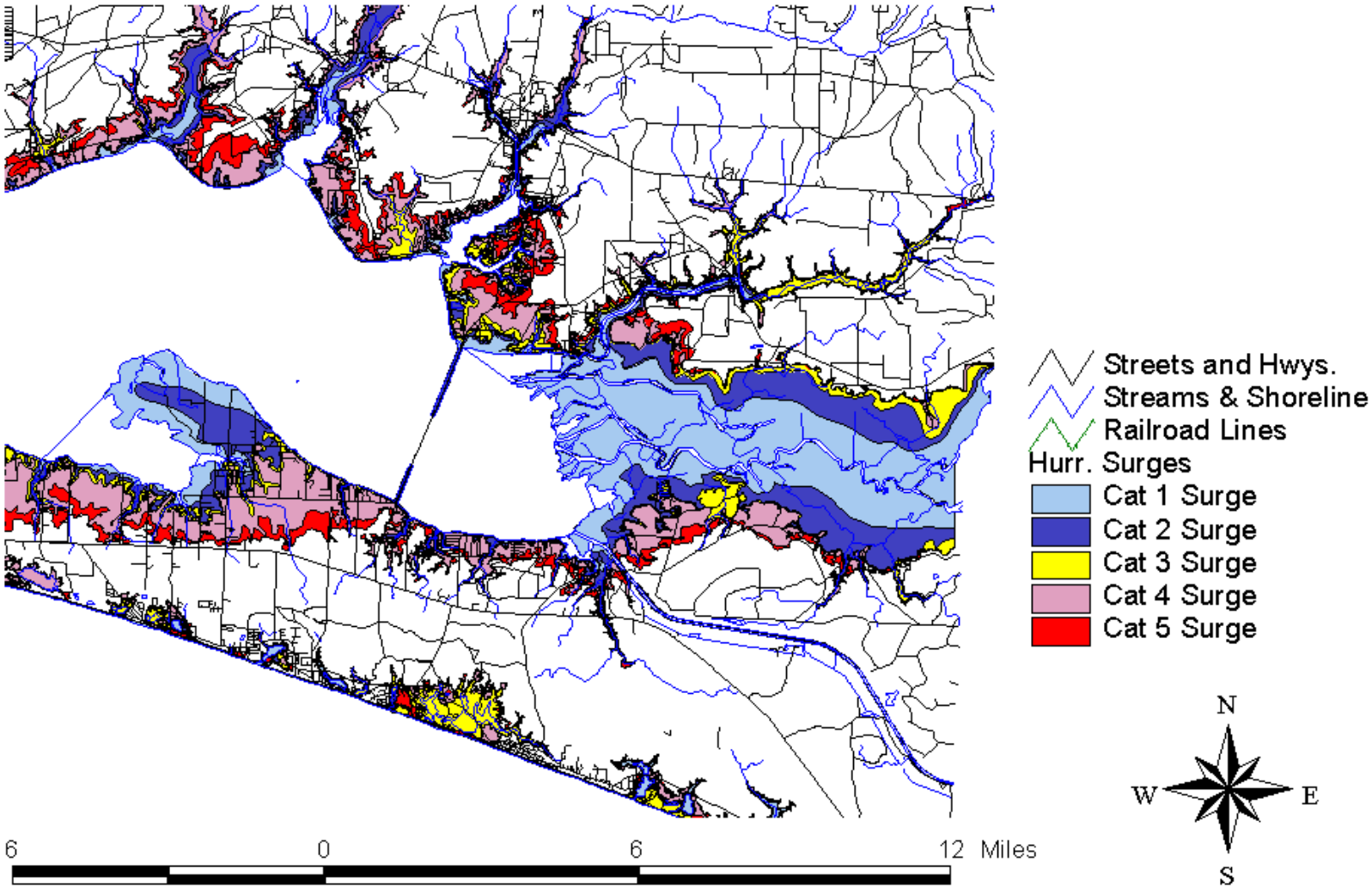


Cat 3 MOM – High Tide



Cat 2 MOM – High Tide

Surge Mapping



TITLE: Effect of Waves and Morphology on Boundary Conditions

PRESENTED BY: Dano Roelvink, UNESCO-IHE, Delft Hydraulics and Delft University of Technology

SUMMARY: The presentation focused on the relationships between waves and morphology to modeling boundary conditions. The effects of wave-induced setup on storm surge levels were discussed. Based on model and field data from the U.S. West Coast, it was concluded that wave effects can be serious, in the order of 1 meter or more. The problem of wave attenuation in very shallow and inundated areas was then discussed. Over-washing and wave–induced currents over inundated barrier islands can lead to disastrous erosion and subsequently leave the back-barriers much more vulnerable to future storms. In general, storm-induced morphological changes can be large and may directly influence the propagation of storm surges. The presentation also discussed the potential of using morphological modeling to assess long-term restoration plans.

Effect of waves and morphology on boundary conditions

New Orleans Hurricane Protection Design Workshop,
20-21 December, 2005

Prof. Dano Roelvink

UNESCO-IHE, Delft Hydraulics and Delft University of Technology

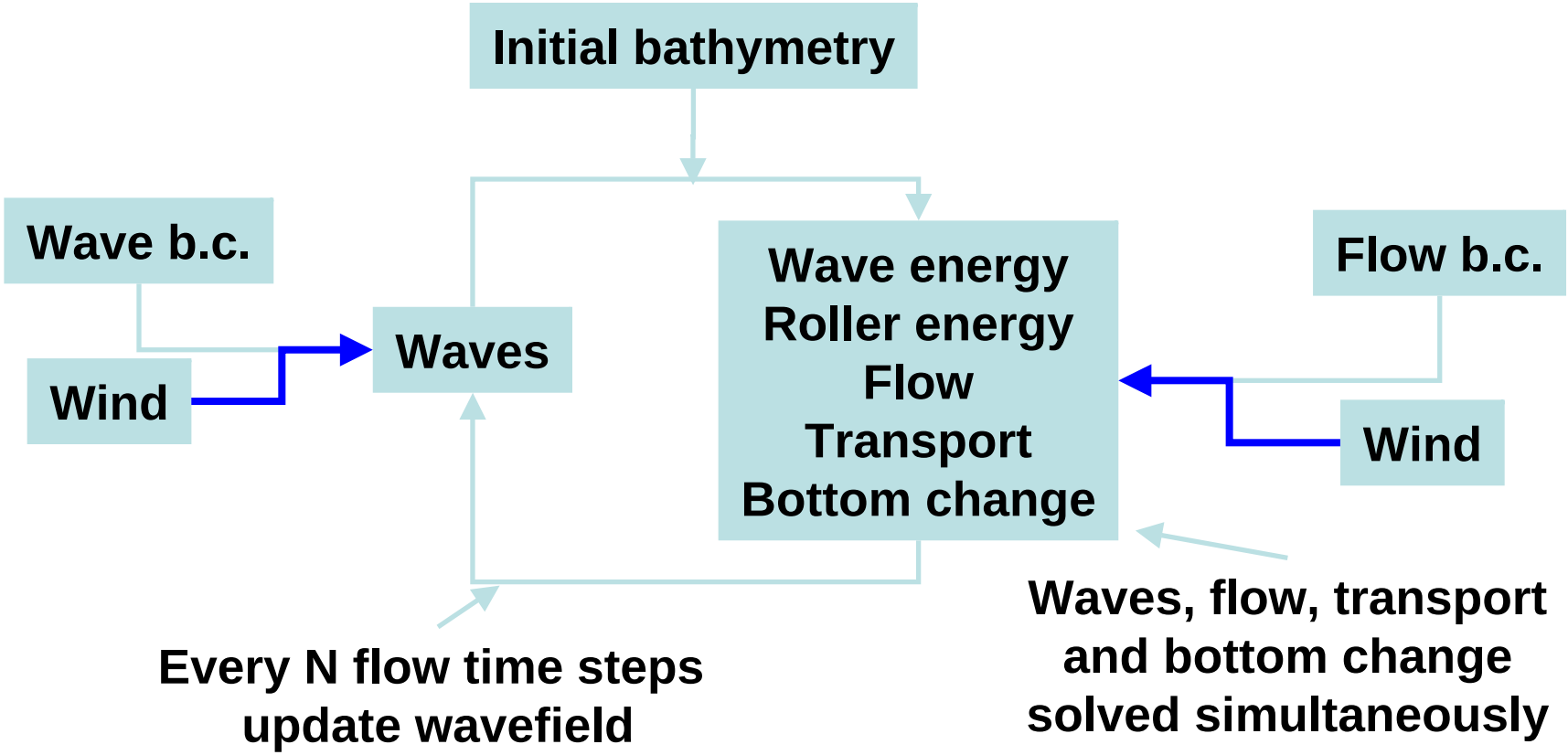
UNESCO-IHE
Institute for Water Education

Contents

- Coupled wave-flow-sediment modelling
- Effects of wave-induced setup on storm surge levels
- Wave-induced currents over inundated barrier islands
- Effects of barrier island breaching and overwashing on nearshore wave climate
- Wave attenuation in the nearshore and effects of marshes
- Waves in inundated areas on open coasts

- Storm-induced morphological changes
- Assessment of long-term morphological restoration plans

Coupled wave-flow-sediment modelling



UNESCO-IHE
Institute for Water Education

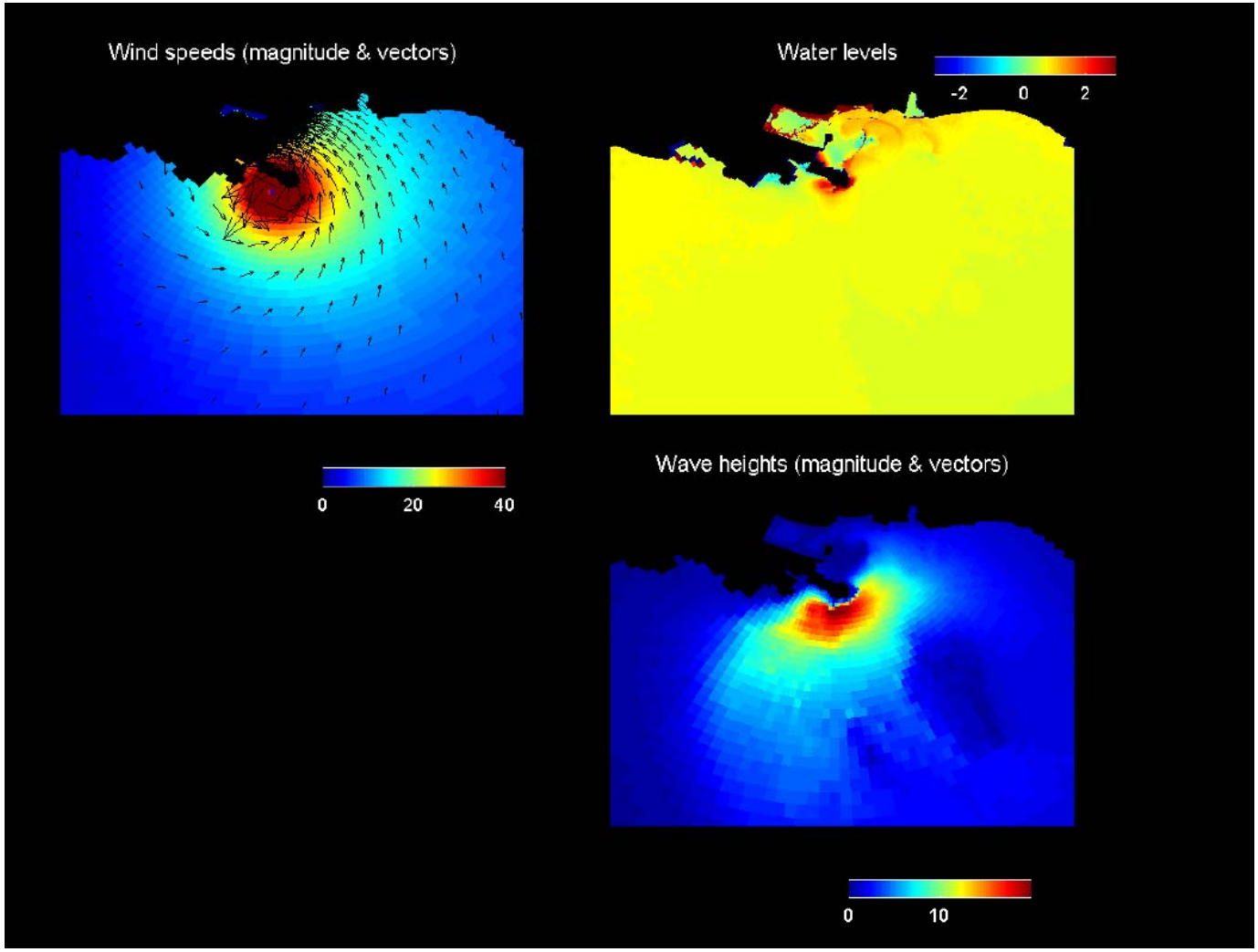
Requirements

- Waves
  - non-stationary
  - good physics
  - shallow water processes
  - water levels, bathymetry and currents from flow model
- Flow
  - non-stationary
  - effects of enhanced bed friction, streaming, radiation stresses, mass fluxes included
  - effects of waves on wind shear stress included?
  - include sediment transport and morphological updating?
- Frequent coupling, i.e. every 10 min.

Unverified example

courtesy
- Arjen Luijendijk
- Deepak Vatvani

Delft Hydraulics



UNESCO-IHE
Institute for Water Education

Effects of wave-induced setup on storm surge levels

- usually in the order of dm's
- significant portion in very shallow surf zone
- can be large-scale effect behind shoals, shallow inlets
- static and dynamic setup
- during hurricane, >1 m?

Cross-shore momentum balance

- Stationary case:

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} - f_{cor}\bar{v} = \frac{\partial}{\partial y} D_h \frac{\partial \bar{u}}{\partial y} + \frac{\tau_{sx}}{\rho h} - \frac{\tau_{bx}}{\rho h} - \frac{1}{\rho}\frac{\partial p_a}{\partial x} - g\frac{\partial \eta}{\partial x} + \frac{F_x}{\rho h}$$

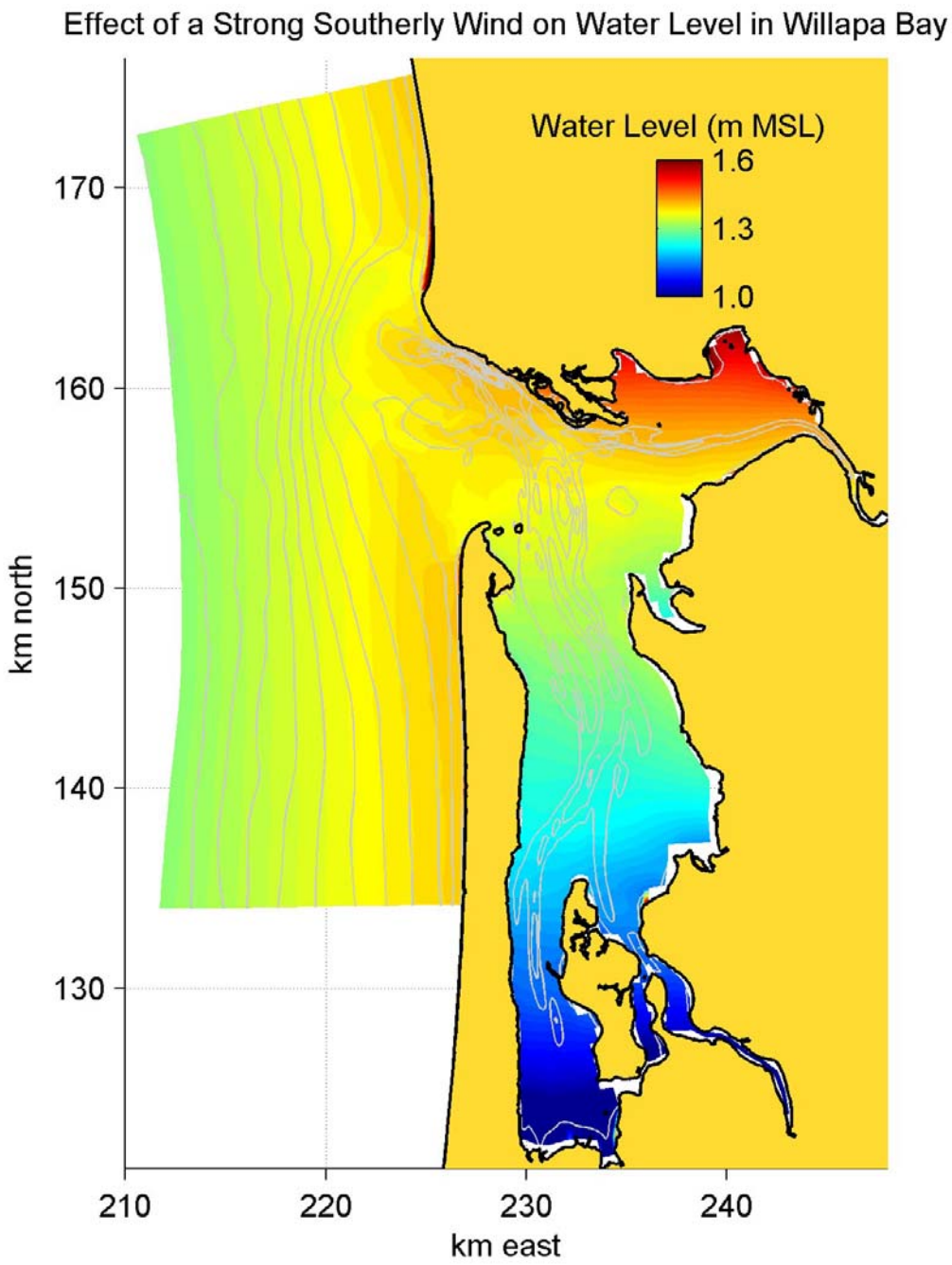
$$g\frac{\partial \eta}{\partial x} = \frac{F_x}{\rho h} + f_{cor} v \Rightarrow$$

$$\Rightarrow \frac{\partial \eta}{\partial x} = -\frac{1}{\rho g h}\frac{\partial}{\partial x}\left[\left(n\cos^2\vartheta + n - \frac{1}{2}\right)E\right] + \frac{f_{cor}}{g} v$$

UNESCO-IHE
Institute for Water Education

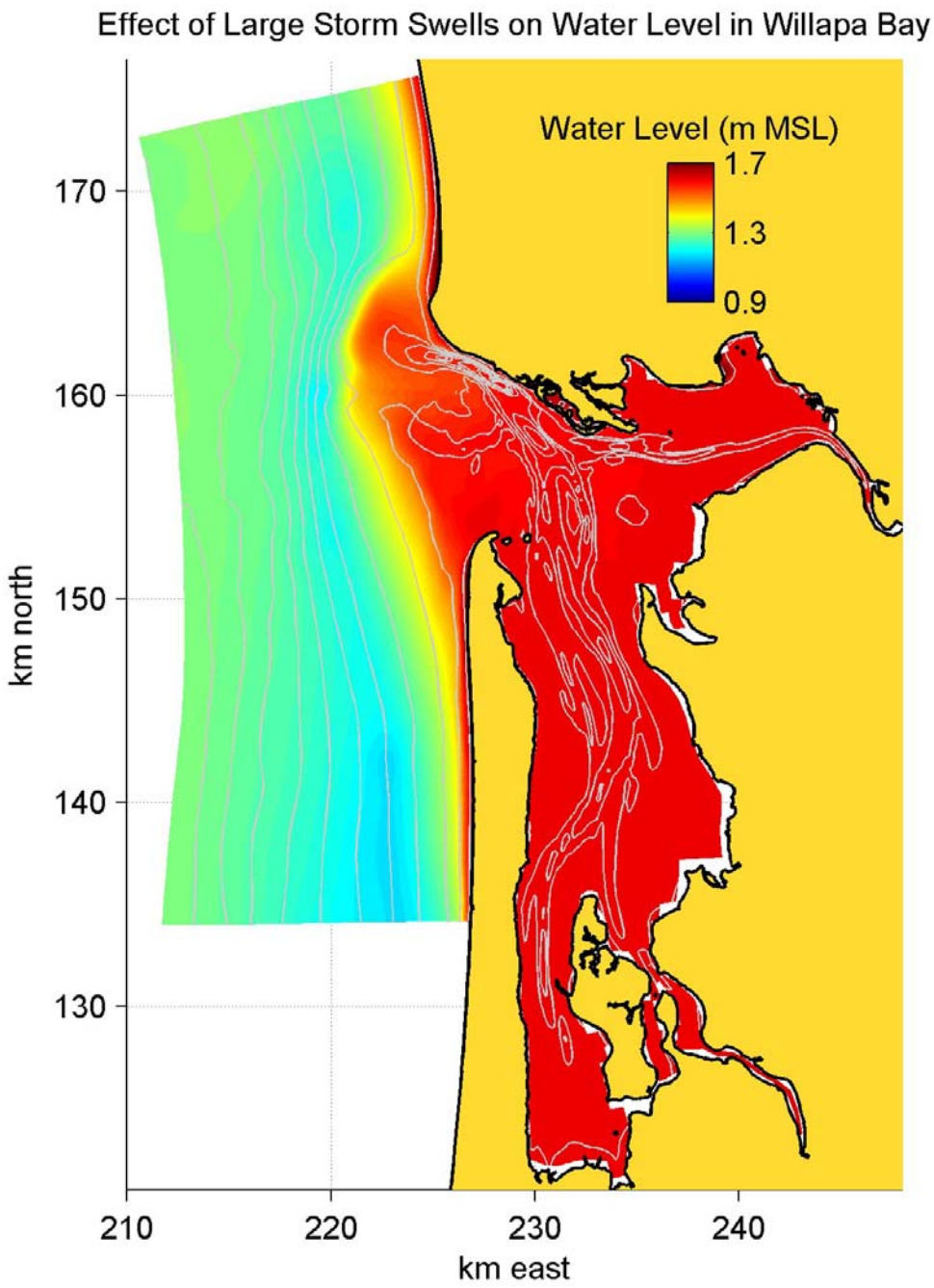
Example: Willapa Bay (Wa)

source: USGS, Giles Lesser



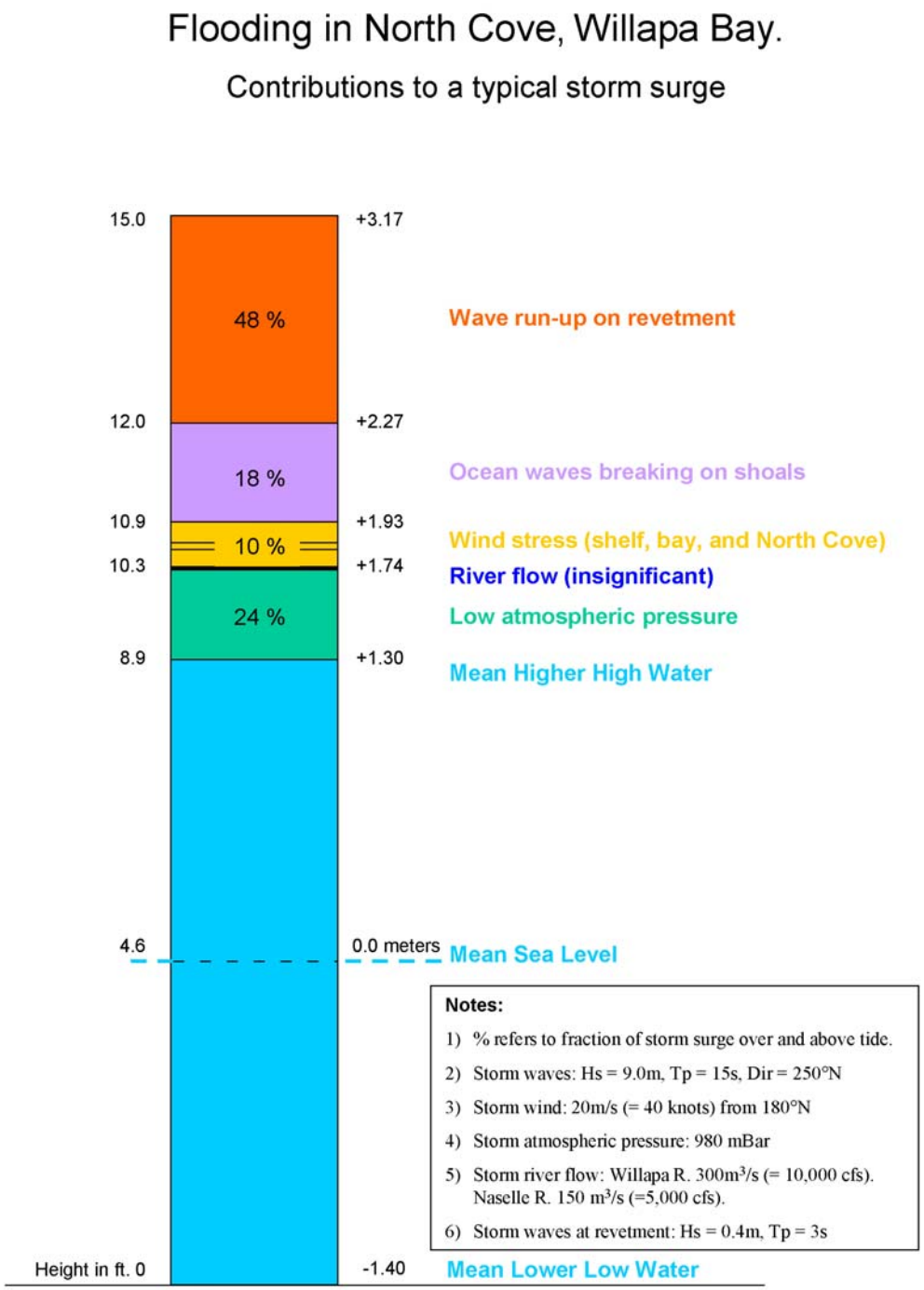
UNESCO-IHE
Institute for Water Education

Effect of large swells on setup



UNESCO-IHE
Institute for Water Education

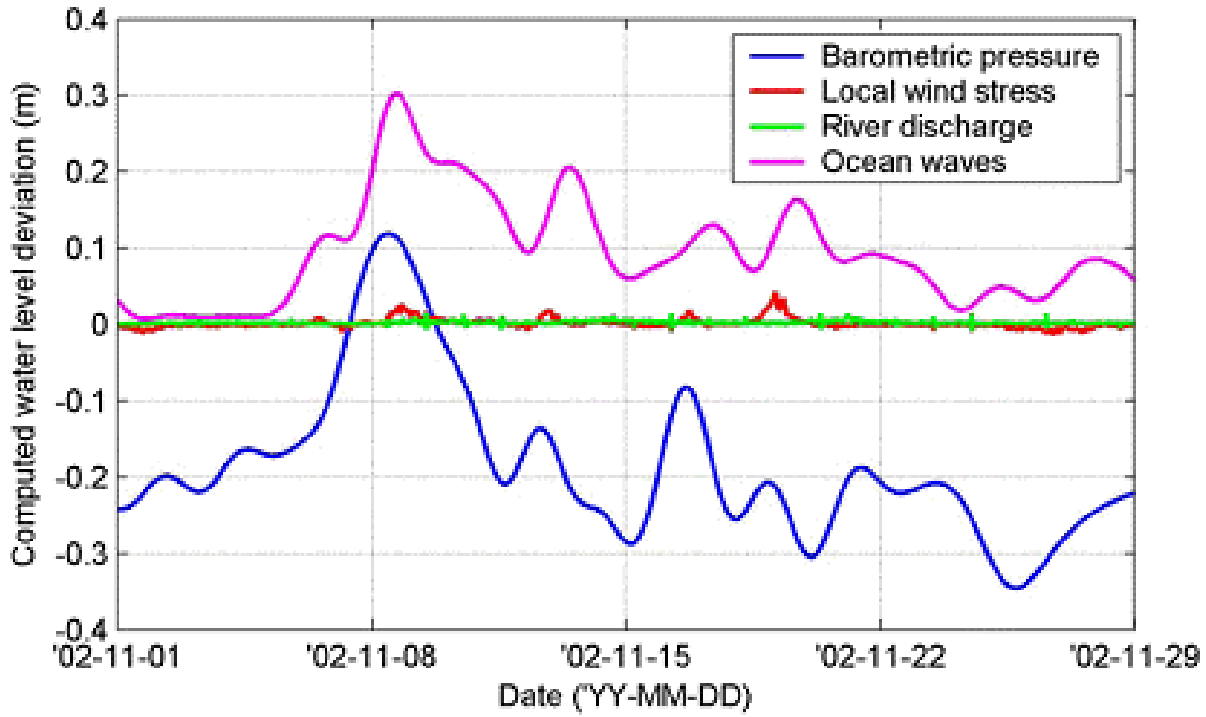
Effect of waves on flooding, North Cove, Willapa Bay



UNESCO-IHE
Institute for Water Education

Non-tidal effects

Toke Point tide station



UNESCO-IHE
Institute for Water Education

Conditions example

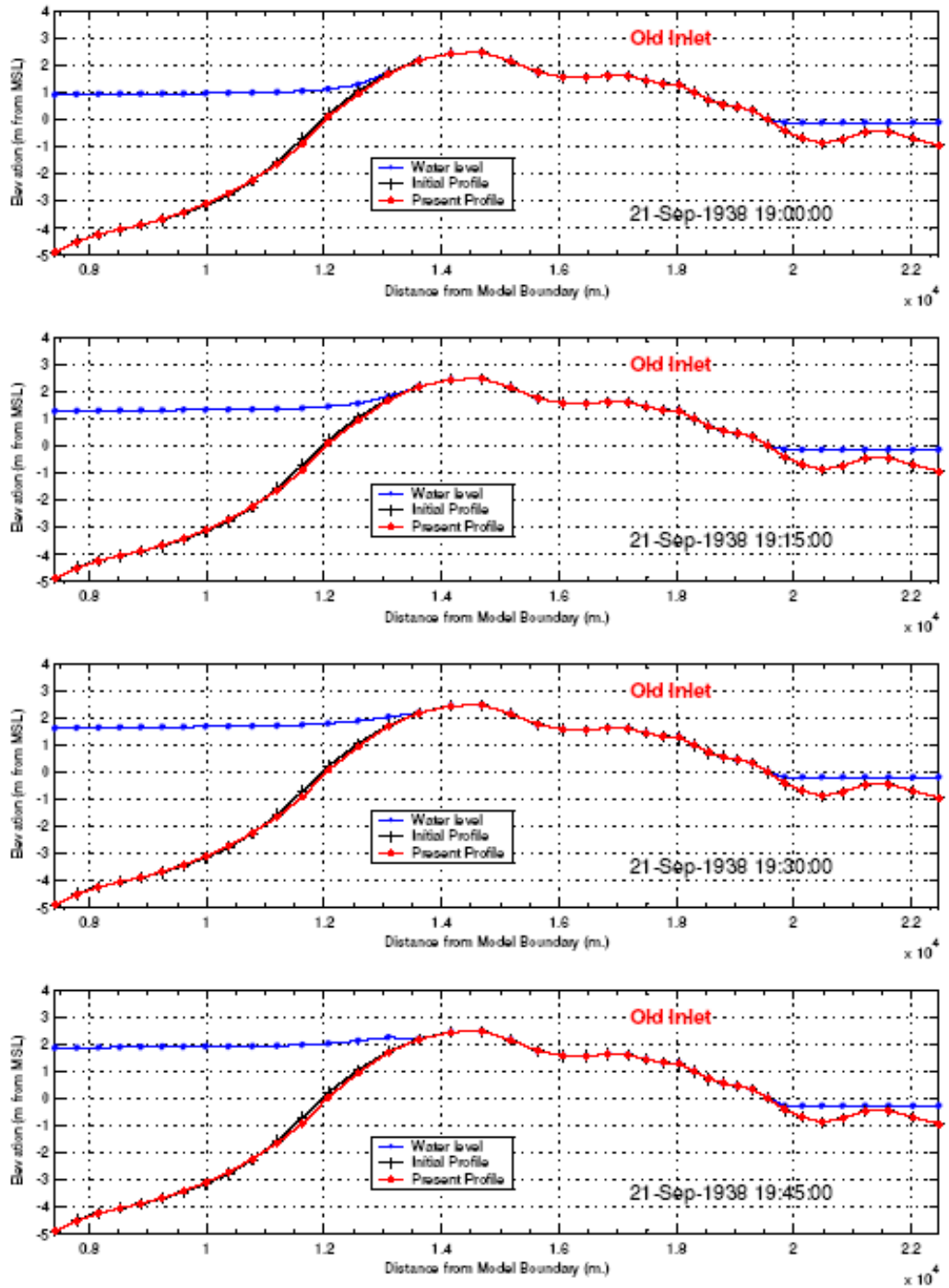
- field experiment in 2002
- At the height of the storm:
  - Hs = 7m,
  - Tp = 18s,
  - Dir = 265 deg.
- Wind speed about 16 m/s from more or less due West.
- Pressure dipped to 991 mBars.

Example: FIMP study, Long Island

- Study carried out by Moffatt and Nichol for New York District, supported by Delft Hydraulics
- dynamic modelling of surge+waves+breaching

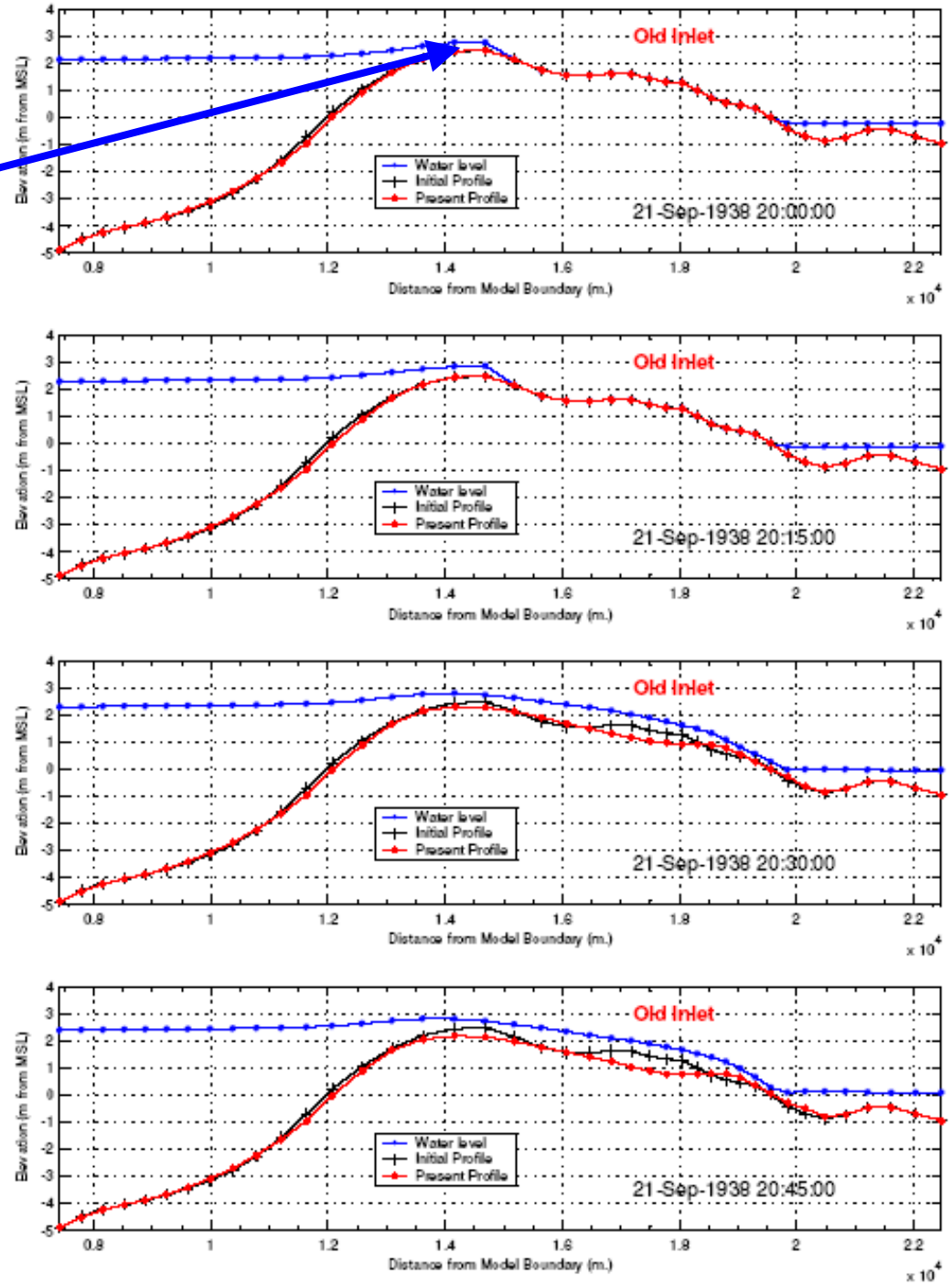
Cross-section Old Inlet during 1938 storm

- 15 min. intervals

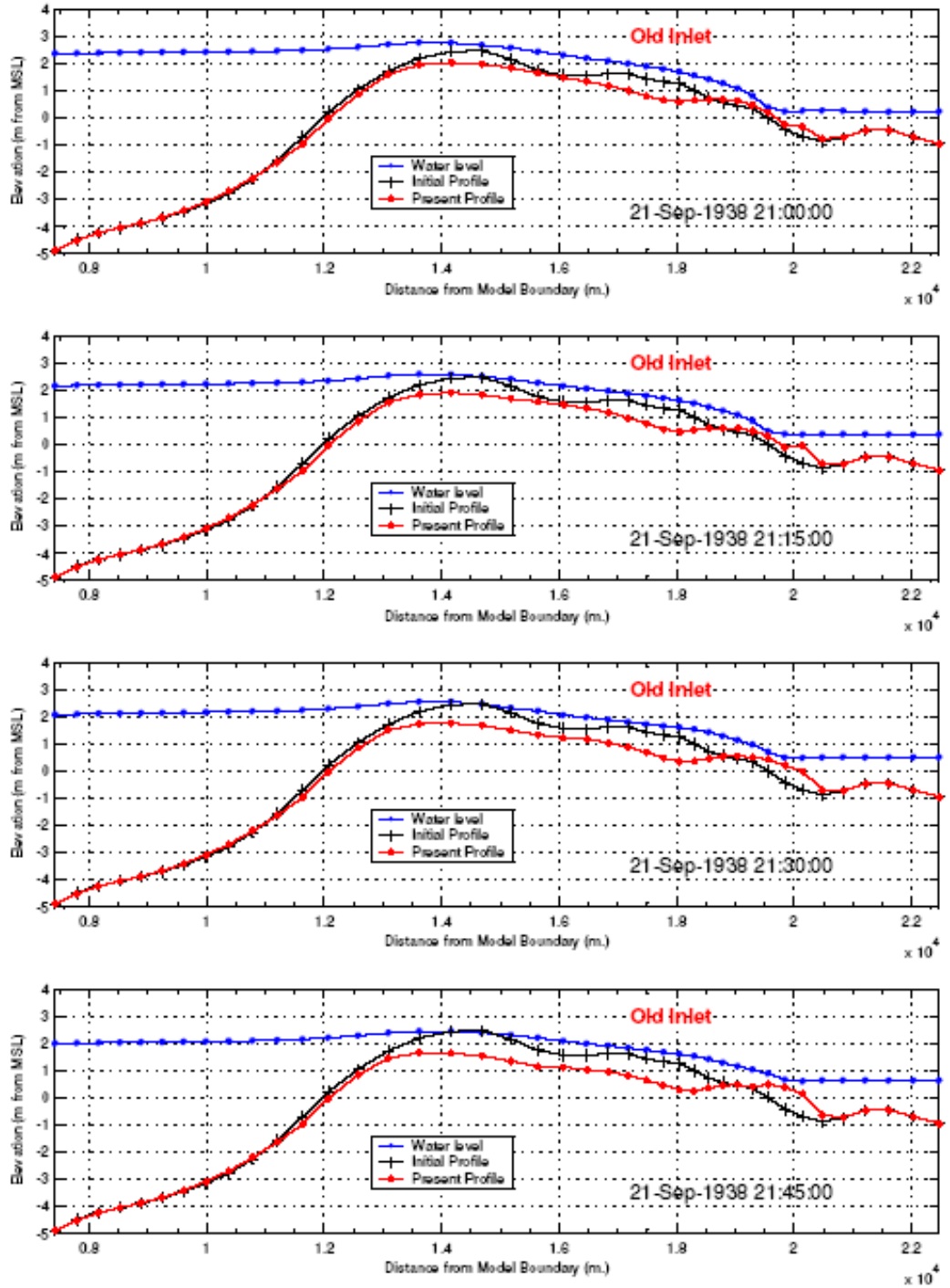


UNESCO-IHE
Institute for Water Education

More than 50 cm local wave setup



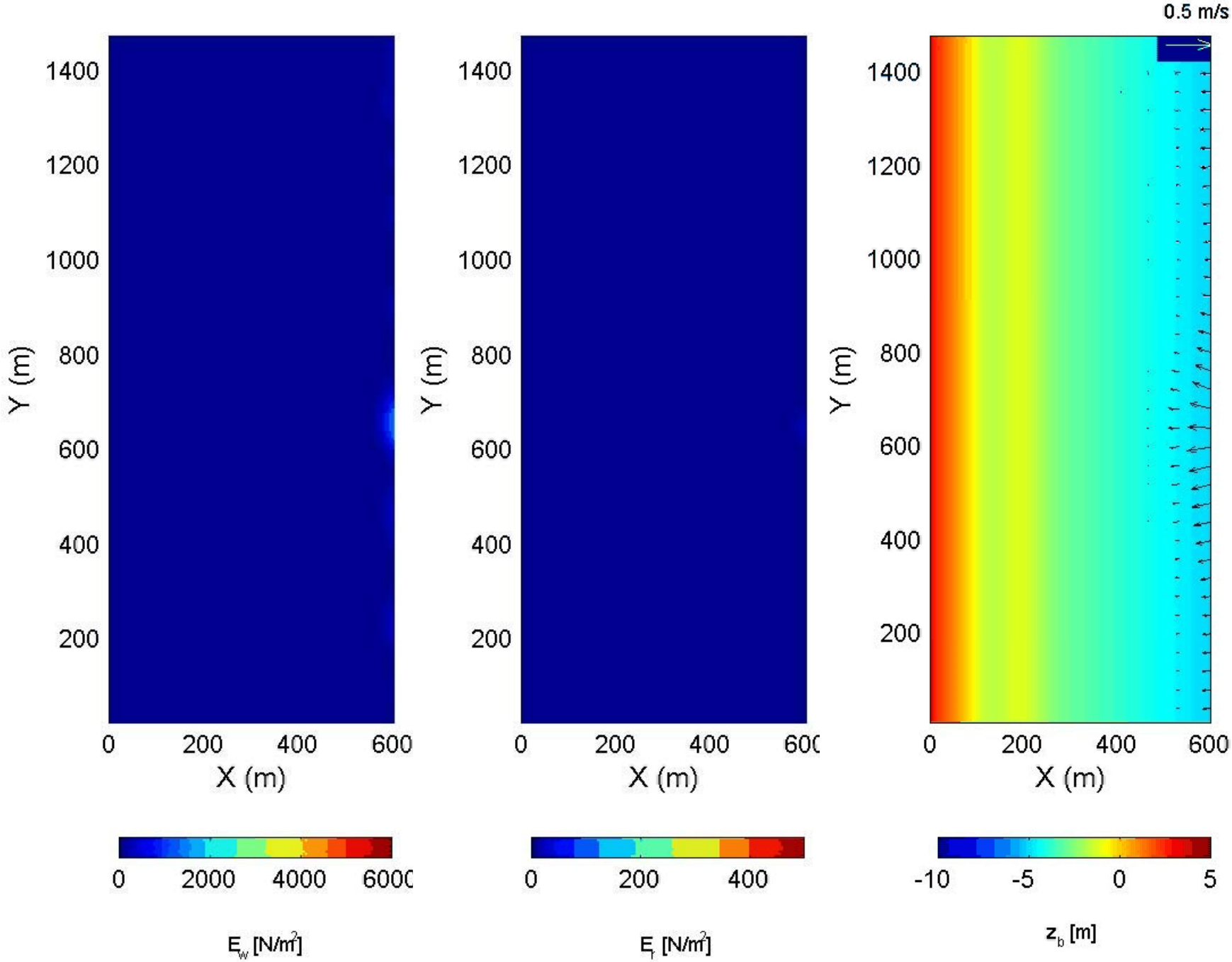
UNESCO-IHE
Institute for Water Education



UNESCO-IHE
Institute for Water Education

Dynamic setup, surfbeat

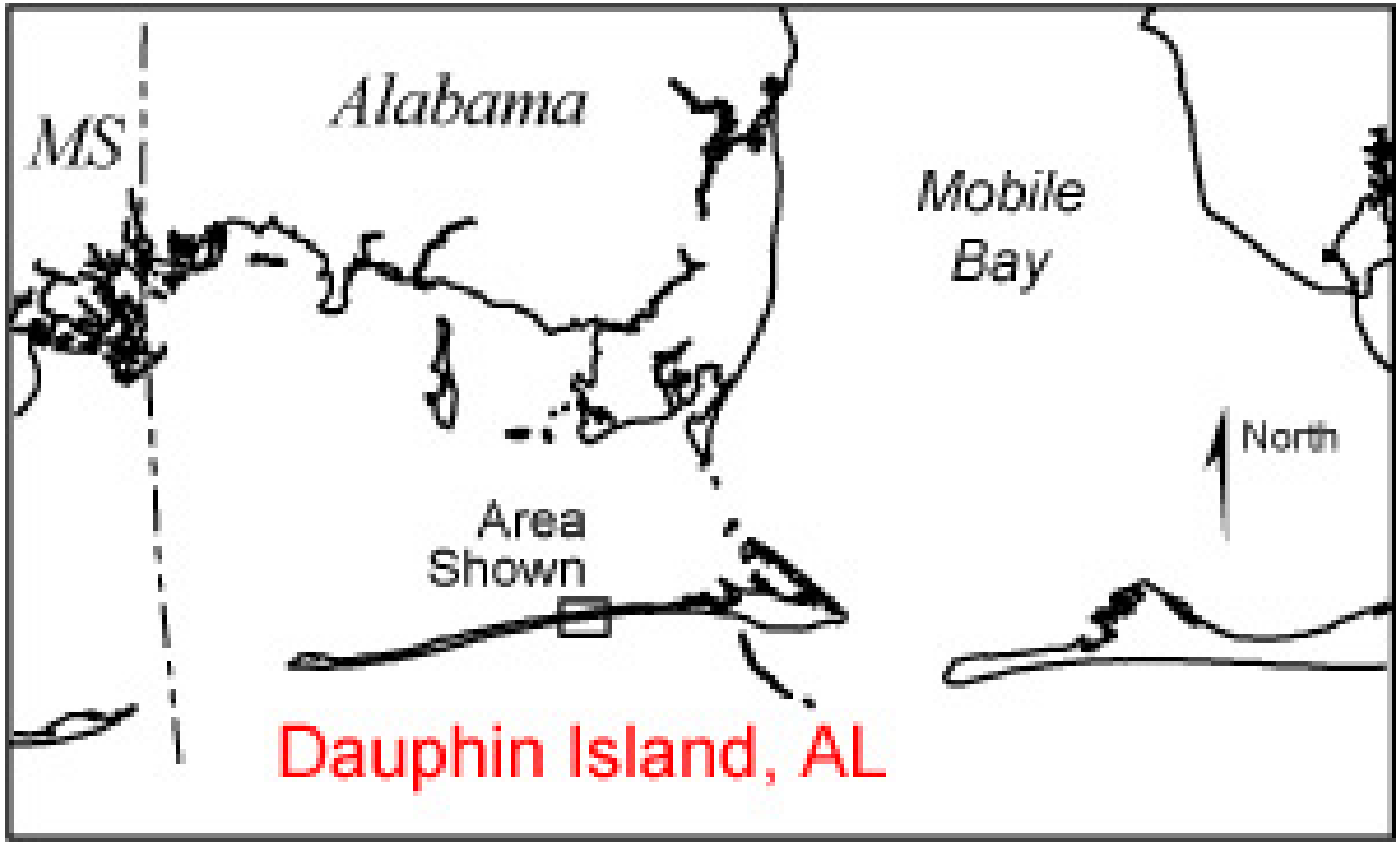
- driven by variations in wave energy on wave group scale
- creates long waves at 5-10 times incident wave period
- dominant mechanism for overwashing
- can initiate breaching


0.5 m/s
1400
1200
1000
800
600
400
200
Y (m)
0
200
400
600
X (m)
0
2000
4000
6000
E_w [N/m^2]
0
200
400
E_r [N/m^2]
-10
-5
0
5
z_b [m]

Wave setup conclusions

- Both large-scale and local effects are important
- Apart from static setup, wave-group related long wave motions important for initial overwashing

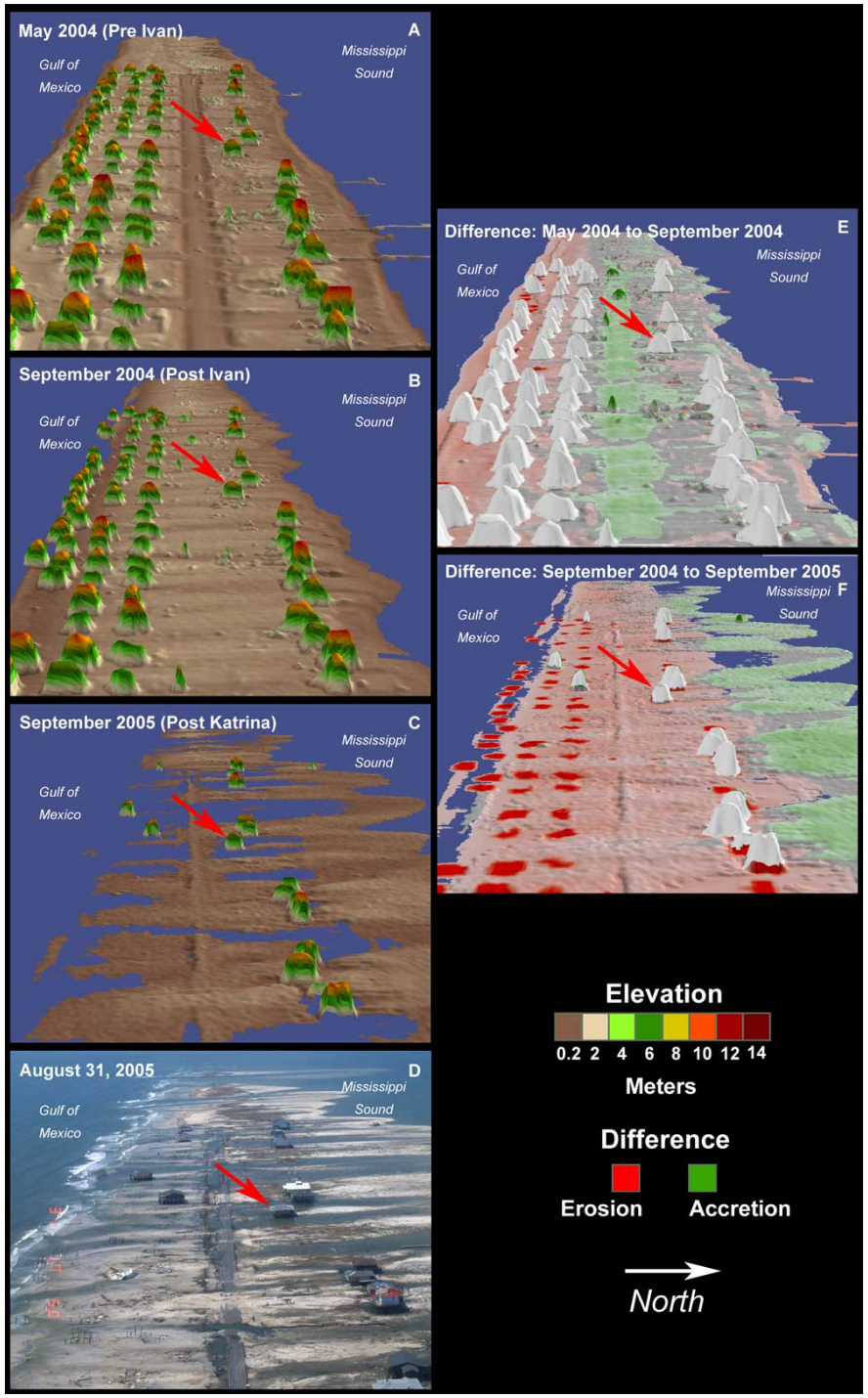
Katrina storm damage



UNESCO-IHE
Institute for Water Education

Ivan vs Katrina

- Many barrier islands wiped out
- severe consequences for inlets in their lee
- need to predict future behaviour

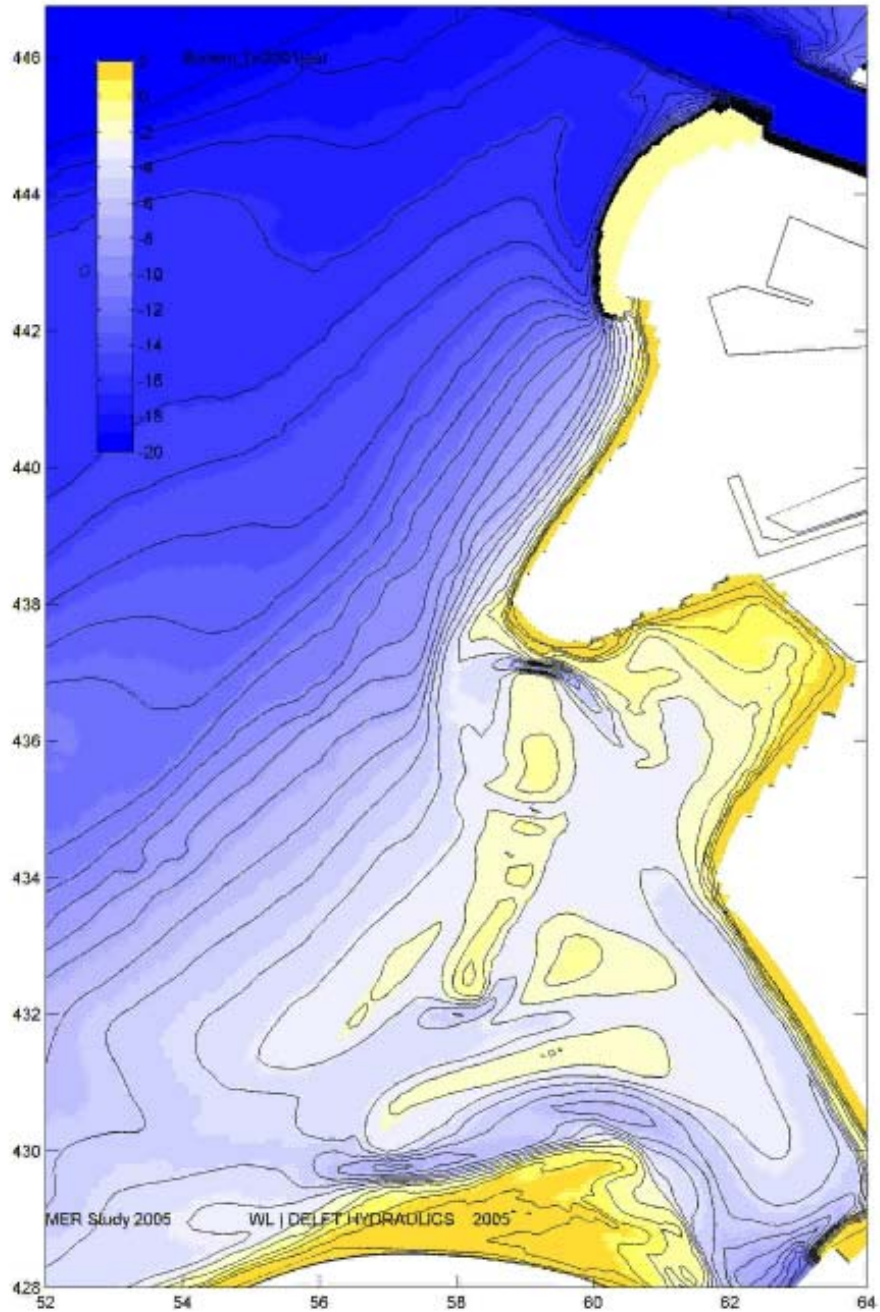


Source: USGS

UNESCO-IHE
Institute for Water Education

What happens next?

- Example: development of Haringvliet mouth
- large shoals with very mobile behaviour
- future of present barrier islands?



UNESCO-IHE
Institute for Water Education

Consequences of damage to barrier islands

- increased surge because of reduction of resistance; even increased wind setup over shallow remains
- increased wave penetration
- increased mobility of islands if left alone, leading to extra uncertainty regarding shoreward conditions

Nearshore wave attenuation

- very strong coupling with water depth and current (2-way)
- strong effect of vegetation
- damping by thick mud layers important?
- some methods available, see next; can be easily integrated in spectral wave model
- need to check dissipation formulations on very mild slopes

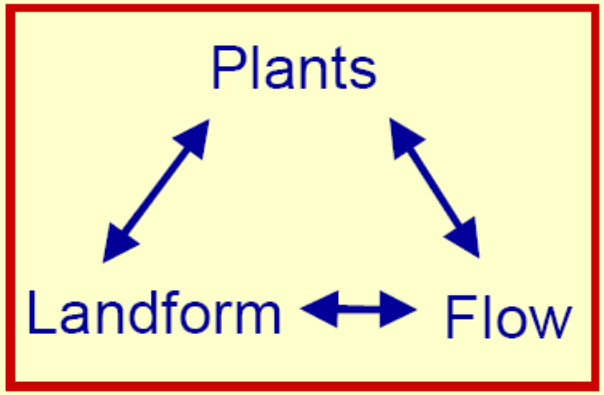
Biogeomorphology platform

- various institutes and universities in Netherlands
- links with EstProc project in UK
- studies interactions wave-flow-morphology-vegetation

Introduction:

plants, flow and landform…

Bio-physical interactions



how do they induce →

Spatial self-organisation

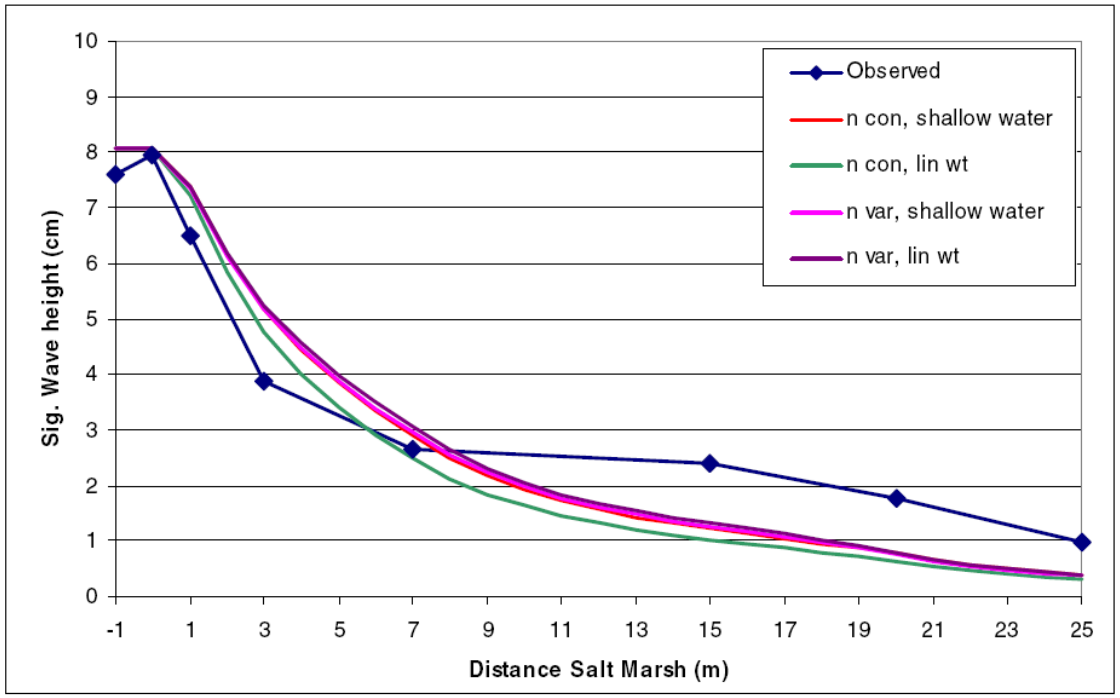
- Unvegetated tidal channels
- Vegetated platform with levees-basins

Can we make a model ??

1. Incorporating short-term interactions (1 tide)
2. Simulating long-term self-organisation (~100 years)

Wave attenuation over salt marsh

- courtesy Arjen Mol
- wave data from Western Scheldt
- not really hurricane conditions



Graph 7.23: SWAN validation for September 11, 20:45

UNESCO-IHE
Institute for Water Education

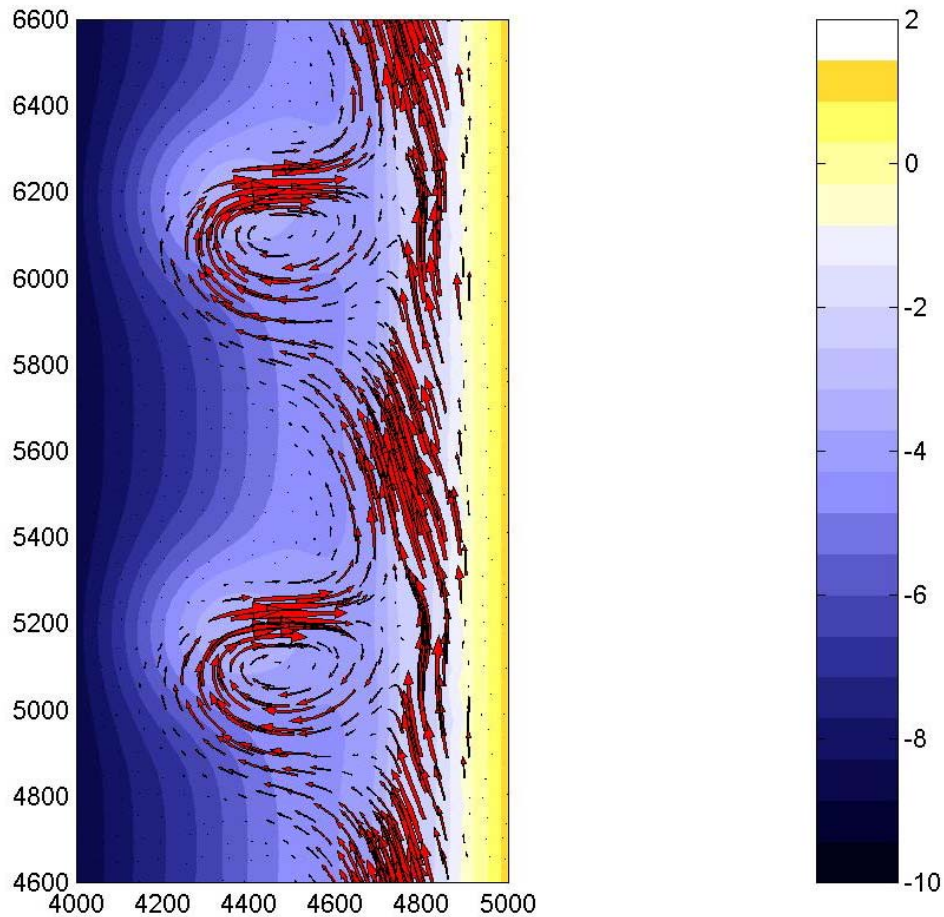
Modelling to support coastal management

- simulation of morphological development
- evaluating scenarios of management
  - maintaining/restoring barrier islands
  - innovative nourishment techniques
  - diverting river outflows
  - create new saltmarshes?
  - designing dune systems?
- take into account effects of vegetation on waves, sedimentation and vv
- predict wave heights, water levels near levees

UNESCO-IHE
Institute for Water Education

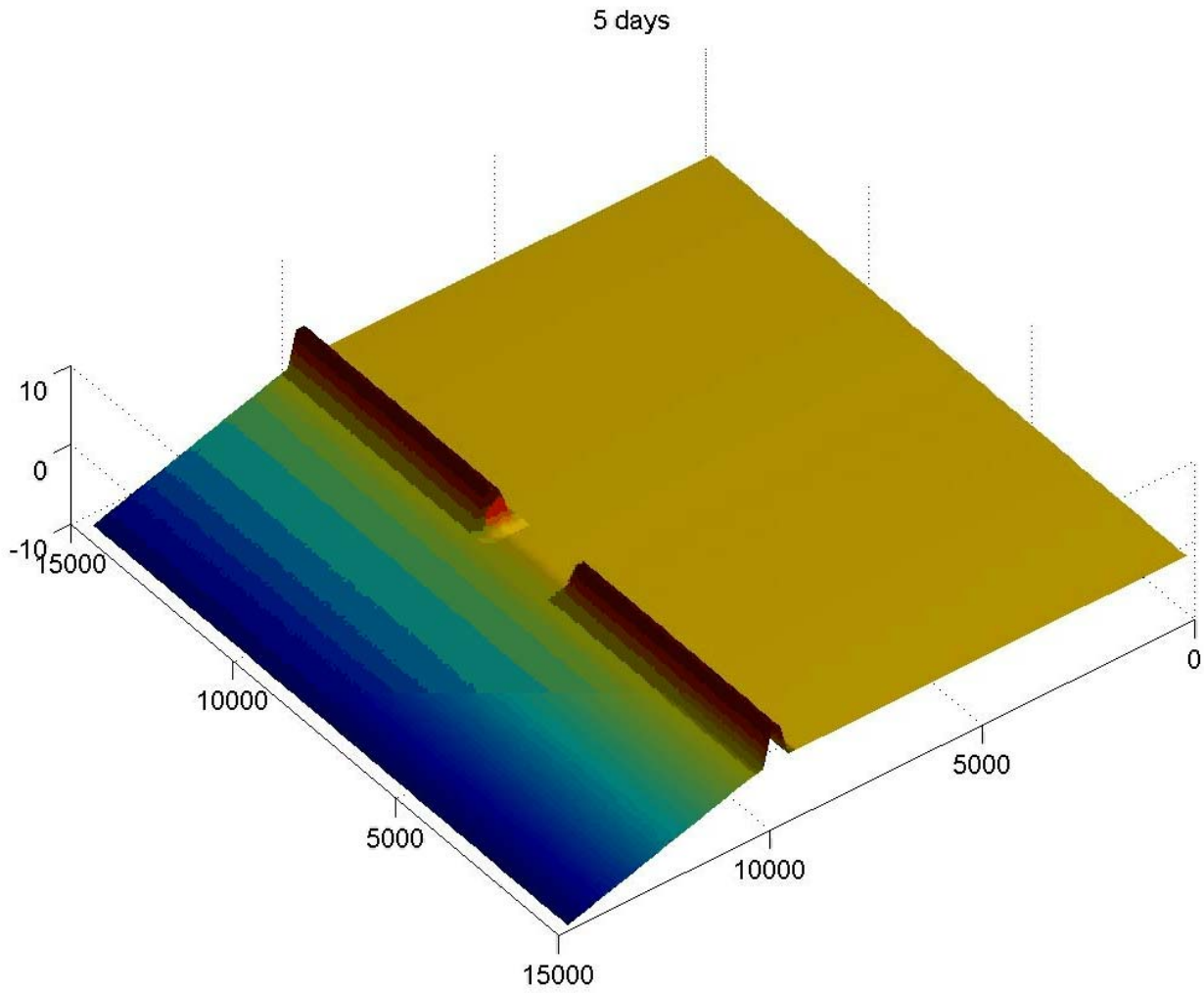
Hump-like nourishments

- promotes wave-driven circulations
- onshore where shallow, high concentrations
- controlled rip currents



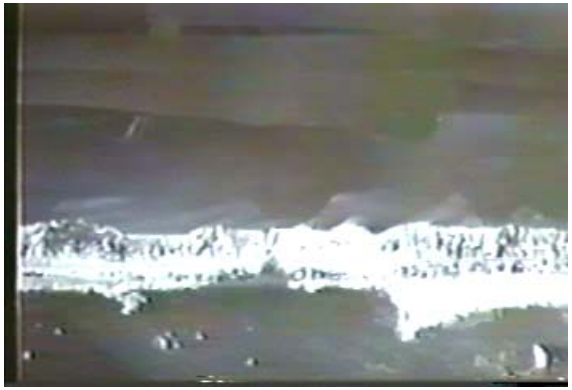
UNESCO-IHE
Institute for Water Education

Idealised case: Inlet development after breaching



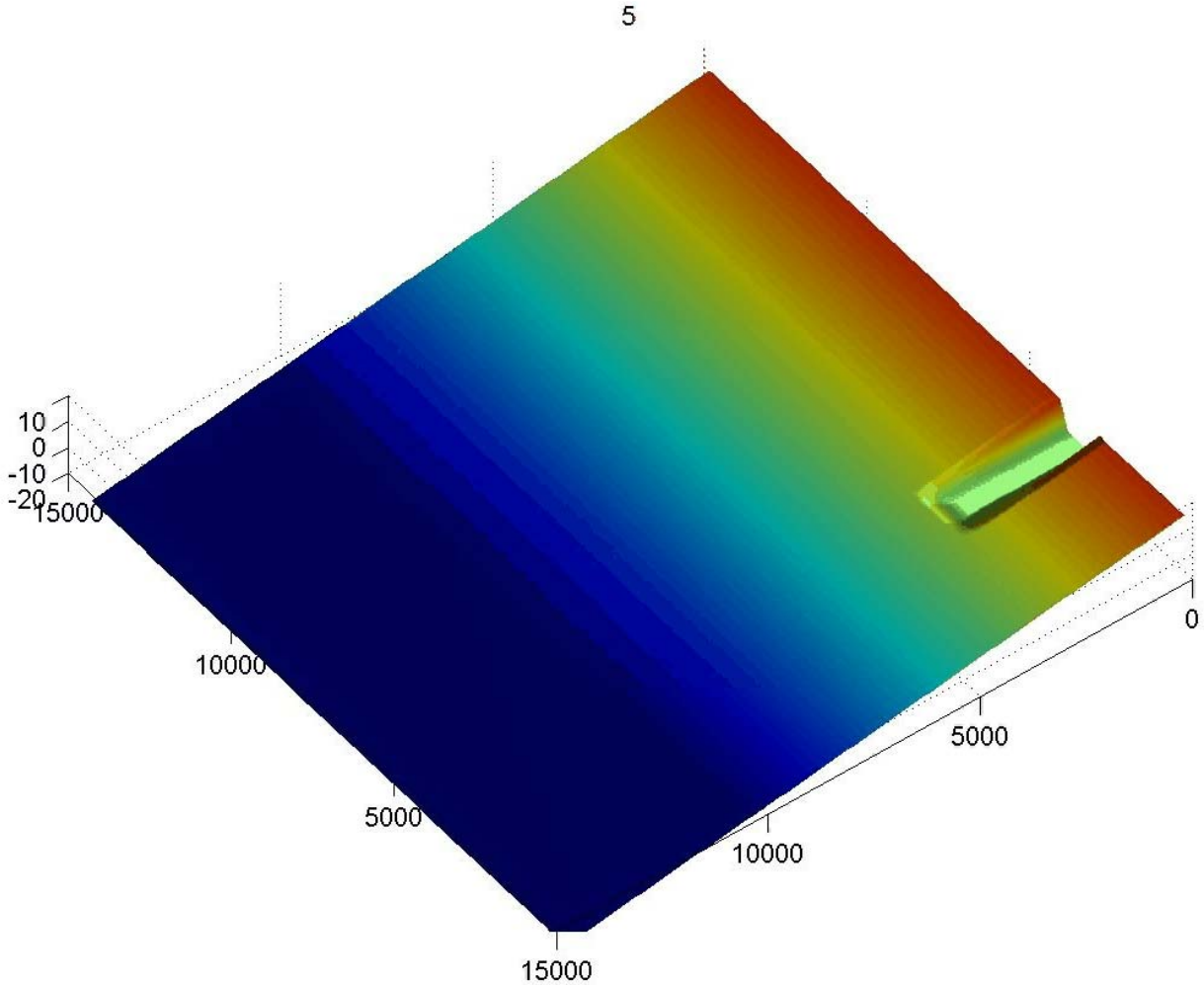
UNESCO-IHE
Institute for Water Education

Pikes Beach



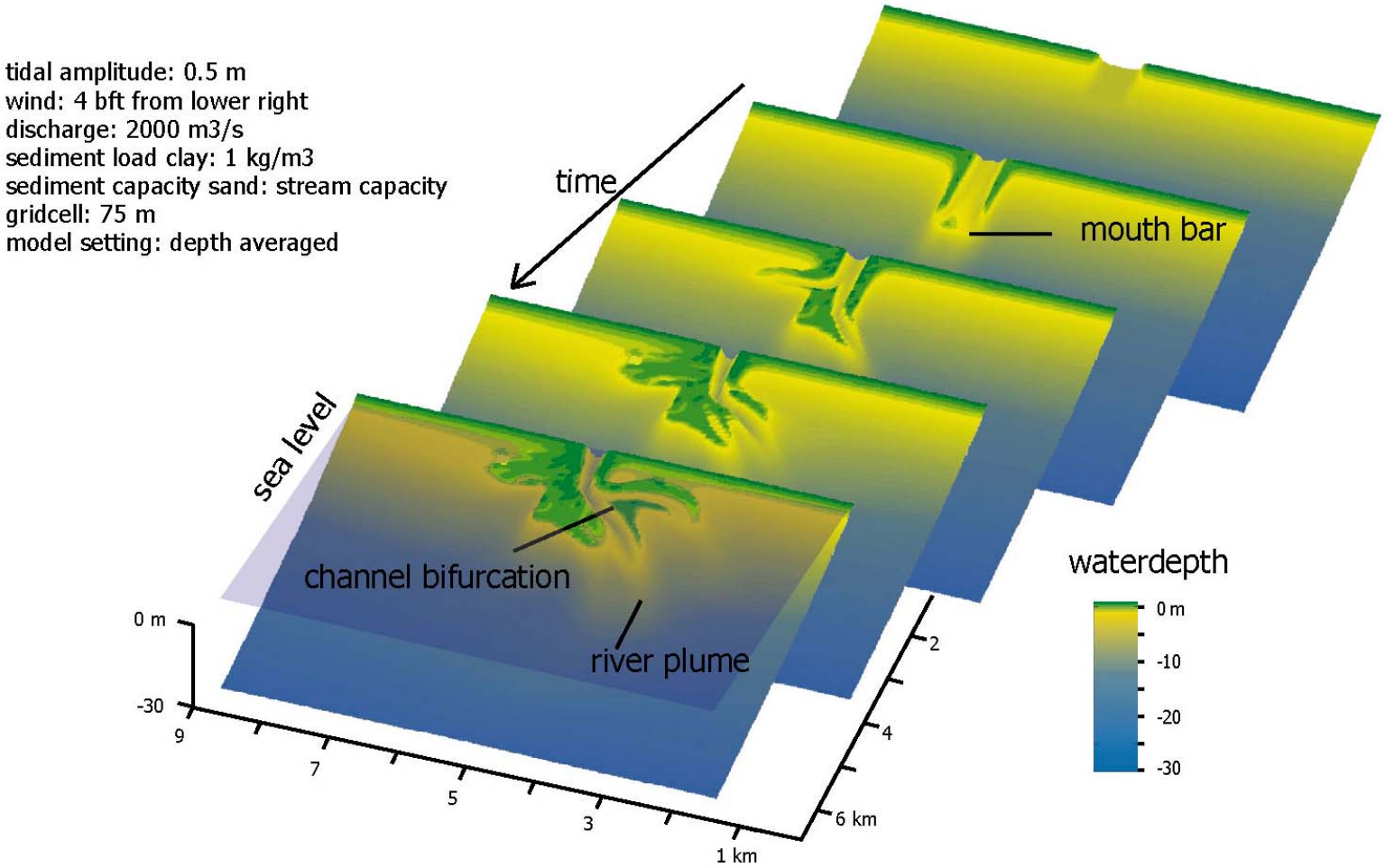
UNESCO-IHE
Institute for Water Education

Idealised case: Delta formation

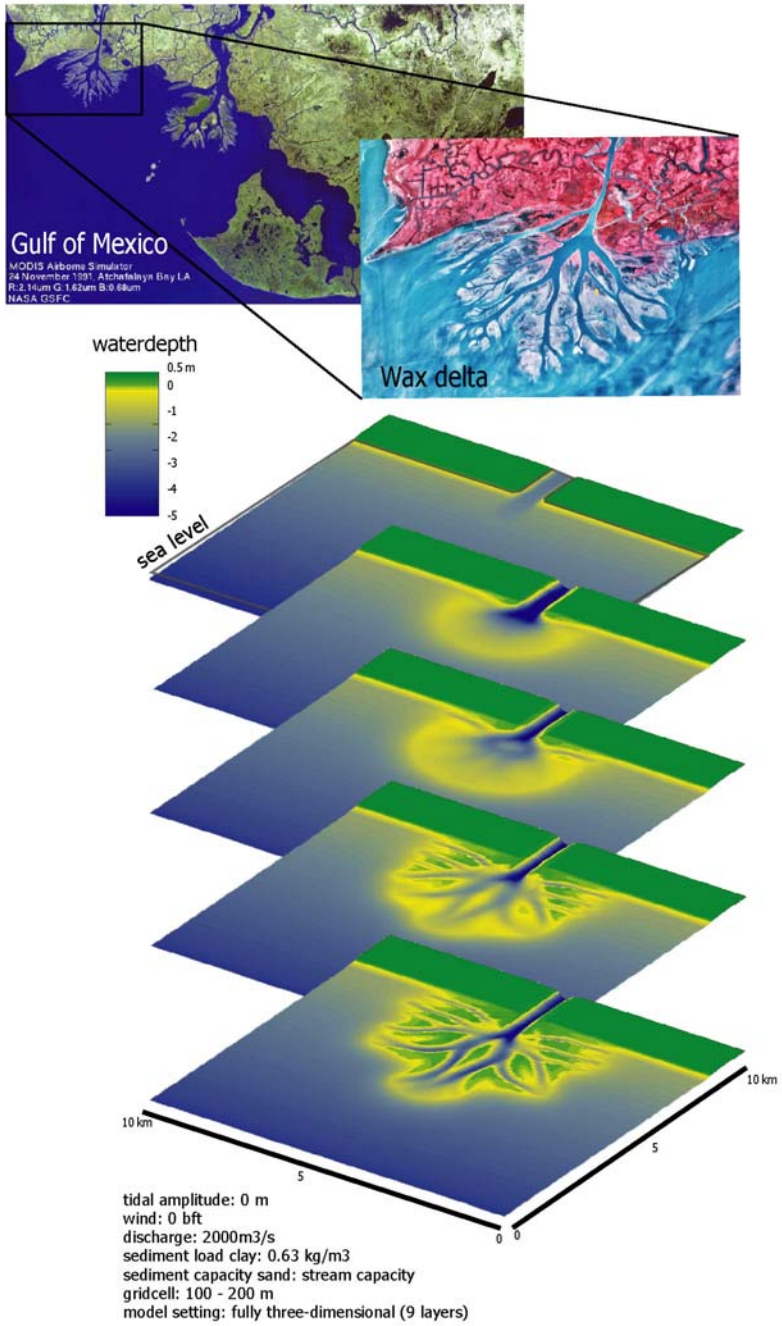


UNESCO-IHE
Institute for Water Education

Delta formation



Courtesy: Joep Storms



UNESCO-IHE
Institute for Water Education

TITLE: Estimating Storm Frequency

PRESENTED BY: Don Resio, USACE-ERDC

SUMMARY: This presentation reviewed the methods for estimating storm probabilities, described the historical storms for the region, and examined the options for developing storm characteristics. The methods discussed for design conditions included the design storm method, joint probability method, empirical simulation technique, empirical track models, and historical data analysis. The characterization of historical hurricanes included an analysis of high water marks with Saffir-Simpson categorization. This correlation is not strong and Saffir-Simpson is not a good indicator surge height. A variety of examples were demonstrated on developing storm characteristics but the overriding concern continues to be balancing statistical sampling with modeling accuracy.

Estimating Storm Frequency

Don Resio

Coastal and Hydraulics Lab, ERDC, Vicksburg, MS

Hurricane Protection Design Workshop
December 20-21, 2005

Purpose of Briefing:

Review Methods for Estimating Storm Probabilities

Present an Historical Perspective for Region

Examine Options for Developing Storm Characteristics

"Forecasting can be very difficult --- particularly when it involves the future."

Yogi Berra

Methods for Design Condition Estimation

Design Storm Method

- Standard Project Hurricane
- Probably Maximum Hurricane

Analysis of Historical Data (including modeled historical storms)

- Distribution-Fitting Methods
- Asymptotic Methods (Peaks Over Threshold - POT)

Joint Probability Method (JPM – Ho and others)

- Models combinations of storm parameters (Πm_n cases)

Empirical Simulation Technique (EST – Borgman and others)

- Uses historical storms plus “hypotheticals”

Empirical Track Model (ETM – Vickery and others))

- Monte Carlo storm sequences

SPH: "one that might be expected from the most severe combination of meteorological conditions that are considered reasonably characteristic of the region" (ex. Sep 1915 – upper 3/lower 4)

1961 SPH max surge hts – Buras 12.4 ft, Shell Beach 14.4 ft

SPH: "one that may be expected from the most severe combination of critical meteorological conditions that are reasonably possible for the region. It has an infinite recurrence period" (no example given)

1961 PMH max surge hts – Buras 15.0 ft, Shell Beach 16.8 ft

Katrina significantly exceeded these PMH values.

Recent Methods for Surge Extremes

Joint Probability Method (JPM)

- assumes hurricane surge is characterized by set of parameters at landfall (wind speed, size, storm speed, landfall location, track angle)
- holds all parameters constant over simulation interval
- simulates discretized parameter space
- uses associated probabilities to estimate CDF and return periods
- parameterized wave effects are added to wind-driven surge estimates
- parameter combinations can become very large
- requires quantification of joint probabilities for hurricane parameters

Empirical Simulation Technique (EST)

- assumes best information is local to site (simulates historical storms)
- Empirical Distribution function estimated as

  $EDF(x) = Z\{1 - n/(N+1)\}$ [n=rank, N=number of years in sample
  Z=Poisson frequency parameter]
- uses re-sampling/"bootstrap" methods to estimate variability (non-parametric)
- Requires extrapolation beyond 1/N and n/N points (parametric with constraints)
- use hypothetical storms to help smooth effects of single large storms (judgment)
- can used coupled wave-surge models since typically small set of events run

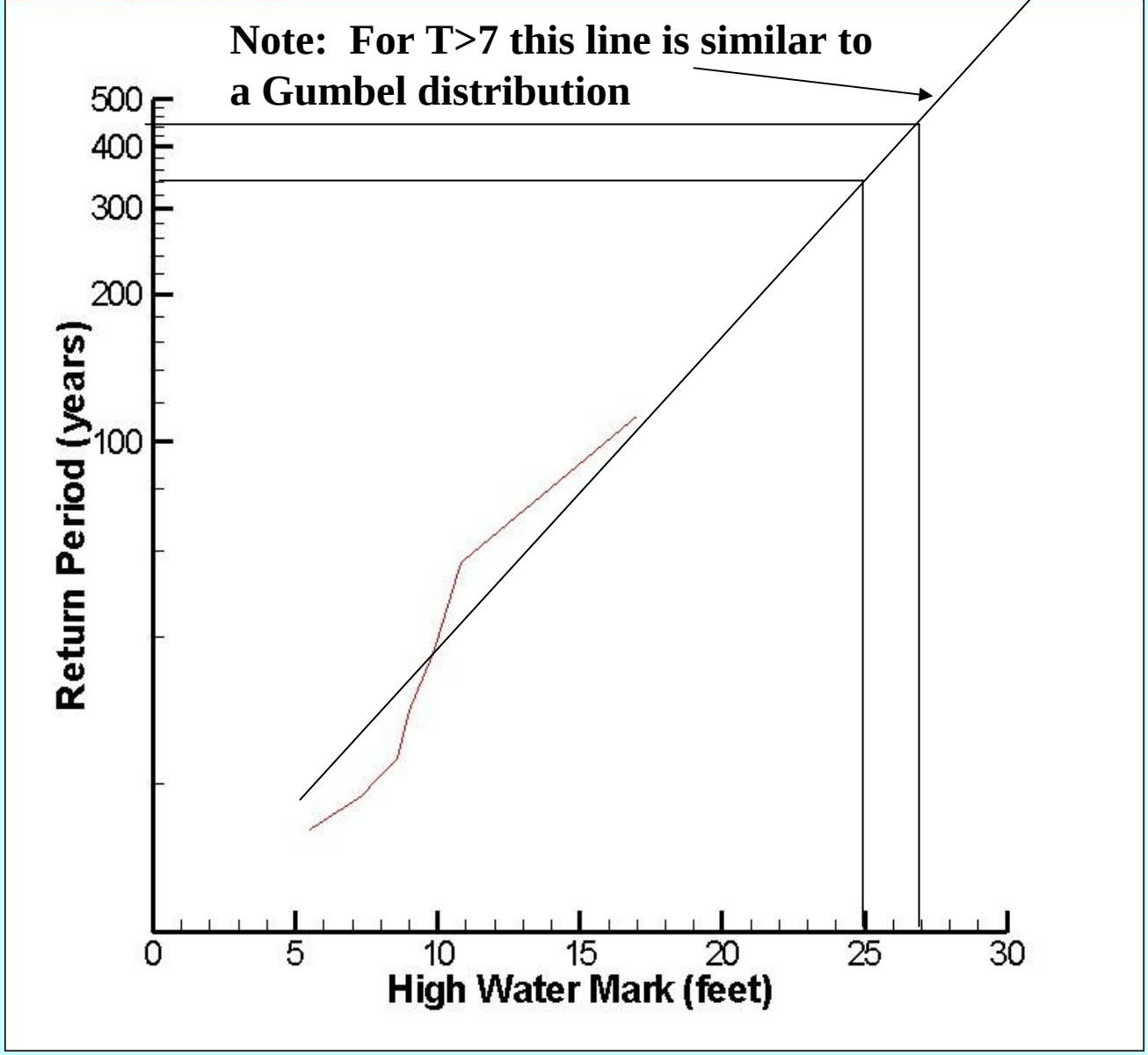
Empirical Track Model (ETM)

- evolved to treat non-constant track parameters
- used Monte Carlo simulation method to run long intervals (>10^5 years)
- used by FEMA for hurricane wind speeds
- simplistic modeling if large number of simulations required

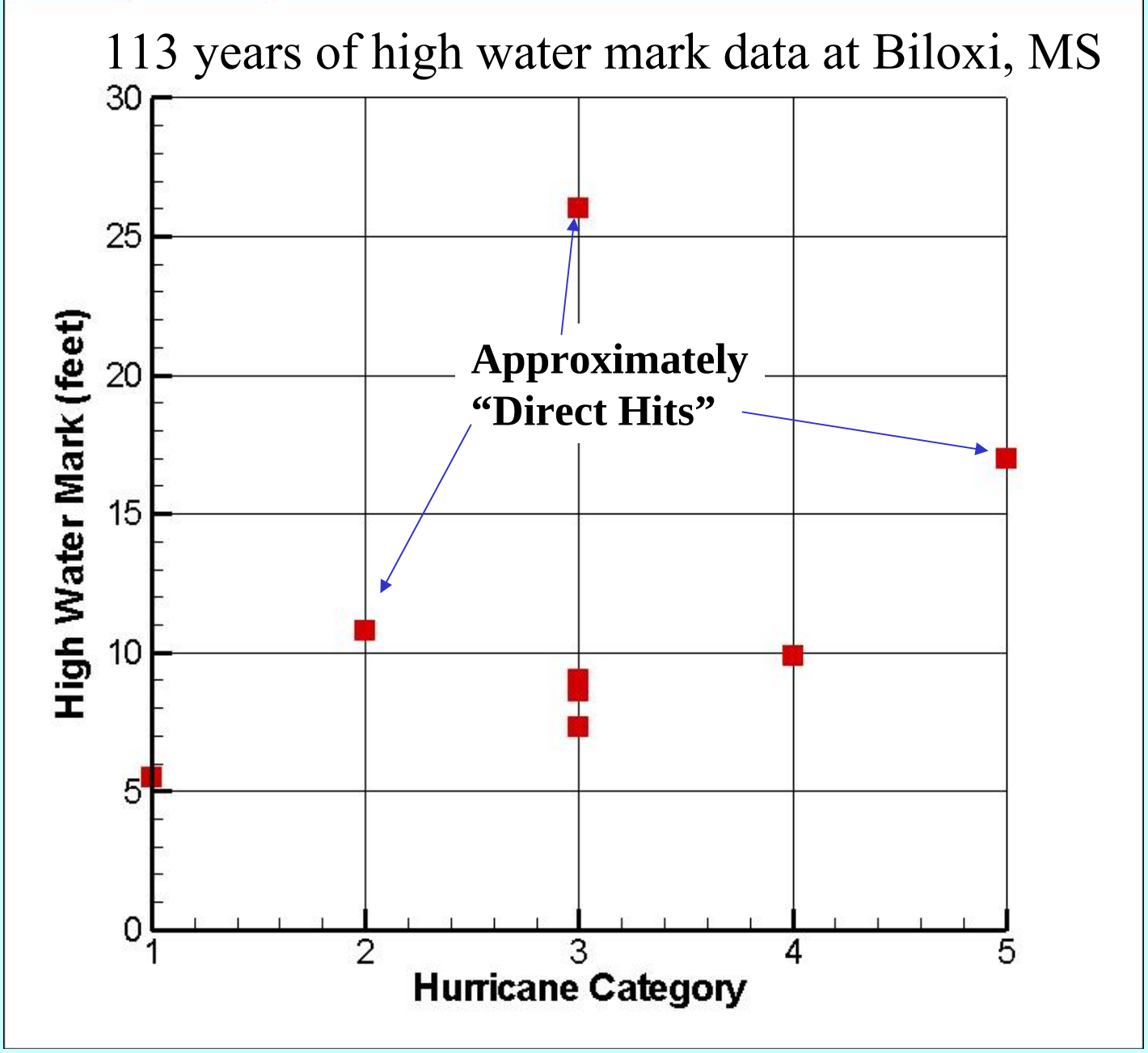
HISTORICAL CHARACTERIZATION

Over 100 Years of High Water Marks
Biloxi, Mississippi

Hurricane	High Water Mark	S-S #
1893	9.0	3
1915	9.9	4
1947	10.8	2
1965 (Betsy)	8.6	3
1969 (Camille)	17.0	5
1985 (Elena)	7.3	3
1998 (Georges)	5.5	1
2005 (Katrina)	26.0	3



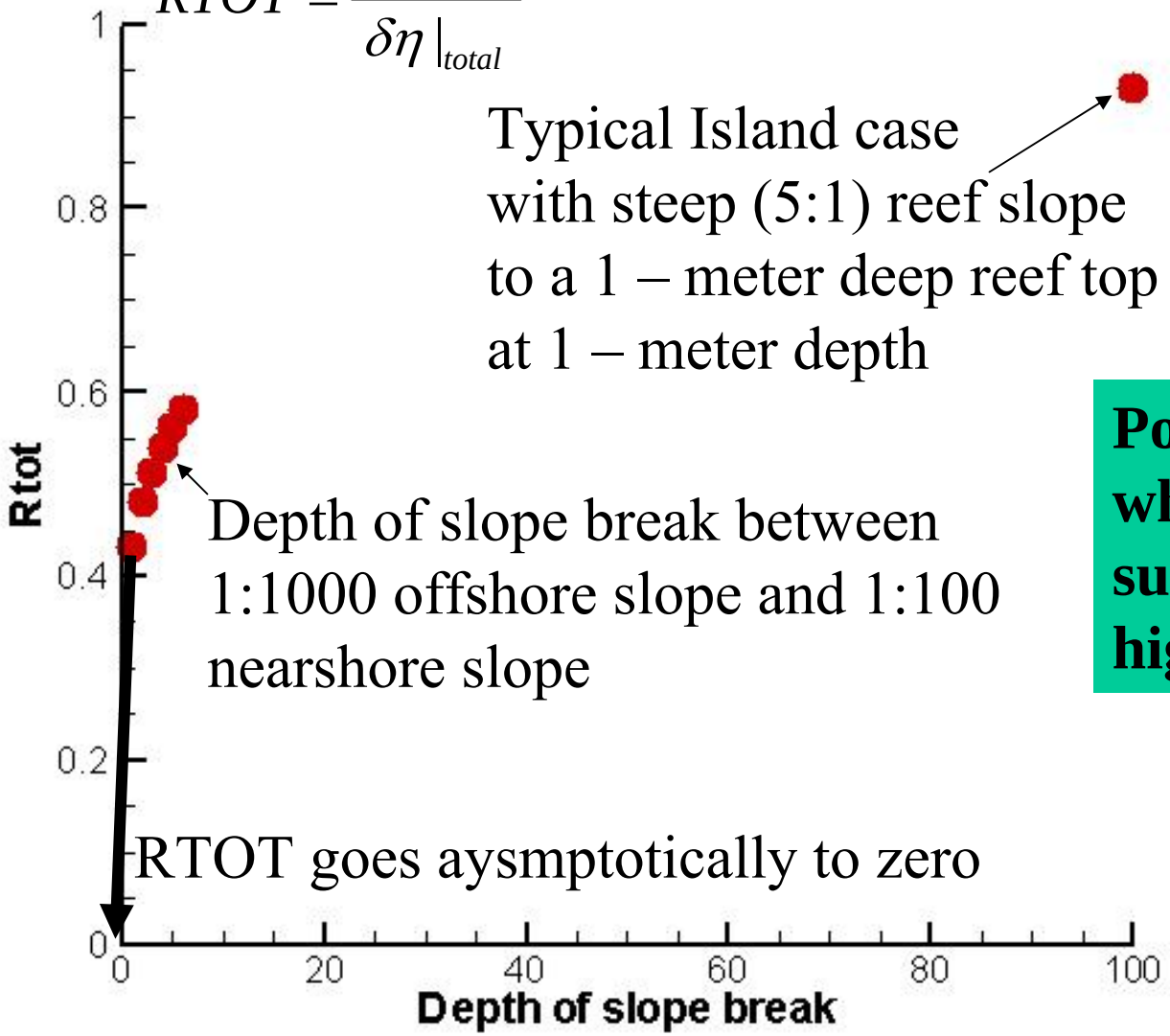
Estimate of Return Period for Katrina based on 112 years of High water marks at Biloxi, MS – (pre-Katrina)



Hurricane Category is not a very good indicator of surge height.

Ratio of wave contribution to surge to total surge,
Assuming energy loss is one of two regions ($k^{-5/2}$ or $H \sim \gamma h$)

$$RTOT = \frac{\delta\eta\,|_{waves}}{\delta\eta\,|_{total}}$$



Typical Island case
with steep (5:1) reef slope
to a 1 – meter deep reef top
at 1 – meter depth

Depth of slope break between
1:1000 offshore slope and 1:100
nearshore slope

RTOT goes aysmptotically to zero

Possible reason why Katrina surges were so high - waves?

Possible adaptation to JPM:

Response of wind driven surge is related to a relaxation parameter of the form:

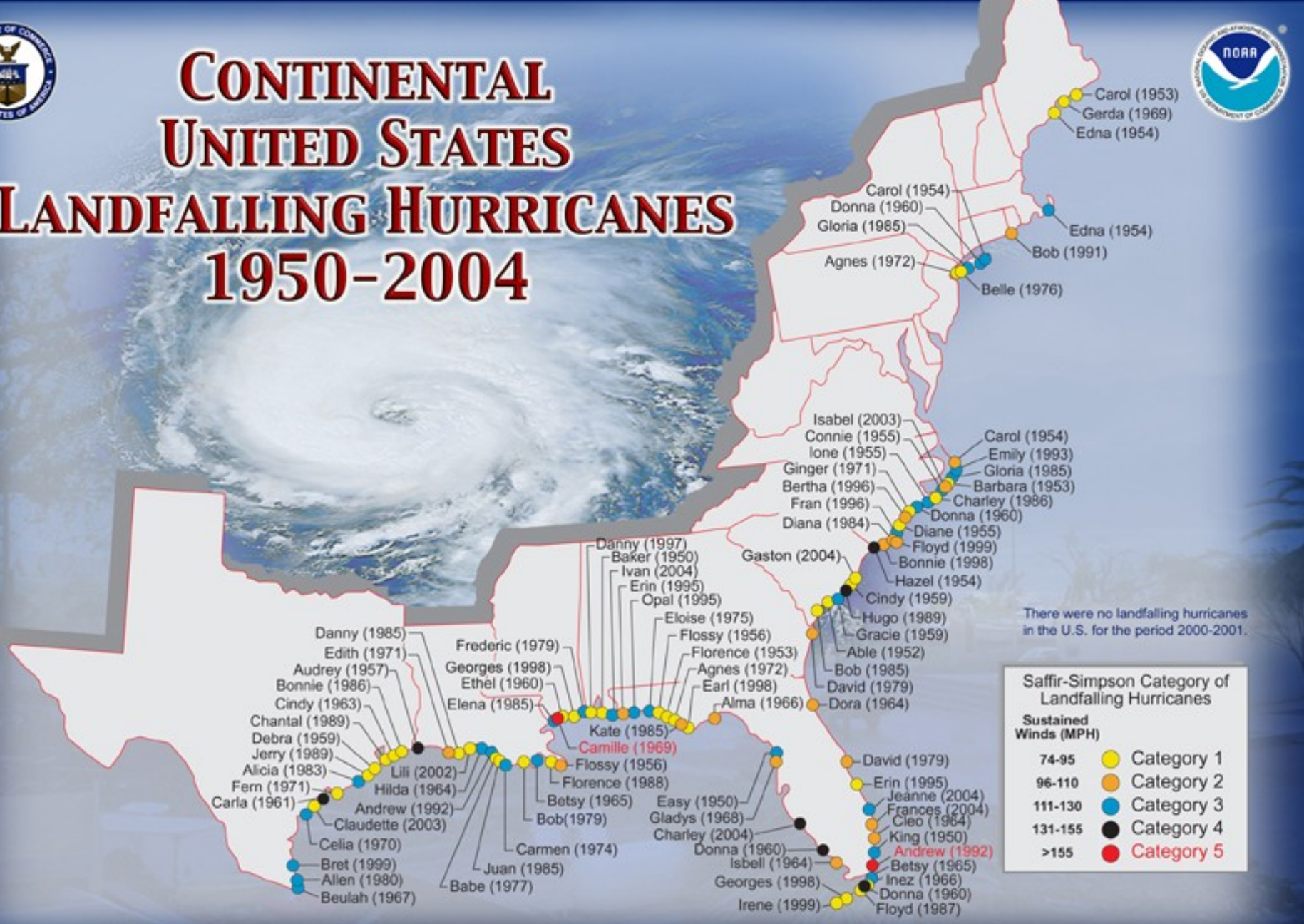
[O(3-6hrs)] $$\tau = \left(\frac{\eta}{u\sqrt{\beta c_d \rho_a / \rho_w}} \right)$$

Response of waves is related to a relaxation parameter of the form:

[O(30-60hrs)] $$\tau_{waves} = \lambda u / g$$

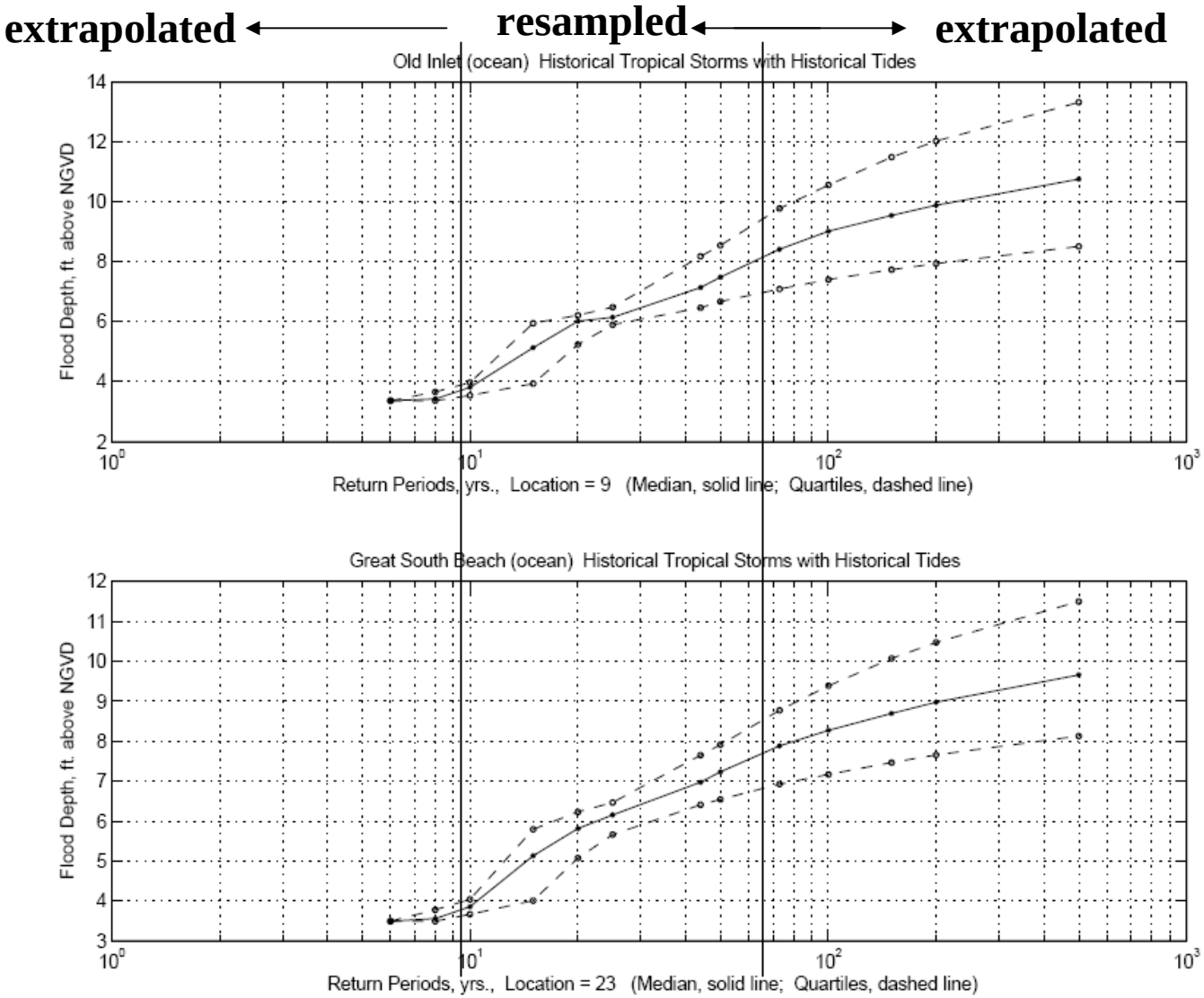
POINT: Wave fields respond to much longer time scale and larger spatial scale than do surge fields.

Continental United States Landfalling Hurricanes 1950-2004



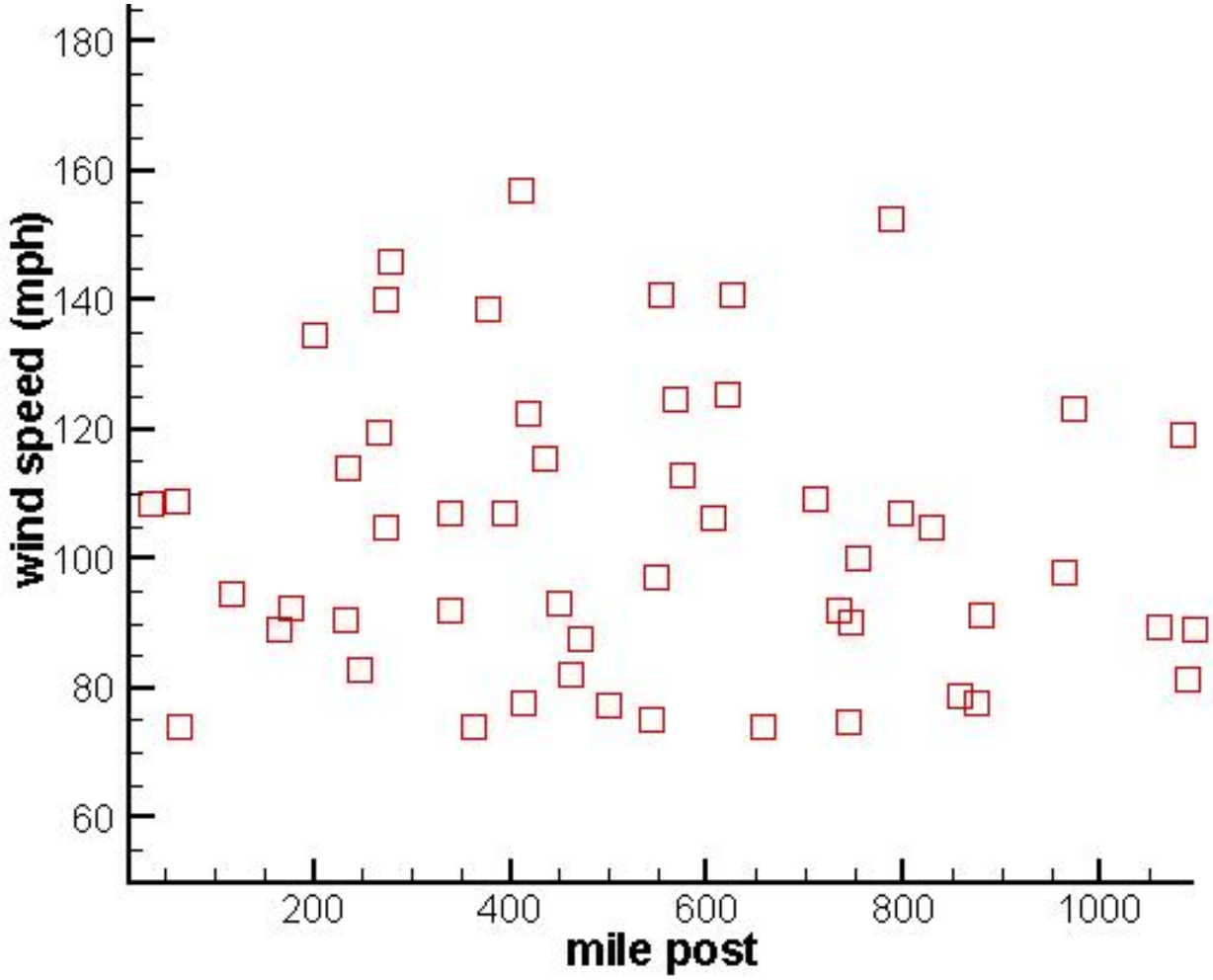
NOAA'S NATIONAL CLIMATIC DATA CENTER, ASHEVILLE, NORTH CAROLINA

Protecting the Past... Revealing the Future

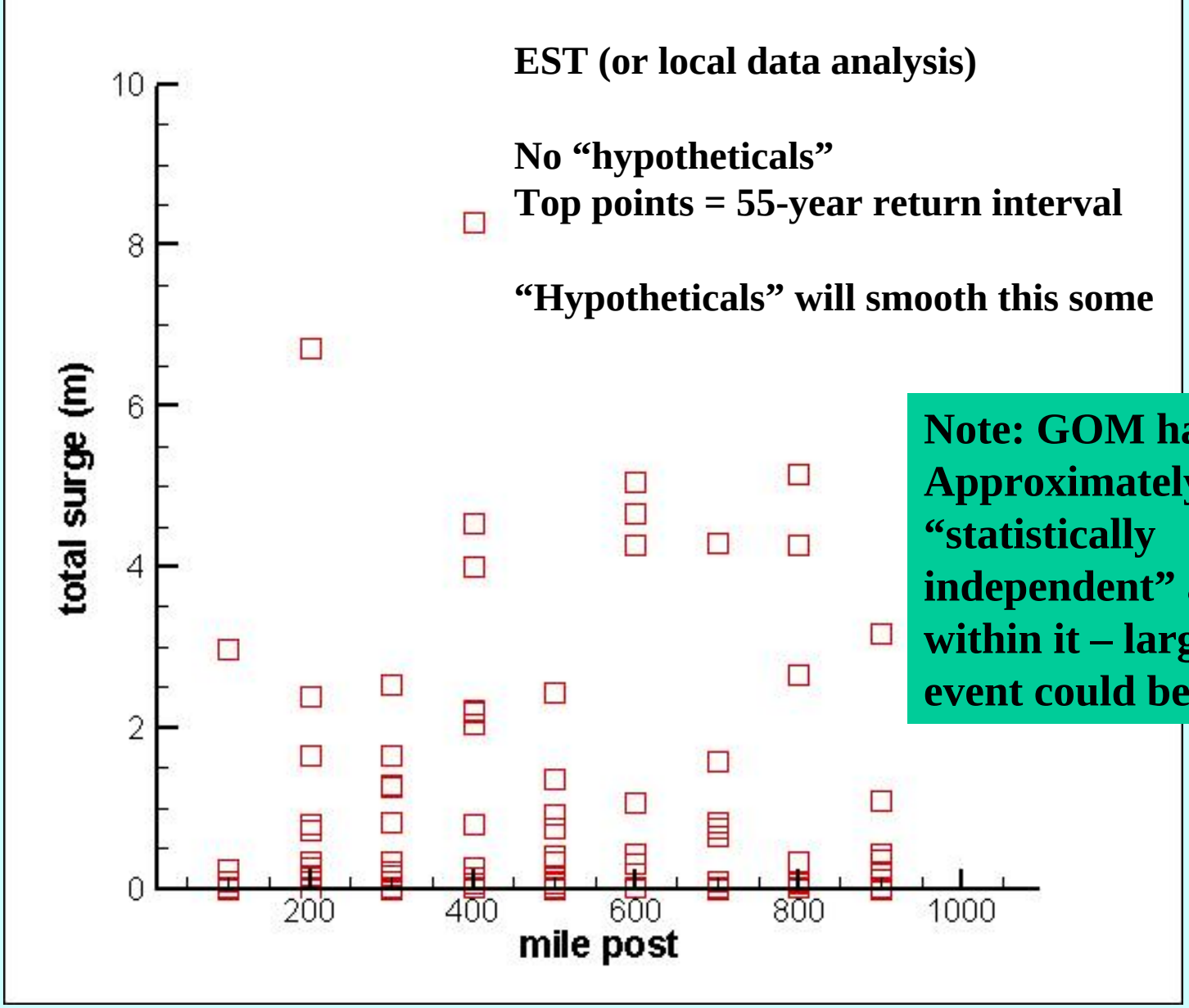


EST results for Fire Island to Montauk Point Study – NY District

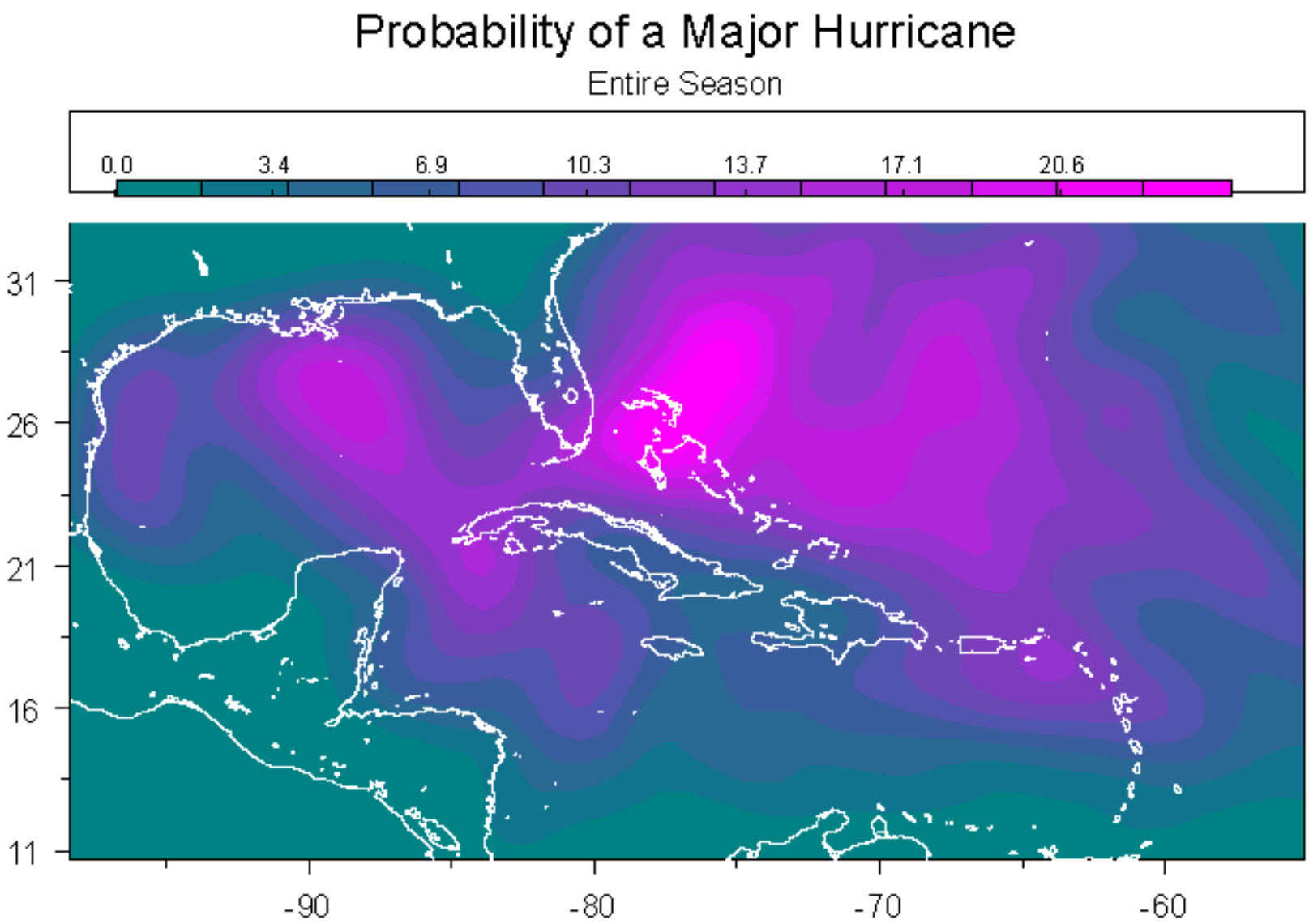
Monte Carlo Simulation of Wind Speeds - based on historical statistics



Random sample of 54 hurricanes along 1100 miles of Gulf coast assuming spatially homogeneous hurricane population



Parameterized surges for case shown in previous slide assuming homogeneous coastal response to forcing. Actual data - more complex.



Major hurricane probabilities are not spatially homogeneous.

NEED TO BALANCE MODELS AND STATISTICS

Models cannot correct for sampling variability

- climatic variability
- “local” information alone can be insufficient

• Lots of runs cannot correct data from poor models

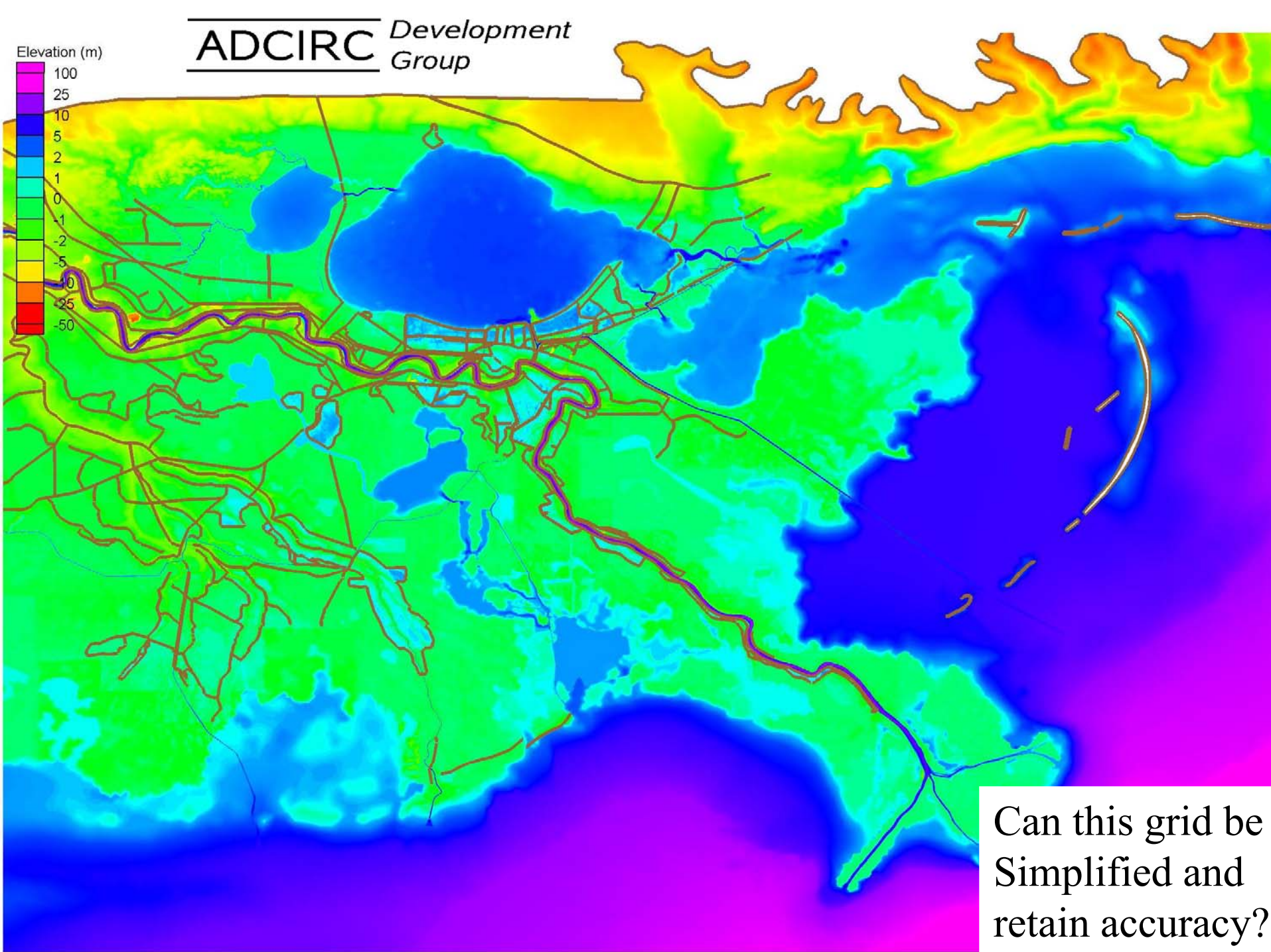
- feedback from levee heights
- role of Mississippi stage in flooding (Betsy example!)
- lack of wave-surge coupling
- precipitation

• Options for diminishing sampling problems

- lots of cases
- optimally sample probability space
- correction for EST via “surge potential” categorization

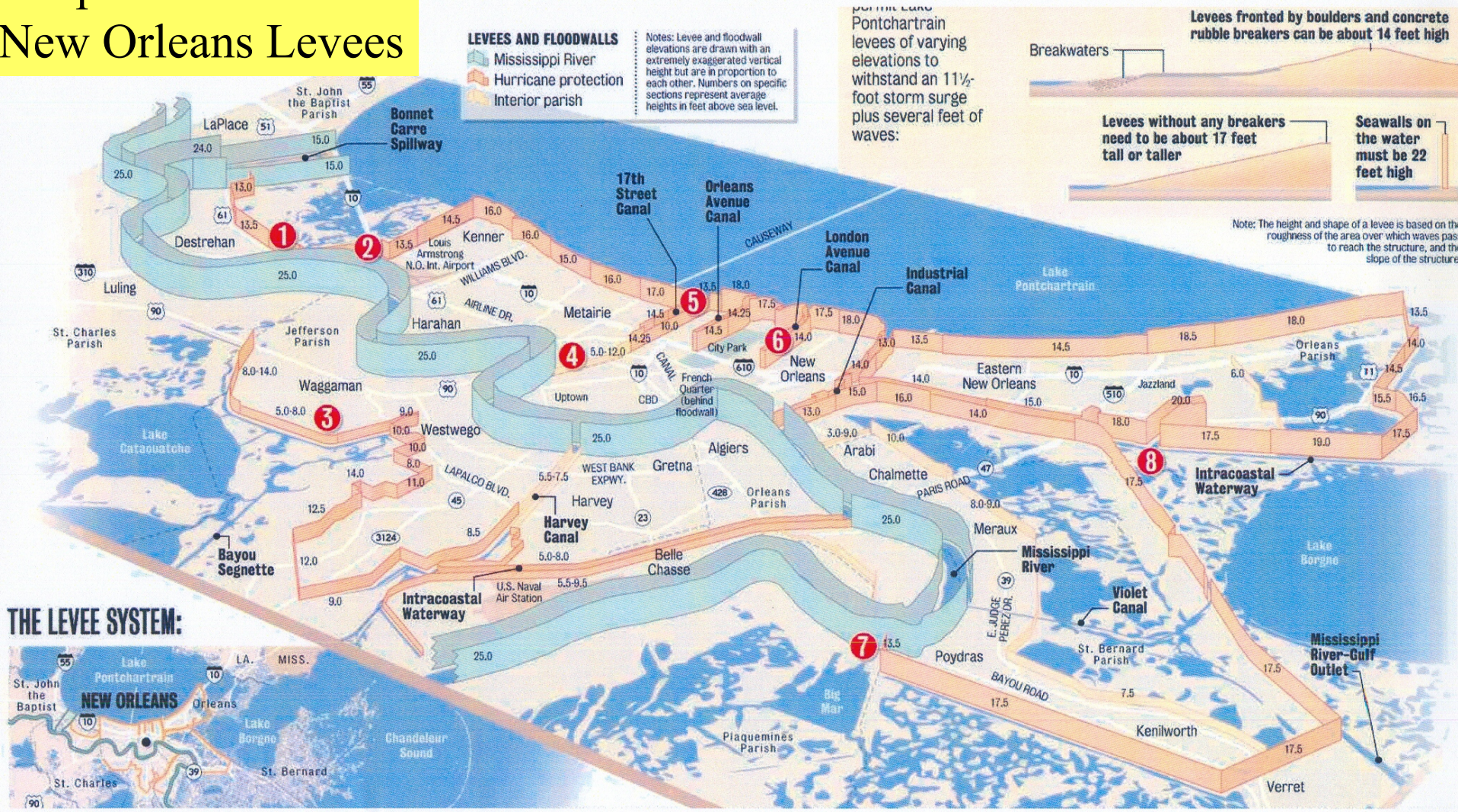
• Options for diminishing model run times

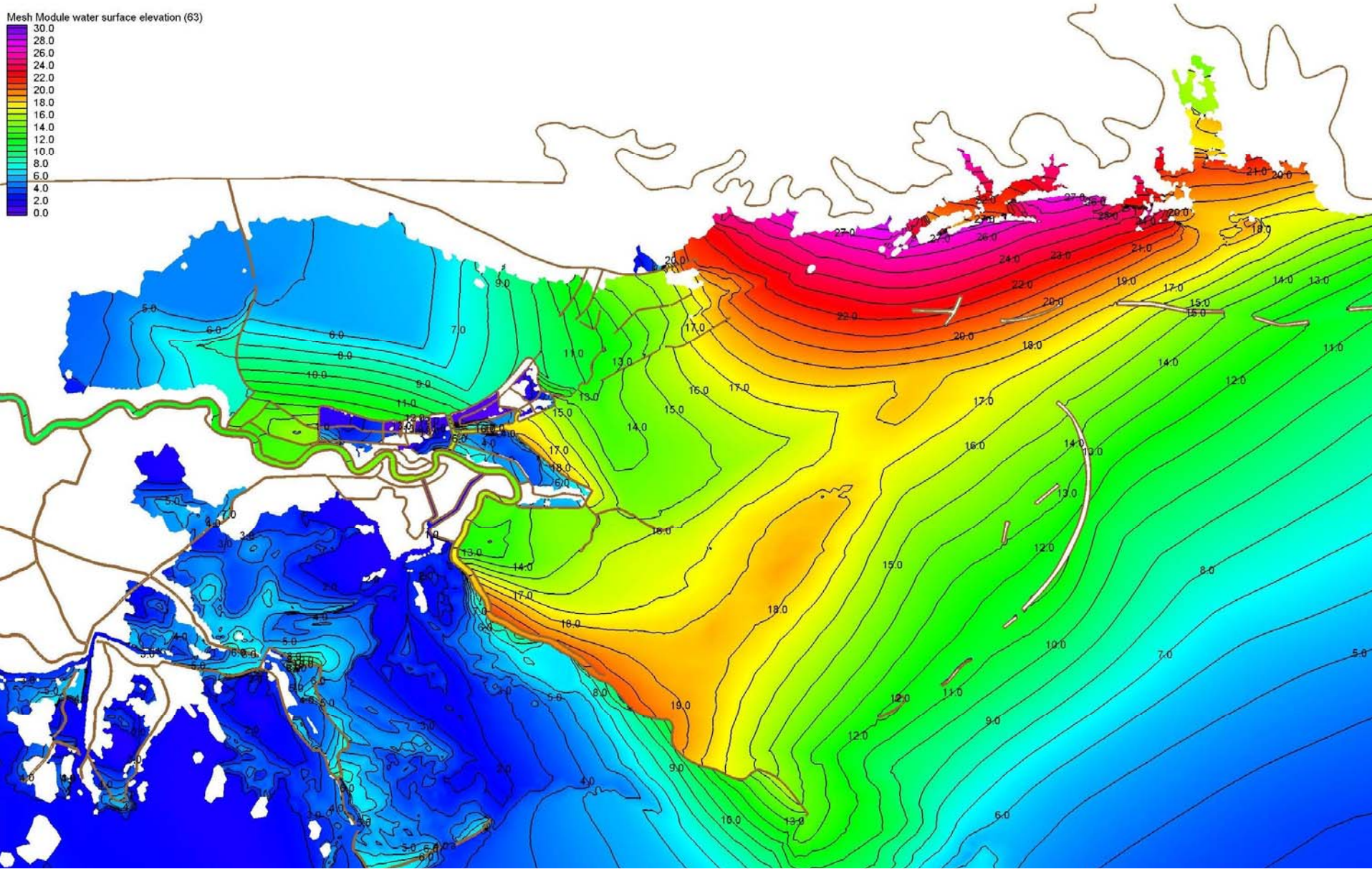
- simplify, simplify, simplify
- must retain functional dependencies
- parameterize processes



Can this grid be Simplified and retain accuracy?

Simplified view of New Orleans Levees





Hindcast Maximum Surge Levels for Katrina. Note the broad scale of variation in areas of very high surges.

Besides reducing model run times wherever possible, we can use more efficient sampling routines - based on the storm surge potential characteristics rather than the local response function or just wind speed

$$p(\eta) = p(\varepsilon_1, \varepsilon_2, ..., \varepsilon_n) J^{-1}$$

$$J^{-1} = \delta[\eta_*(\varepsilon_1, \varepsilon_2, ..., \varepsilon_n) - \eta] \longleftarrow$$ **Hopefully, this mapping is fairly universal**

$$F(\eta) = \int ... \int p(\varepsilon_1, \varepsilon_2, ..., \varepsilon_n) H[\eta_*(\varepsilon_1, \varepsilon_2, ..., \varepsilon_n) - \eta] d\varepsilon_1, \varepsilon_2, ..., \varepsilon_n$$

If certain fairly straightforward conditions are met, this integral can be mapped from one area to another to provide an estimate of the probability of the surge potential of a particular hurricane.

Oddly enough, this could be viewed as a variant of the "design storm" approach, except that now the method is cast in actual probabilistic terms – but it is very unlikely that this will result in the same "characteristic storm" for the entire New Orleans area.

CONCLUSIONS

Historical data is good to frame statistical queries

BUT – it can be very misleading

ex. 82 years up to Camille T(26) > 1000

ex. 56 years from 1965-2005 100-yr value = 38'

Saffir-Simpson scale is not a very good indicator of surge at coast

Need to carefully balance statistical sampling and model accuracies

A Surge Potential Index would allow development of a statistically rigorous Design Storm (local)

Still need to pick design values (failure modes, consequences)

QUESTIONS??

RELATIVE CONTRIBUTION OF WAVES TO SURGE AT COAST
(Case of wind and waves directed normal to coast)

$$\frac{\partial \rho_w \bar{u}}{\partial t} = \rho_a c_d u_n^2 + \frac{\partial \Gamma_M}{\partial n} - \rho_w g h \frac{\partial \eta}{\partial n}$$

$$\frac{\partial \Gamma_M}{\partial n} = \frac{\partial < c_g > M_0}{\partial n} = \frac{\partial \rho_w g \int_0^\infty E(f) \frac{c_g(f)}{c(f)} df}{\partial n} \approx \frac{\rho_w g \partial \left(\frac{c_{g_p}}{c_p} E_0^a \right)}{\partial n}$$

For steady state condition

$$\frac{\partial \eta}{\partial n} = \frac{1}{gh} \left[\frac{\rho_a}{\rho_w} c_d u_n^2 + \frac{\partial \frac{c_{g_p}}{c_p} \rho_w g E_0^a}{\partial n} \right] = \frac{1}{h} \times \frac{\rho_a}{\rho_w} \frac{c_d u_n^2}{g} [1 + R]$$

$$R = \frac{\frac{\partial \left(\frac{c_{g_p}}{c_p} E_0^a \right)}{\partial n}}{\frac{\rho_w}{\rho_a} \frac{c_d u_n^2}{g}}; \quad \eta_{coast} = \Psi_i \int_{x_1}^{x_2} \frac{\tau_{wnd}}{h} [1 + R] dx = \Psi_i \left(\frac{\rho_{a/w} c_d u_n^2}{g} \left(\int_{x_1}^{x_2} \frac{1}{\mathrm{h(x)}} dx \right) + \int_{x_1}^{x_2} \frac{\partial}{\partial x} \left(\frac{\Phi(h,x)}{h} \right) dx \right)$$

ρ_a, ρ_w = density of air, water

c_d = coefficient of drag ($\leq 2.3 \times 10^{-3}$)

Γ_M = momentum flux

u_n = wind speed normal to coast

E_0^a = total (adiabatic) energy

g = gravity

h = depth of water

c_p = phase velocity of waves

c_{g_p} = group velocity of waves

η = mean water surface height

Ψ_i = impulsiveness factor

Constant times distance over depth

Depends on what depth Momentum is lost at

TITLE: Estimating Storm Frequency

PRESENTED BY: Pete Vickery, Applied Research Associates

SUMMARY: This presentation described an approach for assessing hurricane risk at a given location and the end-to-end risk assessment approach. The hurricane risk methodology currently used is the HAZUS model developed for FEMA. The methodology employs the simulation of hurricane tracks, intensities and storm size, and has been validated through comparisons of the characteristics of modeled and historical hurricanes. The incorporation of the NOAA drop sonde data into the development of a new model for the hurricane boundary layer was discussed.

The end-to-end risk assessment approach can be used for designing new levee systems. This approach couples the hurricane risk model, with storm surge and wave models, and levee reliability models. By using a stratified sampling methodology, the number of simulations required can be reduced. This allows for a quantitative evaluation of the system-level reliabilities of candidate levee designs in a risk consistent approach rather than resorting to one or more “design” storms coupled with a deterministic pass/fail criteria.

Assessing Hurricane Risk along the US Coastline

Peter J Vickery
Applied Research Associates
8540 Colonnade Center Drive
Raleigh, NC, 27615

APPLIED RESEARCH ASSOCIATES, INC.
An Employee-Owned Company

Model Overview

HURRICANE SIMULATION MODEL
Models storm Track and Intensity (defined by pressure)

↓

Statistical models for Holland *B*, RMW and Storm Filling

↓

HURRICANE WIND FIELD MODEL

↓

Wave Models, Coastal Models, Damage and Loss Models

RISK ASSESSMENT

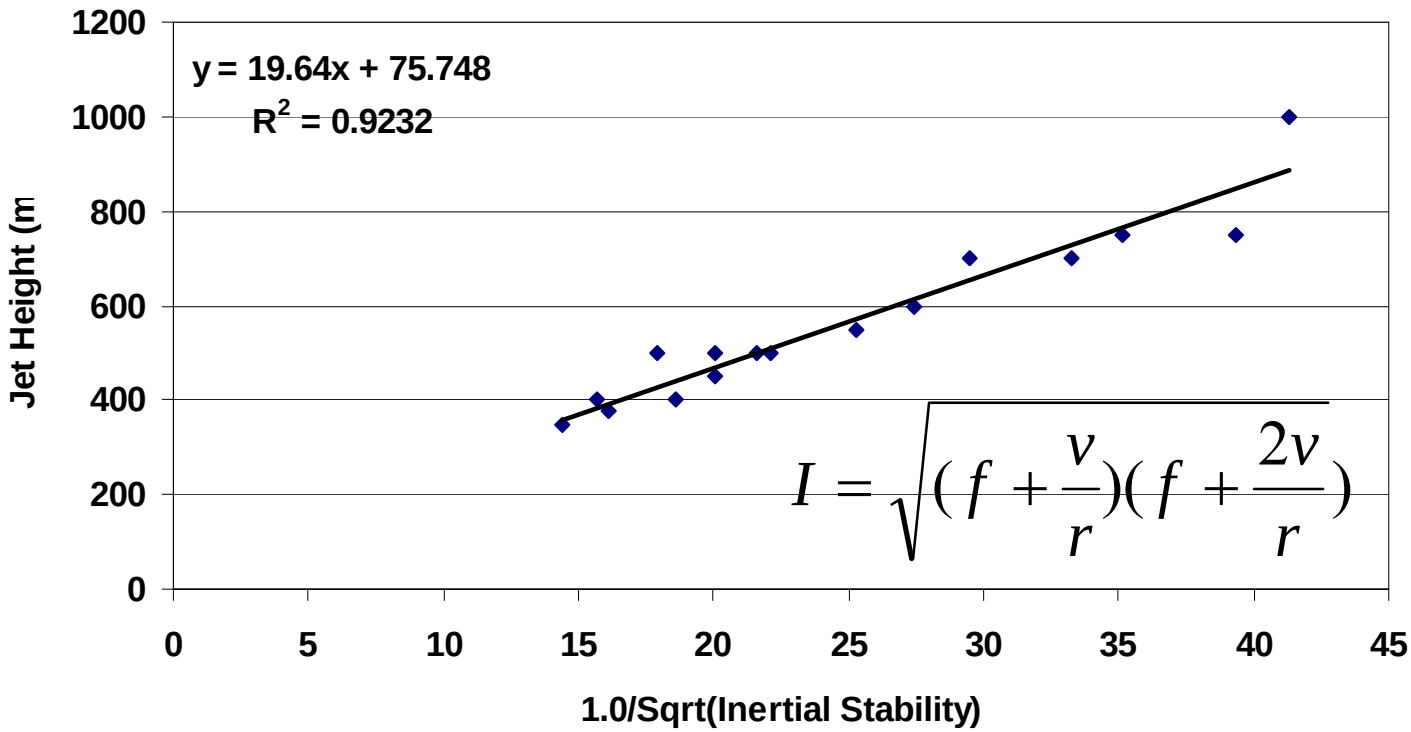
Hurricane Windfield Modeling

- Pre-computed solutions of the numerical model are saved as Fourier series for 3020 combinations of central pressure, radius to maximum winds, Holland *B* parameter, translation speed and drag coefficient (marine and land)
- Solutions for given values of central pressure etc., are obtained through interpolation of the pre-computed wind fields
- Employed so the model can run quickly in simulations

Recent Hurricane Boundary Layer Data

- Data from GPS dropwindsondes indicate that C_d does appear to level of at high wind speeds
- Data confirm the existence of a "jet" with maximum wind speeds occurring at heights between 300m and 1000m above the surface. (PBL model reproduces the magnitude of the jet).
- Air-sea temperature difference does not appear to play a significant role in the boundary layer.
- Boundary layer is logarithmic over the lower 200m – 300m
- Variation of wind speed with height is well modeled with an equation of the form
  - $U(z)=(u_*/k)[\ln(z/z_o)-a(z/H)^2]$ (z<1000m)

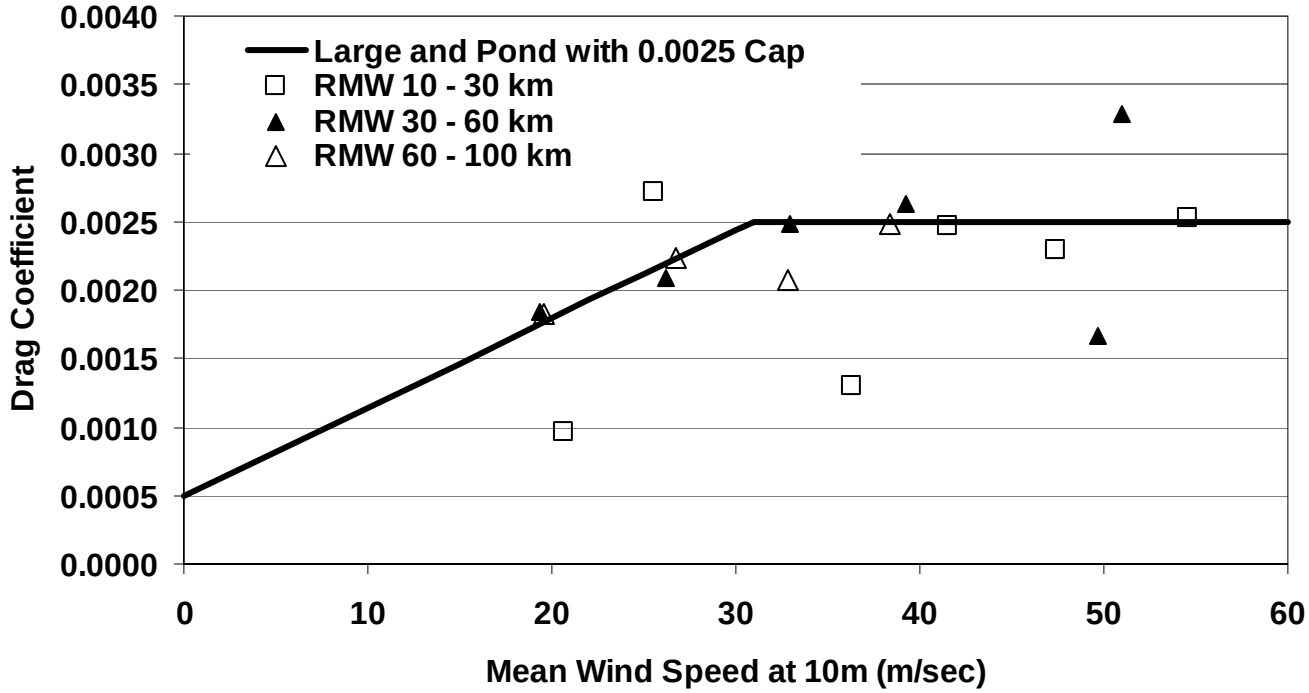
Hurricane Jet Height



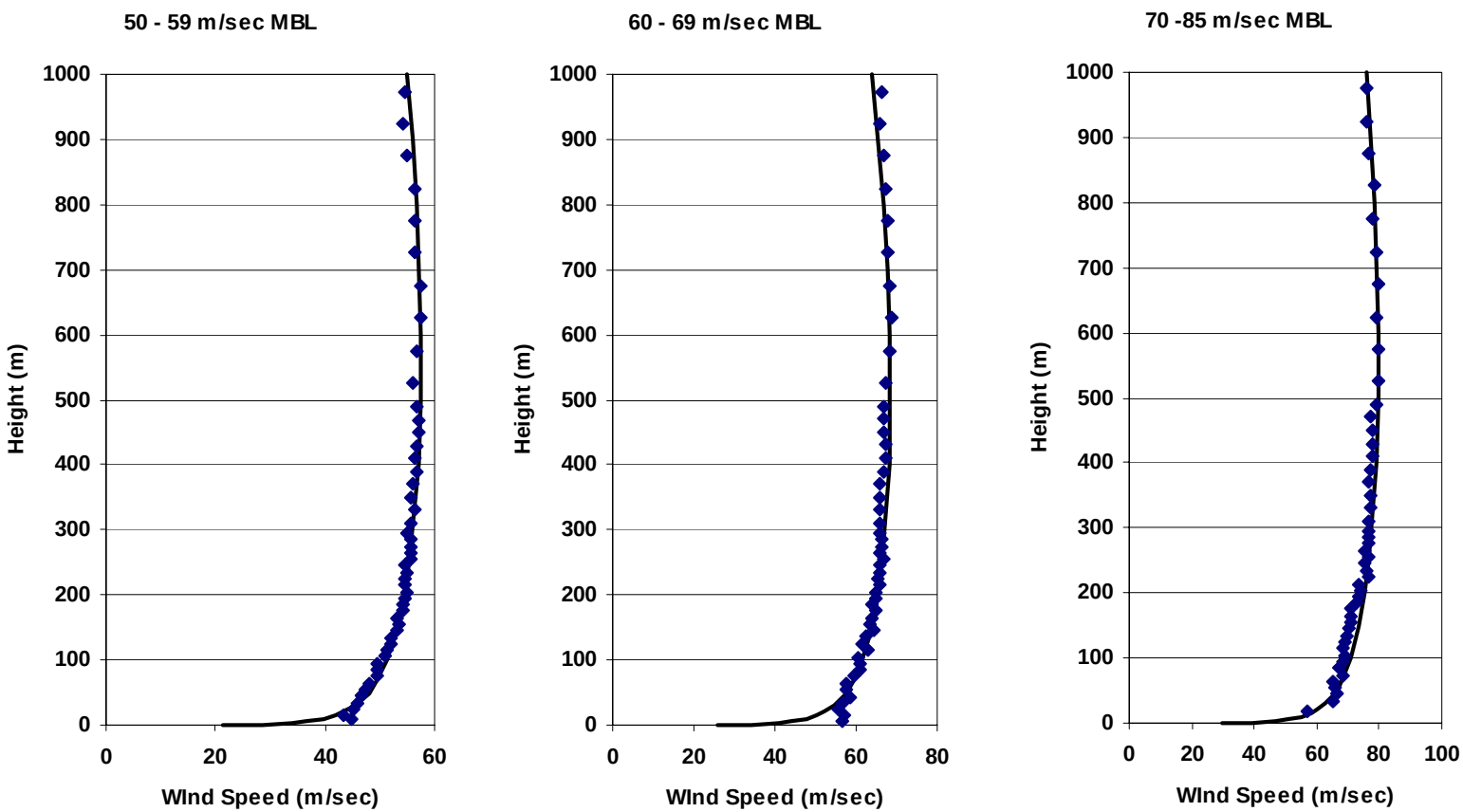
$$I = \sqrt{(f + \frac{v}{r})(f + \frac{2v}{r})}$$

Jet height function of I

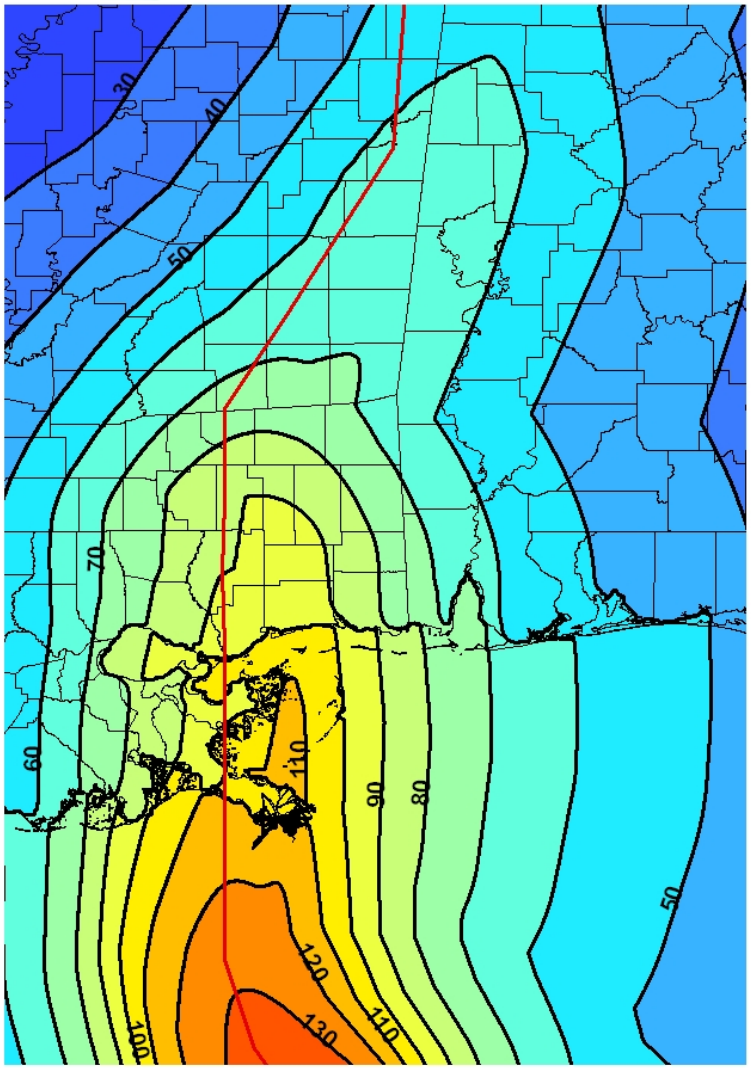
Marine Drag Coefficient



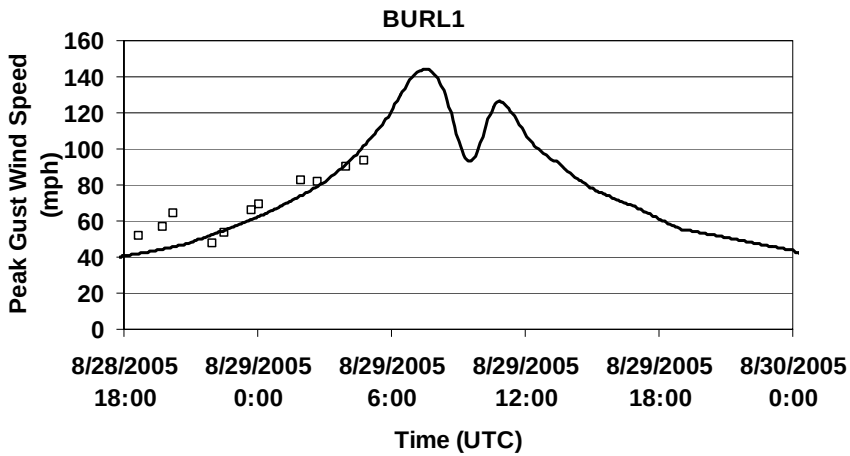
Boundary Layer (RMW 30 – 60 km)

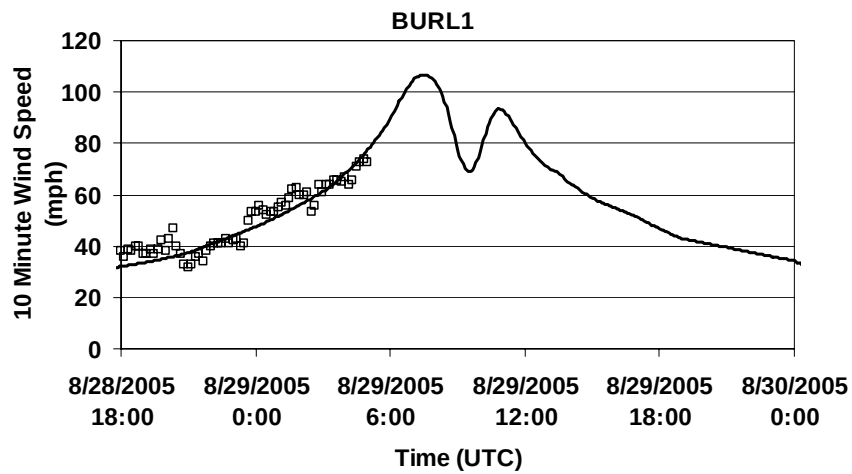


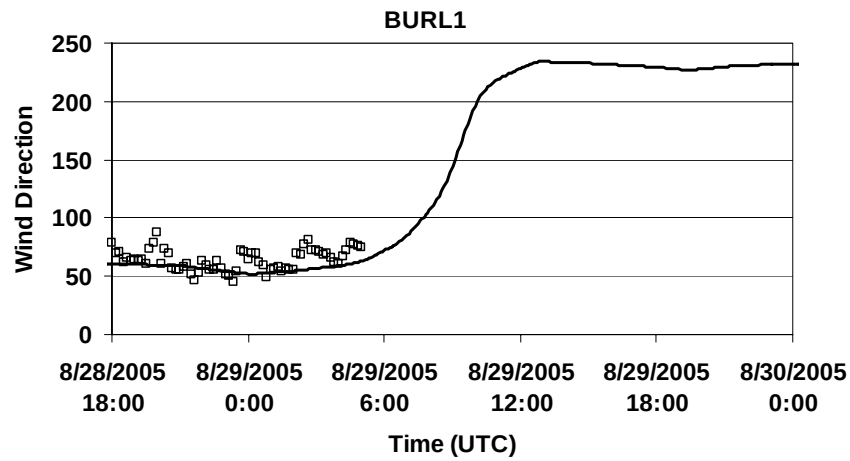
Hurricane Katrina Validation

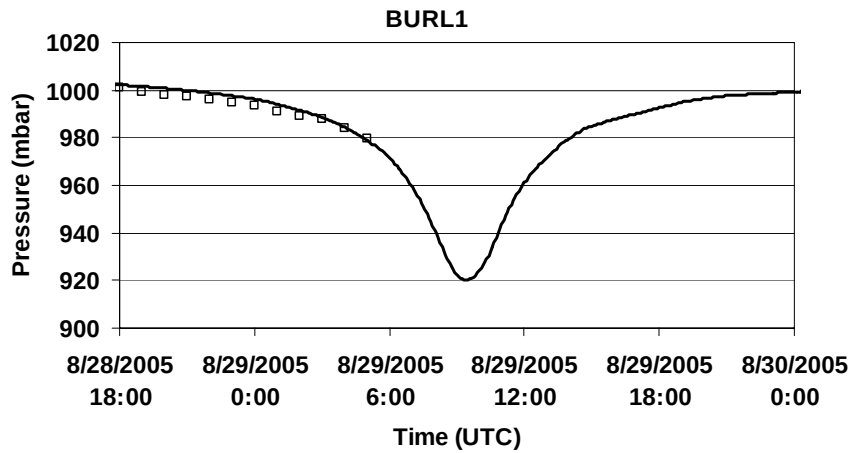


Katrina – BURL1

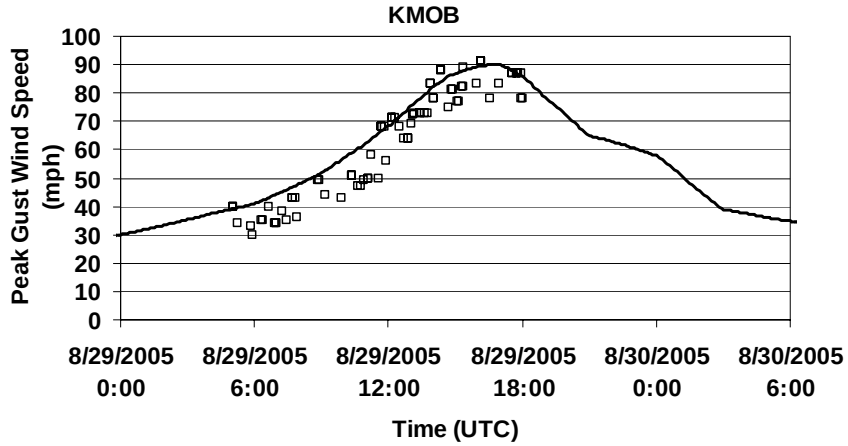


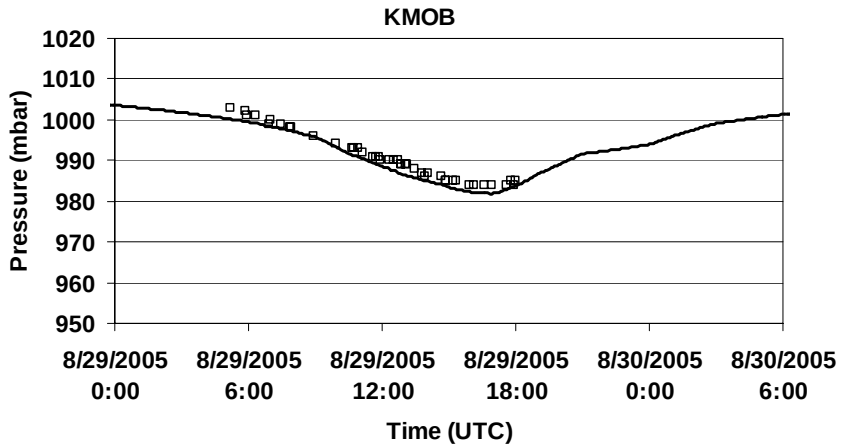


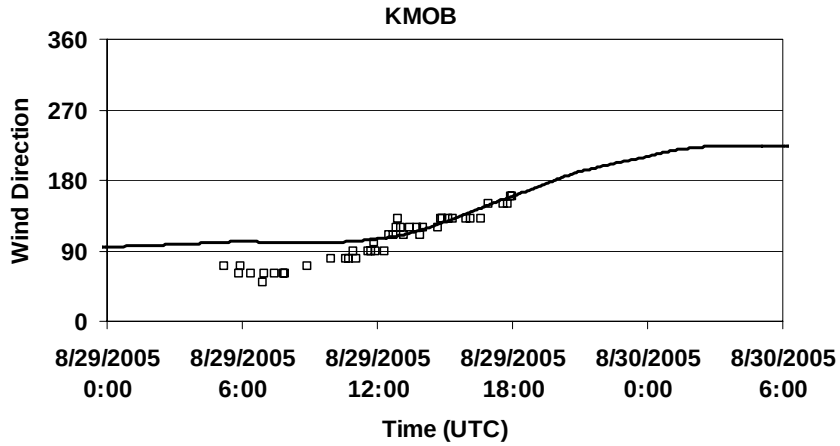




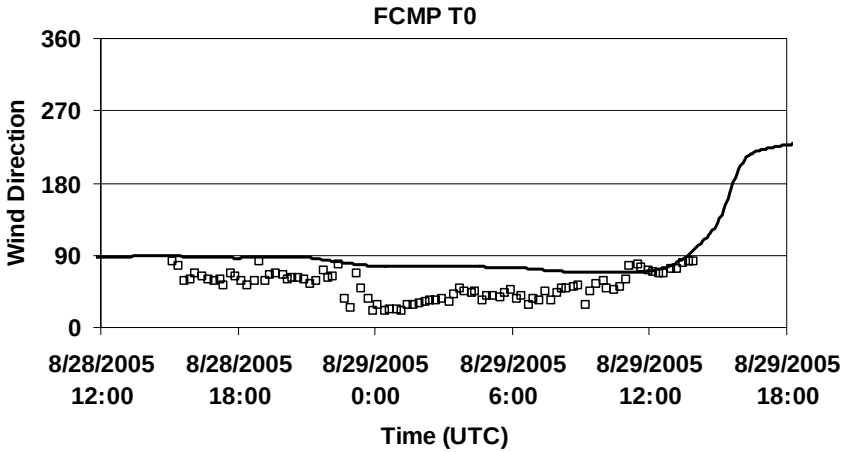
Katrina - KMOB

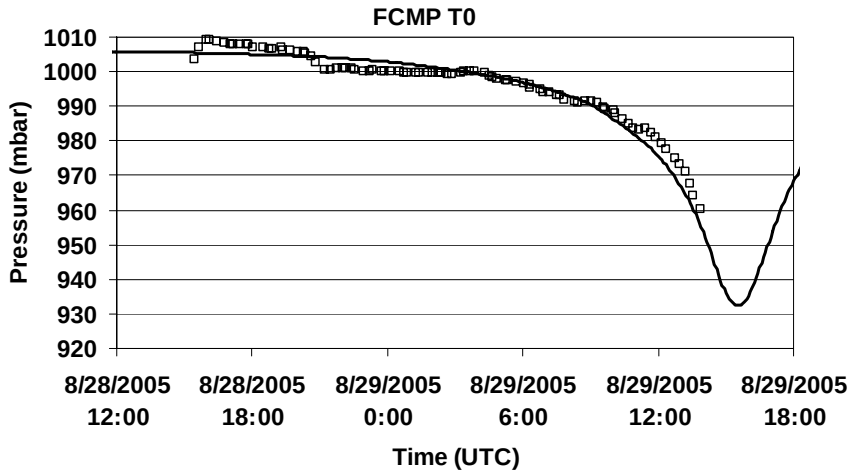


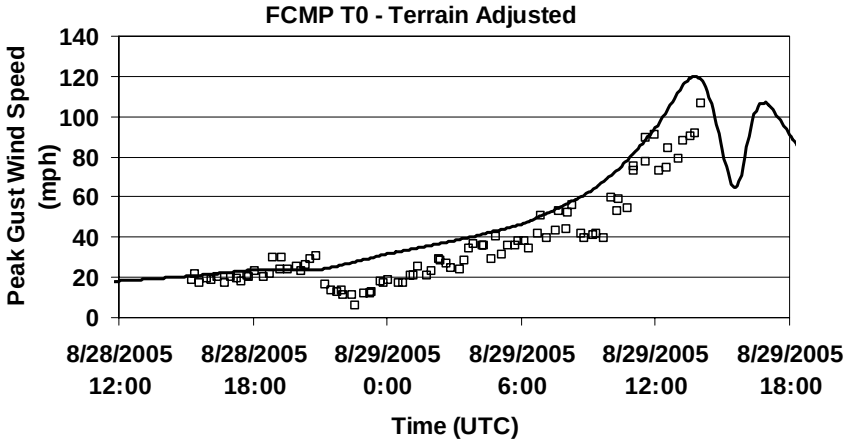


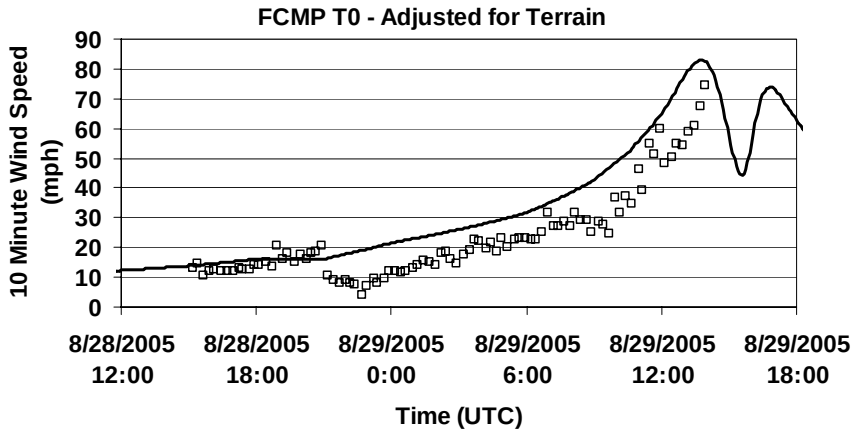


Katrina – FCMP T0

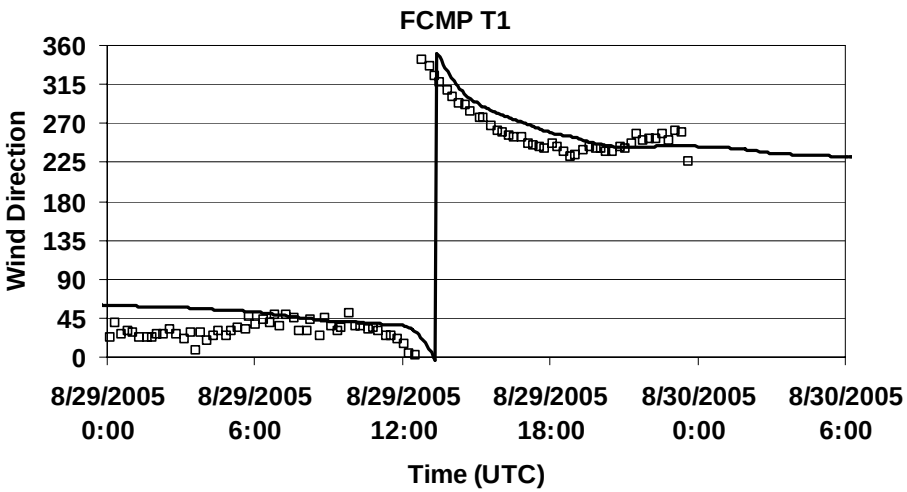


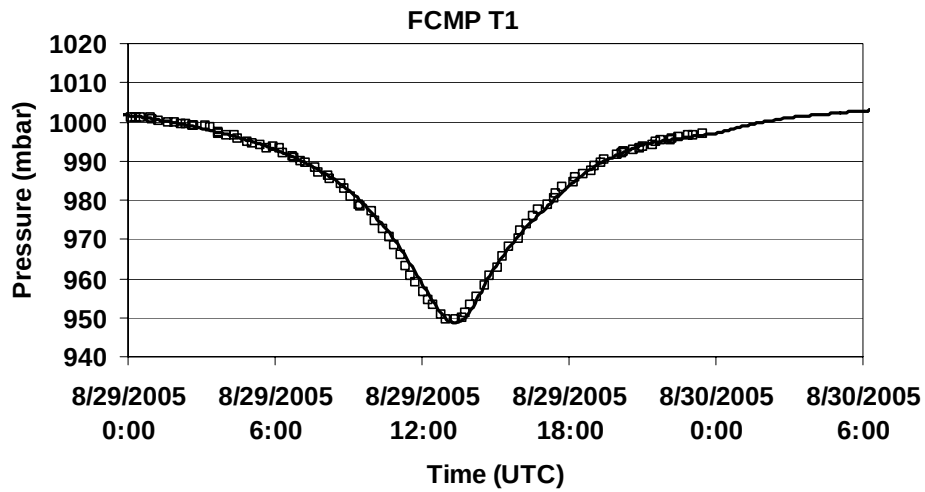


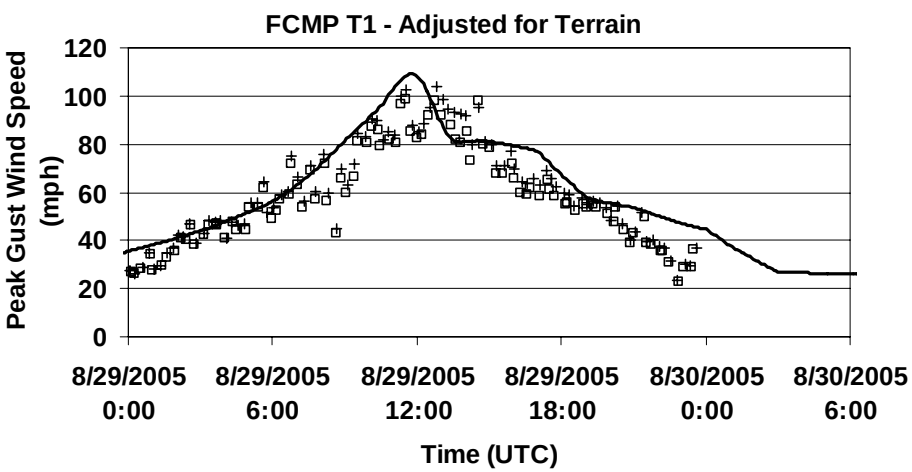


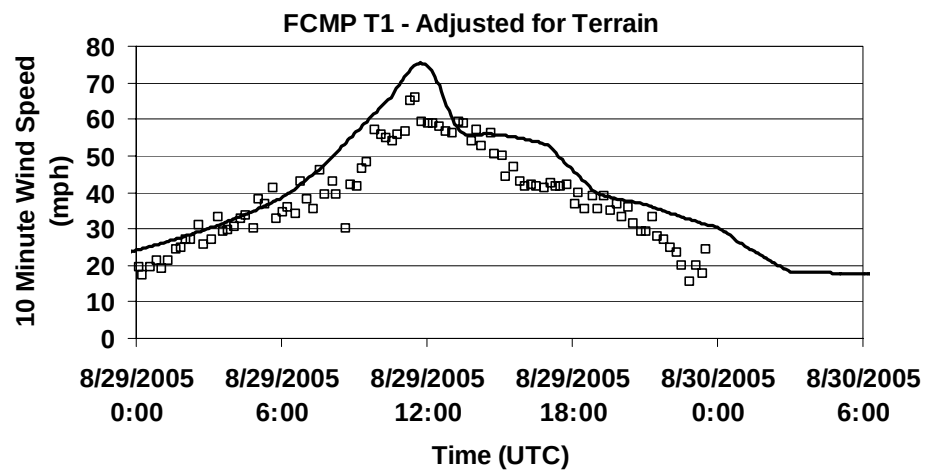


Katrina - FCMP T1

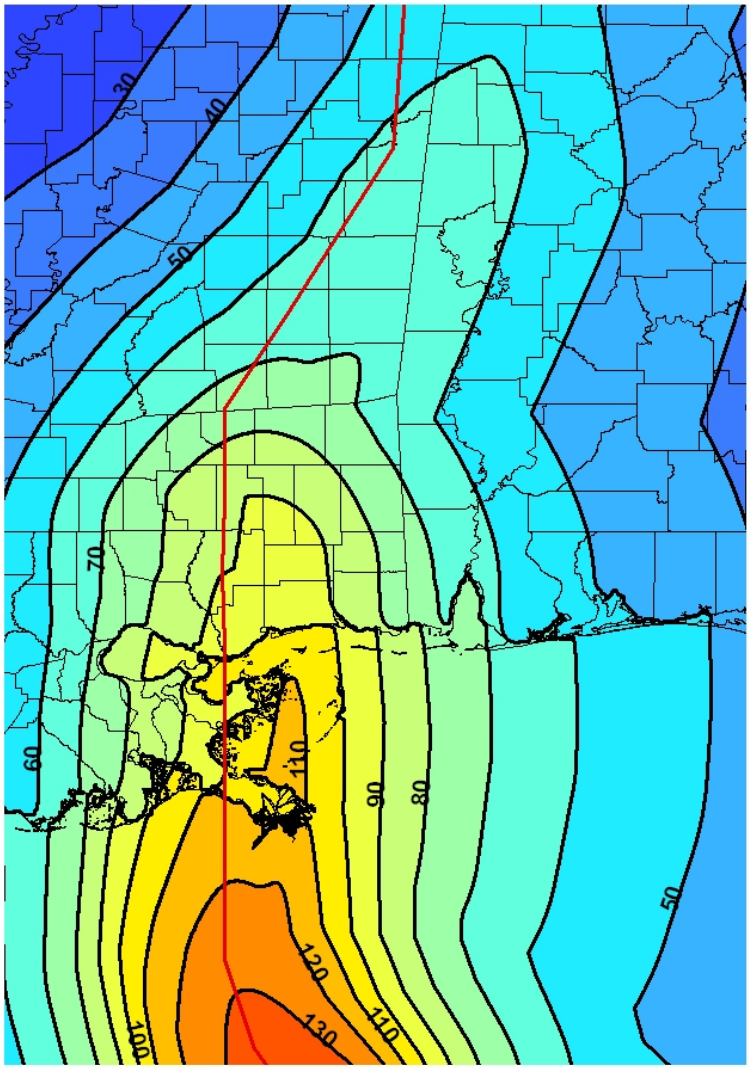






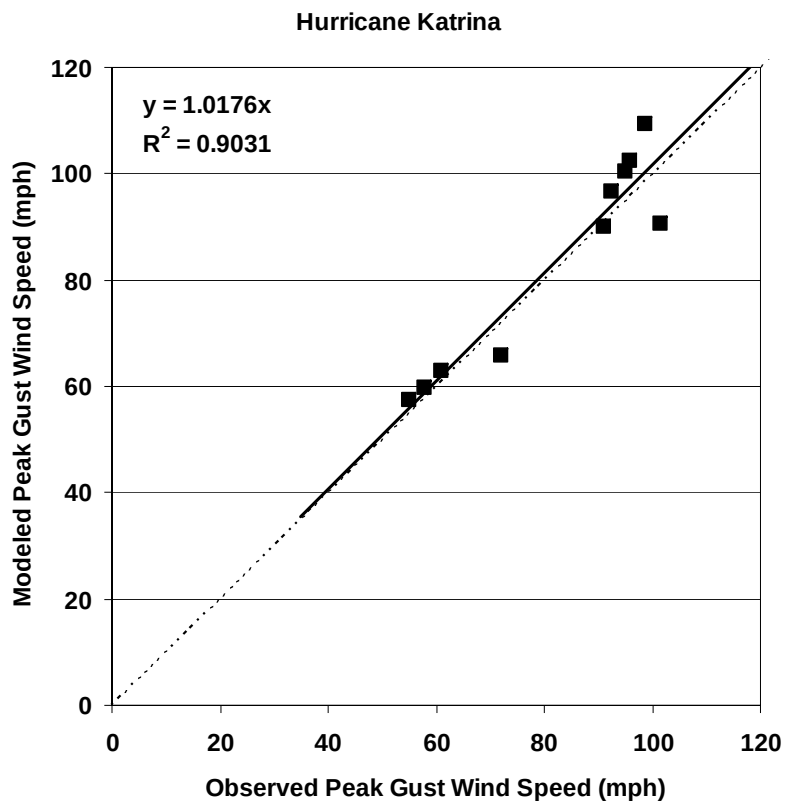


Hurricane Katrina Model Winds



Katrina – Gust Windspeed Summary

Station ID	Observed Wind Speed (mph)	Modeled Wind Speed (mph)	Comments
FCMP T0		120	Maximum not reported
FCMP T1	99	109	Observed Max from Gill anemometer
FCMP T2	96	102	Observed Max from Gill anemometer
FCMP T3	95	100	Observed Max from Gill anemometer
FCMP T5		121	Maximum not reported
KMOB	91	90	
KBTR	61	63	
KGPT		124	Station not reporting
KPNS	72	66	
KNEW		110	Maximum not Reported
KTCL		76	No records during storm peak
KBHM	58	60	
KDTS	55	57	
C-MAN BURL1		144	Marine, Maximum not reported
C-MAN DPIA1	102	91	Marine
Buoy 42040	92	97	Marine
Bouy 42007		120	Station Adfrift

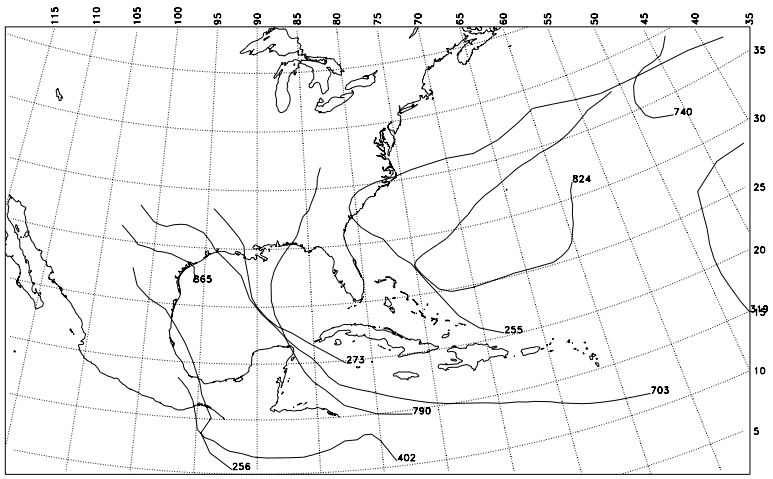


Wind Model Summary

- Comparisons with wind speed and pressure data indicate the wind field can be well modeled with the parameterized numerical wind field model, modeled with a single value of *B* (*B* constant in space, not time)
- In the Hurricane Katrina case, wind data and wind model results suggest Hurricane Katrina was a Category 3 storm (defined by one minute sustained wind over water) for both first and second land falls in Louisiana

EMPIRICAL STORM MODEL

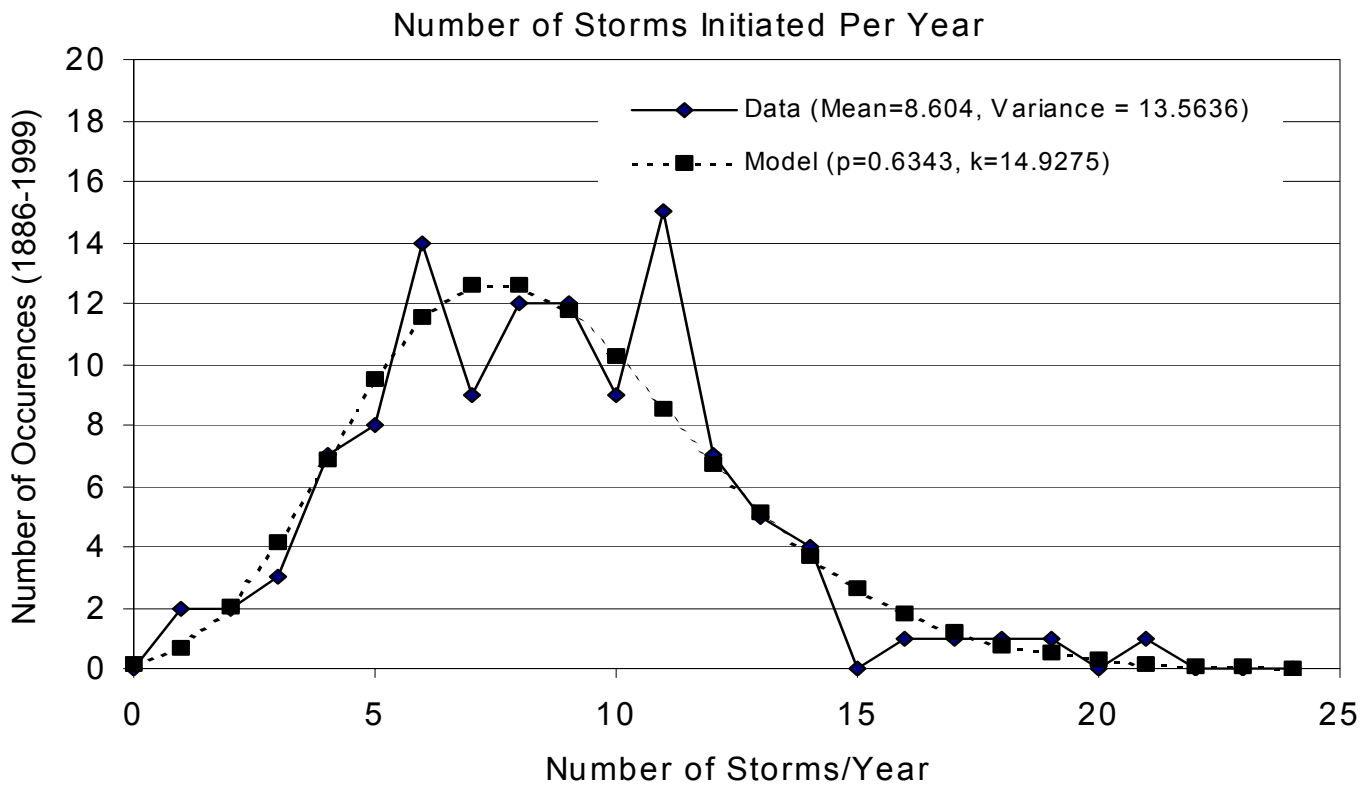
- Storms initiated in Atlantic, Caribbean and Gulf of Mexico
- Models storm curvature and changes in intensity with time
- Central pressure modeled as a function of sea surface temperature
- Approach allows for modeling of multiple land falls
- Uses filling models from Vickery (2005)
- R_{max} - Δp and R_{max} – latitude models which are an improvement of Vickery and Twisdale (1995)



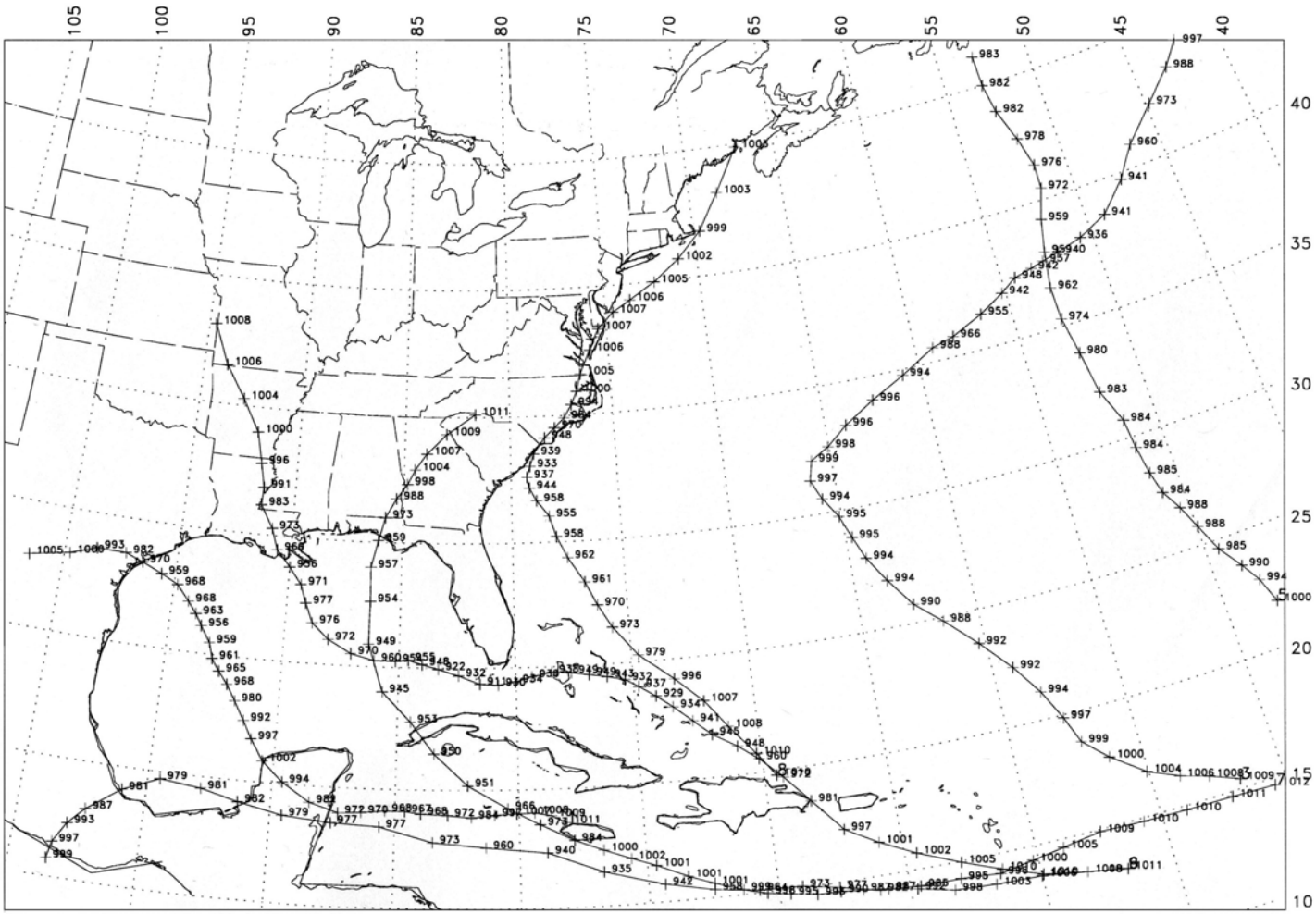
EMPIRICAL STORM MODEL

- Storms are Initiated at the same starting locations and times (day/month) as given in the HURDAT database.
- Storms are modeled approximately as a Markov process where the speed and direction of the next step is function of the speed and direction of the preceding one or two steps.
- Statistical parameters for changes in speed and heading have been developed for each 5 degree square in the Atlantic Basin.
- Separate distribution have been derived for storms heading in easterly and westerly directions (for many grid squares).

Number of Storms/Year

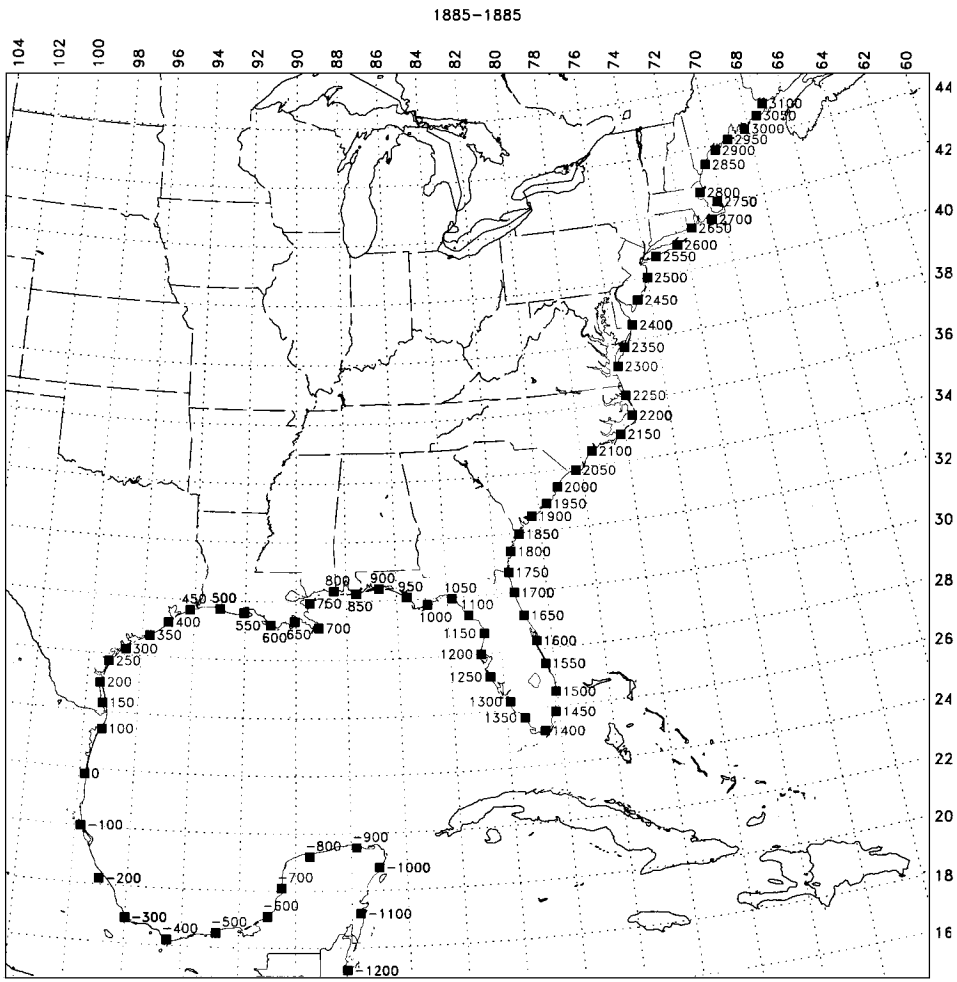


Example Simulated Year



Track Model Validation

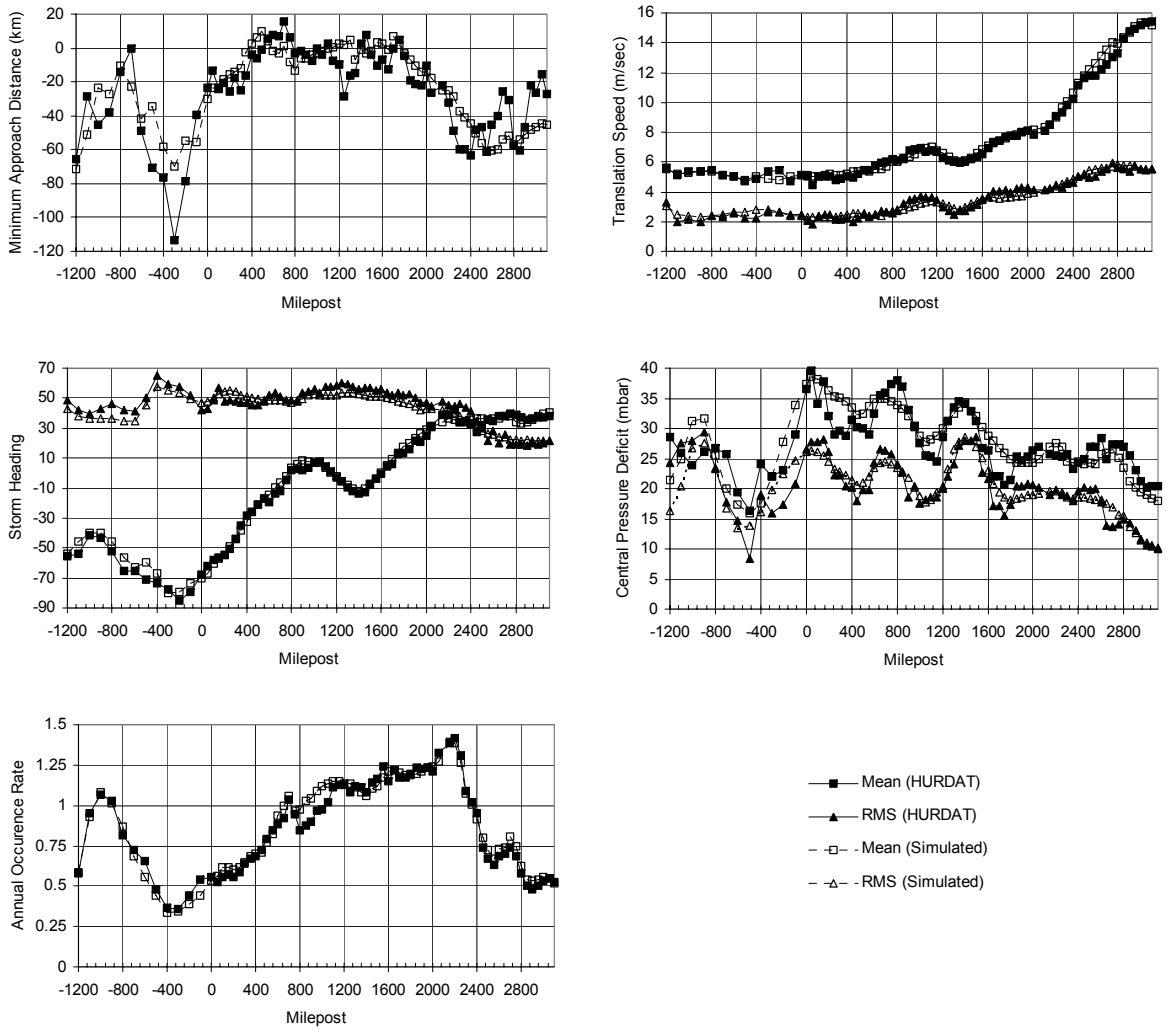
- Validated along entire U.S. Atlantic and Gulf of Mexico Coastline
- Able to reproduce the continuously varying hurricane climatology
  - Translation speed
  - Heading
  - Min. approach distance
  - Annual occurrence rate
  - Central pressure deficit



Track Model Validation

- Compares statistics of HURDAT and simulated storms on a point by point basis along the coast line.
- Comparisons of statistics of key variables passing within 250 km of a point.
- Statistics compared are:
  - d_{min}=distance of closest approach of a storm (while in the circle), positive values indicate a storm passing to the left of the point.
  - Heading = the direction of travel of the storm at the point of closest approach.
  - Translation speed of the storm at the point of closest approach
  - occurrence rate is the number of storms (per year) entering the circle in the period
  - central pressure is the minimum central pressure of the storm while in the circle.

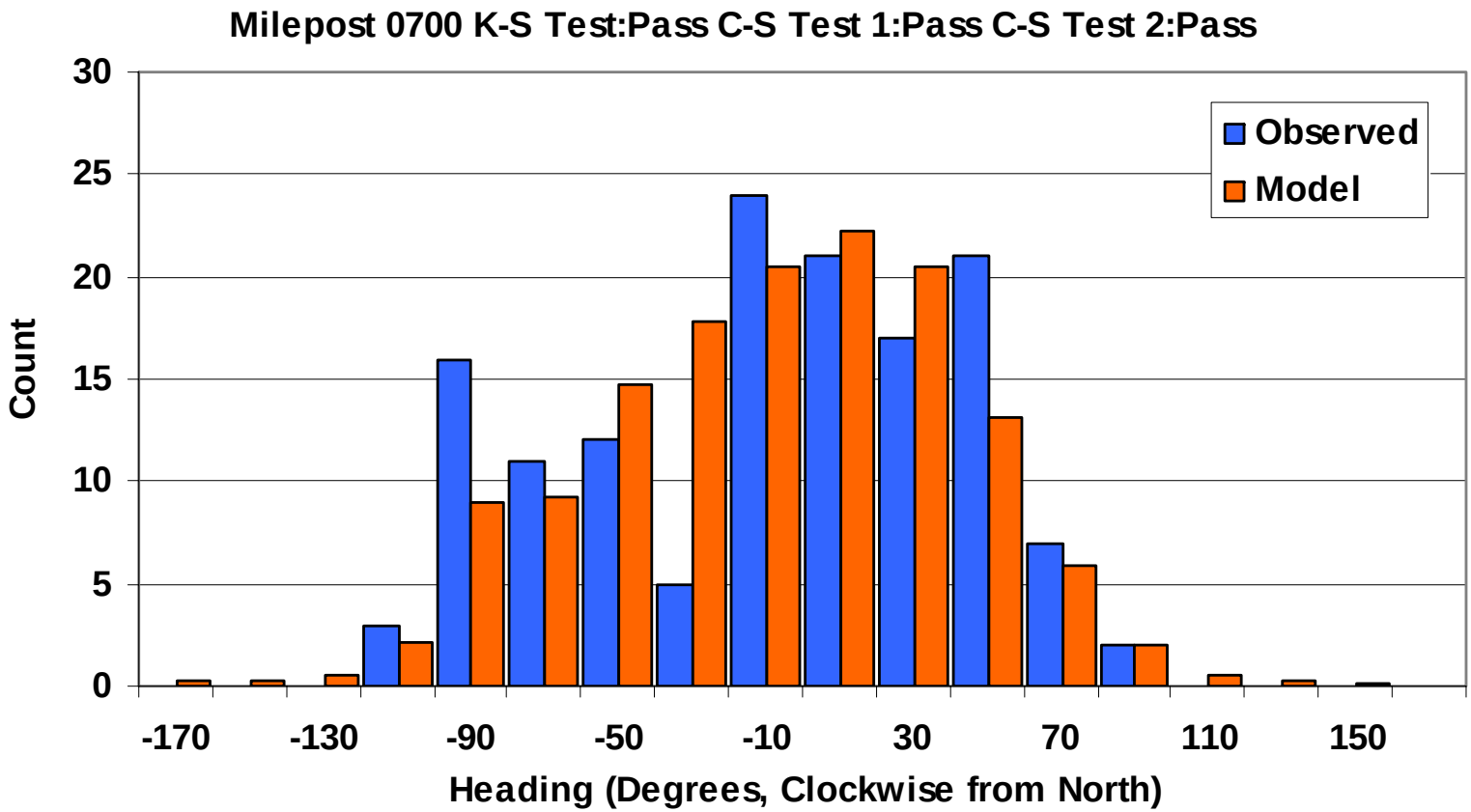
Track Model Validation



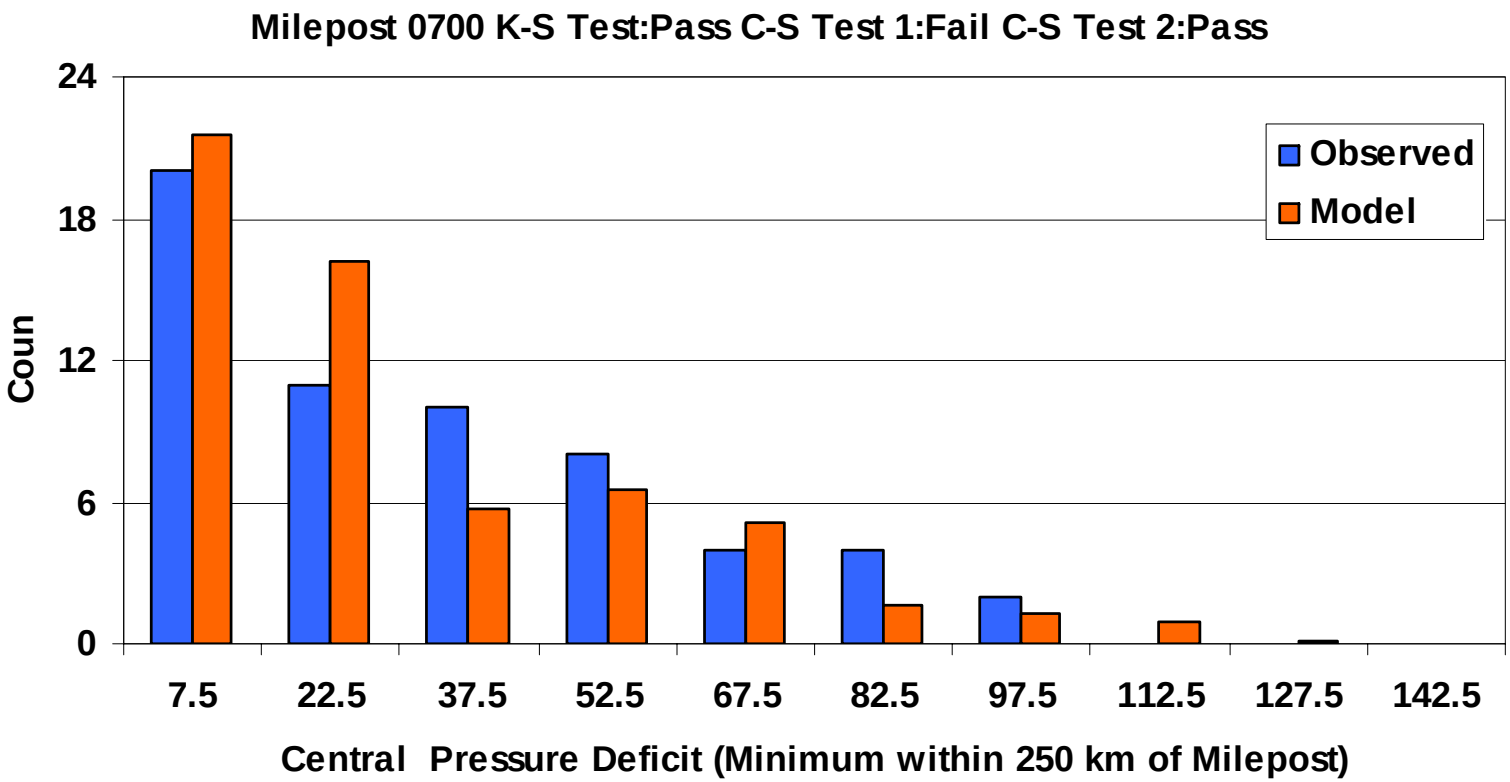
Track Model Validation

- Statistics of key hurricane parameters, distance of closest approach, etc. have been tested using:
  - *t* tests for equivalence of means
  - *F* tests for equivalence of variance
  - Kolmogorov-Smirnov Tests for equivalence of CDF
  - Chi squared tests for equivalence of pdf.

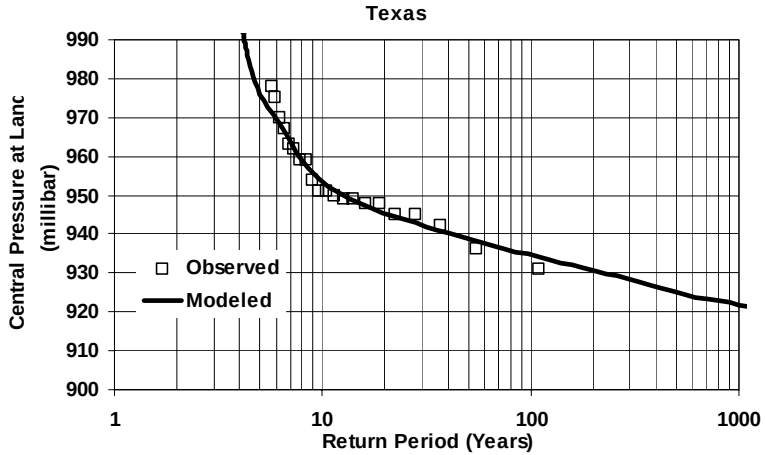
Example Modeled and Heading

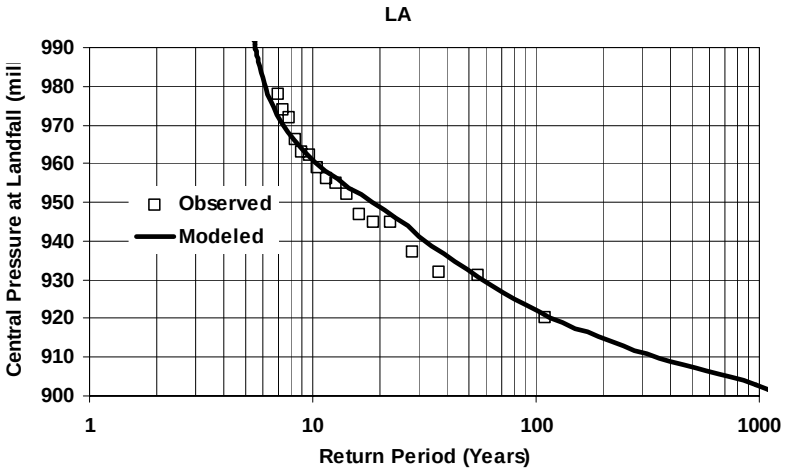


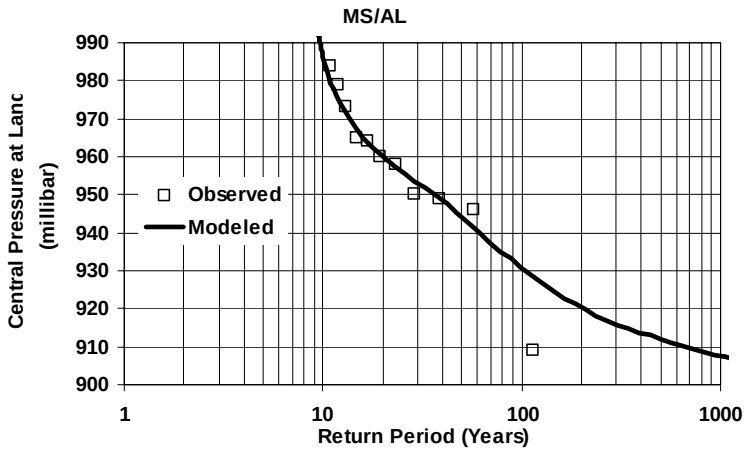
Modeled and Simulated Δp Distribution

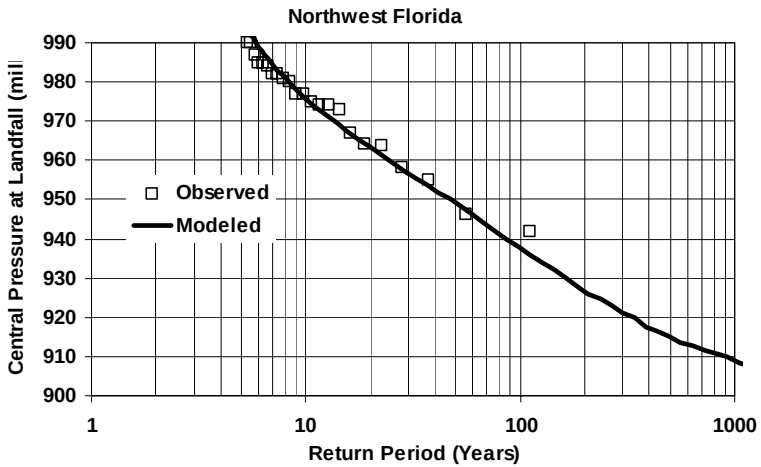


Comparison of Modeled and Observed Landfall Rates

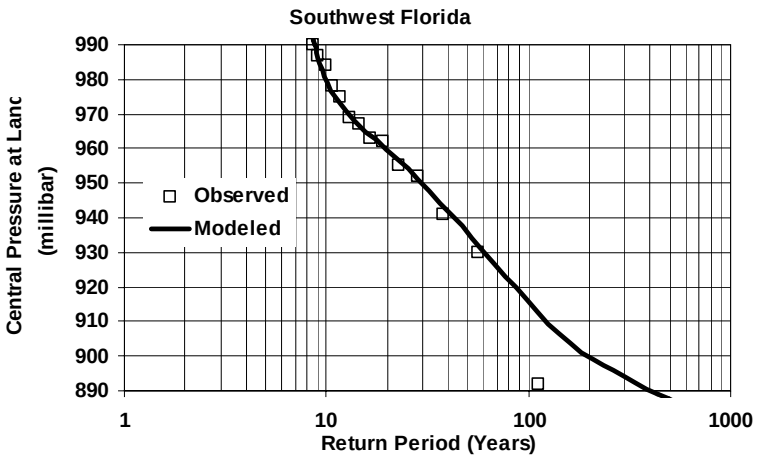


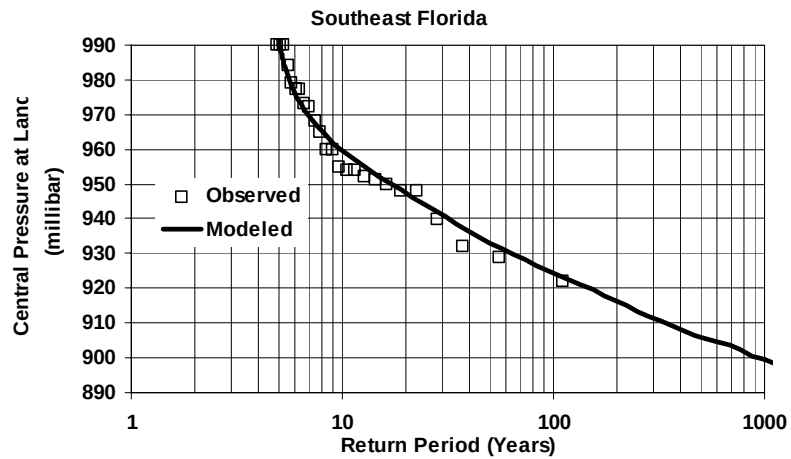


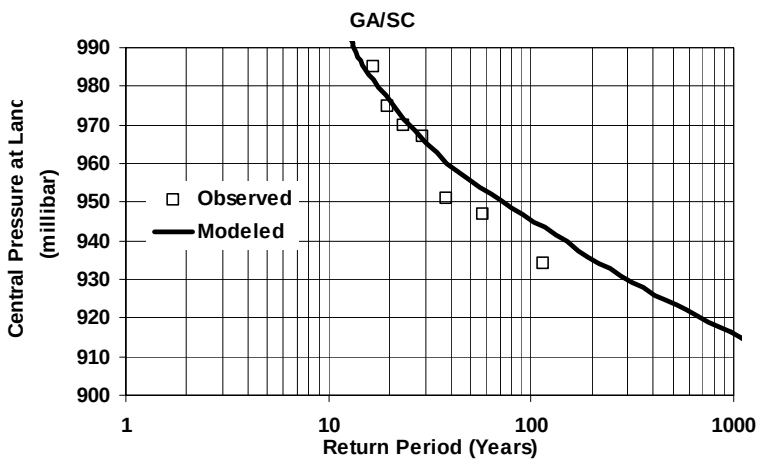


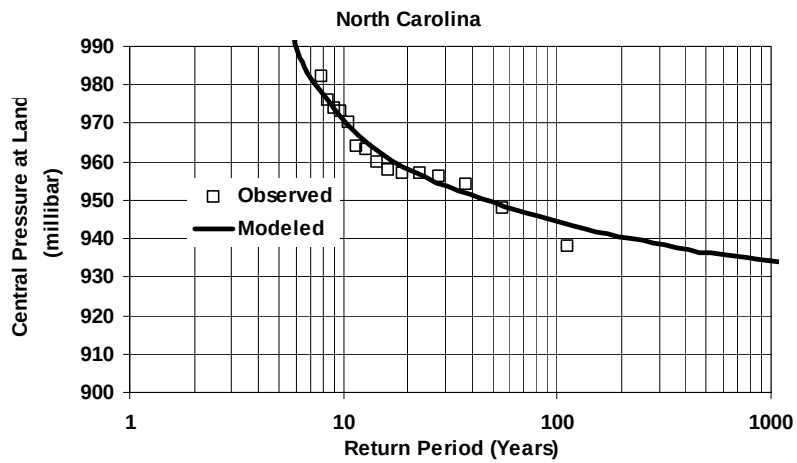


Comparison of Modeled and Observed Landfall Rates

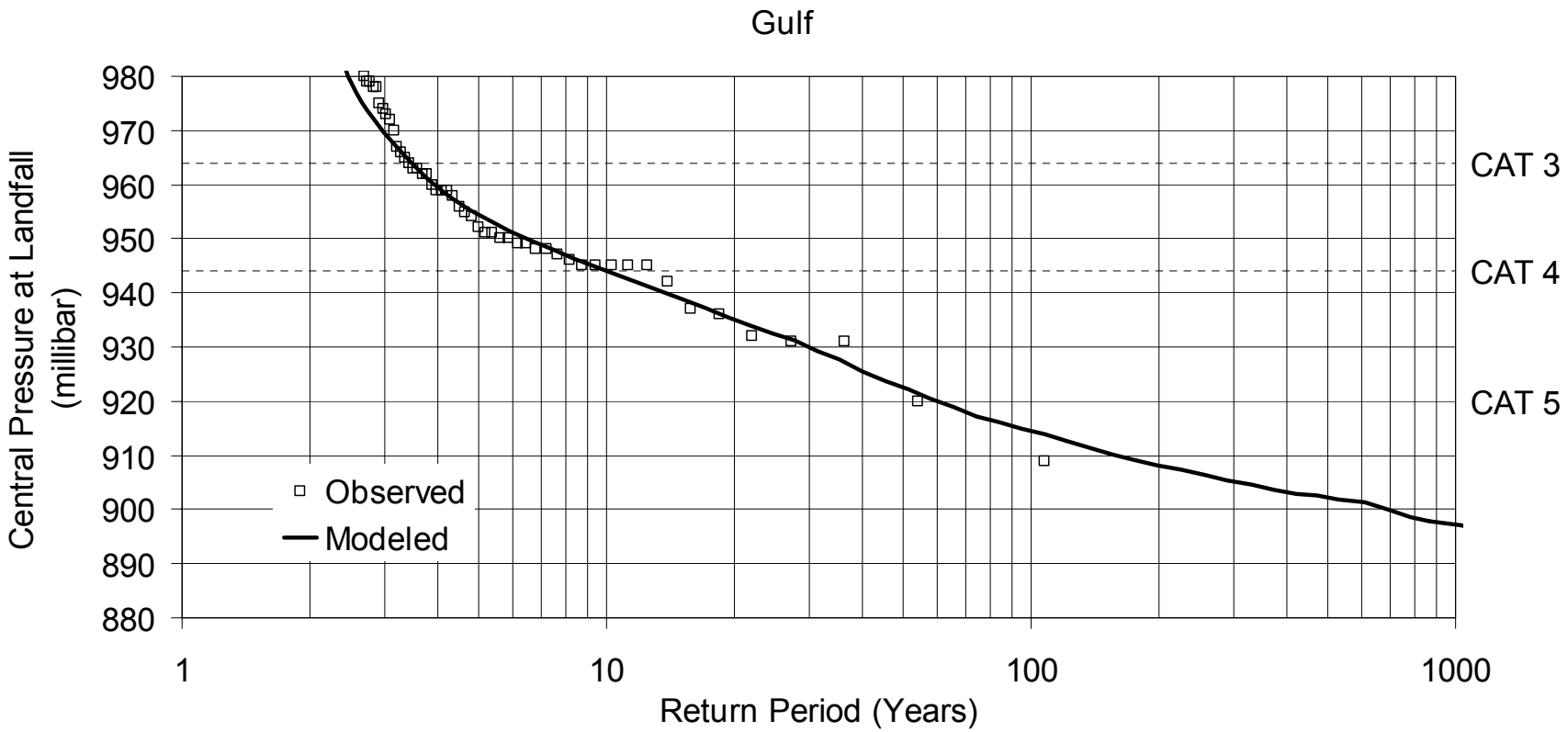




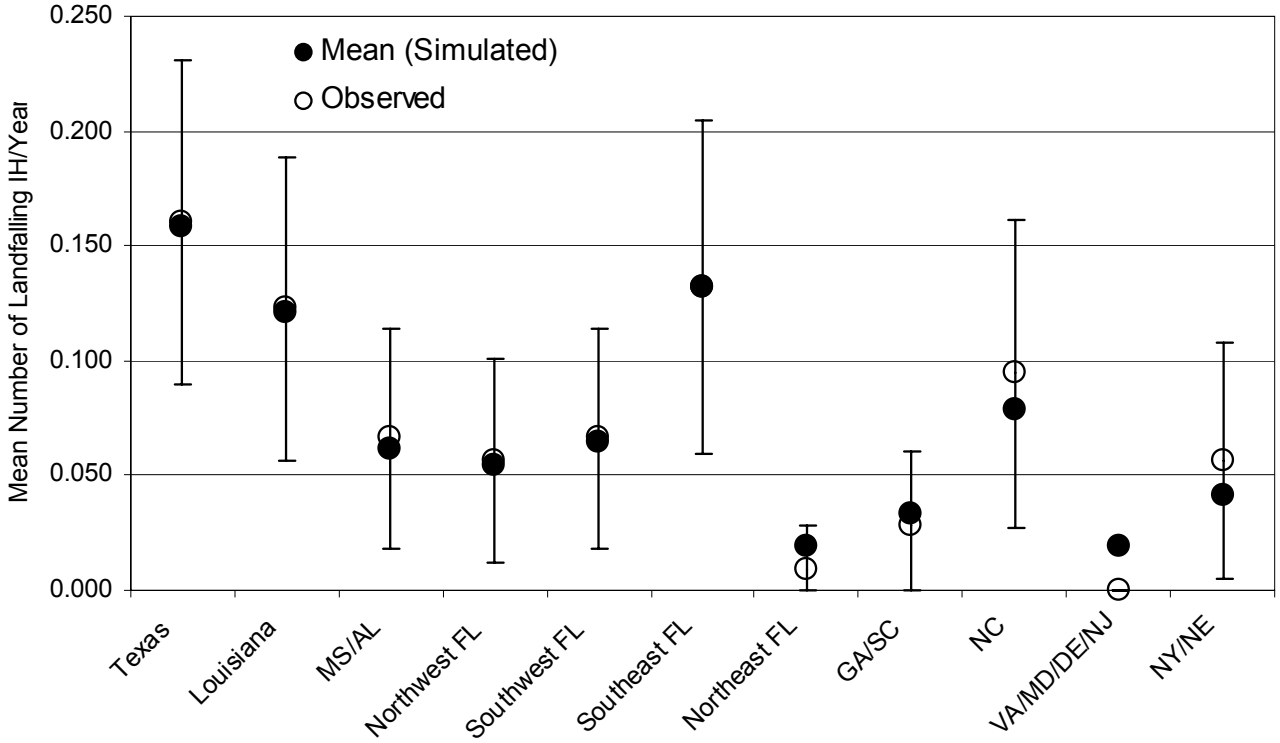




Comparison of Modeled and Observed Landfall Rates



Modeled and Observed Landfall Rates of Intense Storms (defined by pressure)



Holland *B* and Rmax Modeling

- Holland's pressure profile equation (Holland, 1980):

$$p(r) = p_0 + \Delta p \cdot \exp\left[\frac{R_{\max}}{r}\right]^B$$

where P(r) is the surface pressure at a distance r from the storm center, P_0 is the central pressure, Δp is the central pressure difference, R_{max} is the radius to the maximum winds and B is the Holland's pressure profile parameter.

- Holland B model given in Vickery, Skerlj and Twisdale, 2000:

$$B = 1.38 + 0.00184\ \Delta p - 0.00309\ R_{\max}\ , r^2 = 0.026$$

Statistical Model for *B and Rmax*

- B as a function of R_{max}, central pressure difference Δp, Latitude and mean sea surface temperature:

  $$B=-0.258-0.162\ln(R_{max})+0.0910\ln(dP)-0.00536\ln(Lat)+0.569\ln(T_{sea})$$

- R_{max} is modeled as a function of central pressure and latitude in the form:

  $$\mathrm{Ln}(R_{max})= 1.59 + 0.0262(\mathrm{Latitude}) - 0.0000313\ \Delta P^2$$

Model Summary

HURRICANE SIMULATION MODEL
Models storm Track and Intensity (defined by pressure)

↓

Statistical models for Holland *B*, RMW and Storm Filling

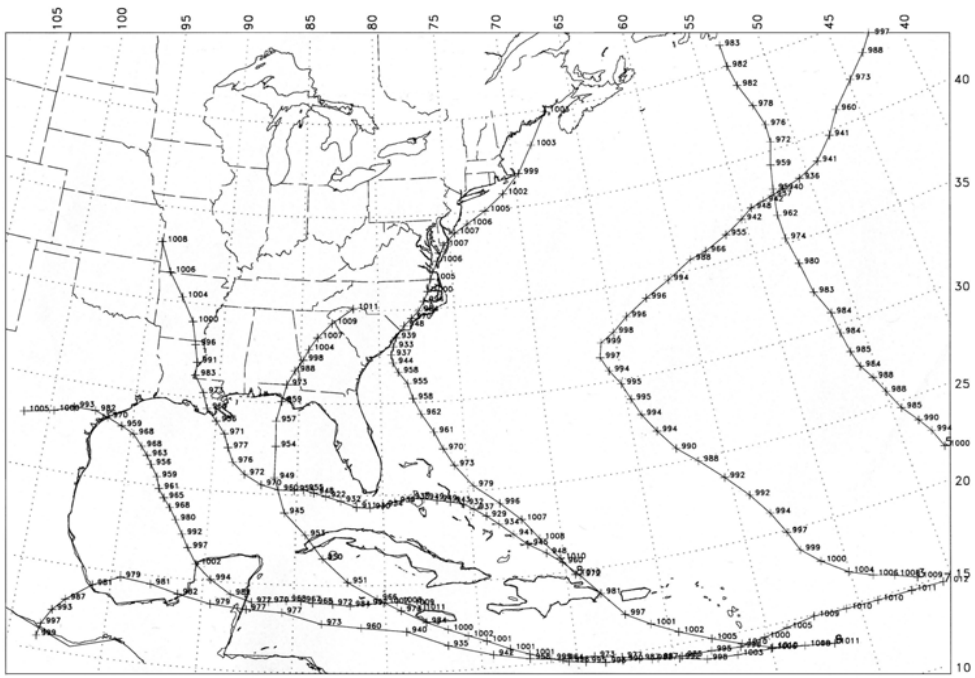
↓

HURRICANE WIND FIELD MODEL

↓

Wave Models, Coastal Models, Damage and Loss Models

RISK ASSESSMENT and DECISIONS

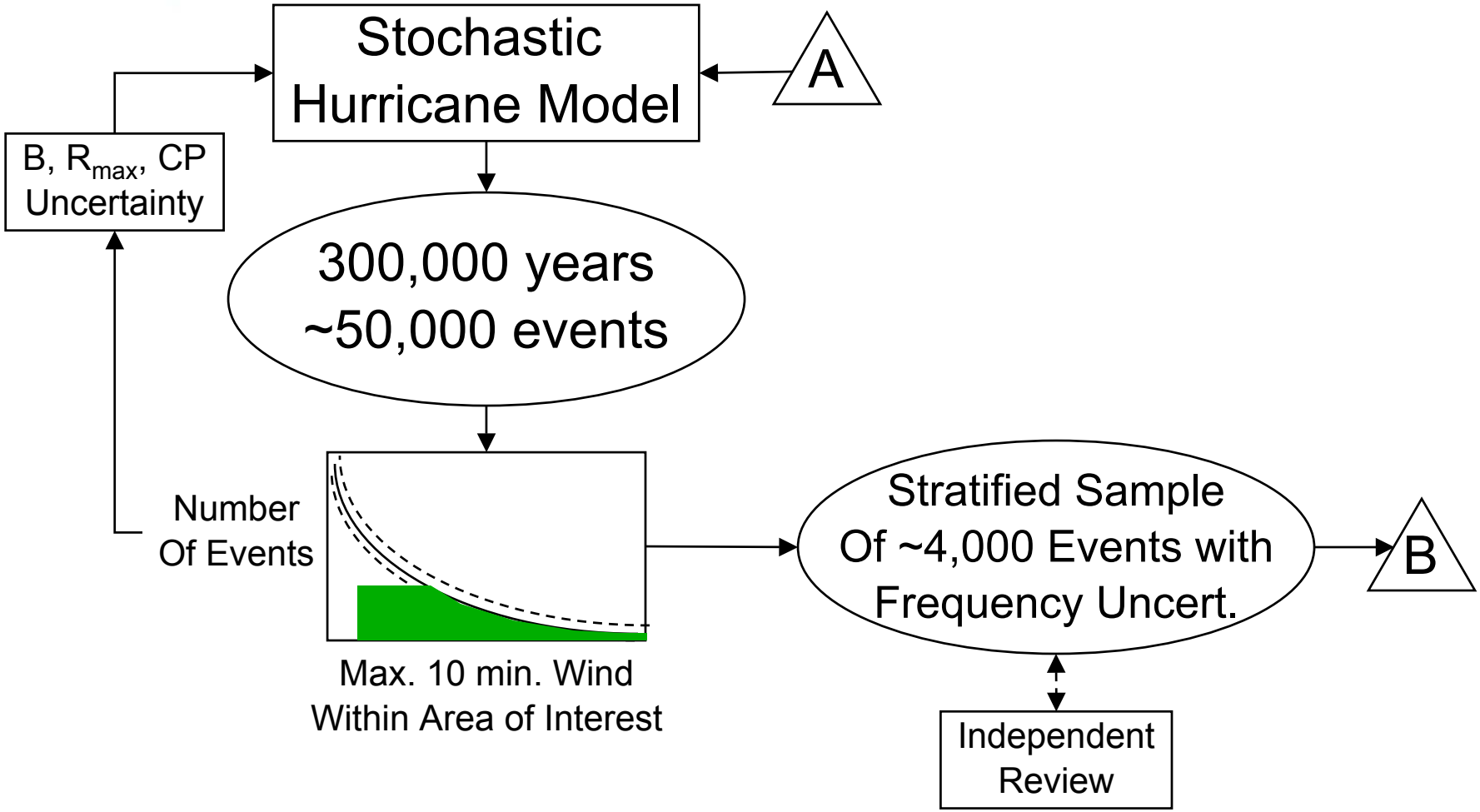


End-to-End Risk Assessment

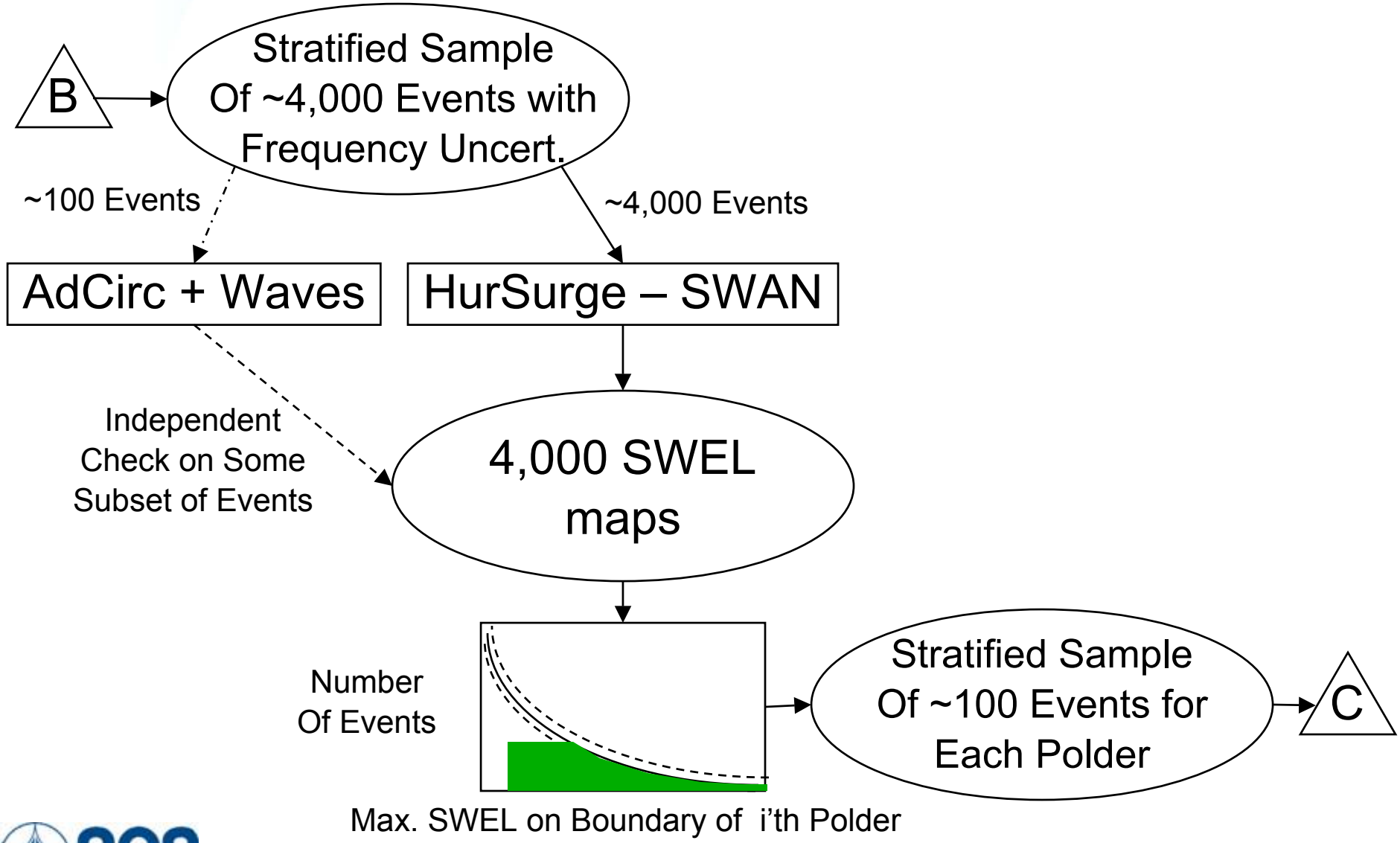
- Quantify wind hazard with uncertainties
- Model flood hazard with uncertainties
  - Surge + waves + other (e.g., impact loads)
- Identify failure modes with uncertainties
  - Overtopping, breach (multiple possible causes)
- Specify system performance criteria (*notional*):

Risk Level	Economic	Social
1%/yr	<$1B	<50 casualties
0.1%/yr	<$10B	<500 casualties
0.01%/yr	<$100B	<5000 casualties

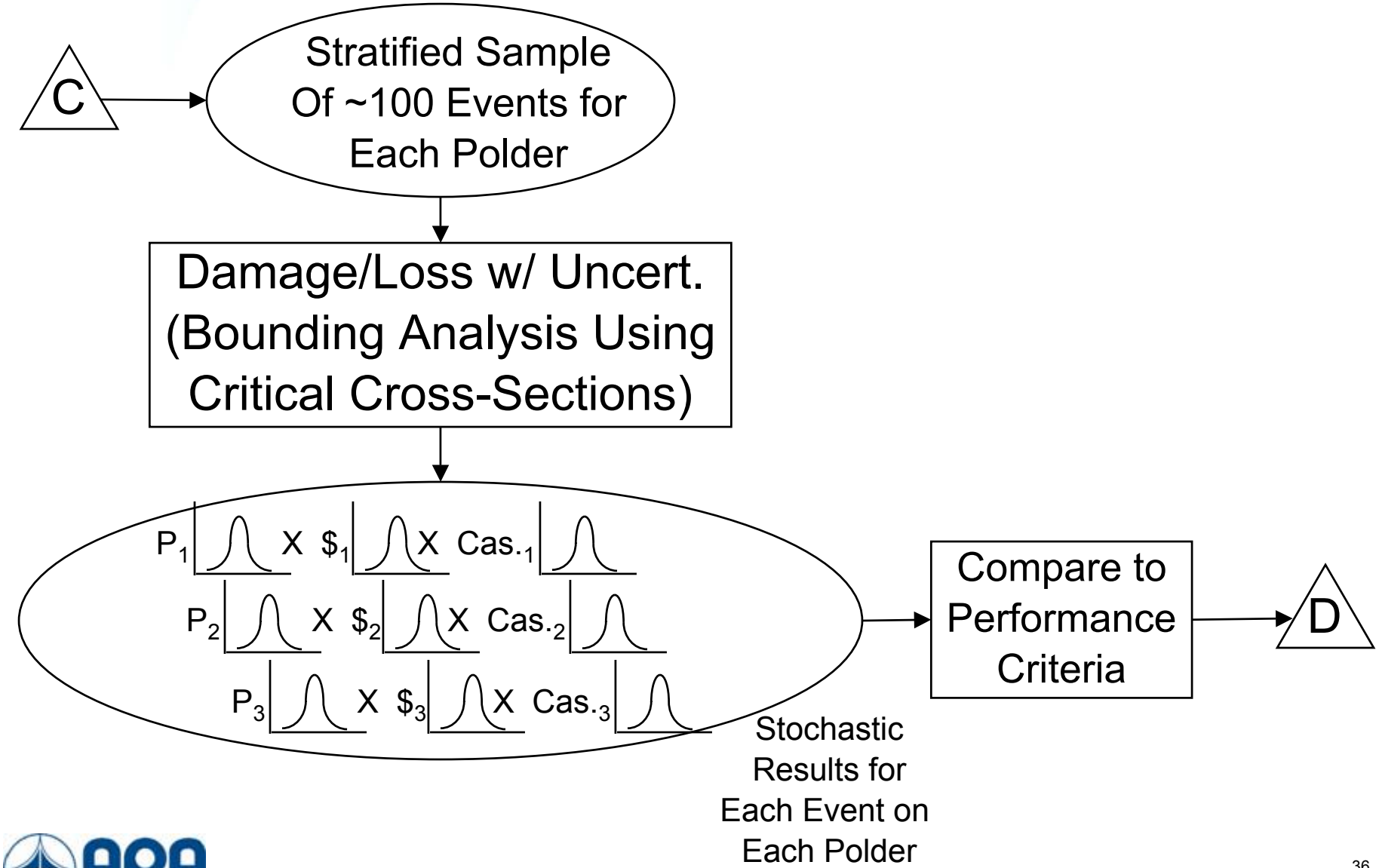
Risk Assessment Framework (A)



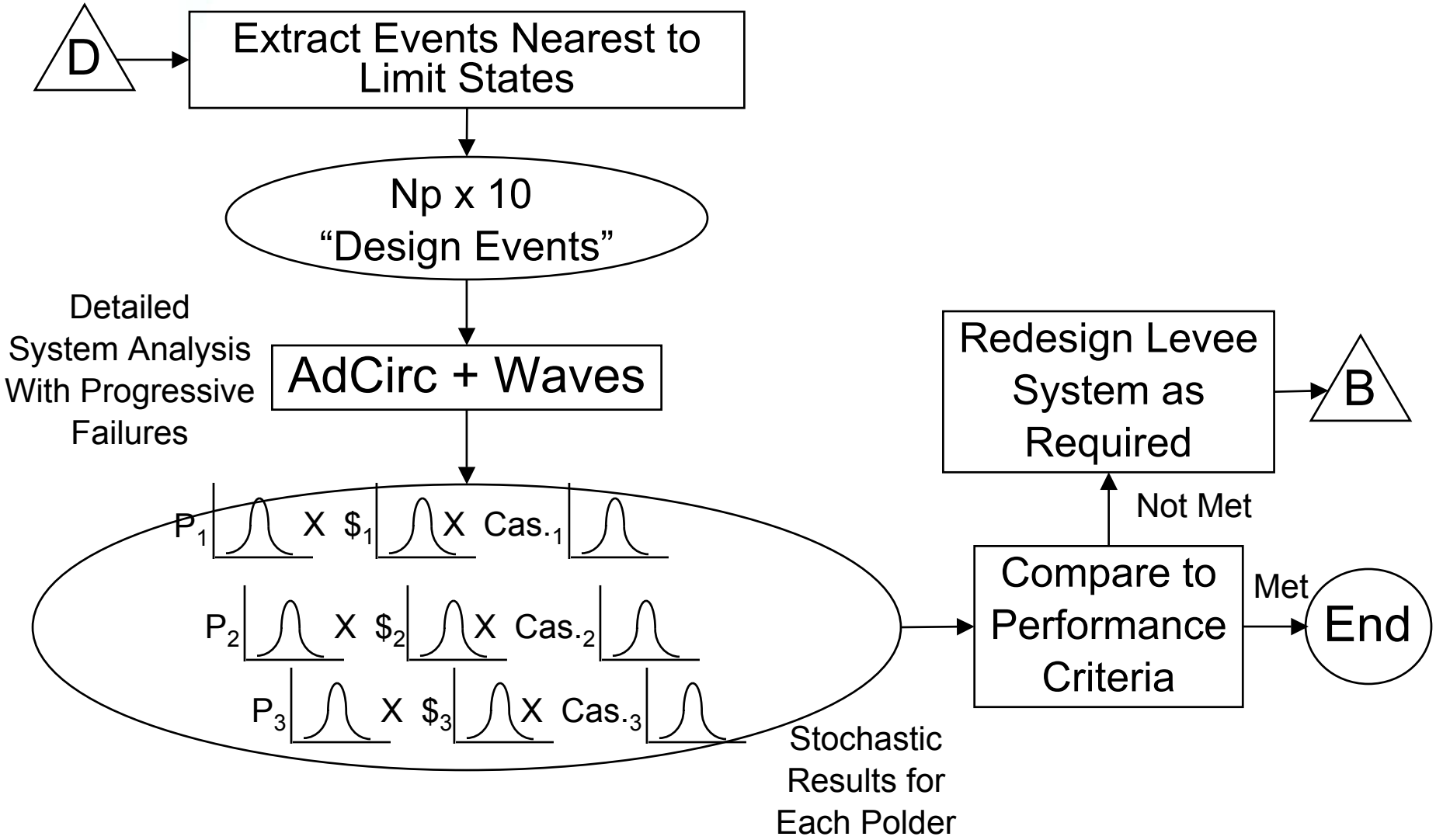
Risk Assessment Framework (B)



Risk Assessment Framework (C)



Risk Assessment Framework (D)



End-to-End Risk Assessment Summary

- End-to-end risk assessment is feasible
- Analysis driven by system performance criteria
- Framework relies on multiple levels of stratified sampling to identify design events
- Substantial computational resources required
- Approach integrates multiple simplified and detailed models into a probabilistic framework