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Subsidence in Louisiana: a Landscape of Contradictions

Elevation and Subsidence Studies of Levees and Roads

FEHRL U.S. SCAN Tour

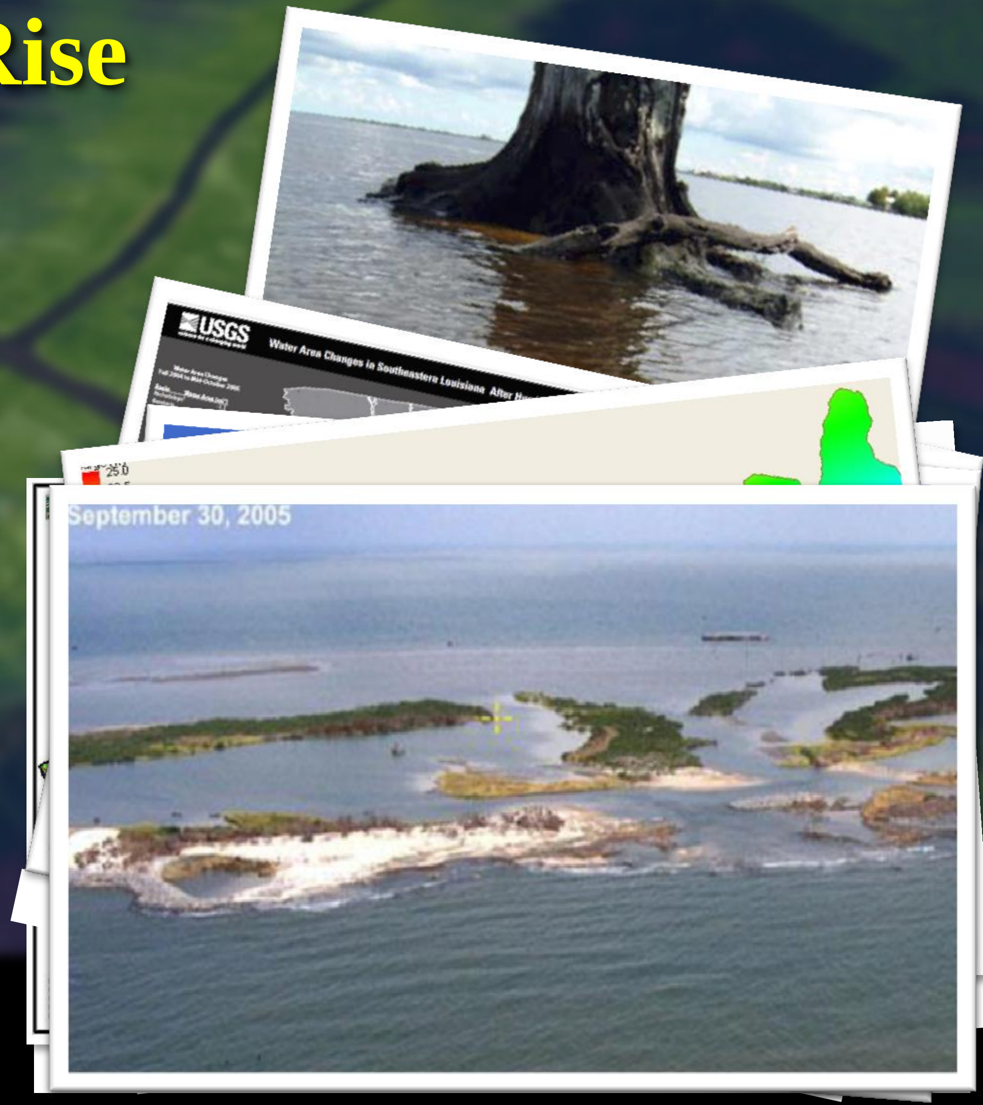
Friday, March 30, 2012

Louisiana's Vanishing Coast

Relative Sea-Level Rise

>10mm yr^{-1}

- 24 sqmi yr^{-1} land loss since 1978[a]
  - 1 football field every 45min
- Louisiana lost 1.2 million acres in the last century
- Louisiana has 30% of the Nation's coast and 90% coastal land loss in the lower 48 states.



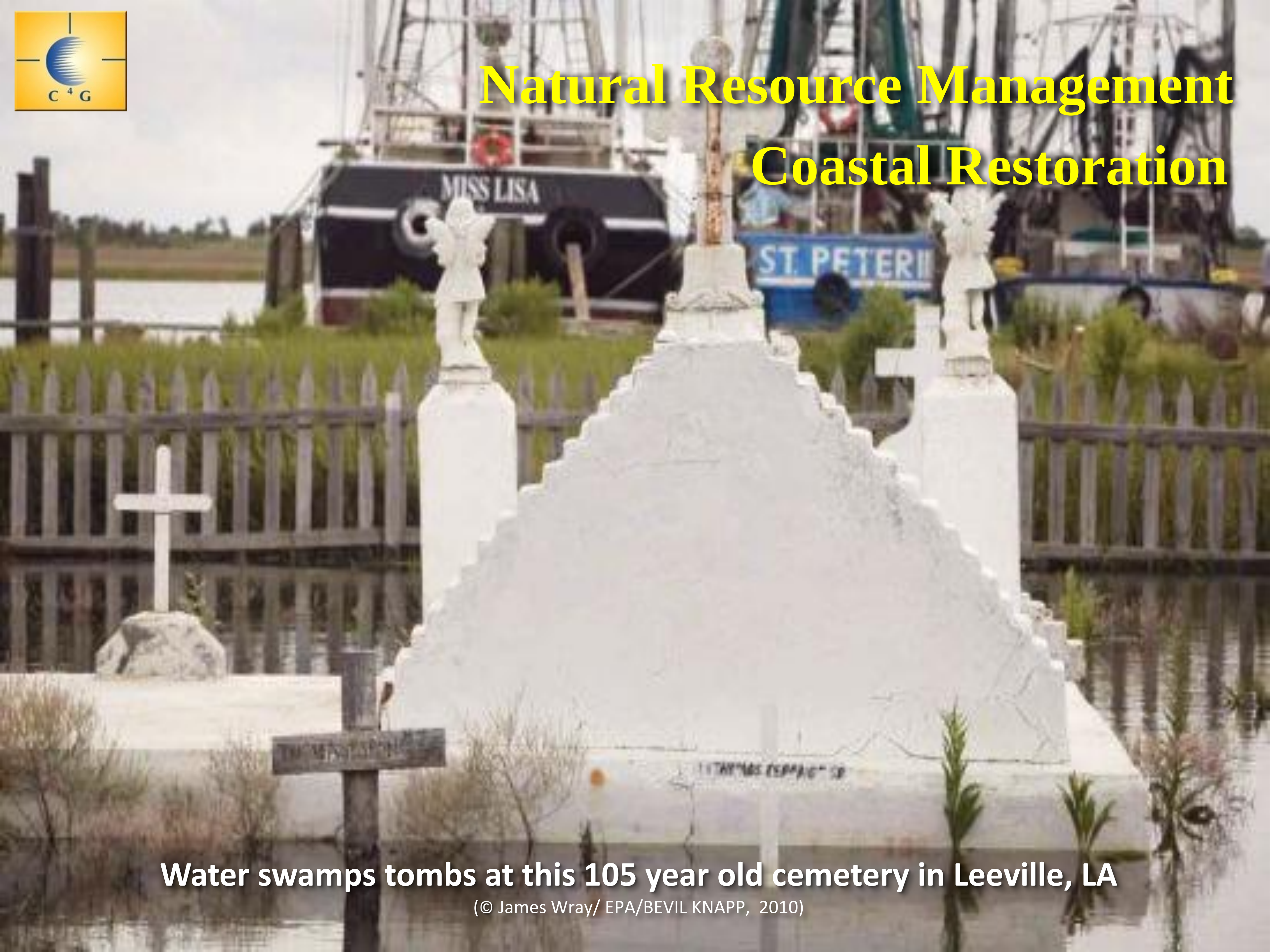
* USGS Open File Report 03-334 | Barras et al., 2004

C 4 G

Consequences to

Land Use Management
Planning & Development

Natural Resource Management
Coastal Restoration



Water swamps tombs at this 105 year old cemetery in Leeville, LA

(© James Wray/ EPA/BEVIL KNAPP, 2010)

Impact of subsidence within urban settings: New Orleans East and elsewhere…

© 2005 Todd Bigelow

Transportation Planning

South of Chauvin, Louisiana
Terrebonne Parish
Photo provided by Terrebonne Levee & Conservation District

A Landscape of Contradictions…

Take-Home Messages of this Talk

- Coastal engineering & design, hazard mitigation planning, and transportation planning, depend on accurate land elevation and bathymetry.
- Subsidence has destroyed Vertical Control from Pensacola, FL, through Louisiana, and to Corpus Christi, TX.
- The lack of Vertical Control has lead to compromised LiDAR, unrealistic surge models, flood maps that do not accurately portray risk, misguided coastal planning policy, and may ultimately lead to an unsustainable coast.
- Although the C4G has solved the technical issues regarding control in Louisiana, there is little understanding by officials, professionals or the public regarding the problem and implications.

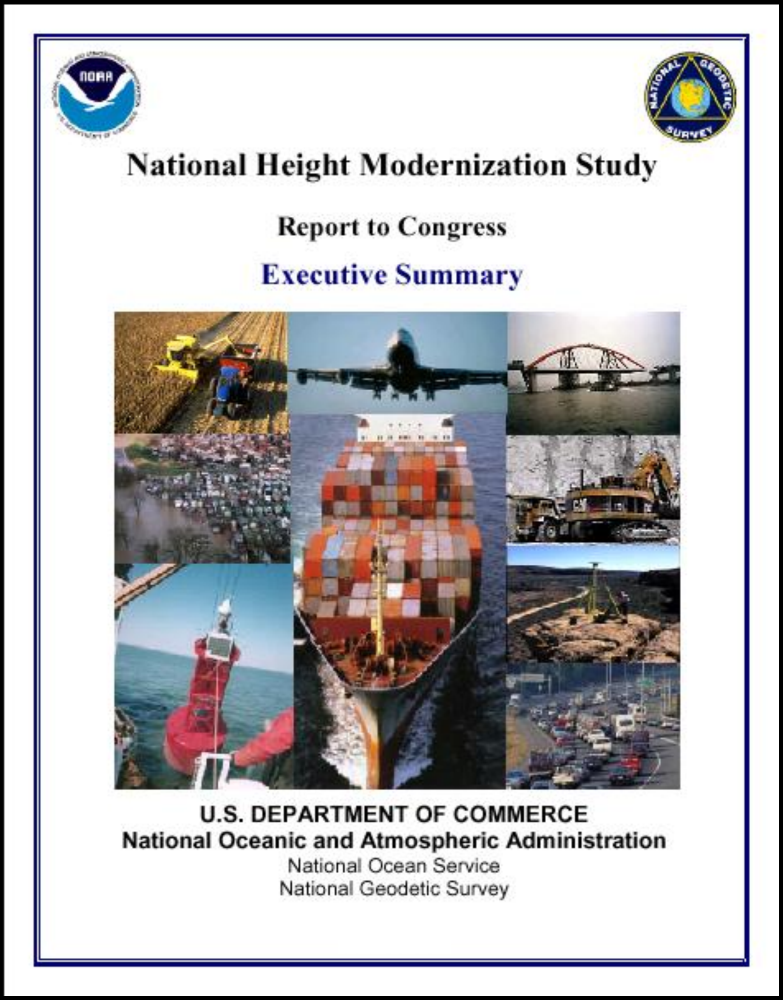
What is Vertical Control?

- A common vertical reference framework for scientific analysis, engineering design and construction, modeling, and operations and maintenance.
- Practical manifestation: National Spatial Reference System, maintained by NGS/NOAA and others. Used to construct national datums like NAVD 88.
- Typically accessed via benchmarks (passive) and CORS (active) access points.

The Problems Maintaining Vertical Control

- The Earth is dynamic. As the Earth moves, so too can the benchmarks.
- Datums are fixed to a date; adjusted as our knowledge of the Earth's shape improves (epochs). Benchmarks provide the measurements for datums.
- Over time, the benchmarks may move several feet with respect to the fixed datum. Benchmark positions are only known for the date they are calibrated.
- Benchmark calibration is very expensive, and go stale quickly.
- Subsidence affects our ability to access the National Spatial Reference System (NSRS). The benchmarks used to base a design, to prepare a flood certificate, or establish the height of a levee, may no longer be valid.

A Report to Congress


National Height Modernization Study

Report to Congress

Executive Summary

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
National Geodetic Survey

NOAA told the U.S. Congress in 2001 that the system used to measure elevations in LA was,

" inaccurate and obsolete and unable to support public safety."

Accurate elevations were not restored until after 2005. Any elevations obtained between 2001 and 2005 were highly suspect.

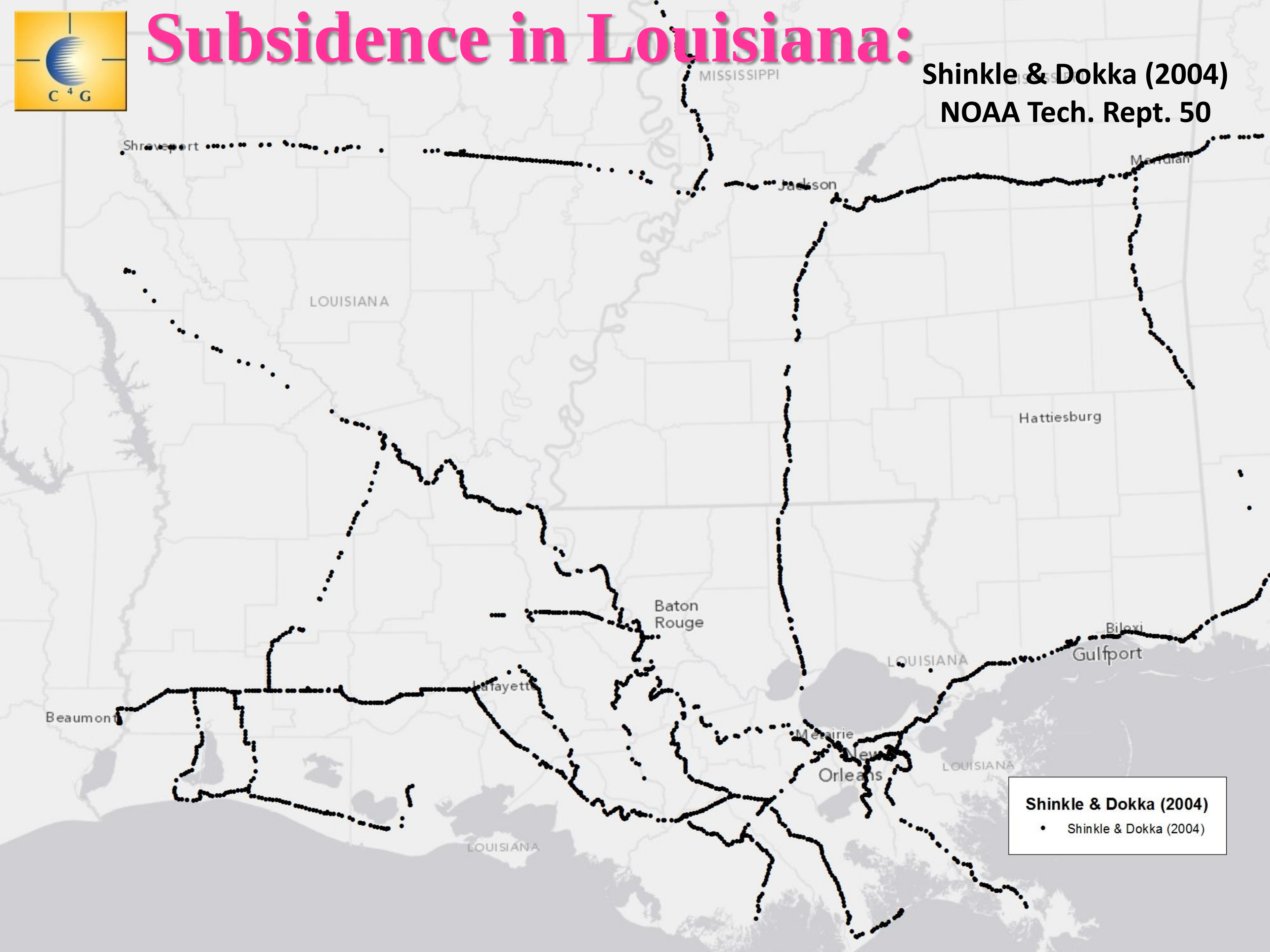
Accurate Elevations have been Impossible to Maintain in LA

Why?

- Subsidence
- A lack of understanding of how and why subsidence occurs.
- A willingness to accept "the best available data" instead of "accurate and sufficiently precise data to meet requirements and the standard of care".
- No Technical Leadership and/or No $$

Subsidence in Louisiana:

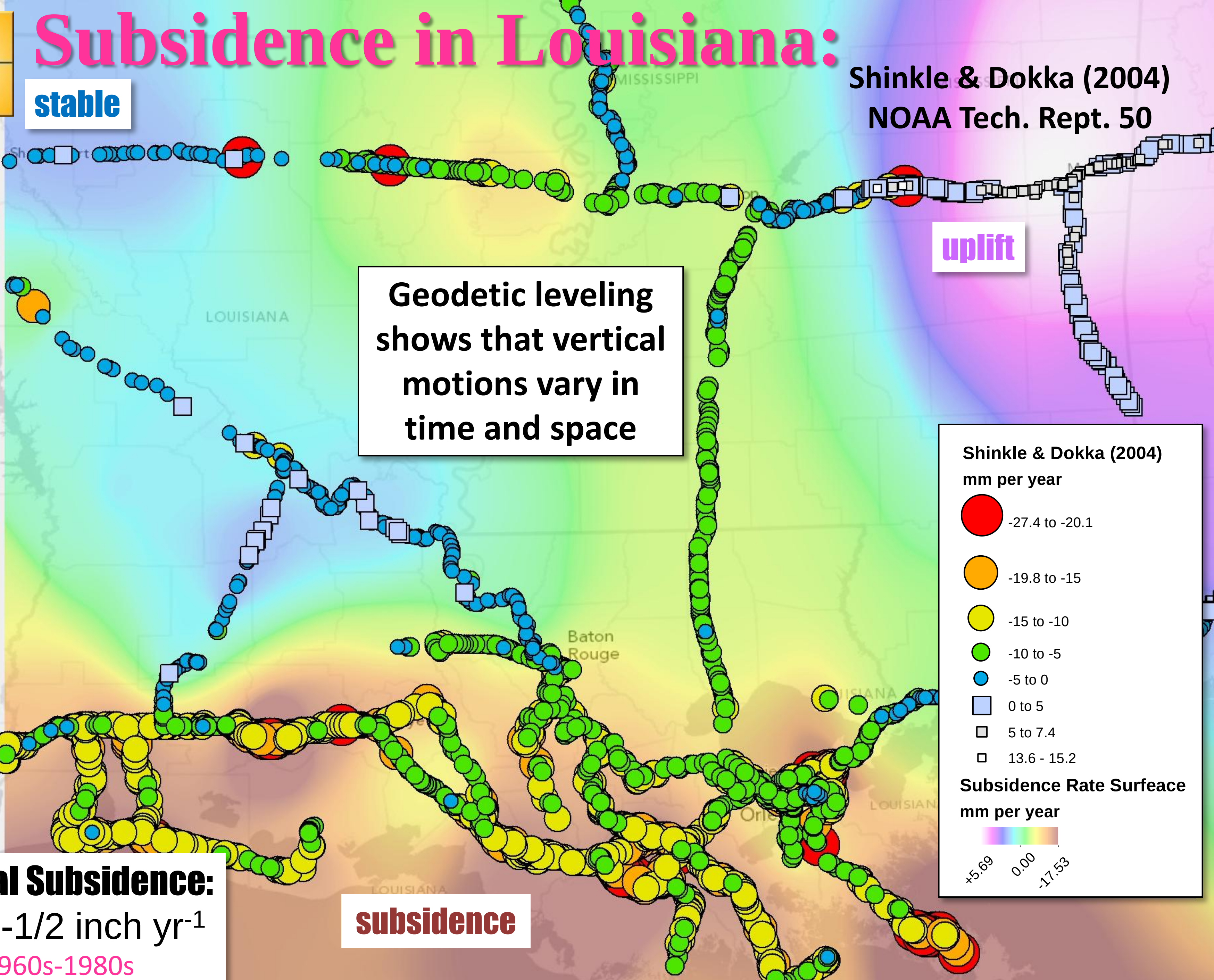
Shinkle & Dokka (2004)
NOAA Tech. Rept. 50



Subsidence in Louisiana:

Shinkle & Dokka (2004)
NOAA Tech. Rept. 50

Geodetic leveling shows that vertical motions vary in time and space

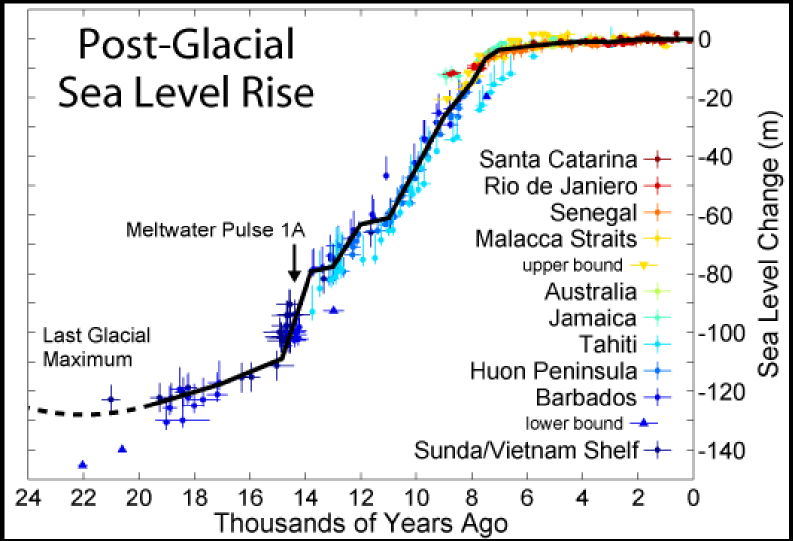


Coastal Subsidence:
avg. -1/2 inch yr^{-1}
1960s-1980s

Understanding Subsidence

- *“The downward movement of the Earth’s surface with respect to a datum.”*
- Subsidence has been misunderstood because of inaccurate measurement and false process assumptions.
- Associated with **any one or many** natural and anthropogenic processes.
- Subsidence is 4-D: and has been measured across south LA, MS, and TX.
- How fast does it occur?
  - *mm/yr to several dm/yr.*
  - *Subsidence rates are variable in time and space*

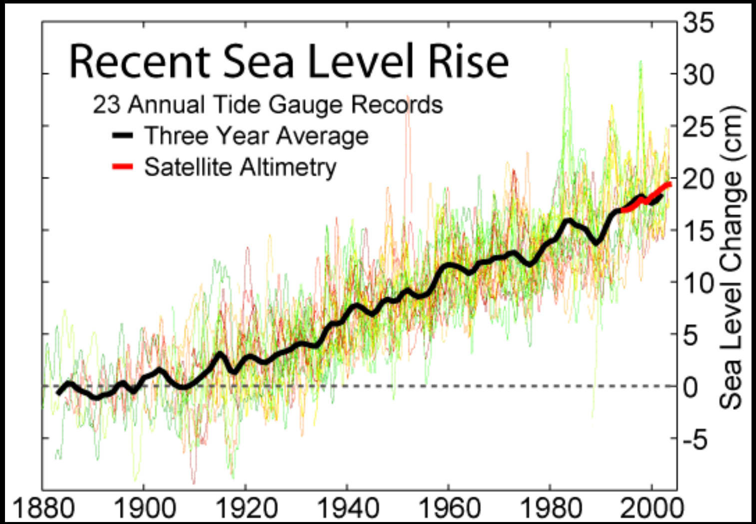
The Rising Seas…



Rohde, 2006

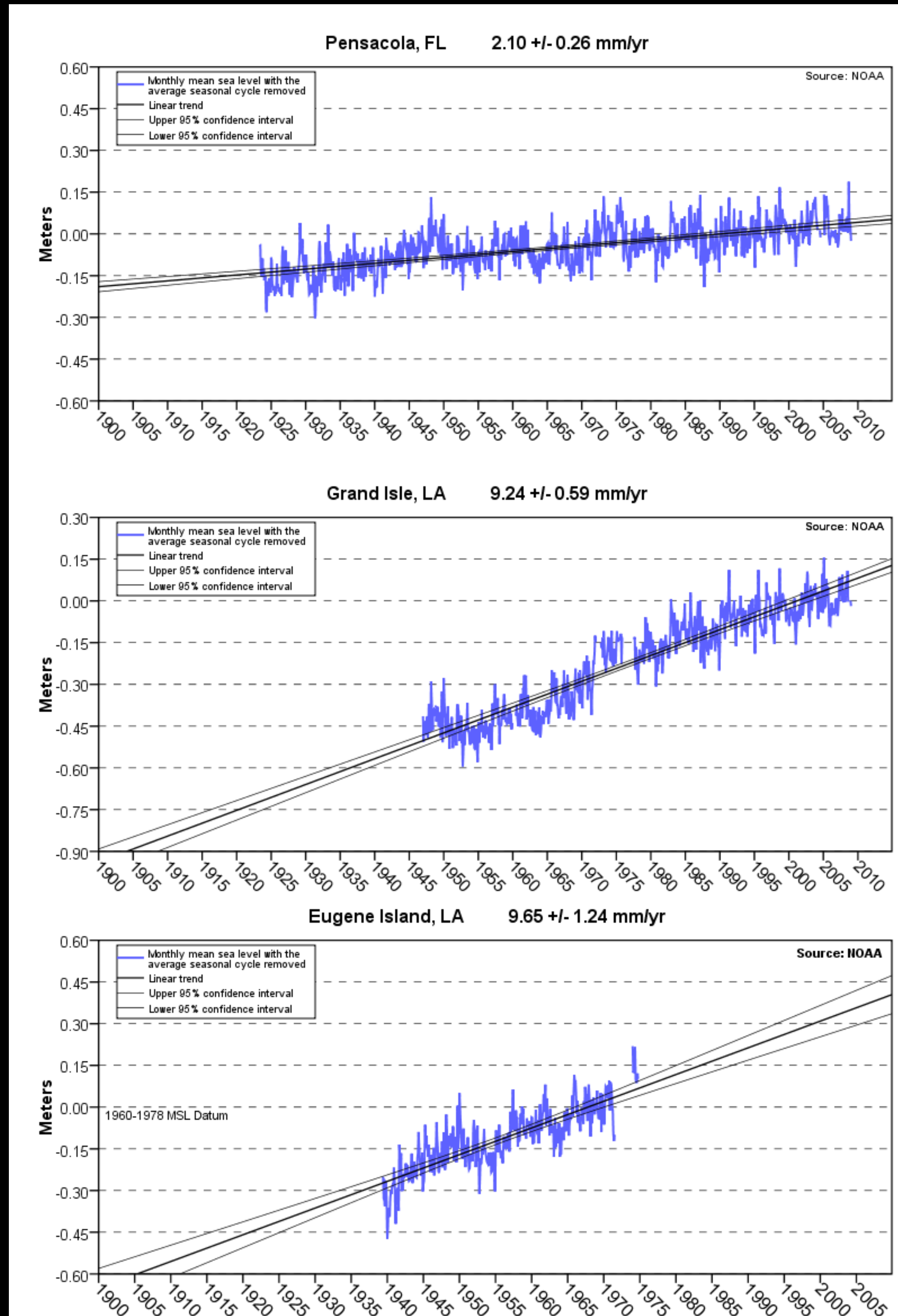
Global sea-level has been slowing since the last glacial maximum.

Global sea-level has been relatively constant over the past 100 years.



Douglas, 1997

Gulf of Mexico Tide Gauges



http://tidesandcurrents.noaa.gov/sltrends/index.shtml

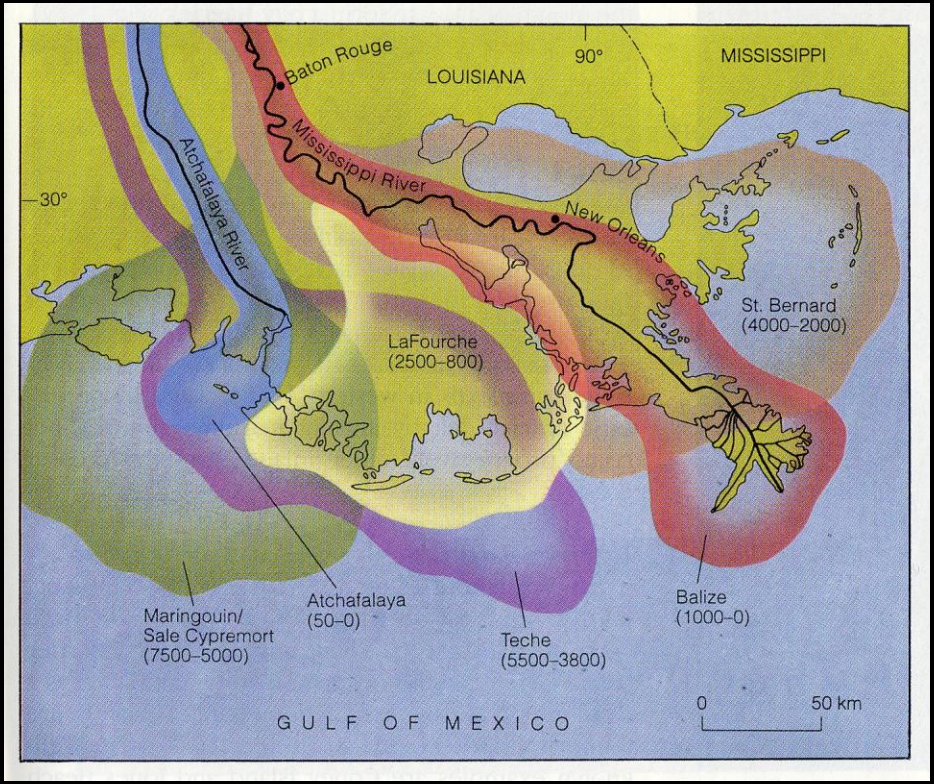
Natural and Anthropogenic Processes that Result in Subsidence

- ***Shallow Processes*** ***(processes above aquifers):***
  - → Natural consolidation and compaction: *≤ 5 mm/yr*
  - → Human-induced consolidation and compaction*: *~ 30 mm/yr*
    - *Desiccation by urbanization (behind levees)*
    - *Organic Soil Oxidation*
- *Deep Processes (processes below and including aquifers):*
  - → Load induced flexure of the lithosphere*: *0 to -8mm/yr*
  - → Faulting: *variable, ≤ -20mm/yr*
  - → Salt evacuation: *variable, 0 to -??mm/yr*
  - → Water pumping*: *variable, ≤ -65mm/yr*
  - → Oil & gas extraction: *variable, 0 to -3 mm/yr*

** The dominant causes of subsidence in LA*

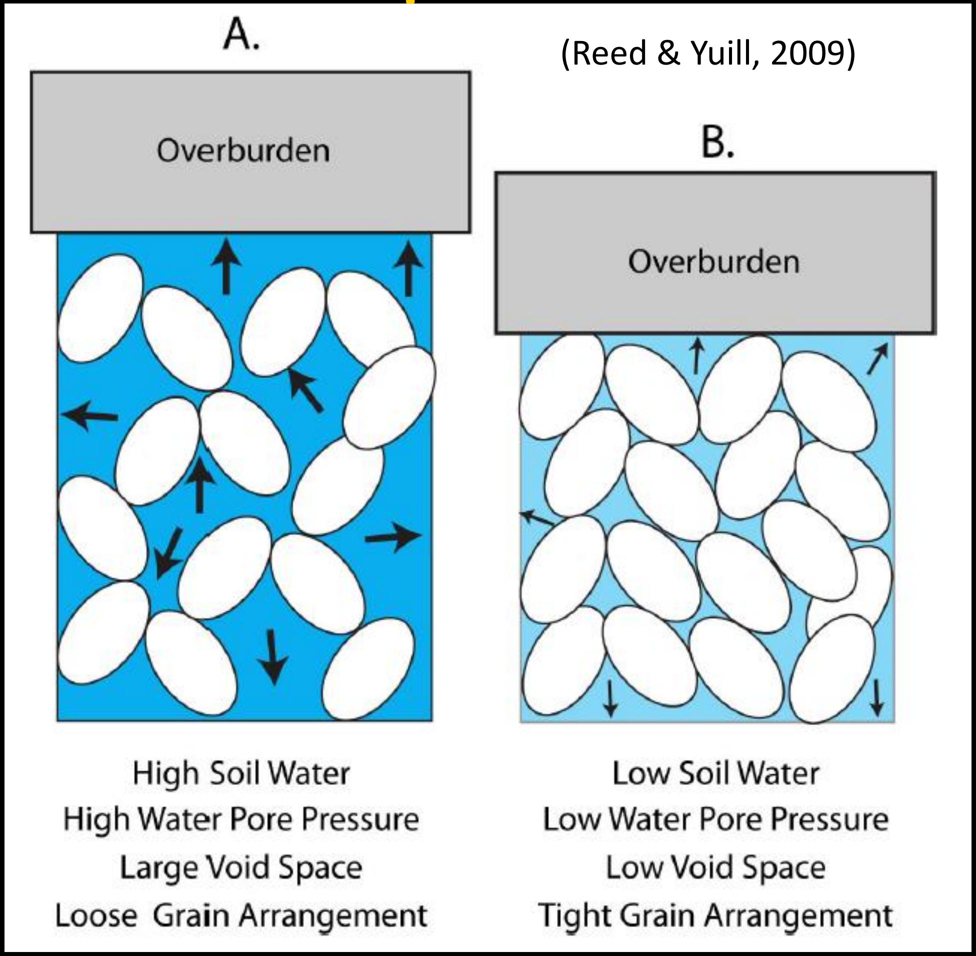
Brief Geologic History of South Louisiana

- Modern Mississippi River delta formed >~8,000 bp
- The landscape was defined through processes of subsidence, sediment accretion, global sea level rise and local oceanographic effects, and hydrologic processes.
- Land built via sediment deposition and wetlands growth ballanced by subsidence and eustatic rise. *Ergo*, deltas could not grow much above sea level.
- New delta lobes formed as the river shifted position with time. When abandoned, flooding stops and accretion ceased.
- Subsidence and sea-level rise continued. Over time, the lobe was slowly inundated by the Gulf.



Today, levees prevent flooding and accretion. Erosion continues. Subsidence and sea-level rise dominate.

Shallow Subsidence: Consolidation & Compaction



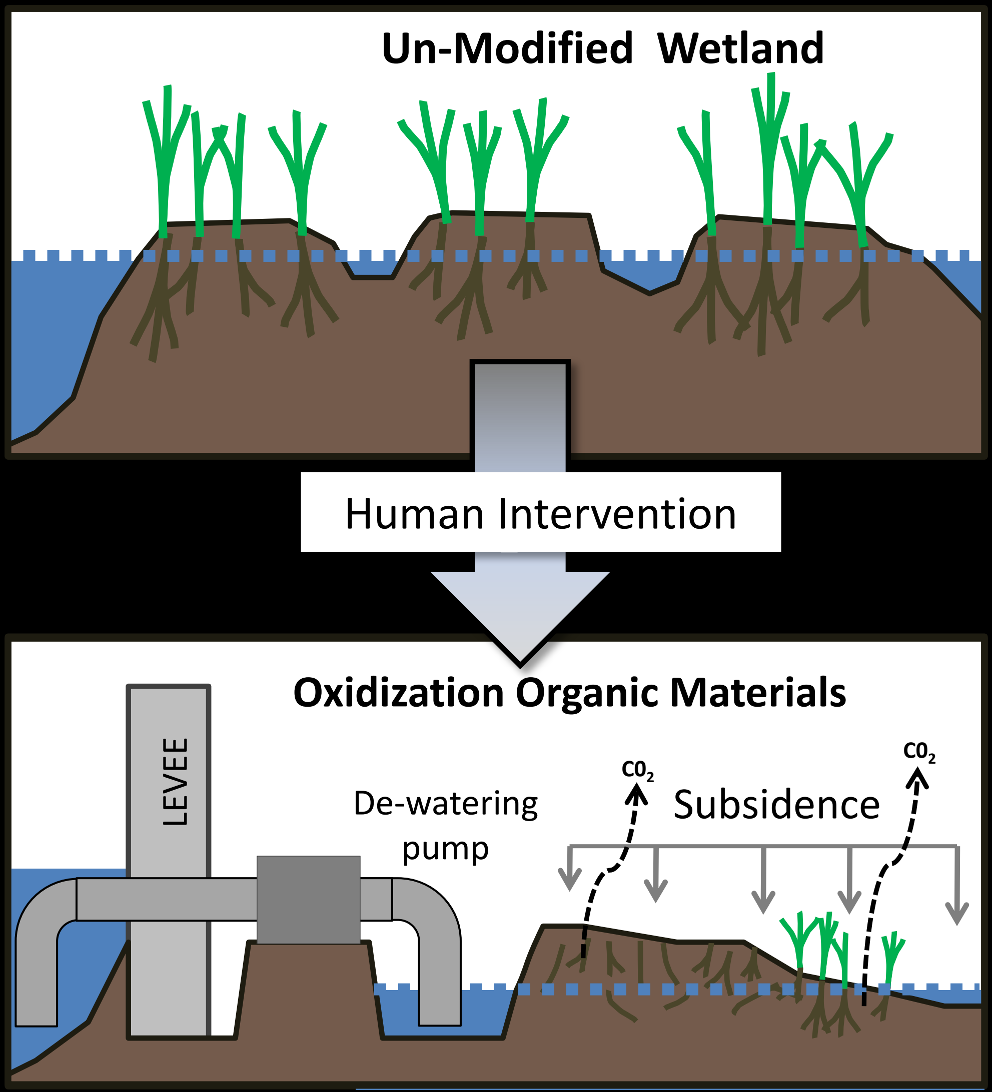
A) Gravity pulls the overburden down, forcing ***consolidation*** by squeezing out water.
B) Continued pressure ***compacts*** the material under the weight of the overburden.

Consolidation & Compaction Subsidence Rates: 0 to -5 mm yr^{-1}

- *Chronostratigraphy* [a]: **≤ -5 mm yr^{-1}**
- *Numerical Models* [b]: **~ -3 mm yr^{-1}**

[a] Törnqvist et al., 2006
[b] Meckel et al., 2006

Shallow Subsidence



(modified from Reed & Yuill, 2009)

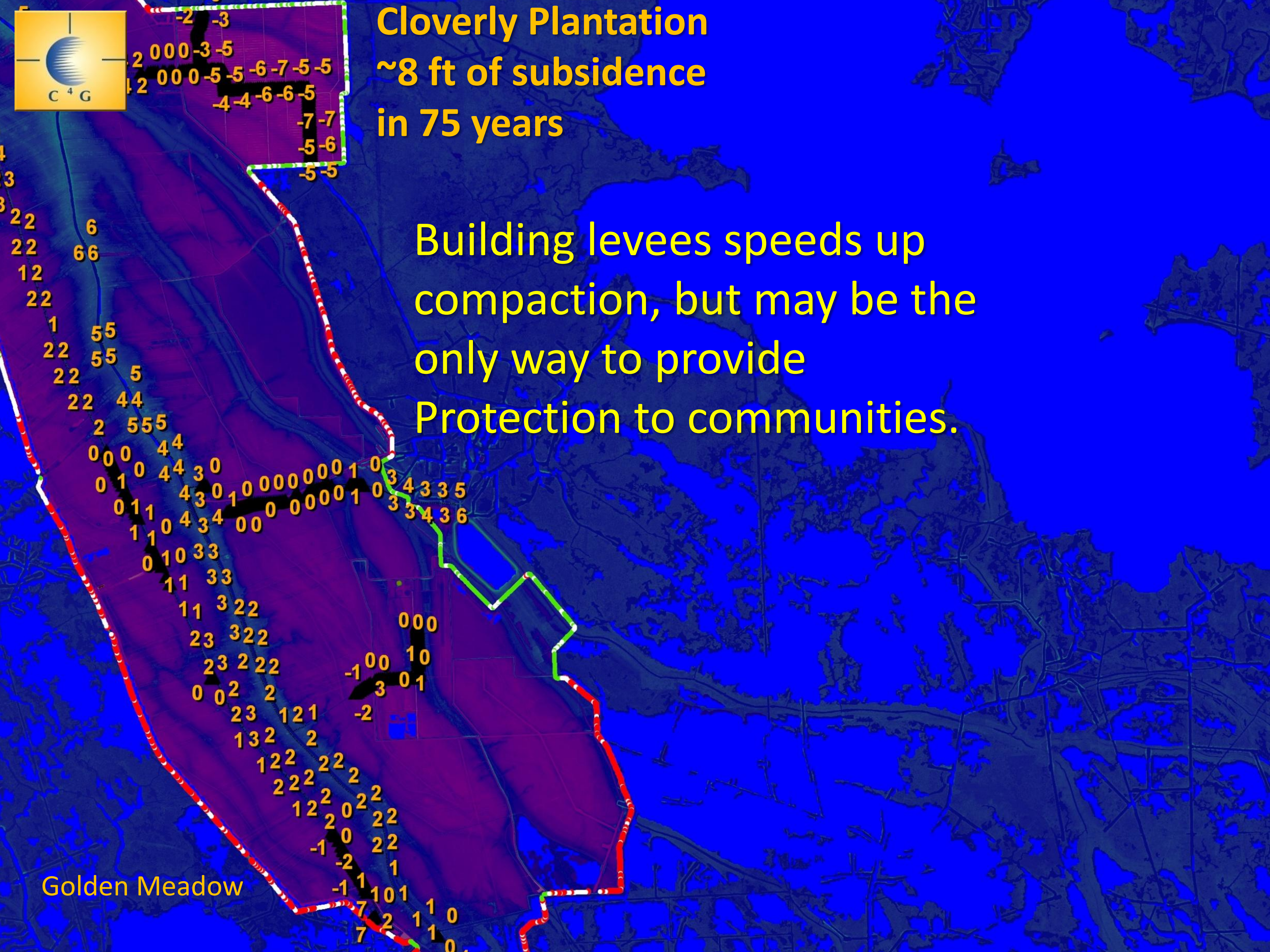
Groundwater withdrawal, oxidation, and compaction of organic materials [a,b,c]: -30 mm yr^{-1}

- Flood Protection
- Water Drainage & Management

[a] Deveral &Rojstaczer, 1996
[b] Stephens & Speir, 1969
[c] Snowden et al. , 1968

Cloverly Plantation
~8 ft of subsidence in 75 years

Building levees speeds up compaction, but may be the only way to provide Protection to communities.

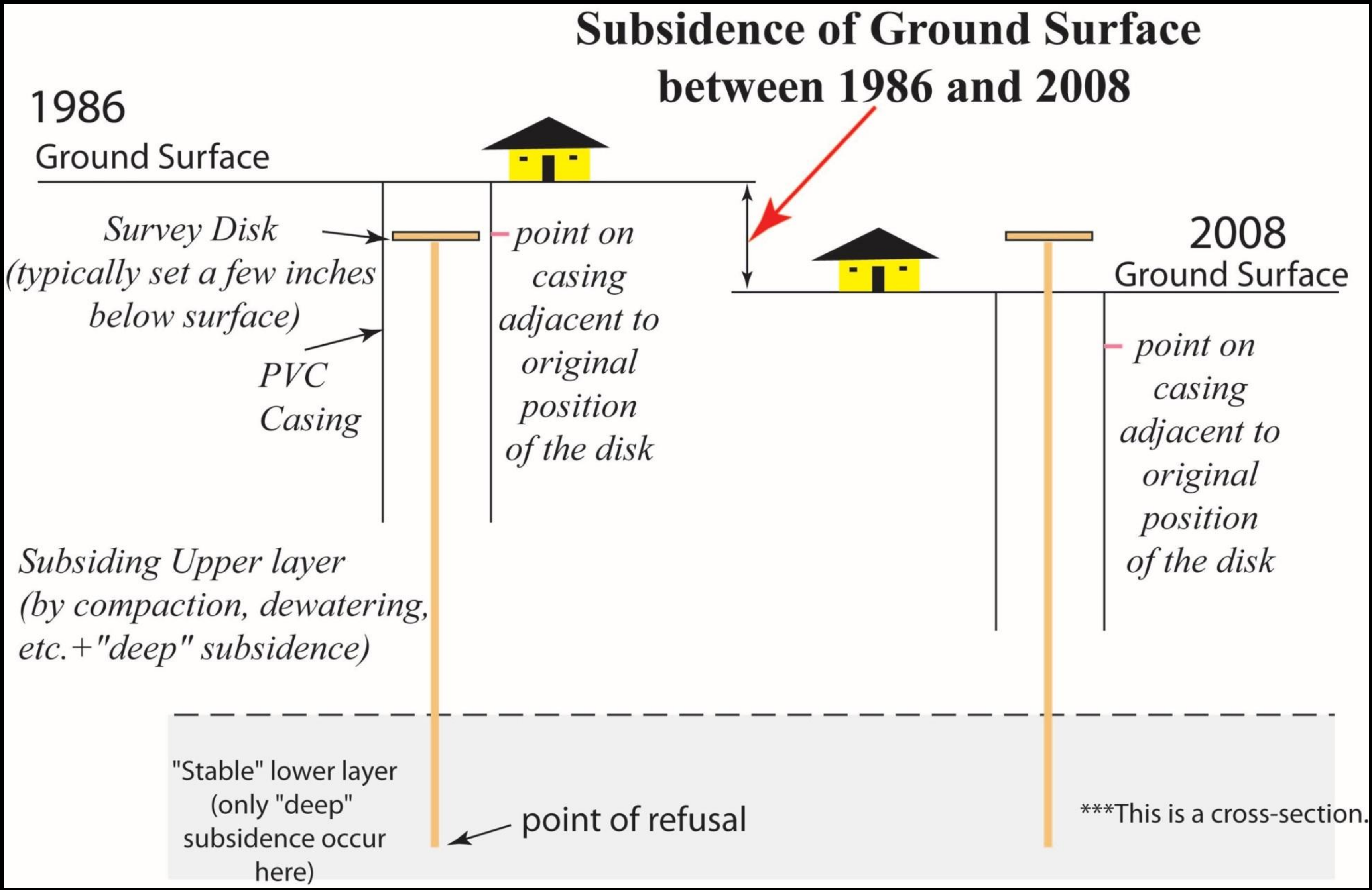


Examples of Shallow Subsidence

Deep Rods & Shallow Subsidence

- Region above producing aquifers.
- Virtually all BMs and CORS are partially affected.
- Most people assume all subsidence is caused by shallow subsidence.

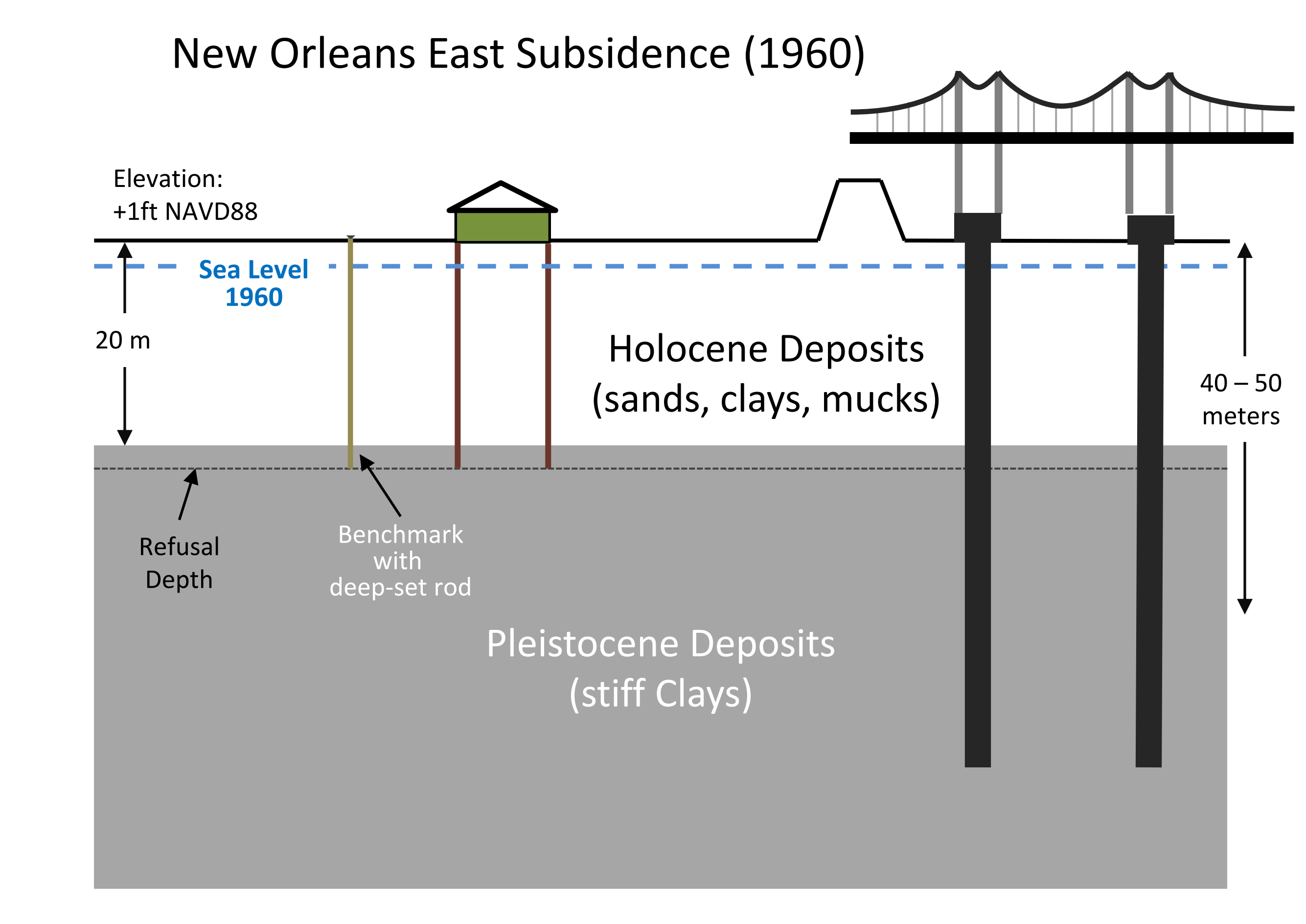
Deep Rods & Shallow Subsidence



Shallow vs. Deep Subsidence

- Conventional wisdom has considered subsidence to be constant in time and space.
- Analysis of geodetic data as a function of depth shows that subsidence is variable in time and space (vertical and horizontal).
- Thus, to measure subsidence, you need to understand what the the underlying processes might be so that a proper measurement strategy can be designed.
- It is all about the monumentation!

Monumentation Determines How Much of the Subsidence You Measure



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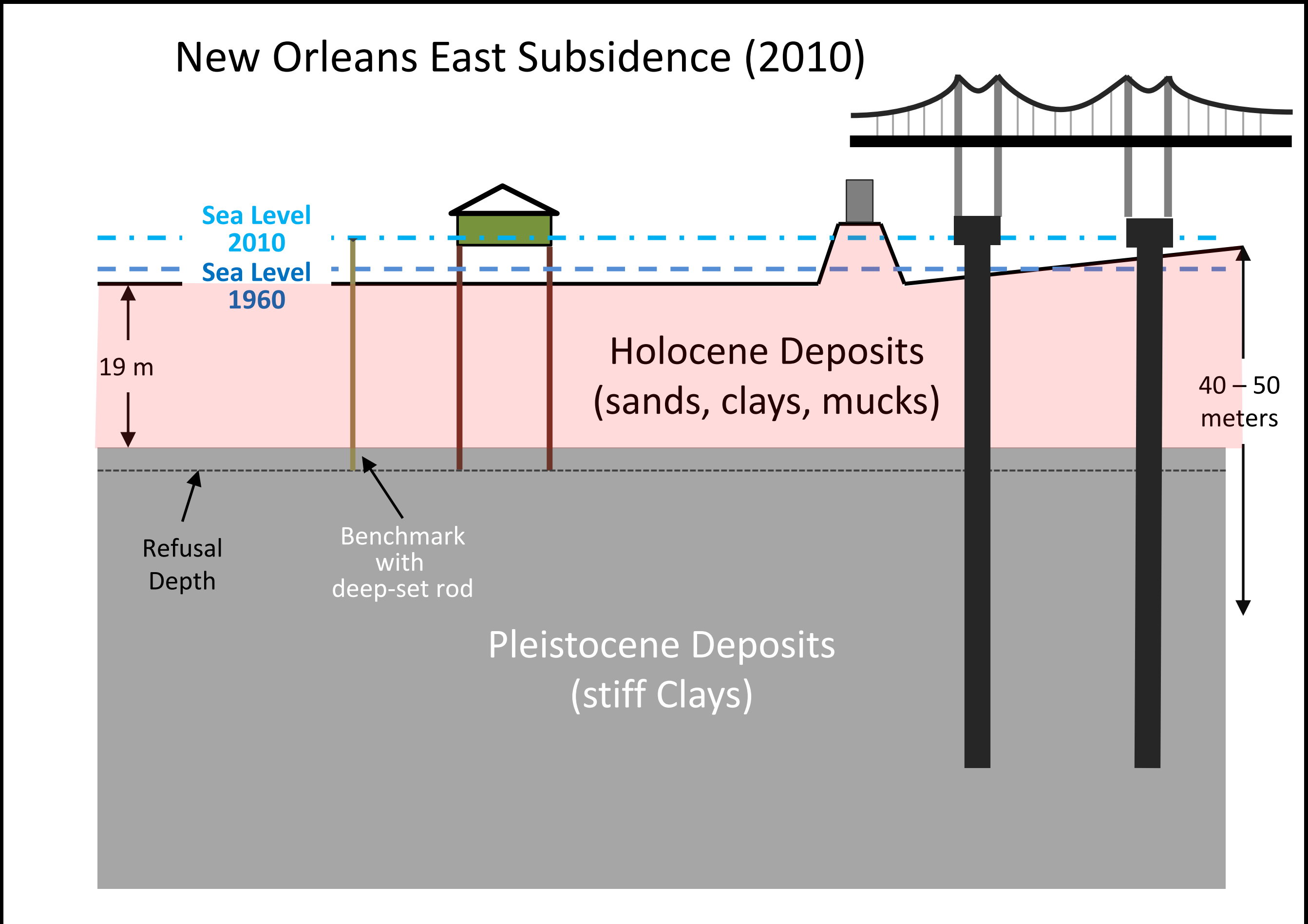

Natural and Anthropogenic Processes that Result in Subsidence

- *Shallow Processes (processes above aquifers):*
  - → Natural consolidation and compaction: constant ≤ *3 mm/yr*
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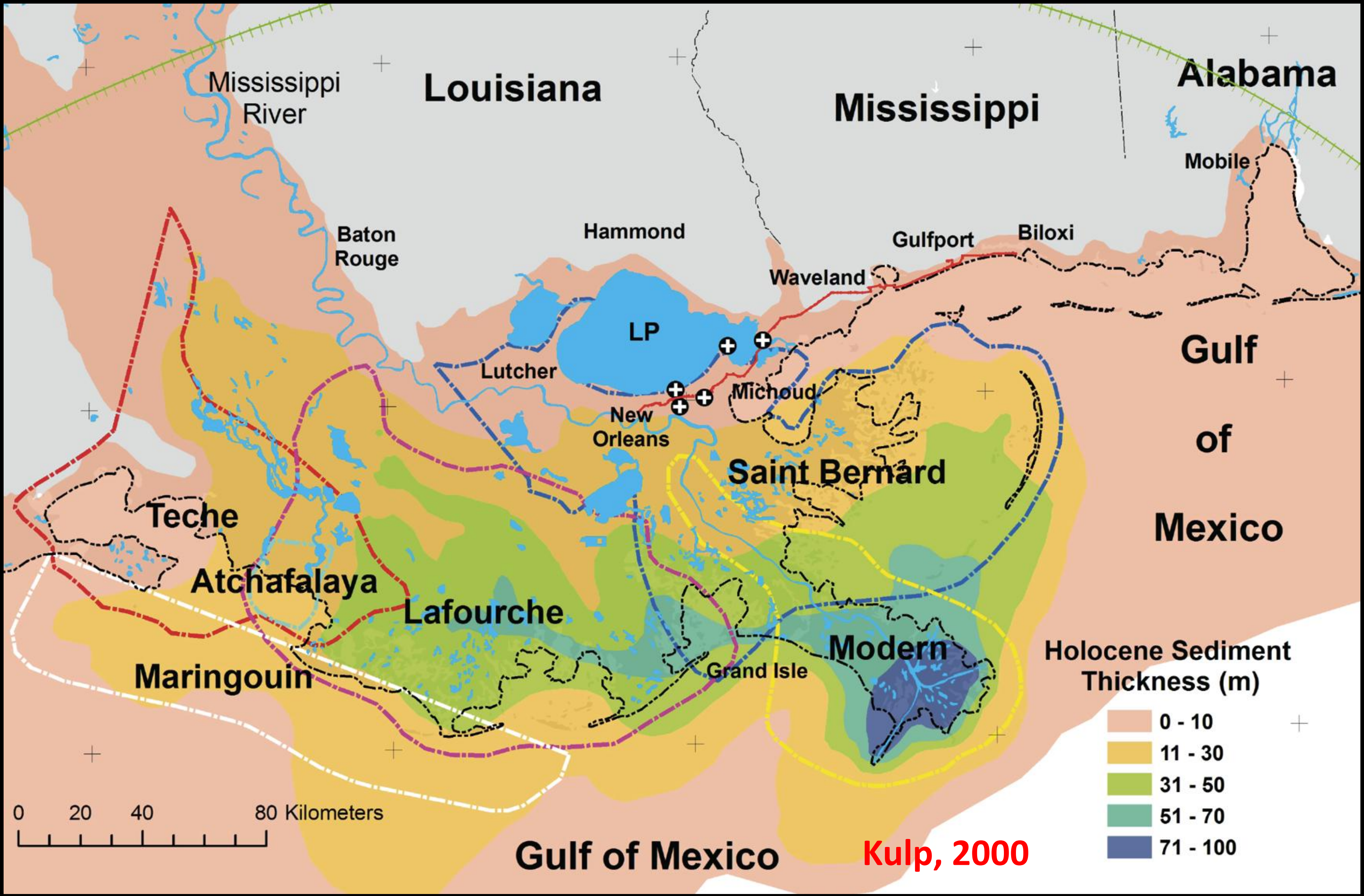
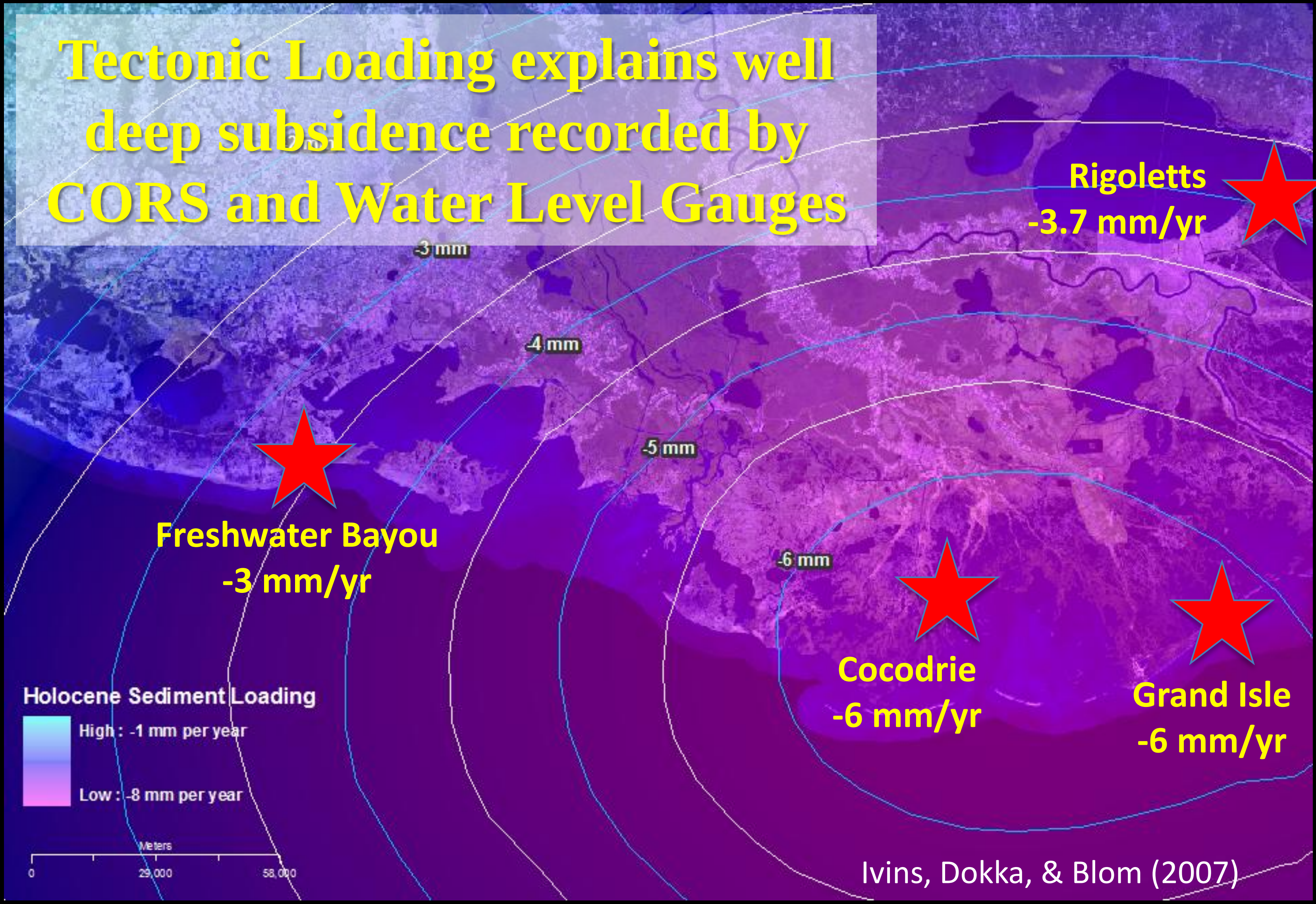
* *The dominant causes of subsidence in LA*

Thickness of the Mississippi River Delta

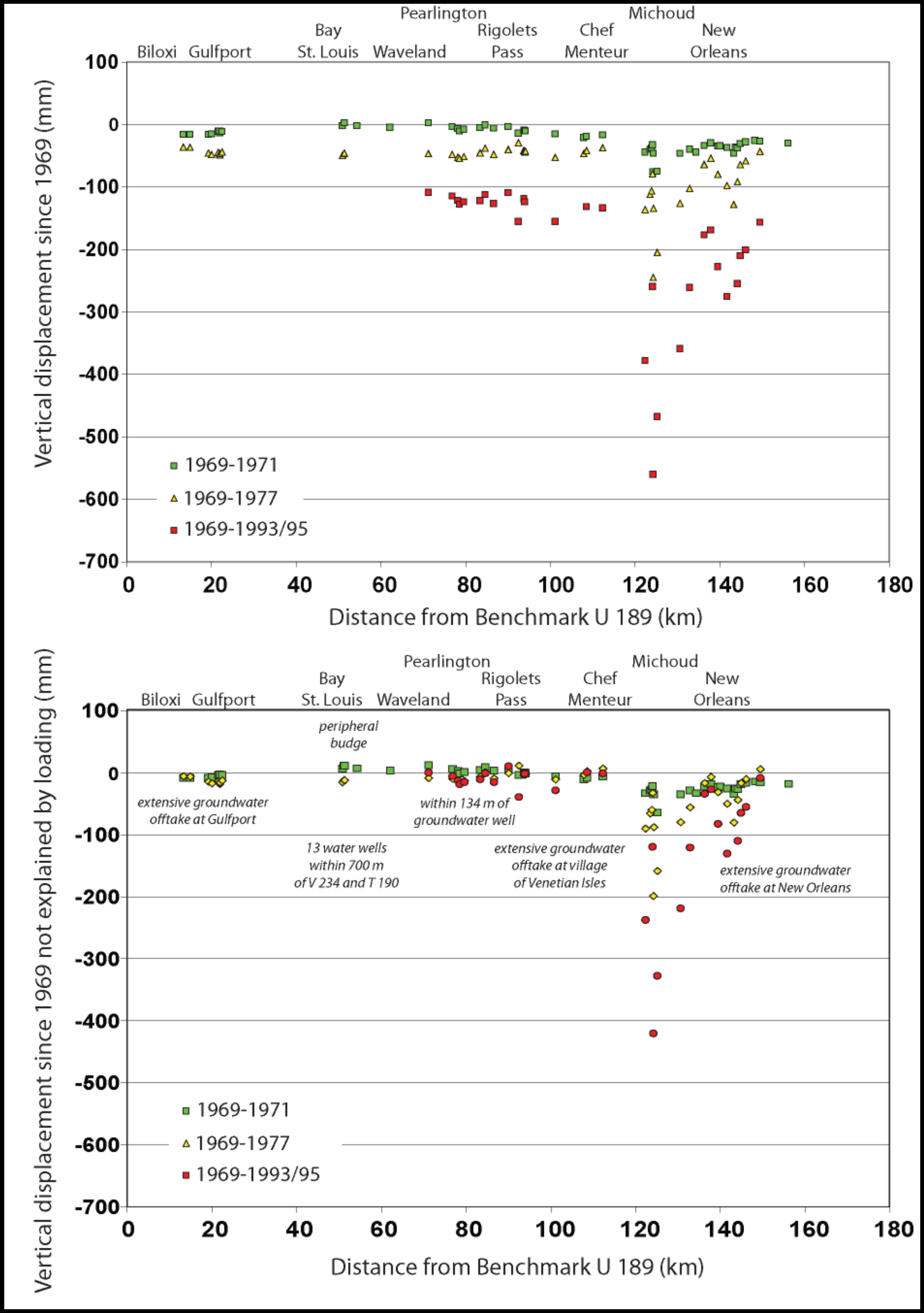


Holocene Sediment Loading on the Lithosphere

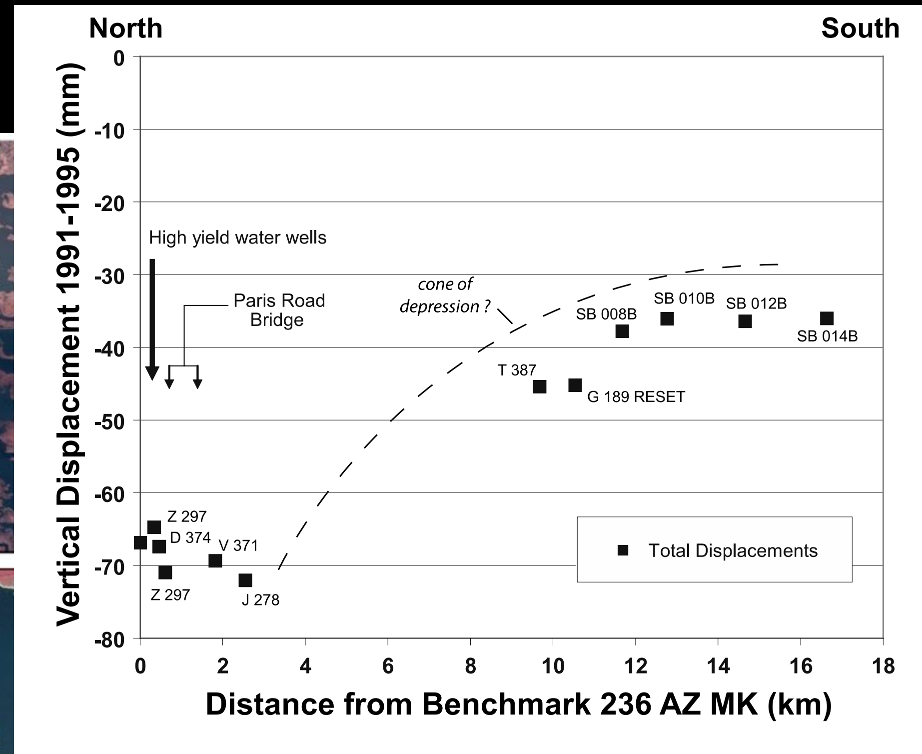


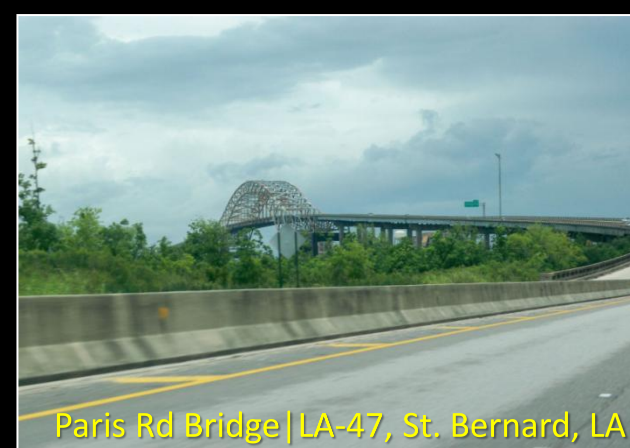
Analysis 1st Order Geodetic Level Data

- 1955-1995
- All monuments set below Holocene.
- No Holocene effects!!
- There is a lot of deep subsidence occurring below the Holocene.
- It's not just compaction.



Paris Rd. Bridge (LA-47): Subsided ~1m in 50 years

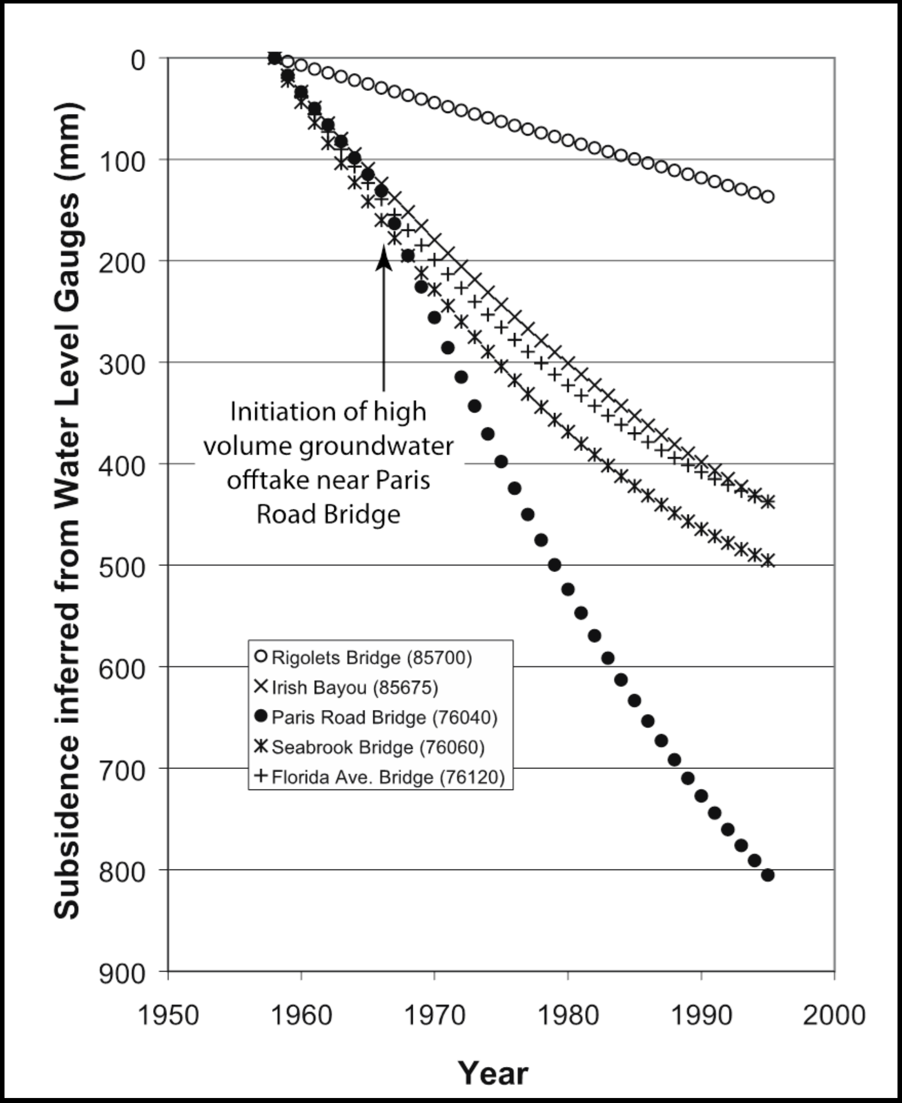




Subsidence from USACE Water Level Gauges in New Orleans: 1960-1995

- Gauges mounted on piles supporting bridges that penetrate well below Holocene sediments…

Consistent with Groundwater Pumping at Municipal Power Station



The Challenge of Maintaining Geodetic Control in Louisiana

- Louisiana spends $0 to maintain control.
- NGS has no $ to maintain control.
- No Technical Leadership.

Center for GeoInformatics

The C4G Operates and Maintains the Statewide, Real-Time Network of 65 CORS

- ≤ 2cm horizontal and ≤ 5cm vertical elevation (geometric)
- Available in Real-Time
- Research Subsidence and Societal Implications.
- Accuracy Assessment of Geospatial Data.

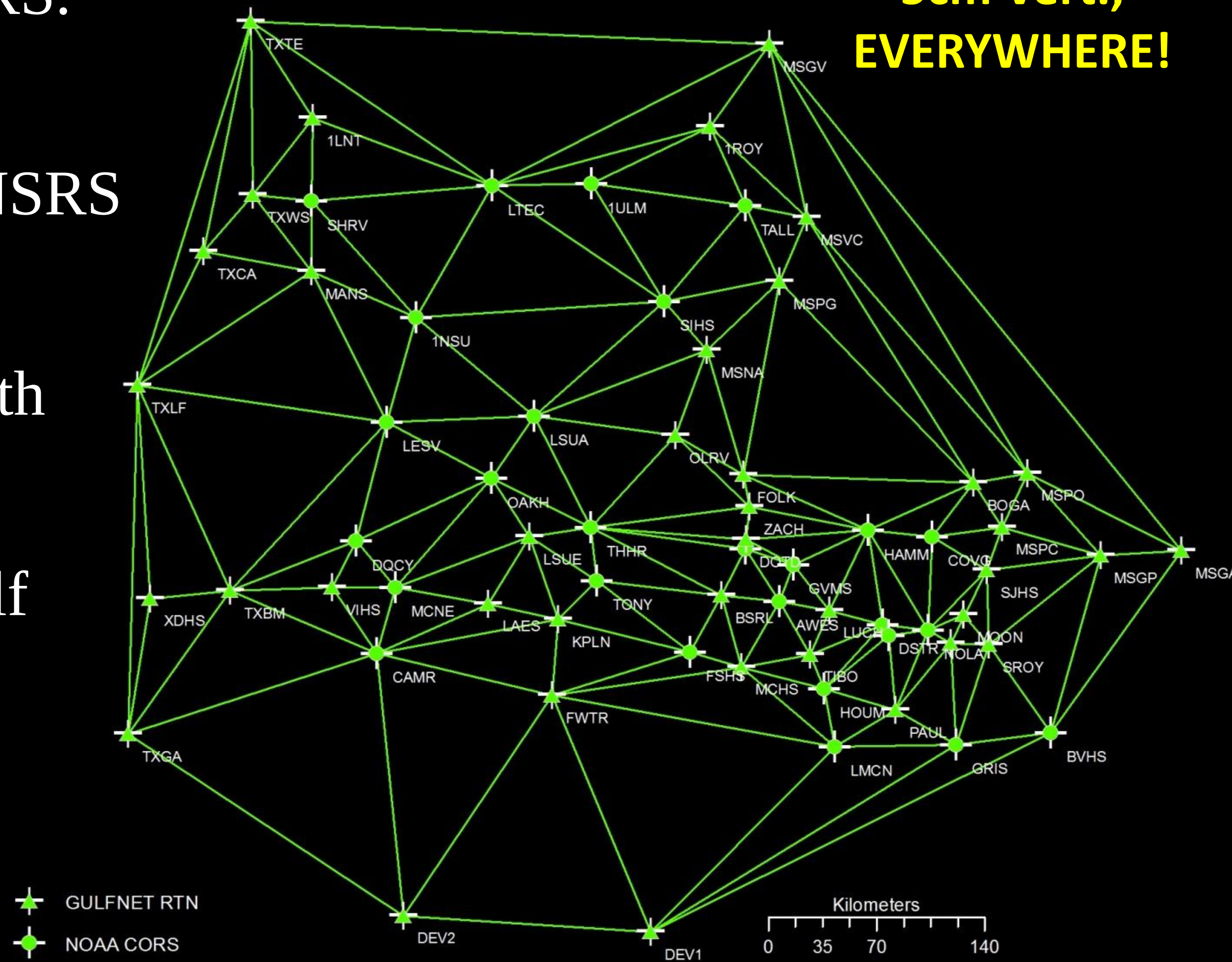
What is the Overall Strategy Regarding 3-D Positioning in LA?

- The ability to obtain accurate elevations has always been a shared responsibility between *NGS*, *local government*, *surveyors*, and *others*.
- NGS is committed to providing access to the NSRS for all users in LA. This means maintaining a basic backbone of about a hundred benchmarks in south Louisiana, supporting CORS, development of technical standards.
- C4G provides the state-wide GNSS technology to facilitate accurate and precise "anywhere, any-time" 3-D positioning.
- Local people will have to decide how they wish to access the NSRS. NGS and C4G are dedicated to helping individual parishes craft viable local solutions to meet local needs according $$ requirements.

C4Gnet: Real-Time Network

Error is 2 cm Horiz.
5cm Vert.,
EVERYWHERE!

- Based on LSU CORS.
- The most reliable component of the NSRS in Louisiana.
- Partially created with funds from FEMA.
- Maintained with self generated funds.



Real-Time Network Based on VRS Technology

"Positioning anywhere, any time"

Relative vertical:
+ 2 cm (3 min.)

Cellular device to connect user to Internet and LSU C4Gnet RTN

Kinematic mode:
+ 0.3 ft (1 sec.)

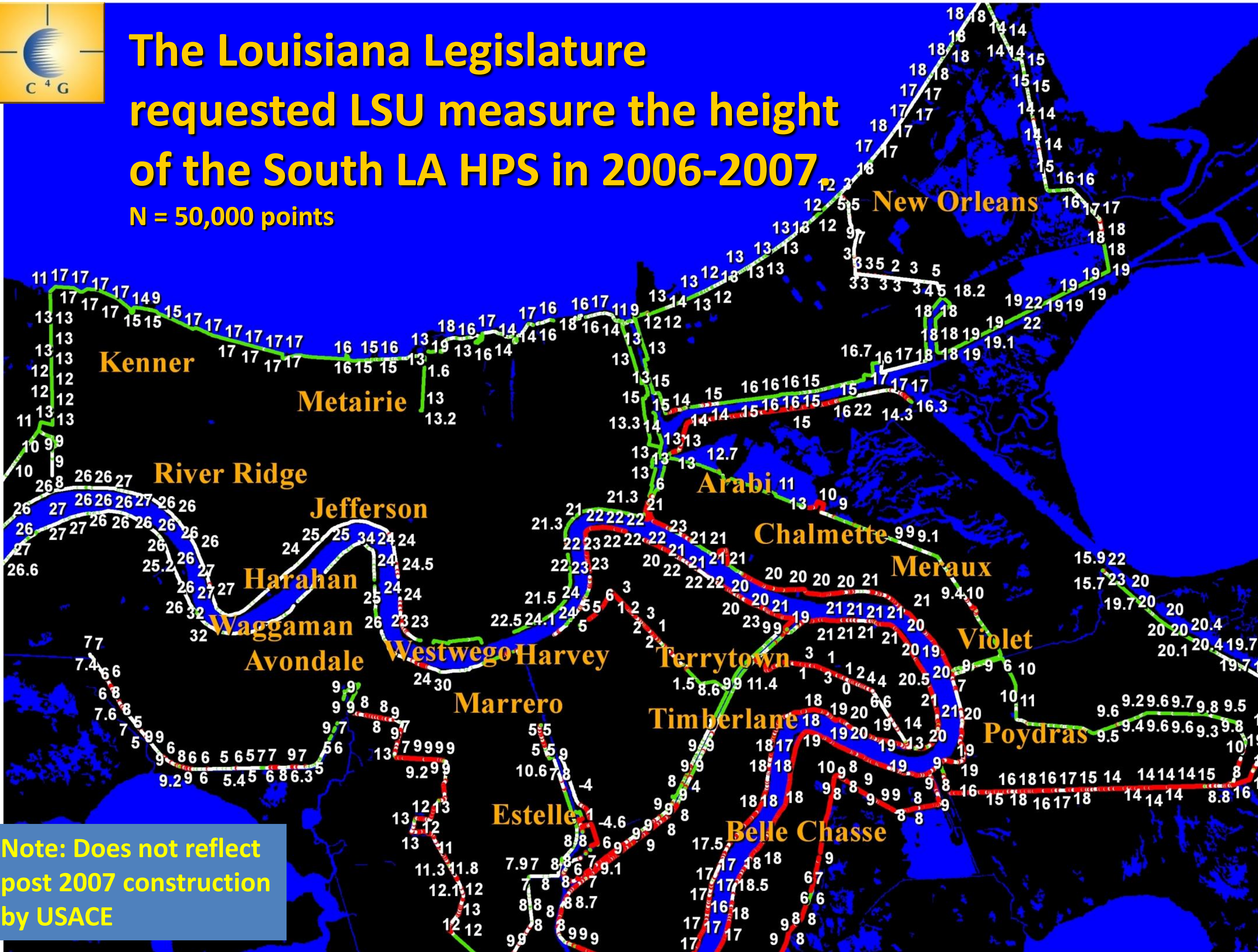
Native output in NAD83 (2011) epoch 2010.0

C4G's Contributions to Subsidence Research

- 2002 – C4G establishes the Louisiana Spatial Reference Center (LSRC) to provide technical leadership, training, and access to CORS network.
- 2006 – Louisiana Legislature makes the LSRC an Official Source for vertical control in LA (Act 194, Sec. 1. R.S. 50:173.1)
- 2006 – State commission to measure flood protection levees
- 2008 – Partnered with NWS, LA DOTD, & U.S. Army Corps to update elevations for storm surge models
- 2008 – Support NWS GPS-MET to measure water vapor in atmosphere
- 2009 – Established 2x Off-Shore CORS in Gulf of Mexico
- 2010 – Measure long-term impact of subsidence on evacuation routes.

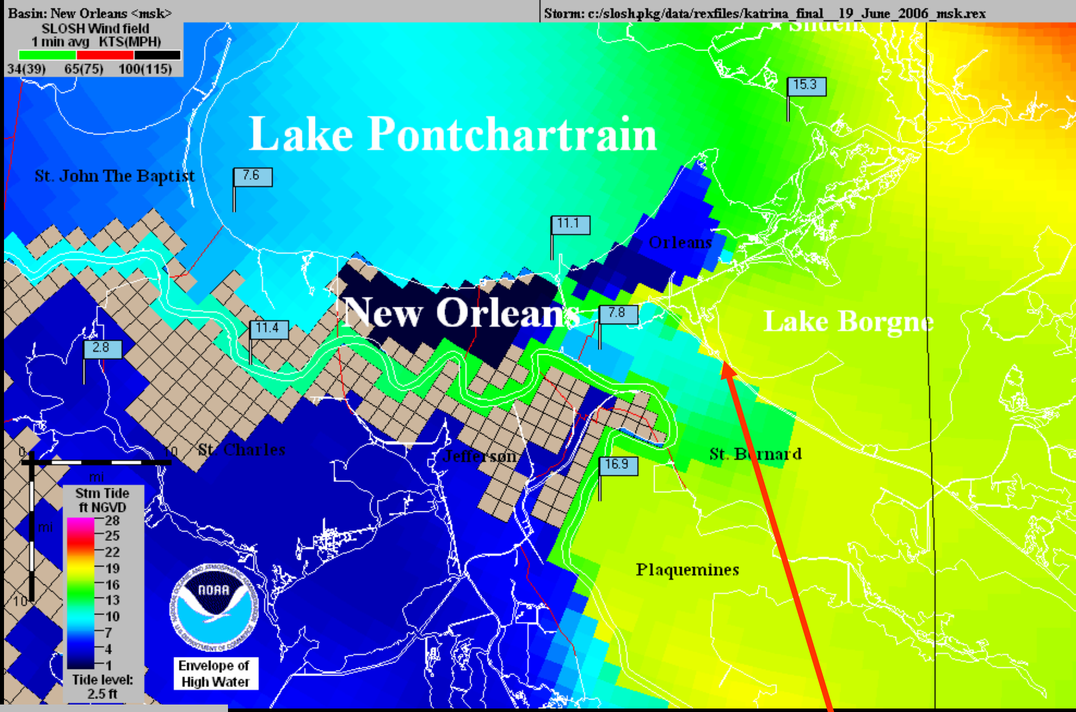
The Louisiana Legislature requested LSU measure the height of the South LA HPS in 2006-2007.

N = 50,000 points

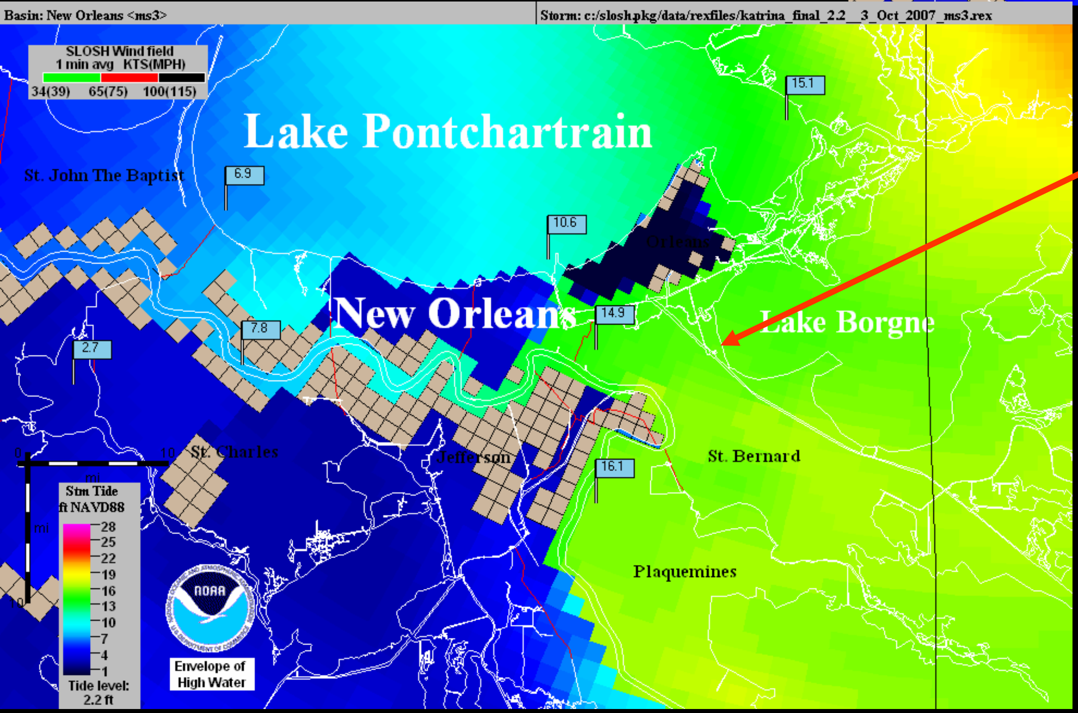


Note: Does not reflect post 2007 construction by USACE

Operational NHC Katrina SLOSH model using outdated or assumed elevation data

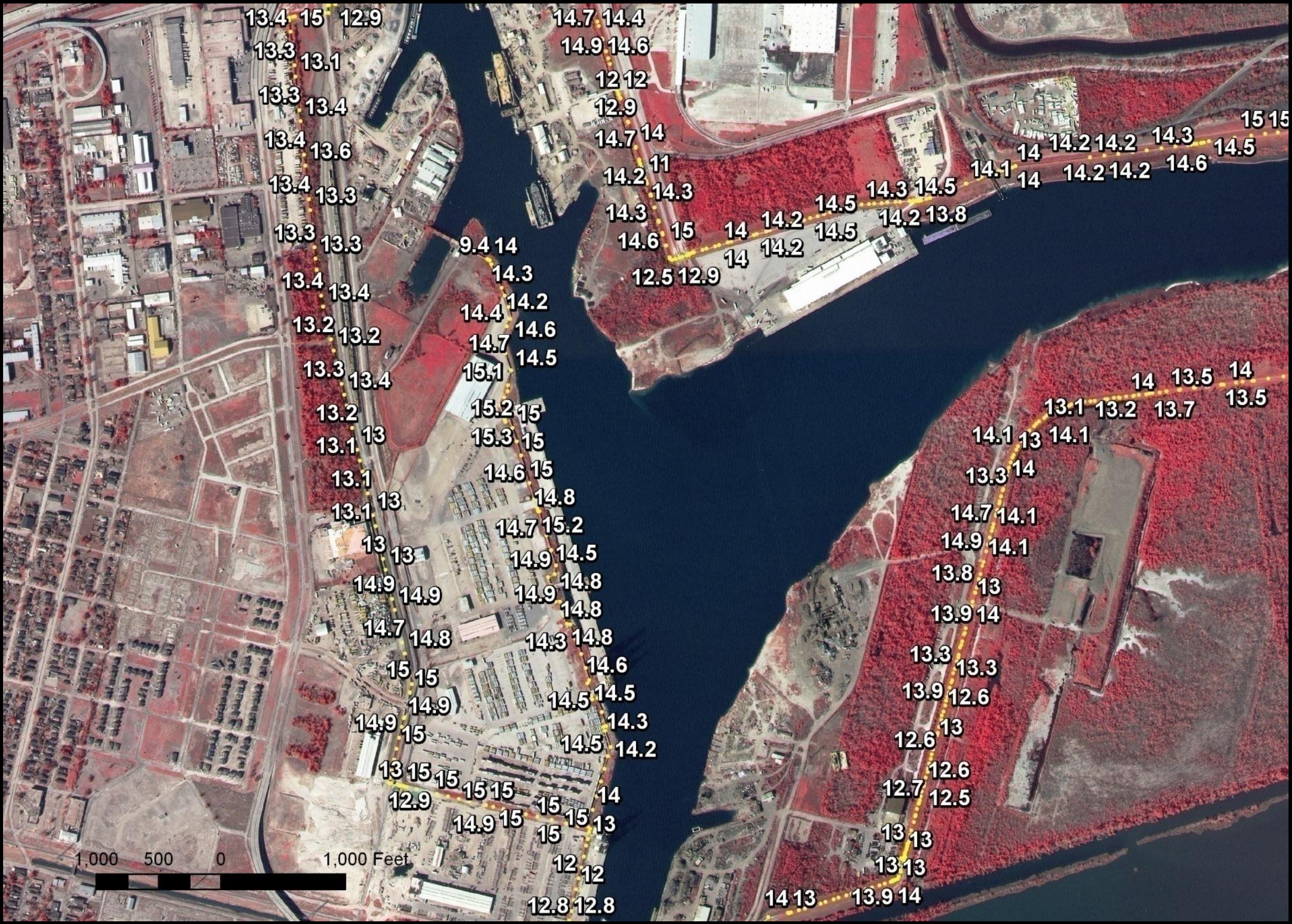


Note: The so-called "funnel" is a modeling artifact caused by the use of authorized elevations instead of valid measurements along south levee of MRGO.

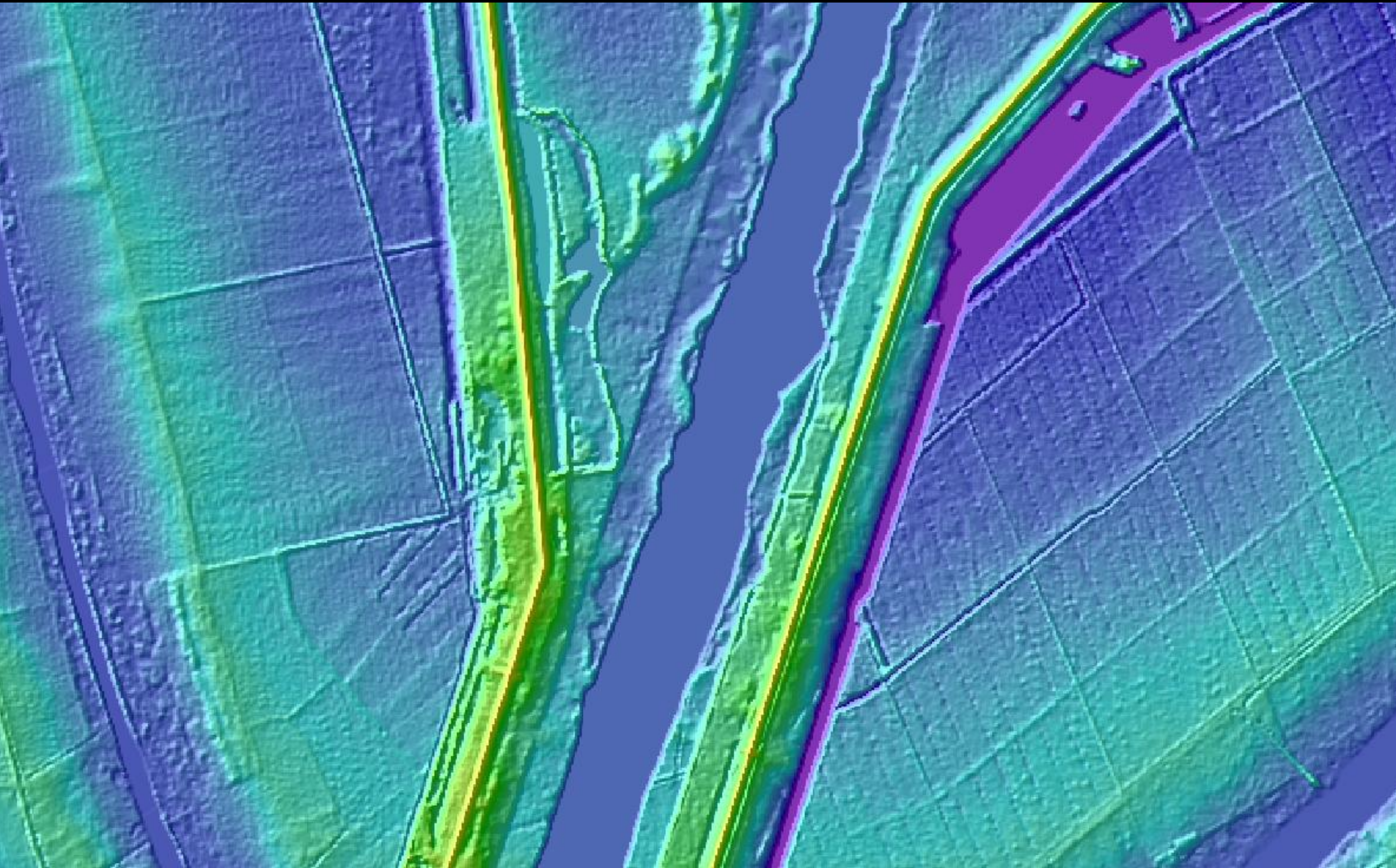


Katrina SLOSH using accurate topography

IHNC-MRGO Floodwalls and Levees



FEMA mapping partners need to use real weir elevations in ADCIRC models



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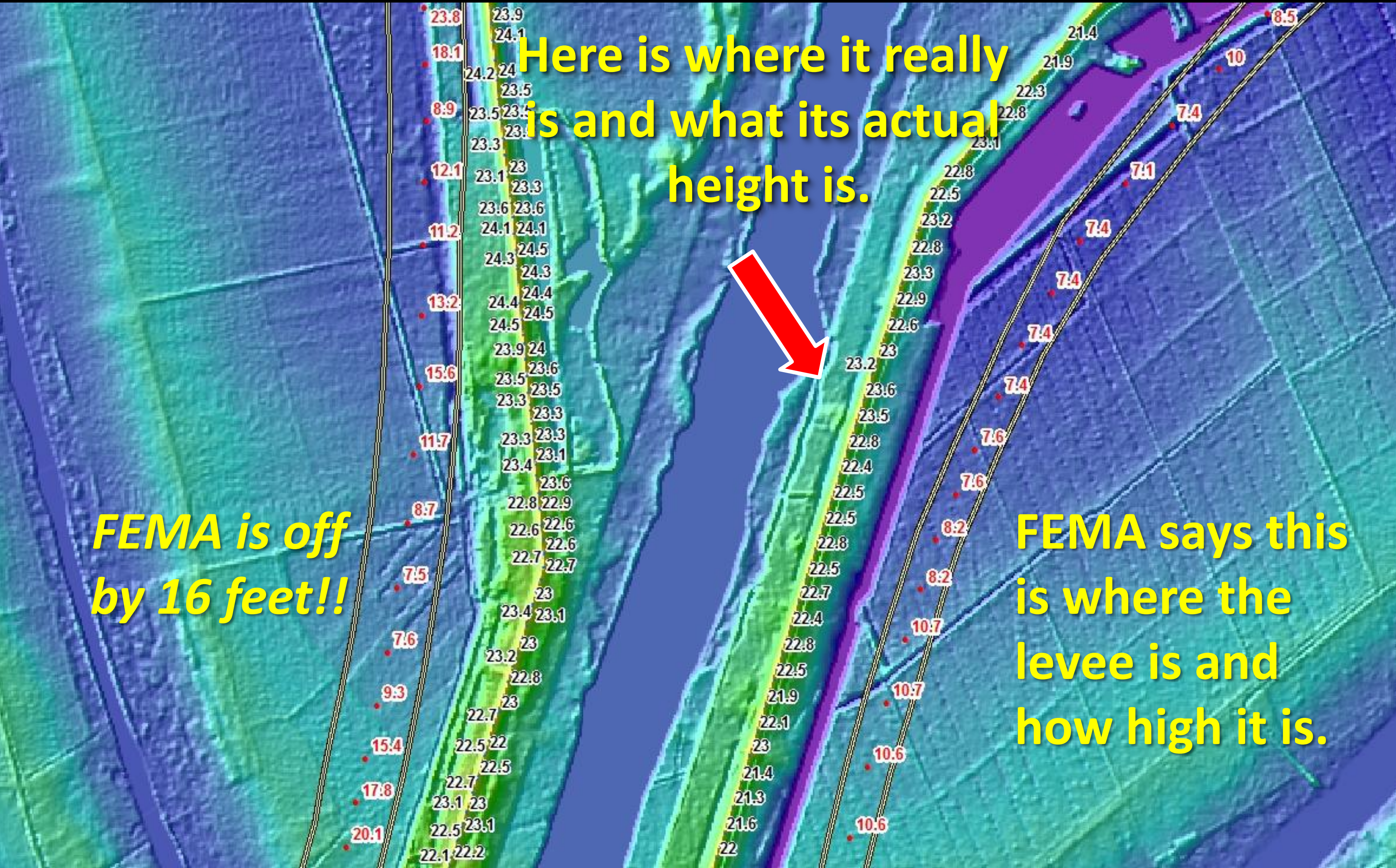
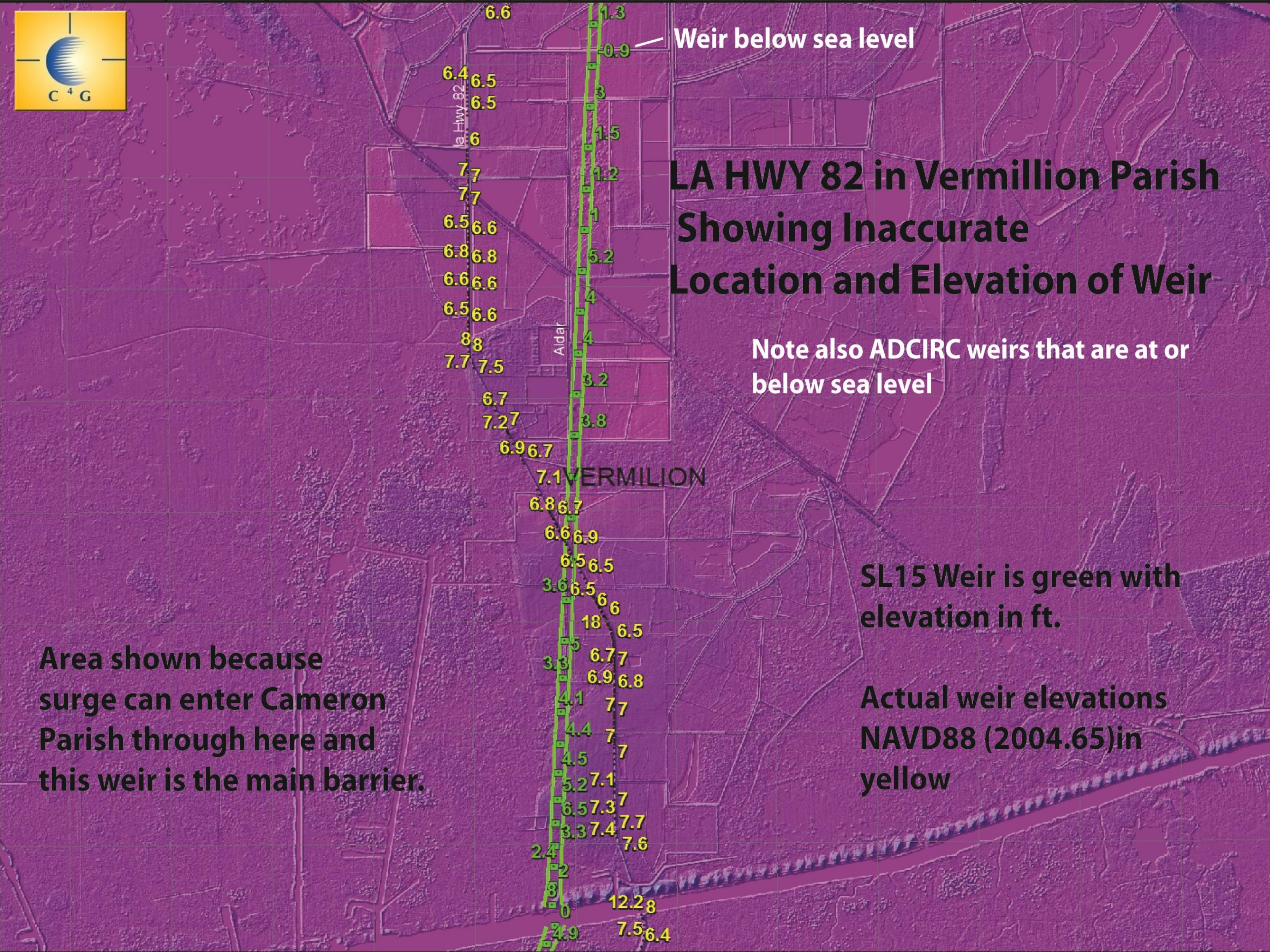
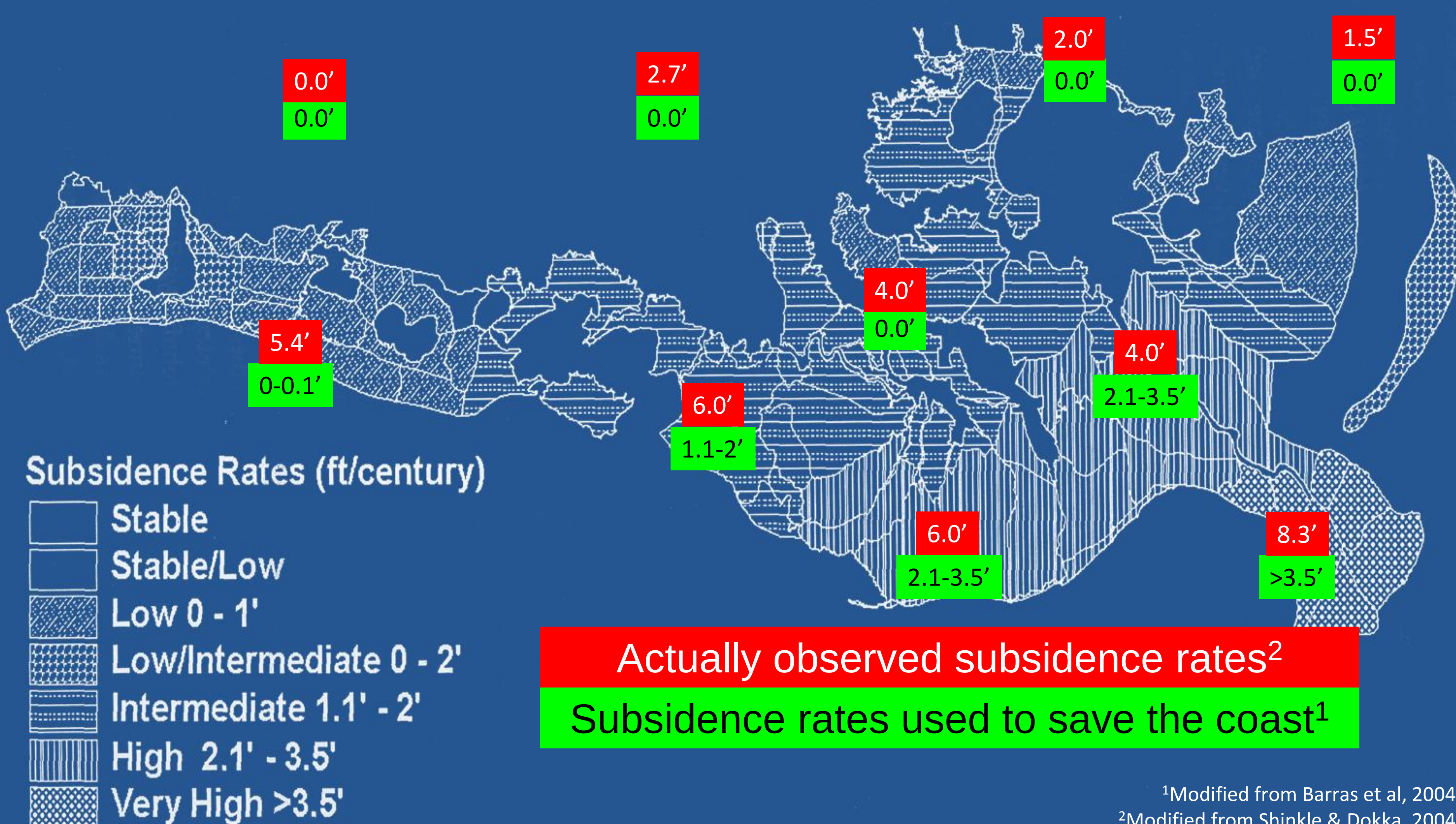




LA HWY 82 in Vermillion Parish
Showing Inaccurate
Location and Elevation of Weir
Weir below sea level
Note also ADCIRC weirs that are at or below sea level
SL15 Weir is green with elevation in ft.
Actual weir elevations NAVD88 (2004.65)in yellow
Area shown because surge can enter Cameron Parish through here and this weir is the main barrier.
VERMILION
La Hwy 82
Aldar
C 4 G

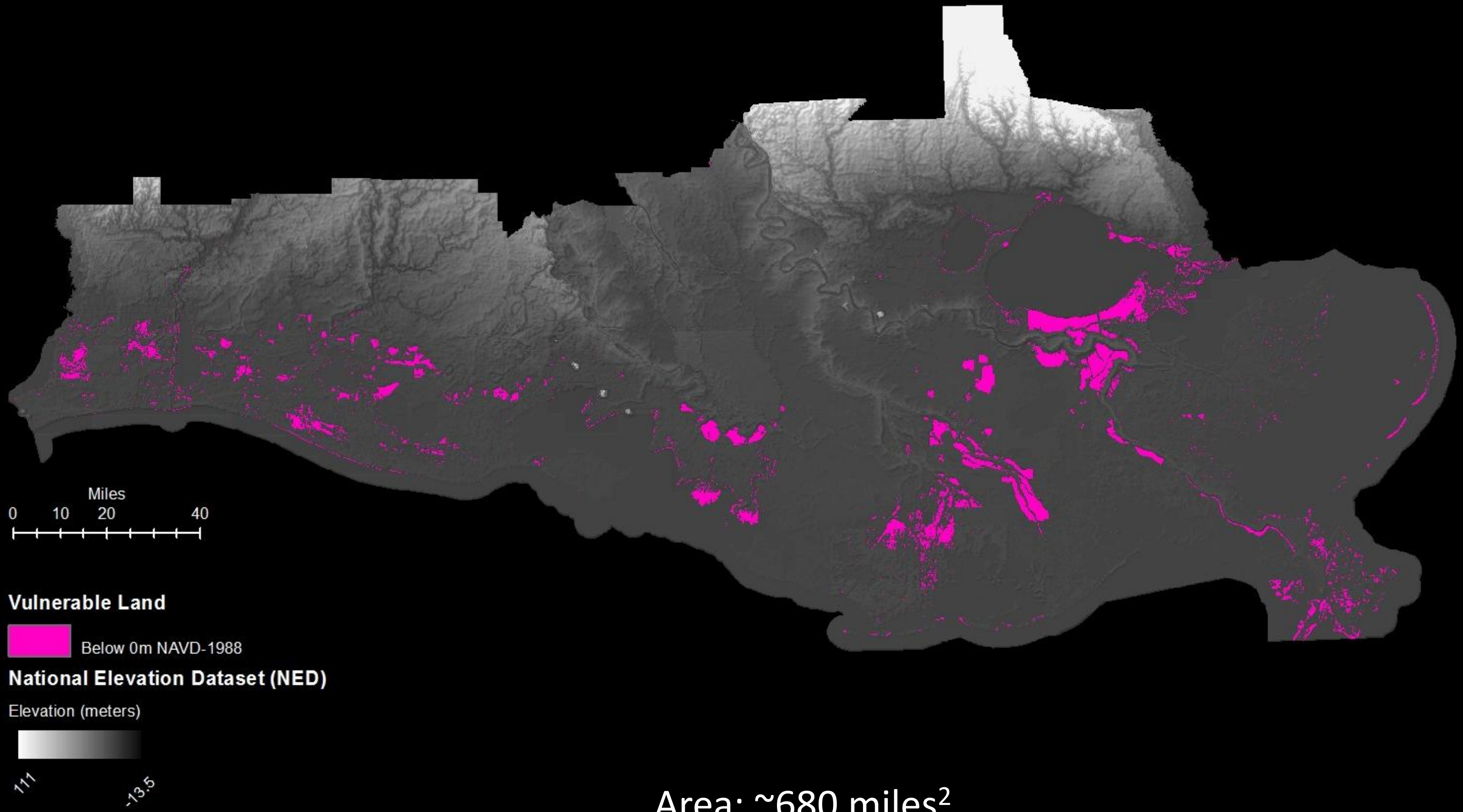
Existing efforts to mitigate erosion and restore Louisiana's coast does not explain the observed rates of subsidence!



[1]Modified from Barras et al, 2004
[2]Modified from Shinkle & Dokka, 2004

Land at or Below 'Sea Level'

~10m USGS Composite DEM: 2002 - 2008



Area: ~680 miles^2

Land at or Below 'Sea Level'

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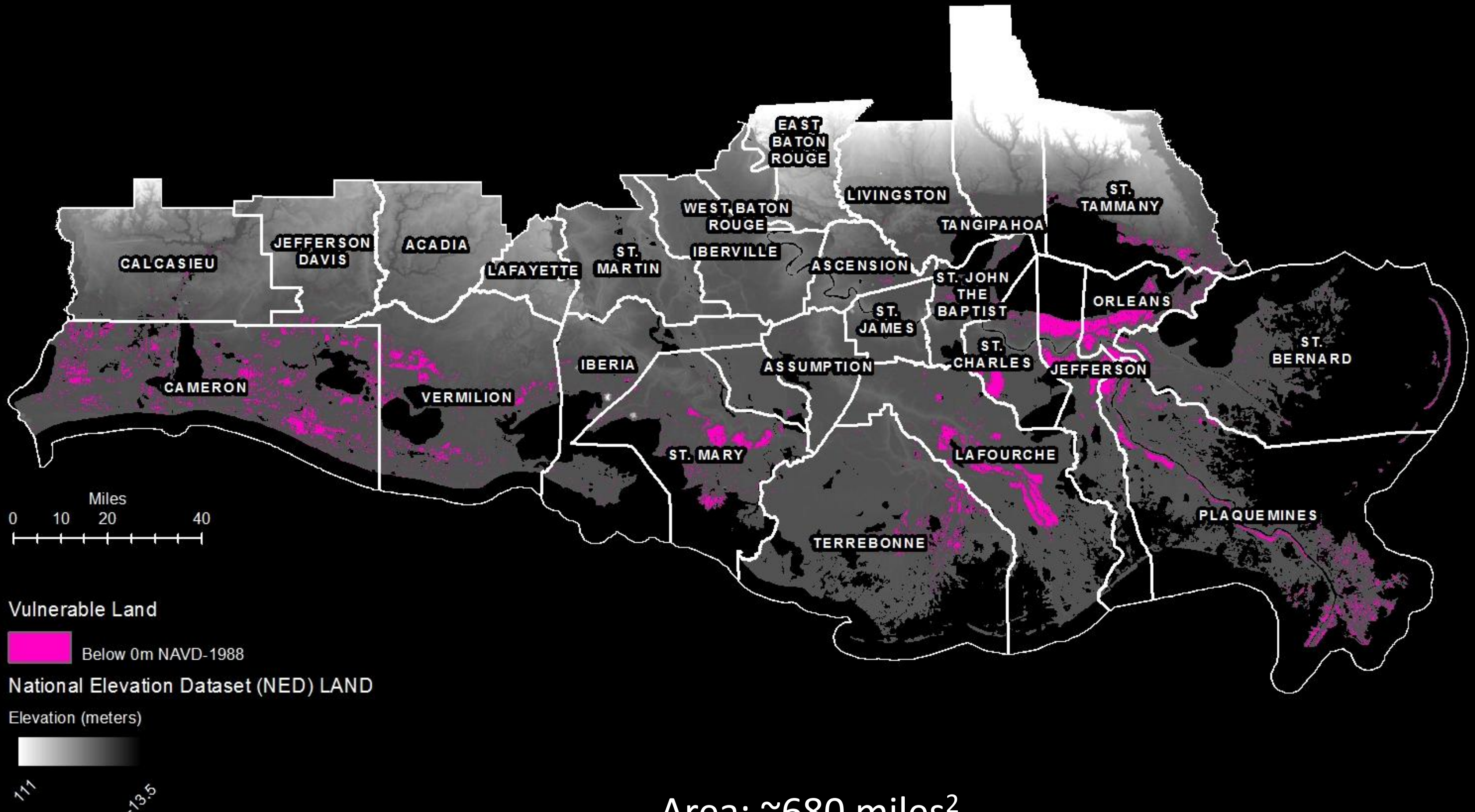

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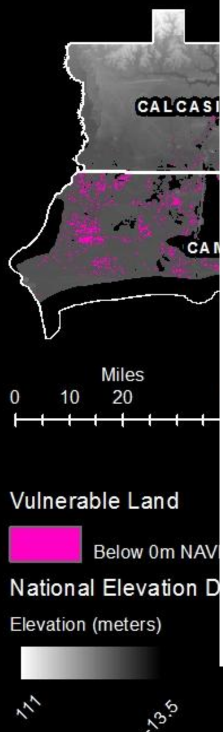
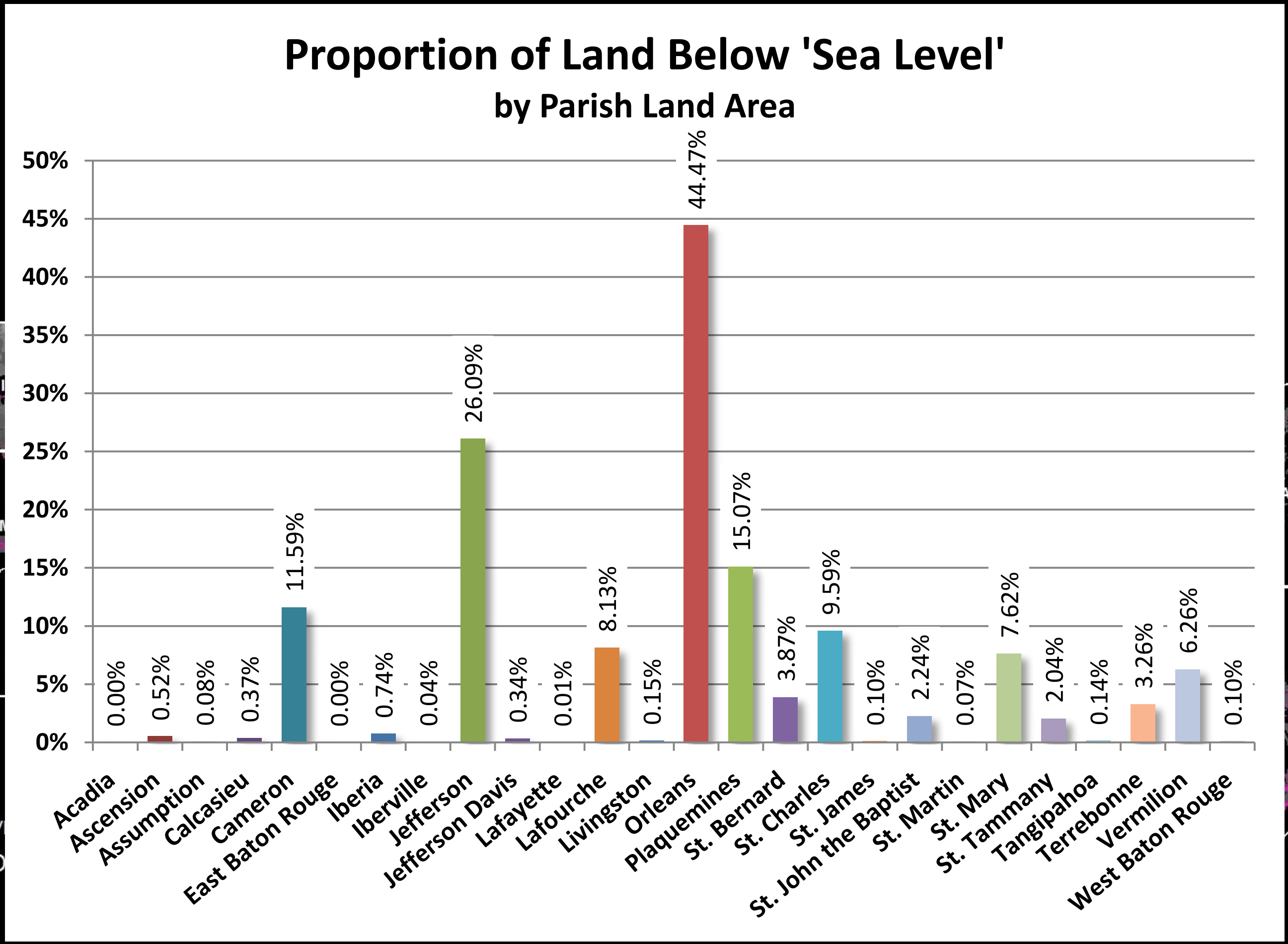


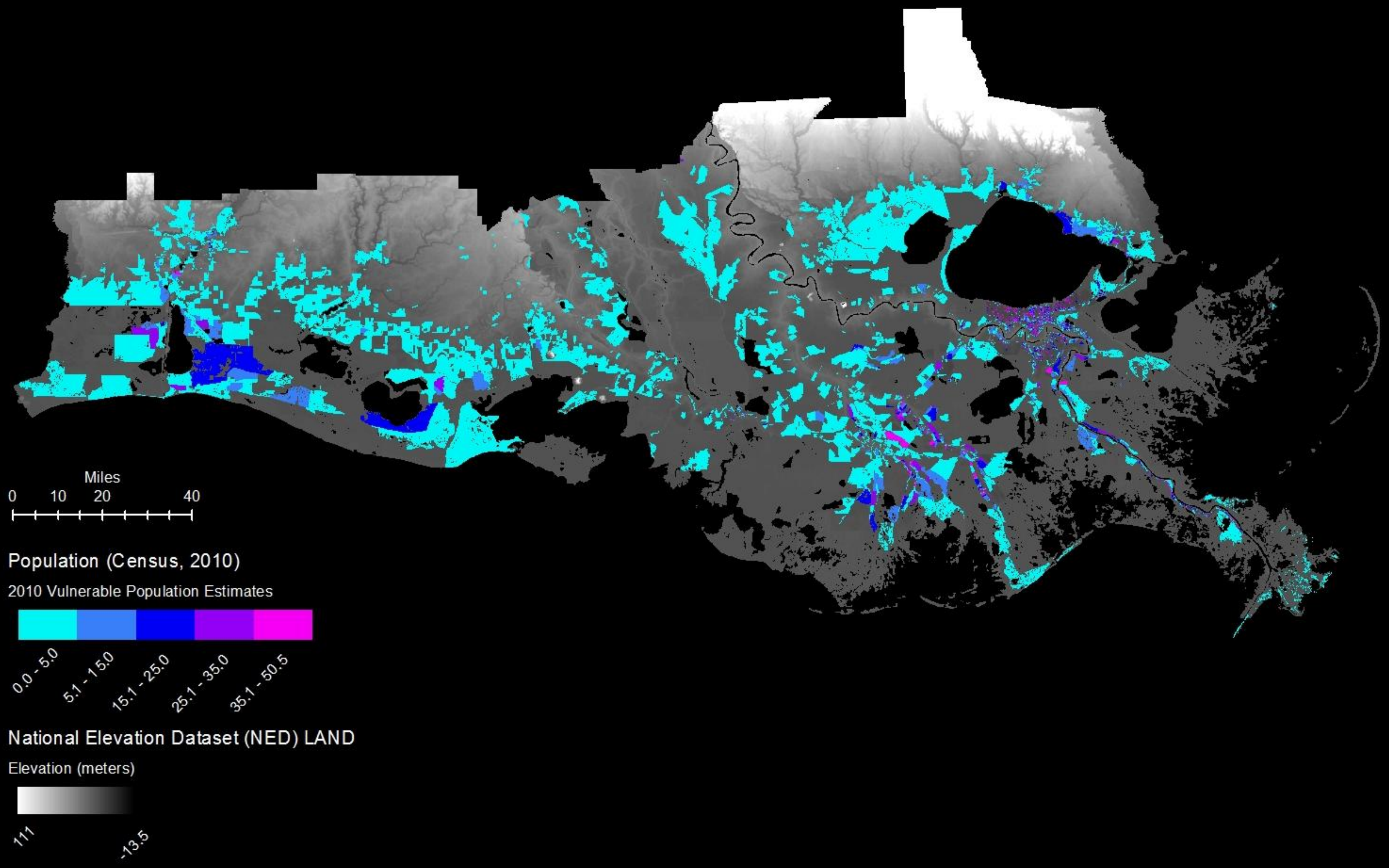


Area: ~680 miles^2

(4.5%)

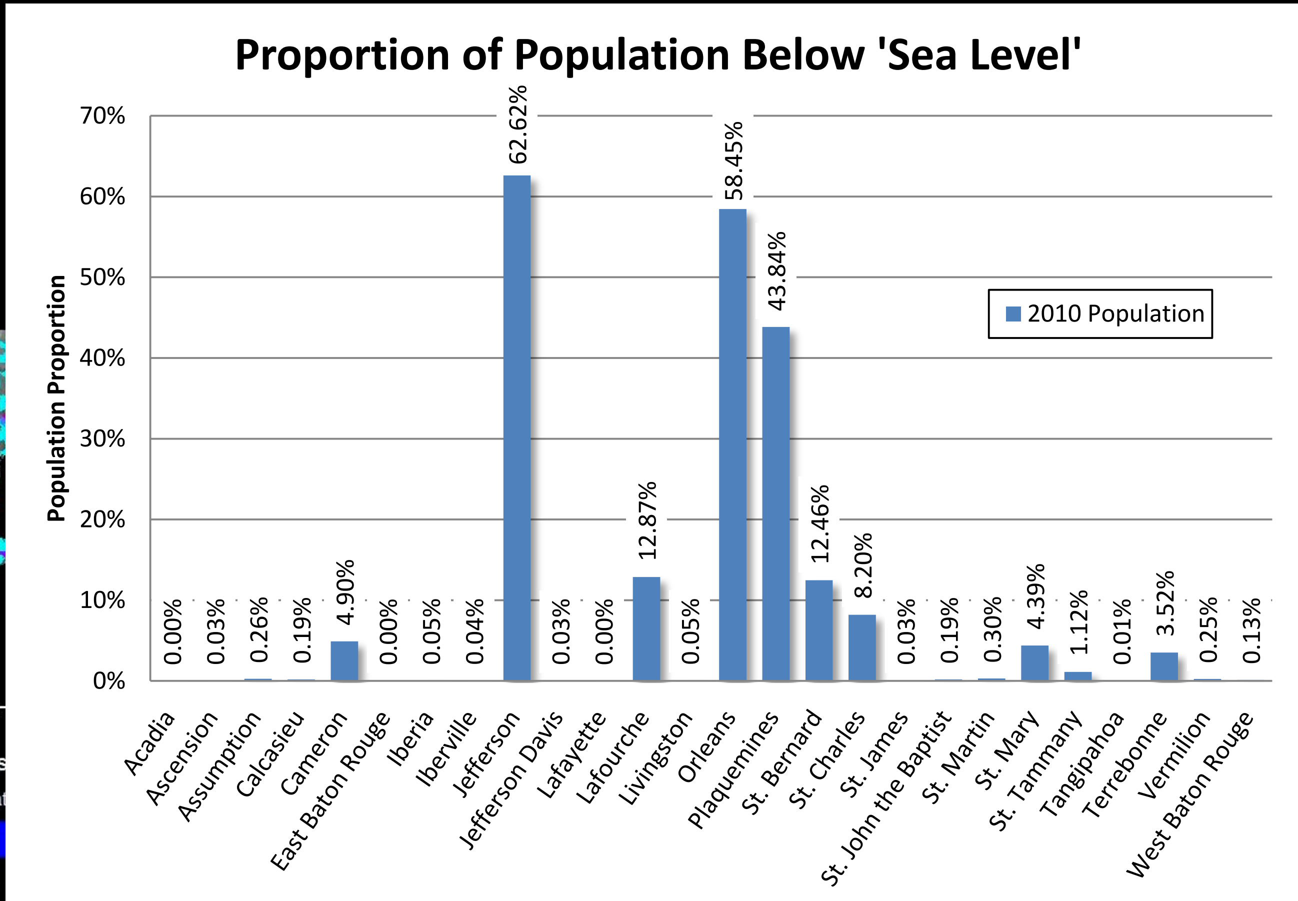
Populations at or Below ‘Sea Level’

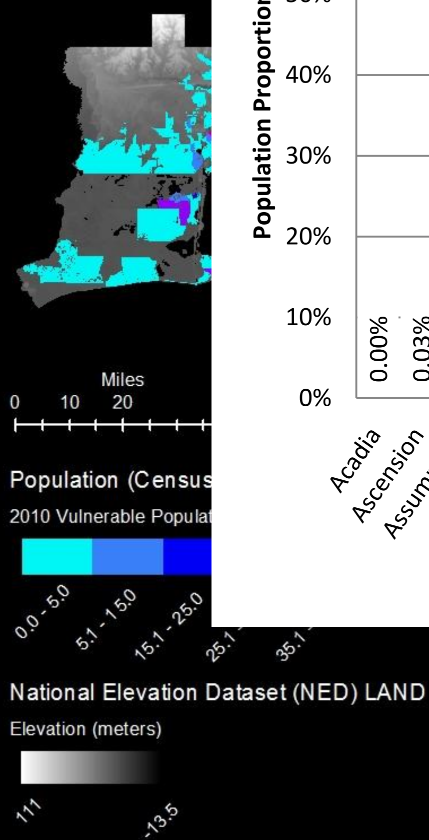
2010 Census Demographics: Households ≤ Sea Level



Populations at or Below ‘Sea Level’

2010 Census Demographics: Households ≤ Sea Level





2010 Population:

513,453 of 874,656 (58.7%)

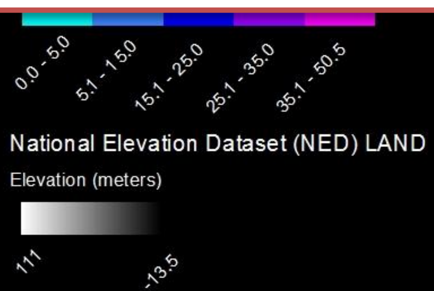
Live on Land Below ‘Sea Level’

Populations at or Below 'Sea Level'

2010 Census Demographics: Households ≤ Sea Level

Subsidence Increases Our Vulnerability To Disaster And Challenges How We Choose To Occupy The Landscape

Communities inhabiting the landscape are at constant risk of flooding in inundation.



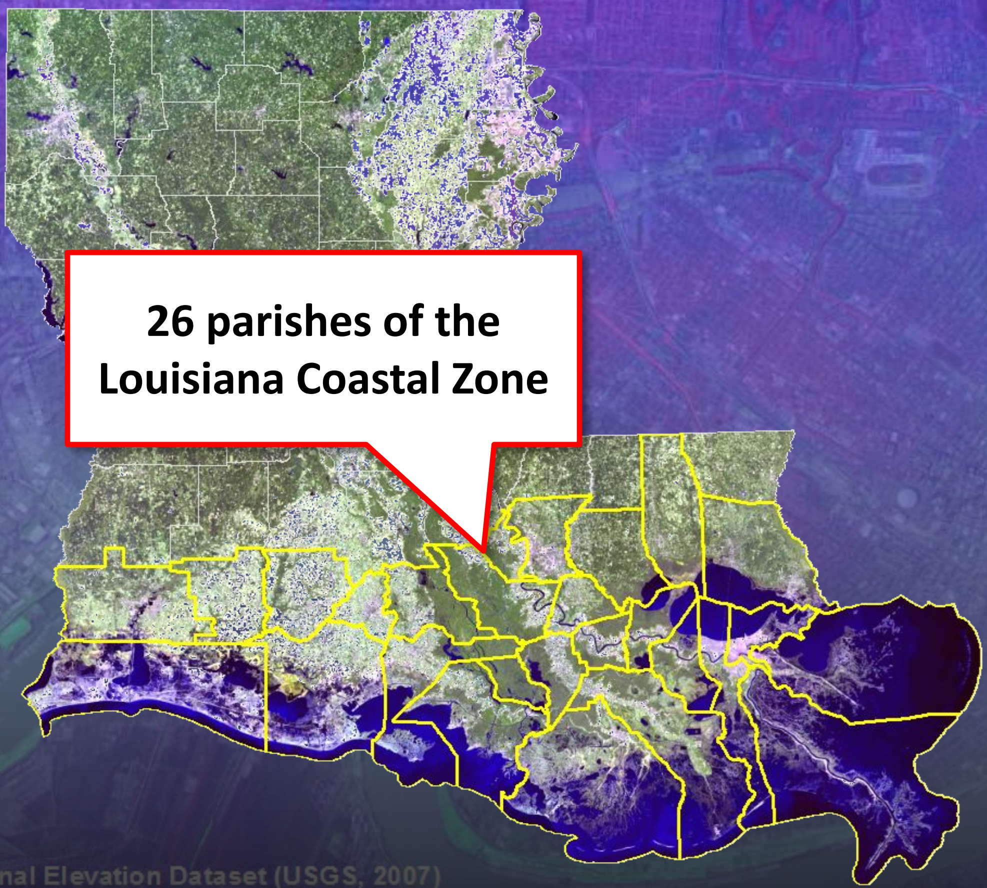
2010 Population:
513,453 of 874,656 (58.7%)
Live on Land Below 'Sea Level'

Develop a Mitigation Strategy Against Long-Term Subsidence

Construct Subsidence Forecast Models For The Remaining Century To Identify Vulnerabilities To Flooding And Storm Surge…

National Elevation Dataset (USGS, 2007)
Elevation (meters)

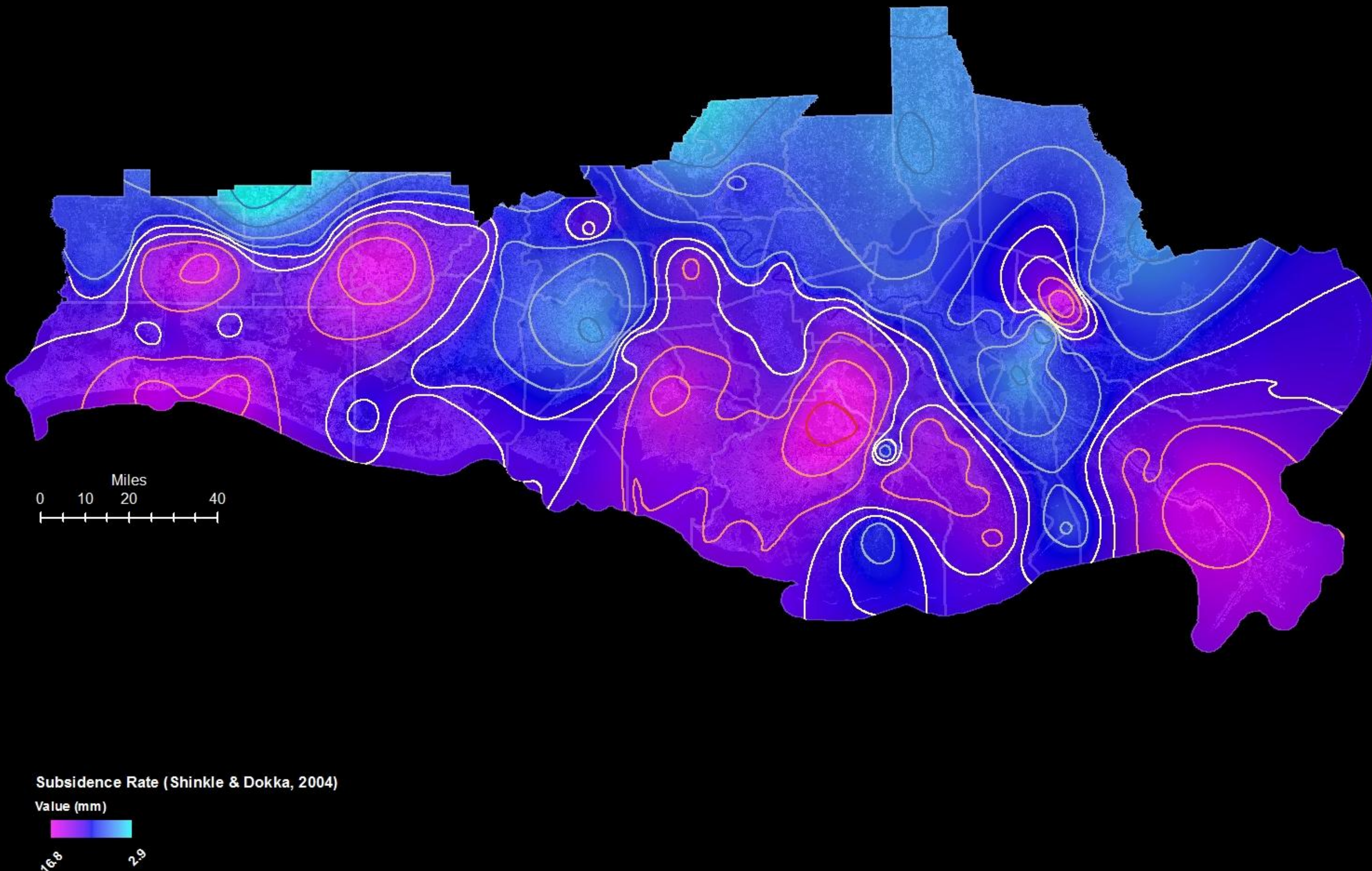
The Data:



National Elevation Dataset (USGS, 2007)
Elevation (meters)

- Published Subsidence Rates
- LDOTD Emergency Evacuation Routes

Subsidence Rate Data: Shinkle & Dokka (2004) Leveling Benchmarks



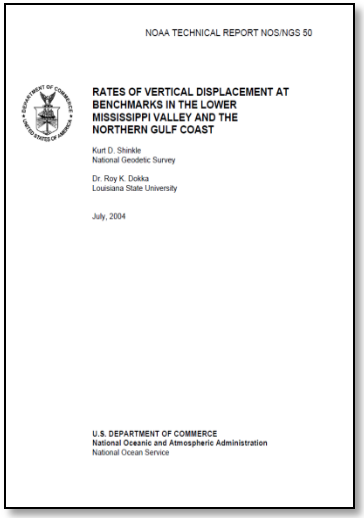
Subsidence Rate Data: Shinkle & Dokka (2004) Leveling Benchmarks

Shinkle & Dokka Subsidence Rates:

- Empirically Derived Rates Measured From ***First-Order Geodetic Leveling*** Surveys Performed Between 1920 - 1995.

$$\mu = 9.4 mm\ yr^{-1},\ \ \sigma = 2.7\ mm$$

- Rasterized using Ordinary Kriging raster interpolation to present the rate over the coastal zone.


NOAA TECHNICAL REPORT NOS/NGS 50

RATES OF VERTICAL DISPLACEMENT AT BENCHMARKS IN THE LOWER MISSISSIPPI VALLEY AND THE NORTHERN GULF COAST

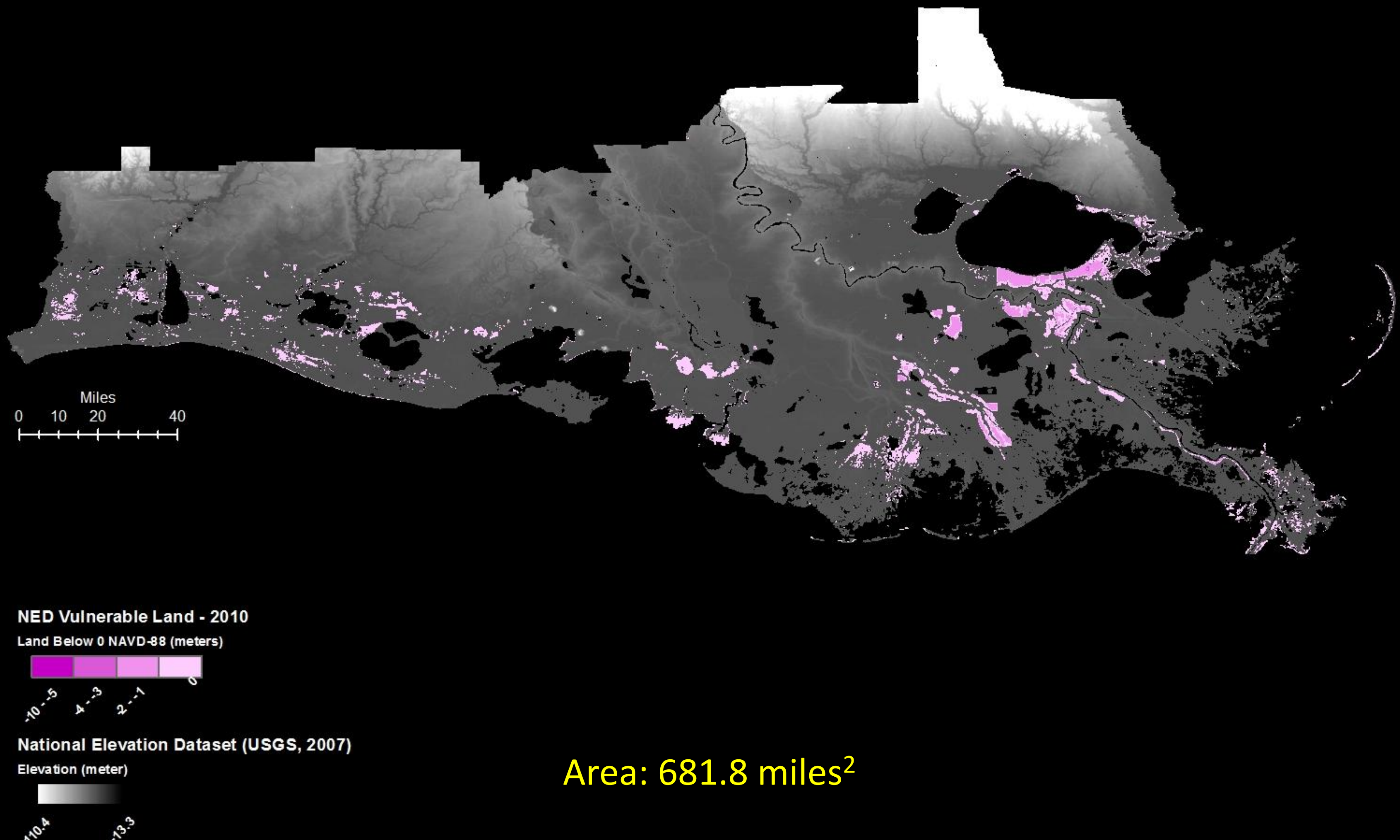
Kurt D. Shinkle
National Geodetic Survey

Dr. Roy K. Dokka
Louisiana State University

July, 2004

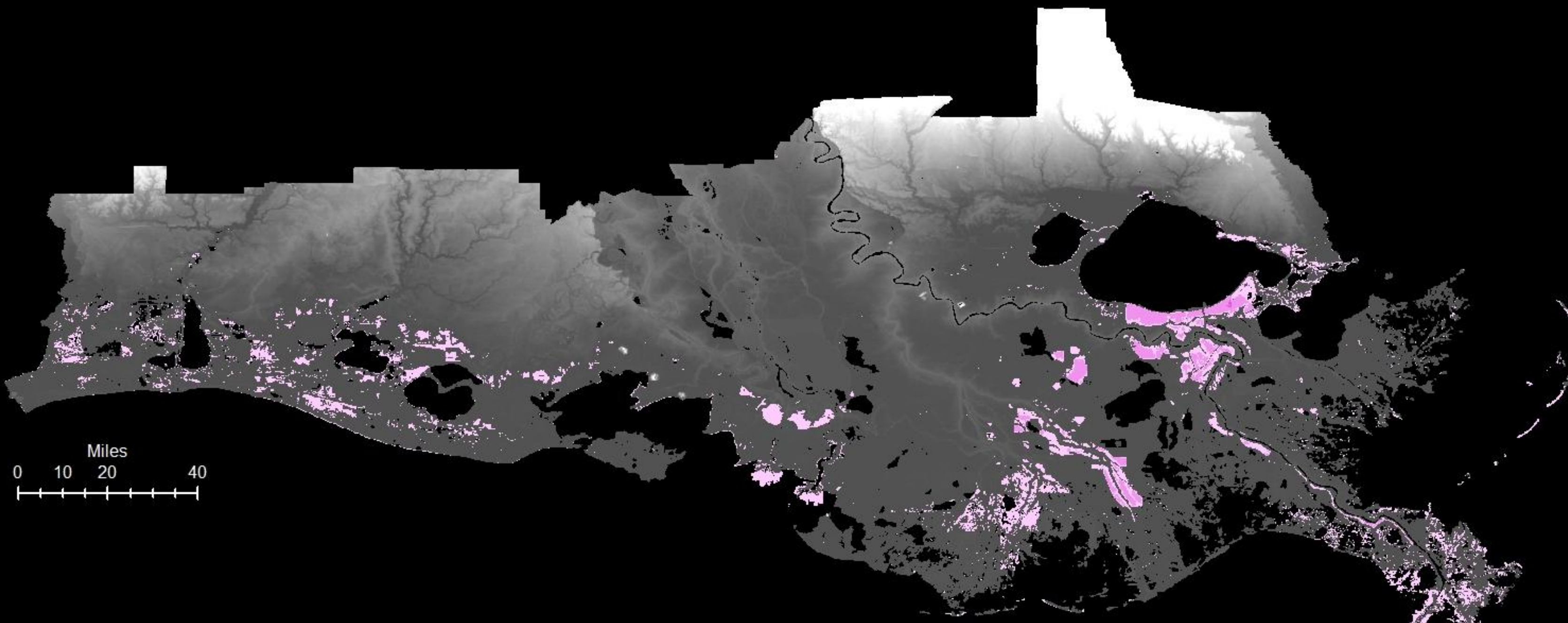
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

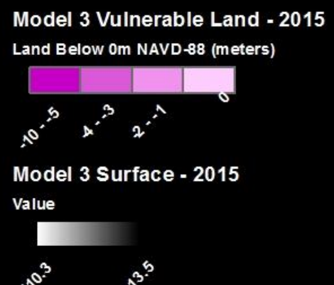
Existing Condition: 2010



Area: 681.8 $miles^2$

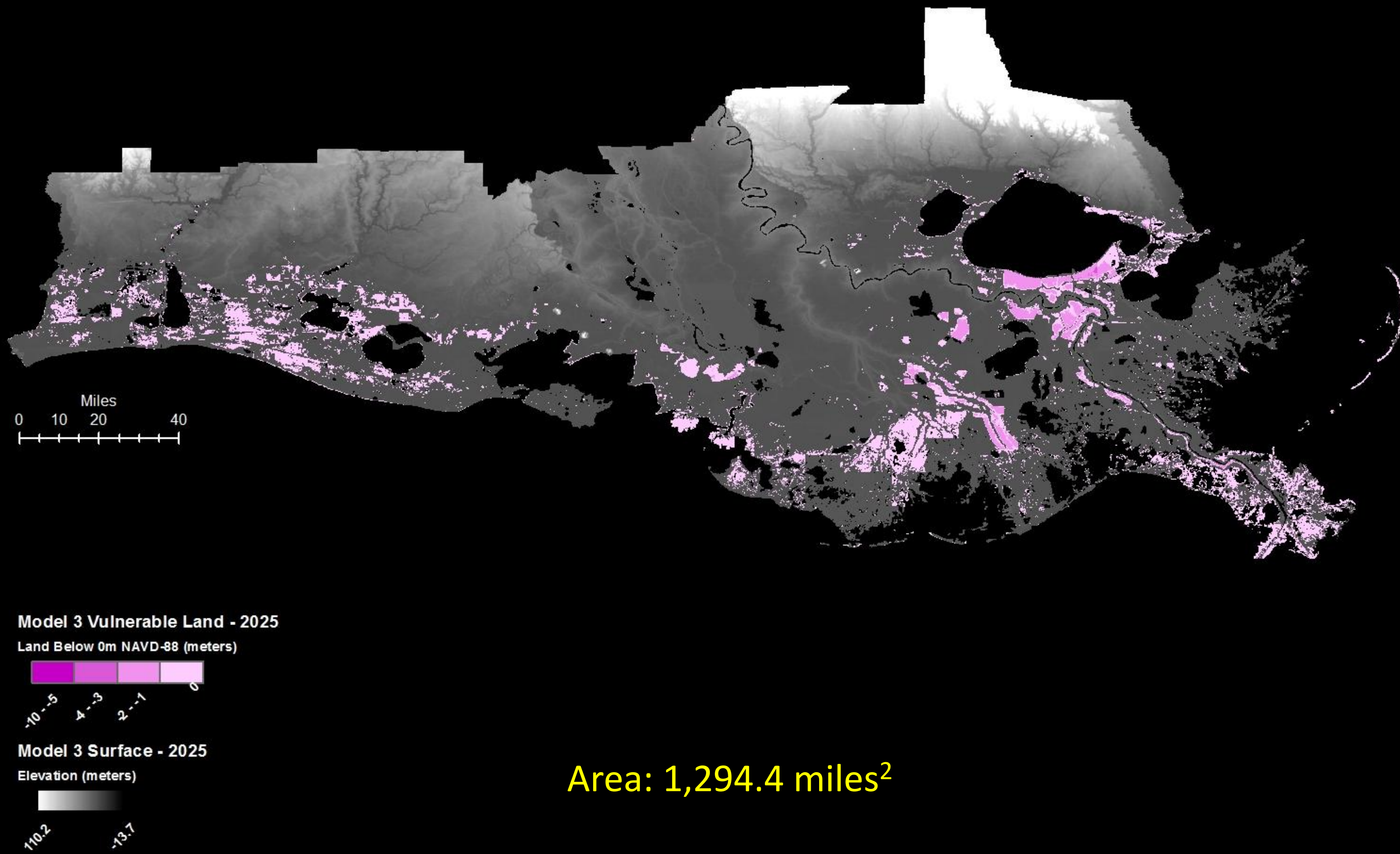
Model 3 Results: 2015





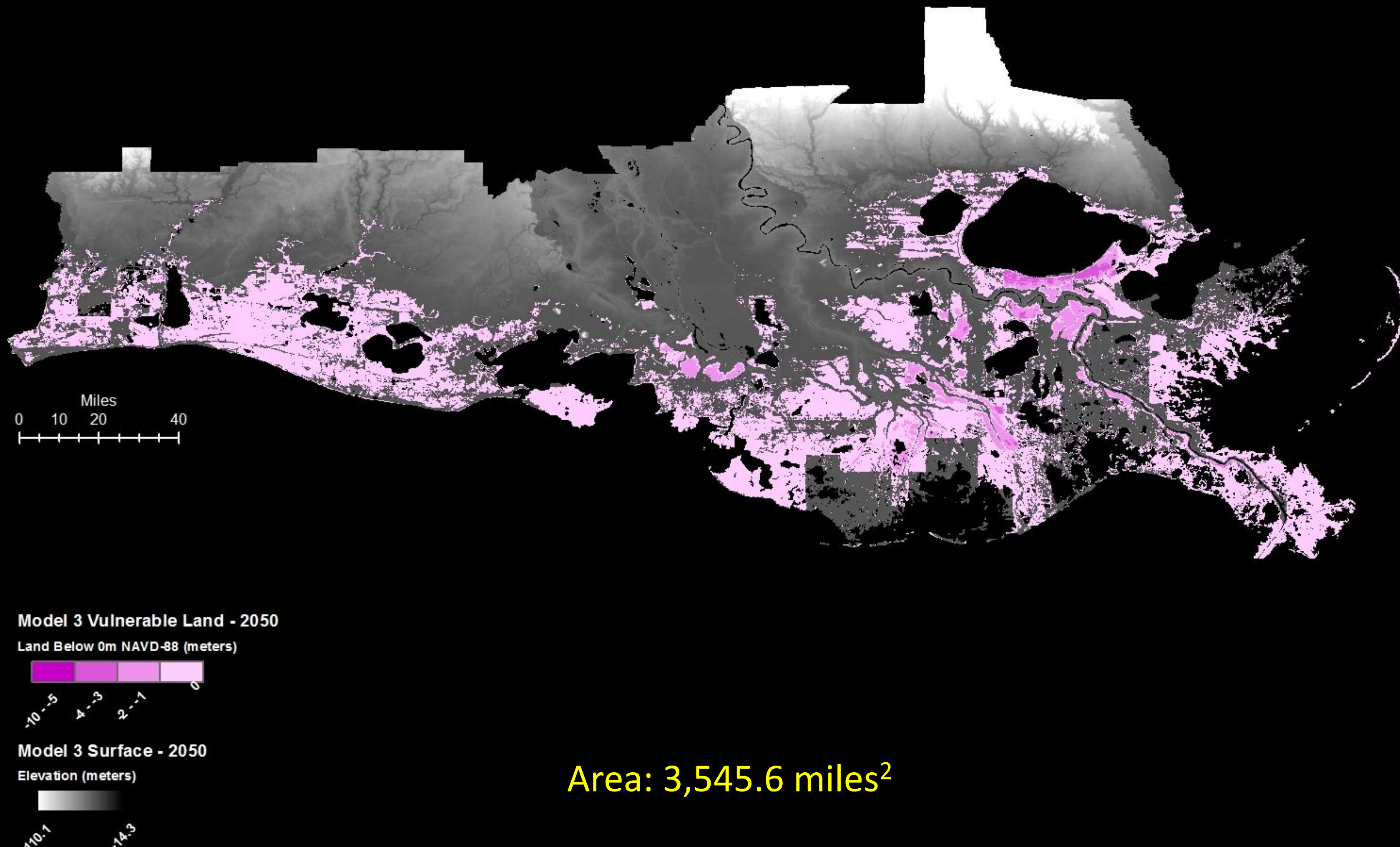
Area: 891.6 $miles^2$

Model 3 Results: 2025



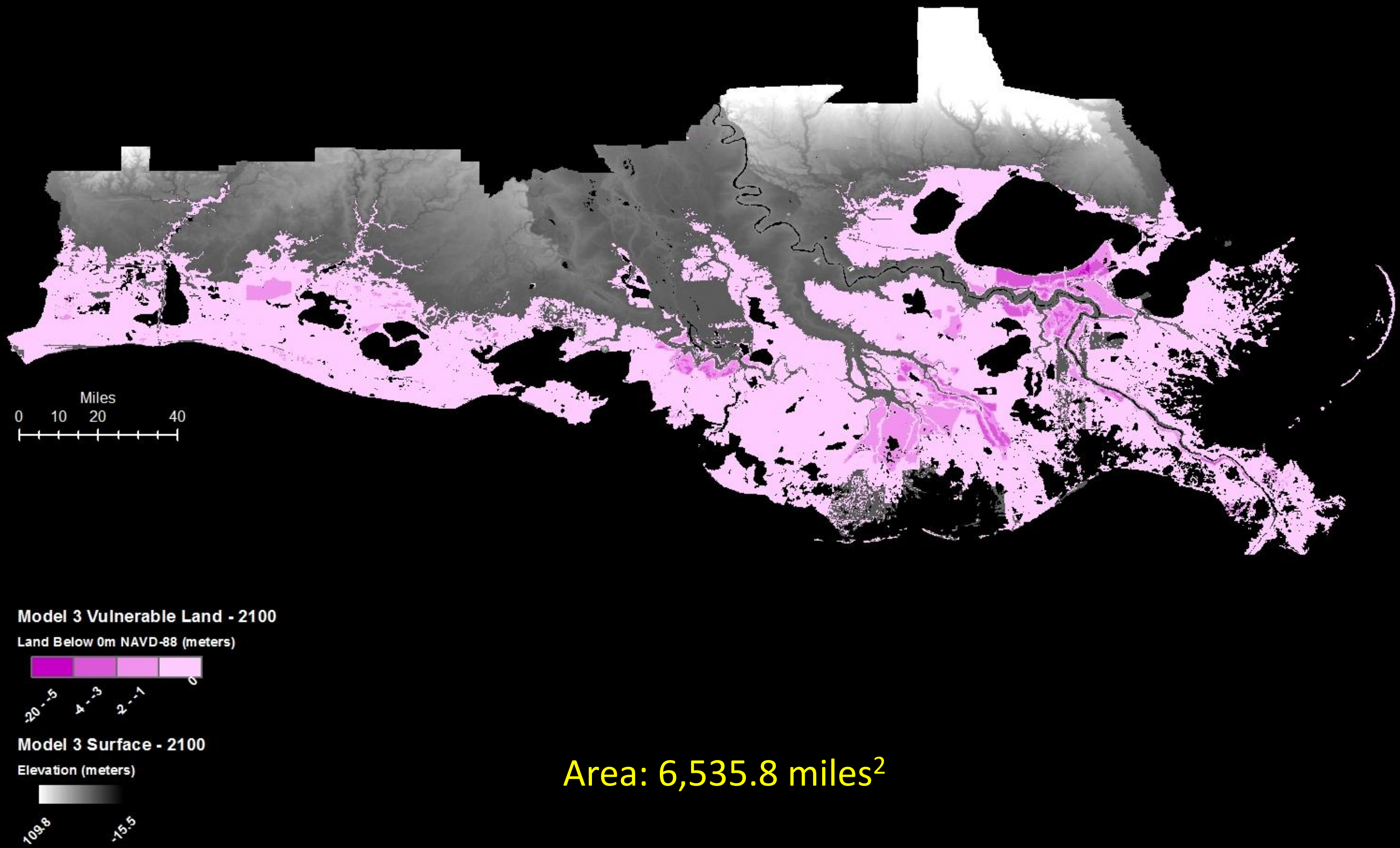
Area: 1,294.4 $miles^2$

Model 3 Results: 2050



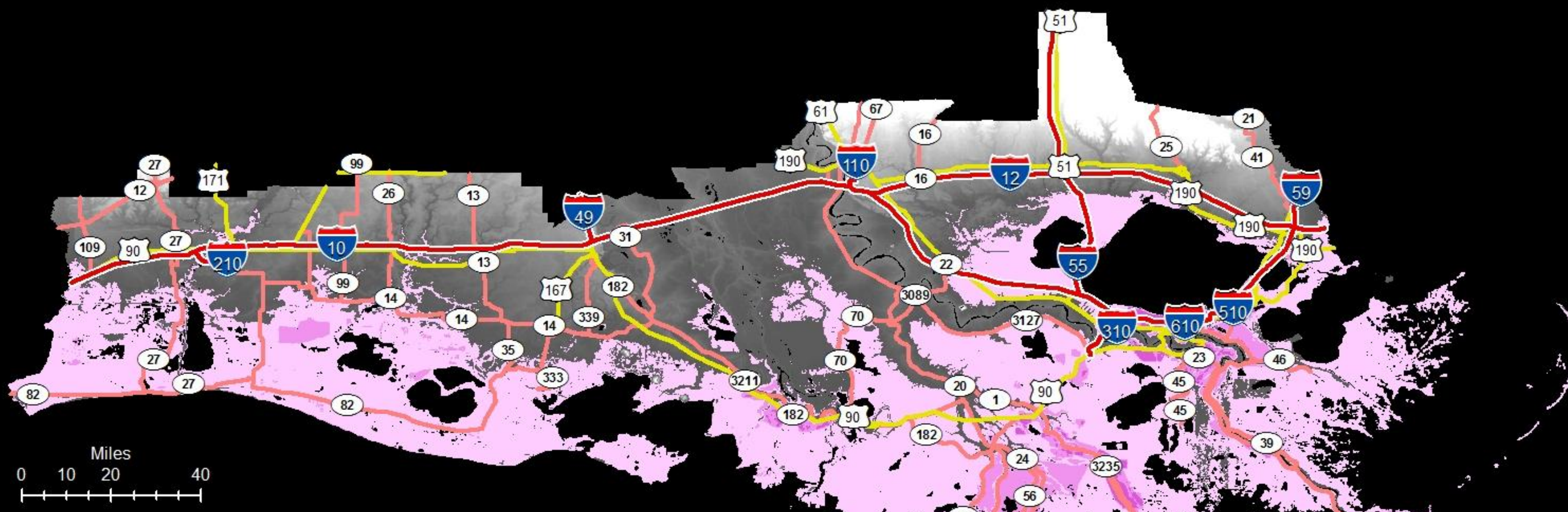
Area: 3,545.6 $miles^2$

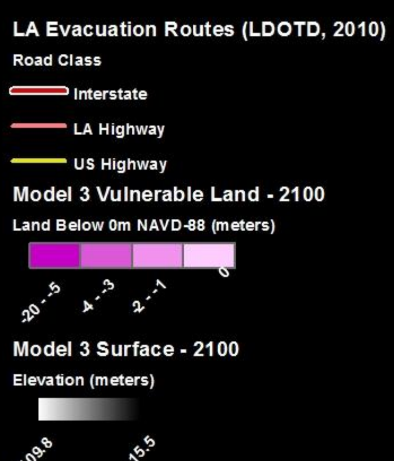
Model 3 Results: 2100



Area: 6,535.8 miles^2

Model 3 Results: 2100





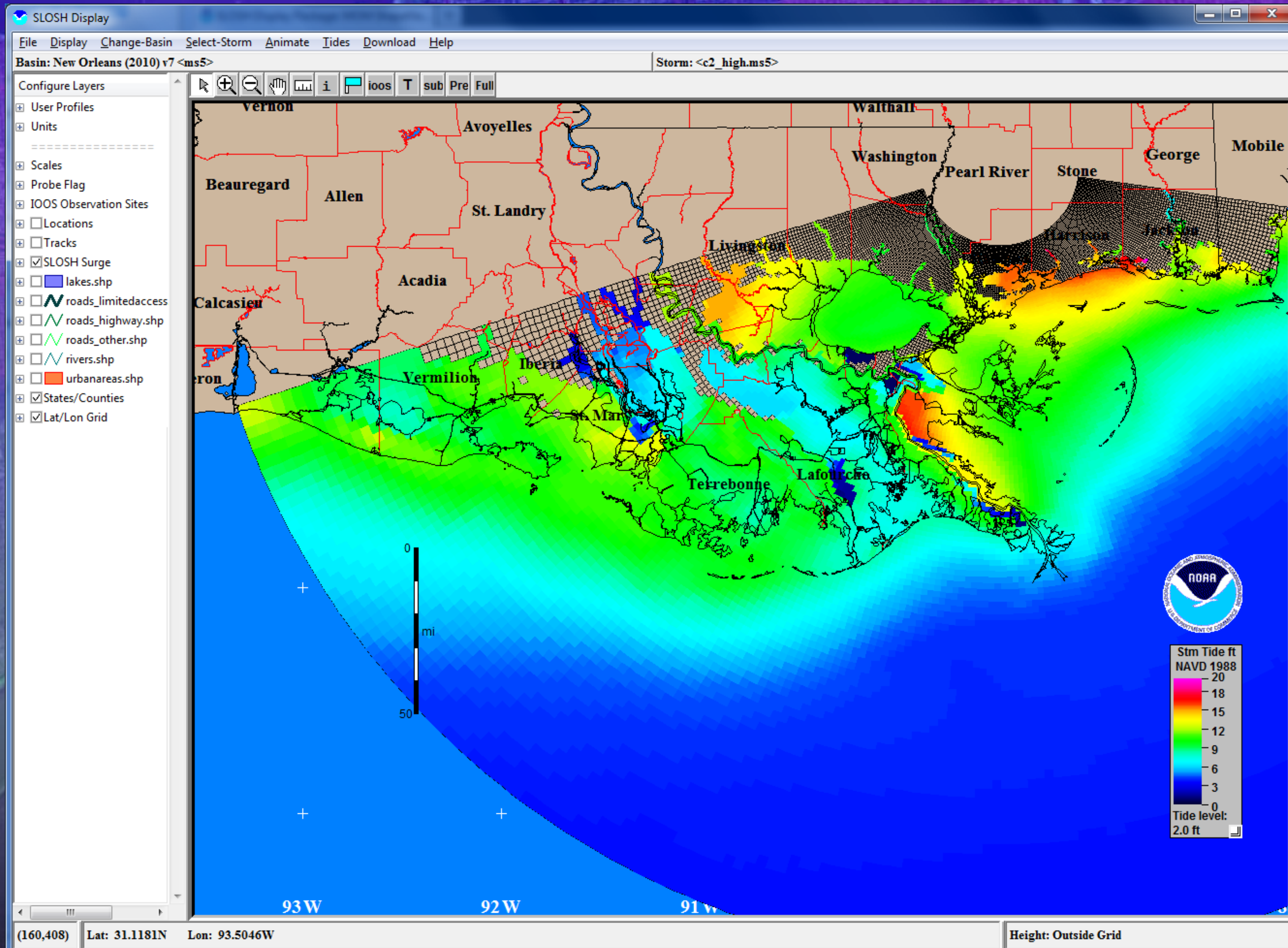
Area: 6,535.8 $miles^2$

Impact on Storm Surge Inundation

Subtract Subsidence Adjusted Digital Elevation Models From Rasterized SLOSH Models:

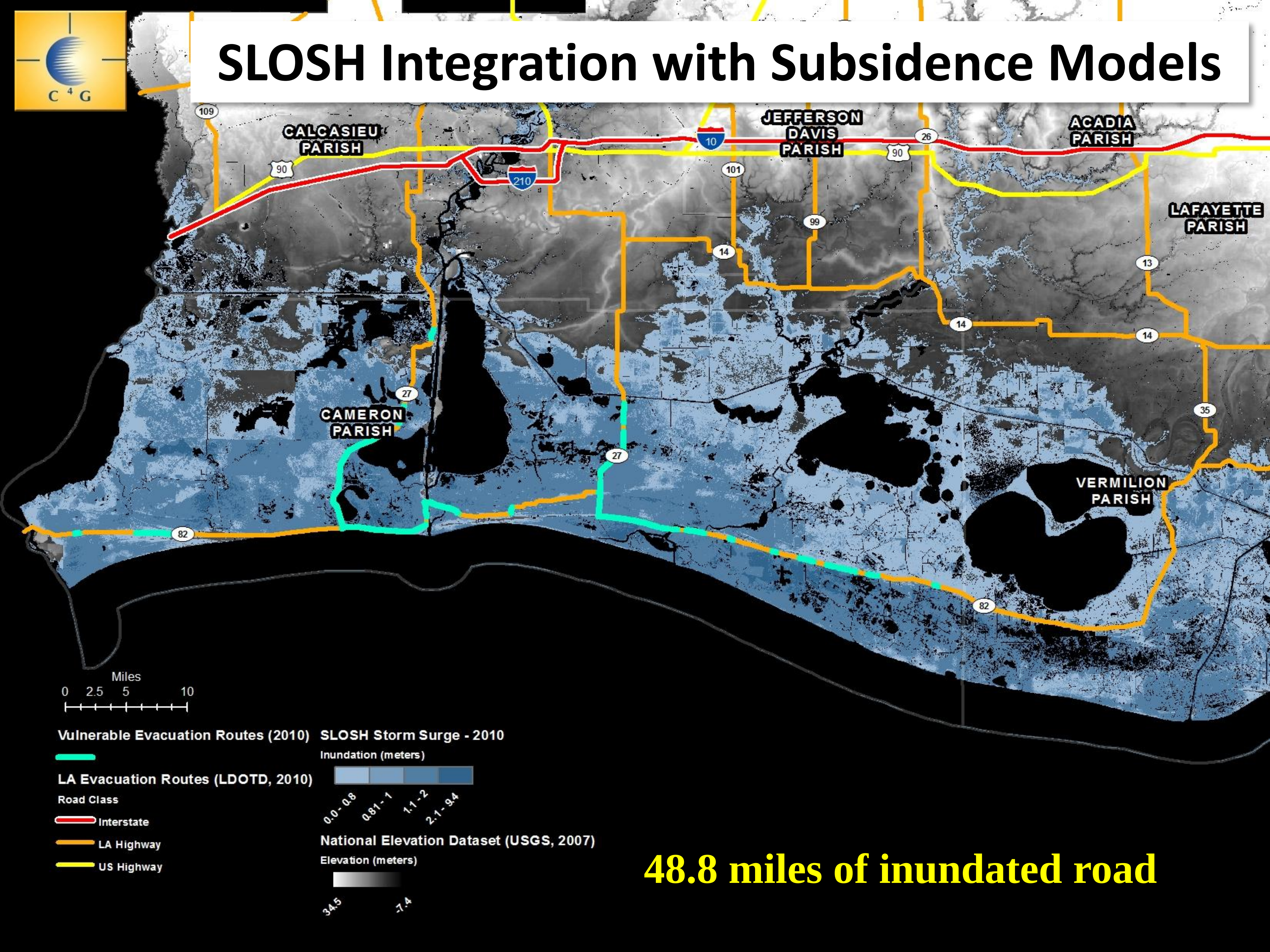
- New Orleans and Sabine Lake Basin (NAVD-1988)
- Limited to Hurricane Categories 1 – 5
- High-tide, Maximum of Maximum Envelope of Water (MOM) – the worse case scenario…

National Elevation Dataset (USGS, 2007)
Elevation (meters)



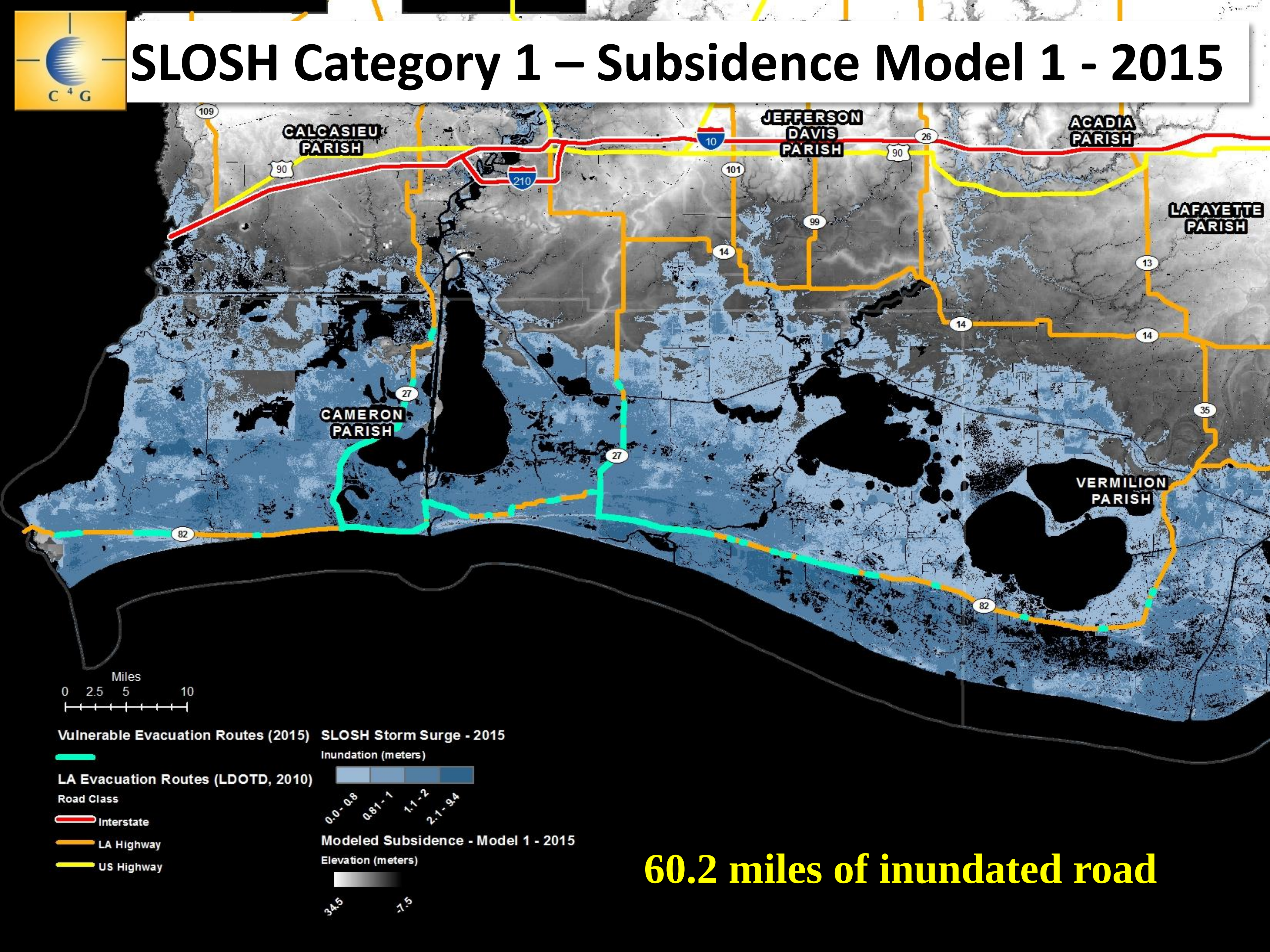
Elevation (meters)

SLOSH Integration with Subsidence Models



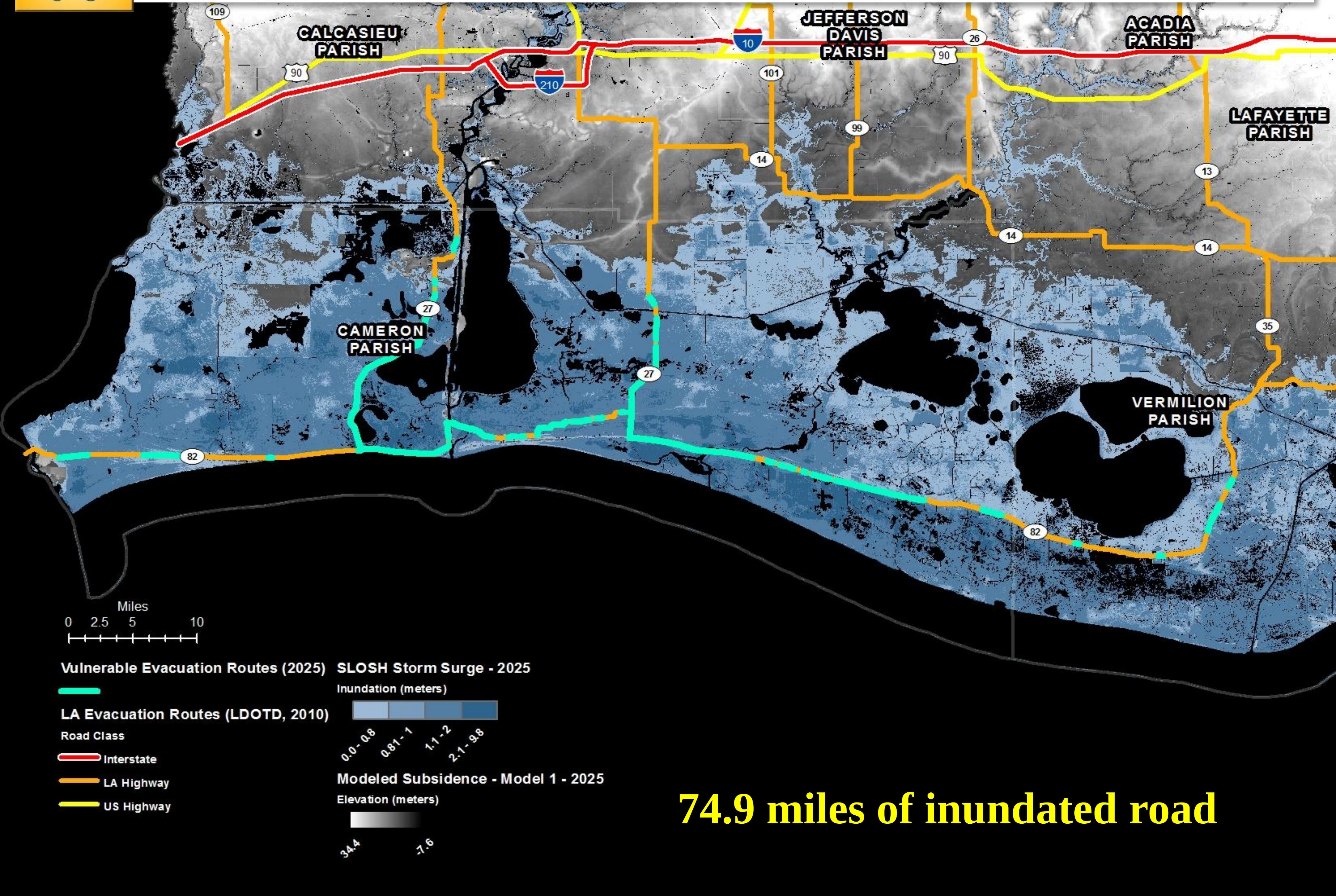
48.8 miles of inundated road

SLOSH Category 1 – Subsidence Model 1 - 2015



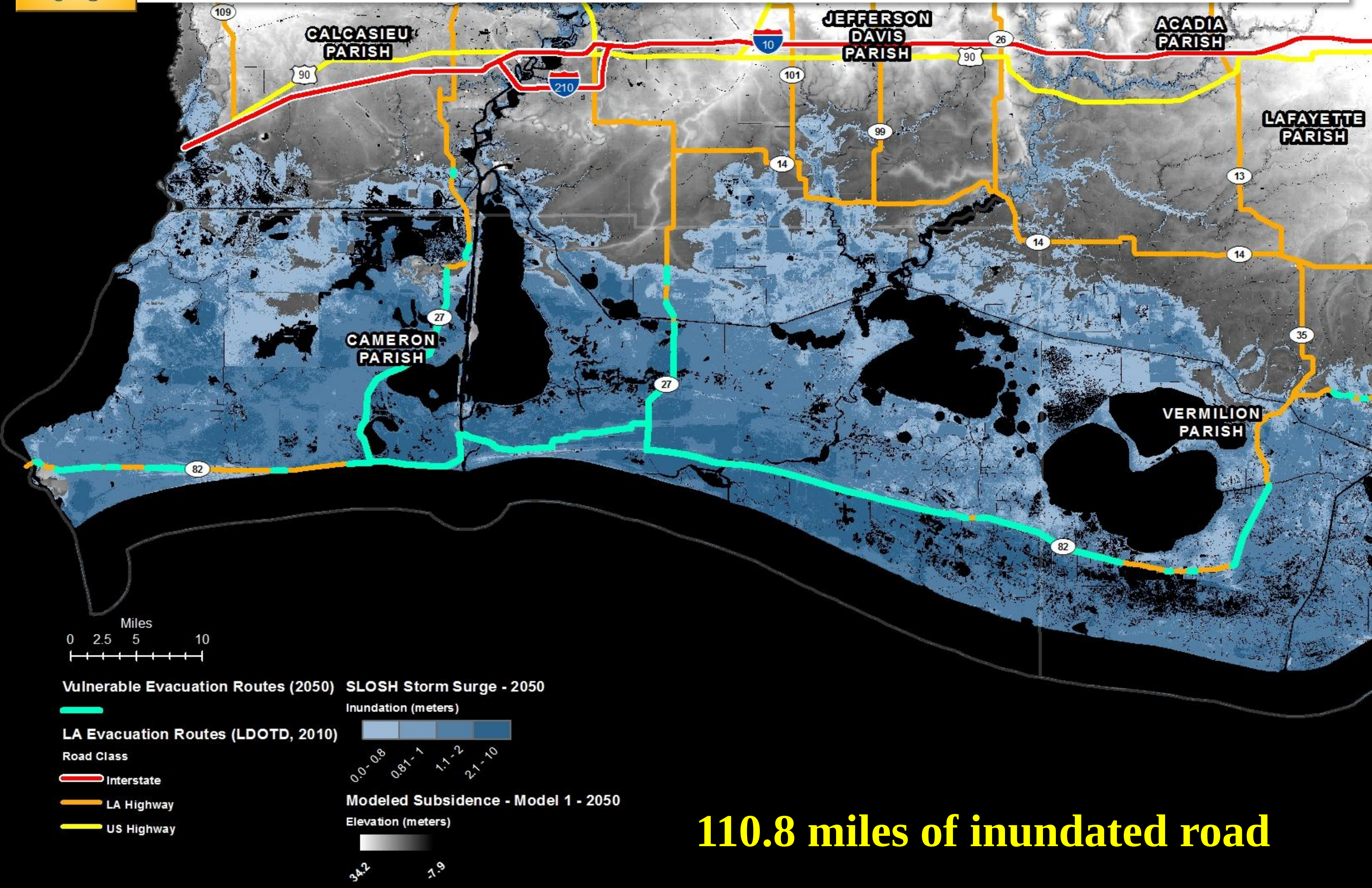
60.2 miles of inundated road

SLOSH Category 1 – Subsidence Model 1 - 2025



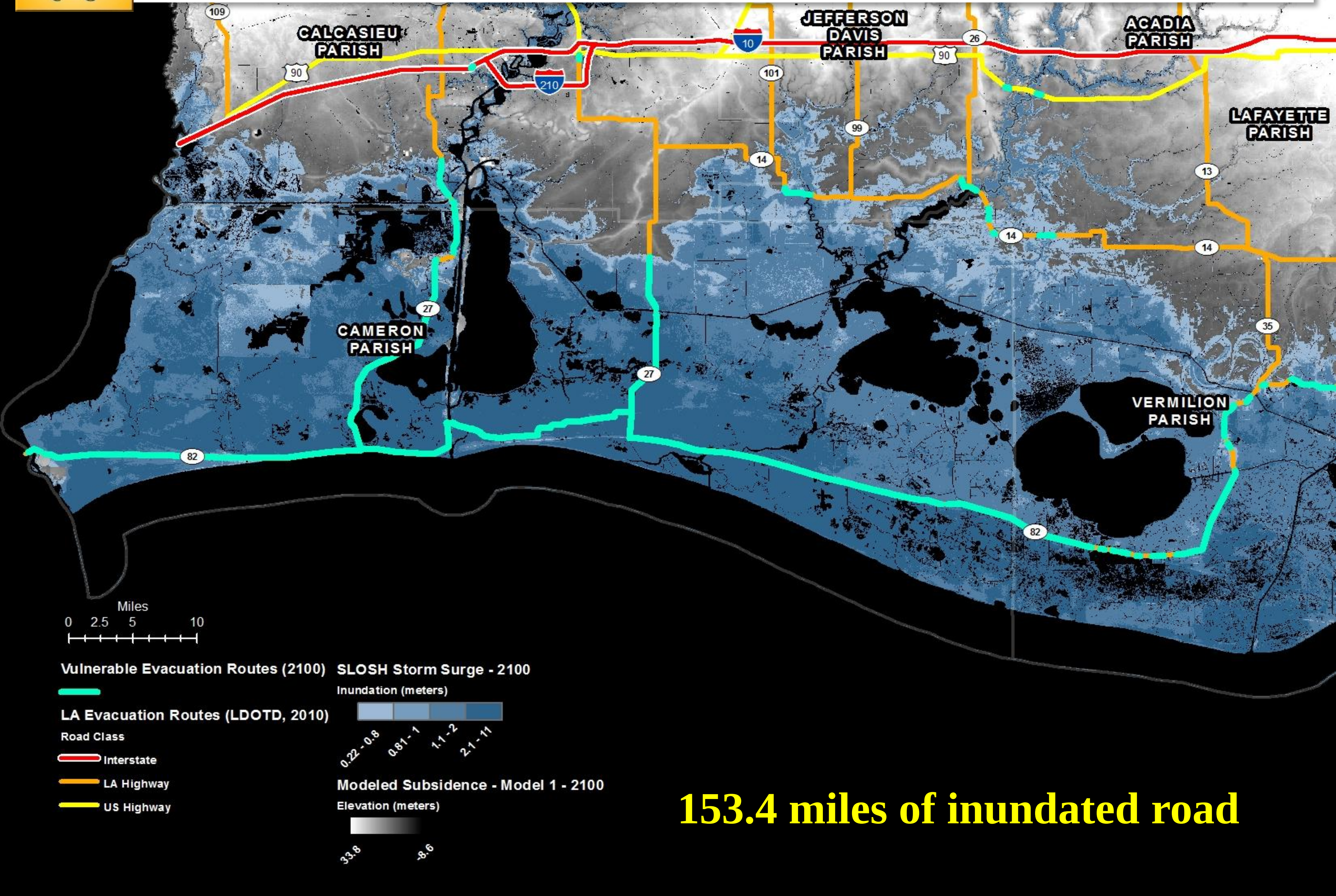
74.9 miles of inundated road

SLOSH Category 1 – Subsidence Model 1 - 2050



110.8 miles of inundated road

SLOSH Category 1 – Subsidence Model 1 – 2100



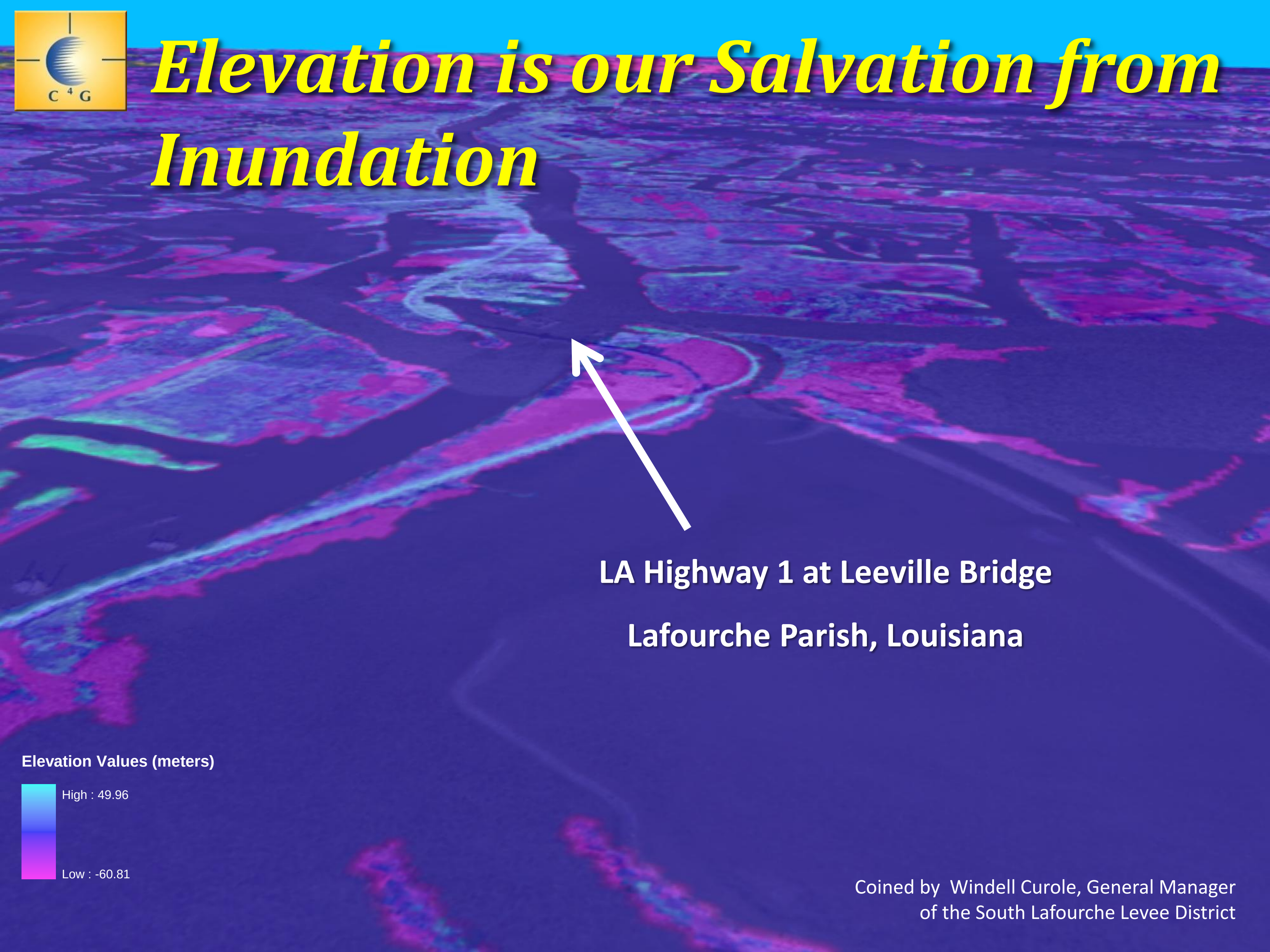
153.4 miles of inundated road

Conclusions

- Subsidence has and continues to be the dominant challenge to maintaining horizontal and vertical control along the Gulf Coast.
- Anthropogenic causes like (shallow) forced drainage and (deep) groundwater pumping dominate subsidence.
- The loss of elevation is making the coast more vulnerable to storms.

National Elevation Dataset (USGS, 2007)
Elevation (meters)

Elevation is our Salvation from Inundation



Coined by Windell Curole, General Manager of the South Lafourche Levee District

Thank You…

Questions?

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Louisiana State University
Baton Rouge, LA 70803
jkent4@lsu.edu
www.c4g.lsu.edu

National Elevation Dataset (USGS, 2007)
Elevation (meters)
13.8
8.2