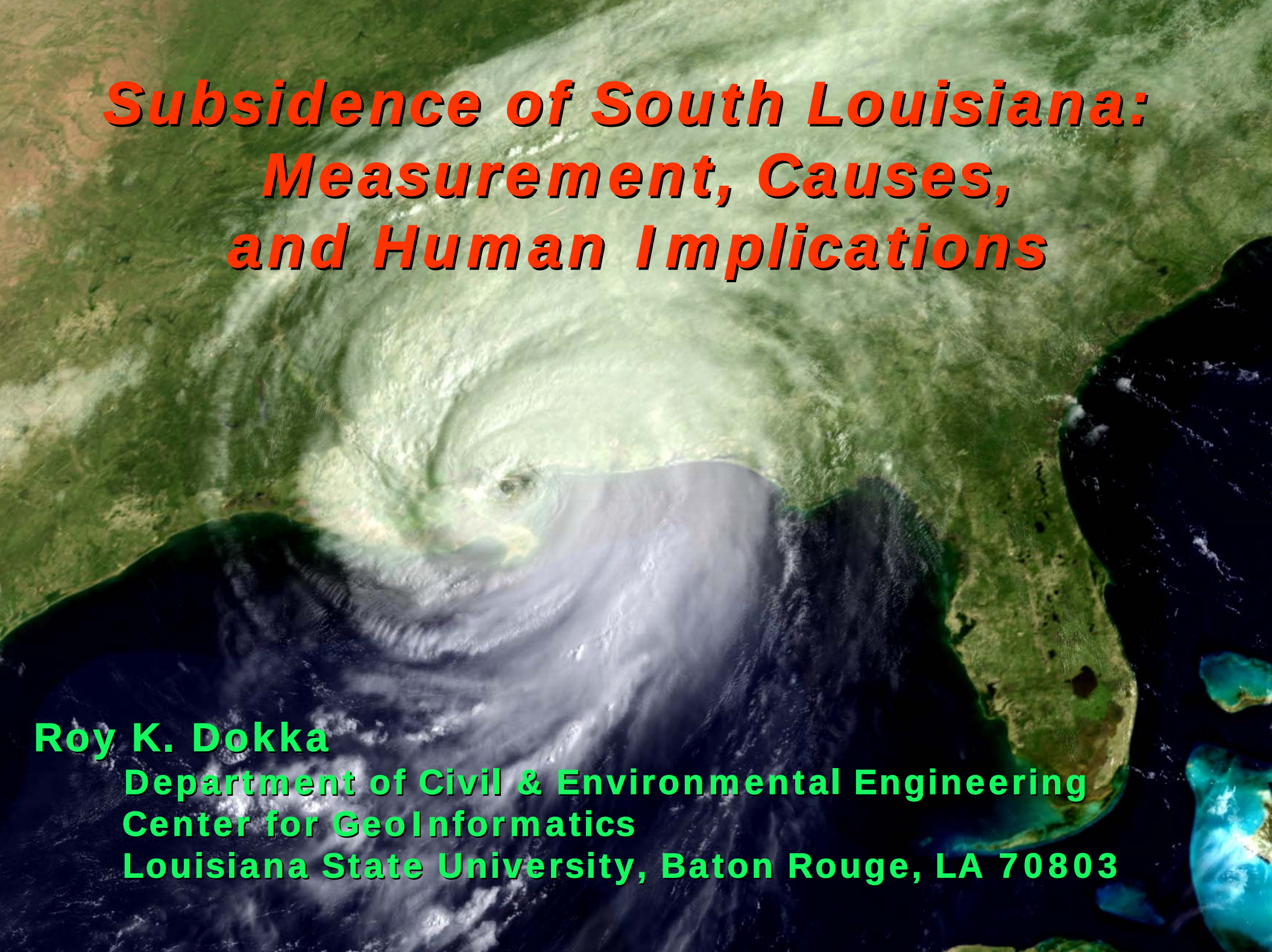


Subsidence of South Louisiana: Measurement, Causes, and Human Implications

Roy K. Dokka
Department of Civil & Environmental Engineering
Center for GeoInformatics
Louisiana State University, Baton Rouge, LA 70803

Themes in this Presentation

- Science is about measurement. How these measurements are conducted ultimately determines the quality of our understanding of Nature.

- Discussion of the scientific paradigm that explains the causes of America's greatest on-going environmental disaster, the inundation and loss of the Louisiana coast. This paradigm helps guide the research of a large multidisciplinary group of scientists. It is also the basis for the public policy was developed to "restore" the coast and to provide communities with protection against storm surge. ***It is also wrong.***

- Explain how a crisis regarding severely moving benchmarks used by surveyors, floodplain managers, and levee engineers have led to a reevaluation of the state of modern landscape change in Louisiana. Understanding this change is critical to rebuilding south Louisiana following the hurricanes and for plans to stop coastal land loss.

- Discuss how the new data has challenged and invalidated essential geological features of the paradigm and how various communities have responded.

- When a scientific issue become public policy, further scientific inquiry suffers.

Measurement 101

To measure a quantity properly, three things are needed:

- **a measurement tool that will actually measure the property desired (reality).**
- **a measurement tool sensitive enough to resolve the quantity at the appropriate spatial and temporal level to answer the specific scientific question of interest (precision).**
- **access to a precise datum with which to reference measurements (accuracy). A datum is the definition of a reference frame (truth) whose topology was determined at a particular time.**

Misunderstandings regarding subsidence in Louisiana are rooted in a lack of under-standing of these measurement tenets.

The Paradigm states that the coast is going away because of processes that affect only the wetlands

Building river levees that starve the wetlands of sediment and fresh water

Subsidence due to:

- Compaction of recent sediments
- Oil & gas extraction
- Water pumping
- Drainage projects

Canal dredging speeds salt water intrusion which kills the freshwater marsh.

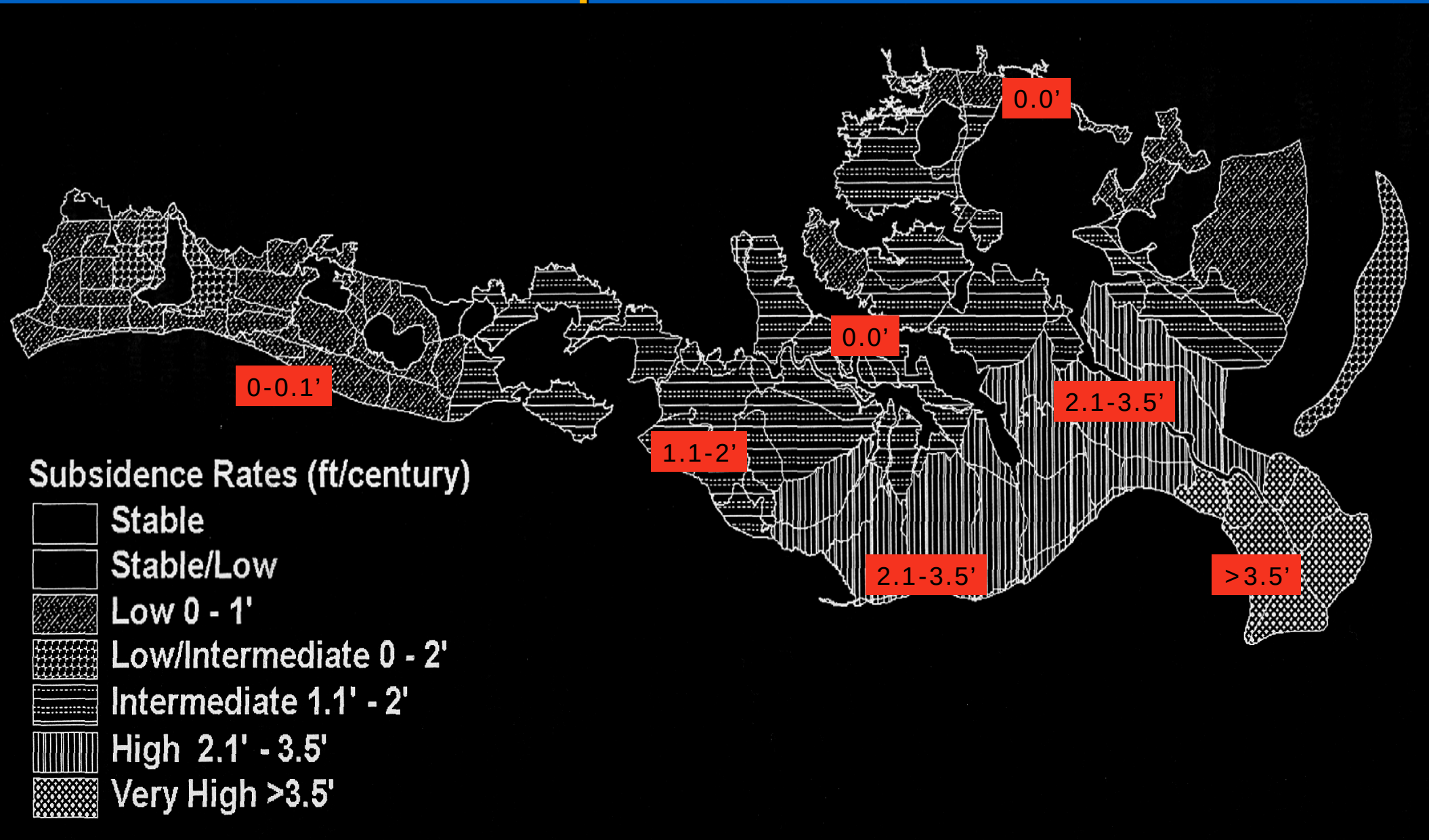
Sea level rise

America's WETLAND
Campaign to Save Coastal Louisiana

It's all true to some extent,

but is there more to it?

The Paradigm (red) underpinning plans to restore the Louisiana coast considers that subsidence only occurs areas of Holocene sediment accretion. No subsidence in upland areas.



Resolution of Time Associated with Local Relative Sea Level Rise Measurements

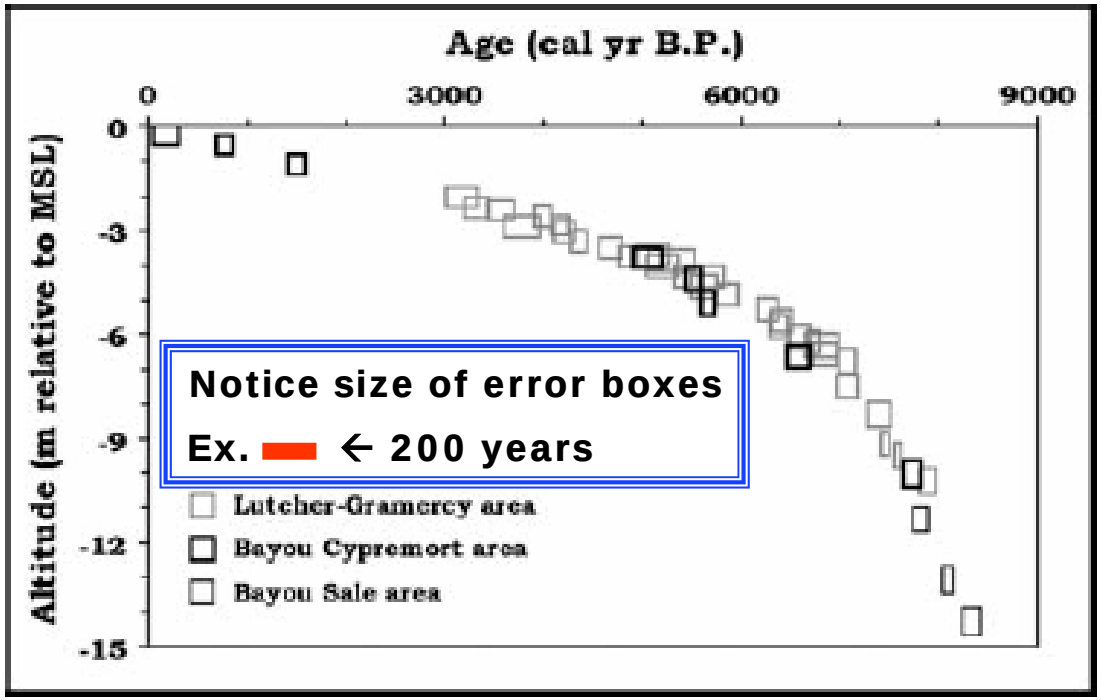


Figure 2. Sea-level index points (error boxes) from Lutcher-Gramercy (after Törnqvist et al., 2004), Bayou Cypremort, and Bayou Sale areas (MSL—mean sea level; cal—calendar). Error boxes are defined such to incorporate rise of mean sea level with at least 95% probability. For location of study areas see Figure 1. Törnqvist et al. (2004)

→95% confidence interval for all measurements is 50 to 300 years. Many are >200yr.

→How is it that rates are quoted in mm/yr rather meters/century?

→Geological methods see very little if any of the 20th century and thus are unable to detect many important processes.

→Geodetic data mainly covers the last half of the 20th century.

Features of the Paradigm just don't make sense!

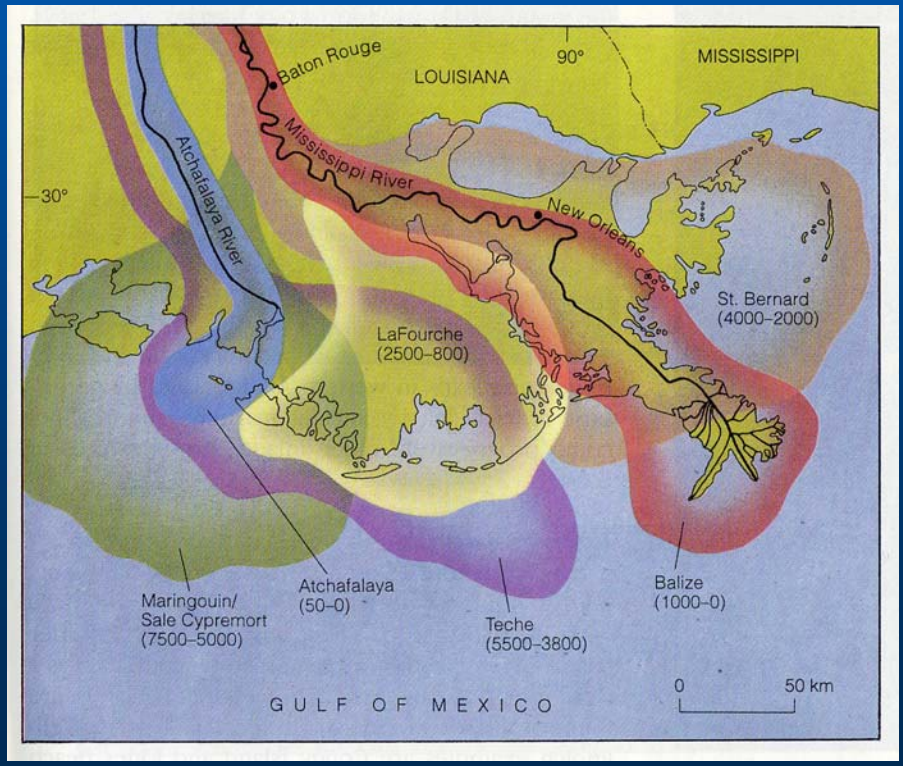
- All previous studies to measure subsidence used methods that are too crude to resolve 20th century change and failed to use proper datums to reference observations. This meant that subsidence was underestimated and processes operating regionally were missed. Roy's first rule of science: "You only find what you look for."

- Furthermore, explanations of subsidence failed to mention the well known (to oil geologists) processes that have created the Gulf of Mexico basin. Sediment loading, faulting, and salt migration and evacuation. Roy's second rule of science: "You only find those things for which your mind is prepared to see."

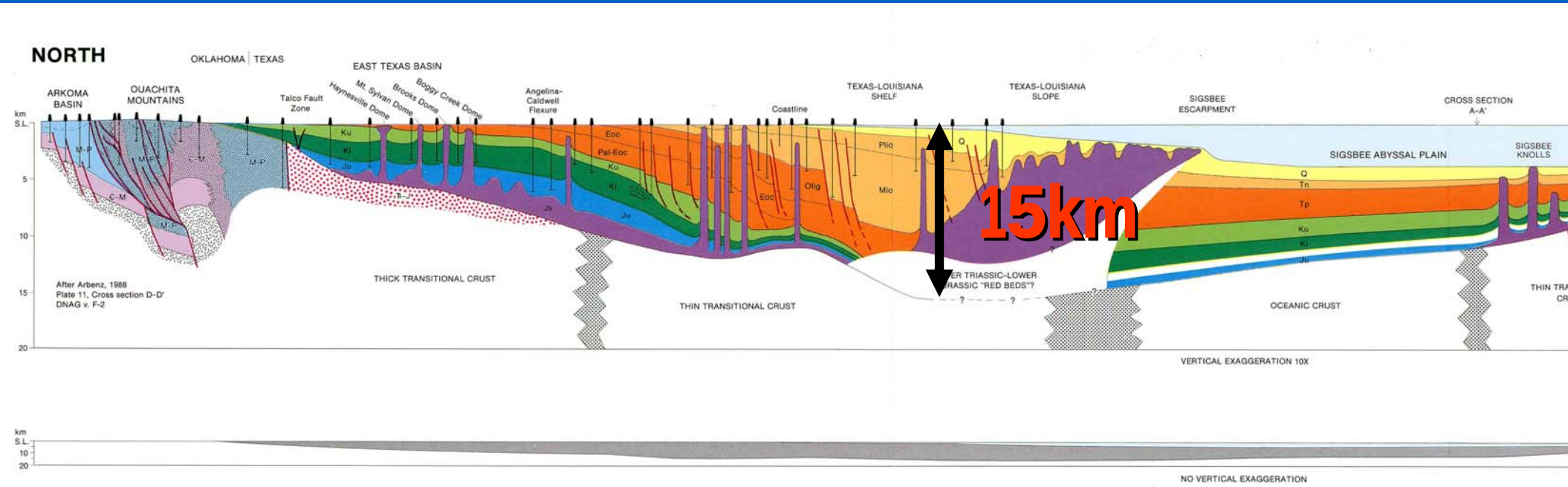
- The massive weight of the combined load of the Mississippi River Delta and rising sea is enough to bend downward the Earth's crust and to cause the underlying mantle to flow away. The Paradigm claims that non-wetland areas of the coast are stable. "Even Louisiana must obey the laws of physics".

Let's review the basic geological truths about modern landscape change in south Louisiana

- The modern Mississippi River delta has formed over last ~8,000 yrs.
- Landscape is due to the interplay between subsidence, accretion, and global sea level rise. Flooding builds land by sediment deposition and stimulates wetlands biologic processes. Deltas cannot grow much above sea level.
- The delta is composed of lobes that formed as the river shifted position with time. As a lobe was abandoned, accretion ceased yet the lobe continued to subside. Over time, the lobe is slowly eroded and inundated by the Gulf.
- An additional load of ~120m of delta sediments and ocean have been added to the Earth's crust and would be expected to cause downwarping.
- Because such a landscape is not favorable for human habitation, current levees were built by order of Congress to benefit the entire USA. Levees prevent flooding but has the unintended consequence of stopping accretion. Subsidence, however, continues.
- Because of their low elevation, wetlands are lost first, followed in time by the land where people live and work. Fixing the wetlands, although important, will not be not enough.

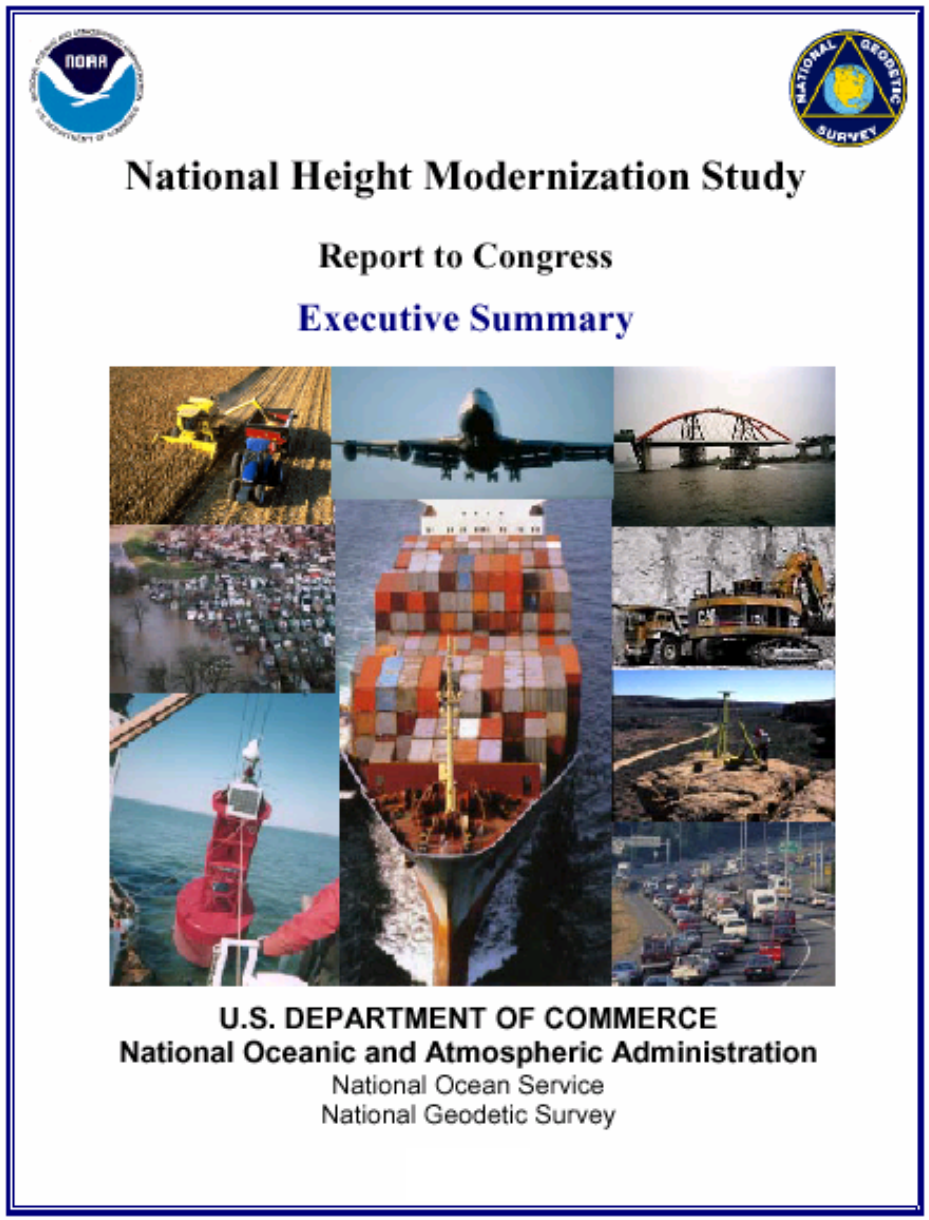


Example: South Louisiana is the product of 200 million years of sedimentation



- ~60,000 ft thick→stack of 10 Grand Canyon sections.
- Delta and shallow marine sediments.
- The "Depositional Space Problem"
  - ✓Sea level rise (range = ~1000 feet)
  - ✓Salt evacuation due to differential loading.
  - ✓Bending of the crust and flow of underlying mantle.

Meanwhile, Louisiana Surveyors were faced with a Continuing Problem: Moving Benchmarks!



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

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

Change measured by superior methods document higher rates of subsidence!

Raceland

Subsidence has lowered evacuation roads throughout coastal Louisiana

Grand Isle

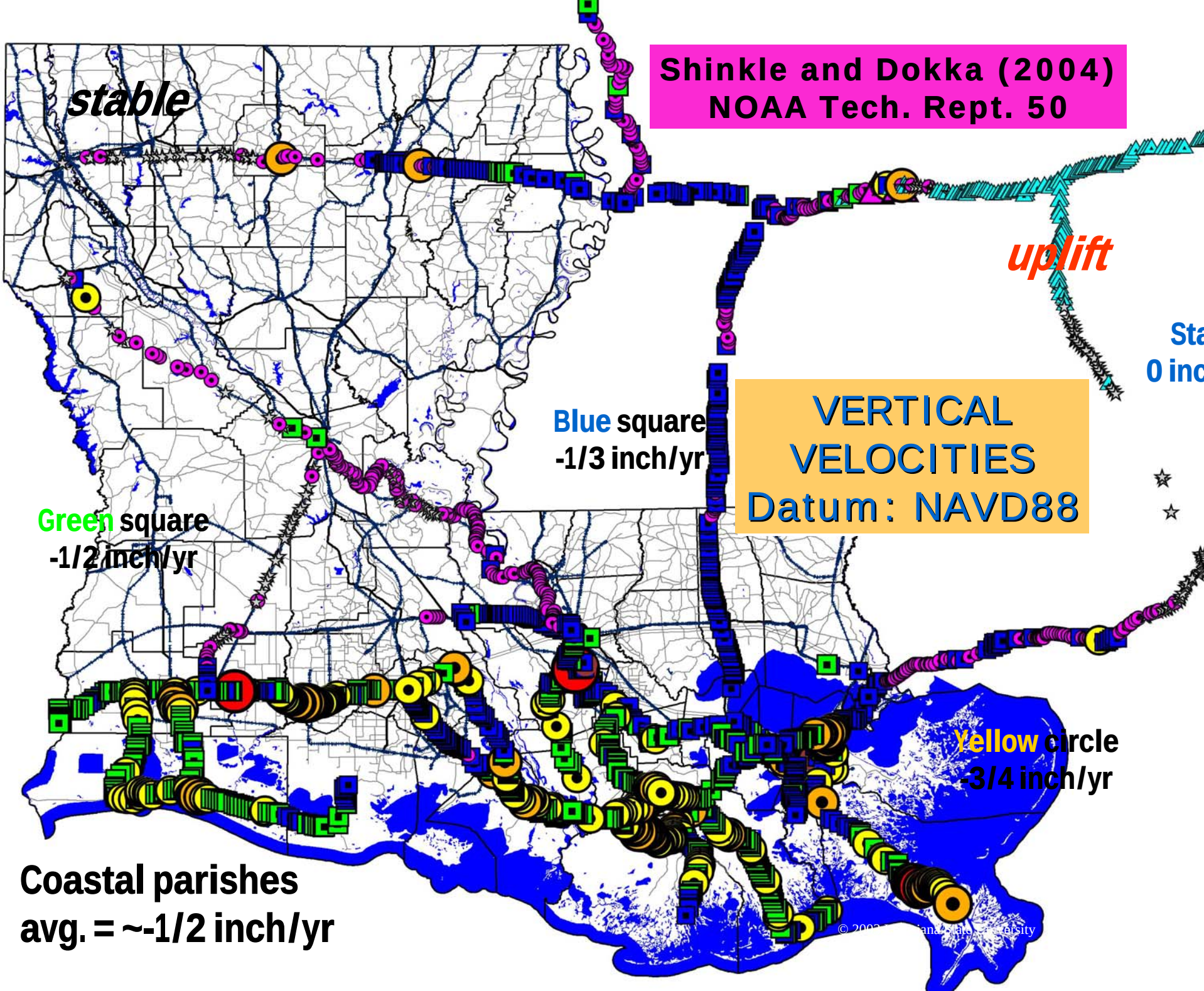
La Hwy 1 sank ~1 foot between 1982 and 2002

Fools rush in...

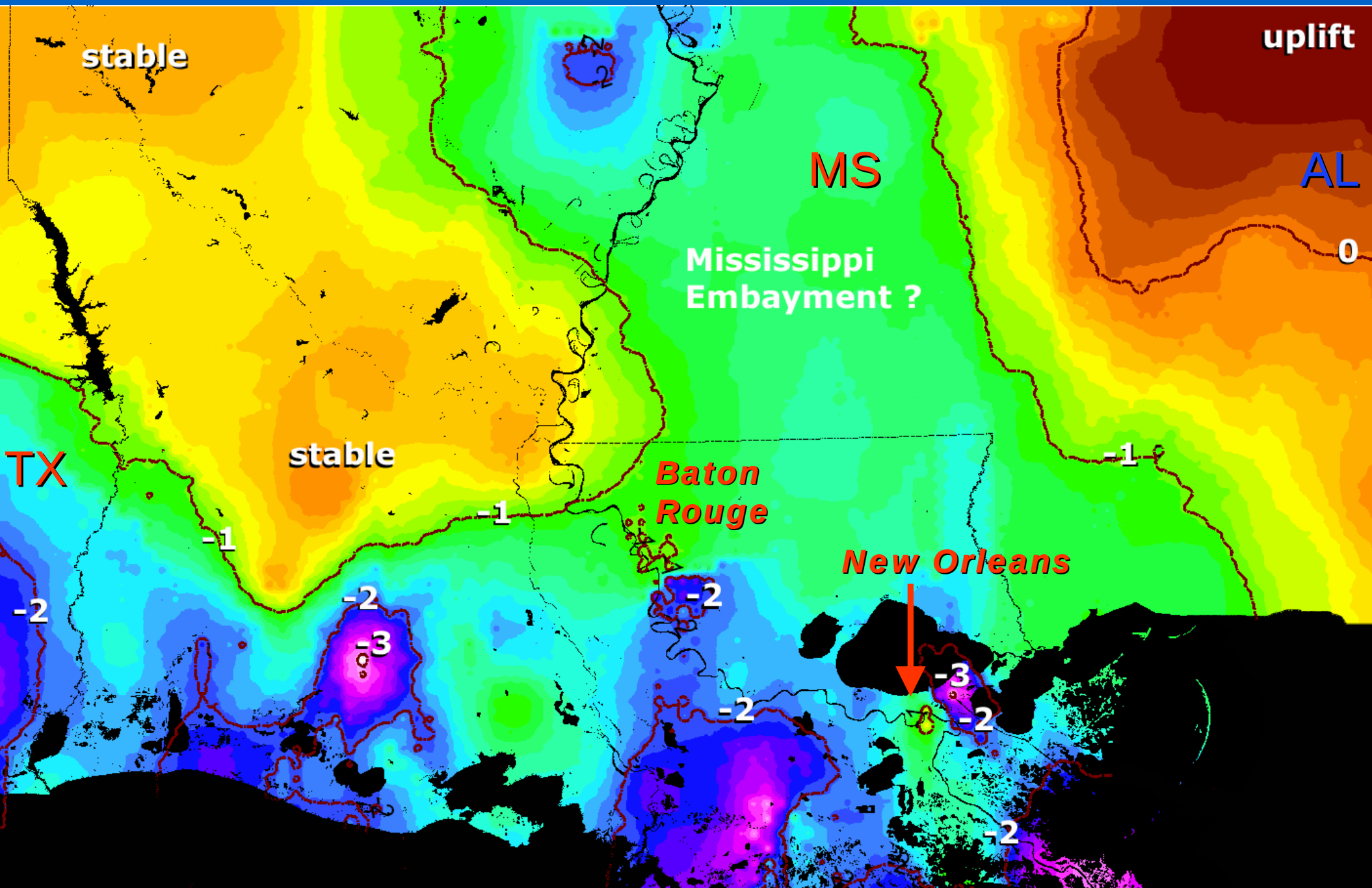
- We were tasked by Congress and NOAA to fix the elevation problem in Louisiana.
- First step: quantify the subsidence and rates over the 20th century by analyzing NOAA's best data, 1st order geodetic leveling.
- Results of the study published is Shinkle and Dokka (2004) and officially sanctioned by NOAA. It is purely geodetic in nature with little interpretation. The book was meticulously peer-reviewed by NOAA and outside referees (including the USGS and the State of Louisiana). No serious problems were found.
- We are examining these data in order to understand underlying geologic and anthropomorphic processes.
- Set up state-wide GPS CORS network to provide elevations and to measure today's and future subsidence. Official positioning service in LA.
- Independent-no coastal restoration funding

1st order Geodetic Leveling: A measurement tool with sub-mm resolution

- Traditional way to establish best elevations in USA by NOAA/National Geodetic Survey.
- Leveling measure height differences between benchmarks.
- NOAA has wealth of data throughout the USA.
- We have used the data from different surveys to compute vertical velocities at over 2700 benchmarks throughout the south-central USA.
- All data was related to the official vertical datum of the US (NAVD88).
- Shinkle and Dokka (2004) results correctly predict motions of all tide gauges in Louisiana, Mississippi, Alabama, and Florida.


Shinkle and Dokka (2004)
NOAA Tech. Rept. 50
stable
uplift
Sta
0 inc
VERTICAL
VELOCITIES
Datum: NAVD88
Blue square
-1/3 inch/yr
Green square
-1/2 inch/yr
Yellow circle
-3/4 inch/yr
Coastal parishes
avg. = ~-1/2 inch/yr

Subsidence in the last 50 years



Subsidence of Benchmarks: The Result of Multiple Regional and Local Processes

Regional Processes:

→Sediment and water load induced flexure of the lithosphere

0 to -8mm/yr

Local Processes:

→Consolidation and compaction

→Organic soil oxidation

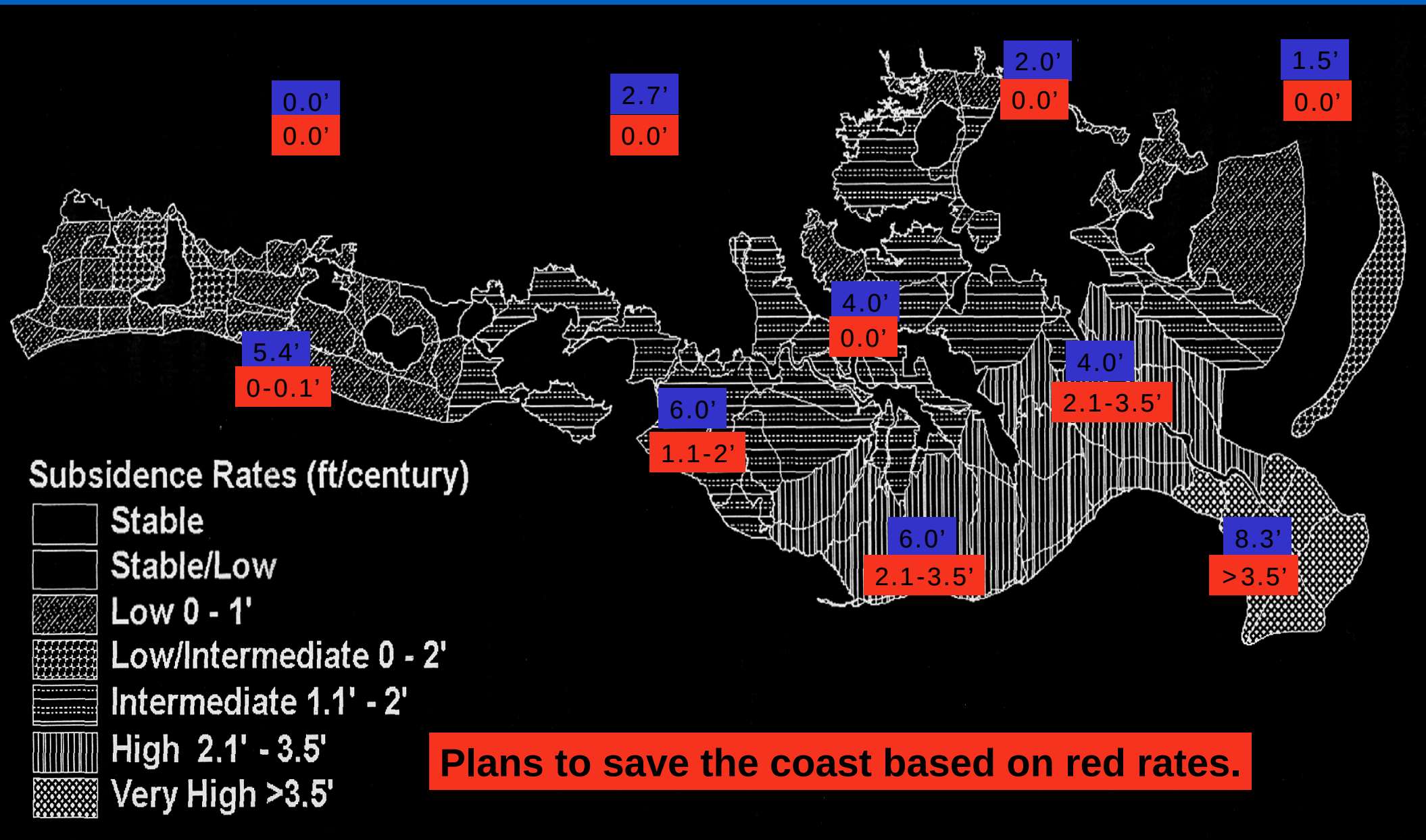
→Faulting *0 to -15mm/yr*

→Oil & gas extraction *0 to -3 mm/yr*

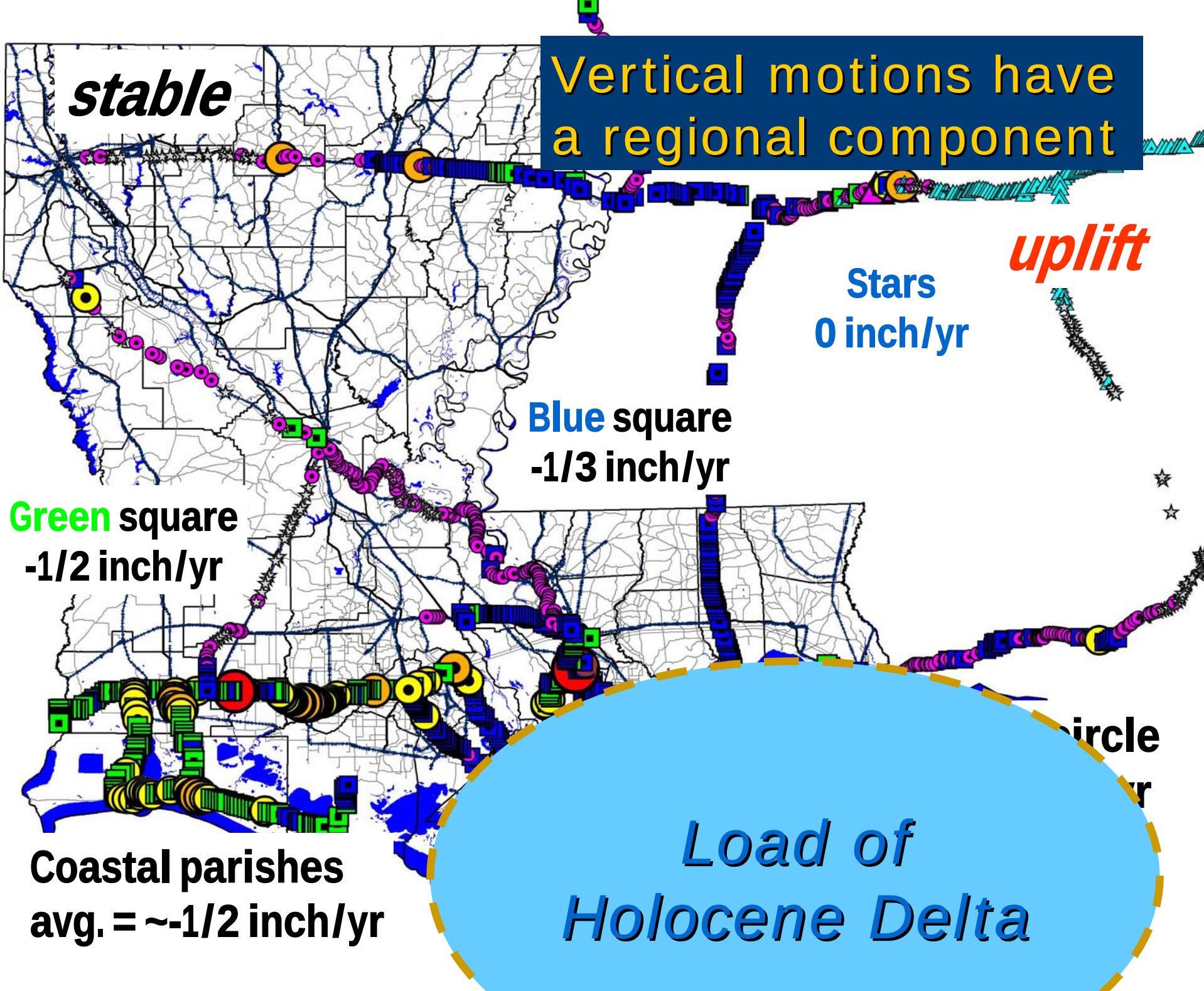
→Water pumping *0 to -50mm/yr*

→Salt evacuation *0 to -15mm/yr*

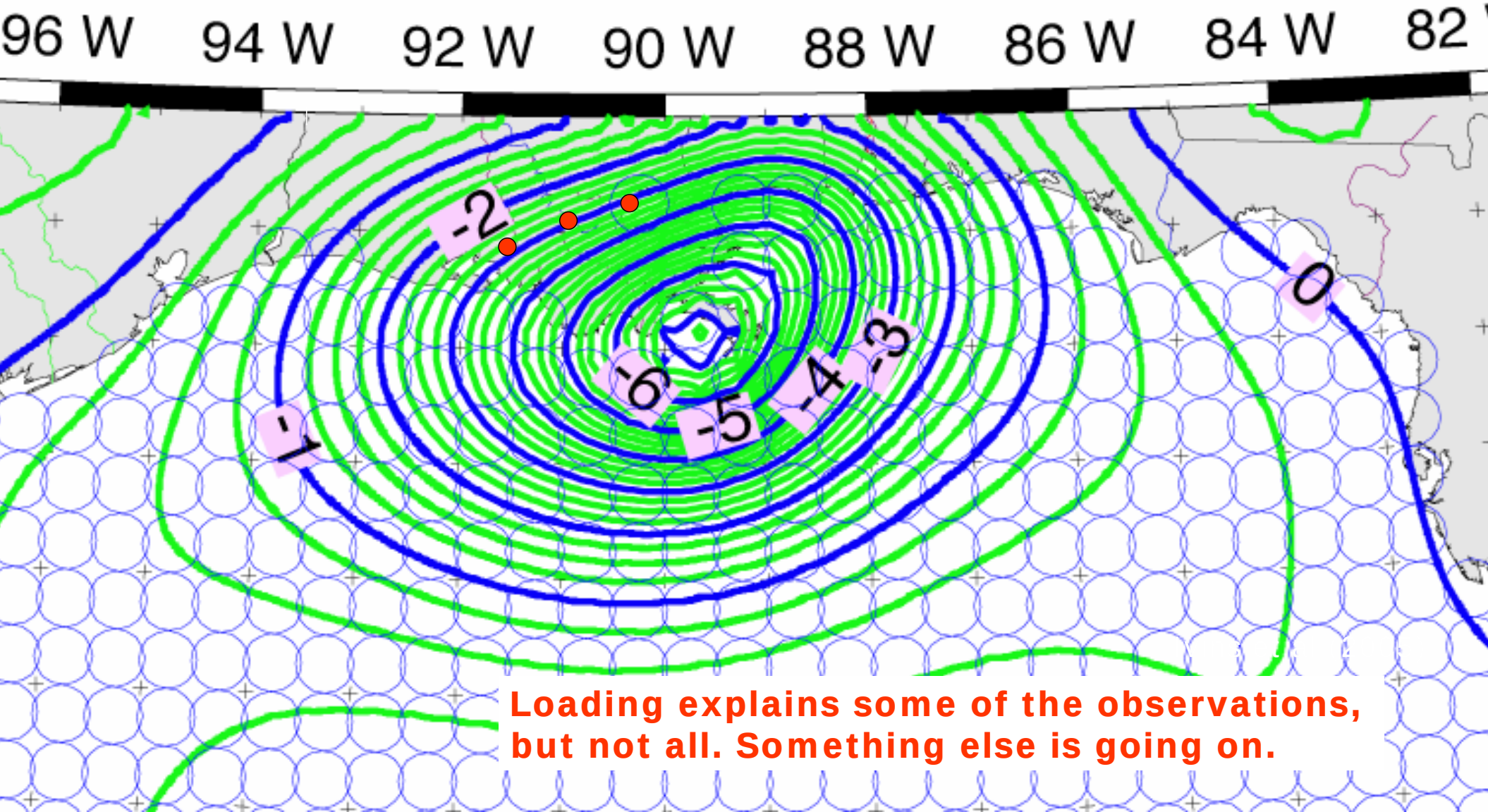
The Paradigm (red) underpinning plans to restore the Louisiana coast cannot explain the observed subsidence. It is not just the wetlands, it is entire coast.



Plans to save the coast based on red rates.


stable
Vertical motions have a regional component
uplift
Stars
0 inch/yr
Blue square
-1/3 inch/yr
Green square
-1/2 inch/yr
Coastal parishes
avg. = ~-1/2 inch/yr
Load of
Holocene Delta

Predicted present-day vertical motions in mm/yr from delta & ocean loads

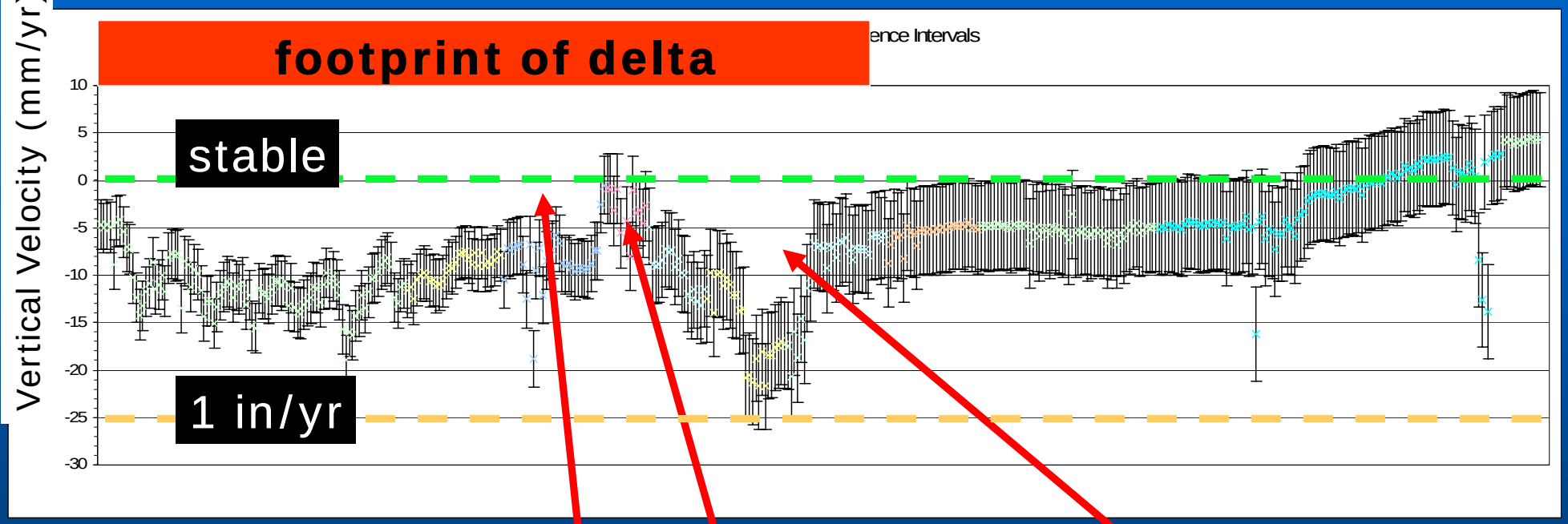


What is that something else?

Grand Isle

A Regional Subsidence Profile

Pensacola

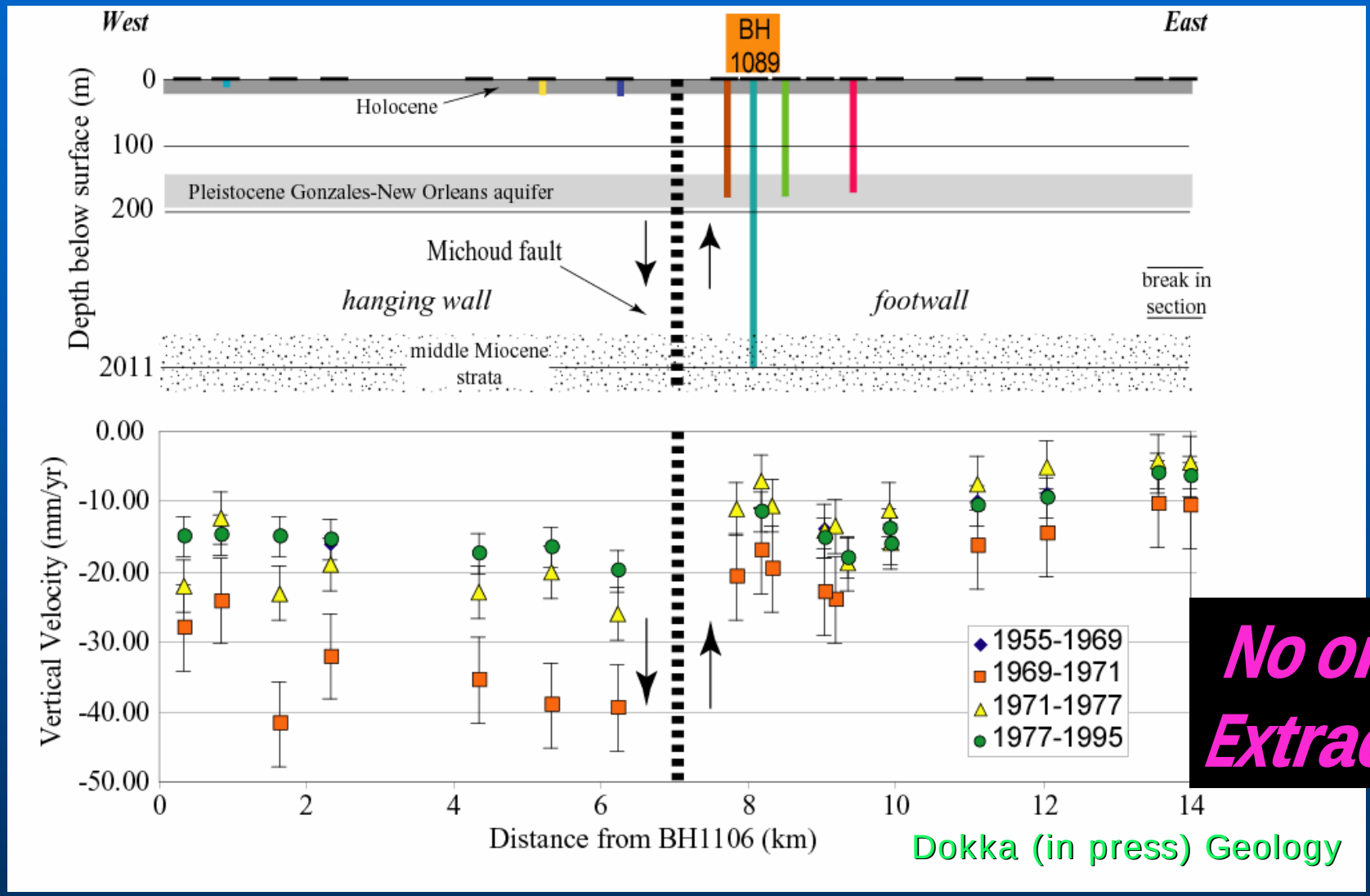


GRETNA
slight subsidence

New Orleans East
severe subsidence

Kenner
moderate subsidence

Michoud-East N.O. processes documented!



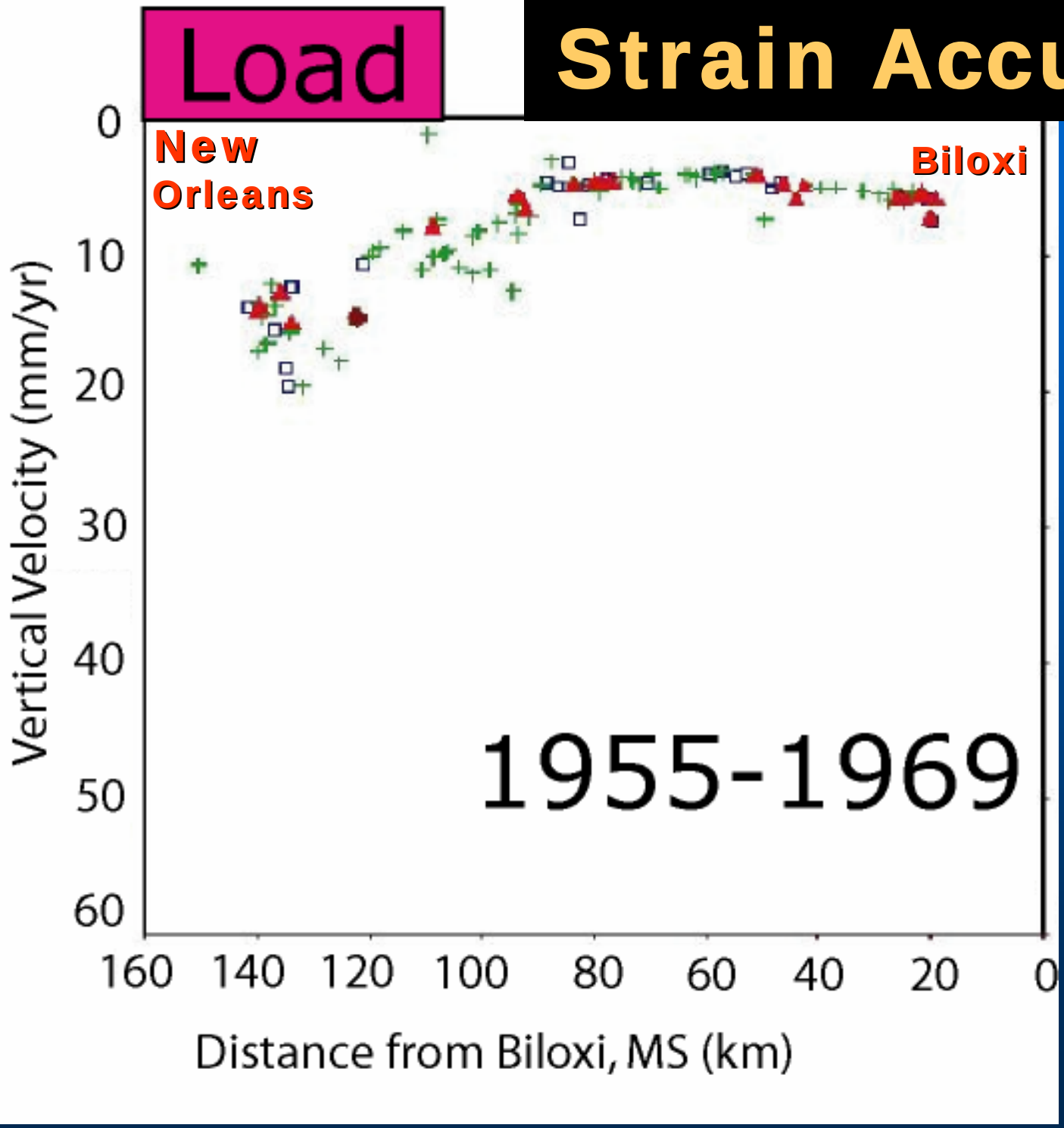
No oil/gas Extraction!!

Deep <-2011 m
Tectonic
1969-1971 = -18 mm/yr
1971-1977 = -8 mm/yr

M. Mio-Pleistocene
compaction
1969-1971= -4.6 mm/yr
1971-1977= -4.6 mm/yr

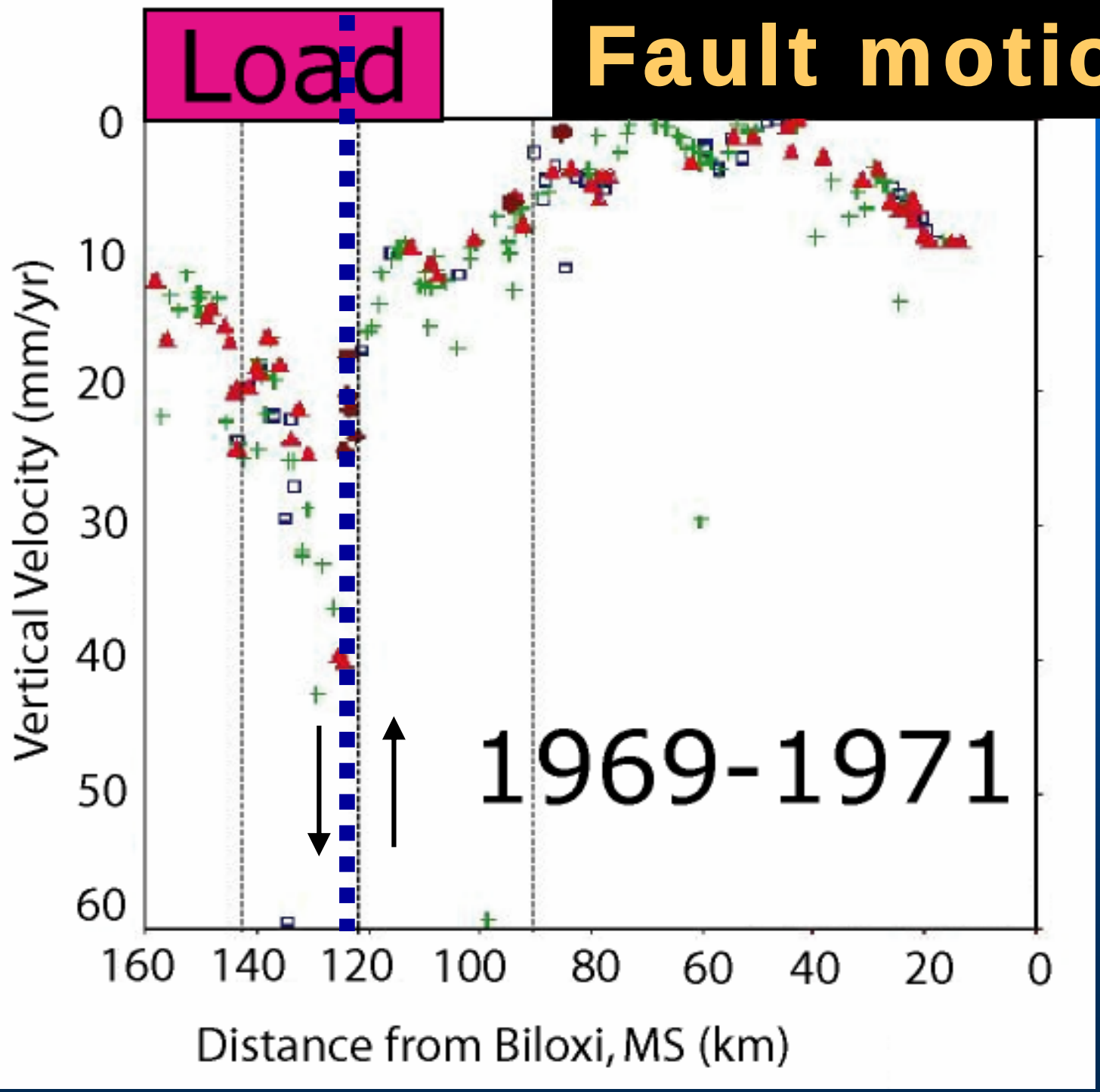
Shallow compaction &
Groundwater
1969-1971 = -2 mm/yr
1971-1977 = -2 mm/yr

Strain Accumulating



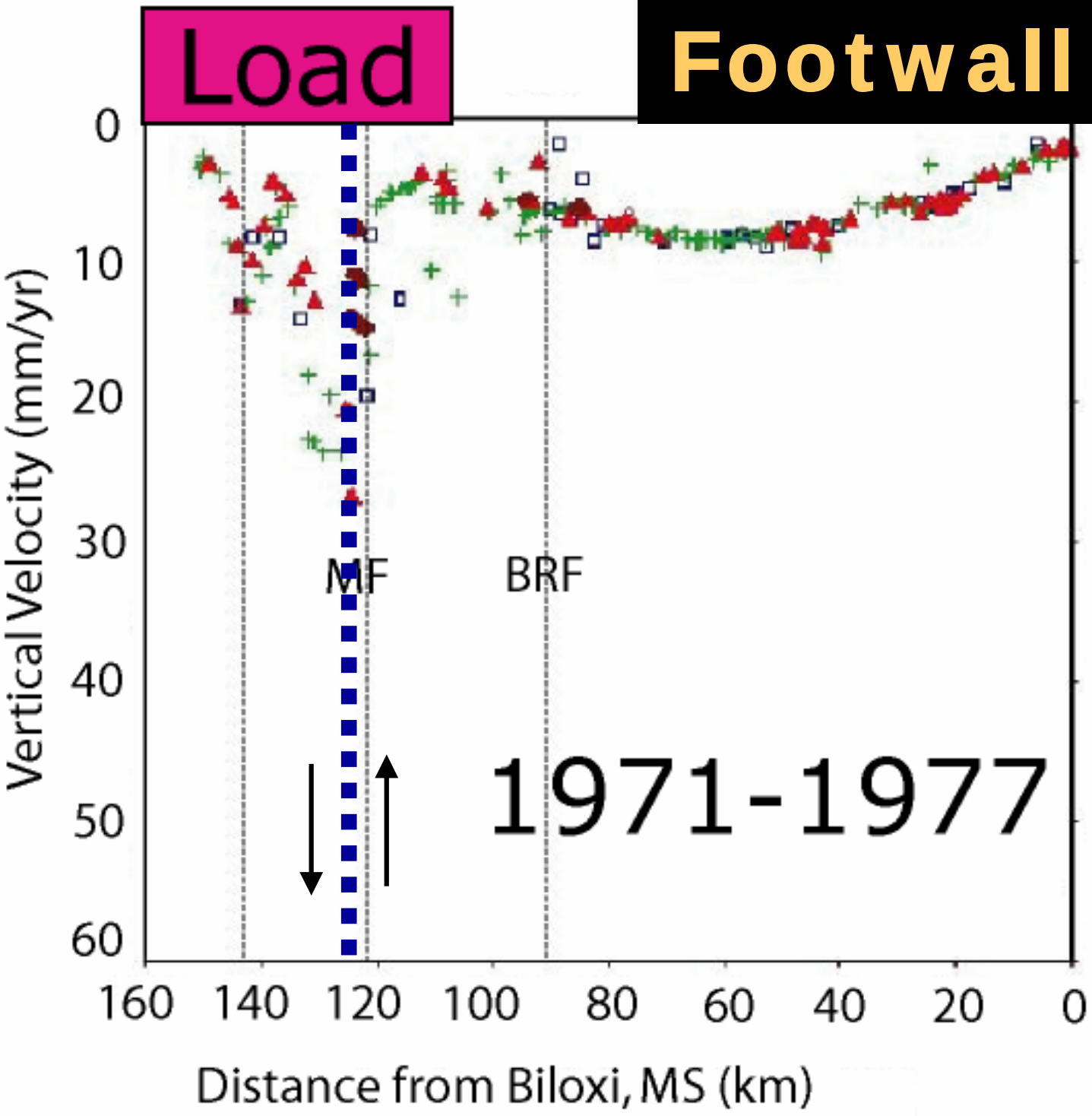
- Bending of elastic crust

Fault motion begins



- Slightly seismic
- 1.5 cm / yr
- Footwall un-loaded → uplift
- Hanging wall rollover
- Subsidence rates soar. So does land loss.
- You've heard of the "BigOne"
- How about the "Big Easy"?

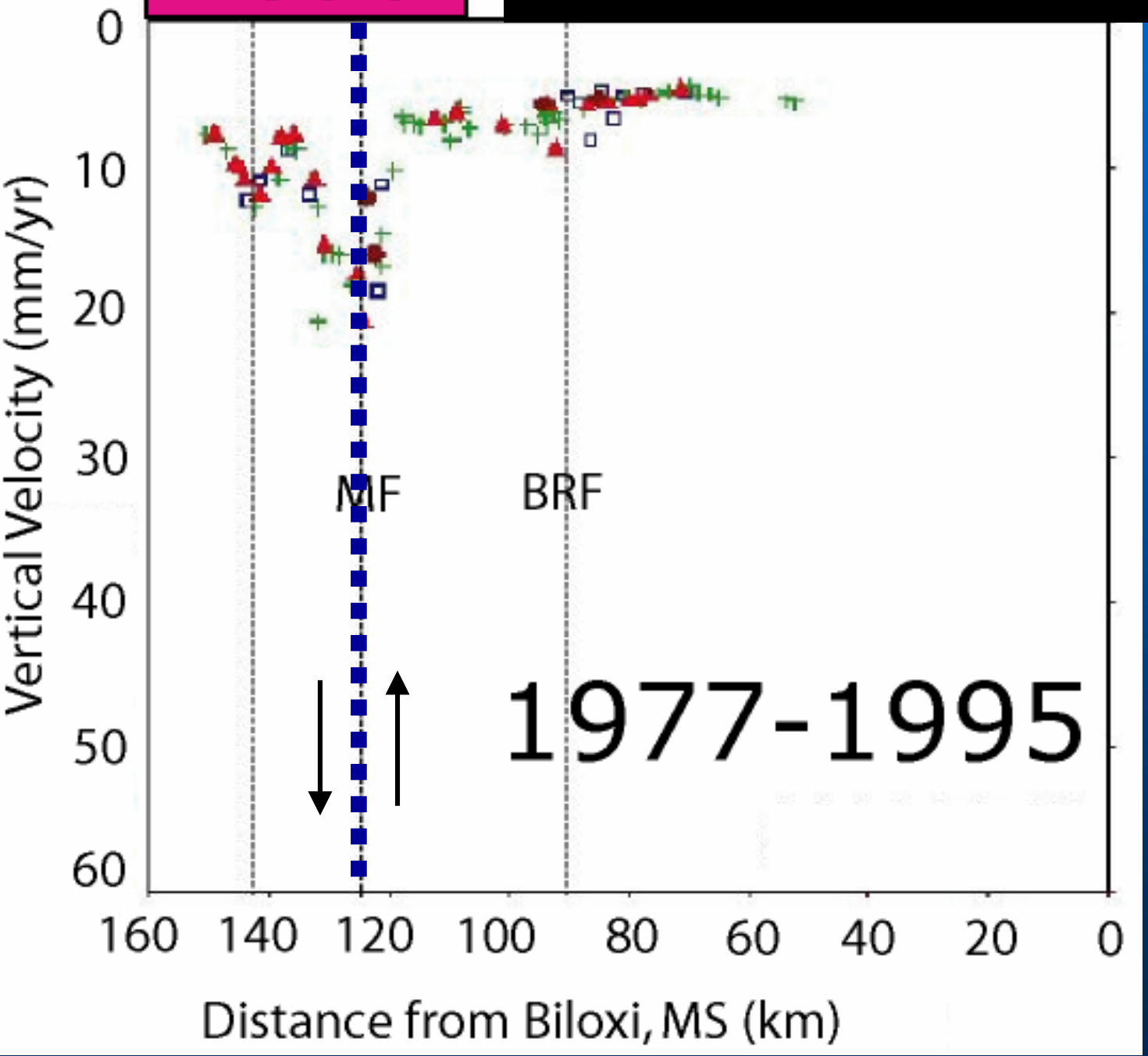
Footwall Rebound



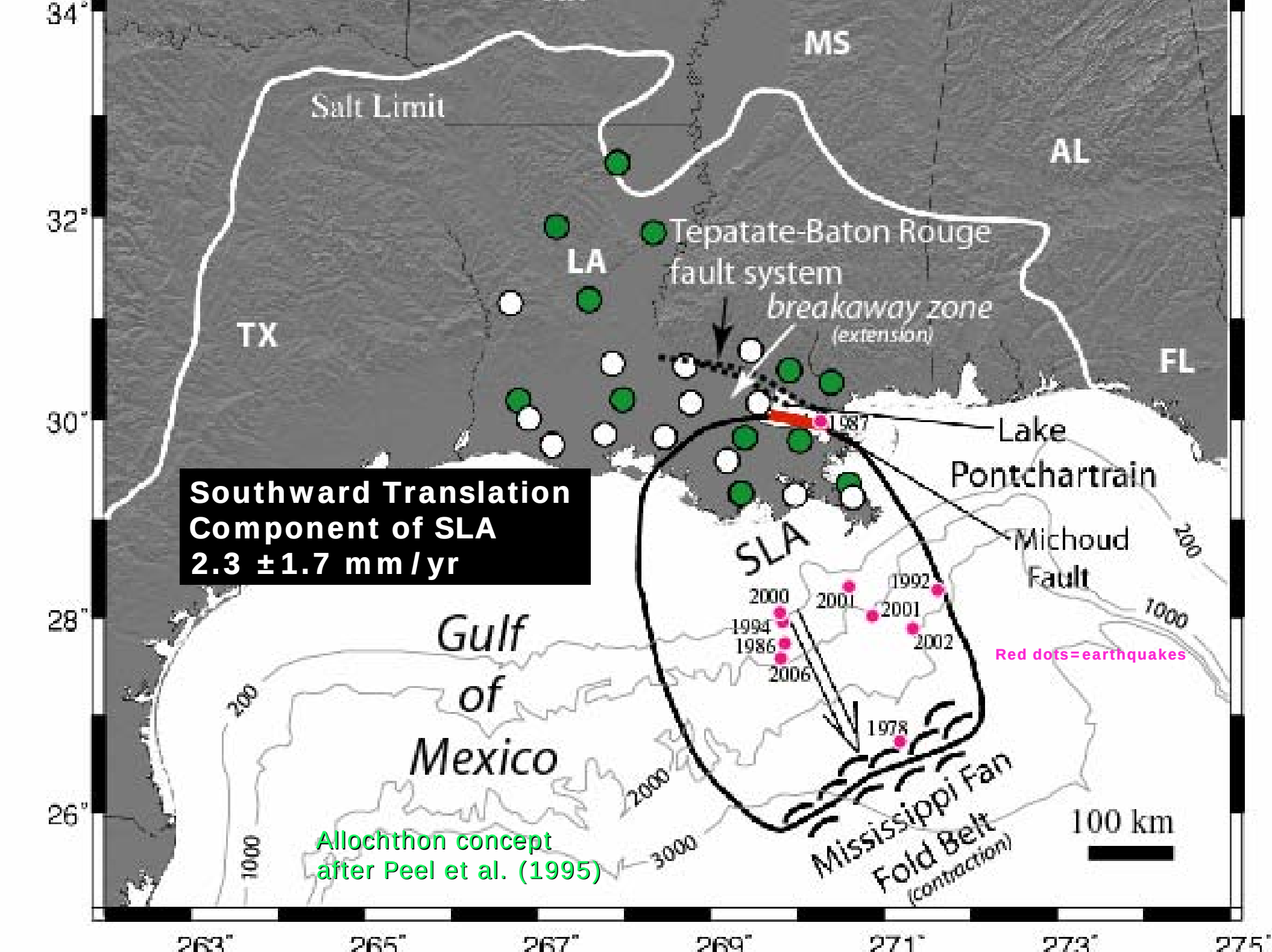
- Still moving
- "Big Easy" slow earthquake
- 1 cm / yr
- Footwall un-loaded → up
- Hanging wall rollover
- Subsidence regional and dynamic.

Load

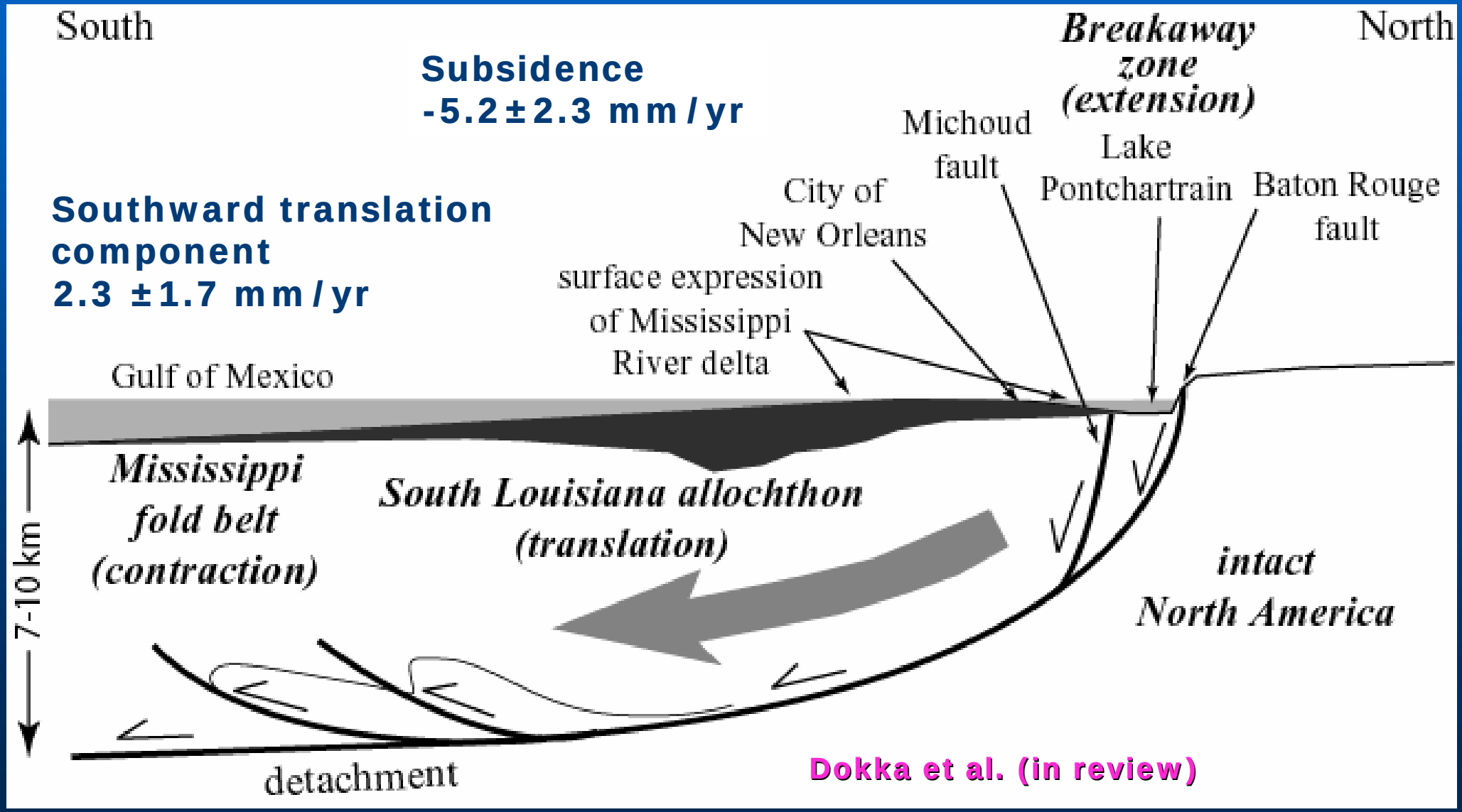
A 30 yr “slow” earthquake



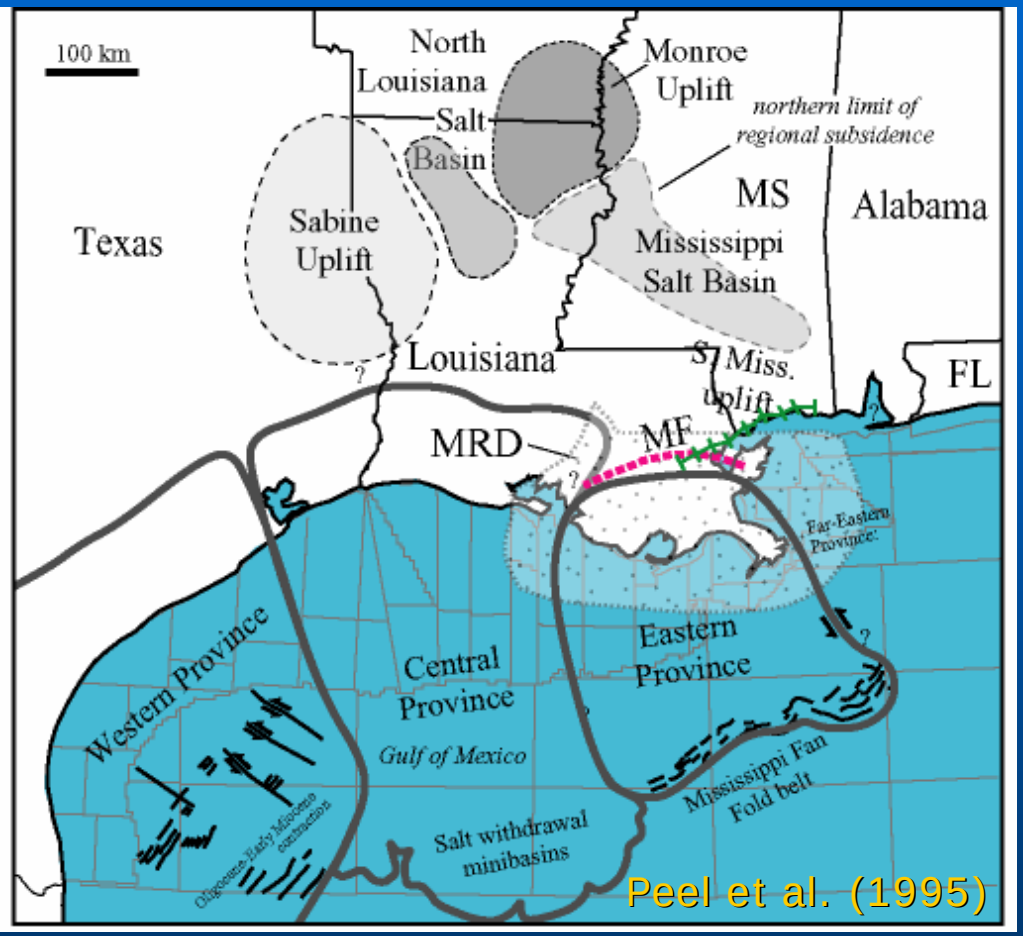
- Still moving
- 0.5 cm / yr
- Hi subsidence localized.
- Faulting stops near 2000, a 30 yr “slow” earthquake!


MS
AL
LA
TX
FL
Salt Limit
Tepatate-Baton Rouge
fault system
breakaway zone
(extension)
1987
Lake
Pontchartrain
Michoud
Fault
SLA
2000
2001
1992
2001
1994
1986
2002
2006
1978
Red dots=earthquakes
Southward Translation
Component of SLA
2.3 ±1.7 mm/yr
Gulf
of
Mexico
Allochthon concept
after Peel et al. (1995)
Mississippi Fan
Fold Belt
(contraction)
100 km
200
1000
2000
3000
34°
32°
30°
28°
26°
263°
265°
267°
269°
271°
273°
275°

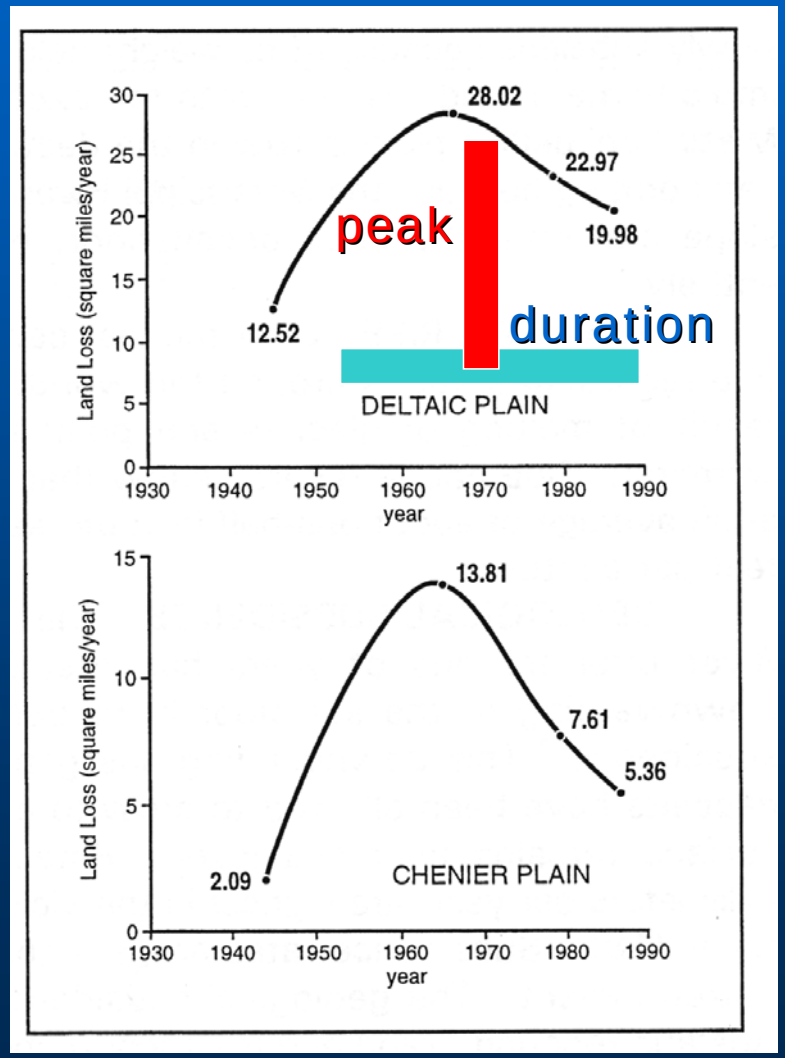
A coupled extensional-contractional complex



The “Big Easy” event coincided with interval of heightened land loss



Coastal land loss



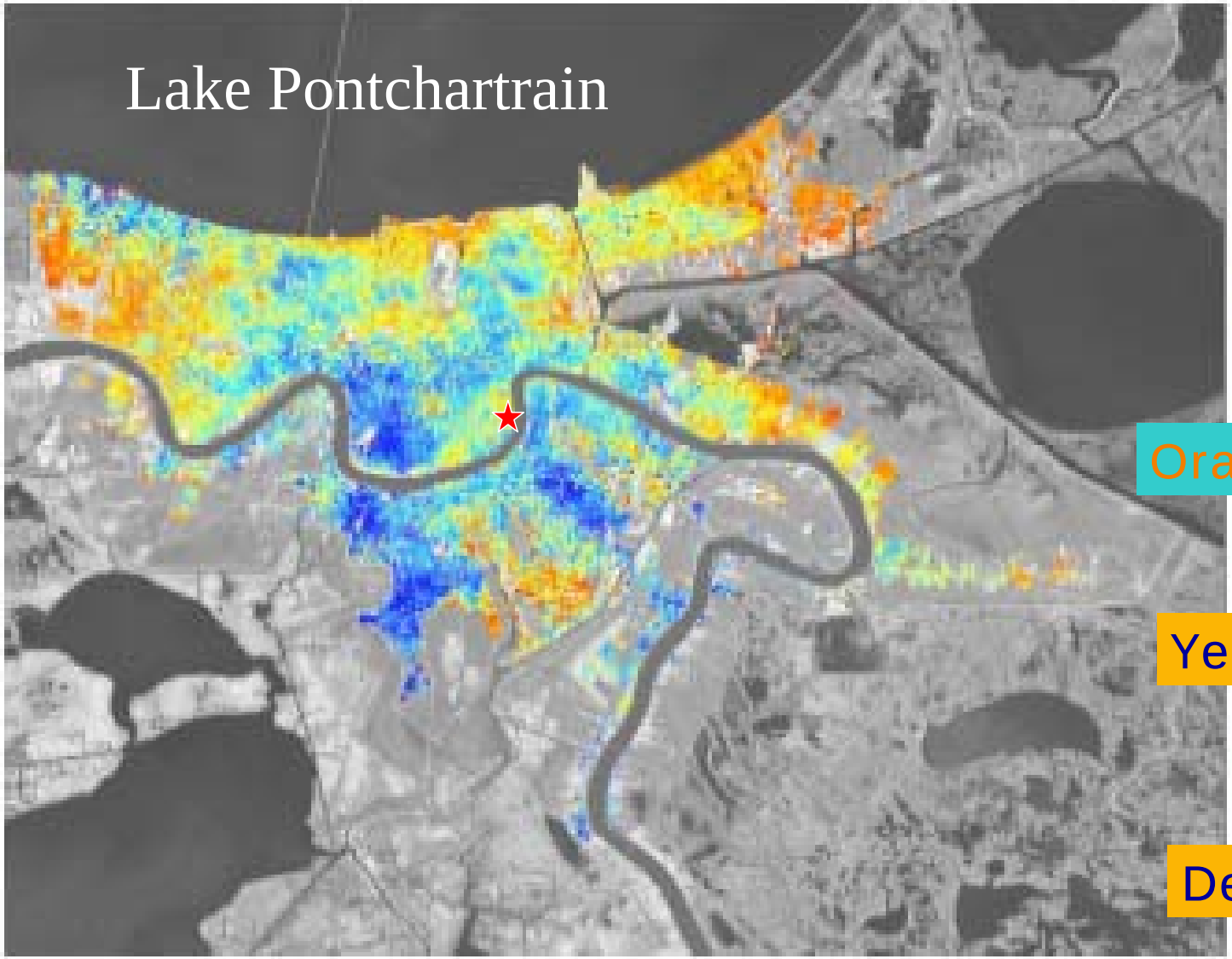
USACE

→Faulting causes subsidence

→Subsidence leads to inundation

→Saltwater intrusion kills the marsh

Radar PS Interferometry 2002-late 2005
Radarsat C-Band (6cm)



Red=<-20mm/yr

Orange =-20--12mm/yr

Yellow =-12-5mm/yr

Deep blue = >-5mm/yr

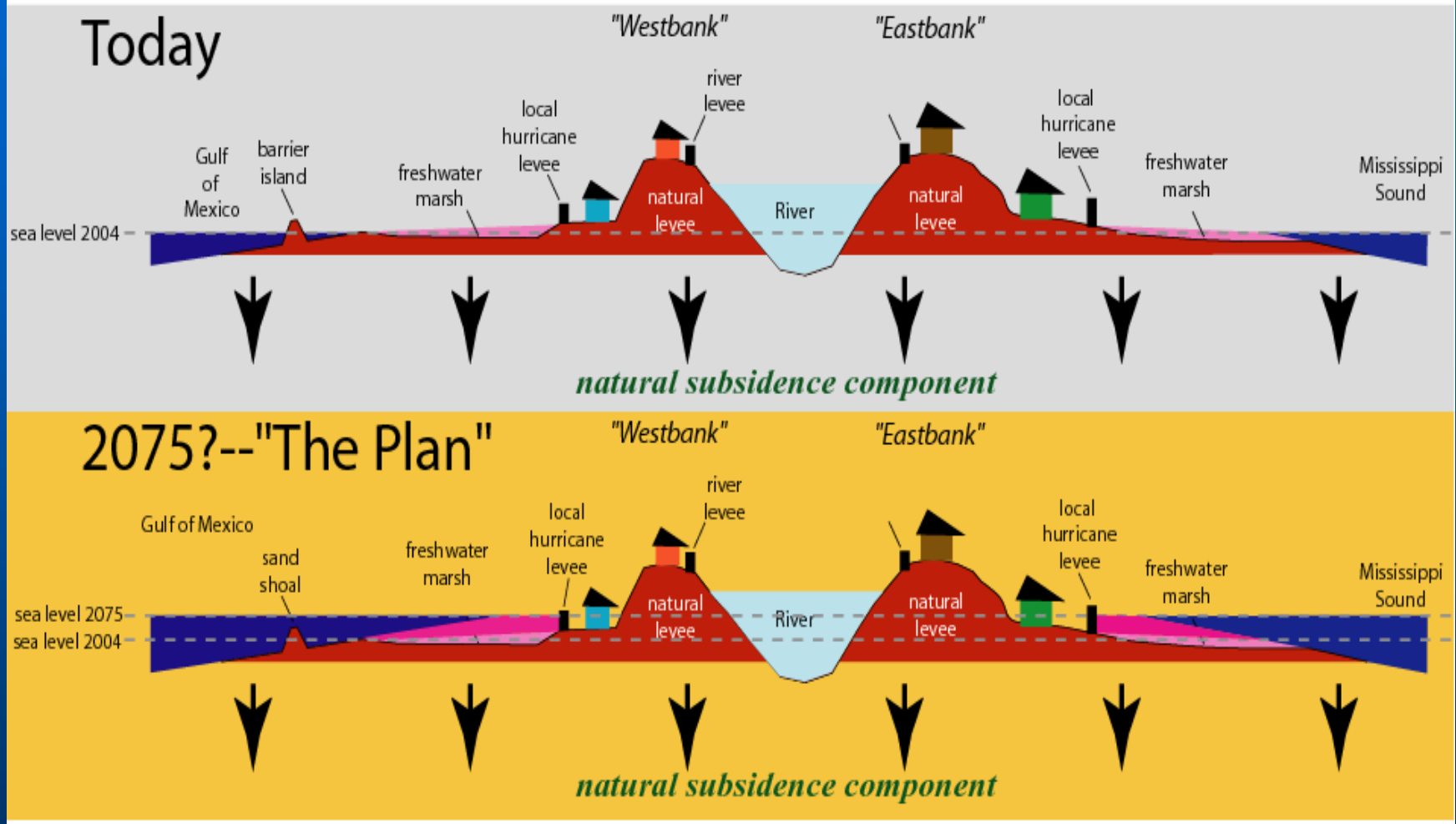
Figure 2. Velocity map (ΔLOS) for permanent scatterers in New Orleans and en

Dixon et al. (2006) Nature

So, what does all of this mean?

- The entire coast and surrounding area are sinking and it occurring at higher rates than previously thought.
- Given the unrelenting natural processes causing much of the subsidence, 20th century rates will likely be similar through this century. Rates based on averaging long-term, millennial change seen in the geological record smooth out critical decadal scale details.
- Merely fixing the wetlands will not save the coast and alone cannot provide adequate protection against storm surge for coastal communities.
- Although federal river levees are the proximal cause of the loss of the coast by disruption of the natural systems, higher and still higher ocean levees will unfortunately be needed for protection of human populations if Society insists on living in this dangerous environment.

Current plans to save the Coast are focused on fixing the wetlands



As the wetlands are restored, coastal communities will continue to sink. Storms will ultimately make coastal communities uninhabitable.

This has already happened in lower Plaquemines Parish. Levees now protect land that has subsided below sea level.

Mississippi River

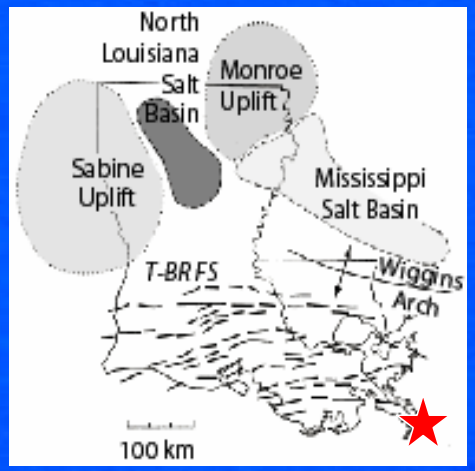
Flood protection levee

Flood protection levee

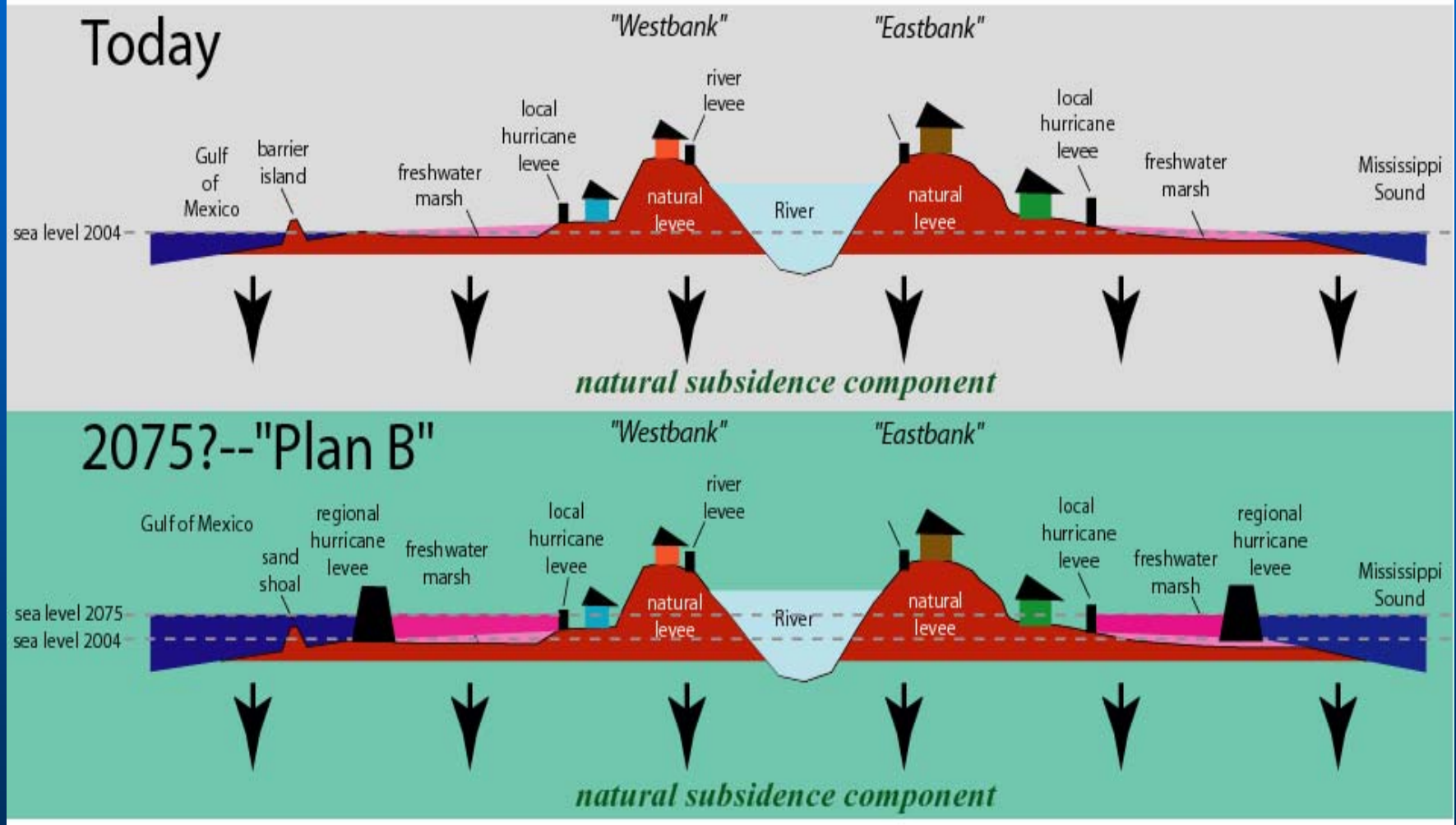
NOAA LIDAR

Hot colors = high; cold colors = low.
Notice that medium blue marks sea level.
Areas in dark blue within the flood protection levees are below sea level.

South



Sea level rise and subsidence will likely result in inundation of the coast.



Solution: Protection for coastal communities.

Or RETREAT!

Questions!

Remember Kids: don't drink the Kool-Aid