"Global Sea Level Change in the 20th Century and Recent Satellite Results"

NC-20, New Bern, NC

Bob Dean and Jim Houston

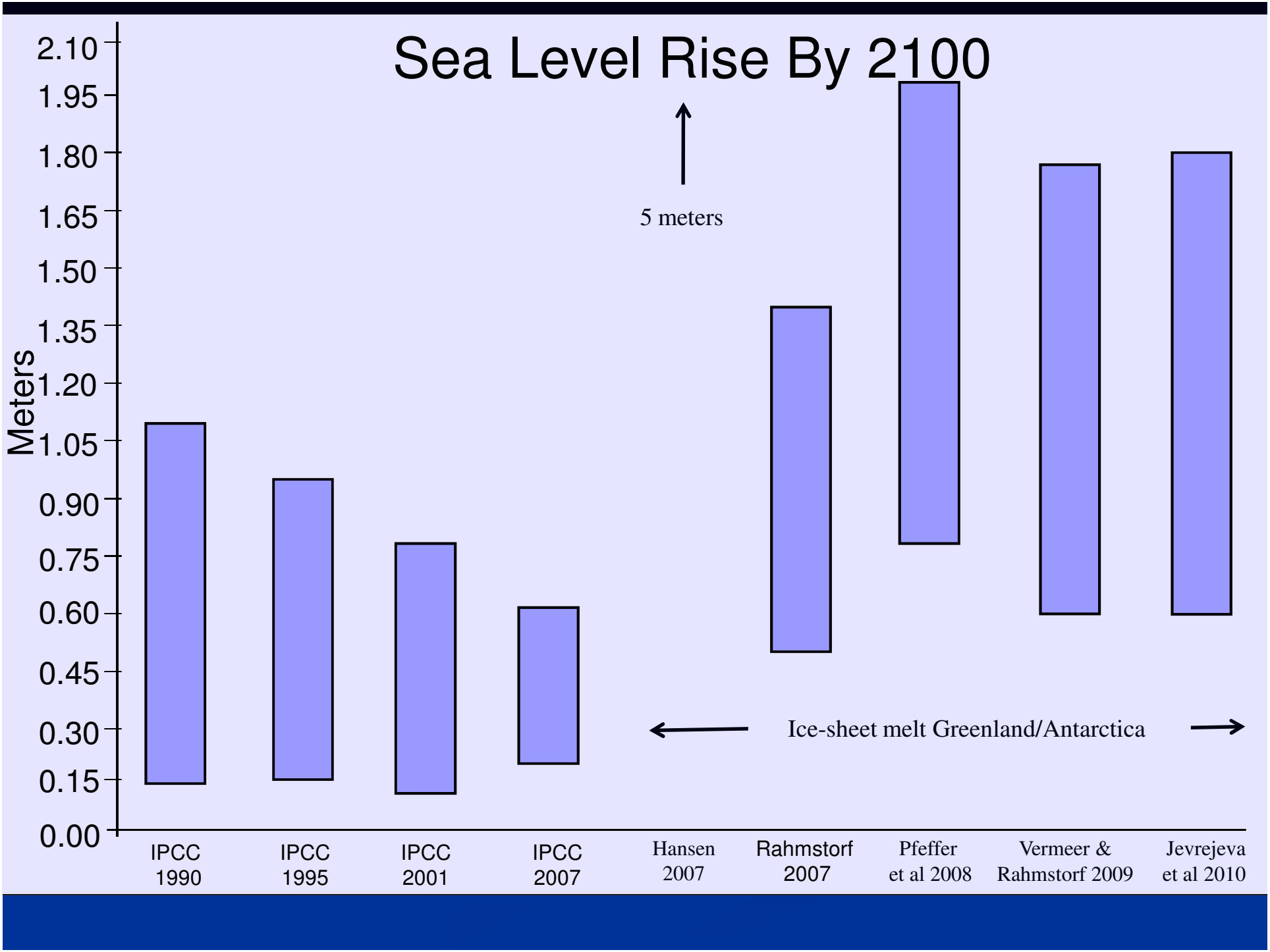
October 7, 2011

Outline

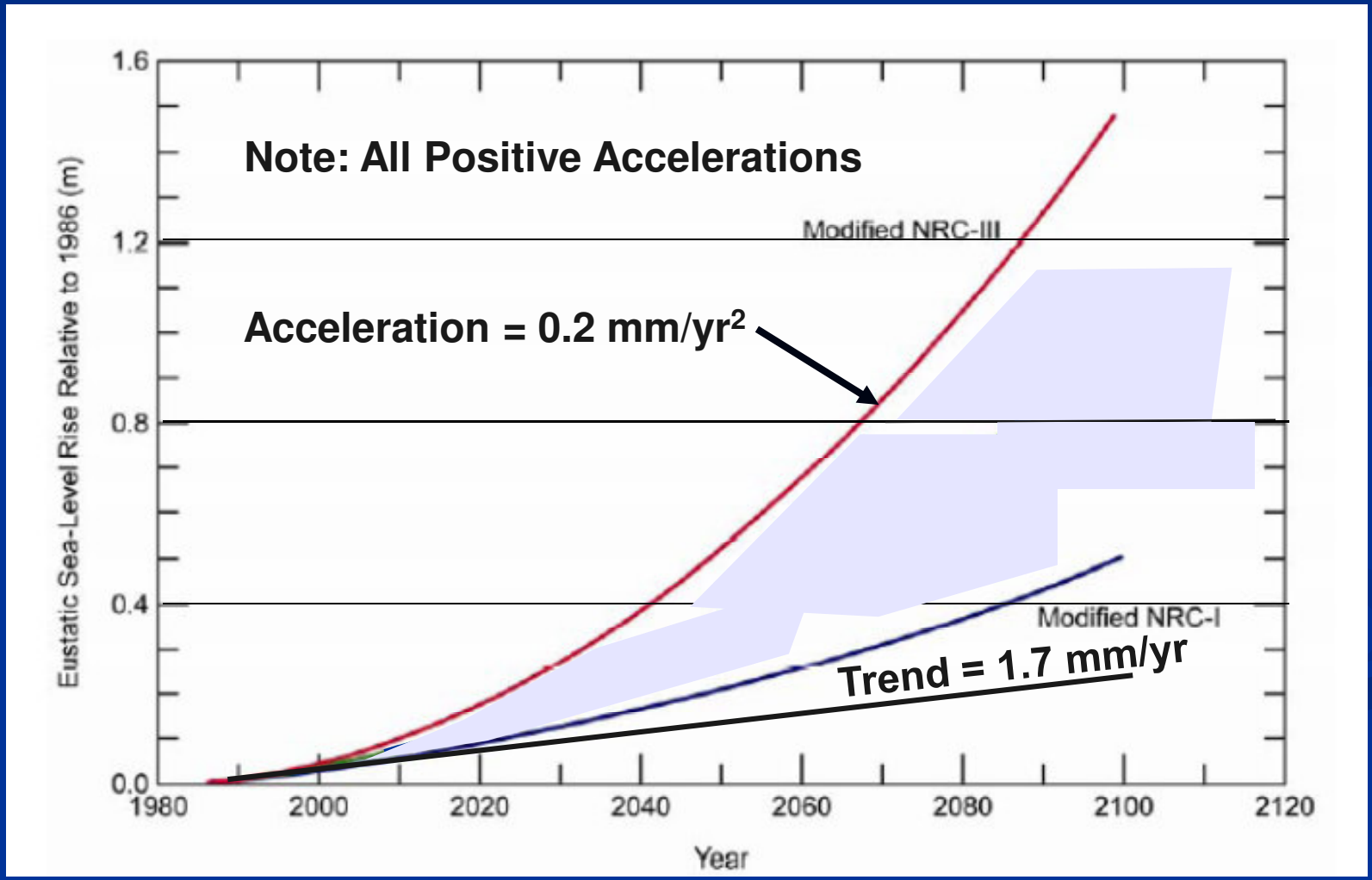
- **Resources available for study of past sea level**
- **Three Studies That Jim and I have Conducted**
  - **Analysis of long-term U. S. Gauges**
  - **Analysis of many world-wide tide gauge records**
  - **Comparison of tide gauge and satellite data**
- **Issues of particular relevance to NC-20**
- **Summary and Conclusions**

Two Related Papers

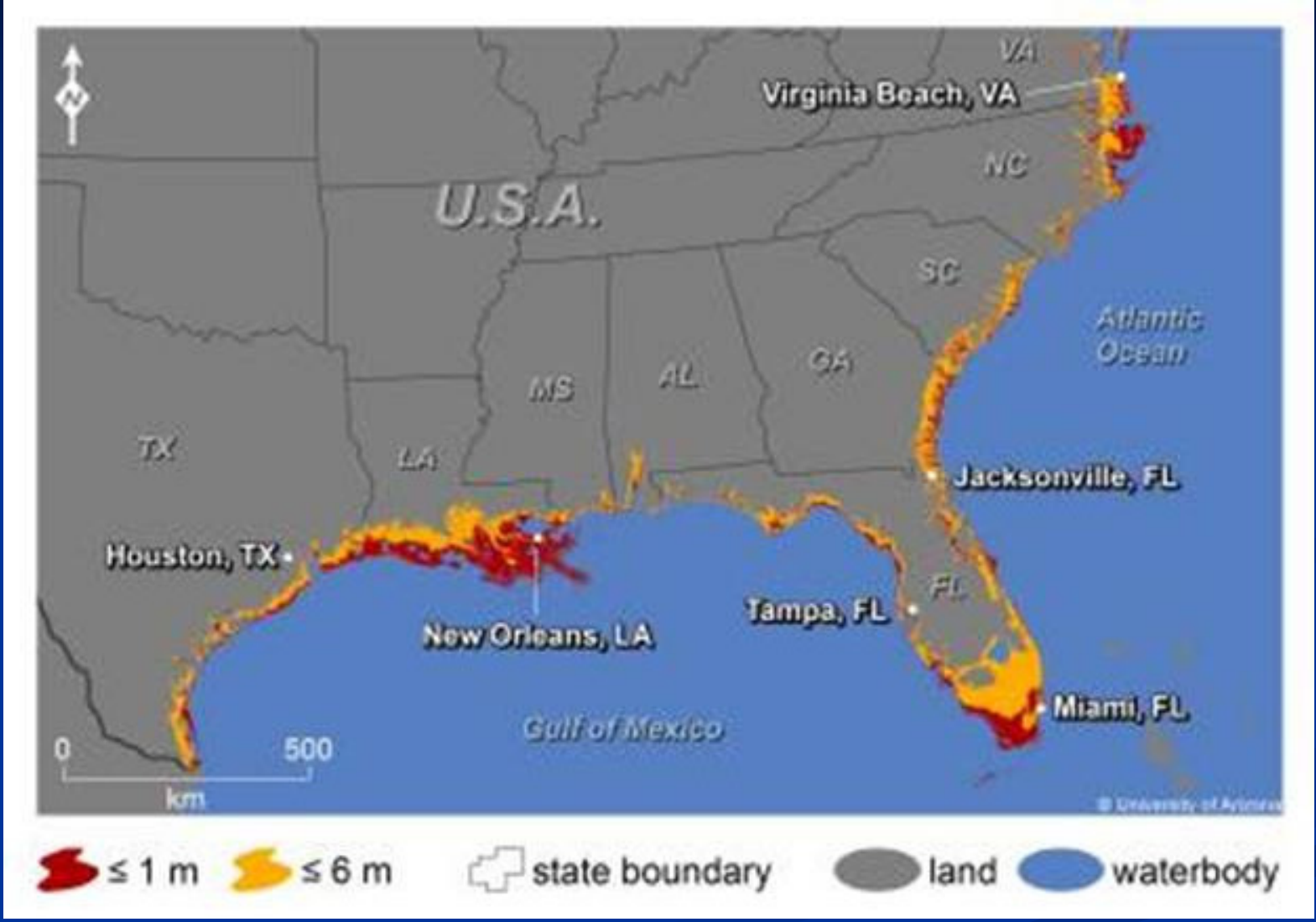
- Watson, P. (2011) "Is There Evidence Yet of Acceleration in Mean Sea Level Rise Around Mainland Australia?:, Journal of Coastal Research, Vol. 27, No. 2.
- Houston, J. R. and R. G. Dean "Sea-Level Acceleration Based on U. S. Tide Gauges and extensions of Previous Global-Gauge Analyses", Journal of Coastal Research, Vol. 27, No. 3


Sea Level Rise By 2100
Meters
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
5 meters
Ice-sheet melt Greenland/Antarctica
IPCC 1990
IPCC 1995
IPCC 2001
IPCC 2007
Hansen 2007
Rahmstorf 2007
Pfeffer et al 2008
Vermeer & Rahmstorf 2009
Jevrejeva et al 2010

Corps of Engineers Guidance for Global Sea Level Rise (2009)



University of Arizona Research Paper



"Greenhouse gas emissions will cause warming which will raise sea level by at least one meter by 2100"

Common Assumption: Sea Level Rise is Accelerating

- *"The rate of sea level rise is accelerating"*

  - Sea Grant (2008)

- *"There is increasing evidence of continued and accelerating sea-level rises around the world"*

  - Royal Society (2009)

- *"Satellite and tide-gauge measurements show that the rate of sea level rise has accelerated"*

  - Copenhagen Diagnosis (2009)

- *"So it is now apparent that SLR has accelerated over the twentieth century"*

  - Pew Center on Global Climate Change (2009)

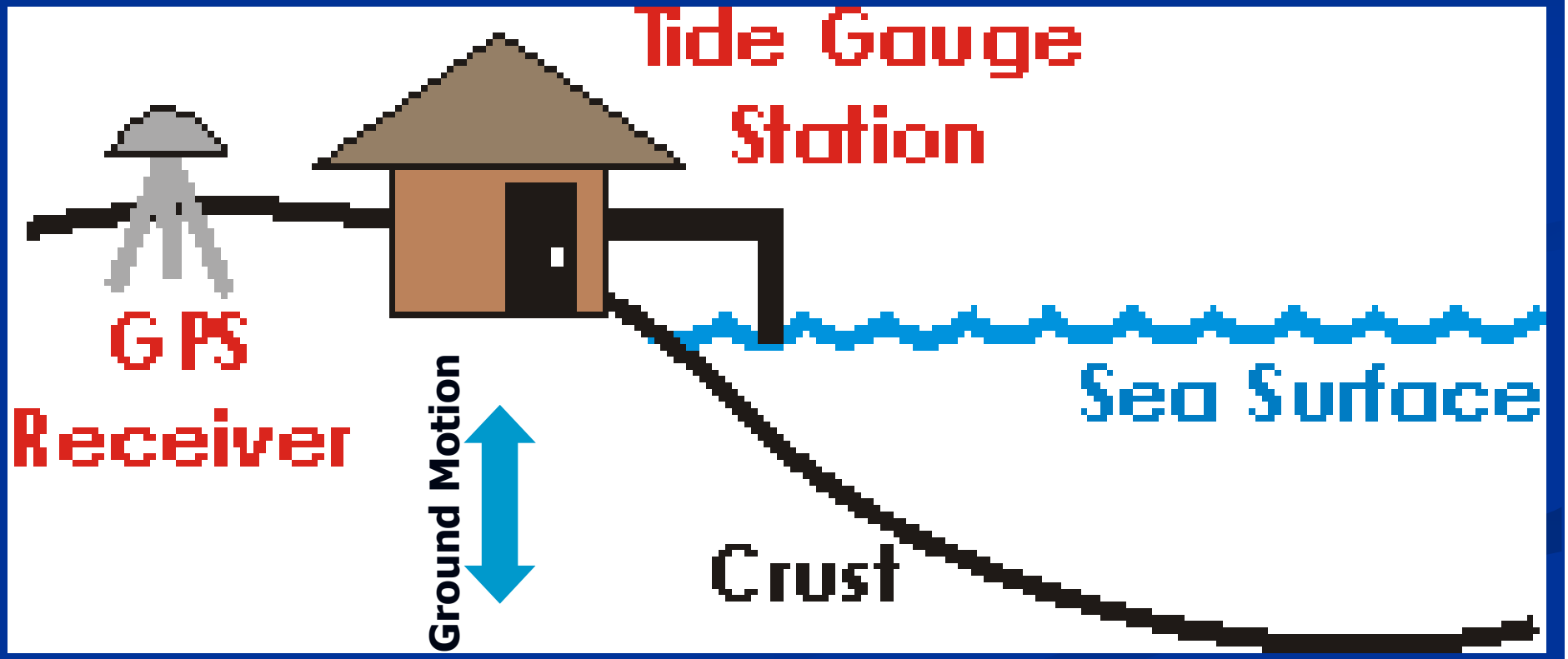
- *"… there is strong scientific consensus that climate change is accelerating sea-level rise …"*

  - U.S. Climate Change Science Program (2009)

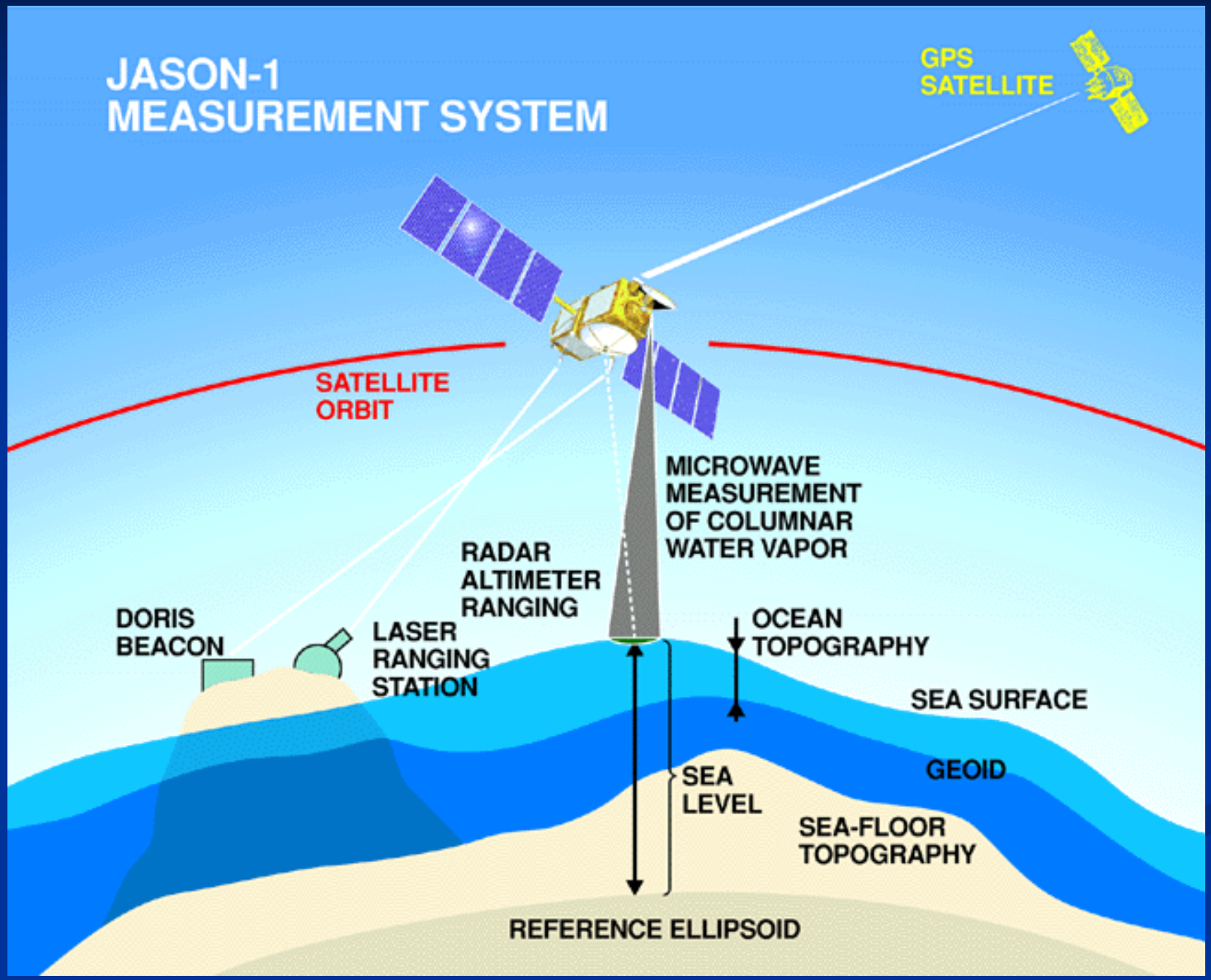
Not According to the Peer Reviewed Literature

- Douglas (1992), Journal of Geophysical Research (JGR), analyzed world-wide gauges and found a deceleration from 1905-1985
- Jevrejeva et al (2006), JGR, found a deceleration for 20th Century
- Holgate (2007), Geophysical Research Letters, found a deceleration from 1904-2003
- Church et al (2004), Journal of Climate, found no increase in the rate of sea level rise from 1*950-2000*
- Woodworth (2006), Philosophical Transactions of the Royal Society, said *"... No definitive long-term acceleration of sea level has been identified using 20th Century data alone"*
- Woodworth et al (2009), International Journal of Climatology, note *"… little evidence has been found in individual gauge records for an ongoing positive acceleration of the sort suggested for the 20th Century by climate models"*

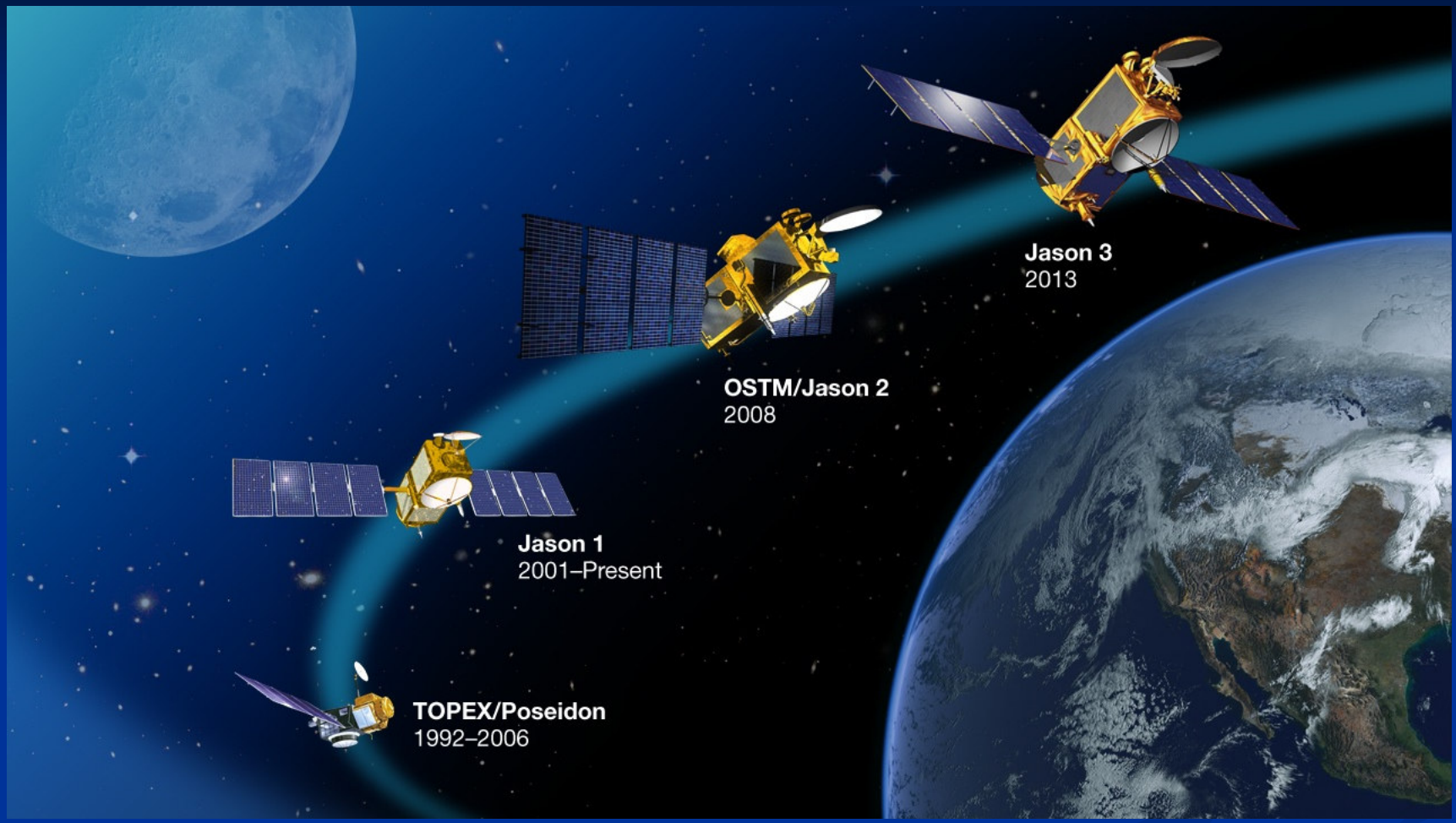
Tide Gauge


Tide Gouge
Station
GPS
Receiver
Ground Motion
Sea Surface
Crust

Satellite Altimetry

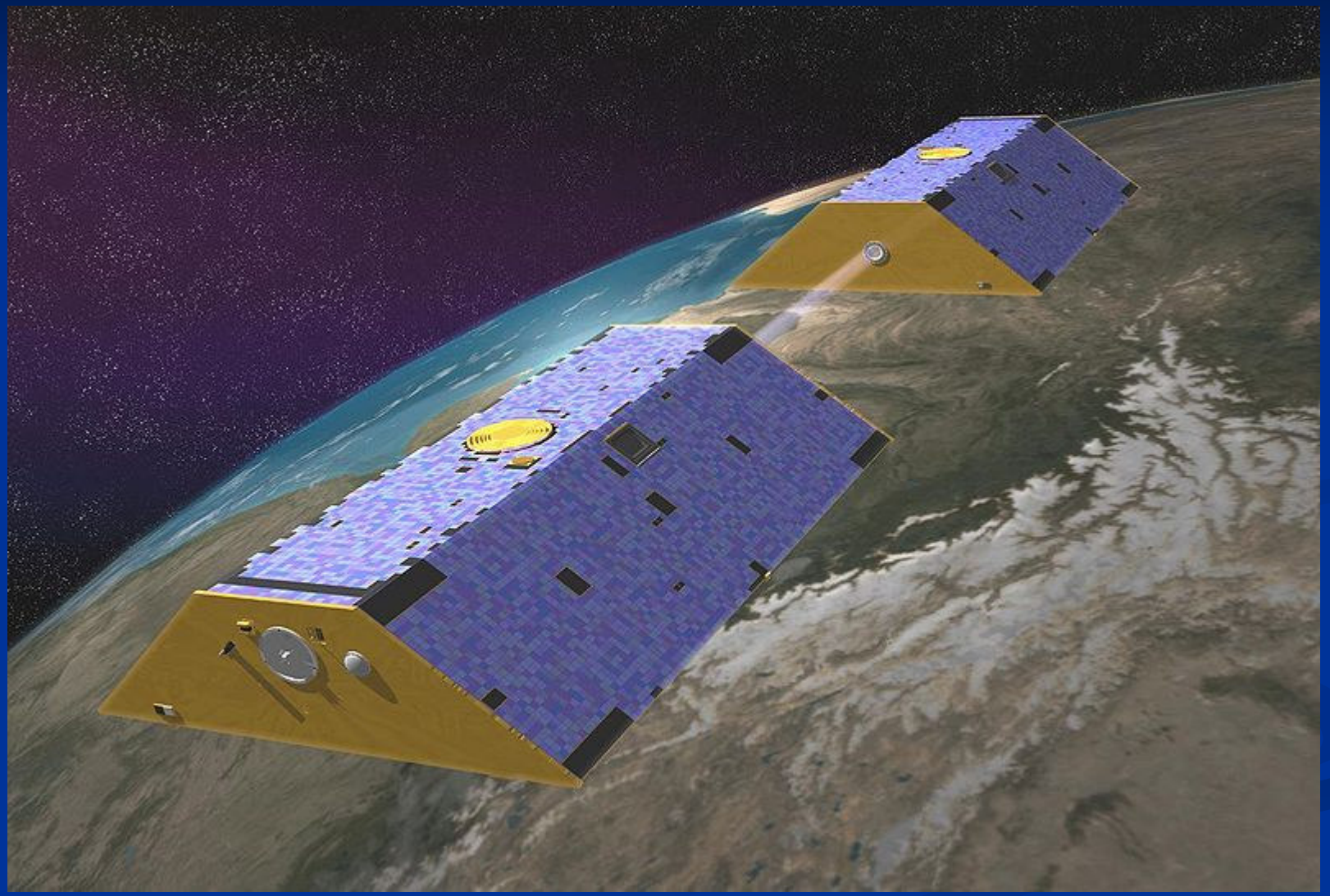


Satellite Altimetry Series



- 830 miles above Earth, can measure ocean surface within 1.3 inches
- Measures ocean surface between -66 degrees and + 66 degrees latitude
- Great WEB Site

GRACE Satellites



300 miles above Earth, 120 miles apart, can detect displacements of the size of a human hair

Sea Level Rise Components as Measured by a Tide Gauge

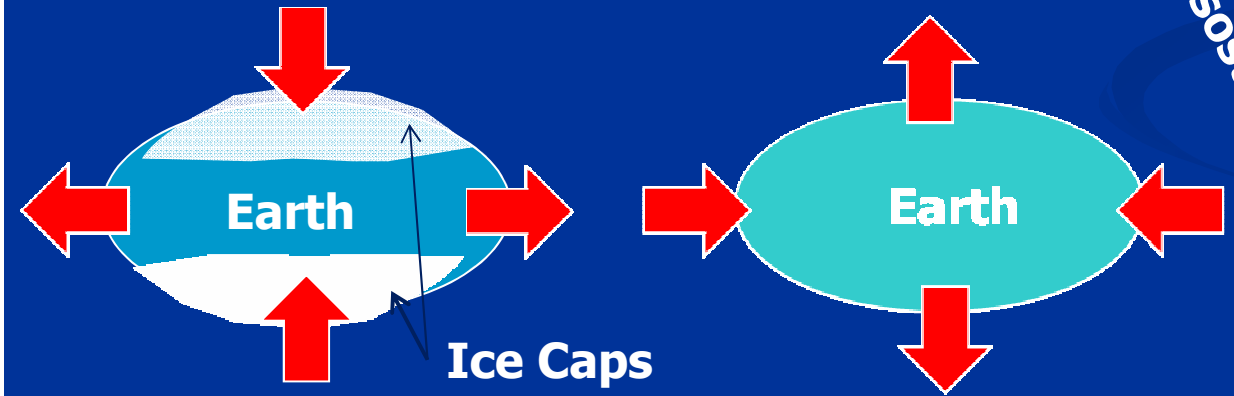
Sea Level Rise Components as Measured by a Tide Gauge

Sea Level = World Wide Sea Level + GIA + Local Effects + Noise

Global Sea Level

Glacial Isostatic Adjustment

Can Be Natural or Anthropogenic



Last Ice Age
20,000 Years Ago

Presently

Glacial Isostatic Adjustment

Examples of Local Effects

Natural

- **Compaction of Underlying Sediments**
- **Earthquakes**

Anthropogenically Induced

- **Withdrawal of Ground Fluids (Gas, Oil, Water)**
- **Building Heavy Structures on Weak Sediments**

It is noteworthy that almost all anthropogenic effects cause a lowering of land and thus a relative rise in sea level

The Algebraic Relationship

$$y = a_0 + a_1 t + \frac{1}{2} a_2 t^2$$

Sea Level

Constant

Initial Trend (mm/yr)

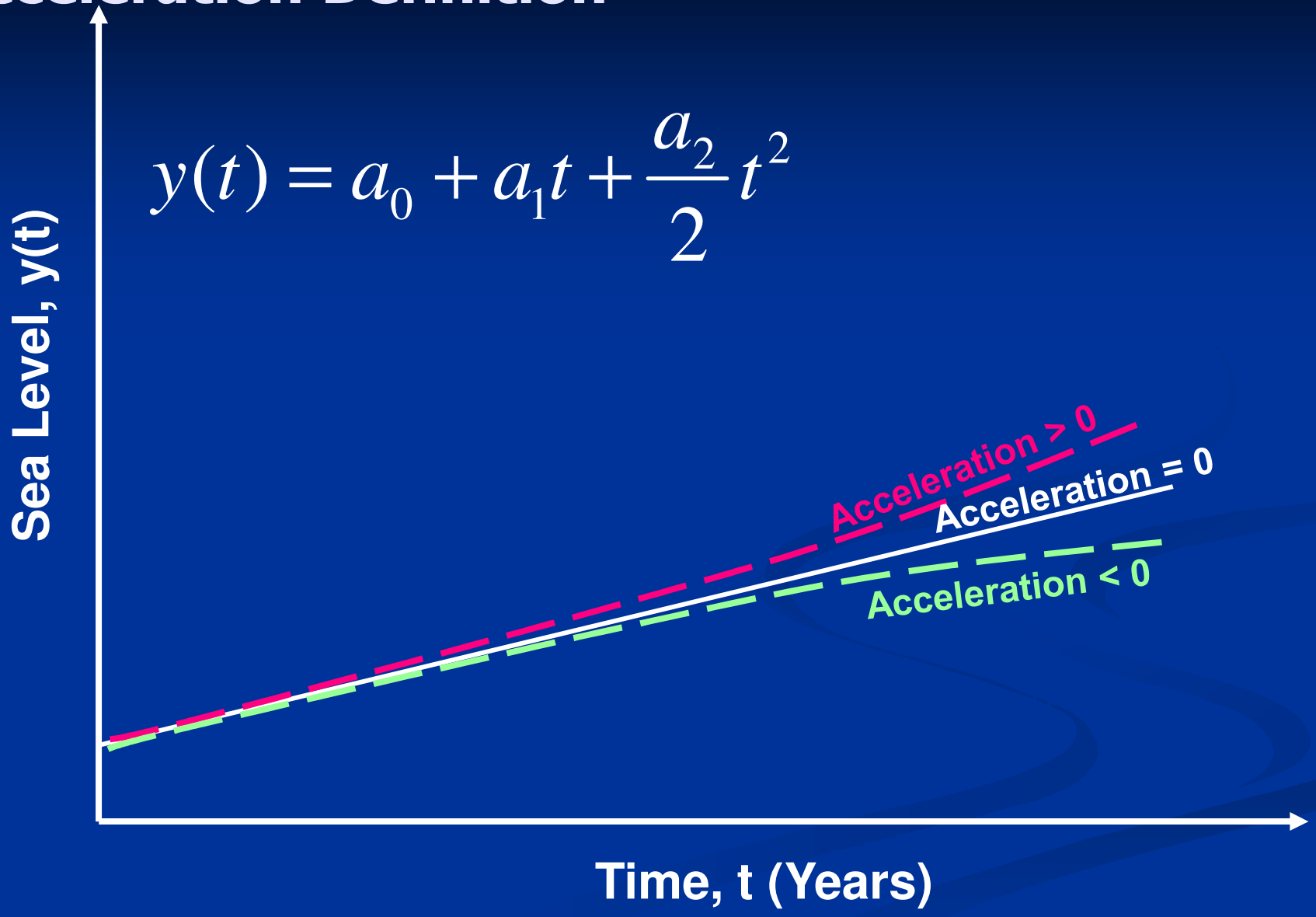
Time (Years)

Acceleration (mm/yr^2)

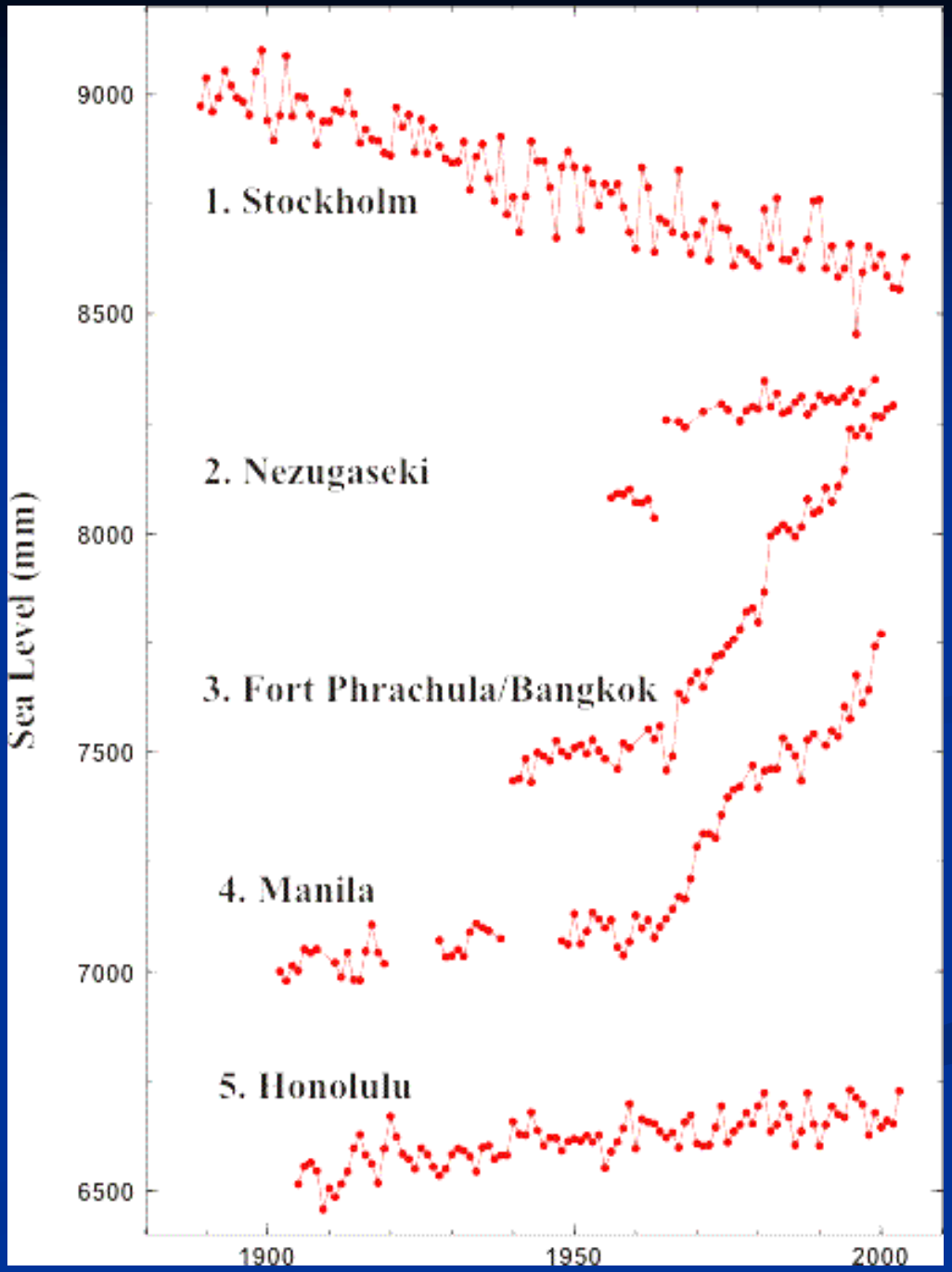
The accepted value of a_1 over the last century for the global trend is approximately 1.7 mm/yr

Acceleration Definition

$$y(t) = a_0 + a_1 t + \frac{a_2}{2} t^2$$



Tide Gauge Data Are Not Always Consistent With the Model



Resources for Sea Level Analysis

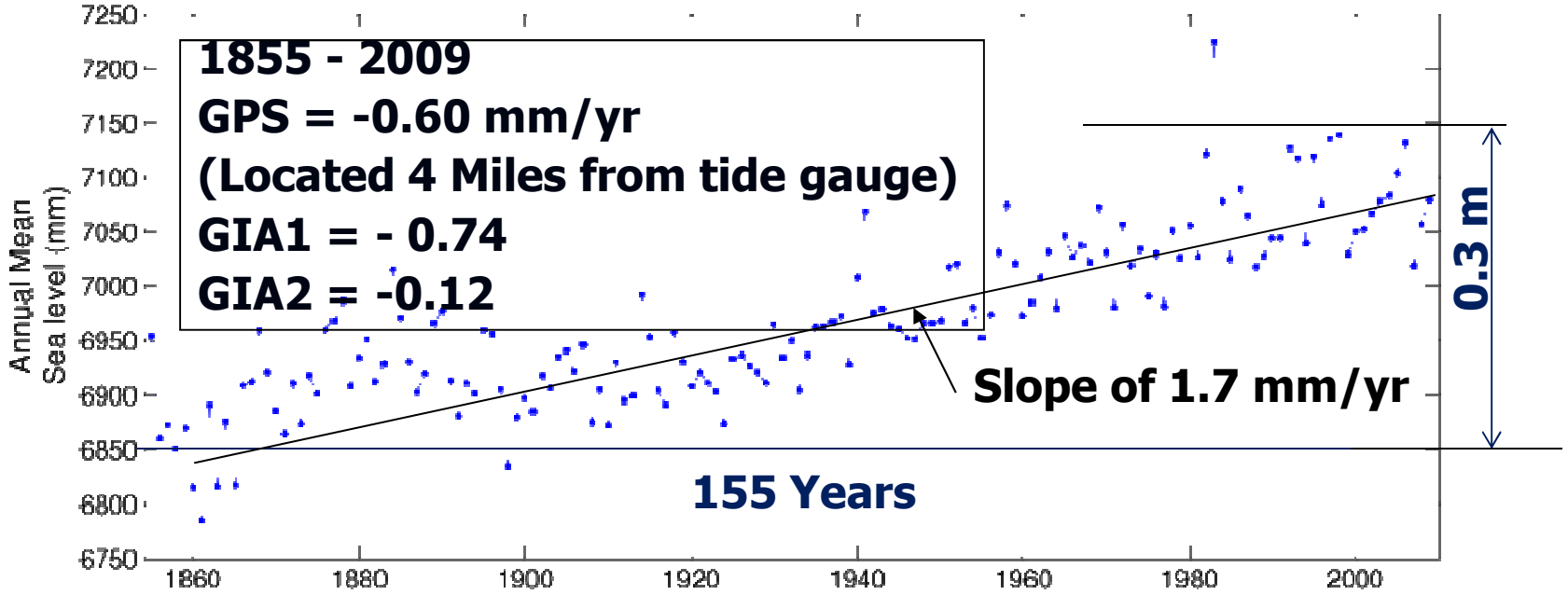
- **Permanent Service for Mean Sea Level (More than 2,000 gauges): http://www.psmsl.org/**
- **University of Colorado Satellite Altimetry Website: http://sealevel.colorado.edu/**
- **SONEL GPS Website: http://www.sonel.org/-GPS,28-.html.**

Ideal Tide Gauge Record

- Long record (At least 50 to 60 years)
- Near continuous (Minimal gaps)
- Location geologically stable
- Lots of gauges of the above type

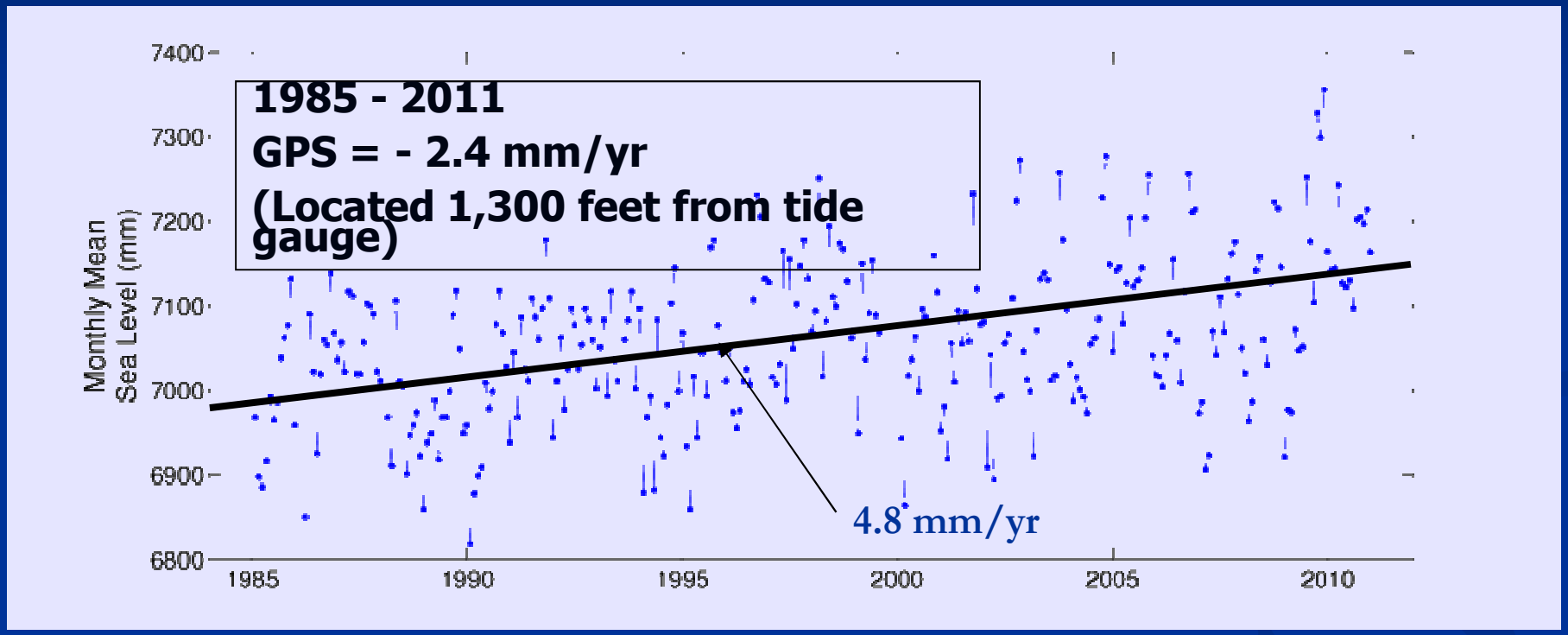
Example of Tide Gauge Record

(San Francisco: The Longest U.S. Gauge)



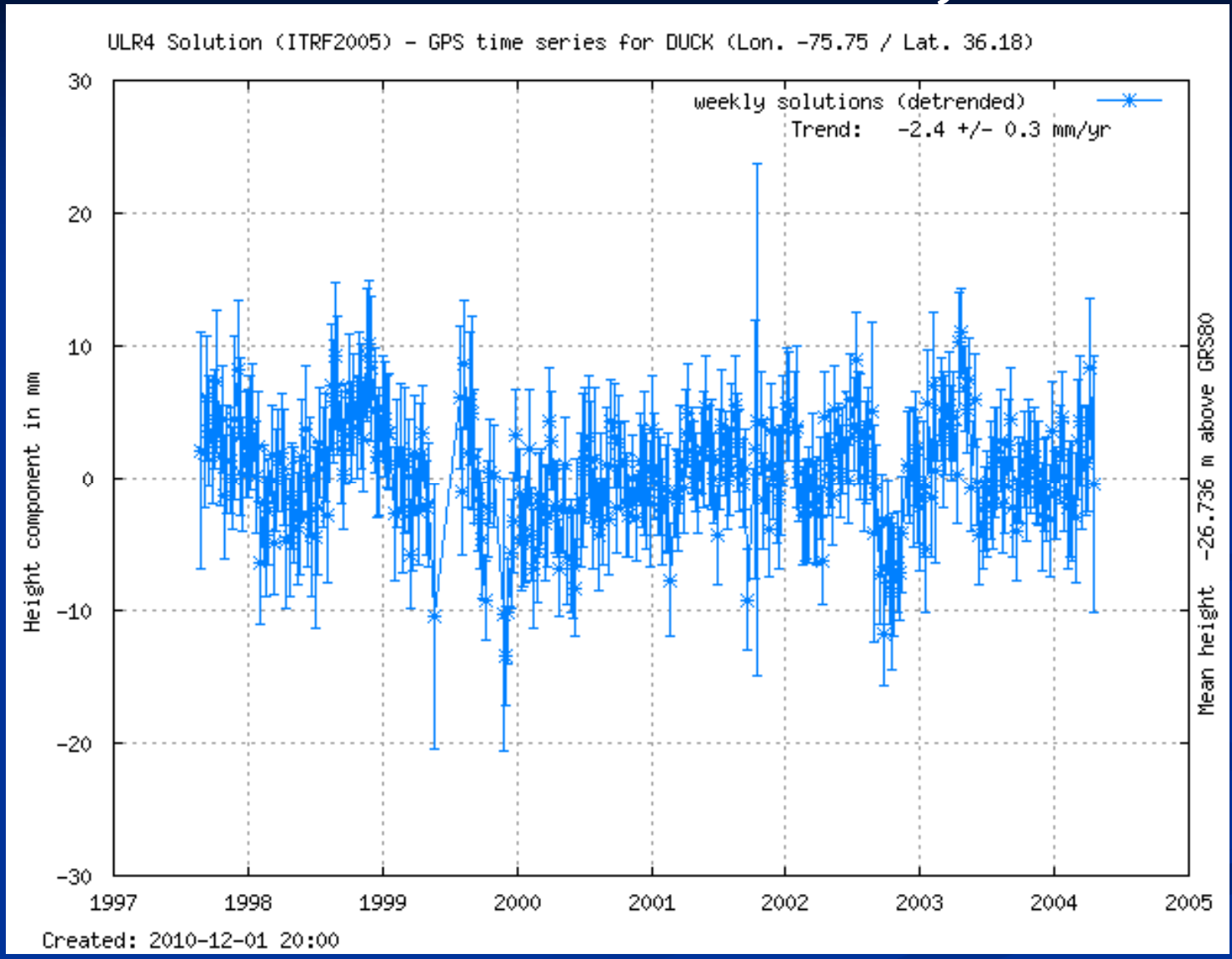
From PSMSL Web Site

Sea Level at Duck Pier, NC



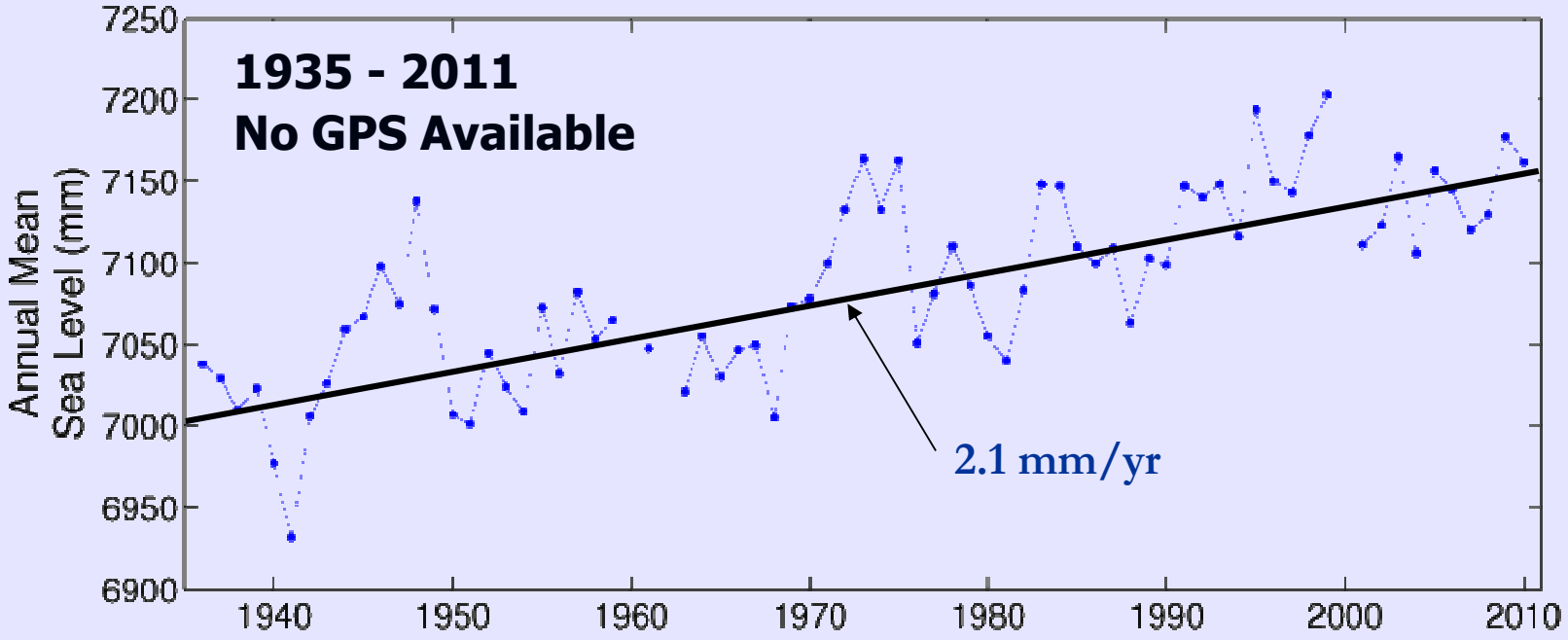
From PSMSL Web Site

GPS Data at Duck, NC



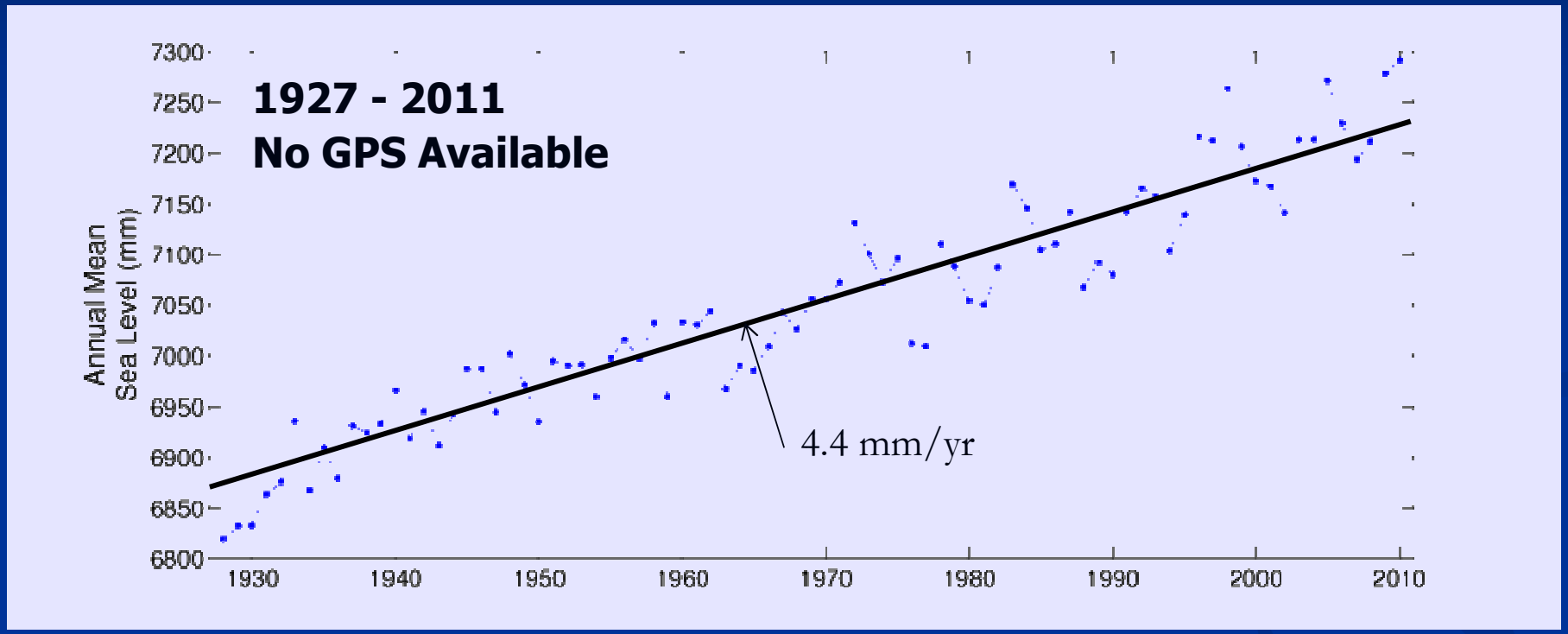
From SONEL Web Site

Sea Level at Wilmington, NC



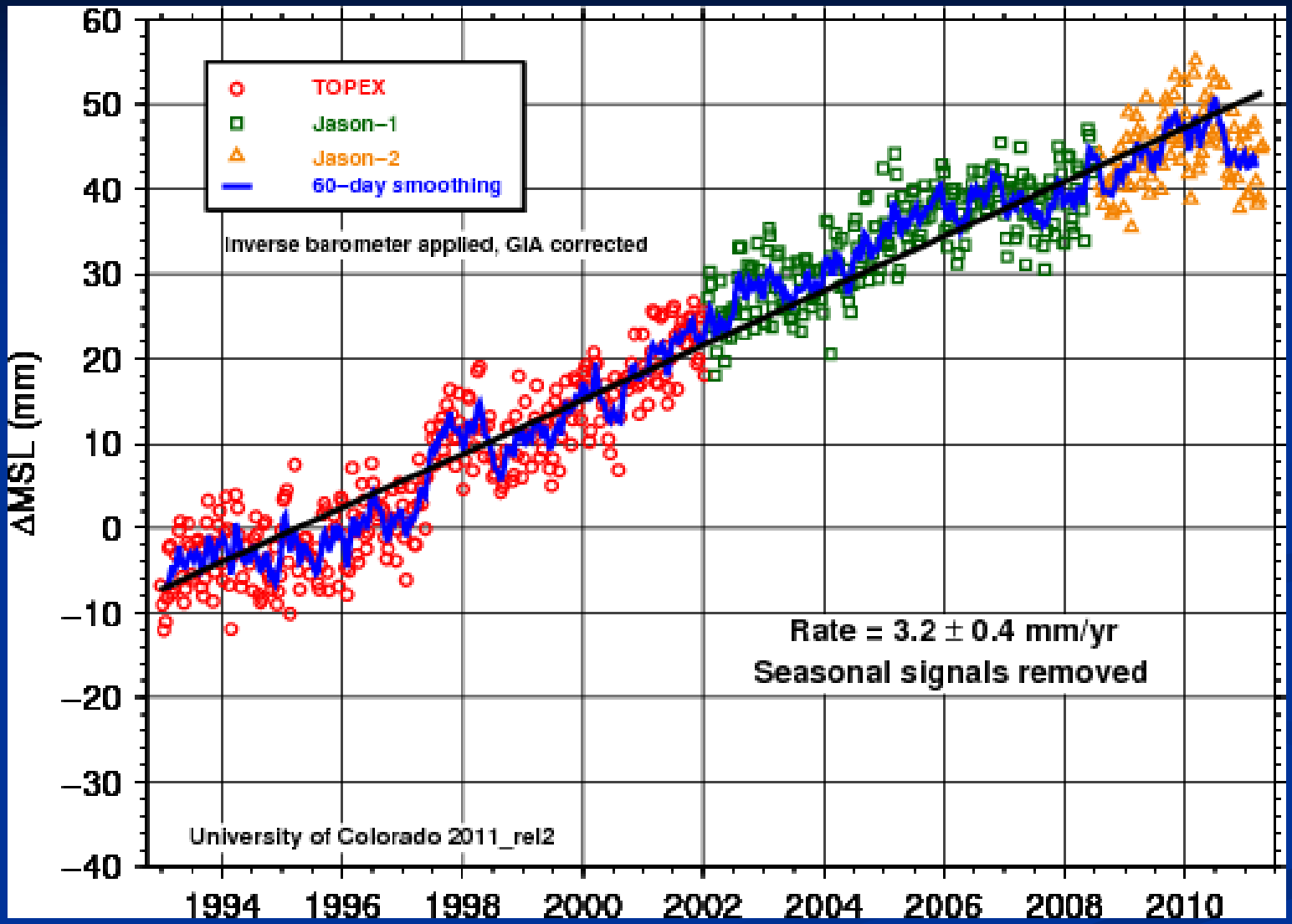
From PSMSL Web Site

Sea Level at Hampton Roads, VA



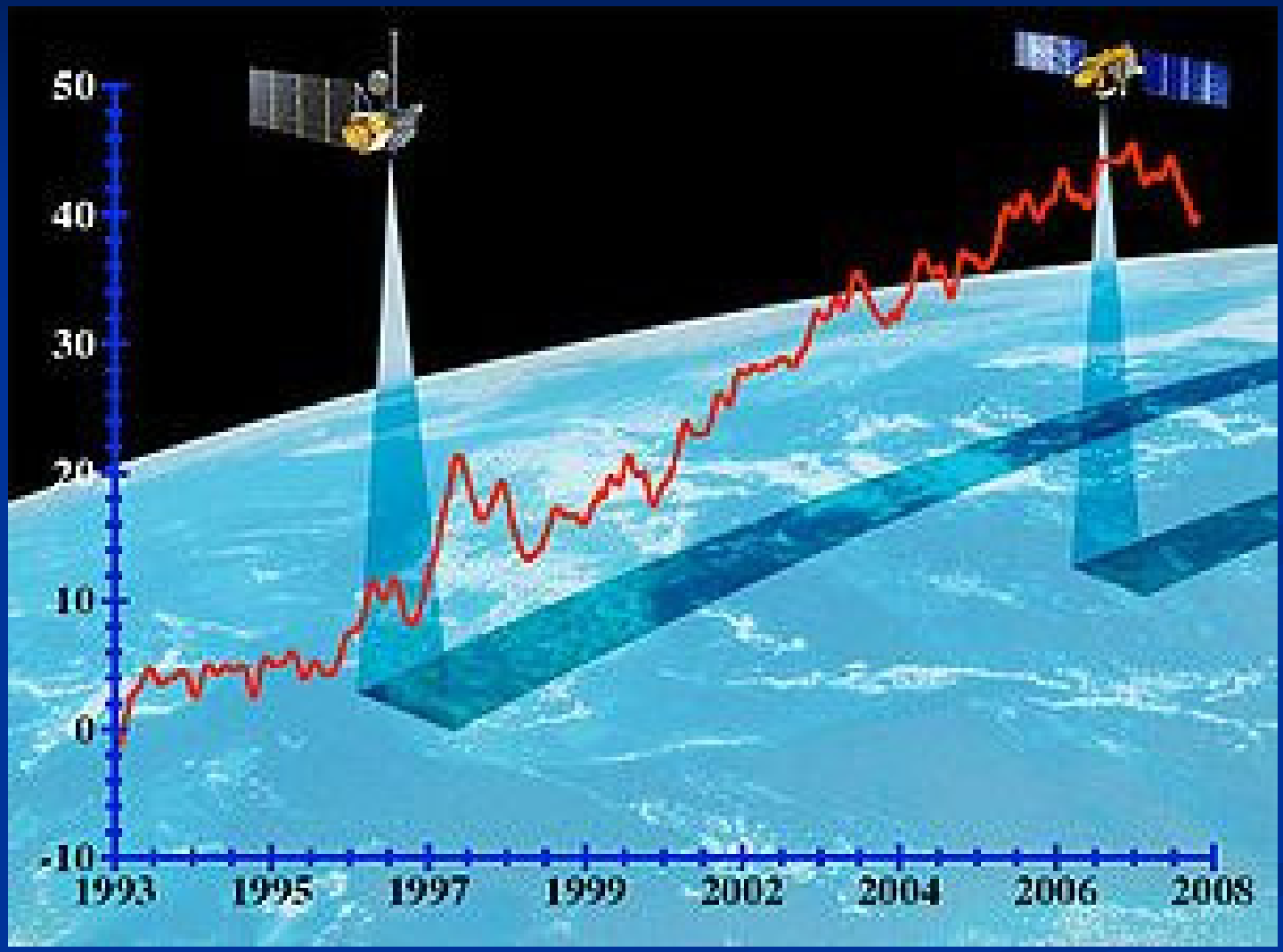
From PSMSL Web Site

Average Sea Level Change From Satellites



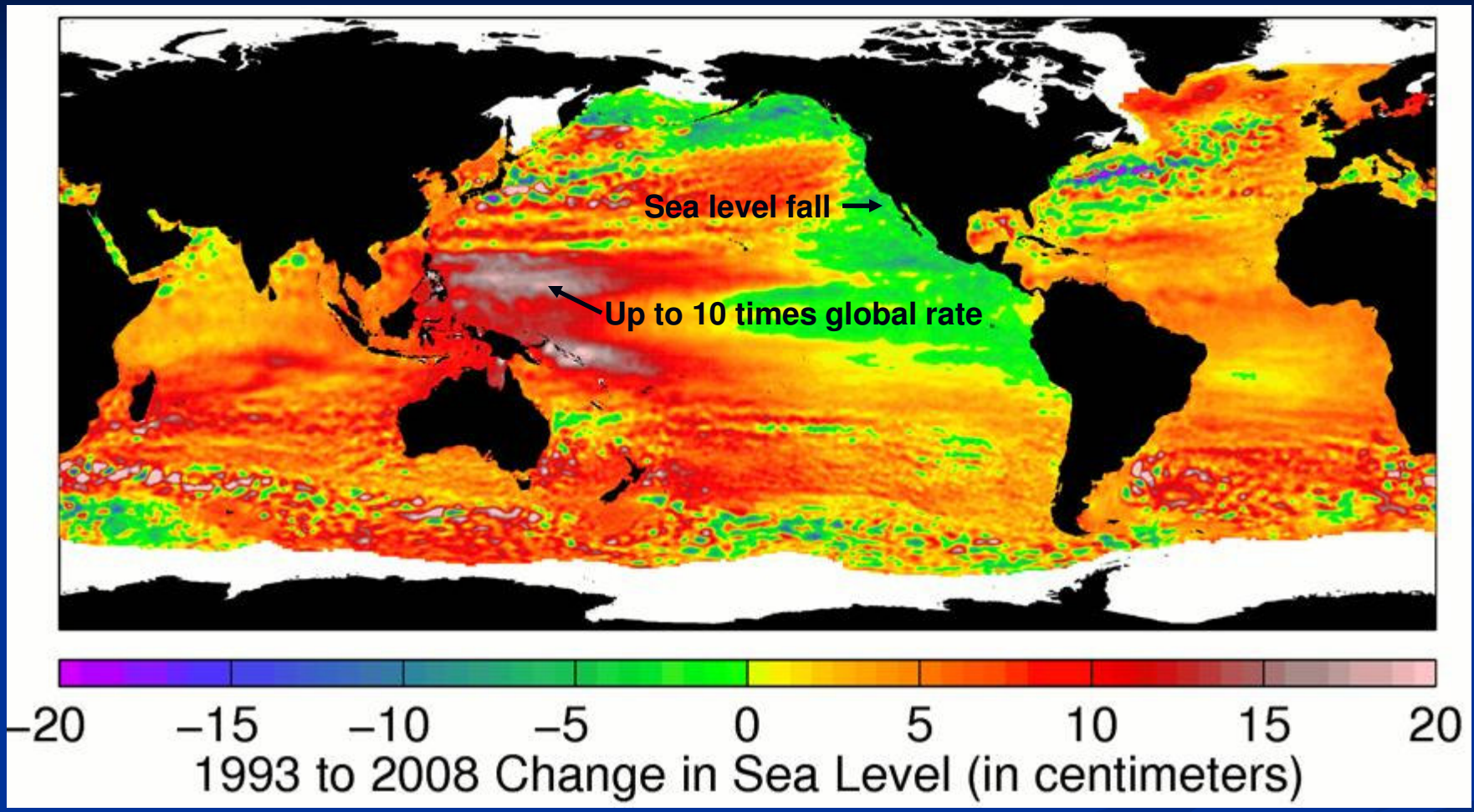
It is noteworthy that Satellite Data are calibrated against a fairly small set (64) of tide gauges!

Are Satellite Measurements 1993-2011 Leading Edge of Acceleration?



3.2 mm/yr trend is greater than 20th Century trend of 1.7 mm/yr

Sea Level Rise Is Spatially Very Non-Uniform



Satellite altimeter measurements over 15 years

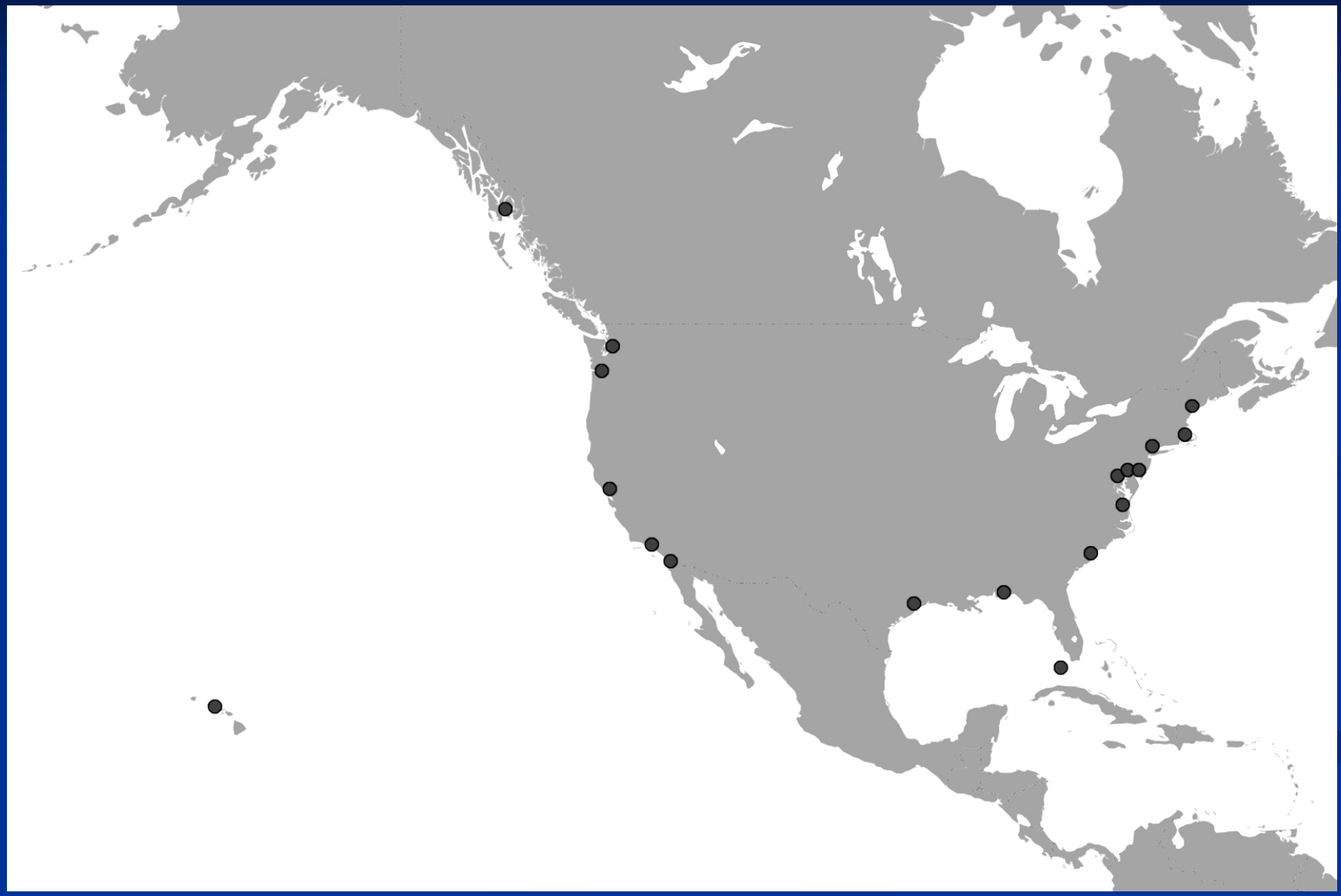
Our Findings to Present

- **Over the 20th Century Global Sea Level:**
  - **Increased at a Rate of Approximately 1.7 mm/yr**
  - **Experienced a Small Negative Deceleration**
- **Since the 1990's Satellites Indicate a Global Sea Level Increase at a Rate of 3.2 mm/year**

Our First Effort

- **Analyzed Long-Term U. S. Tide Gauges to Determine Trends and Accelerations**
- **Two Methods:**
  - **Averaged Gage Records, Analyzed**
  - **Analyzed Individual Records and Averaged Results**

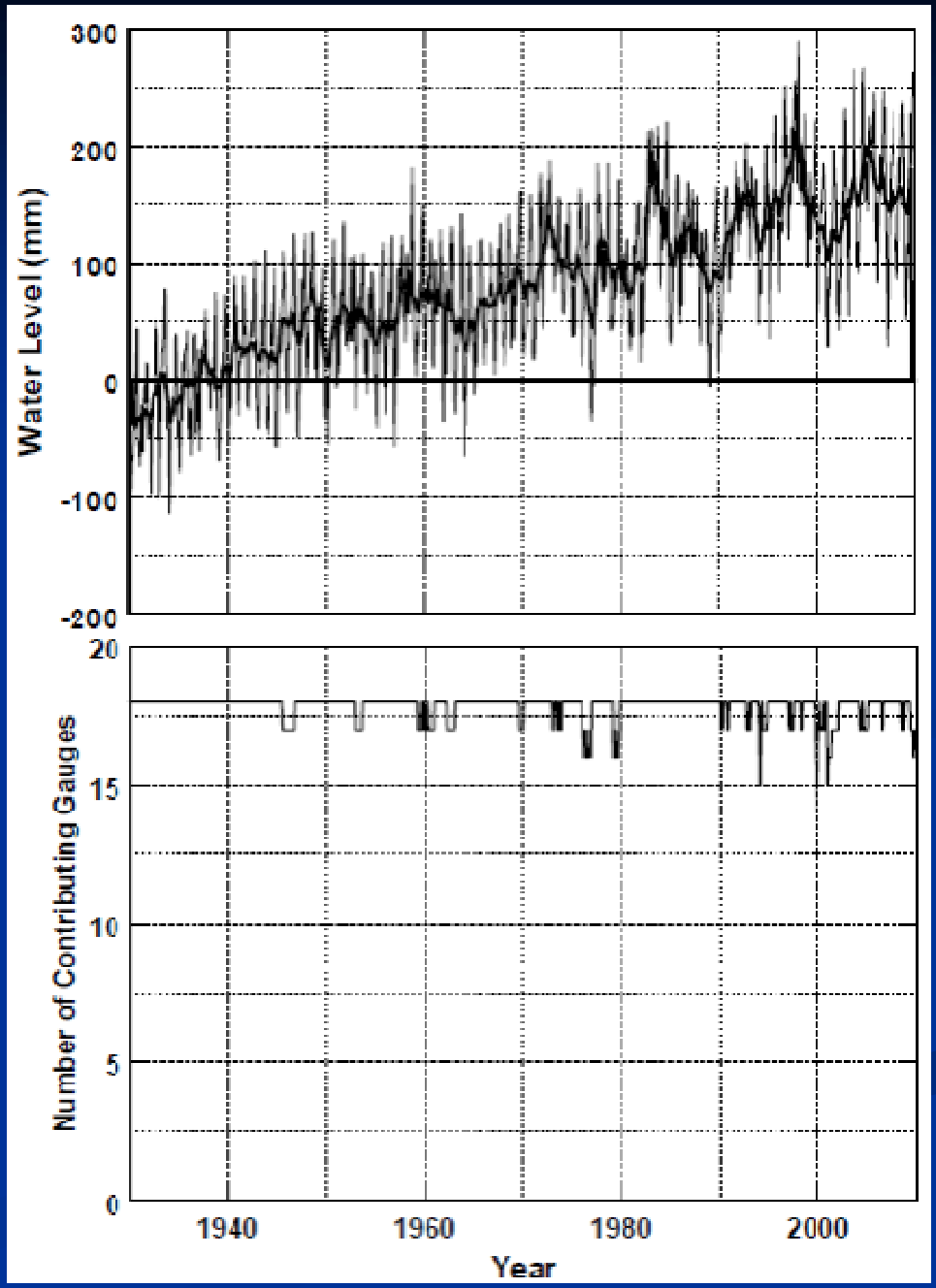
Locations of 18 Long-Term Gages



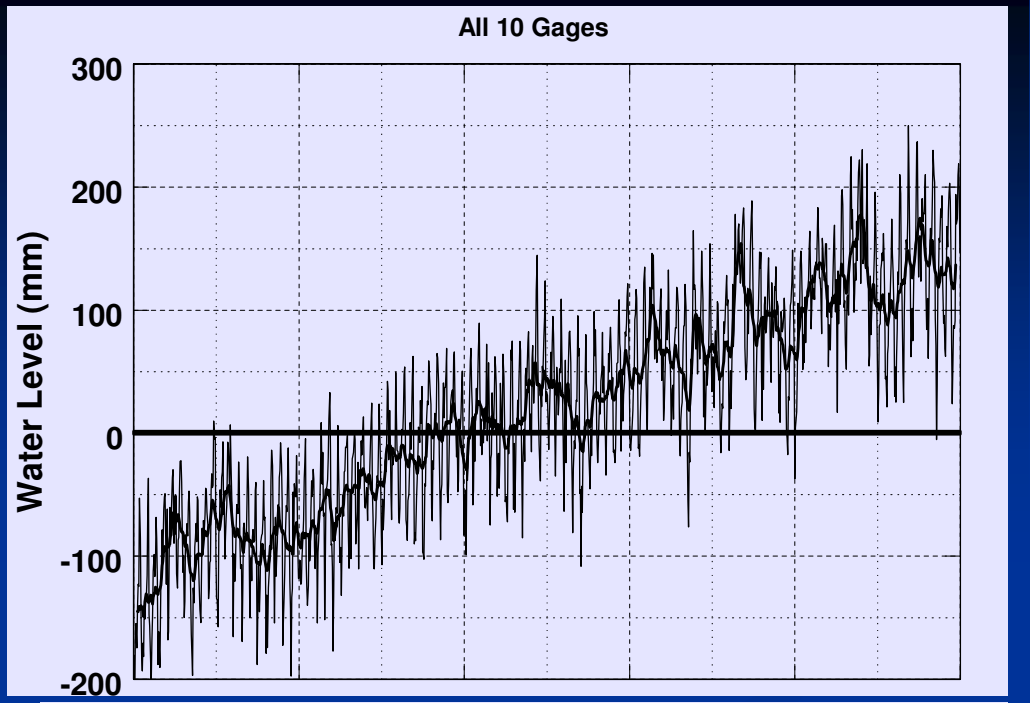
Average Record for 18 Long-Term U. S Gauges (80 Years)

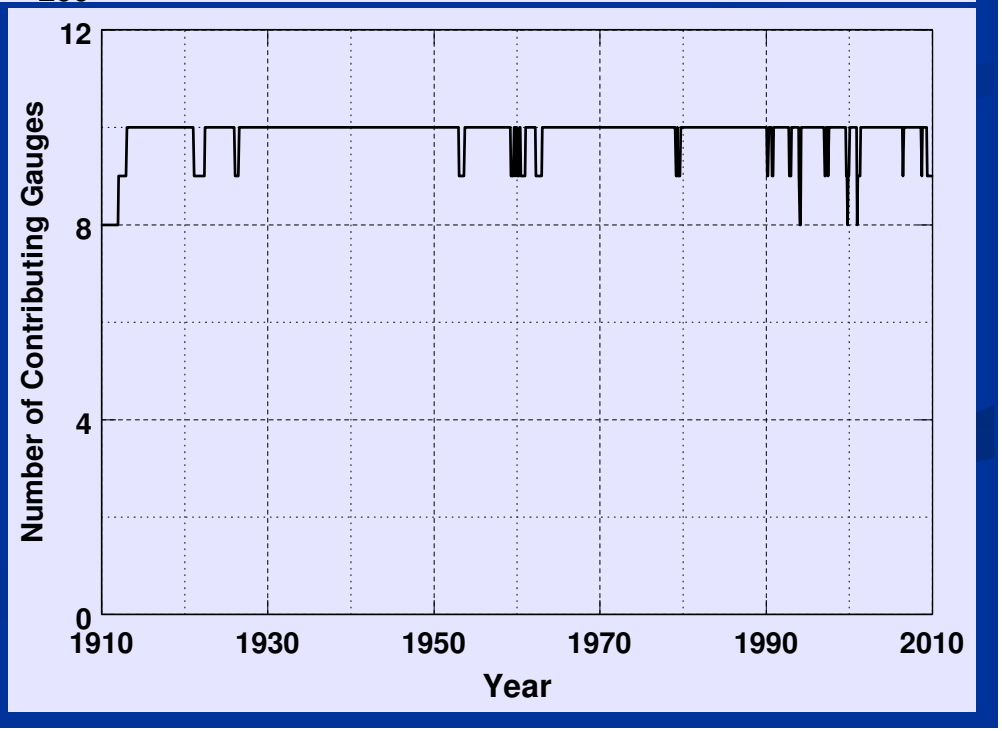
Limited Missing Data to 5%

Average: 1.1 %



Average Record for 10 Long-Term U. S Gauges (100 Years)





Results of Effort 1

Data Group	Analysis Method			
	1 (Average Records, Analyze Average)		2 (Analyze Individual Records, Average Results)	
	Trend (mm/yr)	Acceleration (mm/yr^2)	Trend (mm/yr)	Acceleration (mm/yr^2)
1 (1930 – 2010, 18 Gauges)	2.32	- 0.0134	2.37 ± 0.786	-0.0105 ± 0.0088
2 (1910 – 2010, 10 Gauges)	2.71	- 0.0072	2.47 ± 0.388	- 0.0061 ± 0.0049

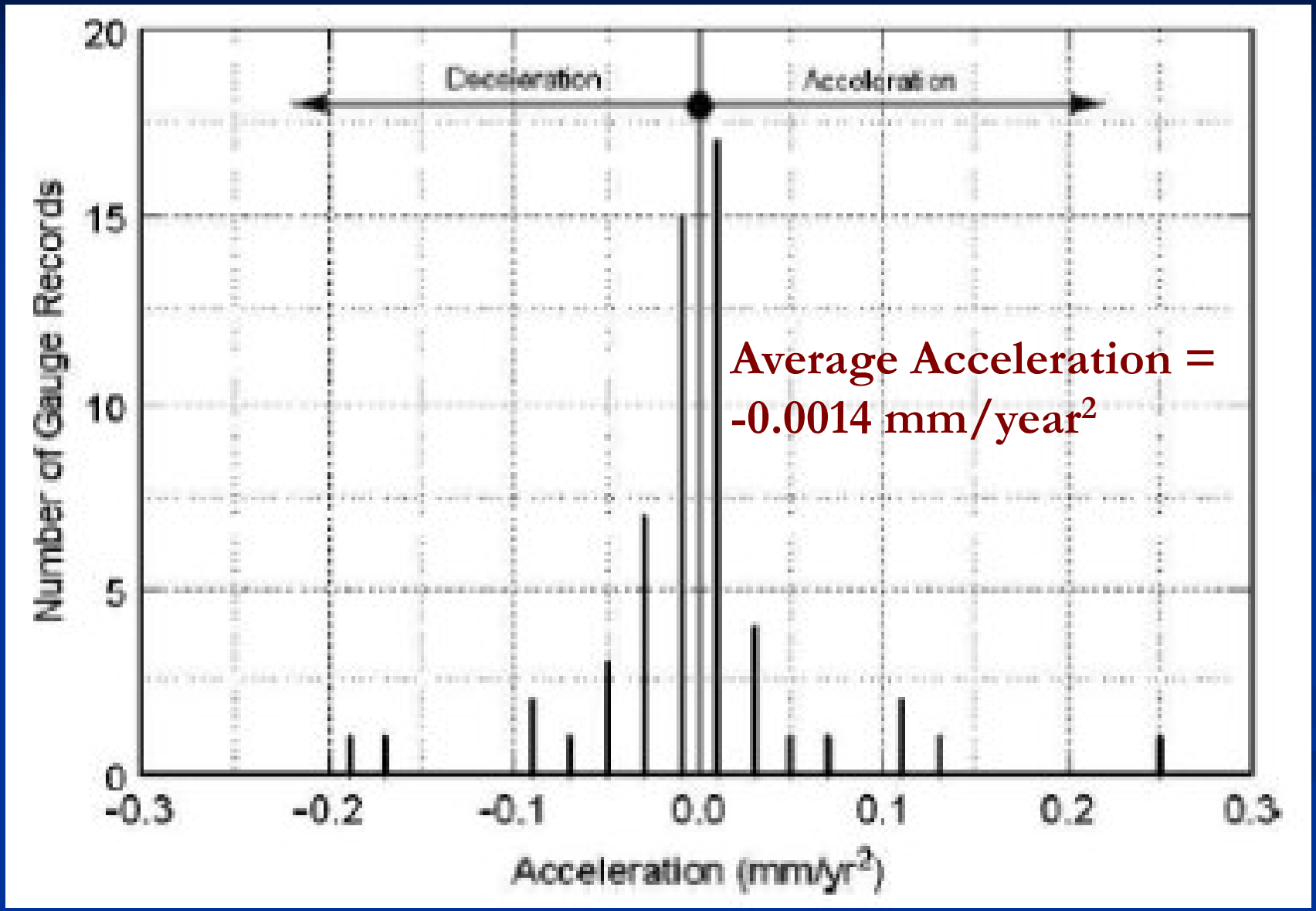
Our Second Effort

- Analyzed 57 U. S. Gages With Average Record Length of 82 Years
- Analyzed 23 World Wide Gauges Selected for Balanced Global Coverage (25 Year Extension of Douglas' 1992 Work)

- Found: Small Negative Accelerations for Both U. S. and Global Coverage

Locations of 57 U. S. Gauges

Example Results From Second Effort



Our Third Effort (Still in Progress)

- Analyzed 460 Tide Gauges with > 50% data completeness over the period 1993 to present (Subset with 85% complete)
- Analyzed subset with GPS present
- Analyzed 313 Satellite records for locations in proximity with tide gauges
- Compared trends and accelerations for gauge and satellite results

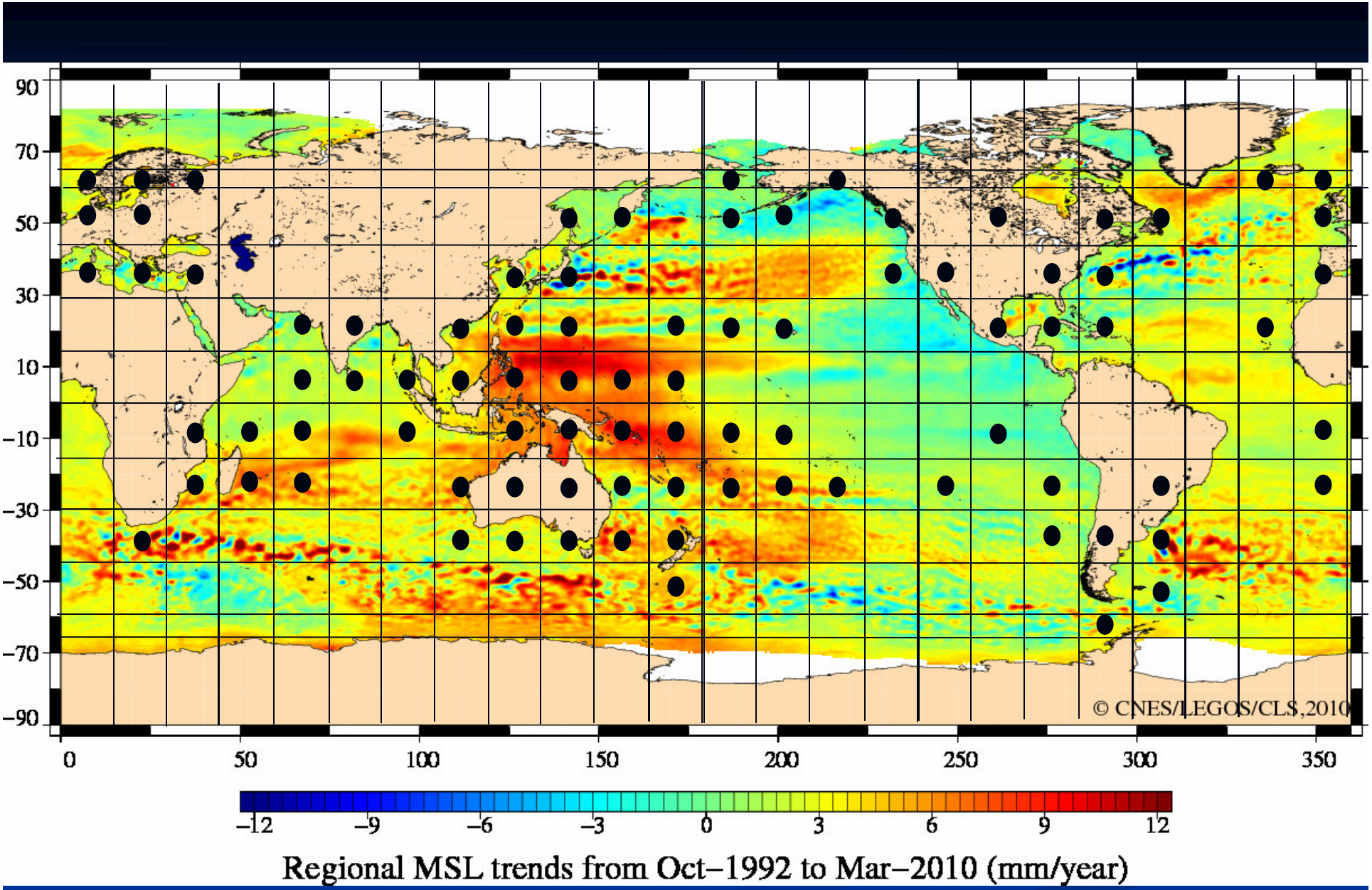


Chart of Sub Areas Occupied by Tide Gauges Analyzed

Analysis of Tide Gauges With 85% Data Complete Since 1993

Data Description	No. of Gauges	Trend (mm/year)	Acceleration (mm/year^2)
All Data	371	3.12± 0.81	- 0.181 ± 0.200
All Data Corrected for GPS if Present	371	3.10± 0.64	- 0.181 ± 0.200
Data With GPS Present	59	2.47 ±1.24	- 0.138 ± 0.229
Data With GPS Present Adjusted for GPS	59	2.28 ±1.04	- 0.138 ± 0.229

Adjustment of Tide Gauge Data for Spatial Bias Using Satellite Data (No Adjustments for GIA or GPS)

$$V_{Tide\ Gauge\ Adjusted} = \frac{V_{Satellite,\ All\ Active\ Subareas}}{V_{Satellite,\ Same\ Subareas\ as\ Gauges}} V_{Tide\ Gauge\ Unadjusted}$$

Adjustment of Tide Gauge Data for Spatial Bias Using Satellite Data (No Adjustments for GIA or GPS)

$$V_{Tide\ Gauge\ Adjusted} = \frac{V_{Satellite,\ All\ Active\ Subareas}}{V_{Satellite,\ Same\ Subareas\ as\ Gauges}} V_{Tide\ Gauge\ Unadjusted}$$

Data Set	Trend (mm/year)	Acceleration (mm/yr^2)
Full (371 Gauges)	2.44 (vs 3.12 Unadjusted)	- 0.172 (vs - 0.181 Unadjusted)
GPS (59 Gauges)	2.26 (vs 2.47 Unadjusted)	- 0.101 (vs – 0.138 Unadjusted)

Summary

1. **Over the last year, we have conducted extensive analyses of quality tide gauge data including world wide and U. S. gauges.**
2. **The results of all of our analyses are consistent - There is no indication of an overall world-wide sea level acceleration in the 20th Century data. Rather, it appears that a weak deceleration was present.**
3. **We have also conducted an extensive comparison of satellite and tide gauge data.**
4. **Satellite data are calibrated with tide gauge data and require a substantial "correction" for drift which increases the trend (0.6 mm/yr).**

Summary (Continued)

5. Our preliminary examination of large numbers (371) of tide gauge records over the period 1993 through 2010 suggest trends of approximately 2.3 to 2.4 mm/yr.

6. The relative dearth of tide gages in the Southern Hemisphere is a serious drawback in determining global sea level characteristics.

7. Relative Sea Level Rise along parts of the North Carolina Coast appears to be approximately 4.8 mm/year (1.6 feet/century). At Wilmington, the trend is approximately 2 mm/yr (0.7 ft/century)

8. At Duck, approximately 60% of the relative sea level rise is due to subsidence; however, this is based on only a 6 year GPS record at Duck Pier.

Summary (Continued)

9. If the 20th Century Global sea level rise rate (of 1.7 mm/yr) were to double, the Relative Sea Level Rise Rate along the NC coast would range between approximately 13 and 23 inches by 2100.
10. It is not clear whether the current satellite results are a new trend or part of a cycle.

Recommendations

1. **Continue collecting tide gauge data.**
2. **In view of the significant differences in the model-produced GIA values, install more GPS units adjacent to longer term tide gauges.**
3. **Continue to monitor the satellite altimetry results.**

Thank You!