What the Science Shows Us about How Sea Level Rise and Weather Events Will Affect Ports

AAPA Climate Change Workshop

January 27, 2011

Richard Edwing

Outline

- Sea Level Change
  - Global and Relative
- Sea Level Trends and Projections
- Incorporating Sea Level Guidance
- Other Impacts of Climate Change

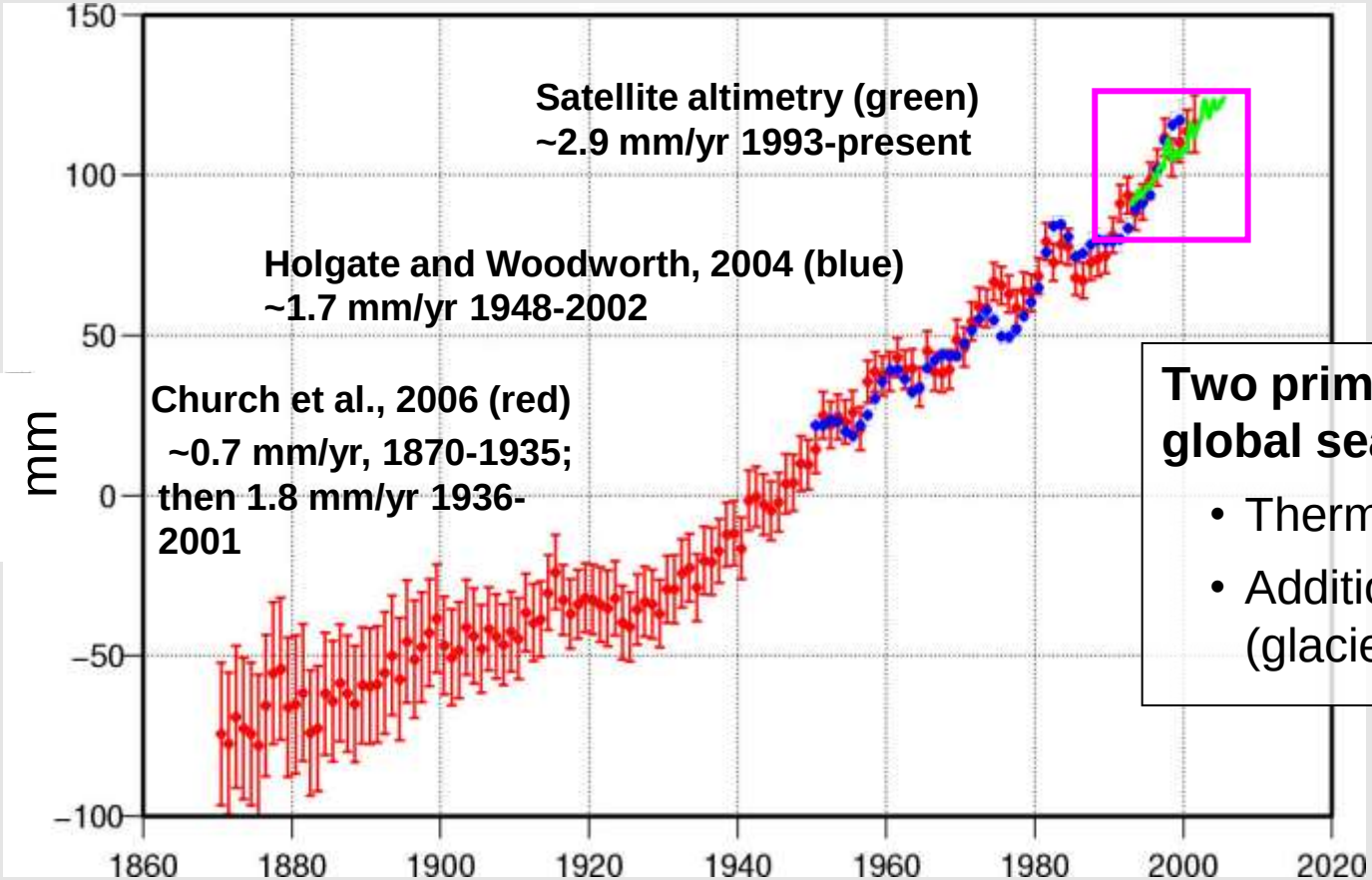
Sea Level Change – Two Distinct Attributes

- **Global Sea Level**
  - The average height of all the Earth's oceans
  - Caused by the global change in the volume of water in the world‘s oceans in response to three climatological processes:
    1. Ocean volume change associated with the ice ages
    2. Density changes from total salinity
    3. Heat content of the world‘s ocean, which recent literature suggests may be potentially accelerating due to global warming

- **Relative Sea Level**
  - The local change in sea level relative to the elevation of the land at a specific point on the coast.

Global Sea Level

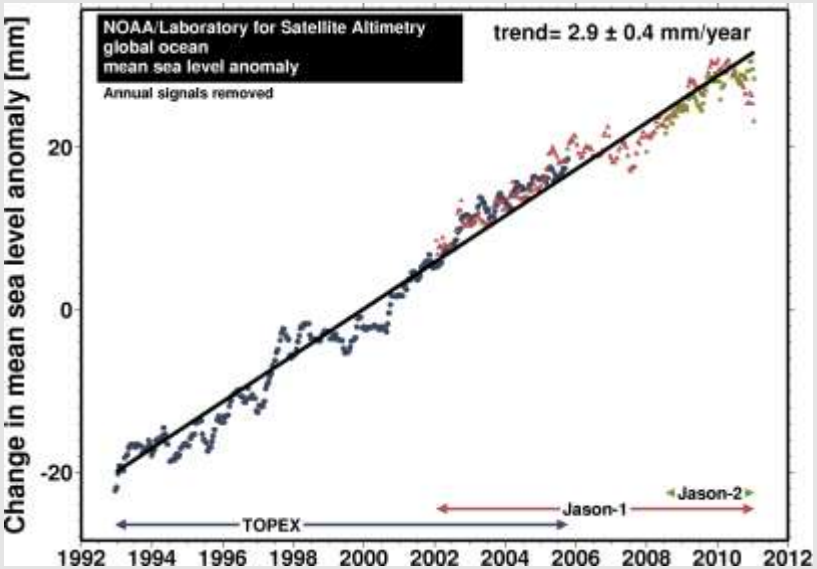
The Global Mean Sea Level Trend From Tide Gauges & Altimetry Suggests a recent Acceleration



Two primary causes of global sea level rise:

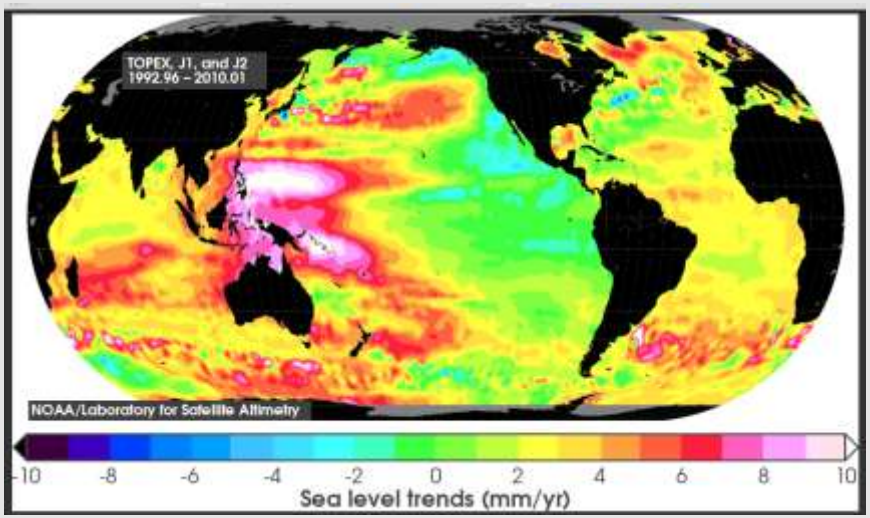
- Thermal expansion
- Addition of water volume (glaciers, ice sheets, etc)

Global Sea Level - The Satellite Altimeter Record

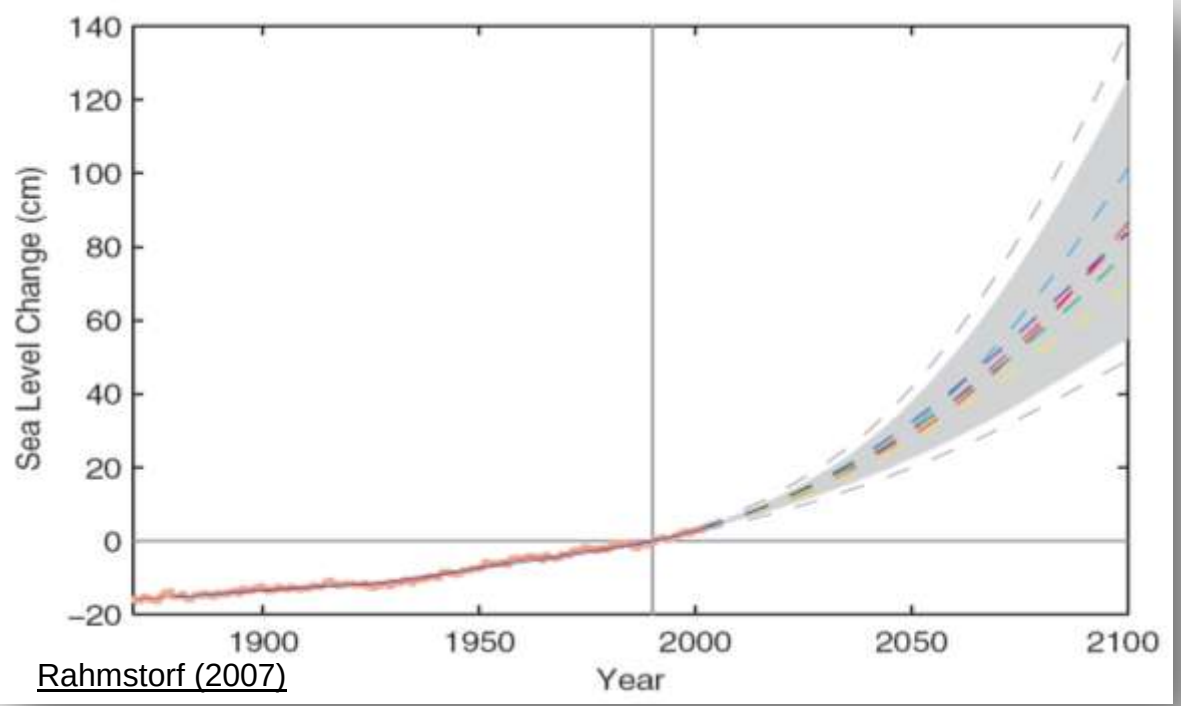


The overall global rate from multiple missions. Coverage from 60N to 60S from 1993 to present.

There is a diversity of regional rates from satellite altimetry that go into the computation of the overall global rate.



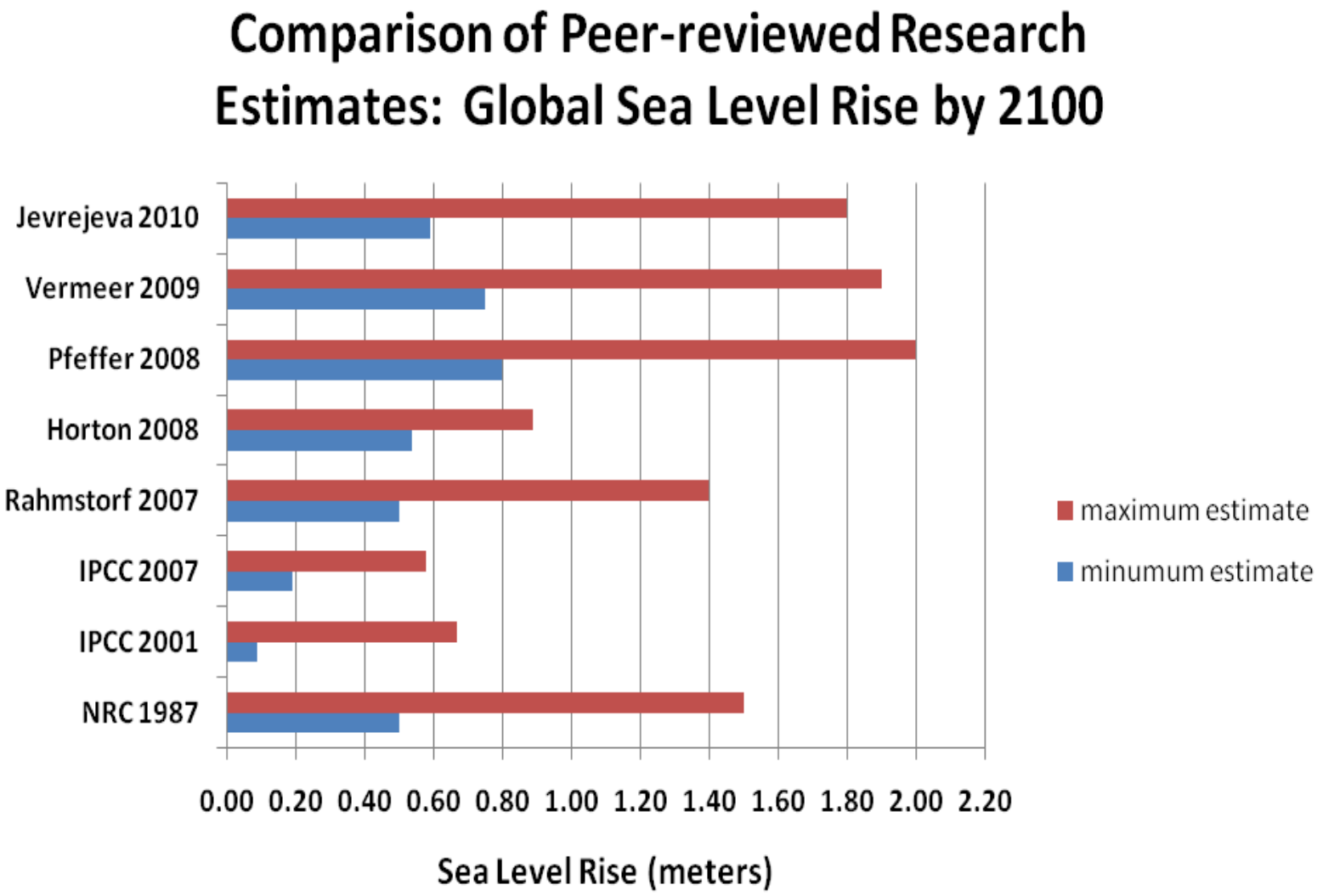
Sea Level Rise Trends and Projections



Rahmstorf (2007)

- **The Intergovernmental Panel on Climate Change (IPCC) 2007 report projected a 18 to 59 cm sea level rise from a 1.1 and 6.4 °C temperature increase during the 21st century.**
- **The Rahmstorf (2007) projection (in gray in the above graphic) considers potential contributions from accelerated ice melt in Greenland and Antarctica which IPCC did not consider.**

Global Sea Level



Local Mean Sea Level

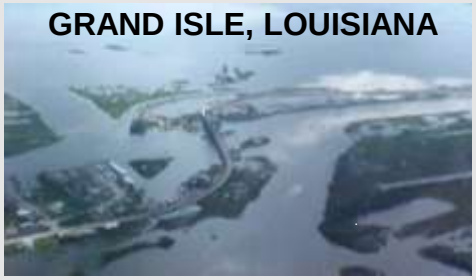
National Water Level Observation Network
210 Permanent Stations

Mean sea level is locally derived through observations at tide stations and tied to bench marks on land

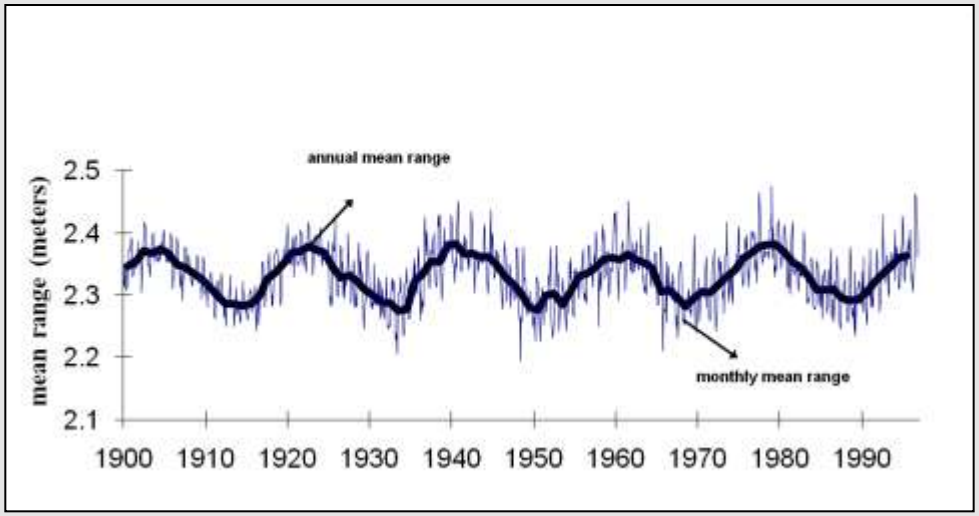
Local mean sea level is dynamic and influenced by :

- Global Sea level
- Astronomical Tides
- Seasonal To Decadal Oceanographic/Meteorological Processes
- Local Land Movement

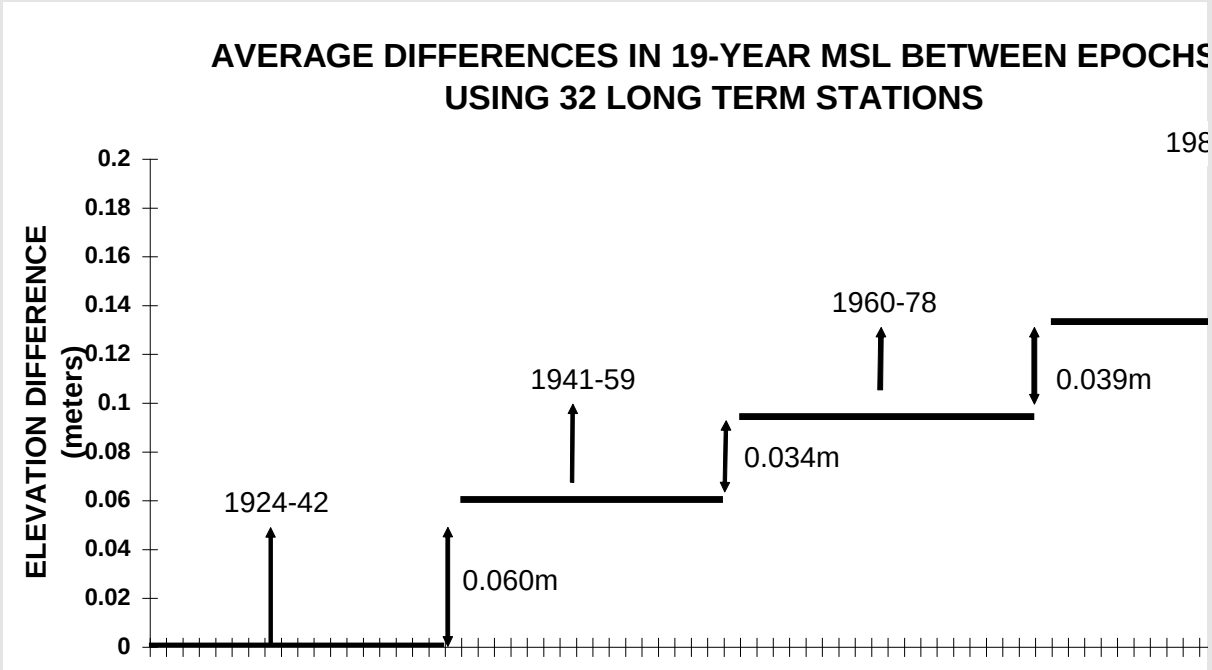
Some coastal areas are particularly susceptible to local sea level rise



National Tidal Datum Epoch (NTDE)



- A specific 19-year period that includes the longest periodic tidal variations caused by the astronomic tide-producing forces.
- Averages out seasonal meteorological, hydrologic, and oceanographic fluctuations.

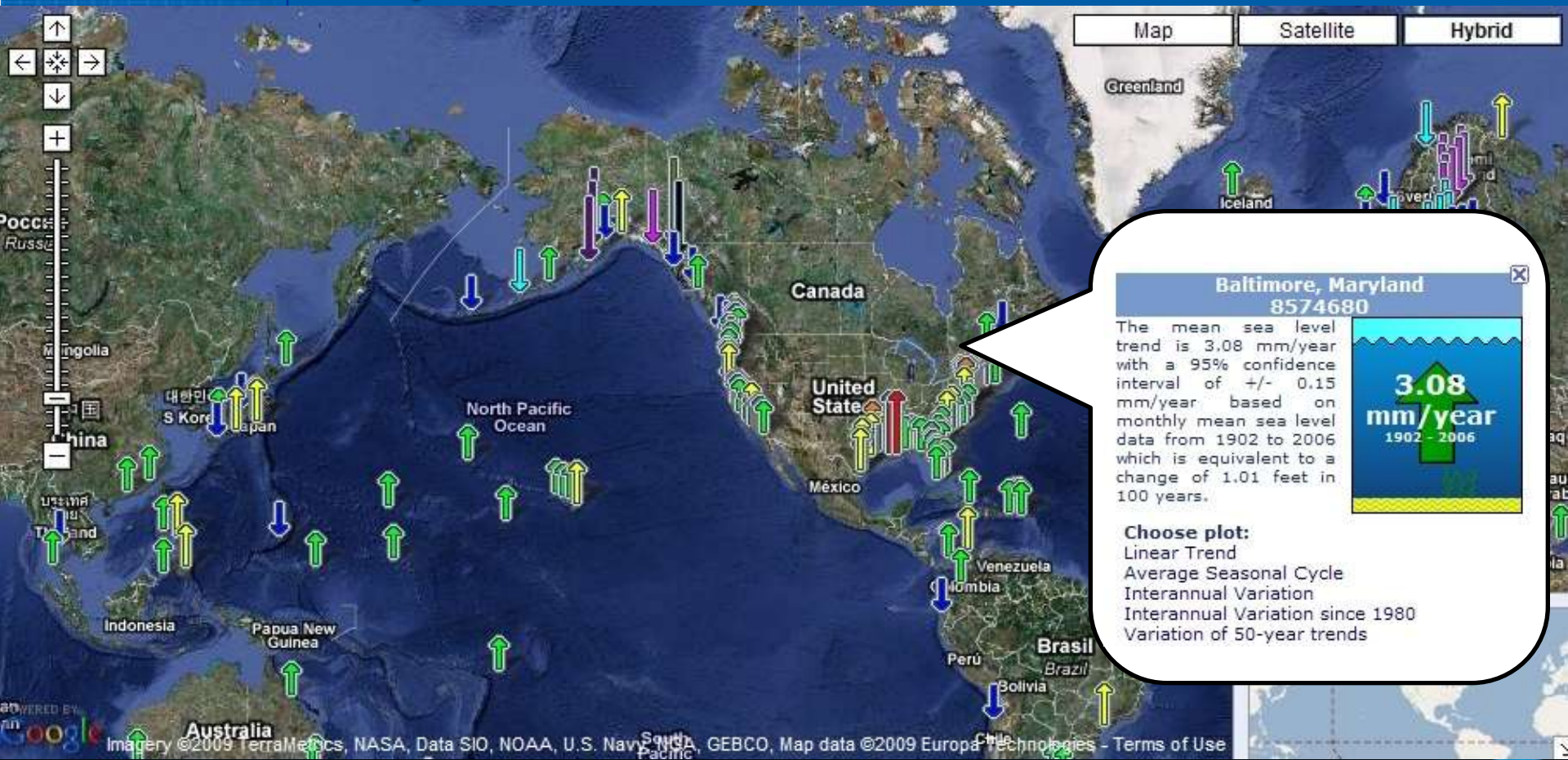


- NTDE's are updated over time to account for sea level change relative to the land. The present NTDE is 1983-2001.

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

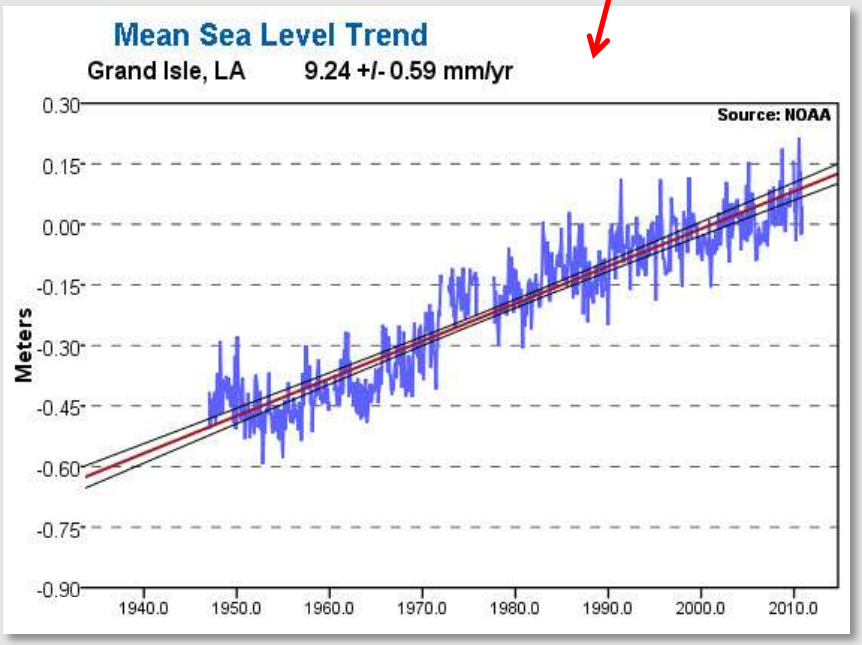
Sea Levels Online

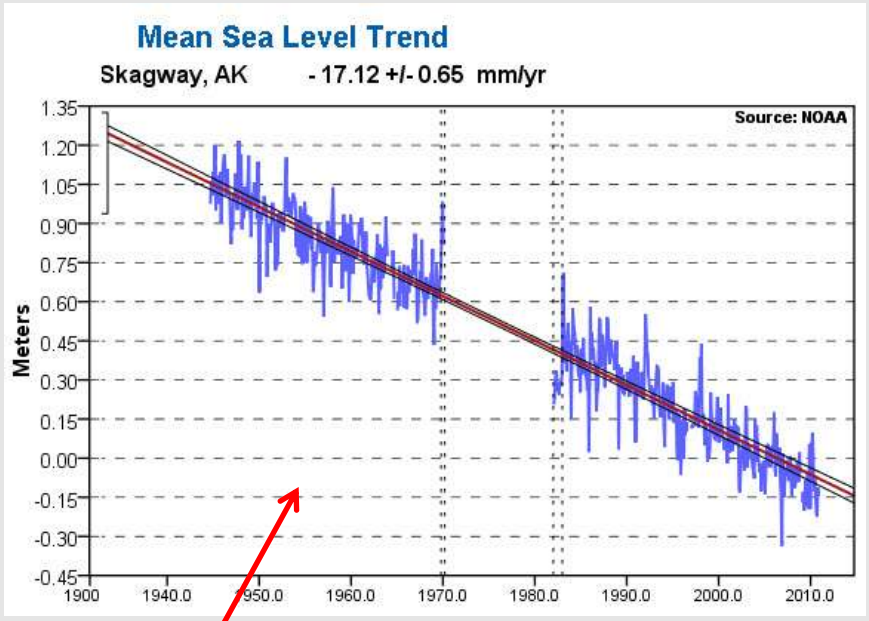
- Only source for local sea level trends in the United States
- Major contributor to Global Sea Level determination



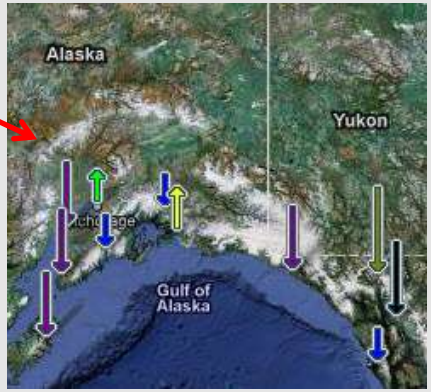
Extremes in Relative Sea Level Trends

Regional land subsidence





Regional land isostatic rebound



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

Incorporating Sea Level Change into Decision-Making

Incorporating sea level in civil works programs

Incorporating sea level change into restoration guidance

Incorporating Sea Level Change into Decision-Making

Guidance Documents

- Water Resource Policies and Authorities **Incorporating Sea-Level Change Considerations** in Civil Works Programs (USACE)

- Programmatic Framework for **Considering Climate Change Impacts** in Coastal Habitat Restoration, Land Acquisition, and Facility Development Investments (NOAA)

Department of the Army
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-CE

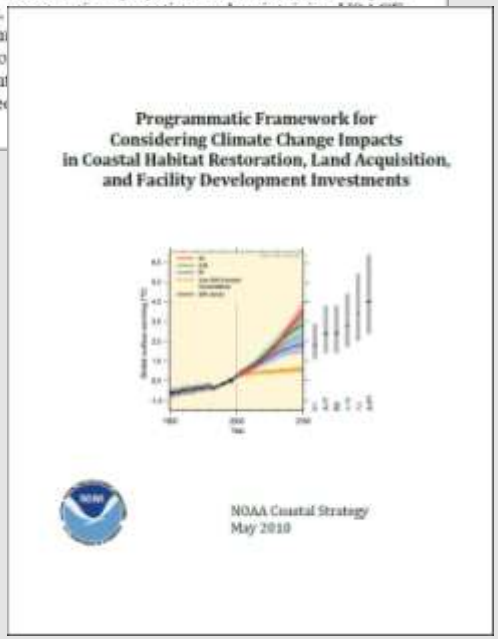
EC 1165-2-211

Circular
No. 1165-2-211

1 July 2009

EXPIRES 1 JULY 2011
WATER RESOURCE POLICIES AND AUTHORITIES
INCORPORATING SEA-LEVEL CHANGE CONSIDERATIONS
IN CIVIL WORKS PROGRAMS

1. Purpose. This circular provides United States Army Corps of Engineers (USACE) guidance for incorporating the direct and indirect physical effects of projected future sea-level change in managing, planning, engineering, designing, projects and systems of projects. Recent clim Climate Change (IPCC) predicts continued o and possibly beyond, which will cause a con Impacts to coastal and estuarine zones cause phases of Civil Works programs.

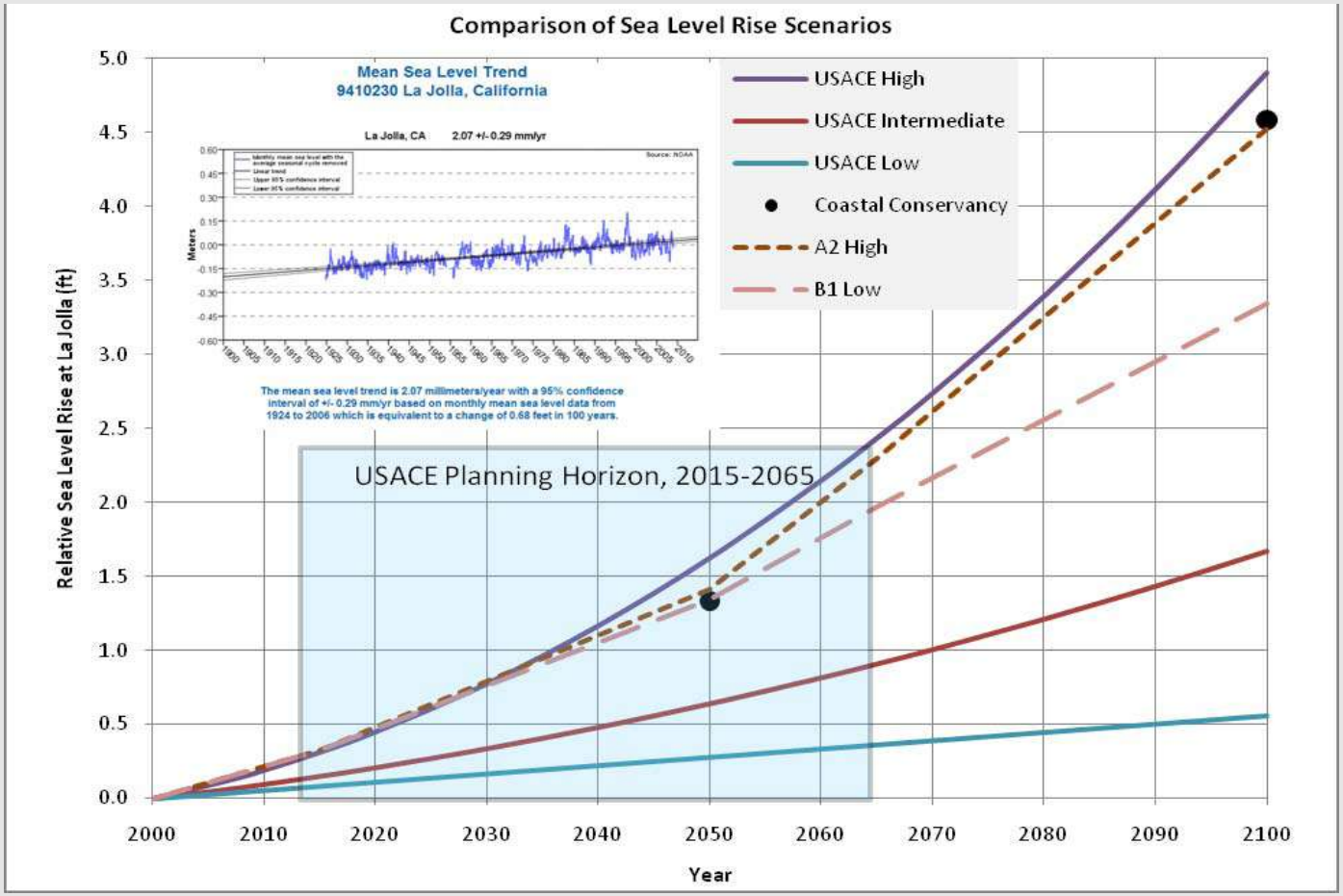


Programmatic Framework for
Considering Climate Change Impacts
in Coastal Habitat Restoration, Land Acquisition,
and Facility Development Investments

NOAA Coastal Strategy
May 2010

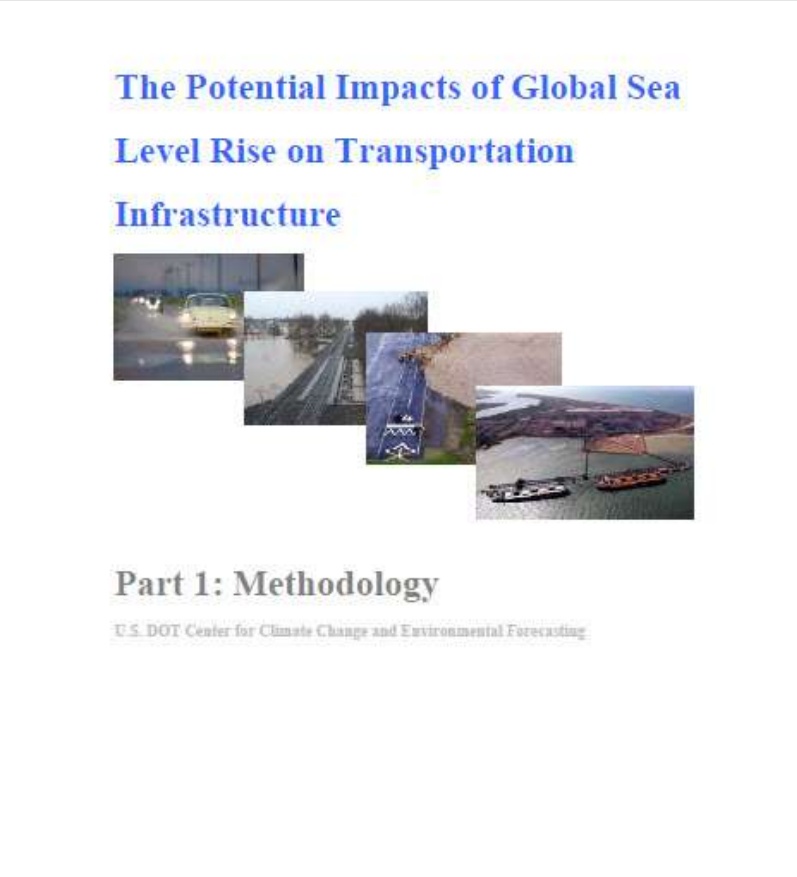
http://collaborate.csc.noaa.gov/climateadaptation/Lists/Resources/DispForm.aspx?ID=298

USACE Engineering Guidance: EC-1165-2-211



Approach to Incorporate Projected Future Sea Level Change into the Encinitas & Solana Beach Shoreline Protection Feasibility Study.

US DOT Impact Study



This study (October 2008) was designed to produce high level estimates of the net effect of sea level rise and storm surge on the national transportation network. It was designed primarily to aid policy makers at the U.S. Department of Transportation by providing estimates of these effects as they relate to roads, rails, airports and ports.

http://climate.dot.gov/impacts-adaptations/pdf/entire.pdf

US DOT Impact Study

The study applied existing predictions of global sea level rise from the Intergovernmental Panel on Climate Change's (IPCC) Third and Fourth Assessment Reports

State of Maryland Statistics	59 cm					
Increase in Eustatic SLR	Regular Inundation		At-Risk		Total	
Length	Km	% Affected	Km	% Affected	Km	% Affected
Interstates	0.1	0%	2.3	0%	2	0%
Non-Interstate Principal Arterials	6.5	0%	14.4	1%	21	1%
NHS Minor Arterials	8.5	1%	57.3	4%	66	4%
National Highway System (NHS)	5.3	0%	13.4	1%	19	1%
Rails	5.5	0%	38.2	1%	44	2%
Area	Acres	% Affected	Acres	% Affected	Acres	% Affected
Ports	186	20%	111	12%	298	32%
Airport Property	65	1%	81	1%	147	1%
Airport Runways	0	0%	2	0%	3	0%
Total Land Area Affected	236,581	4%	237,971	4%	474,552	8%

The study constructed maps based on DEM's using NOAA data for a MHHW surface and Highest Observed Water Levels (HOWL) to incorporate storm surge for various sea-level rise scenarios

Other Climate Change Impacts – Relationships to Increased Intensity and Frequency of storms

Figure 1: Number of Hurricanes and Major Hurricanes (cat. 3-5); Atlantic Basin (1945-2005)

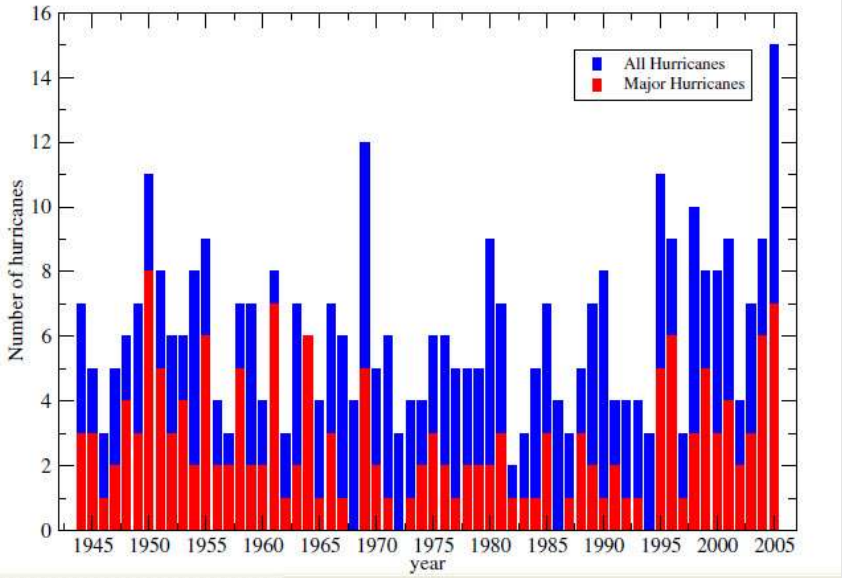
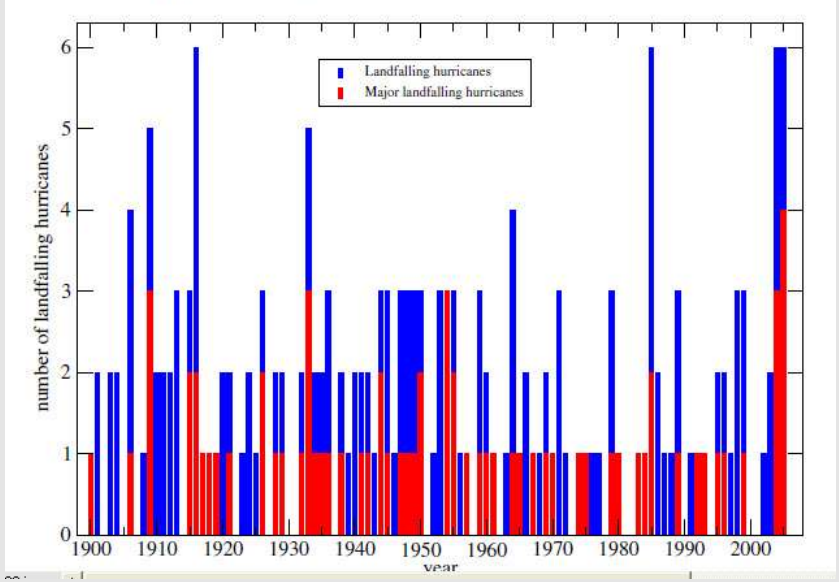


Figure 2: Landfalling Hurricanes and Major Hurricanes (cat. 3-5) in United States



- **Atlantic hurricane seasons since 1995 have been significantly more active, e.g. more hurricanes and more intense hurricanes, than the previous two decades. *(figure 1)***
- **Earlier periods, such as from 1945 to 1970 (and perhaps earlier), were apparently as active as the most recent decade.**
- **The past decade has seen increased U.S. landfalls, however periods of even higher landfalls occurred early in the century. *(figure 2)***

http://hurricanes.noaa.gov/pdf/hurricanes-and-climate-change-09-2006.pdf

Other Climate Change Impacts – Relationships to Increased Intensity and Frequency of storms

- Our science is not mature enough to determine what percentage of anthropogenic climate change and what percentage of natural climate variability is driving our current hurricanes.

- Scientists disagree as to whether currently a sound basis exists for making projections on how long the current active period will last.

- Limited understanding of natural decadal variability, combined with its irregular temporal behavior, preclude definitive statements about how long the active period will last.

- Natural decadal variability suggests high levels of hurricane activity and U.S. landfalls for the next decade and beyond since the previous active period (1945-1970) lasted at least 25 years.

- **Warming suggests more intense hurricanes** (e.g., as increasing surface temperatures provide energy for storm intensification), and some non-NOAA scientists suggest global warming will cause the current active period to persist.

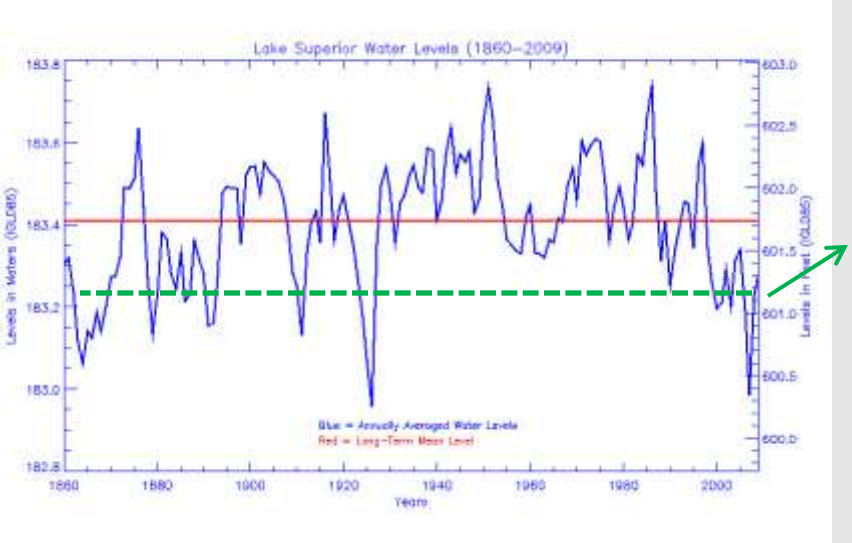
http://hurricanes.noaa.gov/pdf/hurricanes-and-climate-change-09-2006.pdf

Other Climate Change Impacts

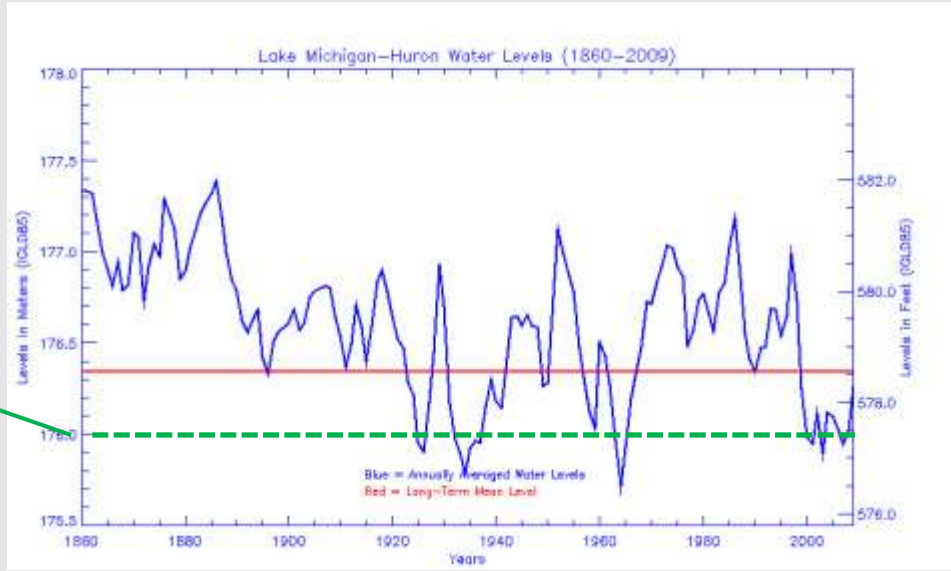
- Hydrologic cycles
  - Temperature
- Salinity
- Waves

Lake Huron shoreline near Georgian Bay, Canada. Researchers have found a gradual decline in water level in Lake Huron and Lake Michigan, since 1973. (Credit: iStockphoto)

Great Lakes Hydrologic Cycles and Climate Variability



LWD – NOAA Chart Datum



LWD – NOAA Chart Datum

http://www.glerl.noaa.gov/data/now/wlevels/levels.html

Climate Change: Waves

Summary

- Wave Climate is changing in response to changes in weather (and wind) patterns and ocean temperature
  - Expect increasing conditions
  - Studies continue, stay tuned!
- Sea Level Rise impacts initially appear during “events”
  - High water, high waves, high wave runup
  - Expect increasing frequency
- We depend on, and are limited by existing data
  - Short records (~35 years), gaps, few extremes
  - Climate changing, not stationary

Emerging New Products

NOAA HOME WEATHER OCEANS FISHERIES CHARTING SATELLITES CLIMATE RESEARCH COASTS CAREERS

NOAA CLIMATE SERVICES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA Climate Portal » ClimateWatch Magazine » Climate Change: Global Sea Level

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Climate Change: Global Sea Level

By **LuAnn Dahlman - NOAA Climate Program Office**

August 30, 2009

View Printable Version

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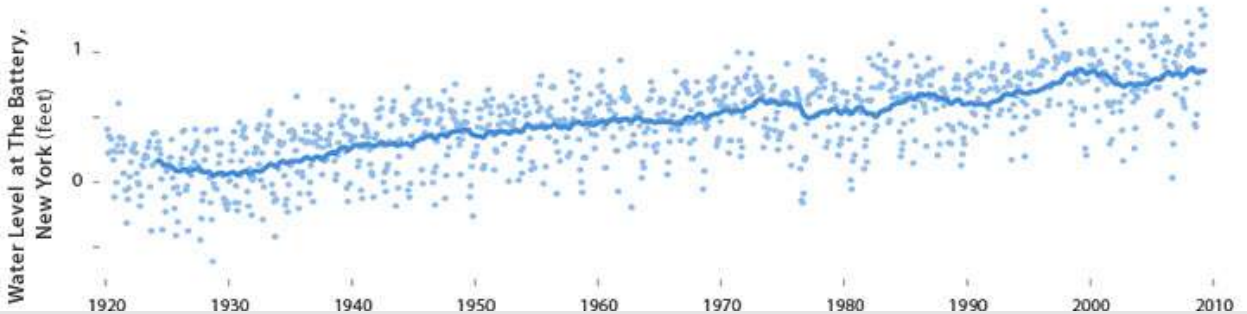
Global sea level is on the rise. The total amount of water on Earth isn't increasing, but the volume of liquid that fills the ocean basins is growing, raising the elevation of the sea's surface and spilling ocean water onto low-lying land. The extra volume of seawater comes from two places. Clearly, melting of ice sheets and glaciers on land adds water to the sea. Less obviously, water expands as it warms, so the more heat energy the ocean absorbs, the more space its water requires. On our warming planet, scientists expect both of these processes to continue and possibly accelerate.



http://www.climatewatch.noaa.gov/2009/articles/climate-change-sea-level

Emerging New Products

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

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- NOAA Watch
- About Pacific Storms
- Regional Overview
- PRODUCTS
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National Climatic Data Center, U.S. Department of Commerce
University of Hawai'i Sea Level Center
IARC
OSU Oregon State University

Pacific Storms climatology products

Coastal storms, and the strong winds, heavy rains, and high seas that accompany them, pose a threat to the lives and livelihoods of the peoples of the Pacific.

To reduce their vulnerability to the social, economic, and environmental risks associated with these phenomena communities and businesses, as well as government agencies and the scientific community, need access to information that enables them to better understand, anticipate, and adapt.

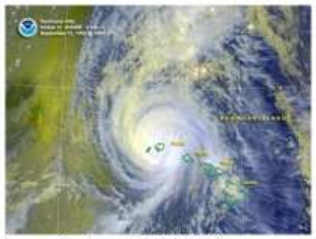


Image Courtesy of NOAA OSEI

This site provides access to an integrated suite of products that delineate patterns and trends of storm frequency and intensity - "storminess"- within the Pacific region. The intent of these products is to help users to explore how extreme events have been expressed historically and may be expected to be expressed in a changing climate.

Go to the query tool to view inter-annual and annual extremes climatology-related data products by region process, indicator, and product type.

This site also provides access to information that will help users to learn about the climate-related processes that govern extreme storm events.

To get an overview of the extremes climatology for various regions within the Pacific, including a description of event types characteristic of a region, simply select the region of interest by clicking on it on the map below.

Go to the regional overviews to get a summary of the extremes climatology for various regions within the Pacific, including a description of characteristic event types for a region.

Privacy Policy | FOIA | Information Quality | Disclaimer | USA.gov | Ready.gov | Contact Webmaster

http://www.pacificstormsclimatology.org/

NOAA Coastal Services Center

Tools

Sea Level Rise and Coastal Flood Frequency Viewer

Produced and distributed by the NOAA Coastal Services Center

Use the slider bar beside the map to see how rates of sea level rise will impact a community. Flooding frequency information is also provided. This visualization tool (the prototype was developed for Wilmington, Delaware) is helpful for those involved in coastal planning and any effort to educate citizens about local sea level rise issues.

Launch Now

Features

- Portrays sea level rise scenarios and potential impacts
- Uses maps with prominent landmarks to increase recognition
- Illustrates how sea level rise will increase tidal flood frequency

Data Requirements

- High resolution elevation data

The Digital Coast Partnership

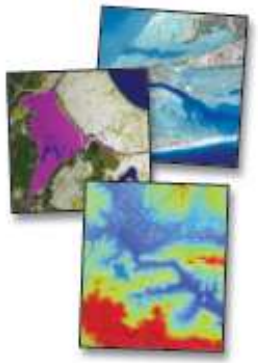
www.csc.noaa.gov/digitalcoast/

IT STARTED WITH A VISION. Wouldn't it be great if coastal data were accessible from one website? And the site could also include the training and tools needed to turn these data into useful information? And examples—the site should provide examples so others can learn.

And since we're dreaming—couldn't we come a little bit closer to changing the world if the site was used not only by the federal government, but also the private sector and nonprofits, county governments, state programs, and anyone else interested in the wise management of coastal resources? What would happen if these groups started working together?

The Digital Coast was developed by the National Oceanic and Atmospheric Administration (NOAA) in response to this vision. Users can download data and easily access the associated training, tools, and application examples.

Phase one incorporates data served by the NOAA Coastal Services Center. Phase two is being led by the Digital Coast partner network. These partners, who are either primary users of the system or content providers, will help NOAA prioritize the components that will be added during phase two and all future expansion efforts.



Digital Coast Partners

- Coastal States Organization
- National Association of Counties
- National States Geographic Information Council
- Association of State Floodplain Managers
- The Nature Conservancy
- NOAA

Partner Benefits

- Easier access, to relevant data, tools, and training.
- Ability to shape the future phases of the Digital Coast
- Opportunity to participate in demonstration projects
- Ability to contribute to a national, unified movement for the coast
- Opportunity to forge new partnership opportunities

TO LEARN MORE,
contact Nicholas (Nikl) Schmidt at (843) 740-1237 or Nicholas.Schmidt@noaa.gov.

DIGITAL COAST
It's More Than Data

NOAA Coastal Services Center
LINKING PEOPLE, INFORMATION, AND TECHNOLOGY

http://www.csc.noaa.gov/

News and Alerts

[2009-08-28]
NOAA Report Explains Sea Level Anomaly this Summer along the Atlantic Coast

[2009-07-02]
East Coast water levels running above predictions

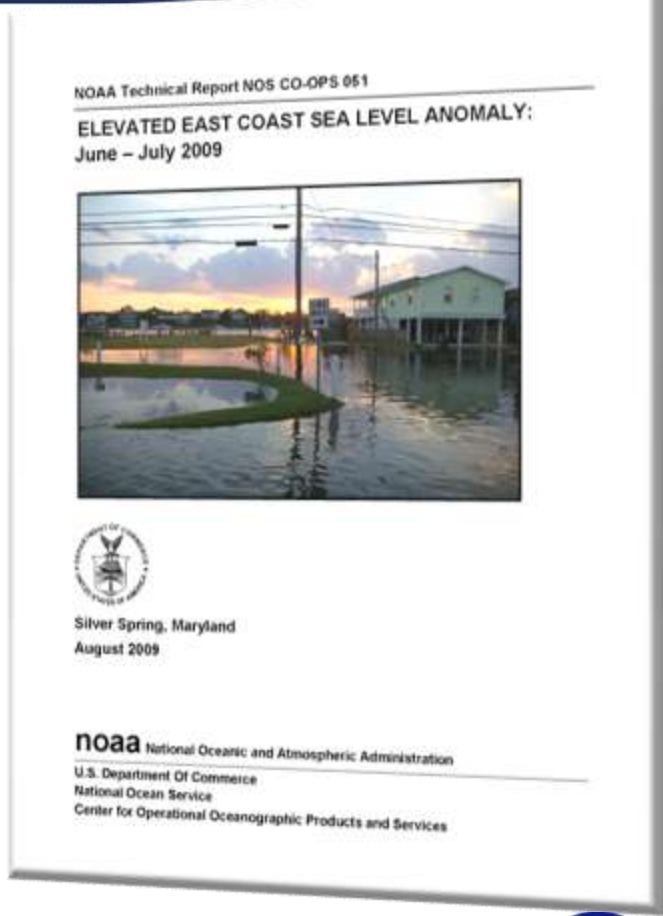
ALERT: East Coast water levels are currently running above predicted tides

Starting in early June 2009, observed tides have been increasingly elevated above predicted tidal elevations along the entire U.S. East Coast from Maine to the east coast of Florida. During the period from June 19 thru June 24 for instance, these water levels were running between 0.6 to 2.0 feet above normal depending upon location. As of July 1, these anomalies continue, but running lower at 0.3 to 1.0 ft. above normal. It is not unusual for smaller regions and estuaries along the U.S. East Coast to experience this type of anomalous event at this time of year, however the fact that the geographic extent of this event that includes the entire East Coast event is anomalous. CO-OPS will continue to monitor this event and will provide further information on the causes, amplitudes, geographic extent, and the duration of the event.

For further information, please contact:

User Services
Center for Operational Oceanographic Products and Services (CO-OPS)
1305 East-West Highway
Silver Spring, MD 20910-3281
E-mail: User Services

Back to Tides & Currents


NOAA Technical Report NOS CO-OPS 051

ELEVATED EAST COAST SEA LEVEL ANOMALY:
June – July 2009

Silver Spring, Maryland
August 2009

noaa National Oceanic and Atmospheric Administration
U.S. Department Of Commerce
National Ocean Service
Center for Operational Oceanographic Products and Services

http://tidesandcurrents.noaa.gov/publications/EastCoastSeaLevelAnomaly_2009.pdf

Additional Resources

- NOAA Climate Services: http://www.climate.gov/#understandingClimate
- Useful links from the ICC: http://www.ipcc.ch/links/links.shtml
- CCSP, 2009: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate* Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)]. U.S. Environmental Protection Agency, Washington D.C., USA, 320 pp.
- Church, J.A., Aarup T., Woodworth P.L., Wilson W.S., Nicholls R.J., Rayner R., Lambeck K., Mitchum G.T., Steffen K., Cazenave A., Blewitt G., Mitrovica J.X. and Lowe J.A. (2010) Sea Level Rise and Variability – Synthesis and Outlook for the Future. (Chapter 13 in Understanding Sea Level Rise and Variability eds. Church J.A., Woodworth P.L., Aarup T. and Wilson W.S. Wiley-Blackwell)
- NOAA Technical Report NOS 2010-01. Technical Considerations for Use of Geospatial Data in Sea Level Change Mapping and Assessment (will be available online soon).
- CCSP, 2008: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change* Research [Savonis, M. J., V.R. Burkett, and J.R. Potter (eds.)]. Department of Transportation, Washington, DC, USA, 445 pp.

Questions

http://tidesandcurrents.noaa.gov/

Background

Causes of Sea Level Change

- Thermal Expansion (~ 1 meter potential)
- Water Exchange with Continents (potential)
  - Greenland Ice (7 meters)
  - Antarctic Ice (60 meters)
  - Mountain Glaciers (0.5 meter)
  - Terrestrial Water Storage Variations (< 0.5 meter)
  - Other (halosteric, etc.)

$$\Delta SL_{Total} = \Delta SL_{Thermosteric} + \Delta SL_{Greenland} + \Delta SL_{Antarctica} + \Delta SL_{Glaciers} + \Delta SL_{Storage} + \Delta SL_{Other}$$

SOURCE: R.S.NEREM, BOWIE LECTURE FALL AGU 2005

References

- **NRC 1987. *Responding to Changes in Sea Level, Engineering Implications*, Committee on Engineering Implications of Changes in Relative Mean Sea Level, Marine Board, Commission on Engineering and Technical Systems, National Research Council. National Academy Press, Washington DC 1987, 148pp.**
- **IPCC 2001. *Climate Change 2001: The Scientific Basis,* edited by J.T. Houghton et al., Cambridge University Press, Cambridge, U.K.**
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The ground elevation at BM "2075A" will become increasingly inundated even if the present day relative sea level rise (RSLR) remains constant in the future.

Estimated Effects of RSLR on Frequency and Duration of Inundation for Port Fourchon, LA Using Present Rate of Sea Level Rise

Using Ground Elevation at Bench Mark "2075 A "

5-yr Time Period	RSLR rate mm/yr)	Occurrences of Inundation (# of tides)	Duration of Inundation (hours (percent of total time))	Elevation Rise Above 2010 MSL (meters)
2005-2009	9.24	1	7 (<1%)	-
2046-2050	9.24	3	623(<1%)	0.4
2096-2100	9.24	569	405(19%)	0.8

Note: In 2005-2009, and in 2050, the average inundation above ground level occurs only during major storm events. In 2100, inundation would occur at many of the normal daily high tides as well, with average inundation of 0.10m.

Climate Change Impacts:
More Intense Storm Impacts

Key Impacts

- Ship and ground traffic delays
- Port closure
- Shipping service disruptions
- Evacuations
- Debris and infrastructure damage

Missouri River flooding, 1993

Hurricane Ike damage (Source: NOAA)

Impacts of Relative Sea Level Rise at Port Fourchon, LA

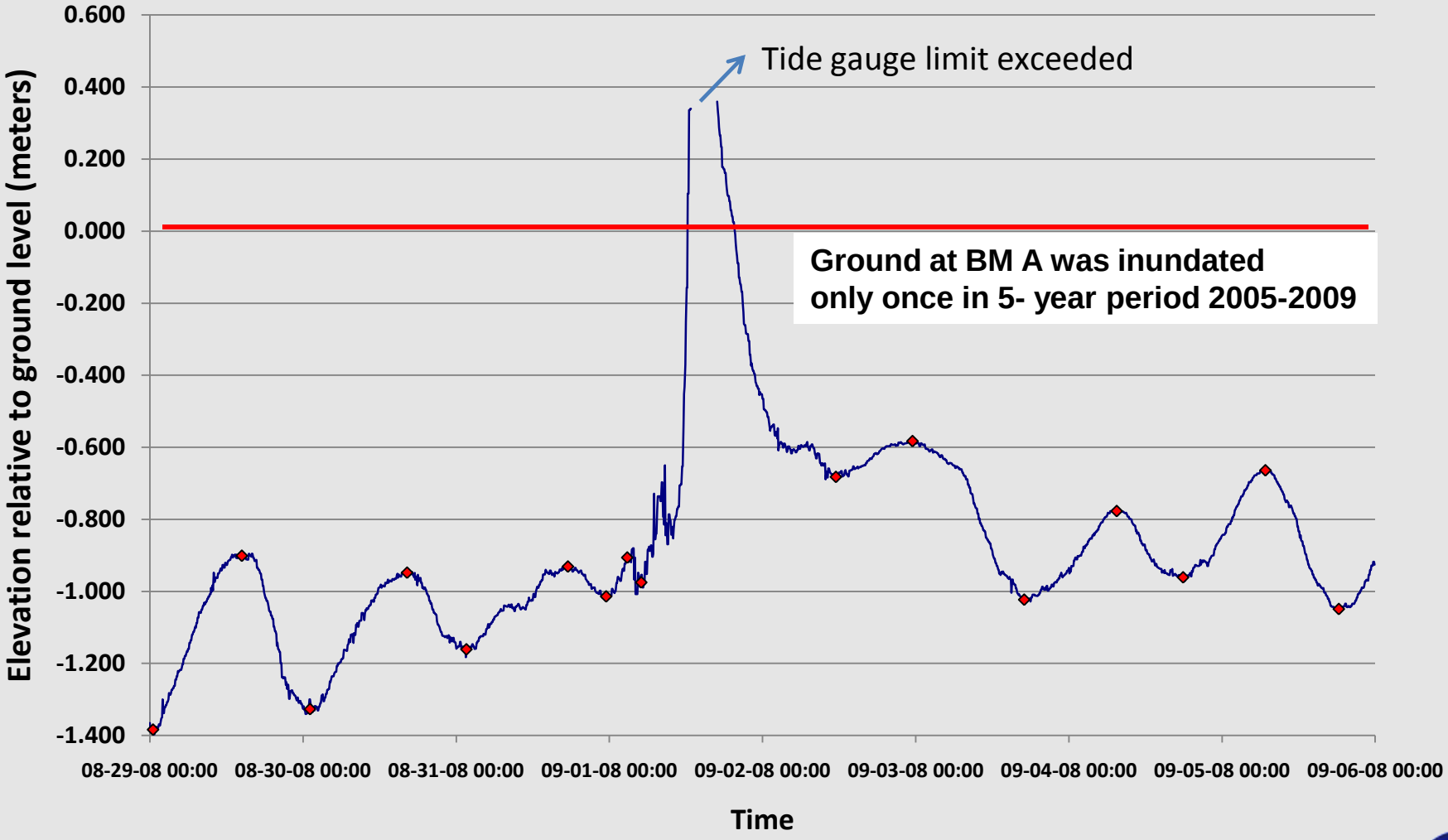
•Tidal bench mark elevations can be used to estimate ground elevations. Bench Mark 2075A 2003 is 0.638m (2.09ft) above Mean Higher High Water (MHHW). T he ground elevation at BM "2075A" will become increasingly inundated even if the present day relative sea level rise (RSLR) of 9.24 mm/yr remains constant in the future.

• In 2005-2009, and in 2050, the average inundation above ground level occurs only during major storm events. In 2100, inundation would occur at many of the normal daily high tides as well, with average inundation of 0.10m.

In

Location of Bench Mark 8762075 A 2003

8762075 PORT FOURCHON, LA - Observed Inundation Above Ground Level at BM "2075A" during Hurricane Gustav in September 2008



8762075 PORT FOURCHON, LA - Project inundation Above Ground Level at BM "2075A" for a Gustav-type Storm in 2100 using a RSLR of 9.24 mm/yr.