Climate Change Considerations for Resiliency Planning

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Overview

- Climate Change Overview
  - Definitions
  - Effects of climate change
  - Available guidance and data
- Resilience Planning
- Sample AECOM Projects
- Questions/Comments/Discussion

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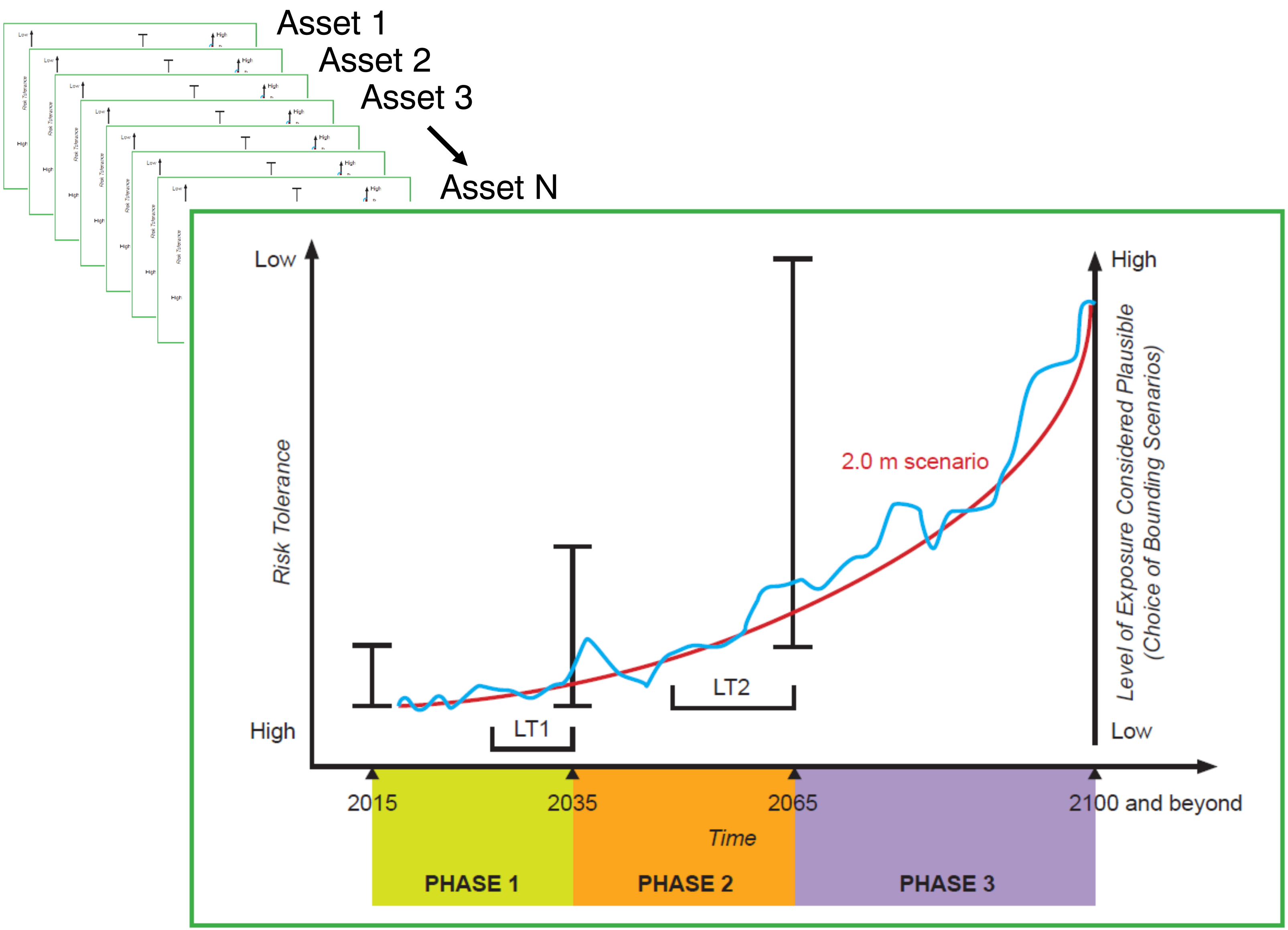
Adaptive Risk Management – What is it?



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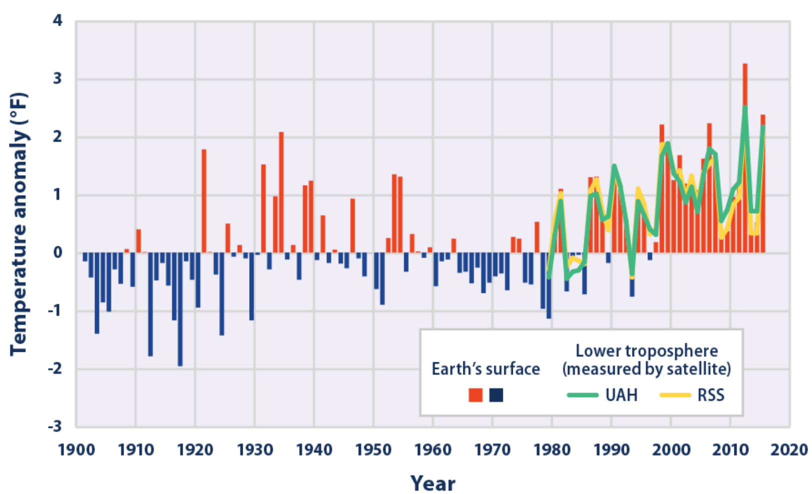
What is Climate / Climate Change?

Climate

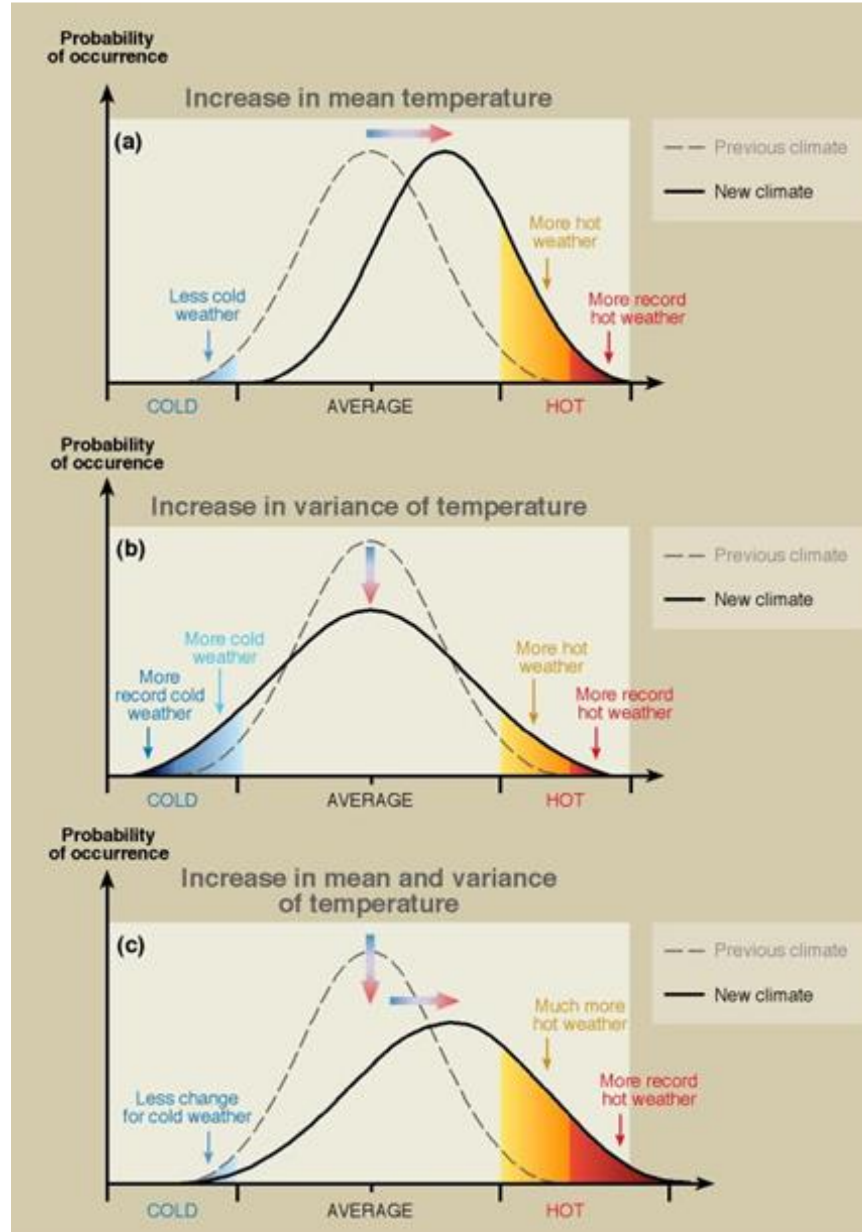
- average or statistical description of weather over long period of time (i.e., mean, variability…~30-years).
- temperature, precipitation, and wind.
- "***climate is what we expect and weather is what we get***".

Climate Change

- Variations in average weather conditions that persist over multiple decades or longer.



Source: *US EPA - Climate Change Indicators: U.S. and Global Temperature*



Source: *IPCC Third Assessment Report: Climate Change 2001 (TAR) – Synthesis Report – Figure 4.1*

Effects of Climate Change

- Changing sea levels
  - Mainly sea level rise
- Changing storm intensity and frequency
  - Hurricanes
  - Nor’easters
- Precipitation changes
  - Heavy downpours (“rain bombs”)
  - Drought
- Temperature changes
  - Heat waves and extreme heat
  - Lower low temperatures

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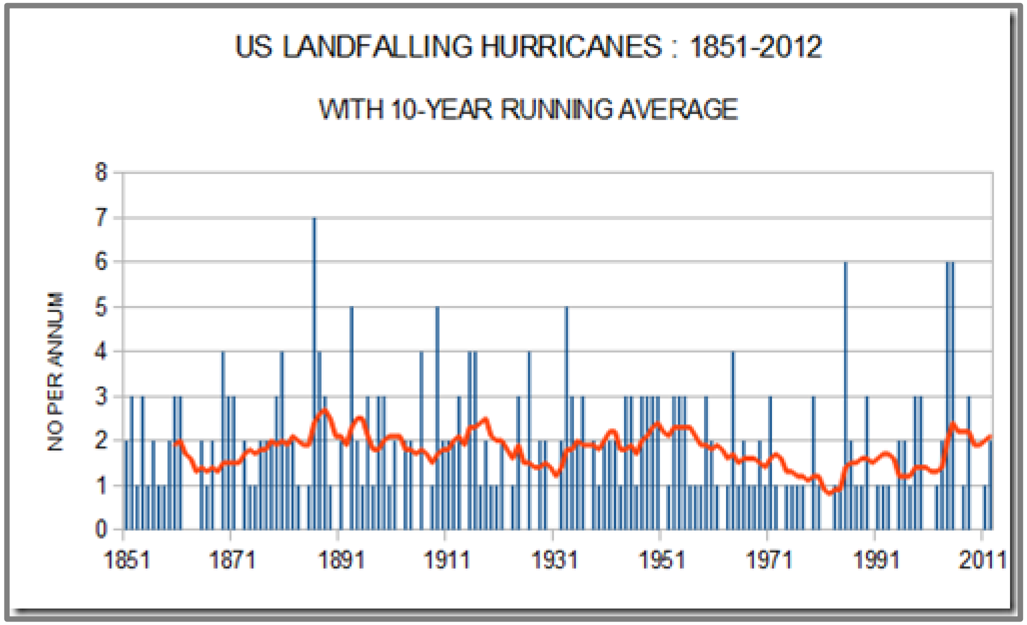
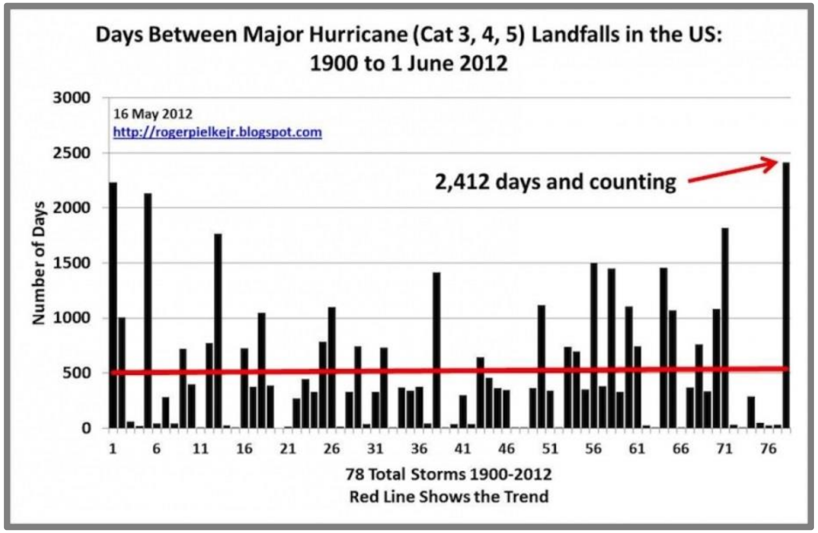
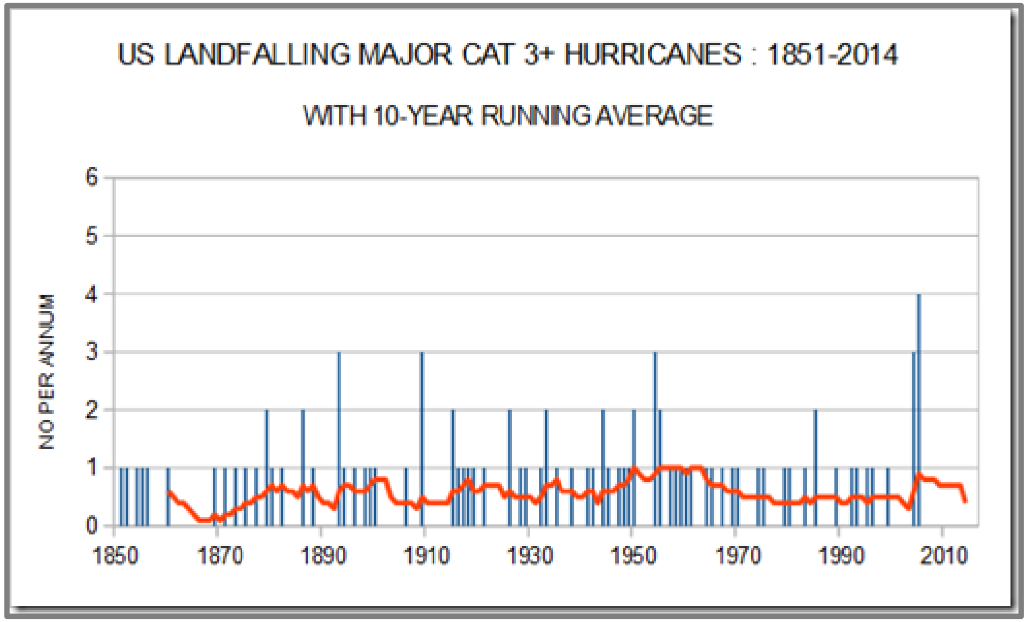
Frequency of Landfalling Hurricanes (NOAA AOML)







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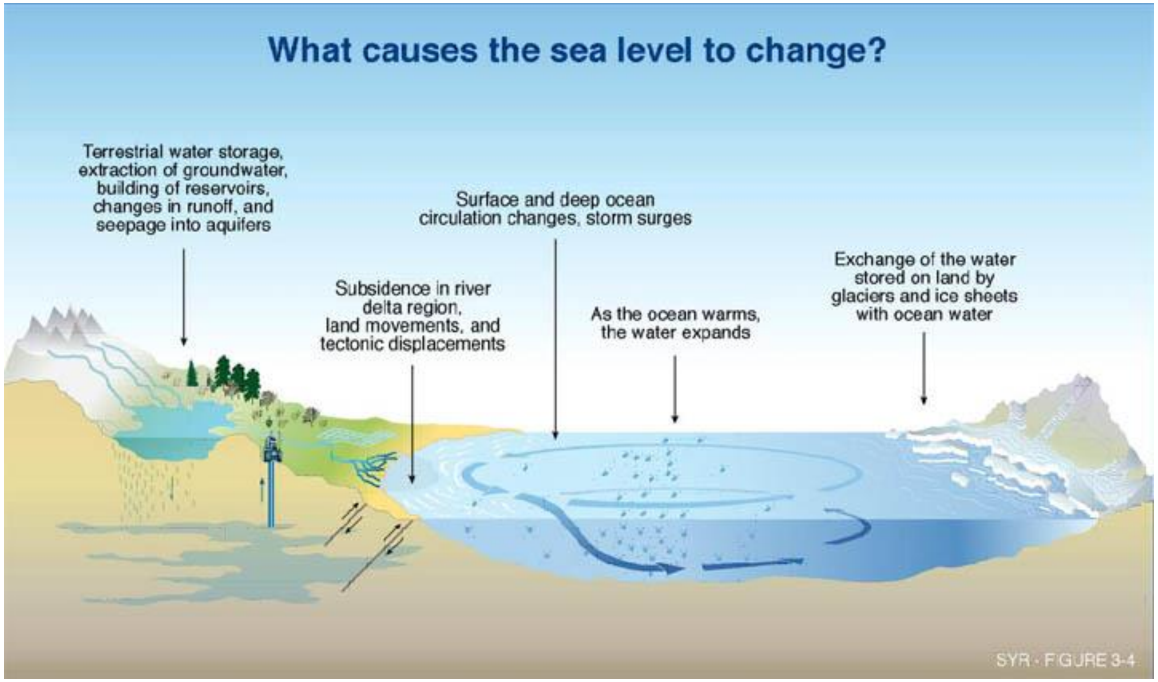
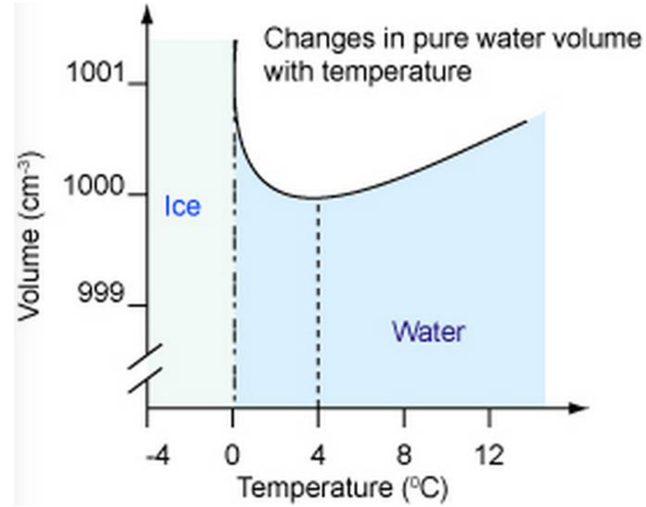
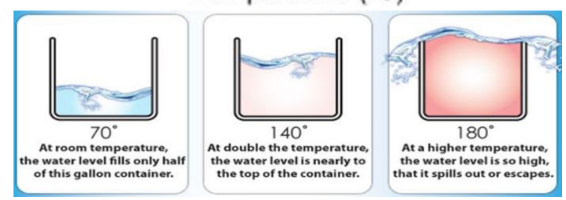
Primary causes of Sea Level Rise



Source: *IPCC Third Assessment Report: Climate Change 2001 (TAR) – Synthesis Report – Figure 3.4*





- Melting of glaciers/ice sheets
- Thermal expansion of ocean water
- Vertical Land Movement (VLM…subsidence)

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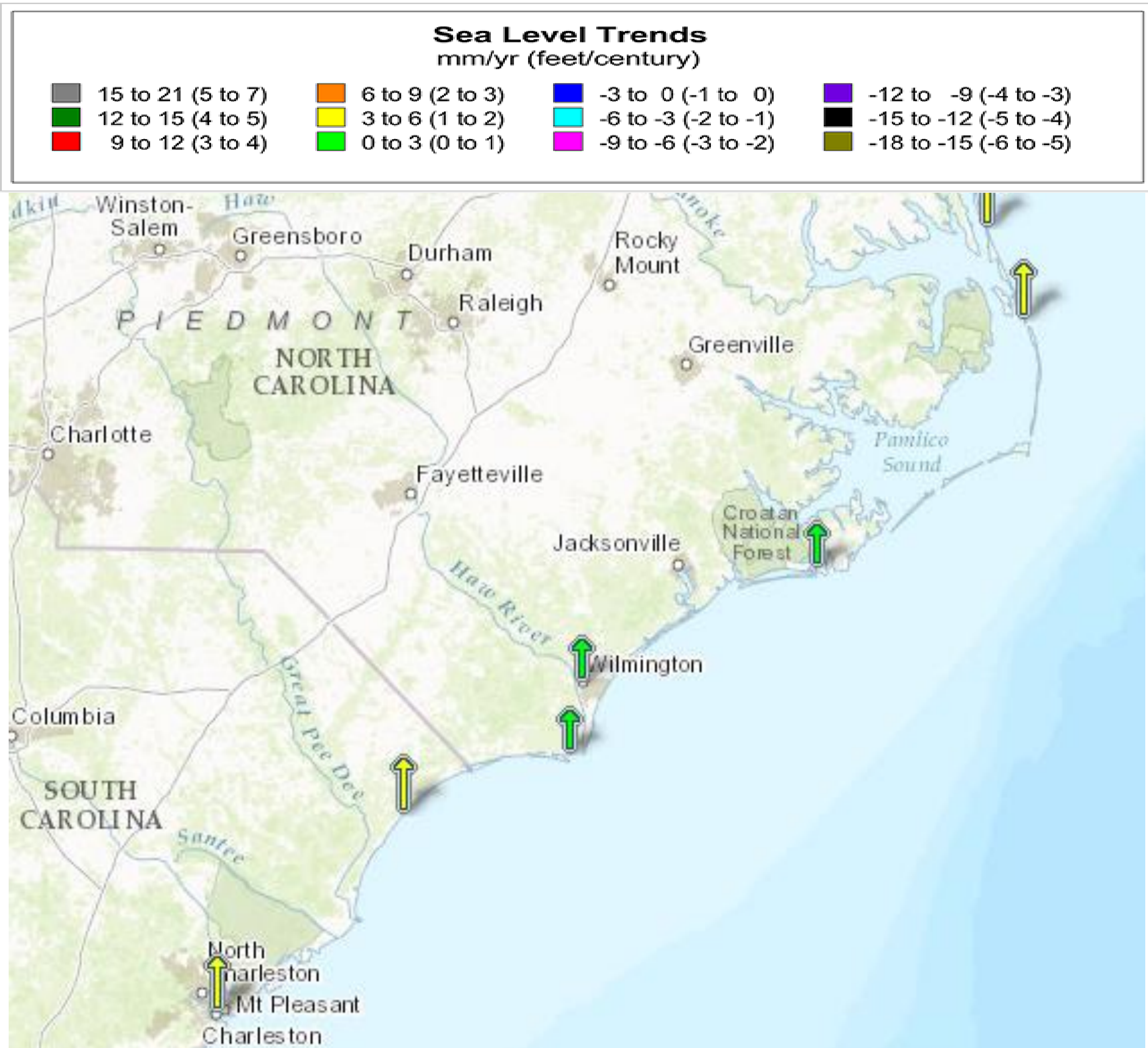
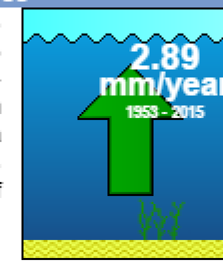
Sea Level Observed Trends (NOAA)



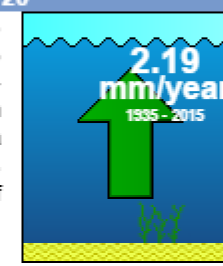
Beaufort, NC
8656483

The mean sea level trend is 2.89 mm/year with a 95% confidence interval of +/- 0.36 mm/year based on monthly mean sea level data from 1953 to 2015 which is equivalent to a change of 0.95 feet in 100 years.



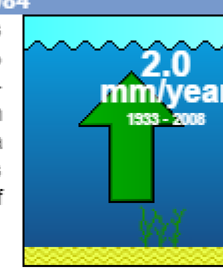
Wilmington, NC
8658120

The mean sea level trend is 2.19 mm/year with a 95% confidence interval of +/- 0.35 mm/year based on monthly mean sea level data from 1935 to 2015 which is equivalent to a change of 0.72 feet in 100 years.

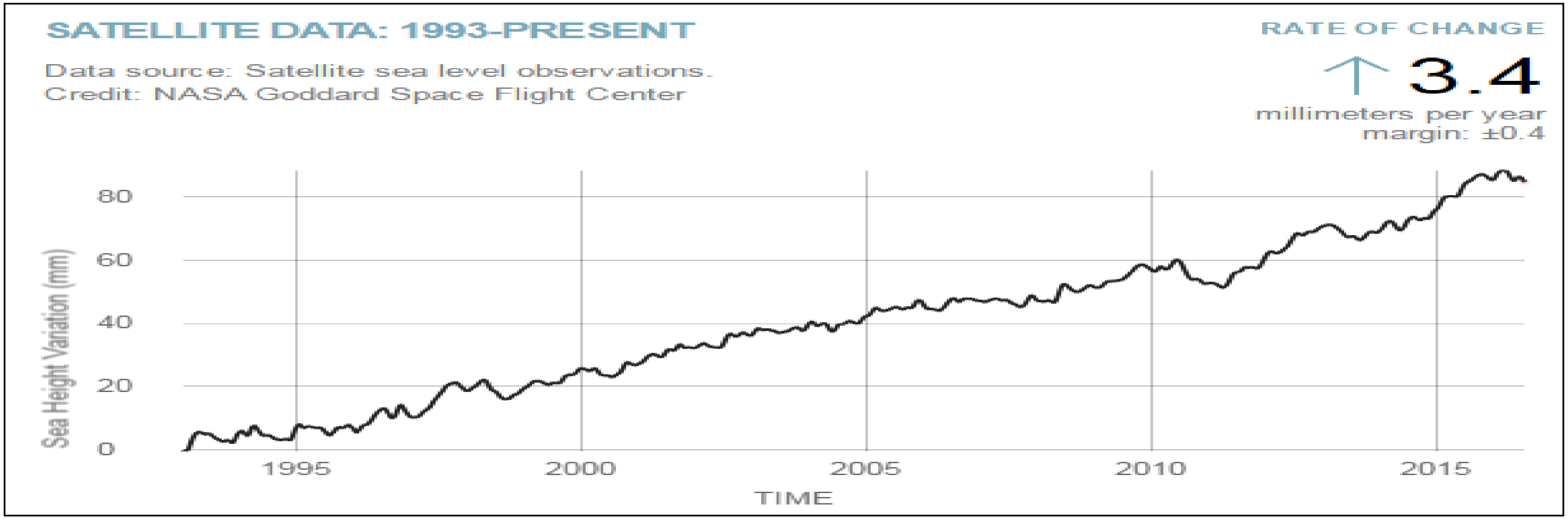


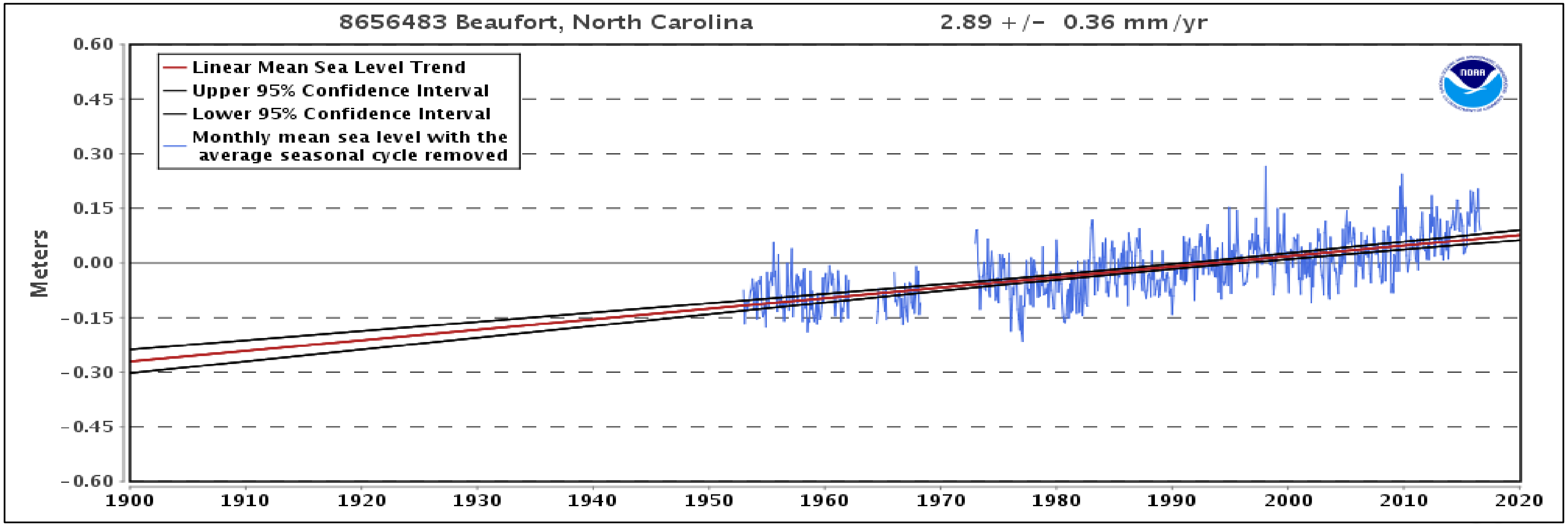
Southport, NC
8659084

The mean sea level trend is 2.0 mm/year with a 95% confidence interval of +/- 0.41 mm/year based on monthly mean sea level data from 1933 to 2008 which is equivalent to a change of 0.66 feet in 100 years.

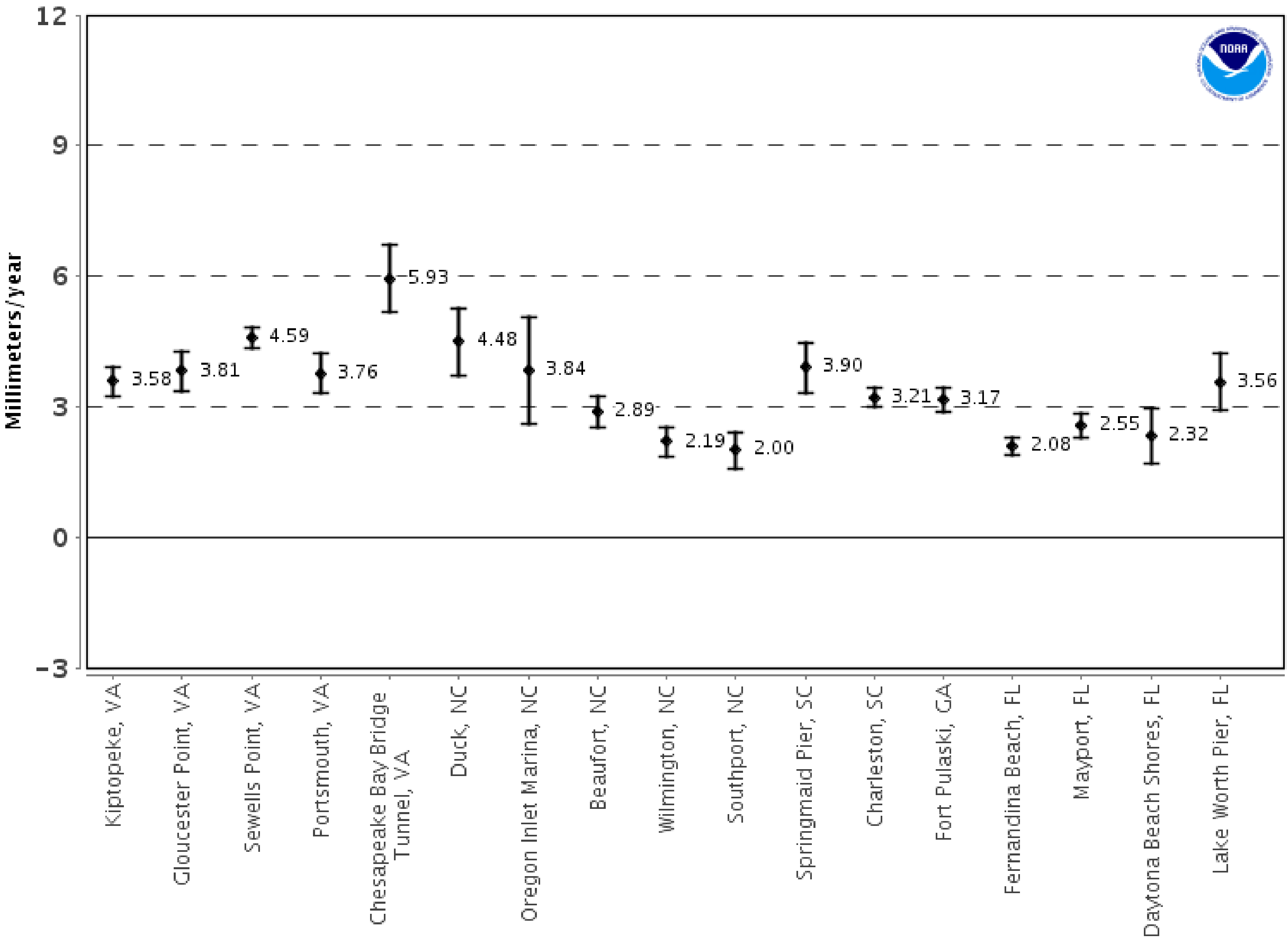


Sea Level Observed Trends (Global & Local)





Sea Level Observed Trends (VA to FL)



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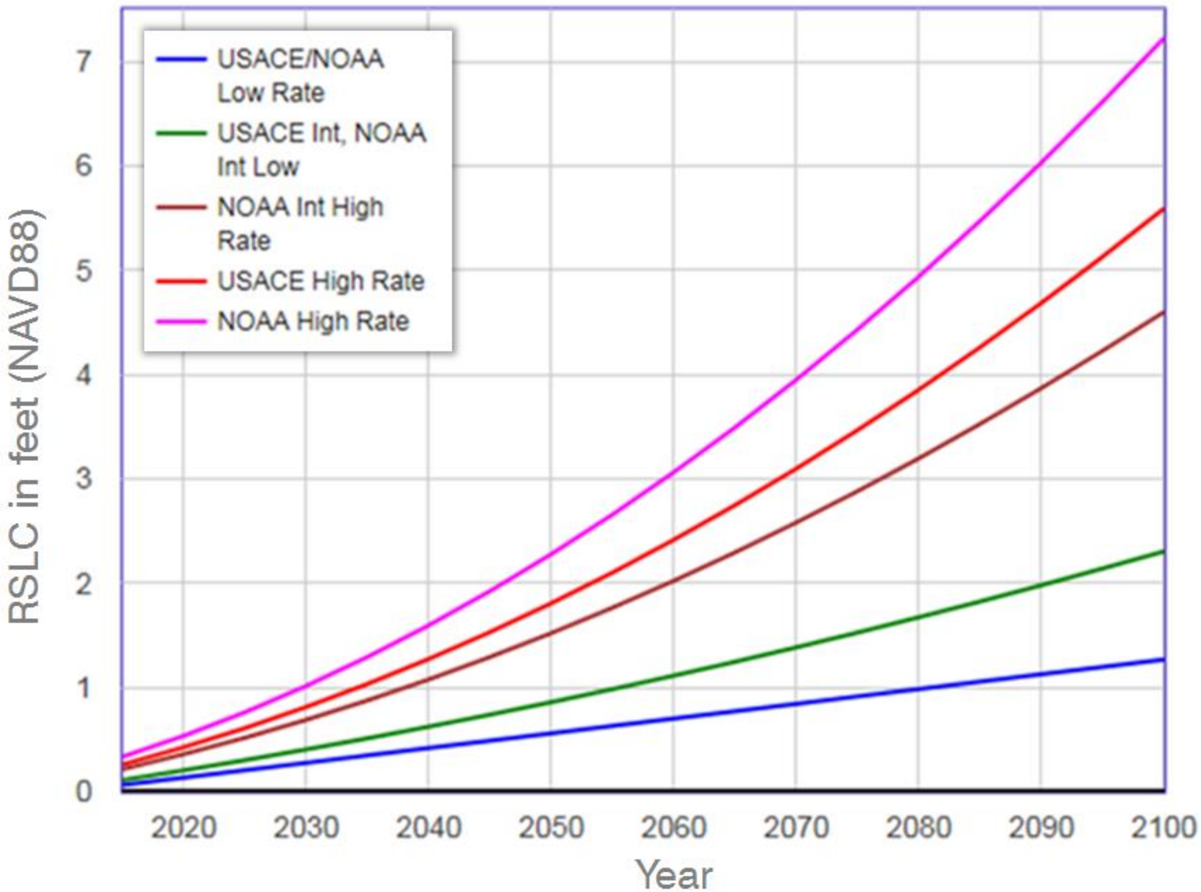
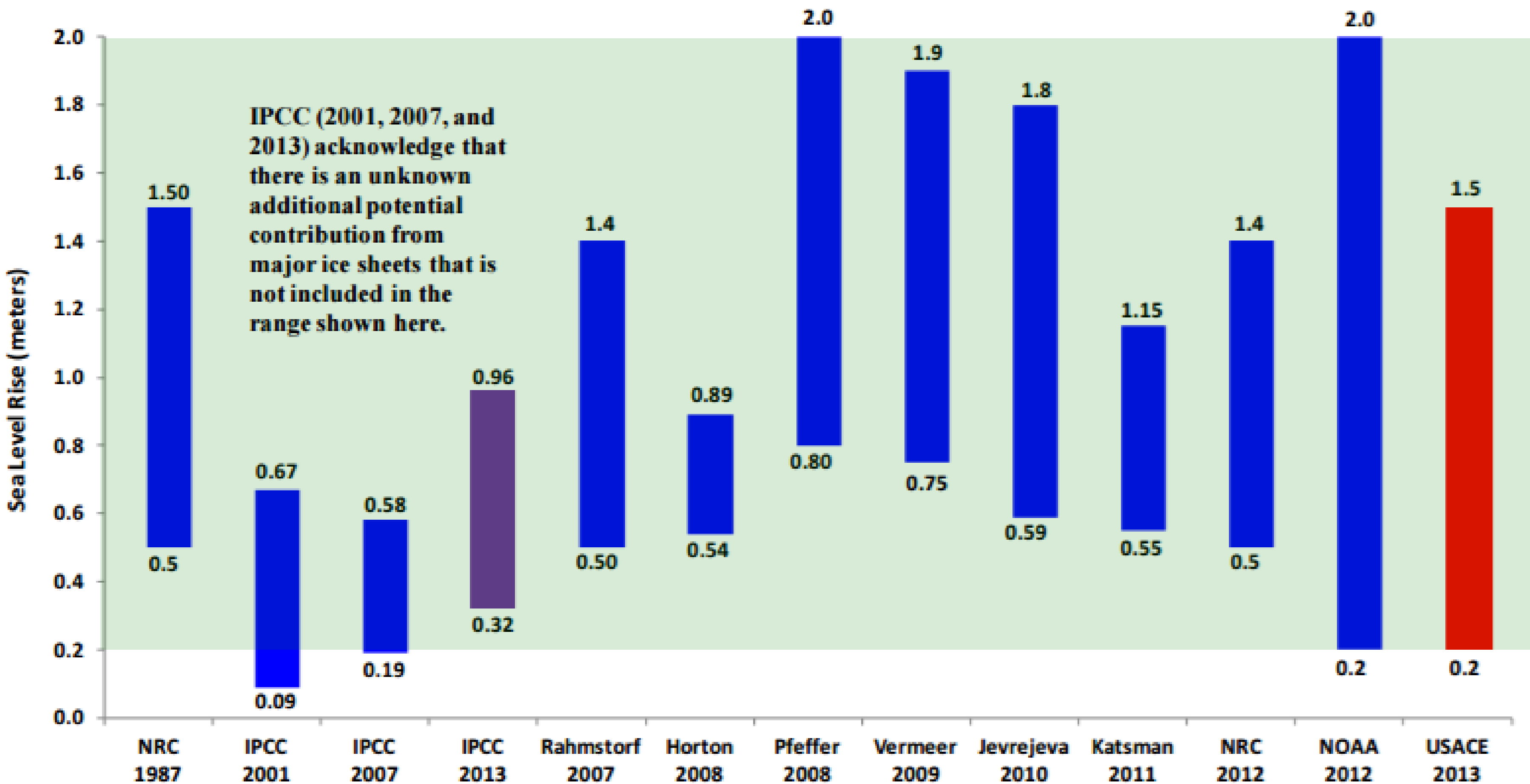
Sea Level Projections – Projections & Uncertainty?



Uncertainty Considerations

- Greenhouse Gas Emissions
- Ice Melt
- Human Behavior
- Numerical Model Scaling
- Subsidence & VLM
- Waves & Setup

Place your Bets!



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Why/How can we leverage so many projections?

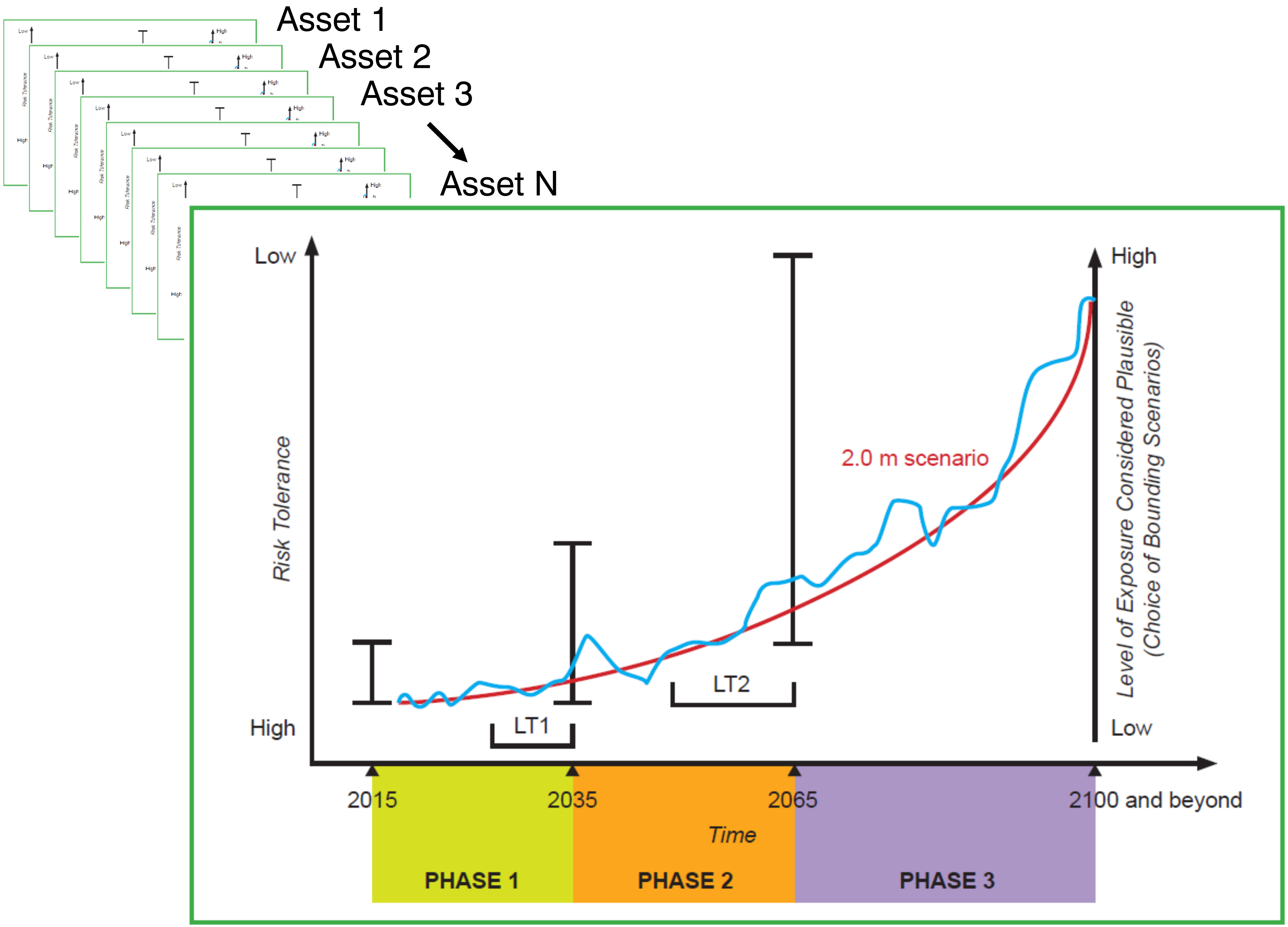
–UNCERTAINTY!

– LOW/ HISTORIC
- Applicable when designing low risk projects
- Easily replaceable infrastructure with short design lives
- Not critical infrastructure/ Limited interdependencies with other infrastructure

– INTERMEDIATE
- Applicable to projects with short –to-mid term planning horizon

– HIGH CURVE
- High risk projects constructed in longer time frames (many decades out)
- Critical infrastructure for services and connectivity
- Not easily replaceable
- Long design life

Adaptive Risk Management – Managing Uncertainty



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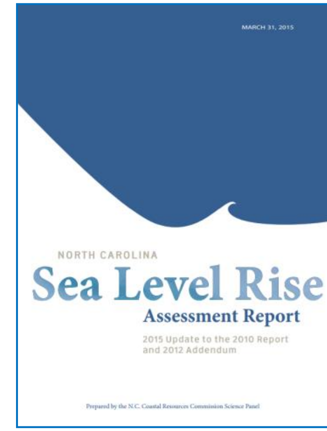
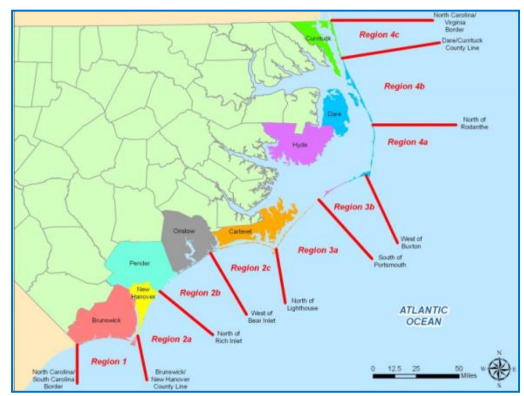
Sea Level Projections - NCDENR & NCDCM

Station	Tide Gauge Projections		IPCC RCP 2.6 + VLM		IPCC RCP 8.5 + VLM	
	RSLR in 30 years (inches)		RSLR in 30 years (inches)		RSLR in 30 years (inches)	
	Mean	Range	Mean	Range	Mean	Range
Duck	5.4	4.4-6.4	7.1	4.8-9.4	8.1	5.5-10.6
Oregon Inlet	4.3	2.7-5.9	6.3	3.9-8.7	7.3	4.7-9.9
Beaufort	3.2	2.8-3.6	6.5	4.2-8.7	7.5	5.0-10.0
Wilmington	2.4	2.0-2.8	5.8	3.5-8.0	6.8	4.3-9.3
Southport	2.4	1.9-2.8	5.9	3.7-8.2	6.9	4.4-9.4

*Note: Projections were rounded to the nearest tenth of an inch.

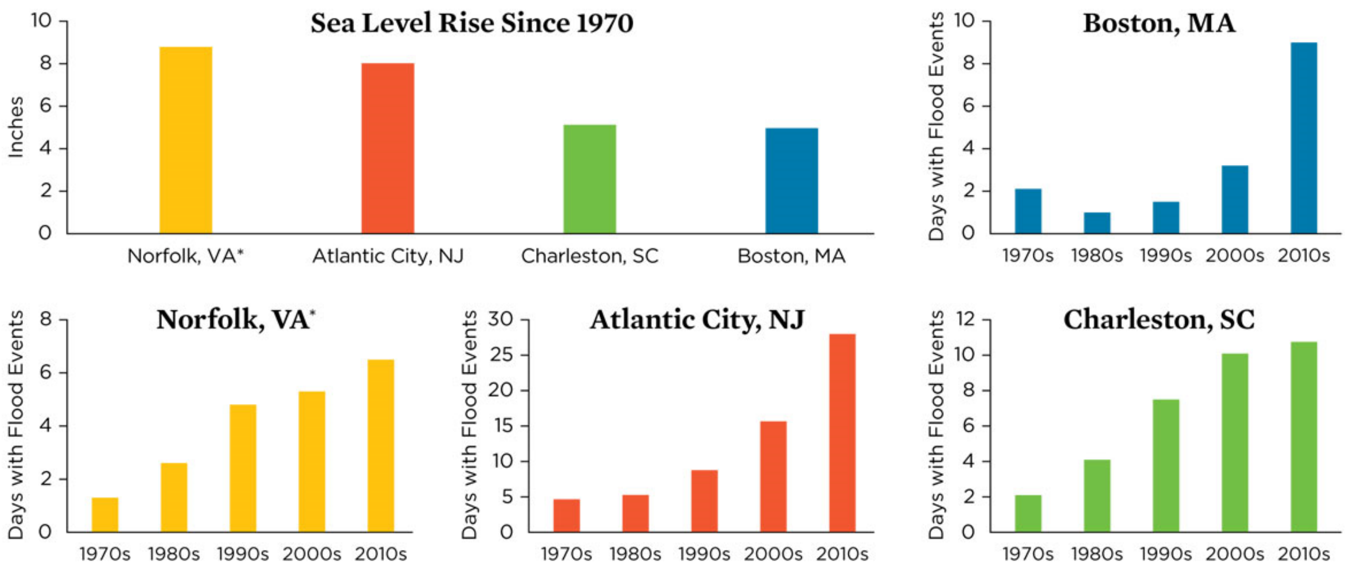


FACTORS CONTRIBUTING TO GLOBAL SEA LEVEL (GSL) FROM 1993-2010	
Thermal Expansion (+) or Contraction (-)	39%
Glaciers (non Greenland and Antarctica)	27%
Greenland and Antarctic ice sheets	21%
Land water storage	13%



King Tide Flooding (a.k.a., “nuisance flooding”)

Local Sea Level Rise and Tidal Flooding, 1970–2012



Sea level has risen by about 3.5 inches globally—but more along the East Coast—since 1970. At Sewells Point, VA, for example, sea level has risen more than eight inches, and at Boston, about five inches. Rising seas mean that communities up and down the East and Gulf Coasts are seeing more days with tidal flooding. Charleston, SC, for example, faced just two to three days with tidal flooding a year in the 1970s. The city now averages 10 or more such days annually.

*Norfolk statistics recorded at the Sewells Point tide gauge.

SOURCES: UCS ANALYSIS; MORALES AND ALSHEIMER 2014; NOAA TIDES AND CURRENTS 2014; NOAA TIDES AND CURRENTS 2013B.

Photos by: Niels Lindquist

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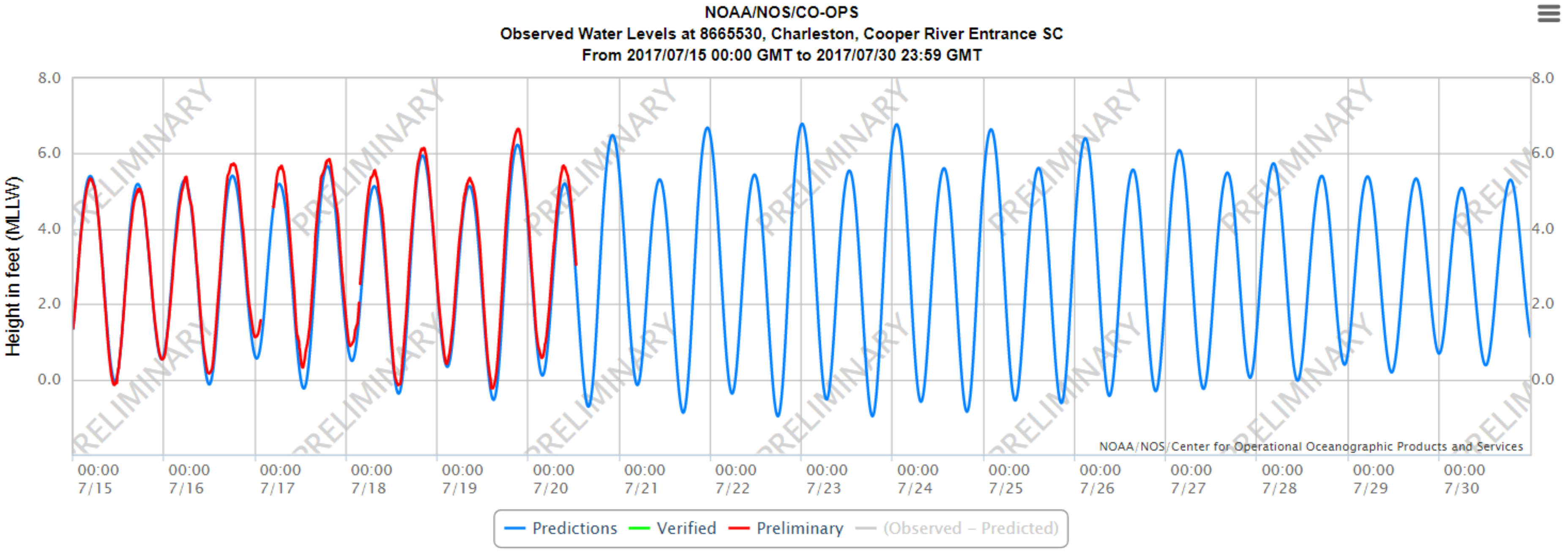
King Tides @ Charleston, SC



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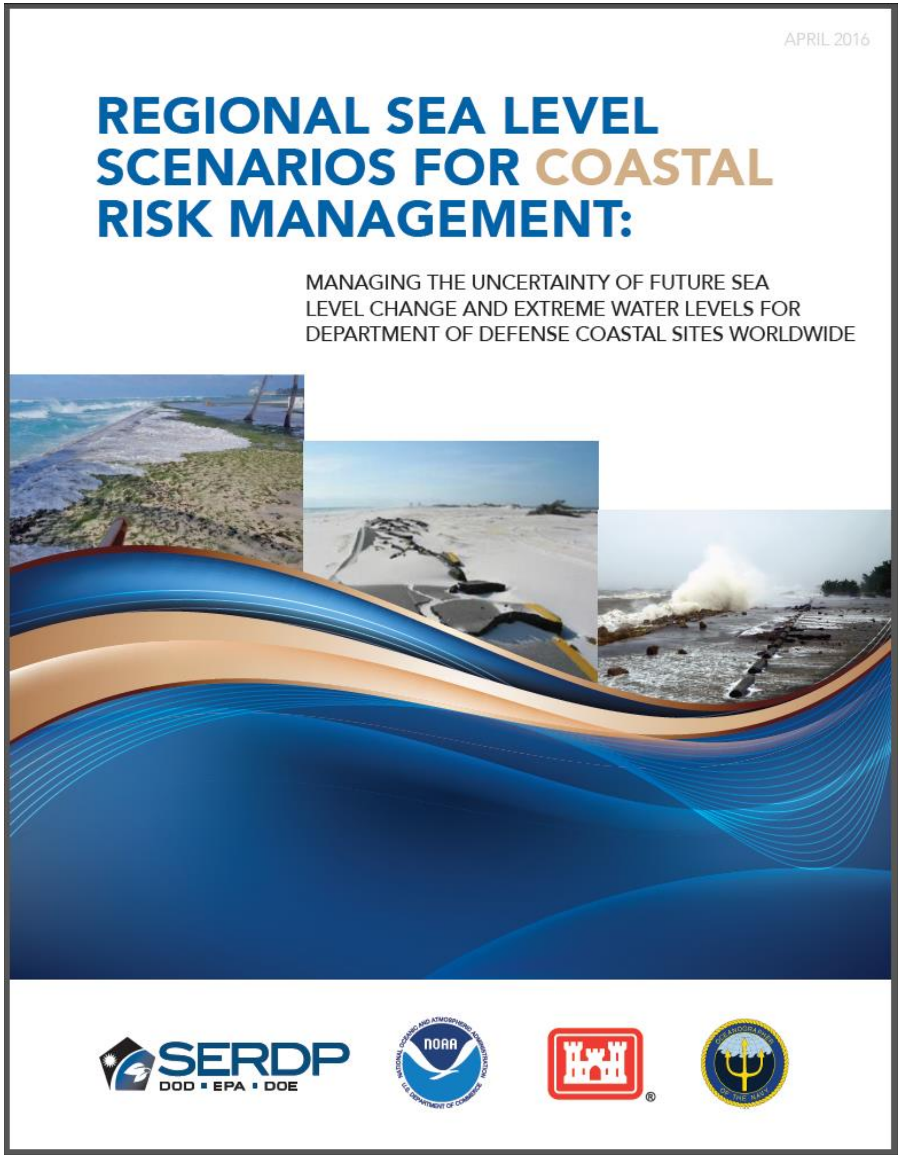
DoD Sea Level Guidance (April 2016)



– Region sea level and extreme water level (EWL) scenarios for 3 future time horizons (2035, 2065, and 2100) for 1,774 DoD sites worldwide.

– …**no one answer exists** to address risk under future potential SLR.

– ….recommend an approach in which multiple **plausible scenarios** of the future are considered within a **risk-based** framing context.

Adaptive Risk Management

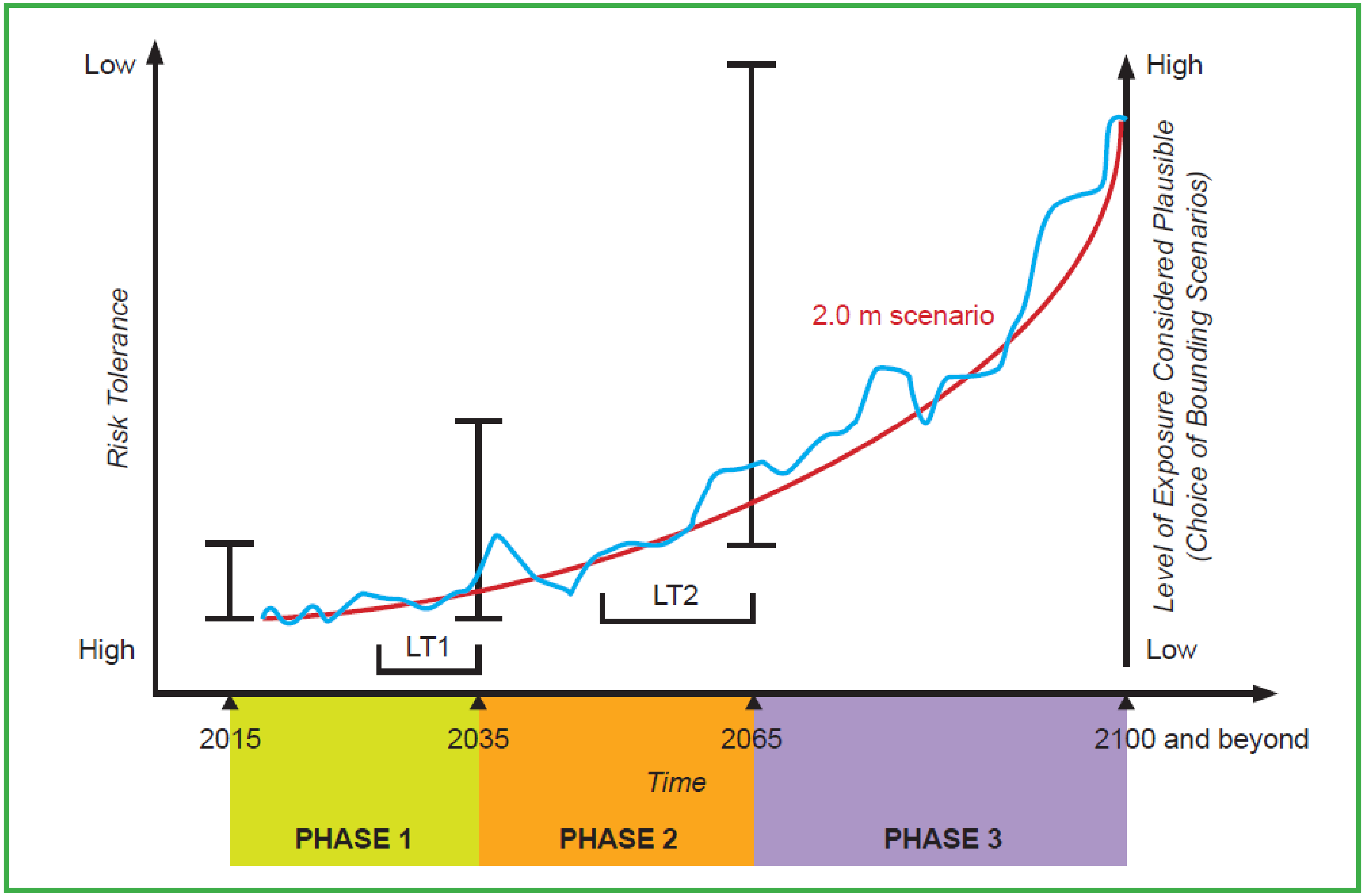
Adaptive Risk Management Strategy:

- Flexible response.
- Resource costs.
- Reversible aspects.
- Robustness of the decision.

Basic Elements of a coastal ARM Approach:

- Apply 20-50 year scenarios and solutions,
- Monitor trends (i.e., SLR, extremes),
- Update the upper bound scenarios for the longer timeframes, and
- Implement new measures accordingly.

Conceptual Diagram of an Adaptive Use of Scenarios



The key points to remember regarding ARM:

- *decision process and points are **iterative,***
- *choice of bounding scenarios should be robust for the **desired timeframe,***
- *should not preclude **future response options**, and*
- *facilitate the **appropriate timing** of the next decision.*

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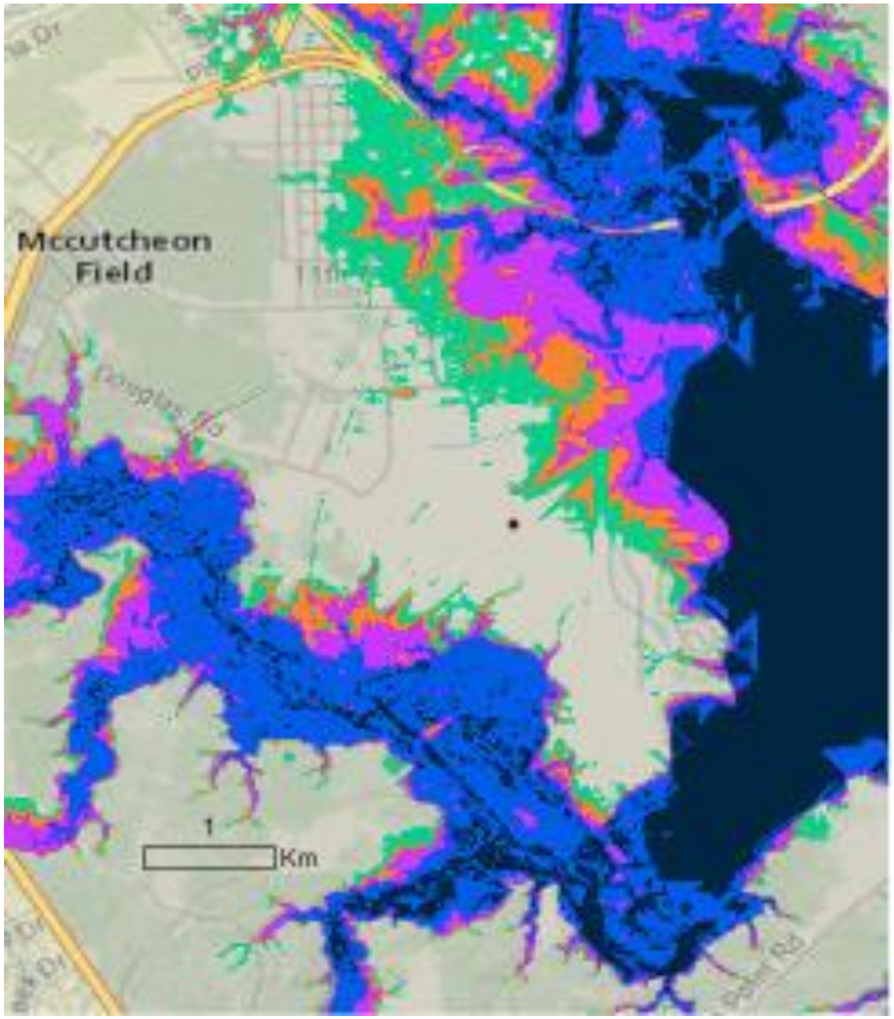
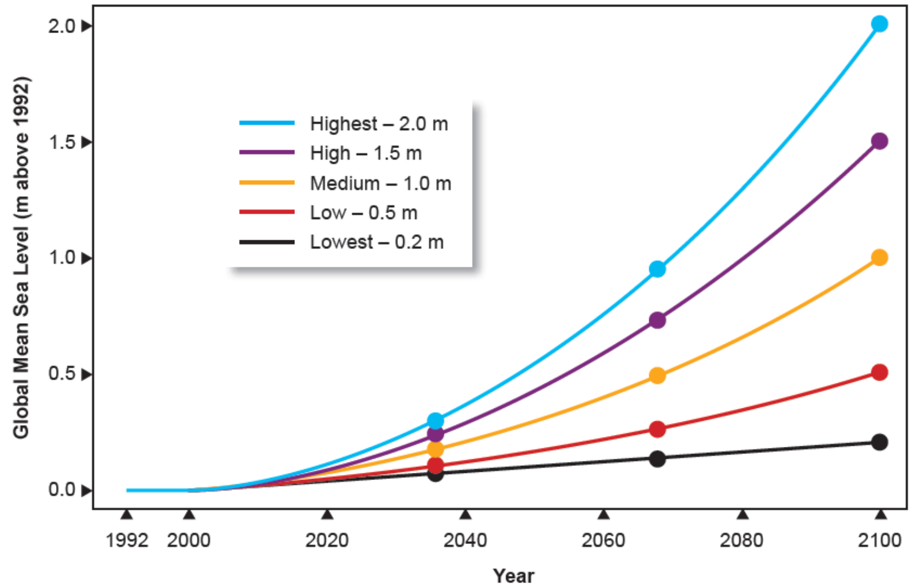
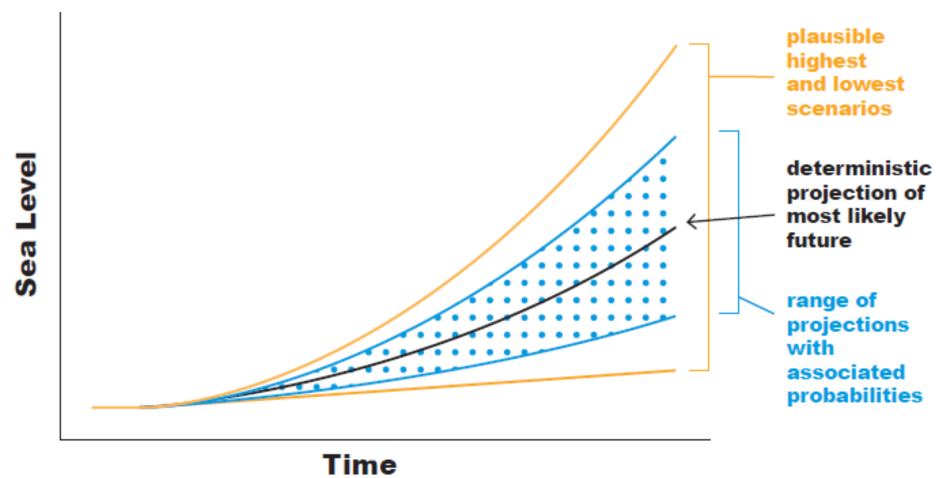
Plausible Scenarios







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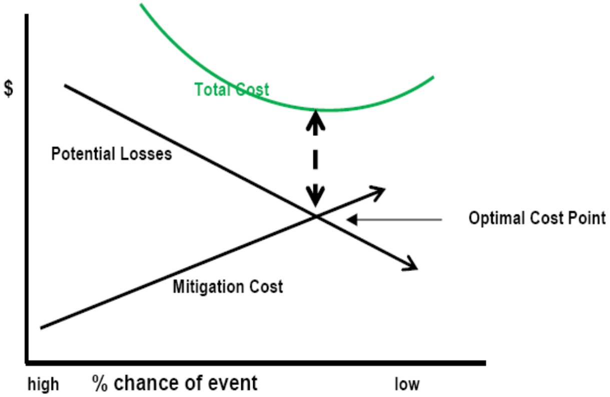
Risk Tolerance

- **High Risk Tolerance:**
  - Use lower scenarios (0.2 and 0.5 meters).
  - Projects with a short lifespan.
  - Planning areas with flexibility to make alternative choices within the near-term.
  - Low criticality.

- **Low Risk Tolerance:**
  - Use higher scenarios (1.0, 1.5, and 2.0 meters).
  - Little tolerance for risk.
  - Projects or assets with a long lifespan, in which losses would be catastrophic.
  - Planning areas with limited flexibility to adapt in the near or long term.
  - Assets that serve critical military functions (e.g., ports and associated infrastructure).



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Summary of Min-Max Values for Regional Adjustments to Global SLC & EWL Values (1,774 DoD Sites)

<table>
<tr><th>Global Scenario</th><th colspan="3">Range of Sea-Level Change Adjustments by Scenario and Time Horizon (meters)</th><th colspan="4">Range of Annual Chance Event Values (ACE) (meters)</th></tr>
<tr><th></th><th>2035</th><th>2065</th><th>2100</th><th>20% ACE</th><th>5% ACE</th><th>2% ACE</th><th>1% ACE</th></tr>
<tr><td>0.2 meters</td><td rowspan="5">-0.9 to 0.5</td><td rowspan="4">-1.6 to 0.8</td><td rowspan="3">-2.3 to 1.2</td><td rowspan="5">0.2 to 3.0</td><td rowspan="5">0.3 to 3.6</td><td rowspan="5">0.3 to 4.0</td><td rowspan="5">0.3 to 4.3</td></tr>
<tr><td>0.5 meters</td></tr>
<tr><td>1.0 meters</td></tr>
<tr><td>1.5 meters</td><td>-2.3 to 1.3</td></tr>
<tr><td>2.0 meters</td><td>-1.6 to 0.9</td><td>-2.2 to 1.5</td></tr>
</table>

"the primary purpose of the scenario values developed and illustrated herein is to support screening level vulnerability and impact assessments for Department of Defense (DoD) sites worldwide"

Federal Tools Relating to Sea-Level Change Depiction and Potential Impacts

- **NOAA Sea Level Rise and Coastal Flooding Impacts Viewer**
- **USACE Sea Level Change Calculator Tool**
- **USGS Coastal Vulnerability Index**

0 feet of Sea Level Rise (MHHW) – Base Camp

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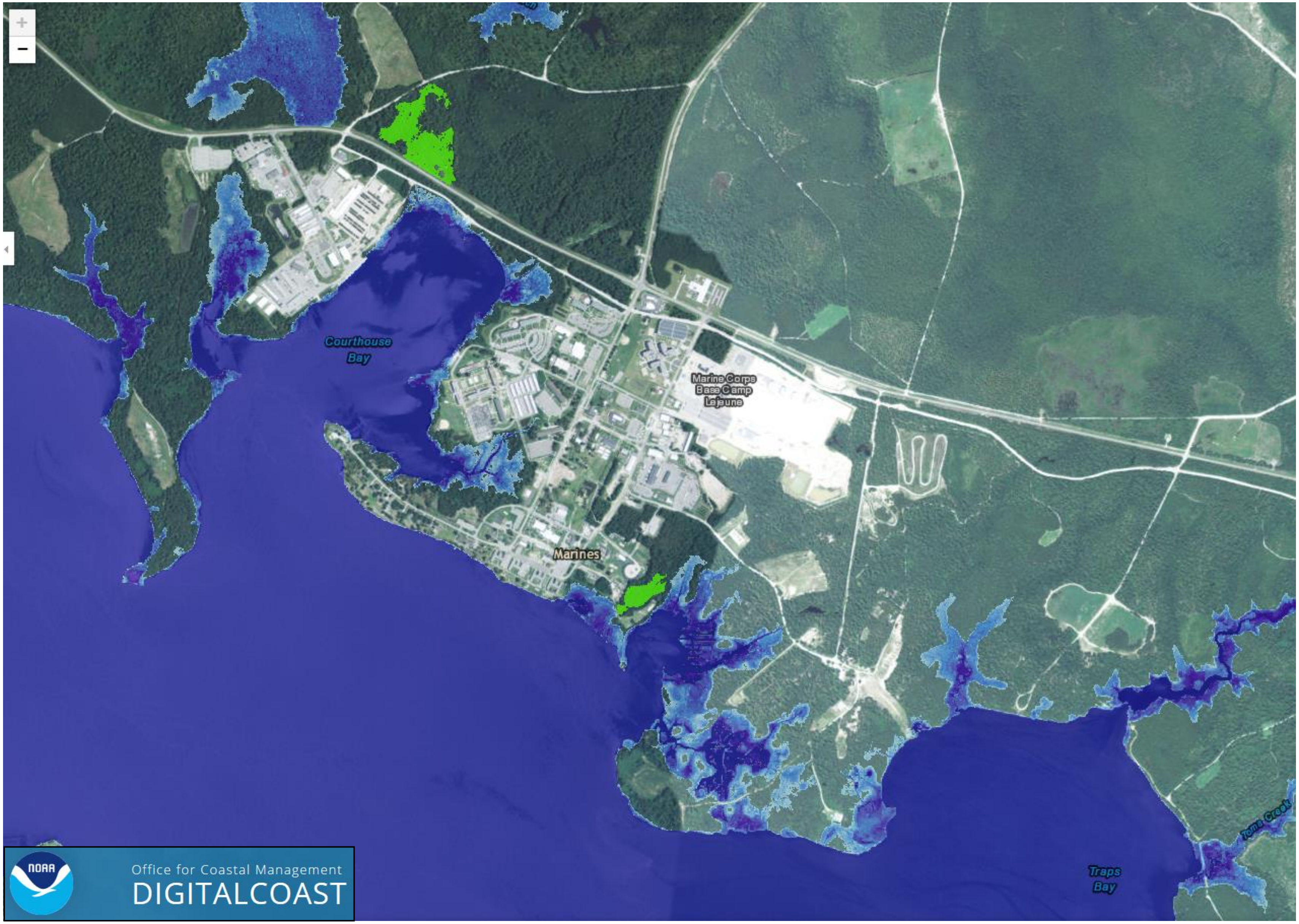
3 feet of Sea Level Rise (MHHW) – Base Camp



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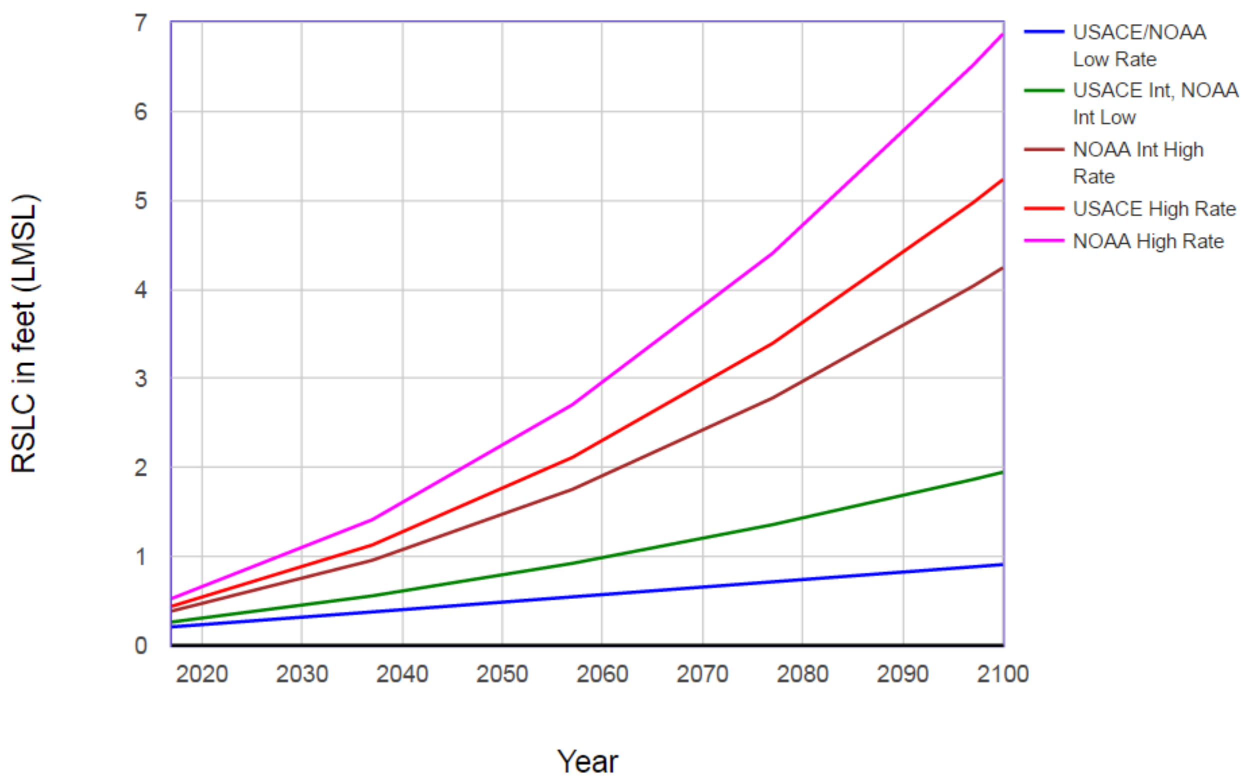
6 feet of Sea Level Rise (MHHW) – Base Camp

USACE Sea Level Change Calculator Tool

US Army Corps of Engineers

Year	USACE Low NOAA Low	USACE Int NOAA Int Low	NOAA Int High	USACE High	NOAA High
2017	0.21	0.27	0.39	0.44	0.53
2037	0.38	0.56	0.96	1.13	1.41
2057	0.55	0.92	1.76	2.11	2.71
2077	0.72	1.36	2.78	3.40	4.41
2097	0.89	1.87	4.04	4.97	6.52
2100	0.91	1.95	4.24	5.24	6.87

Relative Sea Level Change Projections - Gauge: 8656483, Beaufort, NC (05/01/2014)



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USGS Coastal Vulnerability Index

USGS science for a changing world

	Ranking of coastal vulnerability index				
	Very low	Low	Moderate	High	Very high
VARIABLE	1	2	3	4	5
Geomorphology	Rocky, cliffed coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble beaches Estuary Lagoon	Barrier beaches Sand Beaches Salt marsh Mud flats Deltas Mangrove Coral reefs
Coastal Slope (%)	> .2	.2 – .07	.07 – .04	.04 – .025	< .025
Relative sea-level change (mm/yr)	< 1.8	1.8 – 2.5	2.5 – 2.95	2.95 – 3.16	> 3.16
Shoreline erosion/ accretion (m/yr)	>2.0 Accretion	1.0 – 2.0	-1.0 – +1.0 Stable	-1.1 – -2.0	< - 2.0 Erosion
Mean tide range (m)	> 6.0	4.1 – 6.0	2.0 – 4.0	1.0 – 1.9	< 1.0
Mean wave height (m)	<.55	.55 – .85	.85 – 1.05	1.05 – 1.25	>1.25

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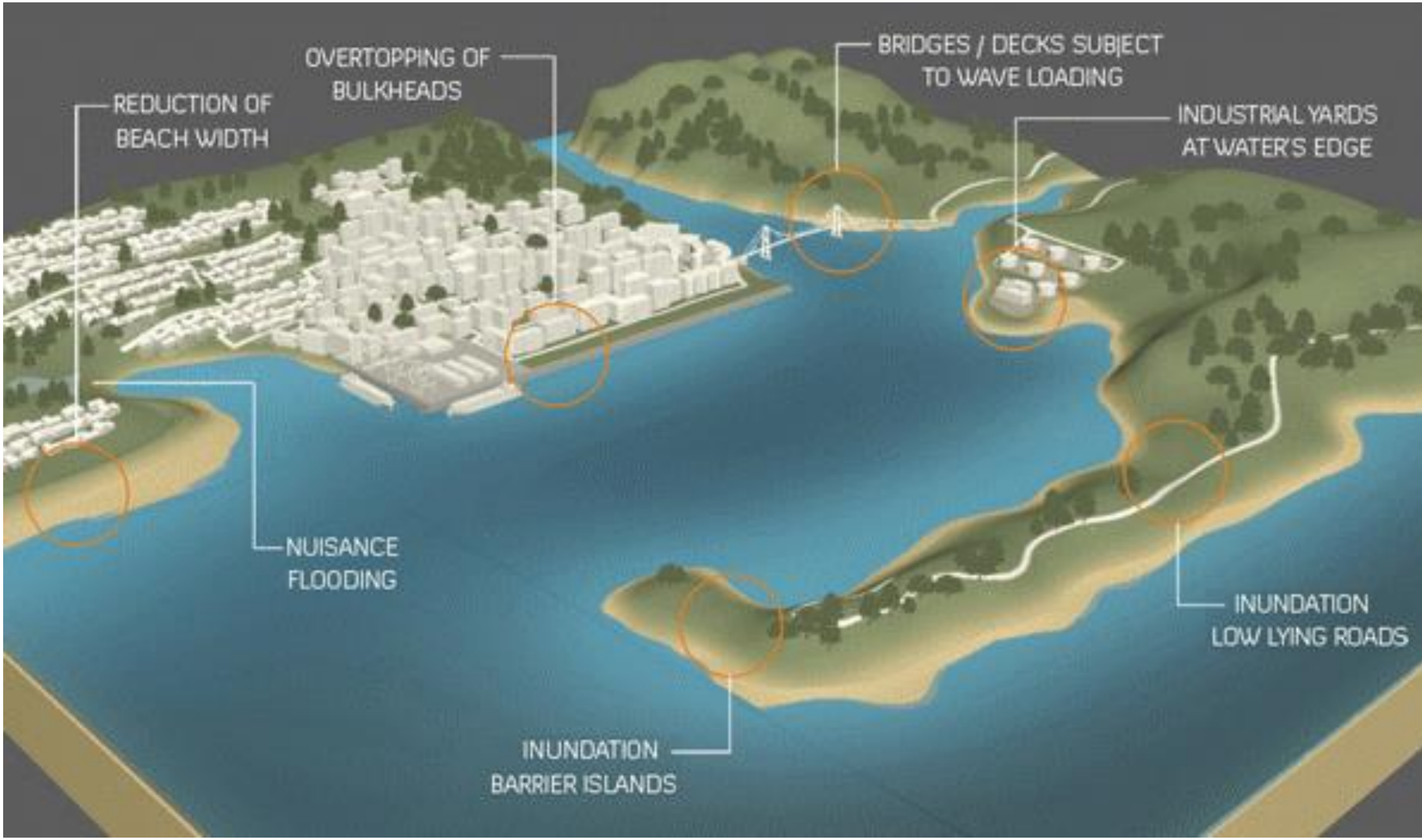
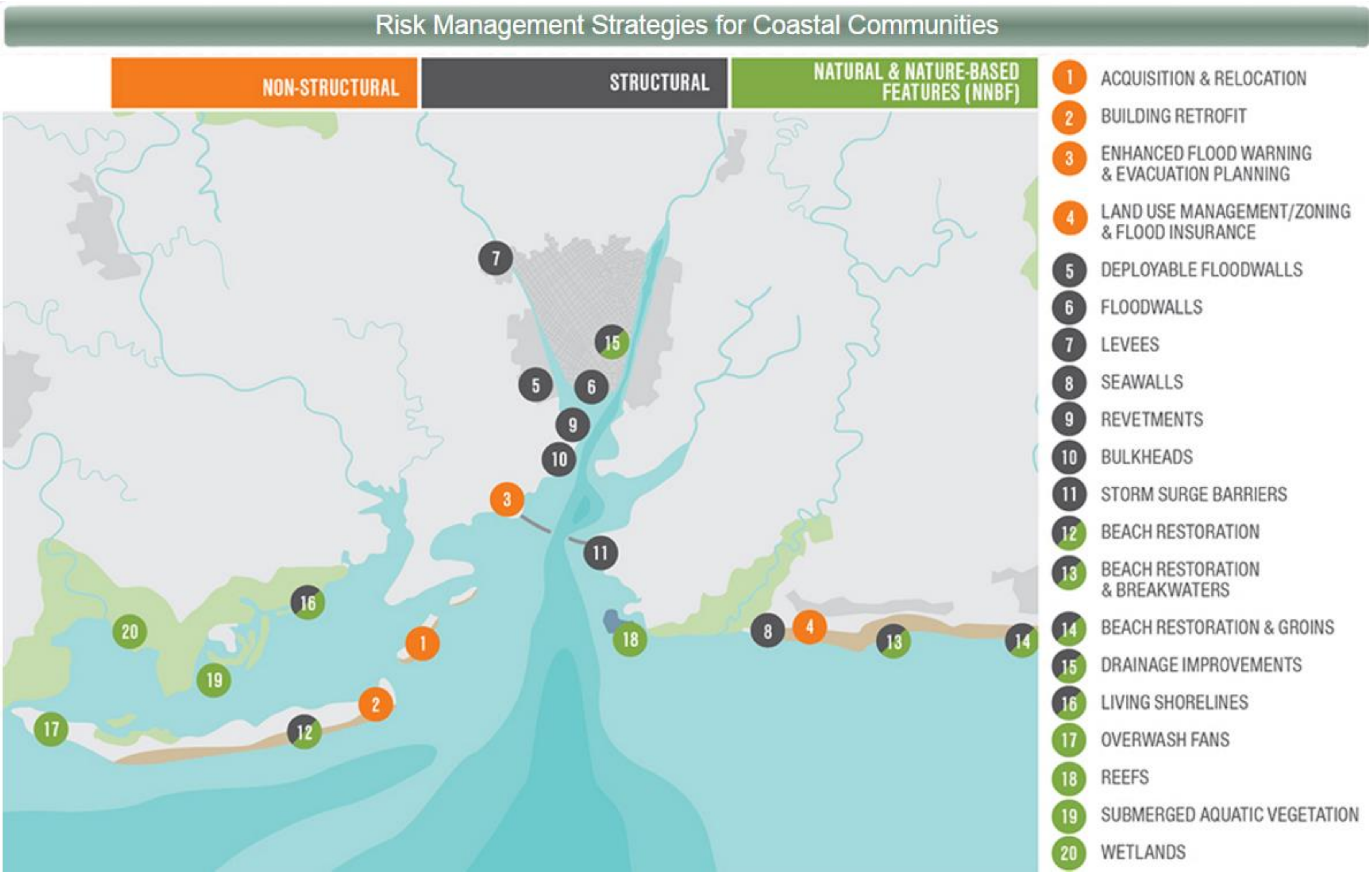
Resilience (USACE Perspective)

US Army Corps of Engineers®



USACE Risk Management Strategies to 2100



Non-structural Approaches

Floodplain Policy and Management	Floodproofing and Impact Reduction	Flood Warning and Preparedness	Relocation
			
Benefits/Processes			
Improved and controlled floodplain development Reduced opportunity for damages Improved natural coast environment	Reduced opportunity for damages Increased community resiliency No increase in flood potential elsewhere	Reduced opportunity for damages Increased community resiliency Improved public awareness and responsibility	Reduced opportunity for damages No increase in flood potential elsewhere Improved natural coast environment
Performance Factors			
Wave height Water level Storm duration Agency collaboration	Wave height Water level Storm duration	Wave height Water level Storm duration	Wave height Water level Storm duration

Structural Approaches

Levees	Storm Surge Barriers	Seawalls and Revetments	Groins	Detached Breakwaters
				
Benefits/Processes				
Surge and wave attenuation and/or dissipation Reduced flooding Reduced risk for vulnerable areas	Surge and wave attenuation Reduced salinity Intrusion	Reduced flooding Reduced wave overtopping Shoreline stabilization behind structure	Shoreline stabilization	Shoreline stabilization behind structure Wave attenuation
Performance Factors				
Levee height, crest width, and slope Wave height and period Water level	Barrier height Wave height Wave period Water level	Wave height Wave period Water level Scour protection	Groin length, height, orientation, permeability, and spacing Depth at seaward end Wave height Water level Longshore transportation rates and distribution	Breakwater height and width Breakwater permeability, proximity to shoreline, orientation, and spacing

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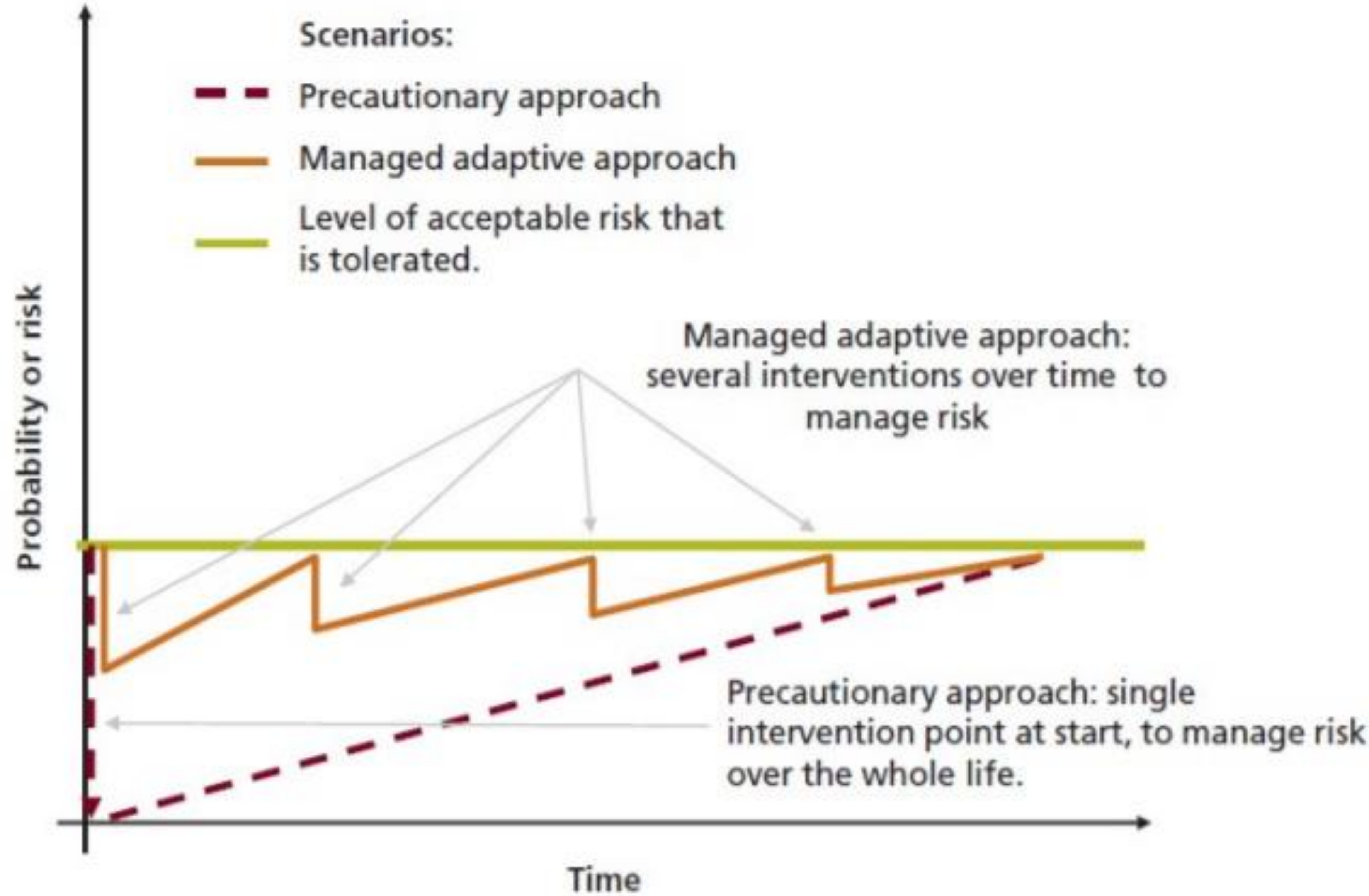
Natural & Nature-based Approaches

Dunes and Beaches	Vegetated Features	Oyster and Coral Reefs	Barrier Islands	Maritime Forests/Shrub Communities
				
Benefits/Processes				
Breaking of offshore waves Attenuation of wave energy Slow inland water transfer	Breaking of offshore waves Attenuation of wave energy Slow inland water transfer Increased infiltration	Breaking of offshore waves Attenuation of wave energy Slow inland water transfer	Wave attenuation and/or dissipation Sediment stabilization	Wave attenuation and/or dissipation Shoreline erosion stabilization Soil retention
Performance Factors				
Berm height and width Beach slope Sediment grain size and supply Dune height, crest, and width Presence of vegetation	Marsh, wetland, or SAV elevation and continuity Vegetation type and density	Marsh, wetland, or SAV elevation and continuity Vegetation type and density	Marsh, wetland, or SAV elevation and continuity Vegetation type and density	Marsh, wetland, or SAV elevation and continuity Vegetation type and density

USACE Risk, Strategy, and Project Purpose



AECOM Resilience Planning Process

Resilience

"Instead of repeated damage and continual demands for federal disaster assistance, resilient communities proactively protect themselves against hazards, build self-sufficiency, and become more sustainable"

—Godschalk, et al., 2009

Resilience is the ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption caused by a hazard.

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Thank You & Q/A?

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