Sustainability in the Face of Climate Challenges

Sub-committee on sea-level change considerations for marine civil works

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Committee chair


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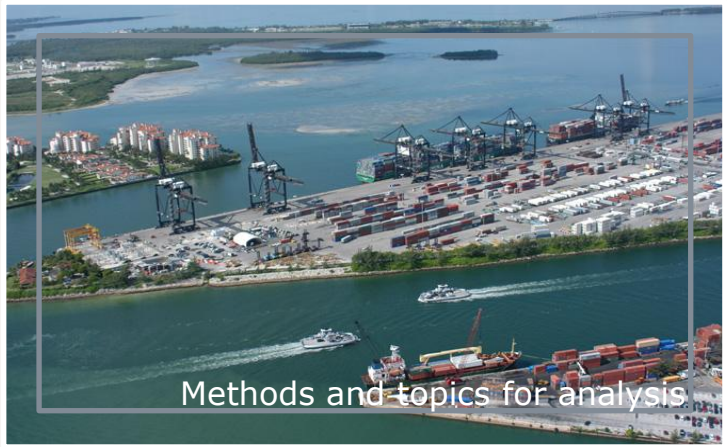
Sea-level changes and processes


Methods and topics for analysis


Purpose
Context


Deliverables

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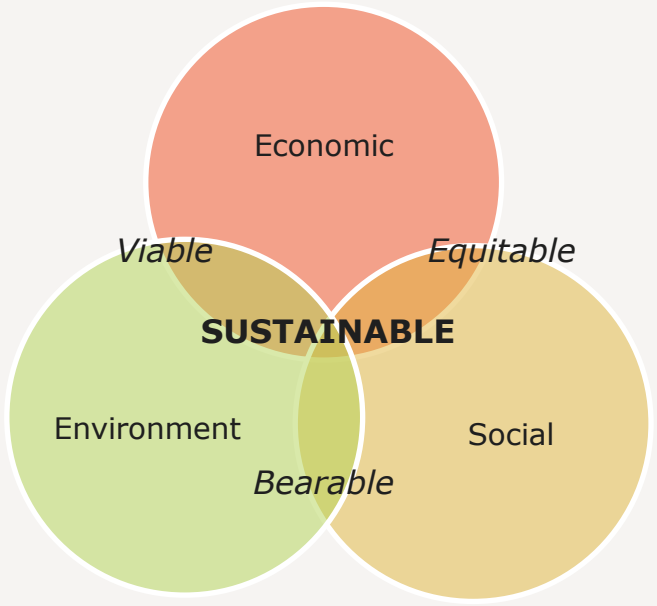
Introducing this committee

Initiative on Sea-Level Change

- ASCE Coasts, Oceans, Ports and Rivers Institute
- Objectives
  - Focus on sea-level change
  - Analyze, quantify
  - Inform practitioner
- Products
  - Manual of best practices
  - Adaptive and resilience-building strategies, by structure



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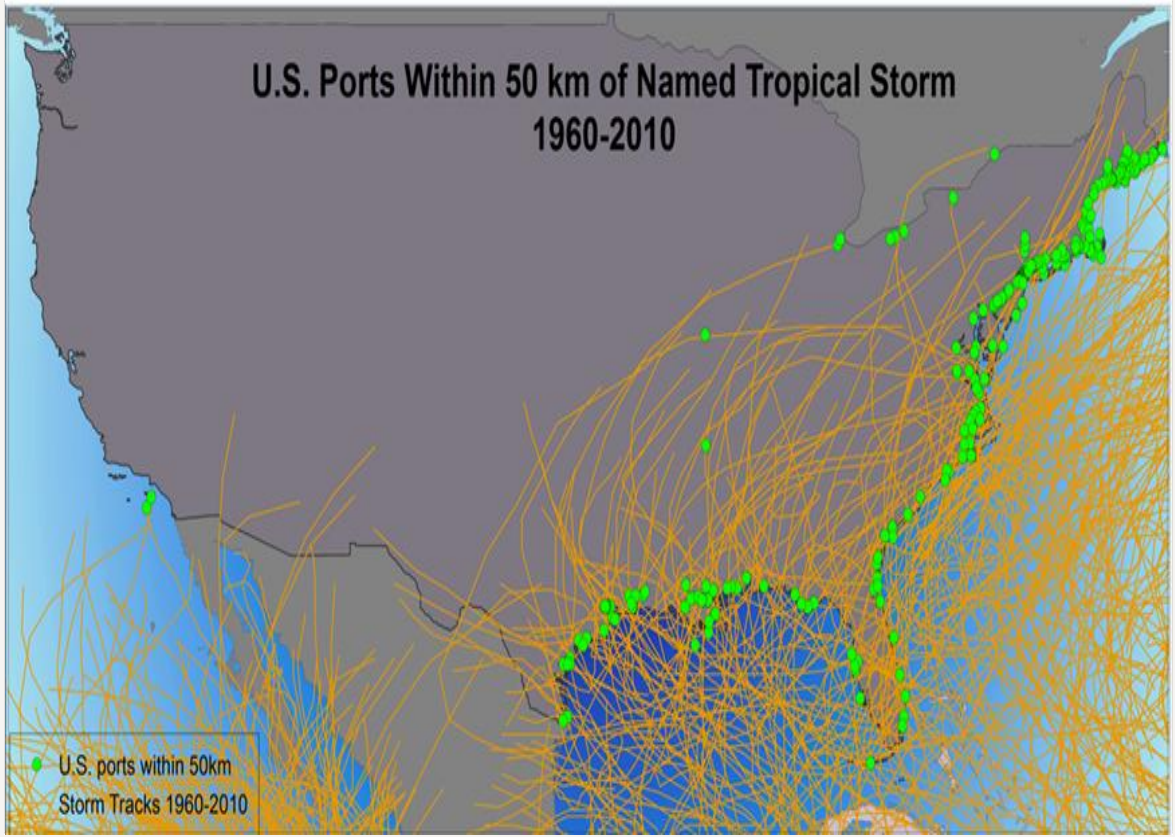

- Seaports as economic powerhouses
  - 5 US ports in the Top 50 according to the World Shipping Council, by TEUs
- Climate change as powerful driver for innovation
  - Vulnerable to climate change, highly exposed
  - Strong incentive for adapting to changing environmental loads and variables
  - Not all ports subject to same challenges

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Sustainability Performance

- Drivers for change
  - Long-term well-being of the nation
  - Key role on climate change adaptation
- Maritime community
  - Well aware
  - Looking for specific information (Becker 2011)
  - Momentum

- Existing benchmarks
  - AAPA Sustainability Task Force
  - PIANC WG 150 ENVICOM
  - EPA sustainable
  - ISI Envision focus on sustainable infrastructure
  - ISO 14001
  - SuPort by ARUP triple bottom line
  - SNAME Marine Vessel Environmental Performance
  - LEED, by USGBC - focus is on buildings and neighborhood-scale developments.

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Context: Risk Analysis

Approach

	Question	Action	This committee
1	*What is the challenge?*	Identification	Literature
2	*How much do we know?*	Data collection	Bathymetric survey, LiDar, etc.
3	*What is the risk?*	Analysis	Risk quantification, analysis & mapping
4	*What can be done about this?*	Adaptation opportunities	Structural and non-structural measures
5	*What is the best solution, and when should it be implemented?*	Measure Screening	Planning

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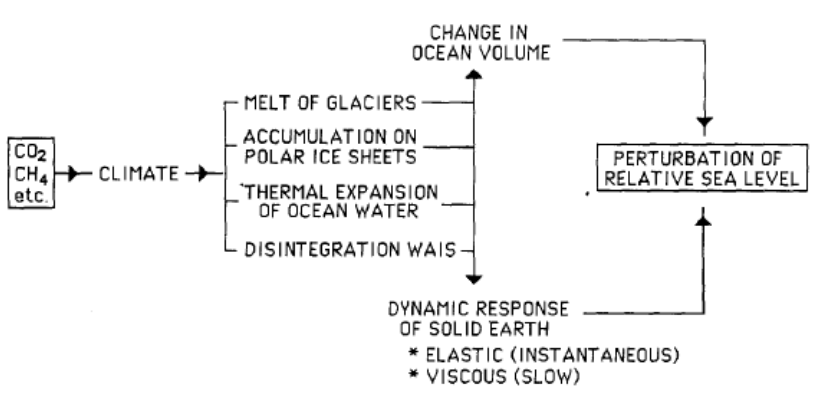
Primer on Sea Level

- Atmospheric forcing
  - Climate response
- Change in ocean volume
  - Glaciers
  - Ice sheets
  - Thermal expansion
  - Other effects (permafrost, methane release, etc.)
  - Vertical motion (up and down)
- Perturbation in relative sea level



- Most important process that determine a change in relative sea-level. After Oerlemans (1989)

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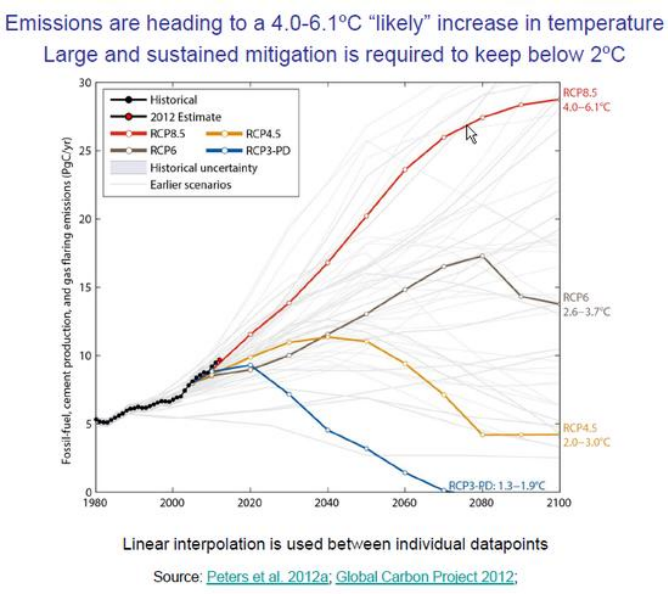
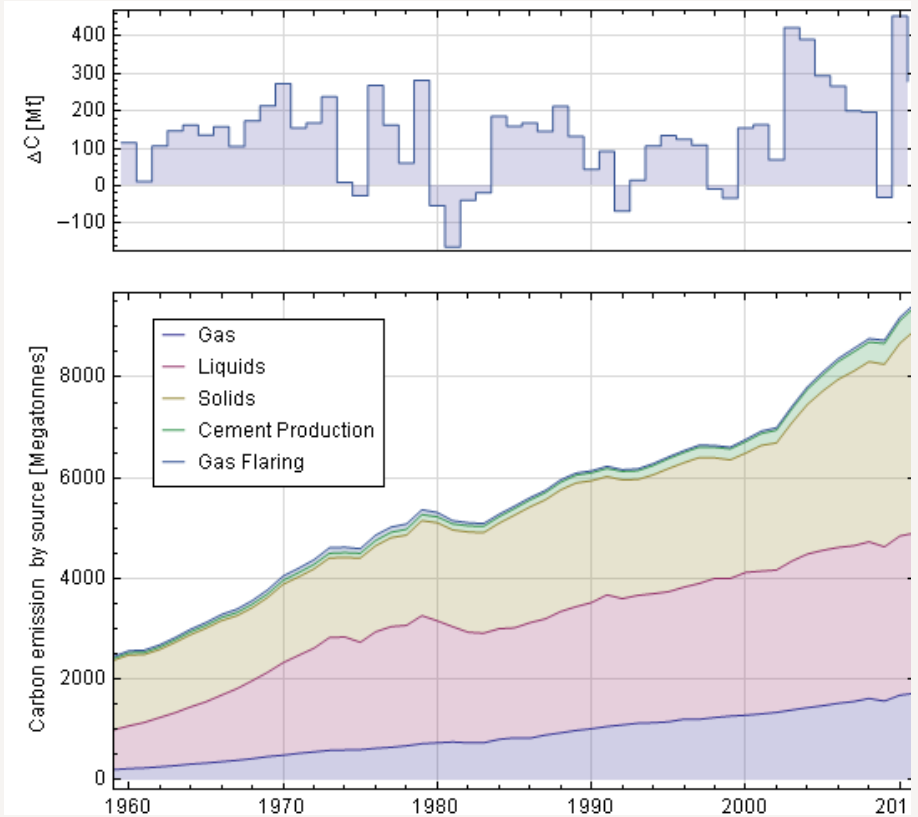
Indicators Ticking Upward





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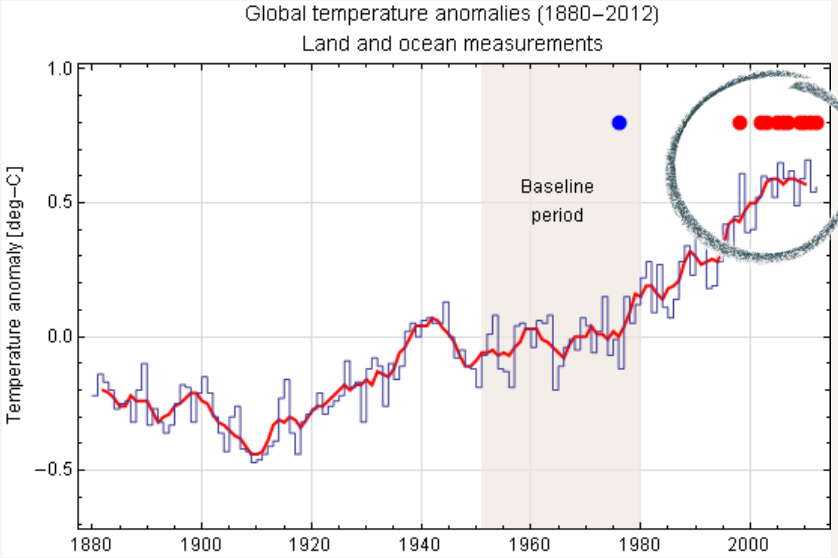
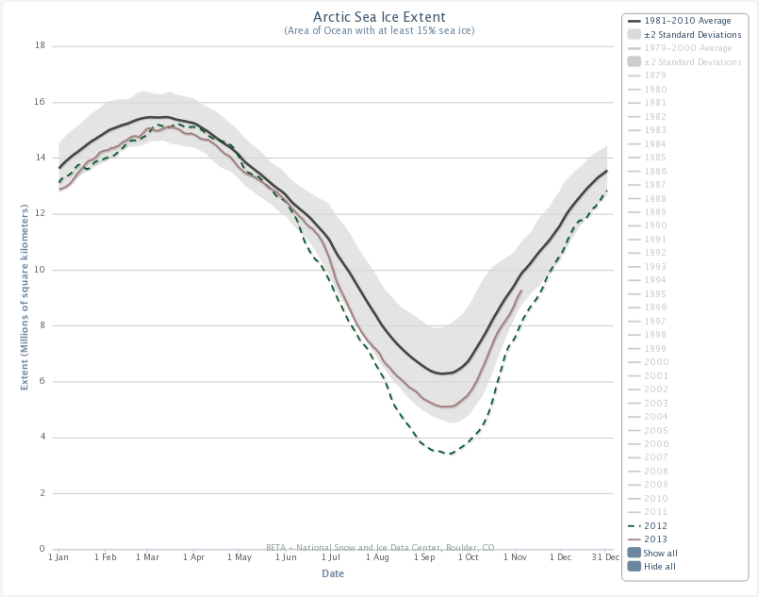
Sea-Surface Temperature and Ice Degradation





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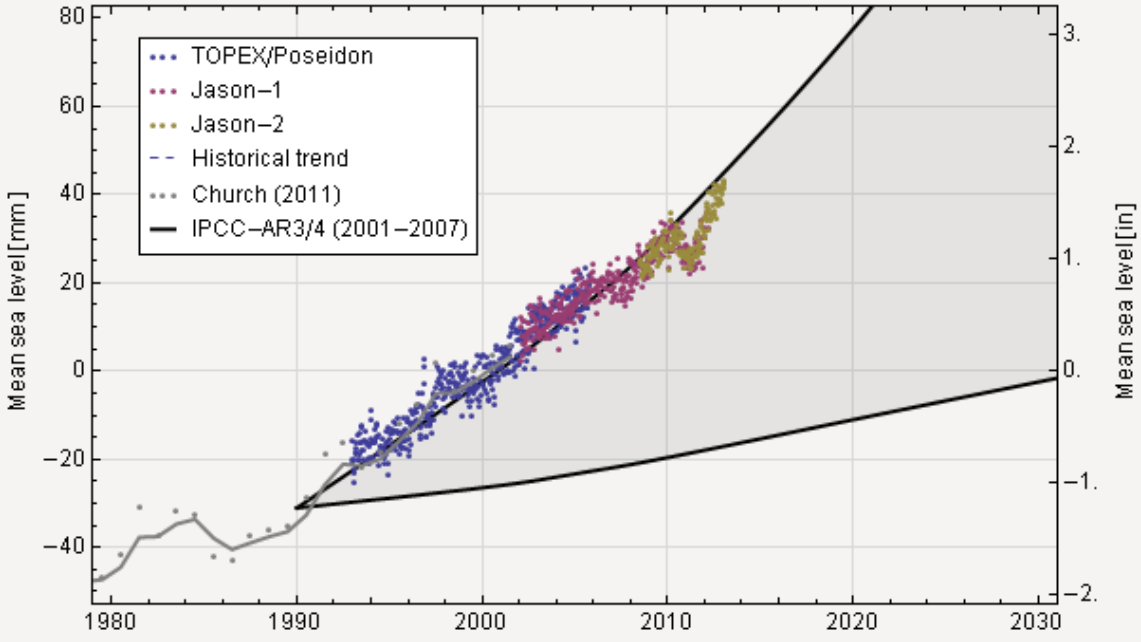
Historical Trends and Projections



- Currently following the most conservative trajectory set by IPCC AR3/4 (2001-2007)
- Upper and lower bounds from over 35 emission scenarios
- IPCC suggested that rapid ice melting cannot be excluded

- Need for an update on SLR projection and guidelines that reflects most recent trends

- **Source**: IPCC AR3/4 for projections and NOAA STAR for satellite data

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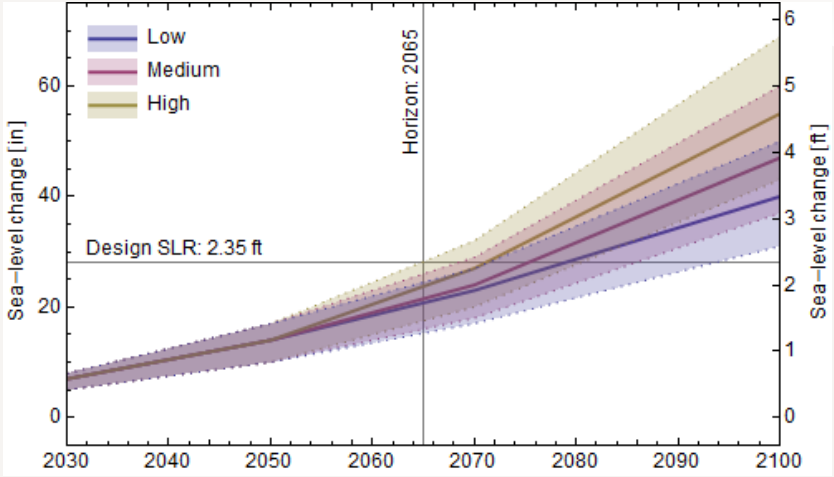
Sea-level Projections

- Long-term projections provided by a wide range of agencies nationwide
  - USACE, NOAA, NRC, EPA
  - State-specific, agencies, cities (NY), etc.
- Goals
  - Review of scenarios
  - Tools for analysis (historical trends, fitting, matching, extrapolation, stitching of trends and historical trends, etc.)



- Sample trend by CO-CAT of California (with strong input from Vermeer and Rahmstorf study) which may extend to Oregon, Washington and possibly British Columbia through the Pacific Coast Collaborative

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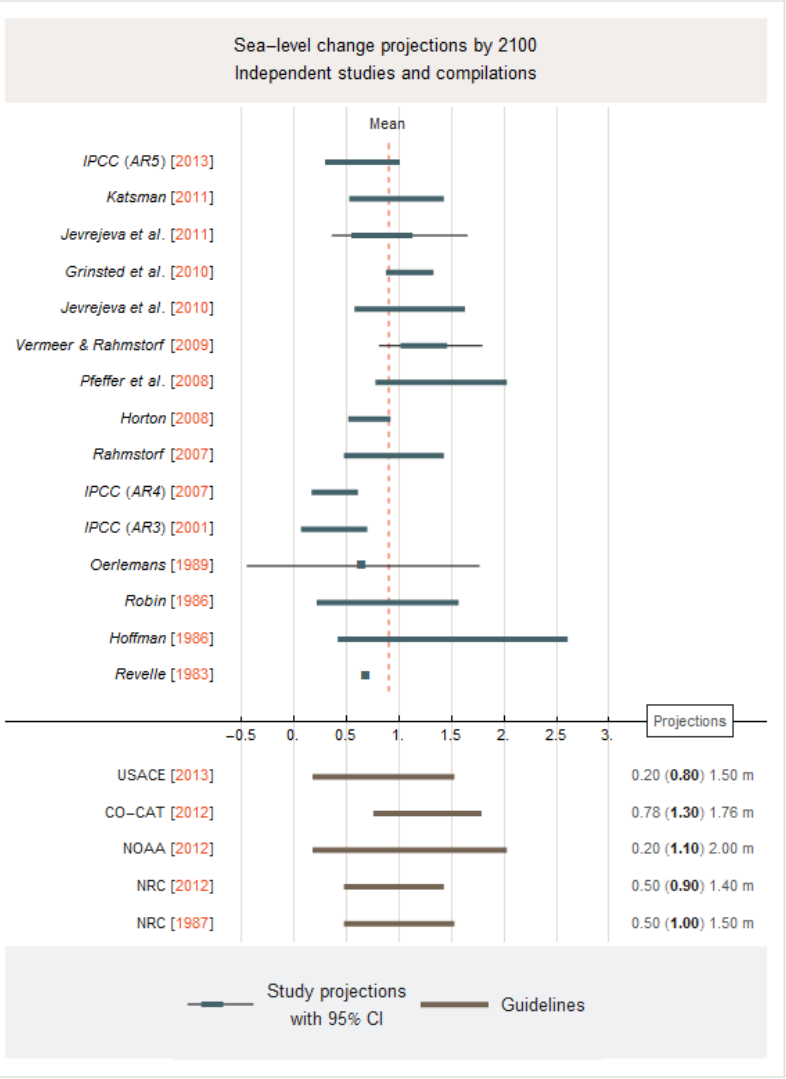
Long-term Projections and uncertainty

- Compilations and independent studies
- 30 years of research
- Classification of methods
  - Semi-empirical (Vermeer, Grinsted, etc.)
  - Global climate model
  - Budget and trends
- Goals
  - Range of guidelines for risk analysis
  - Define low, medium or high
  - Uncertainty

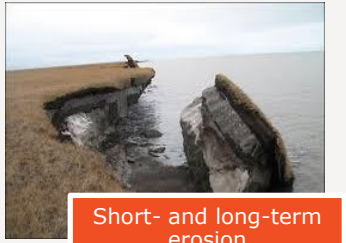


USACE Guidance EC-1165-2-212

Marine & Coastal Processes and Sea-level Changes

Wave attack

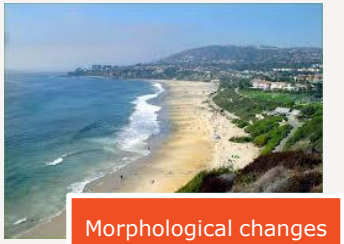
Inundation, storm surge



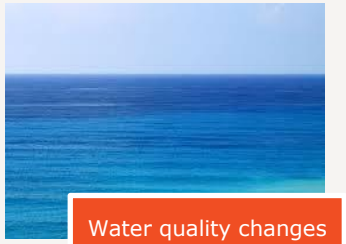
Short- and long-term erosion

Inland water ways and drainage hydraulics

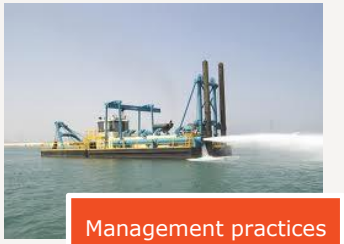
Harbor hydrodynamics



Morphological changes



Water quality changes



Management practices

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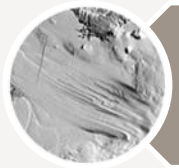
Sea-level Components

- Long-term vs. short term (Ruggiero 2013)
- Local vs. regional
- $\mathrm{TWL} = \mathrm{MSL(t)} + \eta_{\mathrm{Astronomical}} + \eta_{\mathrm{Non-tidal}} + R_{\mathrm{Waves}}$
- Site-specific SLC analysis
- Caveat
  - Recognize but does not evaluate direct effects of rising temperatures and increased precipitation on port infrastructure



Global sea-level trends

Awareness of other contributing factors

Site-specific sea-level trends for risk analysis

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Wave Effects

- **Increased wave activity** (NRC 2012)
- **Overtopping** $Q \sim a \cdot R^{-b}$
- **Run-up** geometry, waves, erosion
- **Wave loads** sea level and wave
- Wave **mechanics** and hydrodynamics
- **Setup**

- "For the coast of the U.S. Pacific Northwest over 30 years, wave height increases have had a more significant role in the increased frequency of coastal flooding and erosion than has the rise in sea level." – Ruggiero, 2013

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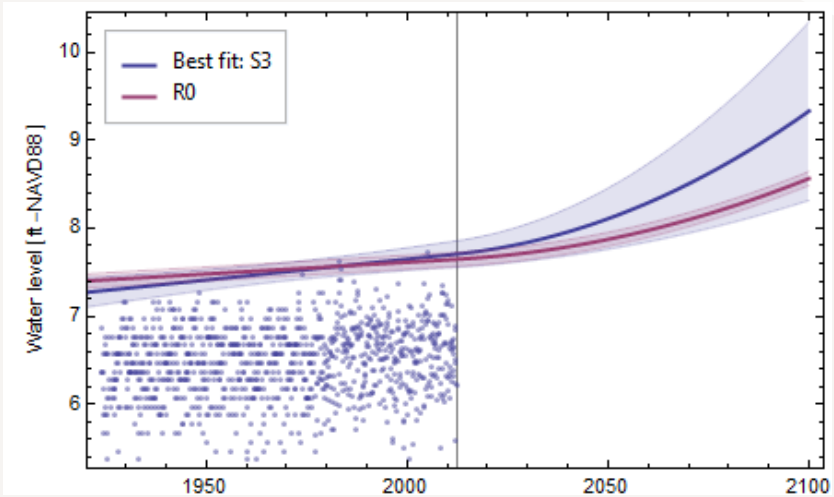
Return Periods and Levels

- Modulated definition of return periods
  - Non-stationary, non-linear: change in SL may induce response in tide + storm surge signal
  - Non-stationary, linear: effective return period of protection level decreases
  - $P = 1 - \left(1 - \frac{1}{T(t)}\right)^n$



- Non-stationary vs. stationary response modeling of TWL at Los Angeles CO-OPS station 9410660

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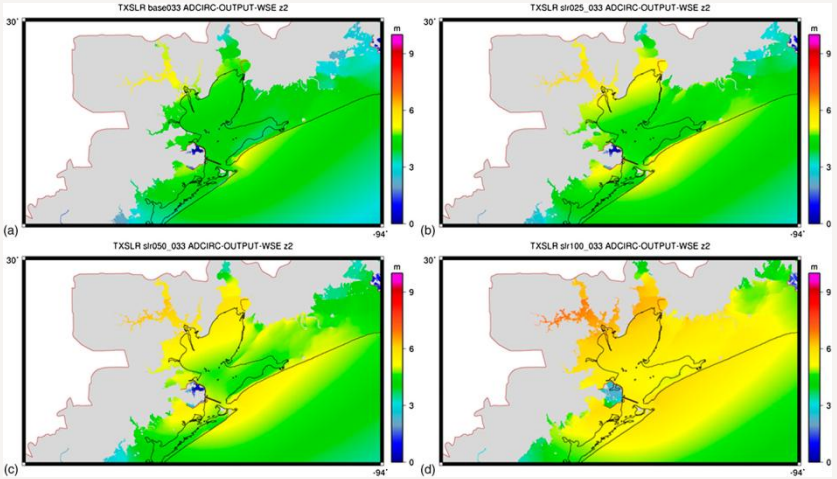
Hurricanes

- Sea-level change modulates hurricane surge response on a large scale
  - Non-linear response of storm surge to SLC
  - Larger water depths and amplified surge means larger waves propagate inland
  - Stronger winds, modified tracks



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Astronomical Tides

- Sea-level change…
  - Effect on tidal cycles (Flick, Murray, and Ewing 2003).
  - Reported increases in the range from high to low astronomical tide

Flooding at Embarcadero district in San Francisco during a "king tide" event

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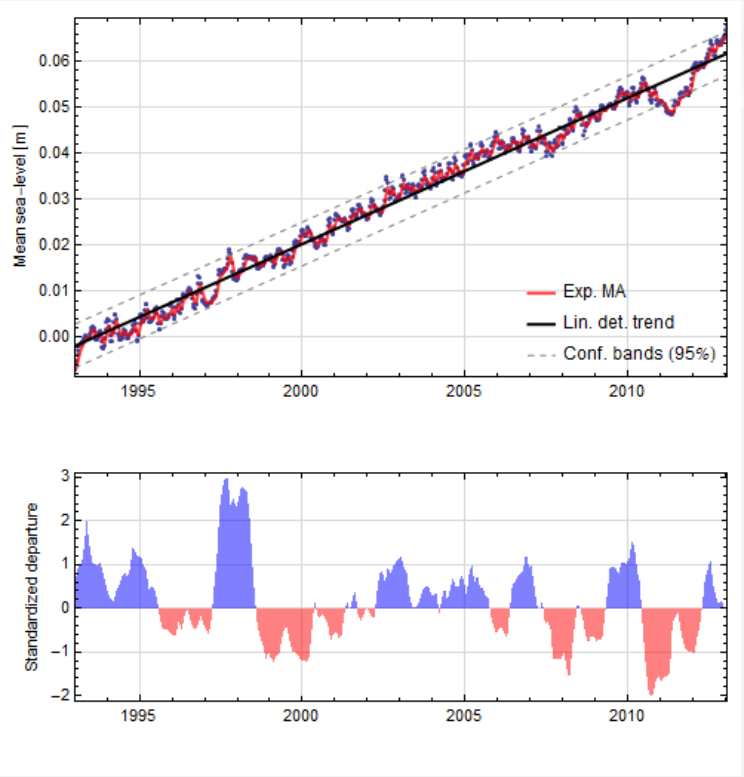
Regional Climate Drivers

- Seasonal effects influence short-term variability in SL data (Méndez et al. 2007)
- El Niño events elevate sea level along the west coast in winter (Seager et al., 2010).
- Stronger seasonality
- Modified tropical storm tracks (NRC 2012)



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Deliverable

Site-Specific Sea-level Change Road Map

Approach	Timing	Regional effects	Estimates	Upgrade approach
☐ Selected guideline	☐ Reference year	☐ Waves	☐ Central	☐ Scheduled
☐ Risk-based design	☐ Present date	☐ Tide sensitivity	☐ Estimate band	☐ Precautionary
☐ Level of risk selected	☐ Project start date	☐ Others…		
	☐ Design life			
	☐ SL at start date			
	☐ SLC			

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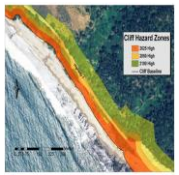
Effects on processes and structures

Protect

Accommodate



Retreat

- Adopt PAR approach (IPCC 2001)
- Survey processes impacted by sea-level change
- Small resiliency steps can provide huge benefits over time
- Examples follow (others exist)

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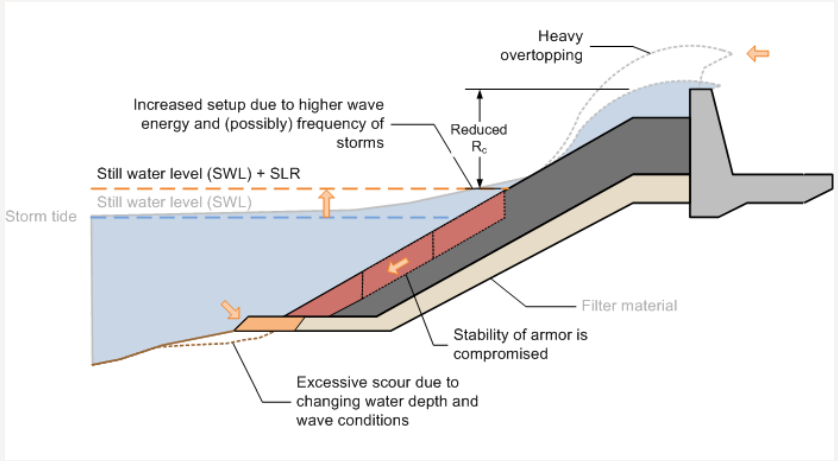
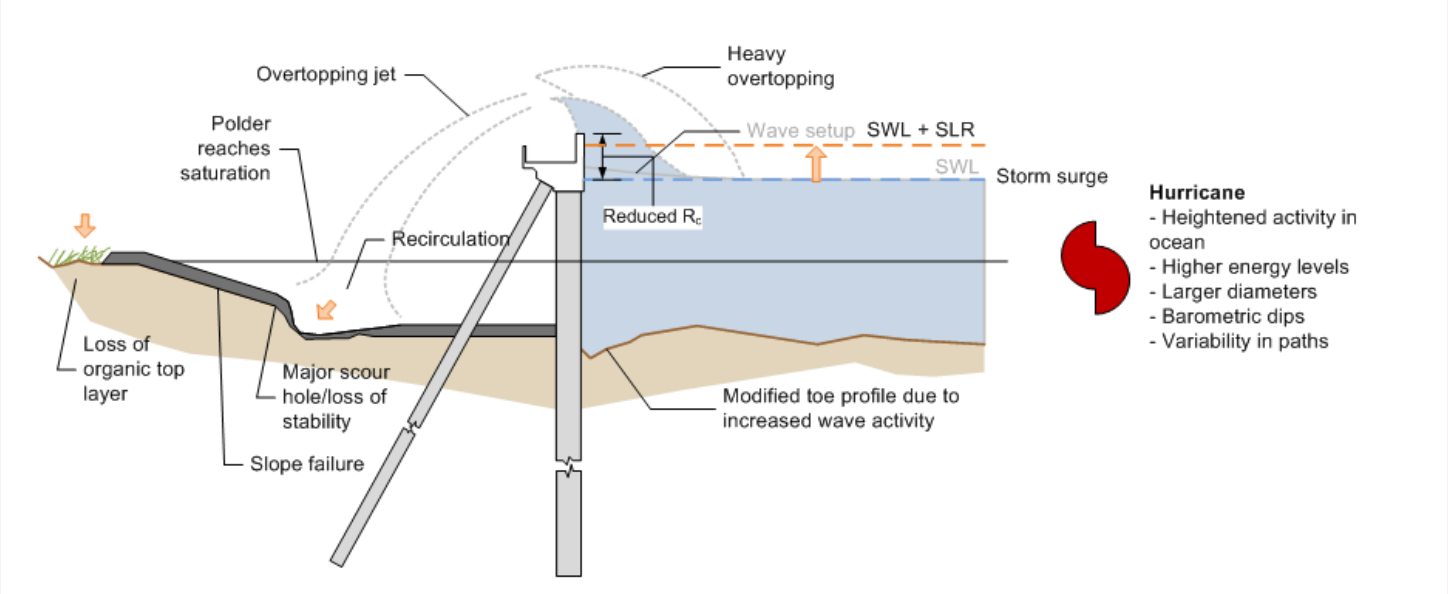
Rubble-mound Structures

- Structural integrity of breakwaters and rubble-mound structures
  - Overtopping and concrete cap damage
  - Scour and instability ("winnowing")
  - Loss of efficiency due to increased wave transmission.
- Goals
  - Transmission guidance (Goda 2010, USACE CEM 2011, others)



Response of engineered structures to changes in sea-level

Flood Control Structures



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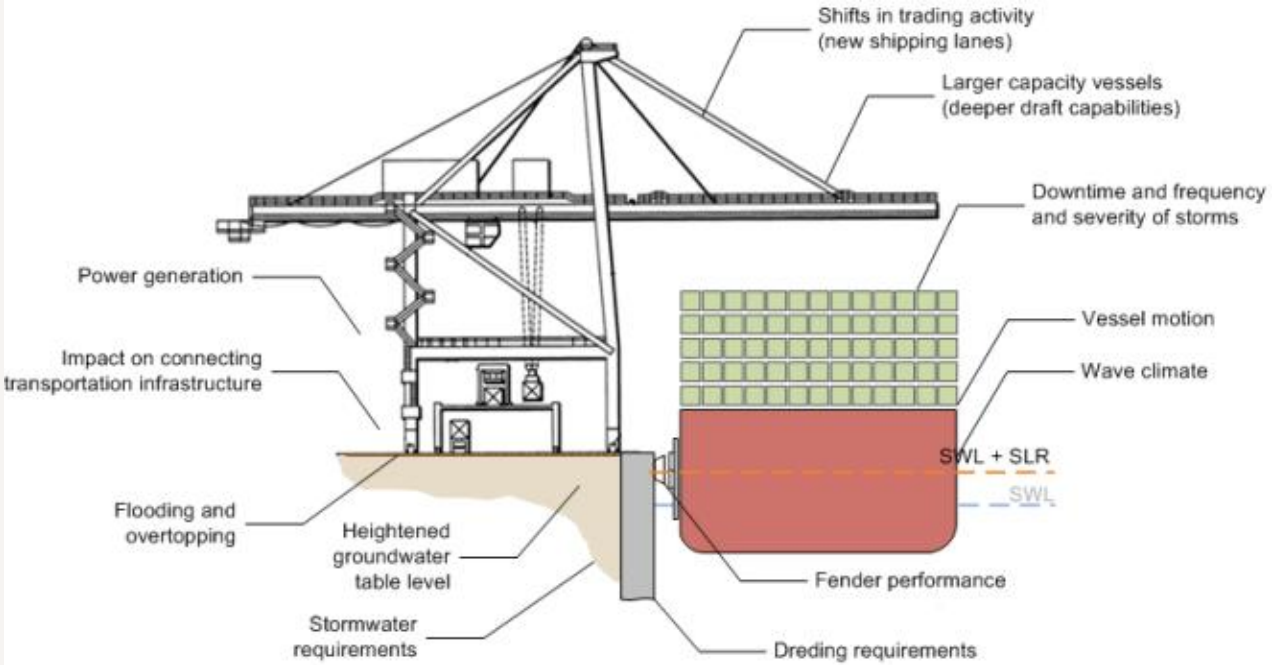
Response of engineered structures to changes in sea-level

Wharves and Operations



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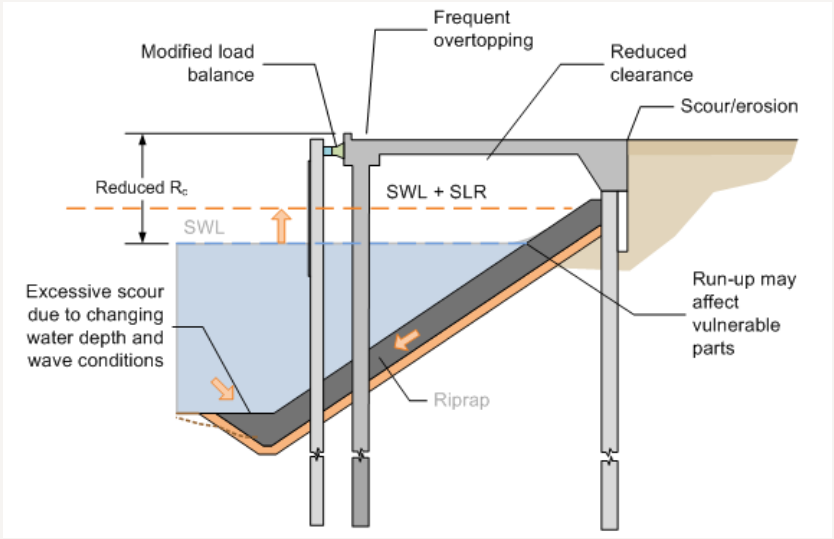
Wharves and Piers

- Standard features vulnerable to changes in sea-level
  - Frequent flooding
  - Fender systems
  - Ship-to-shore systems and power units
  - Changes in sediment transport patterns, scour and accretion with new requirements for dredging
  - Scour, instability, wave climate, and run-up/overtopping.



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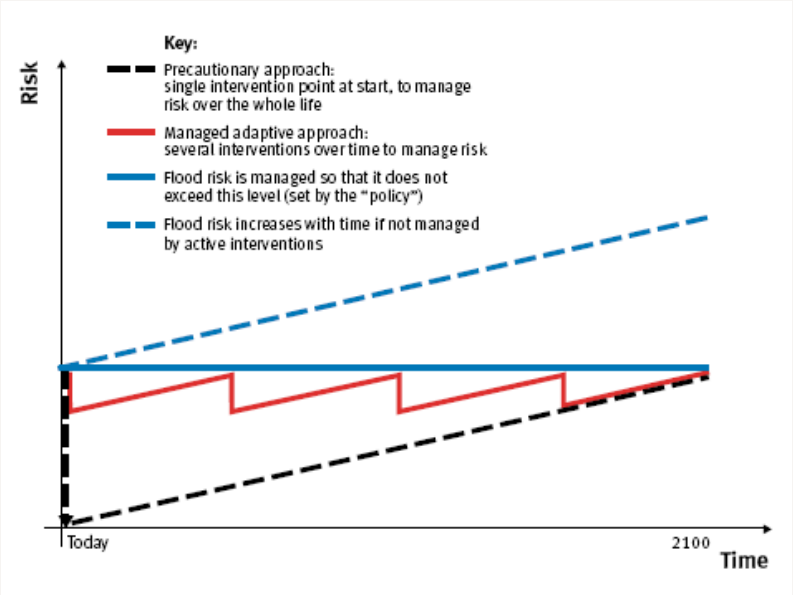
Response to Uncertainty and Capital Improvement Strategies

- Resiliency vs. failure
  - Acceptable risk
  - Routine actions vs. rebuilding/replacement
- Capital improvement schedule
  - Built-in resiliency
  - Easier upgrade and maintenance
  - Opportunistic, precautionary or scheduled



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Our Path Forward and Perspectives

- Mix of hard/soft measures
- December 2013: first draft
- Encourage planning
- Assist seaports stakeholder
- Coordinated study efforts

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Acknowledgments

- Will be available at ASCE Library
- Participation is encouraged at any level

- The team
  - John Atkinson, ARCADIS
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  - Heidi Moritz, USACE Portland
  - Warren Stewart, COWI NA