Managing Extreme Sea Level Rise Scenarios

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Goals of the Port of Los Angeles – RAND Collaboration

- **Help Port of LA develop an initial analysis of potential vulnerabilities and response to future sea level rise**
- **Explore applicability of robust decision methods to infrastructure planning under uncertainty**
- **Evaluate effectiveness of these new methods compared to other approaches**

RAND effort supported by National Science Foundation grant for research on climate change decision making under uncertainty

Broad Threats Related to Sea Level Rise for the Port of Los Angeles to Consider

- **Base Sea Level Rise**
  - **16 inches by 2050?**
  - **55 inches by 2100?**
- **Extreme (Typical or Catastrophic) Events**
  - **More Frequent**
  - **More Powerful**
  - **Longer Lasting**

For many locations, sea-level rise means that the present one-in-a-hundred-year event could potentially occur more than once a year by 2100

- Church et al., 2009

Literature Describes Many Potential Effects of Climate Change

- Changes in temperature
  - More hot days and heat waves
  - Fewer cold days
  - Increase in Arctic temperature
  - Later onset of seasonal freeze; earlier onset of seasonal thaw
- Sea level rise; higher storm surge
- Changes in precipitation
  - Increases in intense precipitation events and flooding
  - Increase in drought conditions in some regions
  - Changes in seasonal precipitation and river flows
- More frequent and more intense storms

Many Expected Changes Pose Risks for the Port of Los Angeles

Climate Change Manifestations	Threats for the Port of Los Angeles
Sea level rise with added storm surge	Chronic flooding or inundation of connecting highway, rail Chronic flooding of open storage areas Reduced bridge clearance Liquefaction of substrate soils Dispersion of buried contaminants
More frequent, more intense, and longer lasting storms (greater precipitation, surge, waves, and wind)	Ship/wharf collisions Containers and other cargo from open storage physically dislodged Wharf or pier structures damaged Terminal buildings damaged or destroyed Specialized terminal equipment damaged or destroyed Pavement and foundations damaged or undermined Flooding of connecting highway, rail Stormwater system capacity overwhelmed Increased storm-related Port closures Increased underwater debris buildup, blockages or loss of markers hindering channel navigation Increased dredging requirements
More intense river runoff and flooding	Increased dredging requirements Increased flooding of adjacent low-lying areas

Appropriate Responses Depends on the Specific Threat (1 of 2)

Port Area / Function	Threat	Adaptation Strategy
Port planning	Investment risk due to uncertain climate effects	Reduce irreversible expenditures Reduce lease lengths
	Loss of business due to Arctic routes	Reduce irreversible expenditures (i.e., new capacity investments)
Entire port complex	Damage due to storm surge and waves	Surge barrier Strengthen and elevate breakwater
	Permanent inundation or frequent flooding due to extreme sea level rise	Relocate port
Navigation channels	Silt deposition, debris, and blockages	Increased channel dredging
Wharves, piers	Damage due to surge, wave action	Strengthen / raise wharves and piers
	Ship collisions during storms	Add or strengthen fenders

Appropriate Responses Depends on the Specific Threat (2 of 2)

Port Area / Function	Threat	Adaptation Strategy
Terminal buildings	Damage due to surge, wave action	Strengthen buildings Easy-to-repair materials
	Liquefaction, weakened foundations	Strengthen foundations
	Flooding	Elevate buildings Plan non-essential or flood tolerant functions at ground level
Terminal equipment	Damage due to surge, wave action	Strengthen equipment, foundations
Open container storage	Containers dislodged by surge, wave action	Raise or relocate container storage areas
Chemical storage	Dispersion of contaminants	Relocate storage areas Remove contaminants
Connecting roads, rail	Inundation or frequent flooding	Raise roads, rails
Bridges	Reduced clearance	Raise bridges

Literature Suggests Useful Taxonomy of Adaptive Responses

Approach	Protect	Accommodate	Retreat
Hard	Dikes, seawalls, groins, breakwaters, salt water intrusion barriers	Building on pilings, adapting drainage, emergency flood shelters	Relocate threatened buildings
Soft	Sand nourishment, dune building, wetland restoration or creation	New building codes, growing flood or salt-tolerant crops, early warning and evacuation systems, risk-based hazard insurance	Land-use restrictions, set-back zones

Study Focus : Should POLA Consider Sea Level Rise When Upgrading Its Terminals?

Approach	Protect	Accommodate	Retreat
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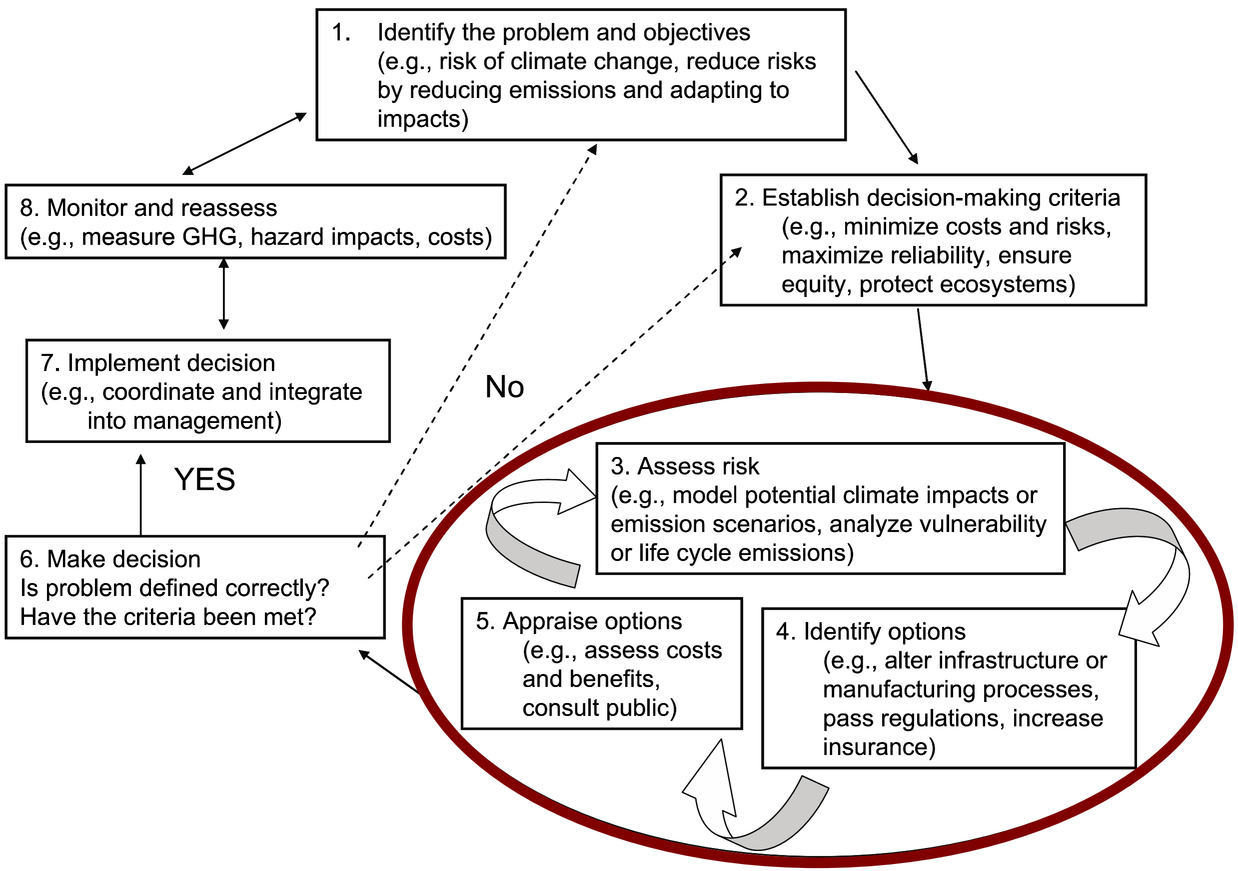
We use a robust decision making approach to address this question

Best Practice Approaches Use Iterative Risk Management Framework to Manage Sea Level Rise

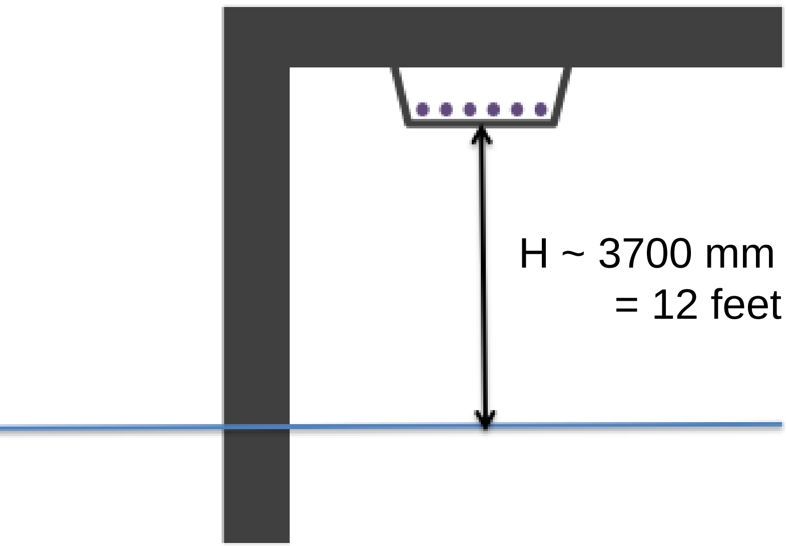


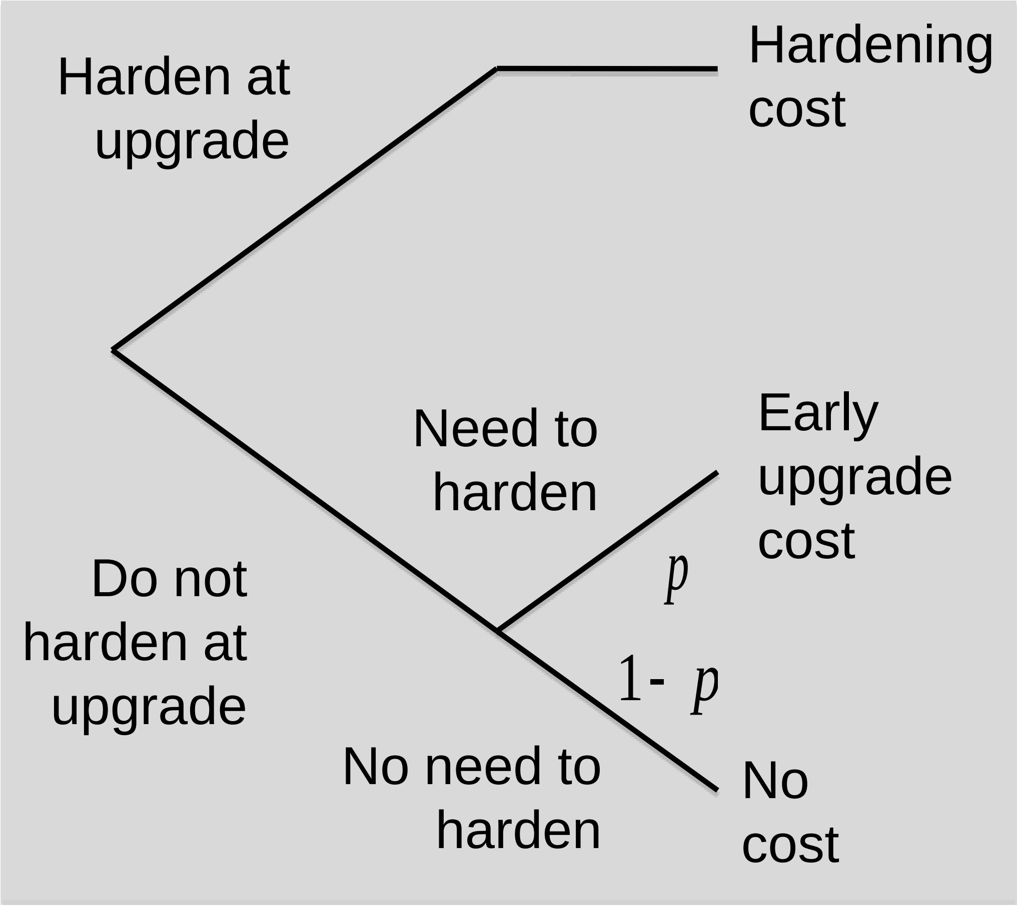
Risk = Probability x Consequence

But in many cases, both terms are at best known imprecisely

How best to assess and evaluate responses to deeply uncertain risks?

Should POLA Harden Terminals Against Sea Level Rise At Next Upgrade?



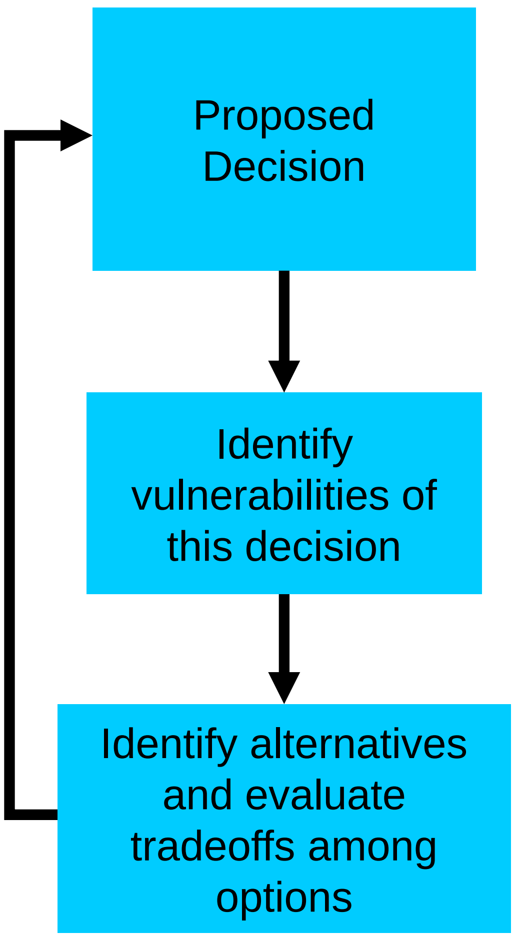


- Terminals are high above current sea level, so relatively invulnerable to all but the most extreme sea level rise
- Cost to harden at next upgrade is much lower than retrofitting between upgrades

General question: How to plan for low probability high consequence events?

Employ Robust Decision Making (RDM)

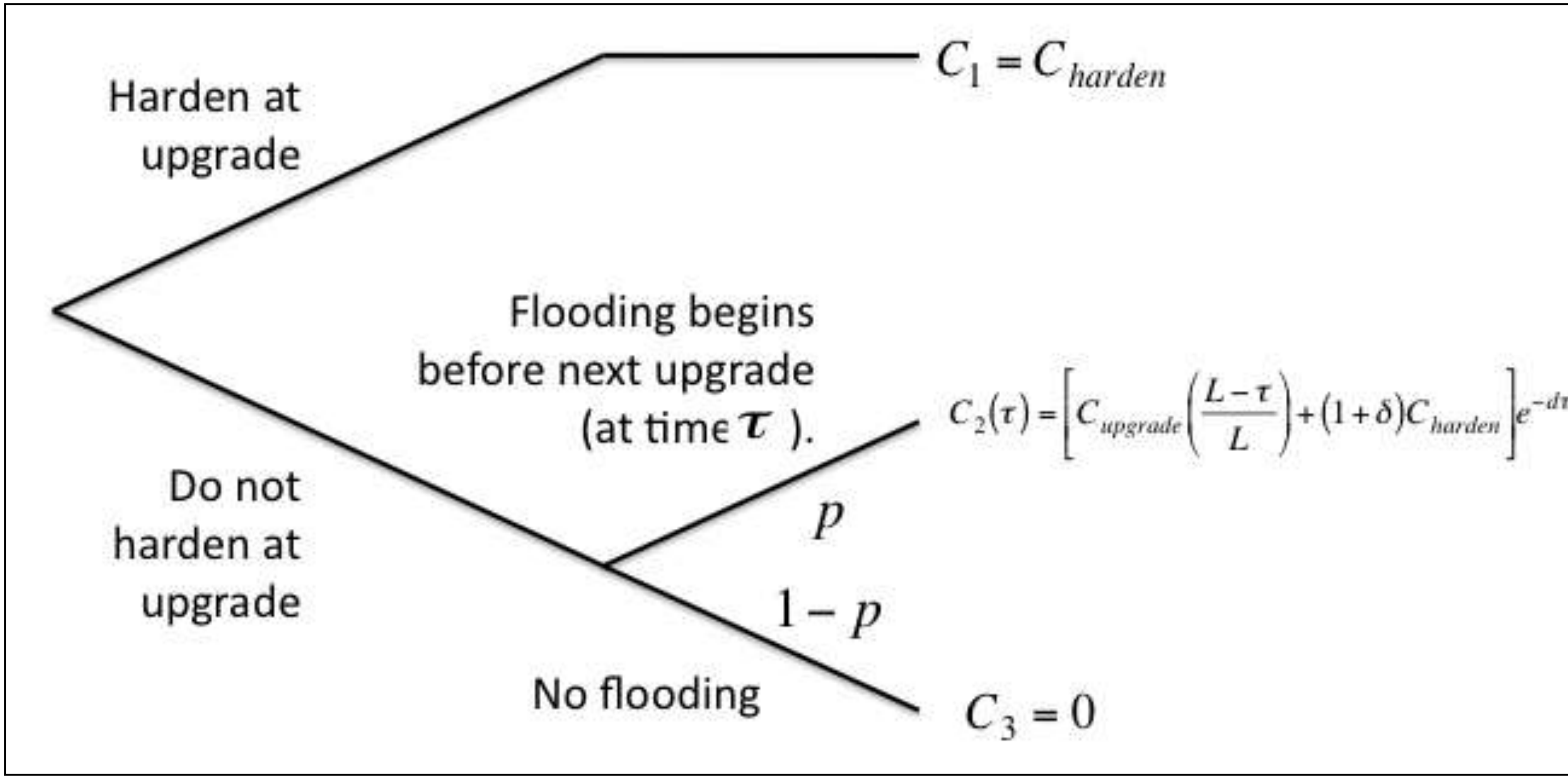
RDM Process



Key Factors Considered in Analysis (XLRM)

Uncertainties (X) Future Sea level •Annual rise •Hourly anomaly Future Management •Terminal lifetime •Tolerance for flooding •Cost of hardening	**Levers (L)** Harden at next upgrade
Relationships (R) Model described in subsequent slides	**Measures (M)** Present value cost

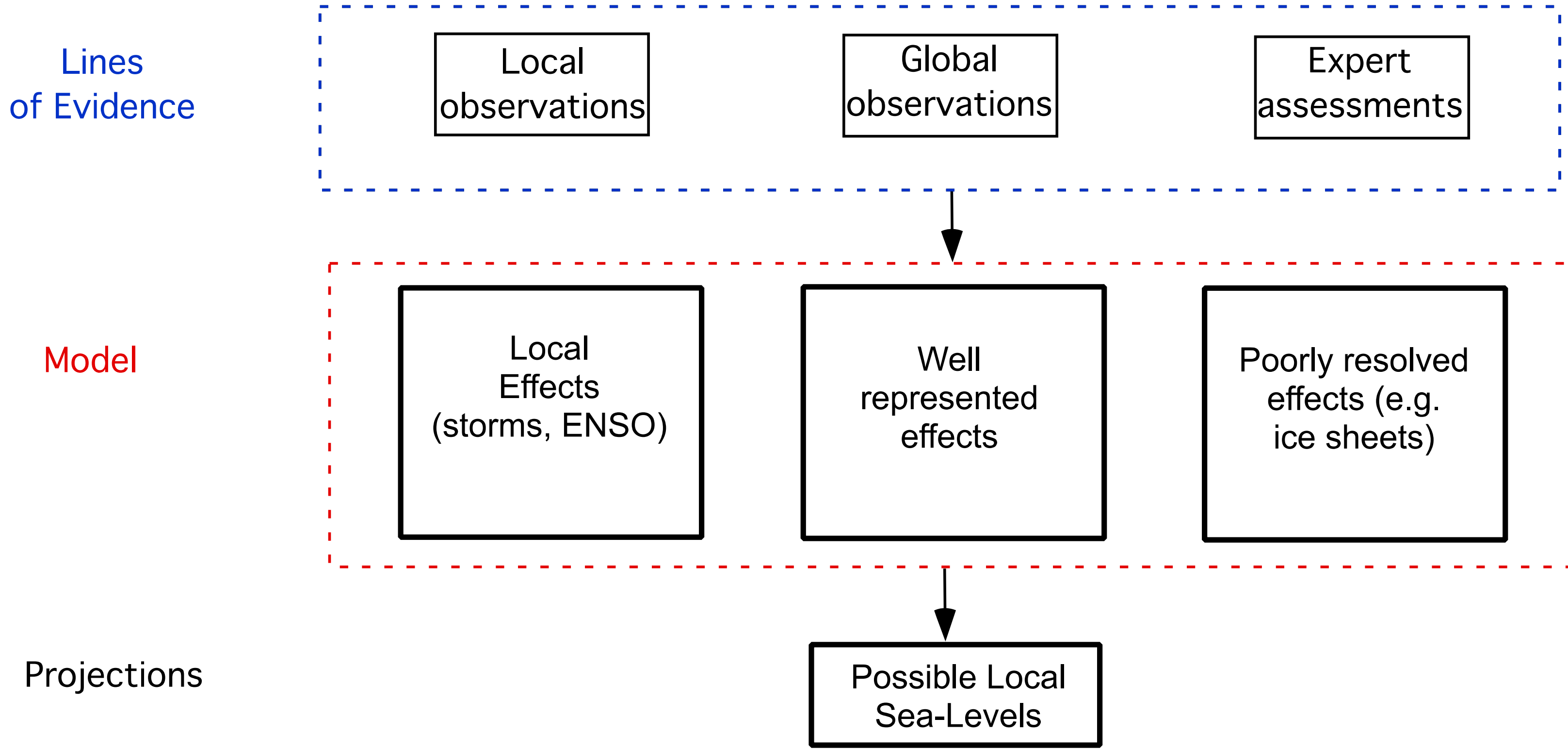
Model Projects Consequences of Options Contingent on Uncertainties



Harden at next upgrade passes expected cost benefit test when:

$$\left\langle \left[\left(\frac{L-\tau}{L}\right) + (1+\delta)\frac{C_{harden}}{C_{upgrade}} \right] e^{-d\tau} \right\rangle_p - \frac{C_{harden}}{C_{upgrade}} > 0$$

Simple Model Synthesizes Different Lines of Evidence to Project Future Sea-Levels at PoLA



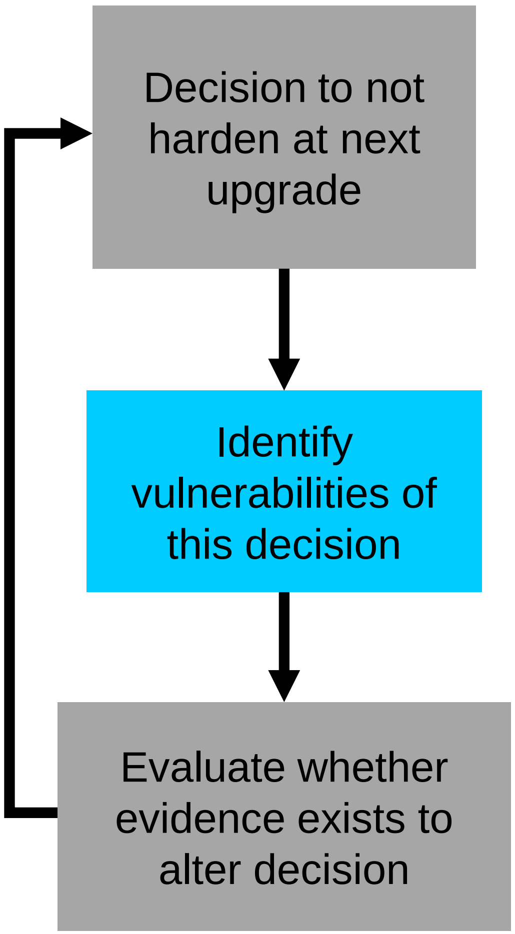
In our model, hourly sea levels at PoLA terminals in year t are approximated by:

$$y_t = \underbrace{a + bt + ct^2}_{\text{well understood annual SLR}} + \underbrace{c^* I(t - t^*)}_{\text{poorly understood anual SLR}} + \underbrace{GEV(m, s, x)}_{\text{hourly mean SL anomalies}}$$

Many Model Parameters Are Deeply Uncertain

	Distribution or [Range]
Future Sea Level	
Sea level in 2011(a)	Small (observed)
Normal rate of sea level rise (b)	3.2 +/- 0.4 mm/yr
Normal rate of sea level rise acceleration (c)	0.013 +/- 0.0006 mm/yr^2
Rate of abrupt sea level rise (c*)	[0 to 30 mm/yr]
Year abrupt rise begins (t*)	[2010 to 2100]
Future change in anomaly scale (ρ)	[0% to 50%]
Future Terminal Management	
Lifetime (L)	[30 to 100 years]
Max allowable overtop probability (p_{crit})	[5% to 50%]
Known at Decision Time	
Hardening cost ($C_{harden}/C_{upgrade}$)	Very low cost: 0.1%
Decision year	2020
Discount rate (d)	5%

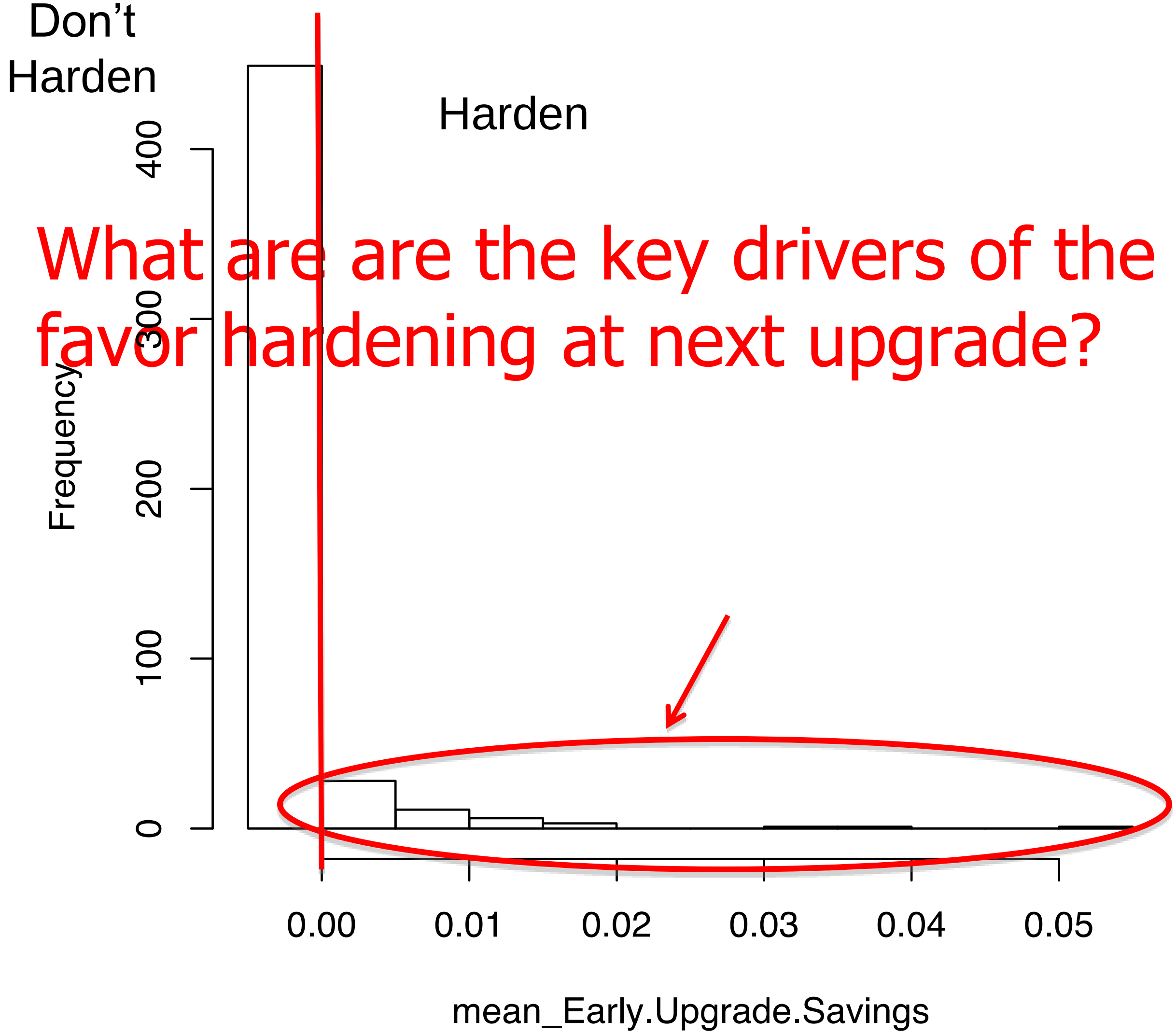
Under Conditions of Deep Uncertainty, RDM Uses Models to Evaluate Vulnerabilities of Proposed Strategies



1) Run model over experimental design of many (500) cases that samples full range of combinations of all uncertainties

2) Conduct “scenario discovery” statistical analysis of database of model results to characterize cases where a decision to harden at next upgrade would be cost effective

A Few Cases in Sample Favor Hardening at Next Upgrade



What are are the key drivers of the cases that favor hardening at next upgrade?

Analysis Yields Scenario Where Hardening at Next Upgrade Passes an Expected Value Cost-Benefit Test

This *Harden at Next Upgrade Scenario* depends on three conditions:

- Near-term and large increase in rate of sea level rise:

$$c^{*}\ {}^{3}\ 14\frac{mm}{yr}+0.3\frac{mm}{yr}\left(t^{*}-2010\right)$$

- Long lifetime of terminals after next upgrade:

$$L\ {}^{3}\ 75\text{ years}$$

- Considerable increase in daily anomaly:

$$r\ {}^{3}\ 5\%$$

Coverage = 71%   Density = 81%

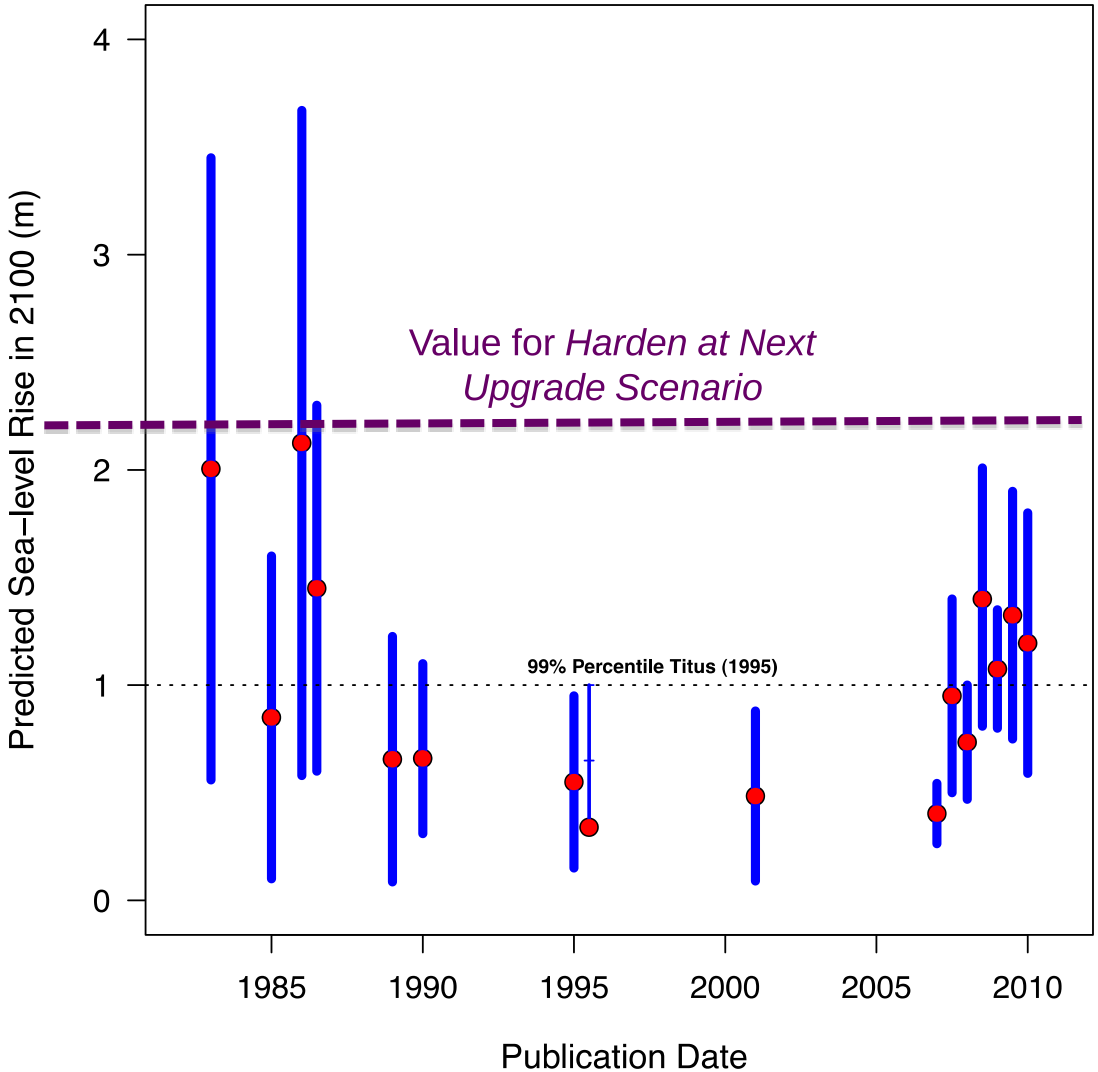
What Sea Level Rise Is Implied by First Condition?

Near-term and large increase in rate of sea level rise

$$c^{*}\ {}^{3}\ 14\frac{mm}{yr} + 0.3\frac{mm}{yr}\left(t^{*} - 2010\right)$$

Gives a sea level rise of about 2000 mm in 2100

Harden At Next Upgrade Scenario Overlaps with High End of Recent Global SLR Projections for 2100



Summary

- "Insurance for terminals against sea level rise" (hardening at next upgrade) is not worth buying at a cost of $C_{harden}/U_{upgrade} = 0.1\%$
- This result is sensitive to factors including:
  - Cost of hardening and height of terminal
  - Reversibility (on decadal time scale) of decision
- The RDM approach used here could prove useful for many decisions related to sea level rise

Important Caveats and Disclaimers

- Our new results are still preliminary (being tested, written up, and submitted to peer review).
- Current sea-level rise projections (including the ones discussed in this presentation)
  - hinge critically on subjective expert judgments
  - are deeply uncertain
  - neglect many known uncertainties and (of course) unknown unknowns and may hence be overconfident
  - are likely to change as new evidence becomes available.

Thank You

The RDM approach used here could prove useful for many decisions related to sea level rise

- Start with proposed plan
- Run simulation over wide range of plausible futures to identify conditions where proposed plan would not meet its goals
- Identify options for reducing these vulnerabilities and evaluate whether evidence exists to suggest these options are worth taking