A Coastal Storm Modeling System for determination of flood hazards along a high energy coast in response to SLR and 21st century storms

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Motivation & Background

GOAL of the work: To assess the vulnerability of the coastal margin to flooding due to **21st century sea level rise** and **coastal storms**

Objectives of the work:

- Emphasis on directly **supporting** federal and state climate change guidance and vulnerability assessments
- Location-independent methodology (widely applicable)
- Address all relevant contributions to total water levels and flooding
  - ◦SLR ◦ tides ◦ steric effects ◦ storm surge, ◦ waves ◦ river discharge ◦ levees and seawalls ◦ non-linear interactions

Presentation objectives

- elucidate on the added benefit (or not) of accounting for the influence of SLR on storm induced flood hazards along high-energy coastlines

and

- provide an overview of web tools and the underlying CoSMoS model developed for evaluating future flood vulnerabilities

Talk outline

1. Overview of the end-user web tool and modeling approach
2. Example application to North-Central California
3. Findings
   - flood levels are non-linearly related to increases in SLR
   - accounting for storms in combination with SLR, substantially increases flood extents, but is strongly a reflection of the topography (duh, no surprise!)

1. Overview of the end-user tool and modeling approach

Stakeholder input and participation

Two workshops were held in August 2011 to solicit management information needs for the decision support tool. Fifty-five coastal managers and planners who use sea level rise and storm data and information in decision-making participated in the workshops. The Coastal Manager Scoping Workshops Summary Report is available at http:// prbo.org/ocof.

Workshop participants defined the highest priority *management questions related to sea level rise and storms*, and the desired *tool capabilities to address them*.

Highest Priority Management Questions:

⇒ What are the projected threats to:
- Infrastructure
- Recreation
- Habitats

⇒ When and where will coastal erosion occur and what will it affect?

⇒ What restoration sites should be prioritized and what areas may not be suitable in the future?

⇒ What areas are vulnerable to multi-hazard impacts, such as flood fire, earthquake, etc.

Highest Priority Tool Capabilities:

⇒ Accommodate different user capabilities

⇒ Address model uncertainty

⇒ Provide user training resources

⇒ Easy interface

⇒ Accommodate new data; ability to update

⇒ Customize through use of own data

⇒ Ability to upload/download shapefiles

⇒ Make available to the public

⇒ Ability to draw points, lines and polygons and generate a report on the chosen area

OCOF web tool

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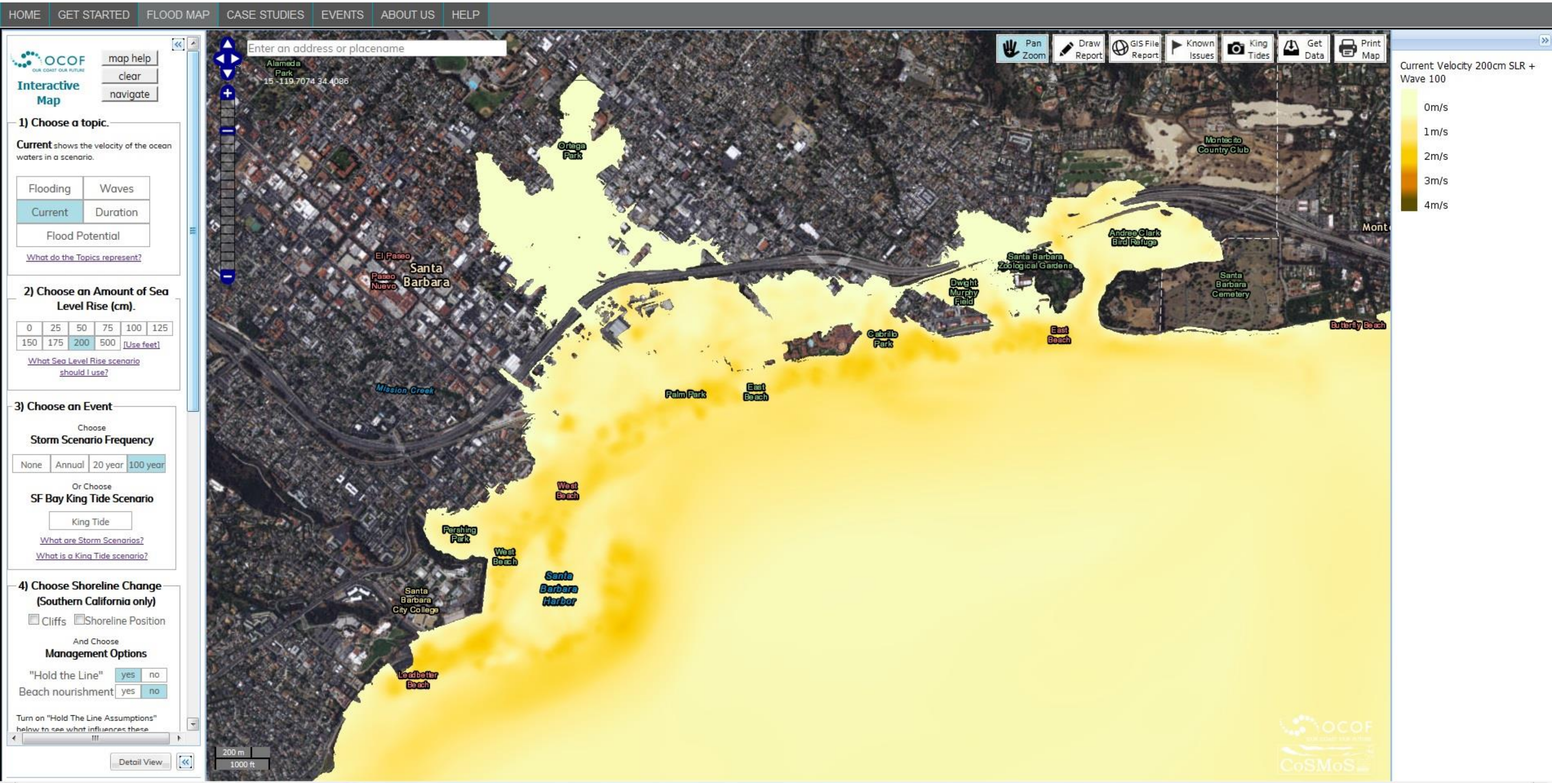
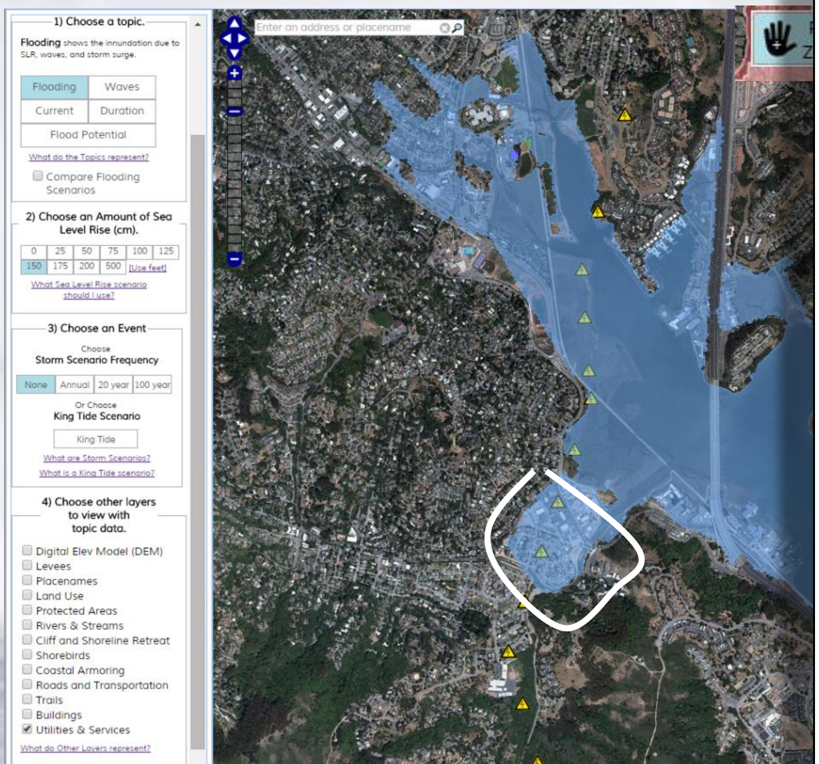
OCOF web tool



Generate summary reports of your area of interest…



OCOF Sea Level Rise and Scenario Report
by Our Coast Our Future project
www.pointblue.org/ocof
Report created: Jul 10,2015 12:48 pm

This is the sea level rise and storm scenario report for the area you selected. This report was designed to provide information to help you identify vulnerabilities to sea level rise and storm surges.

Area and Elevation Information

Area is the size of selected polygon, in square meters, acres and hectares, and Elevation is the average, minimum and maximum elevation from the Digital Elevation Model (DEM) within the polgyon.

Area:	383,654.79 m² 94.80 ac 38.37 ha	Elevation:	Mean - 8.21 meters Minimum - 0.26 meters Maximum - 53.72 meters

Projected Percent Area Flooded for the Selected Area

Values indicate the percentage of the selected area flooded for the Storm and Sea Level Rise Scenario combination.

Storm Scenario							
	100 yr Storm	38%	47%	51%	53%	54%	59%
	20 yr Storm	12%	45%	50%	53%	54%	59%
	Annual Storm	1%	22%	41%	47%	51%	56%
	No Storm	5%	10%	39%	47%	50%	56%
		none	50 cm	100 cm	150 cm	200 cm	500 cm
	Sea Level Rise Scenario						

under 25% flooded | 25-50% flooded | 50-75% flooded | over 75% flooded

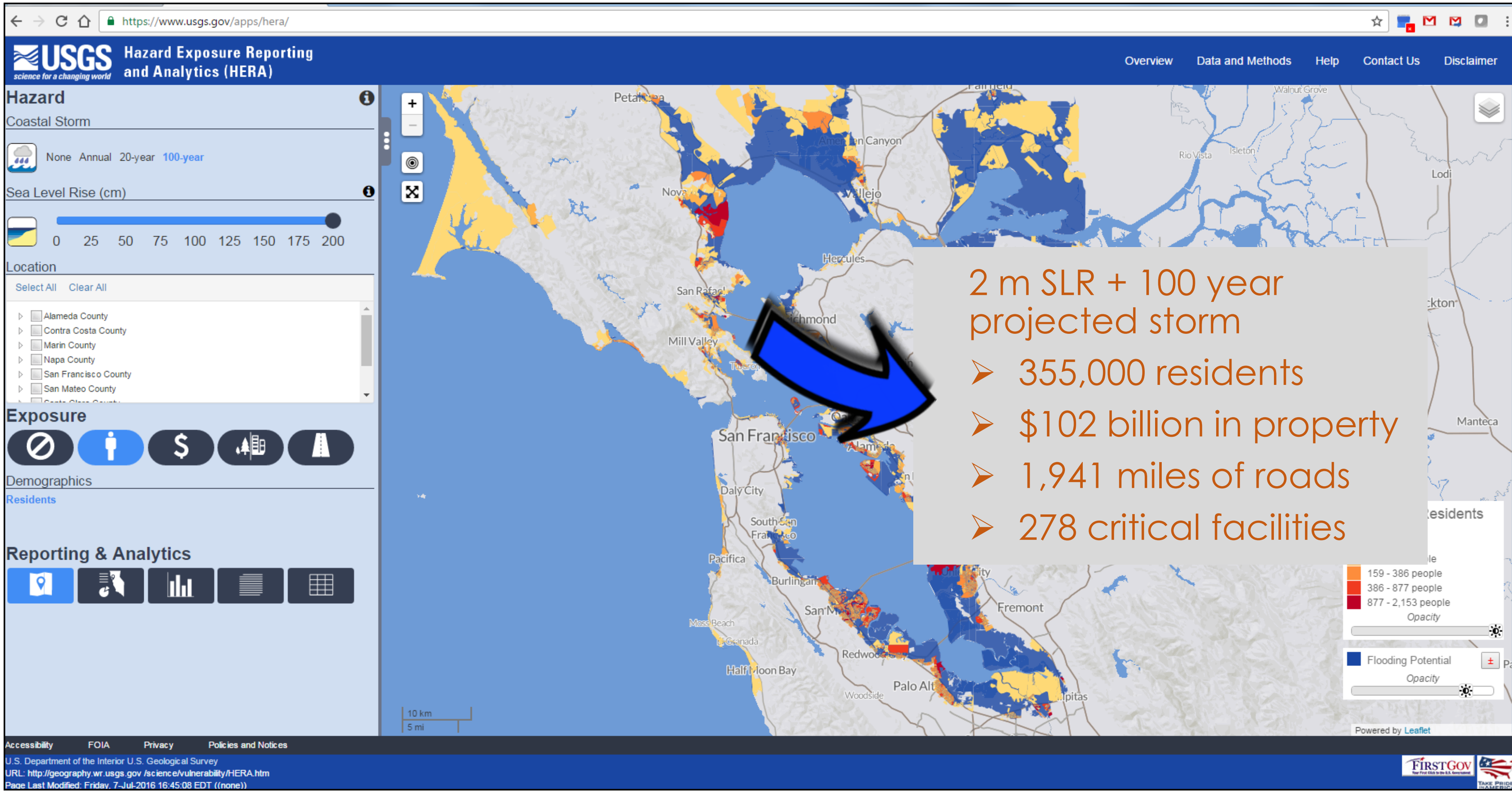
Projected Average Flood Depth for the Selected Area

Values indicate the average flood depth (in feet and centimeters) over the Mean Higher High Water (MHHW) within the selected area for each Storm and Sea Level Rise Scenario combination. Values include modeling uncertainty bracket of +/- 40 cm.

Storm Scenario							
	100 yr Storm	55 - 135 cm 1.8 - 4.4 ft	85 - 165 cm 2.8 - 5.4 ft	125 - 205 cm 4.1 - 6.7 ft	165 - 245 cm 5.4 - 8 ft	210 - 290 cm 6.9 - 9.5 ft	480 - 560 cm 15.7 - 18.4 ft
	20 yr Storm	35 - 115 cm 1.1 - 3.8 ft	65 - 145 cm 2.1 - 4.8 ft	110 - 190 cm 3.6 - 6.2 ft	160 - 240 cm 5.2 - 7.9 ft	210 - 290 cm 6.9 - 9.5 ft	485 - 565 cm 15.9 - 18.5 ft
	Annual Storm	55 - 135 cm 1.8 - 4.4 ft	25 - 105 cm 0.8 - 3.4 ft	65 - 145 cm 2.1 - 4.8 ft	95 - 175 cm 3.1 - 5.7 ft	150 - 230 cm 4.9 - 7.5 ft	425 - 505 cm 13.9 - 16.6 ft
	No Storm	40 - 120 cm 1.3 - 3.9 ft	35 - 115 cm 1.1 - 3.8 ft	60 - 140 cm 2 - 4.6 ft	95 - 175 cm 3.1 - 5.7 ft	125 - 205 cm 4.1 - 6.7 ft	415 - 495 cm 13.6 - 16.2 ft
		none	50 cm	100 cm	150 cm	200 cm	500 cm
	Sea Level Rise Scenario						

average less than 1 ft | 1 to 3 ft | 3 to 5 ft | over 5 ft

HERA web tool



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web tools & underlying model

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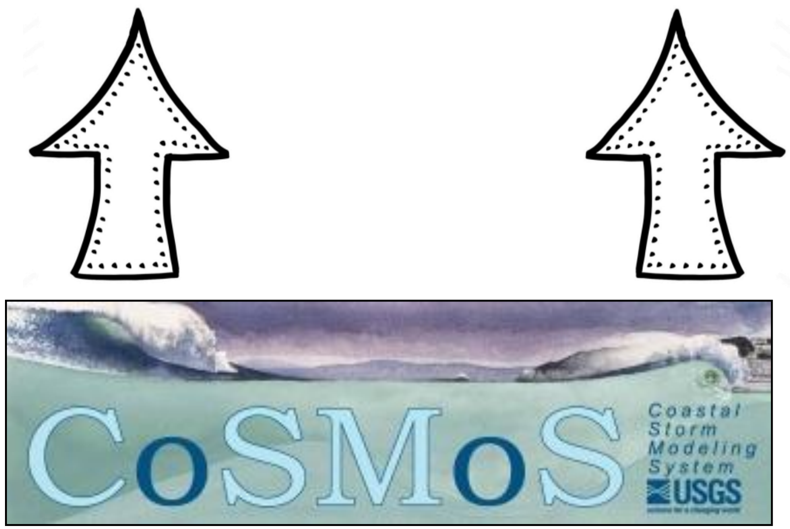
Web tool for data visualization, synthesis, and download
http://outcoastourfuture.org

Hazard Exposure Reporting and Analytics (HERA)

Web tool for socio-economic web
www.usgs.gov/apps/hera

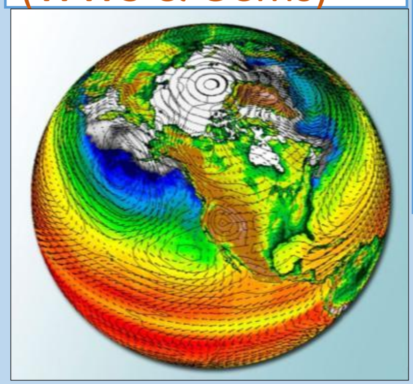


CoSMoS modeling approach

Global Scale

Deep water wave generation & propagation

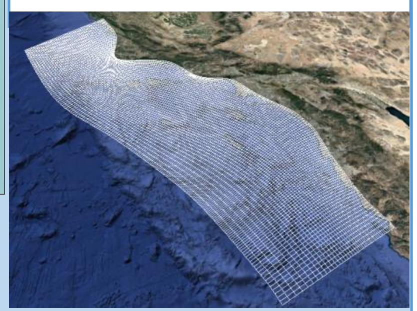
(WW3 & GCMs)



Regional Scale

Swell propagation, wave generation, storm surge, and astronomic tides

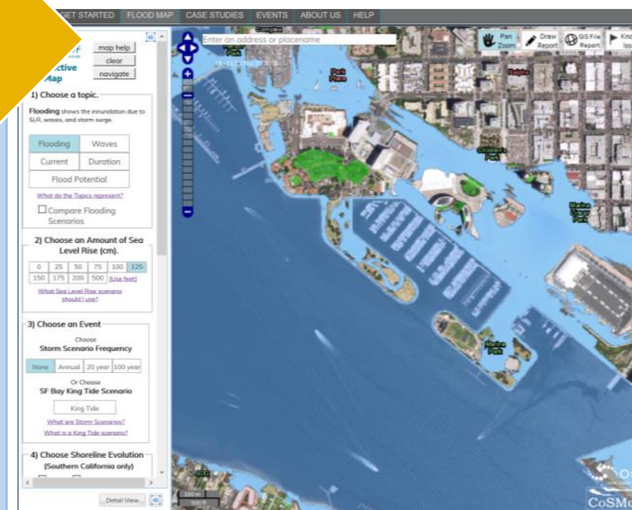
(Delft3D+SWAN)



Local Scale

Nearshore waves, wave setup and runup, storm surge, tides, overland flow, fluvial discharge, long-term topo-bathy change

(Delft3D+SWAN + XBEACH)

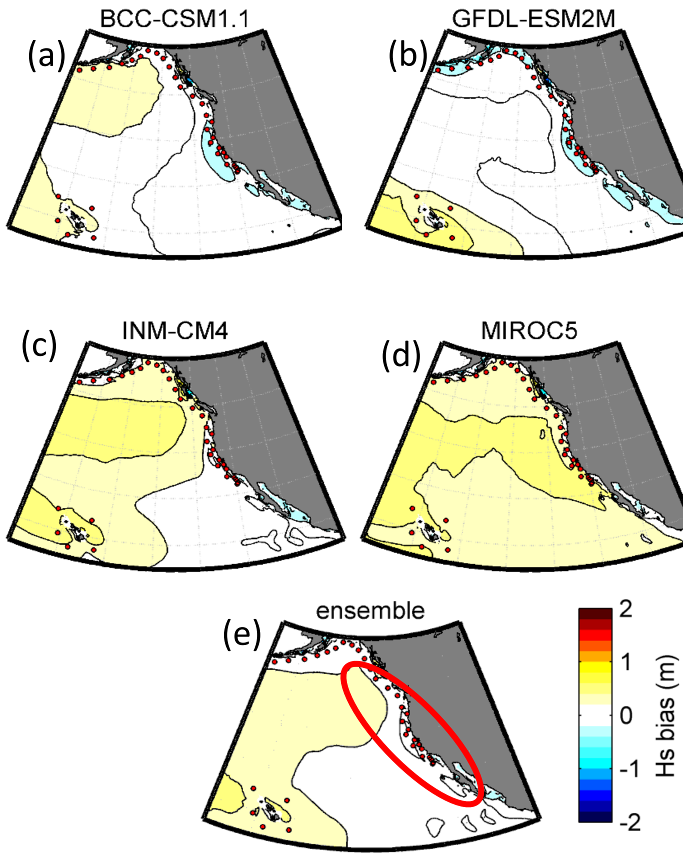


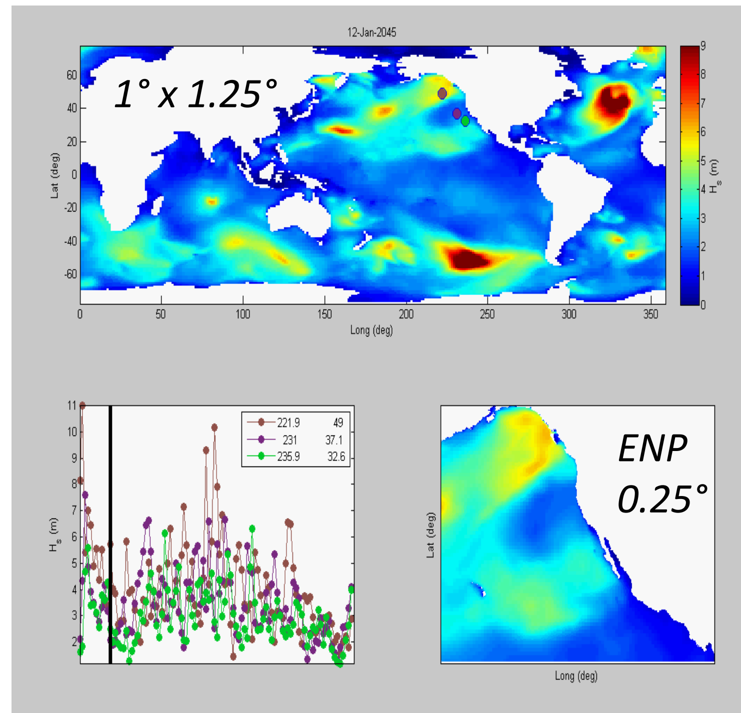
I/O, pre- & post-processing scripts (Matlab)

CoSMoS global-scale modeling

WW3 (ver. 3.14, TC physics pack.) **winds from 4 CMIP5 GCMs** for simulation of deep water waves; **historical, RCP4.5 & RCP 8.5**

Bias compared to ERA-I (all months) 1979-2005

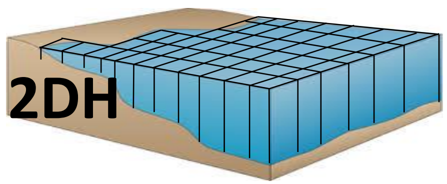




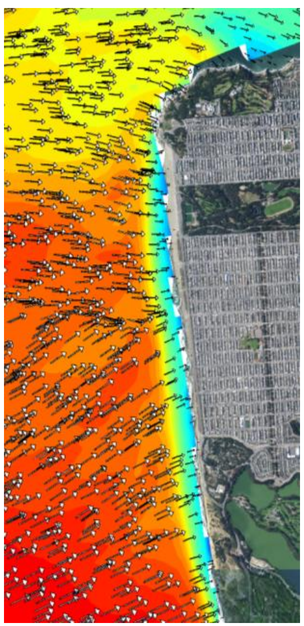
Example wave model simulation - 2045

Regional & local-scale modeling

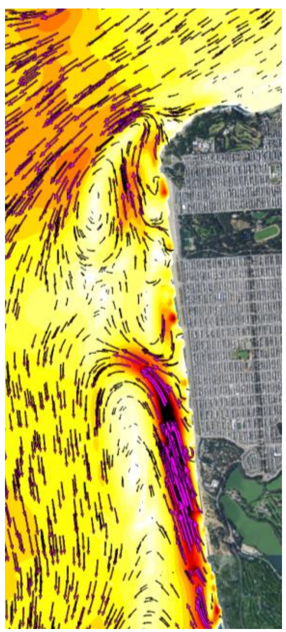
Regional Scale
Local Scale



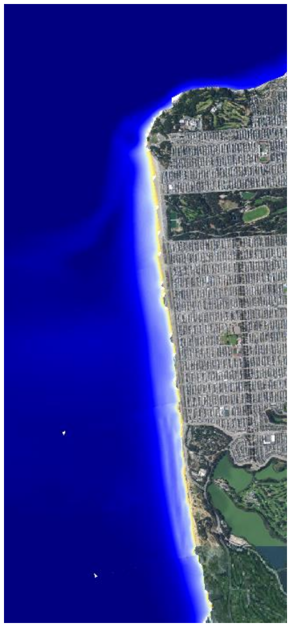
Delft3D & SWAN



waves

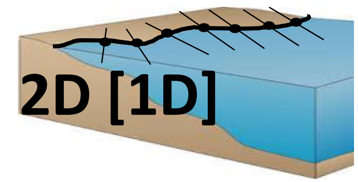


currents

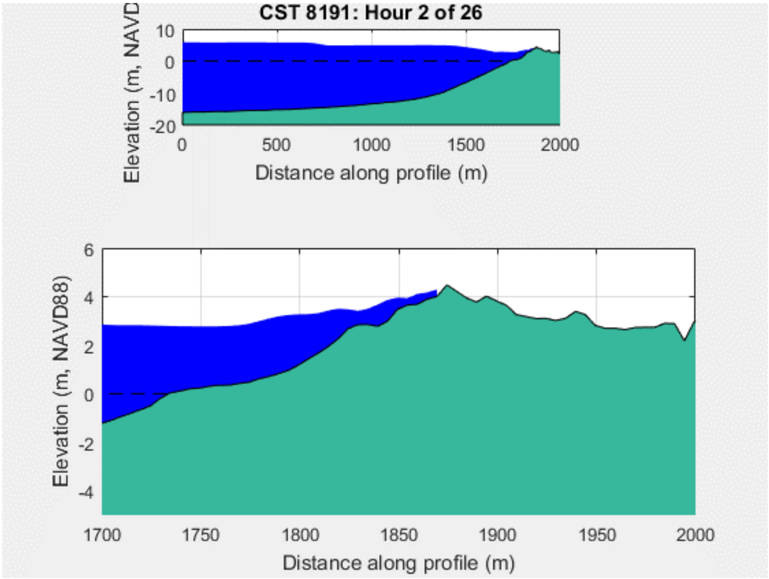


depths

Local Scale



XBeach



Waves, currents, WLs, event-based morphodynamic change

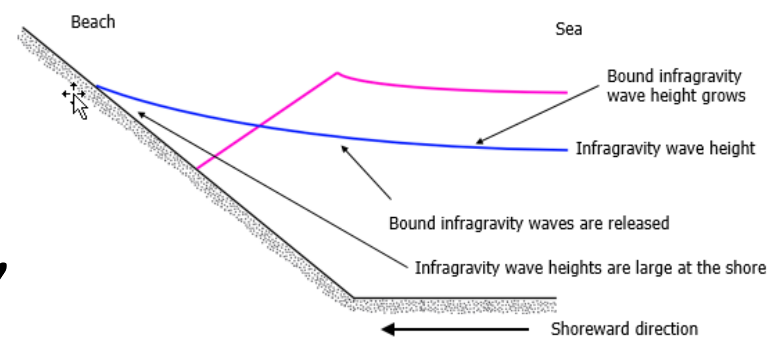
Why XBeach in model train?

- Rapid compuation of event-driven morphodynamic change
- Inclusion of infragravity (IG) wave energy
  - Incident band is important to generate offshore transport and stir sediment
  - Infragravity band required to help short waves reach the upper beach and dune, modulate strong offshore currents, and is often main contributor for overwash
  - Both types required for accurate modelling

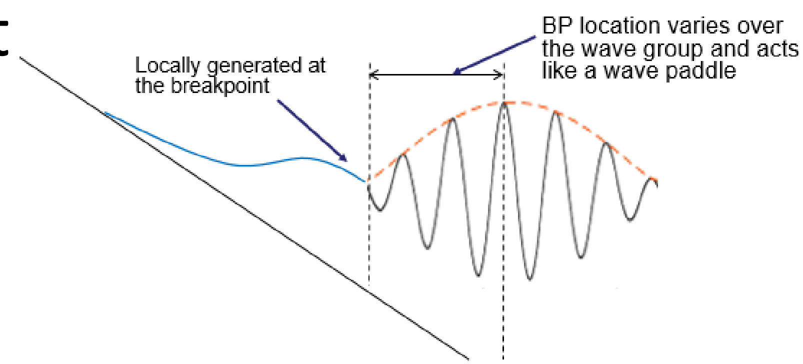
Why XBeach in model train?

Two main types of IG waves

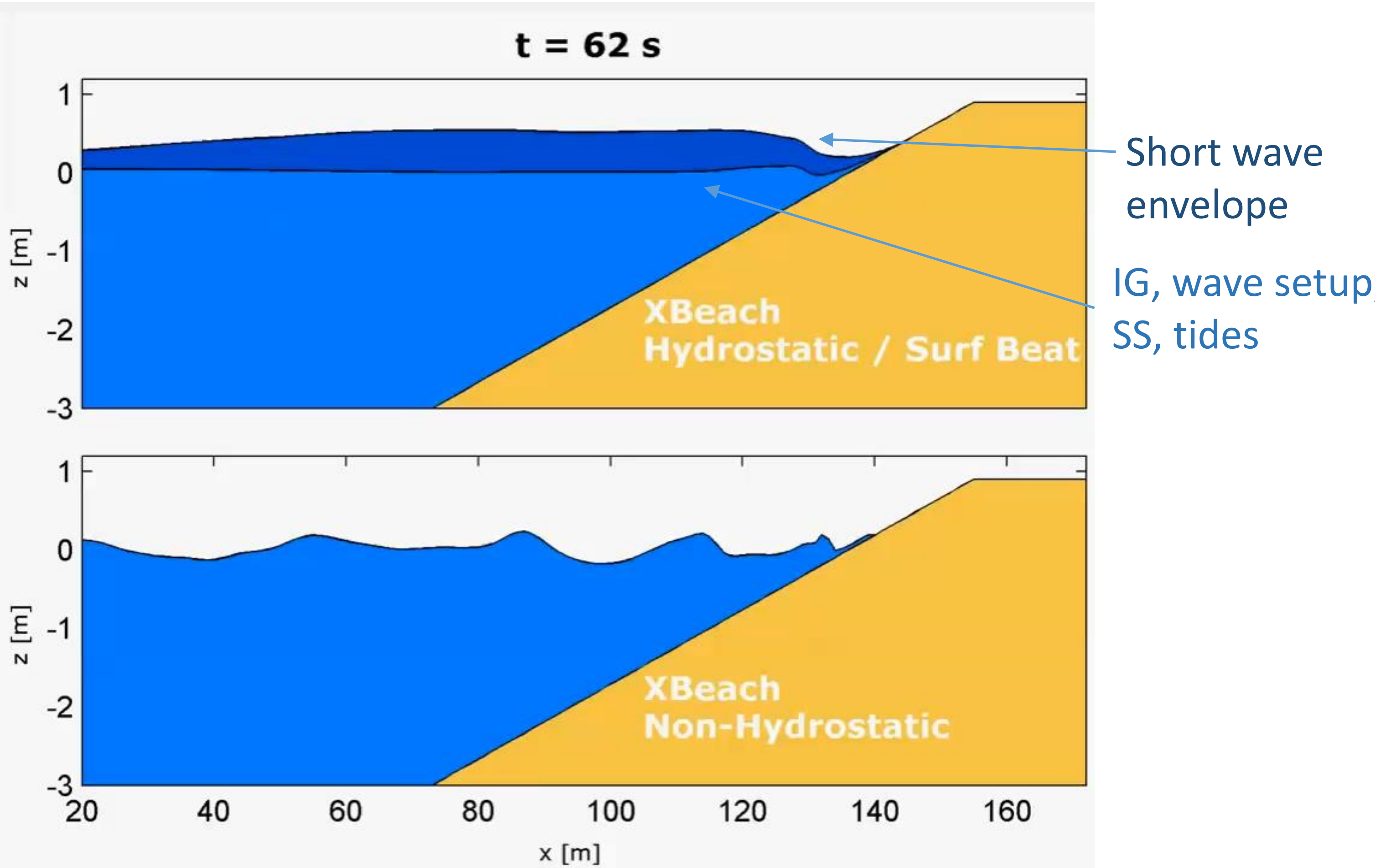
- bound infragravity waves generated offshore by, and travelling with, wave groups (generally dominant on shallow, dissipative beaches)



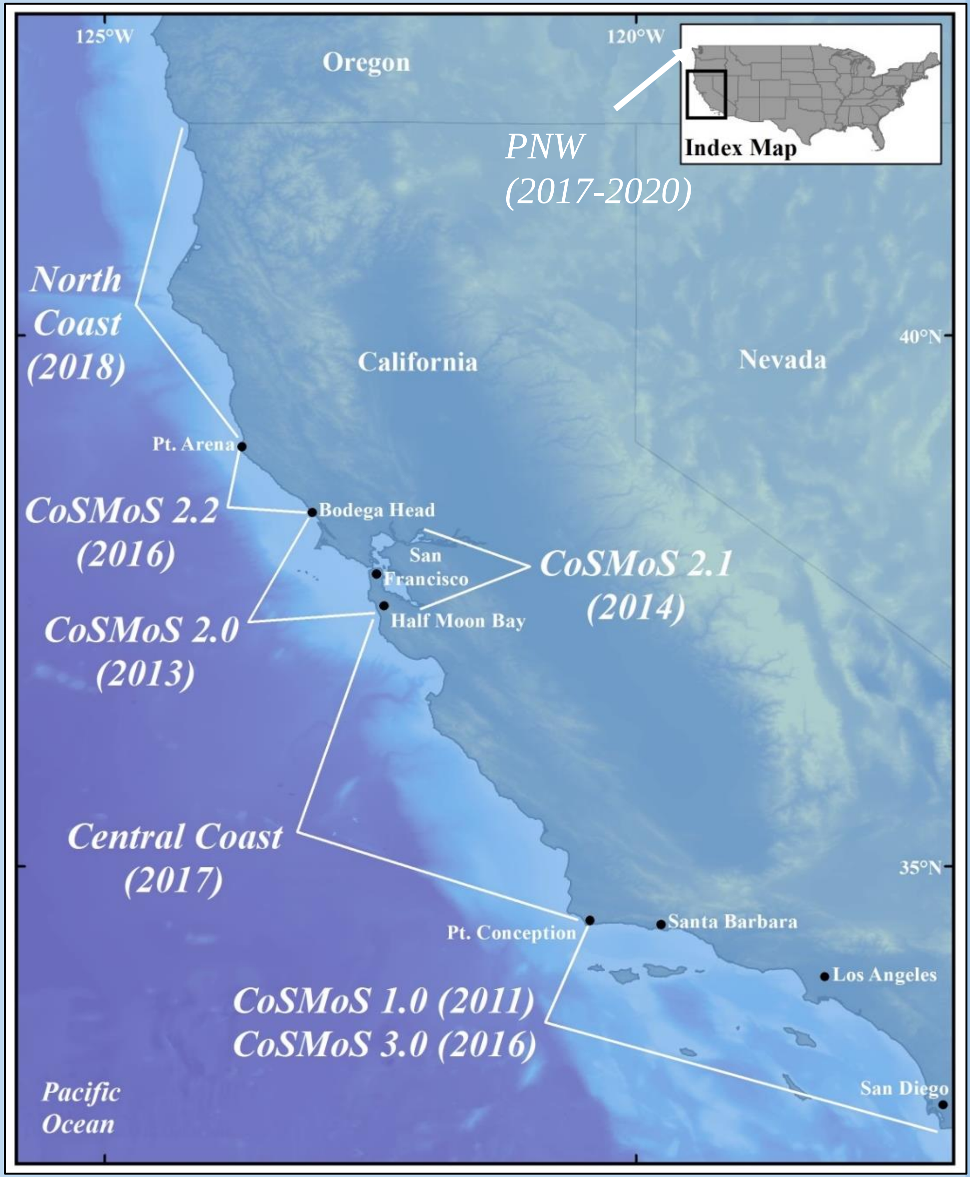
- breakpoint generated IG waves; created at the breakpoint of short waves (moving breakpoint mechanism; more important on steep beaches)



Why XBeach in model train?



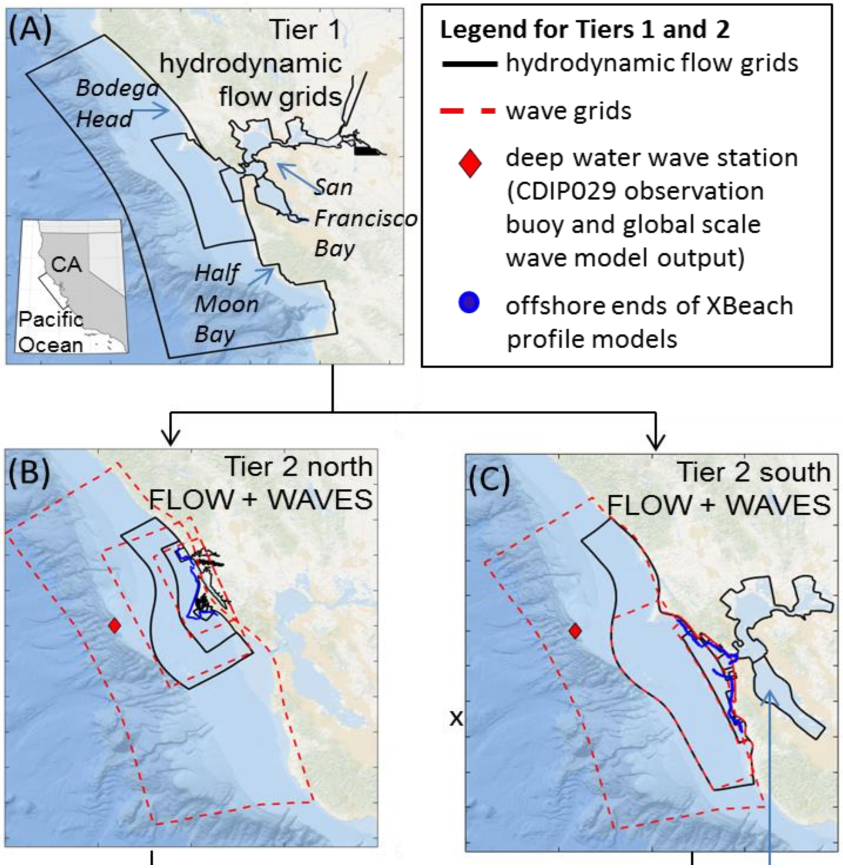
Courtesy: Robert McCall, Deltares



2. Example application to North-Central California

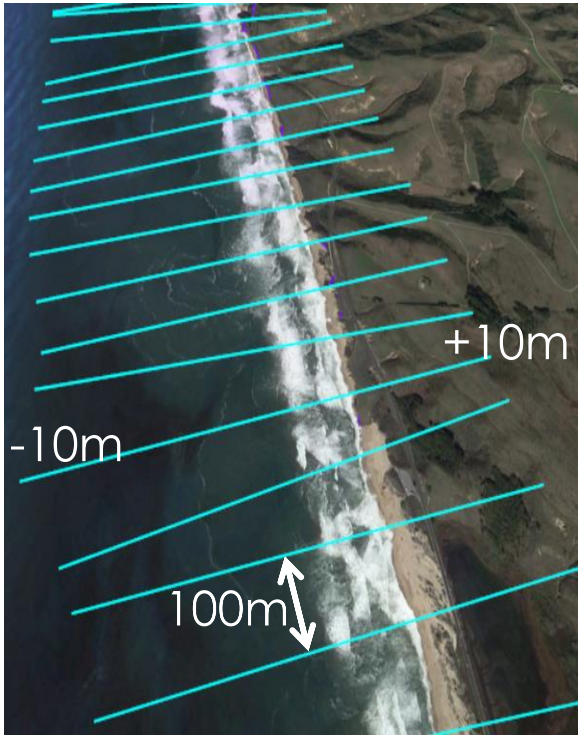
Delft3D and SWAN model grids

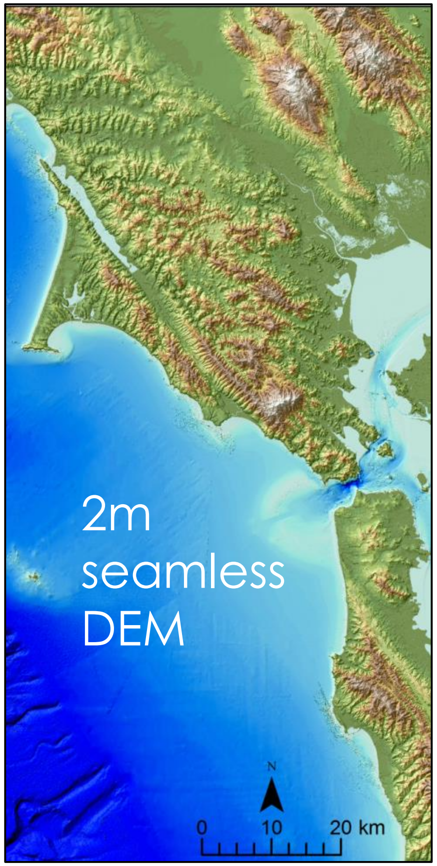
	# grid cells	Res. (m^2)
Tier 1 FLOW	157,112	2k to 4k
Tier 2 FLOW north	560,368	9 to 688
Tier 2 FLOW south	342,019	6 to 980
Tier 2 WAVES north	96,812	76 to 611
Tier 2 WAVES south	98,127	64 to 725



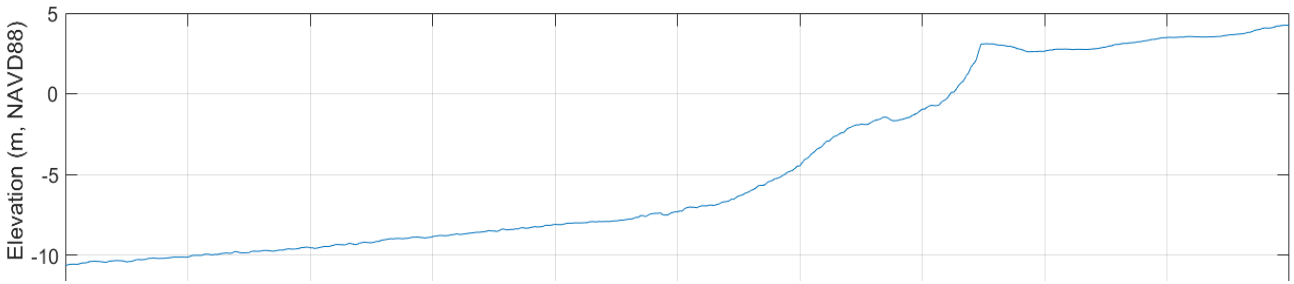
XBeach model grids

- 933 profiles
- Topo and bathy extracted from 2m DEM
- 30m resolution offshore
- 5m resolution shoreward of the 2.5m water depth
- Sub-areal profile sections with slopes > 32° considered to be immobile revetments or cliffs

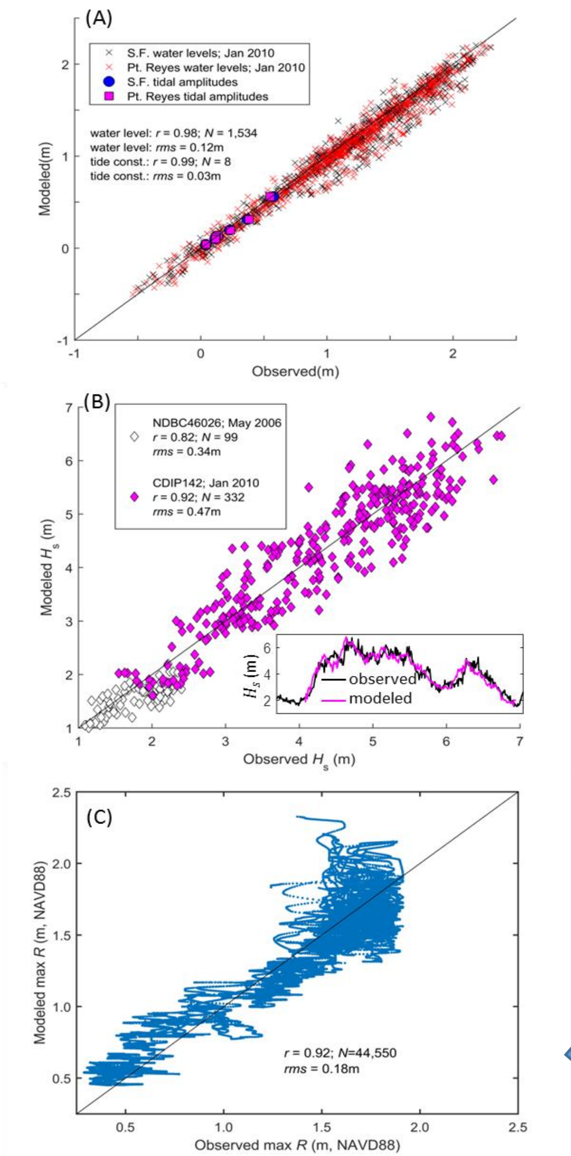


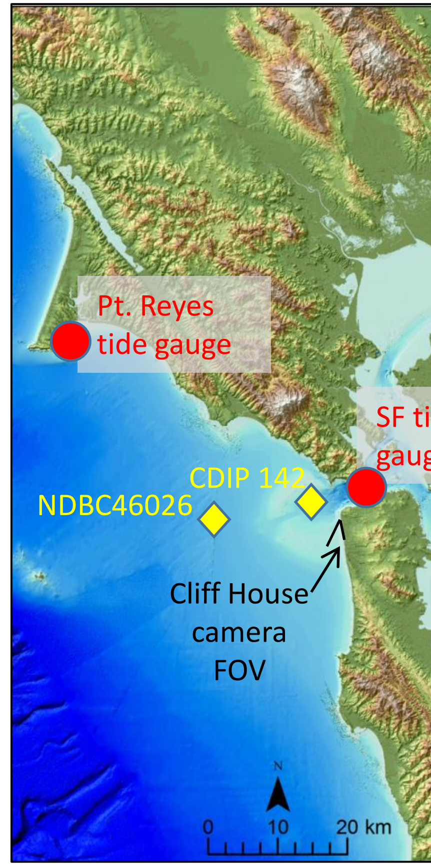


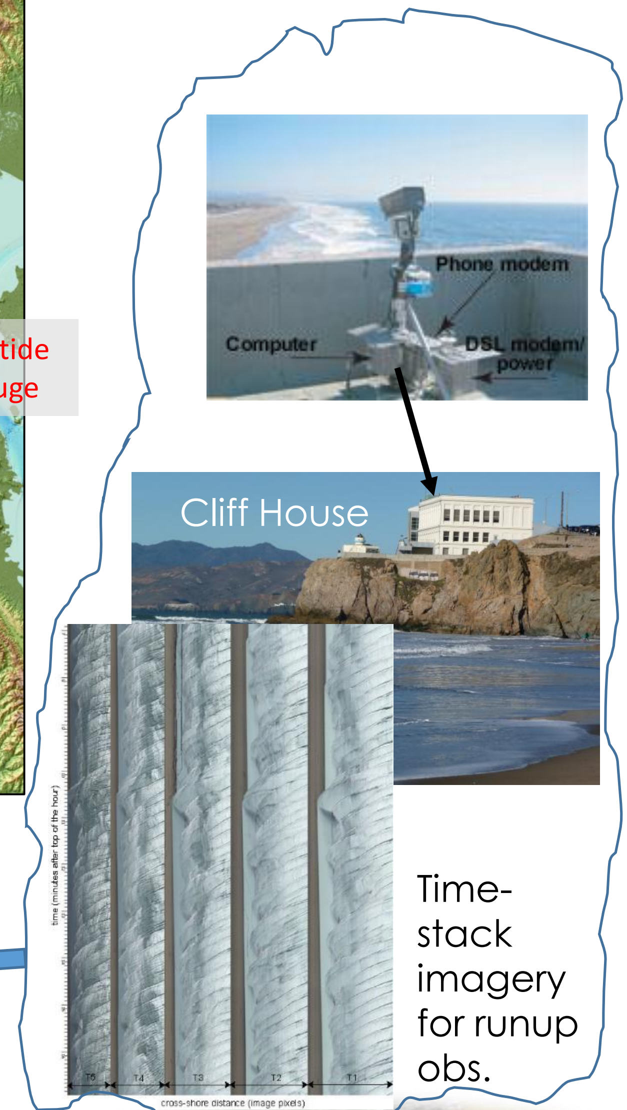
http://topotools.cr.usgs.gov/topobathy_viewer



Evaluation of model skill



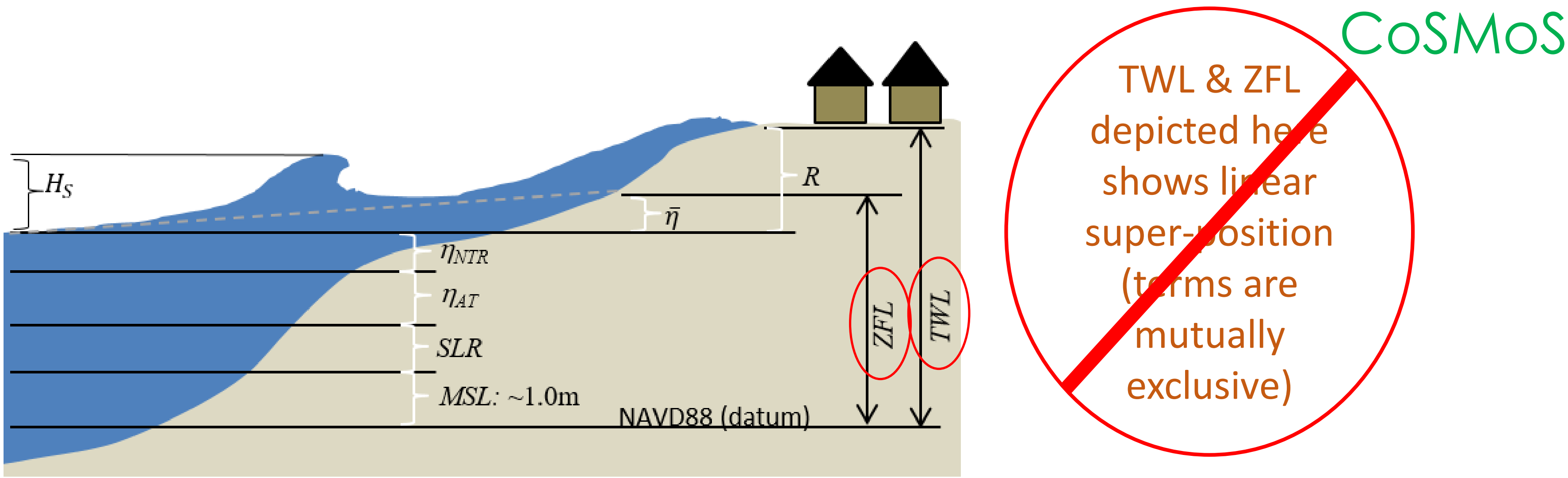




3. Findings

…storm-related flood potentials are non-linearly related to SLR…

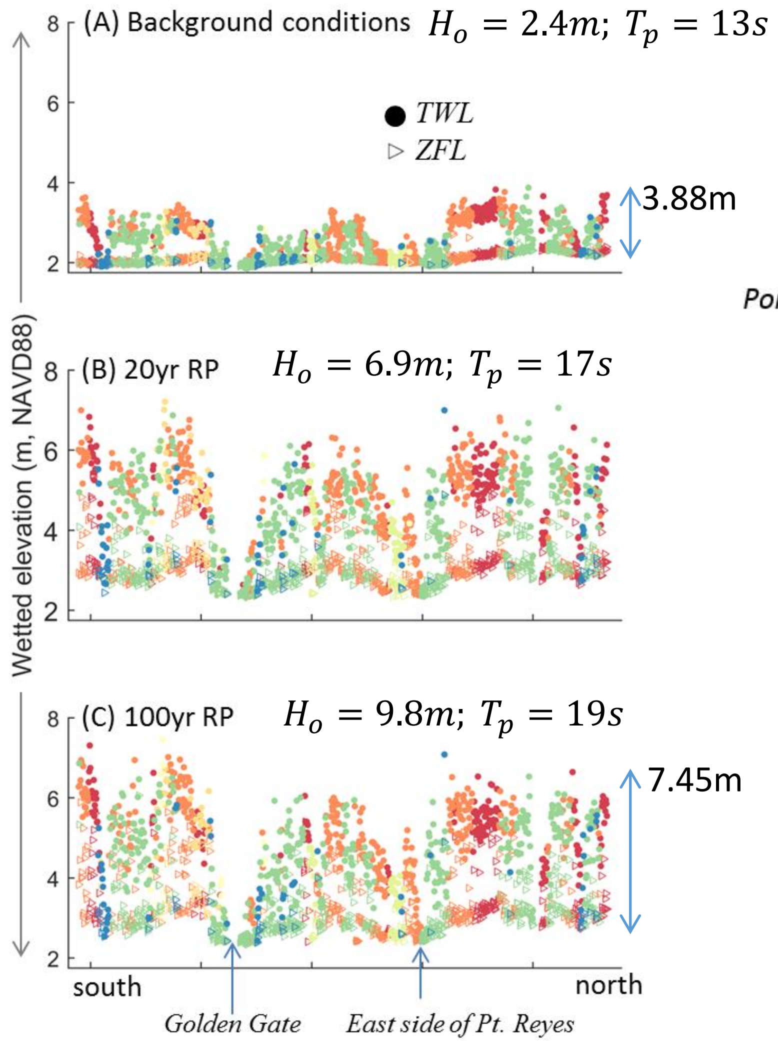
Coastal flood elevation potentials

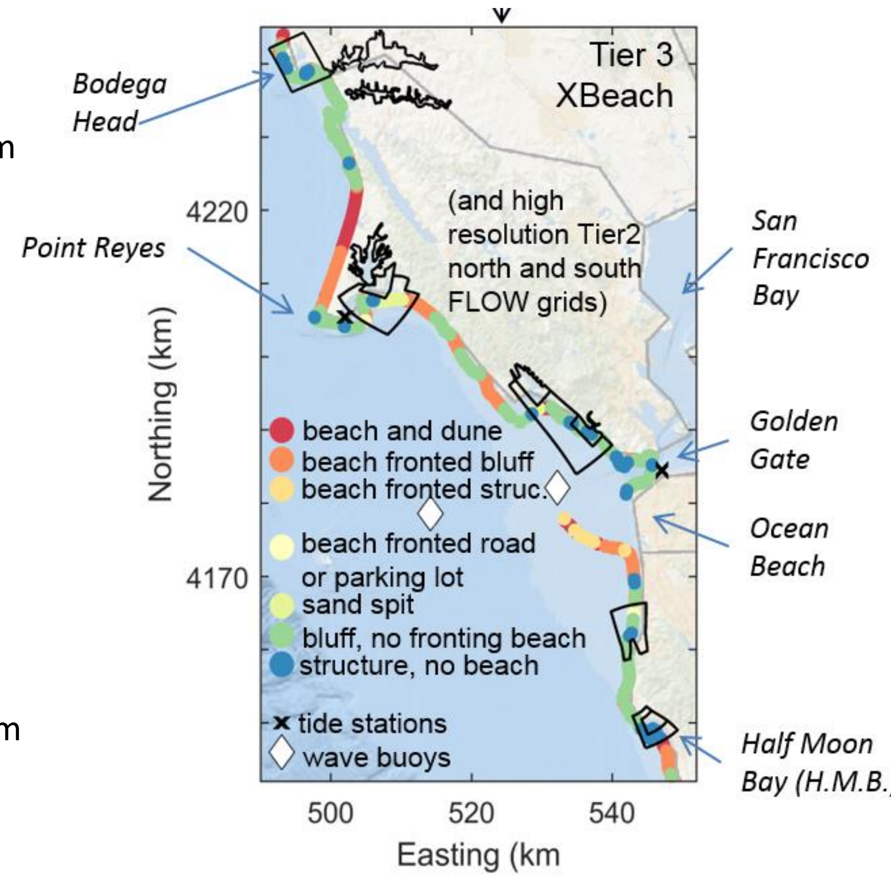


Total water levels, $TWL = f(SLR, \eta_{AT}, \eta_{NTR}, R)$

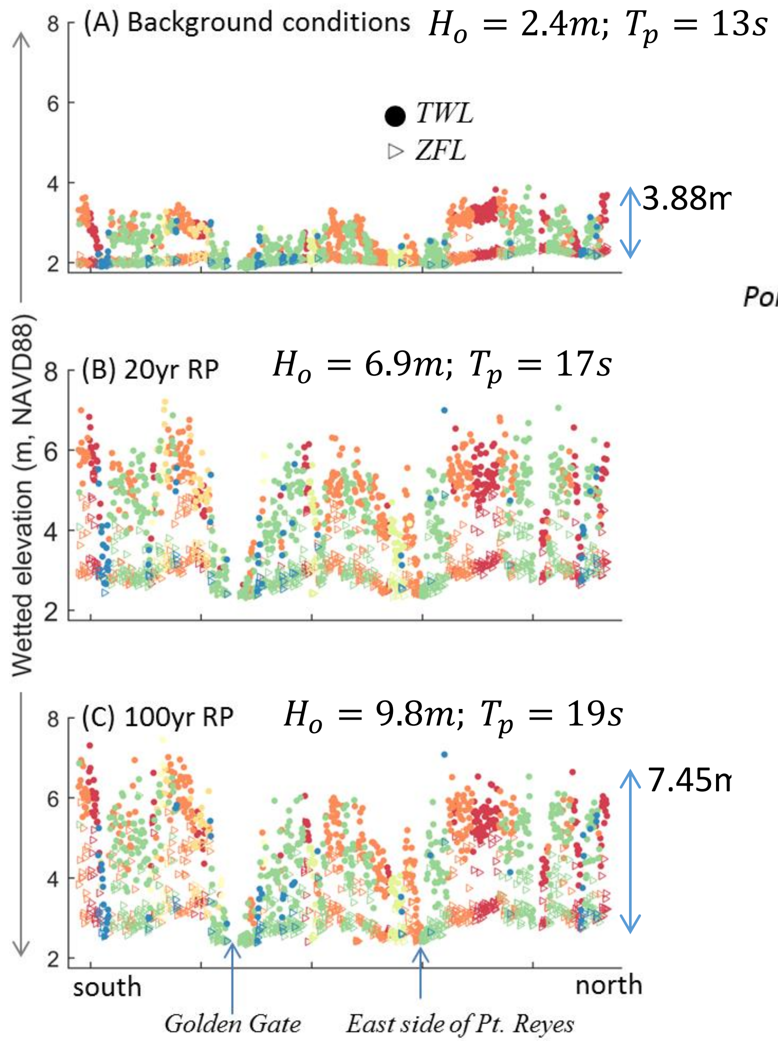
For flood hazard analysis, the use of wave setup rather than wave runup is often preferred since the swash lens is often thin and contains a limited volume of seawater (e.g., Barnard et al. 2014), $ZFL = f(SLR, \eta_{AT}, \eta_{NTR}, \bar{\eta})$.

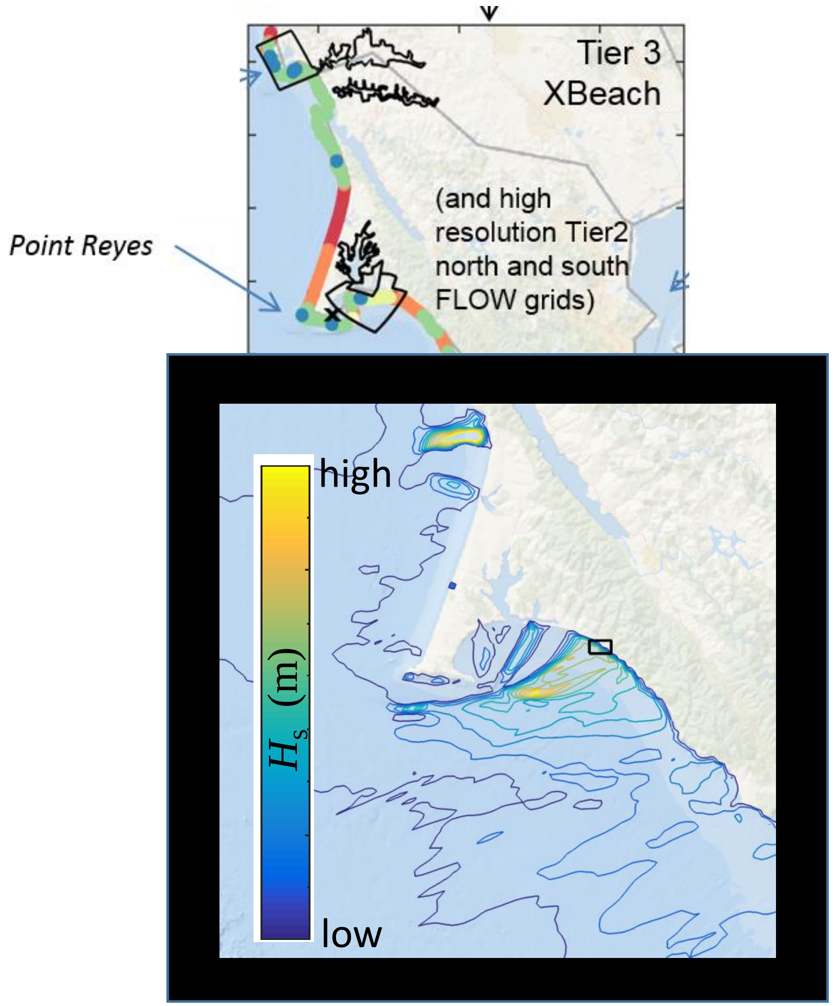
TWLs and ZFLs without SLR



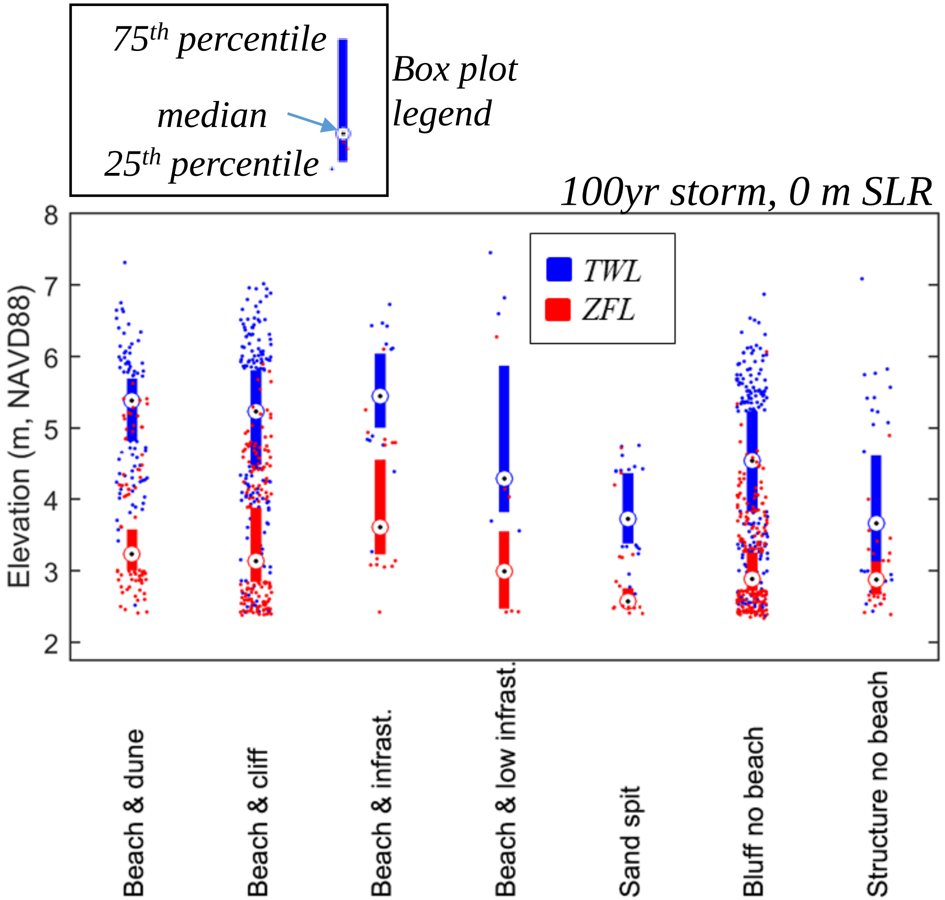


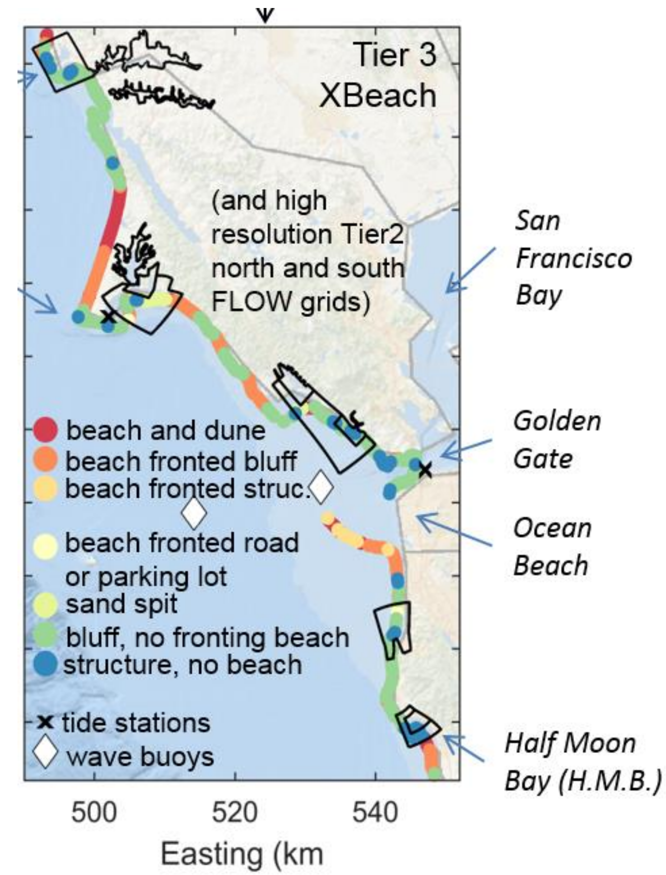
TWLs and ZFLs without SLR





TWLs and ZFLs without SLR





medians highest at beach-fronted infrastructure, but maximum values are fairly consistent for all back-beach types

except sand spits where overwash occurs during storm events.

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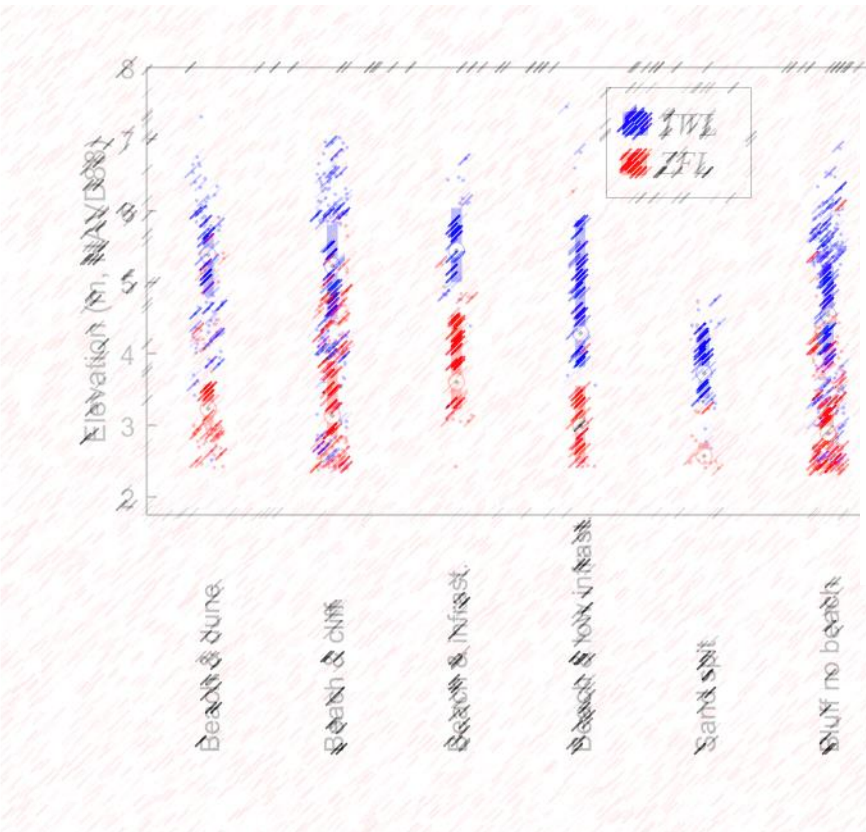
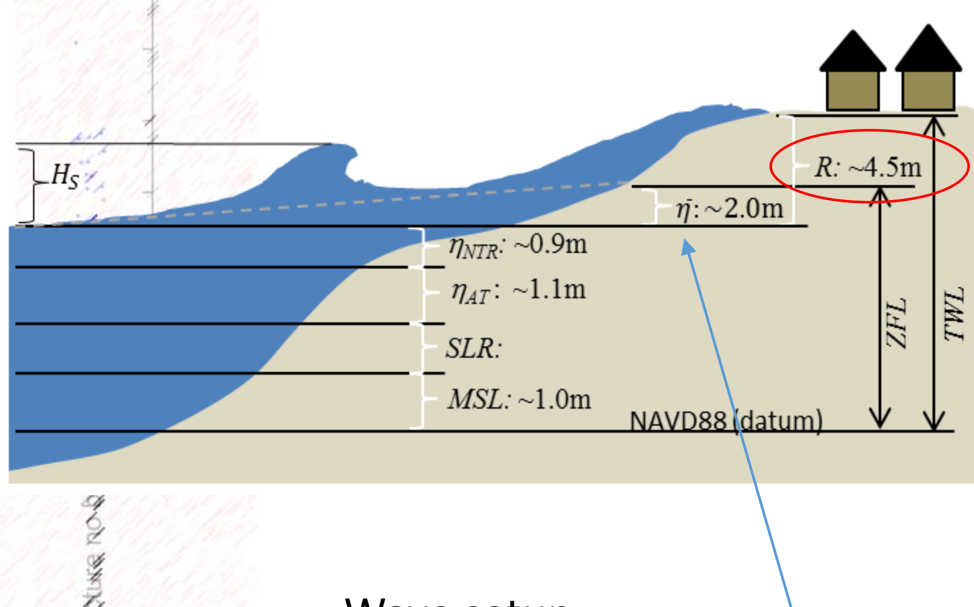
TWLs and ZFLs without SLR



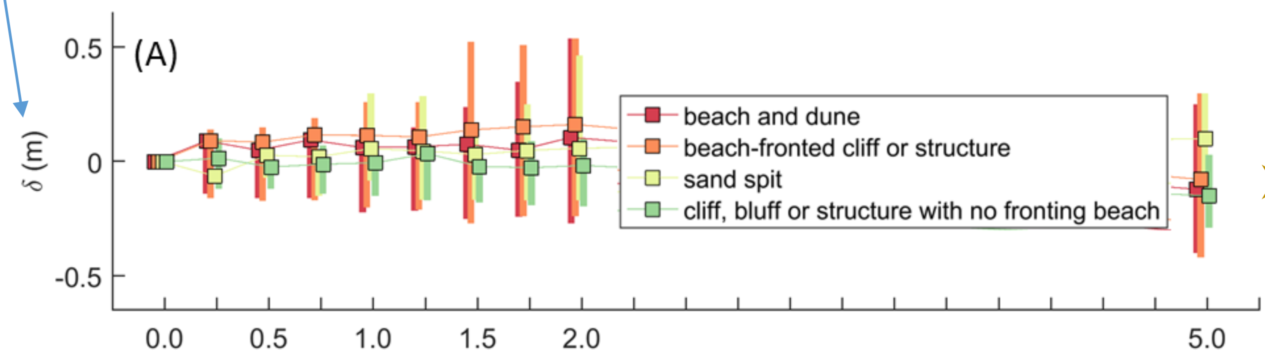


Wave setup…

$ZFL - (\eta_{NTR} + \eta_{AT} + MSL)$

Non-linear flood potential w.r.t. SLR

$\delta^i = (ZFL^i_{SLR} - SLR) - ZFL^i_{000}$



- δ is small for low SLRs but quite high for *SLR*s ≥ 1.5m
- particularly for beaches, dunes, and beach-fronted cliffs and structures for which the 75th percentile difference is ~60cm *(linear superposition would under-estimate ZFL)*
- Cliffs, bluffs and structures with no fronting beach are less prone to this error since waves approaching these types of configurations are likely to break close to or upon impact with the bluff or structure leaving little accommodation space for wave setup to develop.

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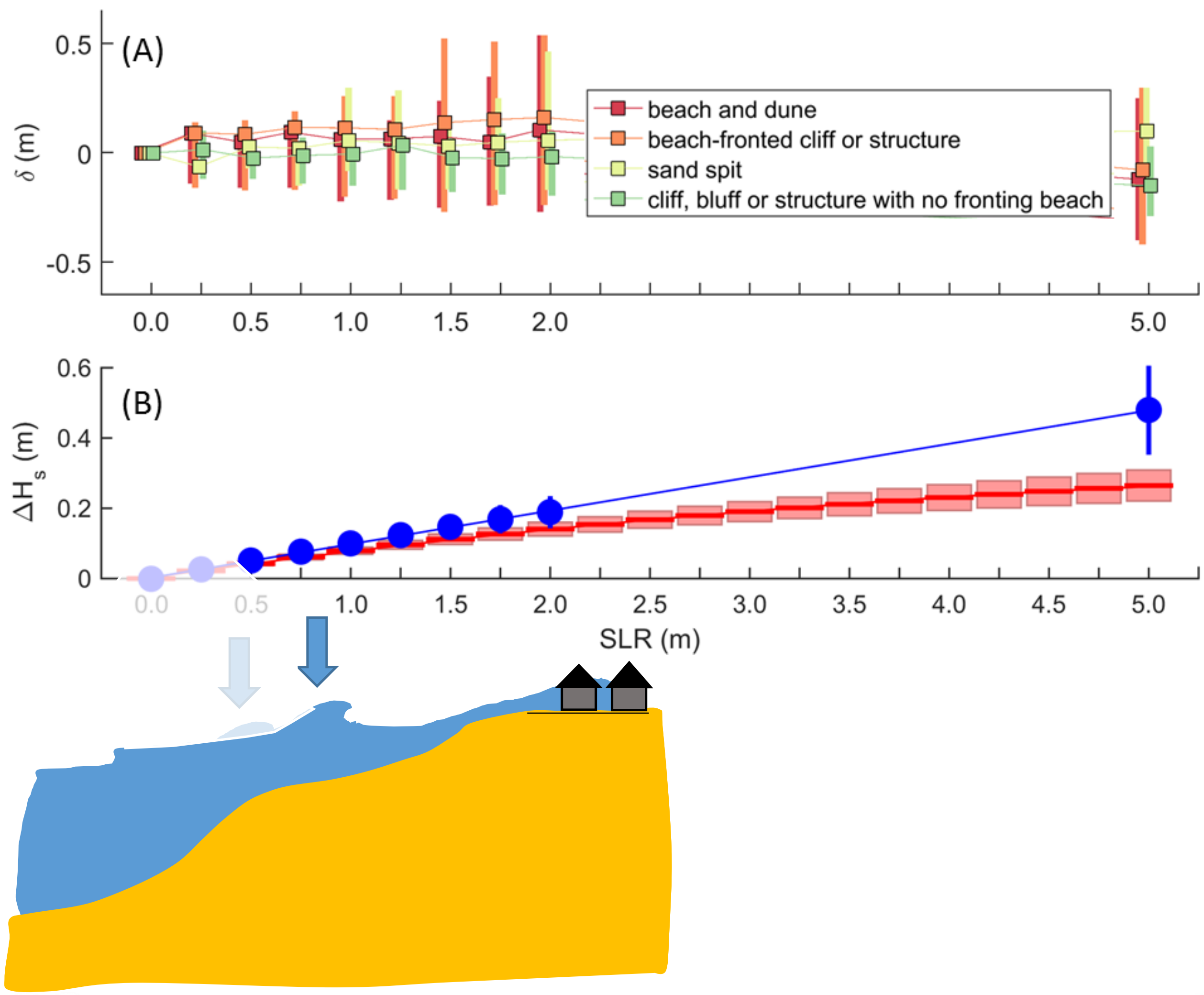
Non-linear flood potential w.r.t. SLR



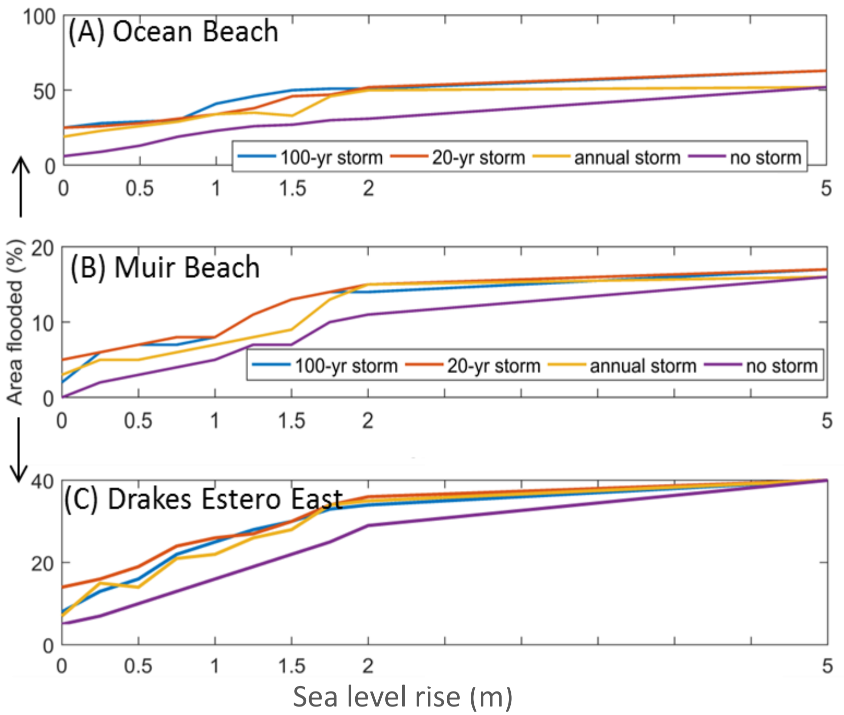
at least 2 likely reasons

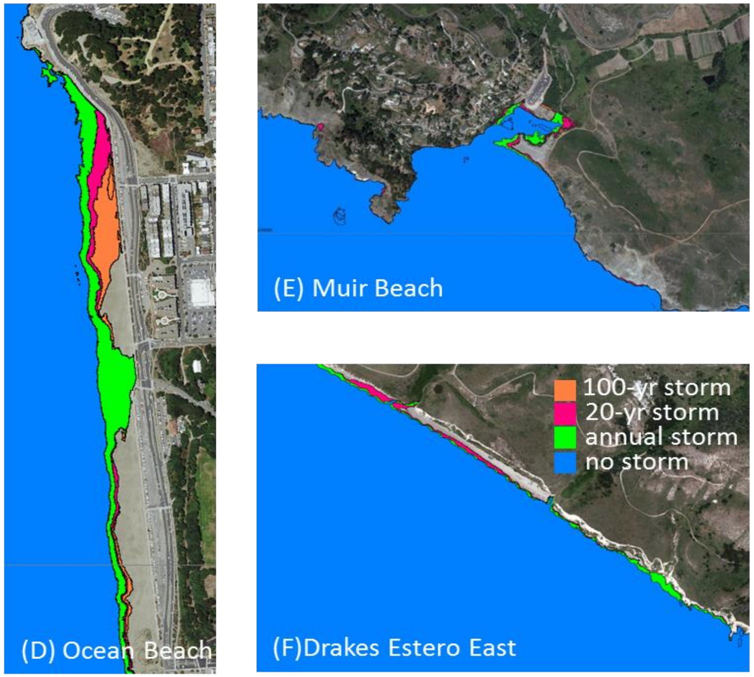
- Greater water depths allow waves to reach close to shore before shoaling, refraction, and consequent energy dissipation.
- Assumed initial static profile combined with immediate SLR results in wave breaking and runup along a different sections of the profile.

3. Findings

… effect on flood extents …

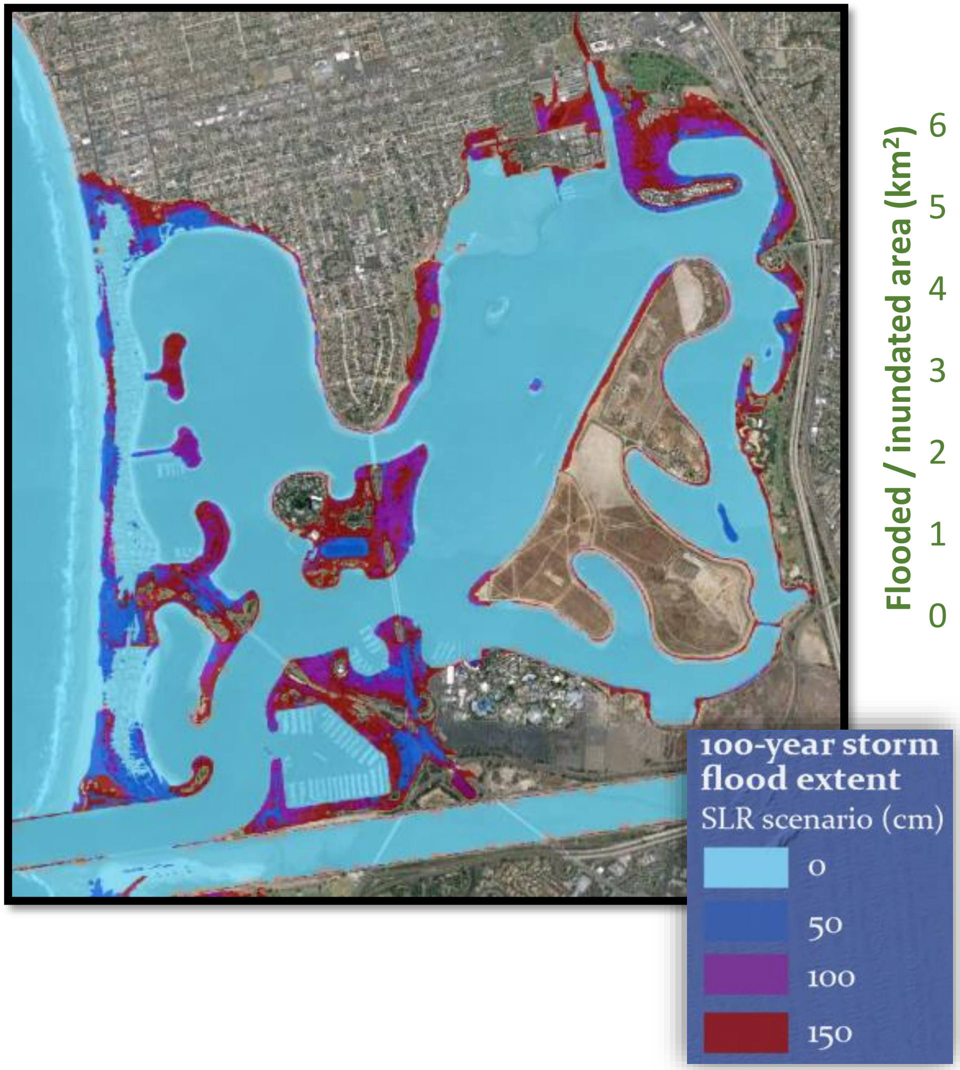
Importance of accounting for storms

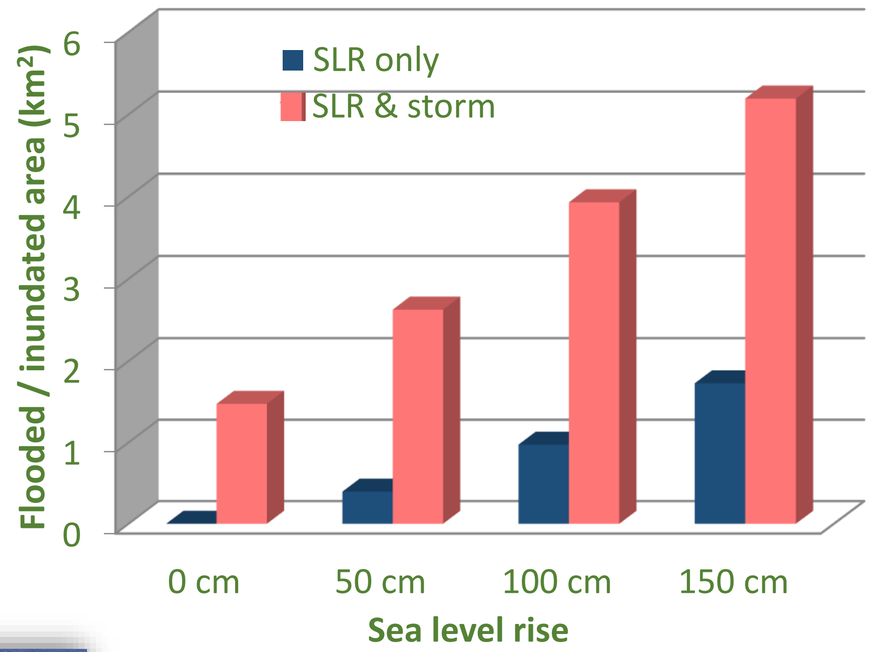




- Flooding increases dramatically with SLR
- Including storms increases flood extents by another 4% (Muir) to 20% (Ocean Beach)
- The added contribution from storms is negligible at 5m SLR for 2 sites, a reflection of the steeper topography further inland

Importance in accounting for storms





Summary and Conclusions

Summary and conclusions

- CoSMoS and associated web tools developed with the aim of **supporting** federal and state climate change guidance and vulnerability assessments
- Aims to address all relevant contributions to total water levels and future flood hazards, considering SLR ◦ tides ◦ steric effects ◦ storm surge, ◦ waves ◦ river discharge ◦ levees and seawalls ◦ non-linear interactions
- Each of the components that contribute to ZFL and TWL are computed numerically including SLR effects on wave propagation and wave-current interactions, but at a high computation cost … is it worth the computation cost?

Summary and conclusions

- Flood levels are shown to be non-linearly related to SLR, suggesting that simple linear superposition of static flood levels with SLR will results in under or over-estimates of flood hazards
- Non-linearity increases with SLR, and is most prominent for SLR>1.5m
- Non-linearity particularly evident at beaches, dunes, and beach fronted cliffs/structures (75th percentiles deviate by ~0.6m from simple linear super-position)
- Cliffs, bluffs and structures with no fronting beach less prone to the non-linear response in Z to SLR

Summary and conclusions

The non-linear response of Z to SLR, is in part due to

1. swell reaching the shore are greater compared to the no SLR case
   - deeper nearshore waters (increased SLR) allow waves to reach closer to shore before loosing energy due to shoaling & refraction, ($\sim 0.05 \cdot SLR$)
   - changes in wave current interactions (increase swell by another 5% for a total of $\sim 0.10 \cdot SLR$)
2. and because raising SLR onto an assumed initial static profile enables wave breaking, setup, and runup to act along different section of the profile

   largely due to waves breaking close to or upon impact with bluff or structure leaving little accommodation space for wave setup to develop

Limitations, uncertainties & future steps

- assumes an unchanged initial profile… future profiles will have evolved with SLR and in areas with infrastructure, coastal squeeze may significantly alter the profile, increasing the potential flood vulnerability

- Local wind-wave growth is not accounted for in these results
  - potential to increase the d discrepancy (under-estimate of linear super-position)
  - seas have been computed in all other CoSMoS simulations, but have yet to be analyzed for d

Thank you…. Questions?