4TH INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES, AND COASTAL HAZARDS
Incorporating the 18th International Waves Workshop

Modeling Recent Bomb Swell Events in Santa Cruz, California, and Their Implications for Coastal Risk Modeling

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Santander, Spain
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Photo credits: Ben Ingram

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OUR VOICES WILL DEFINE THE CENTURY

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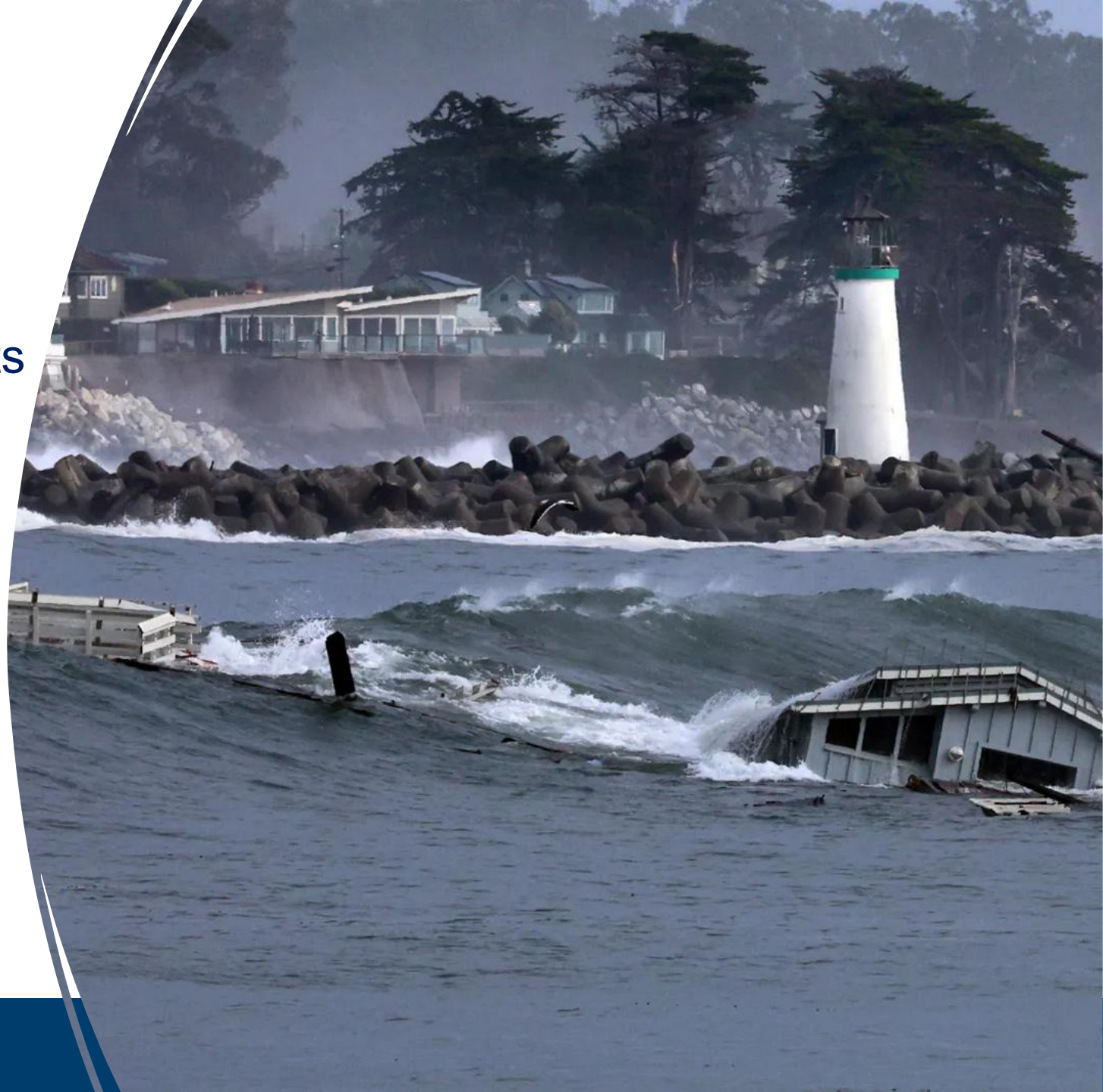
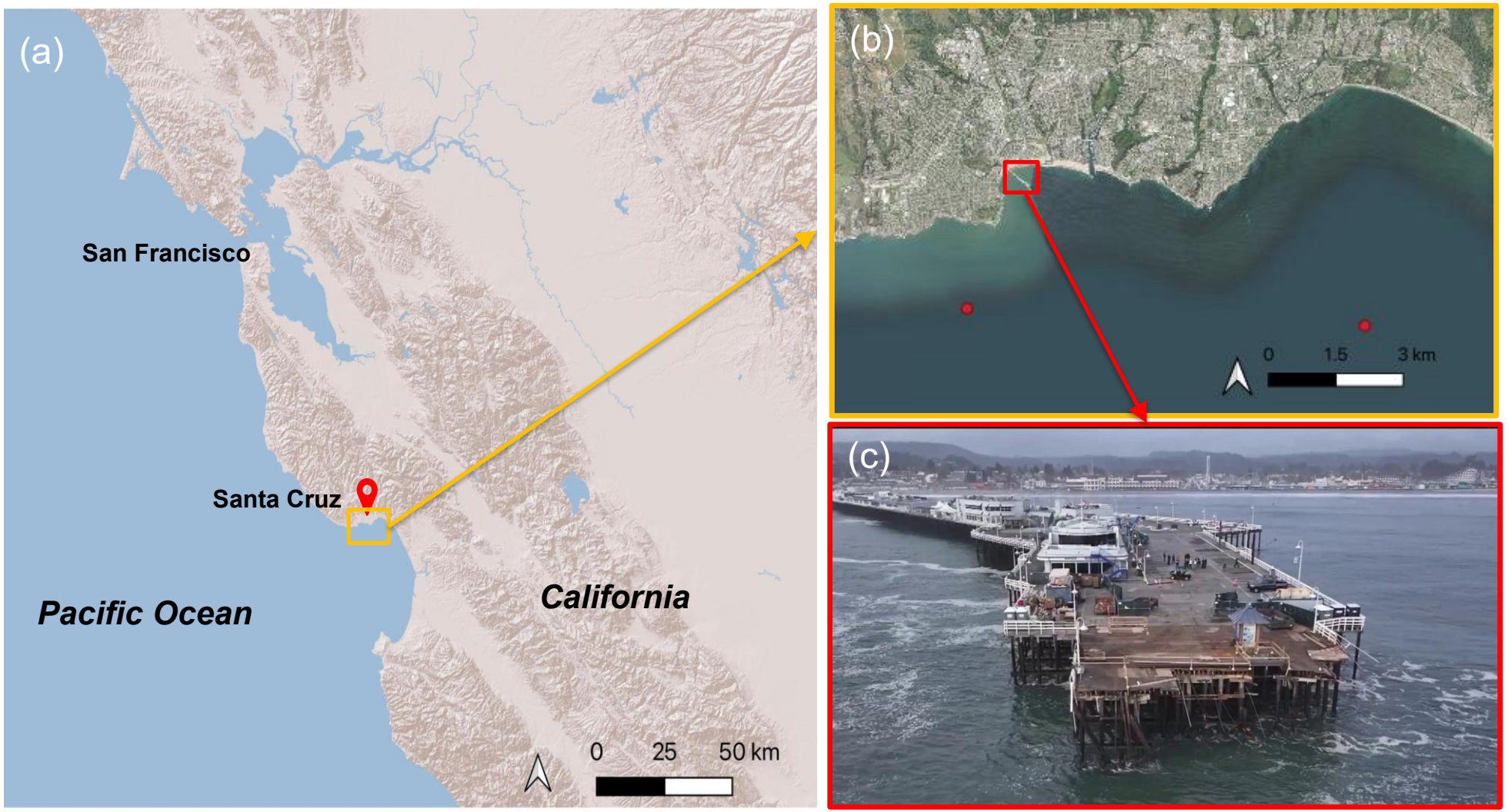


Study site: Santa Cruz

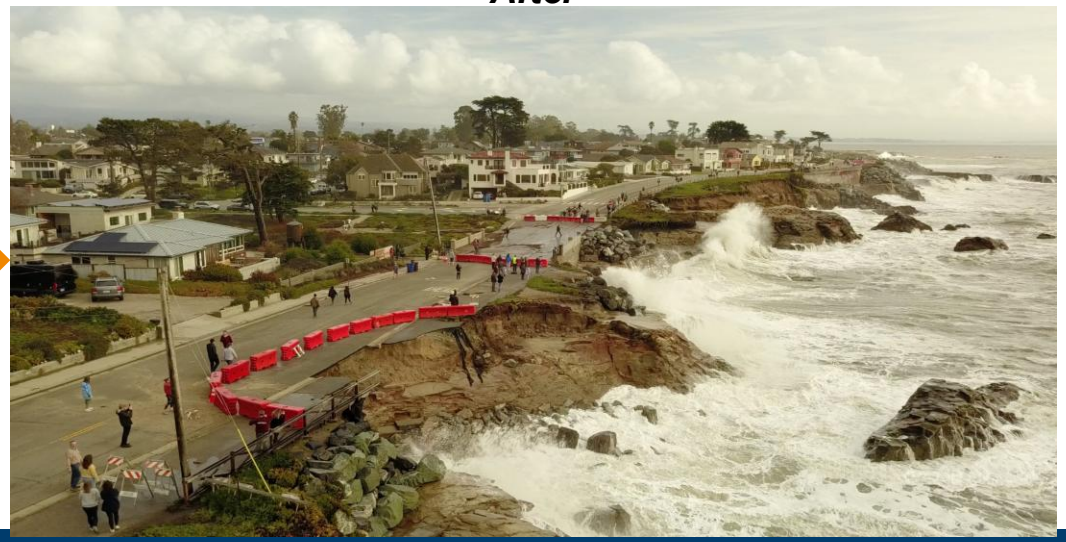


Two Bomb Swell Events

Jan 2023

Before

After

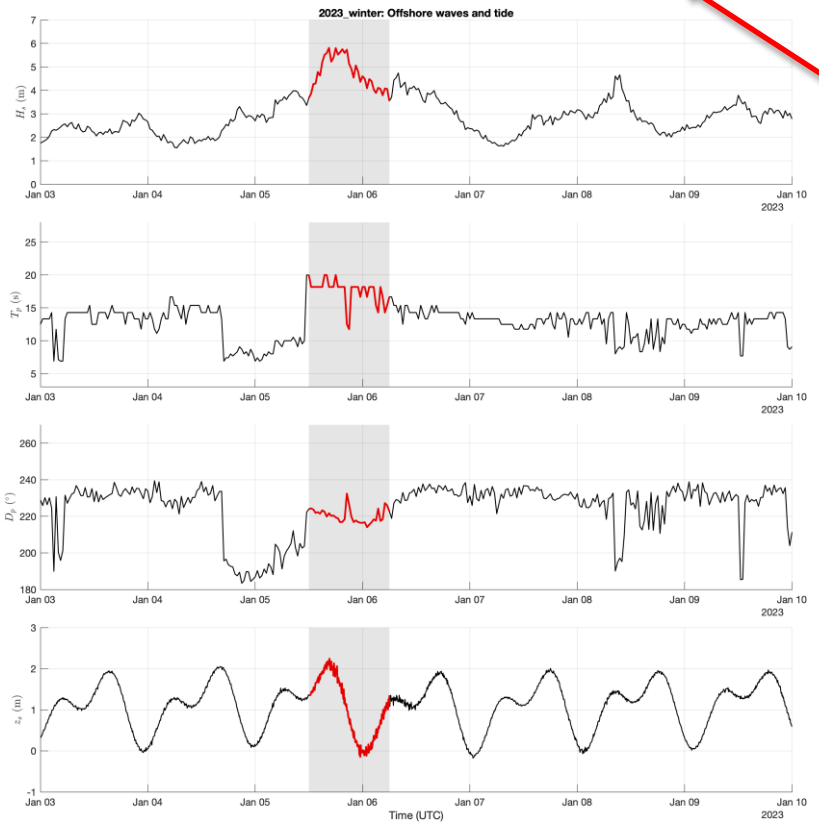


Two Bomb Swell Events

Dec 2024

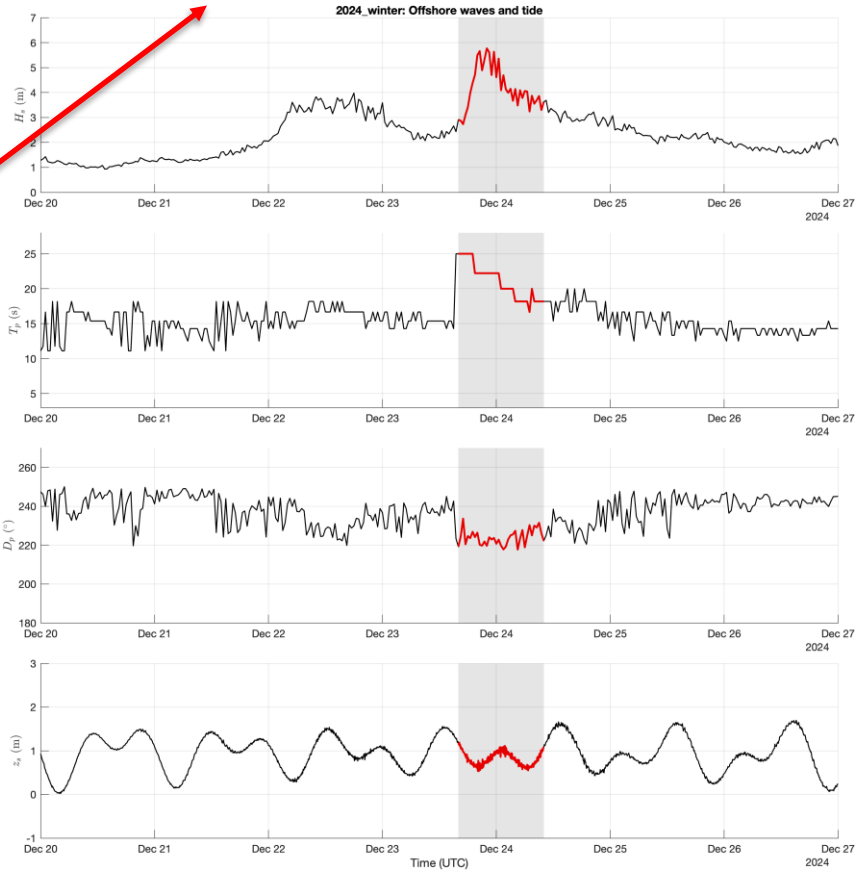
Characteristics of the storm event

2023 January storm event



CDIP
coastal data information program
cdip.ucsd.edu

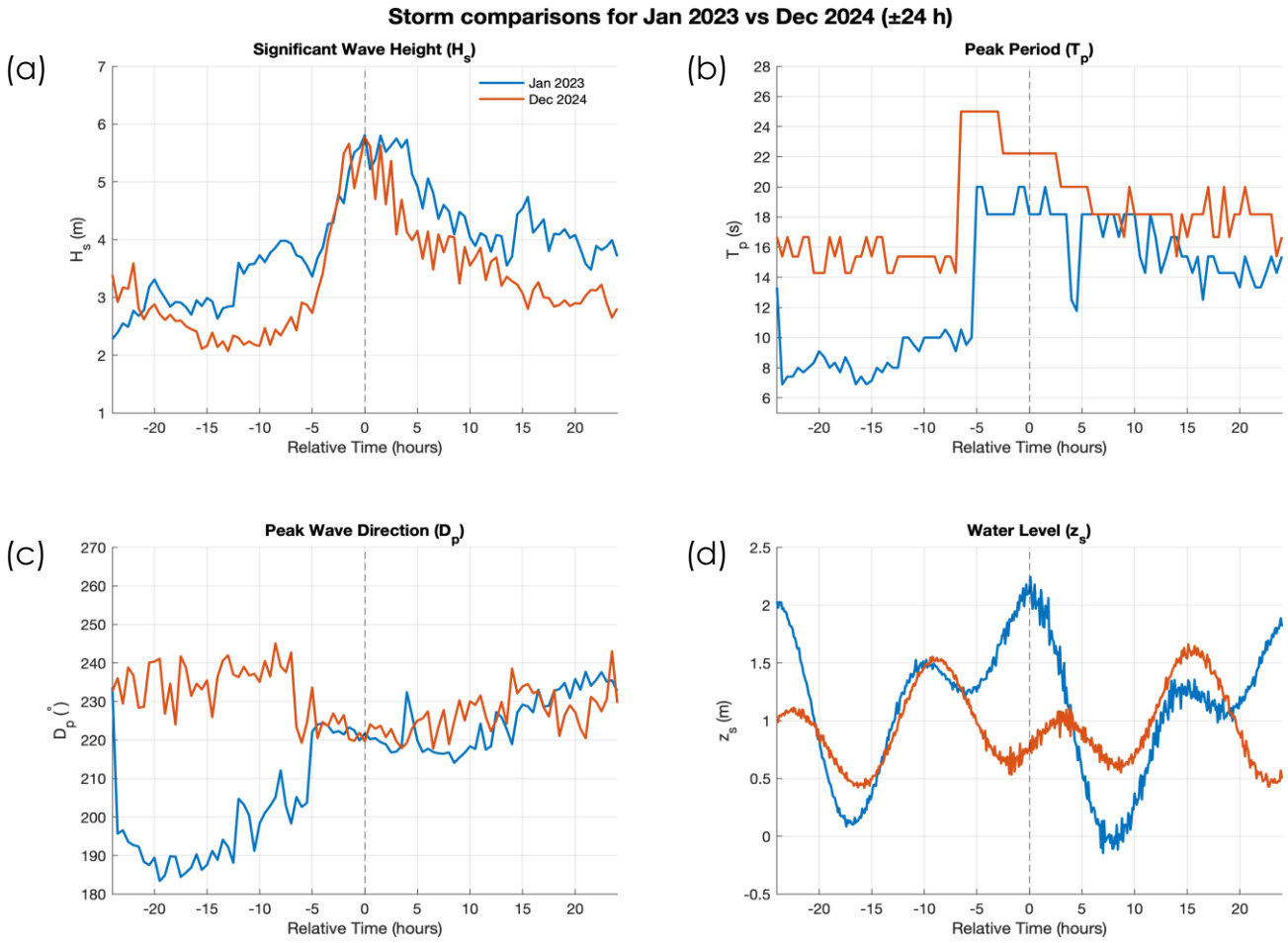
2024 December storm event



--- Event summary (05-Jan-2023 12:00:00 to 06-Jan-2023 06:00:00 UTC) ---
Peak Hs = 5.81 m at 05-Jan-2023 16:30:00
Tp (median/max) = 18.2 / 20.0 s
Median Dp = 219.9 deg
Peak WL (verified) = 2.25 m at 05-Jan-2023 16:36:00

--- Event summary (23-Dec-2024 16:00:00 to 24-Dec-2024 10:00:00 UTC) ---
Peak Hs = 5.77 m at 23-Dec-2024 22:00:00
Tp (median/max) = 20.0 / 25.0 s
Median Dp = 223.7 deg
Peak WL (verified) = 1.19 m at 23-Dec-2024 16:12:00

Characteristics of the storm event



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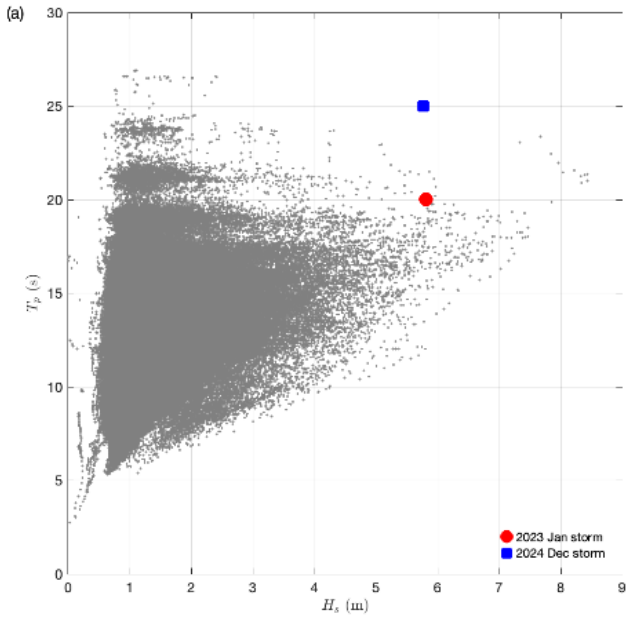
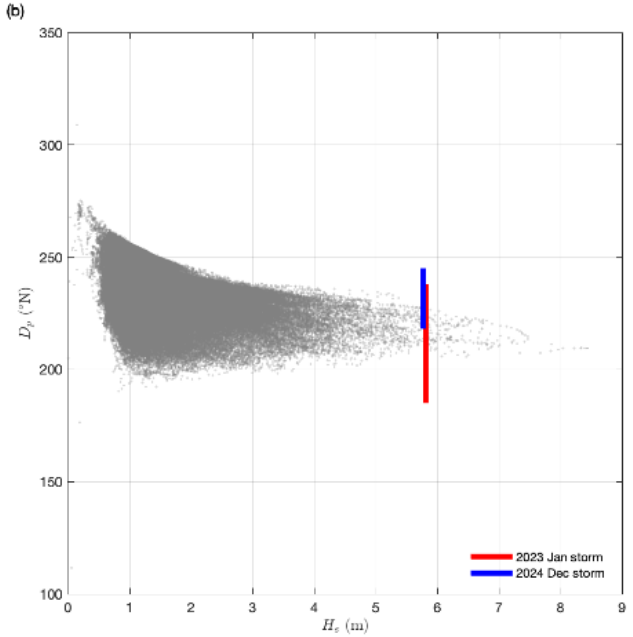
Irregularity of the storm event

- Joint distributions of **Hs–Tp** and **Hs–Dp** highlight the rarity of both 2023 and 2024 storms.
- 2023: higher **Hs** (~5.8 m) with shorter **Tp** (~20 s), coincide with **high tide level (2.25 m).**
- 2024: slightly lower **Hs** but unusually long **Tp** (~25 s.
- Both events lie **outside historical clusters**, indicating compound extremity.
- **Univariate EVA may underestimate risk** → multivariate analysis is essential for hazard assessment and coastal design.





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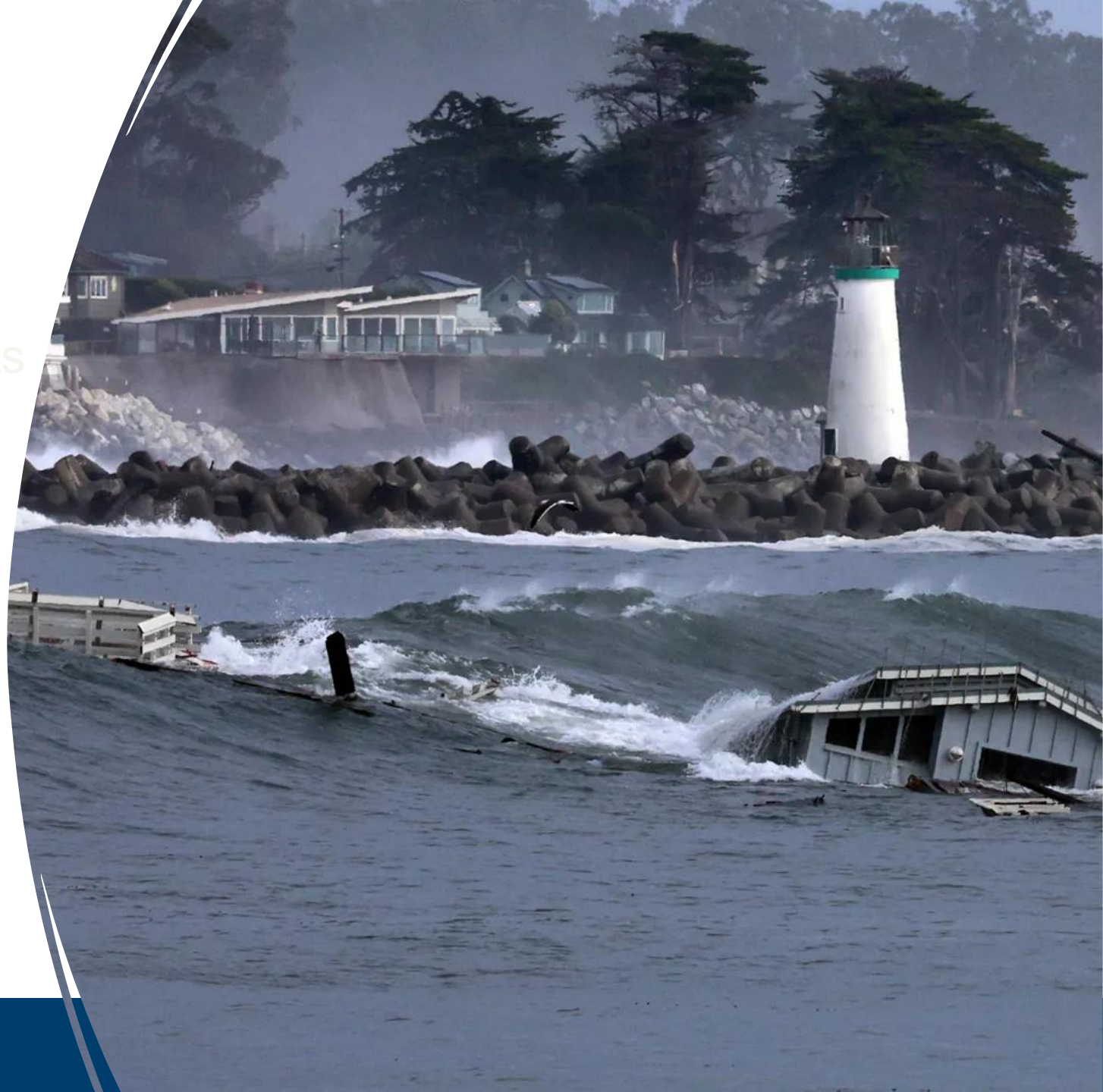
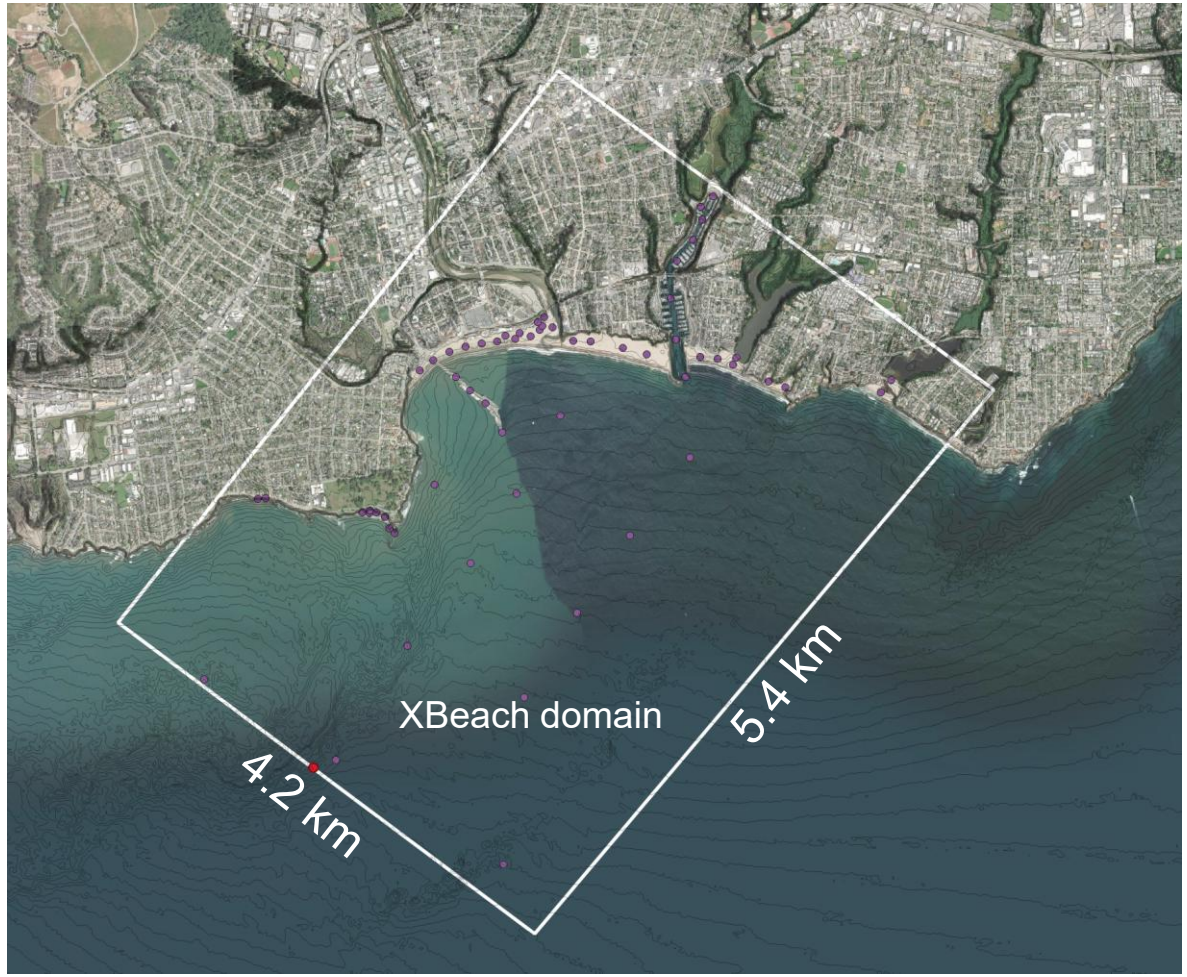


Model domain and data source



23.0 km^2

INPUT:

- **Bathymetry**

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Coastal National Elevation Database (CoNED)

- **Tide level**

NOAA TIDES & CURRENTS

- **Land use**

USGS science for a changing world

National Land Cover Database

- **Offshore wave**

CDIP coastal data information program

cdip.ucsd.edu

XBeach non-hydrostatic mode

- dx = 2 m
- dy = 2 m
- Angle of rotation: 49.8542 degrees
- Total number of cells: 5.52 million
- Storm duration: 18 h

Visualization

Flooding map

January 2023

December 2024

- **January 2023 storm**: Higher peak water level (~2.25 m) led to more widespread coastal inundation.
- **December 2024 storm**: Despite similar offshore wave height, lower tide (~1.2 m) resulted in less extensive flooding.
- **Key takeaway**: Flooding impacts depend not only on wave extremes, but also on **timing with tide and water level**.

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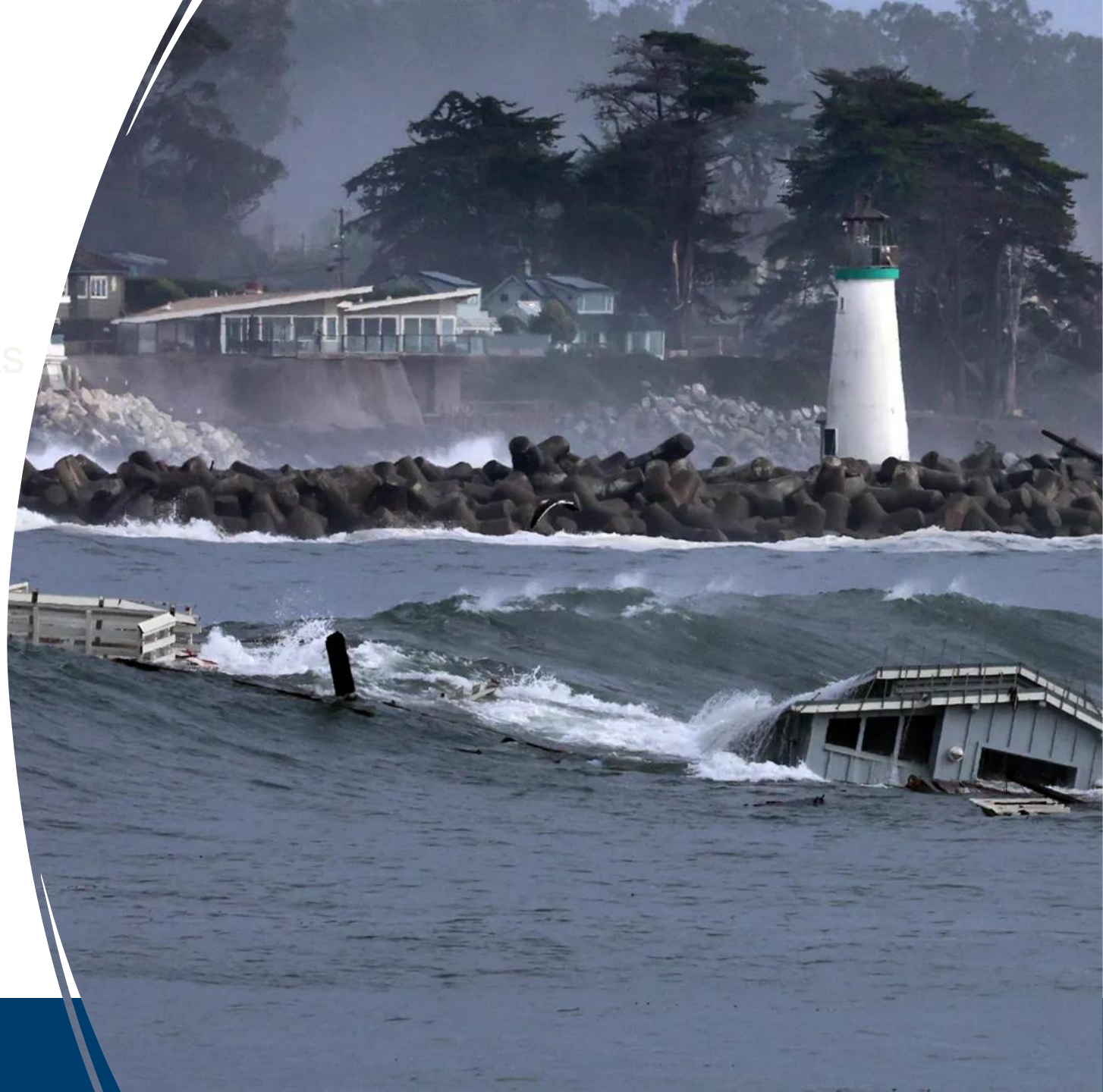
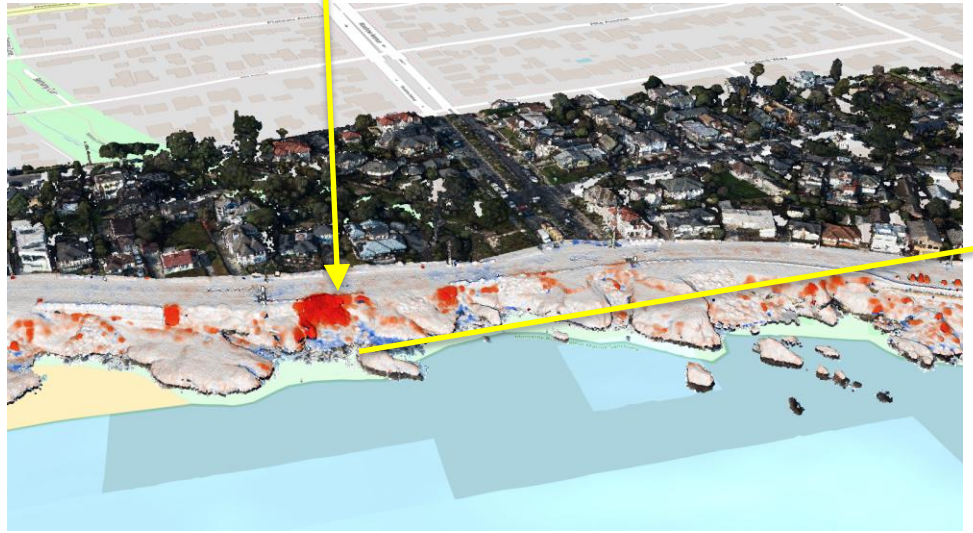
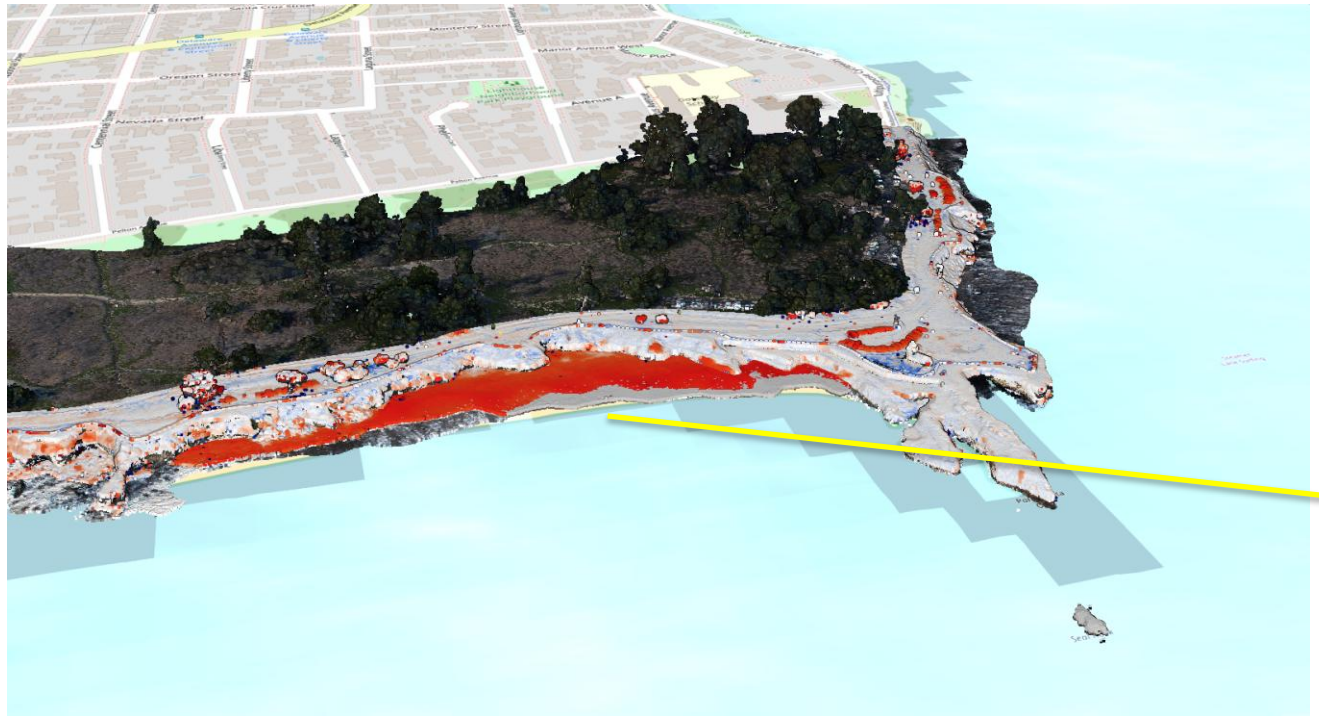


Validations (Cliff erosion)

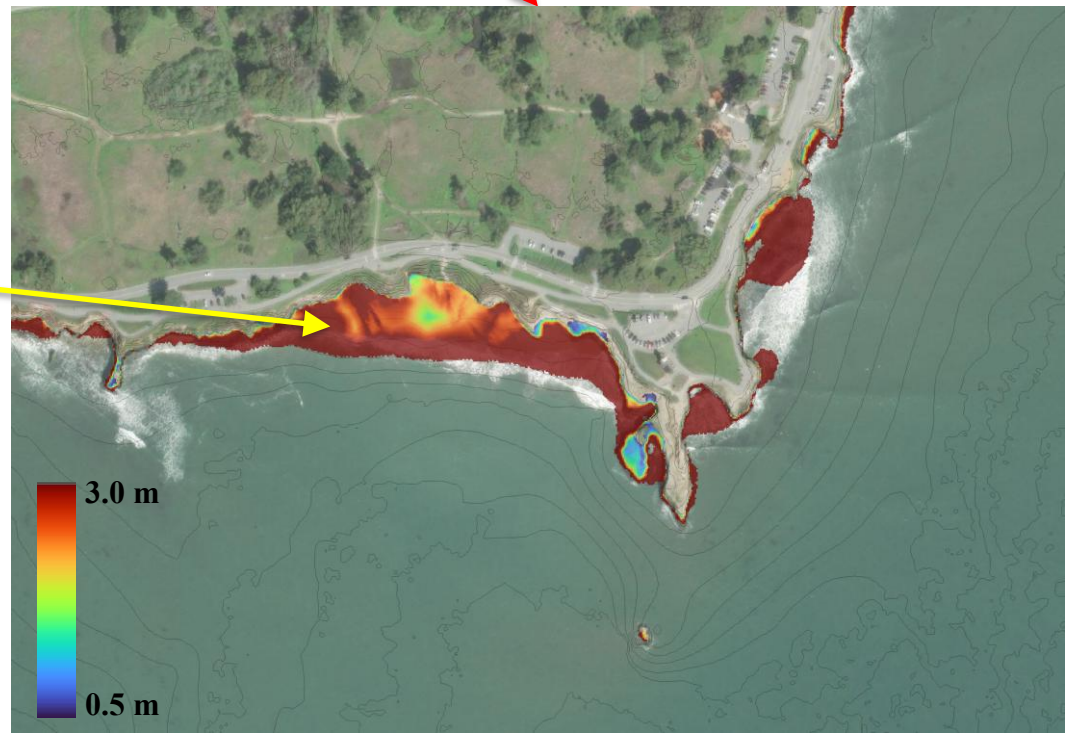


The USGS has collected and released topographic data that show the erosional effects of the January 2023 storms on the coast for the Santa Cruz region of California.

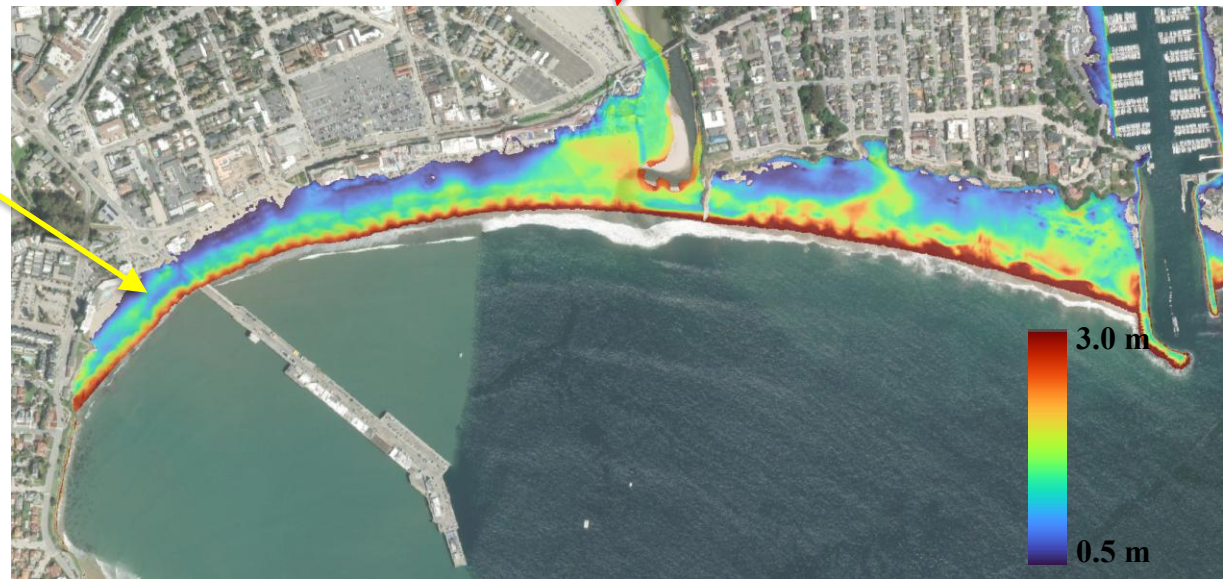
Validations (Cliff erosion)



USGS remote sensing data

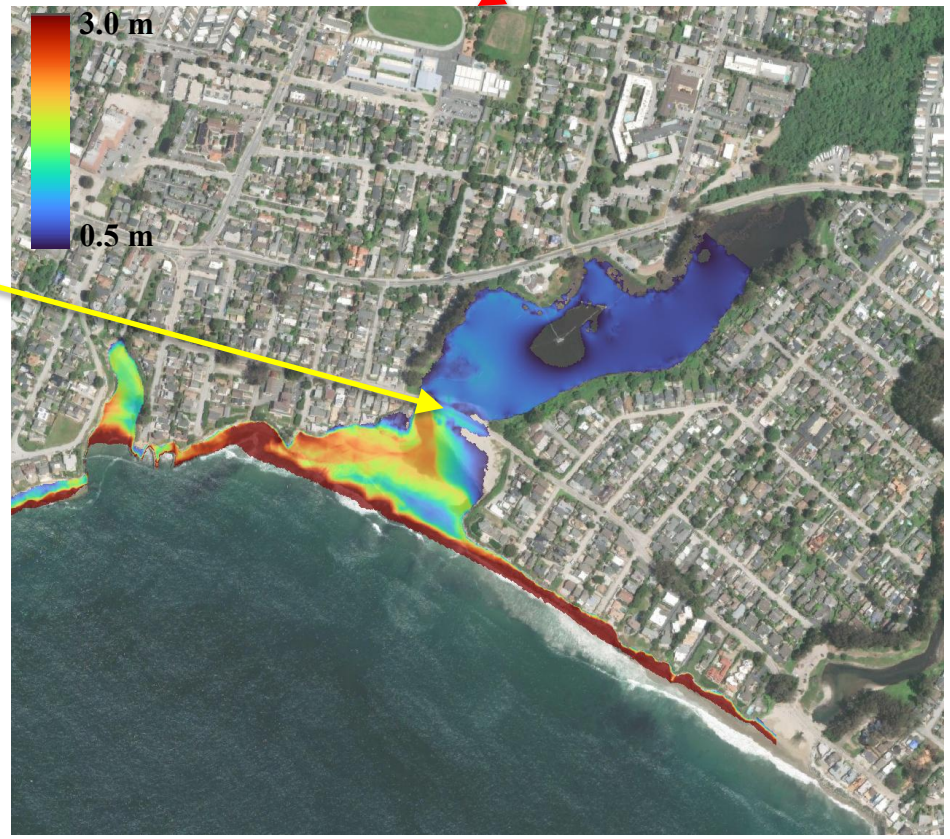


Validations (Flooding at Main Beach)



Validations (Flooding at East Cliff)

Credit: Michael Beck, Director, UCSC Center for Coastal Climate Resilience



Summary and future work

Summary

- Recent Bomb Swell events highlight increasing climate variability and extreme weather.
- Applied a non-hydrostatic XBeach model to simulate storm impacts at high resolution.
- Visualization outputs provide a tool to raise public awareness of coastal risk.
- Conducted qualitative validations through comparison with USGS video camera observations.

Future Work

- Extend to multivariate extreme analysis for compound hazard assessment.
- Perform quantitative validations, including shoreline change and inundation extent from video data.
- Apply high-resolution storm modeling to better quantify flooding cliff erosion processes, harbor resonance, and wharf stability under extreme wave conditions.

Thank you

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Validations (Flooding at Main Beach)