WCRP & PS-CoSMoS Wave Modeling

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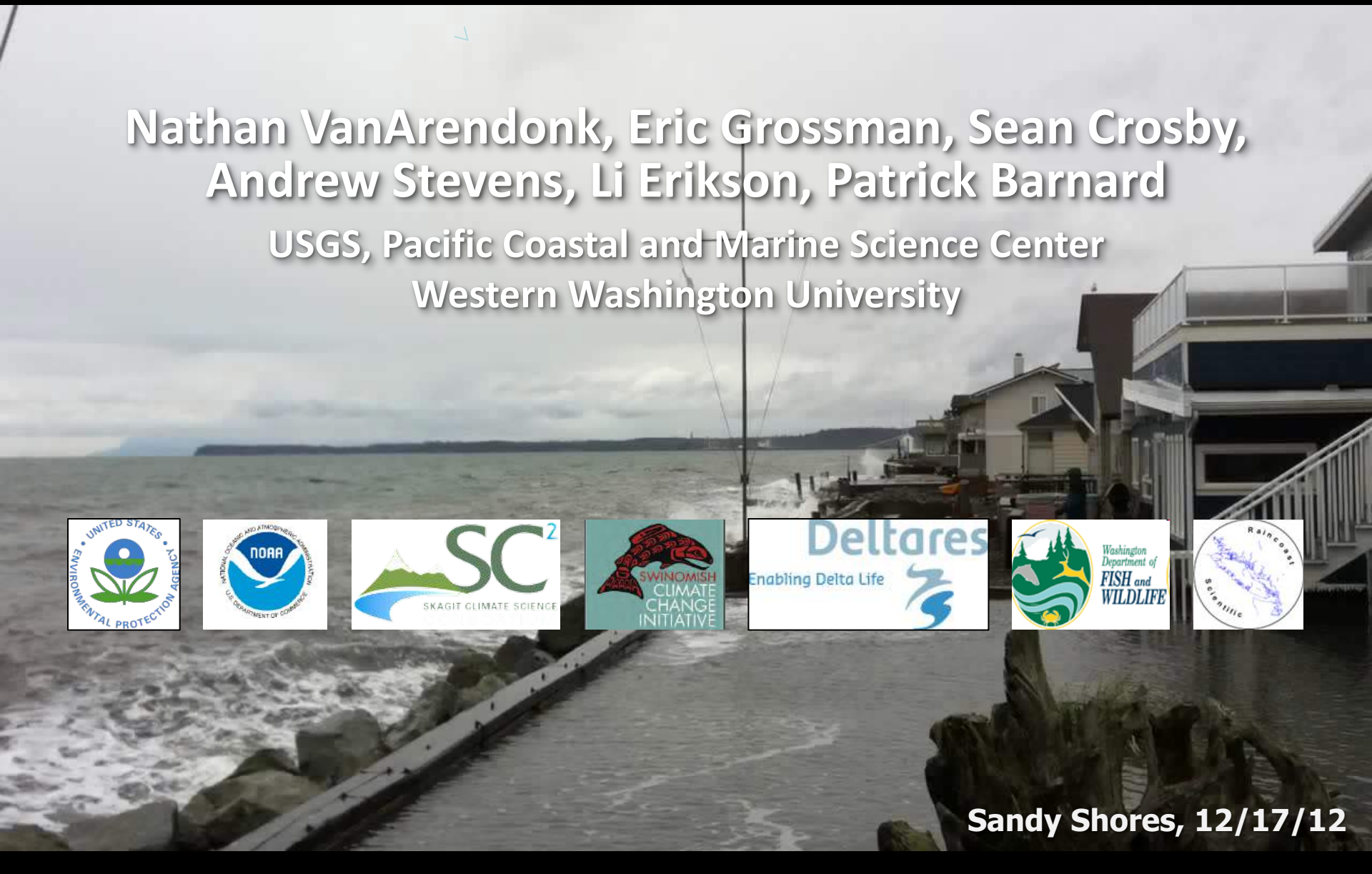
USGS, Pacific Coastal and Marine Science Center
Western Washington University



Sandy Shores, 12/17/12

Talk Outline

Importance of Storms/Waves

Modeling Goals & Mechanics

- Integration with USGS PS-CoSMoS
- Model Construction

Initial Results

- Wave Sensitivity
- Climatology
- Weather model consistency
- Wave Scenarios

Expected Products & Next steps

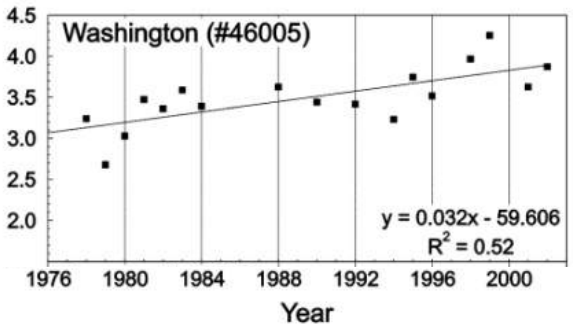
Three Tree Point, Nov. 2011 *(R. Schmidt)*

Gulf Road, Whatcom County, Dec. 17, 2012 (*E. Kilanowski)*

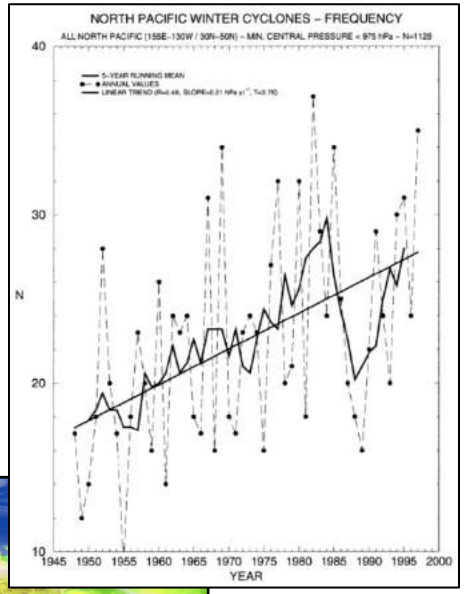
Why Coastal Storms and Waves?

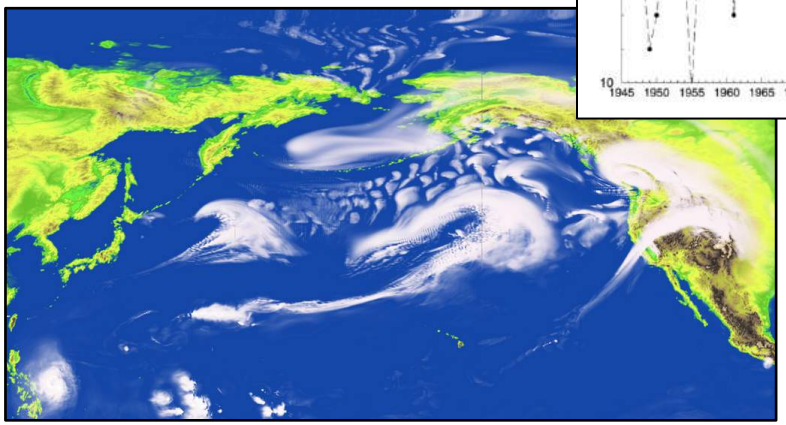
1. Significantly different impact to shorelines, infrastructure, habitats than sea-level rise alone - *erosion, sediment transport*

2. Intensity/frequency <u>increasing</u> and <u>enhanced</u> by sea level rise, *less friction, greater fetch where depth-limited*



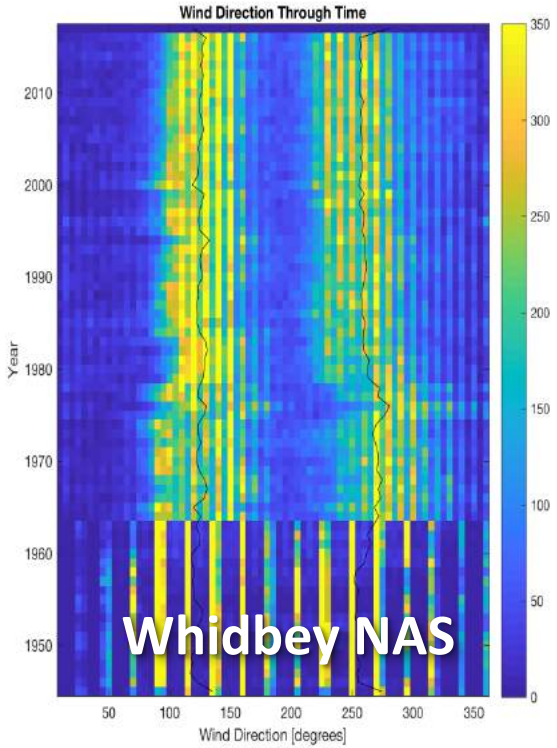
Allan and Komar 2006





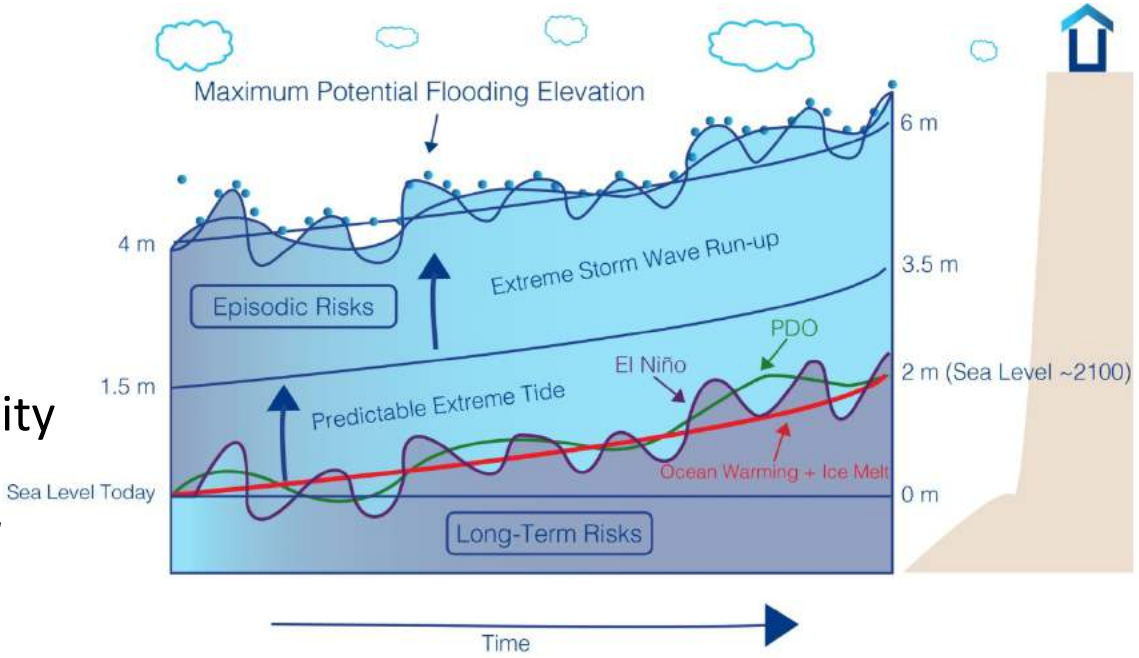
El Ninos and atmospheric rivers to increase in intensity, shift northward

Why Coastal Storms and Waves?

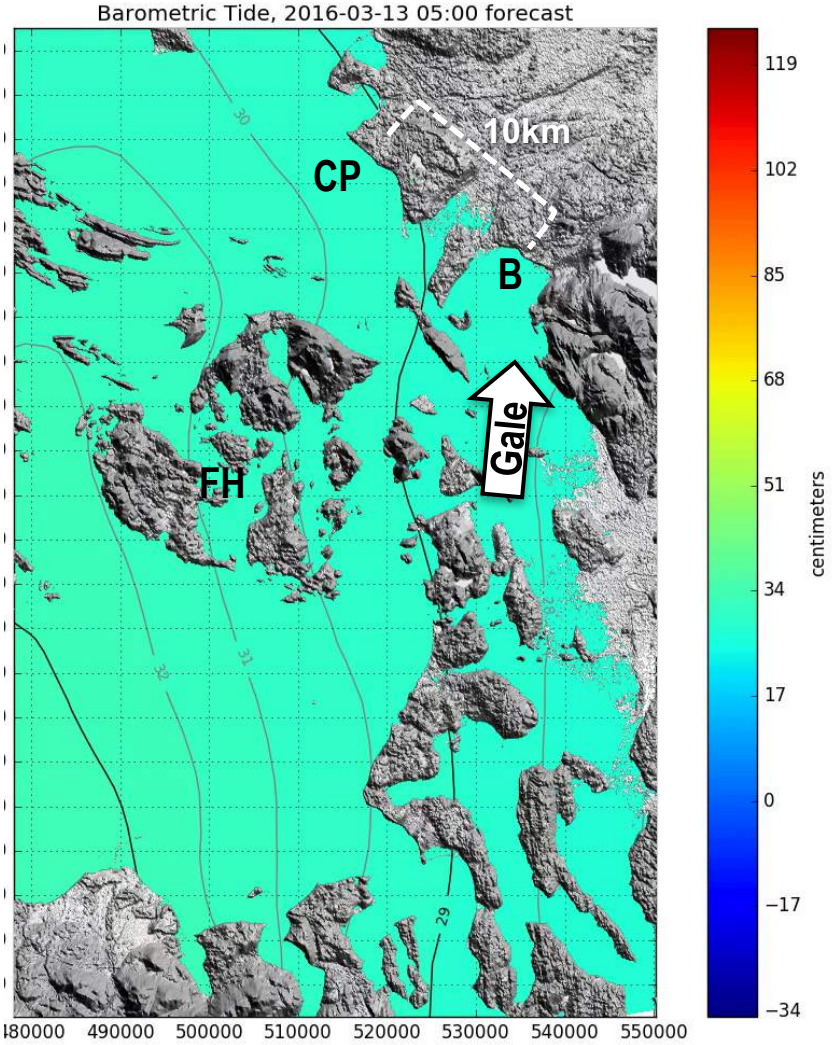


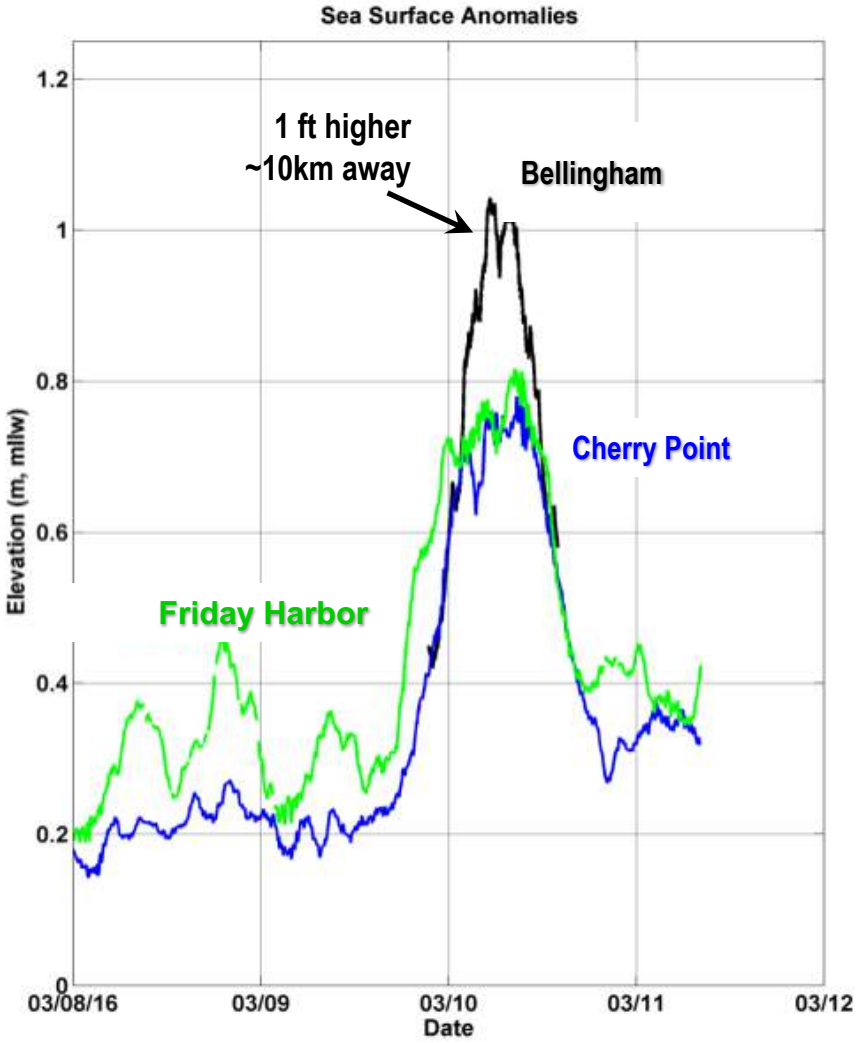
3. Variations in wave forcing inside Puget Sound that drive incident wave energy *e.g. decadal oscillations in wind direction of 10-15 degrees*

4. Dynamic, vary through time (ENSO, PDO, wind direction) added, episodic risk/probability - *Regional integrated model fills priority information need*



Wind-Wave Setup





WCRP Wave Model Goals

Assess changes to regional deep water wave energy by modeling historic extreme events for

1. Present water level
2. Probabilistic SLR estimates (I. Miller)

Case Studies:

A. ESRP – regional vulnerability of investments/prioritization

B. City of Tacoma – influences to shoreline infrastructure (roads, port?)

Integrated/phased with USGS PS-Coastal Storm Modeling System (PS-CoSMoS)

Objective 1 wave model = Tier 1 PS-CoSMoS

- intended to force nested tier 2, 3 wave transformation and flood models at ~50 to 100m resolution to predict flooding, coastal/habitat change

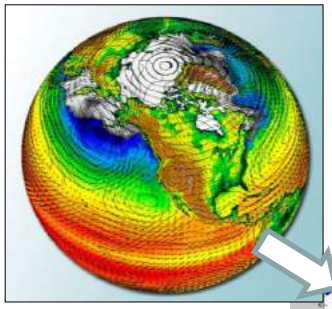
CoSMoS Framework

- 40 scenarios of SLR + storms
- Latest Global Climate Models (CMIP5)
- Downscaled future winds and waves

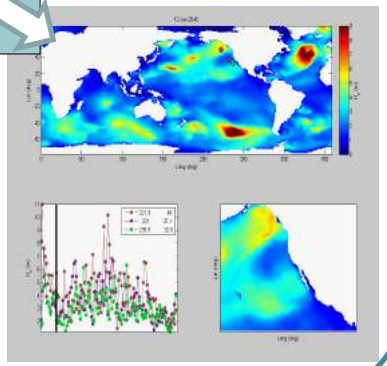
WCRP Wave Model

Global

Global climate models (GCMs)



GCM winds

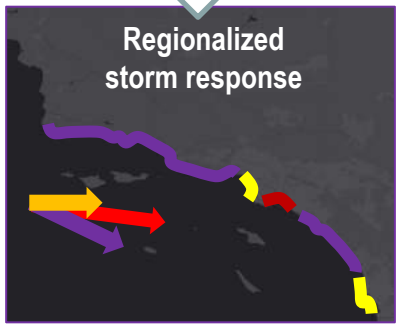


WW3 wave model

Downscaled winds and SLPs

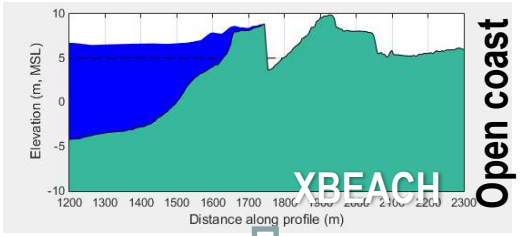
Regional

Tides, water levels, and regional forcing



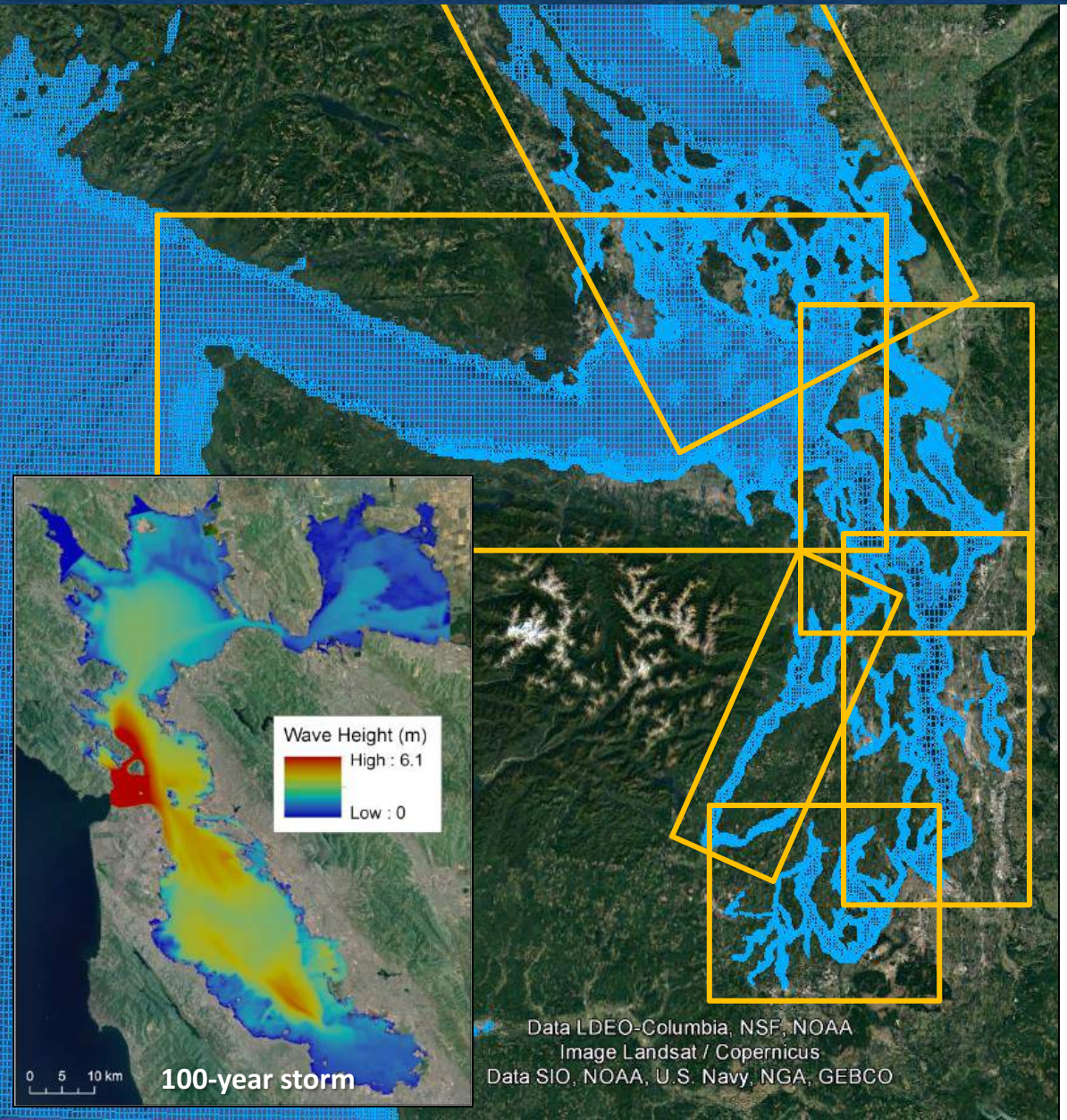
Local

High resolution hydrodynamics, waves, & fluvial discharge



results projected onto hi-res DEM

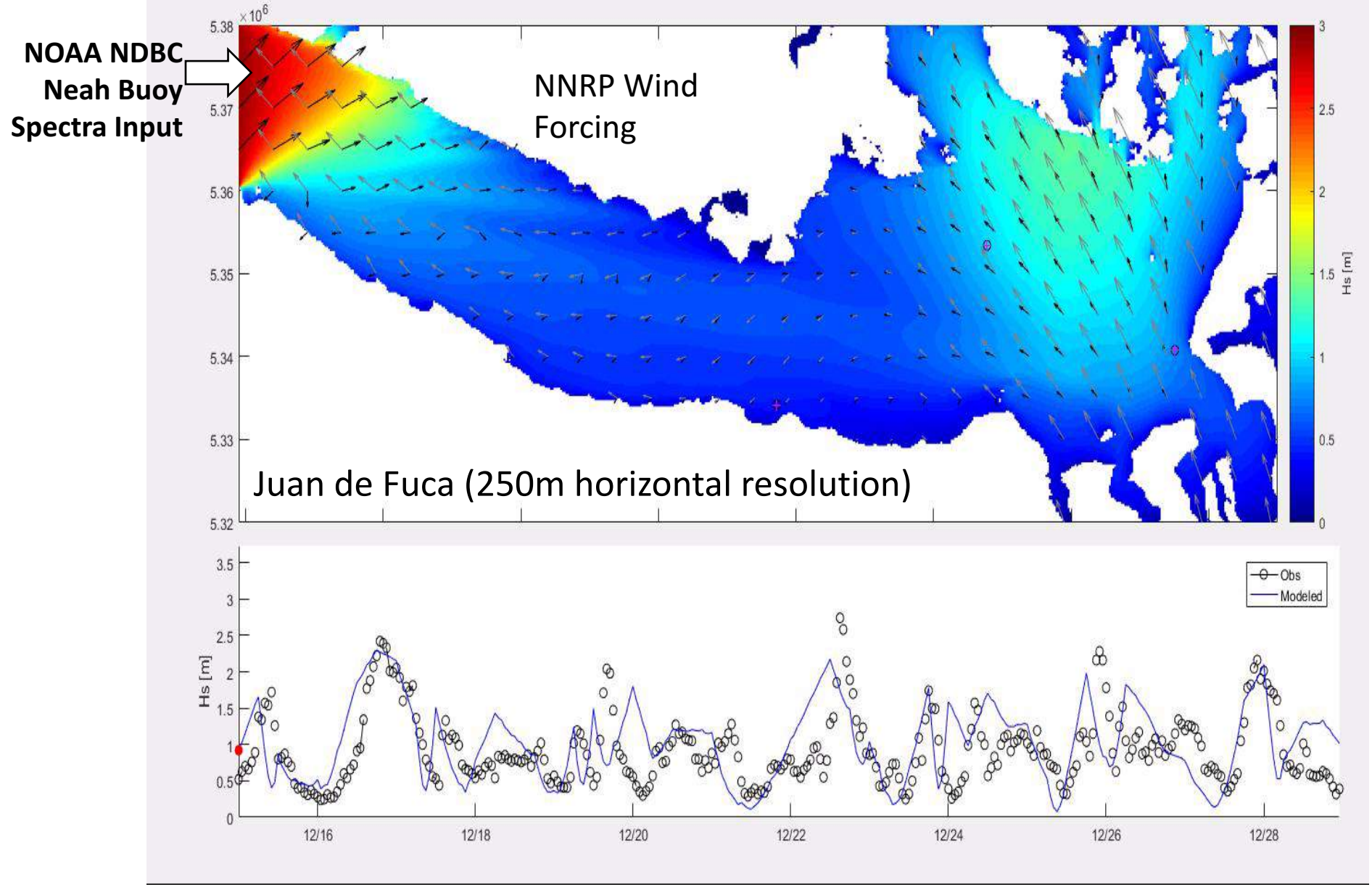
WCRP Wave Model



- **Unstructured FLOW model (DelftFM)**
  - 65 m coastal resolution
  - 0.5 million nodes
- Validation with NOAA tide gauges
  - tidal/storm surge propagation
  - extreme value analysis (TLW)

- **Structured WAVE model (DelftFM)**
- Validation
  - NDBC (Hein Bank), EC (2 buoys)
  - ~12 short term data sets
  - 2017 winter deployment
  - Total WL, flooding (SS network)
- Extreme waves + sea-level rise
  - Variability alongshore
  - Change in Hsig, energy flux, wave power

Results: Model Validation



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Wave Model Validation

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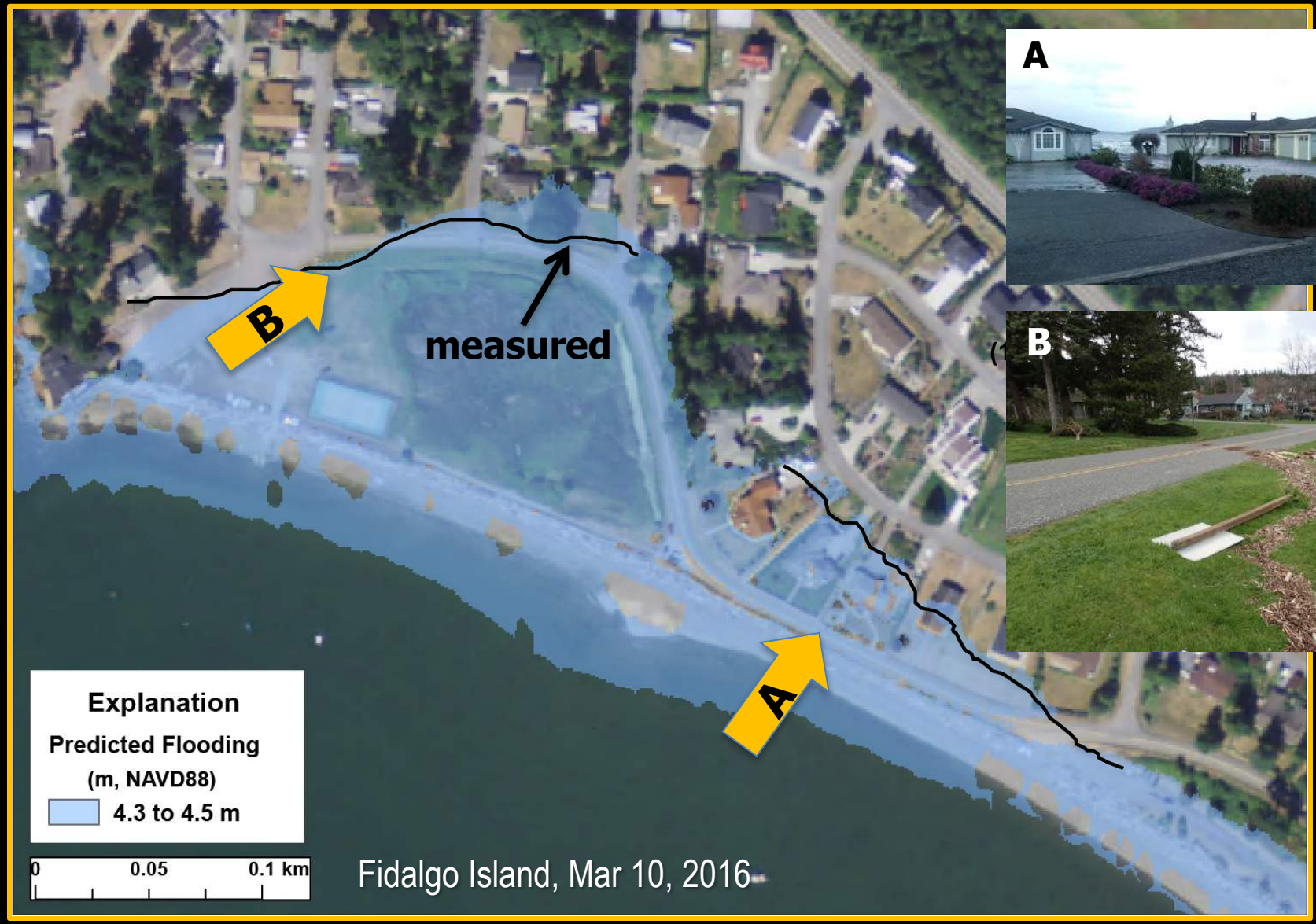
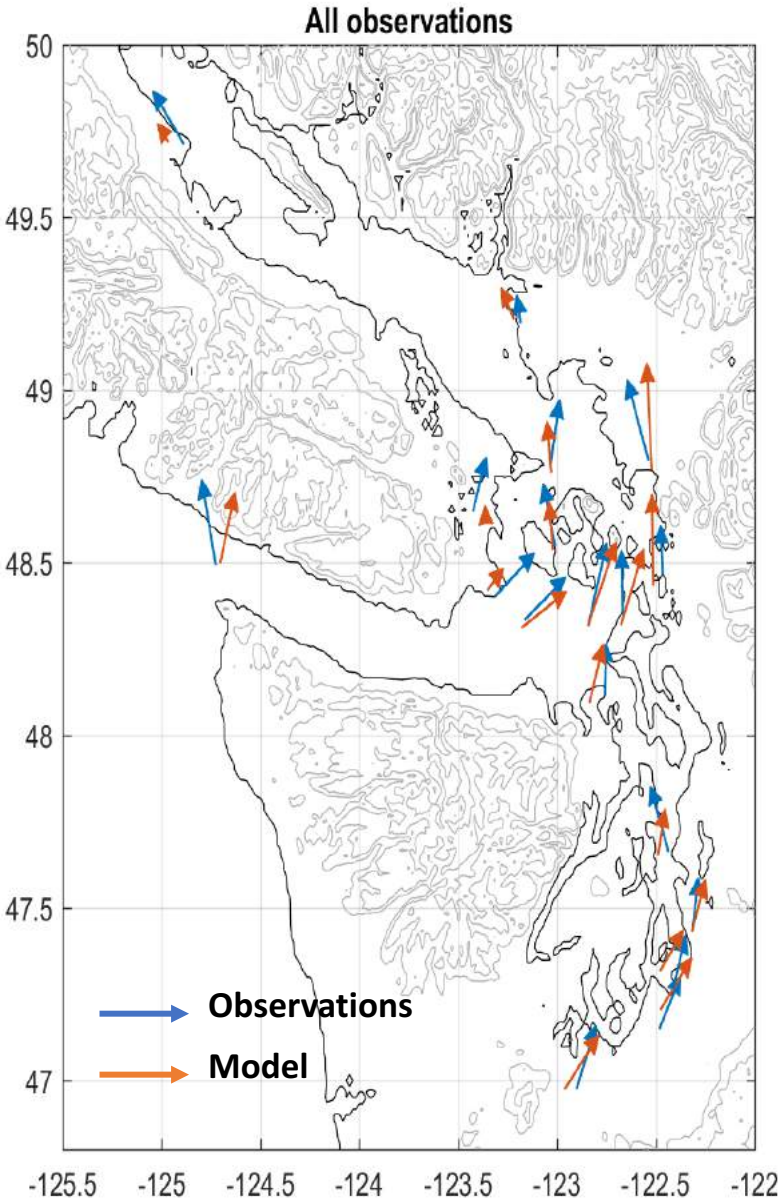
Wave Model Validation



Results: Climatology

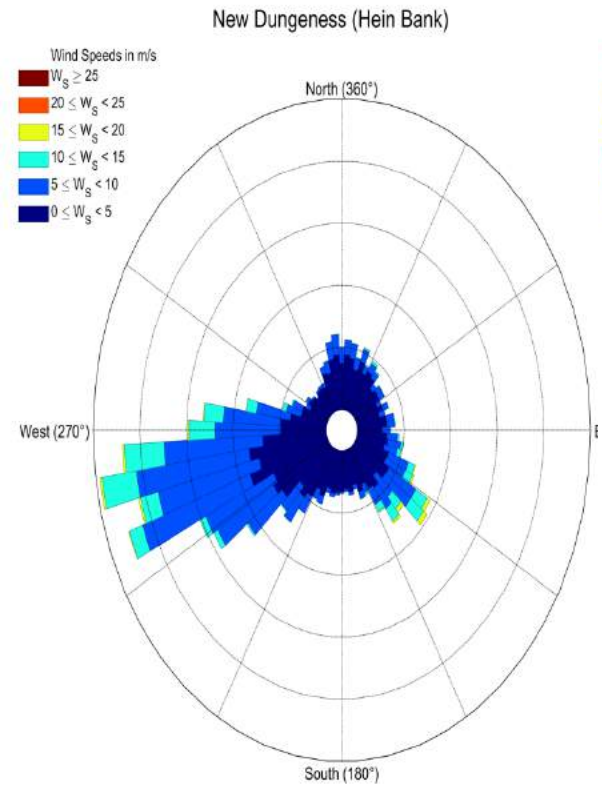
~40 stations
>30 years



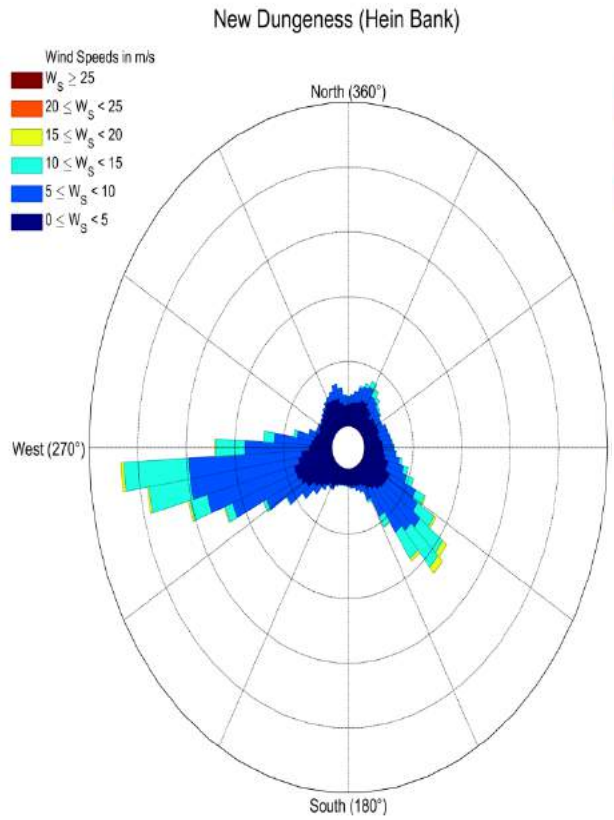
Results: Weather Products

Climatology NCDC Hein Bank (New Dungeness)

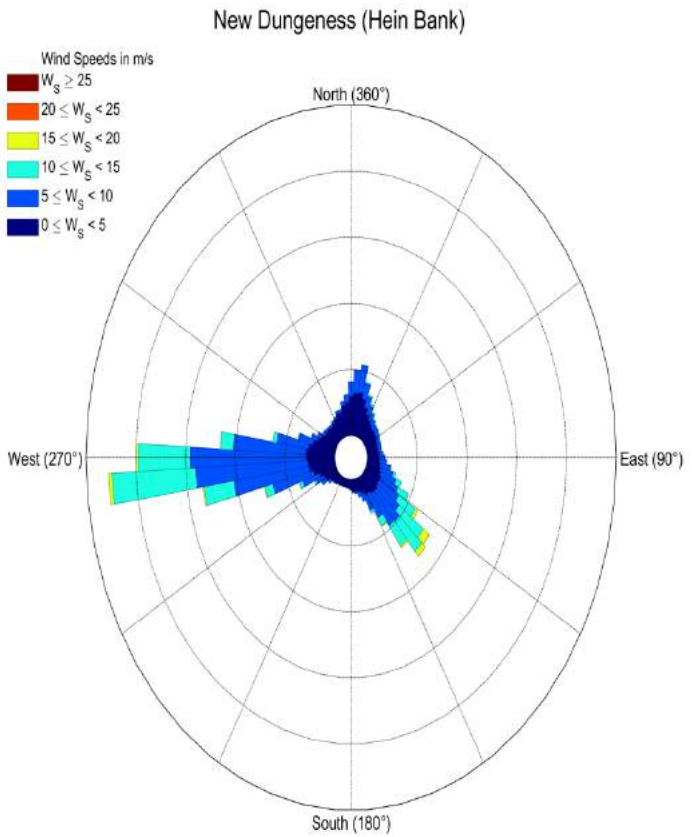
Observations



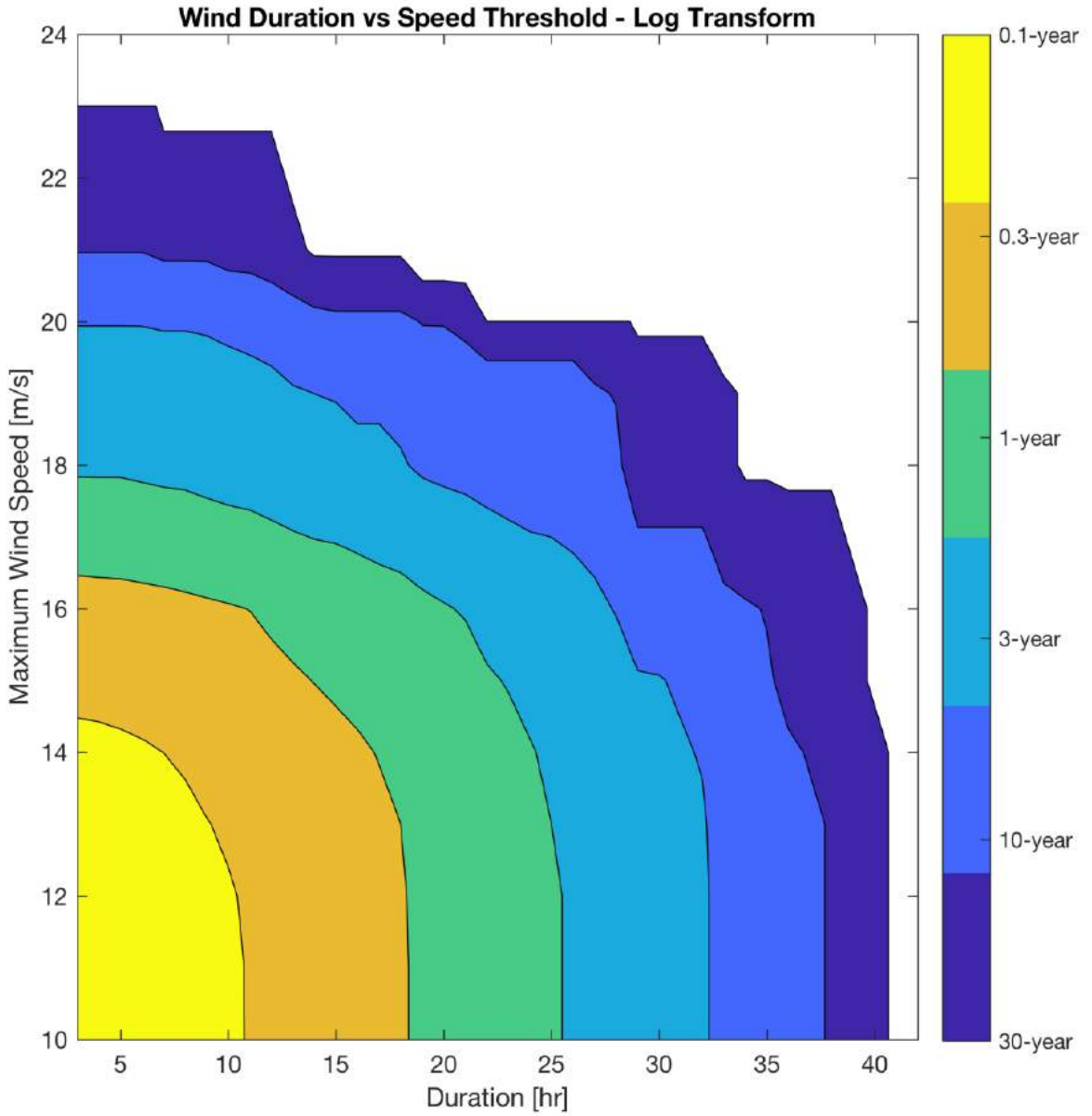
HRDPS (2.5km) Predictions 2016 (forecast hour #3)



NNRP (12km) Predictions

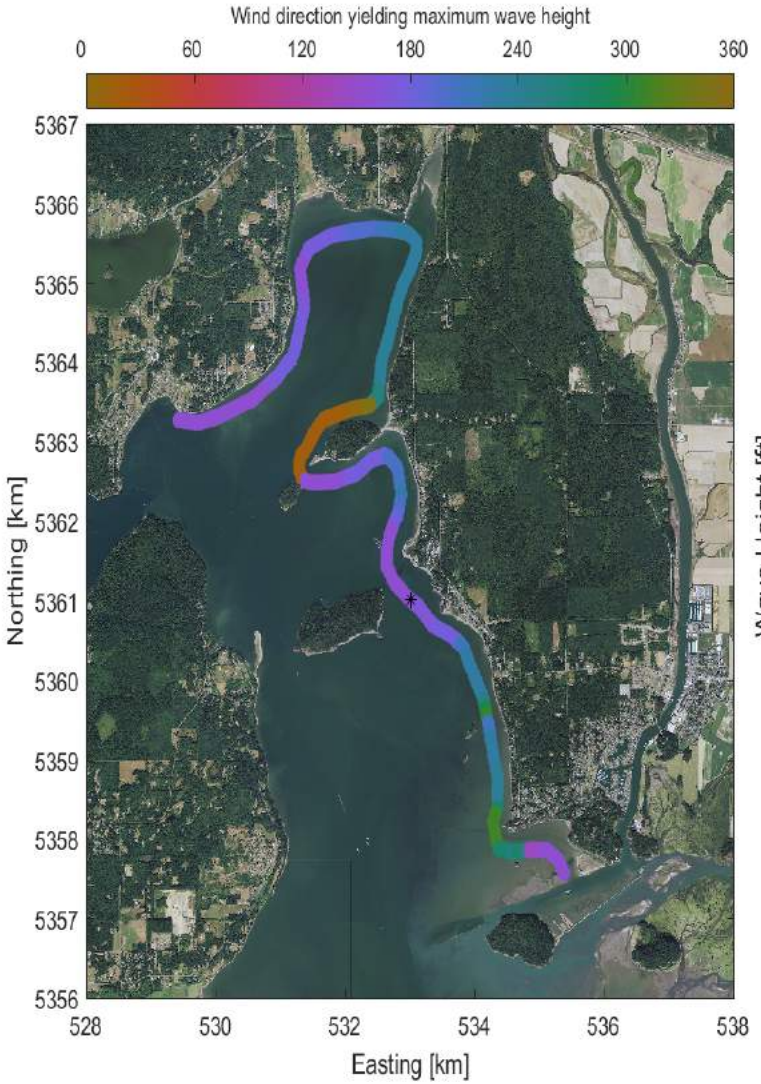


Results: Wind Forcing, Metrics

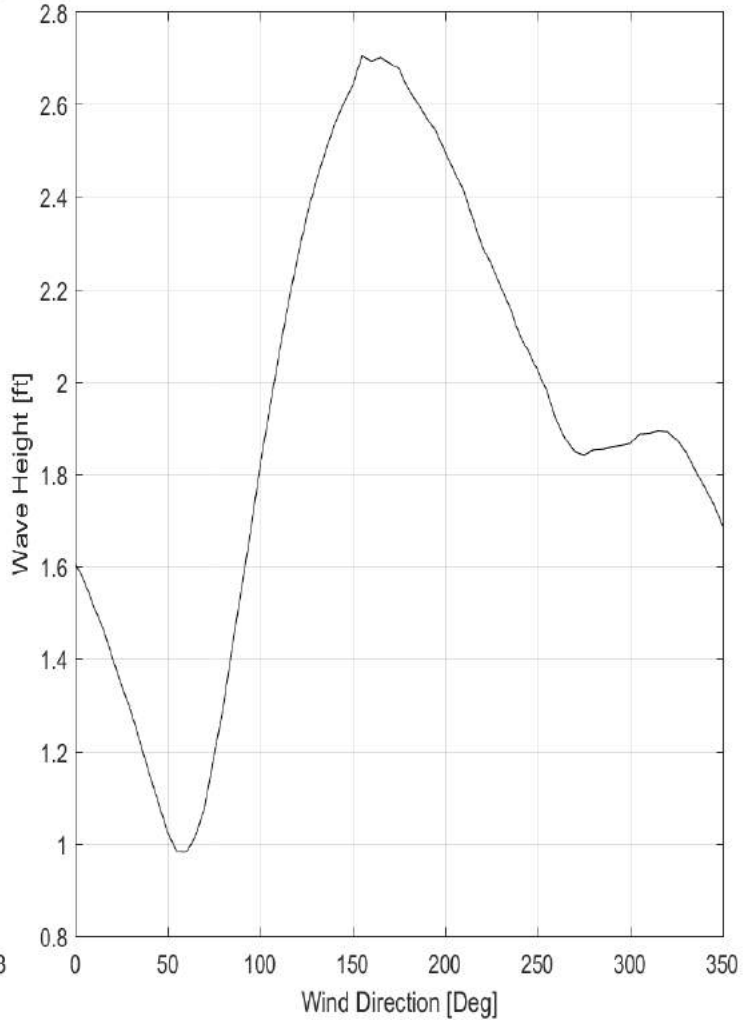


Wave Sensitivity

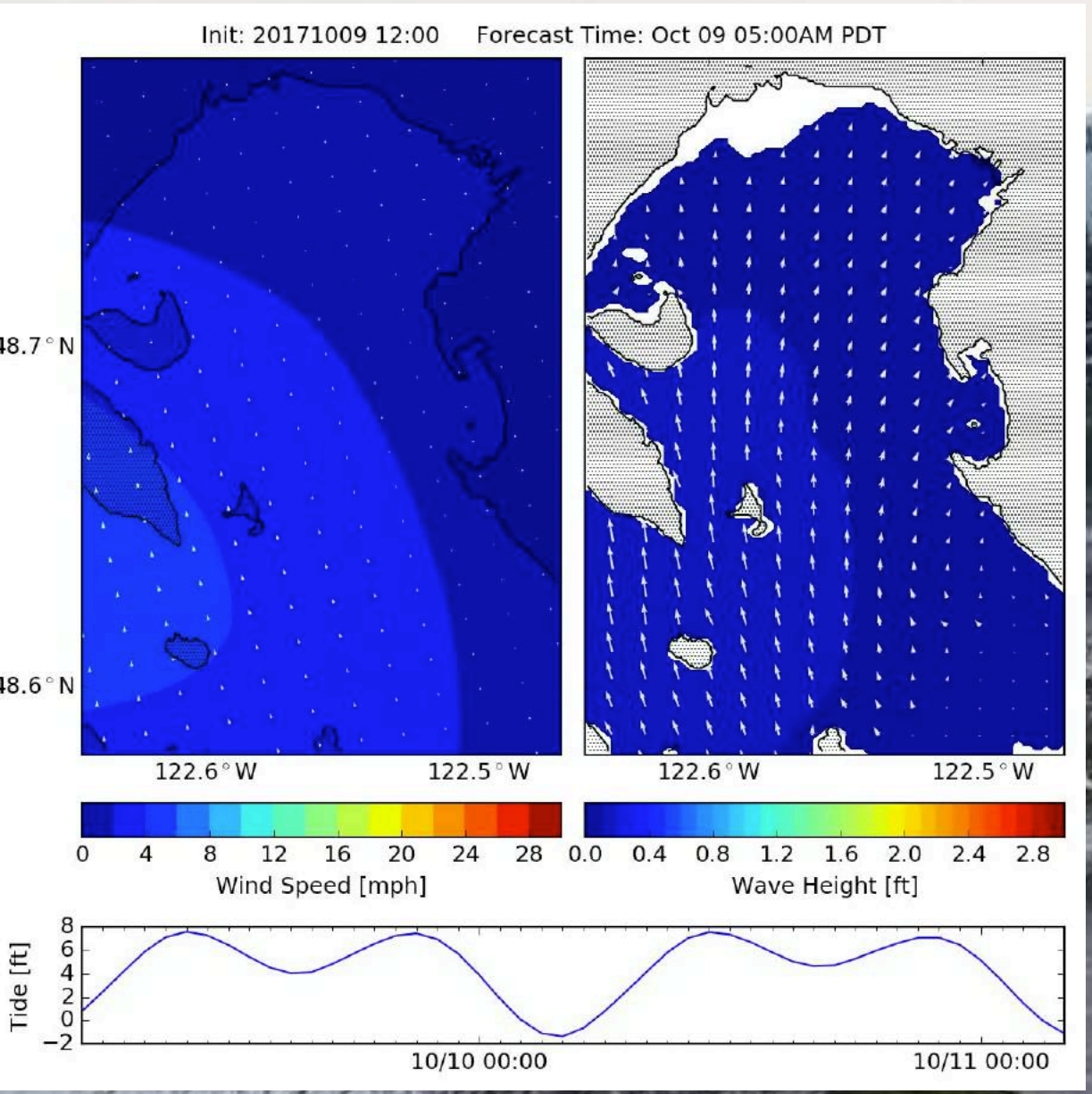
Wind direction yielding maximum incident energy in Skagit Bay



(wind 15m/s, water level 4.0 m)



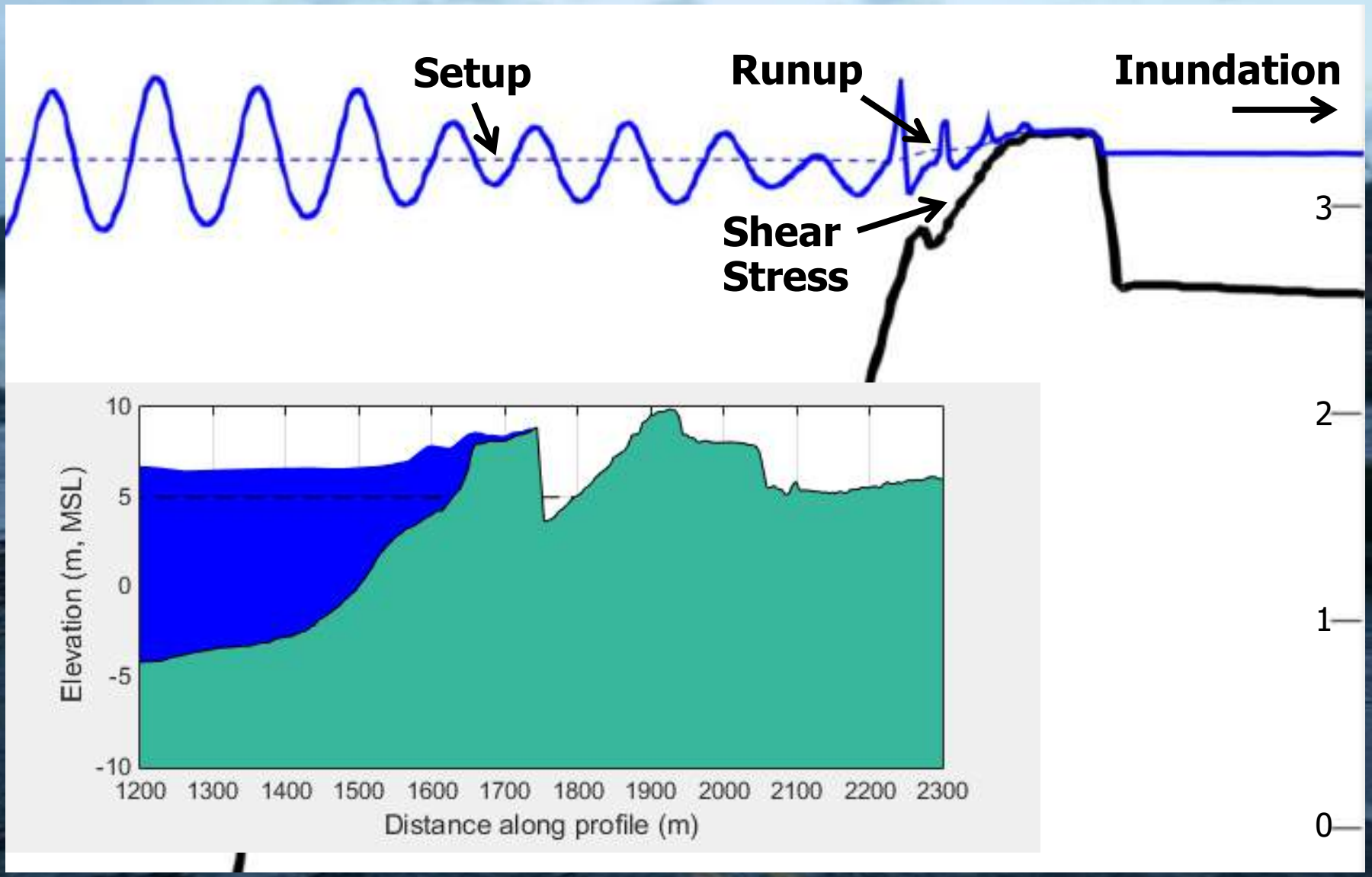
Wave Model: Bellingham Bay



Operational Model: 48-hour forecasts every 6 hours

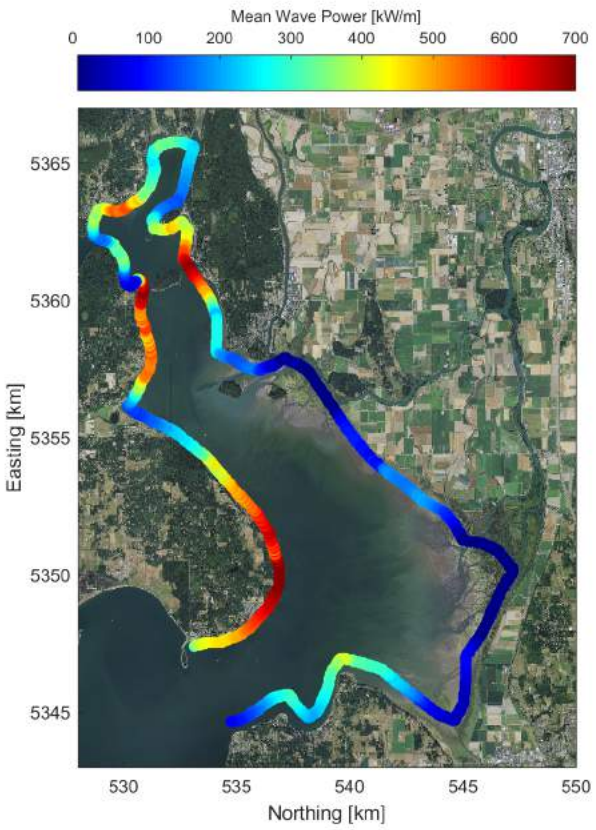
Future Projections: 2050, 2100 sea level rise

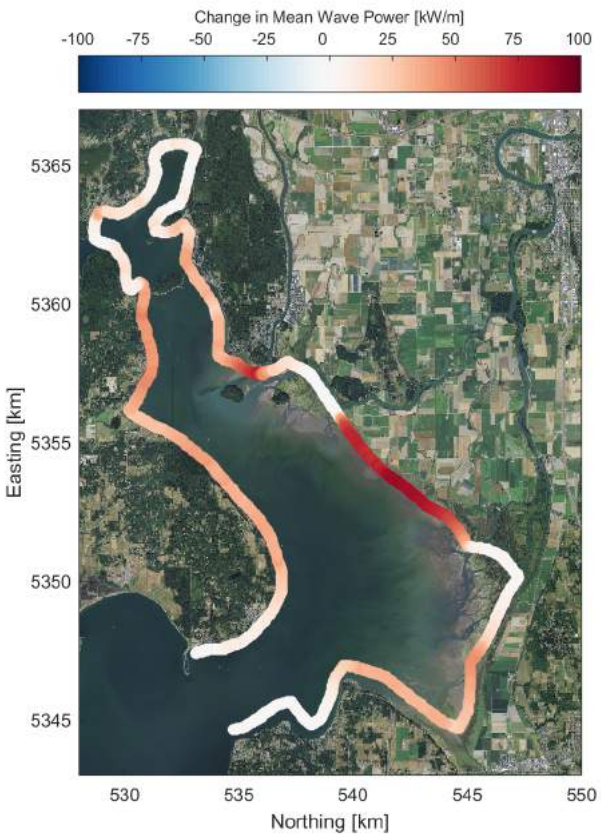
Wave Model Outputs, Metrics

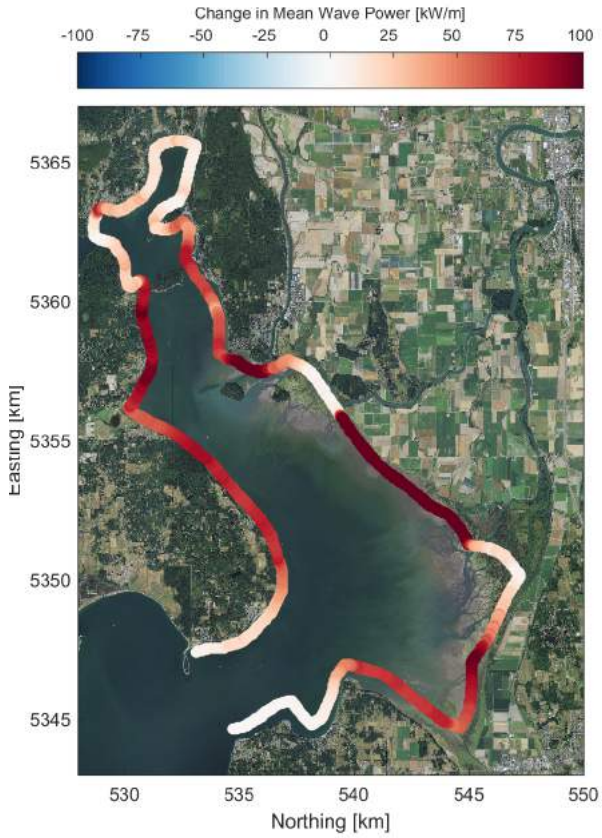


Expected Outputs

Change in incident wave power with SLR in Skagit Bay







Summary

Coastal storms, waves have significantly different impact to shorelines, infrastructure, habitats than sea-level rise alone.

The intensity/frequency of wave impacts increasing and enhanced by sea-level rise.

Decadal variability in wave forcing within Puget Sound likely drives notable differences in incident wave energy.

Storms and waves are dynamic, vary through time (ENSO, PDO, wind direction) contributing to additional/episodic risk that our model intends to help evaluate.

Questions?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Questions?
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Results: Weather Products

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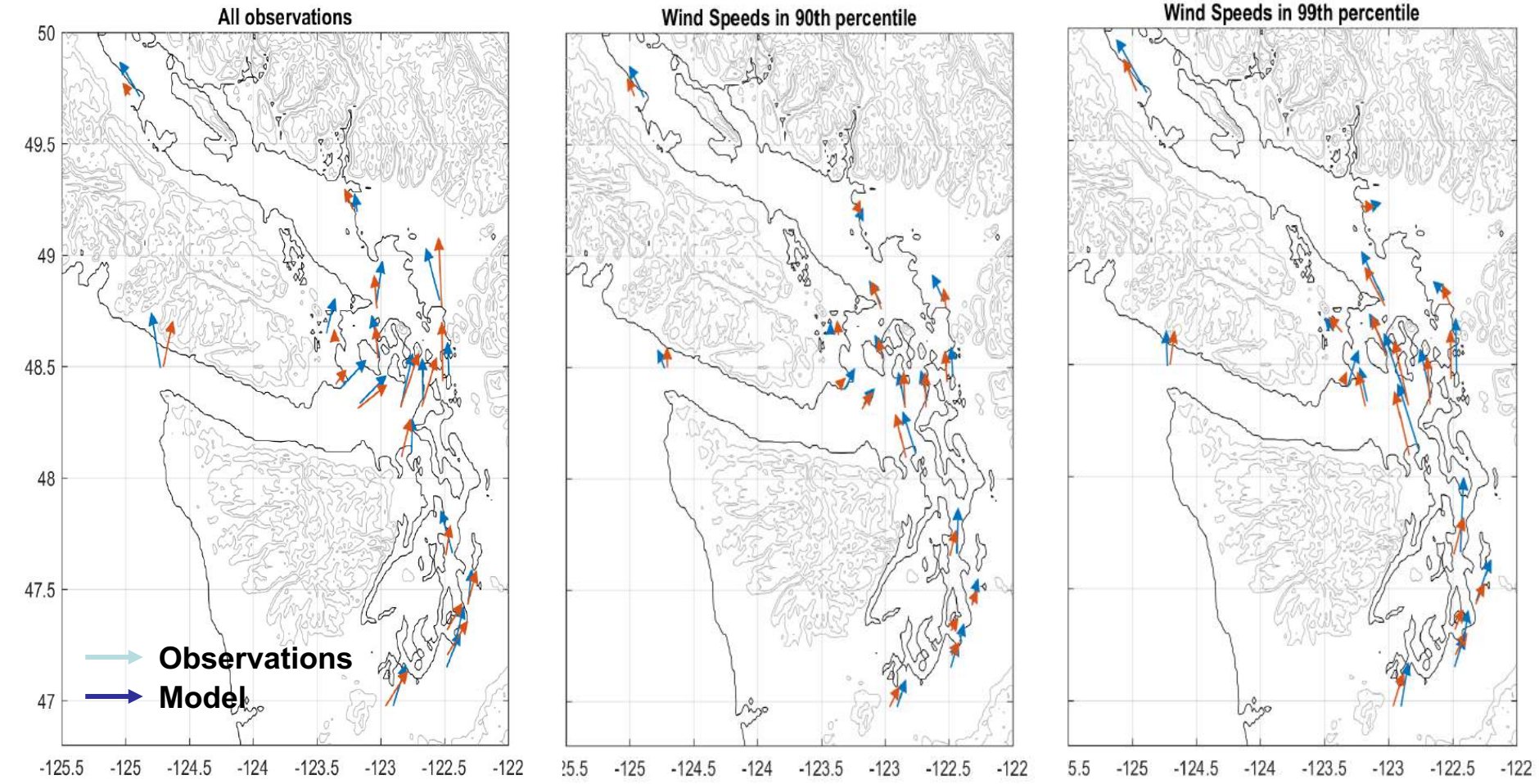
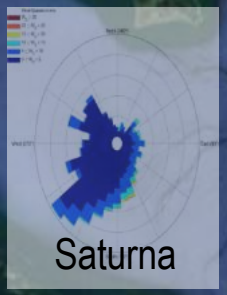
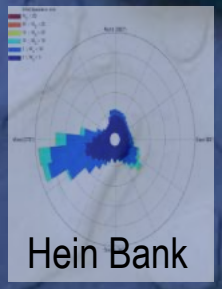
UW NNRP (12.5km) surface wind prediction comparison to observations



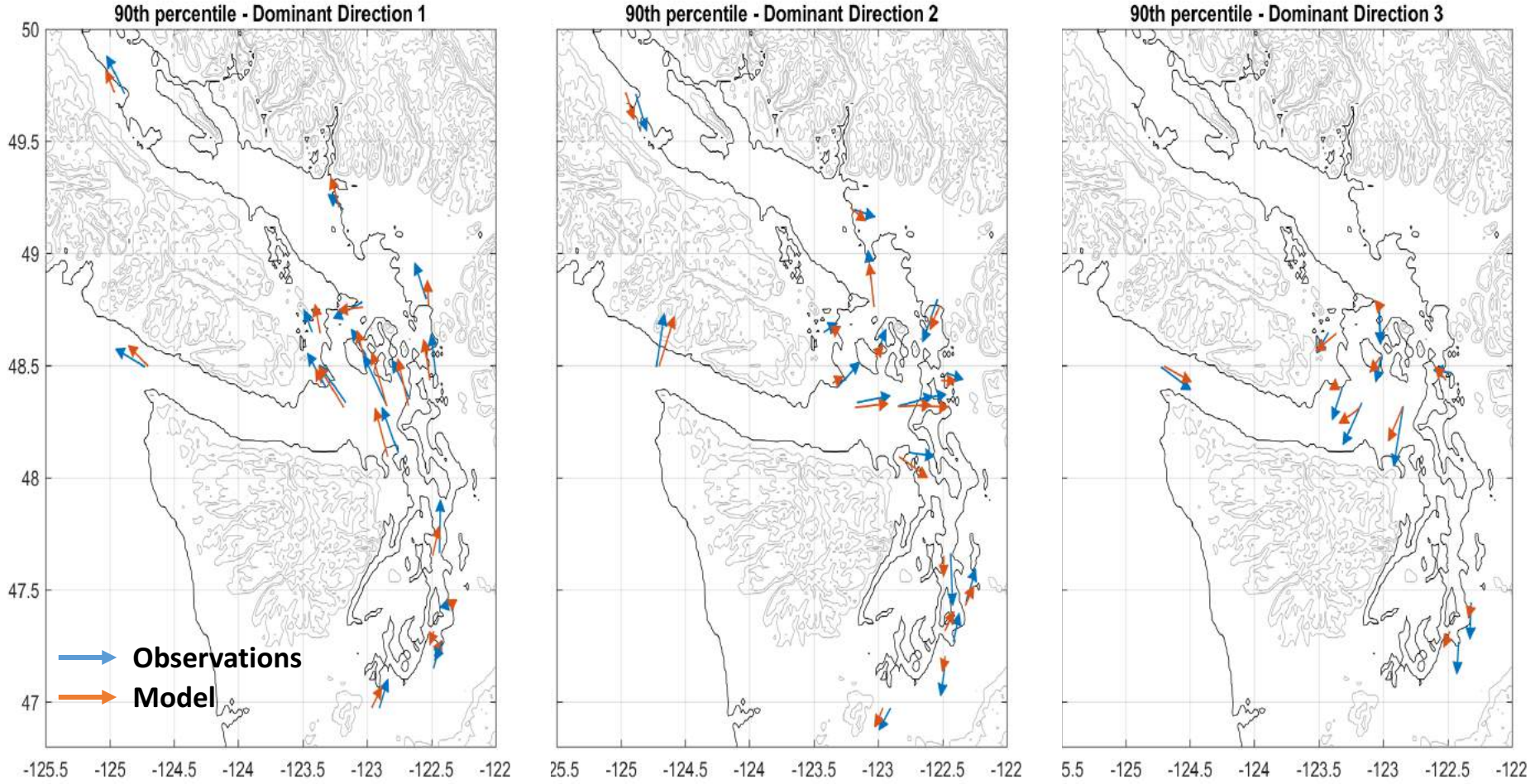
Results: Climatology





Results: Weather Products

Filtered by dominant directions



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CoSMoS Coastal Storm Modeling System USGS

CoSMoS: A Dynamic Coastal Flooding Model

- **Predicts coastal hazards for the full range of sea level rise (0-2, 3 and 5 m) and storm possibilities (up to 100-yr storm)**

- **Developing coastal vulnerability tools with guidance from federal (e.g., EPA, NOAA, USACE), state, and local governments to meet their planning and adaptation needs**

- **Predictions of coastal flooding will inform management endpoints: property damage, habitat change, public safety, community vulnerability, ecosystem recovery planning**

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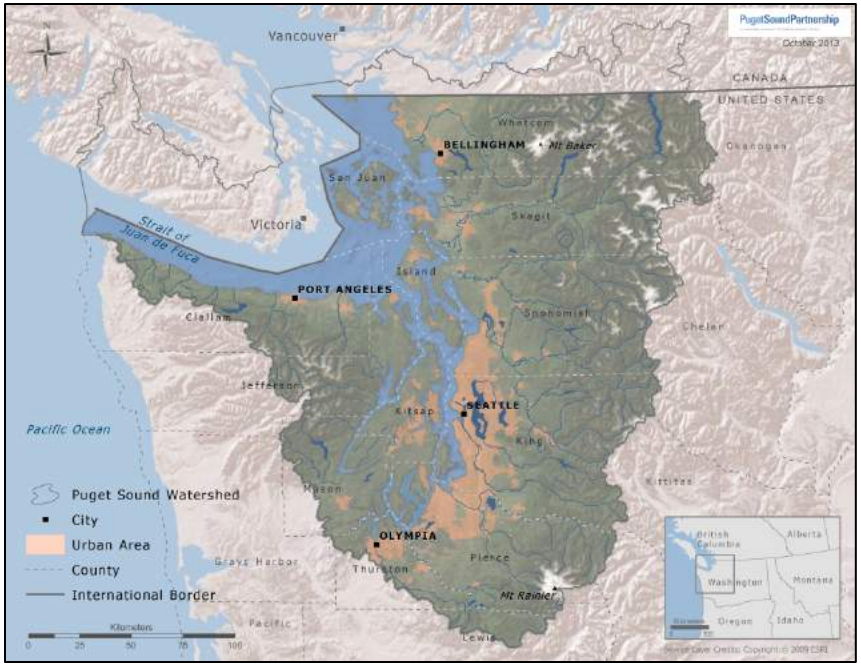
CoSMoS Development and Applications

- 10 years of research and development in partnership with leading oceanographic research institutions
- Applications across California, including complex estuarine coastlines, including San Francisco Bay
- Operational model development for integrated ocean-watershed flood modeling
- Extensive outreach and interaction with end-users throughout the public and private sectors
- Increasing emphasis on directly supporting federal and state-supported climate change guidance and vulnerability assessments



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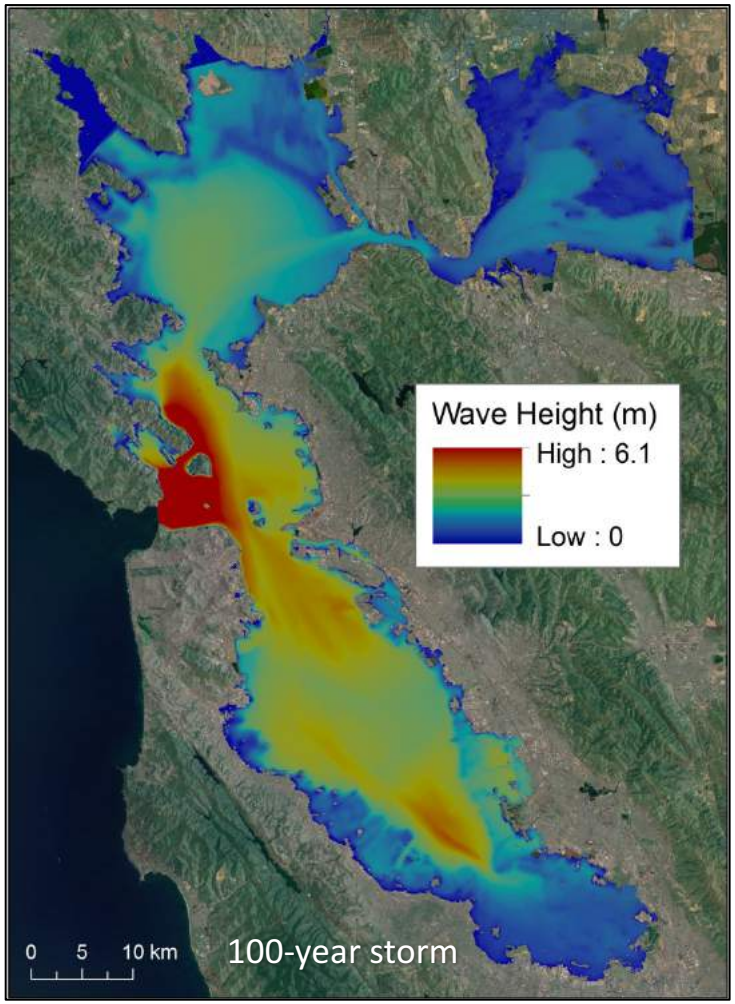
CoSMoS in San Francisco Bay

- Downscaled wind and wave climate to handle complex orographic effects
- Integrated ocean and watershed flooding
- High spatial and temporal resolution of vertical land motion (VLM)
- Quantification of uncertainty, including tidal marsh accretion and VLM



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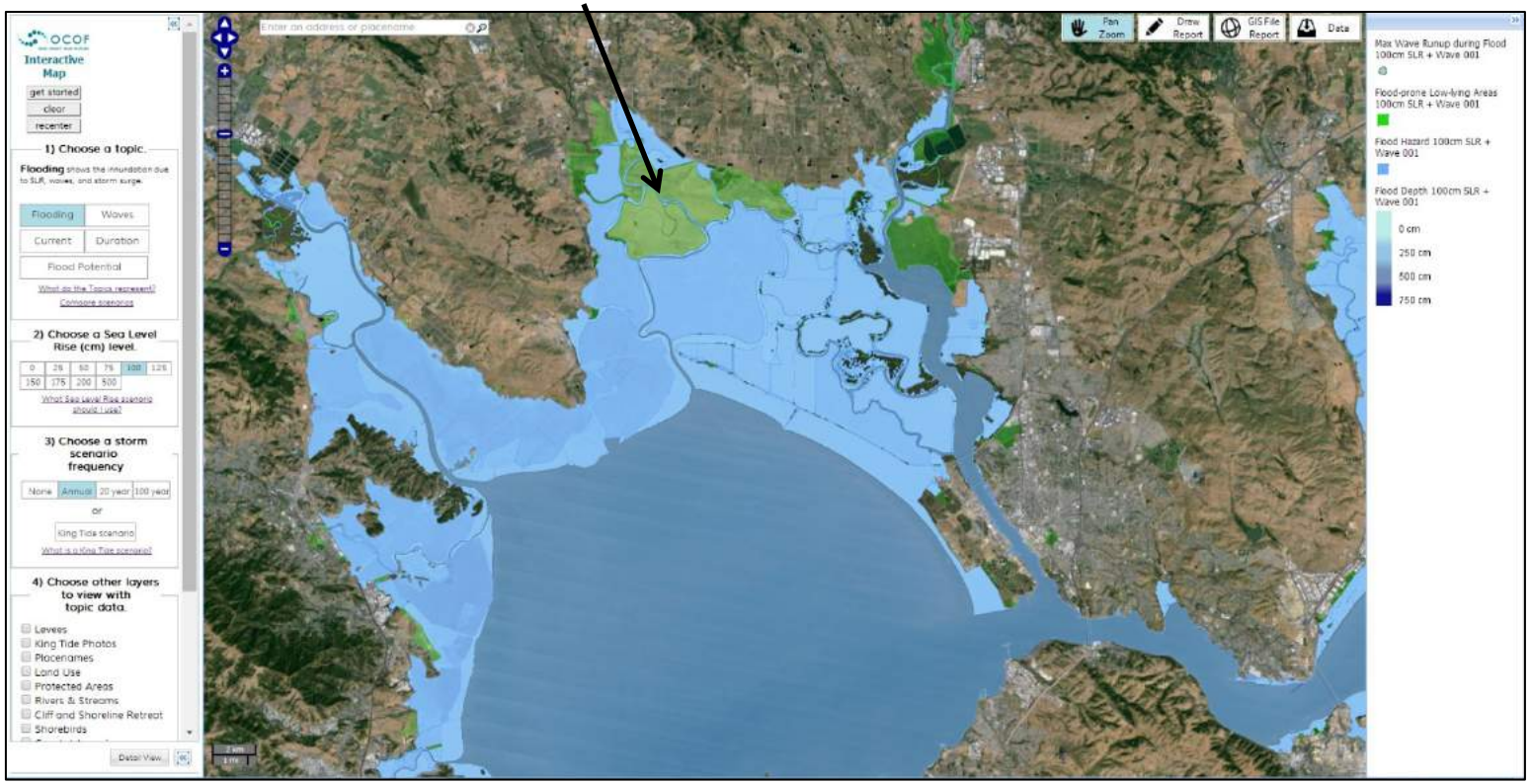
Web Tool - Flooding

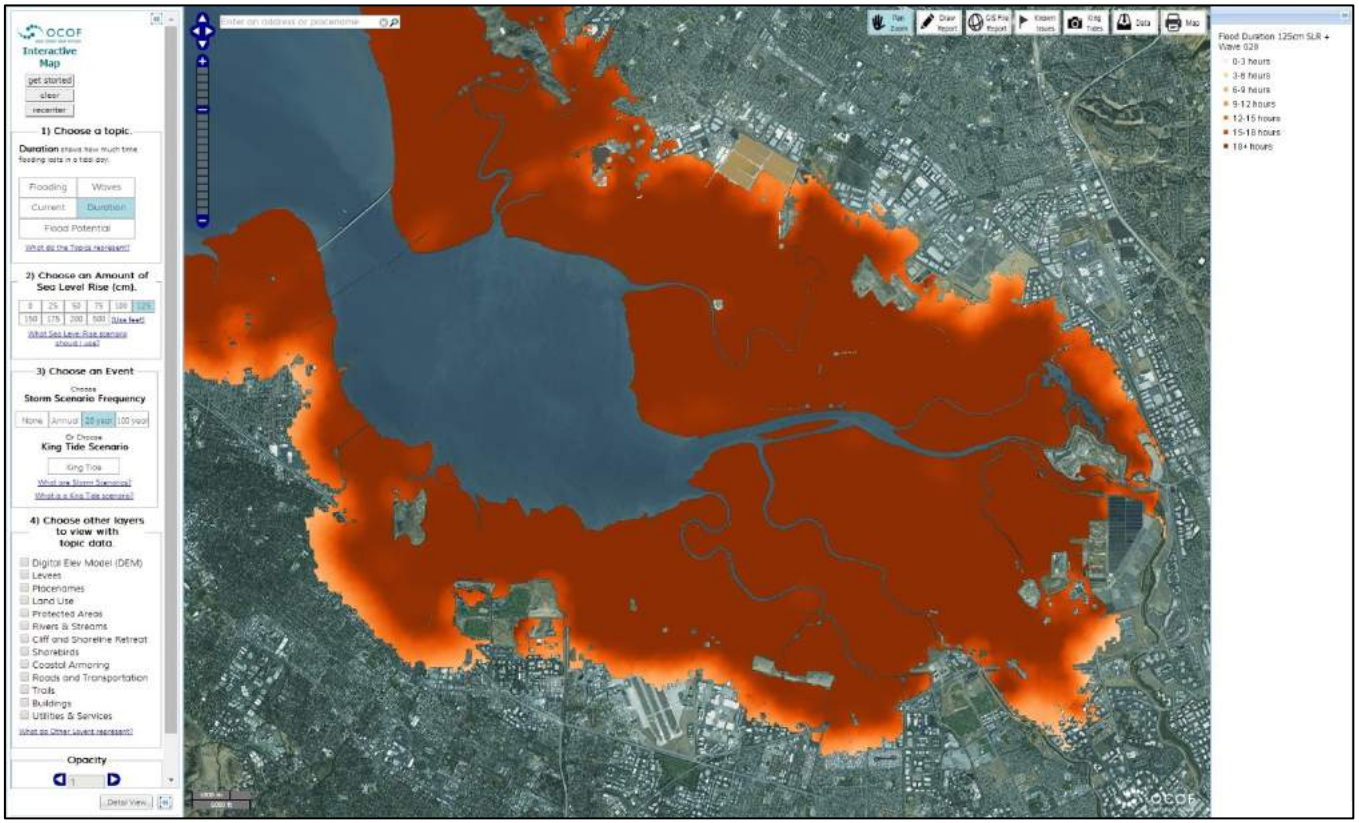
- Maximum extent of flooding during storm
- Hydrological connectivity
- Vulnerable areas designated



Our Coast- Our Future tool: *www.ourcoastourfuture.org*

Flood Duration

- # hours flooded during storm simulation



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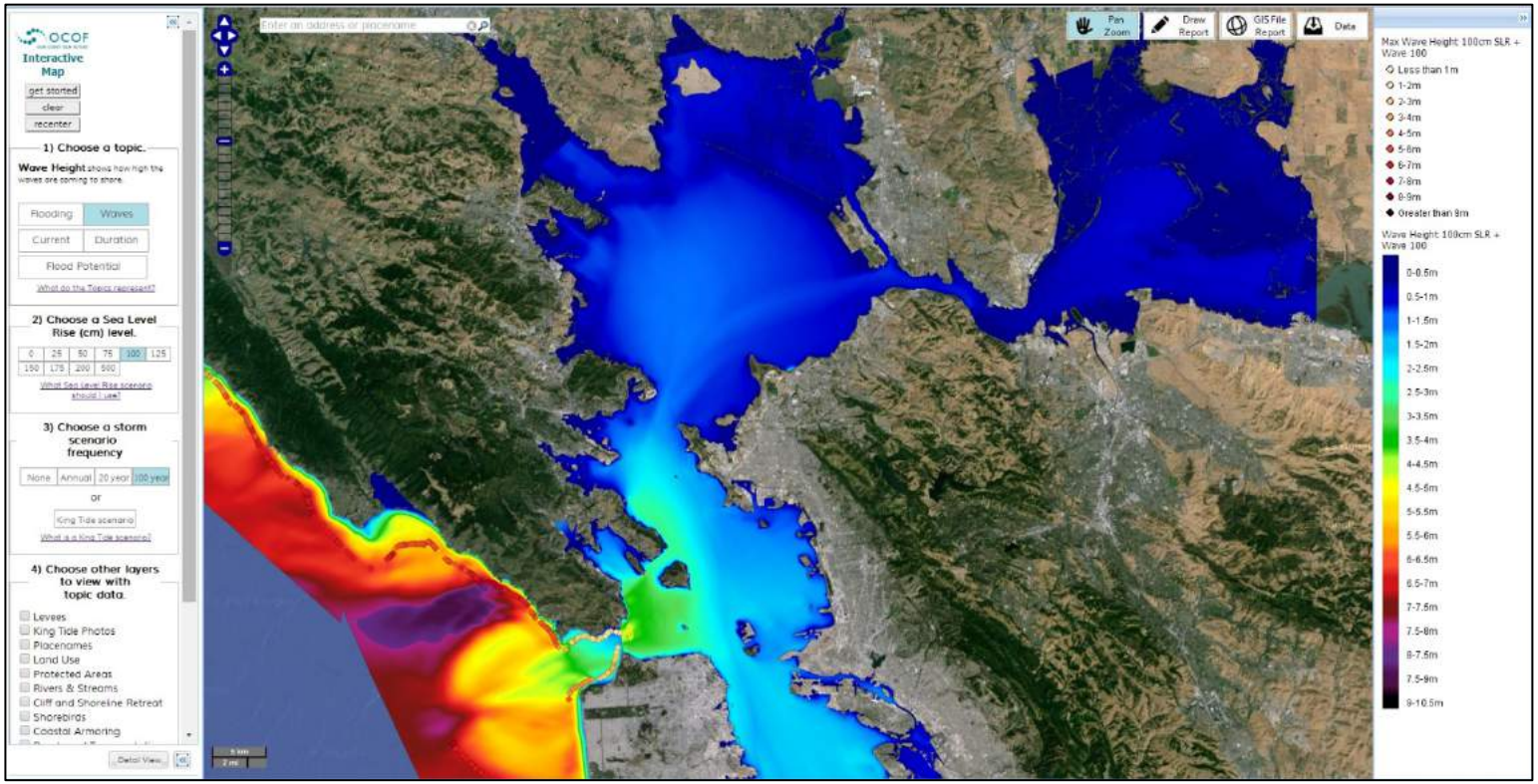
Waves

- Maximum wave height for each grid cell during the storm simulation



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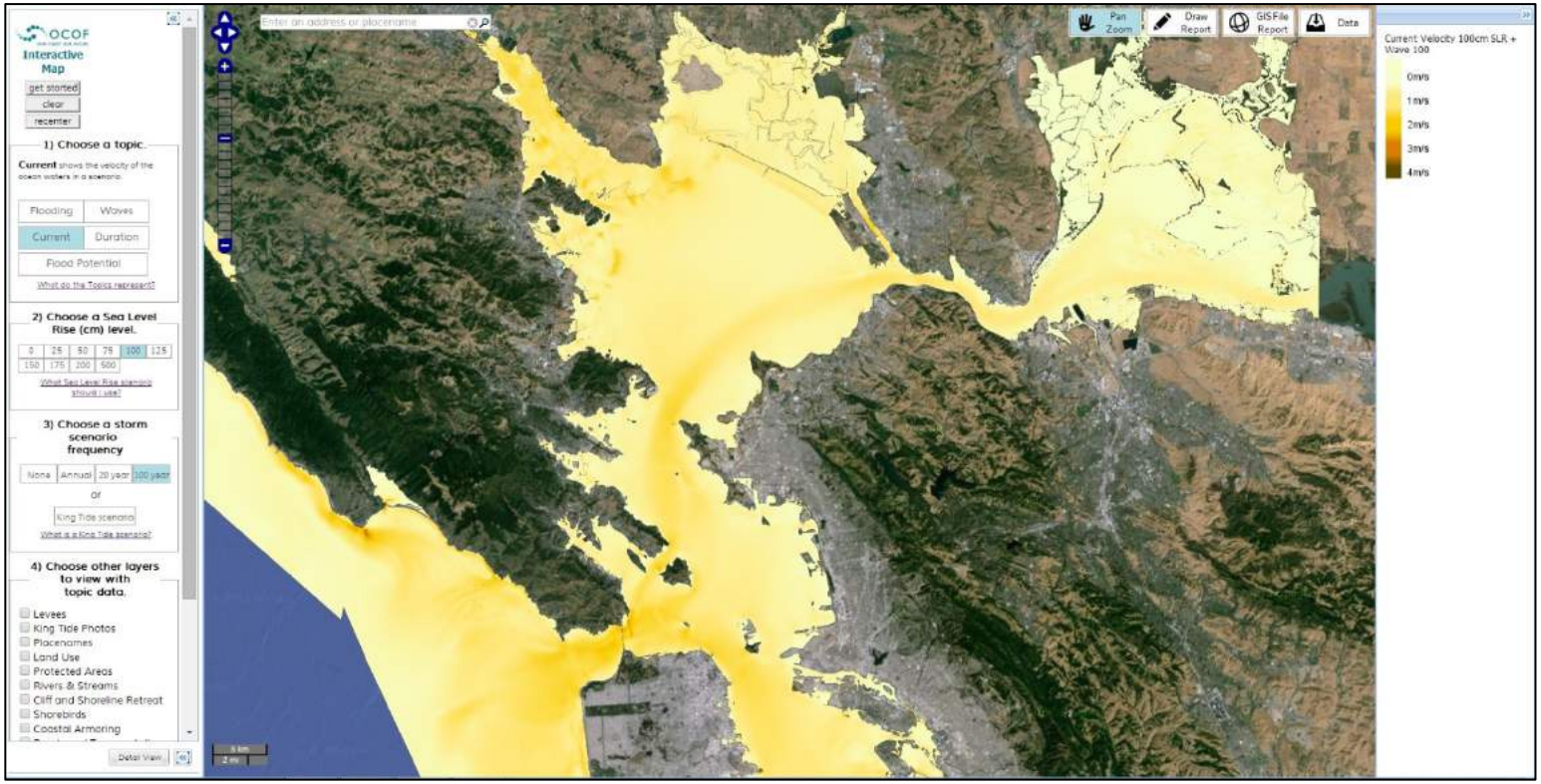
Tidal Currents

- Maximum tidal current for each grid cell during the storm simulation



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Socioeconomic Impacts

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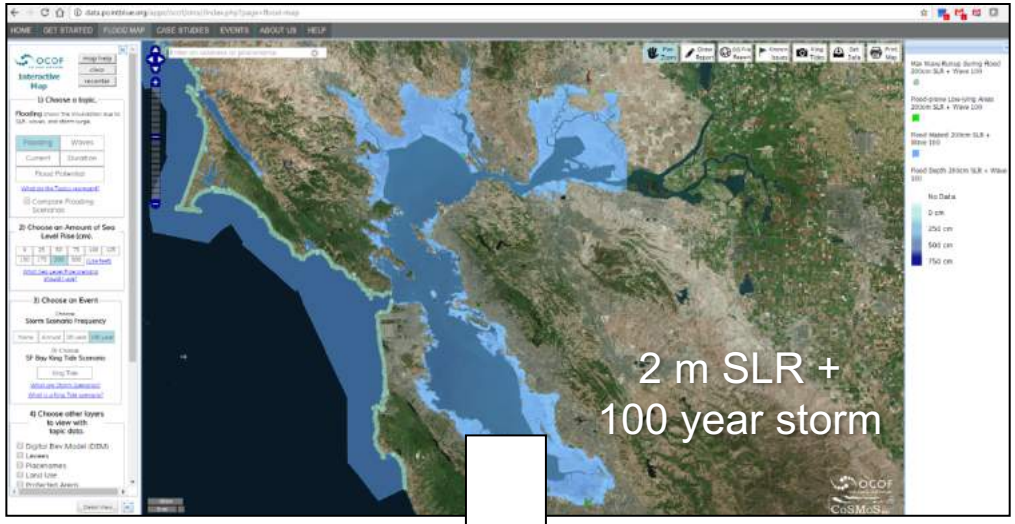

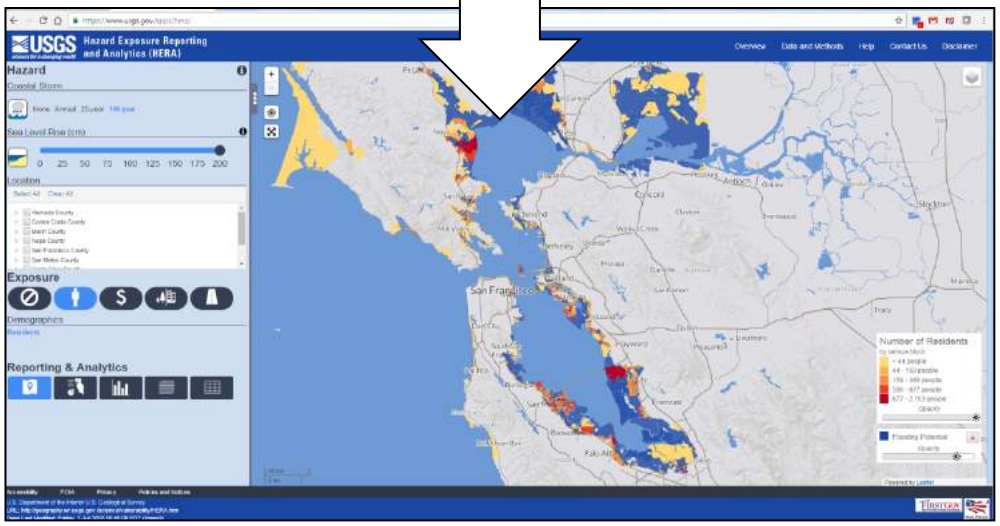

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Hazard Exposure Reporting and Analytics (HERA)

- **600,000+ residents**
- **$150 billion in property**
- **4,700 km of roads**
- **350 critical facilities**

www.usgs.gov/apps/hera

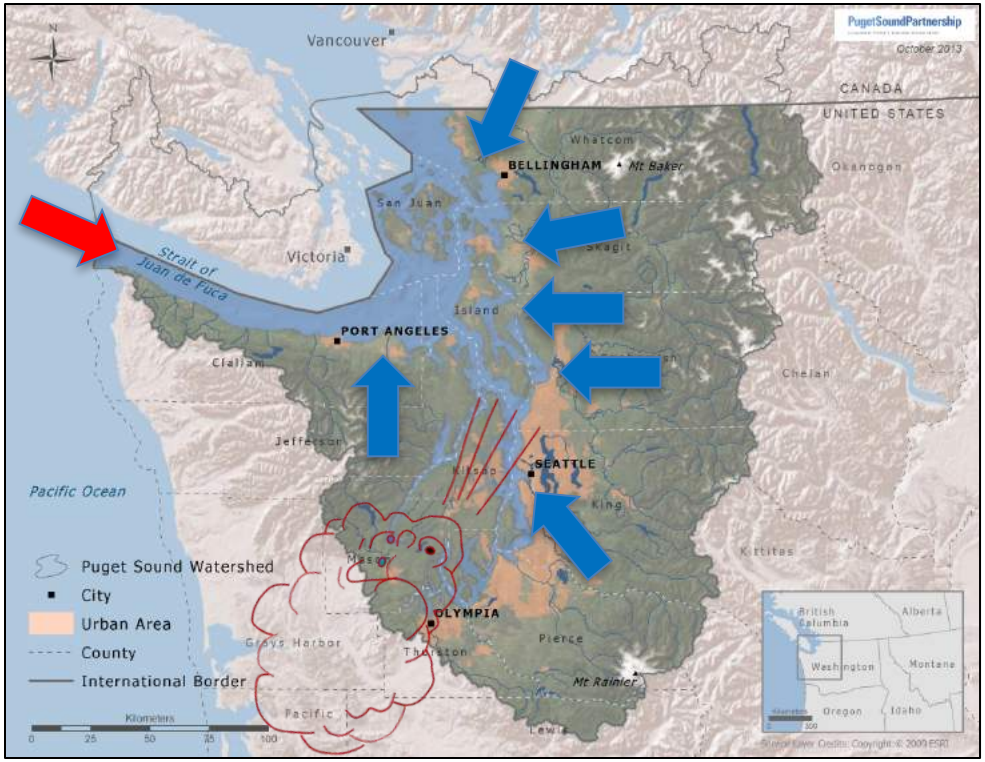
PS-CoSMoS Objectives

- **Apply a modeling system to robustly assess the impacts of climate change on Puget Sound shorelines at a resolution suitable for coastal decision makers**
- **Include all the relevant factors that affect flooding: atmospheric conditions, tides, storm surge, waves, river flow, vertical land motion, coastal change**
- **Include climate change projections of sea-level rise, oceanographic forcing conditions (waves), atmospheric conditions (precipitation), river flooding**
- **Produce a web-based tool to make the data easily accessible and useable**

CoSMoS Coastal Storm Modeling System USGS

CoSMoS in Puget Sound- Key Considerations

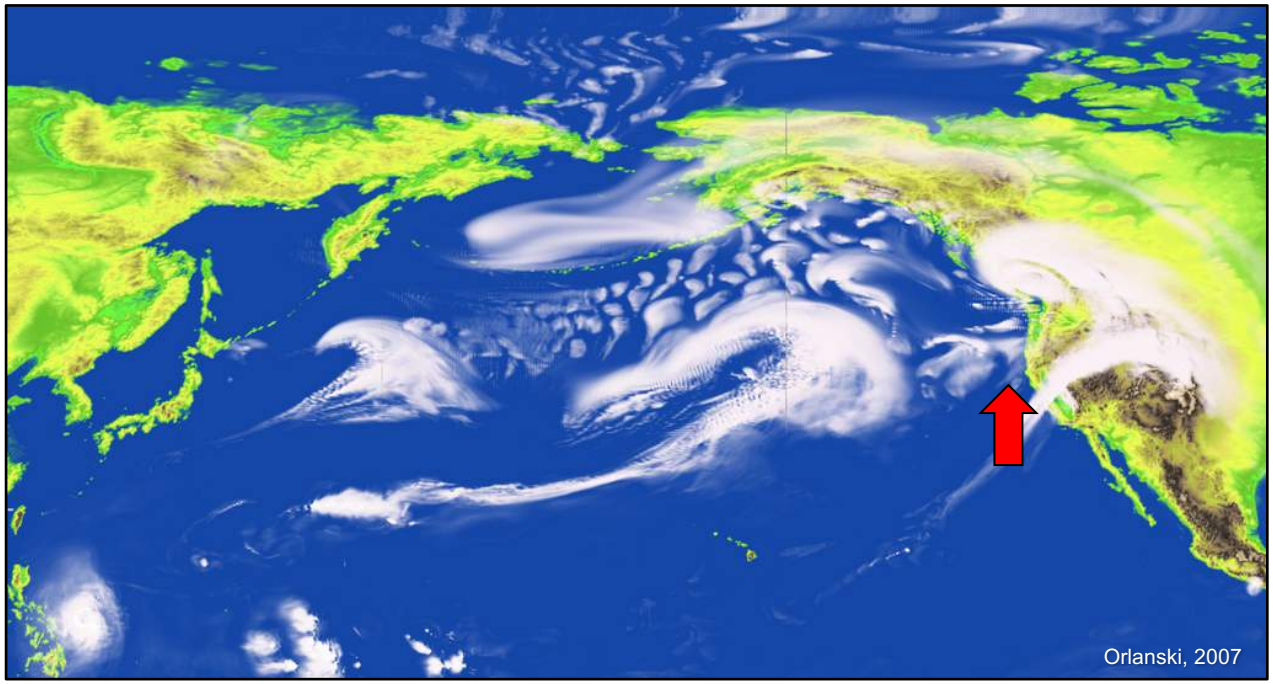
- Swell penetration
- Integrated ocean and watershed flooding
- Locally-generated surge and seas
- Detailed hydrodynamics and coastal geomorphology
- Vertical land motion

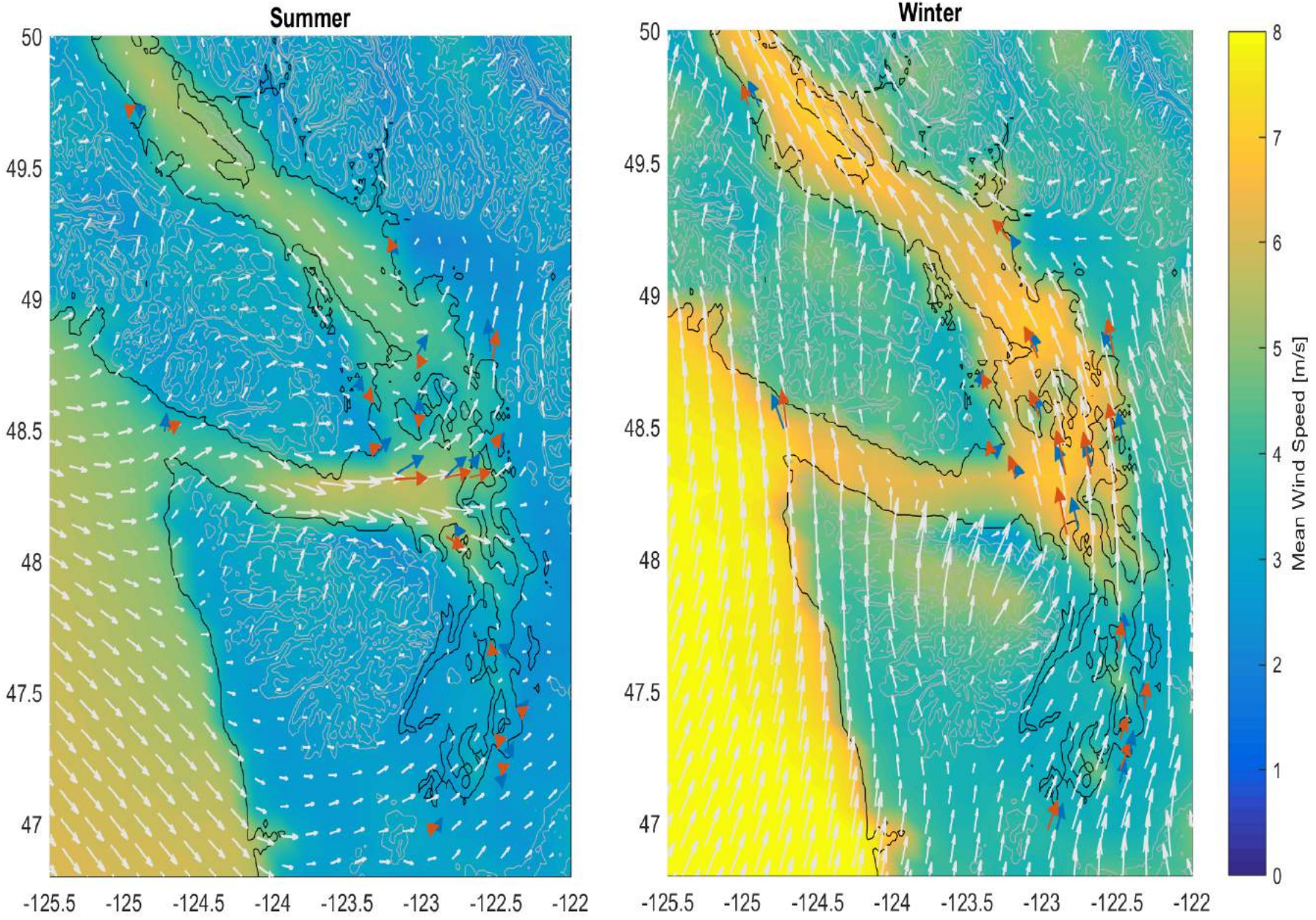


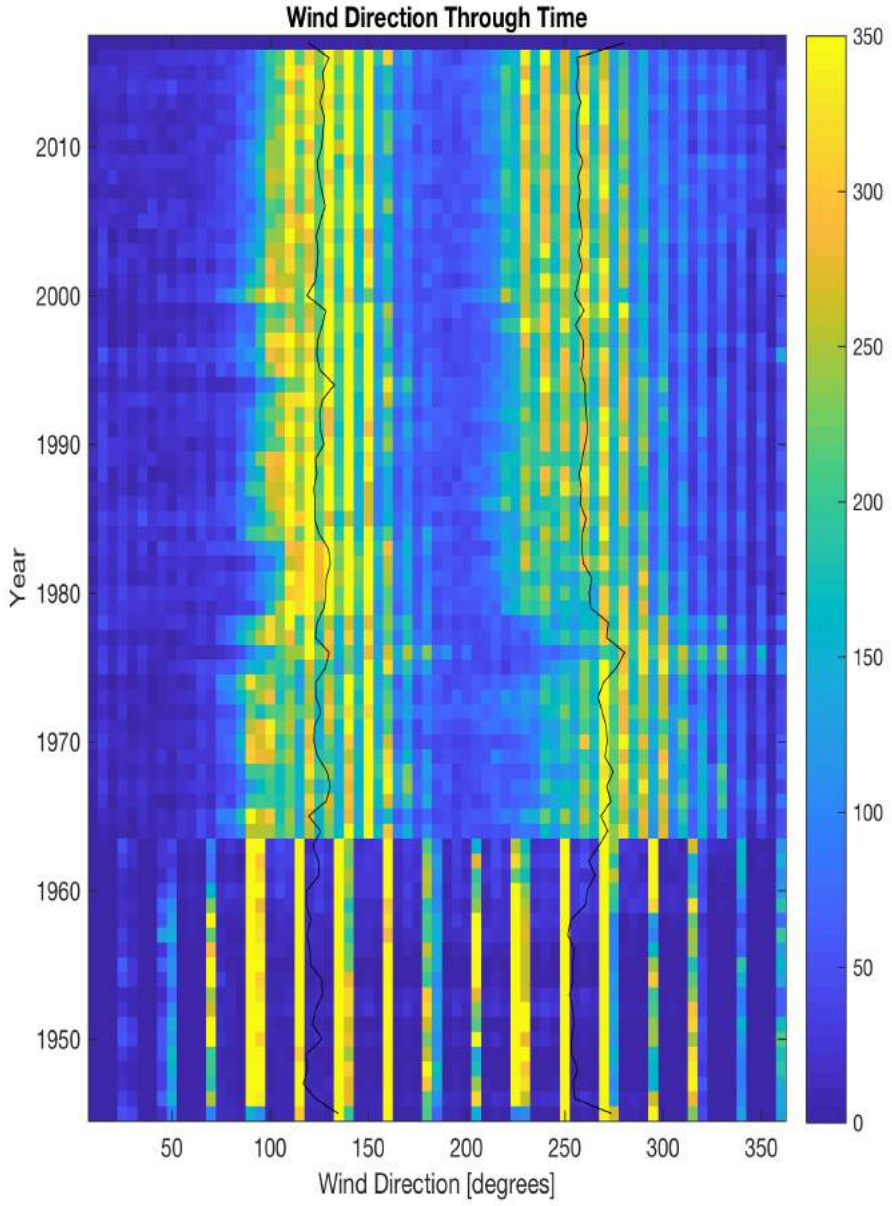
CoSMoS Coastal Storm Modeling System USGS

El Niño Trends and Projections

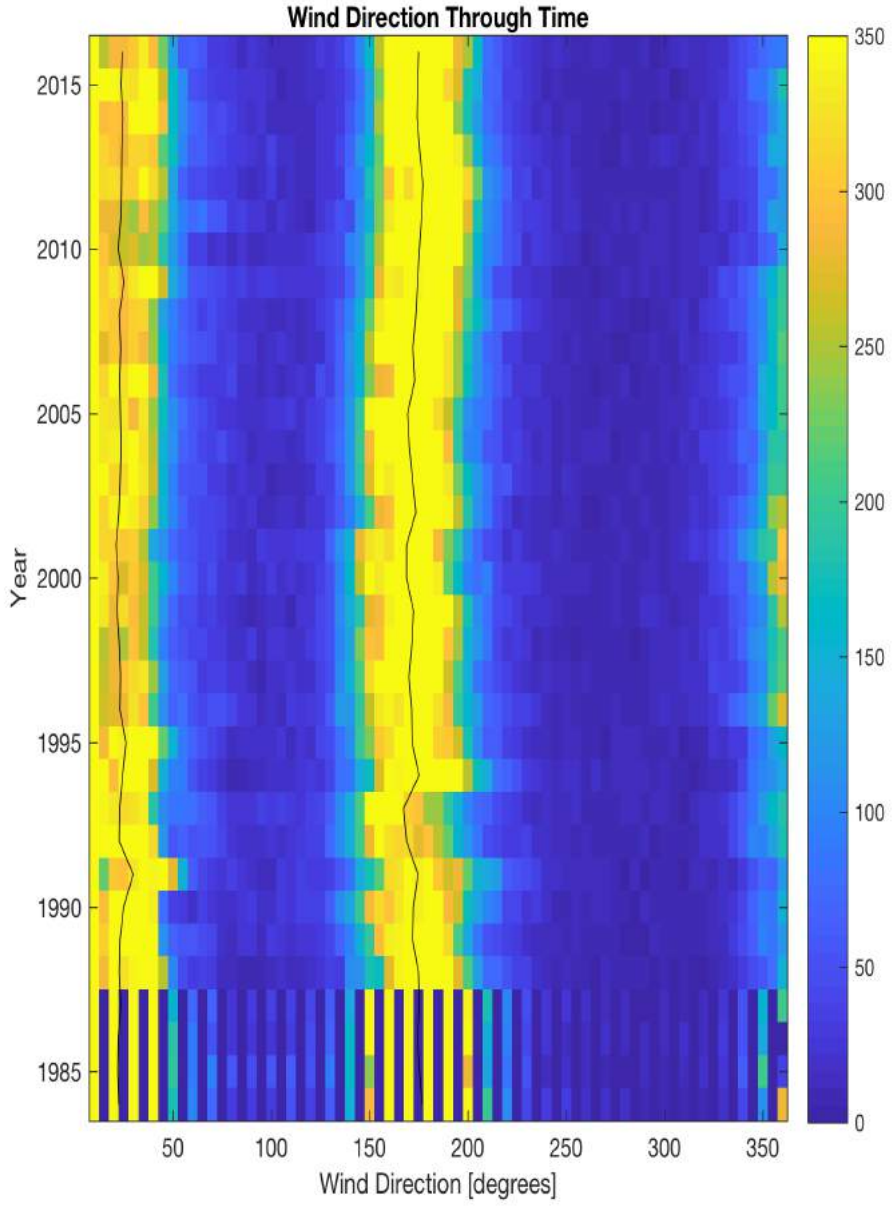
- **The 2015-16 El Niño was one of the most powerful events of the last 150 years**
- **More frequent extreme El Niño events for the 21st century**
- **Northerly shift in primary storm tracks**



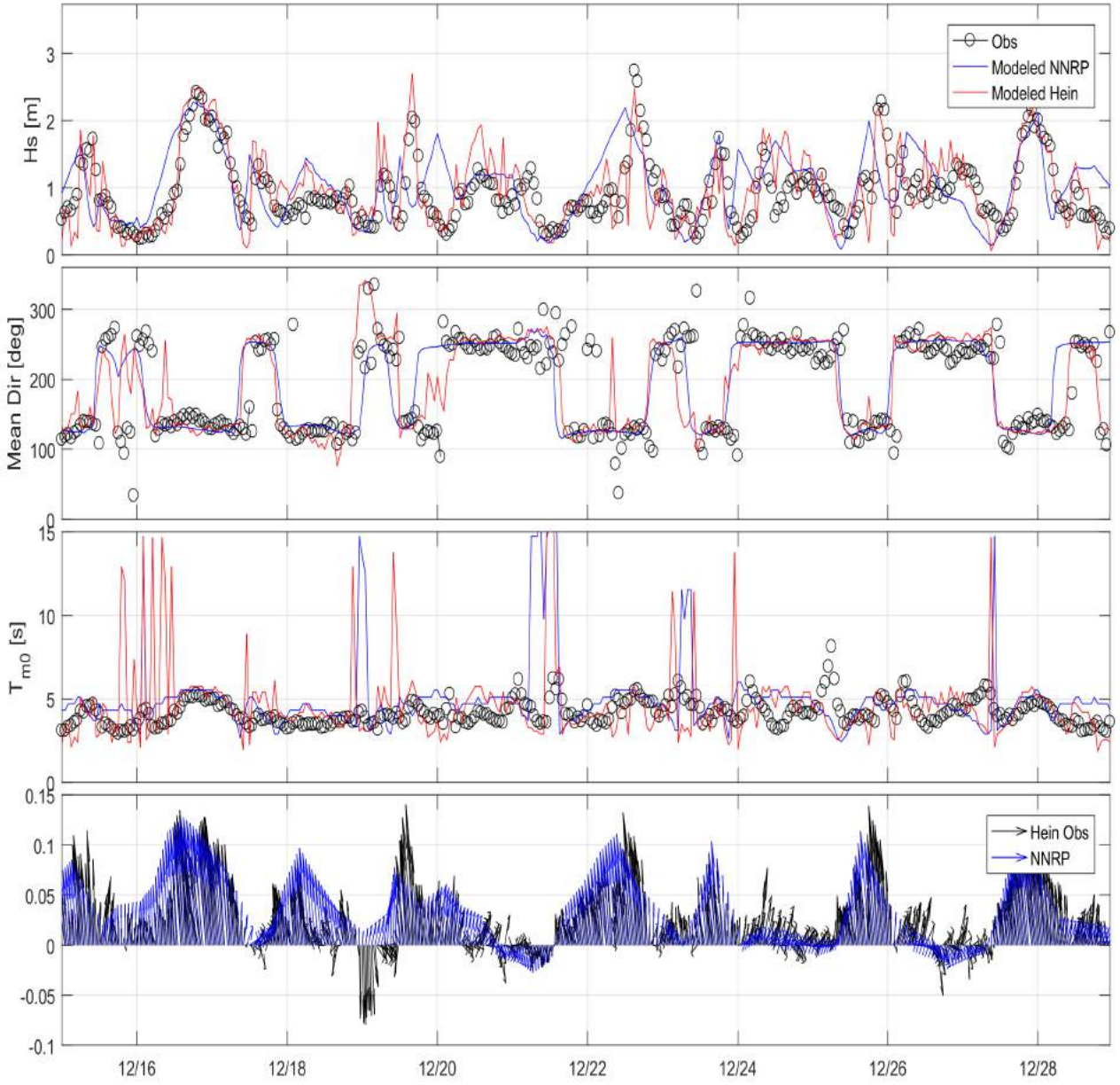

Summer
Winter
50
49.5
49
48.5
48
47.5
47
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
-122
Mean Wind Speed [m/s]
0
1
2
3
4
5
6
7
8



Whidbey NAS



Seattle – WPOW1


Obs
Modeled NNRP
Modeled Hein
Hs [m]
Mean Dir [deg]
T_{m0} [s]
Hein Obs
NNRP
12/16
12/18
12/20
12/22
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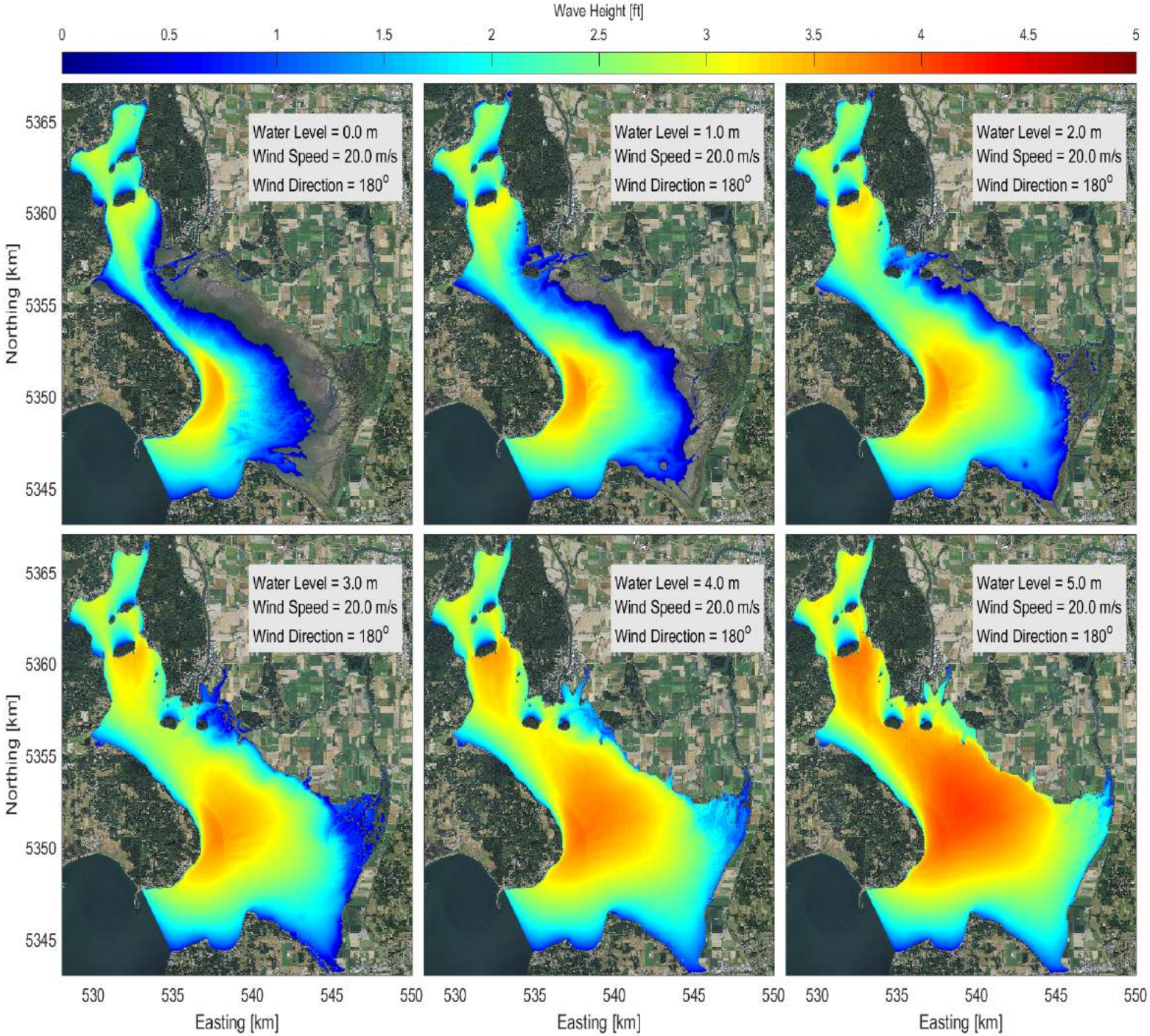
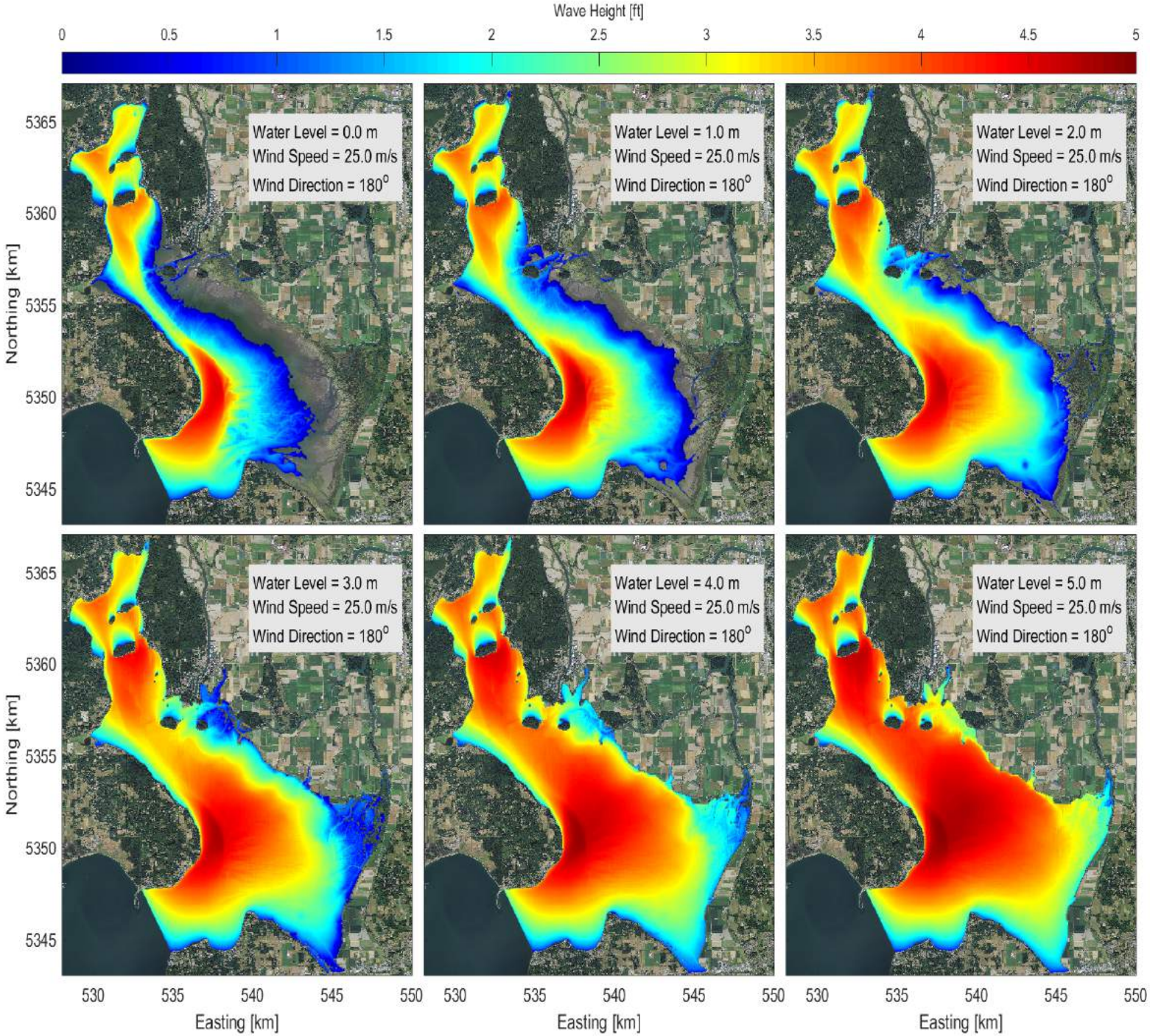
12/26
12/28


Wave Height [ft]
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Water Level = 0.0 m
Wind Speed = 20.0 m/s
Wind Direction = 180°
Water Level = 1.0 m
Wind Speed = 20.0 m/s
Wind Direction = 180°
Water Level = 2.0 m
Wind Speed = 20.0 m/s
Wind Direction = 180°
Water Level = 3.0 m
Wind Speed = 20.0 m/s
Wind Direction = 180°
Water Level = 4.0 m
Wind Speed = 20.0 m/s
Wind Direction = 180°
Water Level = 5.0 m
Wind Speed = 20.0 m/s
Wind Direction = 180°
Northing [km]
5365
5360
5355
5350
5345
Easting [km]
530
535
540
545
550


Wave Height [ft]
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Water Level = 0.0 m
Wind Speed = 25.0 m/s
Wind Direction = 180°
Water Level = 1.0 m
Wind Speed = 25.0 m/s
Wind Direction = 180°
Water Level = 2.0 m
Wind Speed = 25.0 m/s
Wind Direction = 180°
Water Level = 3.0 m
Wind Speed = 25.0 m/s
Wind Direction = 180°
Water Level = 4.0 m
Wind Speed = 25.0 m/s
Wind Direction = 180°
Water Level = 5.0 m
Wind Speed = 25.0 m/s
Wind Direction = 180°
Northing [km]
5365
5360
5355
5350
5345
Easting [km]
530
535
540
545
550

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CoSMoS Unique Features

- 40 scenarios of SLR + storms
- Utilizes the latest Global Climate Models (CMIP5)
- Future projections based on downscaling of winds and waves
- Detailed hydrodynamic modeling
- Integrated fluvial and ocean-based flooding (incl. operational)
- Interactive web tool
- Socioeconomic exposure analysis

CoSMoS Coastal Storm Modeling System USGS

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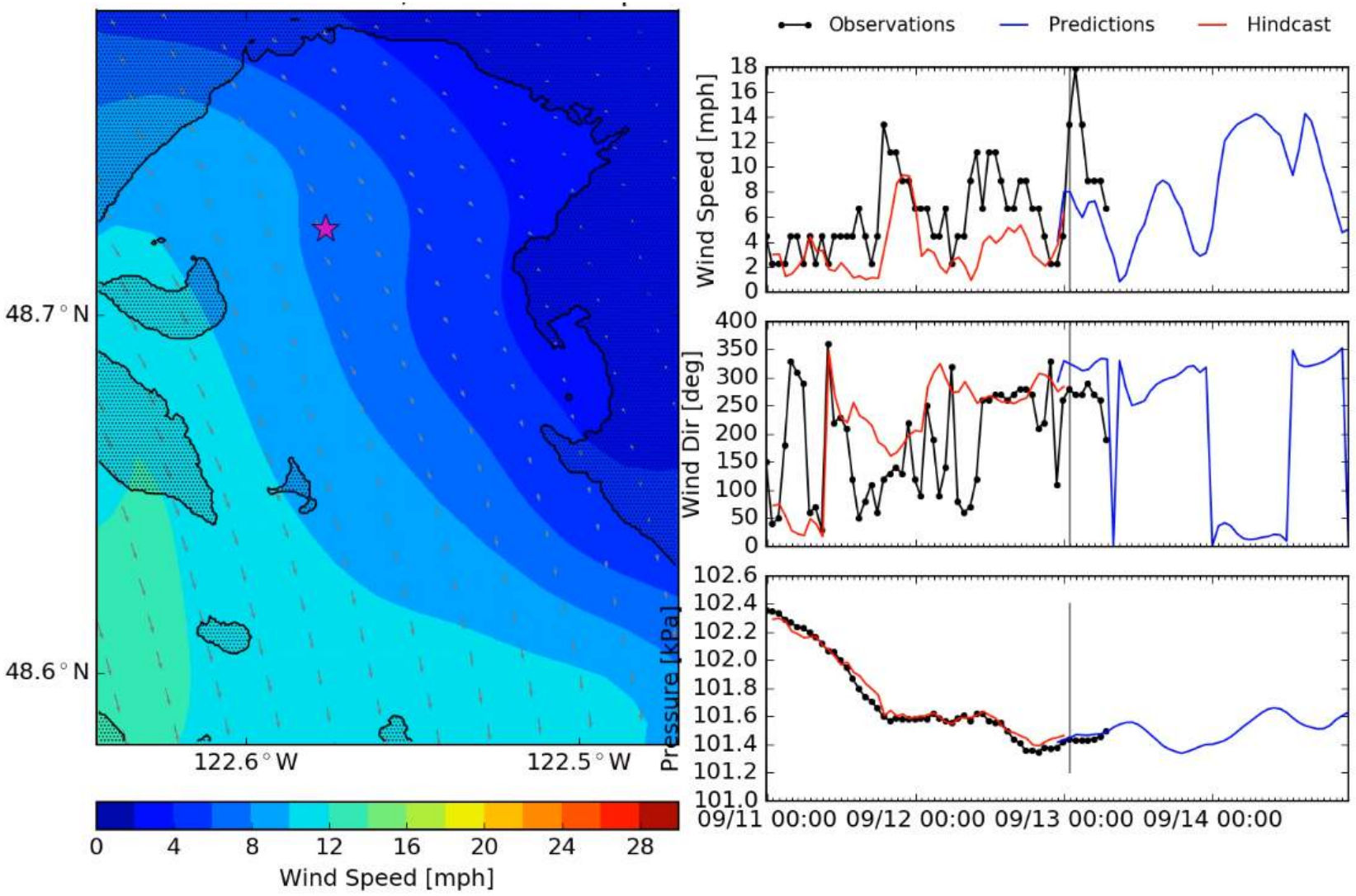
PS-CoSMoS Progress

- Support from EPA and USGS to jump start initial model development (Tier 1)
- Unstructured FLOW model set-up and tested across region with 65 m coastal resolution (runs 1 day in 24 mins, 0.5 million nodes)
- Preliminary evaluation against tide gauges
- Wave testing and extreme value analysis
- DEM construction underway (est. July 2018)

Operational Validation Forcing



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Storm-driven Coastal Flooding in Puget Sound

Patrick Barnard, Guy Gelfenbaum
Eric Grossman, Juliette Finzi Hart and Bill Labiosa

United States Geological Survey
Pacific Coastal and Marine Science Center
Santa Cruz, CA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Deltares
Enabling Delta Life

WESTERN WASHINGTON UNIVERSITY

CoSMoS Coastal Storm Modeling System USGS

December 17, 2012 (*C. Mass)*

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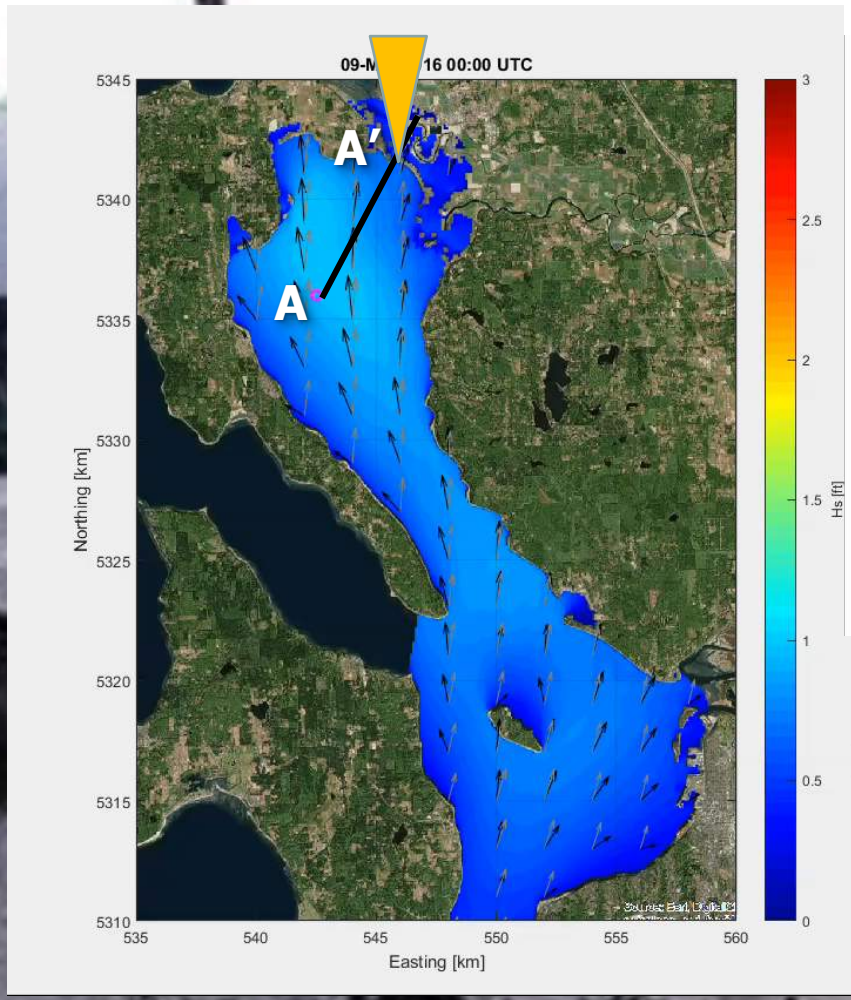
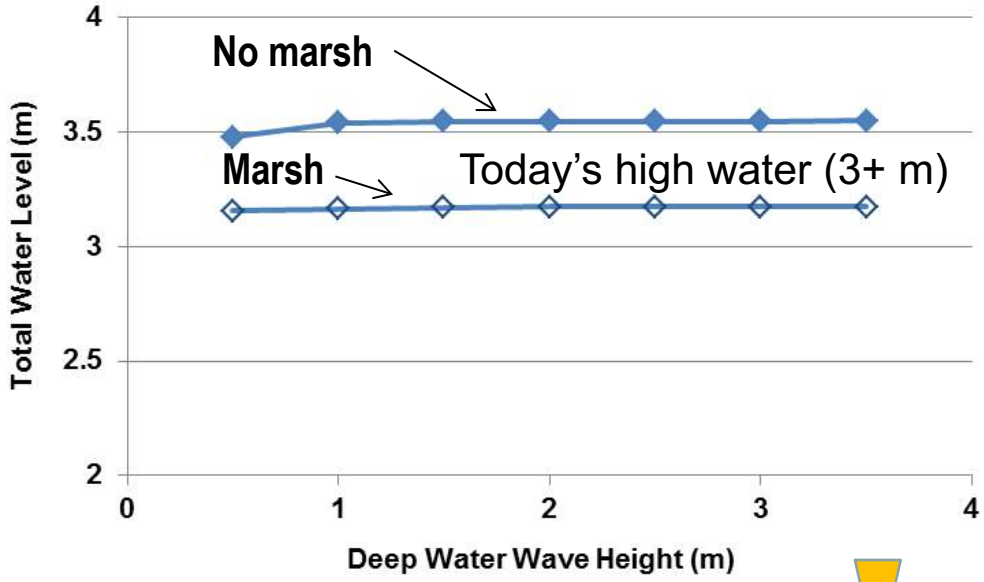
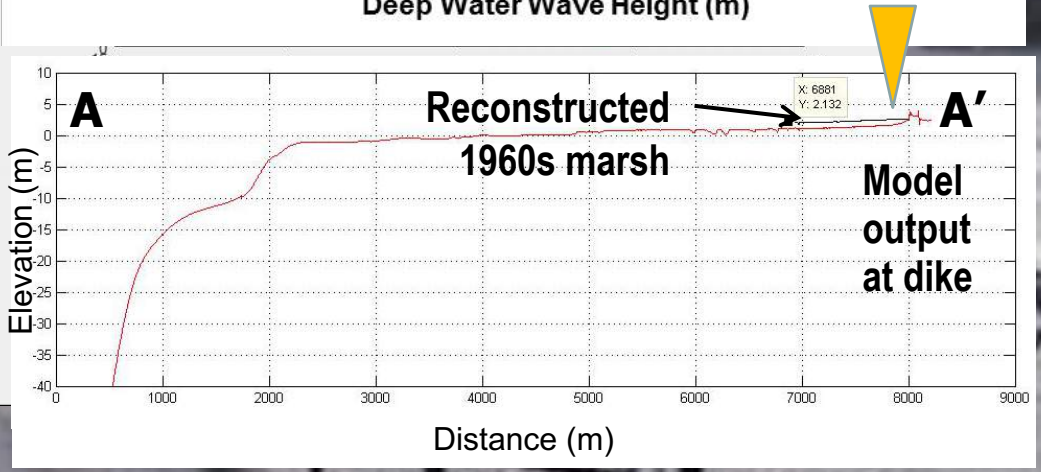
Evaluate Marsh Potential for Prot

WESTERN WASHINGTON UNIVERSITY



Marsh topography reduces wave impacts





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Summ

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Coastal storms and waves:

1. Elevate water levels 1-3 m, surge frequency to increasingly coincide with high stream flows, king tides
2. High spatial variability and interact with other processes
3. Lead to complex changes in sediment transport and habitat

PS-CoSMoS modeling/assessment helps inform:

1. Extent, timing of habitat change, migration, squeeze
2. Restoration function, siting/phasing/prioritization
3. Opportunities for coordinated investments

- habitat restoration reduces natural hazards risk

Iverson Spit/Lagoon, March 2016