Spectral wave climate database for California

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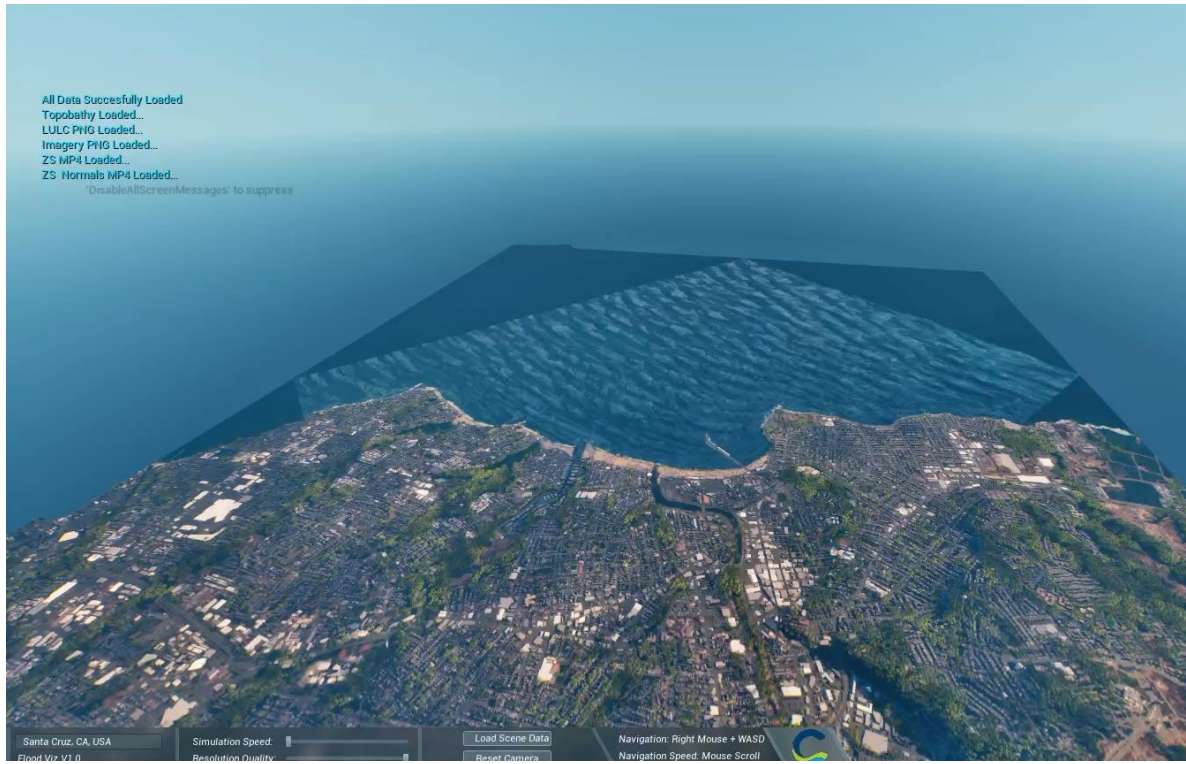
Motivation

- Recent large swells demonstrate increasing impacts and costs from coastal hazards
- Growing interest in advancing adaptation options across coastal districts.
- Goal: characterization of **multivariate**, **local** wave climate across scales.

Los Angeles Times



XB-NH swells of Dec 2024

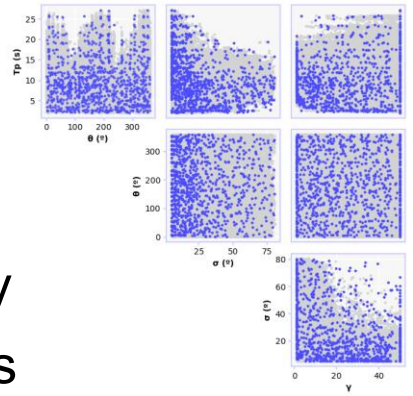
Downscaling methods

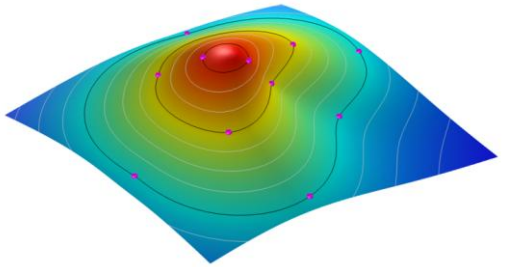
- **Dynamic downscaling**: e.g. CoSMoS (Barnard et al 2019), selected storms
- **Hybrid downscaling:**
  - Downscaling Ocean Waves - Camus et al (2011) → MDA + RBF reconstruction
  - Downscaling of Extreme events - Gouldby et al (2014) → JPM
  - Hybrid downscaling of multimodal wave spectra (HyWaves) - Ricondo et al (2023) → Spectrum partitions
  - Additive hybrid method to downscale directional wave spectra (BinWaves) - Cagigal et al, (2024) → Complete spectra, constant boundary (i.e. *super point*)

- **California** –The California coastal wave monitoring and prediction system (O'Reilly et al , 2016)
  - Backward ray-tracing linear spectral refraction model - from deep water buoy stations to nearshore prediction points
  - Nowcast and forecast

Initial approach

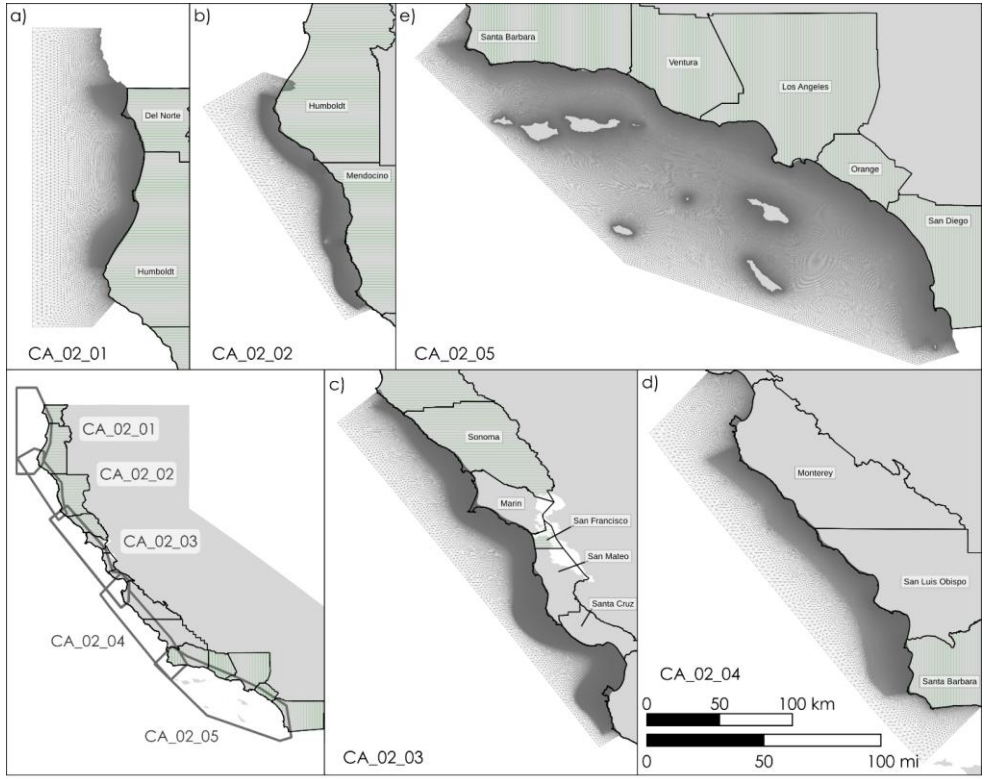
1. Hybrid Downscaling MDA (Camus et al 2011)
2. 1,000 unSWAN statationary simulations, uniform boundary
3. Non-linear reconstruction based on Radial Basis Functions





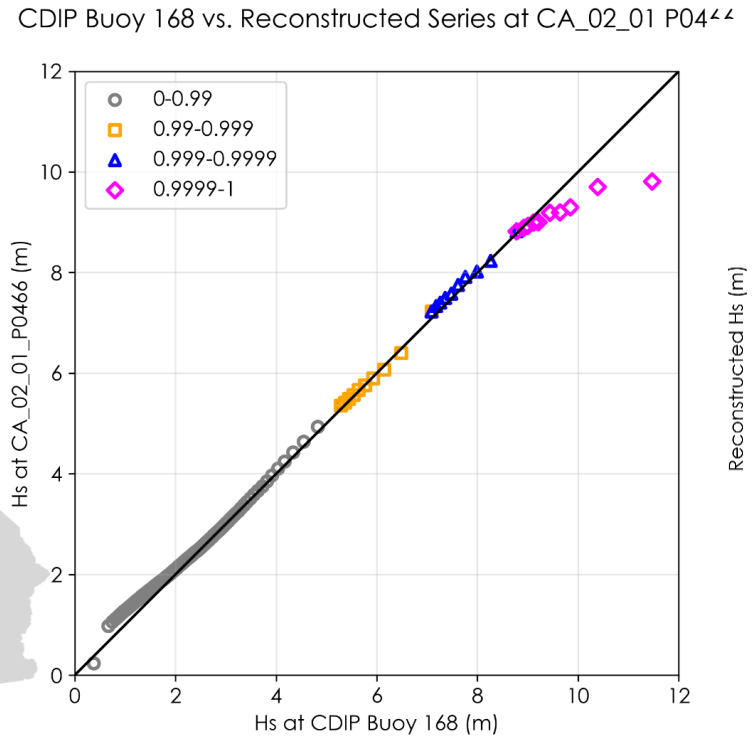
Offshore forcing

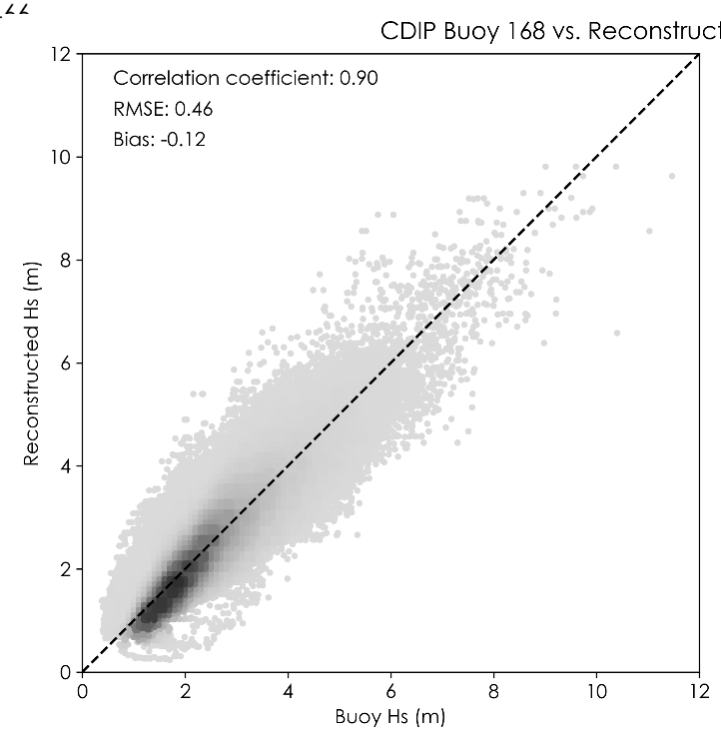
ECMWF/**ERA5** (Hersbach et al, 2017)	1940-	85 yr
CSIRO/**CAWCR** (Durrant et al., 2019, 2014; Smith et al., 2021)	1979-	46 yr
CSIRO/WHACS (Smith et al, 2024) in progress	1979-	45 yr
USGS/**CMIP6 HR** (Erikson et al, 2022)	1979-14, 2020-50	67 yr
CSIRO140 (Meucci et al, 2023)	1961-2100	140 yr
		925 years

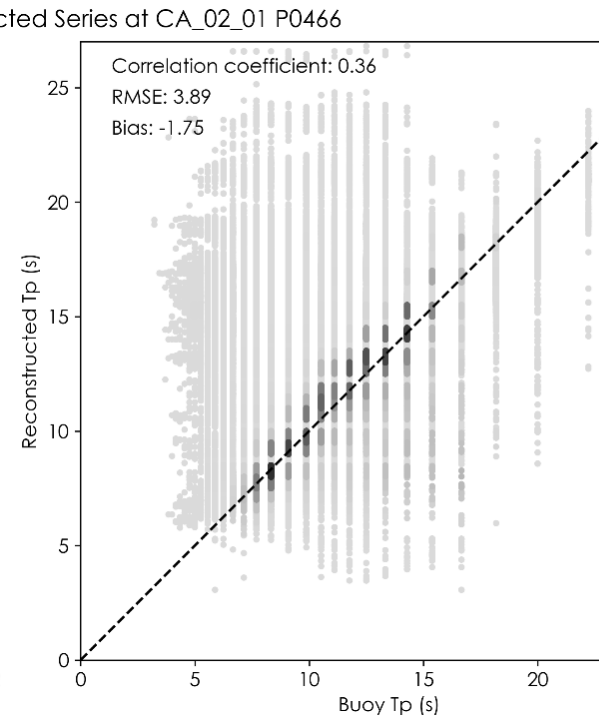


Results: CalWaves, validation with buoys

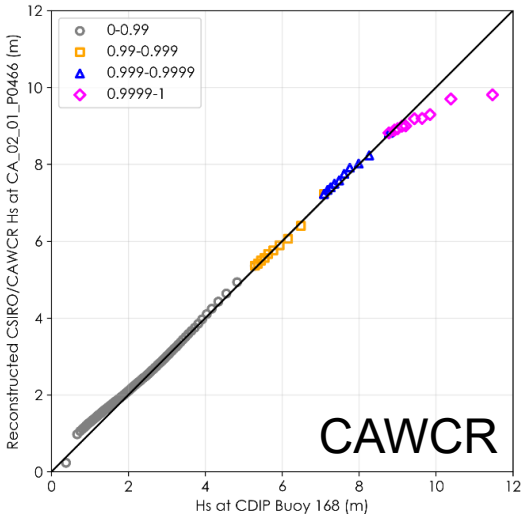
- ~3,000 output points (~1 point every 2 km)
- 10, 20, 50 and 100 m depth
- Buoy data from Coastal Data Information Program (CDIP) (Datawell Waveriders)

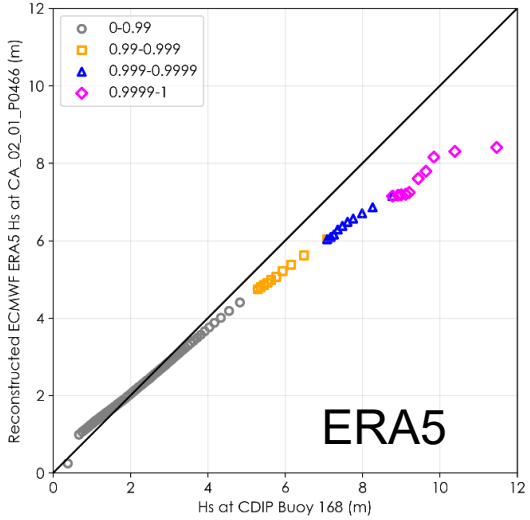


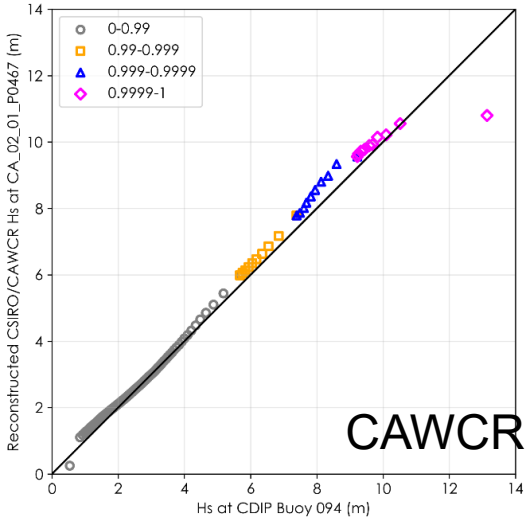


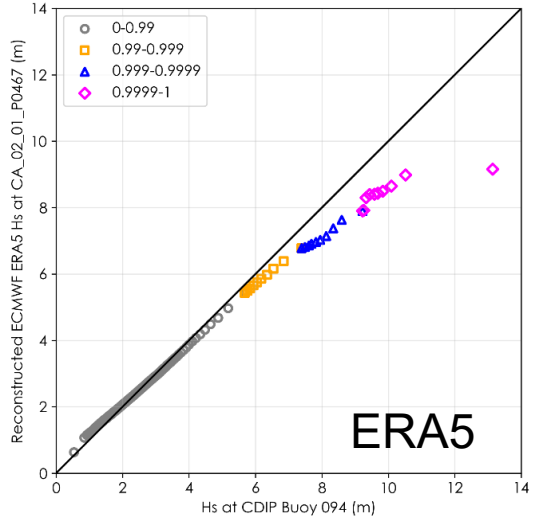


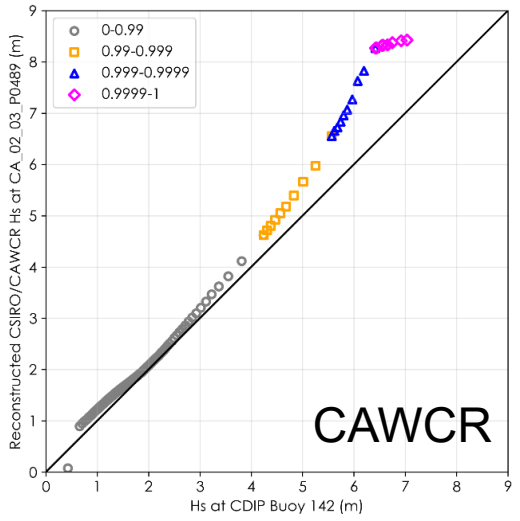
Results: CAWCR vs ERA5

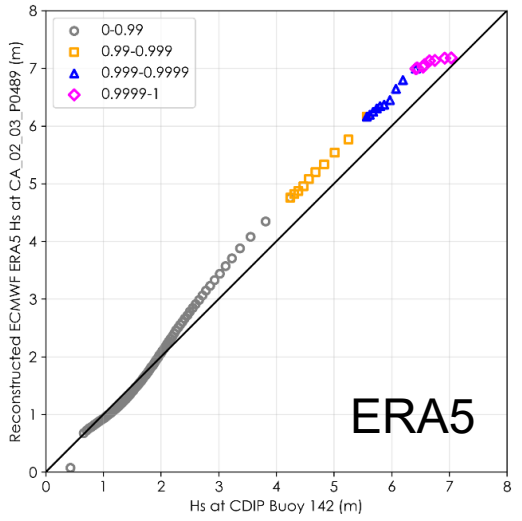


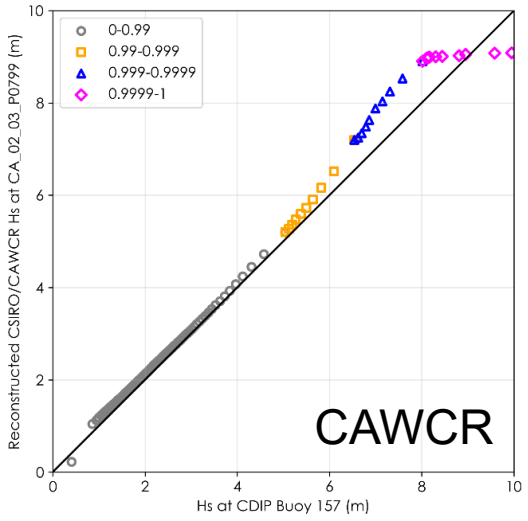


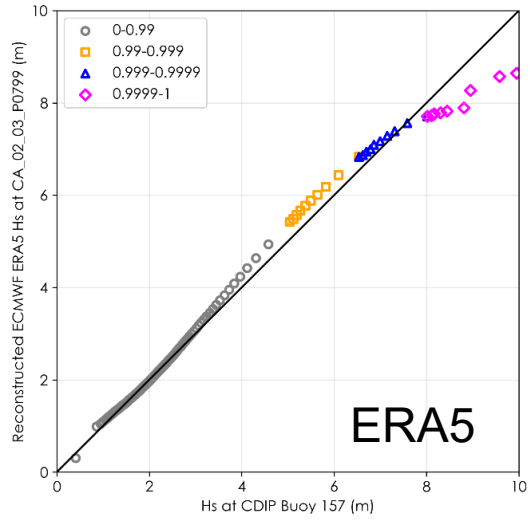




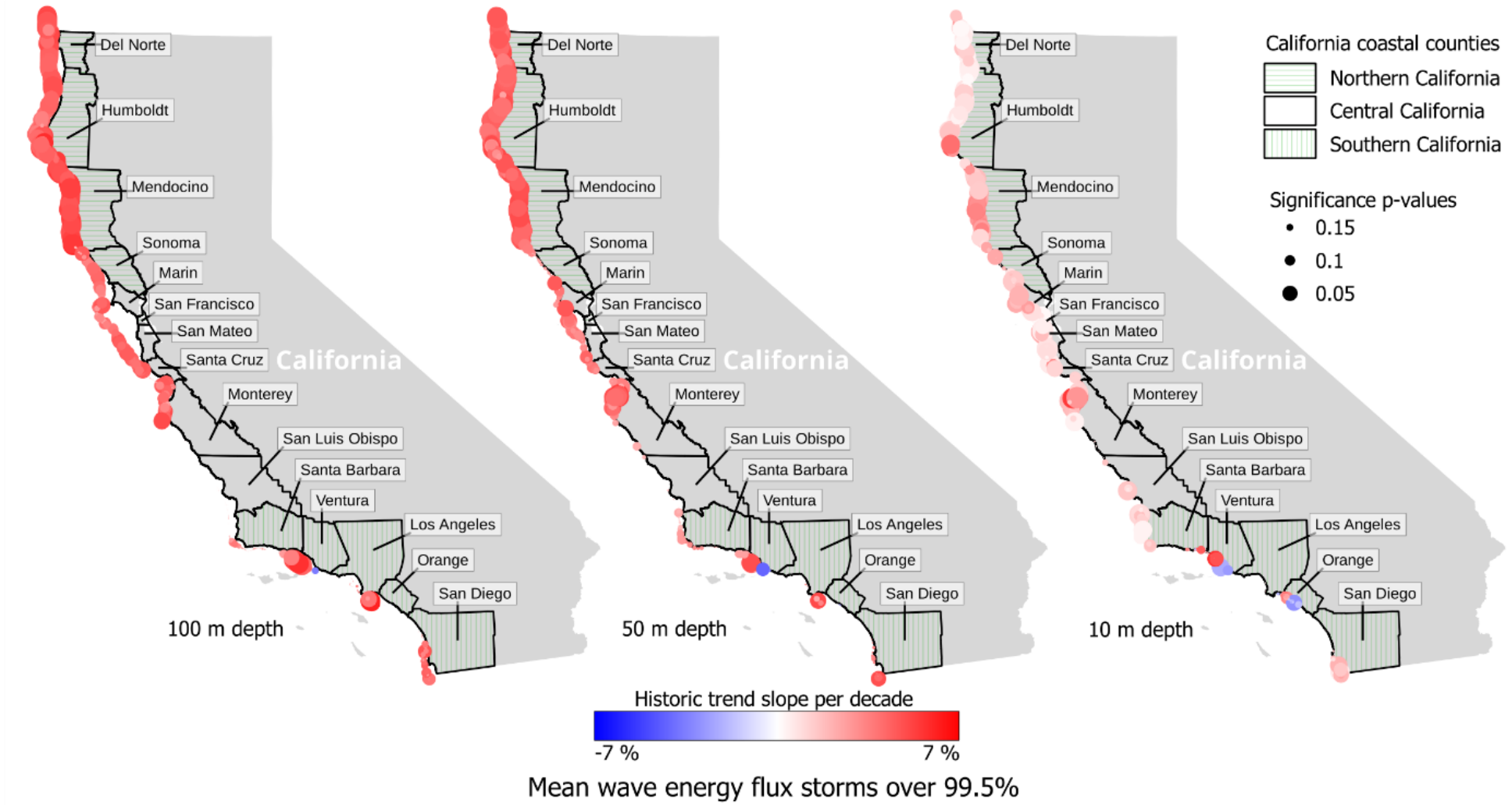






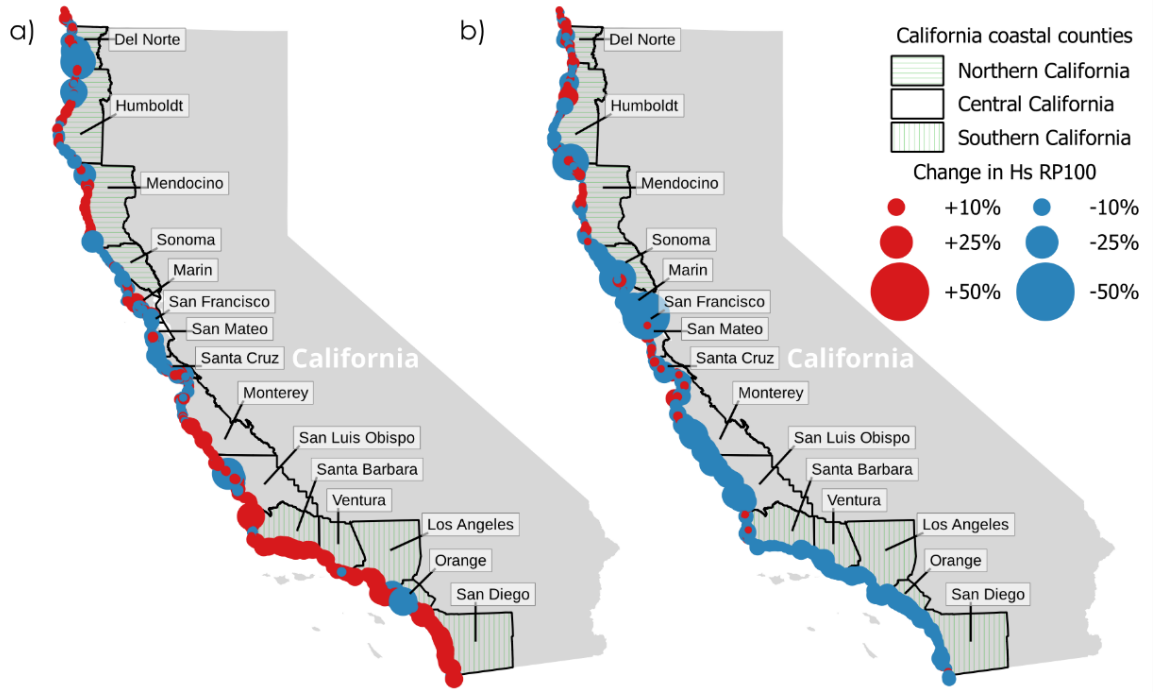


Results: Historic changes - CAWCR



Gutierrez-Barcelo et al, in prep

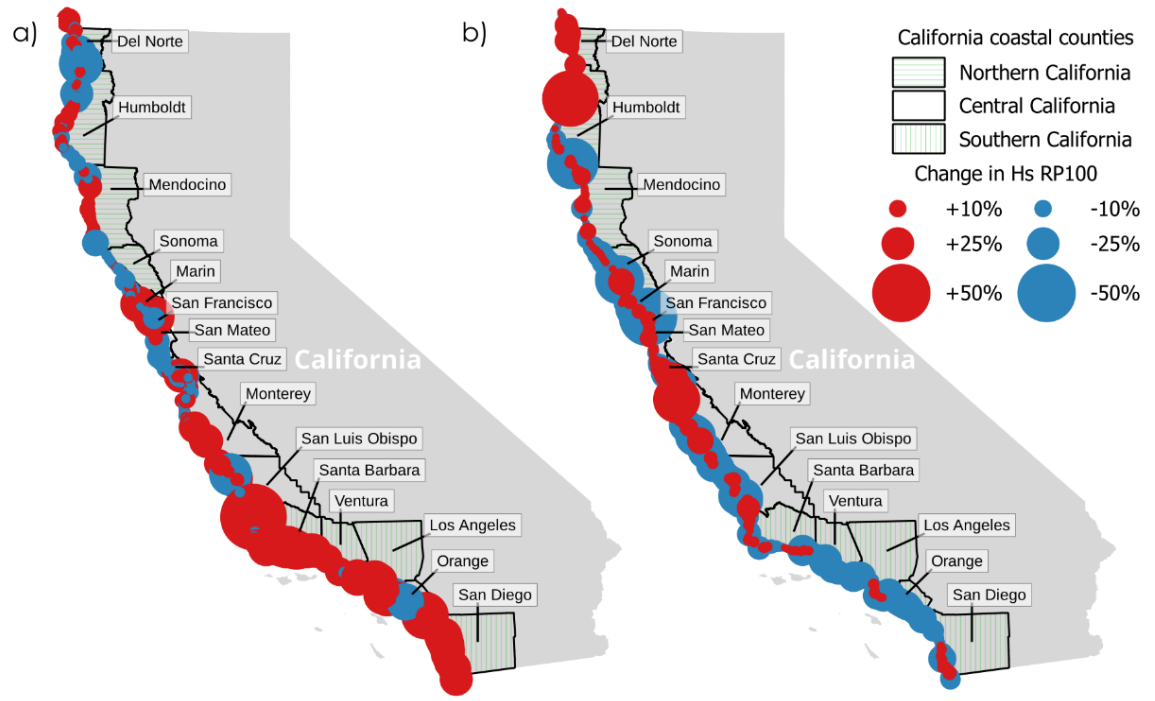
Results: Changes in extreme wave heights (Hs100) - CSIRO140



ACCESS-CM2 EC-EARTH3

Ratio Hs RP100 in 2055 / Hs RP100 in 2025 for two GCMs at 10 meters

2055/2025

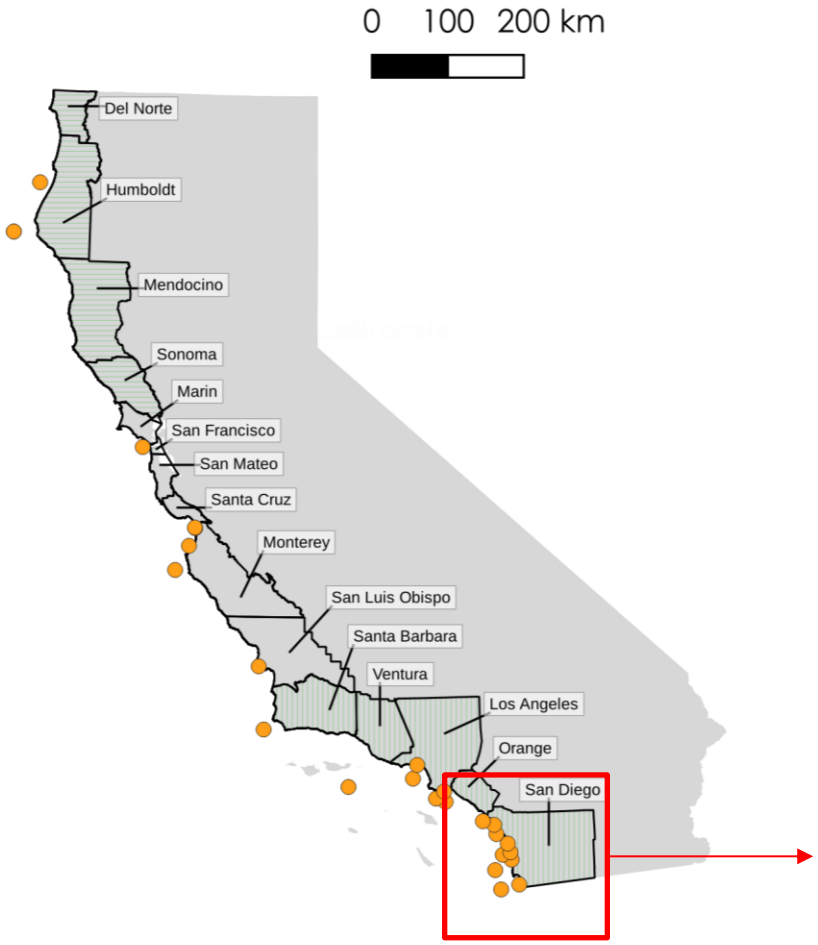


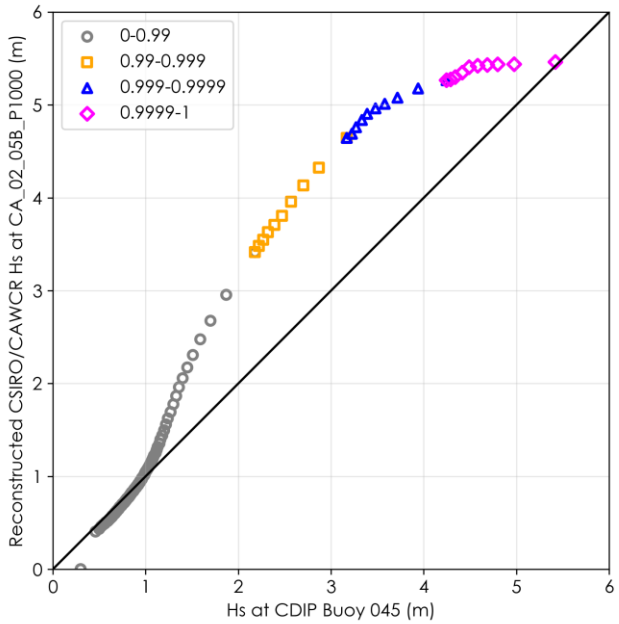
ACCESS-CM2 EC-EARTH3

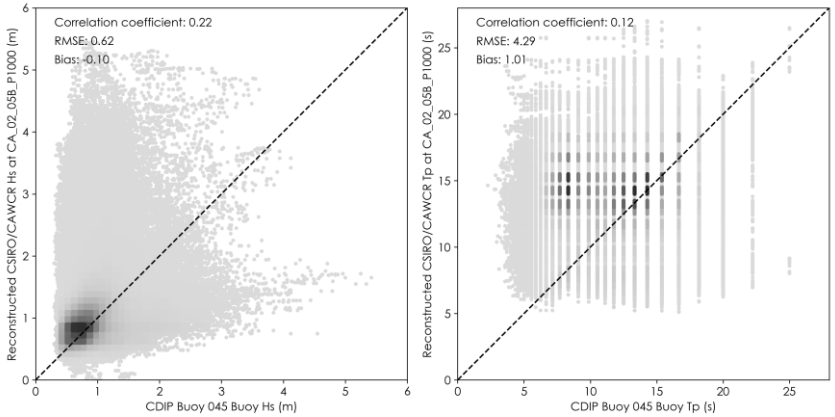
Ratio Hs RP100 in 2085 / Hs RP100 in 2025 for two GCMs at 10 meters

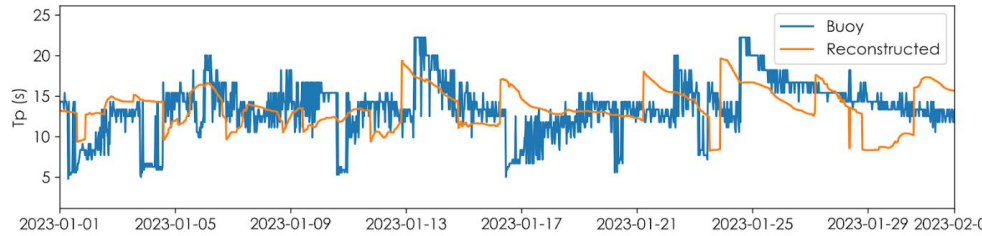
2085/2025

But not perfect…

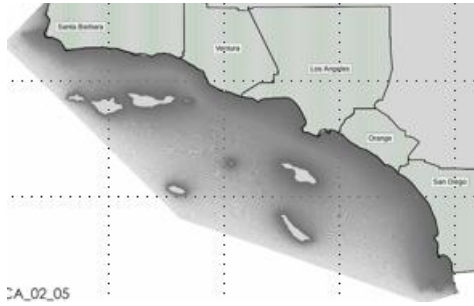






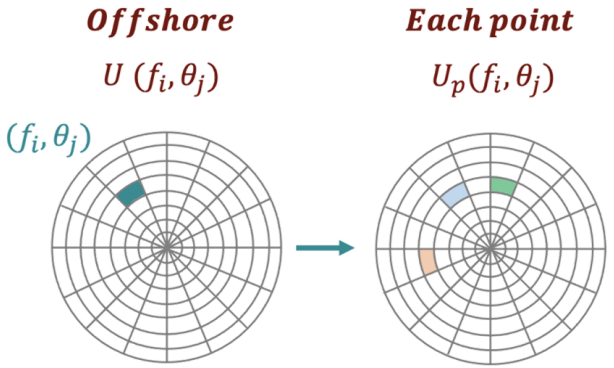


- Mesh is too large, breaks stationary assumption
- Multimodal states are poorly represented in the MDA
- Neglects local generation & non-uniform boundary (time lag)



Spectral non-stat solution

A hybrid model for propagating full directional wave spectra to nearshore locations with multimodal inputs and outputs



$$K_p(f_i, \theta_j) = \frac{U_p(f_i, \theta_j)}{\iint U(f_i, \theta_j)\, df\, d\theta}$$

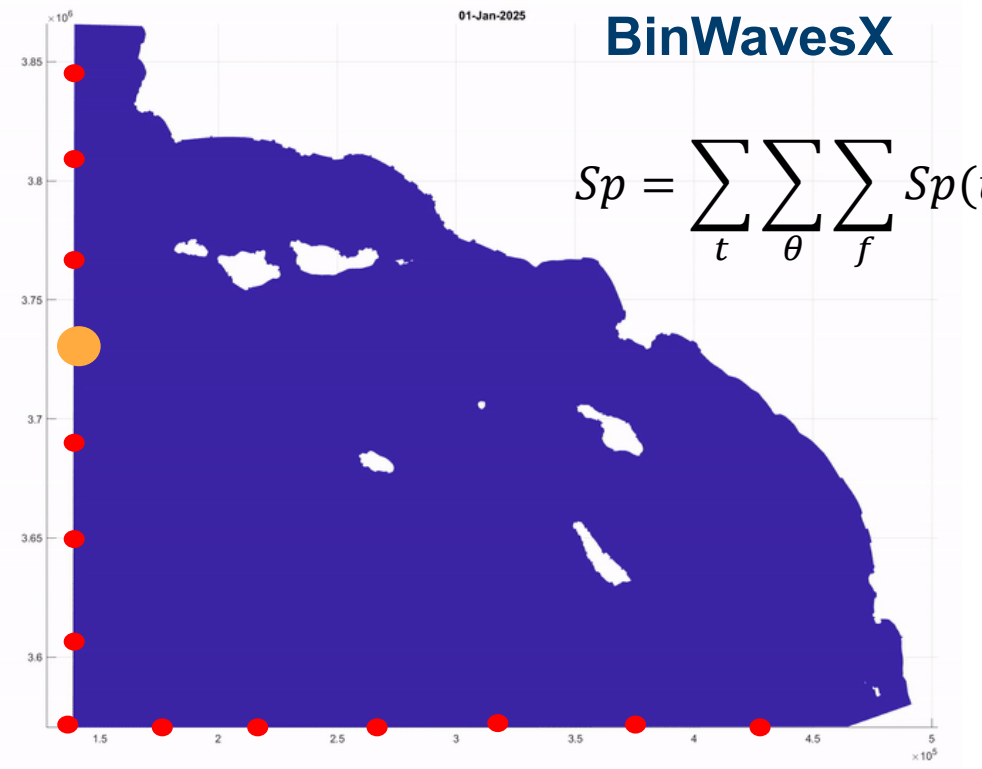
Cagigal et al., (2024)

1. Spectra partitions (**Binwaves**, Cagigal et al 2024)

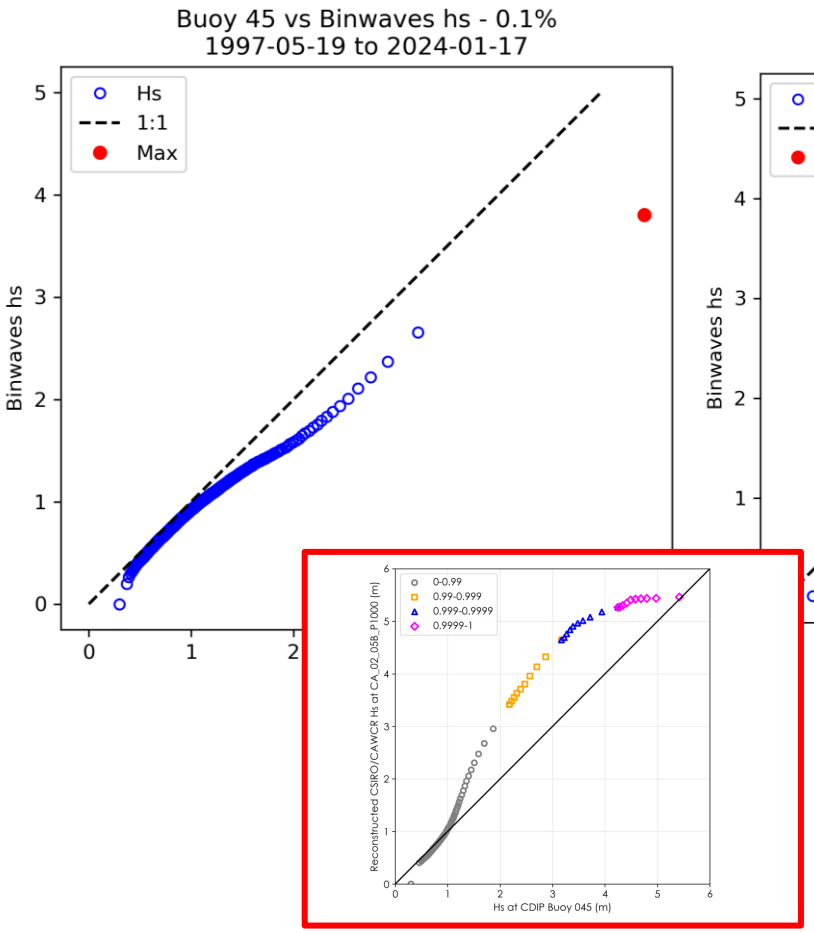
2. Multipoint boundary and unstructured grid (arbitrary number of boundary input nodes)

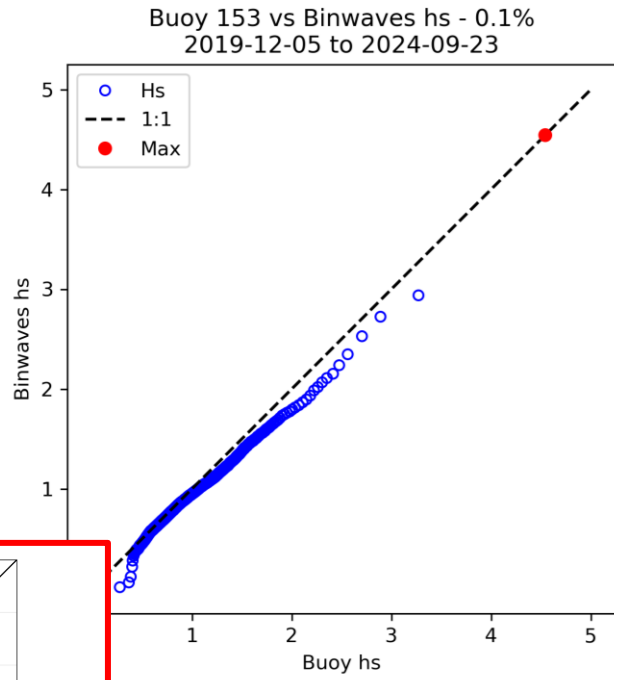
3. Propagate pulses of energy per frequency, direction and boundary point, in non-stationary mode (unswan, w variable time step and duration)

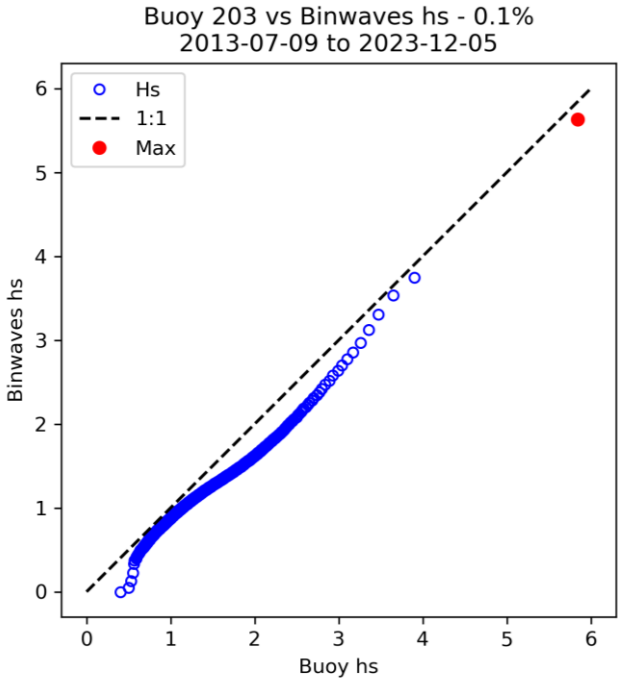
4. Time series of reconstructed spectra (GPU implementation) – **BinwavesX**

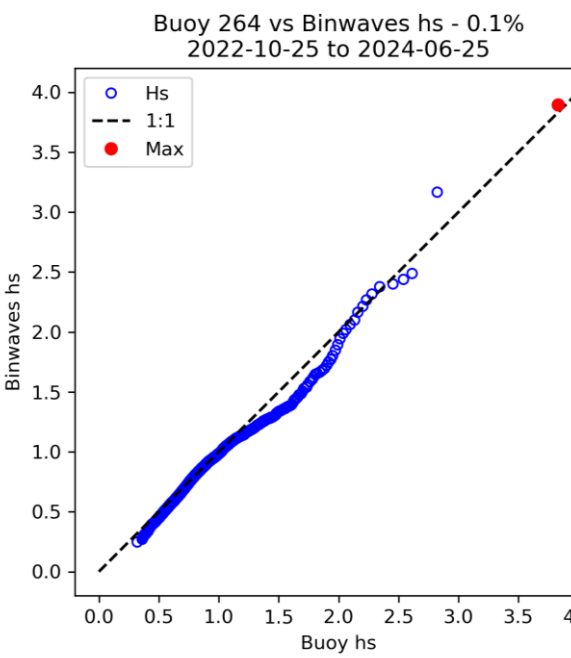


BinWavesX validation









Conclusions

- At large scales, uniform boundary simulations still cost-effective for nearshore wave climatology in open coasts (stat and low variability in boundaries)
- Non-uniform and non-stationary assumptions challenges existing hybrid models methods in **Southern California Bight**
- Historic wave climate:
  - ERA5 – reproduces historic variability
  - CSIRO/CAWCR better for the extremes
- The new spectral downscaling method addresses non-stationary wave propagation in Southern California

Next steps CalWaves:

- Expand BinWavesX to the rest of the state
- Add local winds
- Calibrate boundary conditions
- Integration in BlueMath

Thank you

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