A Monte Carlo Emulator for Tropical Cyclone-Driven Extreme Sea Levels

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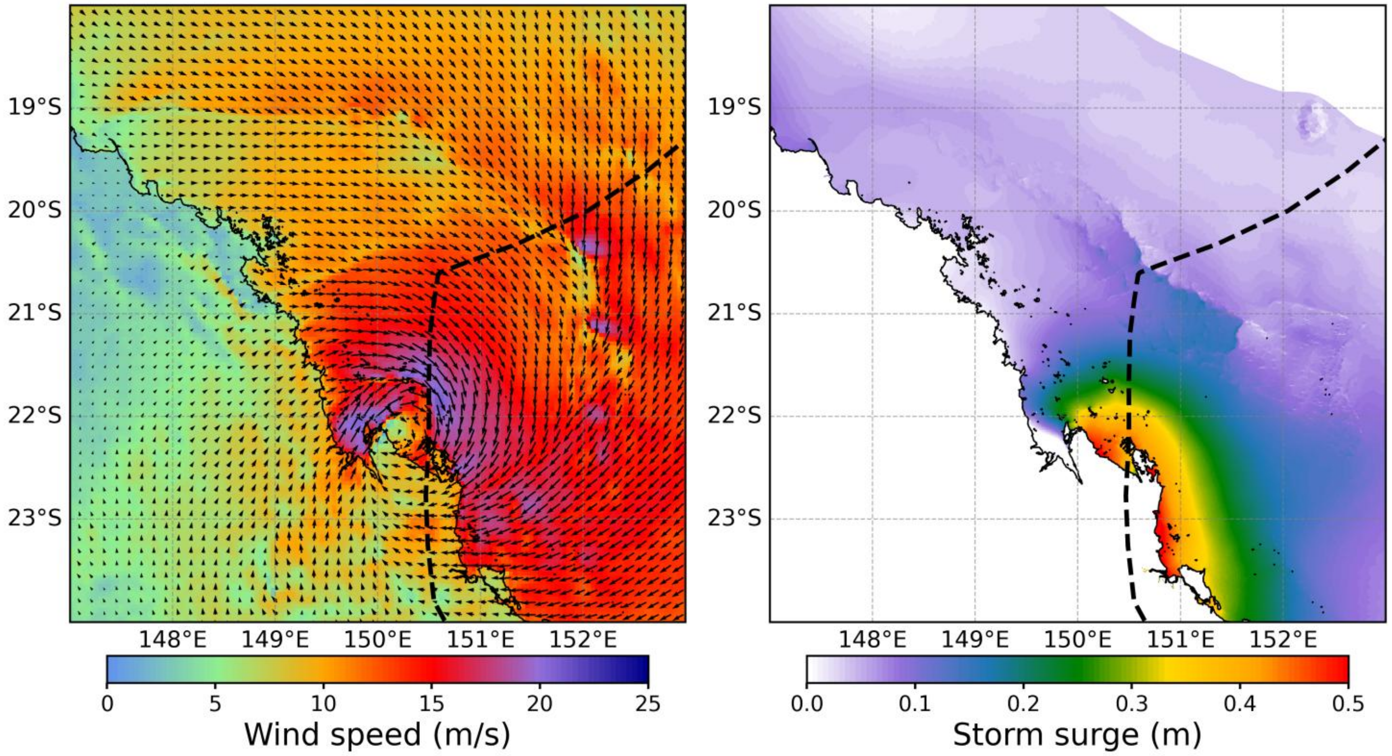
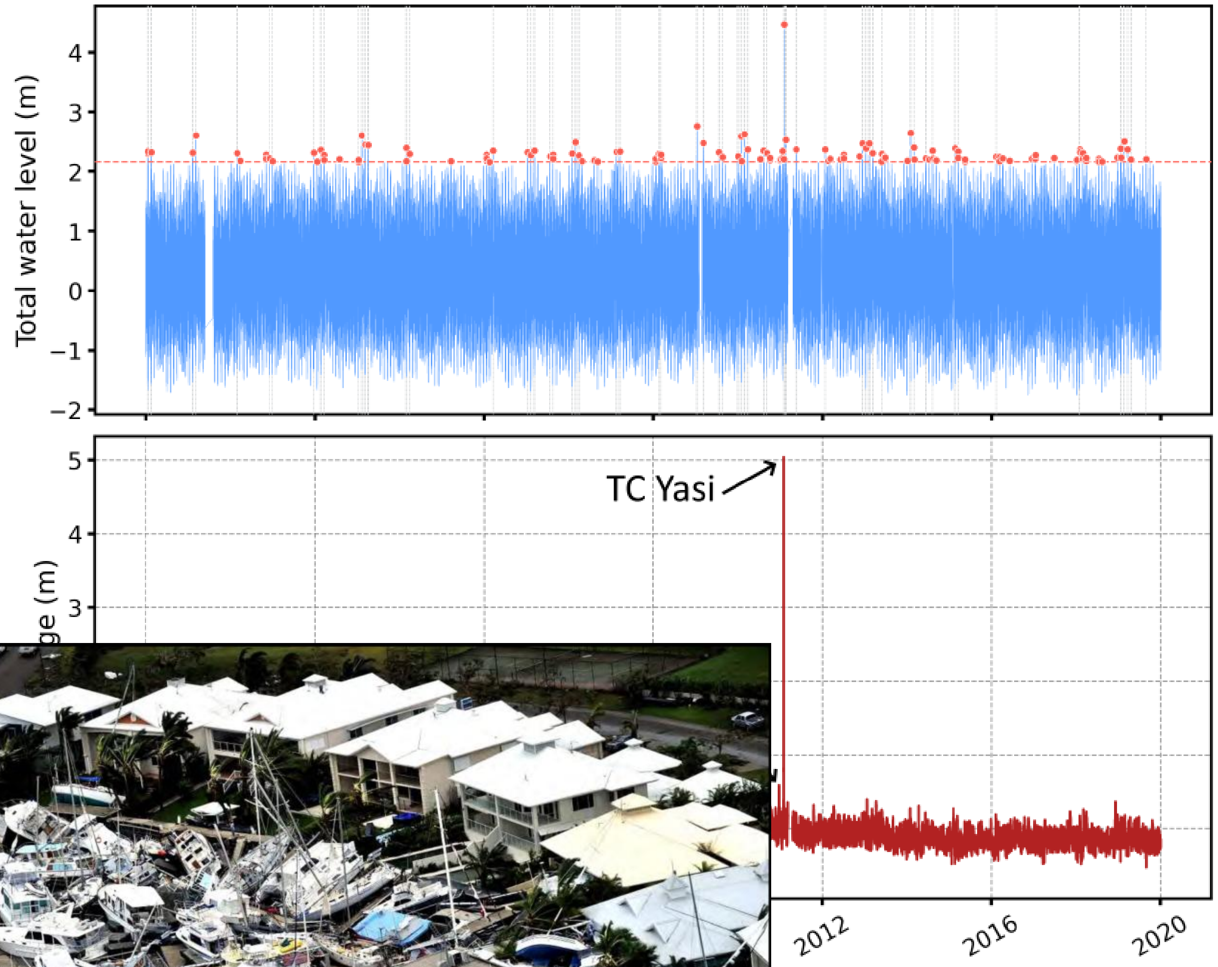
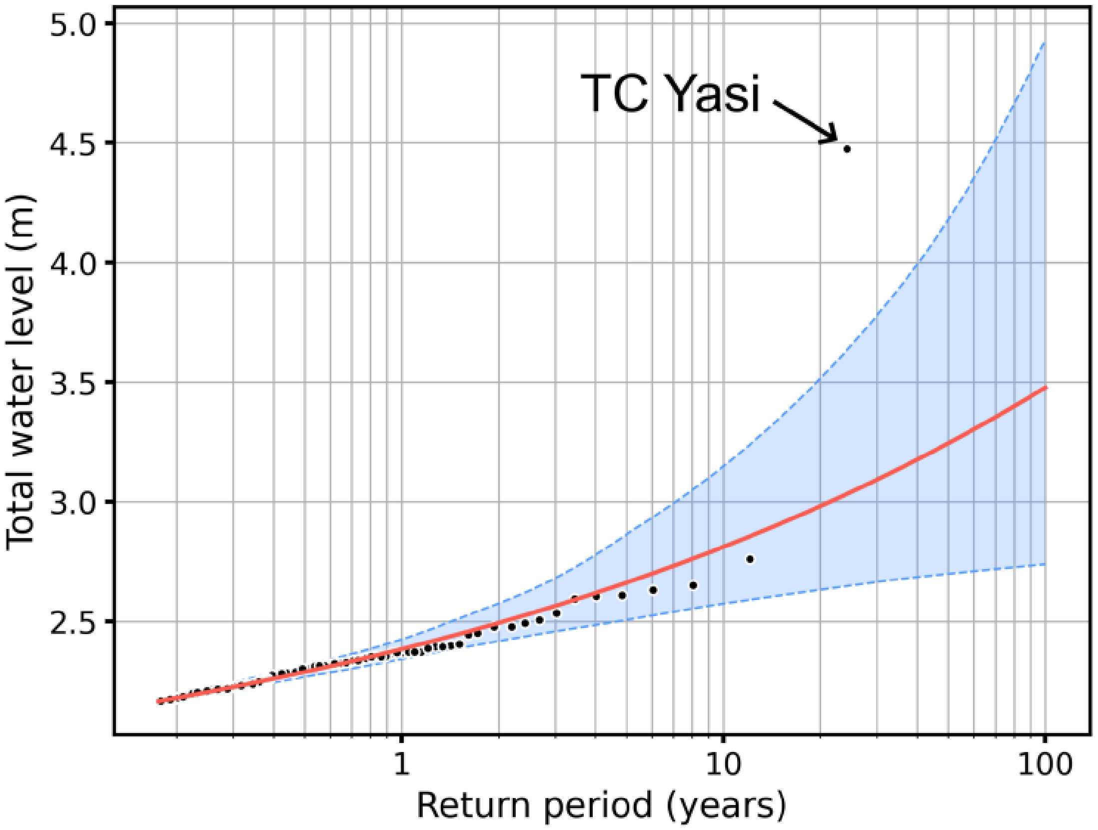


Sea Level, Waves and Coastal Extremes
CSIRO
Australian Government
Australian Climate Service
GeoOcean
University of Cantabria

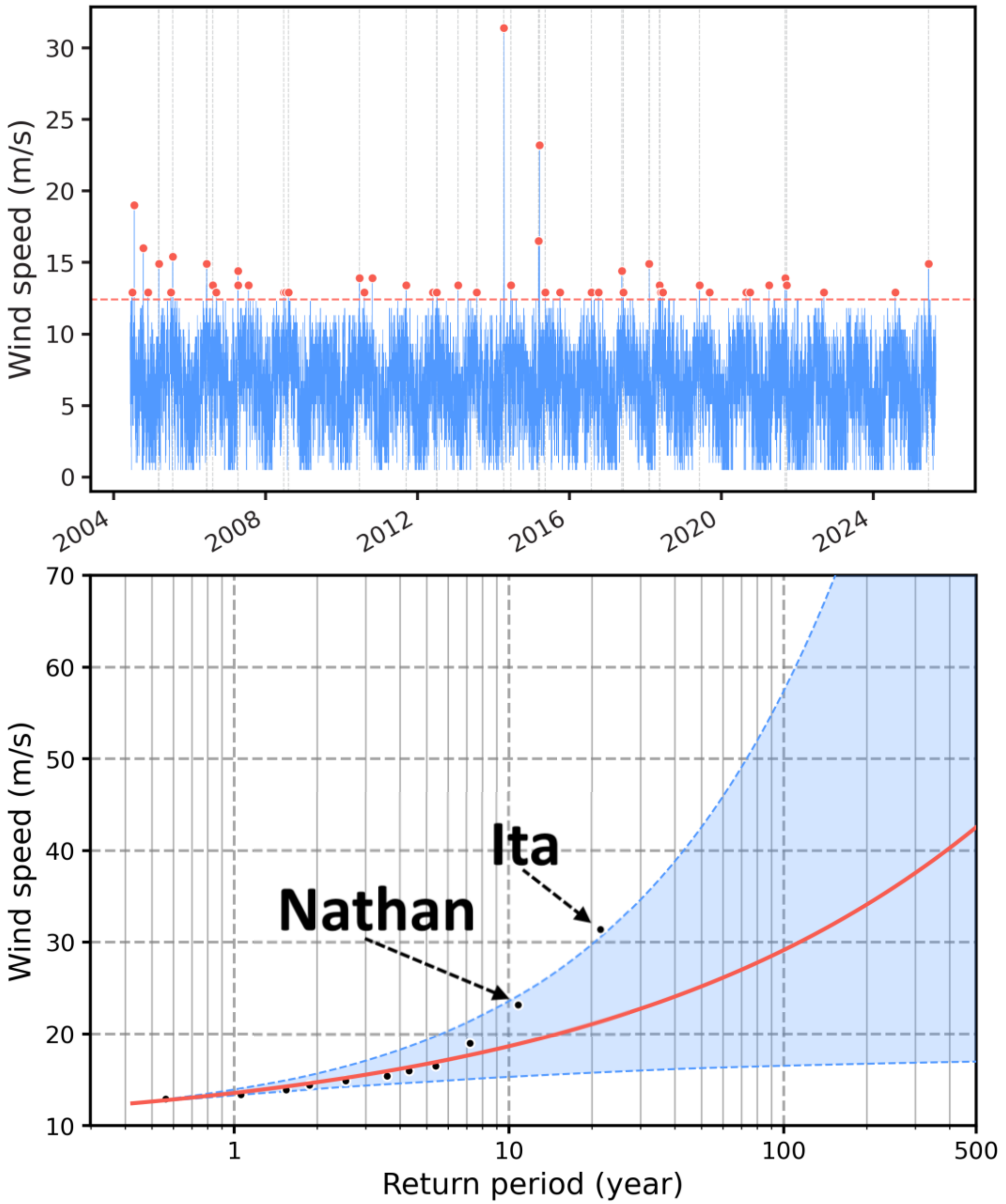
Problem: Rare but intense TC events introduce large uncertainties in extreme value estimates



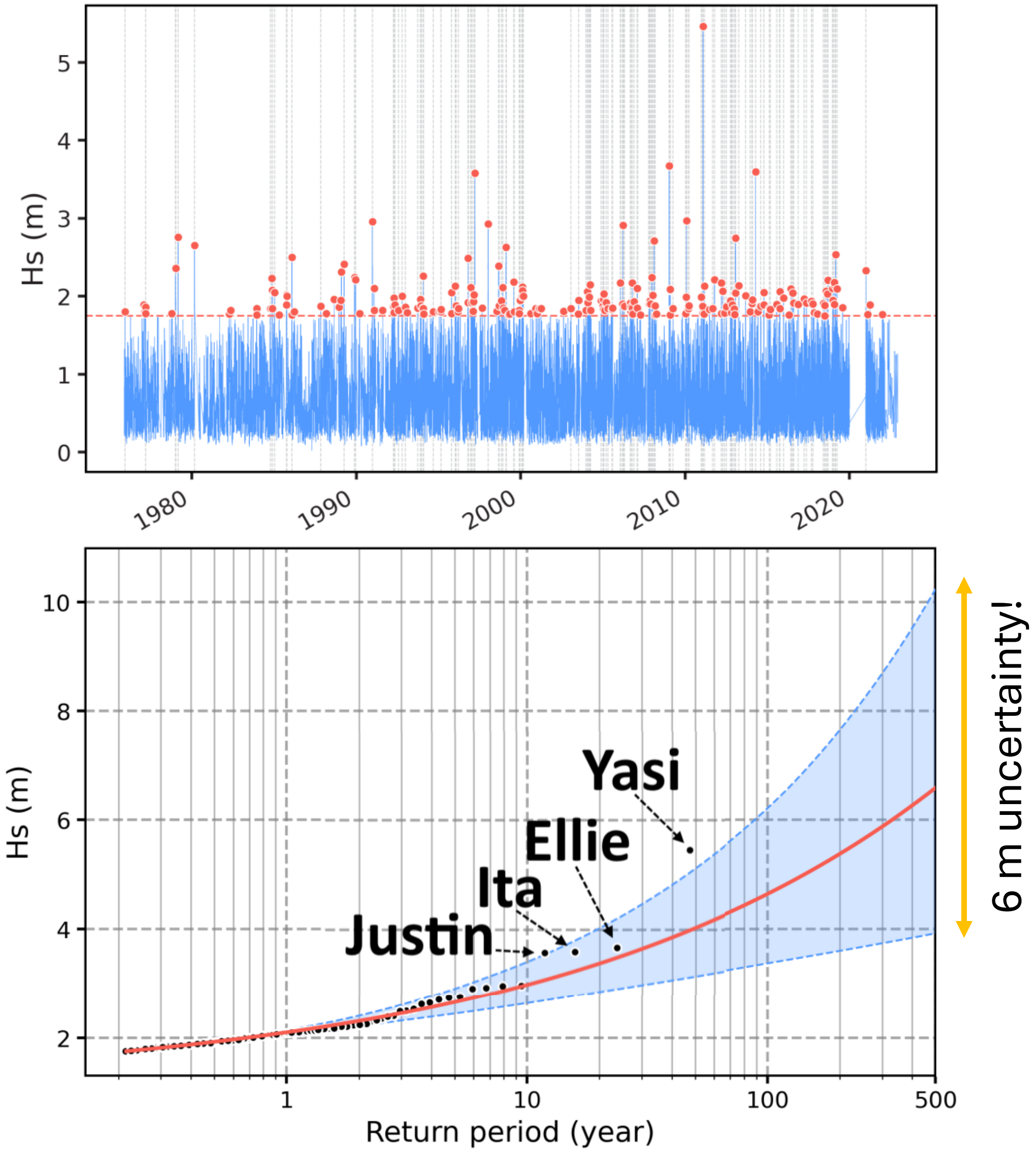


Estimated costs of **$3.5 billion** and insured losses around **$1.4 billion**

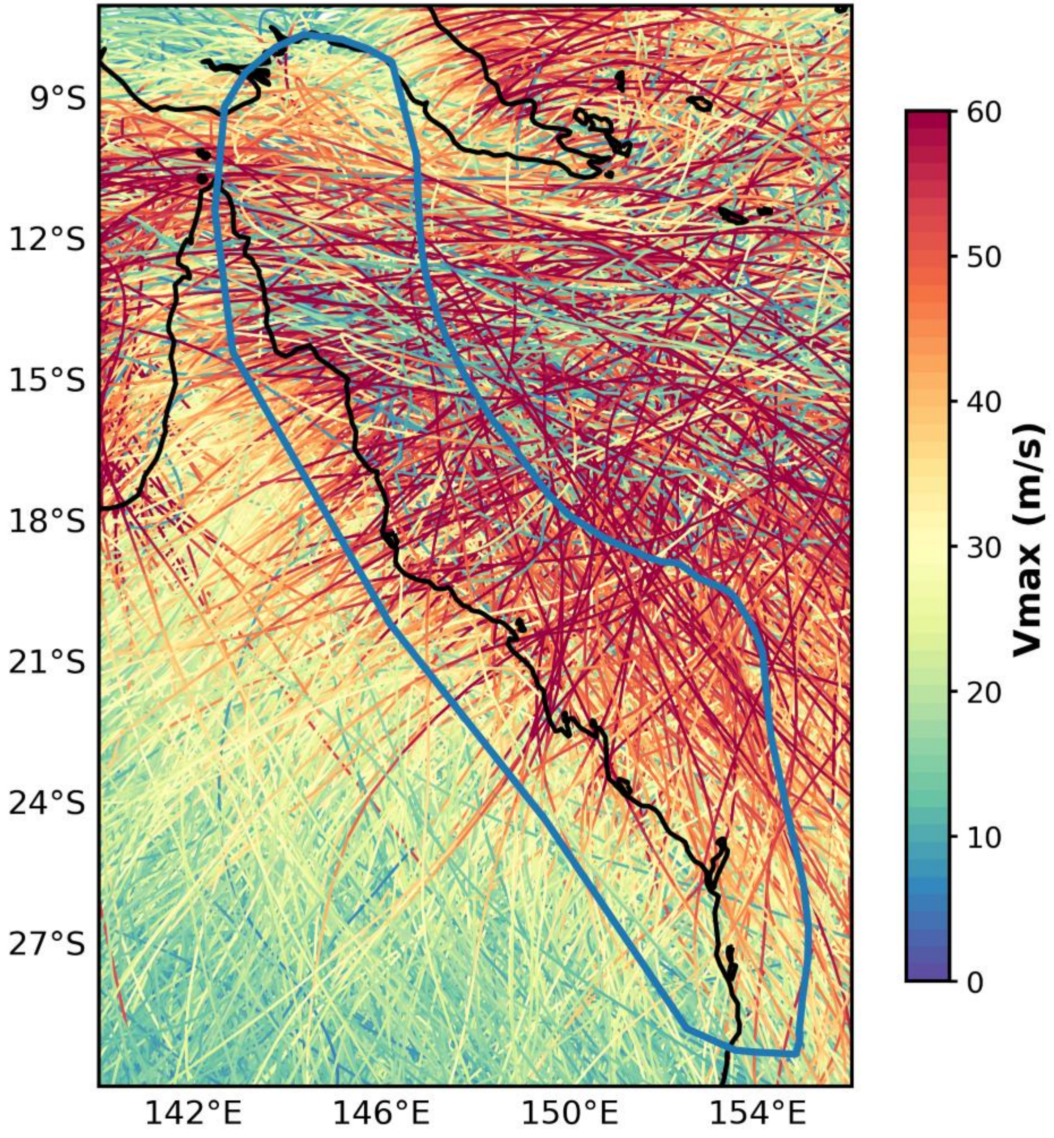
Wind speed observations at Cape Flattery



Significant wave heights at the Townsville wave buoy



<u>Motivation</u>: Make more robust estimates of TC-derived extremes
<u>Solution</u>: Use synthetic TCs to increase the TC population size



Lin et al. (2023) synthetic TC model

- Open-source, physics-based TC downscaling model
- Simulates the full cycle of TCs using environmental data (e.g, ERA5) such as SST, wind shear and humidity to guide storm development and track.
- We applied the Lin model to northeast Australia using data from ERA5 from 1980-2020, generating a total of ~17,000 synthetic TCs.

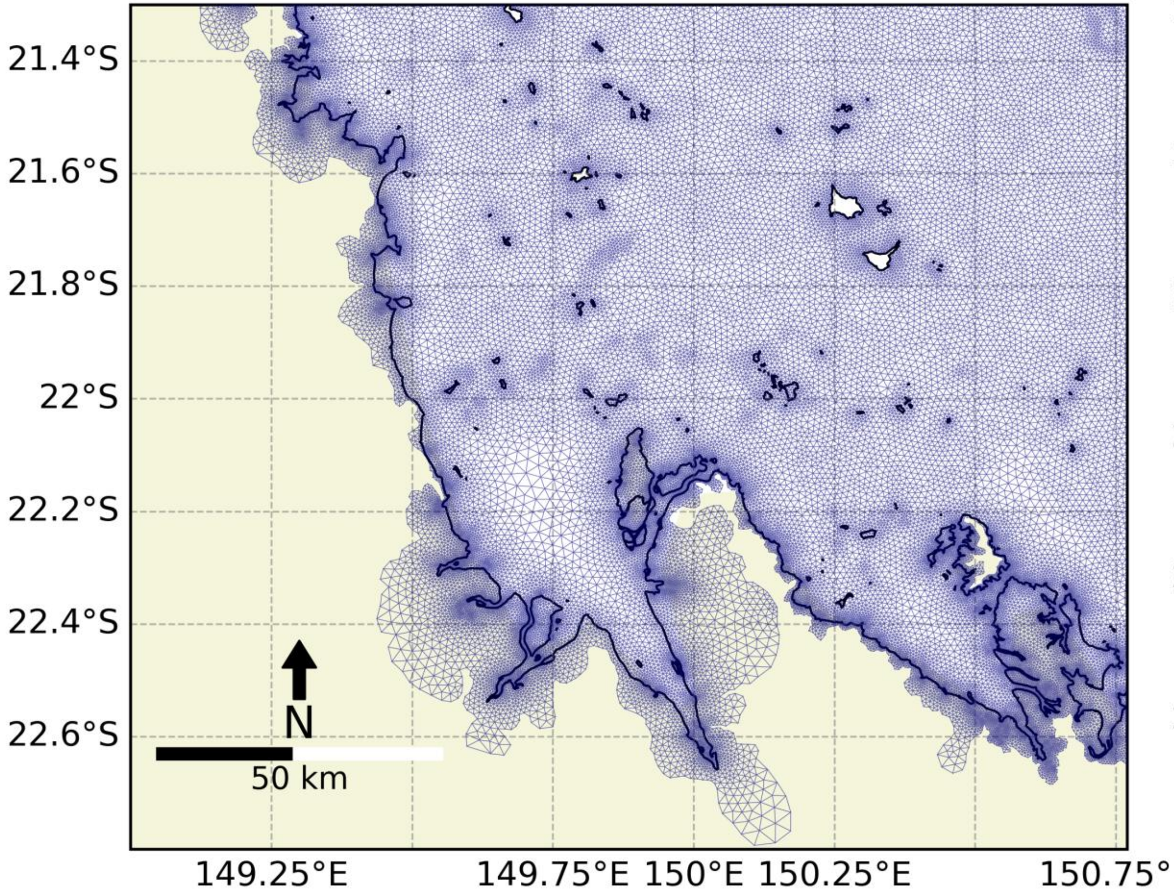
https://github.com/linjonathan/tropical_cyclone_risk

SCHISM-WWMIII model

Unstructured computational mesh resolution: ~250 m @coastline (100 m in major river mouths) to ~5 km @open ocean boundary.

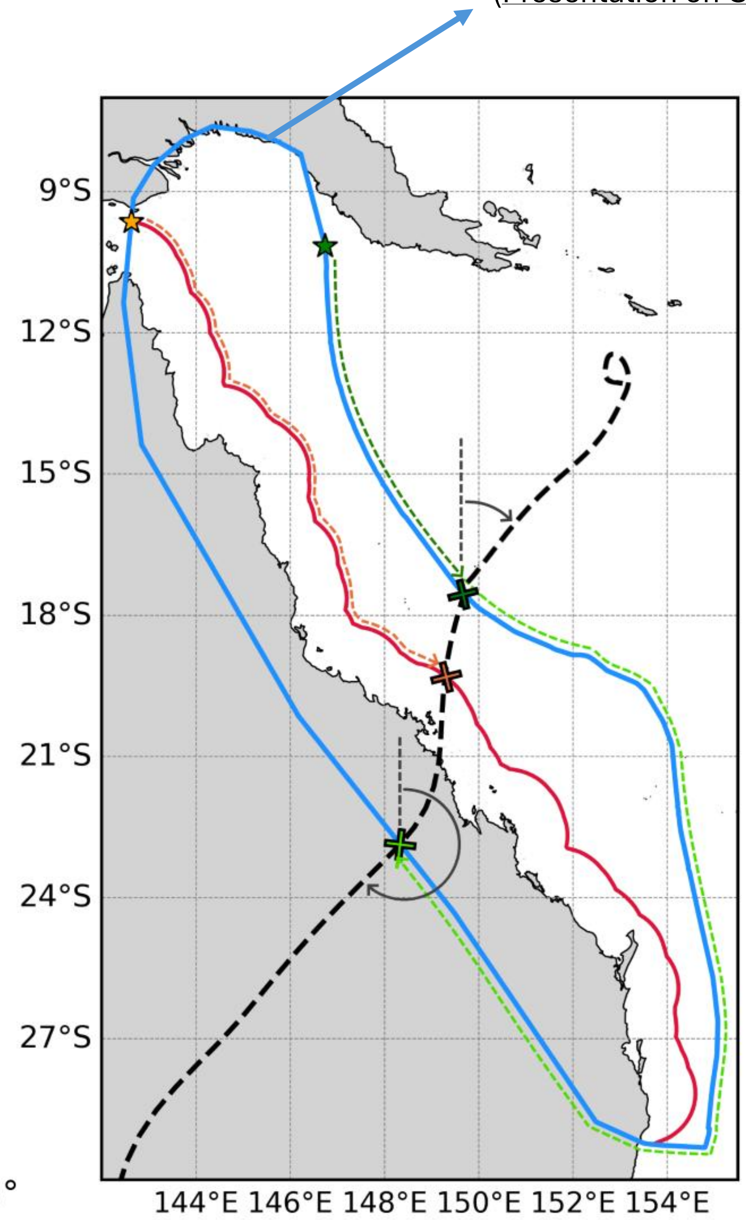
CLE15 winds (Chavas, Lin & Emanuel, 2015).

SHyTCWaves for wave boundary conditions.

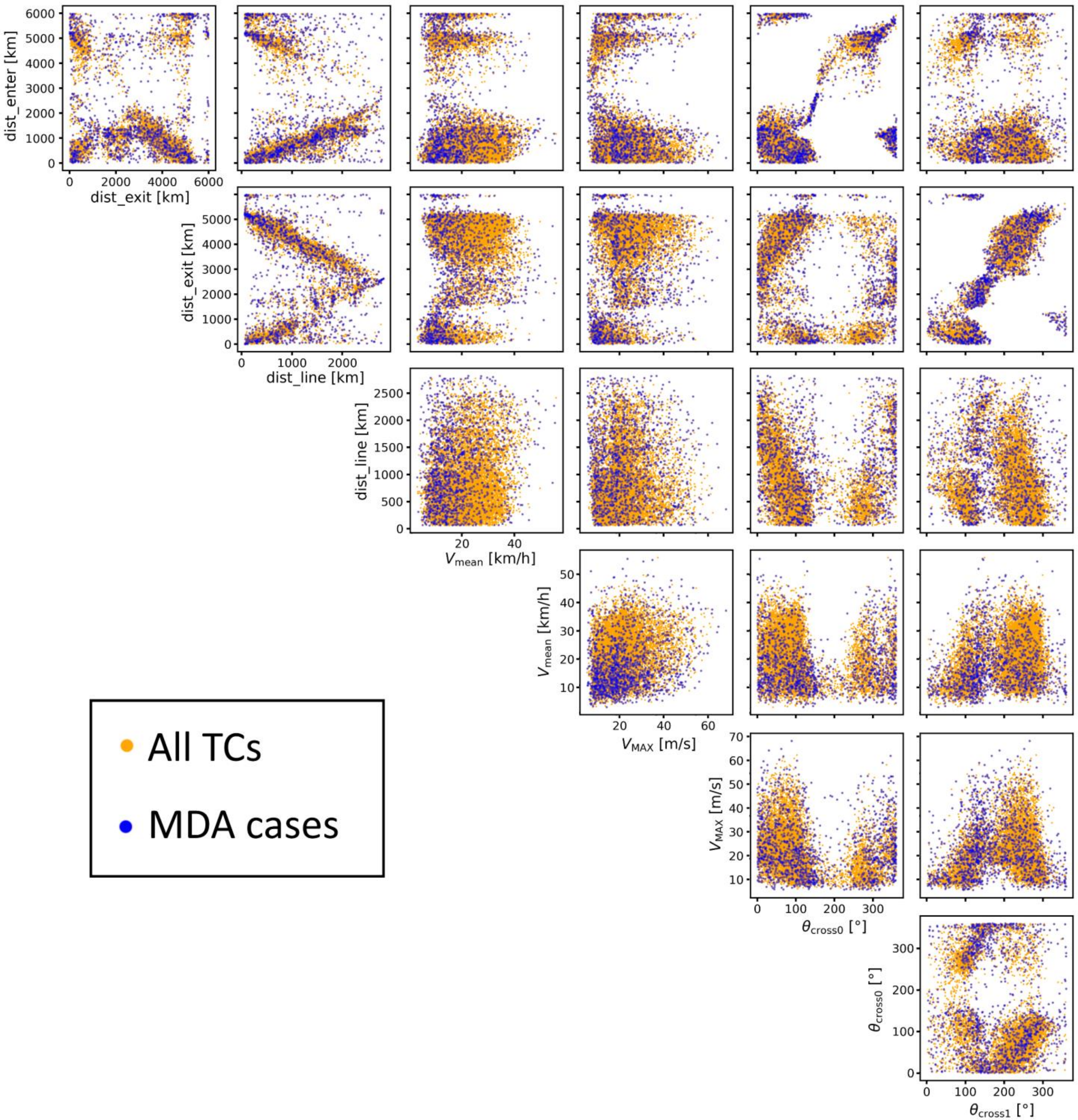


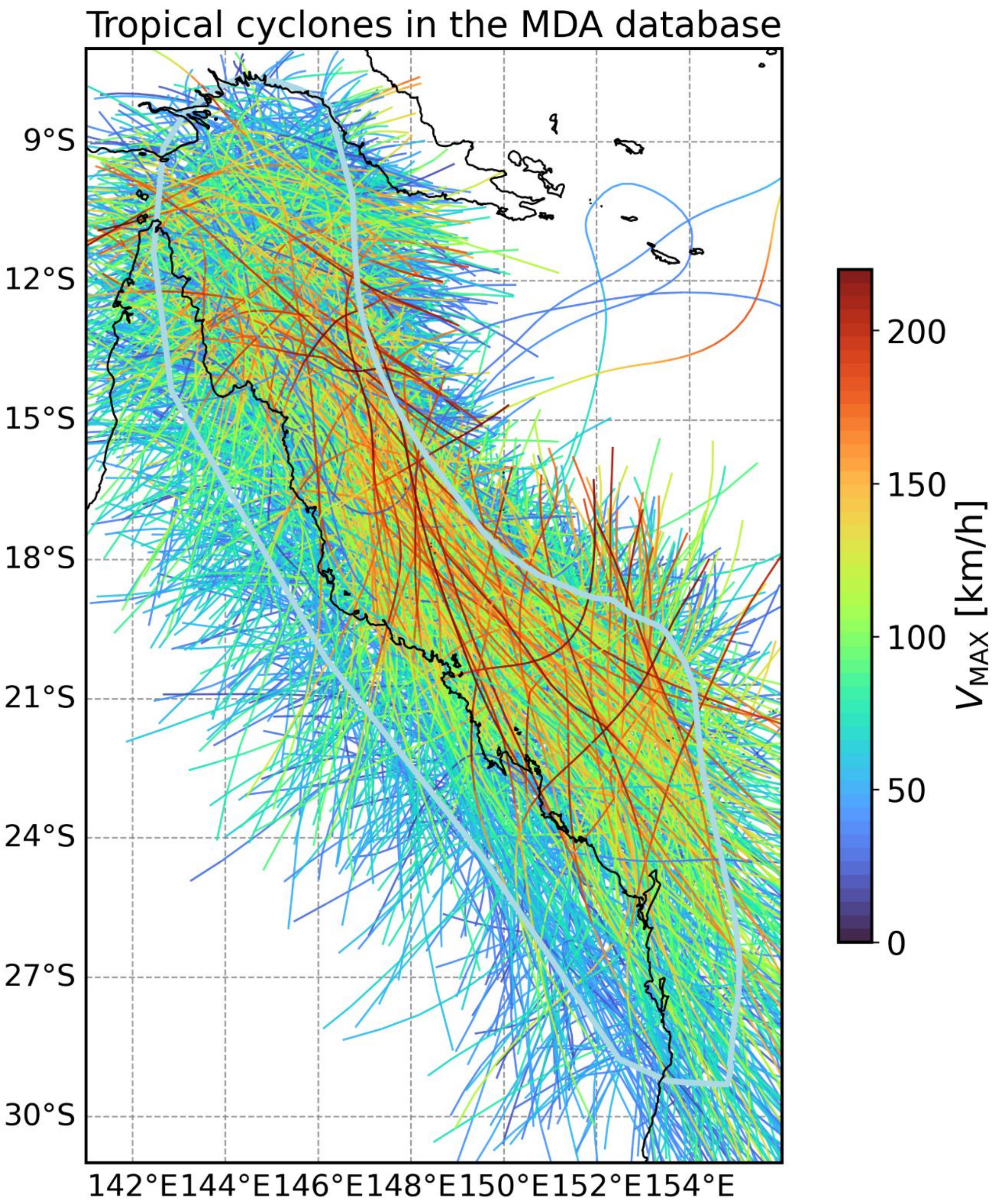
Subset of the CCHaPS national grid

(Presentation on Coastal Extremes session)



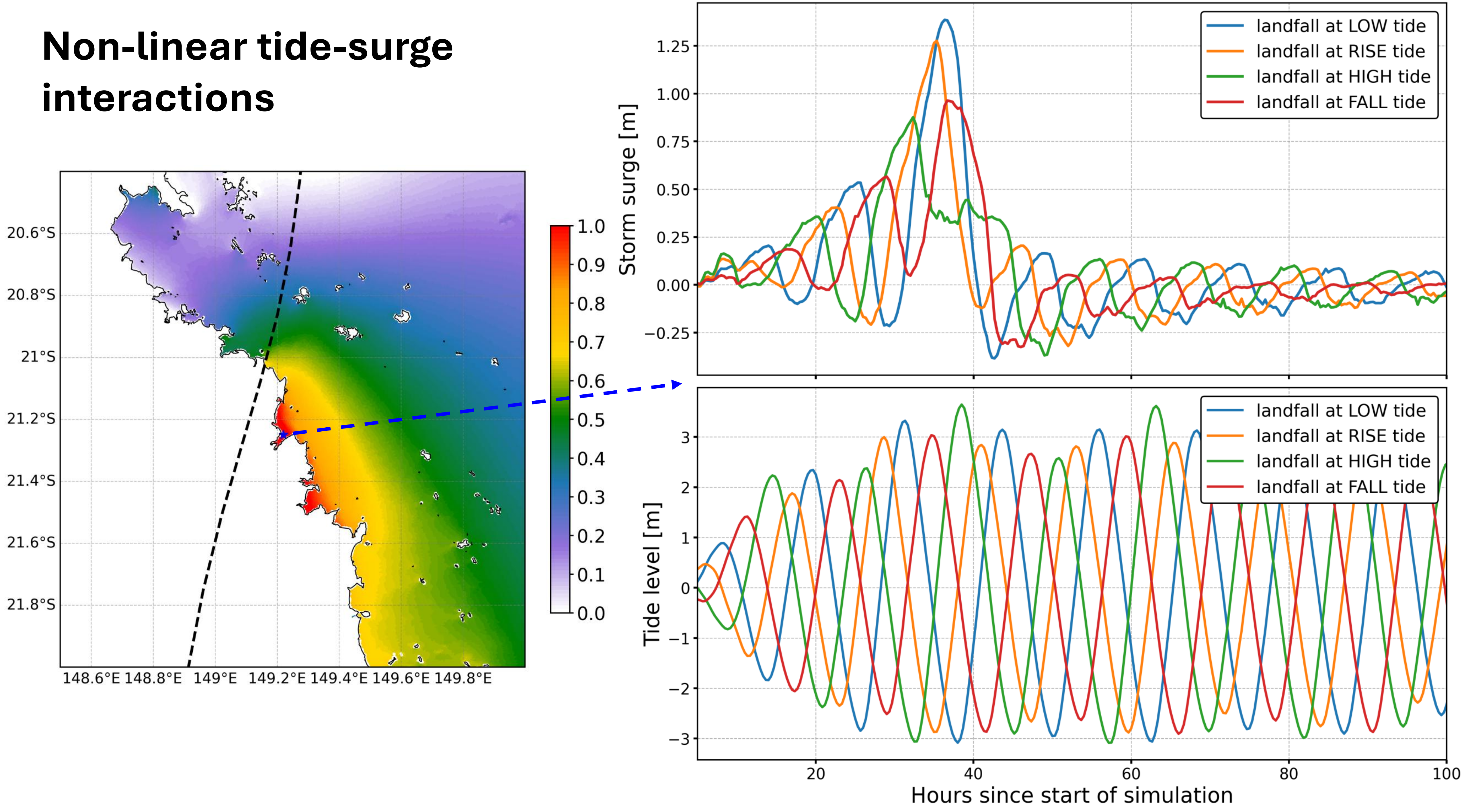
dist_enter	= 1000 km
θ_{cross0}	= 40°
dist_line	= 1300 km
dist_exit	= 3000 km
θ_{cross1}	= 225°
V_{mean}	= 15 km/h
V_{MAX}	= 30 m/s



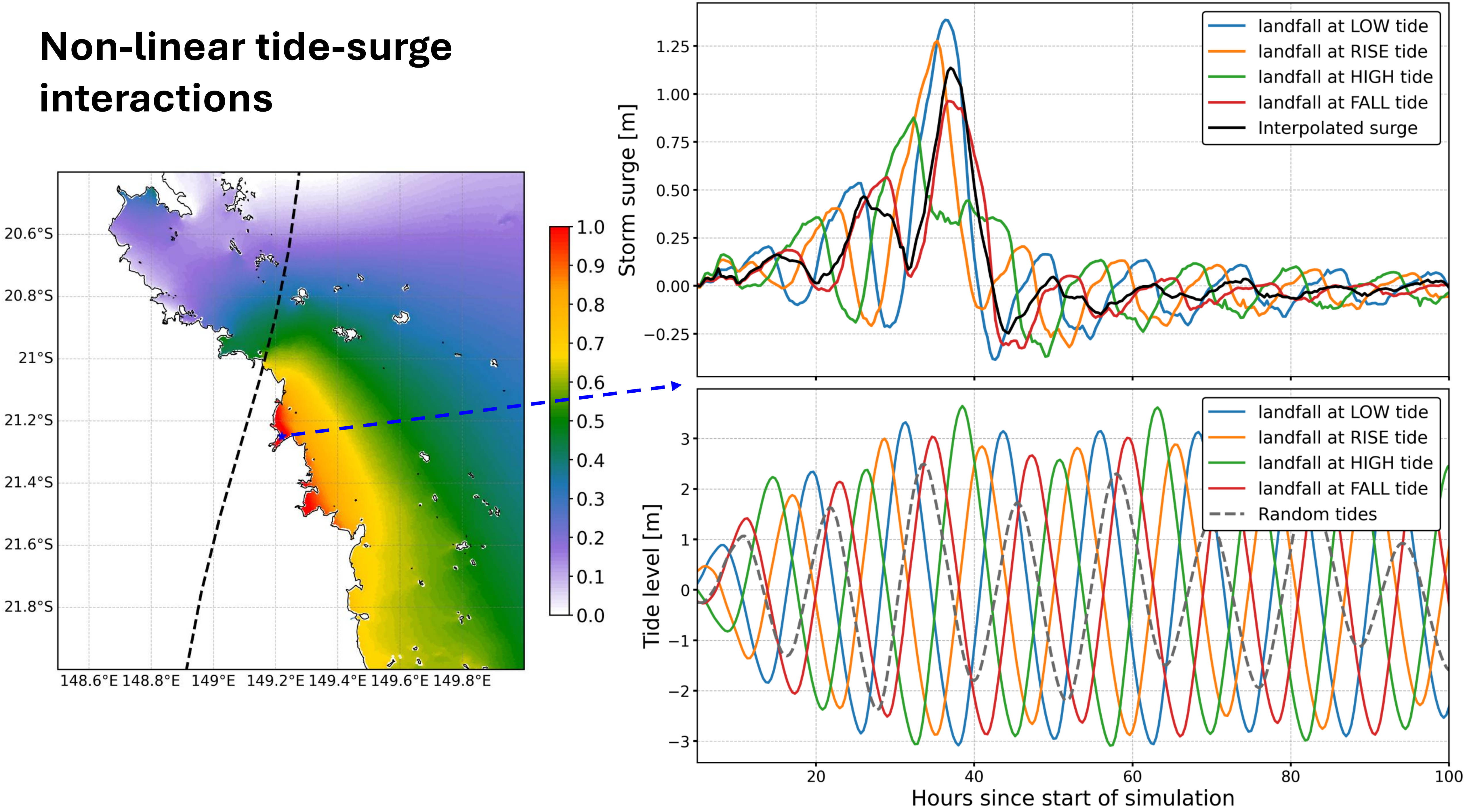


We ran simulations for each of these TCs

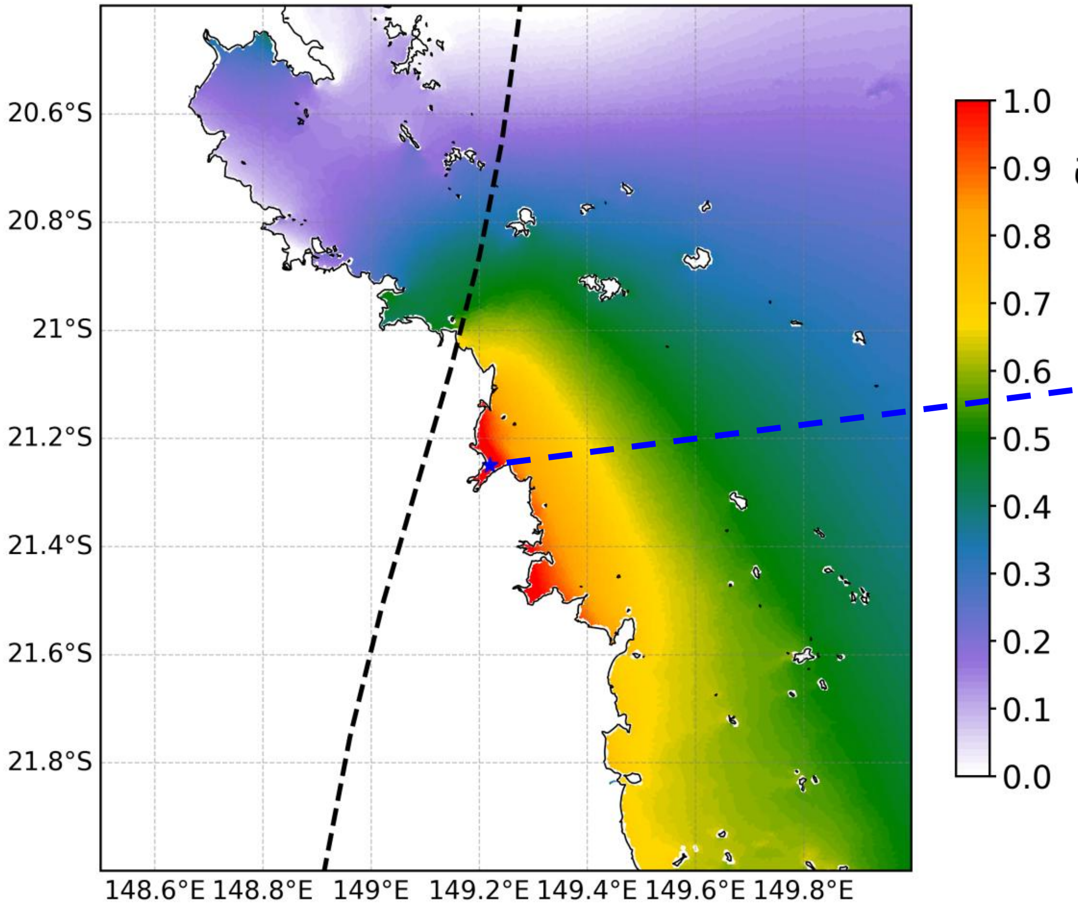
Non-linear tide-surge interactions

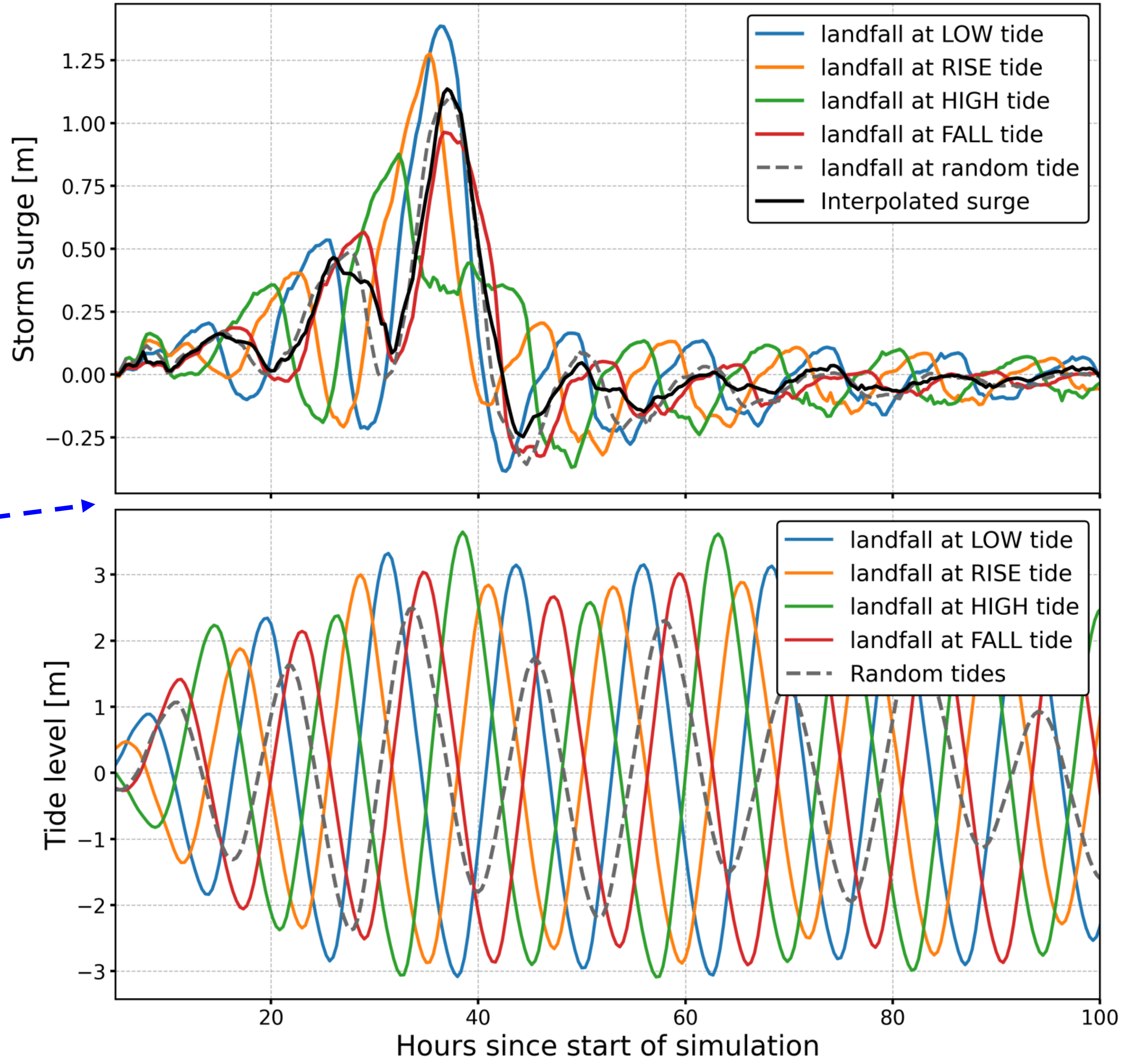


Non-linear tide-surge interactions



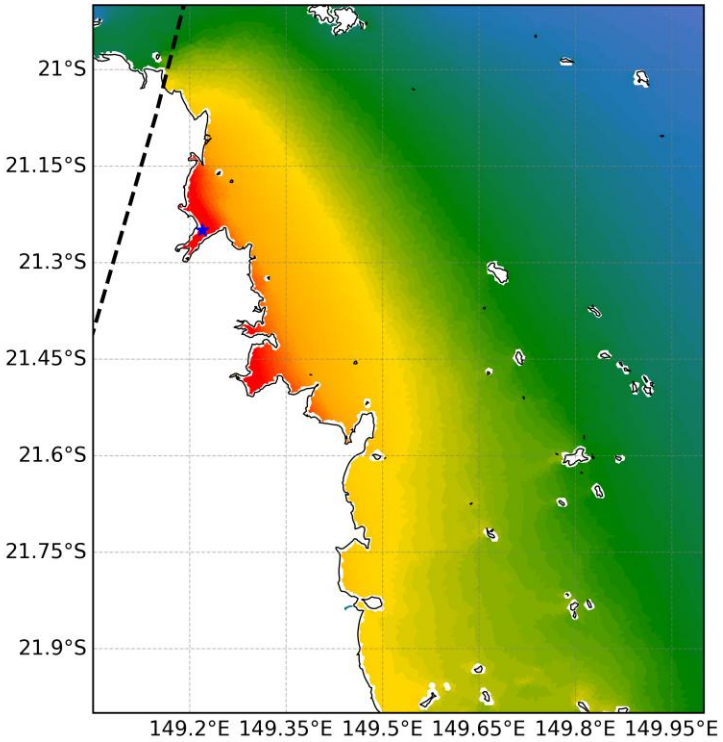
Non-linear tide-surge interactions



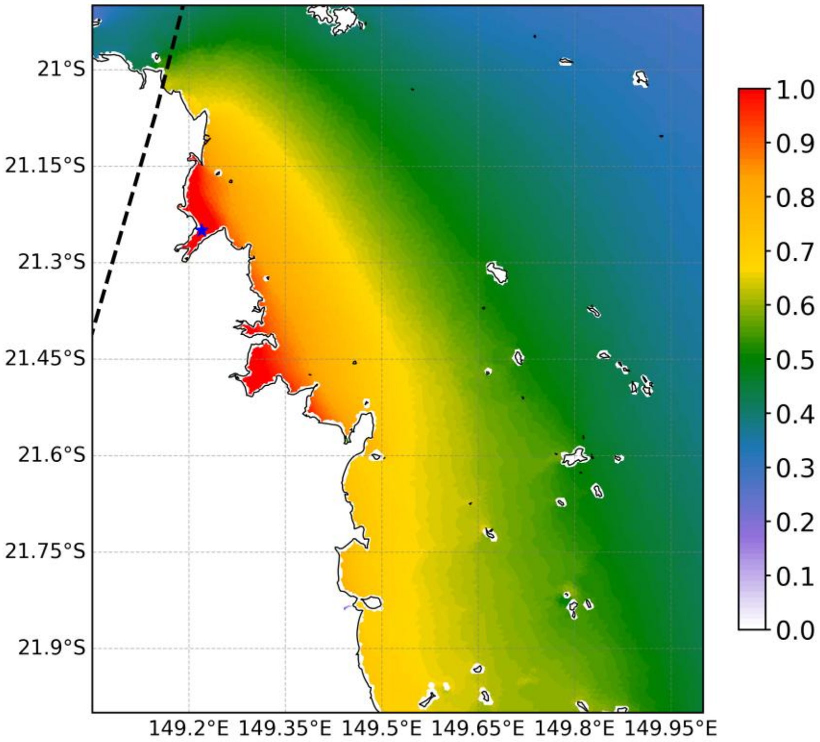


Non-linear tide-surge interactions

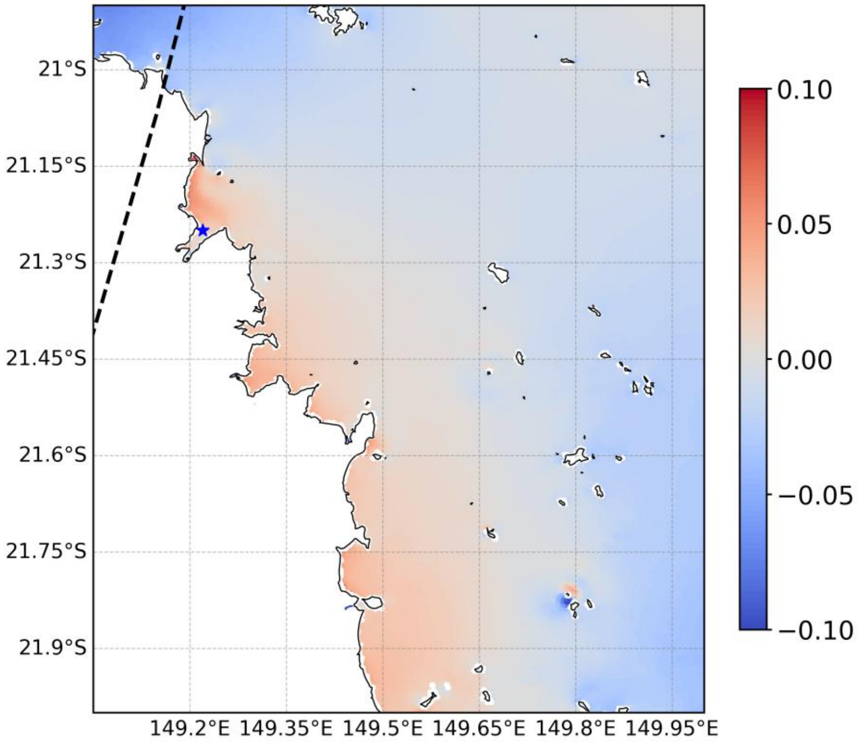
Storm surge (SCHISM)



Storm surge (Interpolated)

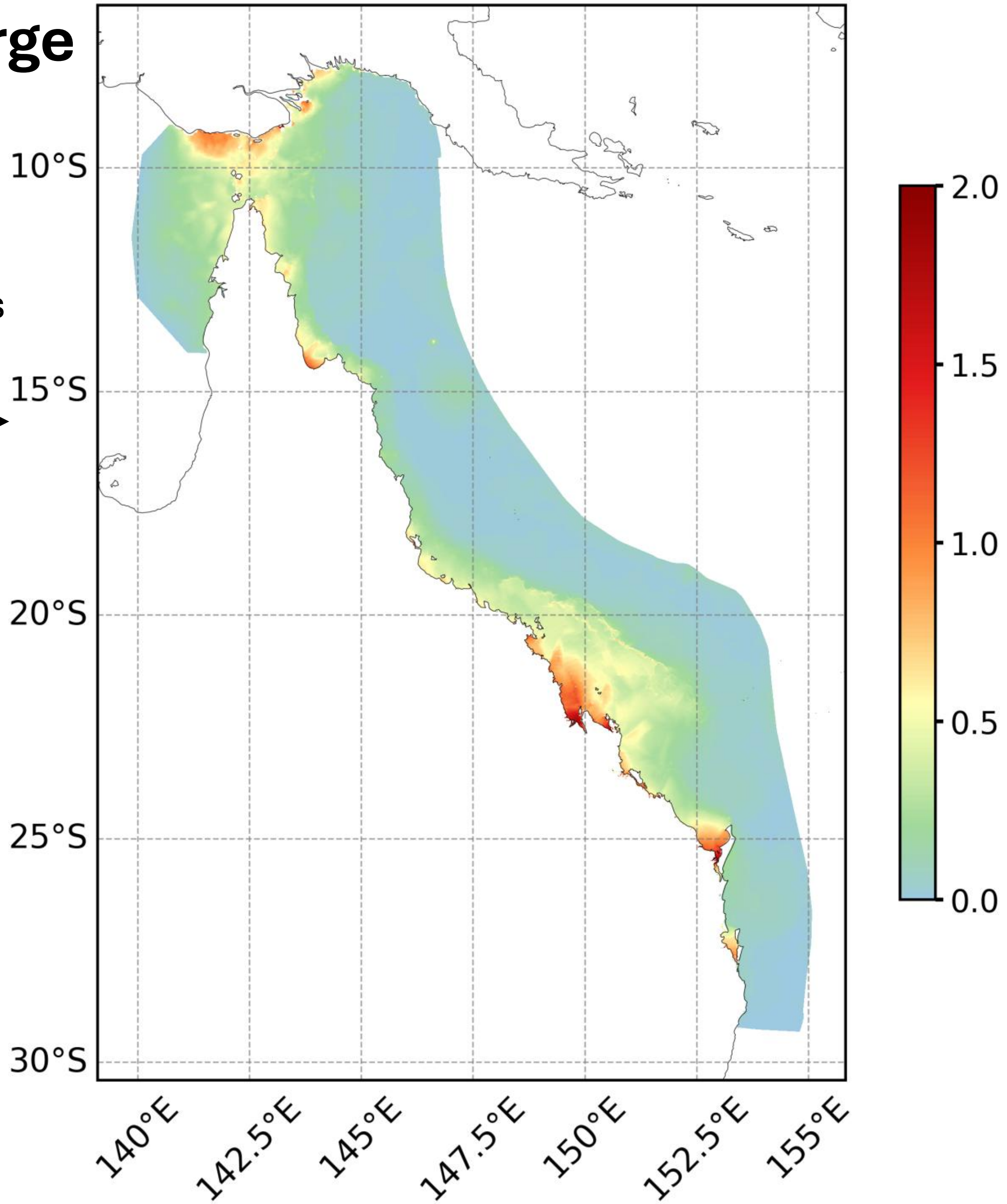


Differences

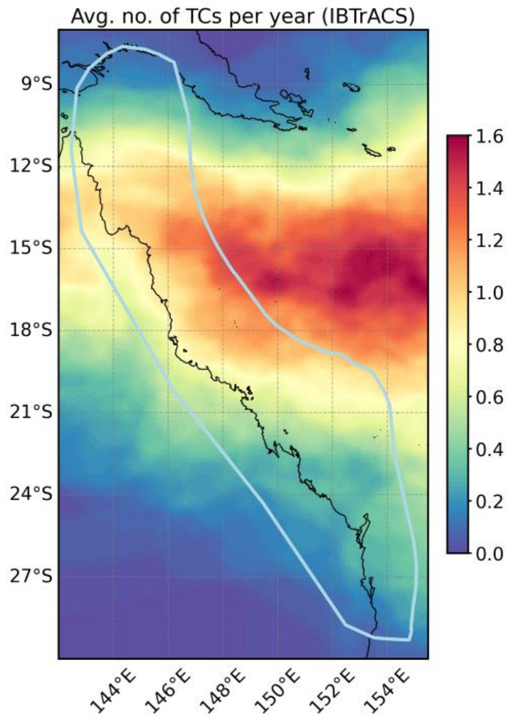


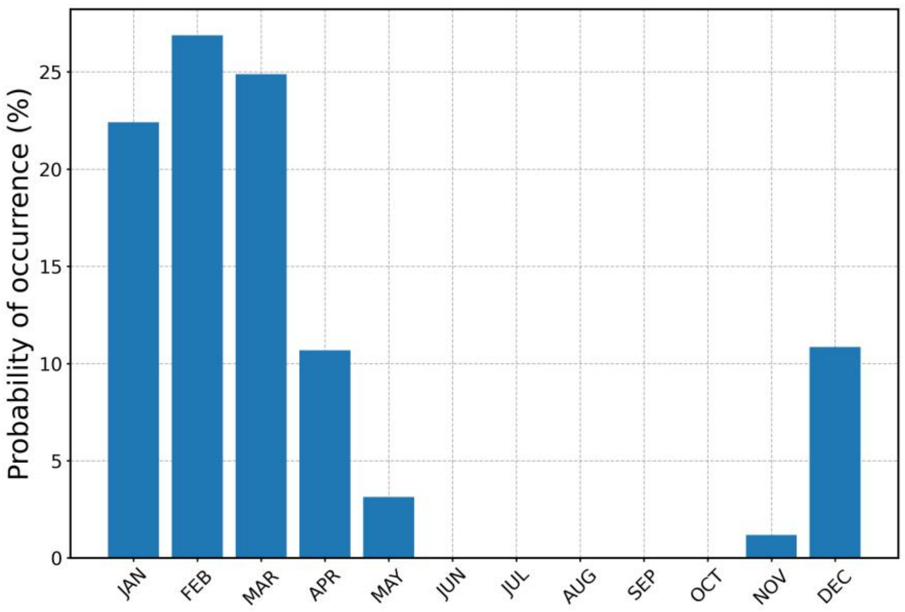
Non-linear tide-surge interactions

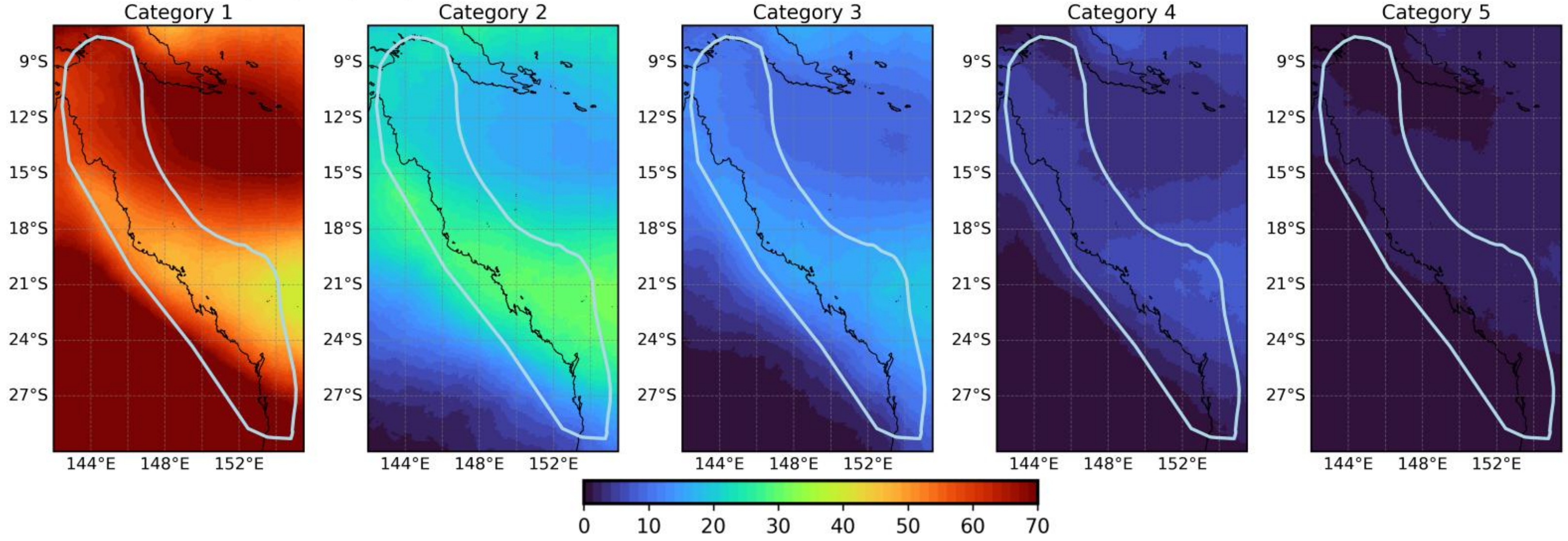
Maximum difference in storm surge across all TC simulations



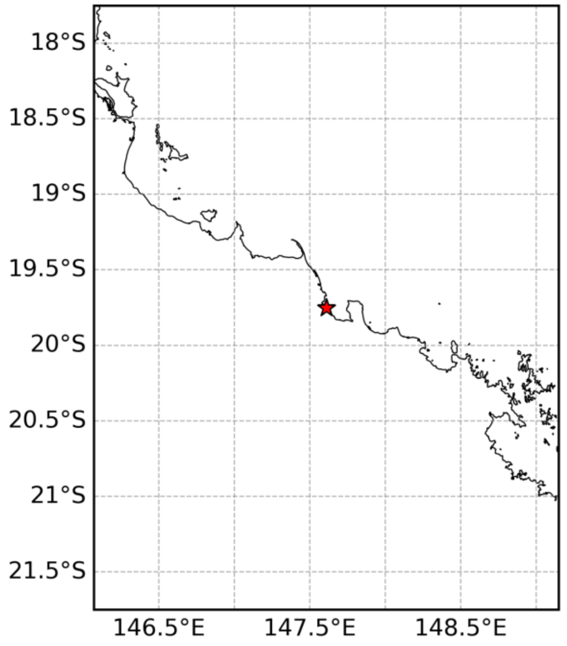
Tropical Cyclone probability distributions

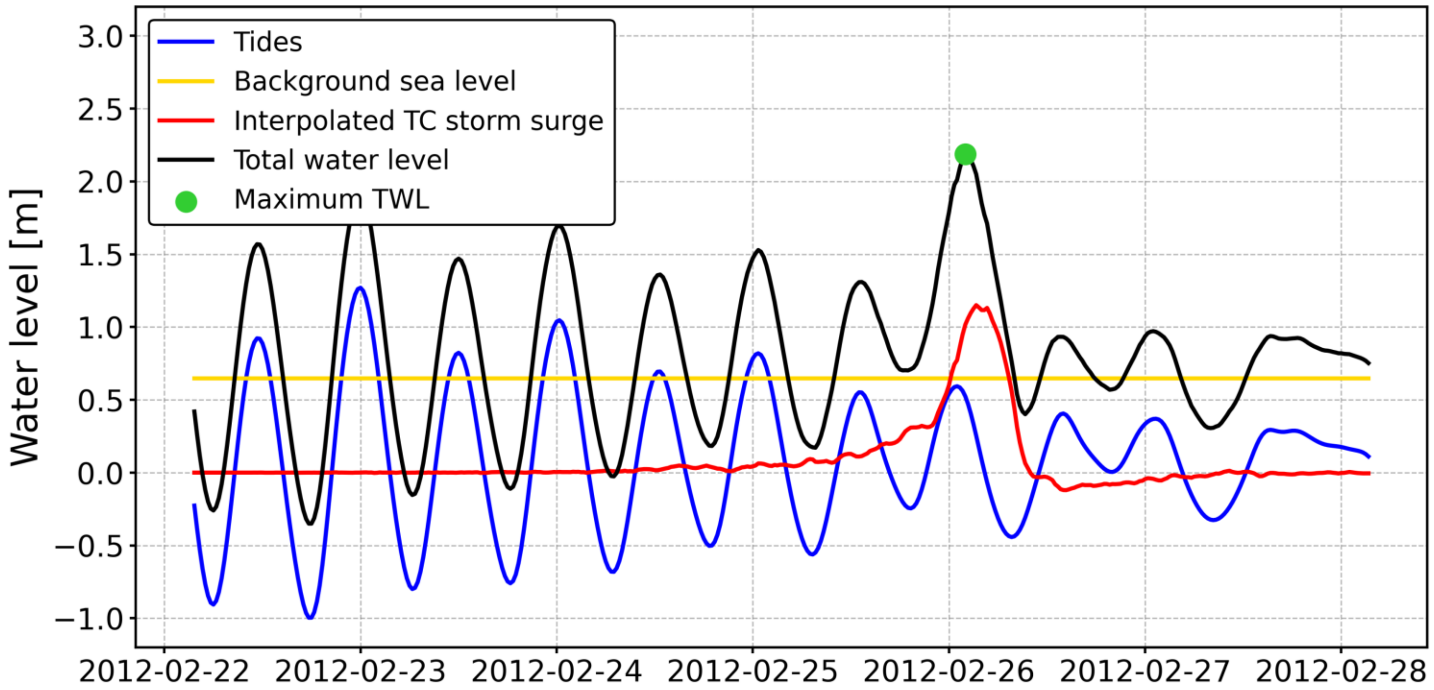


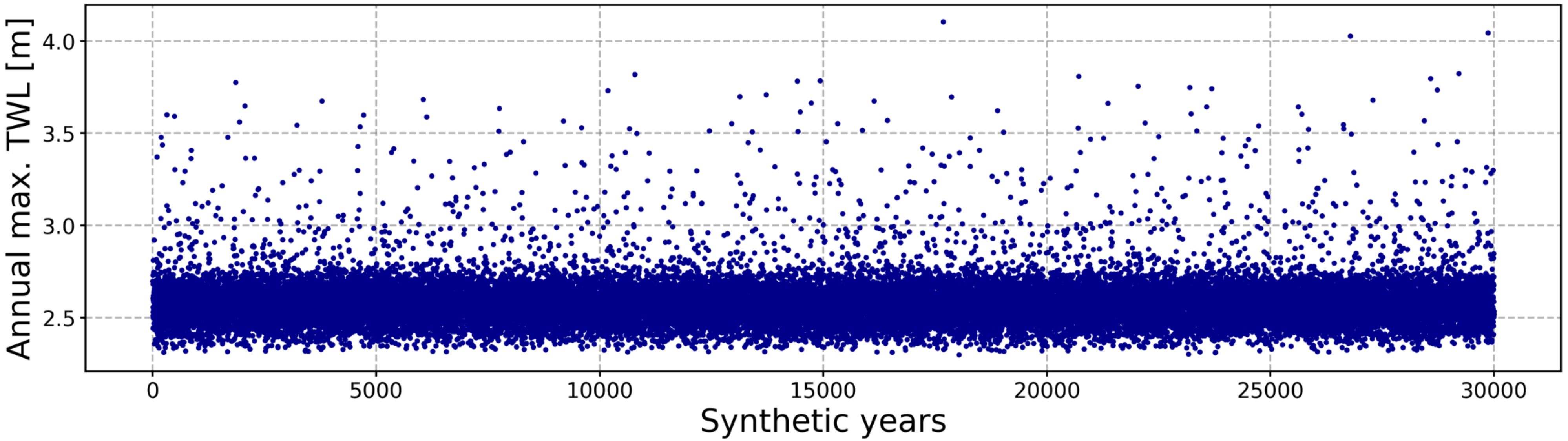


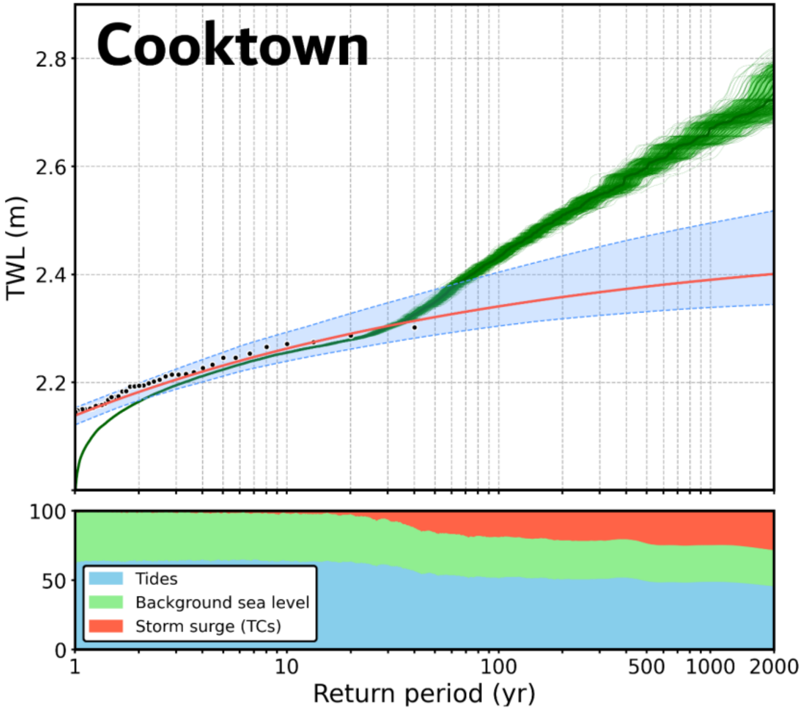


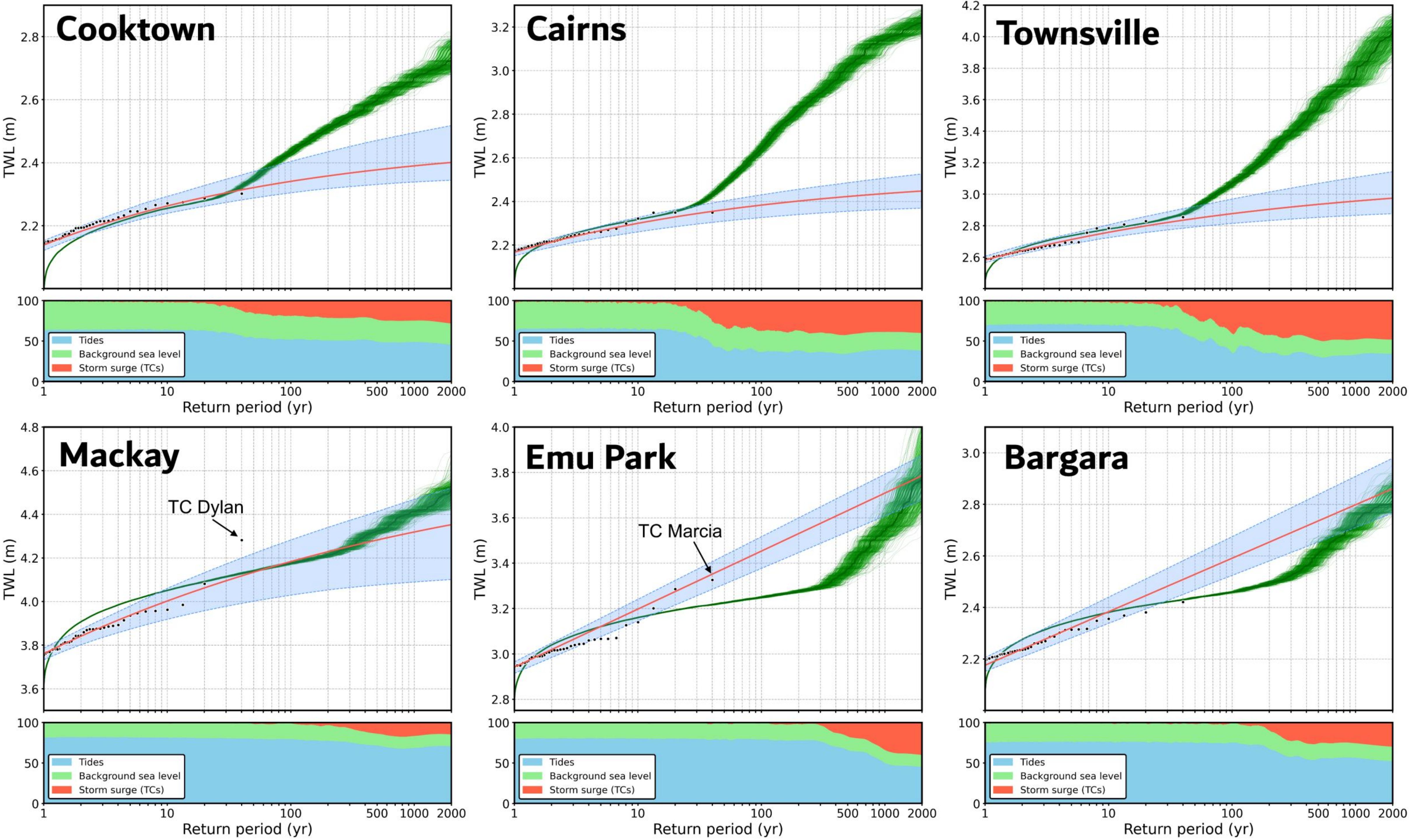
Total Water Level (TWL) emulator





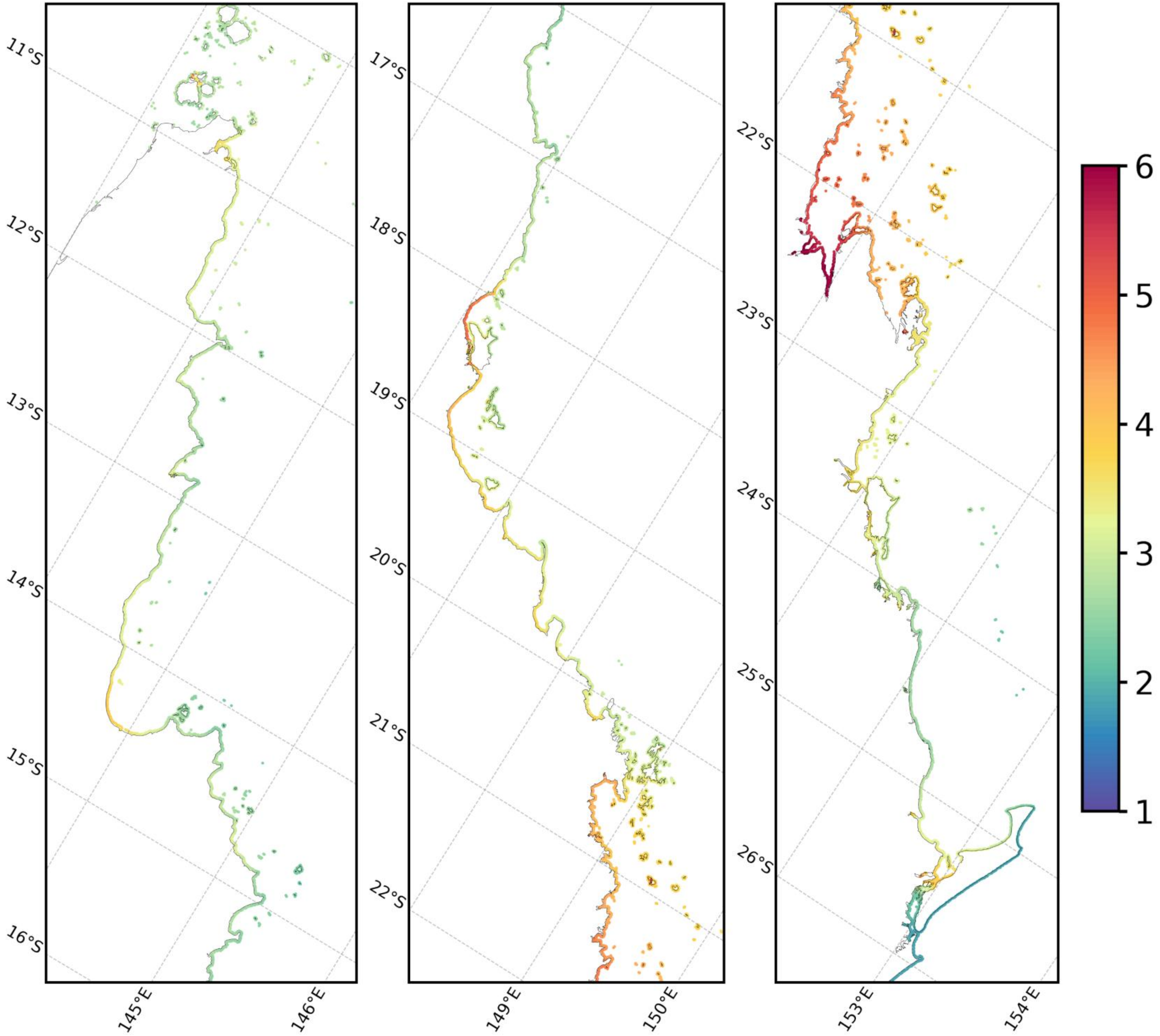



Cooktown
TWL (m)
2.8
2.6
2.4
2.2
100
50
0
Tides
Background sea level
Storm surge (TCs)
1
10
100
500
1000
2000
Return period (yr)



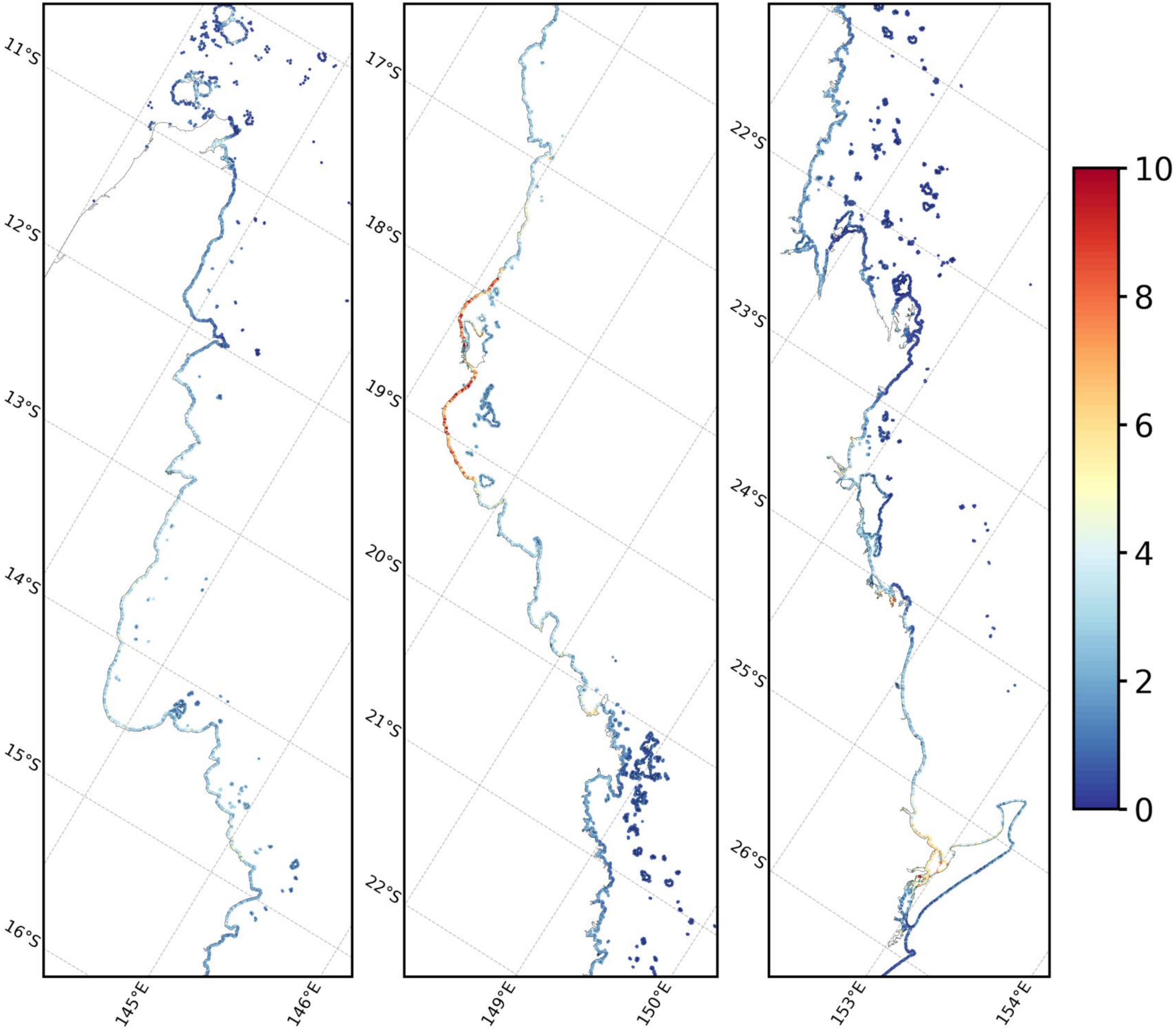
Cooktown
Cairns
Townsville
Mackay
TC Dylan
Emu Park
TC Marcia
Bargara
TWL (m)
Return period (yr)
Tides
Background sea level
Storm surge (TCs)

0.1% AEP TWL [m]



11°S
12°S
13°S
14°S
15°S
16°S
145°E
146°E
17°S
18°S
19°S
20°S
21°S
22°S
149°E
150°E
22°S
23°S
24°S
25°S
26°S
153°E
154°E
6
5
4
3
2
1

Uncertainty in 0.1% AEP TWL [%]



Conclusions

- The Monte Carlo emulator generates plausible realisations of coastal extreme sea levels, considering tides, background sea level and the impacts of TCs.
- It explicitly handles the strong non-linear interactions between tides and storm surge.
- Scalable and quick, which allows us to:
    - Improve the emulator by adding more TC simulations
    - Use a different TC probability distribution (e.g., future climate/ENSO)
    - Include sea level rise
- We're expanding this emulator to make robust estimations of wind speeds and wave heights around Australia

Thank you!

Questions?

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