Assessment of TC-Induced waves and storm surge in Vanuatu using a hybrid downscaling approach
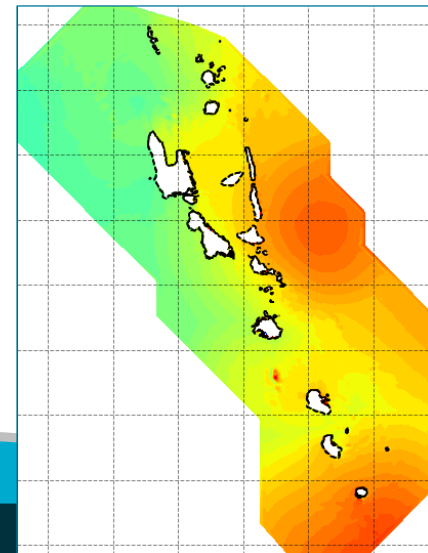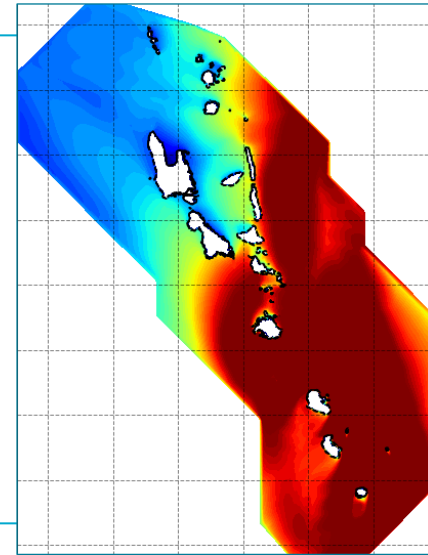

Climate Science Centre

Vanessa Hernaman, Ron Hoeke, Claire Trenham, Julian O'Grady, Hamish Ramsay

Sara O. van Vloten, Beatriz Pérez-Díaz, Jared Ortiz-Angulo, Laura Cagigal, Sonia Castanedo Bárcena, Fernando J. Méndez

Climate Information Services for Resilient Development in Vanuatu (Van-KIRAP)*

Climate Information Services for Resilient Development in Vanuatu (Van-KIRAP)

Activity 1.2.3: Projections for key climate variables (Temperature, Rainfall, Drought, Tropical cyclones)

Activity 1.2.4: Sea level and coastal inundation hazard analysis
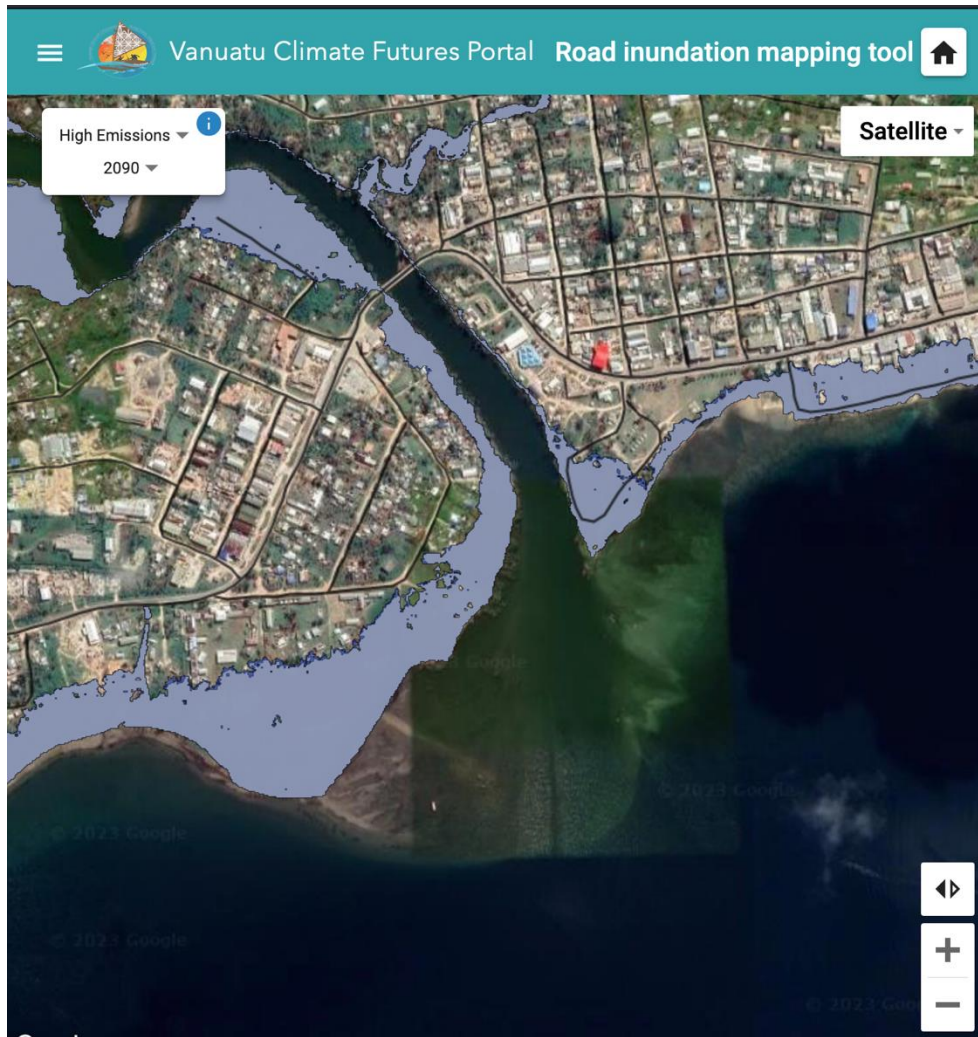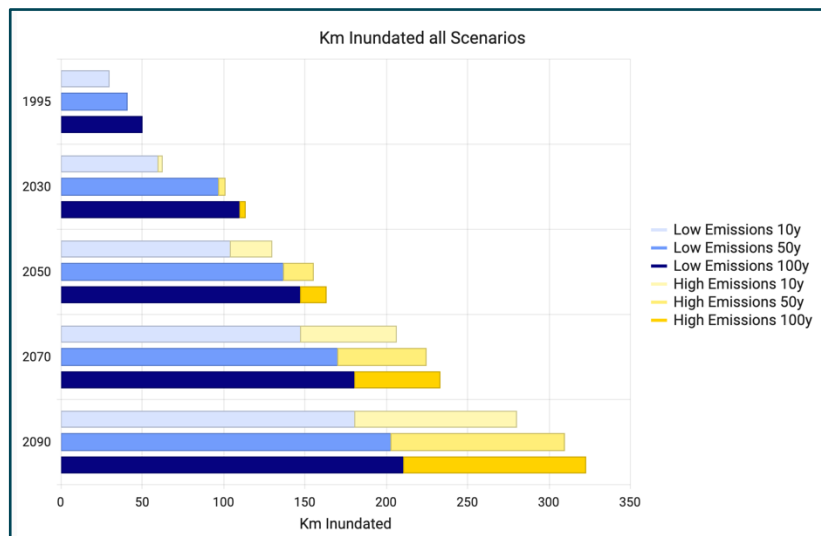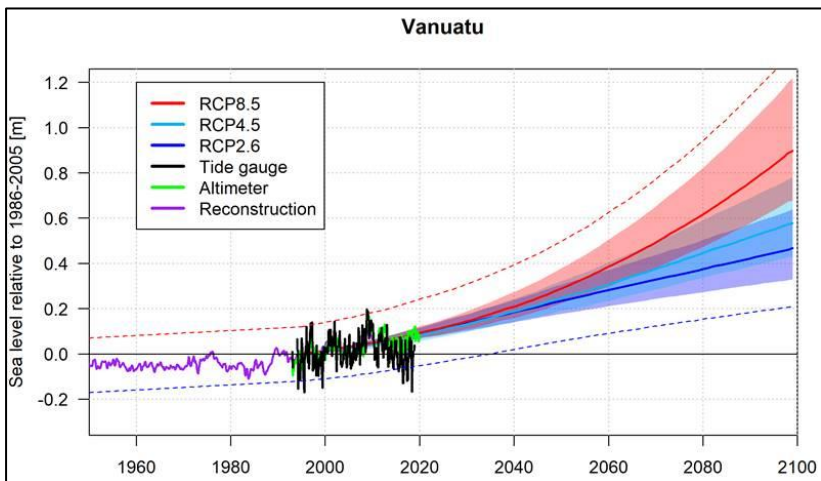
Activity 1.2.5: Ocean warming and acidification

Goal: Contribute meaningful coastal hazard and seal level rise information to relevant Vanuatu sectors at climate timescales

CSIRO and SPREP, " Current and future climate for Vanuatu: enhanced 'NextGen' projections Technical report," https://doi.org/10.25919/hexz-1r10

Vanuatu

★ National capital
TORBA Province name
◉ Province capital
── Road

0 25 50 75 100 Kilometers
0 25 50 75 100 Miles

Mercator Projection

Cyclone Pam: UN confirms 24 dead and 3,300 displaced in Vanuatu

🕒 16 March 2015

GETTY IMAGES

The devastation is widespread

https://www.bbc.com

■■■ BBC

Cyclone Harold : Superstorm hits Vanuatu after killing 27 in Solomons

A cyclone bringing winds of 135mph (215km/h) has arrived in the Pacific nation of Vanuatu.

6/04/2020

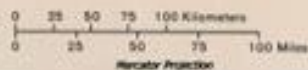# State of emergency declared in Vanuatu after second cyclone in a week

4 March 2023 https://www.theguardian.com

Cyclone Kevin passed over the capital Port Vila less than three days after Cyclone Judy cut power in the city

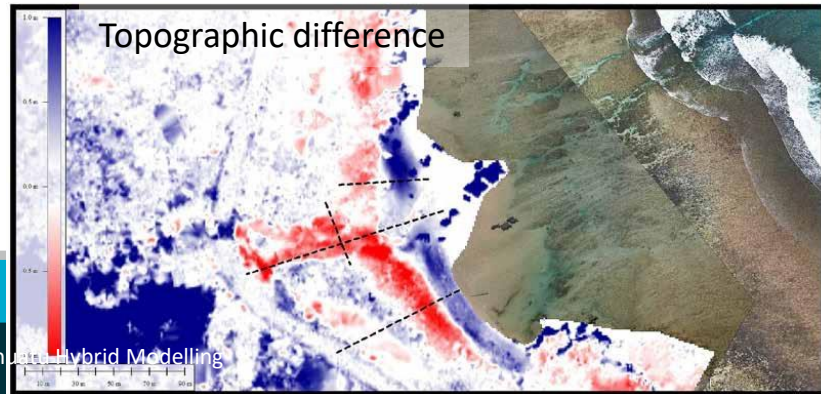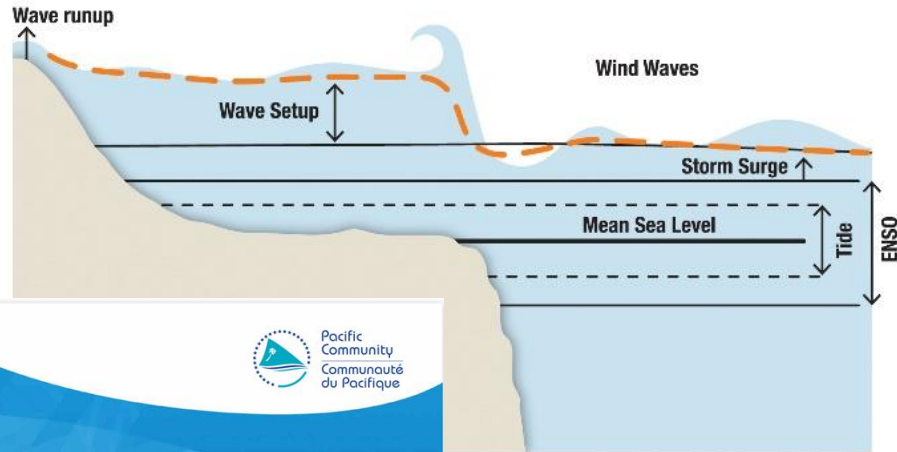# Oceanic islands: wave setup significant contributor to coastal extreme sea levels
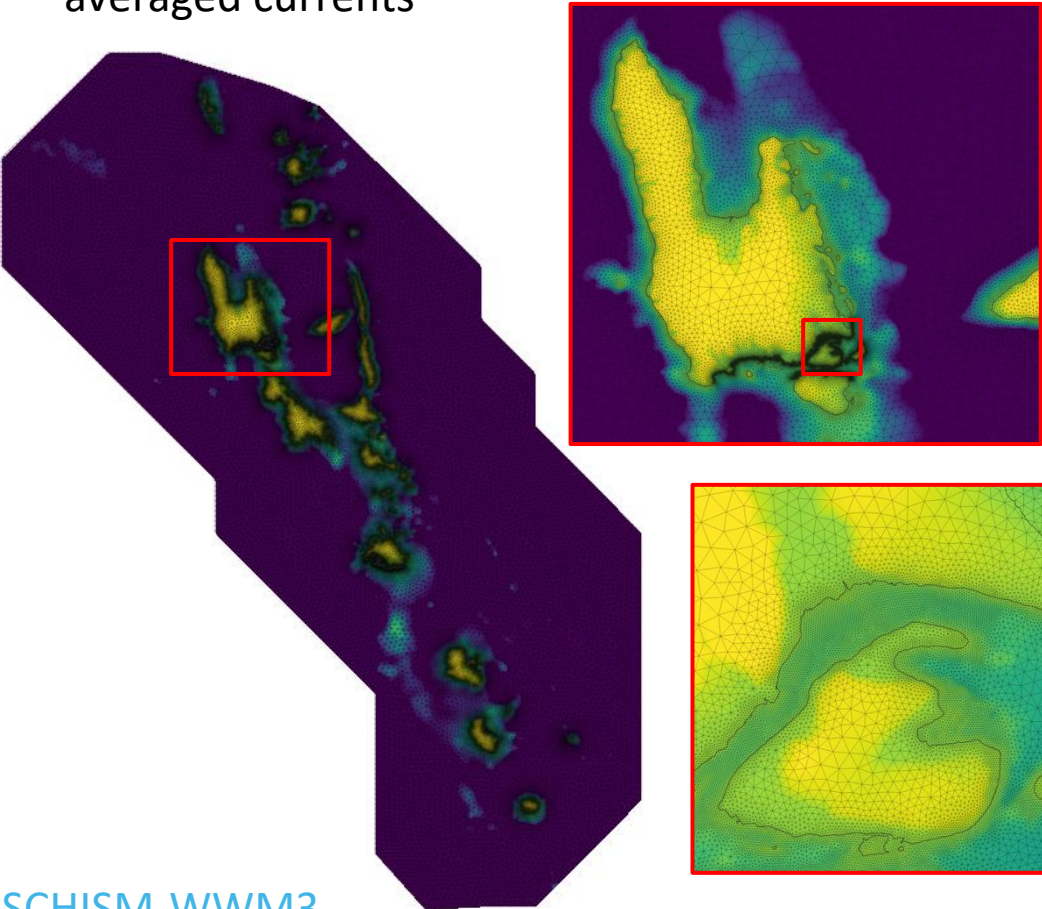

Before

After

Topographic difference

Vanuatu Coastal Hazard Modelling System

National-scale wave-flow coupled numerical model
- 40-year historical hindcast (1980 – 2020)
- Hourly outputs of waves, water levels, depth-averaged currents

~110k nodes/400k elements	~100m resolution near coastline
Astronomical tides and currents	TPXO version 9.2
Surface winds and sea-level pressure	NOAA CFSR + Holland vortex winds
Sea level variability and rise	ECMWF ORAS5 (w/ geodetic correction)
Wind-waves (SS)	BoM/CSIRO CAWCR Wave hindcast spectral output
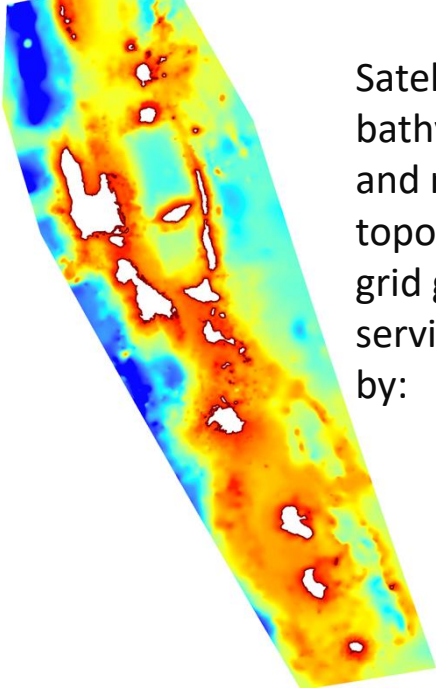
Satellite-derived bathymetry (SDB) and multisource topo/bathymetry grid generation services provided by:
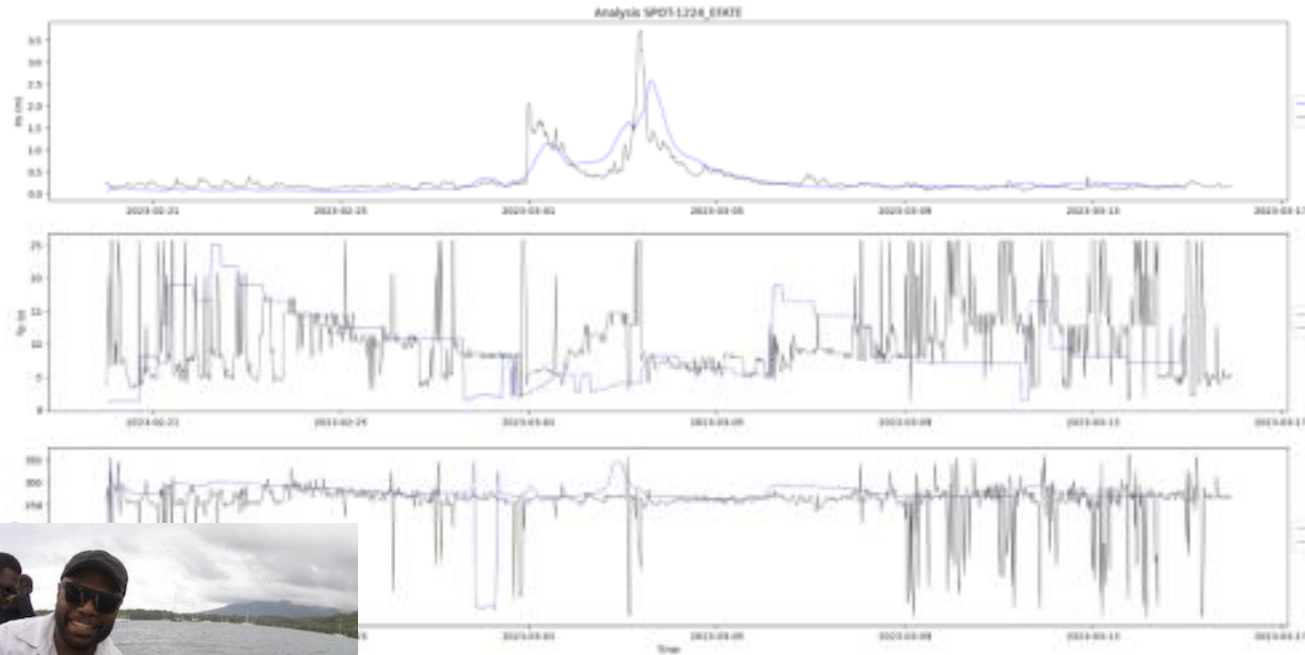
EOMAP
detect more.

SCHISM-WWM3

Y. J. Zhang, F. Ye, E. V Stanev, and S. Grashorn, "Seamless cross-scale modeling with SCHISM," *Ocean Model (Oxf)*, vol. 102, pp. 64–81, Jun. 2016, doi: 10.1016/j.ocemod.2016.05.002.

CSIRO
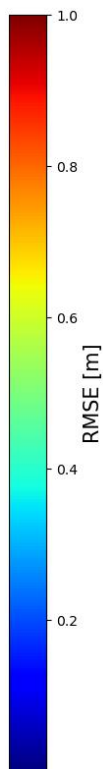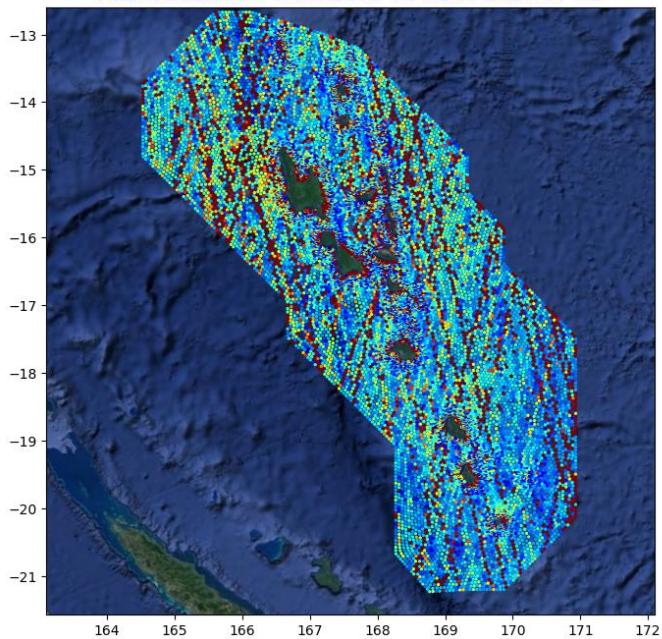
Vanuatu Coastal Monitoring

Supported procurement and deployment of Sofar Spotters, RBR sub-surface recorders and OA Test kits on behalf of VMGD and Fisheries
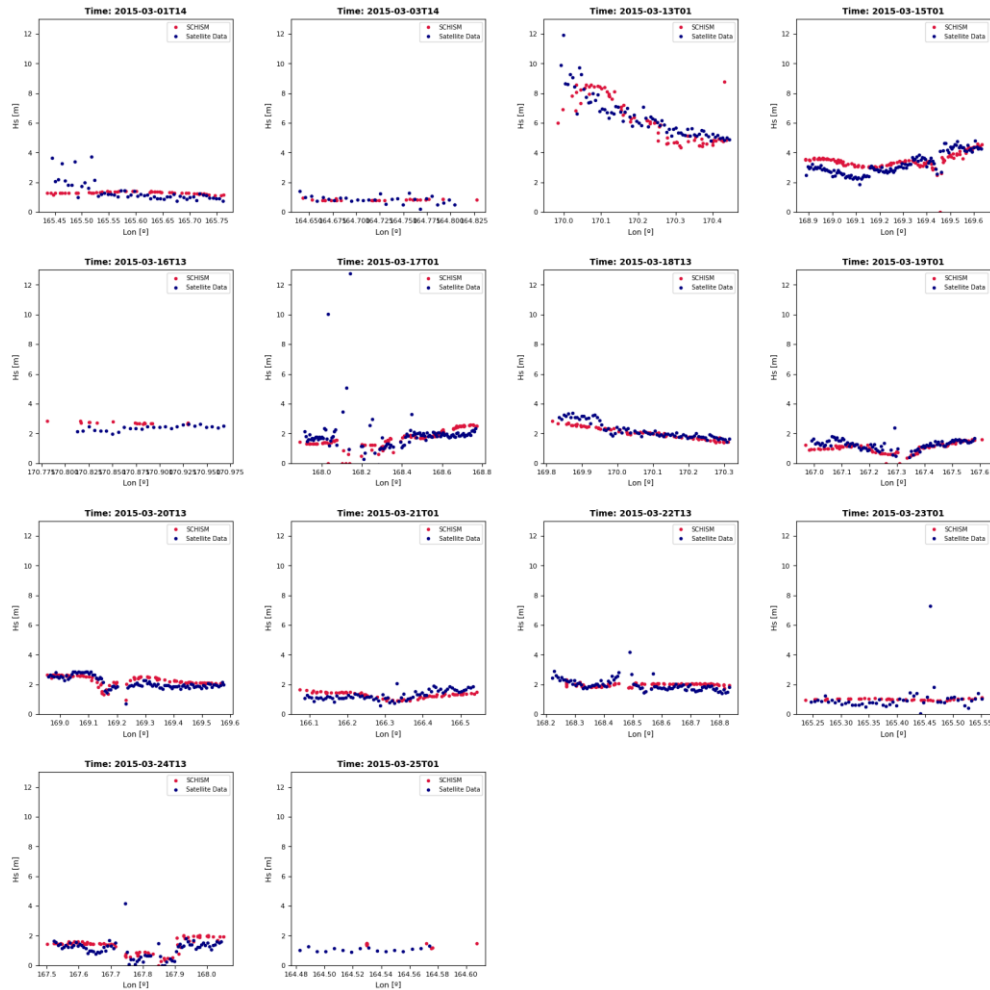
Vanuatu Coastal Hazard Modelling System: verification
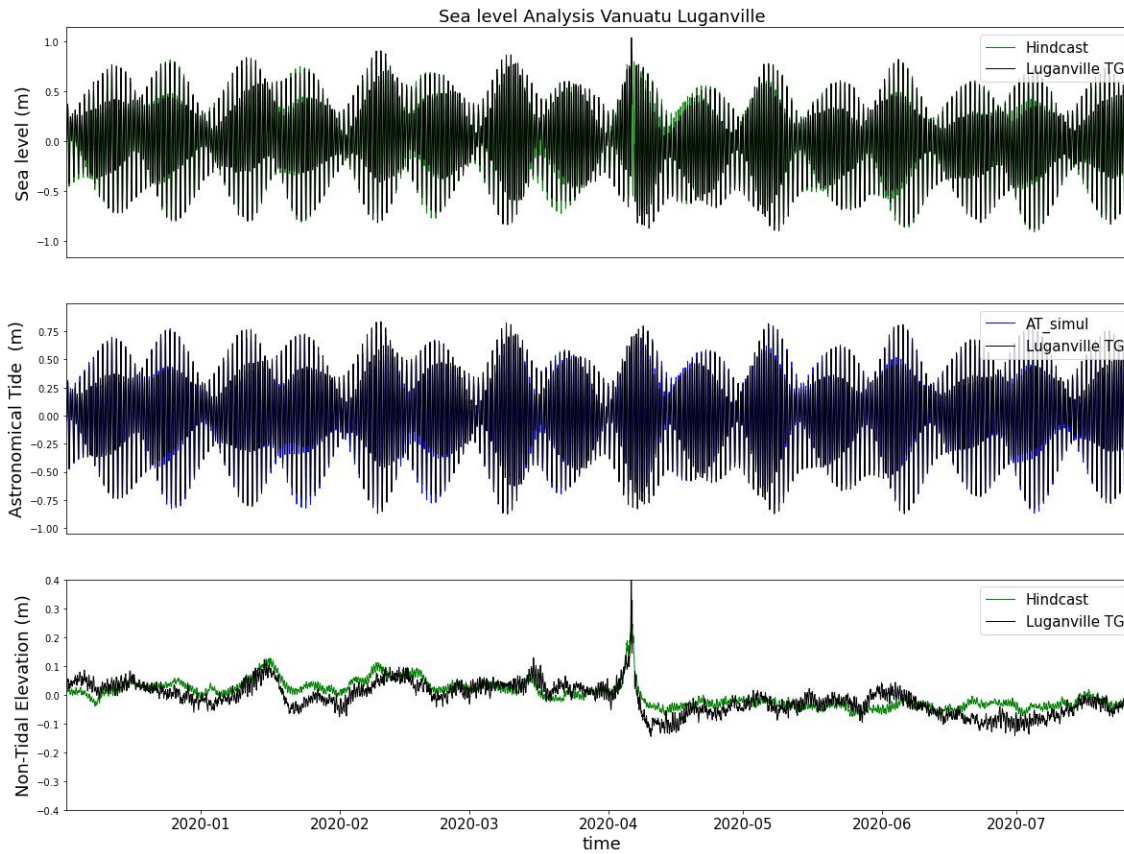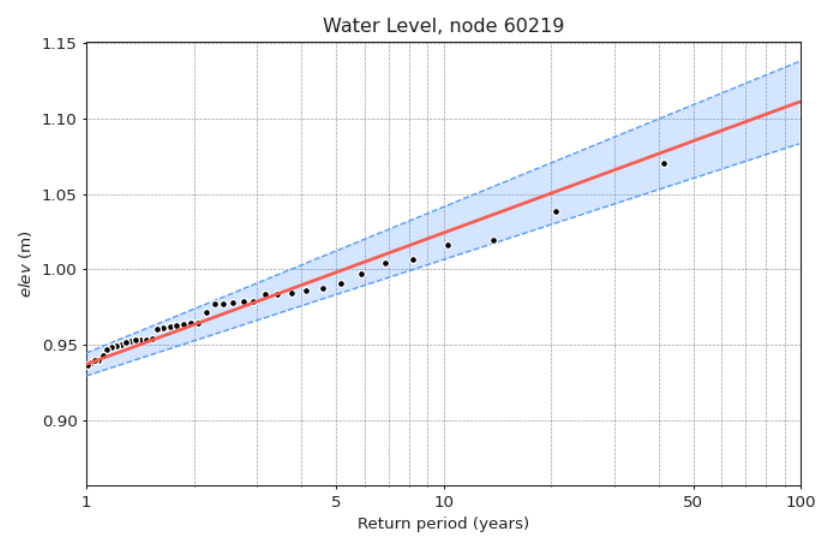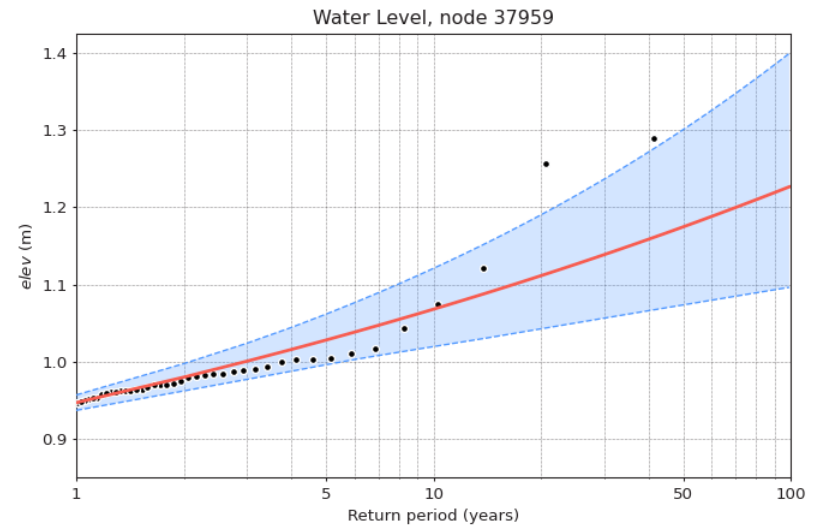
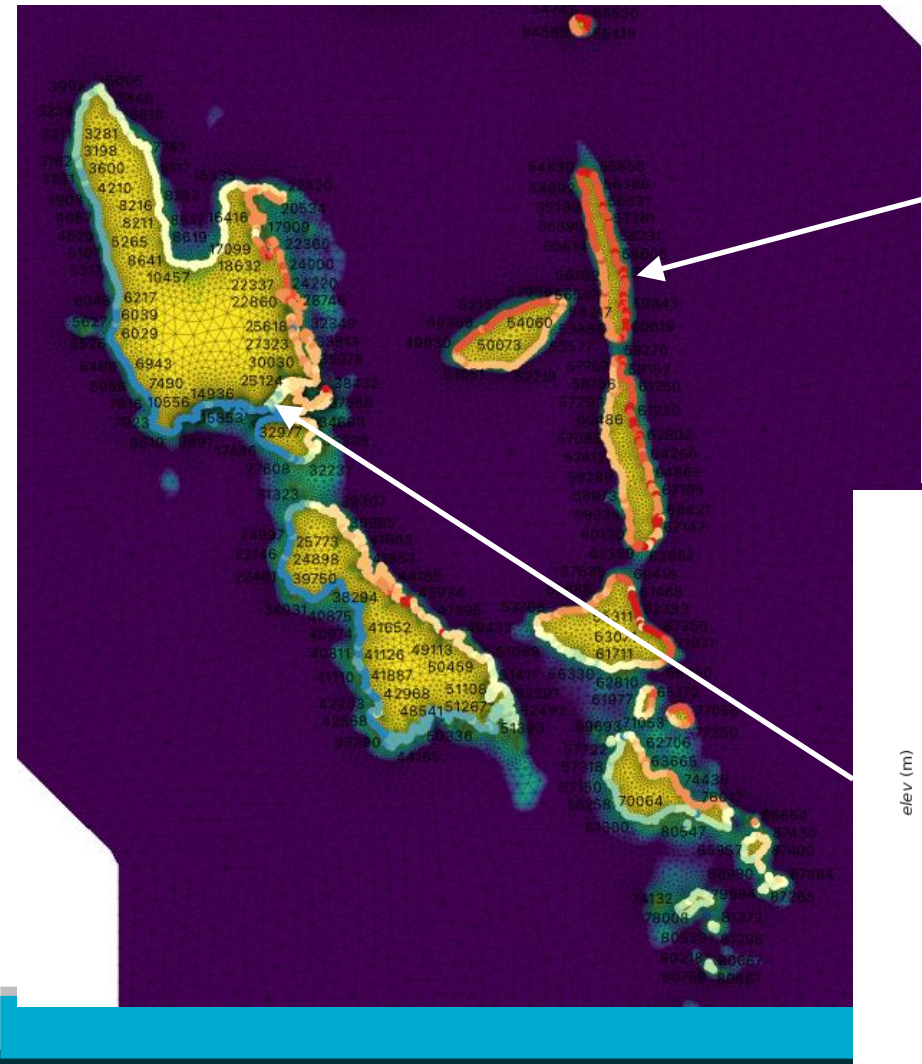## Waves
Satellite altimetry

Vanuatu Coastal Hazard Modelling System:
verification
## Port Vila and Luganville tide gauges
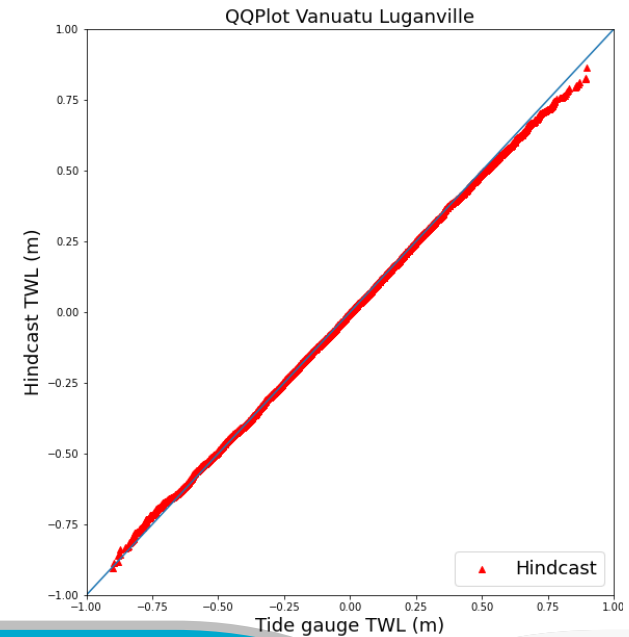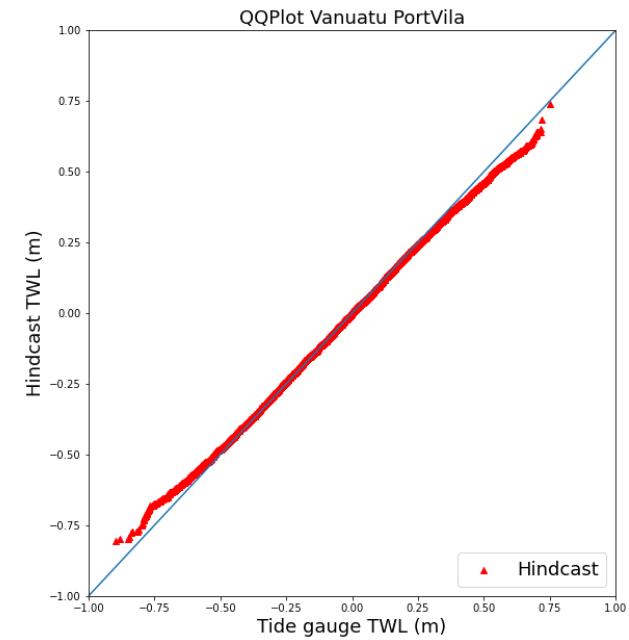
Vanuatu Coastal Hazard Modelling System:

The problem: Tropical Cyclones (TCs) are locally rare, high impact events, resulting in high uncertainty: coastal extreme water levels
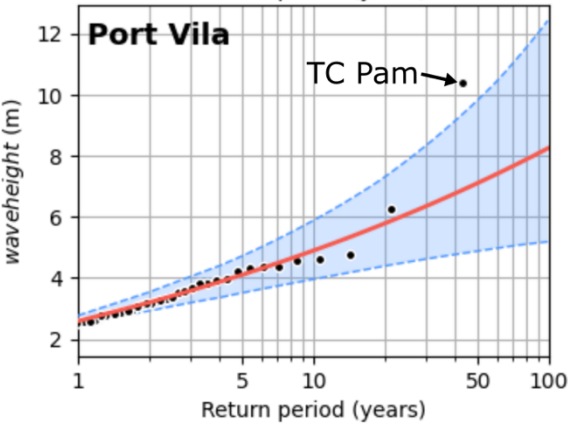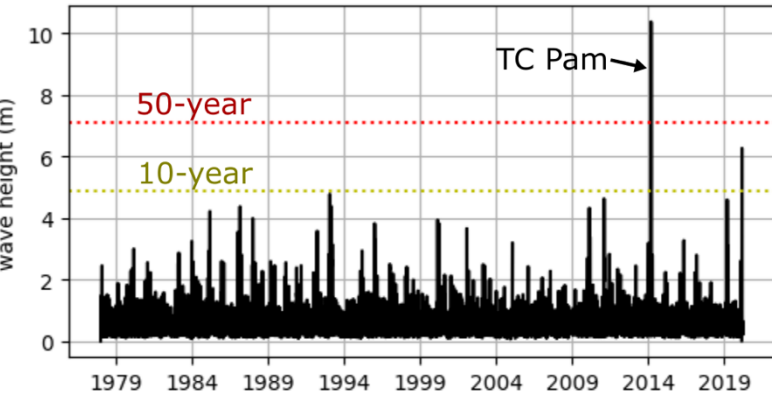
Vanuatu Coastal Hazard Modelling System:

The problem: Tropical Cyclones are locally rare, high impact events, resulting in high uncertainty: Storm Waves
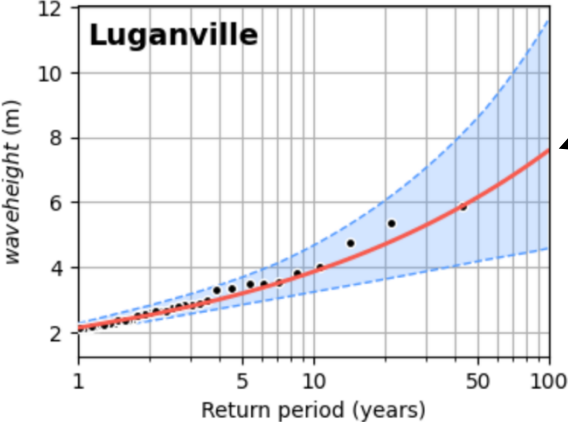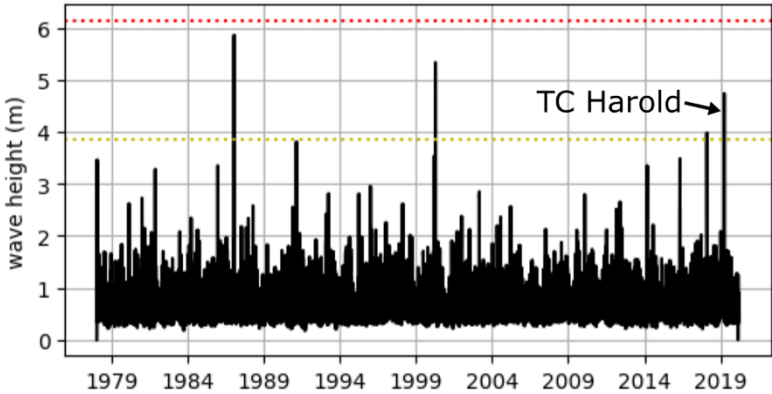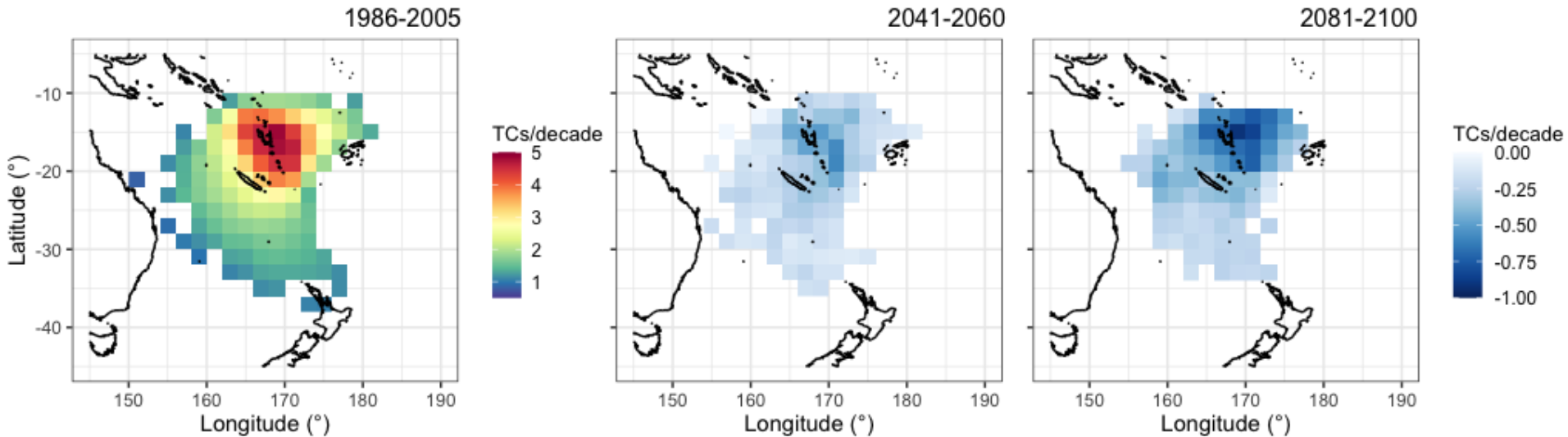

Is the 1-in-100 year storm wave 5 m or 12 m?

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Vanuatu Coastal Hazard Modelling System:

Dynamic/probabilistic synthetic TC populations* with different climate reanalysis and regional/CMIP models

MIT regional synthetic track model (e.g., Emanuel et al., 2008; Emanuel, 2013); able to reproduce the observed spatial characteristics of TCs as well as their seasonal cycle (Ramsay et al. 2018) in the Southern Hemisphere.

* Developed by Created by Hamish Ramsey (CSIRO), based on (e.g.):

Emanuel, Sundararajan, Williams, 2008. Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. *BAMS*, 89 (3), pp.347-368.

Emanuel, 2013. Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. *PNAS*, 110 (30), pp.12219-12224.

Ramsay, Chand, Camargo, 2018: A statistical assessment of Southern Hemisphere tropical cyclone tracks in climate models. *J. Climate*, 31 (10), pp.081-10

CSIRO

Vanuatu Coastal Hazard Modelling System:
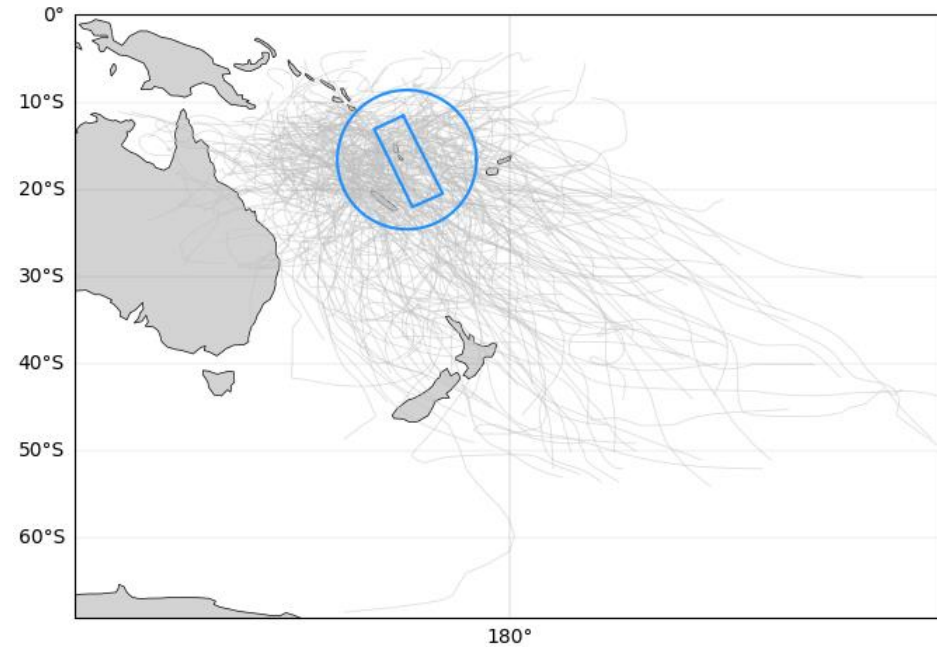## TC characterisation: geometric considerations
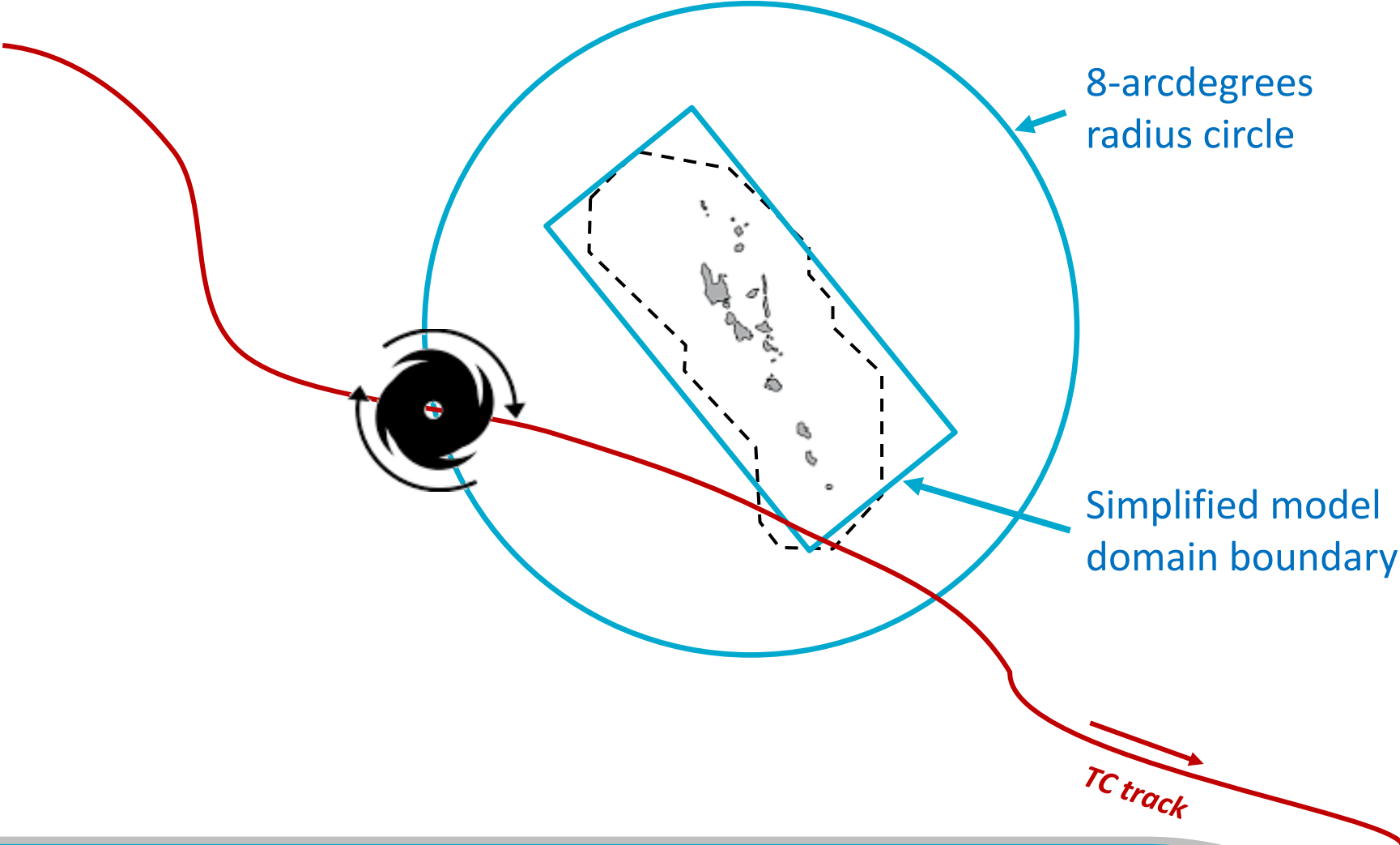
8-arcdegrees radius circle
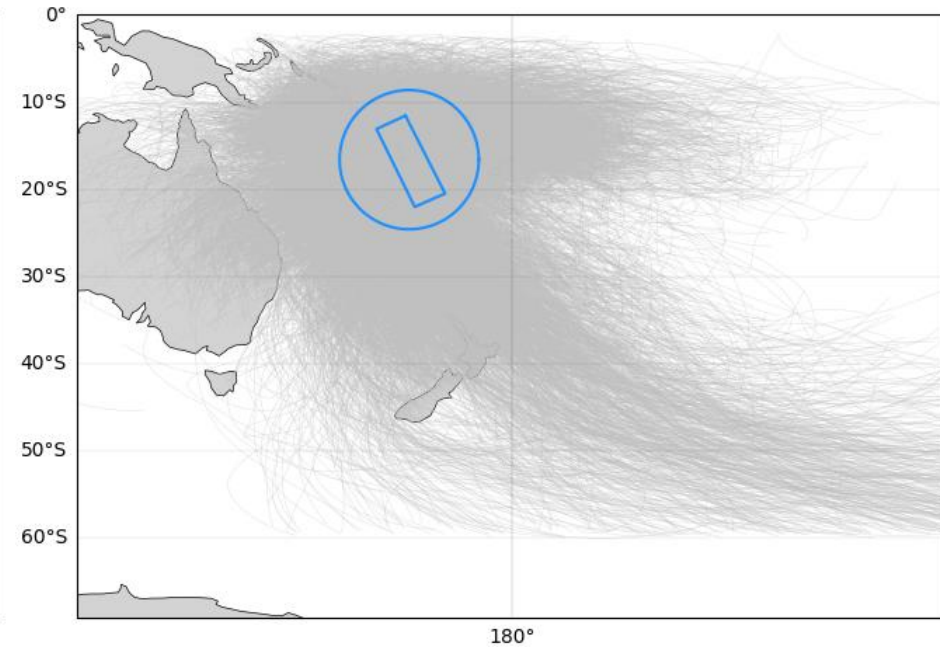
Simplified model domain boundary

TC track

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Vanuatu Coastal Hazard Modelling System:

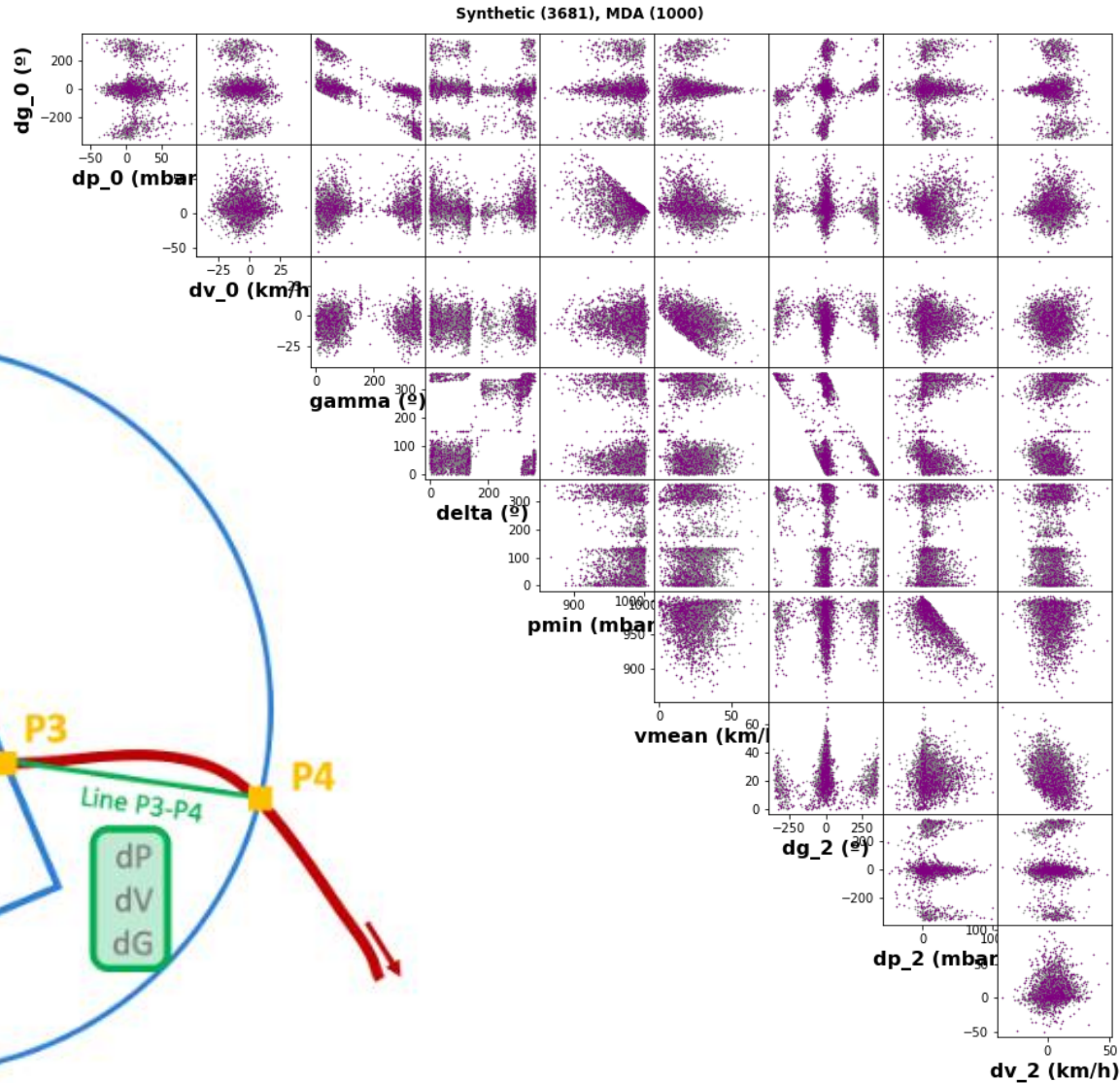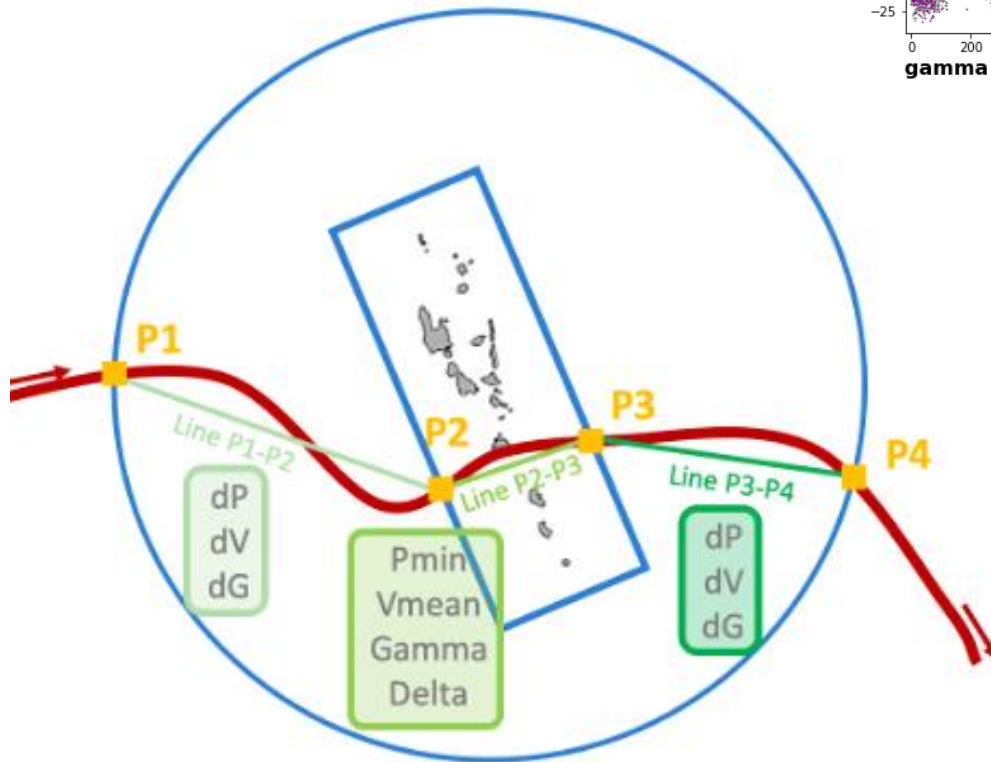Historical versus synthetic TC populations

Historical (IBTrACS): 105 TCs

Synthetic: 3852 TCs

NCEP-based

CSIRO

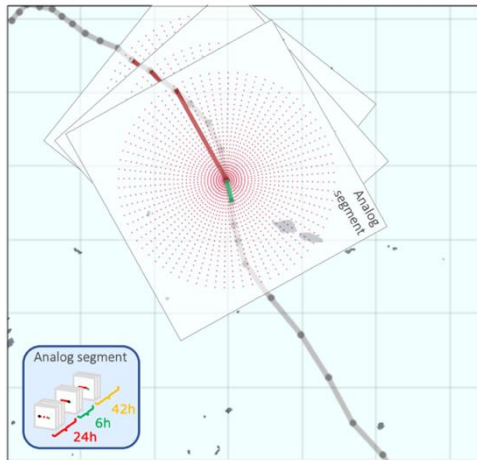# National scale hybrid TC Storm surge and storm wave modelling:

Step 1: maximum dissimilarity algorithm (MDA), select 1000 TCs

National scale hybrid TC Storm surge and storm wave modelling:

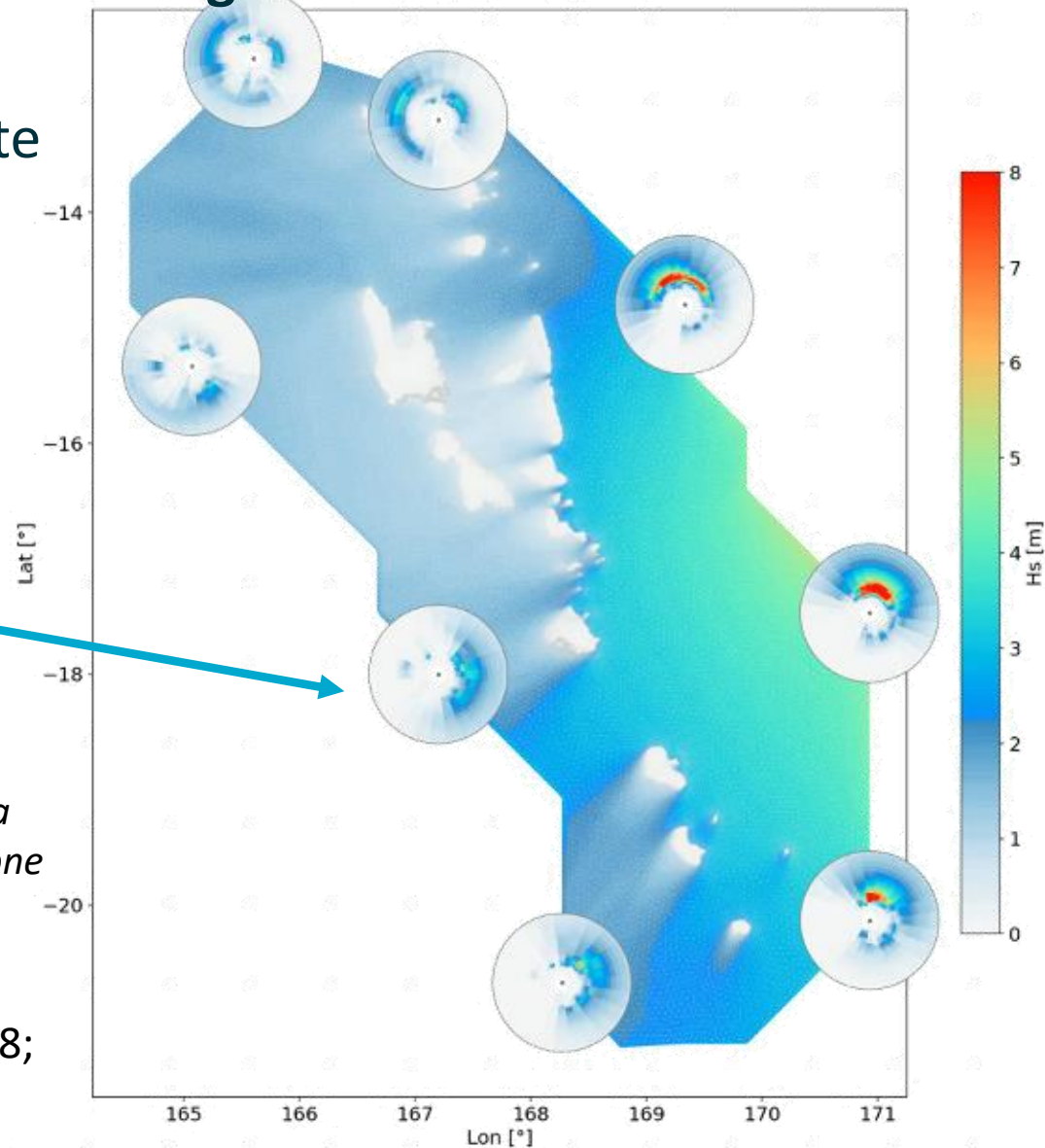## Step 2: dynamically simulate 1000 synthetic TCs

Wave boundary forcing:

van Vloten, et al, (in review), *SHyTCWaves: a Stop-motion Hybrid Model for Tropical Cyclone induced Waves*, Ocean Engineering.
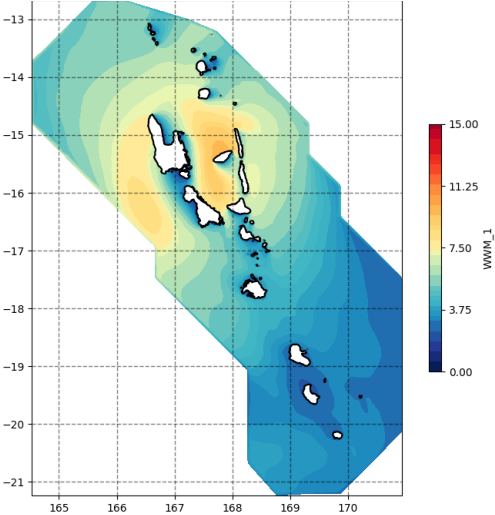
Inside computational domain:

Modified Holland Vortex (Fleming, 2008; Holland, 2010)

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National scale hybrid TC Storm surge and storm wave modelling:

CFSR + CAWCR
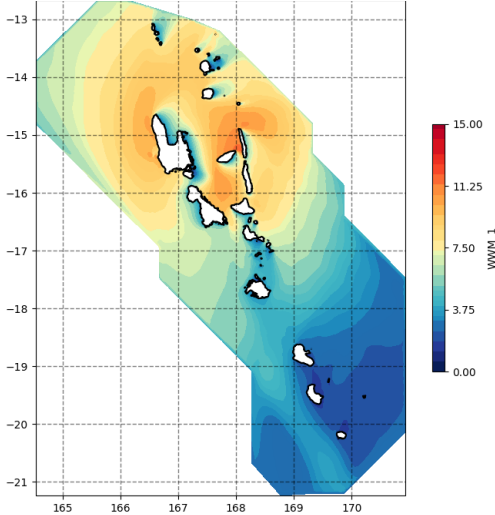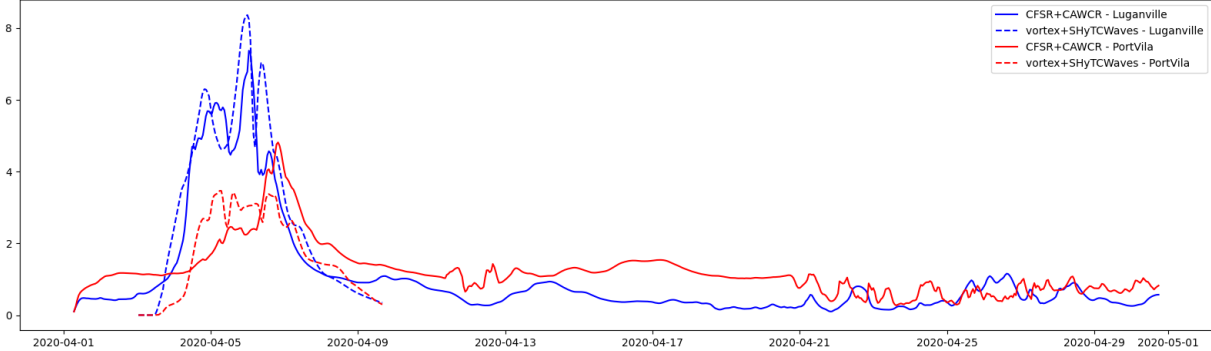
Vortex + ShyTCWaves

TC Harold

National scale hybrid TC Storm surge and storm wave modelling:
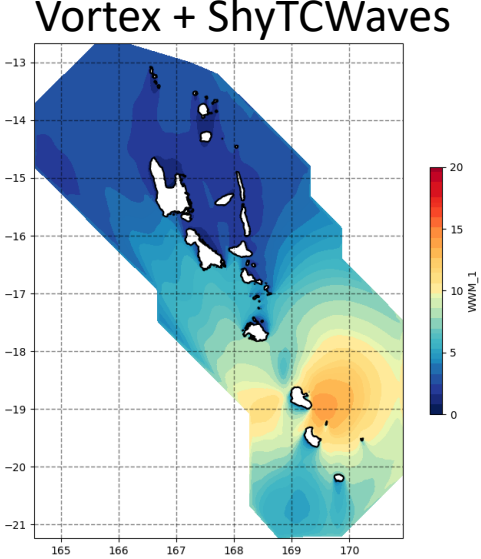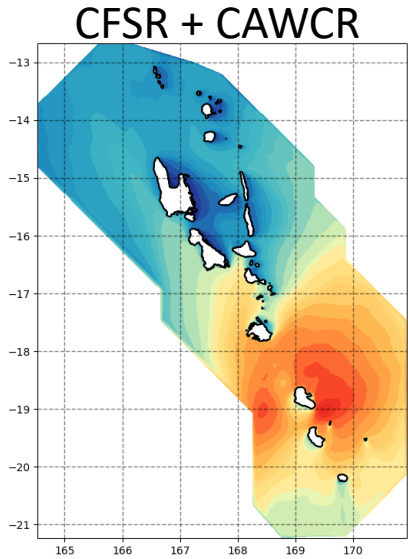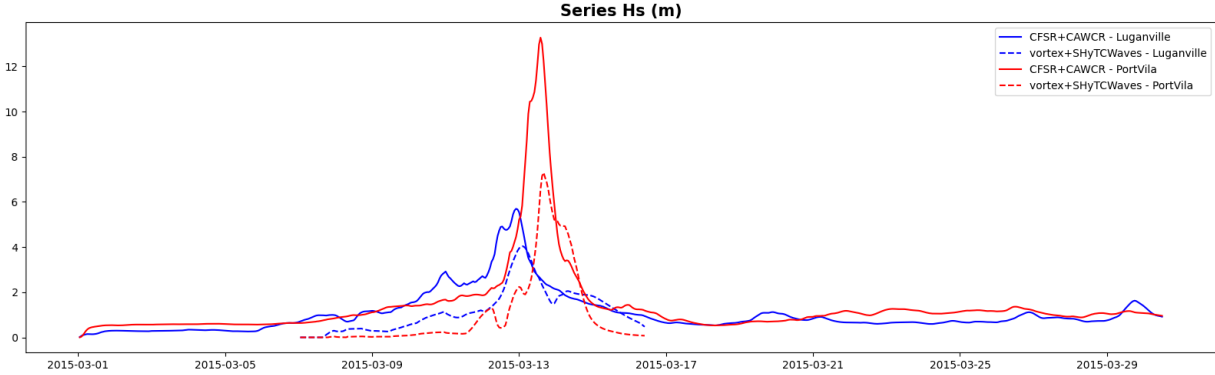
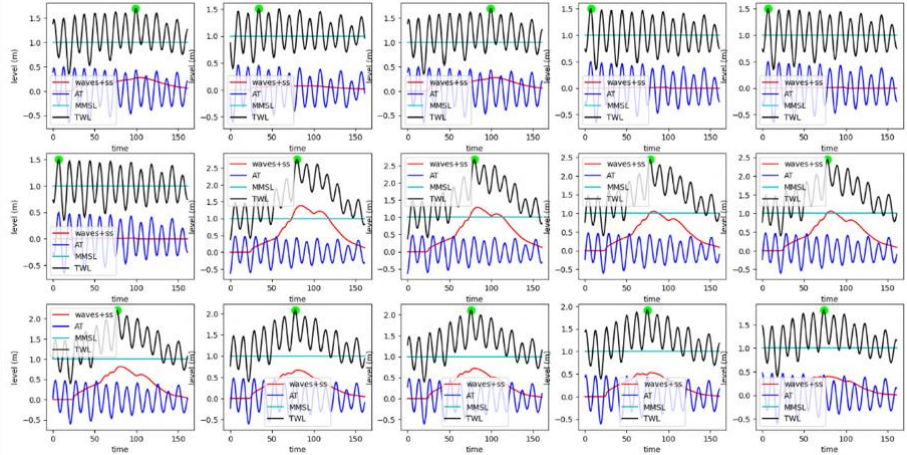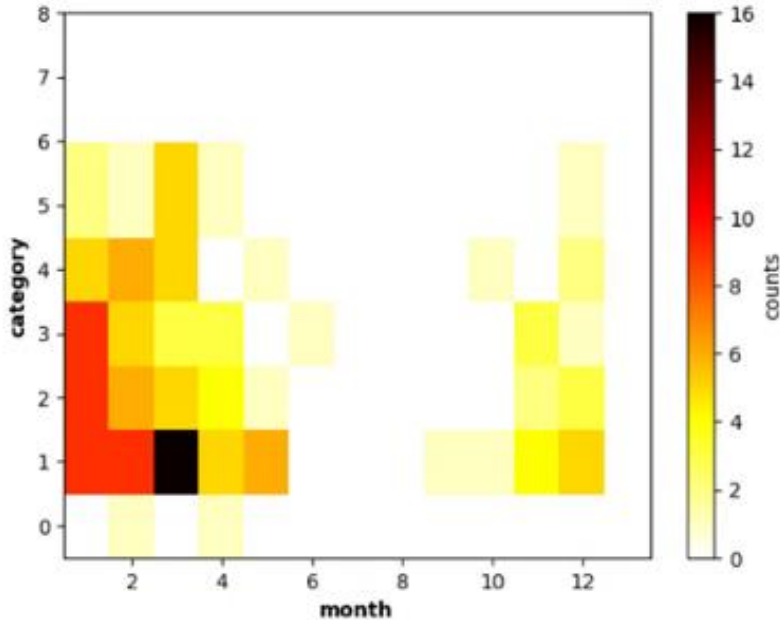

CFSR + CAWCR

Vortex + ShyTCWaves

TC Pam

Series Hs (m)

National scale hybrid TC Storm surge and storm wave modelling:

Step 3: Montecarlo simulation of annual maximum total water level (TWL)
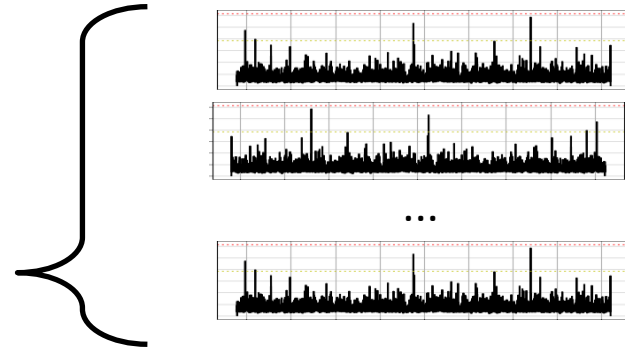
$$TWL = AT + SL + [SS+Waves]$$

Selected via Poisson distribution/constrained random selection

National scale hybrid TC Storm surge and storm wave modelling:
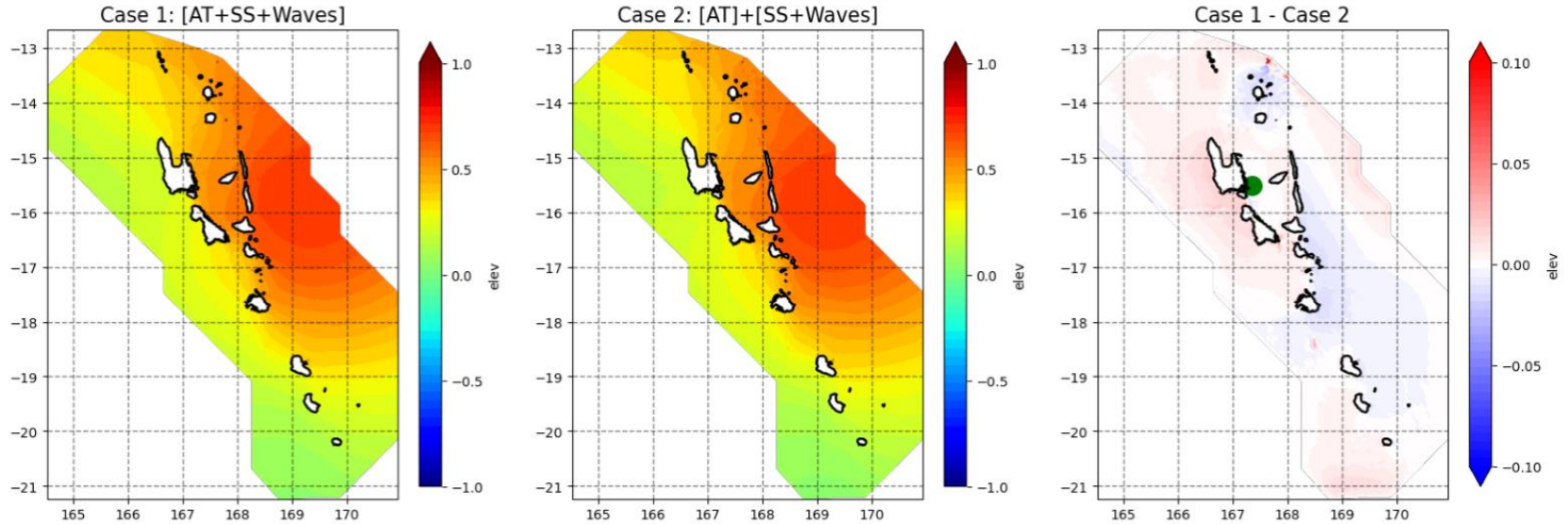
Linearity tests show TWL can be estimated by decoupling simulations of astronomical tides (AT), sea level variability/rise (SL) and waves+storm surge.
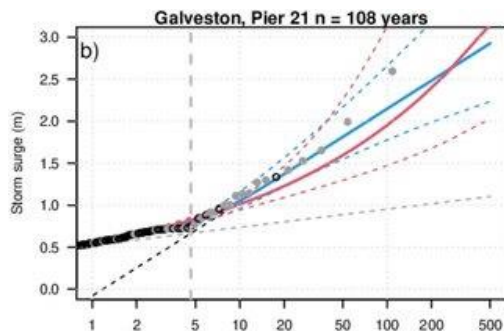
$$TWL = AT + SL + [SS+Waves]$$

...

"Ensemble" TWL (e.g. n=50)
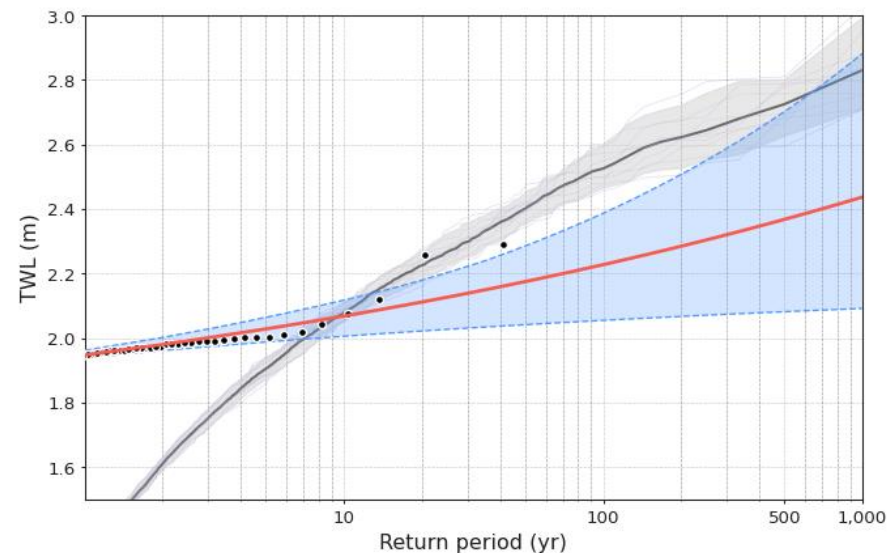
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National scale hybrid TC Storm surge and storm wave modelling:

EVA/comparison with deterministic (hindcast) solution

Probabilistic "hybrid" TWL:

Deterministic 40-year hindcast

O'Grady, et al (2022). *Gauging mixed climate extreme value distributions in tropical cyclone regions*

CSIRO
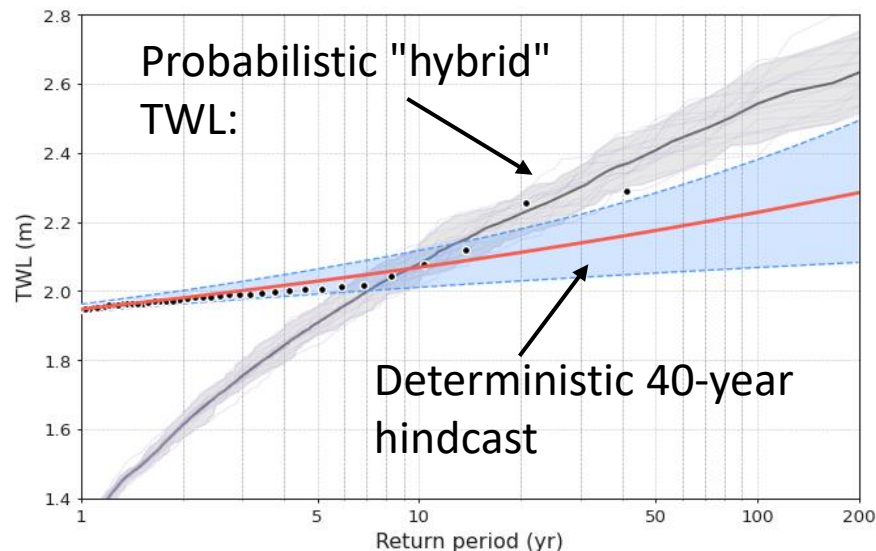
Hybrid solution: nearshore extreme wave heights

Return period 100 years - CI50%

Hybrid solution: nearshore extreme wave heights

Return period 100 years - CI(95-50%)

Greatly reduced statistical uncertainties

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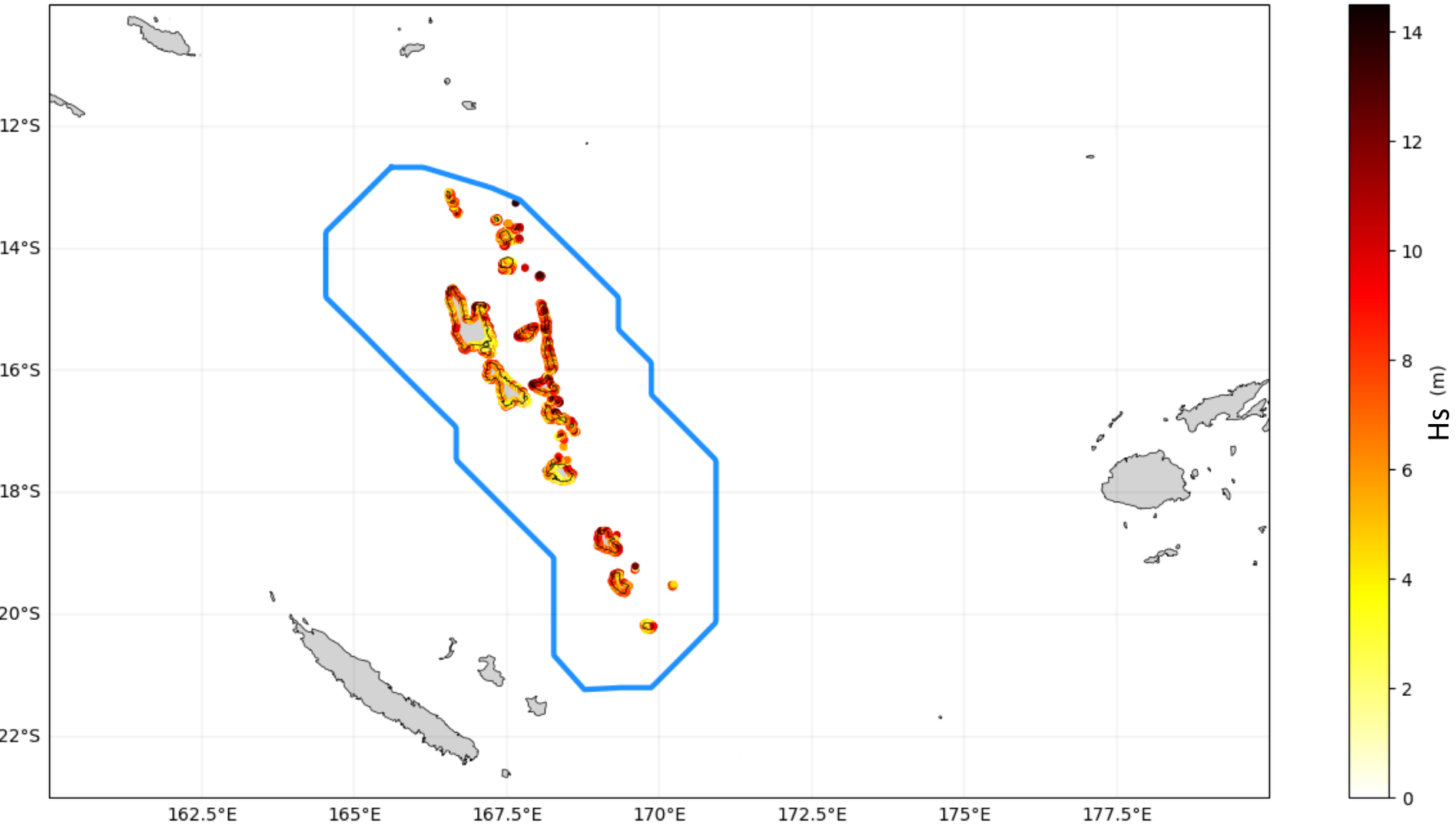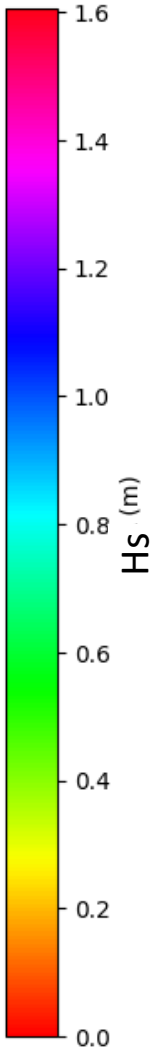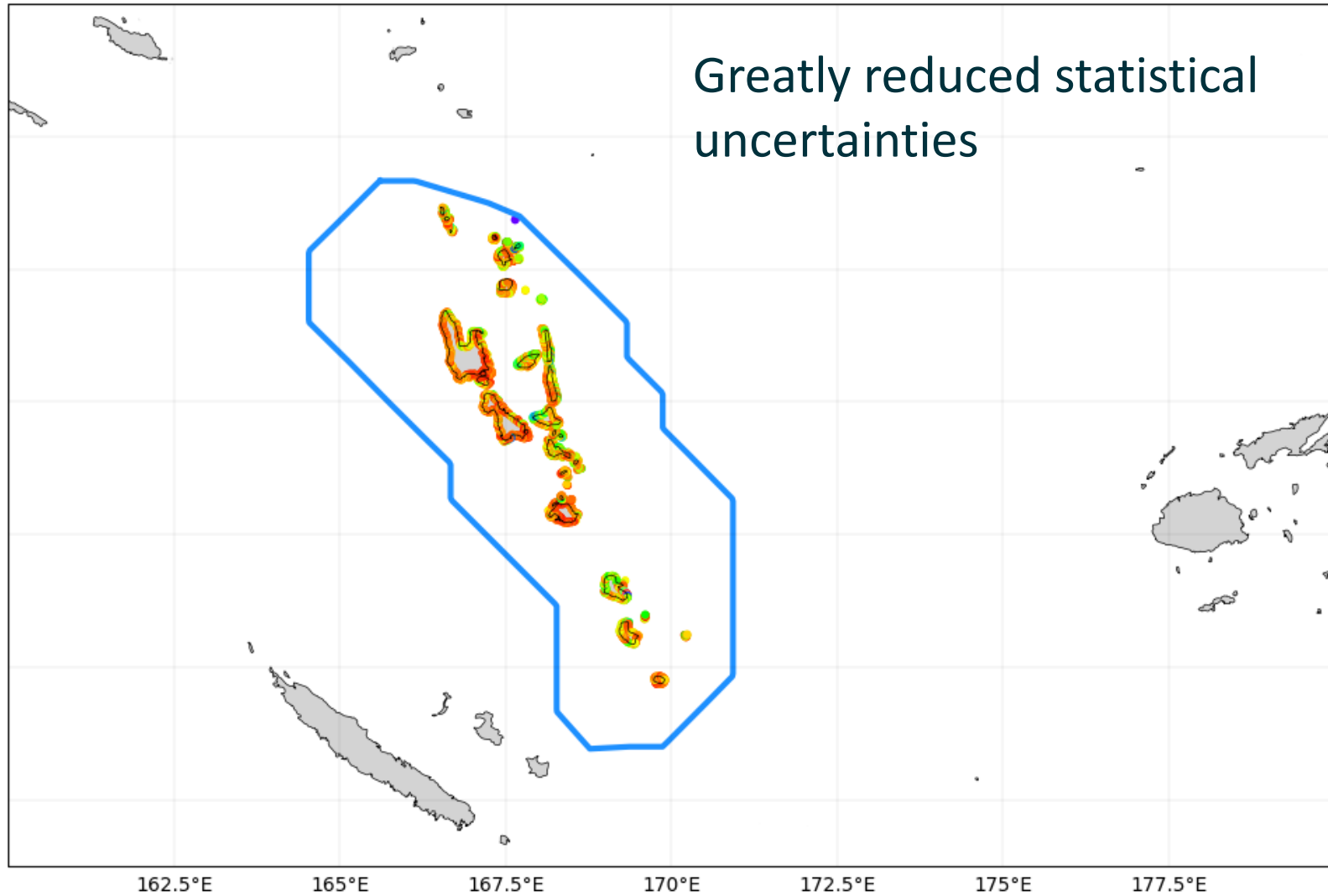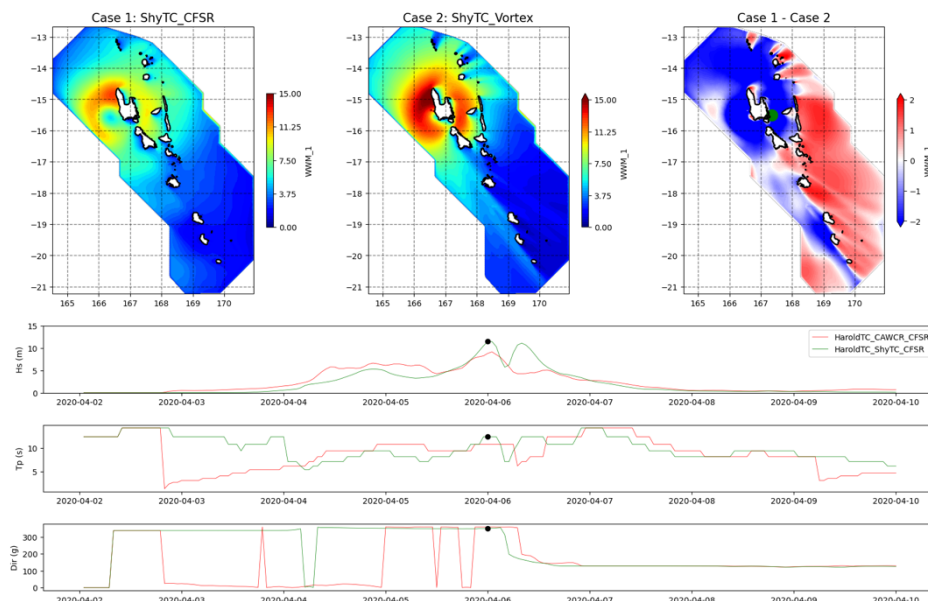# VanKIRAP extreme sea level hazard modelling system Summary

- Historic "mode" hindcast (1980 – 2020): hourly data

- Probabilistic "mode": Synthetic TC simulations (+ hybrid/Montecarlo TWL)

- Plan to make data available via the CSIRO Data Access Portal (https://data.csiro.au) and to PCCOS Ocean Catalogue (https://pccos.spc.int/ocean-catalogue)*

- EVA return periods used as input in the Vanuatu Climate Futures Portal Inundation Risk layers (for use by various sector stakeholders)

*Pending approval from Vanuatu Government and SPREP

VanKIRAP extreme sea level hazard modelling system
Future Work?

- Revisit/Rerun as new LiDAR and/or other detailed digital elevation model information becomes available

- Run multiple CMIP5/6 based synthetic TC populations to examine TC frequency and intensity associated with climate change.

- National and/or local wave runup/erosion hazard estimation

- Compound modelling with fluvial/pluvial input?
  - i.e. hybrid **downscaling** using XBeach, Lisflood, SFINCS, BG-Flood, other?

CSIRO

Thank you

For more information:

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Vanessa.Hernaman@csiro.au

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