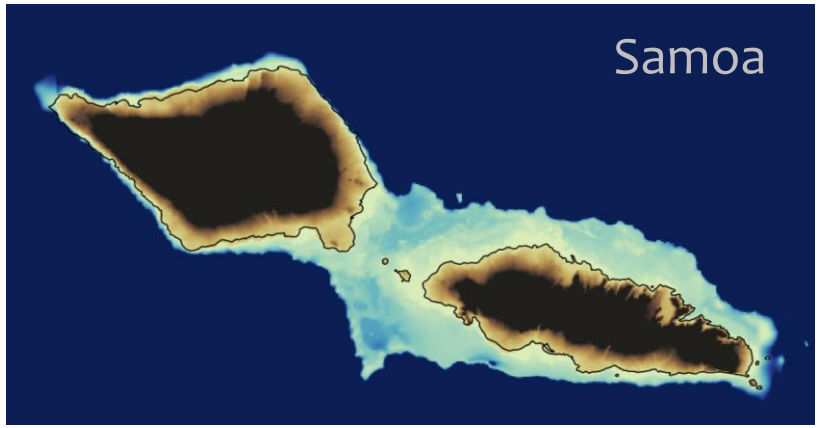
A hybrid flooding early warning system for small islands affected by tropical cyclones

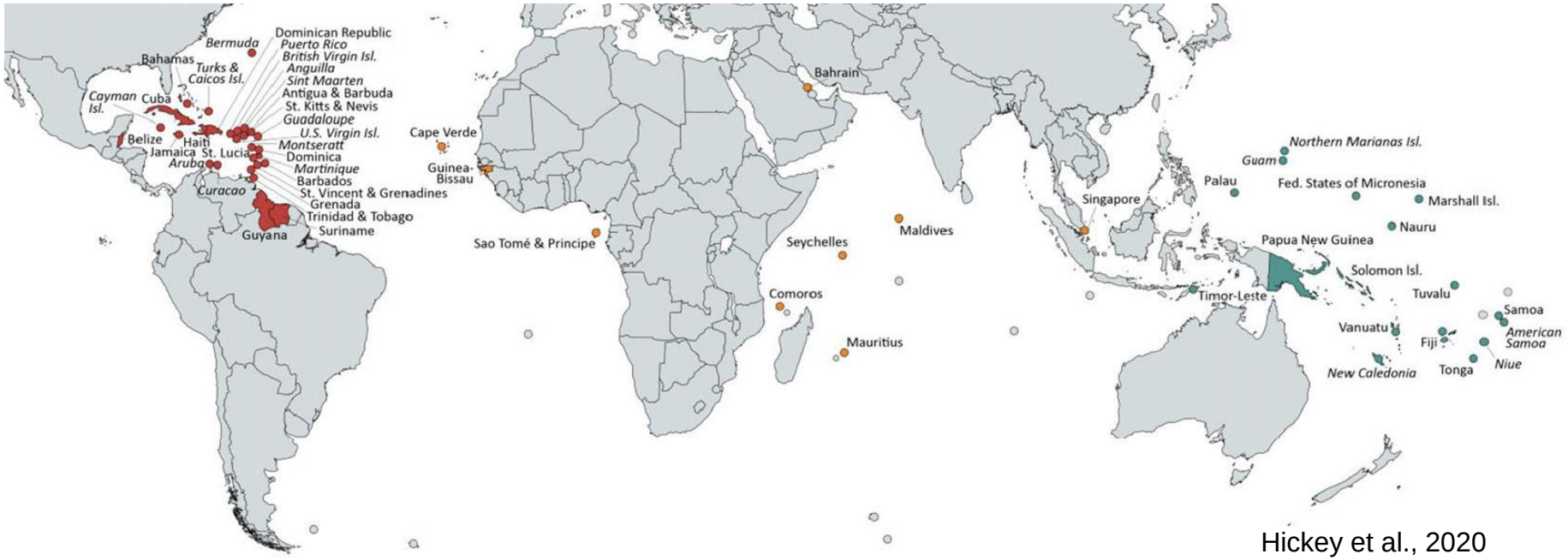
Laura Cagigal, Beatriz Pérez-Díaz, Sara O. van Vloten, Alba Ricondo, Manuel Zornoza, Ana Rueda, Sonia Castanedo, Fernando Méndez

Study Area

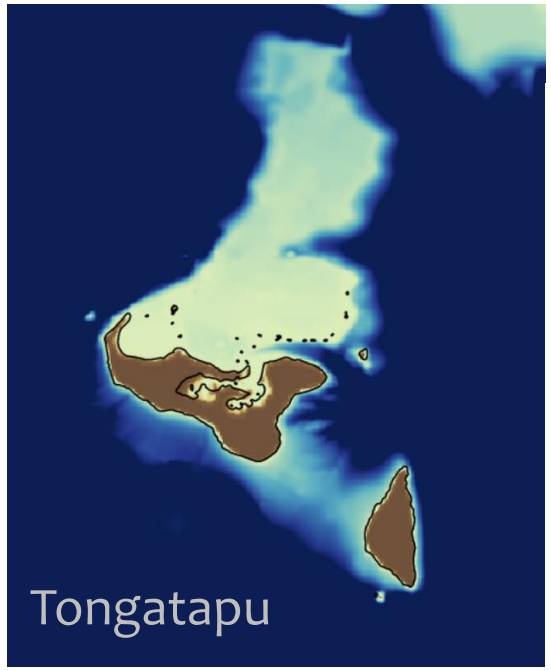
- Samoa and Tonga are 2 out of the 58 Small Island Developing States (SIDS)

- Low Computational Resources





Hickey et al., 2020



Introduction

Pacific Resilience Project (PREP I).
Impact Forecasting Consultancy in Samoa and Tonga

- Swell Inundation System {operational}
- TC Rainfall Inundation System {operational}
- TESLA System {climate}
- Seasonal Forecast Swells {operational}
- TC Coastal Inundation System {operational}
- TC Wind System {operational}
- Tsunami Inundation System {operational}
- Seasonal Forecast TCs {operational}
- Multi-hazard **Impact Forecast** System {operational}
- Multi-hazard **Risk Assessment** {climate}

THE WORLD BANK

Pacific Community
Communauté du Pacifique

50UC Universidad de Cantabria
Geomatics and Ocean Engineering Group
UNIVERSIDAD DE CANTABRIA

NIWA
Taihoro Nukurangi

Hybrid Models

Strengths:

- Fast prediction HR results
- Low computational resources
- Any climate (regular, extreme, TC)
- High Fidelity Numerical Models
- Probabilistic

Hybrid Models

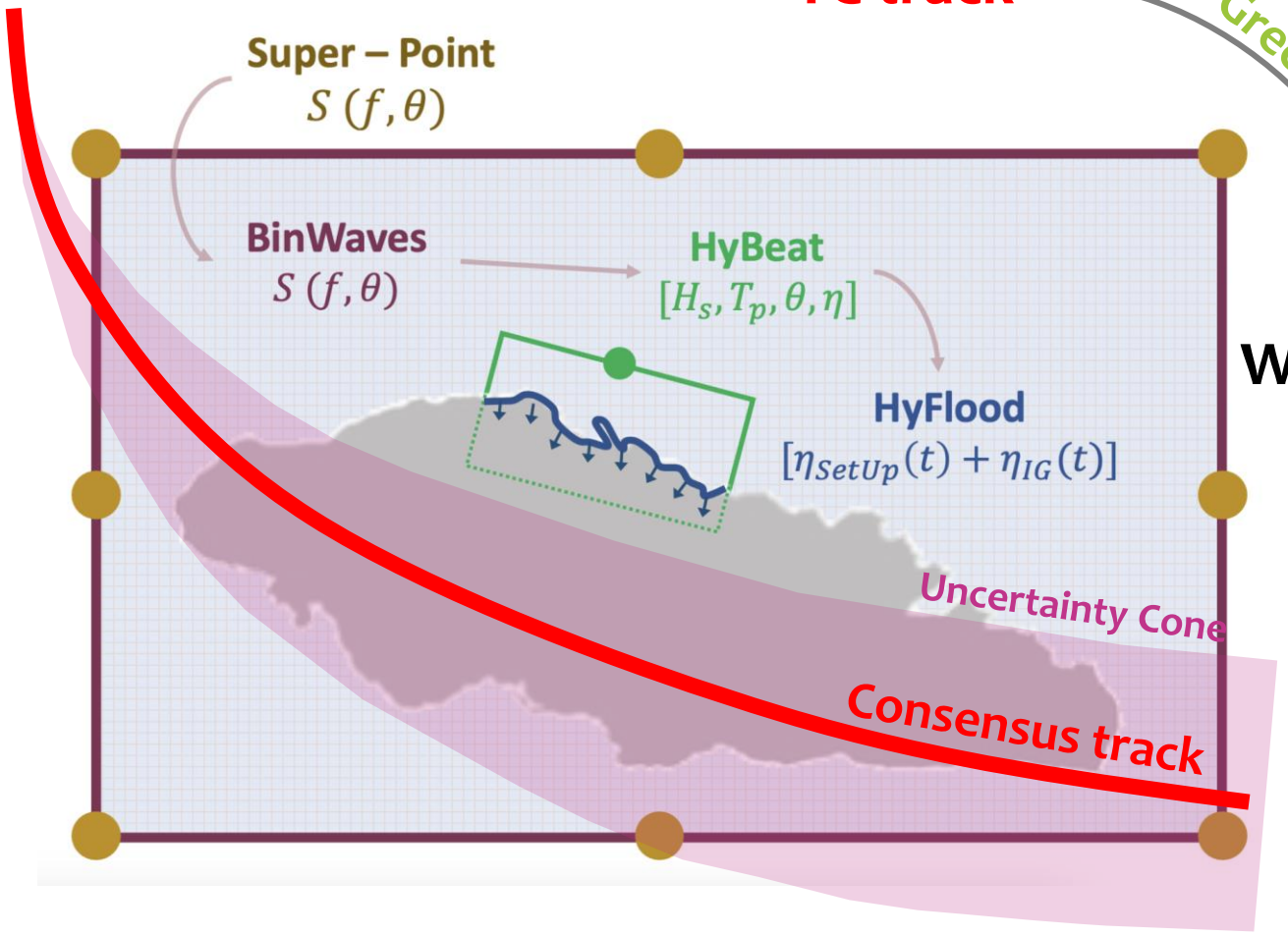
Metamodel

Combination of High Fidelity Hydrodynamic Models + Data Science

Additive Model

Linear summation of the physical processes + High Fidelity Hydrodynamic Models

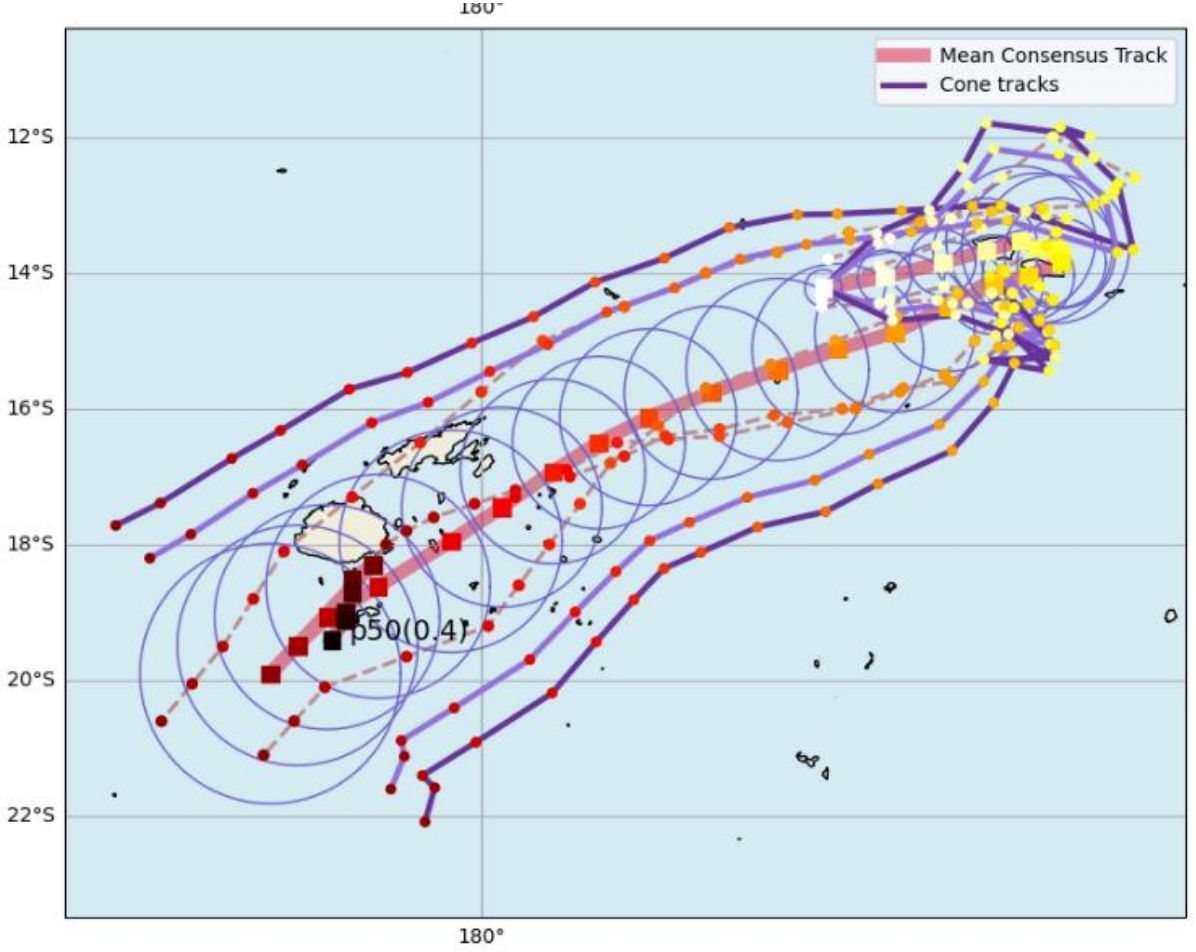
TC Inundation System



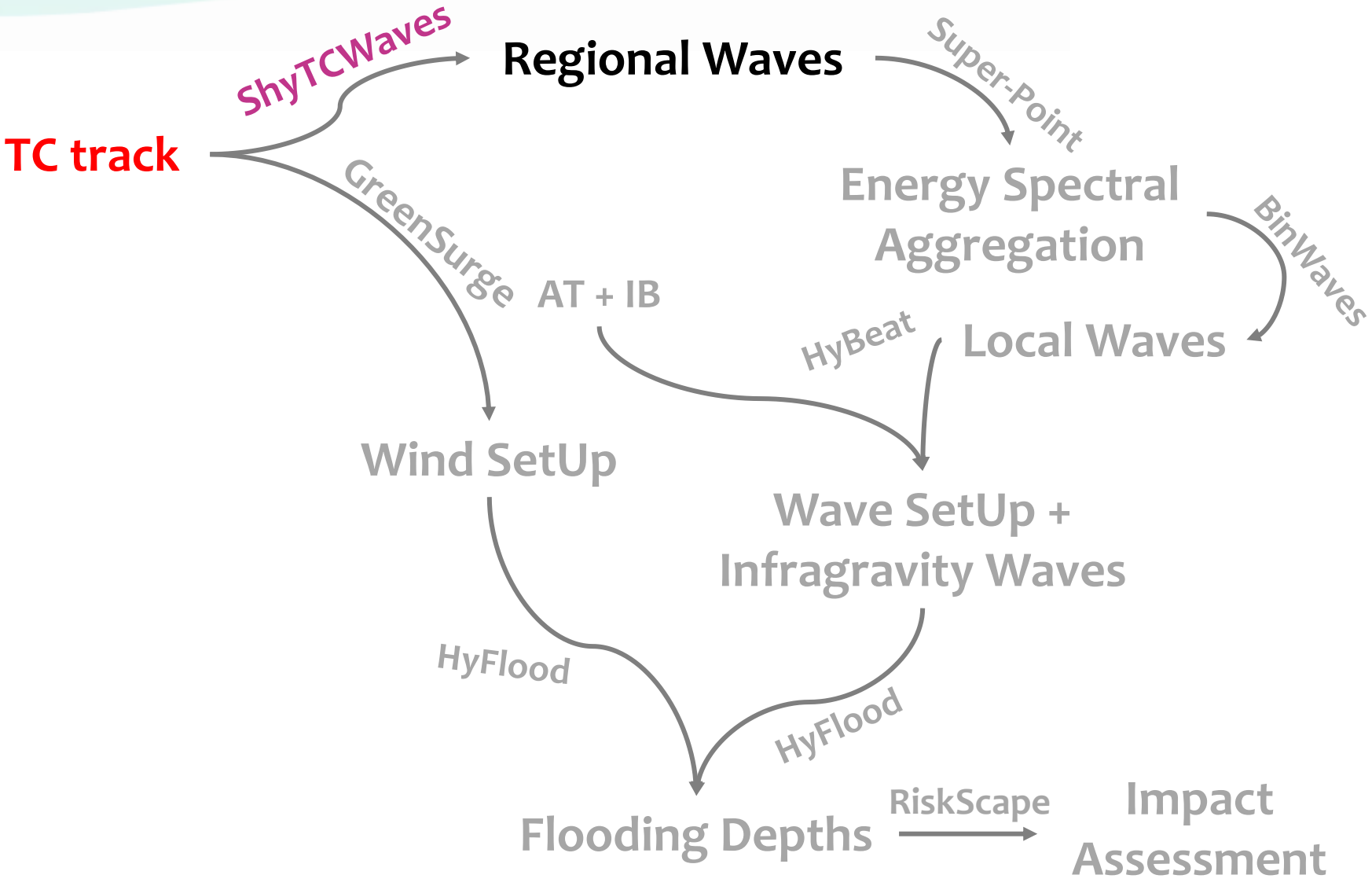
TC Track

Tracks from JTWC

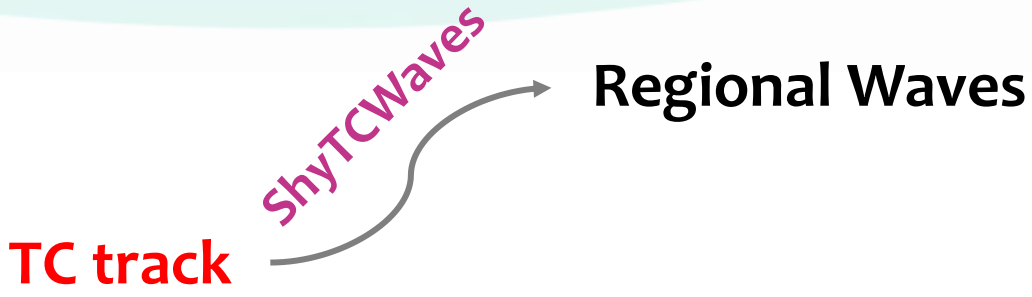
UNCERTAINTY CONE



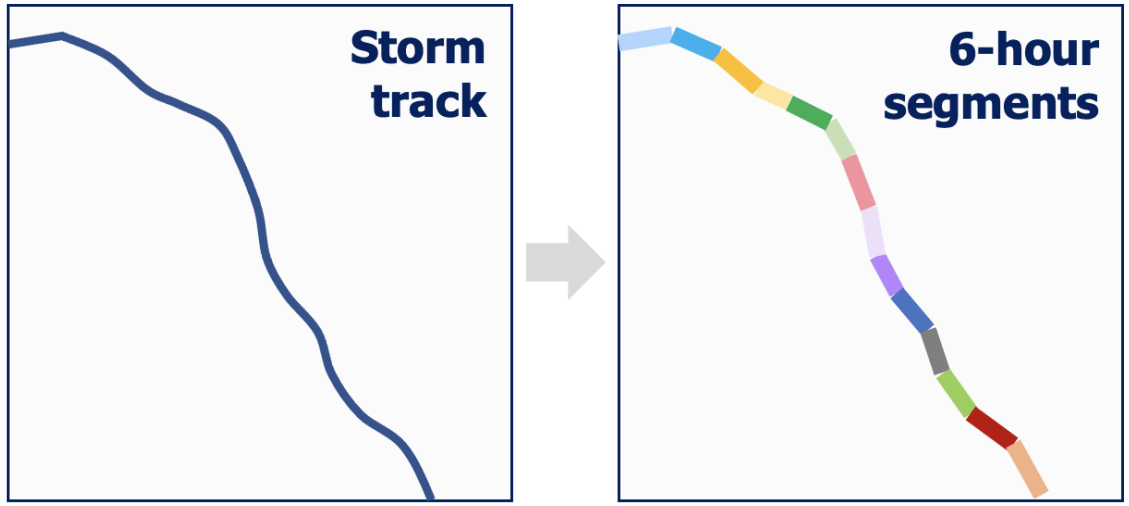
TC Inundation System



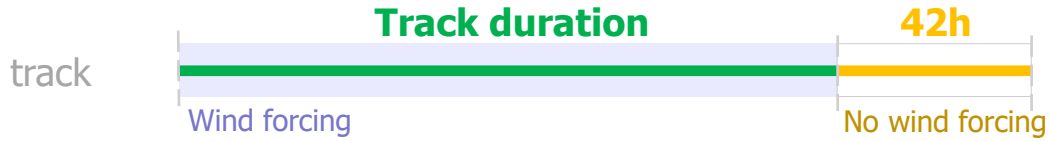
ShyTCWaves



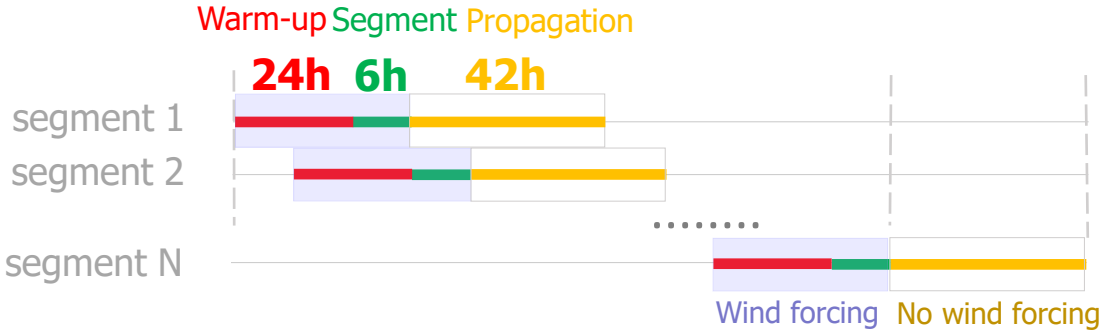
Type of Hybrid model:	**Metamodel**
Numerical model:	**Swan**
Number of numerical simulations:	**5000**
Spatial Resolution:	**15 Km**



Real storm set-up



Stop-motion set-up



ShyTCWaves

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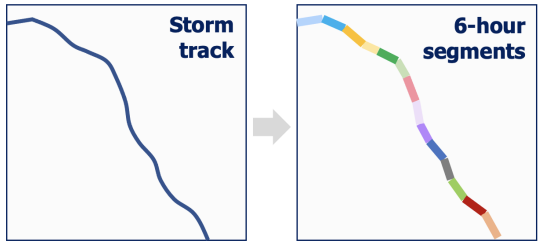
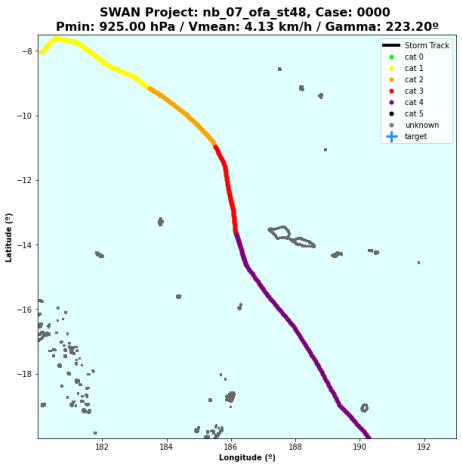
GeOcean

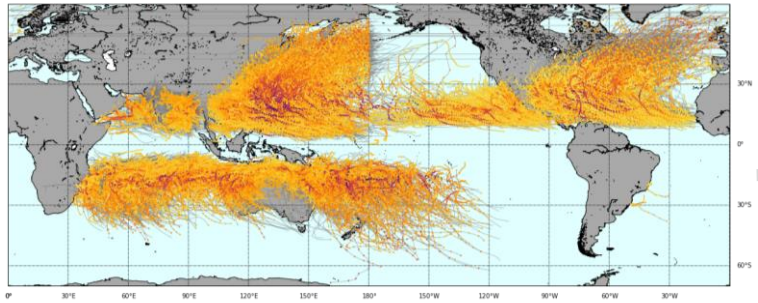
1 STORM TRACK PARAMETERIZATION



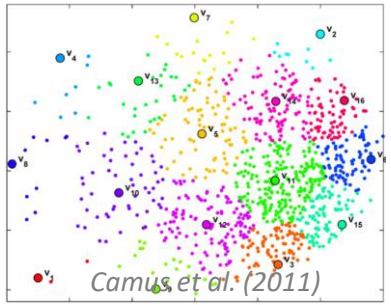


TC track

2 SEGMENTS DATABASE

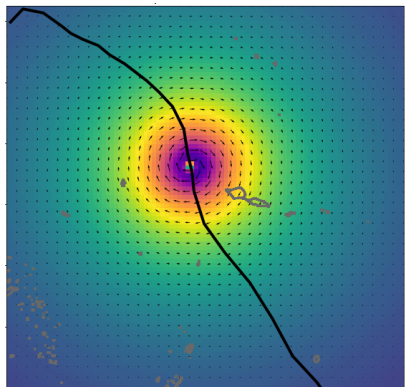


3 MDA SELECTION

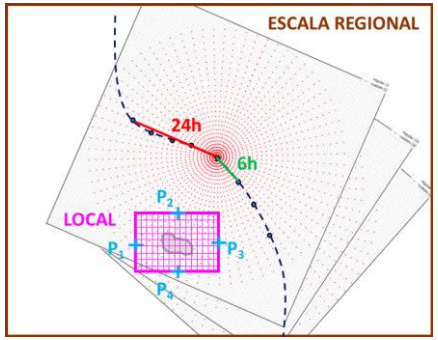


Camus et al. (2011)

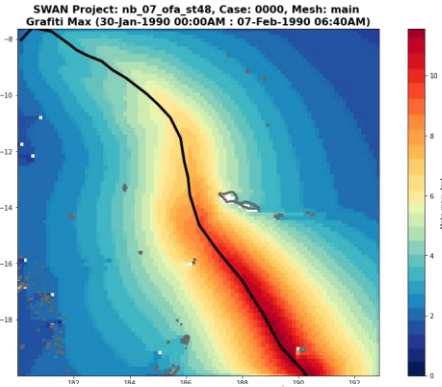
4 NUMERICAL MODELING



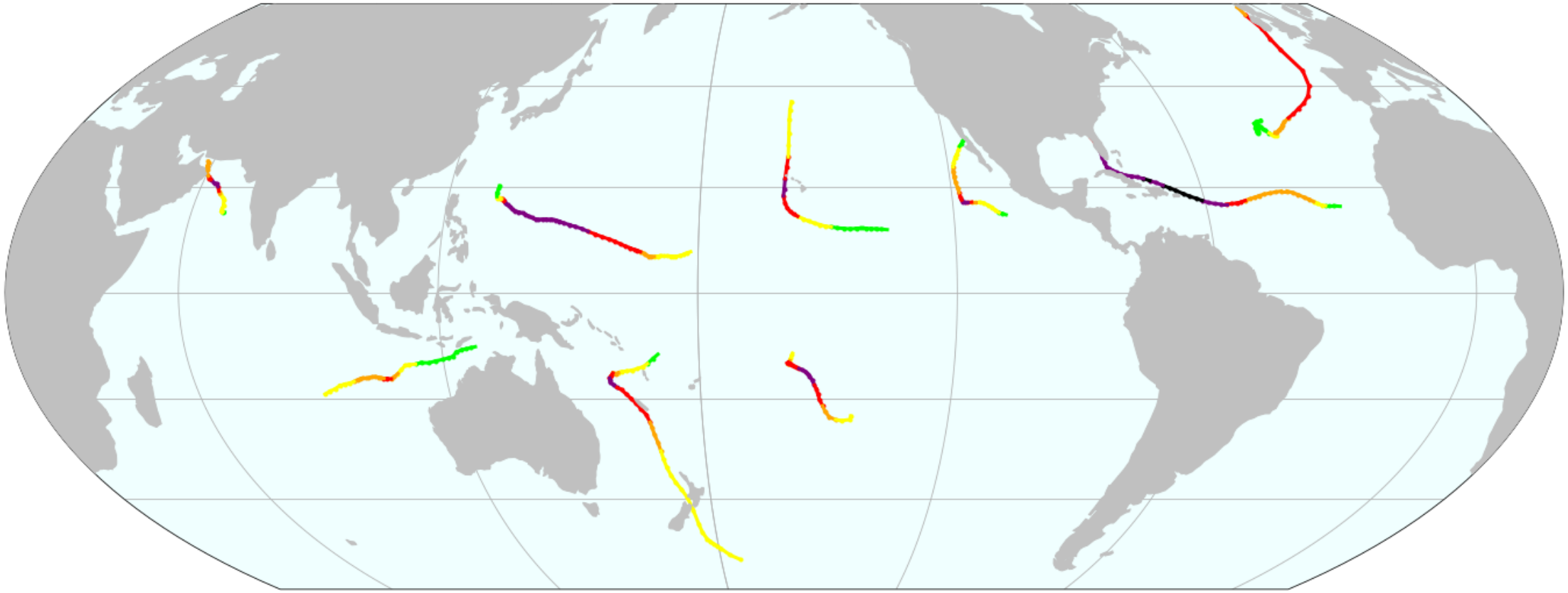
5 STOP-MOTION ENSEMBLE



WAVE FIELD



ShyTCWaves



ShyTCWaves

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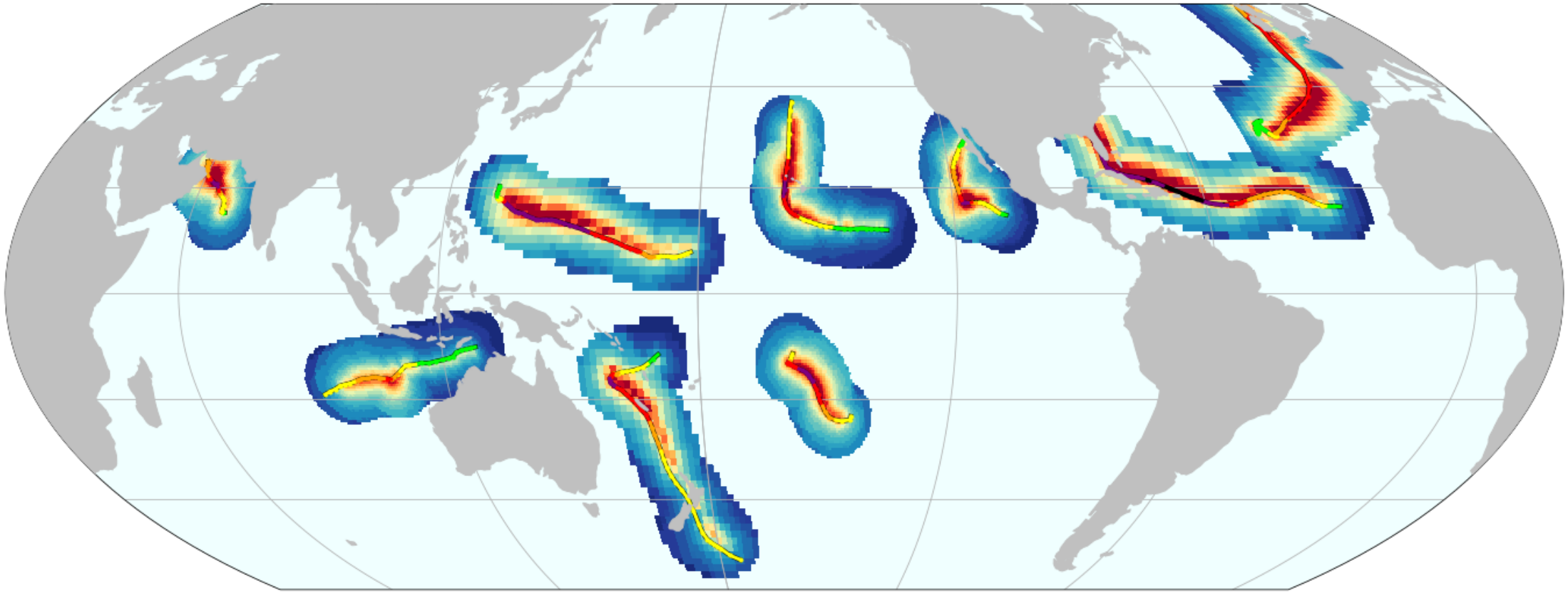
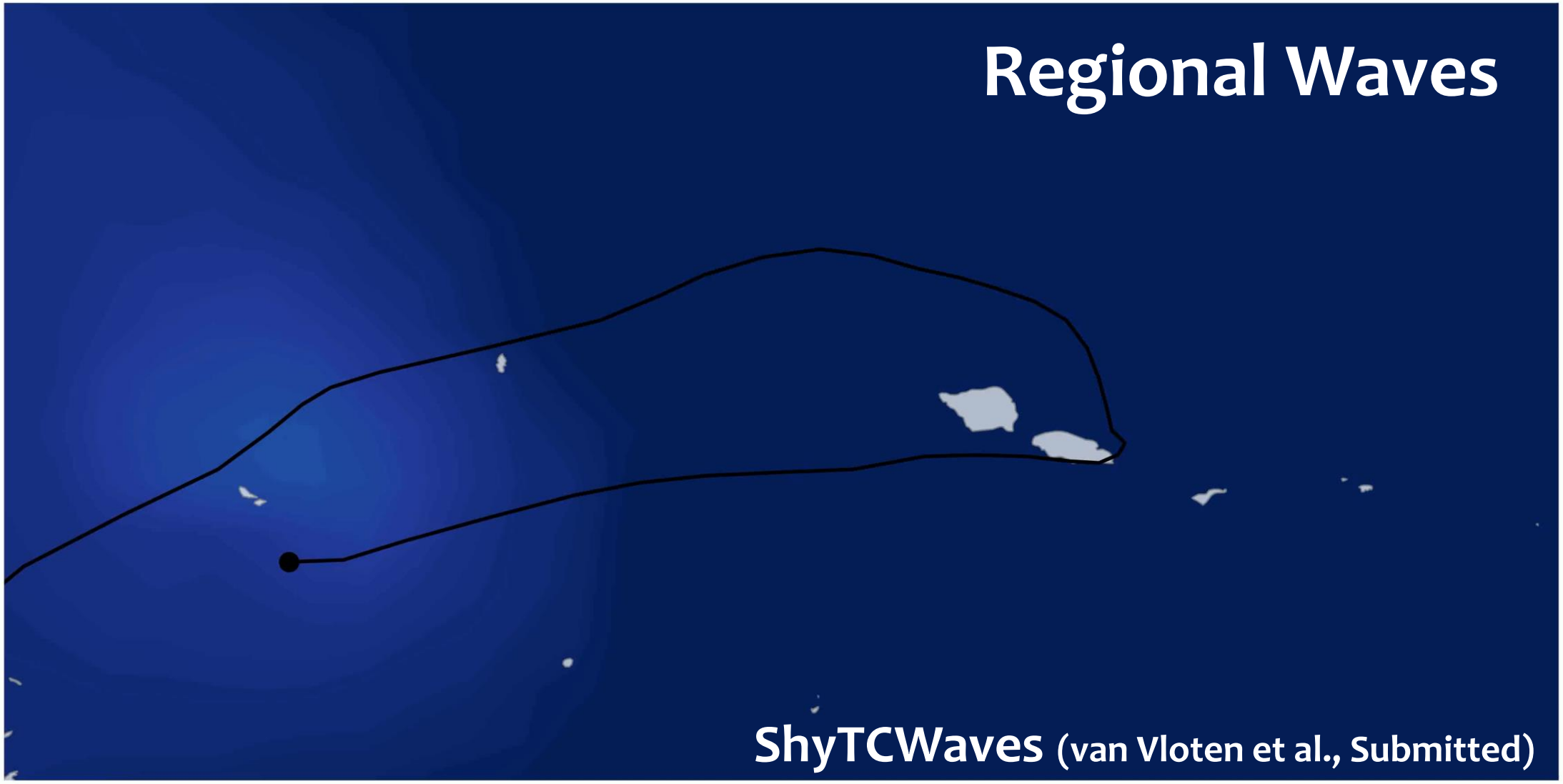
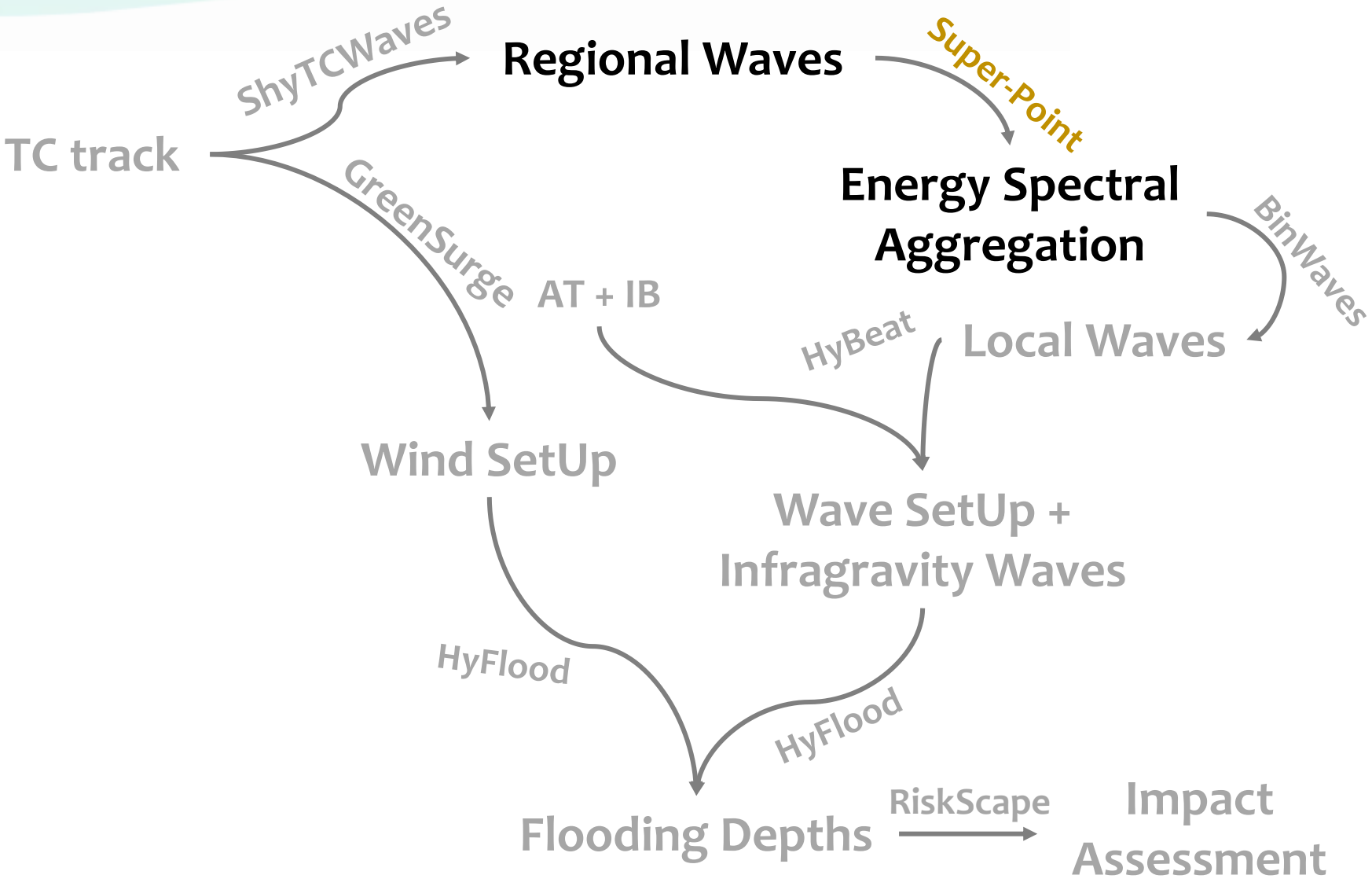


ShyTCWaves


Regional Waves
11.00
9.78
8.56
7.33
6.11
4.89
3.67
2.44
1.22
0.00
Hs (m)
ShyTCWaves (van Vloten et al., Submitted)

TC Inundation System



Super-Point

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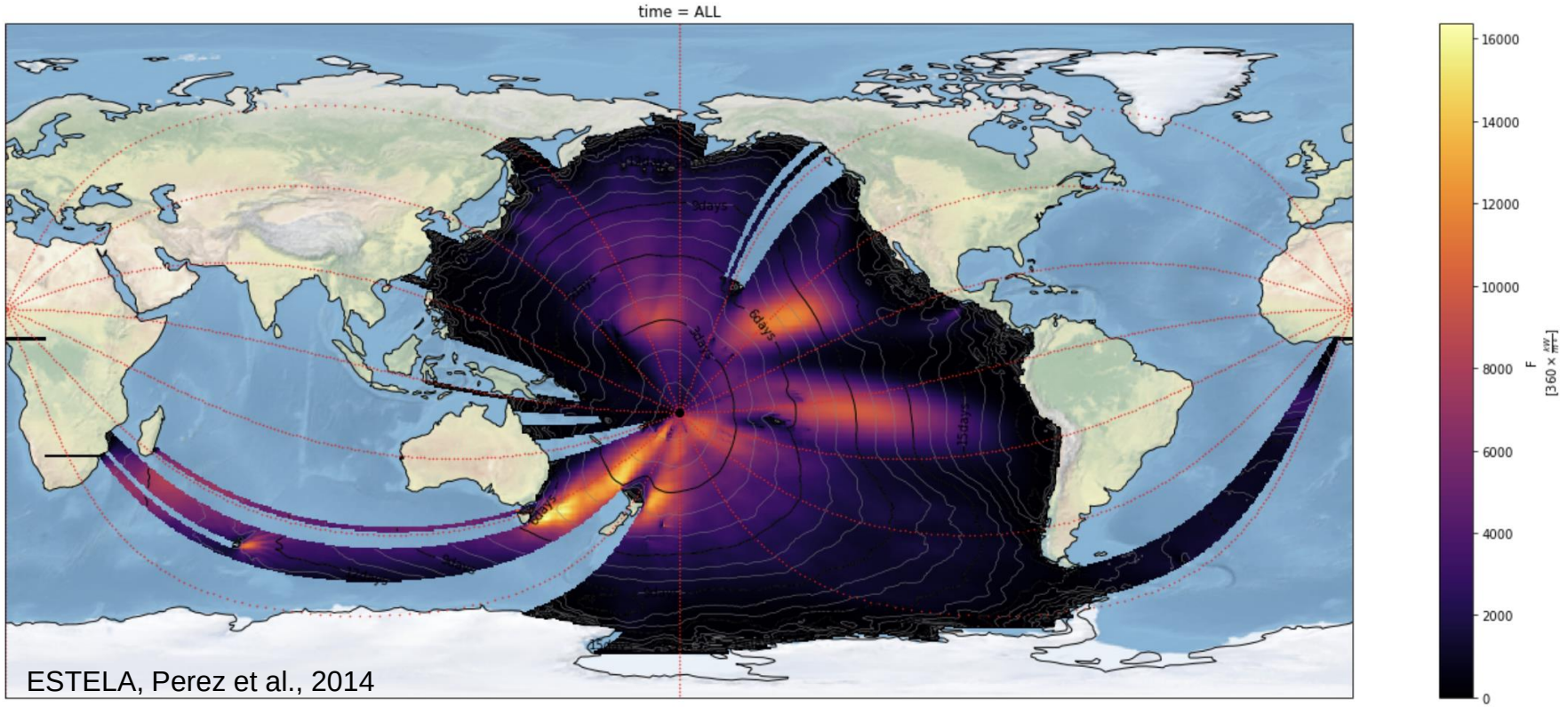
GeOcean

Regional Waves

Super-Point

Energy Spectral Aggregation



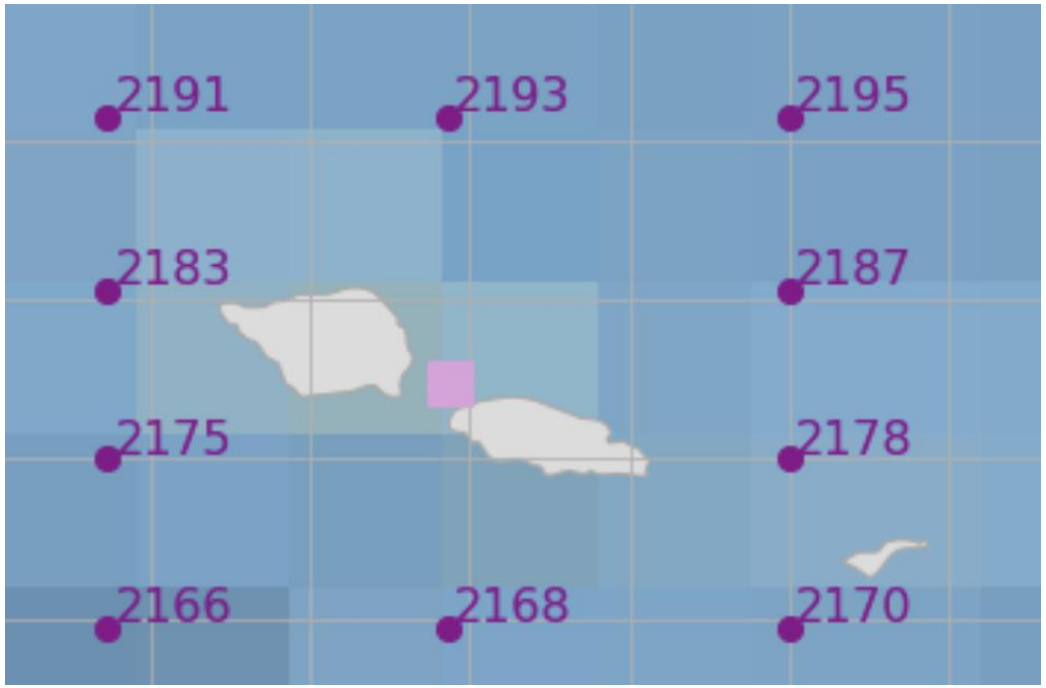
ESTELA, Perez et al., 2014

Super-Point

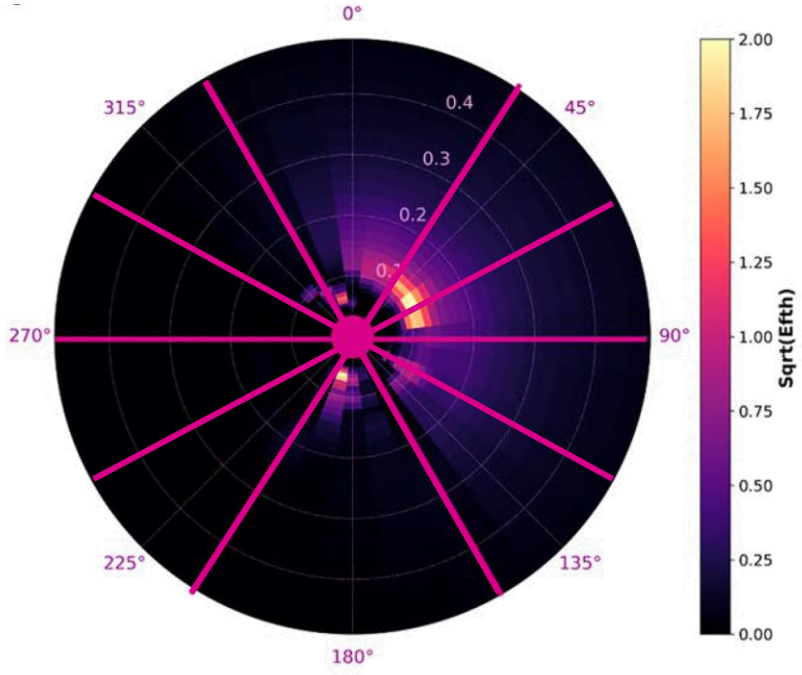
Regional Waves

Super-Point

Energy Spectral Aggregation



7 days GFS-Wave Forecast , NOAA



Super-Point - Cagigal et al., 2021

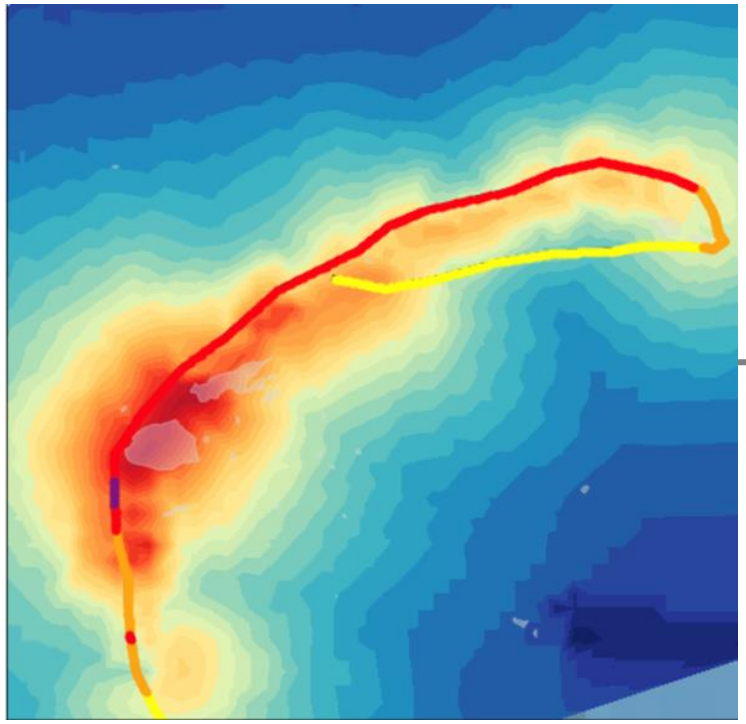
Super-Point

Regional Waves

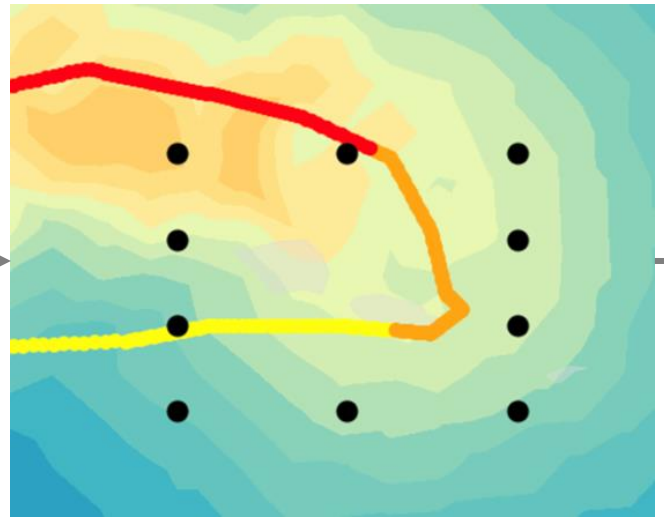
Super-Point

Energy Spectral Aggregation

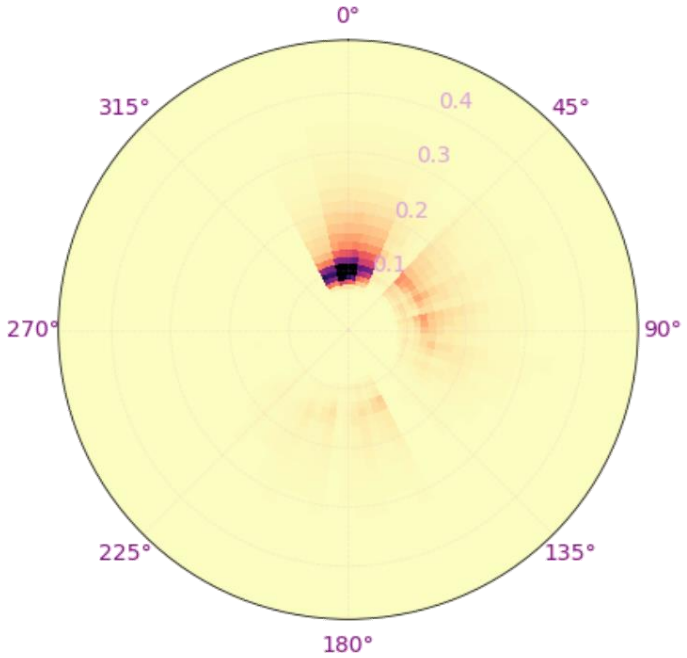
Evan 2012



Regional Waves

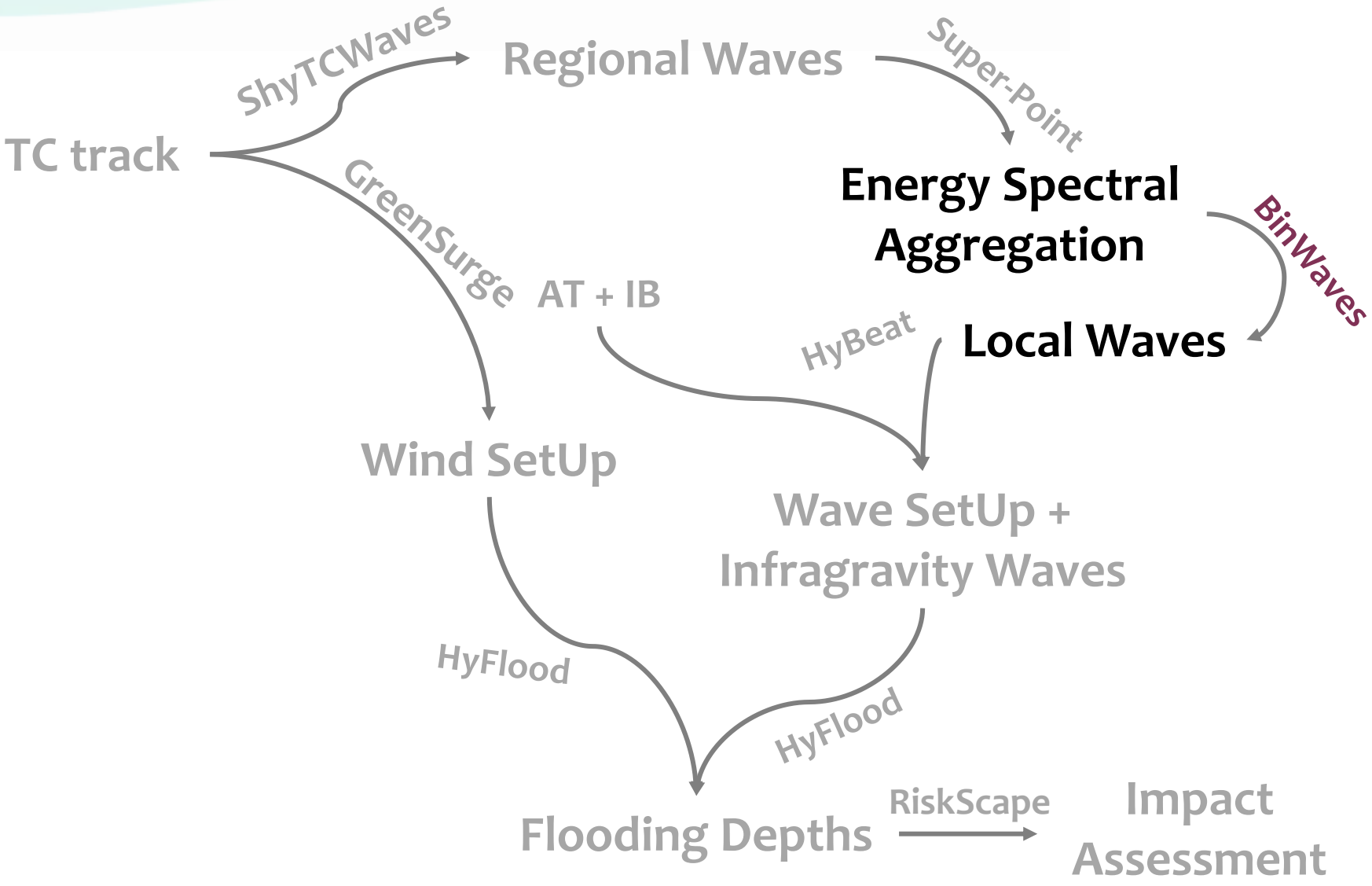


Points Selection



Super-Point

TC Inundation System



BinWaves

Energy Spectral Aggregation

BinWaves

Local Waves

Type of Hybrid model:	**Additive Model**
Numerical model:	**SWAN**
Number of numerical simulations:	**696**
Spatial Resolution:	**250m**

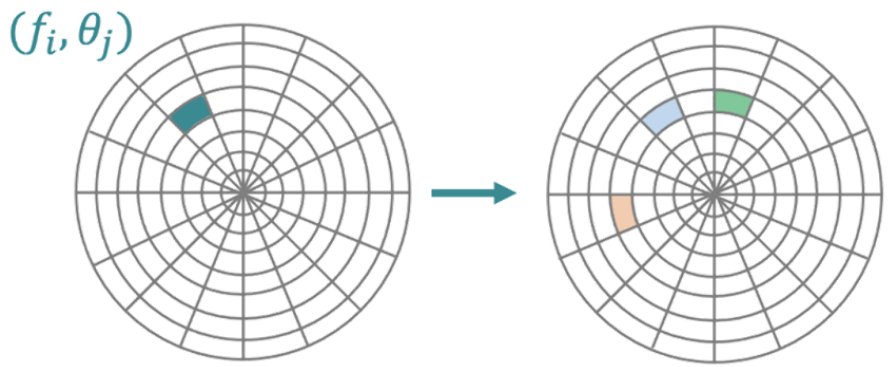
Split the spectra into Energy "bins" characterized by one frequency and one direction to obtain Propagation Coefficients (Kp)

Offshore

$U\ (f_i, \theta_j)$

Each point

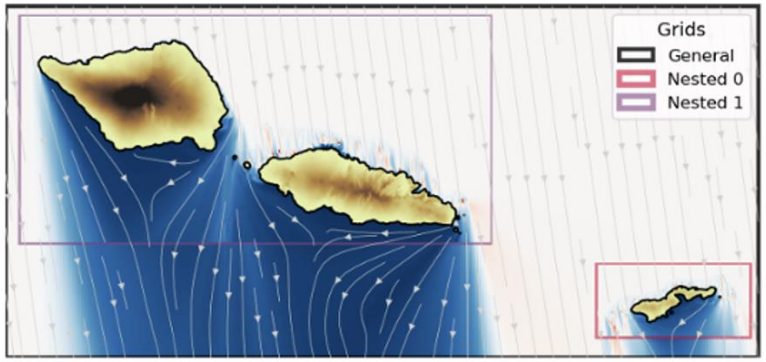
$U_p(f_i, \theta_j)$

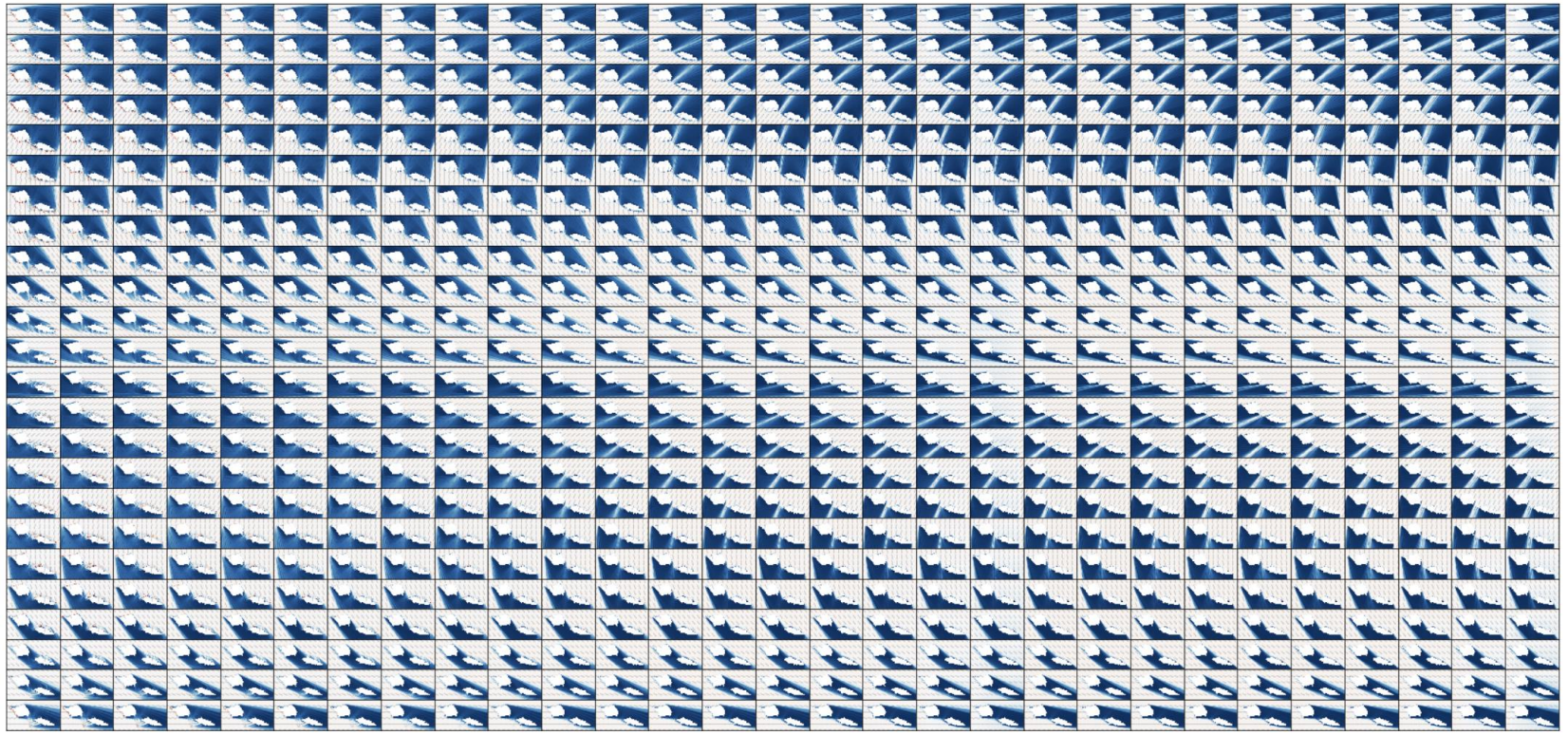


$$K_p(f_i, \theta_j) = \frac{U_p(f_i, \theta_j)}{\iint U\ (f_i, \theta_j)\ d_f\ d_\theta}$$

Cagigal et al., in prep.

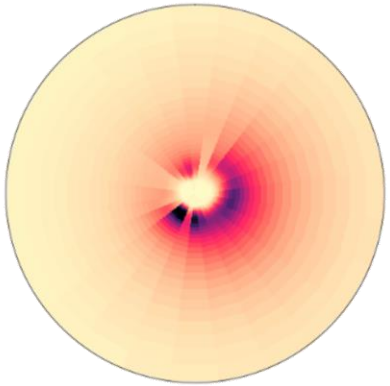
BinWaves





A generic directional spectrum

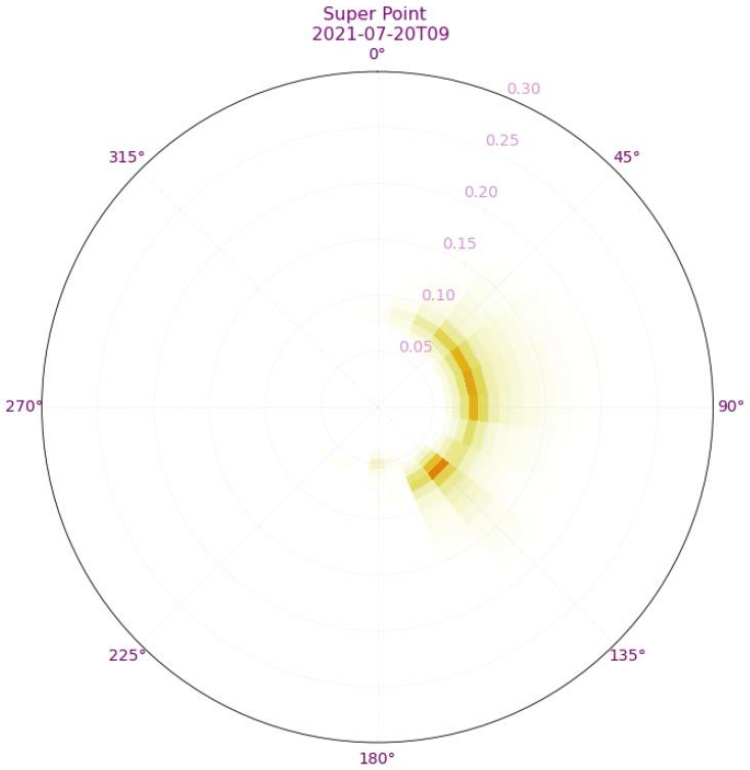
$$S(f,\theta)$$

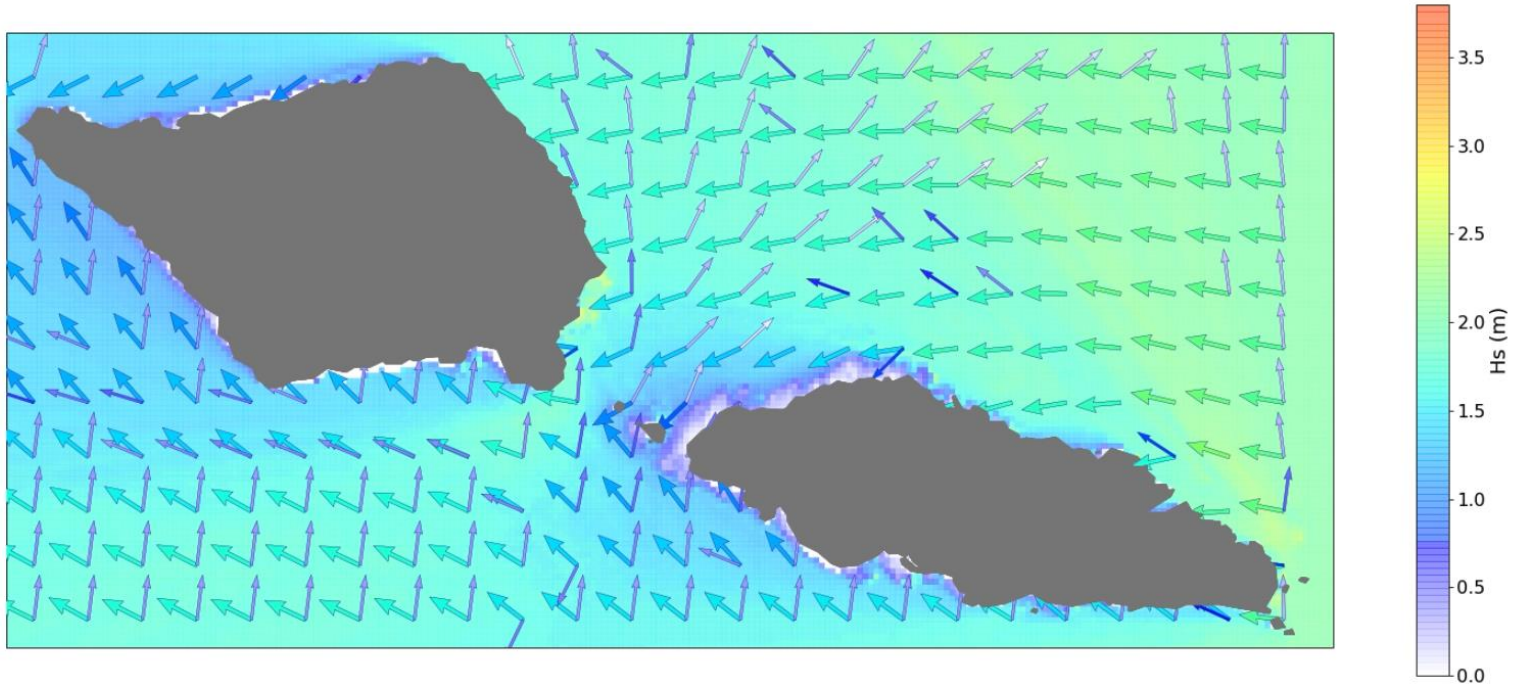


Each point

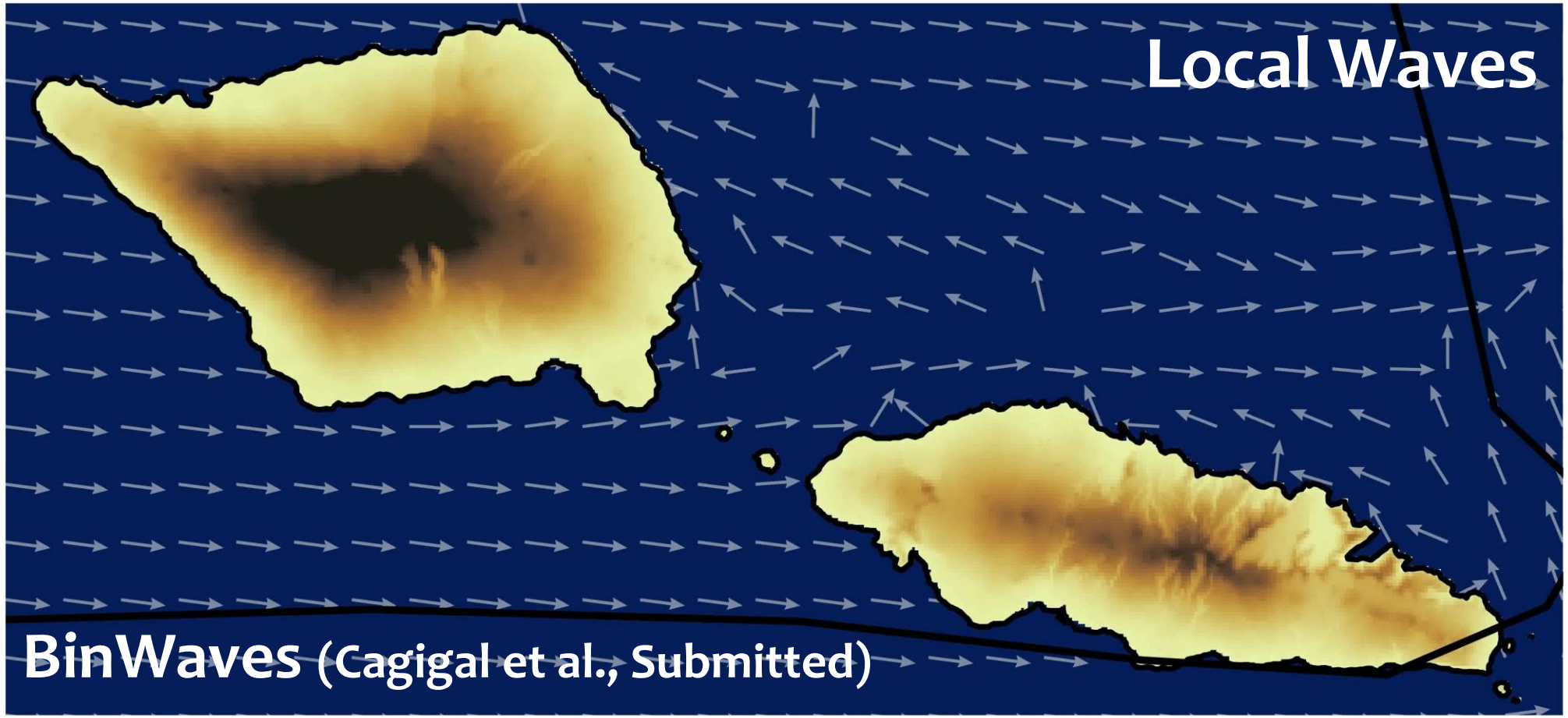
$$Sp(f_i,\theta_j) = \sum_i \sum_j S(f_i,\theta_j) * K_p{}^2(f_i,\theta_j)$$

BinWaves

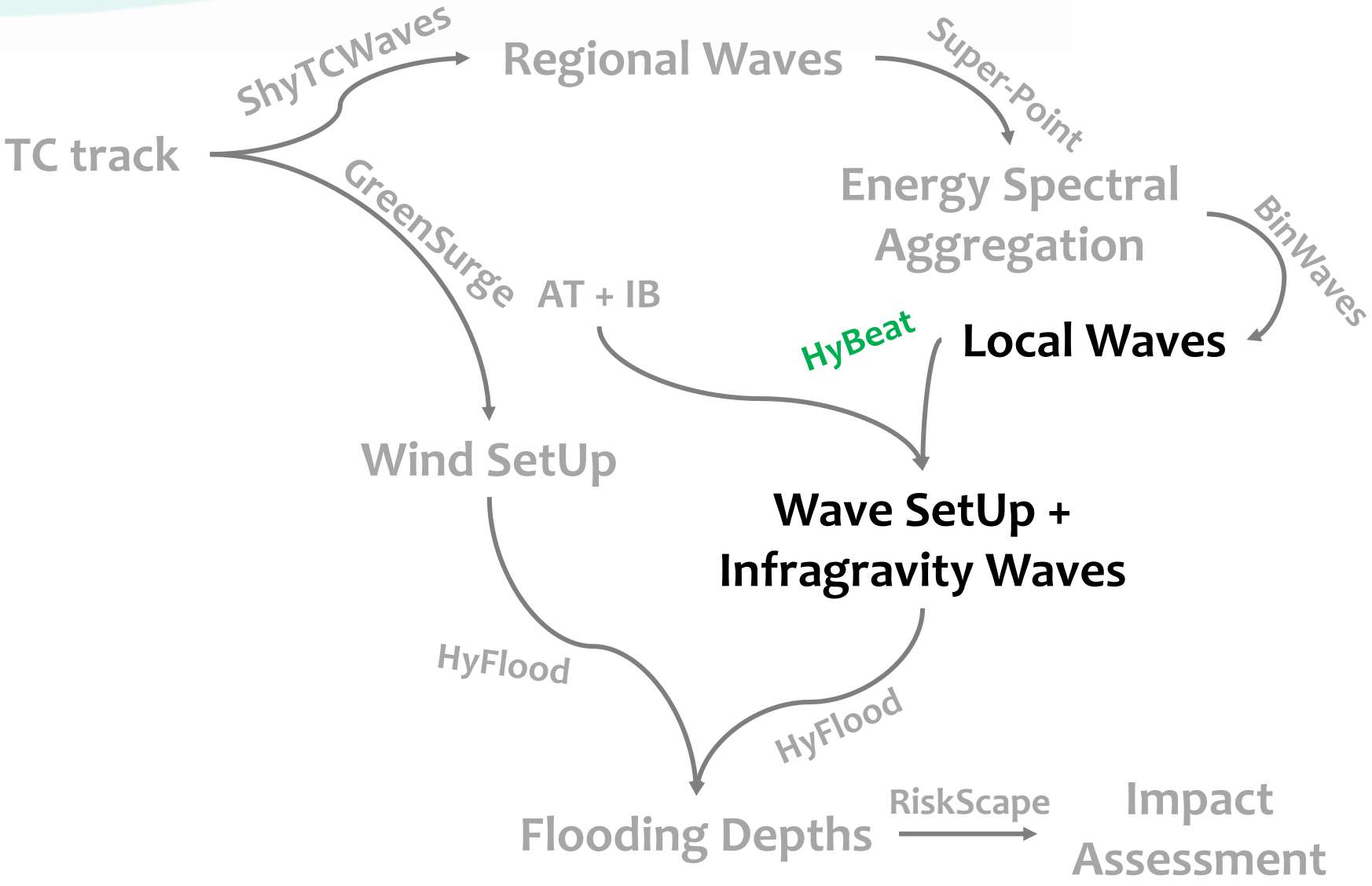

Super Point
2021-07-20T09
0°
45°
90°
135°
180°
225°
270°
315°
0.30
0.25
0.20
0.15
0.10
0.05


3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Hs (m)

BinWaves


Local Waves
BinWaves (Cagigal et al., Submitted)
0.000
0.603
1.206
1.809
2.412
3.016
3.619
4.222
4.825
5.428
Hs (m)

TC Inundation System

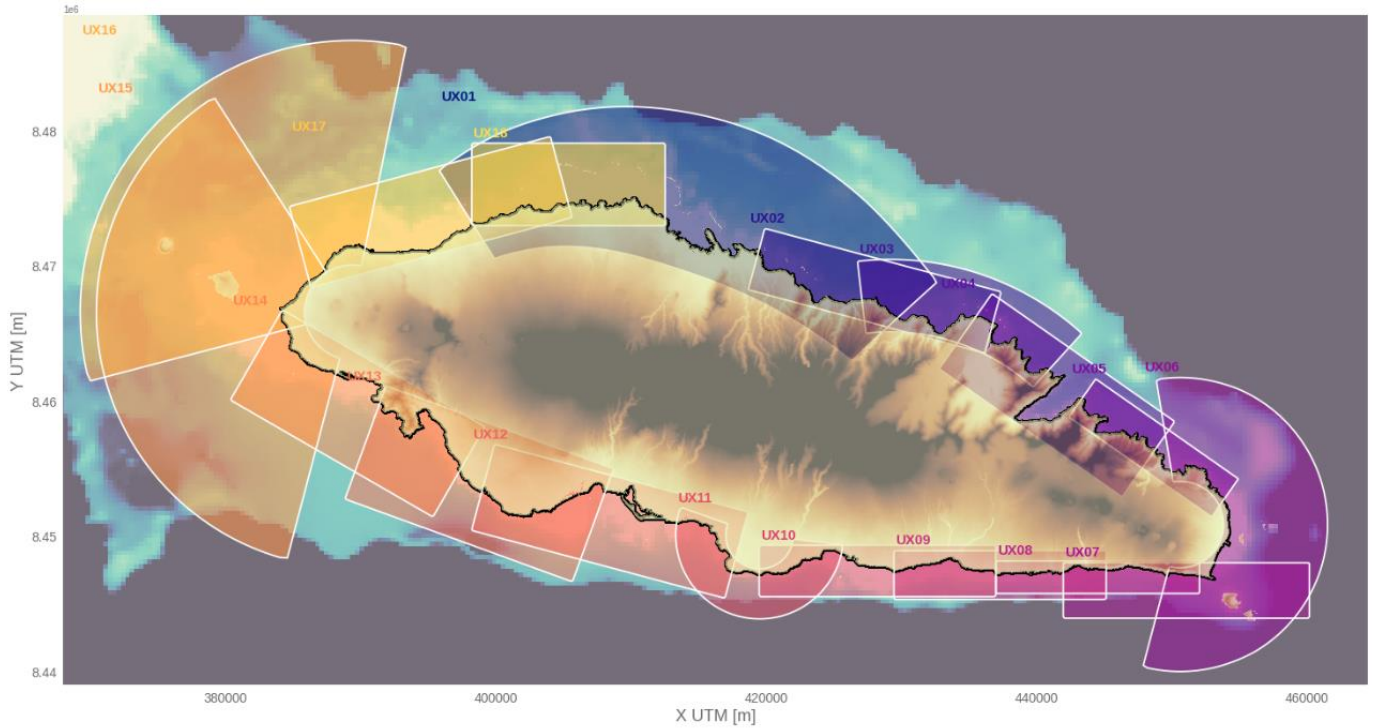


HyBeat

HyBeat → **Local Waves**

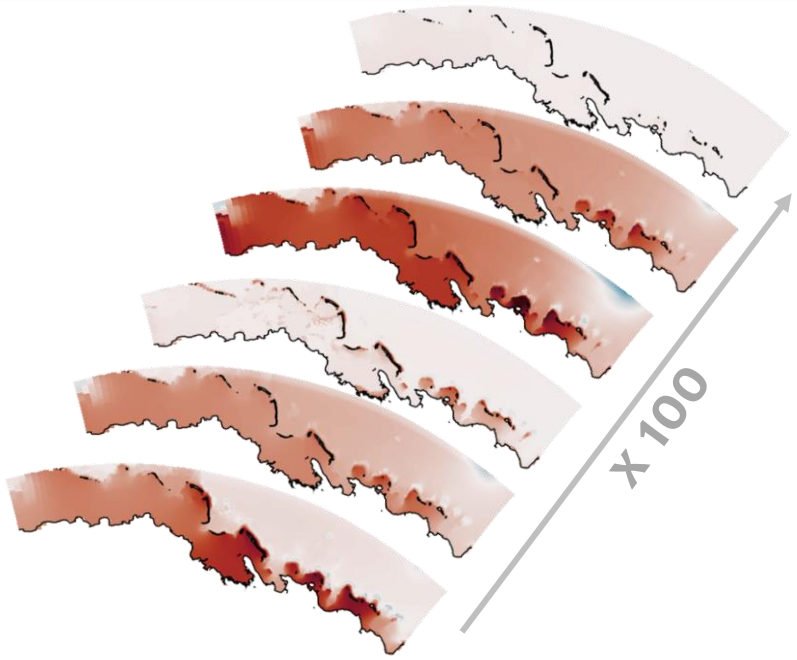
Wave SetUp +
Infragravity Waves

Type of Hybrid model:	**Metamodel**
Numerical model:	**Xbeach - SurfBeat**
Number of numerical simulations:	**100/Mesh**
Spatial Resolution:	**~ 5/10 m**



Pérez-Díaz et al., in prep.

HyBeat

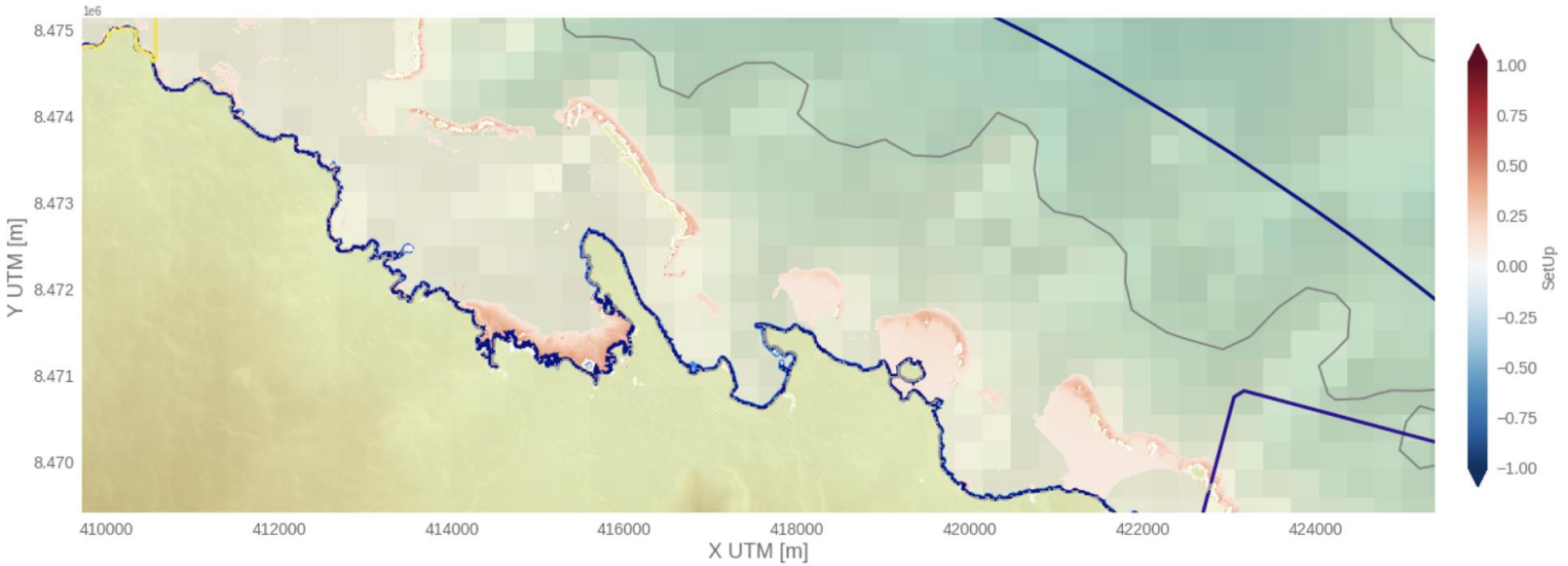


Selection of Representative Cases

Run Library of cases with XBeach

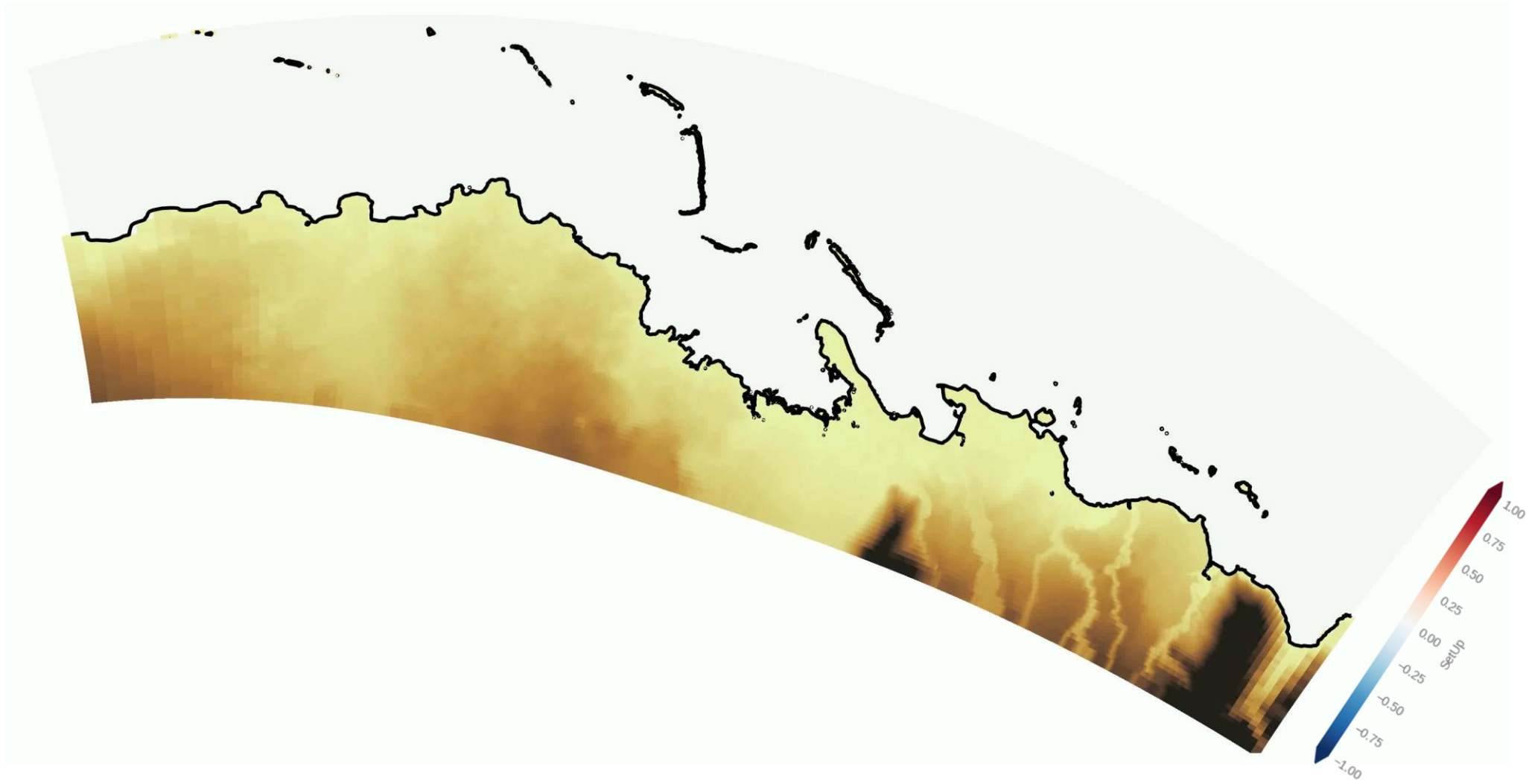
PCA Analysis

Spatial Reconstruction of Mean Wave SetUp and Infragravity Waves

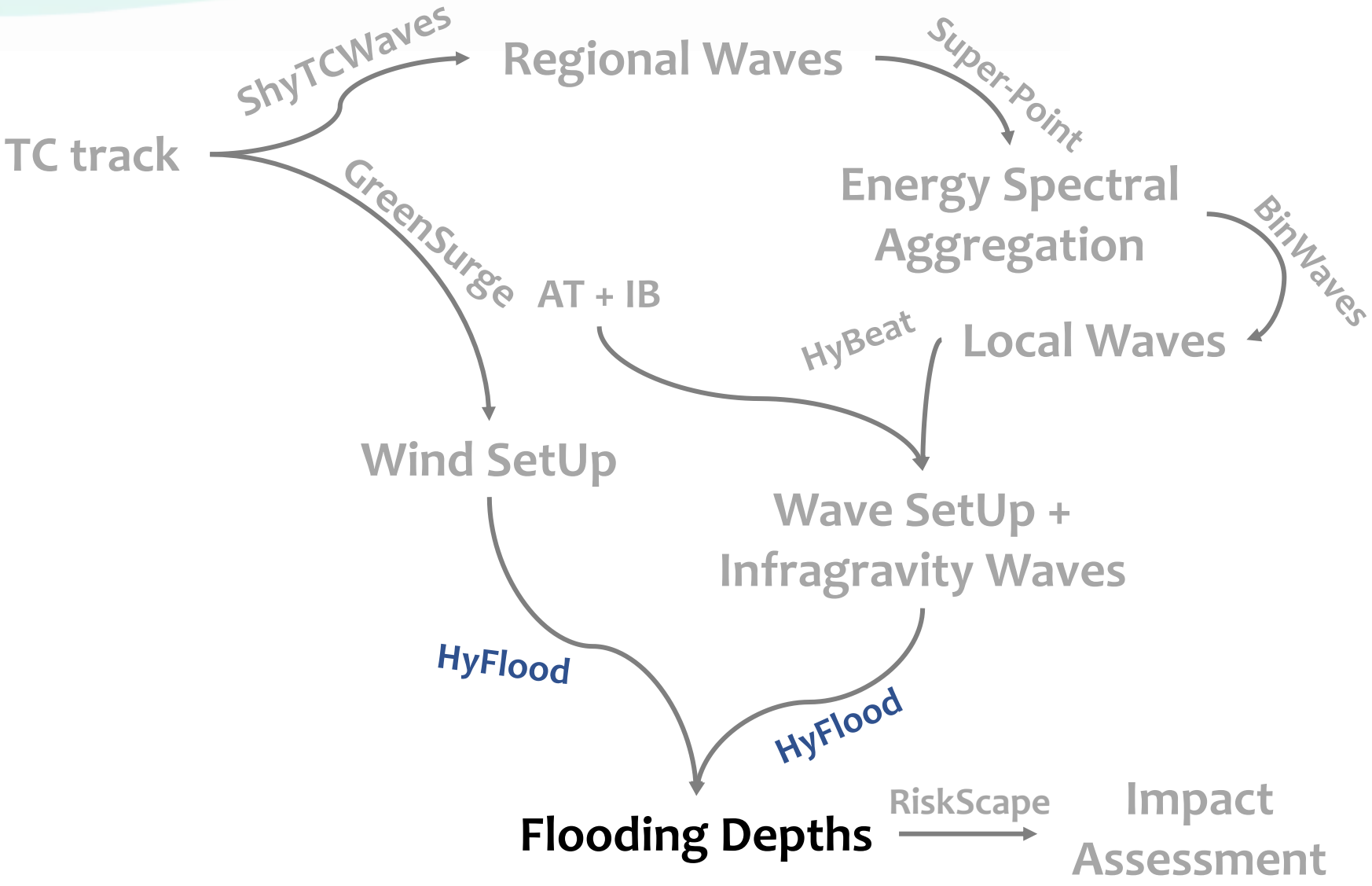


HyBeat

High Resolution Wave SetUp + IG



TC Inundation System



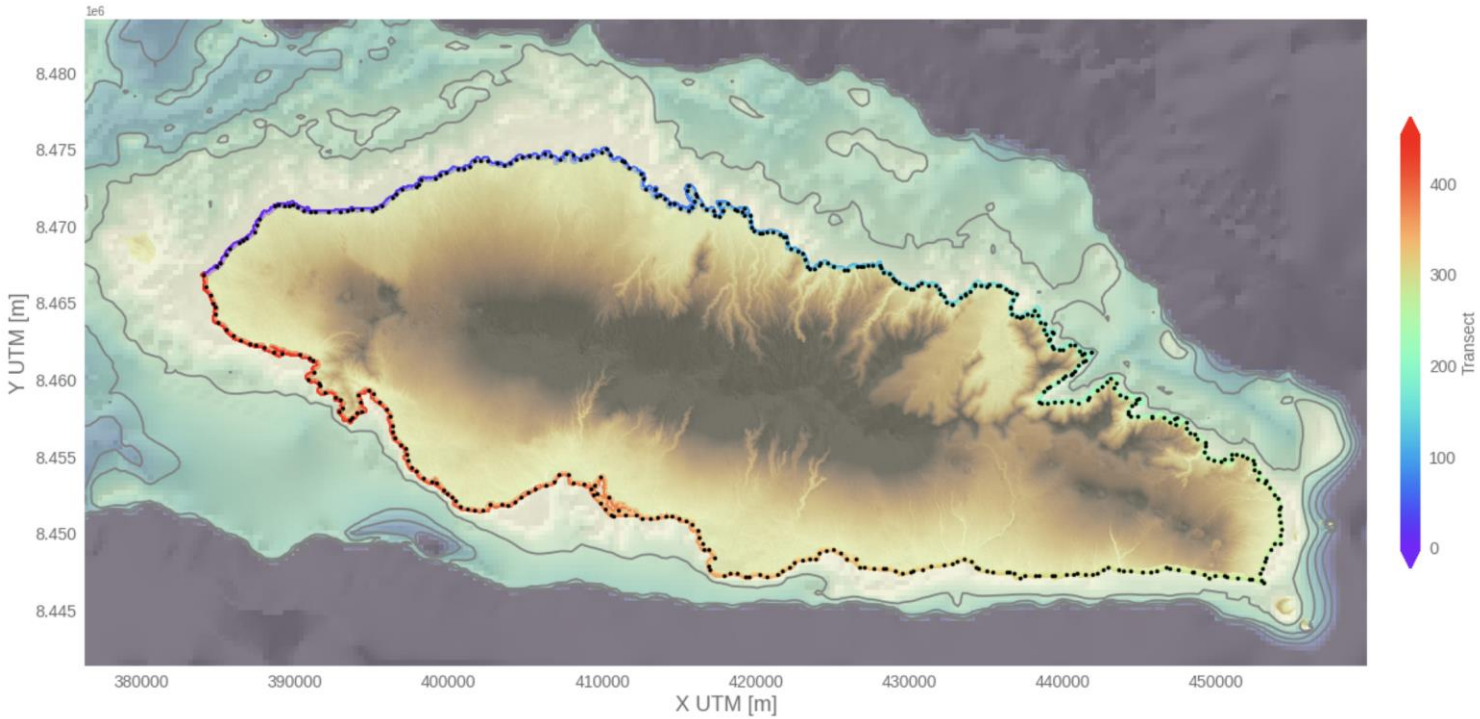
HyFlood

Wave SetUp +
Infragravity Waves

HyFlood

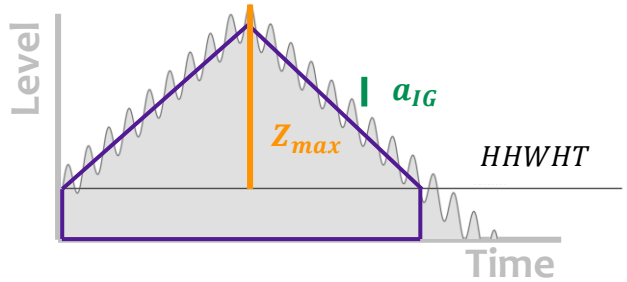
Flooding Depths

Type of Hybrid model:	**Metamodel**
Numerical model:	**Lisflood - FP**
Number of numerical simulations:	**50/Transect**
Spatial Resolution:	**5 m**



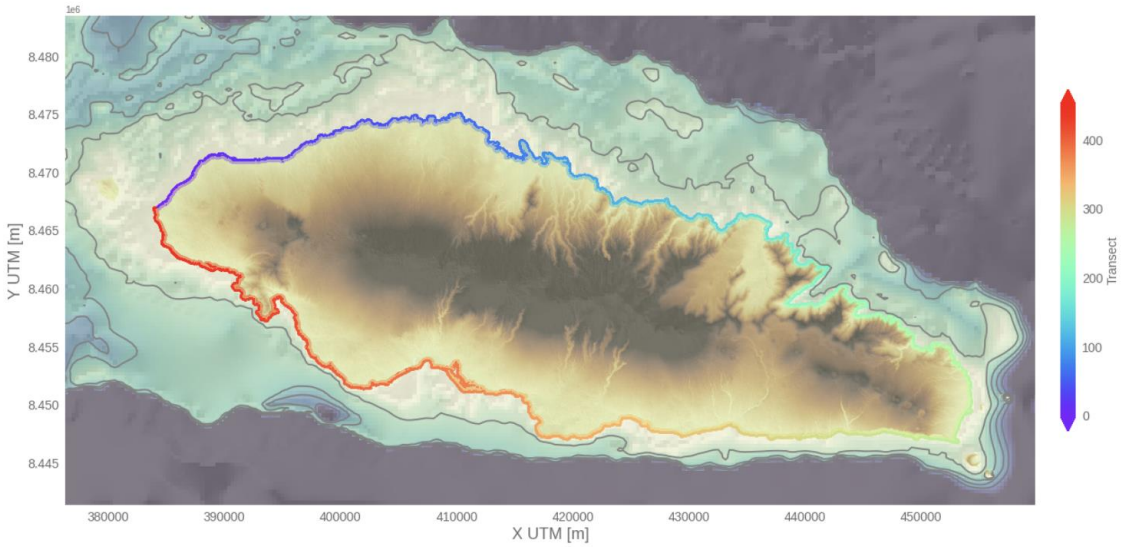
HyFlood

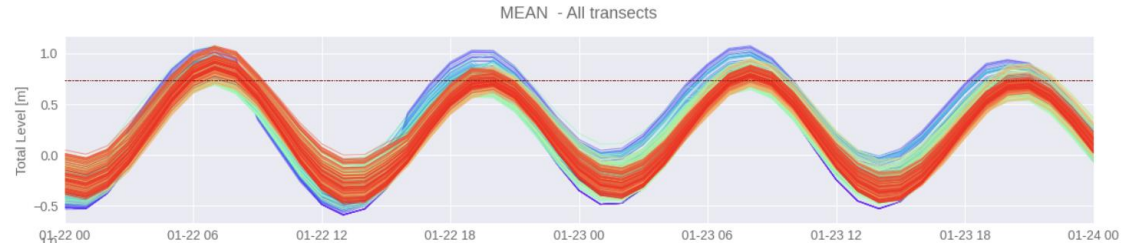
Selection of Representative Cases

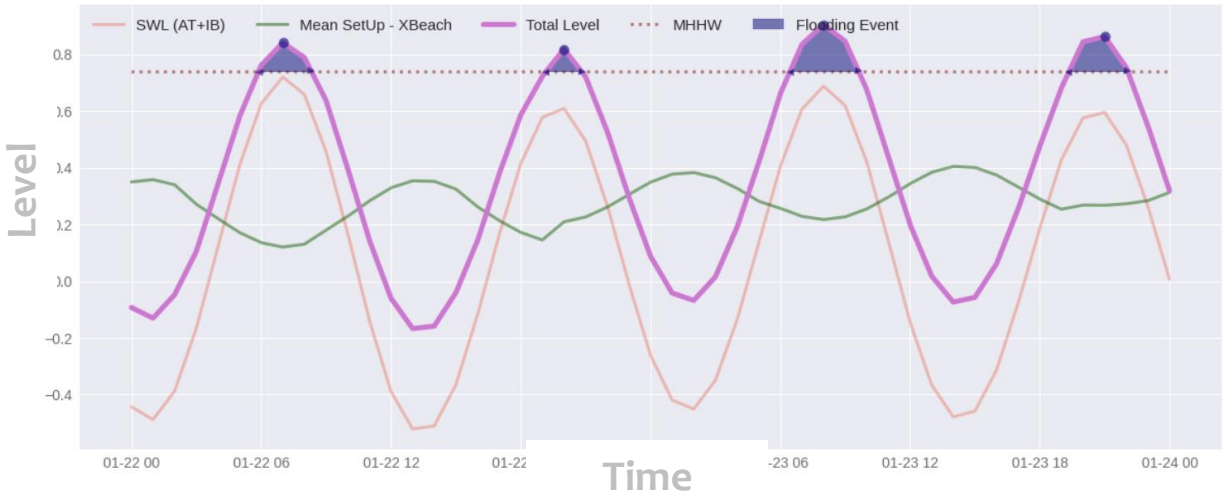


Run Library of cases with Lisflood-FP

Spatial Reconstruction of Flooding Extents

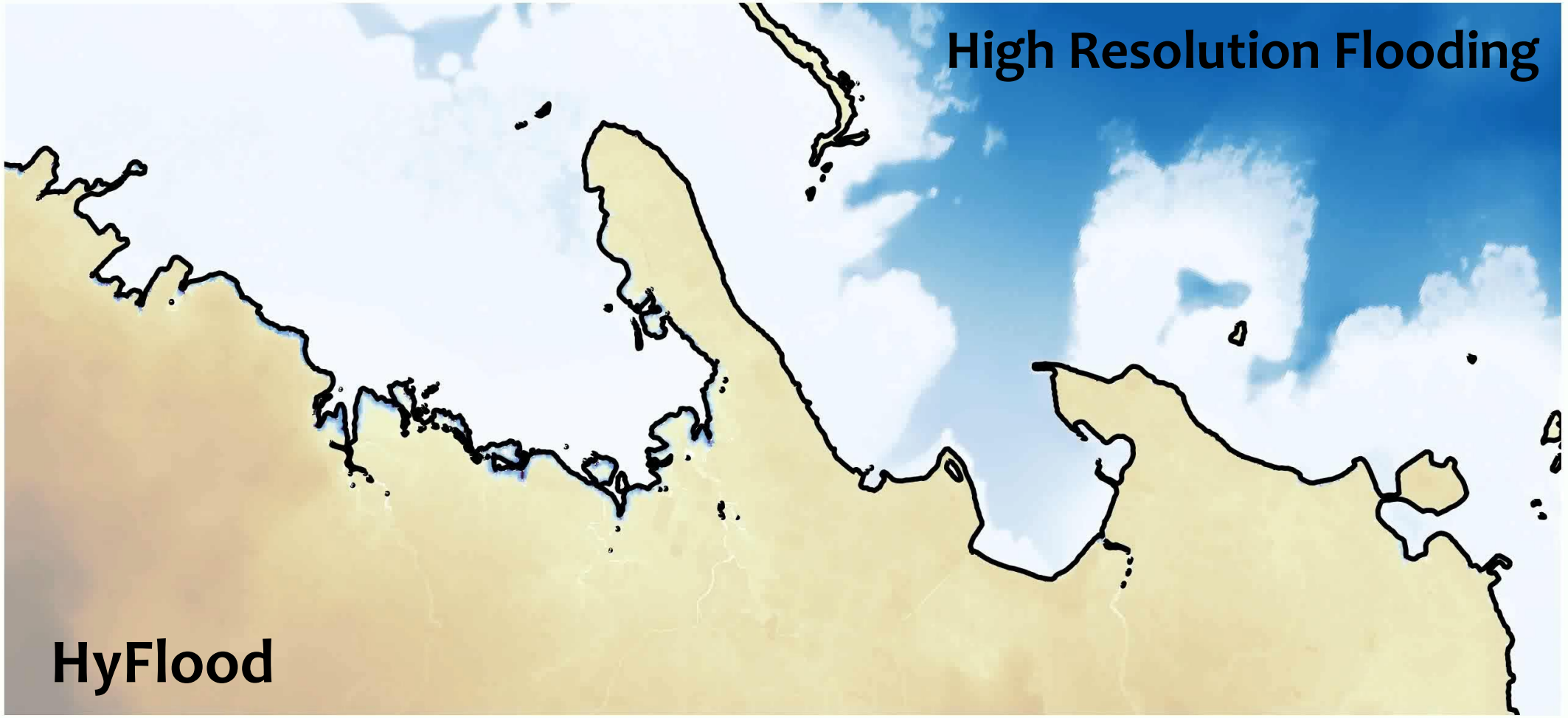




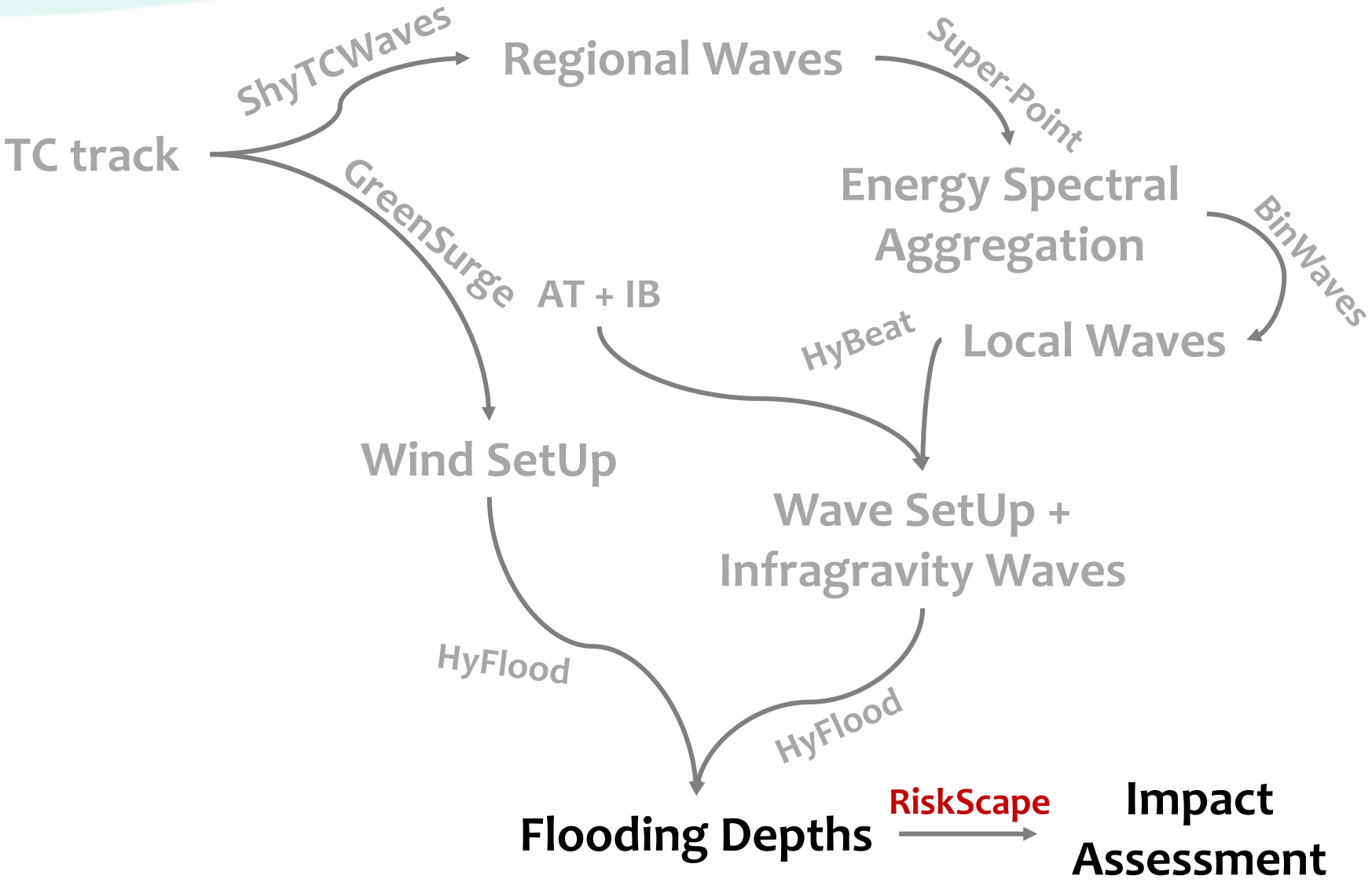


$$TWL = AT + SS + \bar{\eta} + \eta_{IG}$$

HyFlood



TC Inundation System



Riskscape

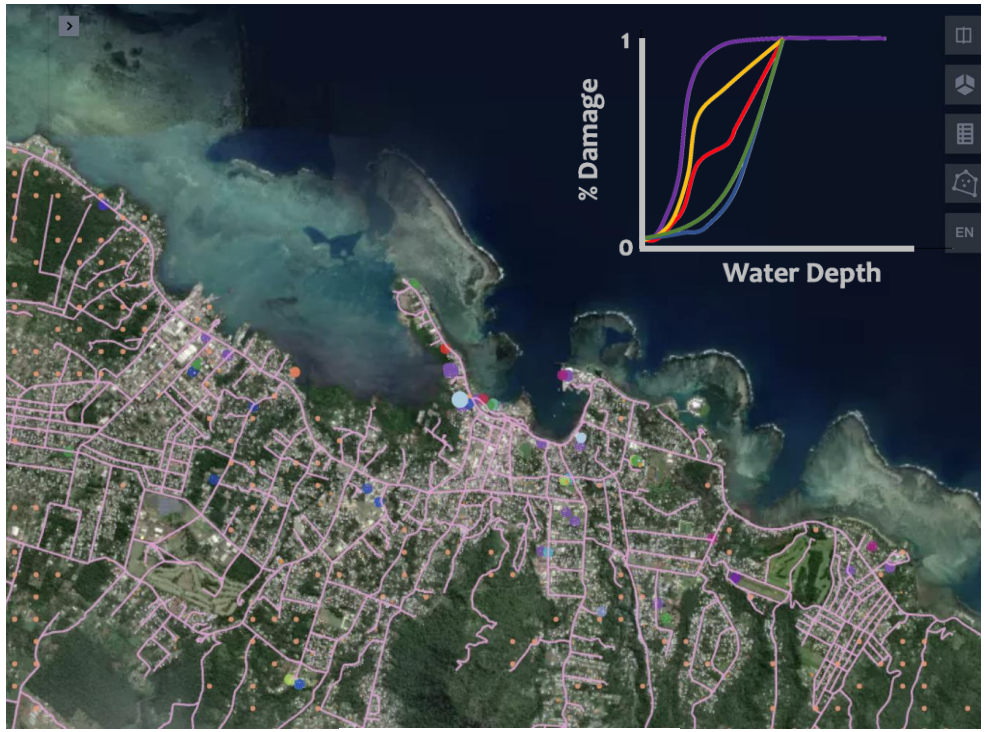
Hazard Layer

RiskScape

Open-source spatial data processing application used for multi-hazard risk analysis

Developed by NIWA, NZ

Exposure Layers and Damage Functions



Riskscape

PCRAFI + RiskScape

Exposure layers and damage functions

Model to cross exposure and hazard layers

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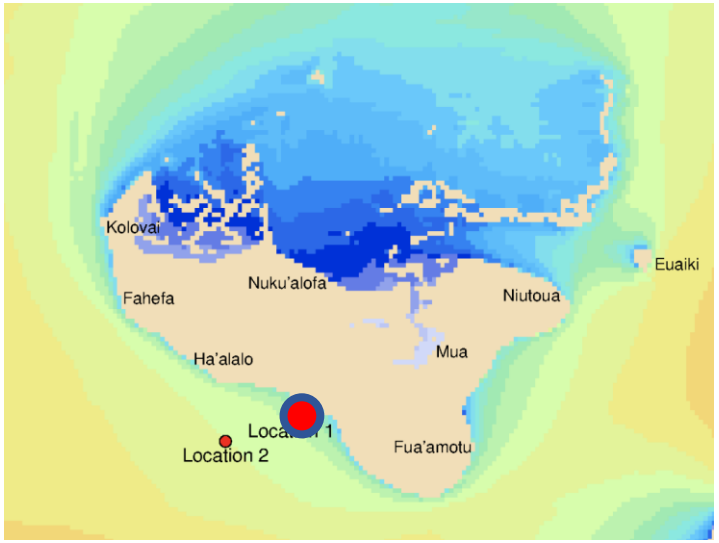
GeOcean
Geomatics and Ocean Engineering Group

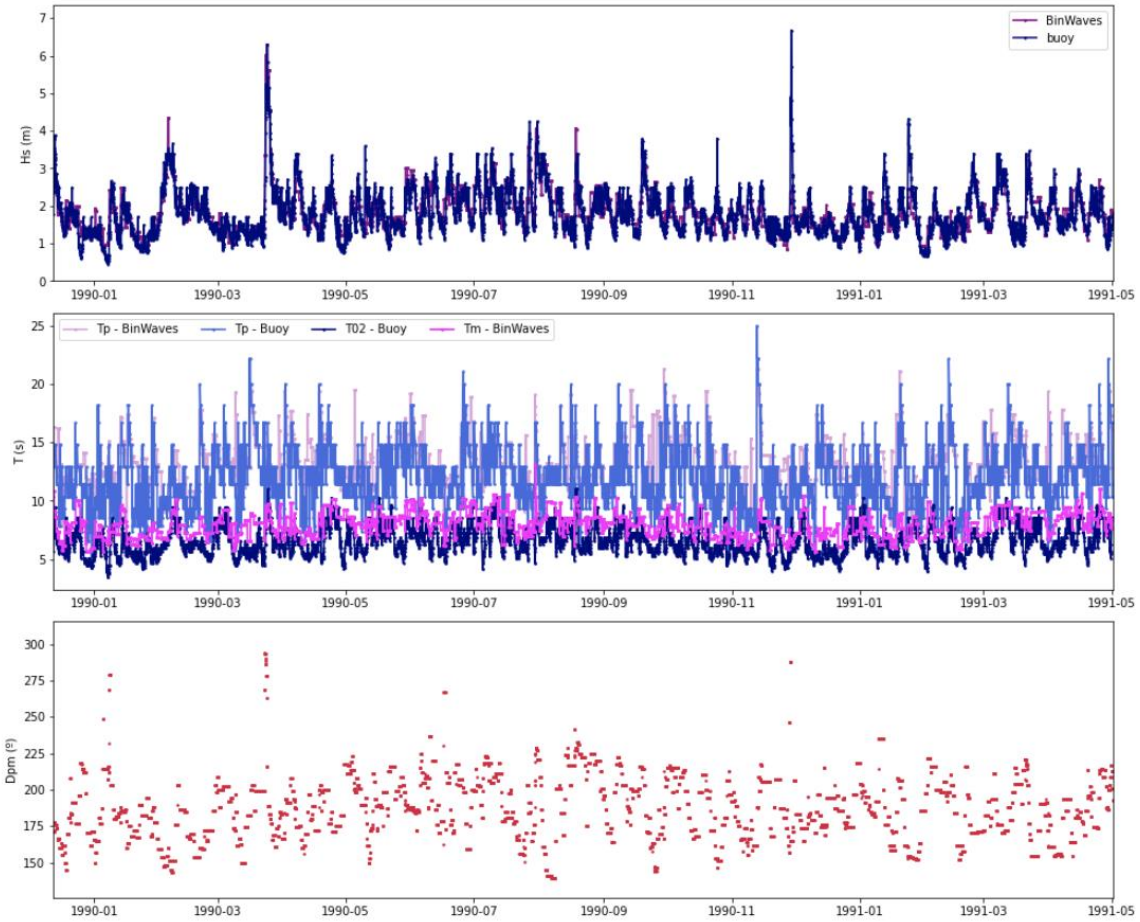
Thank you

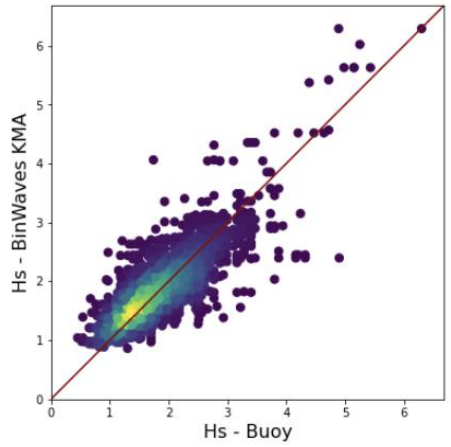
laura.cagigal@unican.es
https://geoocean.unican.es/

Validation- BinWaves

Tongatapu

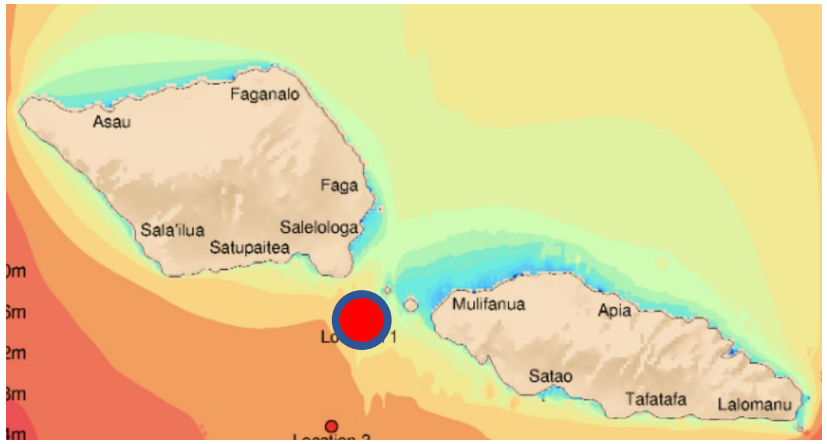


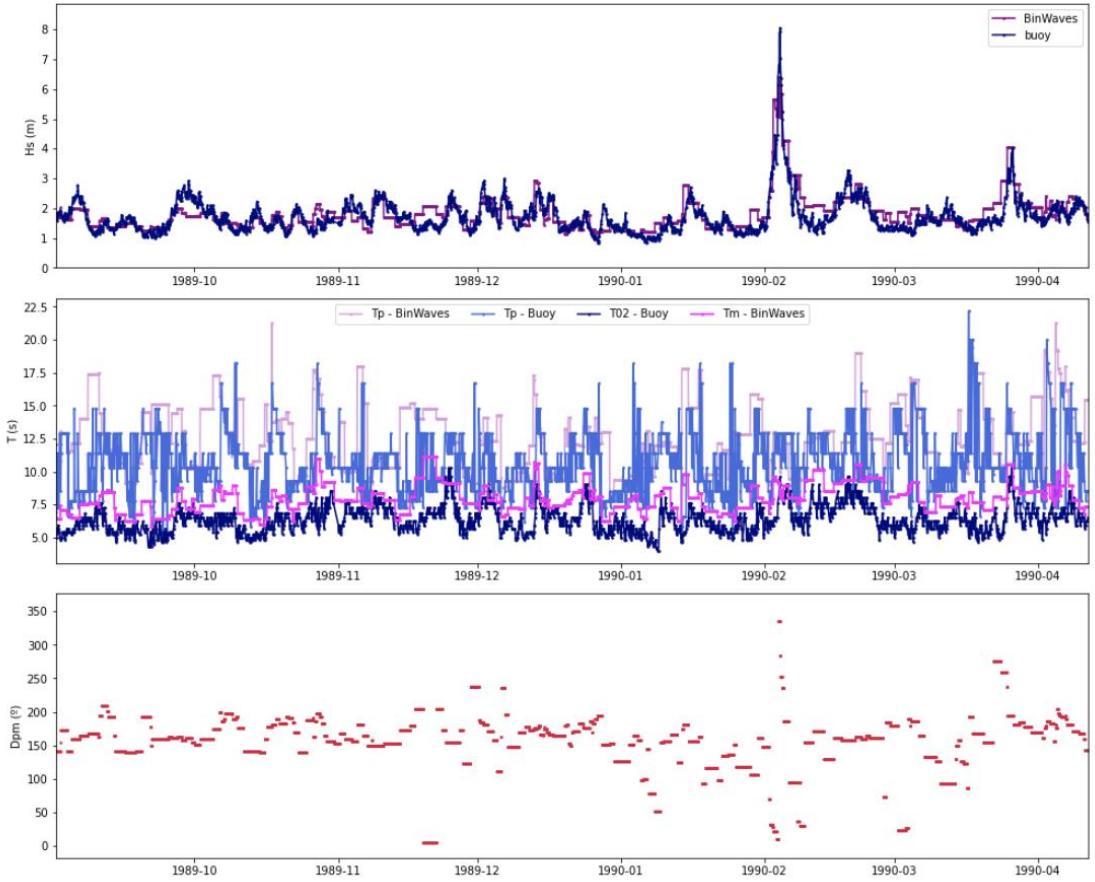


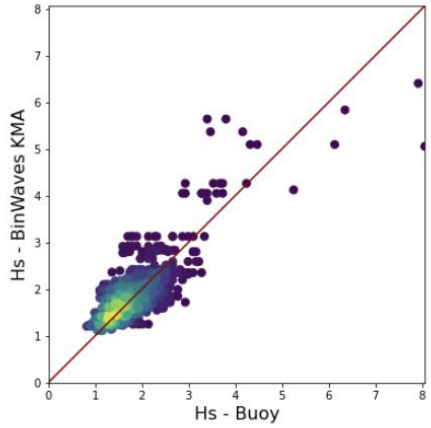


Validation- BinWaves

Samoa

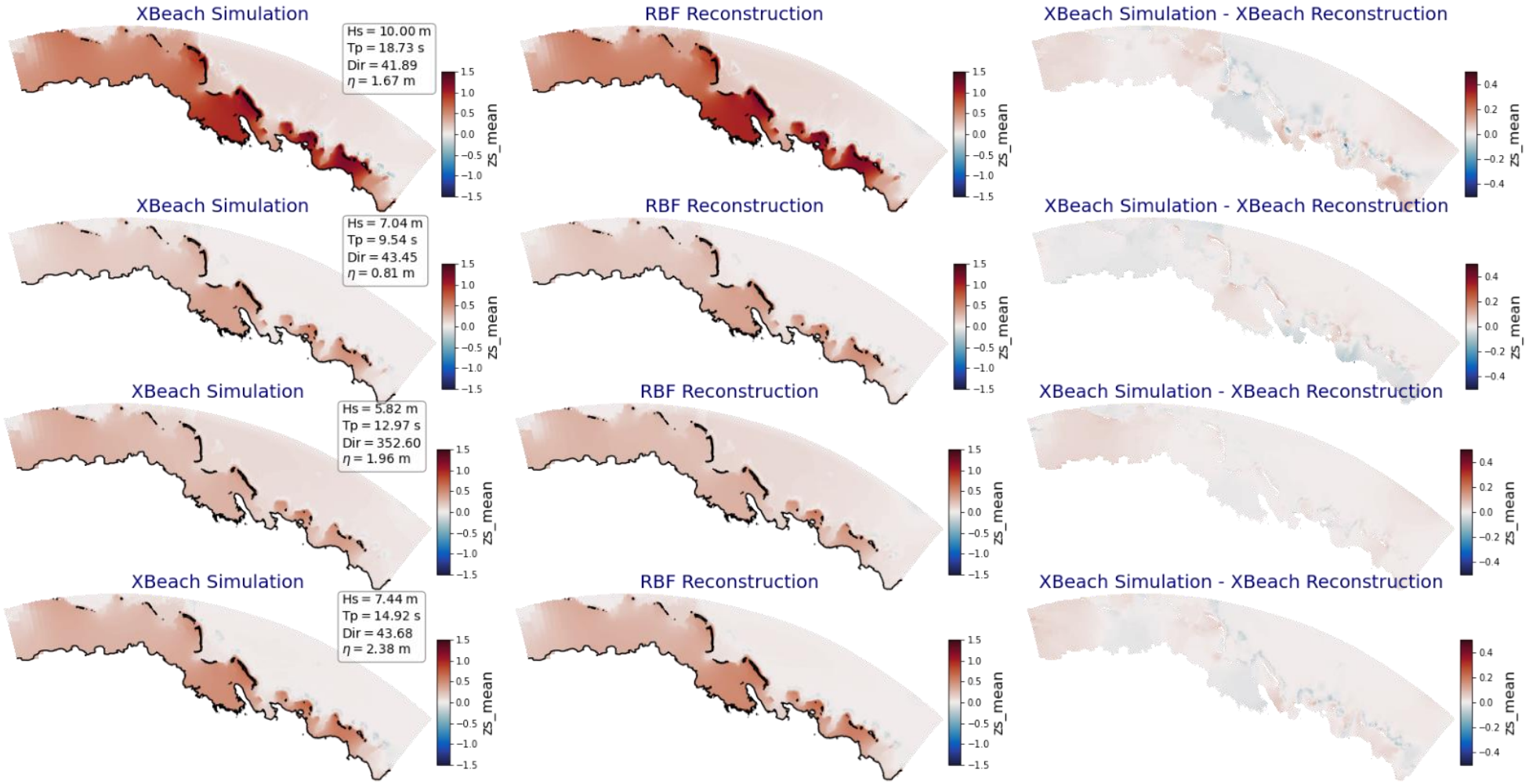






Validation- HyBeat

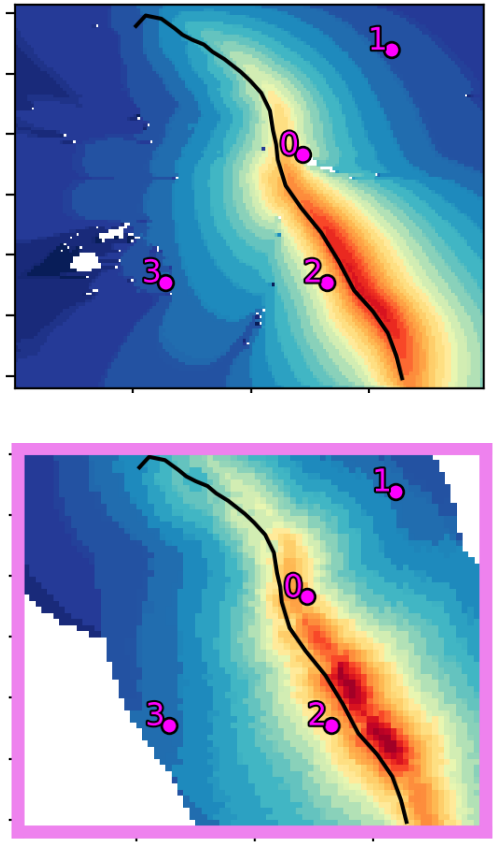
Reconstruction (RBF)

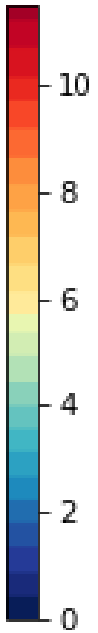


Validation- ShyTCWaves

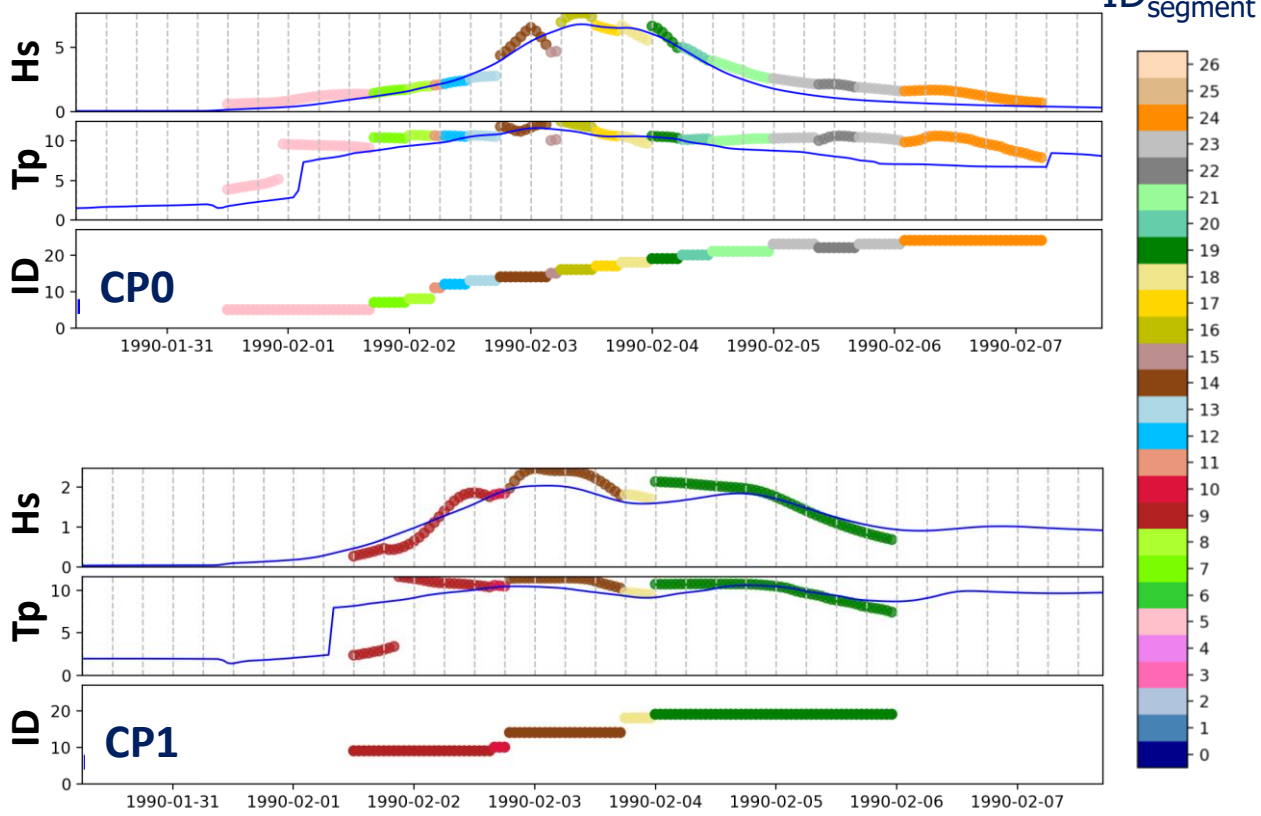
TC OFA (1990)

Swath map

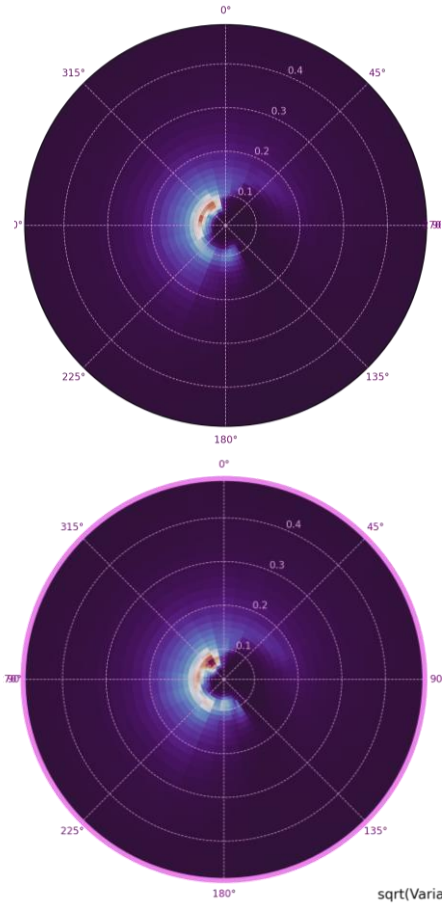




Time series

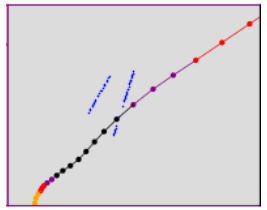


Swath spectra



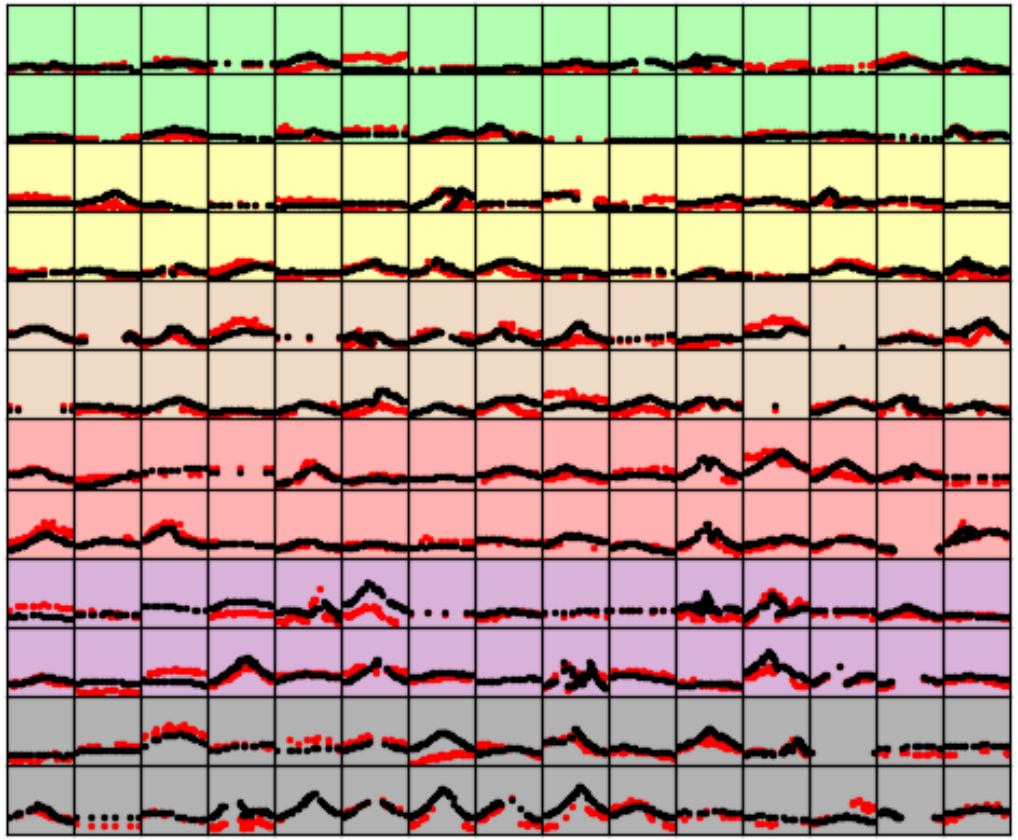
Validation- ShyTCWaves

Longitudinal profiles



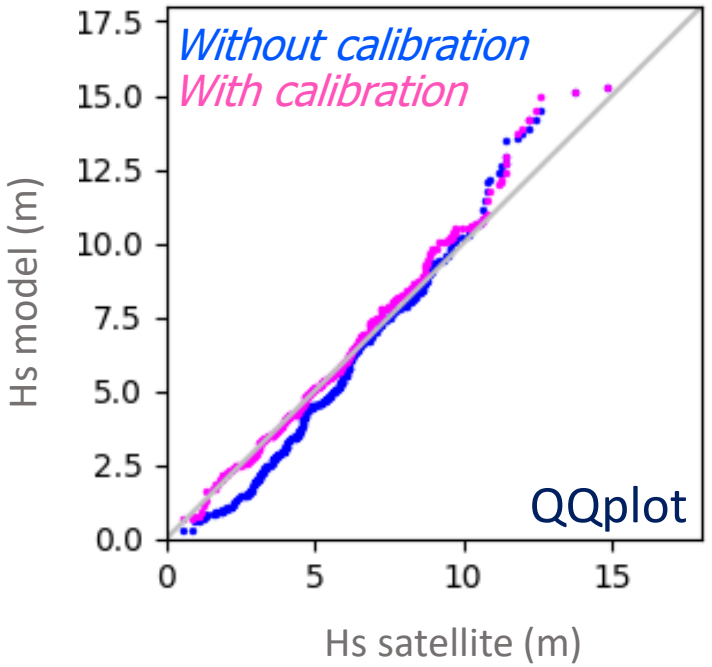
(*) IMOS satellite altimeter

Hs along profiles (Y-axis [0-20m])



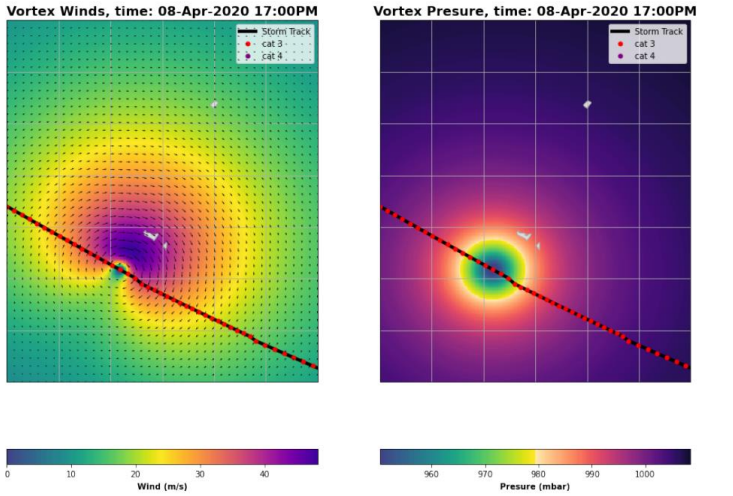
Calibration

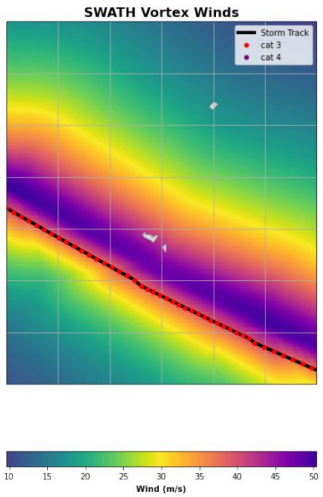
dP = f(Pmin)

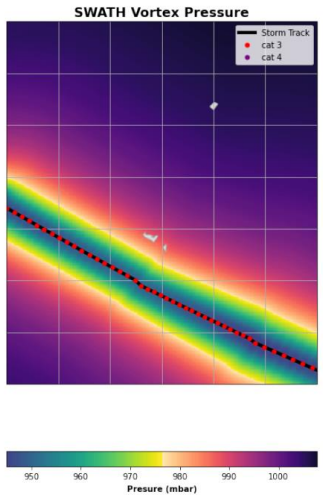


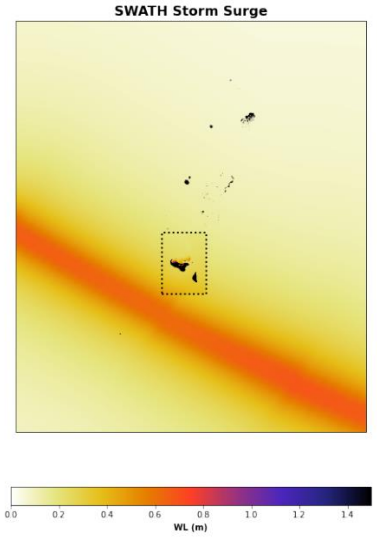
Validation- GreenSurge

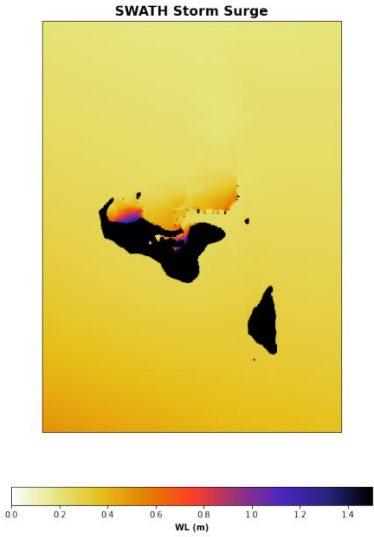
Harold 2020

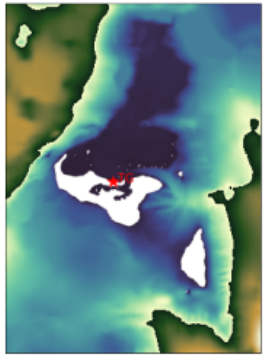


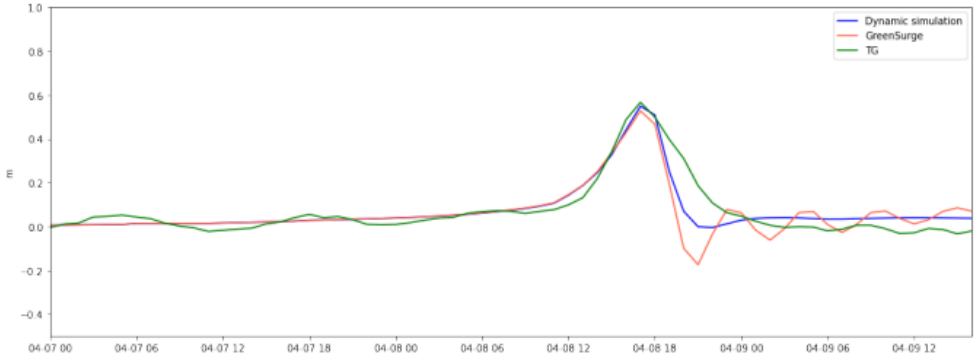












Validation- GreenSurge