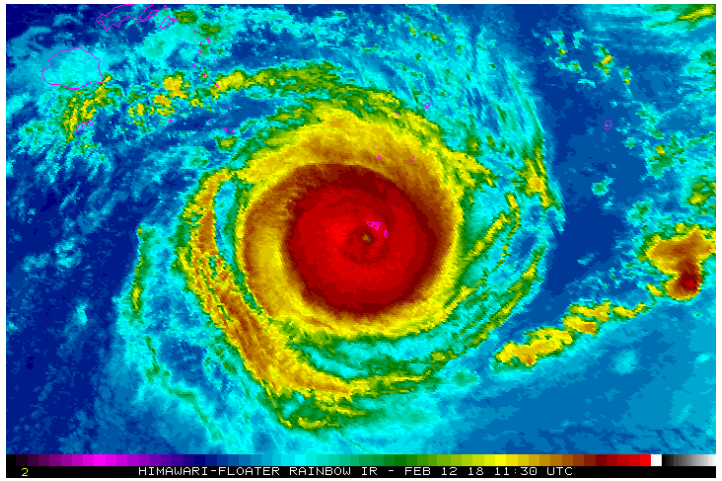
Tropical Cyclones are impacting Africa

Physical Impacts: Wind, Rainfall, Waves, Surge, Flooding

Socieconomical Impacts: Casualties, Destruction of infrastructures, economical damage



People shelter from destructive cyclone off the coast of Mozambique

TC Chido, December 14 2024

Death toll in French territory of Mayotte from Cyclone Chido is 'several hundred,' top official says

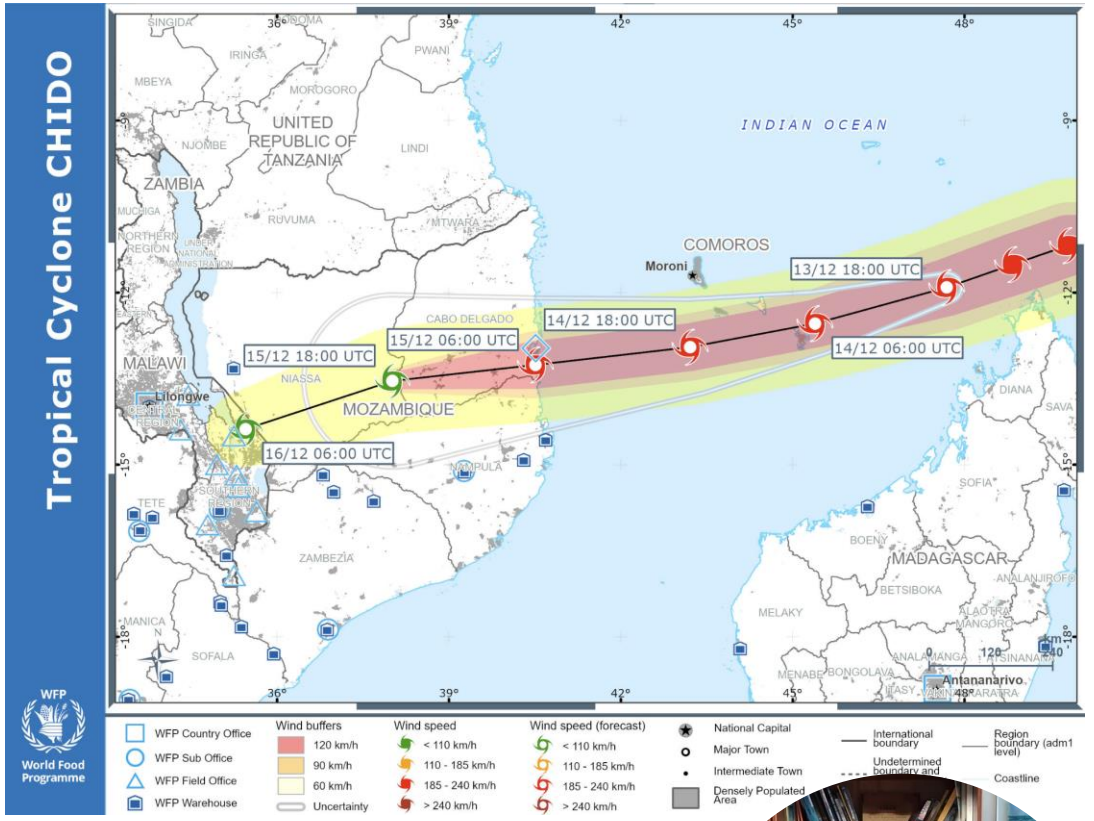
By By GERALD IMRAY and SYLVIE CORBET, Associated Press

Sunday, Dec 15, 2024 3:23 AM **Updated Sunday, Dec. 15, 2024 11:59 AM**

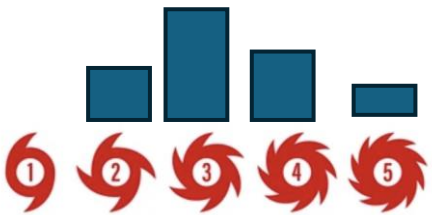
This undated photo provided by NGO Medecins du M
2024, shows a devastated hill on the French territory
Ocean, after Cyclone Chido caused extensive damage
fatalities. (Medecins du Monde via AP)

Forecasting of Tropical Cyclones (wind, waves, surge, rainfall, flooding) is needed for an efficient Early Warning System

TC Chido, December 14 2024



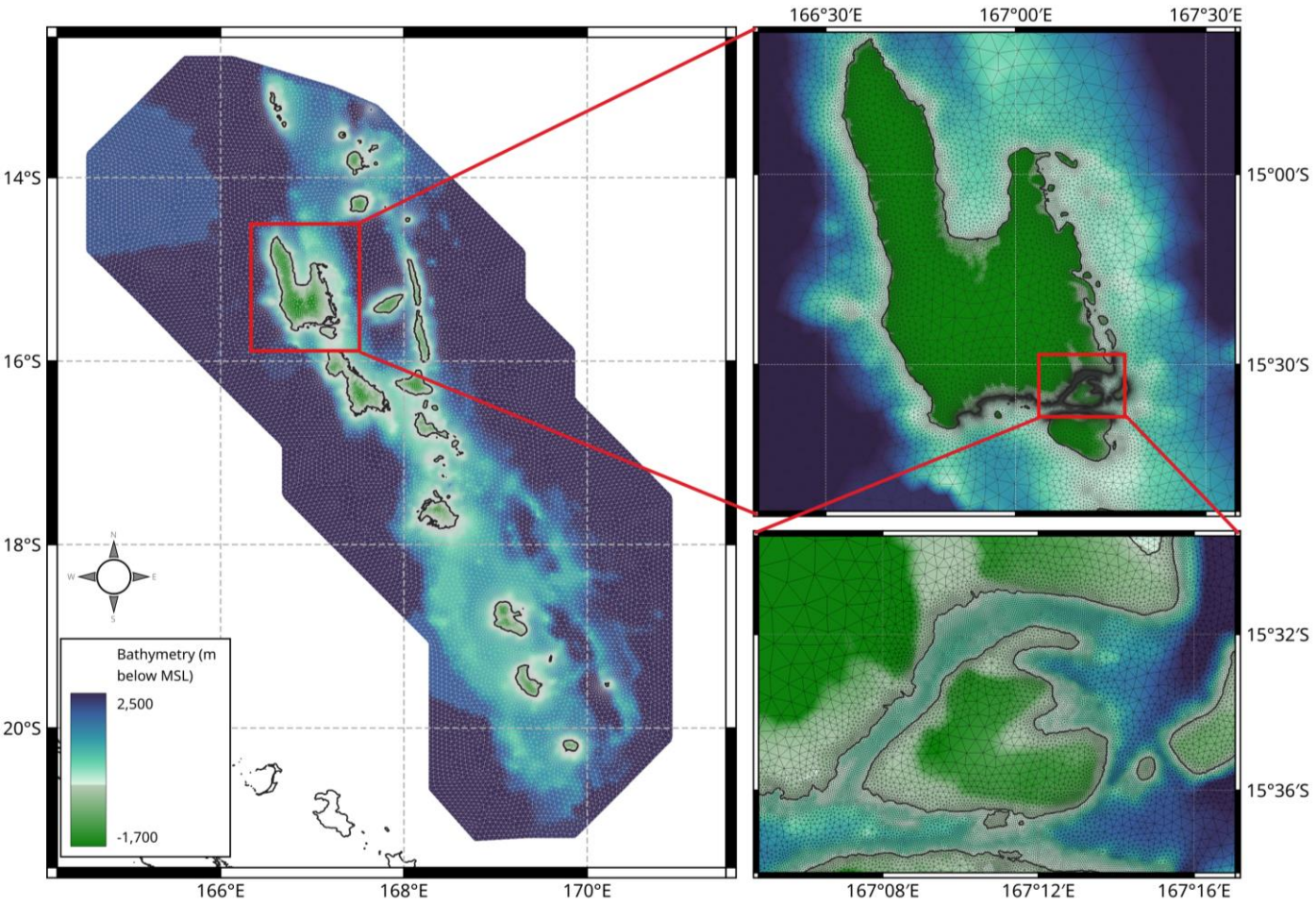
The track and intensity of a TC is uncertain. It is need
ensemble of plausible tracks to forecast probabilis



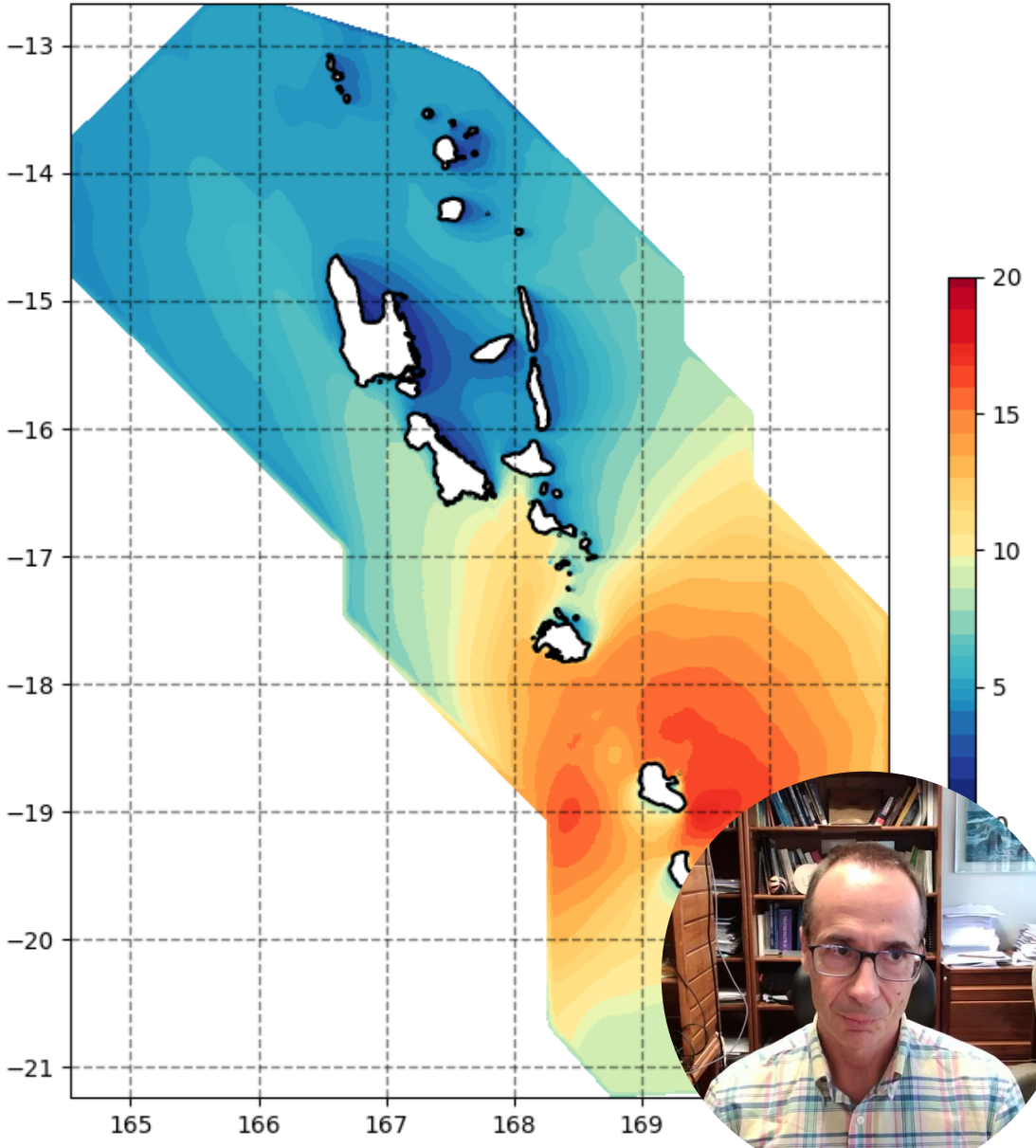
Probability of intensity landfall point

Traditional Methods for computation of these variables are too heavy computationally

Example: Grid in Vanuatu, 40 million of nodes
1 simulation of waves and surge: 10 hours in 192 cores



Unstructured Grid for SCHISM – Vanuatu (cell sizes between 1 km and 10 m)

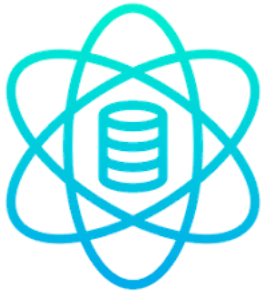


Snapshot of simulation of waves due to a tropi… …e

Hybrid Probabilistic approach: fast and allows an estimation of uncertainty

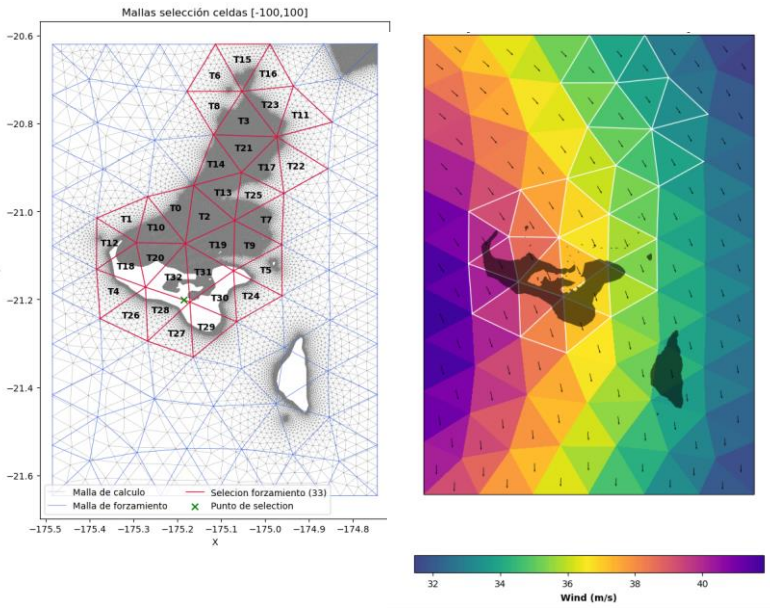
- Fast (less than 1hr)
- Low Computational Resources (one desktop computer)
- Open source
- Waves / Surge / Tide / Rainfall / Wind / Flooding / Impacts
- Probabilistic (x N simulations) based on Joint Typhoon Warning Center Tracks
- Hybrid Models / Surrogate Models / Meta Models
- Combination of High Fidelity Hydrodynamic Models + Data Science

Data mining for selecting cases

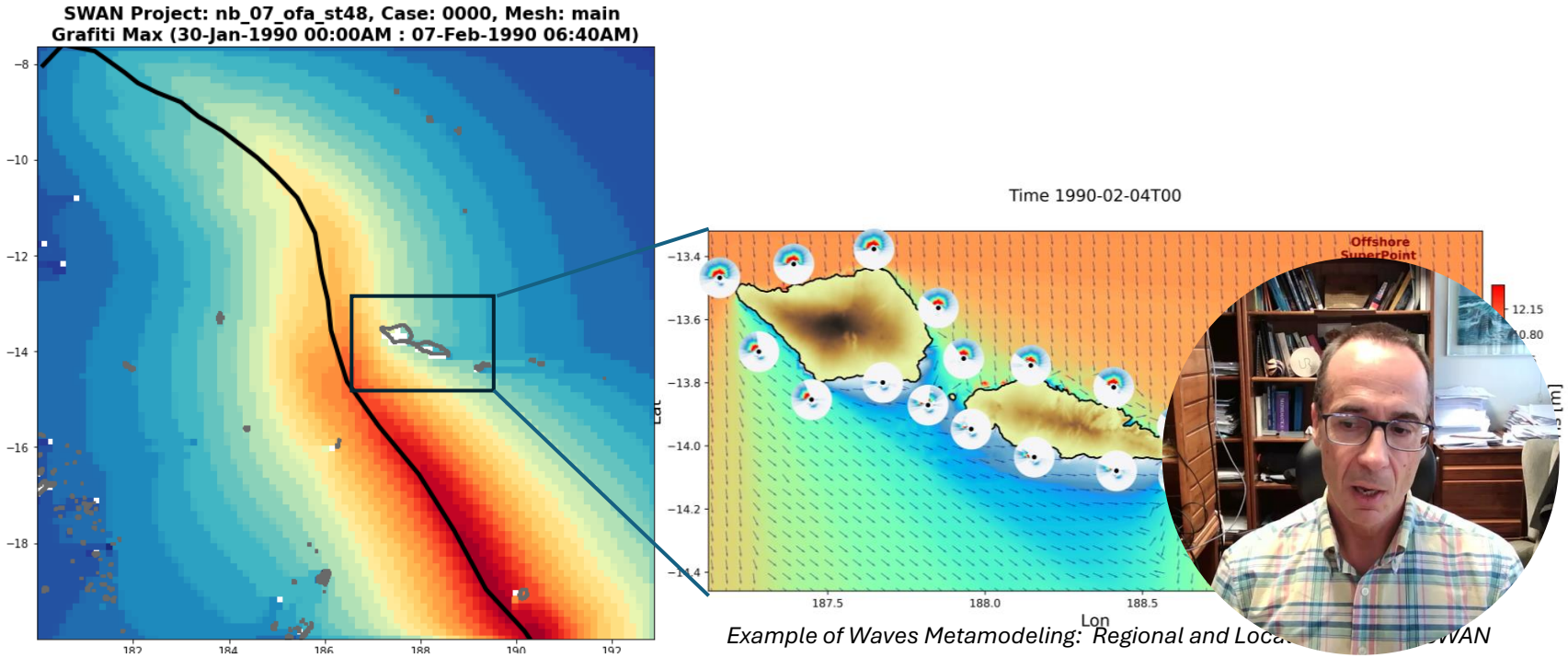


Library of pre-run cases

Hybrid Reconstruction



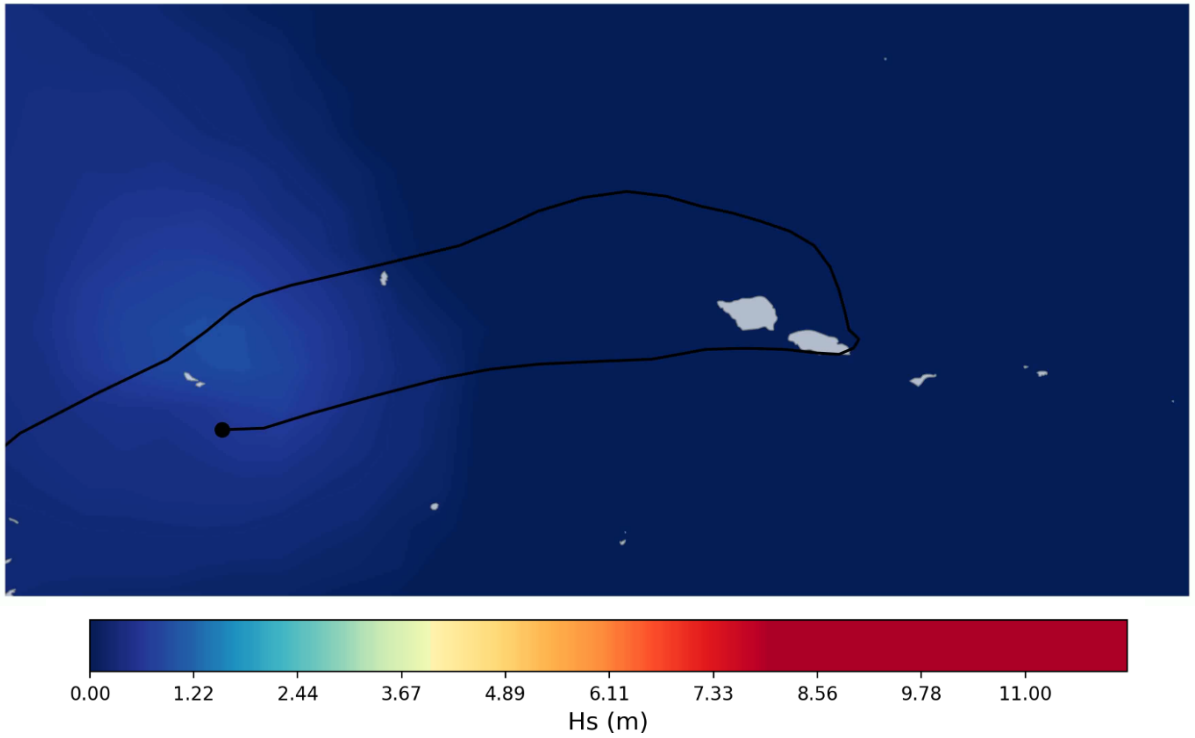
Automatic definition of unstructed grid and forcing for storm surge using Delft3DFM

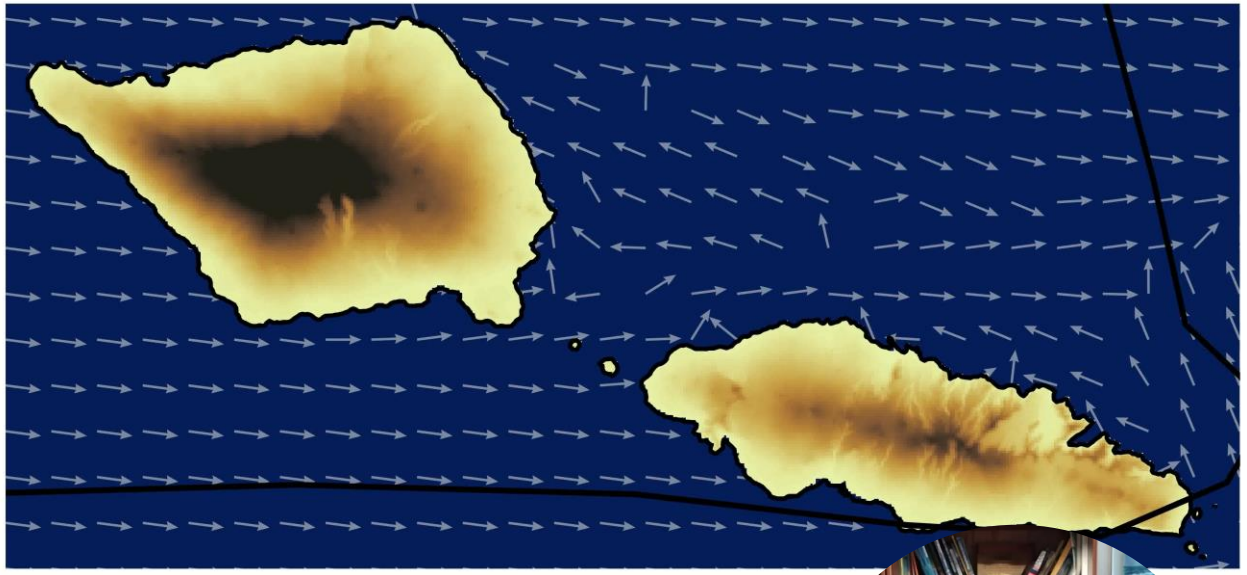


Example of Waves Metamodeling: Regional and Loca… SWAN

SHyTCWaves + BinWaves

TC Evan 2012





Our experience: Research

Ocean Modelling 178 (2022) 102100

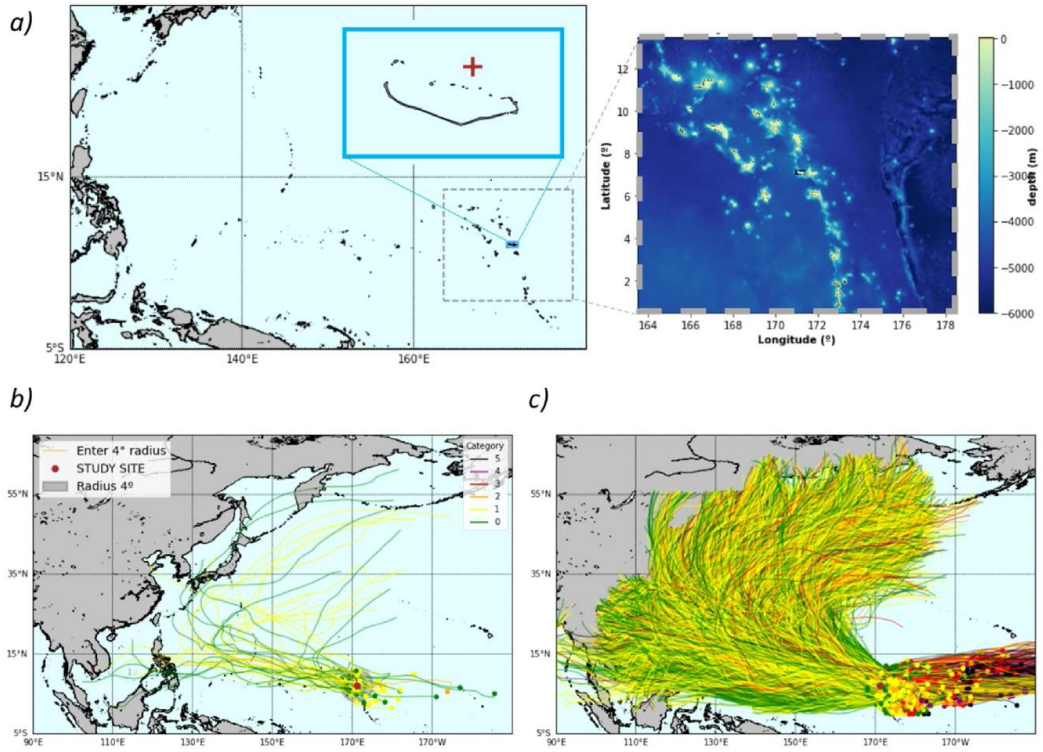
Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

HyTCWaves: A Hybrid model for downscaling Tropical Cyclone induced extreme Waves climate

Sara O. van Vloten *, Laura Cagigal, Ana Rueda, Nicolás Ripoll, Fernando J. Méndez



Ocean Modelling 188 (2024) 102341

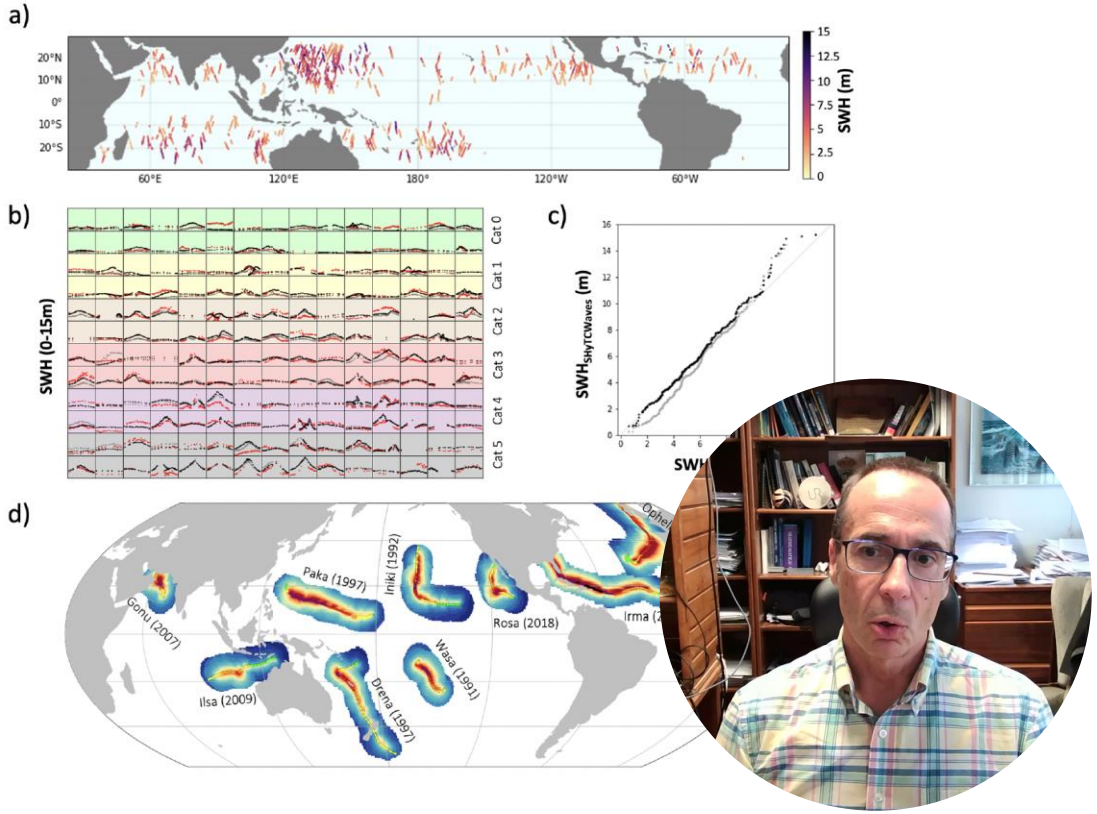
Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

SHyTCWaves: A stop-motion hybrid model to predict tropical cyclone induced waves

Sara O. van Vloten [a], Laura Cagigal [a,*], Beatriz Pérez-Díaz [a], Ron Hoeke [b], Fernando J. Méndez [a]



Our experience: Research

Ocean Modelling 189 (2024) 102346

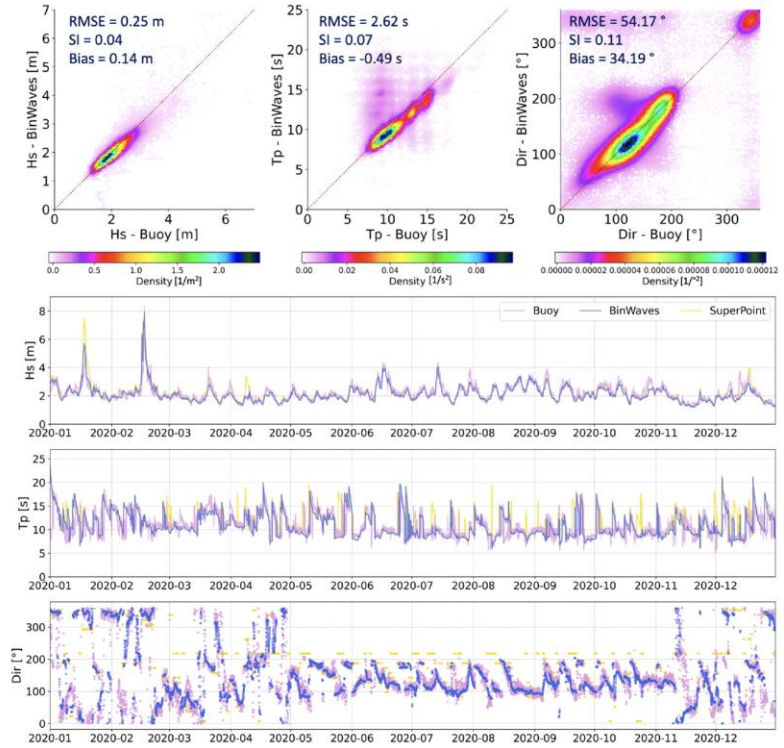
Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

BinWaves: An additive hybrid method to downscale directional wave spectra to nearshore areas

Laura Cagigal [a,*], Fernando J. Méndez [a], Alba Ricondo [a], David Gutiérrez-Barceló [b], Cyprien Bosserelle [c], Ron Hoeke [d]



Coastal Engineering 197 (2025) 104691

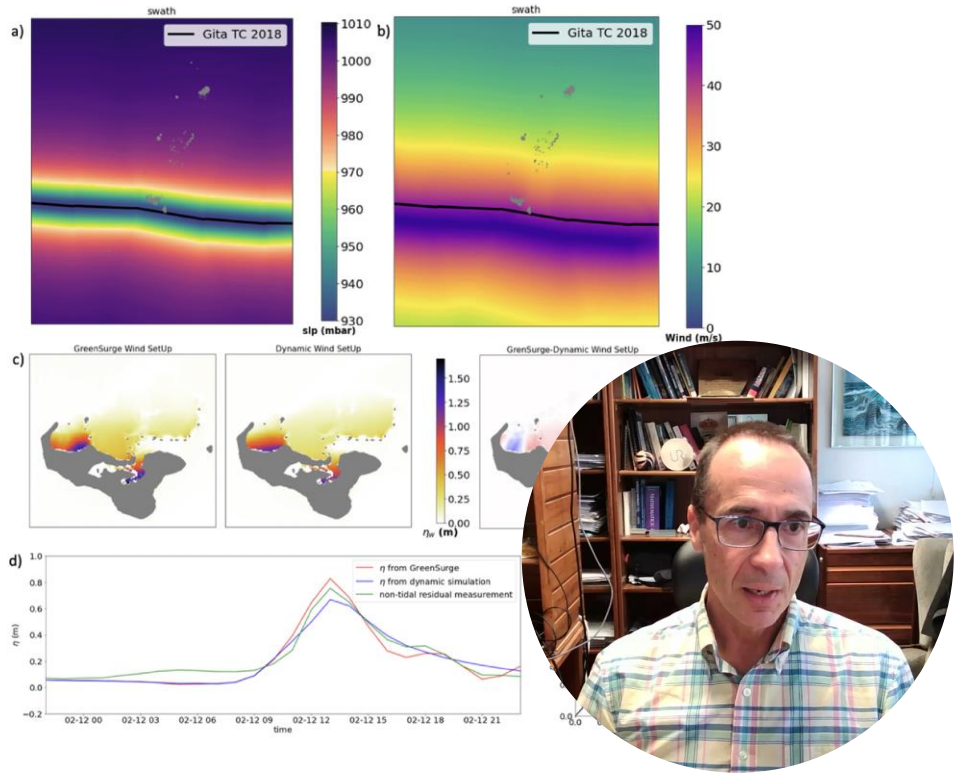
Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

GreenSurge: An efficient additive model for predicting storm surge induced by tropical cyclones

Beatriz Pérez-Díaz *, Laura Cagigal, Sonia Castanedo, Valvanuz Fernandez-Quiruelas, Fernando J. Méndez



Our experience: Research Projects – Modeling TC-induced waves and storm surge

- Great Barrier Reef (Univ. Sydney)
- Vanuatu (CSIRO)
- Republic of Marshall Islands (SPC, USGS, NOAA, OSU)
- Hawaii, Guam, Gulf of Mexico (NOAA, USGS, Scripps, OSU)
- New Zealand (Univ. Auckland)
- Carolinas, USA (Duke University)

Our experience: Pacific Resilience Project (PREP I). **Impact Forecasting Consultancy** in Tonga and Samoa
2-year project funded by World Bank, managed by Pacific Community (SPC)

- Probabilistic Forecast of Storm Surge Levels
- Probabilistic Forecast of Waves at Regional Scale
- Probabilistic Forecast of Waves at Local Scale
- Probabilistic Forecast of Total Water Level at Local Scale
- Probabilistic Forecast of Flooding Extents at High Resolution
- Seasonal Outlook of Tropical Cyclone Activity (1 to 6 months)
- Training

Swell Inundation System {operational}

TC Coastal Inundation System {operational}

Multi-hazard **Impact Forecast** System{operational}

TC Rainfall Inundation System {operational}

TC Wind System {operational}

Multi-hazard **Risk Assessment**{climate}

TESLA System {climate}

Tsunami Inundation System {operational}

Seasonal Forecast Swells {operational}

Seasonal Forecast TCs {operational}

THE WORLD BANK

Pacific Community
Communauté du Pacifique

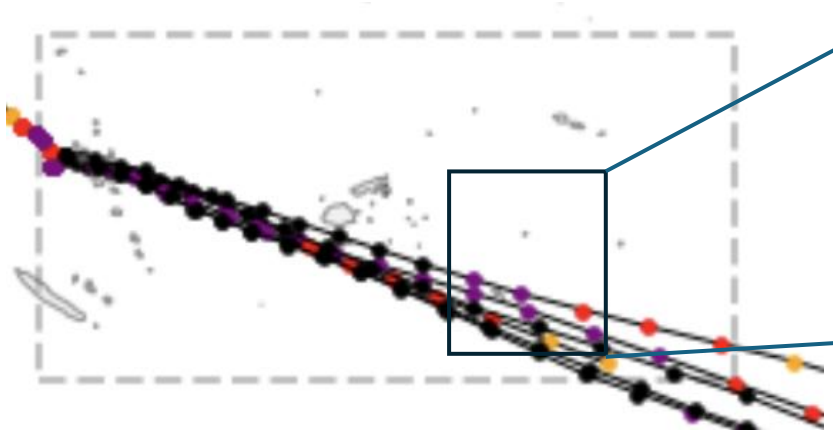
50 UC Universidad de Cantabria

Geomatics and Ocean Engineering Group
UNIVERSIDAD DE CANTABRIA

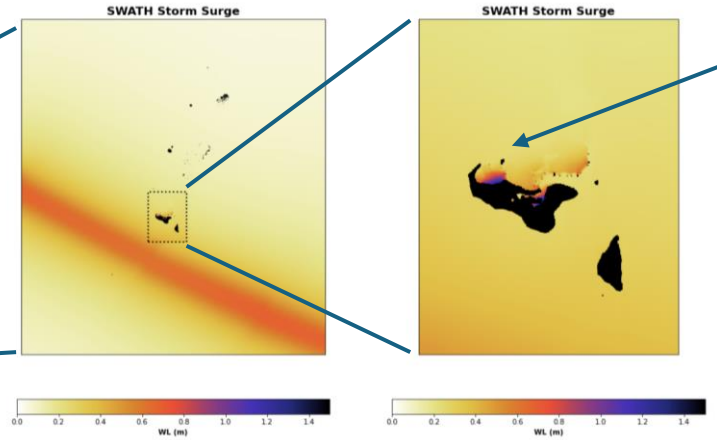
NIWA
Taihoro Nukurangi

Our experience: Pacific Resilience Project (PREP I). **Impact Forecasting Consultancy** in Tonga and Samoa
2-year project funded by World Bank, managed by Pacific Community (SPC)

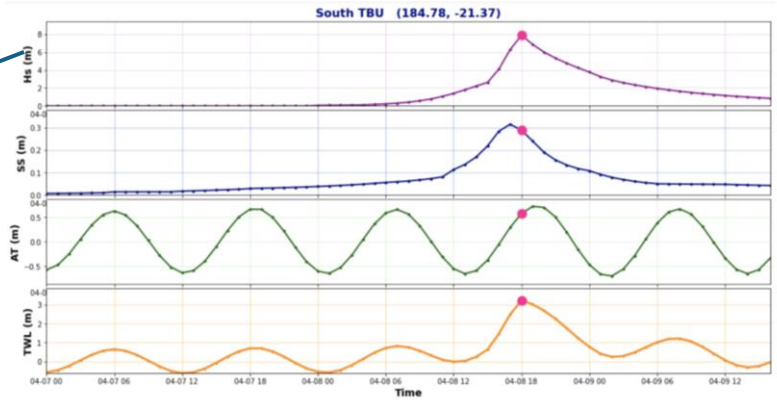
1. Downloading Tracks from JTWC



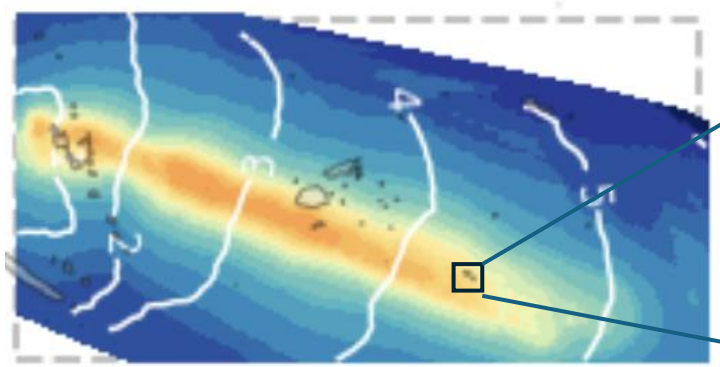
2. TC-induced Storm Surge Levels



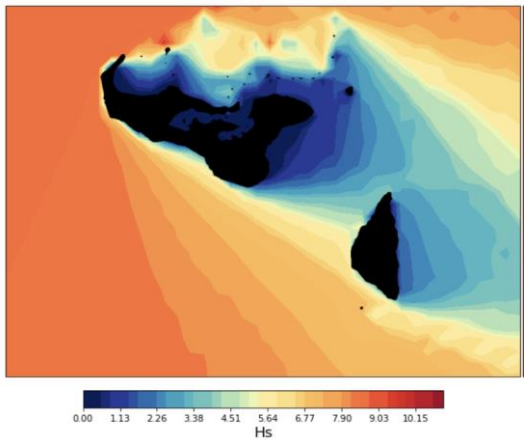
6. Forecast of Total Water Level



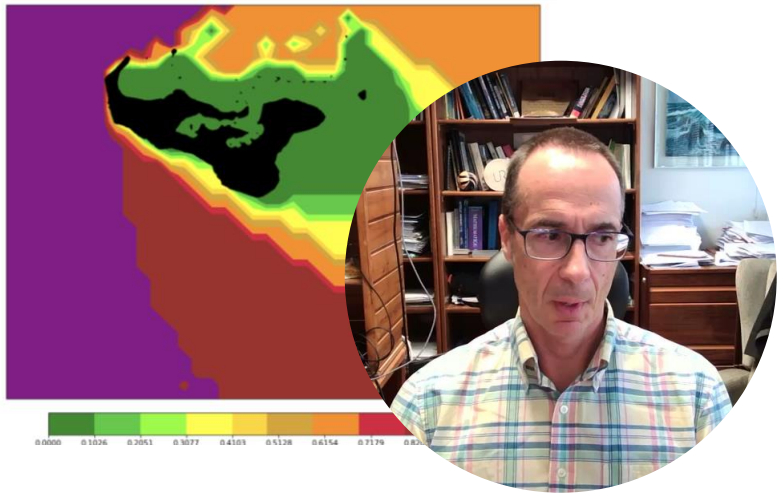
3. TC-induced Waves at Regional Scale



4. TC-induced Waves at Local Scale



5. Probabilistic forecast of Waves (Hs>8m)



Jupyter Books

- HTML
- PDF

Run in One Desktop Computer:

- Jupyter Notebooks
- Dashboard to visualize the results

TC Inundation System : Samoa

SHyTCWaves Library

SHyTCWaves ensemble

Historical storm tracks database (IBTrACS)

Storm track

Pre-run storm segments, 10 parameters

LOCAL SCALE

```
# common
import os
import os.path as op

# pip
import numpy as np
import pandas as pd
import xarray as xr
import matplotlib.pyplot as plt
import pickle

# dev library
import sys
sys.path.insert(0, op.join(os.path.abspath(''), '..

# swan wrap module
from hywaves.swan.storms import check_storm_data, h
historic_track_interpolation, track_triming
from hywaves.swan.stopmotion import *
from hywaves.swan.superpoint import *
from hywaves.swan.plots.stopmotion import *
from hywaves.swan.plots.common import custom_cmap,
from hywaves.swan.videos import *

# path directories
p_data = op.abspath(op.join(os.path.abspath(''), '.
p_hywaves_resources = r'/media/administrador/Disco/
 ↪swan/resources/'
p_library = r'/media/administrador/HD8/conf_drm4g/o
p_stopmotion = op.join(p_data, 'stopmotion')

# colormaps
cmap_wind = custom_cmap(100, 'plasma_r', 0.05, 0.9,
```

TC Inundation System : Samoa

Wind forcing partition

$\eta(x)$ = η_1 +

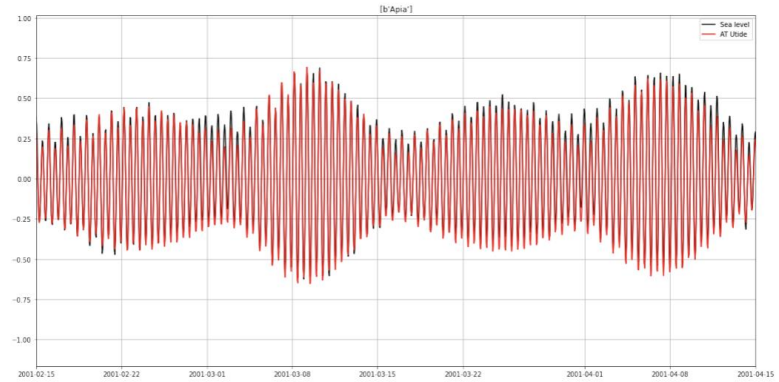
$\forall t$

```
#!/usr/bin/env python
# -*- coding: utf-8 -*-
import warnings
warnings.filterwarnings('ignore')

# common
import os
import os.path as op

# pip
import numpy as np
import pandas as pd
import xarray as xr
import matplotlib.pyplot as plt
import matplotlib.ticker as mticker
from matplotlib import gridspec, animation
# from mpl_toolkits.basemap import Basemap
# from pyproj import Proj
import cartopy
from cartopy import crs as ccrs
from cartopy.io.shapereader import Reader
import cartopy.io.shapereader as shpreader
from cartopy.feature import ShapelyFeature
import time
```

TESLAKIT.2.0



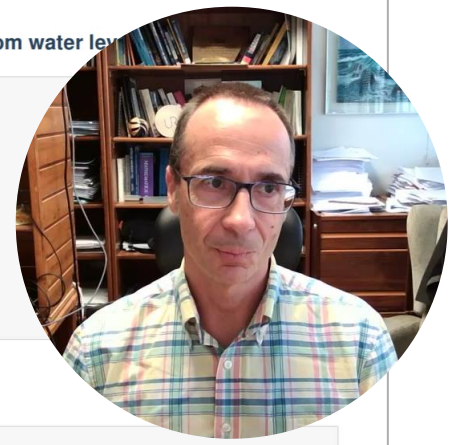
2.2.5 Historical Predicted Tide and Residuals from water lev

```
xds_hist = xr.Dataset(
    {
        'WaterLevels': (('time'), wl),
        'Residual': (('time'), residuals),
        'Predicted': (('time'), tide_tt),
    },
    coords = {'time': time}
)

# round times
xds_hist['time'] = xds_hist['time'].dt.round('H')

save_nc(xds_hist, AT_hist_file)
```

2.2.6 Astronomical Tide - Prediction



Dashboard for visualizing the operational system. Short-term forecast

CLiDEsc Portal

Laura Cagigal

Definition of Variables

Water Level Components

Seasonal Forecast

Swells

TCs

Short-term Forecast

Swells - Maps

TCs

Tsunami

© 2020 NIWA, New Zealand. All rights reserved.

POWERED BY CLIDESC V 0.22.211102P

Multi-Hazard Impact Forecast System - Tonga Local

2024-05-17 00:16:51 Local Time fullscreen contact help

Swell Inundation Spatial Fields

18

Time: 2024-05-13T06:00:00

SL (m)

Hs (m)

TWL (m)

Legend - Swell Inundation - Spatial Fields

Swell inundation for the next 7-days at a local scale of 250 m resolution

Swell Inundation Wave Fields

18

2024-05-13T06

0° 45° 90° 135° 225° 270° 315°

0.200 0.175 0.150 0.125 0.100 0.075 0.050 0.025

Hs (m)

Legend - Swell Inundation - Wave Fields

Left Figure: Directional Wave Spectra. The radial axis defines the frequency of the wave systems and the directions follow the nautical convection (the direction where waves are coming from).

Right Figure: Wave field map of Hs (m) where wave system directions are represented by the arrows.

Dashboard for visualizing the operational system. Seasonal forecast of TC activity

CLiDEsc Portal

Multi-Hazard Impact Forecast System - Samoa TCs

2023-08-30 05:50:23 Local Time fullscreen contact help

Definition of Variables

Water Level Components

Seasonal Forecast

Swells

TCs

Short-term Forecast

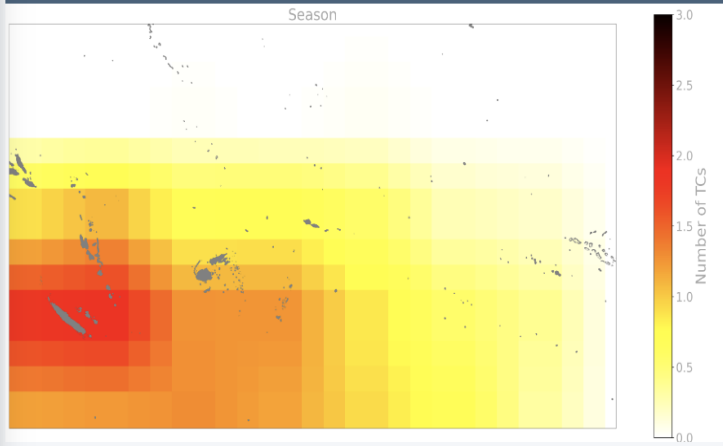
TCs

Swells - Maps

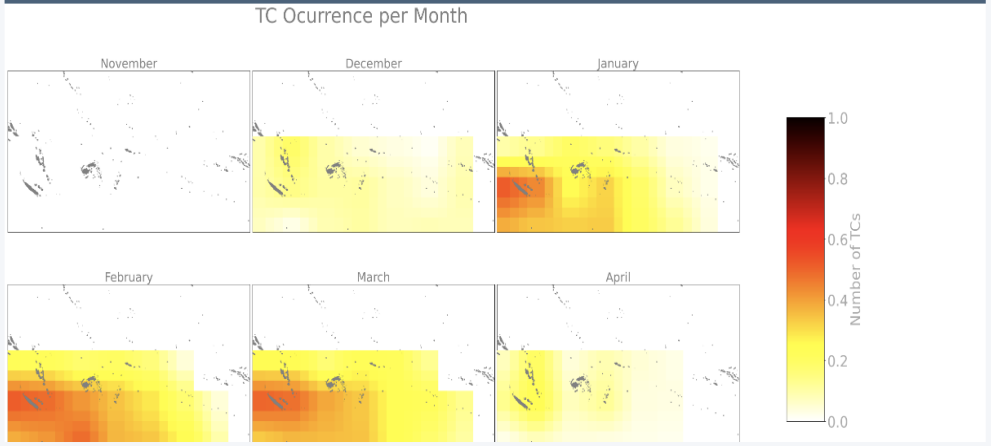
Swells - Sites

Tsunami

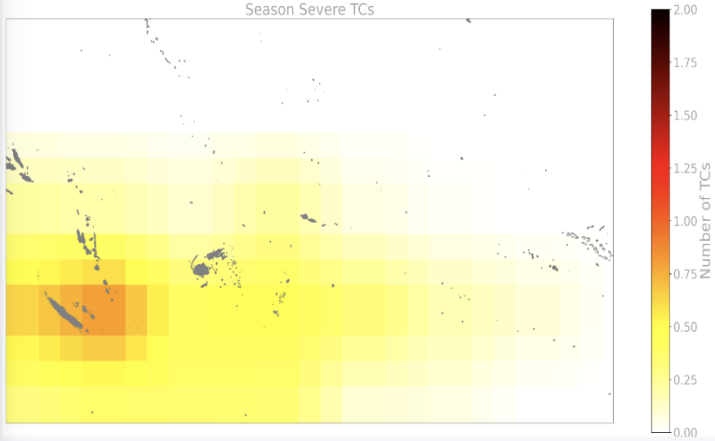
Expected Seasonal TC counts



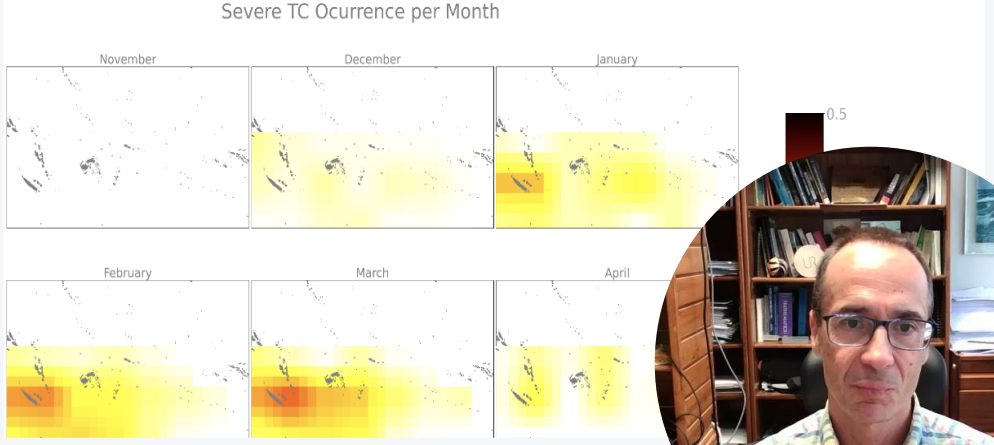
Monthly TC counts



Expected Seasonal counts of severe TCs (cateogy > 3)



Monthly Severe TC counts (category > 3)



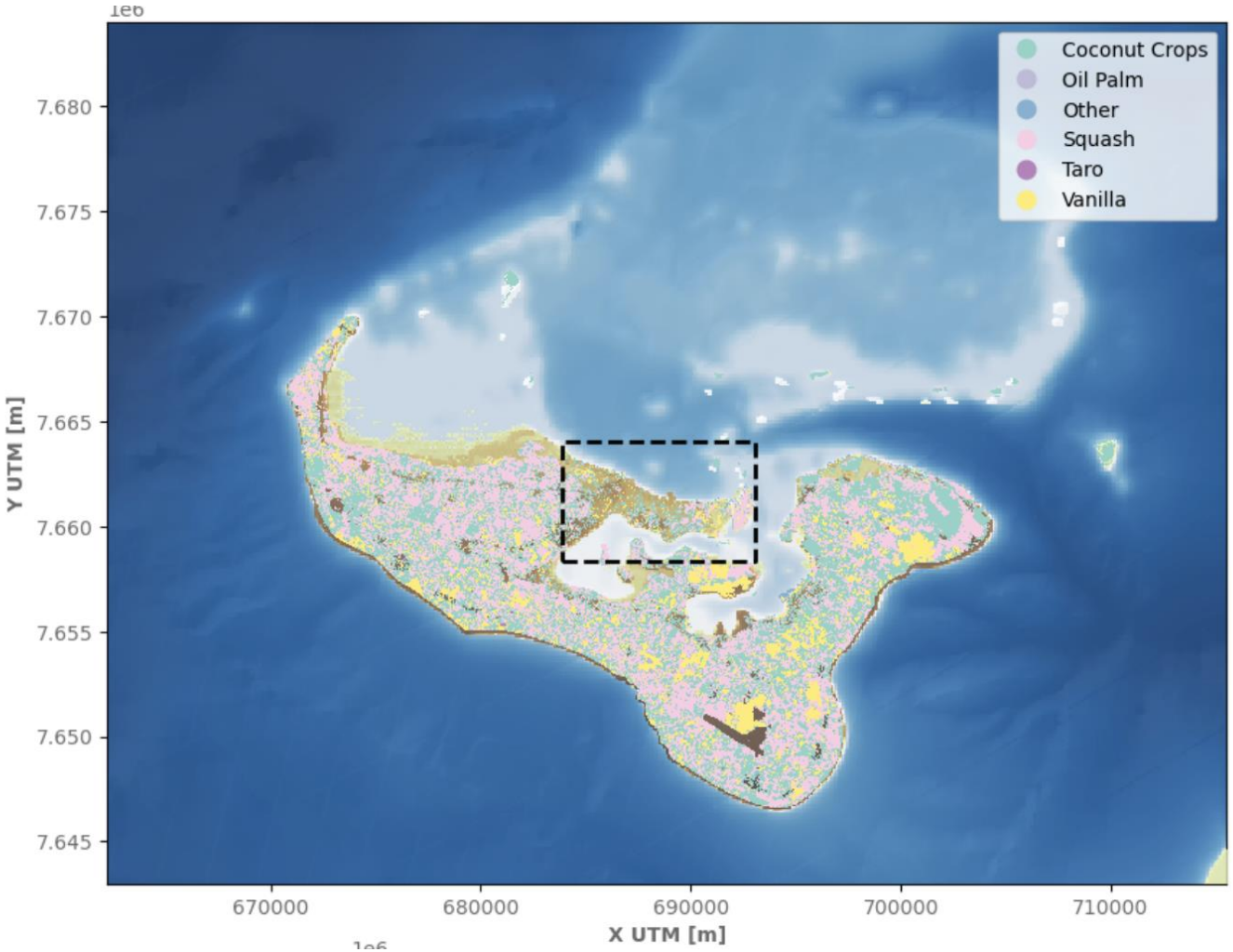
Legend - TCs Anomaly

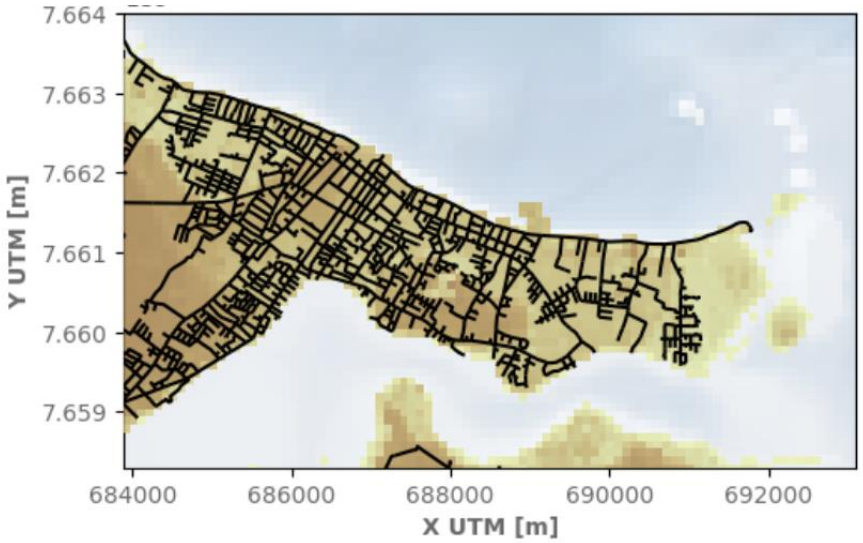
Southwest Pacific Tropical Cyclone Outlook for the following months, updated daily and performed at 2° spatial resolution. Anomalies are calculated as the differences over and above the a

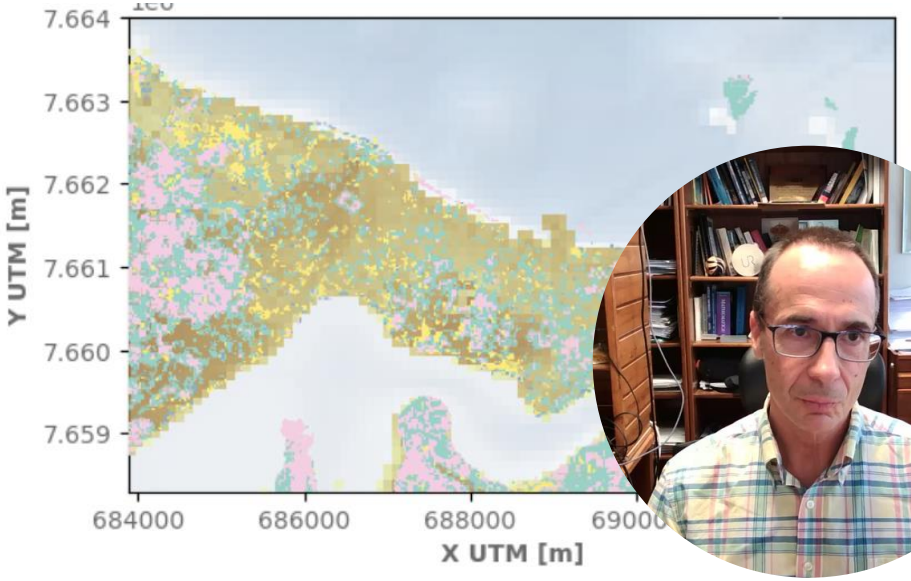
© 2020 NIWA, New Zealand. All rights reserved.

POWERED BY CLIDESC V 0.22.211102P

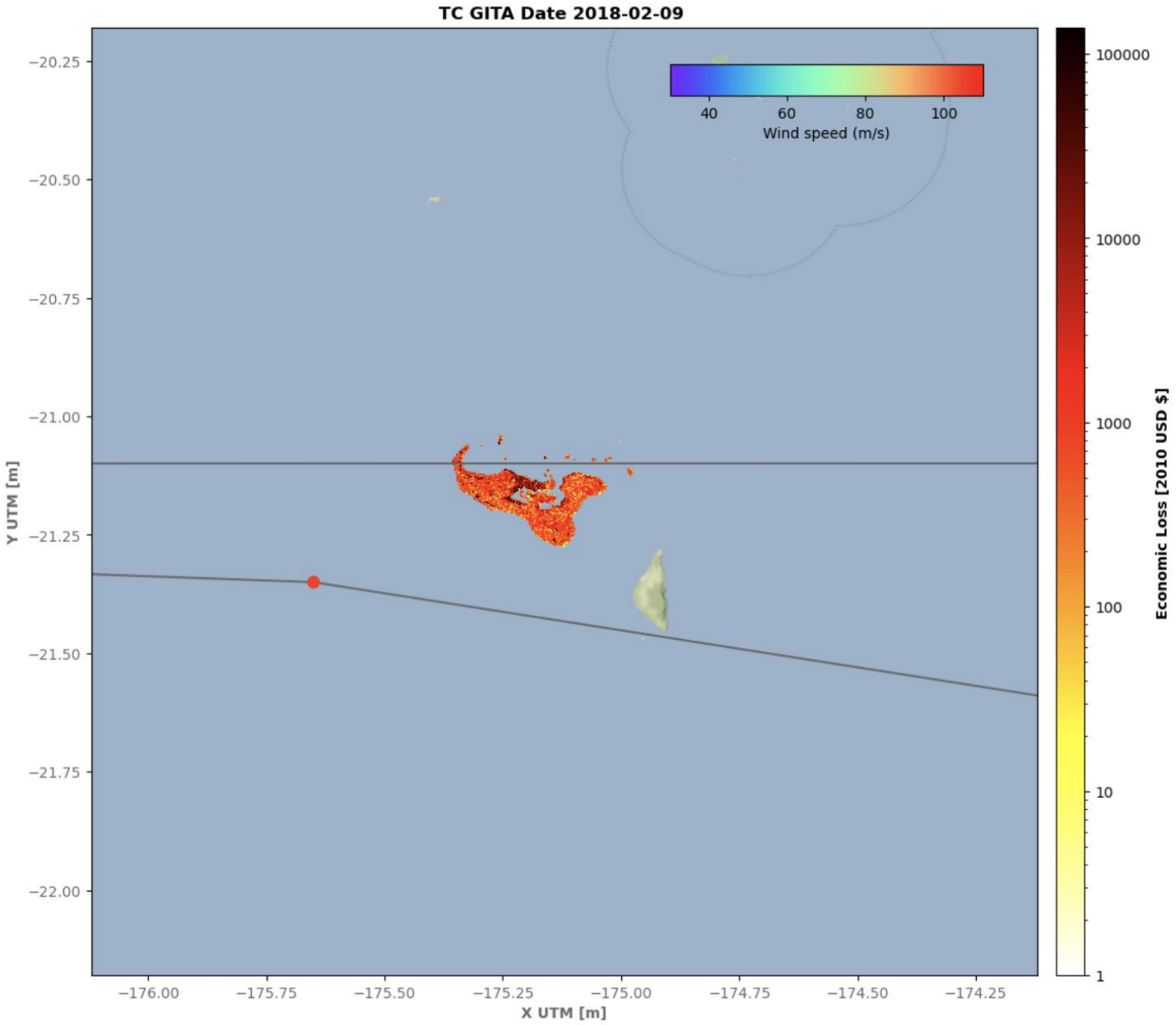
Impact-based forecast: Example of Exposure layers in Tongatapu (Tonga) for the

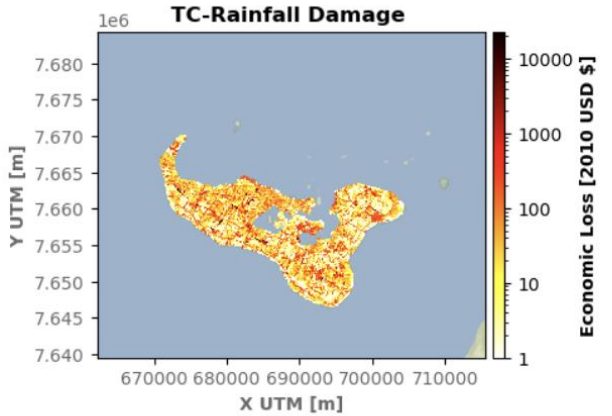


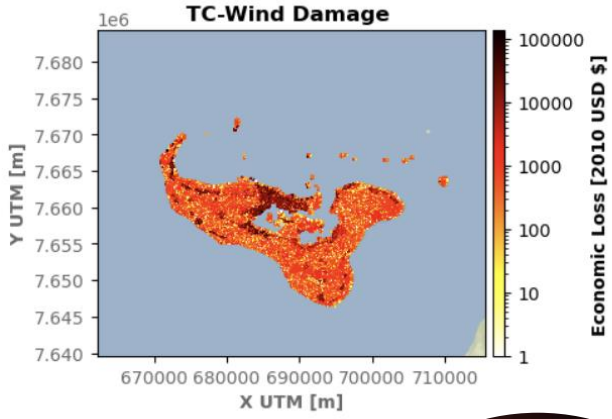


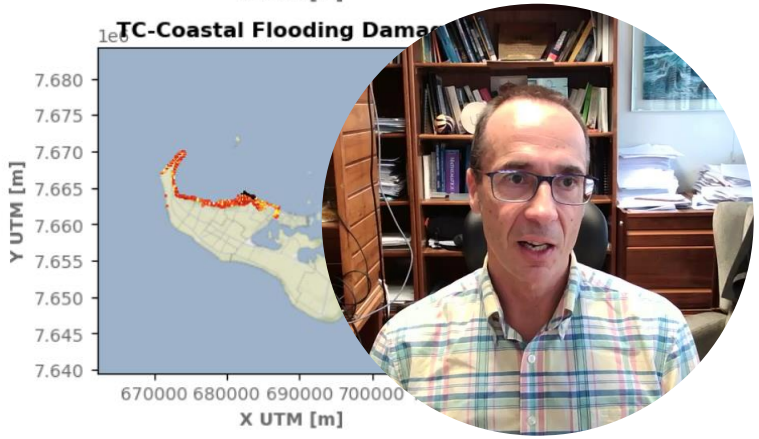


Example of Damages due to Rainfall, Wind and Coastal flooding in Tongatapu (Tonga) for TC Gita



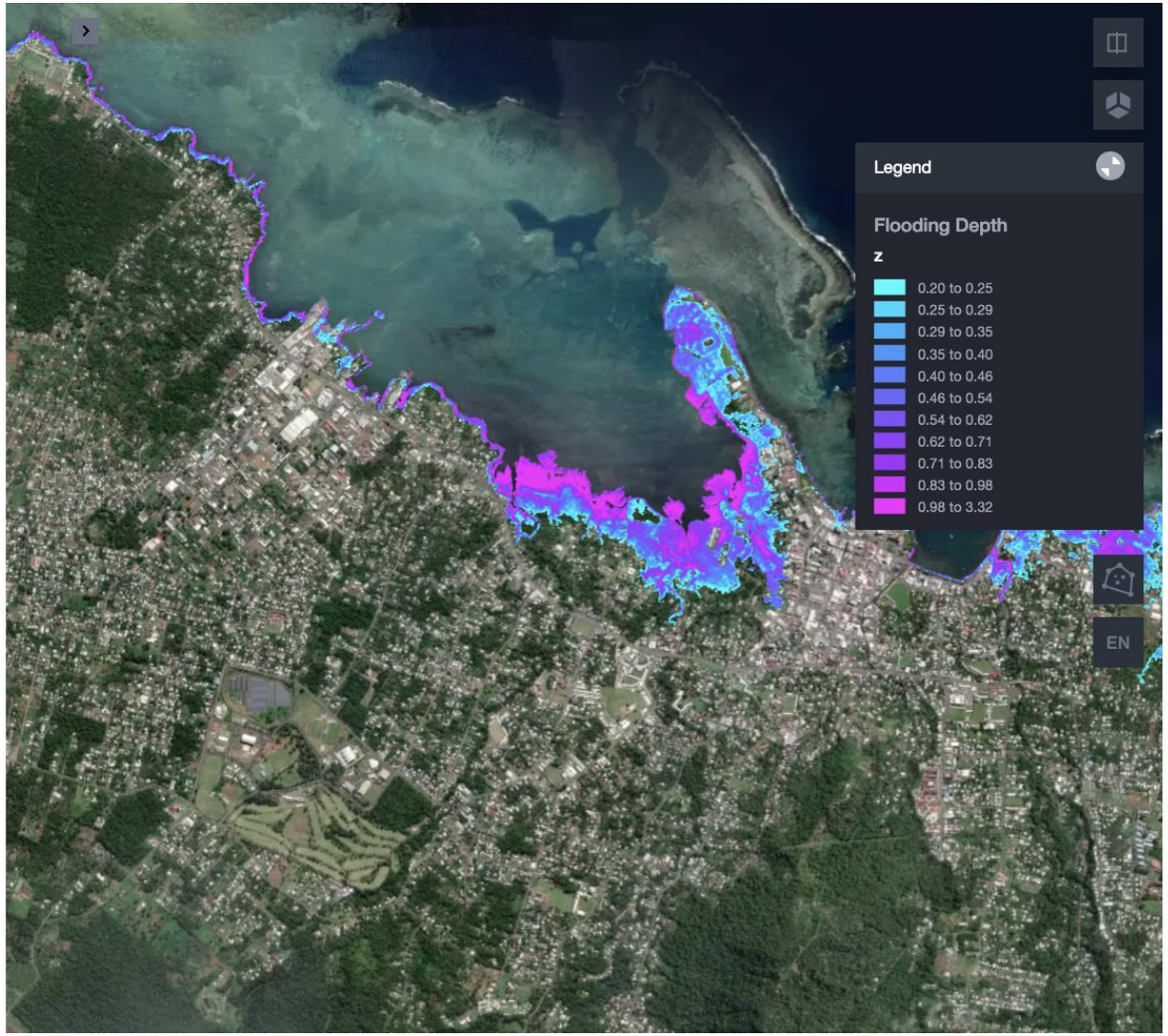




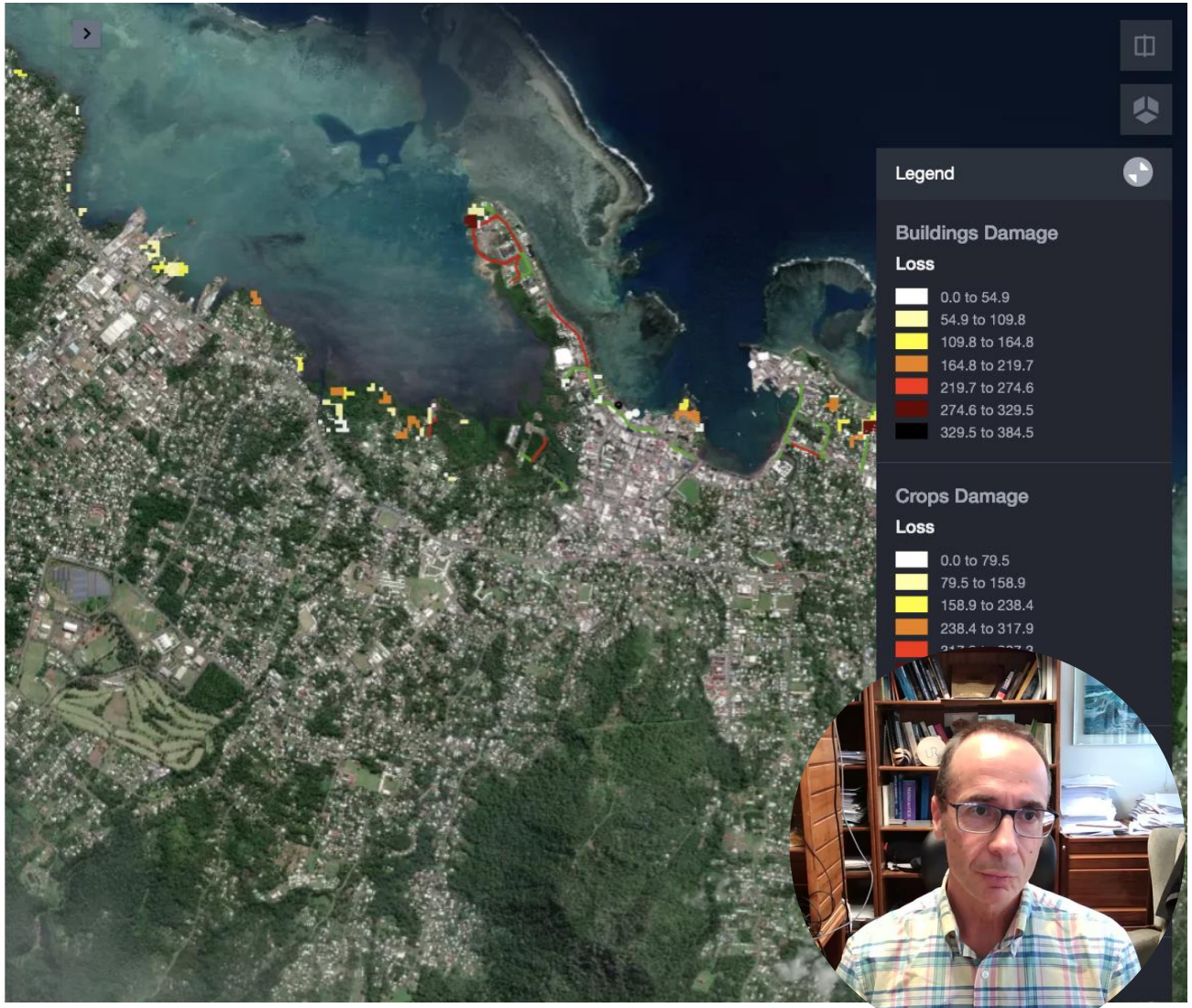


Example of TC-induced coastal flooding map + economical impact

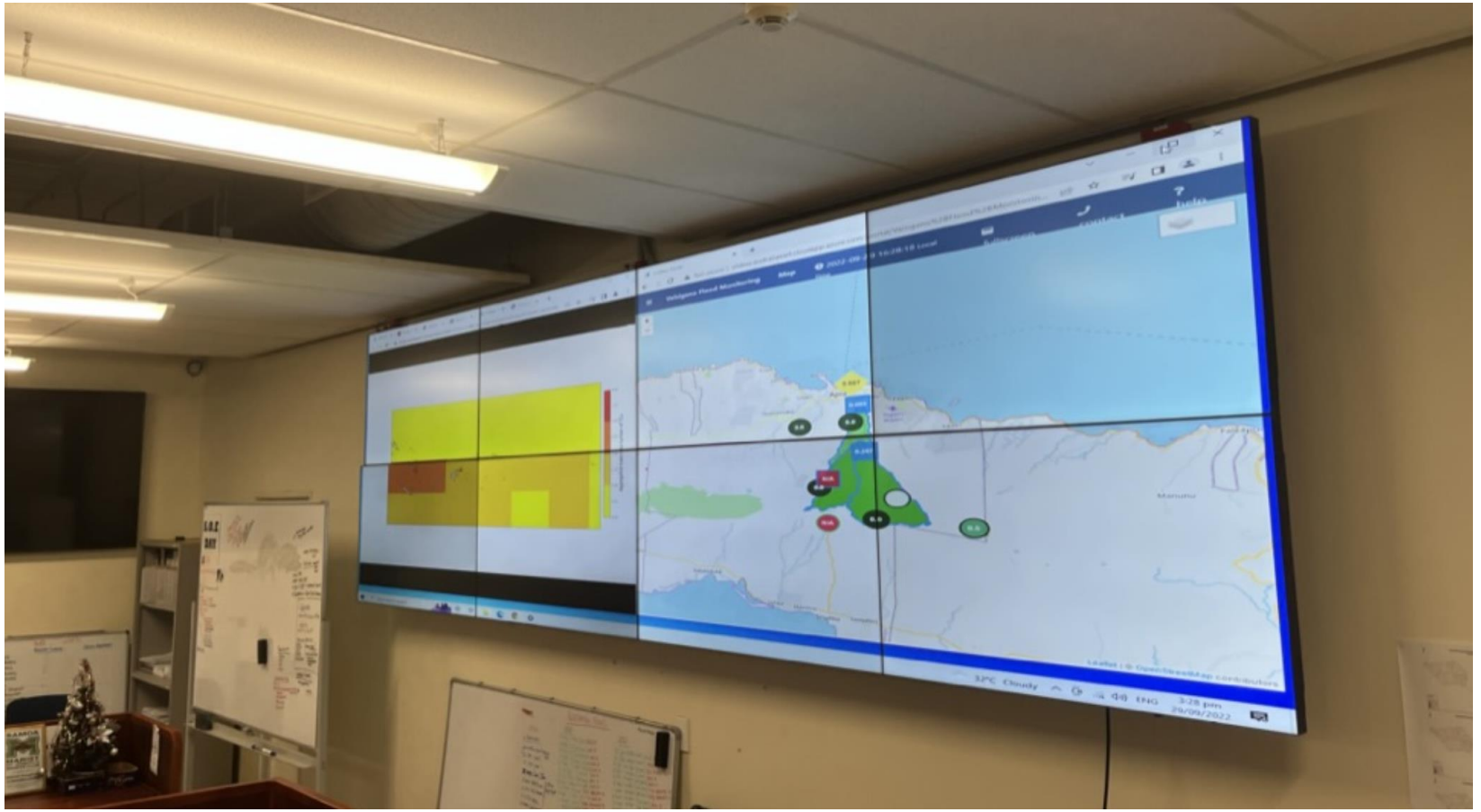
COASTAL FLOODING



DAMAGE



Our experience: Pacific Resilience Project (PREP I). **Impact Forecasting Consultancy** in Tonga and Samoa
2-year project funded by World Bank, managed by Pacific Community (SPC)



(Seasonal Outlook of Tropical Cyclone Activity, 1 to 6 months)

Early Warning Cent

Local Engagement, Capacity Building and Knowledge Transfer to Local Met Services

Contact Information

UNIVERSIDAD DE CANTABRIA

Geomatics and Ocean Engineering Group
UNIVERSIDAD DE CANTABRIA

Fernando Méndez: fernando.mendez@unican.es
Sonia Castanedo: sonia.castanedo@unican.es

https://geoocean.unican.es/

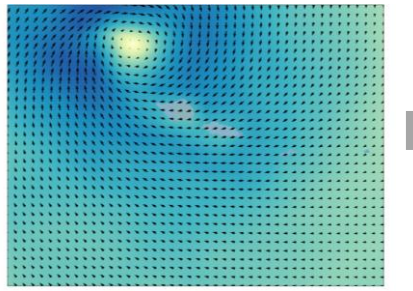
Perez-Diaz et al (submitted)

GreenSurge

Green-based Hybrid modelling of TC-induced Storm Surge

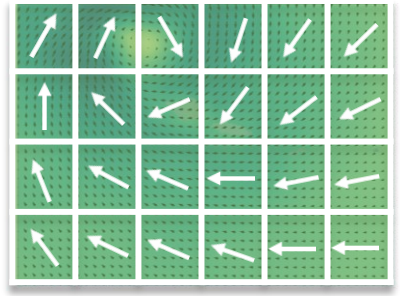
Methodology

Under linear dynamics framework



t_j

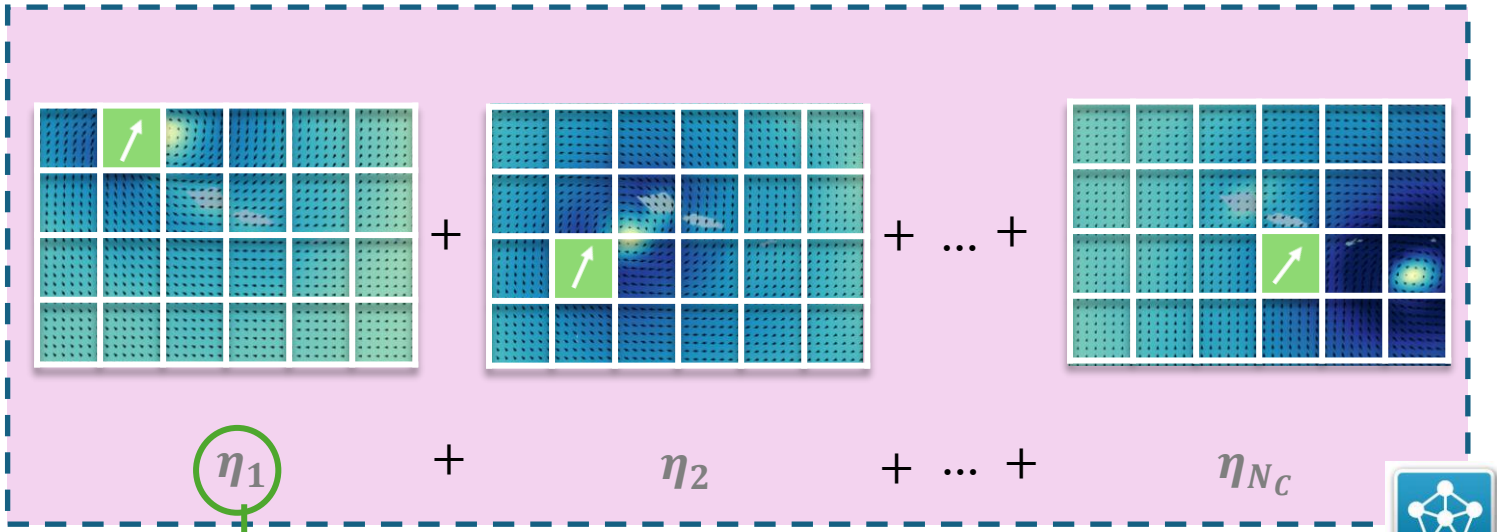
Wind forcing partition



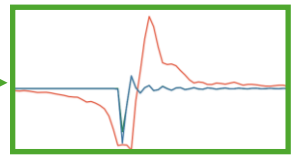
$\eta(x)$

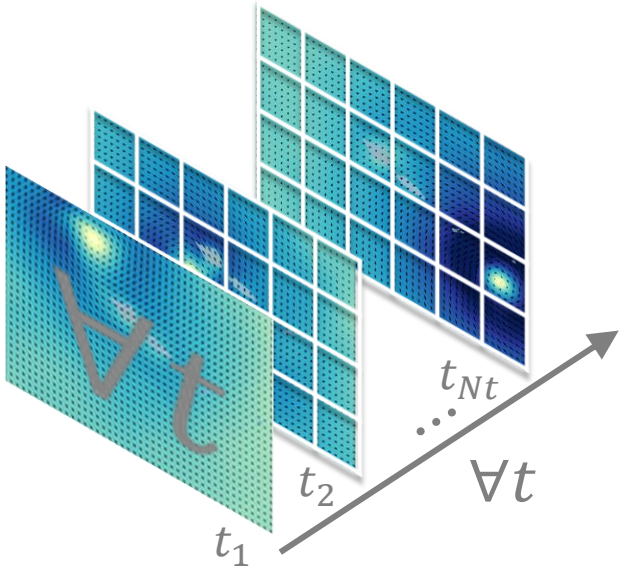
$=$

$=$



Delft3D





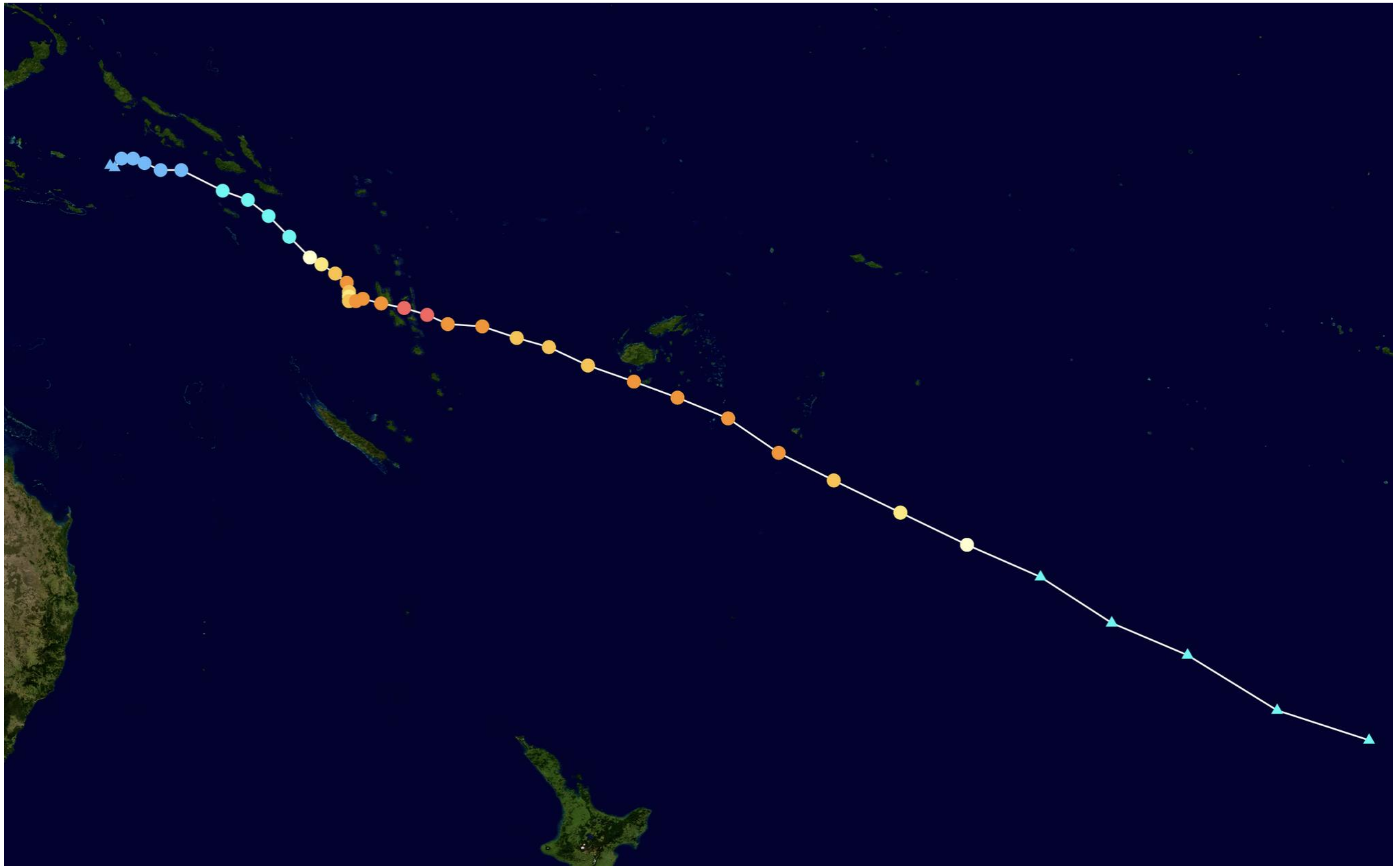
Ensemble (Green's function summation)

$$\eta(x,t) = \sum_{i=1}^{Nc} \sum_{j=1}^{Nt} \alpha \eta_{ij}$$

$$\alpha = f(W, C_D)$$

re-scaling

TC Haroid (2020)

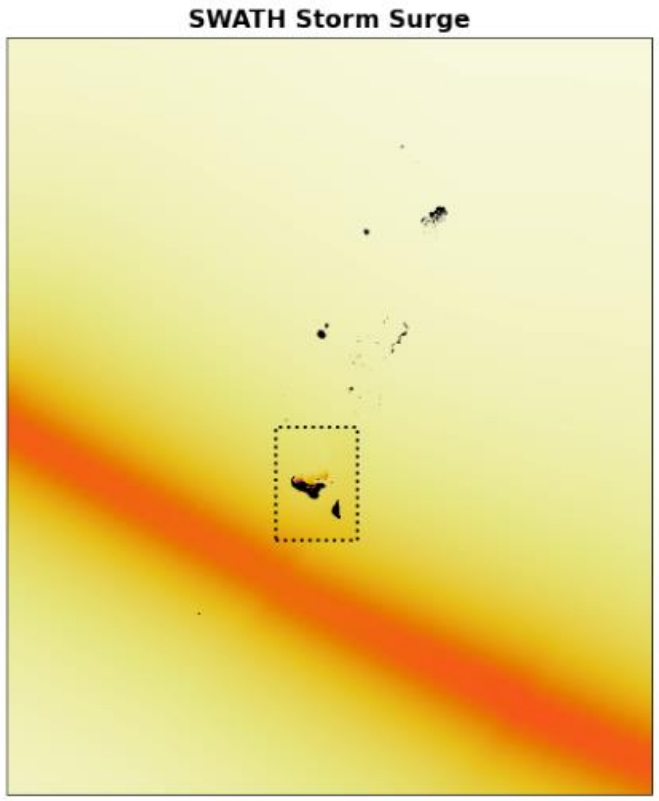


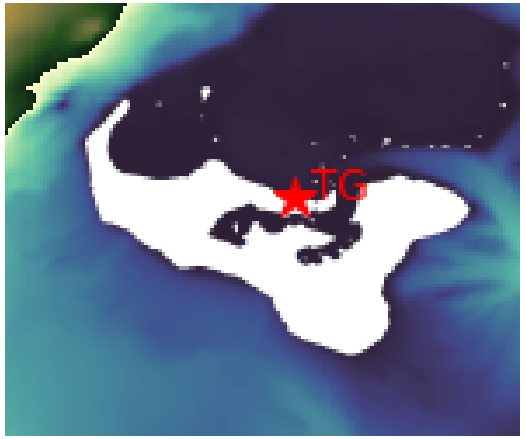
Validation. Tide gauge

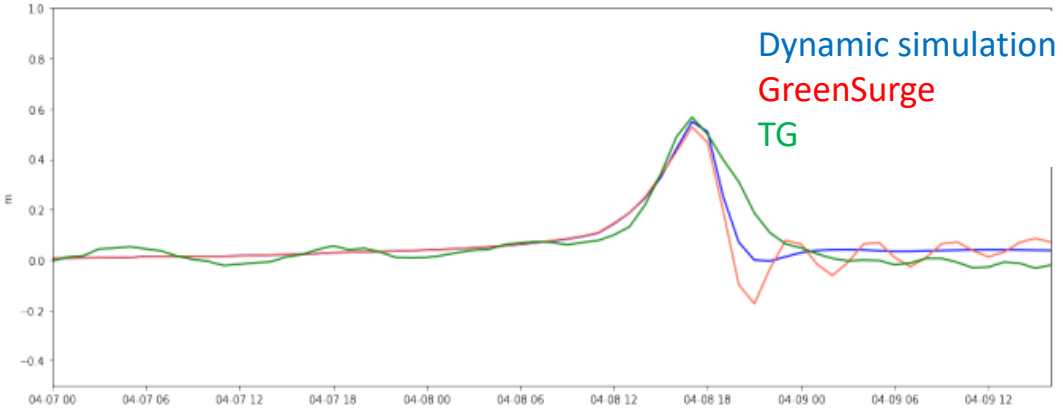
Green-based Hybrid modelling of TCs-induced Storm Surge

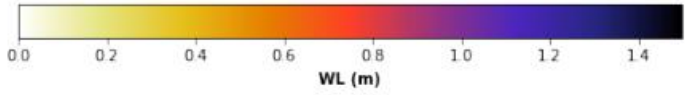
SS = IB + WindSetup-GS

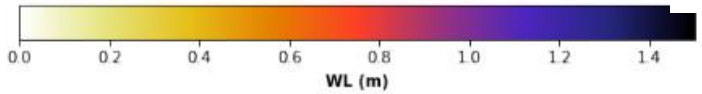
Reconstruction of **Harold 2020**





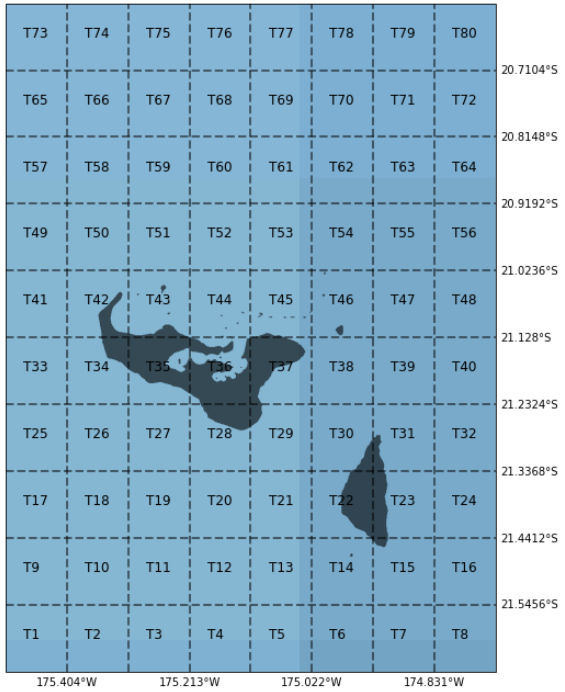




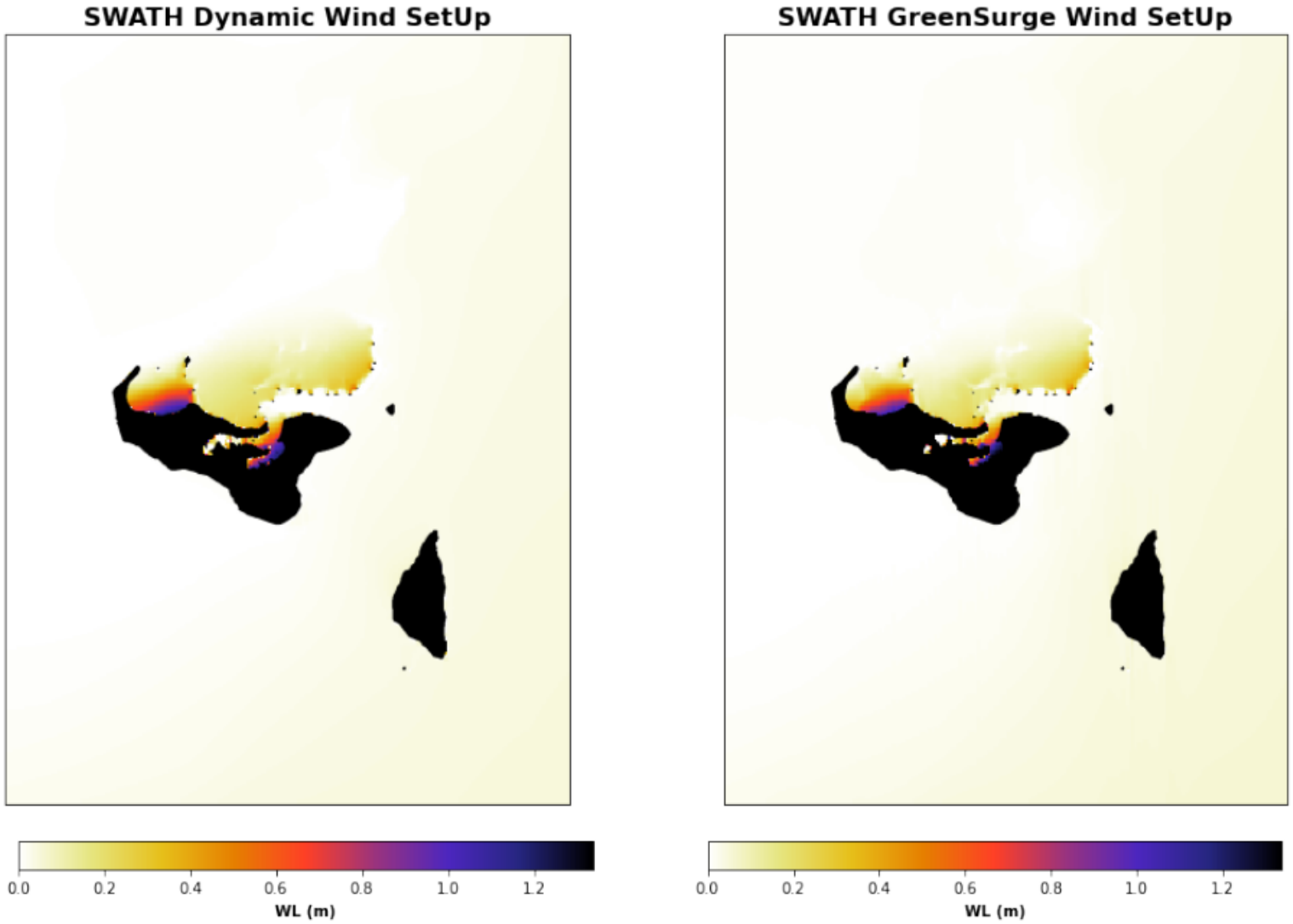


Numerical Validation

Green-based Hybrid modelling of TCs-induced Storm Surge

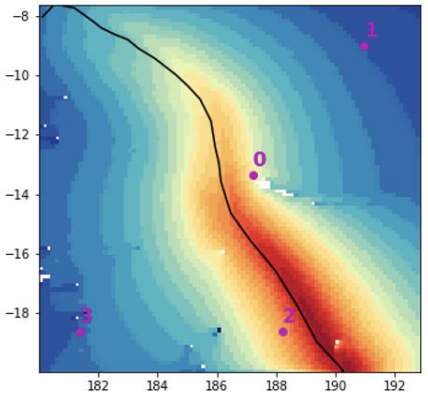


Reconstruction of Harold 2020



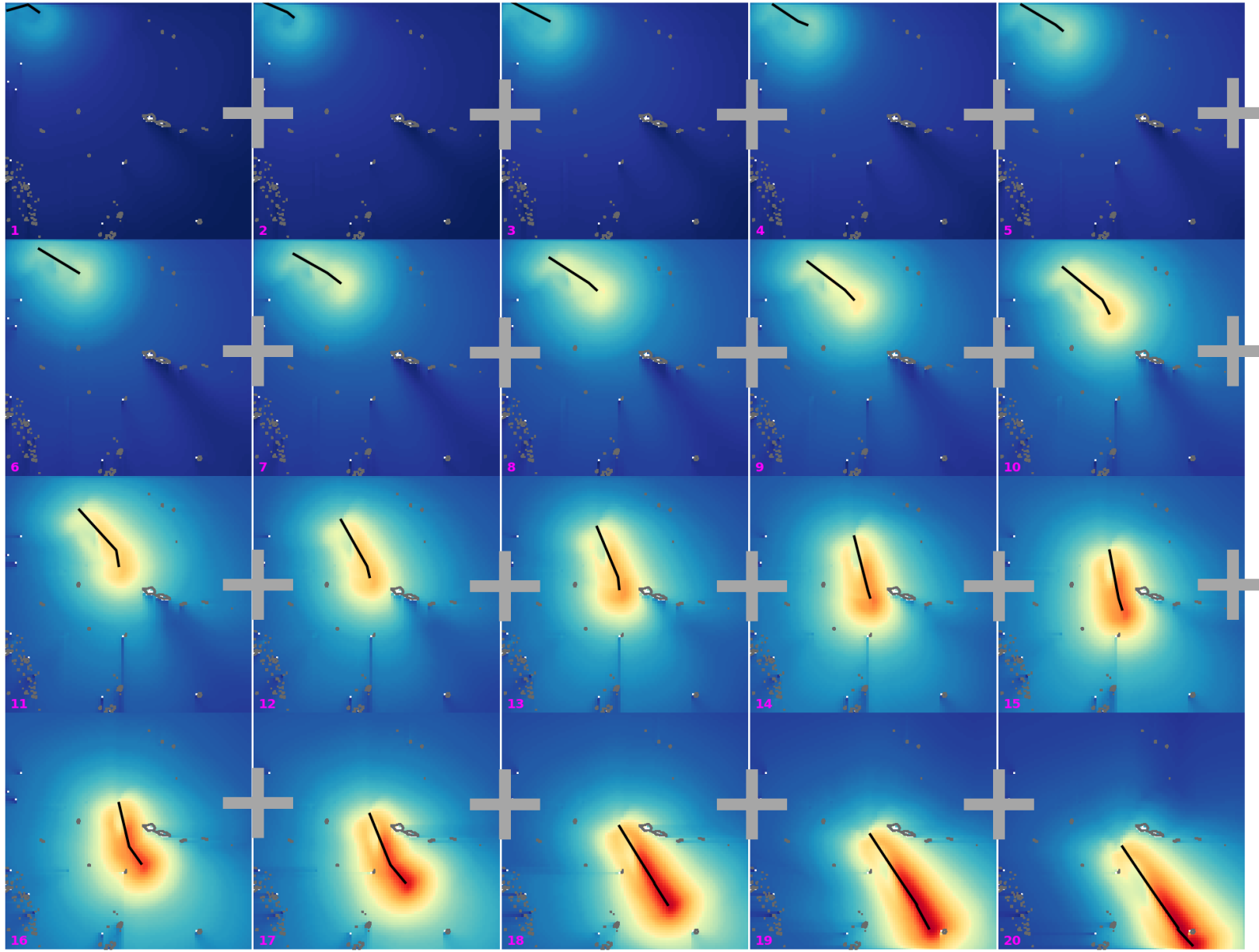
SHyTCWaves

Van Vloten et al (2023)



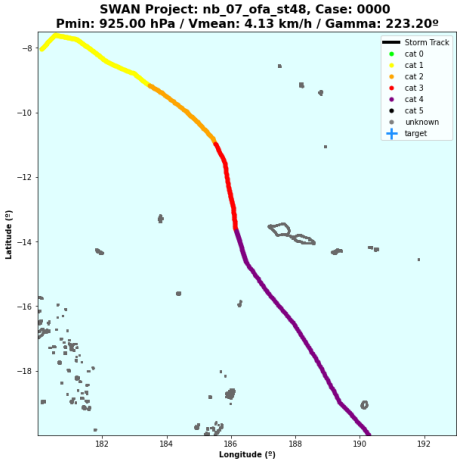
=

Summation of the effects of 6-hour segments



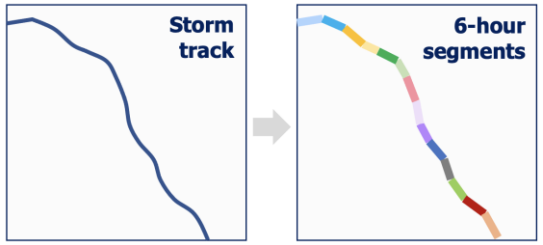
SHyTCWaves

Van Vloten et al (2023)

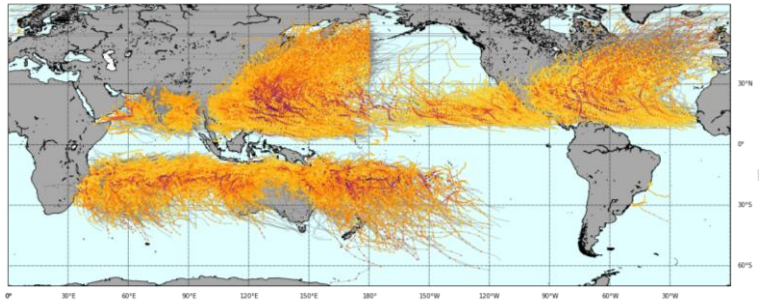


TC track

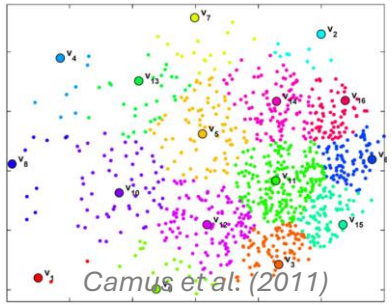
1 STORM TRACK PARAMETERIZATION



2 SEGMENTS DATABASE

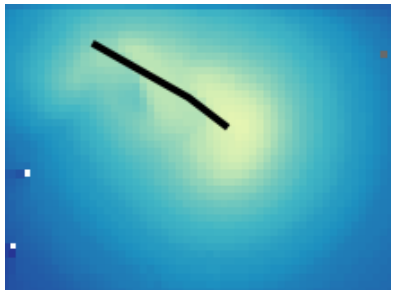


3 MDA SELECTION

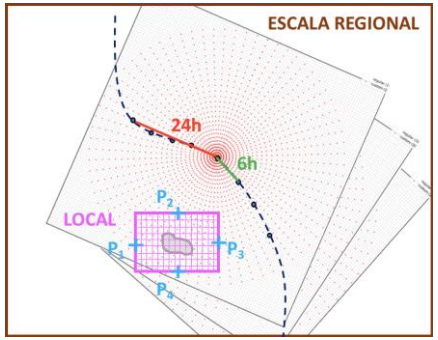


Camus et al. (2011)

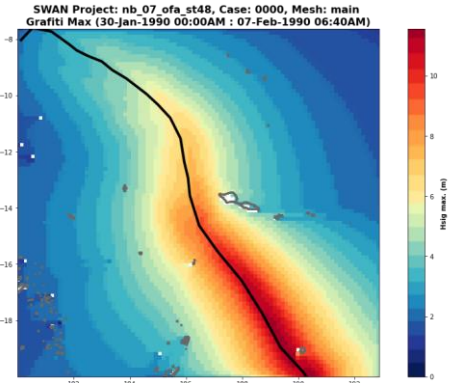
4 NUMERICAL MODELING



5 STOP-MOTION ENSEMBLE

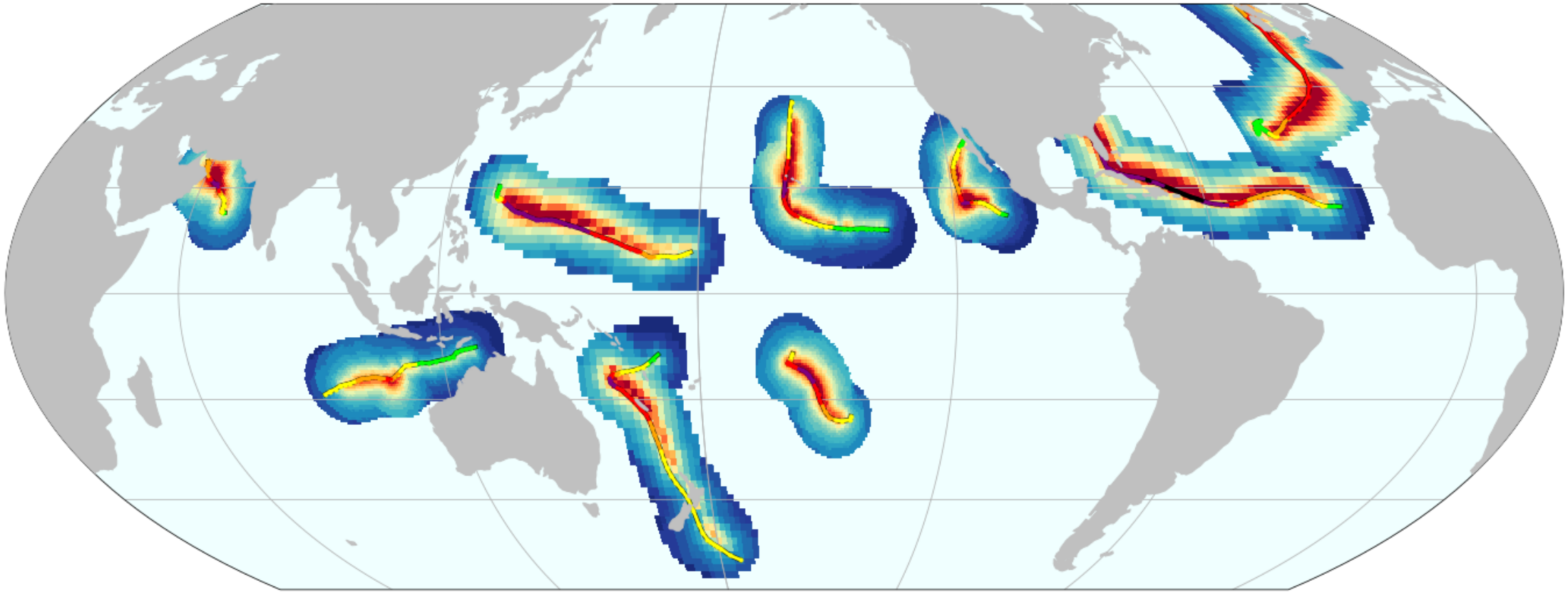


WAVE FIELD



SHyTCWaves

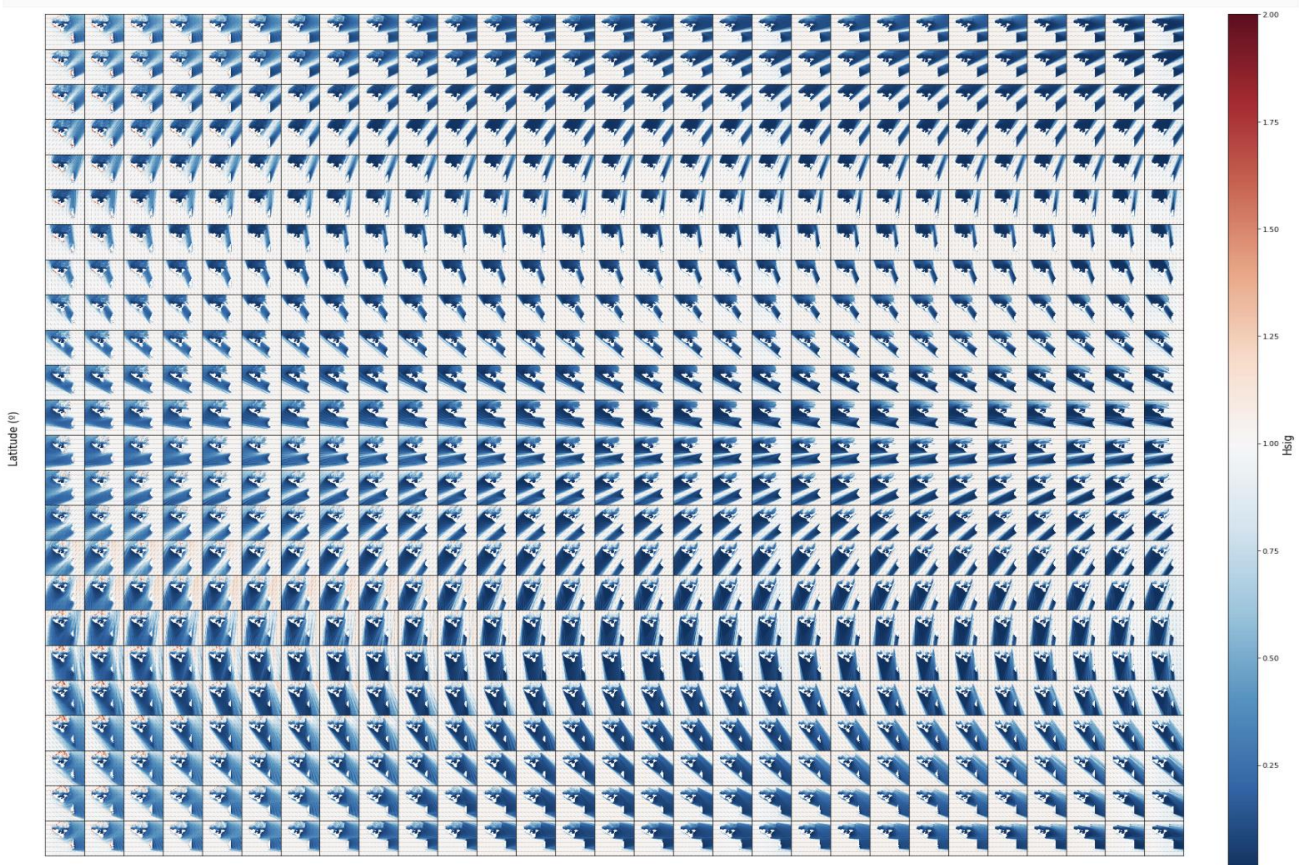
Van Vloten et al (2023)

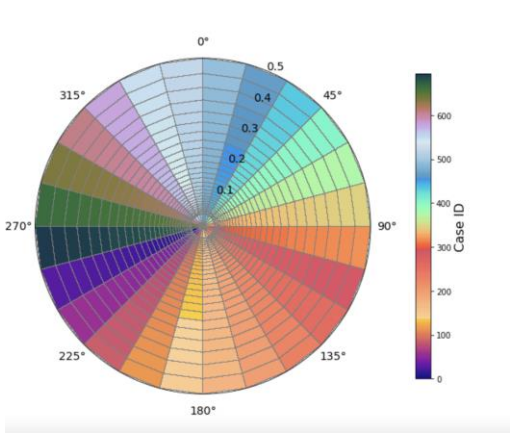


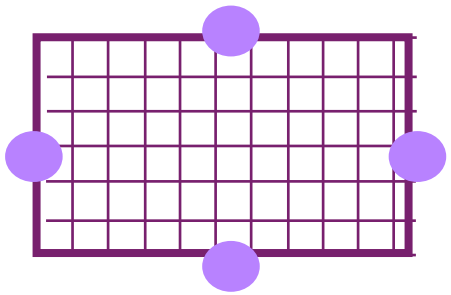
BinWaves

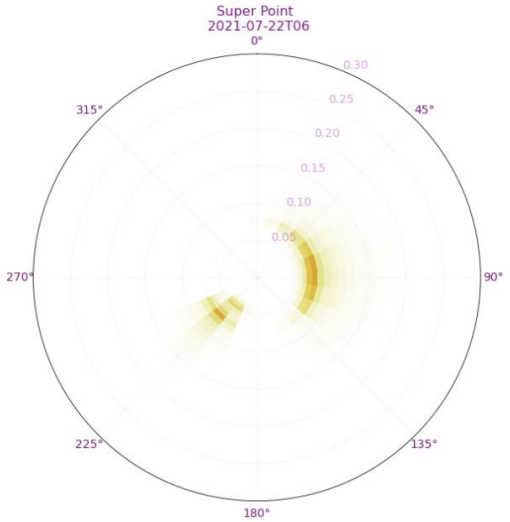
Cagigal et al (2023)

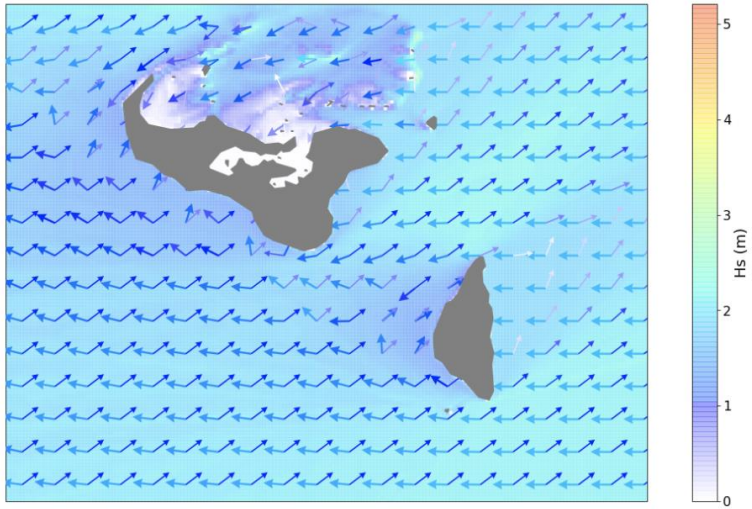
Summation of of energies of each bin of direction and frequency











SHyTCWaves + BinWaves

Evan 2012