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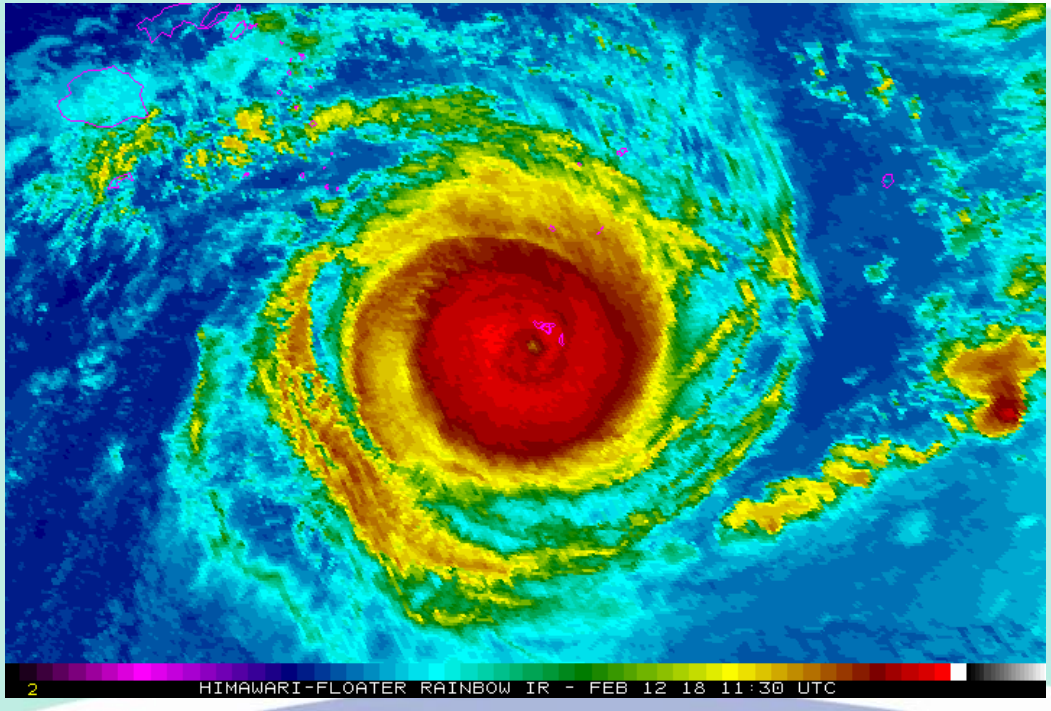
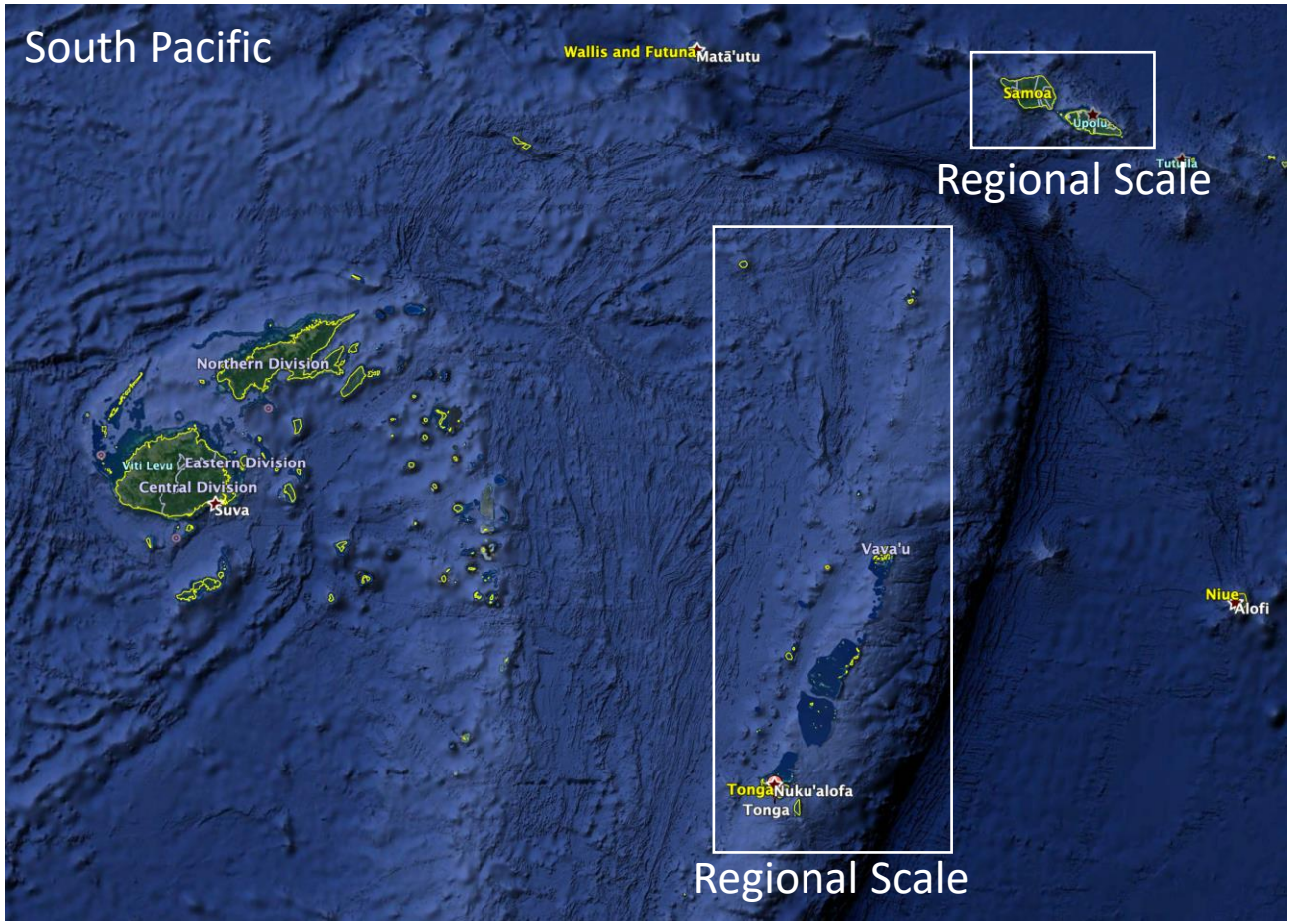


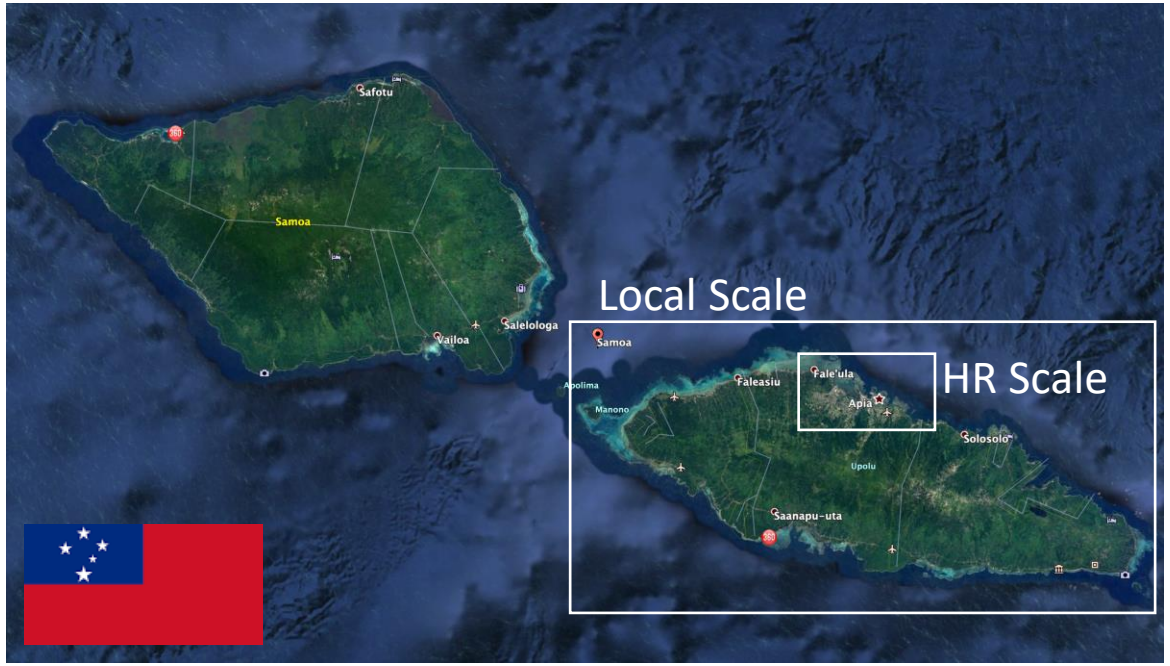
GreenSurge: an efficient Additive Model to assess Storm Surge induced by Tropical Cyclones

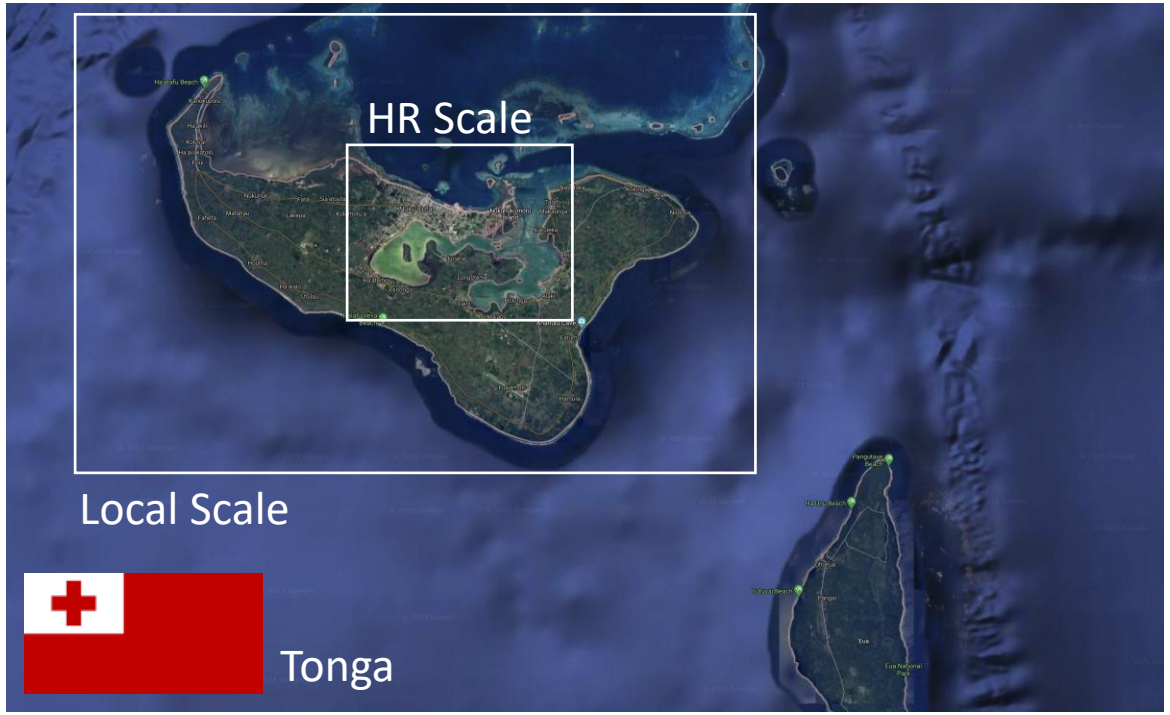
Beatriz Pérez-Diaz, Fernando Méndez,
Laura Cagigal, Sonia Castanedo

3nd International Workshop on Waves, Storm Surge and Coastal Hazards

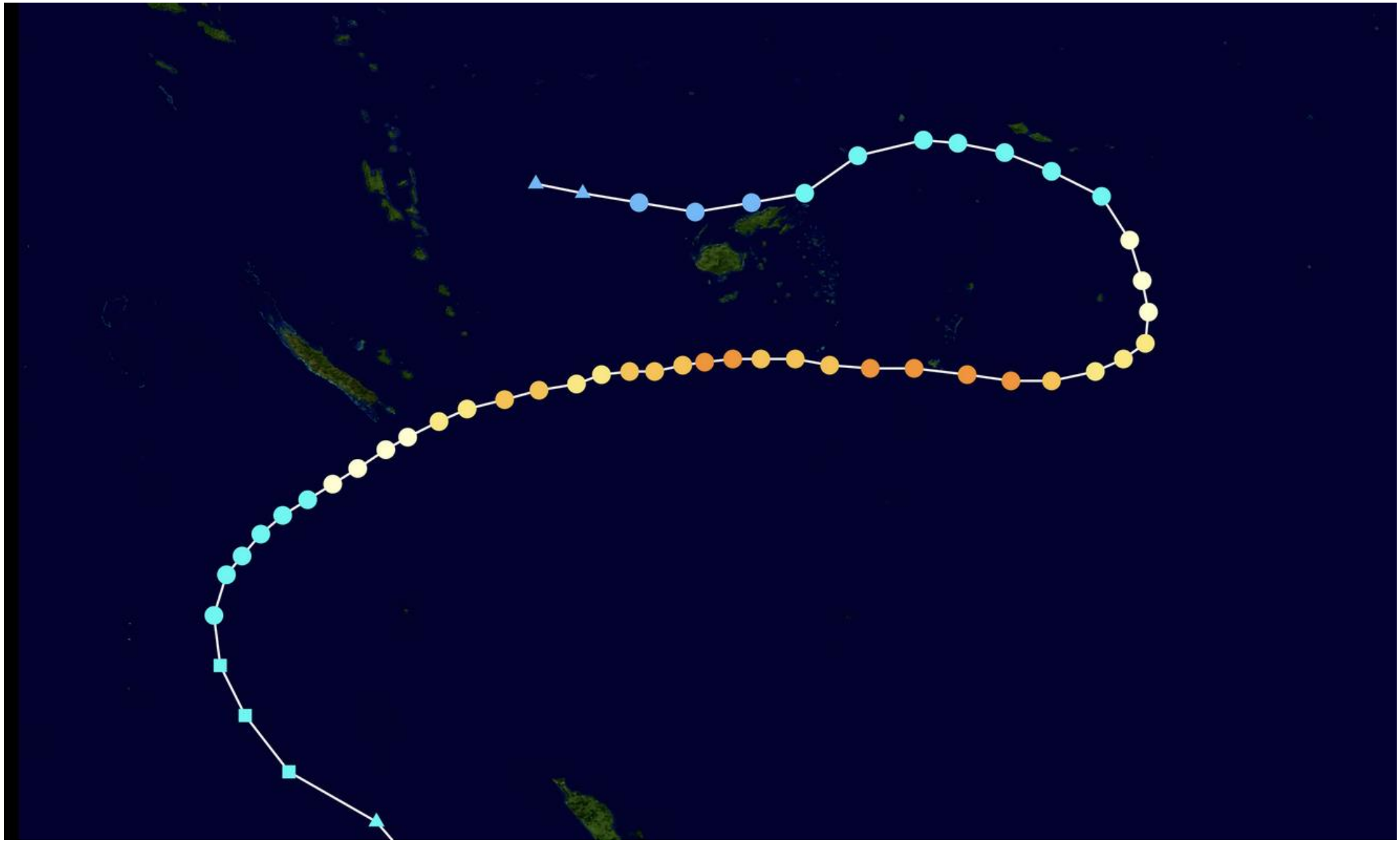
Spatial Scales







TC Gita (2018)



Introduction

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Cyclone Gita: Tonga devastated by worst storm in 60 years

Winds of more than 230km/h recorded as parliament building flattened and power lines brought down

The aftermath of cyclone Gita is seen in Nuku'alofa, Tonga. Photograph: Social Media/Reuters

1/10

In this Friday, Feb. 9, 2018 photo, first responders with a backhoe work amid strong winds and heavy rain from Tropical Storm Gita to clear part of the main road at Fagaalu village in American Samoa. Officials in American Samoa began a full assessment Monday, Feb. 12, of damage caused by tropical storm Gita over the weekend. (AP Photo/Fili Sagapolutele)

Introduction

HR Storm Surge assessment
Dynamic downscaling approach

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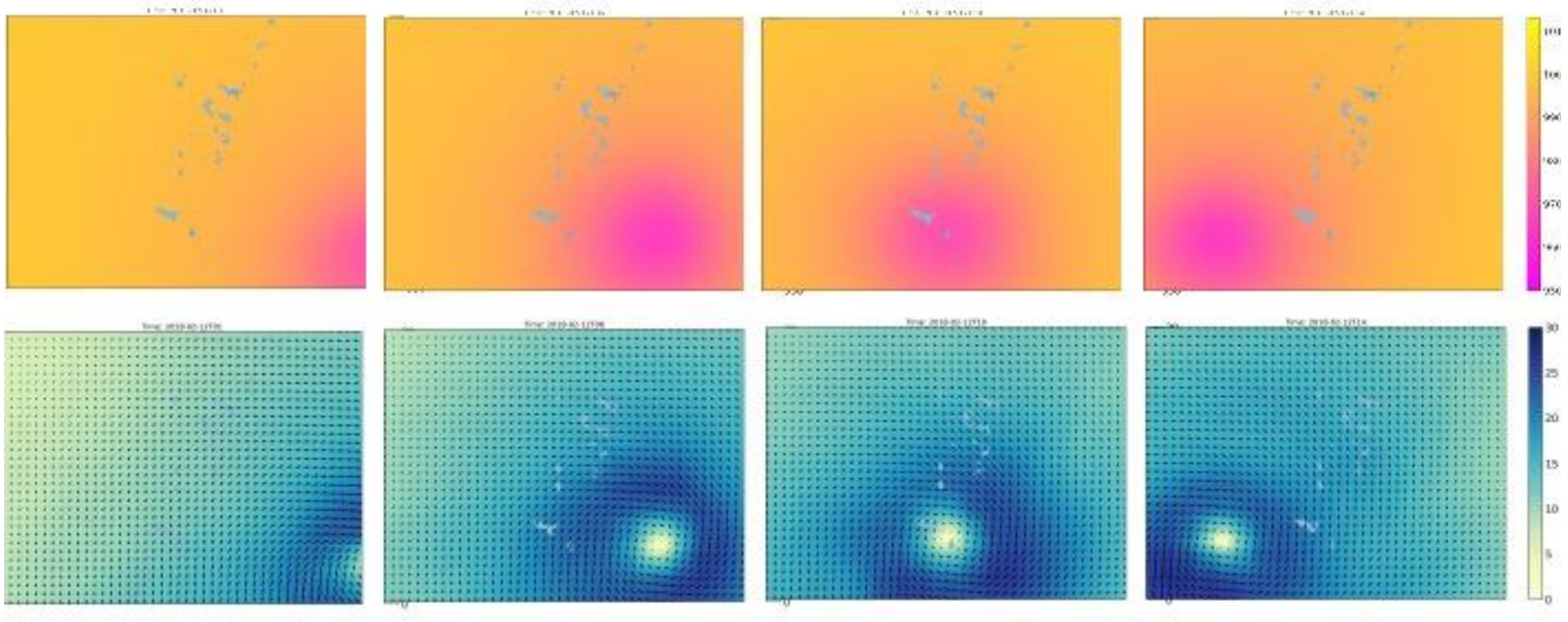
TC-GITA 2018/02
Pmin 929mb

t1 t2 t3 t4

Pmsl

Wind



Introduction

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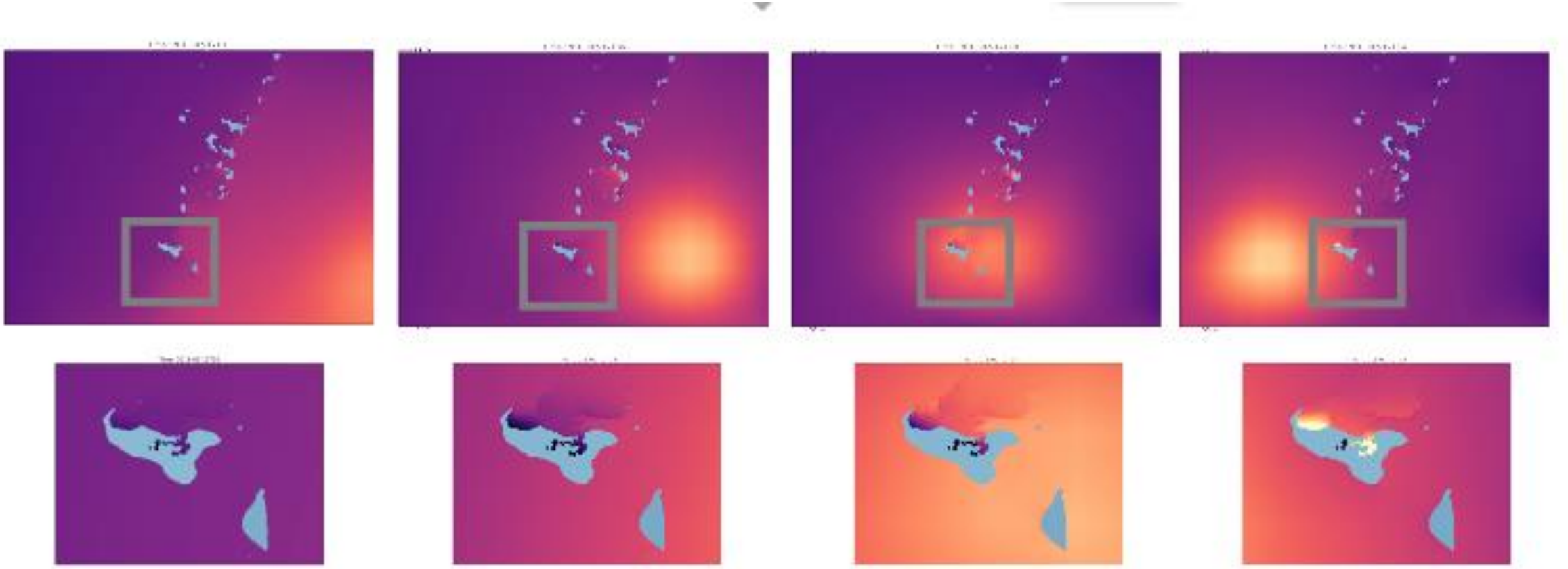
HR Storm Surge assessment
Dynamic downscaling approach

Delft3D
(full dynamic simulation)

TC-GITA 2018/02
Pmin 929mb



Introduction

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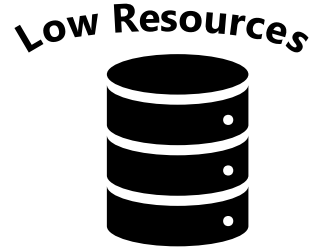
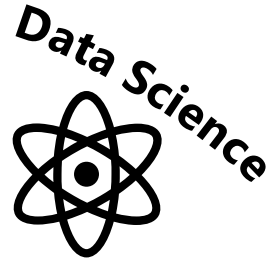
Downscaling approach --> **Hybrid Additive model**

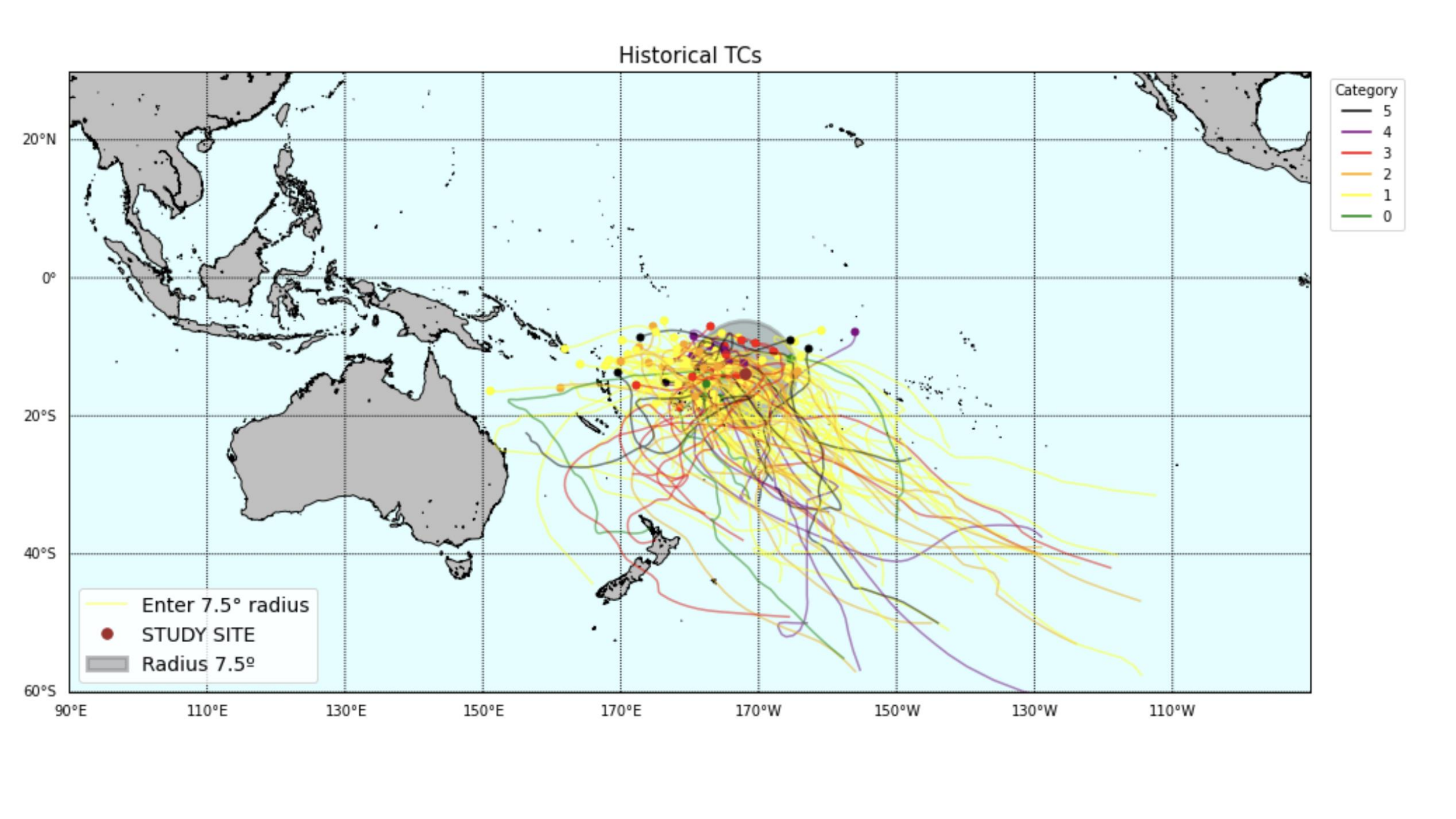
Linear summation of the physical processes + High Fidelity Hydrodynamic model

Strengths/objectives:

- **Fast** prediction HR results
- **Low computational** resources
- Any climate (regular, extreme, tropical cyclone...)
- **High Fidelity Numerical** (Hydrodynamic, Atmospheric) Models
- Probabilistic (x N simulations)



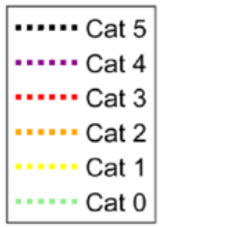


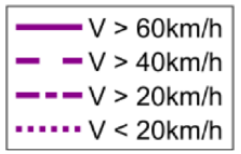

Historical TCs
Category
5
4
3
2
1
0
20°N
0°
20°S
40°S
60°S
90°E
110°E
130°E
150°E
170°E
170°W
150°W
130°W
110°W
Enter 7.5° radius
STUDY SITE
Radius 7.5º

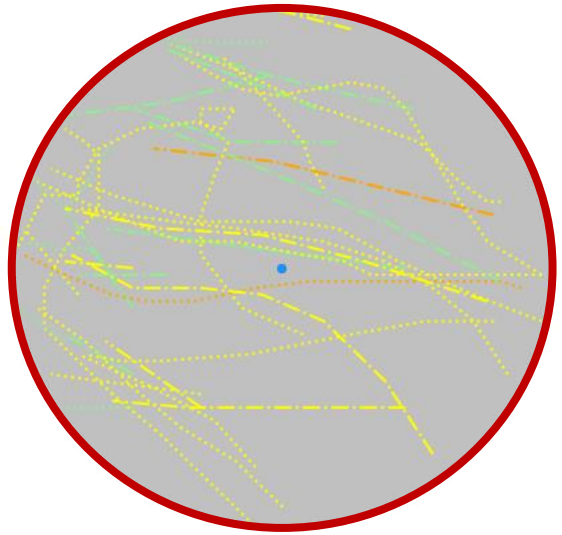
Initial Idea: Parameterization of the track (HyTCWaves, van Vloten et al 2022)

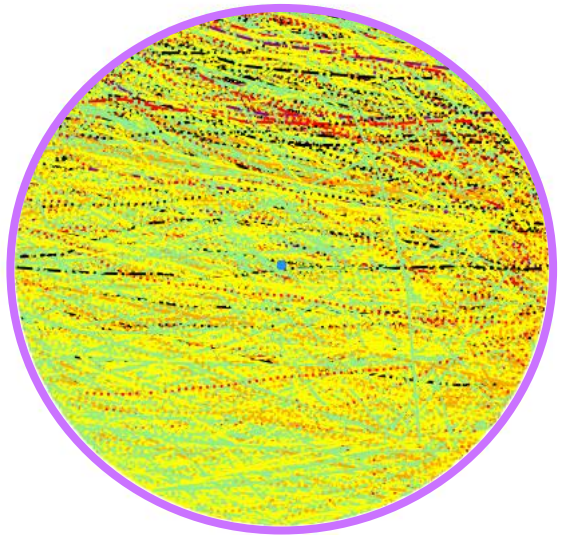
Historical

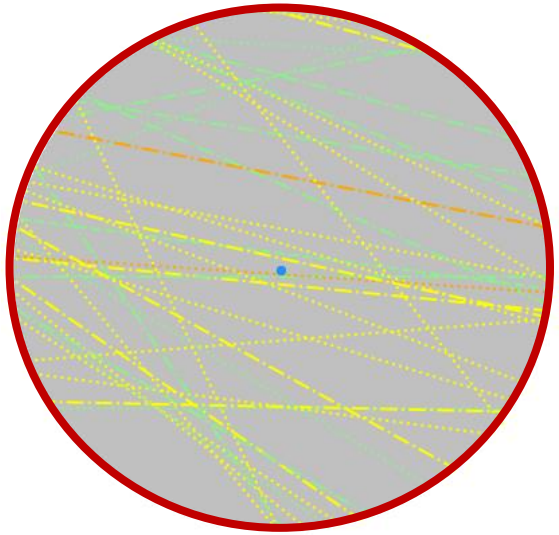
Synthetic

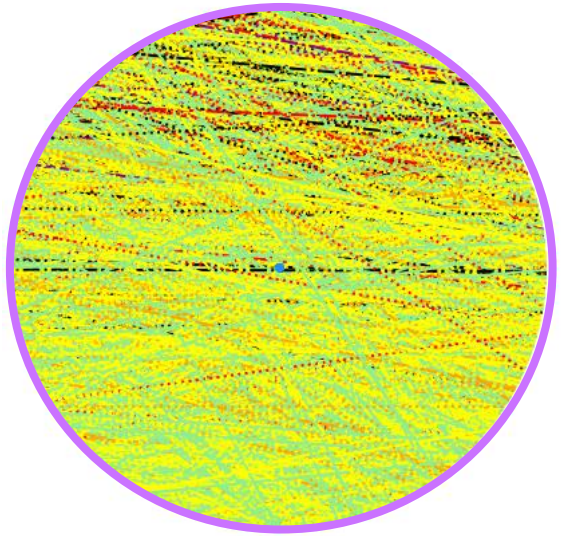






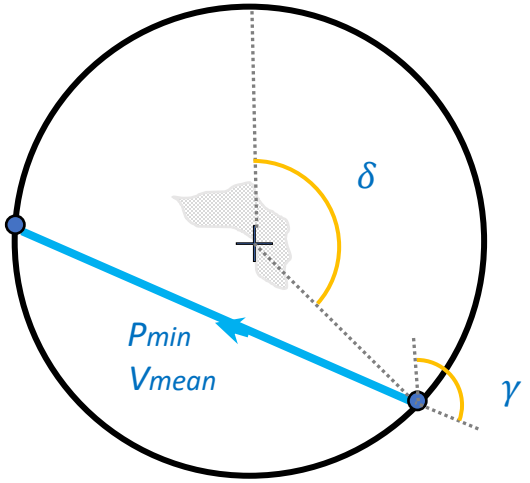




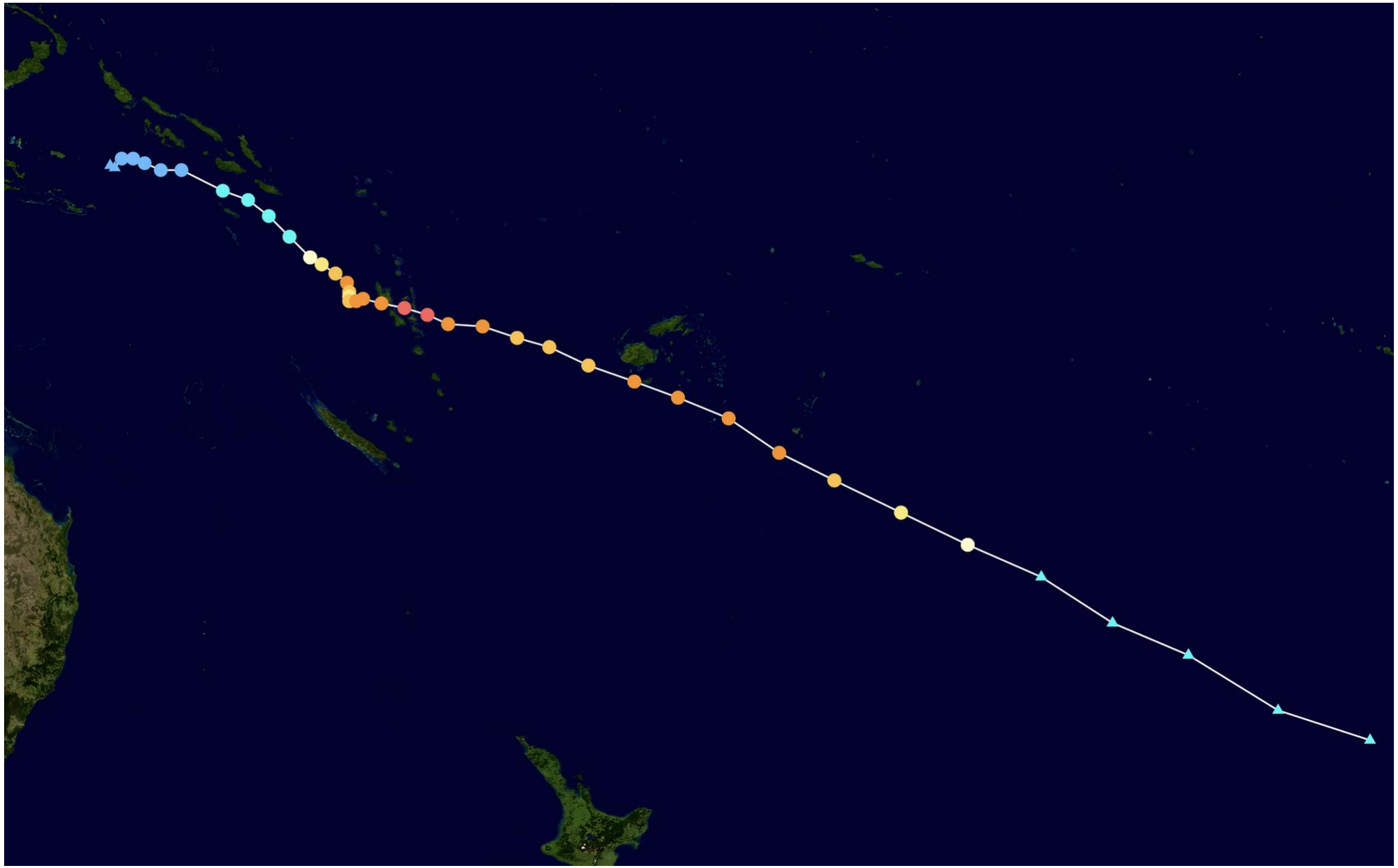


Storm track parameterization

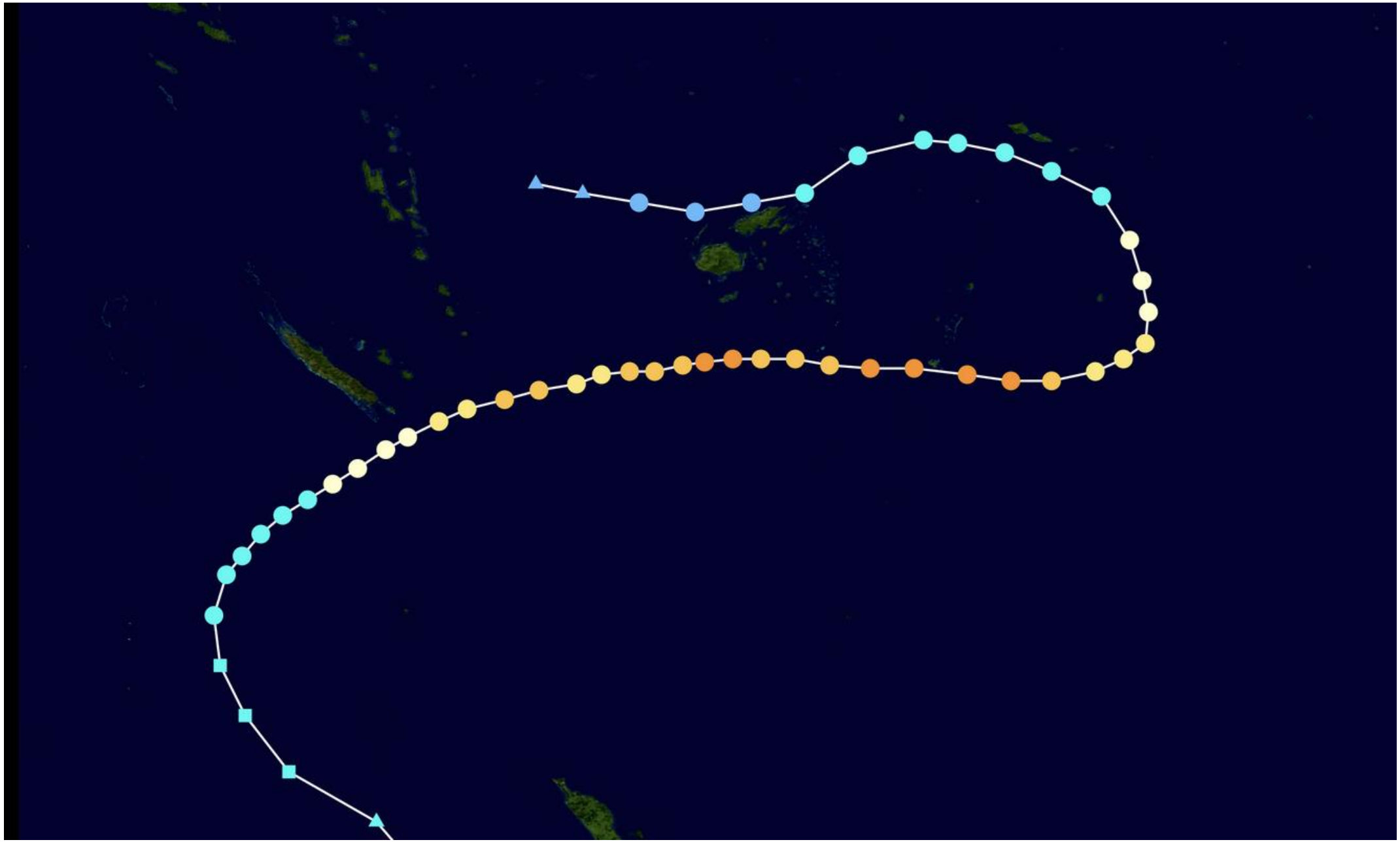
- *Minimum central pressure*
- *Mean translational velocity*
- *Angle of entrance*
- *Angle of forward direction*



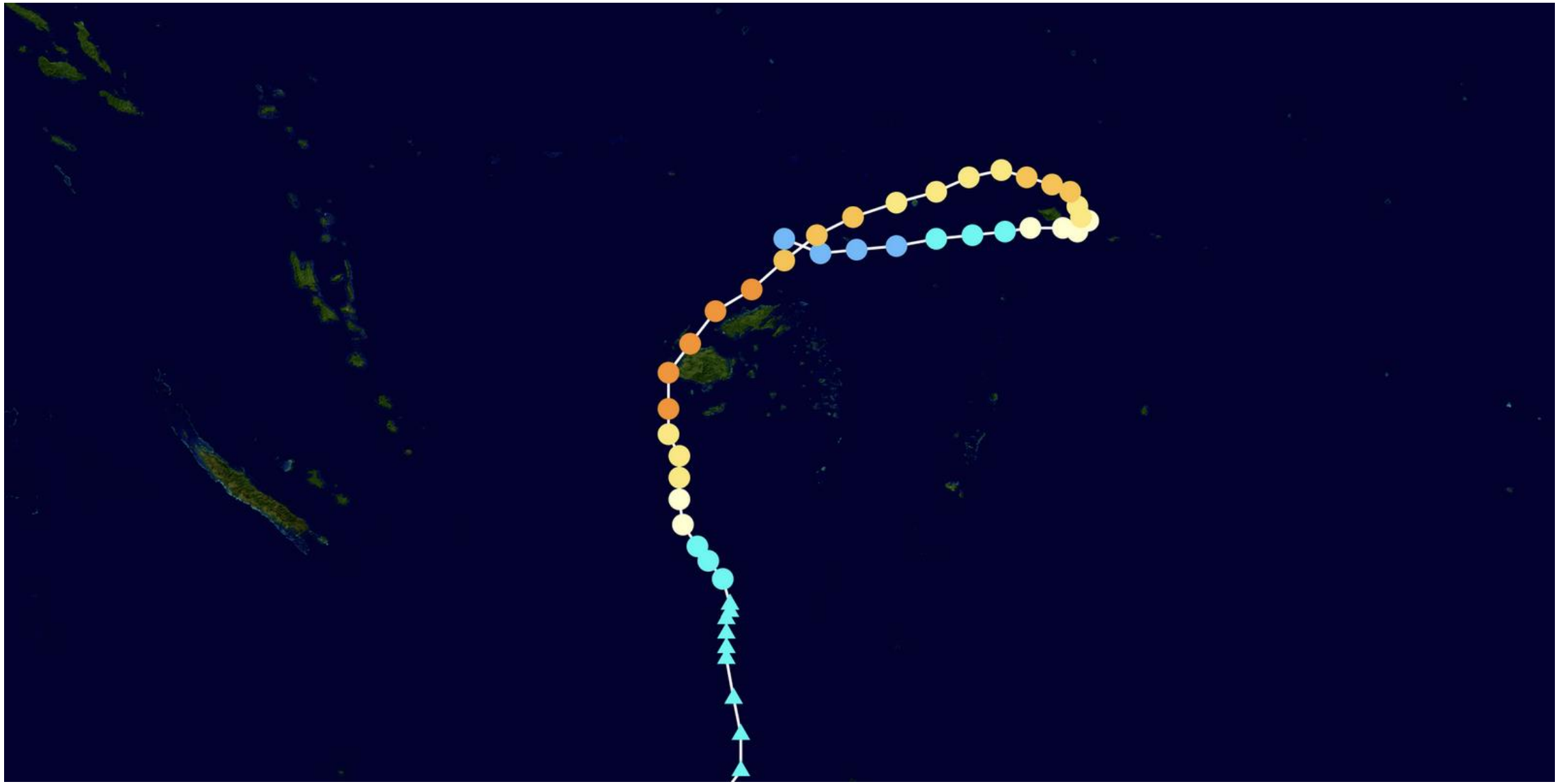
TC Haroid (2020)



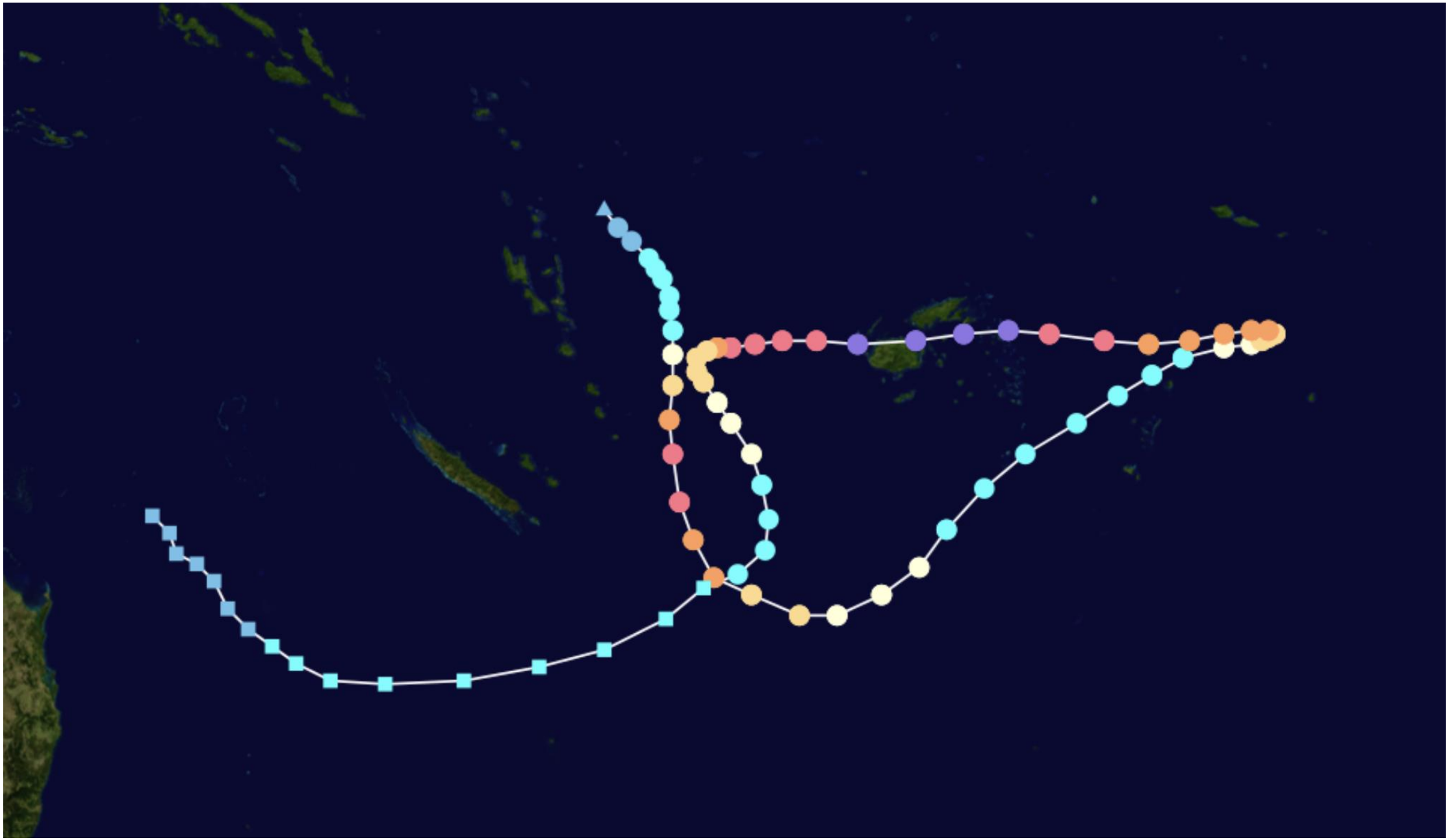
TC Gita (2018)



TC Evan (2012)



TC Winston (2016)



Introduction

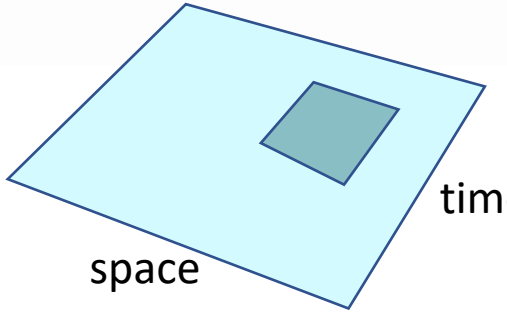
Hybrid models: Additive Model

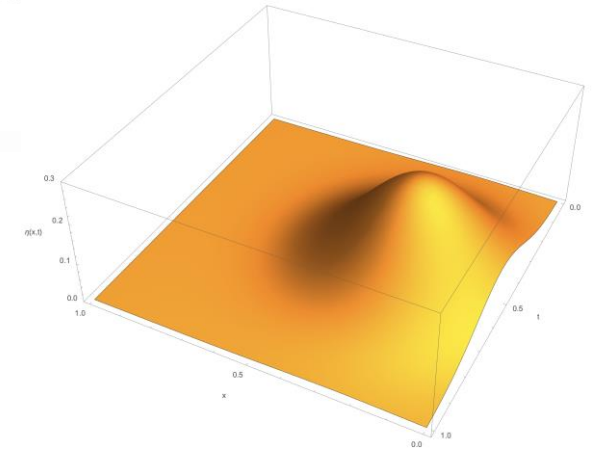
1) Discretize the problem in unitary or binary scales of forcings (wind, fault bump, wave bins) at space and time

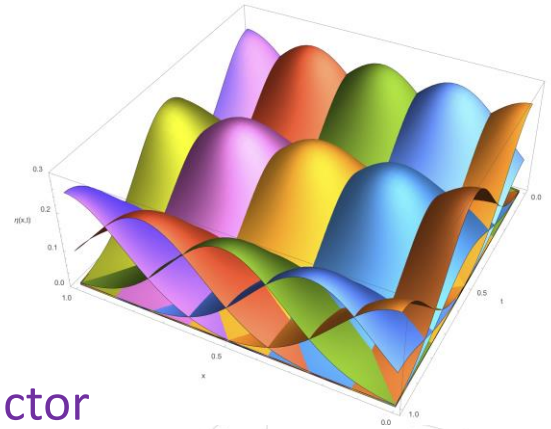
2) Pre-run Library of M binary cases

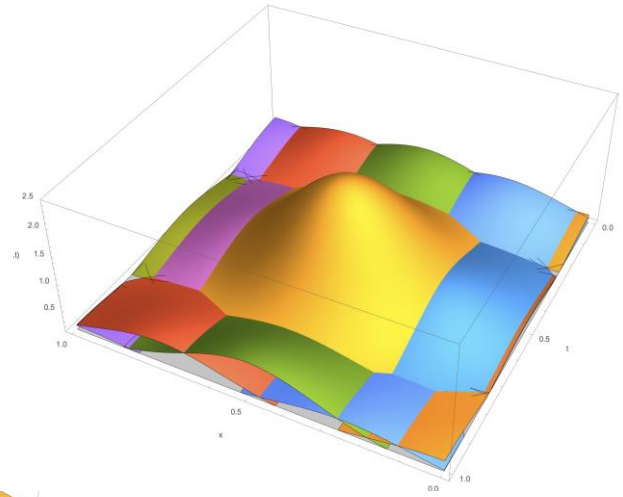
3) Reconstruction 1: Application of scaling Factor

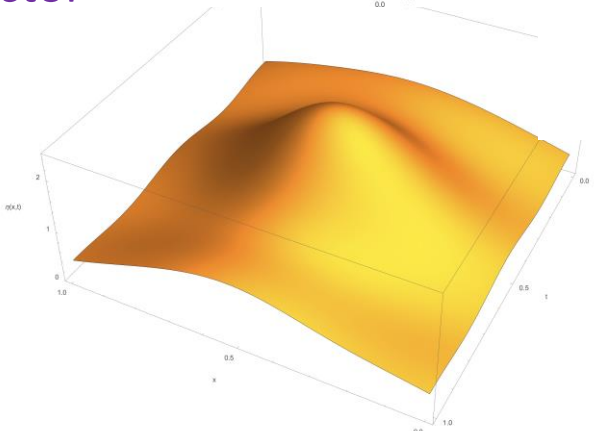
4) Reconstruction 2: summation of bins











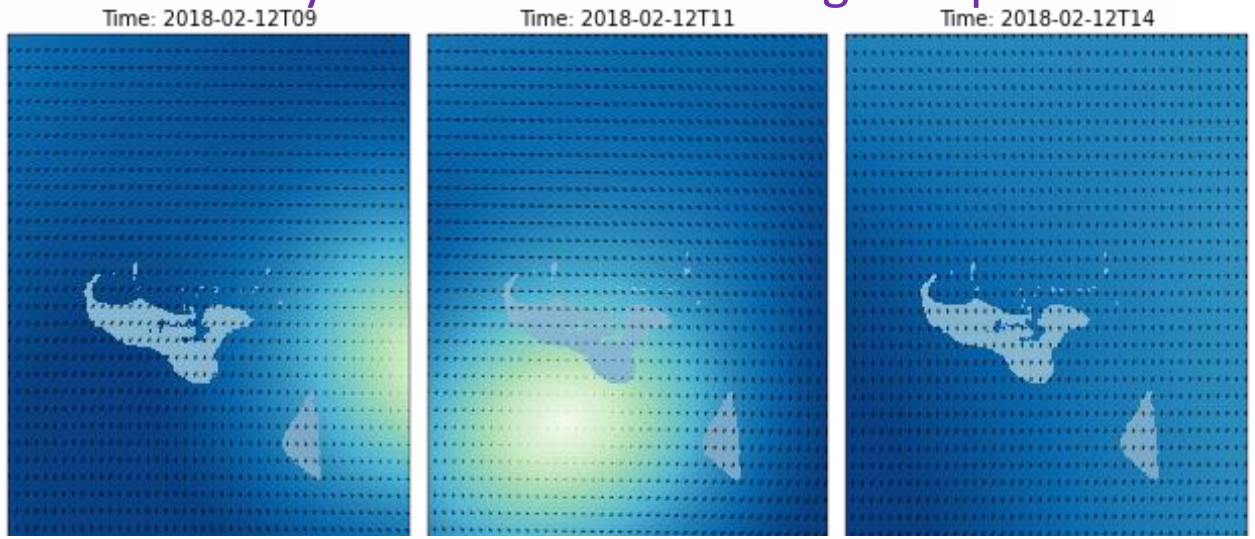
Examples:

- **Tsunamis** *Guan-Yu Chen et al., 2020*
- **BinWaves** *Cagigal et al. 2023*

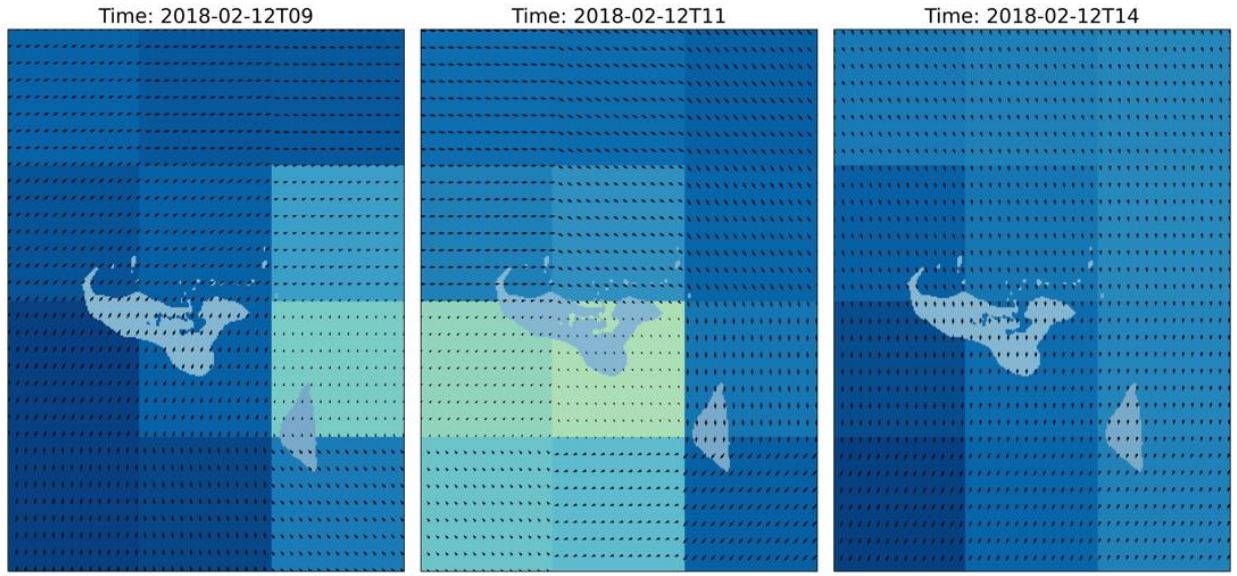
Methodology

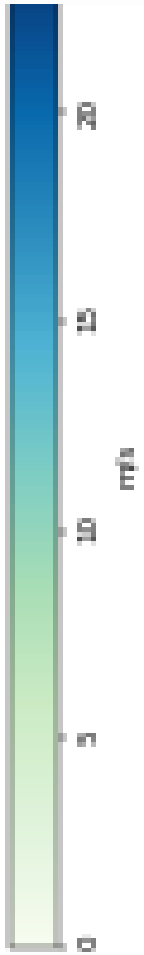
Green-based Hybrid modelling of TCs-induced Storm Surge

1) Discretize the problem in unitary scales of wind forcings at space and time



12 cells
28 km





Methodology

Green-based Hybrid modelling of TCs-induced Storm Surge

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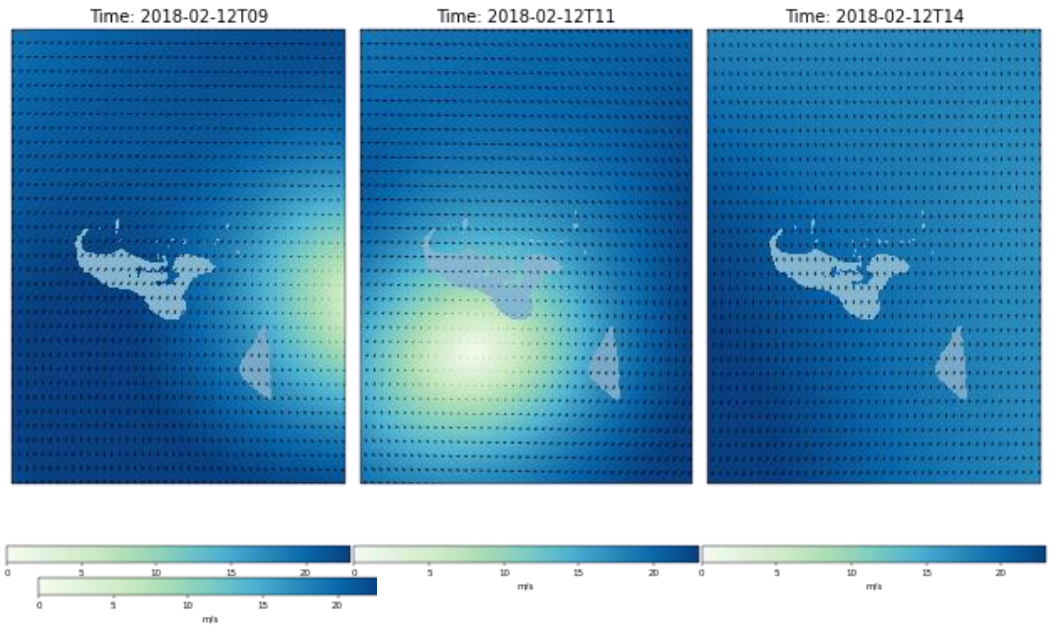
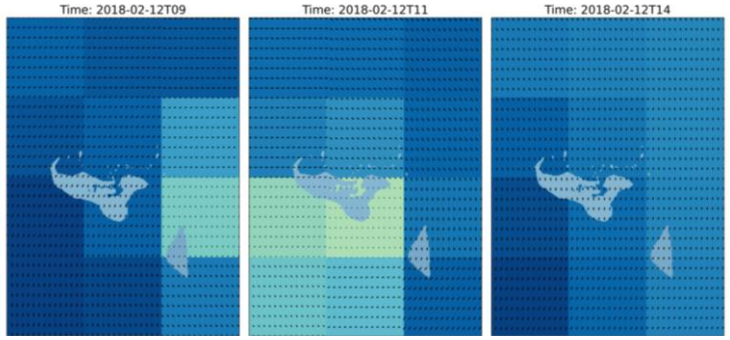
1) Discretize the problem in unitary scales of wind forcings at space and time

GeenSurge parameters (site dependent):

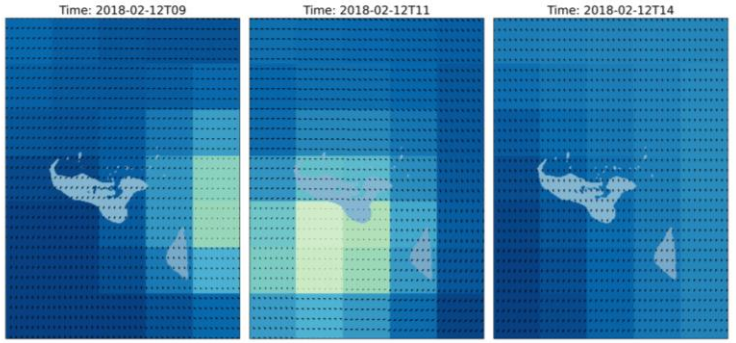
- Spatial partition discretization:
  - Square-shaped cells of 20km
- Wind direction discretization: 24



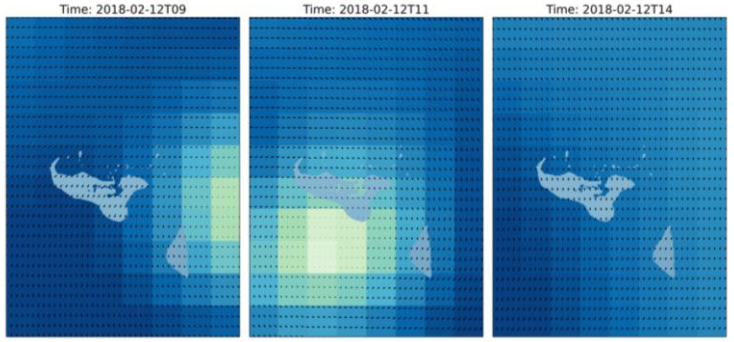
12 cells
28 km



35 cells
16 km



80 cells
10 km



Methodology

Green-based Hybrid modelling of TCs-induced Storm Surge

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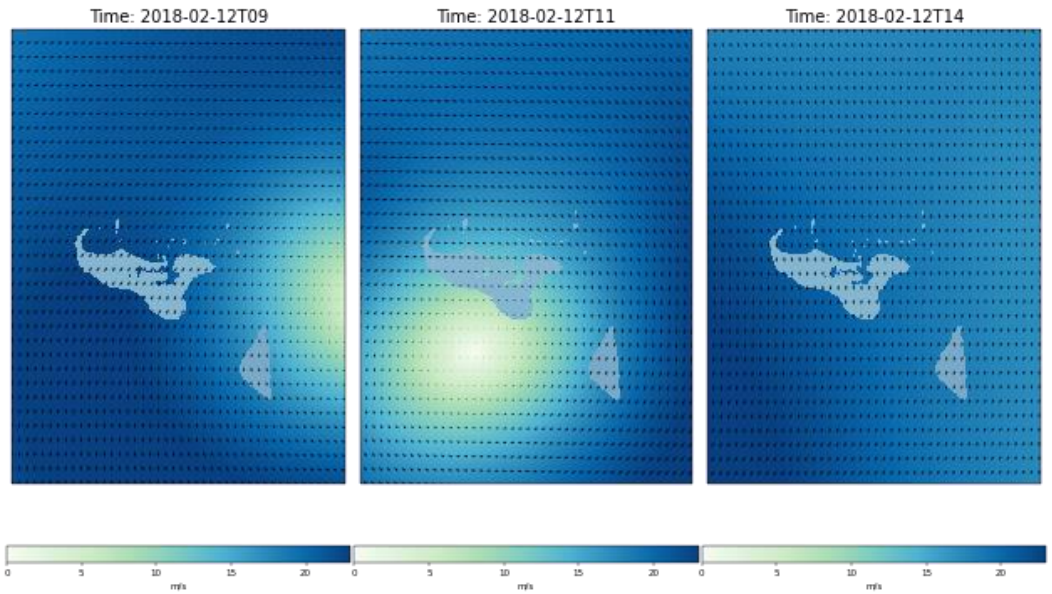
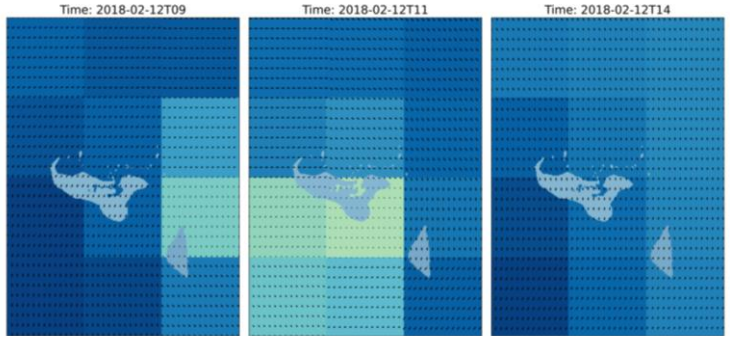
1) Discretize the problem in unitary scales of wind forcings at space and time

GeenSurge parameters 1 (site dependent):

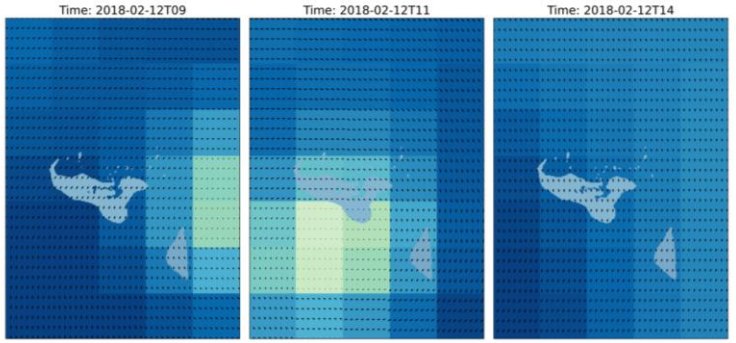
- Spatial partition discretization:
  - Square-shaped cells/tiles/tesellas of 10km
- Wind direction discretization: 24



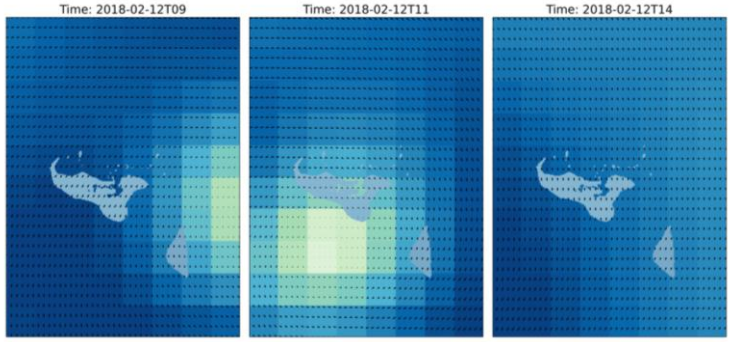
12 cells
28 km



12 cells
16 km



80 cells
10 km



Methodology

Green-based Hybrid modelling of TCs-induced Storm Surge

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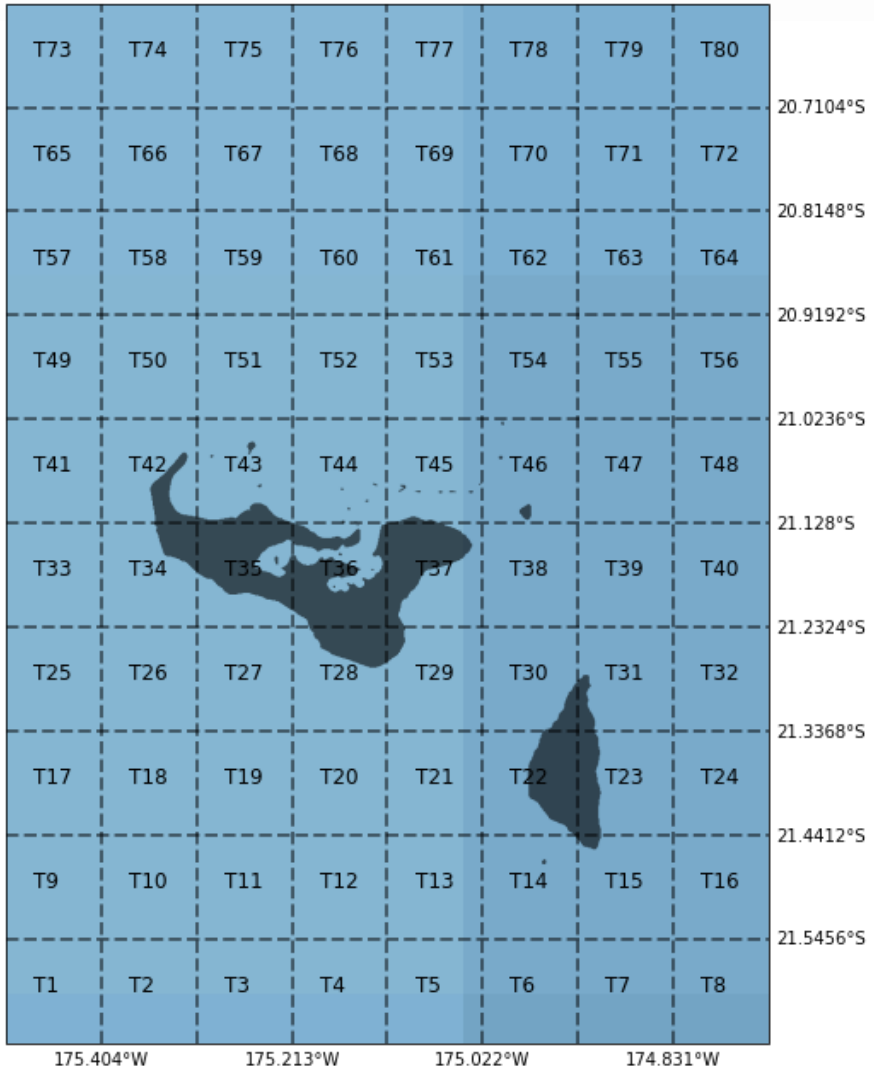
2) Pre-run Library of M binary cases

GeenSurge parameters:

- Unit wind magnitude: 40 m/s
- Drag coefficient function: Wu (1982)
- Wind direction discretization: 24 (15º)
- Delft3D-Flow
- Spatial Resolution 200 m
- 10x8 tiles – tesellas
- Time discretization: 1+23h
  - 1h sustained wind
  - 23h time afterwards



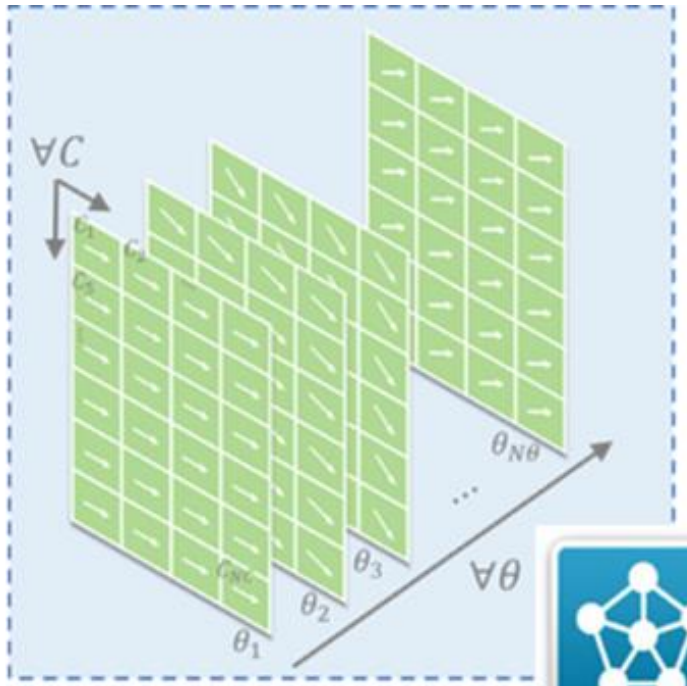
Methodology

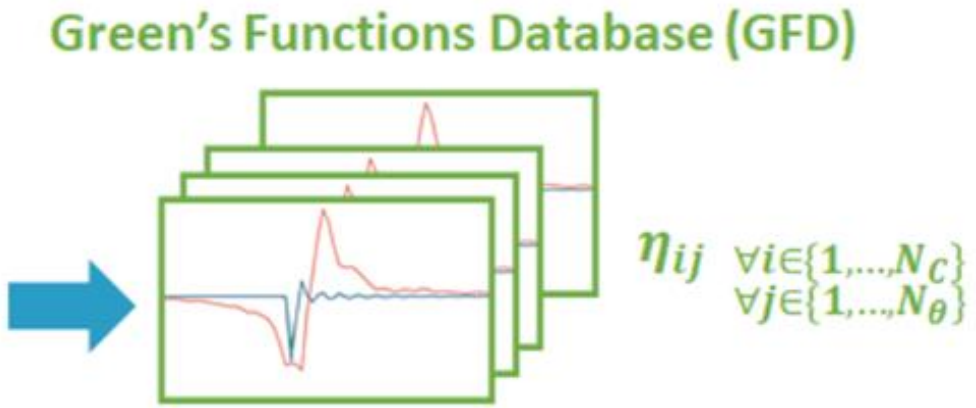
Green-based Hybrid modelling of TCs-induced Storm Surge

2) Pre-run Library of M binary cases

Generation Green's Functions Database (GFD)

database of sea level response to unit wind-sources from any direction over pre-defined regions (wind cells)





Tongatapu example

$$N_C = 80$$
$$N_\theta = 24$$

1920 Simulations

Methodology

Green-based Hybrid modelling of TCs-induced Storm Surge

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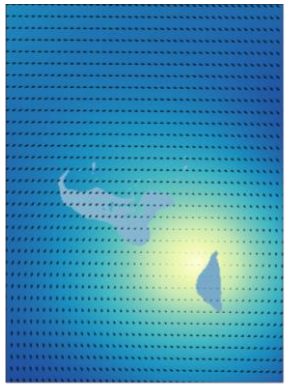
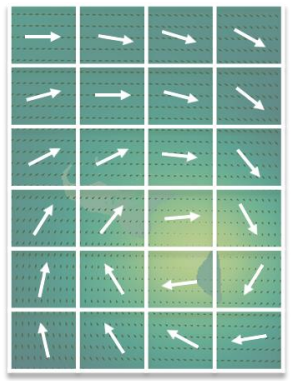
Under linear dynamics framework

4) Reconstruction: re-scaling and ensemble (Green's function summation)

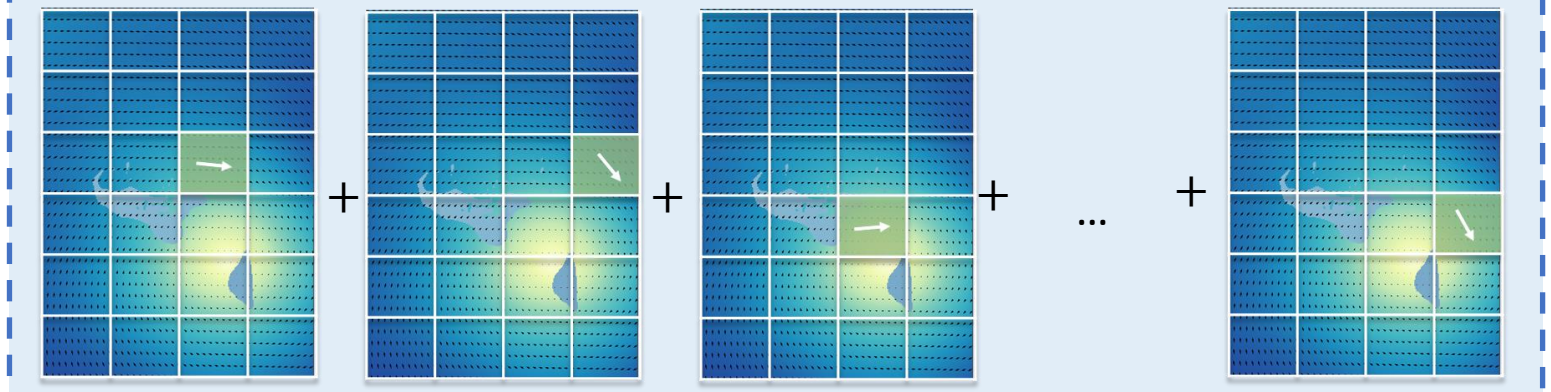


Wind forcing partition

t_j

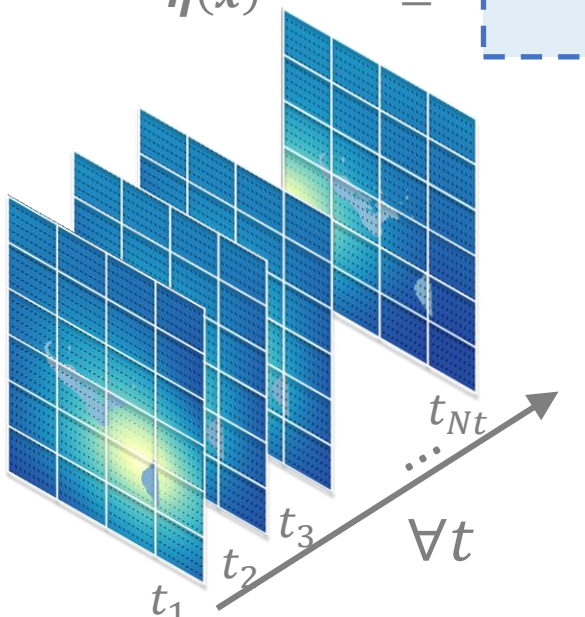


$\eta(x)$ =



$\eta_1 + \eta_2 + \eta_3 + \cdots + \eta_{Nc}$

Delft3D



Linear Summation

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

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

re-scaling

Numerical Validation

Green-based Hybrid modelling of TCs-induced Storm Surge

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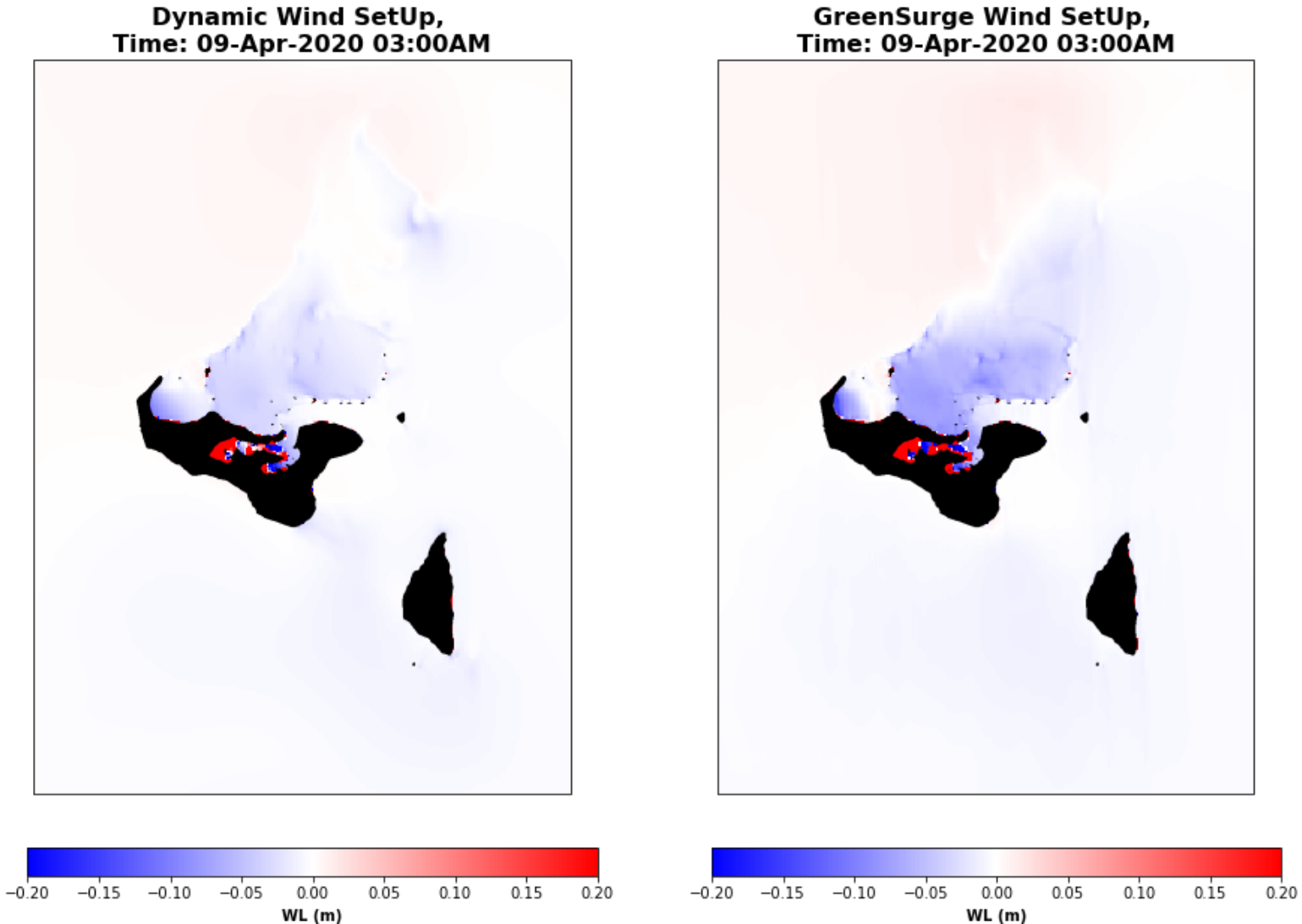
Reconstruction of **Harold 2020**



Numerical Validation

Green-based Hybrid modelling of TCs-induced Storm Surge

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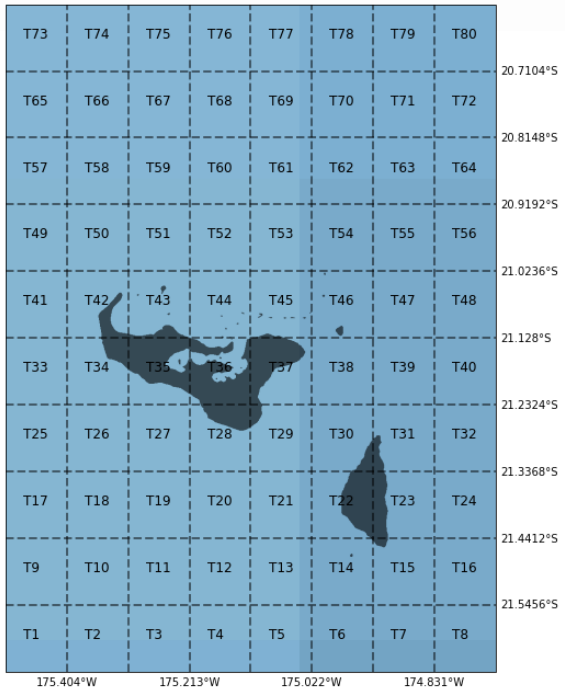
Reconstruction of **Harold 2020**



Numerical Validation

Green-based Hybrid modelling of TCs-induced Storm Surge

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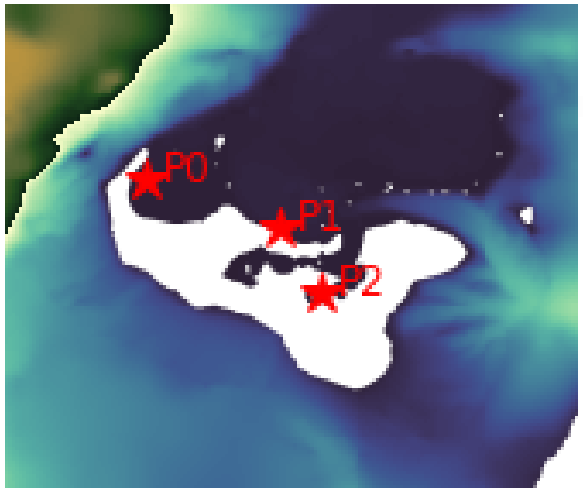
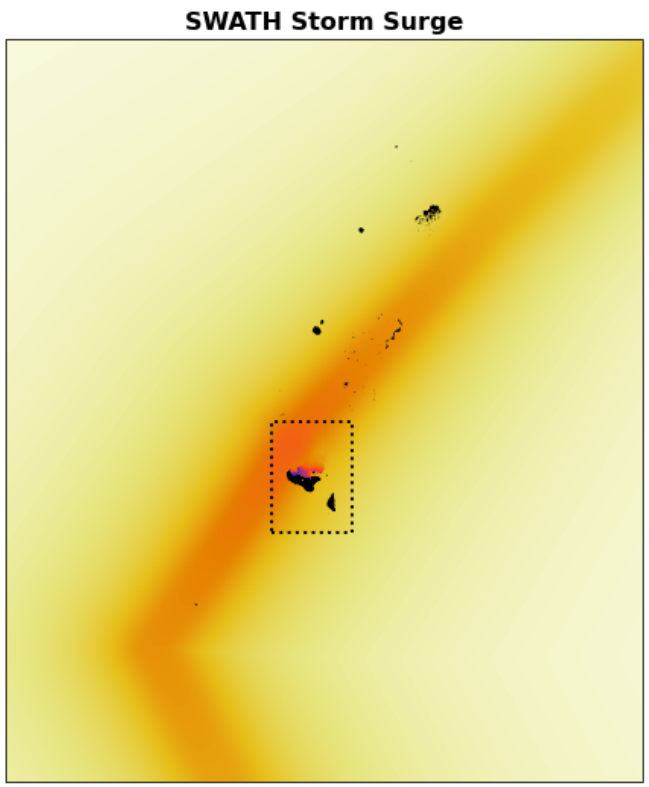
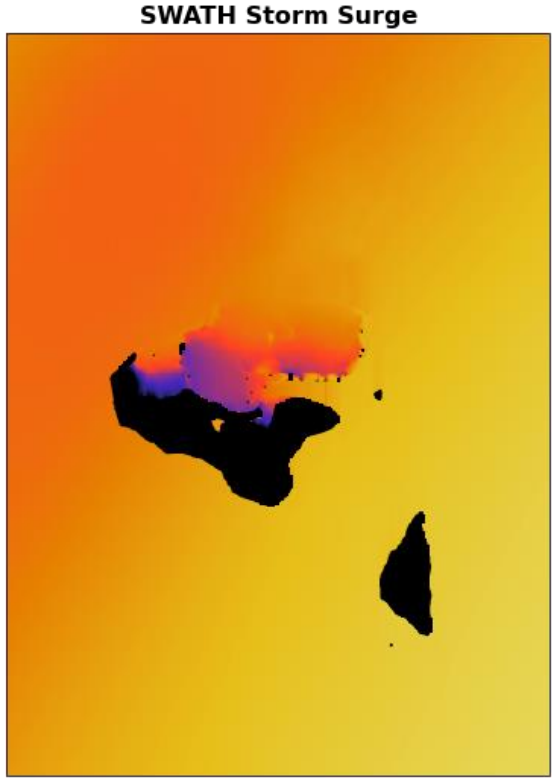
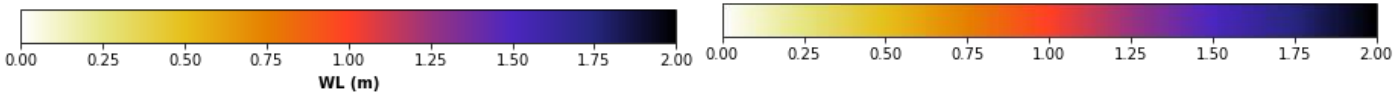
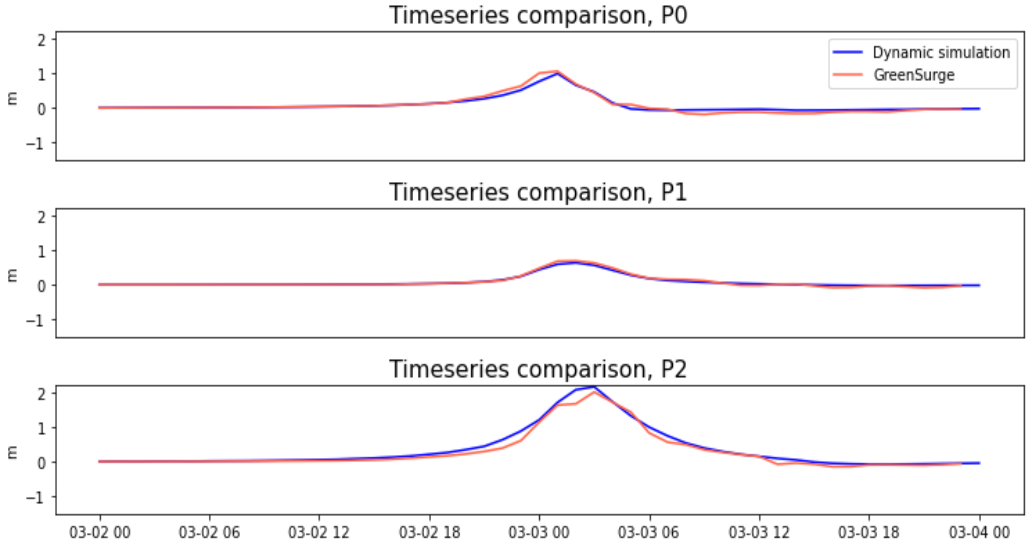
Reconstruction of Isaac 1982









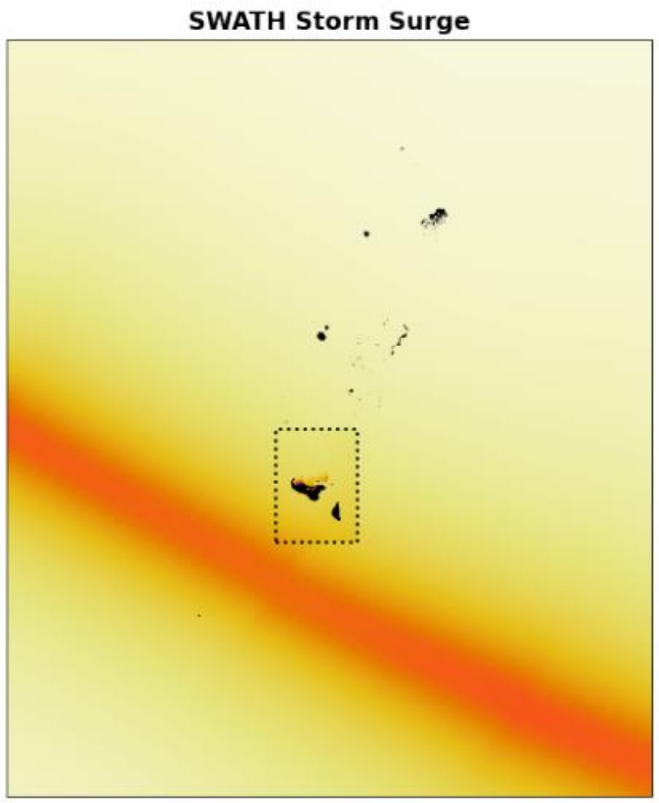


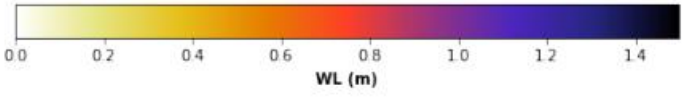
Validation. Tide gauge

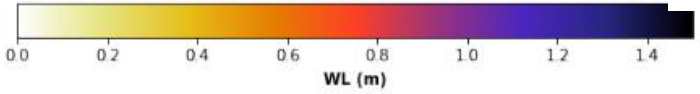
Green-based Hybrid modelling of TCs-induced Storm Surge

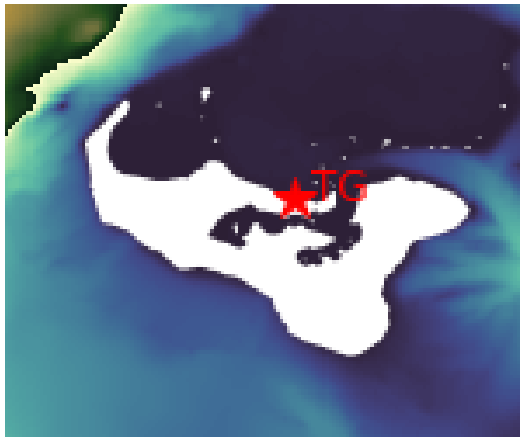
SS = IB + WindSetup-GS

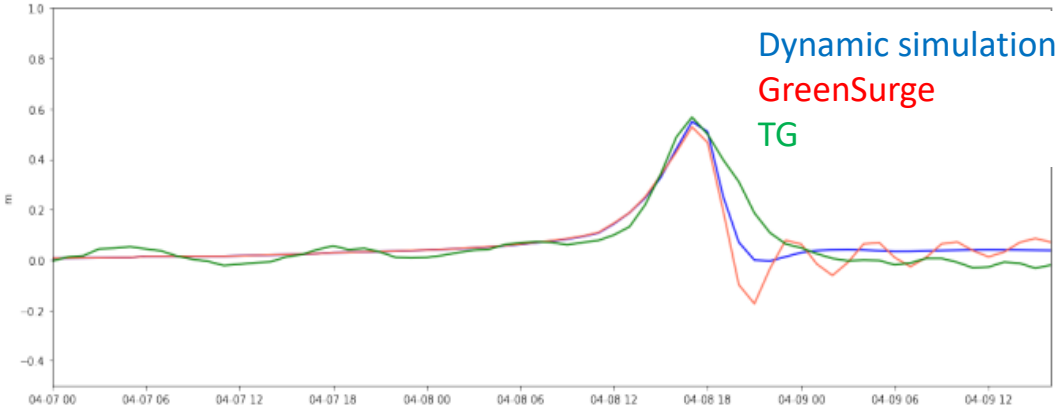
Reconstruction of **Harold 2020**







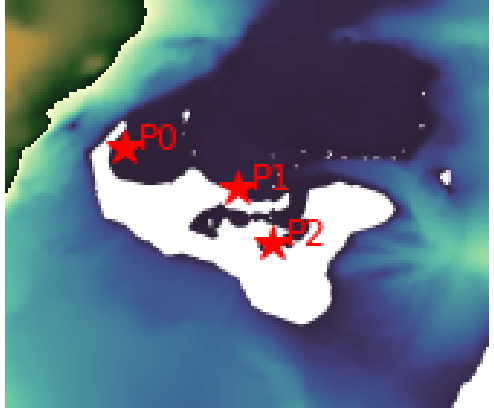


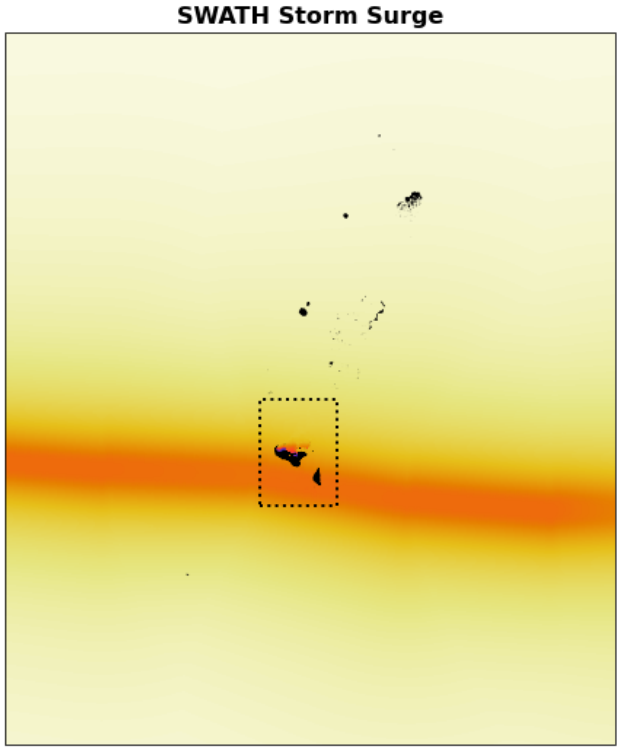


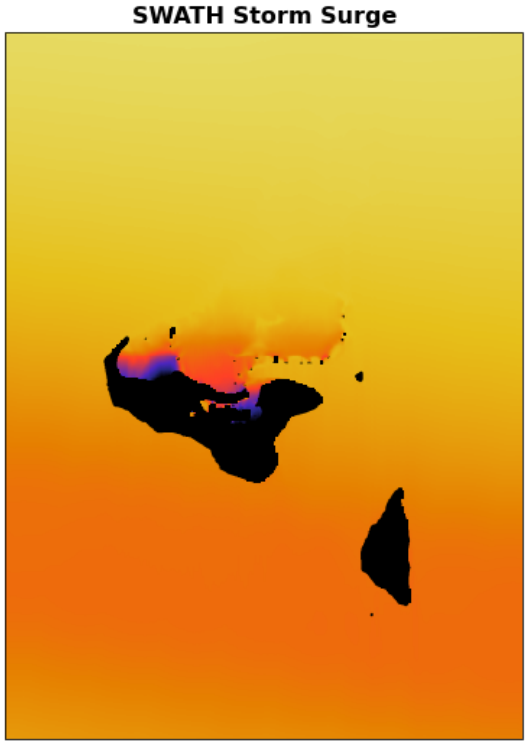
Validation. Tide Gauge

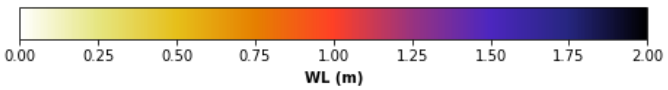
Green-based Hybrid modelling of TCs-induced Storm Surge

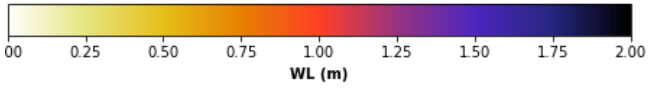
Reconstruction of Gita 2018

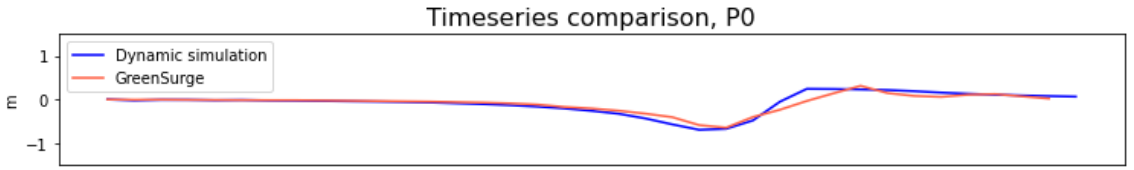


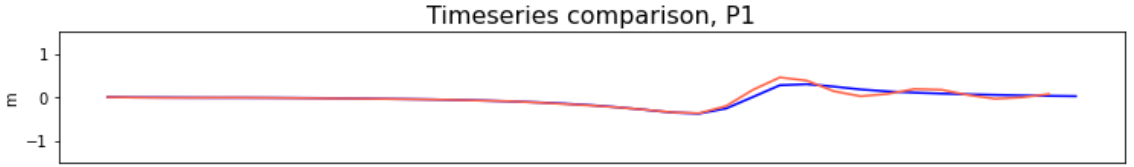


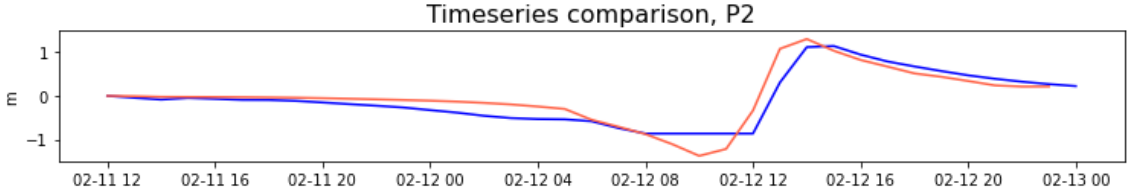


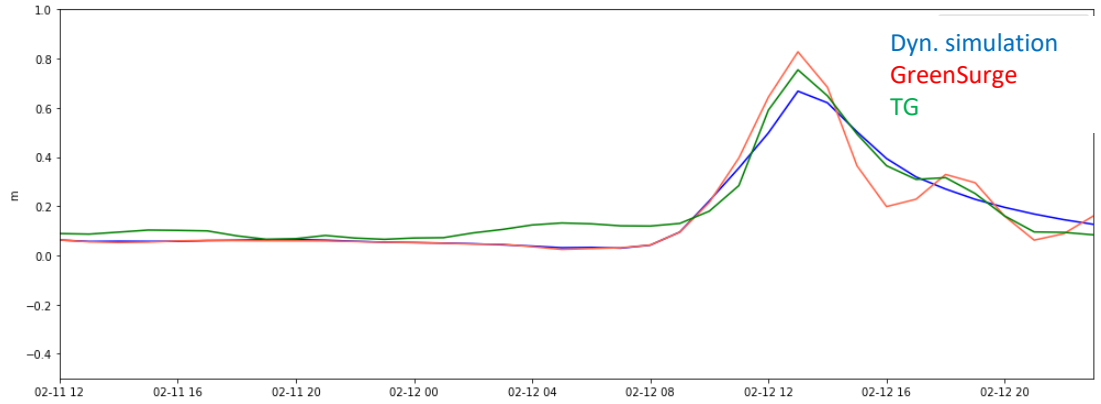




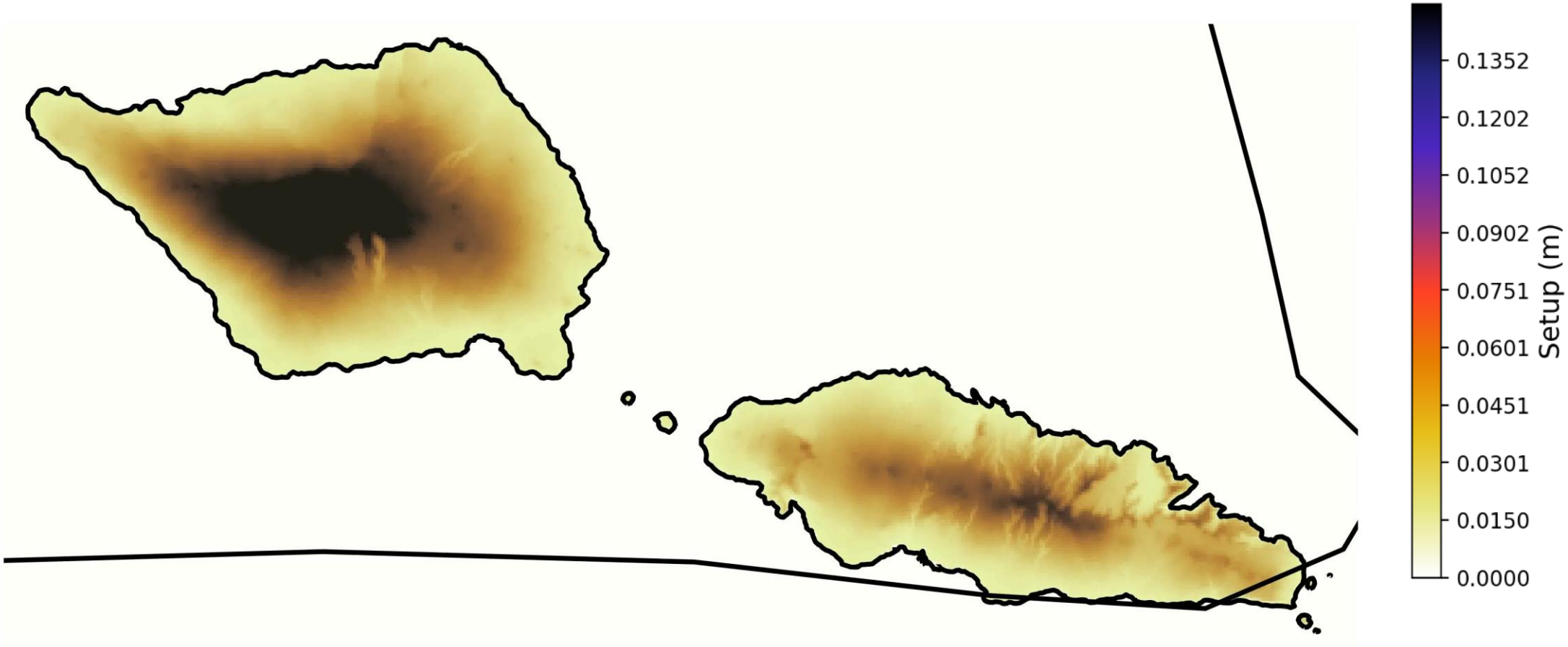








TC Evan (2012). GreenSurge application.
Run in less than 1 min in one laptop



Beatriz Pérez-Diaz, Fernando Méndez, Laura Cagigal, Sonia Castanedo
perezdb@unican.es

https://geoocean.unican.es

UC UNIVERSIDAD DE CANTABRIA
Geomatics and Ocean Engineering Group
UNIVERSIDAD DE CANTABRIA