SnapWave
a fast wave component in coastal model systems

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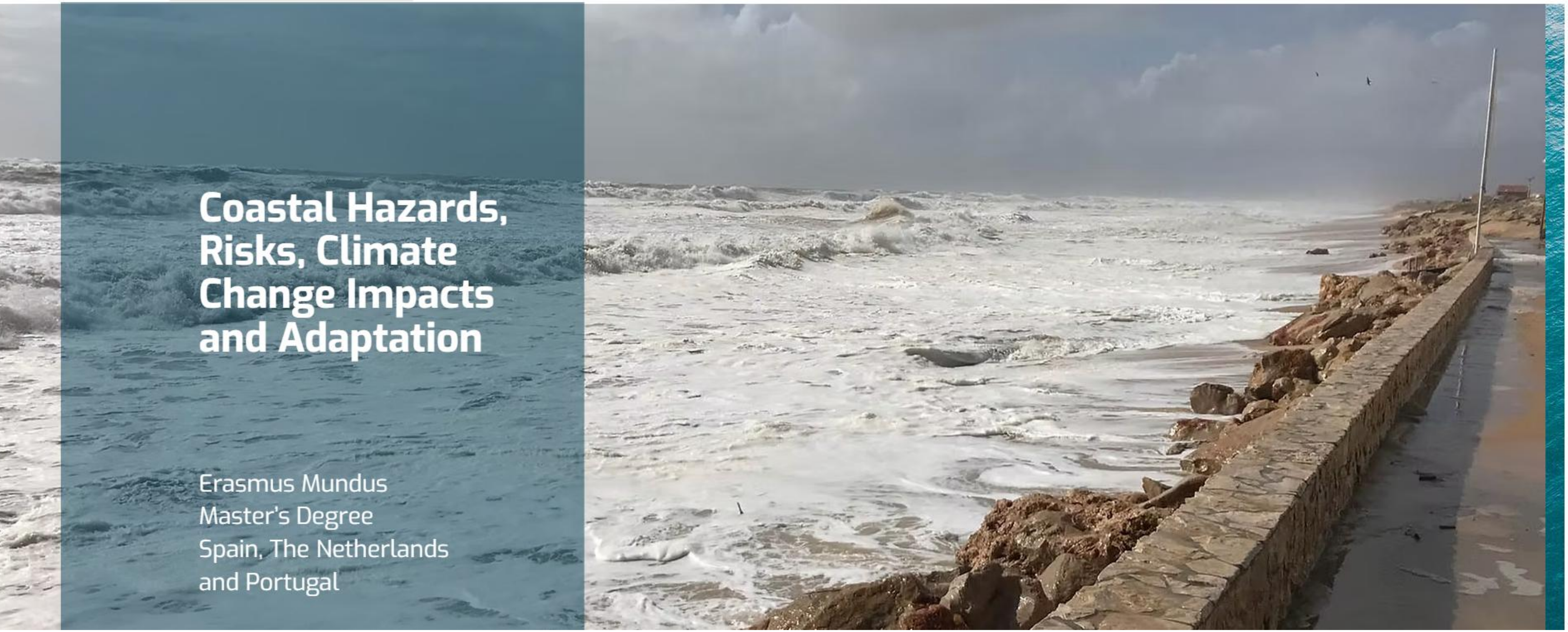

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Why SnapWave?

- Wave simulations take up majority of runtime in morphology modelling
- Nearshore processes in e.g. SWAN dominated by refraction, shoaling, dissipation by friction and wave breaking: 'simple' processes
- In tidal basins, lakes and estuaries, wave growth by wind is important
- Directional spreading is important but frequency can be parameterized
- Reduced physics similar to HISWA often sufficient
- Resolving nearshore spatial gradients given predicted offshore waves and wind fields.

SnapWave is used as:

- an unstructured solver to resolve wave conditions along a nearshore depth contour, for coastline modelling in ShorelineS (Roelvink et al., 2020)
- an improved stationary wave solver for XBeach (Roelvink et al., 2009), allowing wave propagation in all directions;
- a stationary wave solver for unstructured grids consisting of triangular and quadrangular cells in Delft3D-FM (Reyns et al., 2023);
- a fast nearshore wave solver coupled with SFINCS, to resolve wave setup in inundation modelling (Leijnse et al., 2024).

Wave energy balance

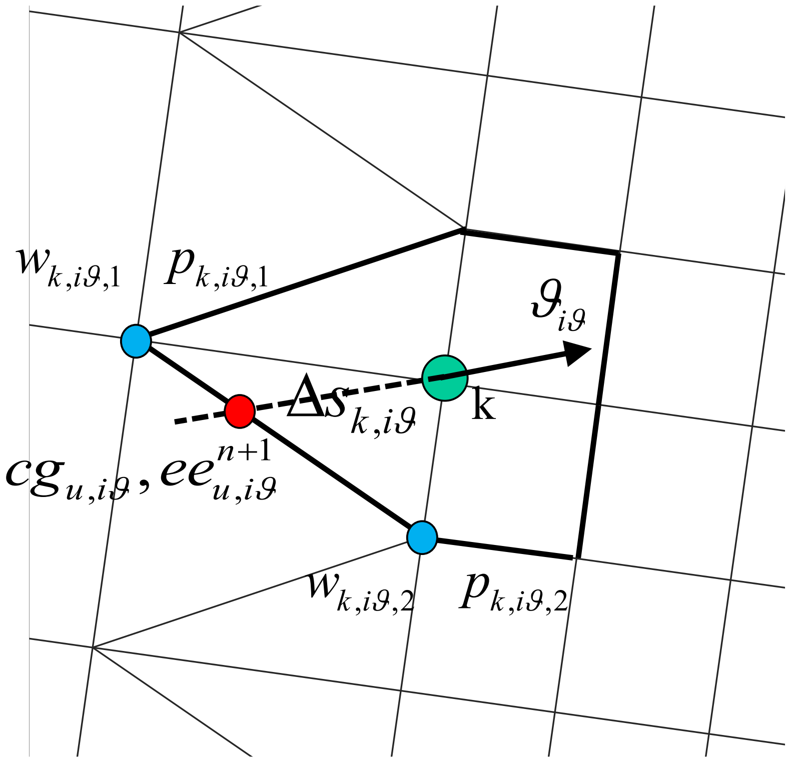
- As in XBeach:

$$\frac{\partial ee}{\partial t}+\frac{\partial ee\,C_g\cos\vartheta}{\partial x}+\frac{\partial ee\,C_g\sin\vartheta}{\partial y}+\frac{\partial ee\,C_\vartheta}{\partial\vartheta}+dd=0$$

- Along each wave direction:

$$\frac{\partial ee}{\partial t}+\frac{\partial ee\,C_g}{\partial s}+\frac{\partial ee\,C_\vartheta}{\partial\vartheta}+dd=0$$

Unstructured grid (any combination of triangles and quadrilateral cells)



Discretization

- Refraction taken upwind

$$c_{\vartheta,k,i\vartheta} > 0$$

$$\frac{ee_{k,i\vartheta}^{n+1} - ee_{ik,i\vartheta}^{n}}{\Delta t} + \frac{c_{g,k} ee_{k,i\vartheta}^{n+1} - c_{g,prev,i\vartheta} ee_{prev,i\vartheta}^{n+1}}{\Delta s_{k,i\vartheta}} +$$

$$\frac{c_{\vartheta,k,i\vartheta} ee_{k,i\vartheta}^{n+1} - c_{\vartheta,k,i\vartheta-1} ee_{k,i\vartheta-1}^{n+1}}{\Delta \vartheta} + \frac{D_k}{E_k} ee_{k,i\vartheta}^{n+1} = 0,$$

Tridiagonal system per point

$$A\,ee_{k,i\vartheta-1}^{n+1} + B\,ee_{k,i\vartheta}^{n+1} + C\,ee_{k,i\vartheta+1}^{n+1} = R(ee_{k,i\vartheta}^{n}, ee_{prev,i\vartheta}^{n+1})$$

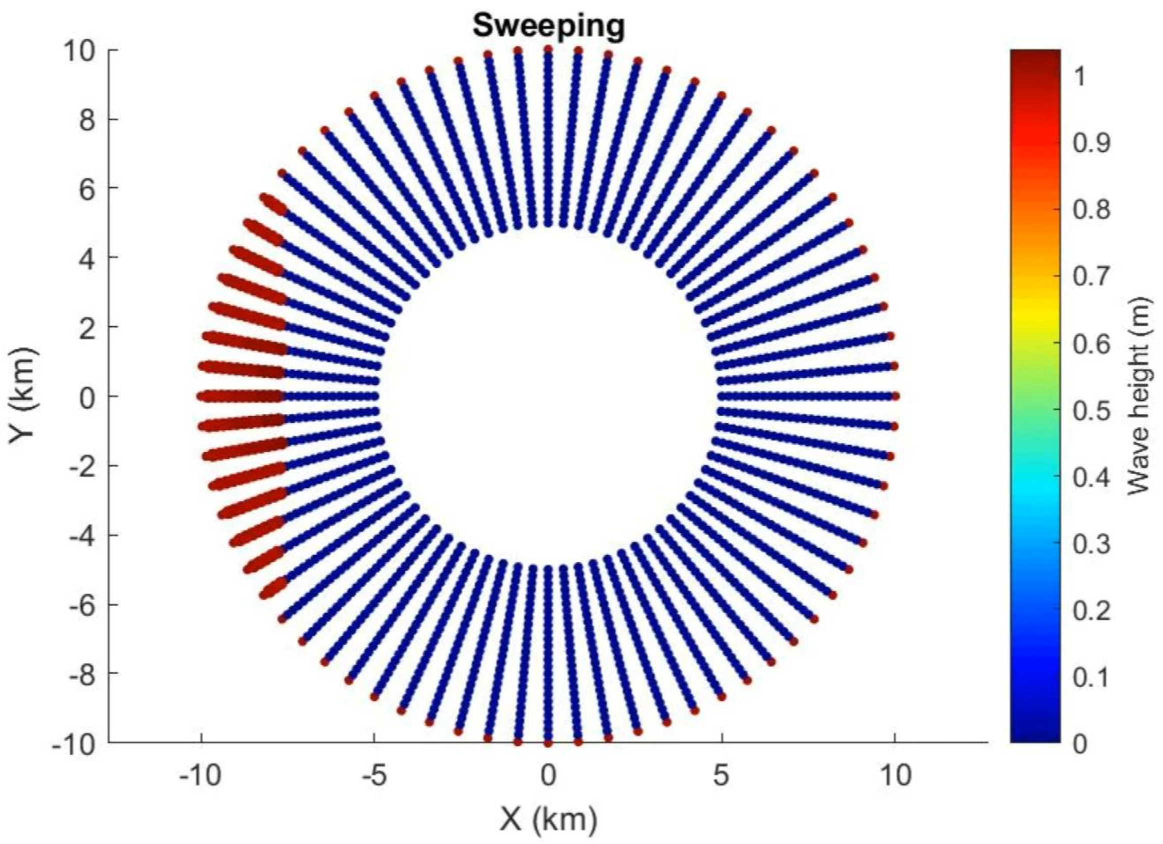
$$A = \frac{-c_{\vartheta k,i\vartheta-1}}{\Delta\vartheta} \qquad B = \frac{1}{\Delta t} + \frac{c_{gx,}}{\Delta s_{k,i\vartheta}} + \frac{c_{\vartheta,k,i\vartheta}}{\Delta\vartheta} + \frac{D_k}{E_k} \qquad C = 0 \qquad R = \frac{ee_{k,i\vartheta}^{n}}{\Delta t} + \frac{c_{gx,prev}\,ee_{prev}^{n+1}}{\Delta s_{k,i\vartheta}}, \quad c_{\vartheta,k,i\vartheta} > 0$$

$$A = 0 \qquad B = \frac{1}{\Delta t} + \frac{c_{gx,}}{\Delta s_{k,i\vartheta}} - \frac{c_{\vartheta,k,i\vartheta}}{\Delta\vartheta} + \frac{D_k}{E_k} \qquad C = \frac{c_{\vartheta,k,i\vartheta+1}}{\Delta\vartheta} \qquad R = \frac{ee_{k,i\vartheta}^{n}}{\Delta t} + \frac{c_{gx,prev}\,ee_{prev}^{n+1}}{\Delta s_{k,i\vartheta}}, \quad c_{\vartheta,k,i\vartheta} < 0$$

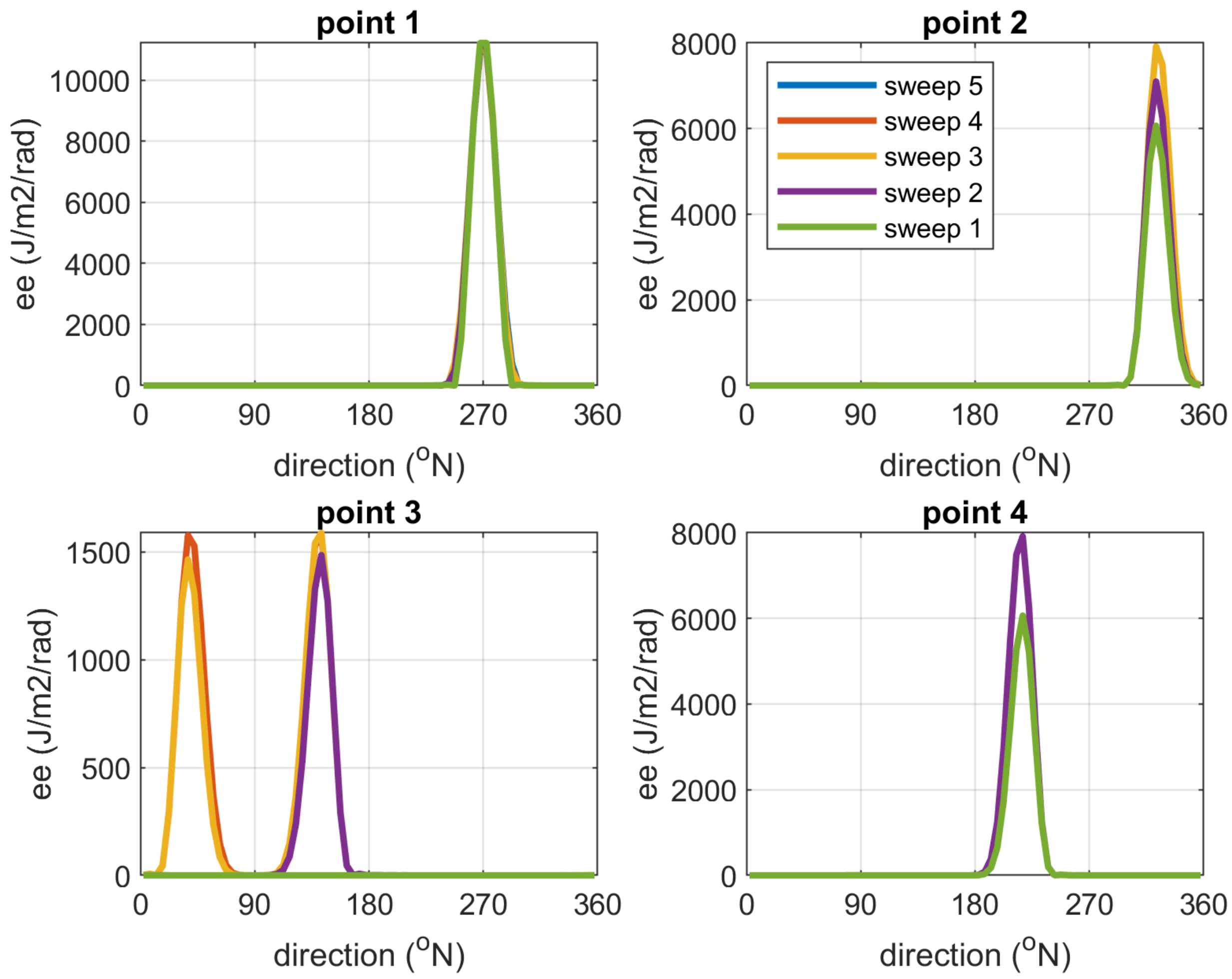
Solution scheme

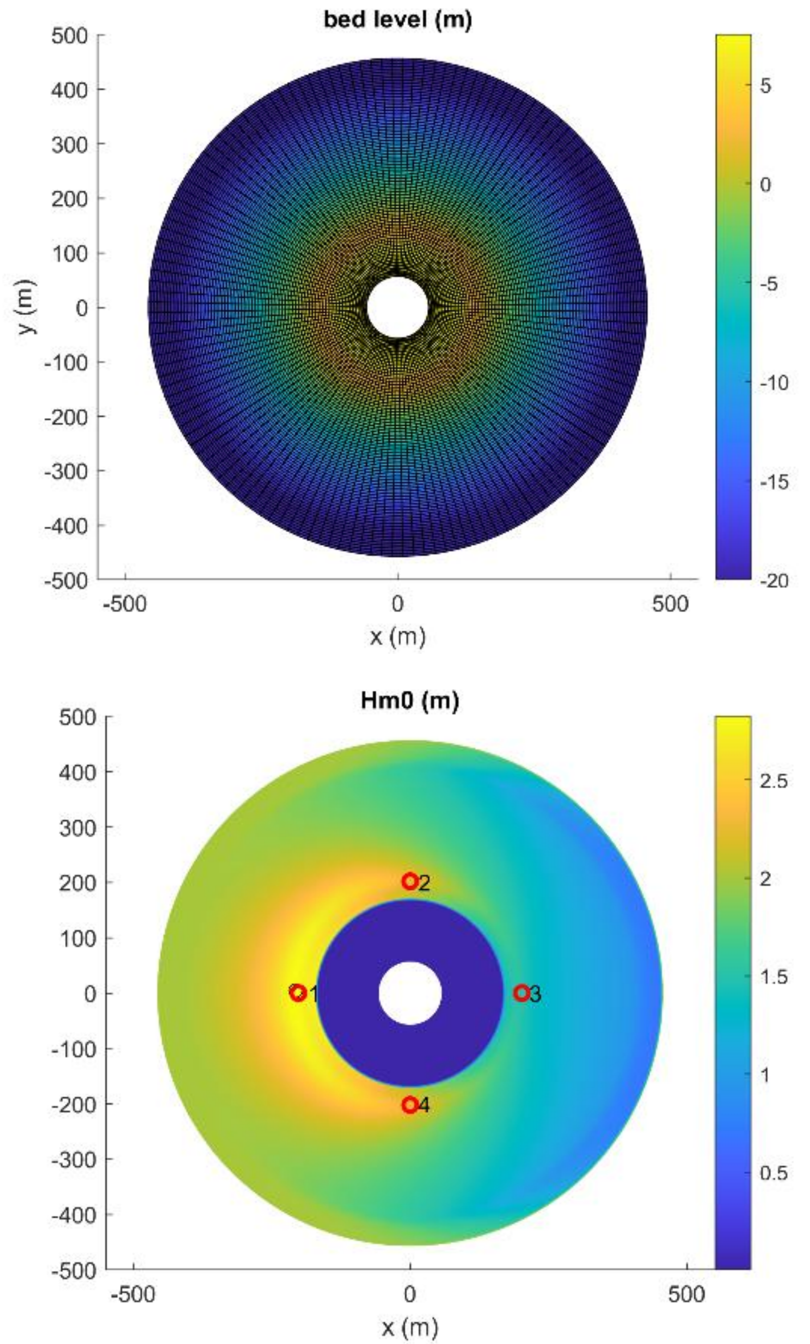
- Sort grid points in 4 directions, starting in mean wave direction
- For each iteration
  - Carry out 4 sweeps solving the wave energy in each point in the order of each sweep
  - After sweep 4 check convergence
  - Take out points already converged
  - Repeat until all are converged

First 4 sweeps – curved grid



Circular island sweeping process





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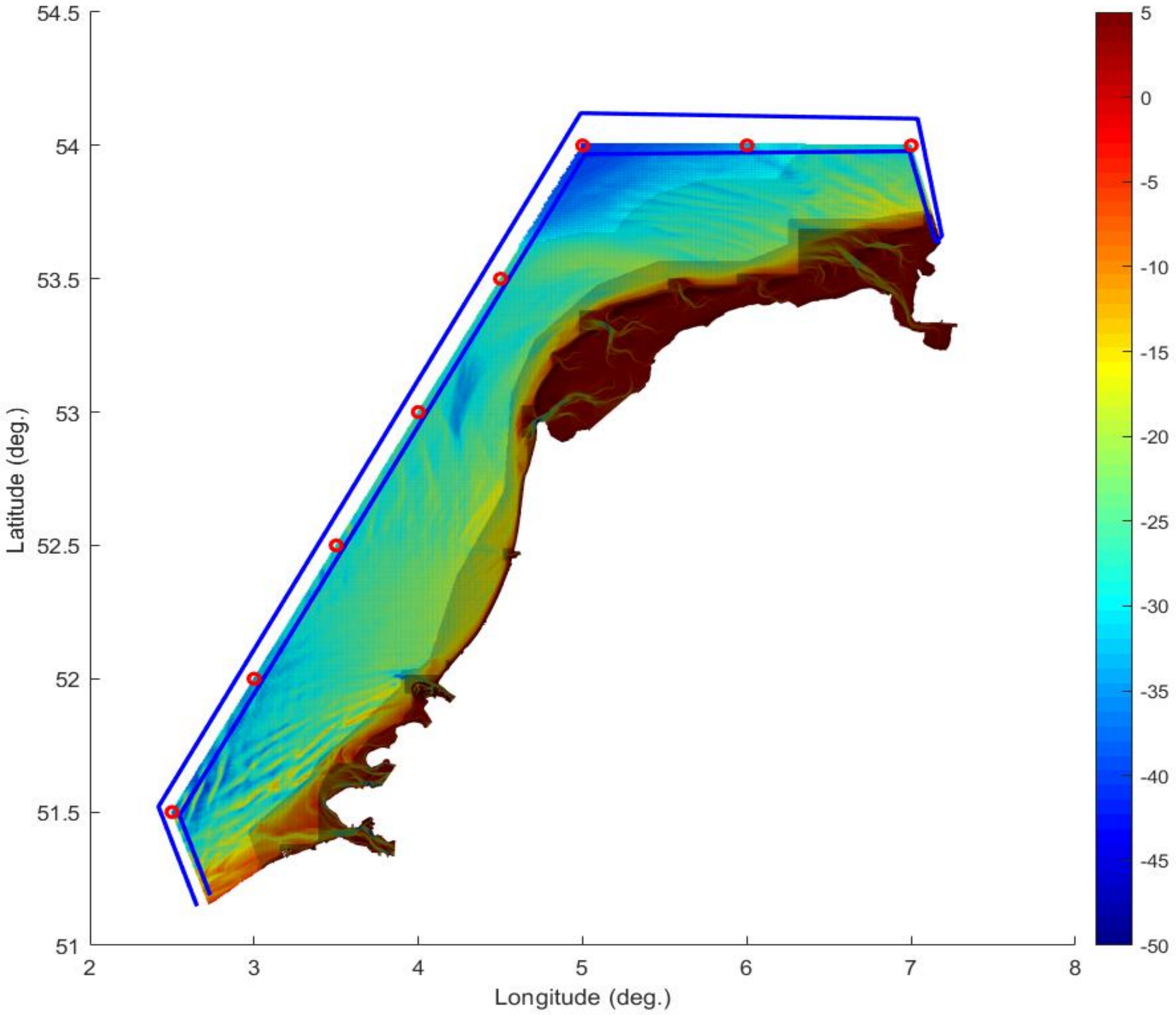
NL example transforming waves to nearshore

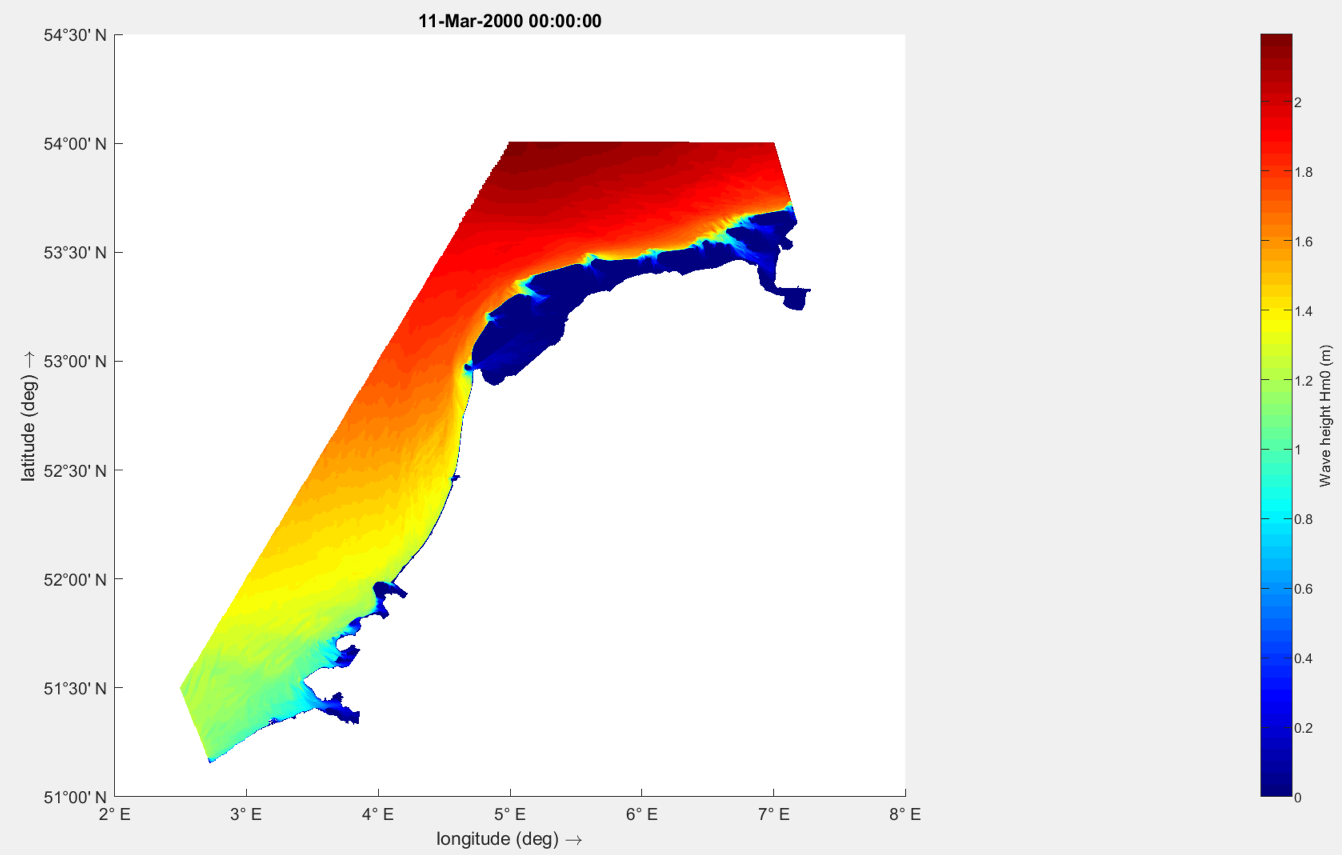
- ~650,000 points, resolution 800 – 100m
- Red dots boundary points (from ERA5)
- Blue polygon boundary enclosure
- Grid can be arbitrarily cut out of unstructured mesh



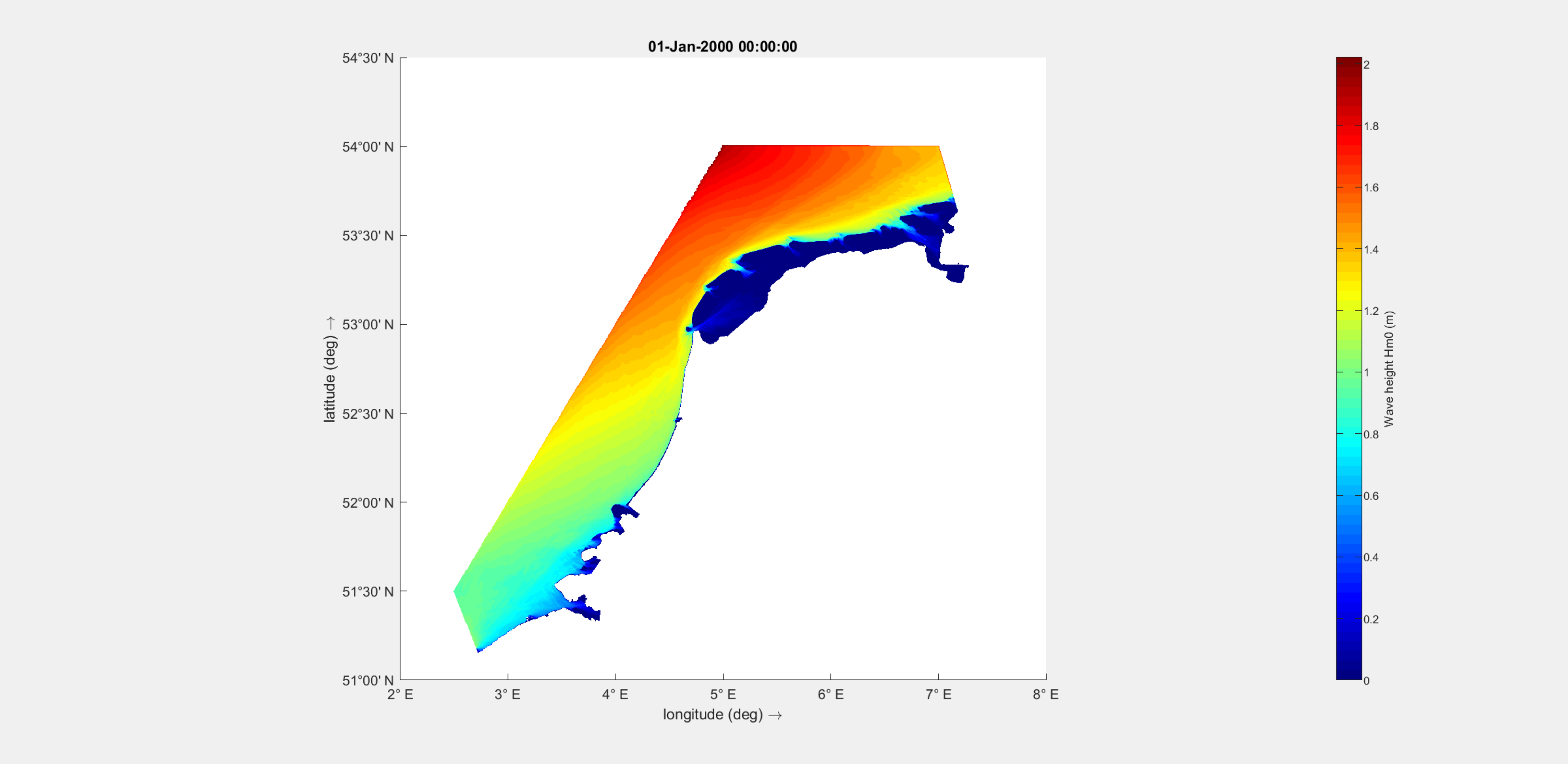
Example

- Boundary conditions from ERA5
- Some snapshots of wave height
- Validation against nearshore observations in Coast3D campaign

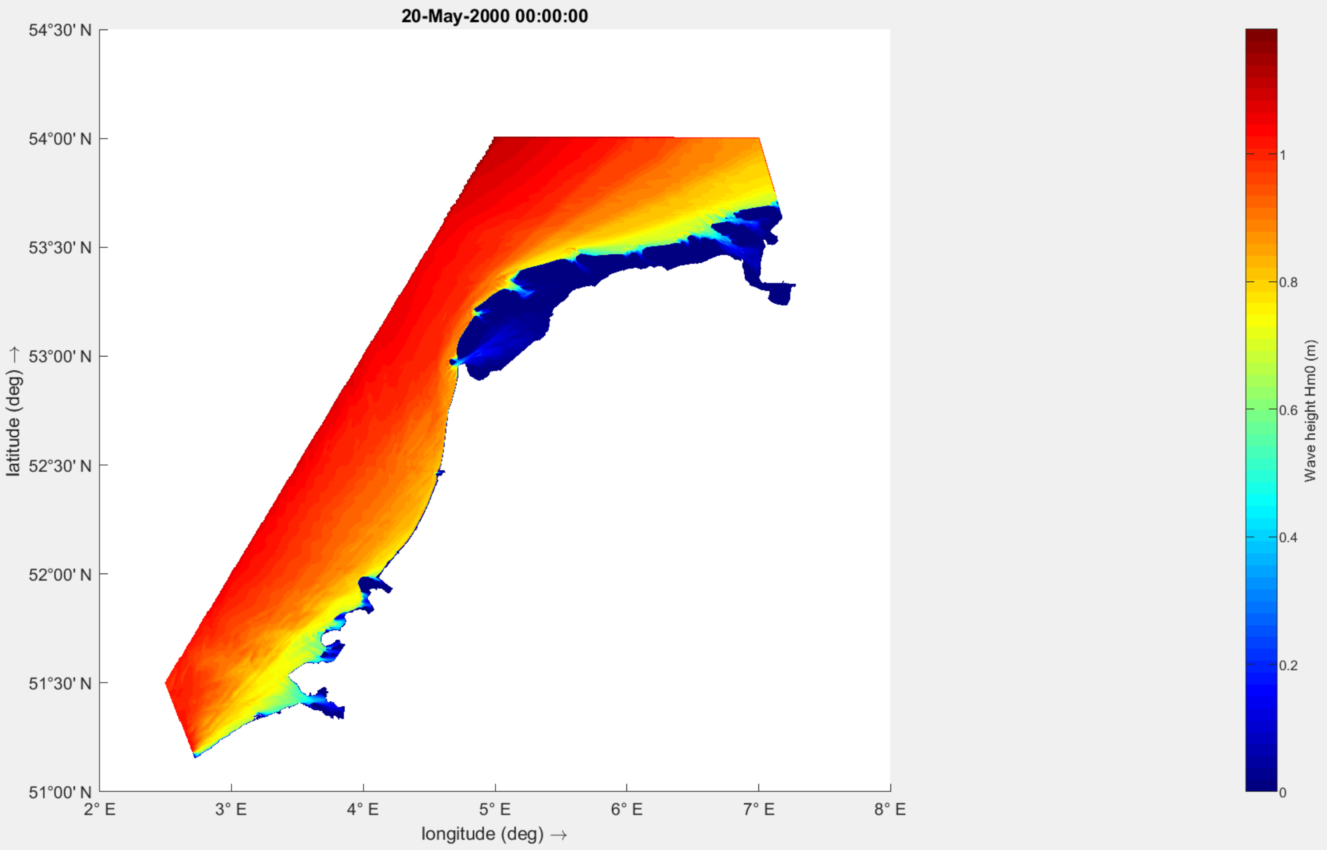
Hm0



11-Mar-2000 00:00:00
54°30' N
54°00' N
53°30' N
53°00' N
52°30' N
52°00' N
51°30' N
51°00' N
latitude (deg) →
2° E
3° E
4° E
5° E
6° E
7° E
8° E
longitude (deg) →
Wave height Hm0 (m)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

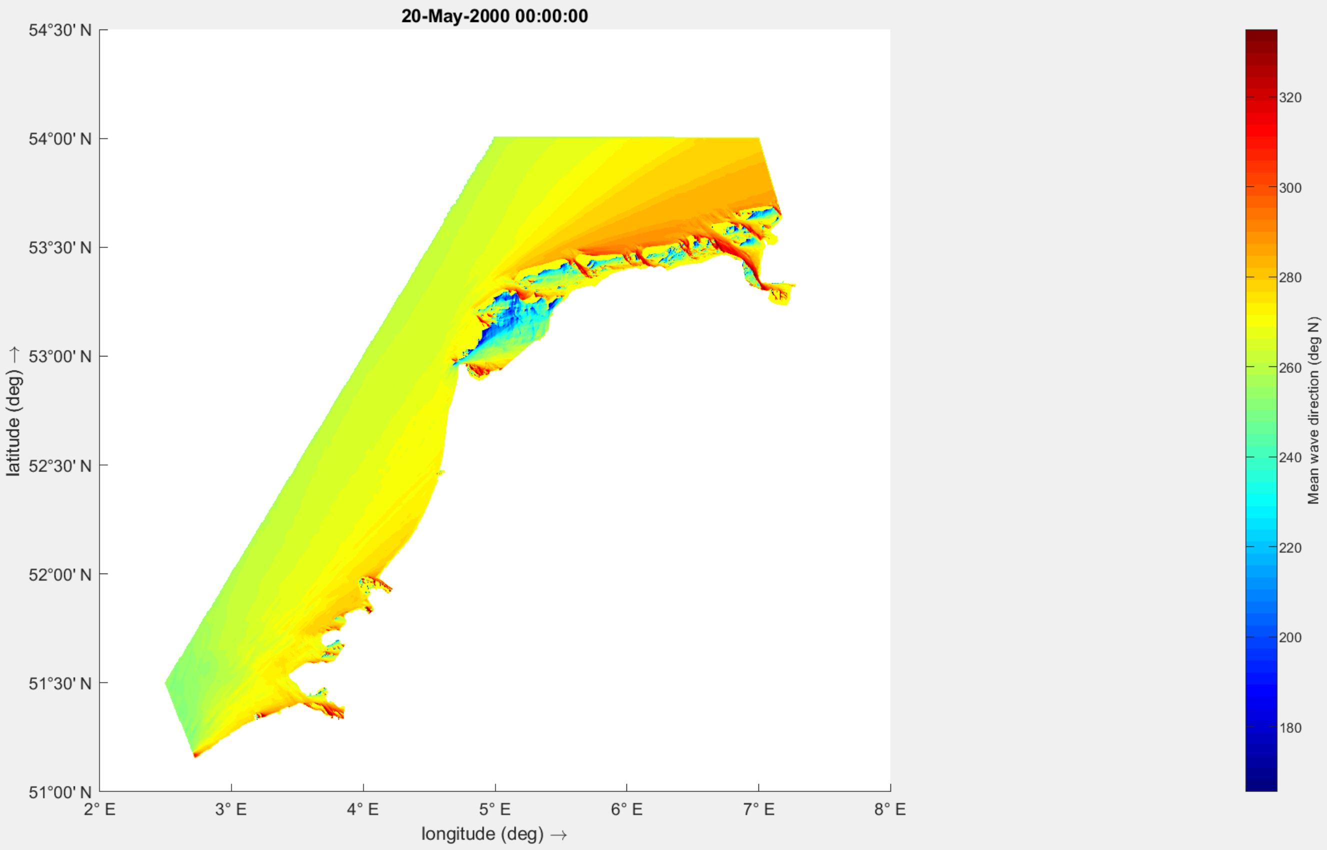


01-Jan-2000 00:00:00
54°30' N
54°00' N
53°30' N
53°00' N
52°30' N
52°00' N
51°30' N
51°00' N
latitude (deg) →
2° E
3° E
4° E
5° E
6° E
7° E
8° E
longitude (deg) →
Wave height Hm0 (m)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0



20-May-2000 00:00:00
54°30' N
54°00' N
53°30' N
53°00' N
52°30' N
52°00' N
51°30' N
51°00' N
latitude (deg) →
2° E
3° E
4° E
5° E
6° E
7° E
8° E
longitude (deg) →
Wave height Hm0 (m)
1
0.8
0.6
0.4
0.2
0

Wave direction



Netherlands coastal model

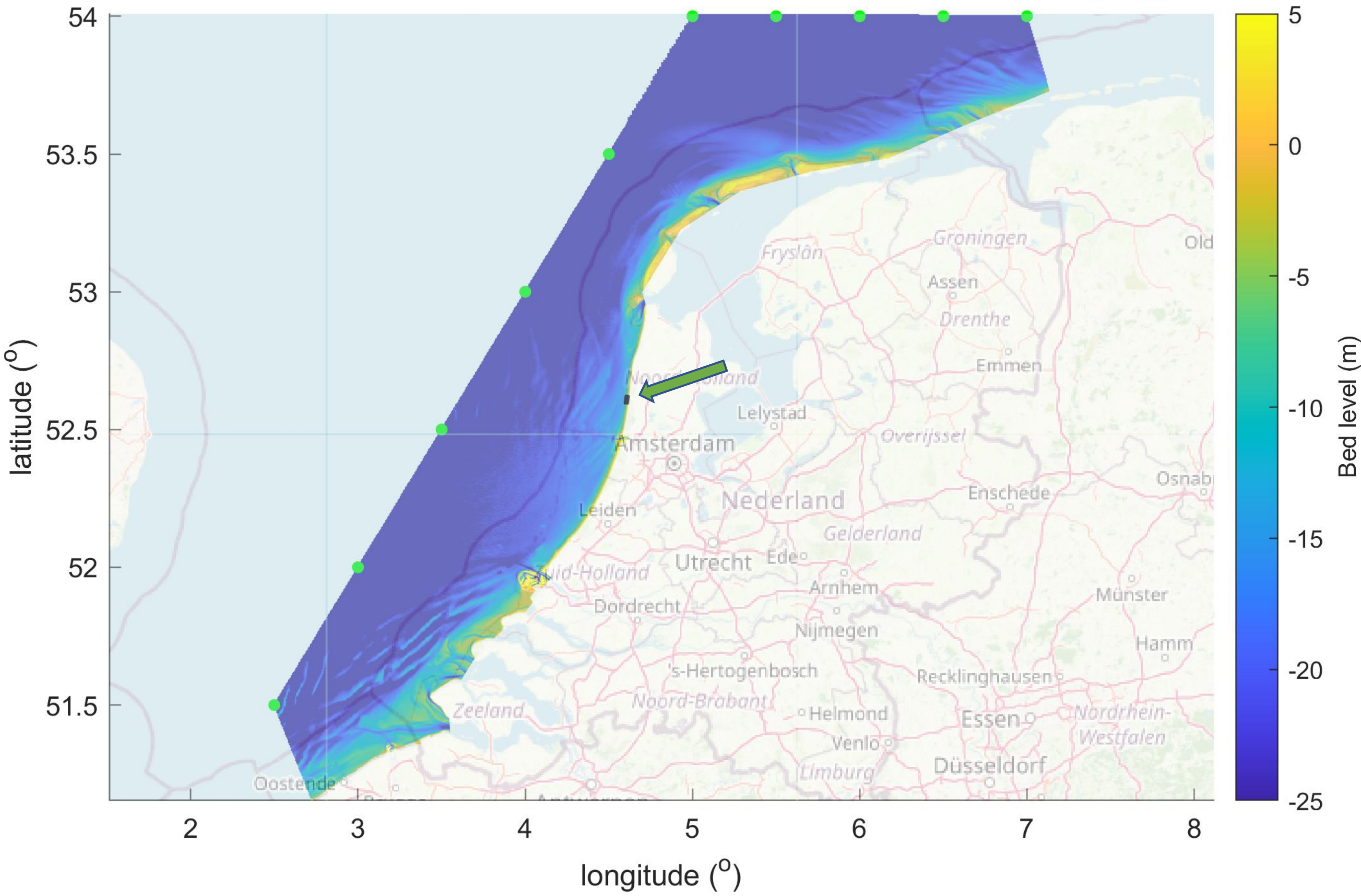
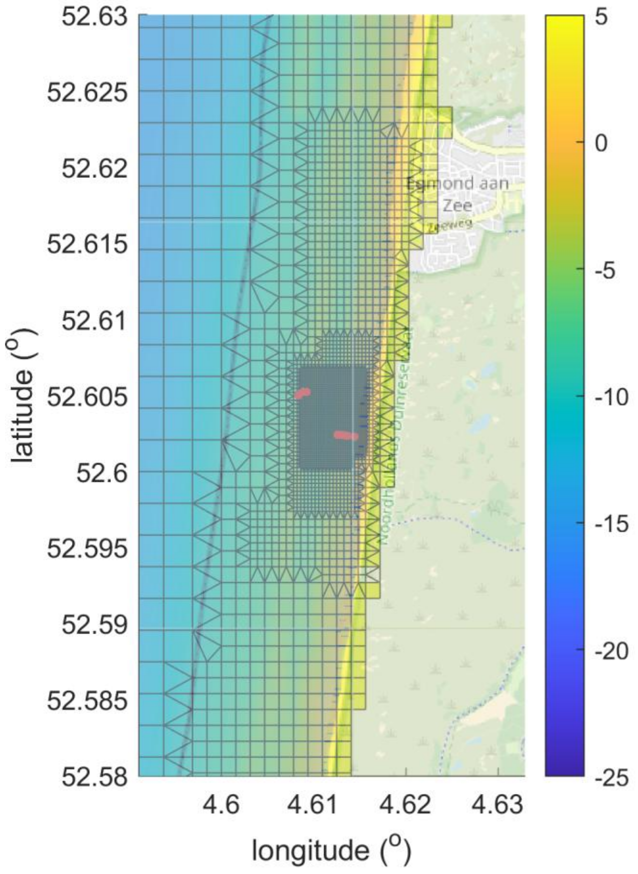


Figure 8 Overview of Holland coast, with bathymetry of large-scale model domain; black rectangle in North Holland: location of Egmond field campaign. Green dots: locations of ERA5 boundary points.

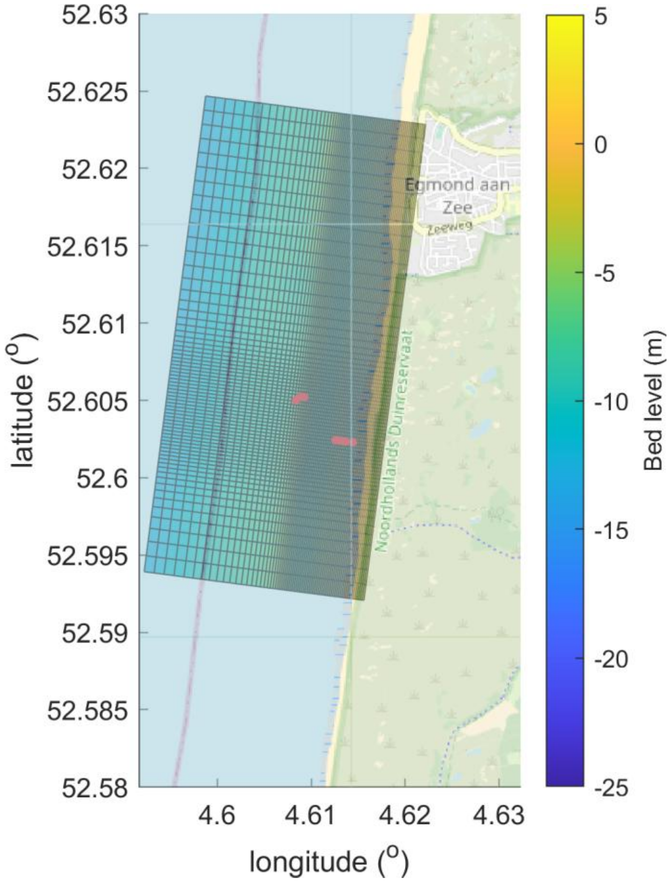
Coast3D campaign

- Grid kms -> 40m -> 5 m
- Irregular bar system

Large-scale model



Local model



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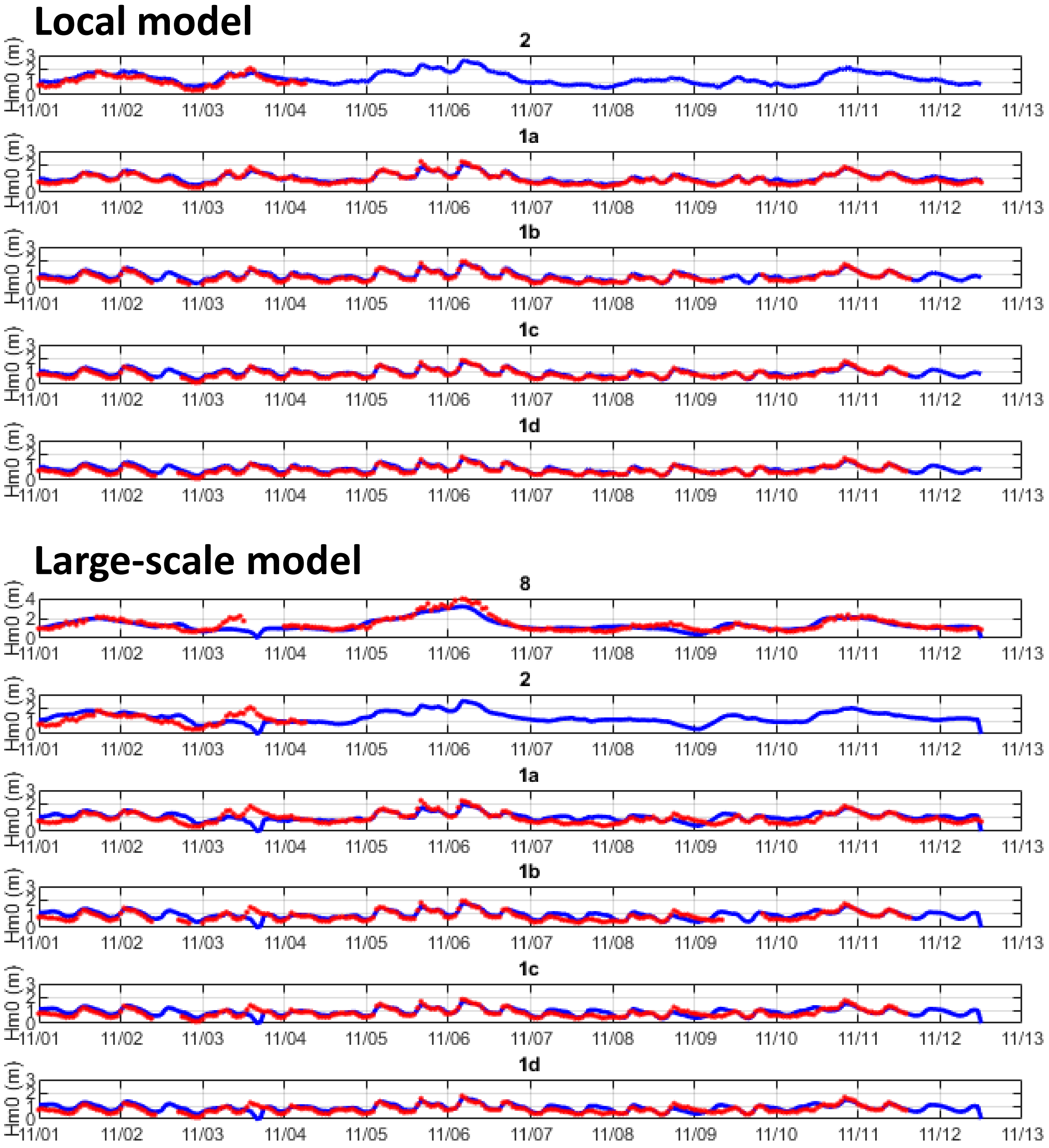
Coast3D validation

- Intensive measurement campaign in 1998
- Reproduced using ERA5 hindcast as boundary conditions for SnapWave
- Typical case for nearshore applications



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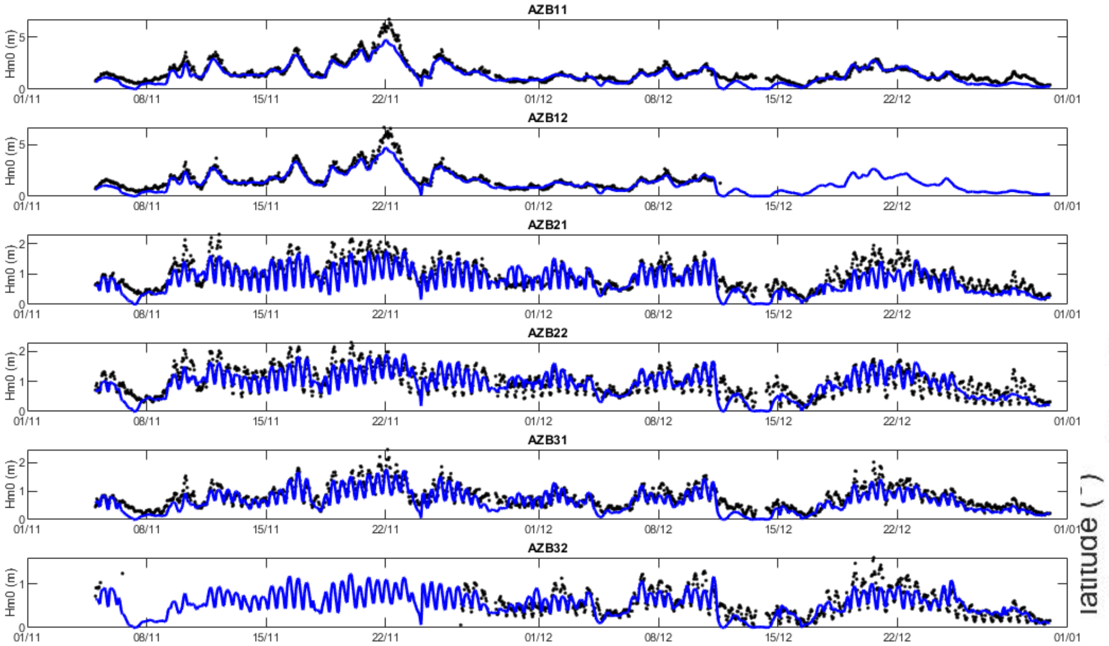
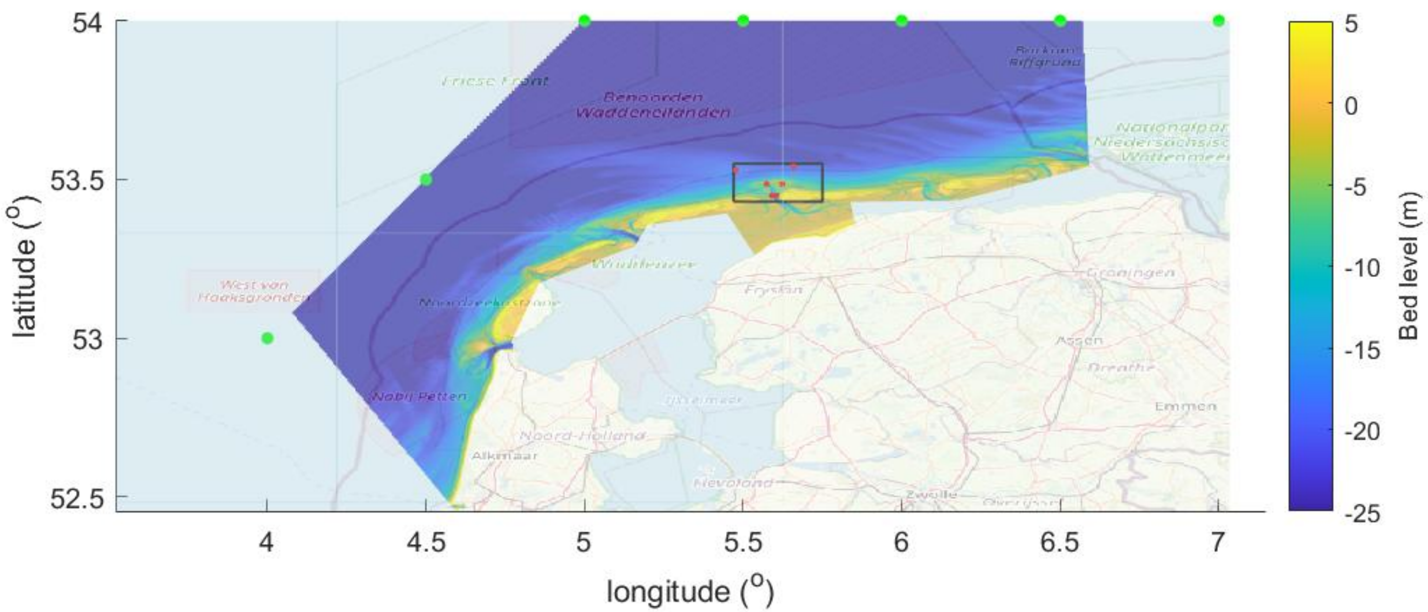
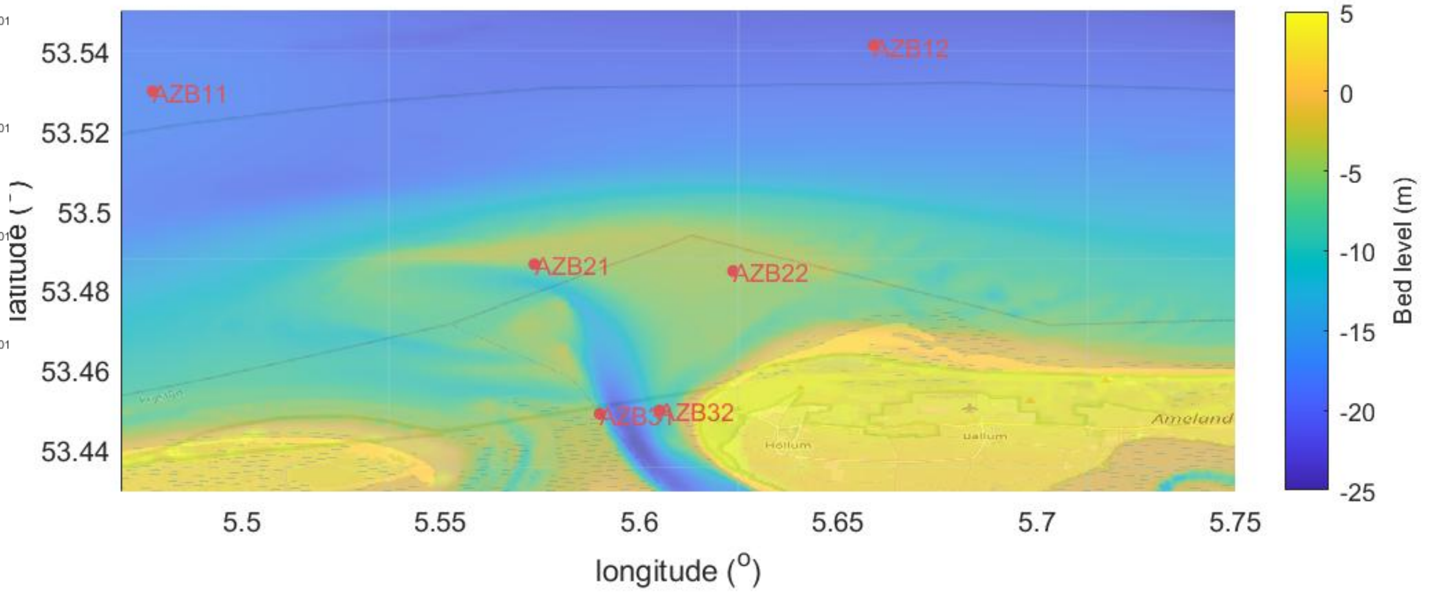
Ameland Inlet



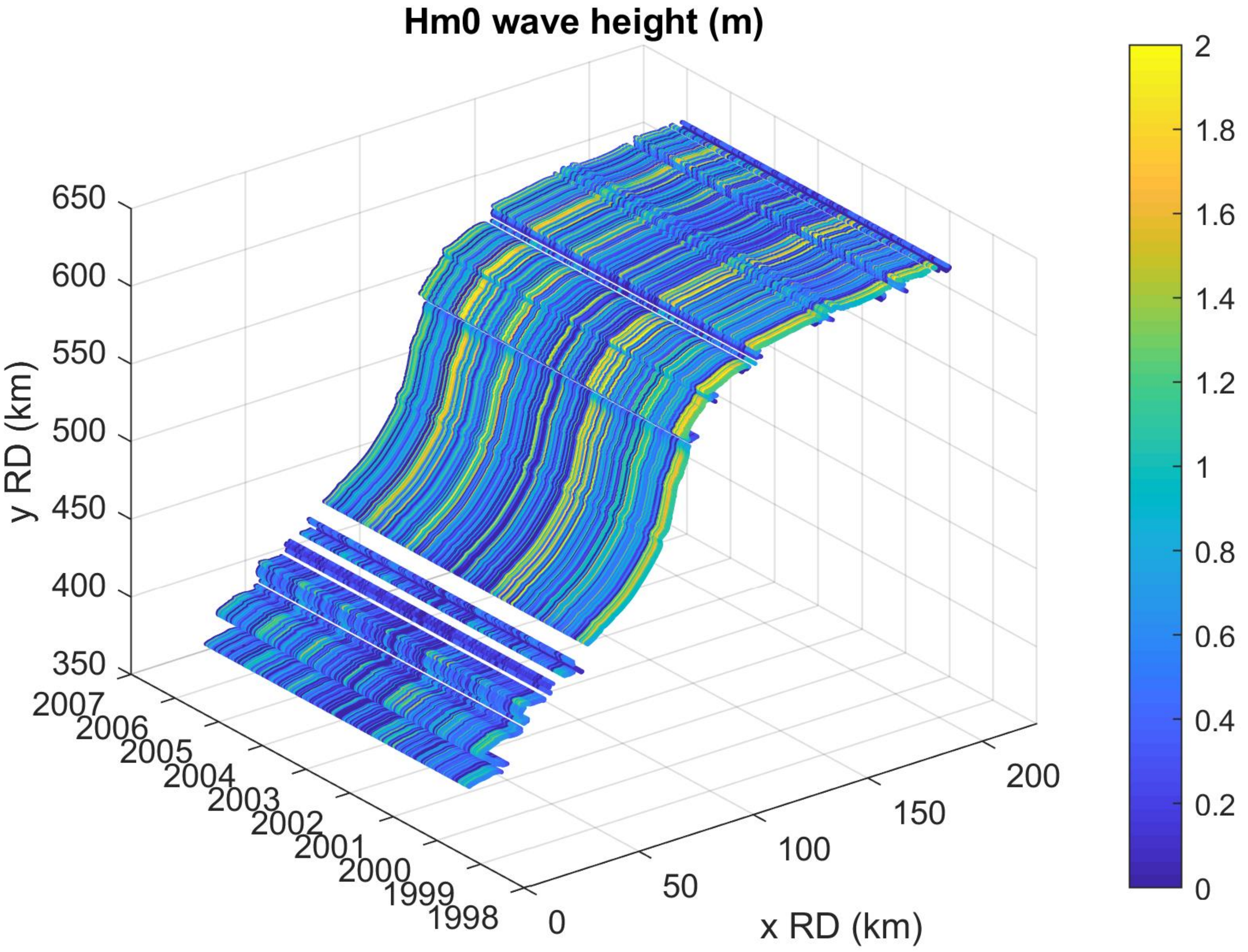




CPU time

Model	# nodes	# wave bins	Runtime per wave condition (s)
Coast3D large-scale	338292	18	1.9
Coast3D local	4964	18	0.016
Ameland large-scale	226258	36	2.4
St Croix	36236	36	0.82
Ningaloo large-scale	100146	36	1.1
Ningaloo local	46146	36	0.26

Sample application: producing boundary conditions for ShorelineS model



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Abstract | Assets | Discussion | Metrics

24 Mar 2025

SnapWave: fast, implicit wave transformation from offshore to nearshore

Dano Roelvink, Maarten van Ormondt, Johan Reyns, and Marlies van der Lugt

Abstract. This paper presents an efficient, implicit, unstructured-grid wave propagation model,

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Short summary
Existing wave models are often quite heavy for coastal applications. The SnapWave model...

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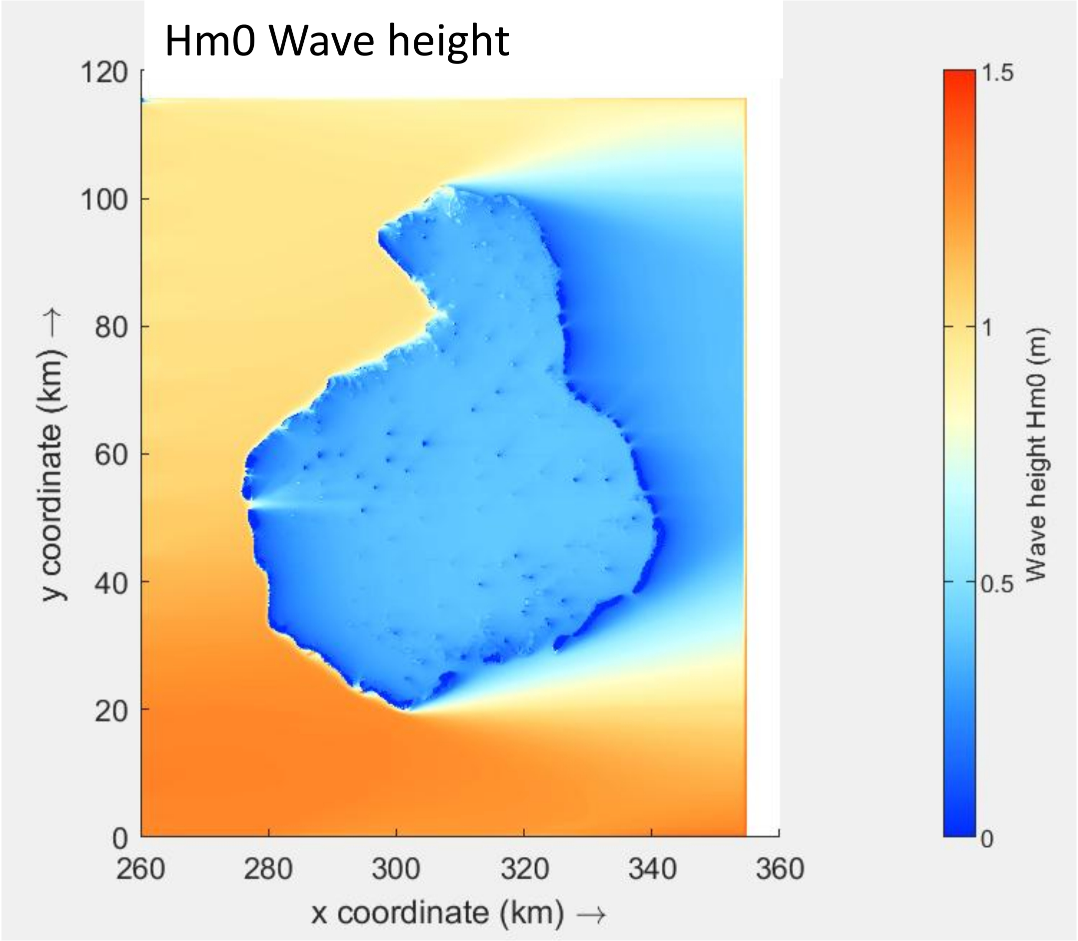
Main conclusions GMD paper

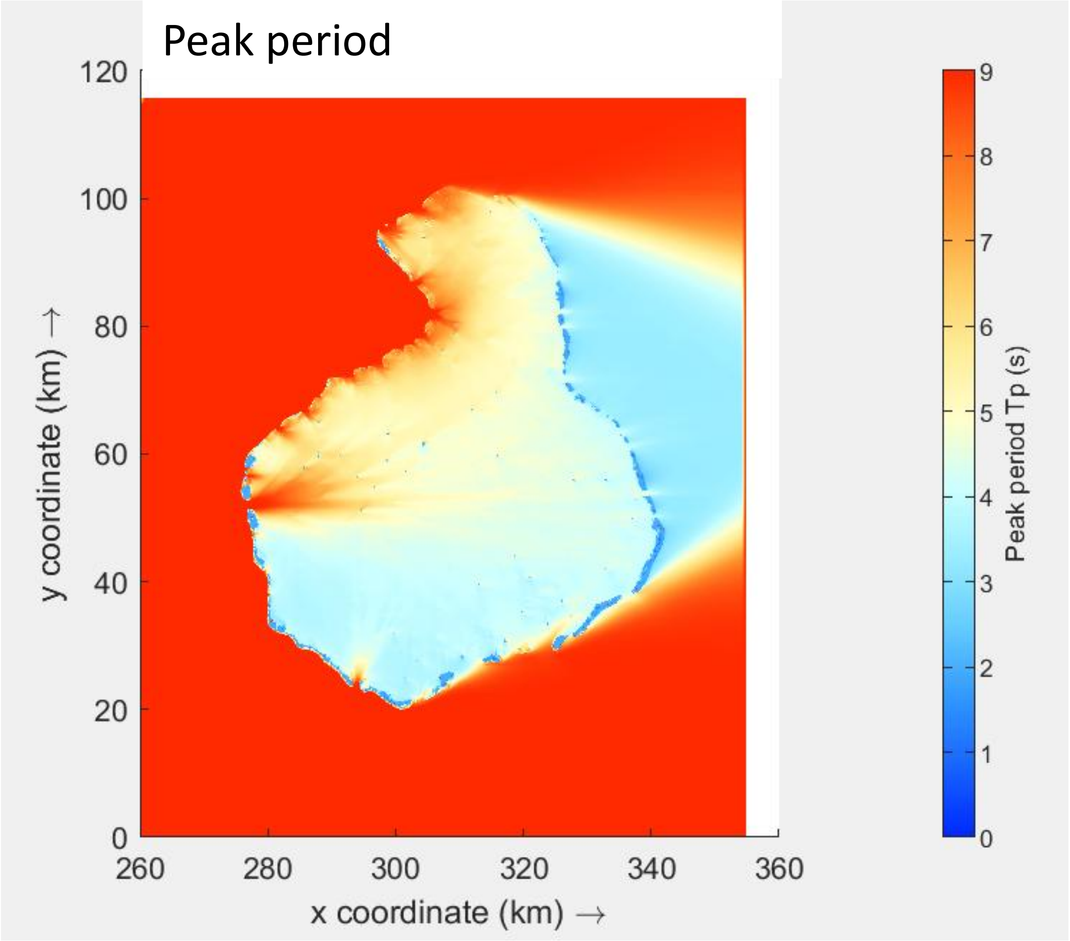
- SnapWave is efficient and effective in transforming ERA5 wave conditions to nearshore locations
- The model correctly simulates nearshore wave propagation and dissipation for directionally spread waves specified at points typically 50-100 km offshore
- The combination of ERA5 and SnapWave is able to reproduce time series of wave heights at nearshore locations with significant skill

New developments

- Wave growth included by solving energy and action balance simultaneously
- Source and sink terms rederived to match growth curves and regulate behaviour towards them
- Robust coupling with SFINCS (water levels) including prediction of IG waves; todo: current refraction
- Applications in North Carolina (Leijnse et al, 2025), Denmark, Maldives, Black Sea
- Wind growth publication in prep.

Maldives example for one atoll

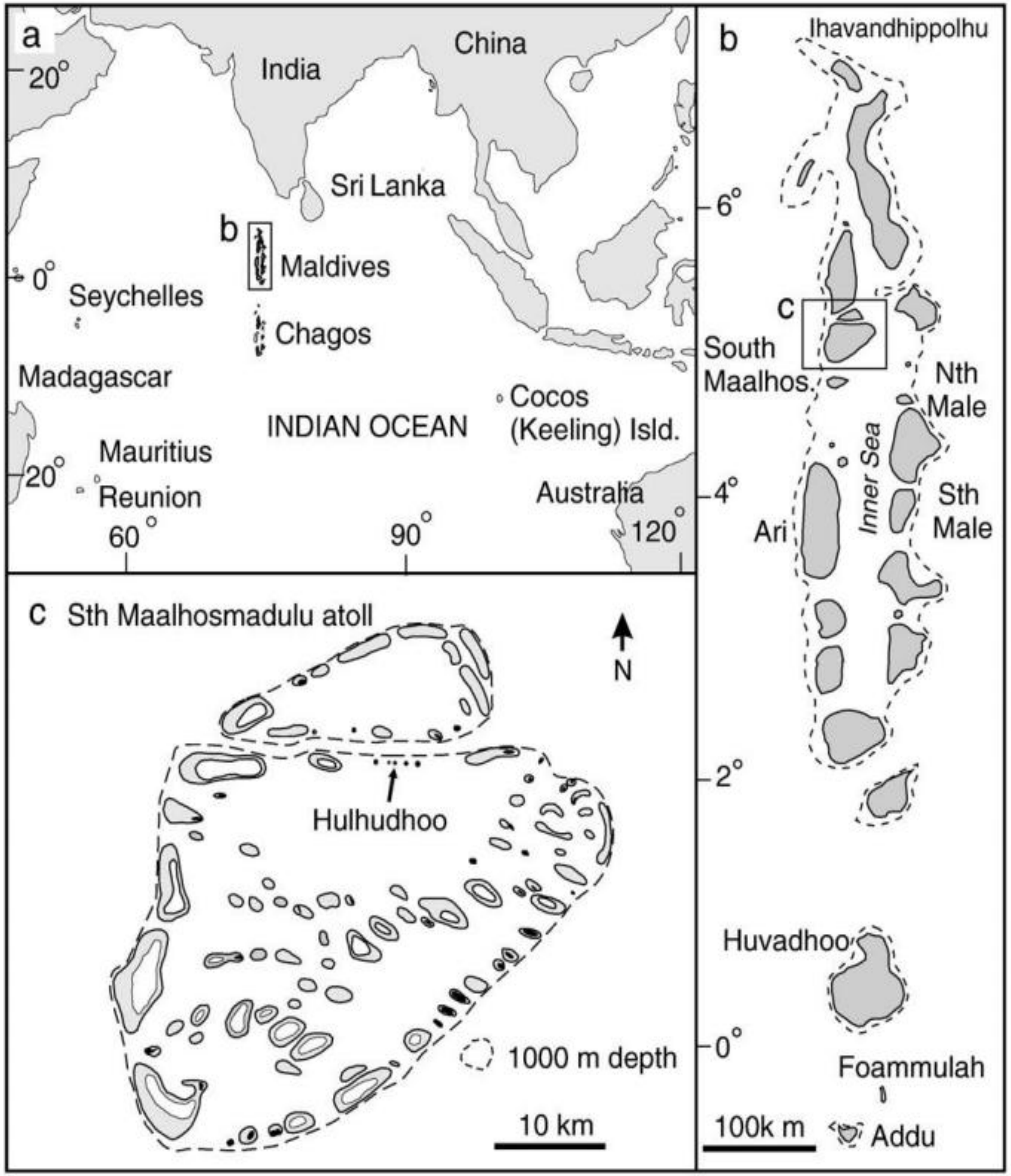




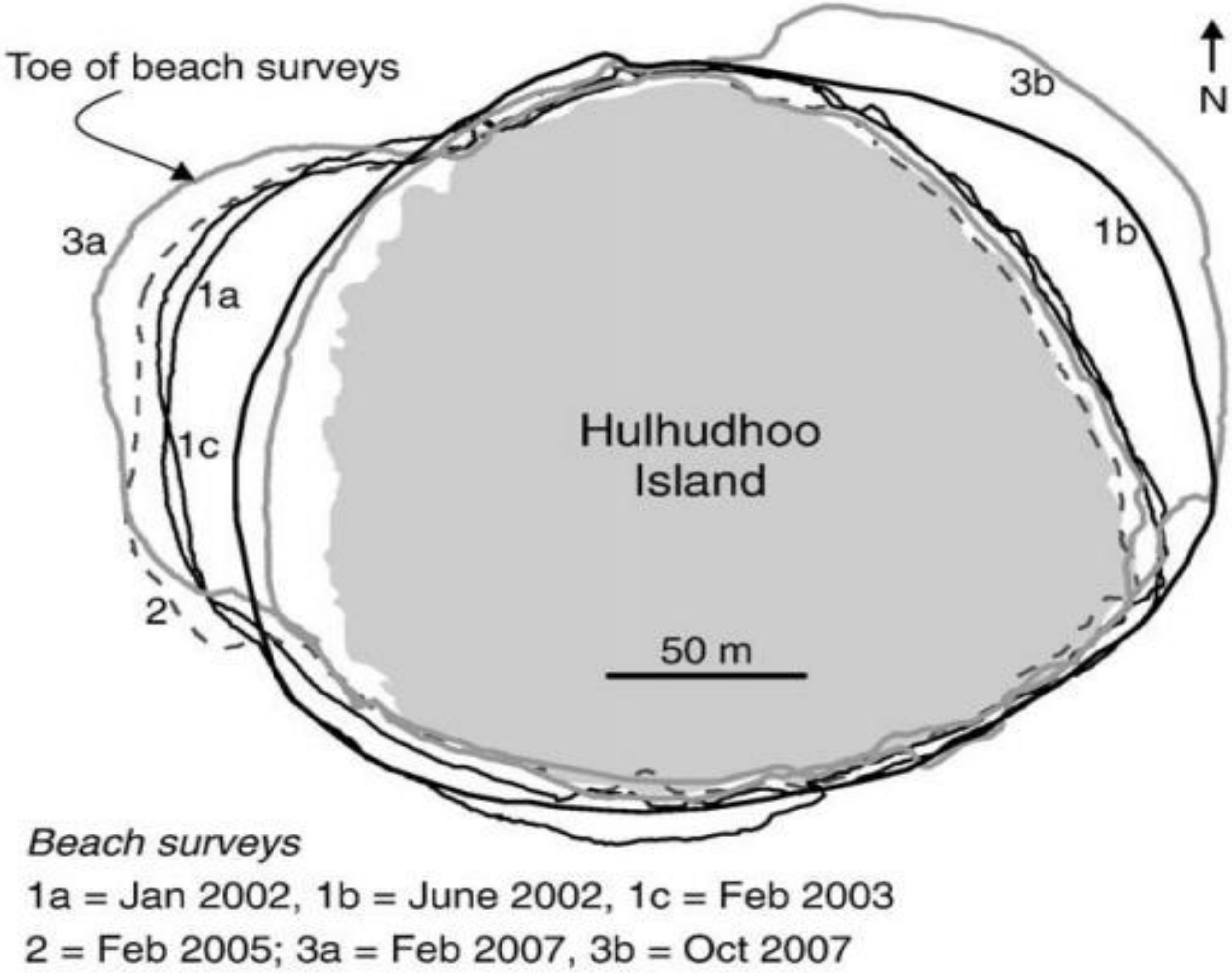

Thanks for your attention!

Coral island coastline change

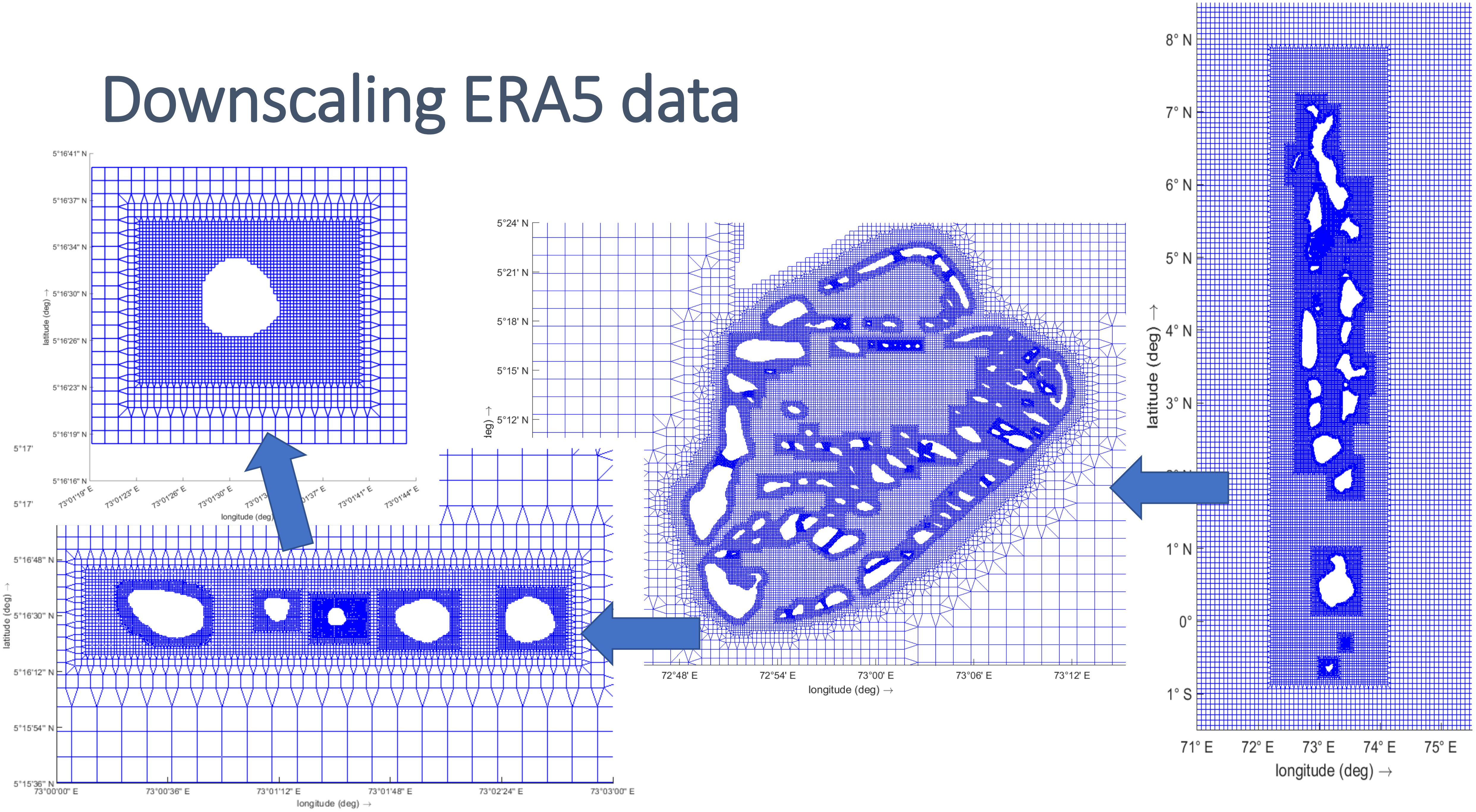
- MSc study Maumoon Saleem
- ~400m diameter island within ~50 km atoll in Maldives spanning thousands of km
- Big seasonal variation due to monsoon system

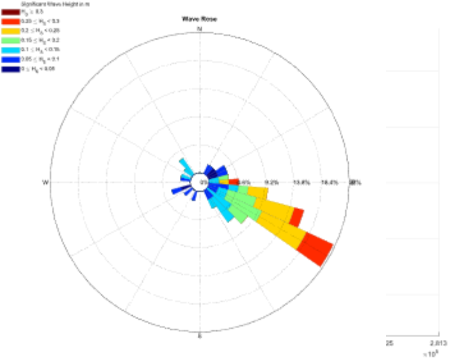


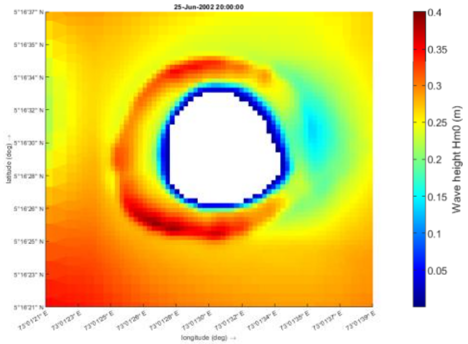
Data Paul Kench, NUS

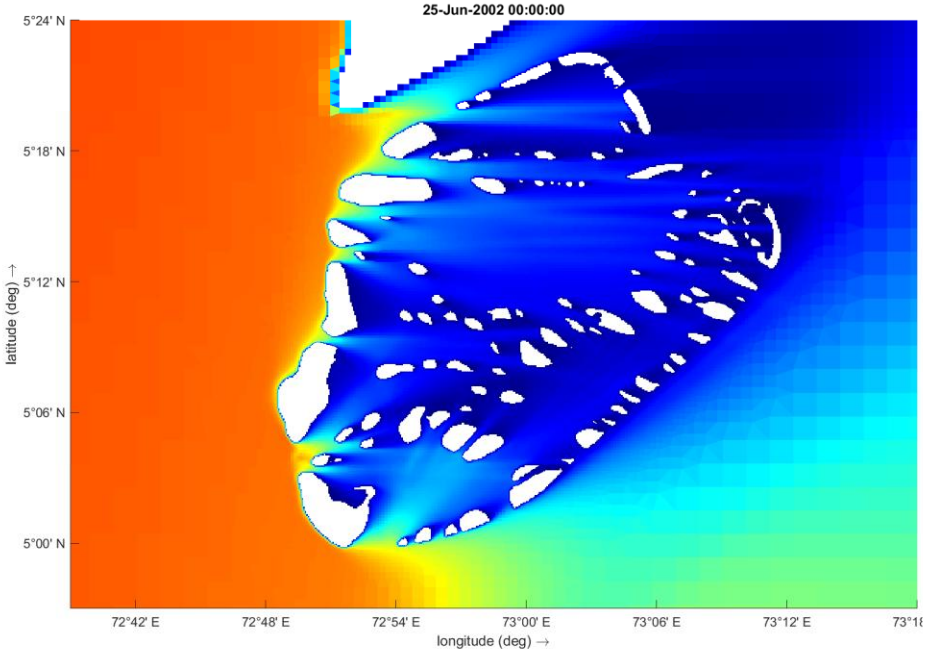


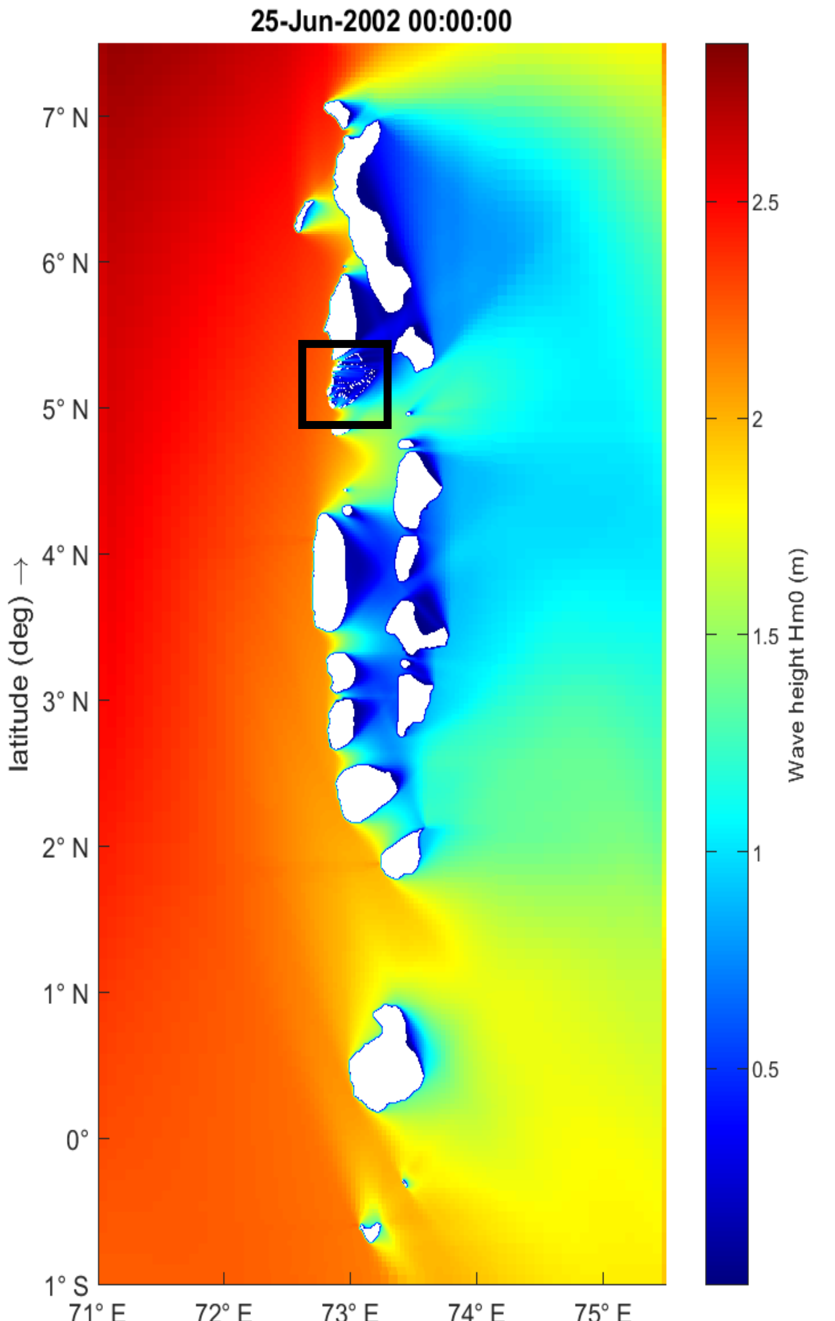
Downscaling ERA5 data











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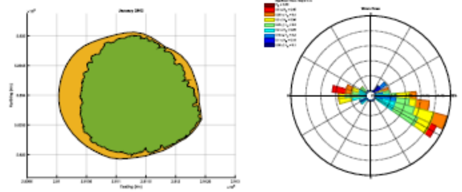
ShorelineS model simulation



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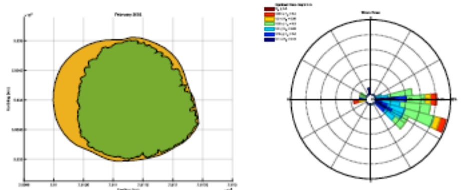

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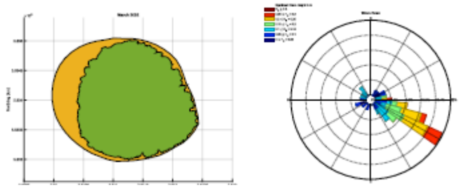

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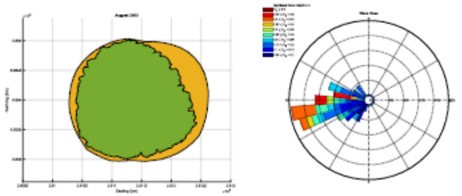

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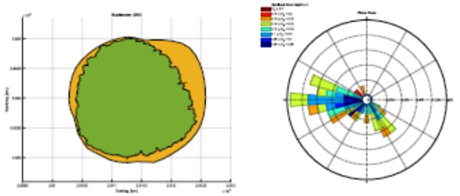

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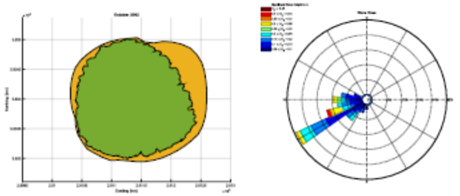

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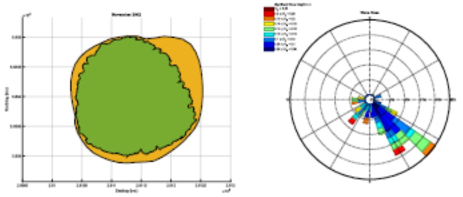

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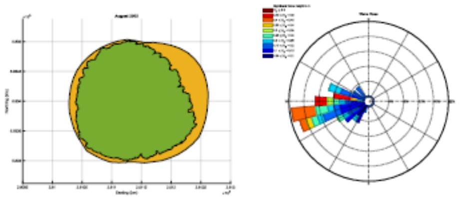

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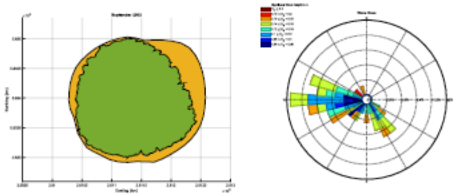

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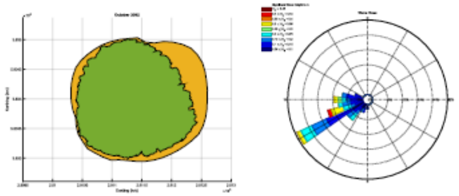

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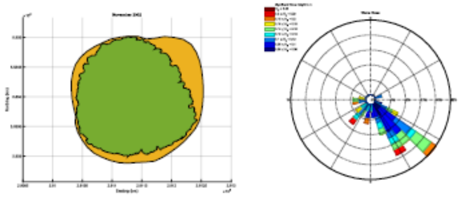

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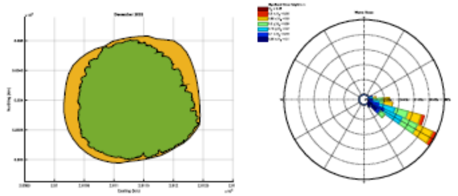

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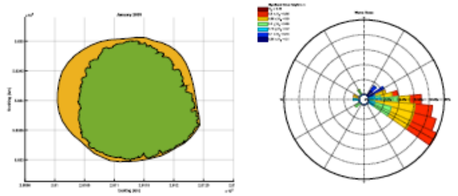

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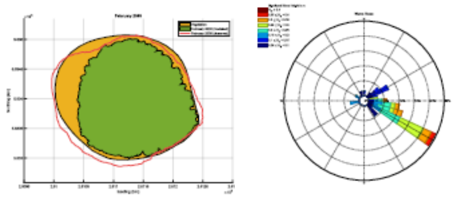

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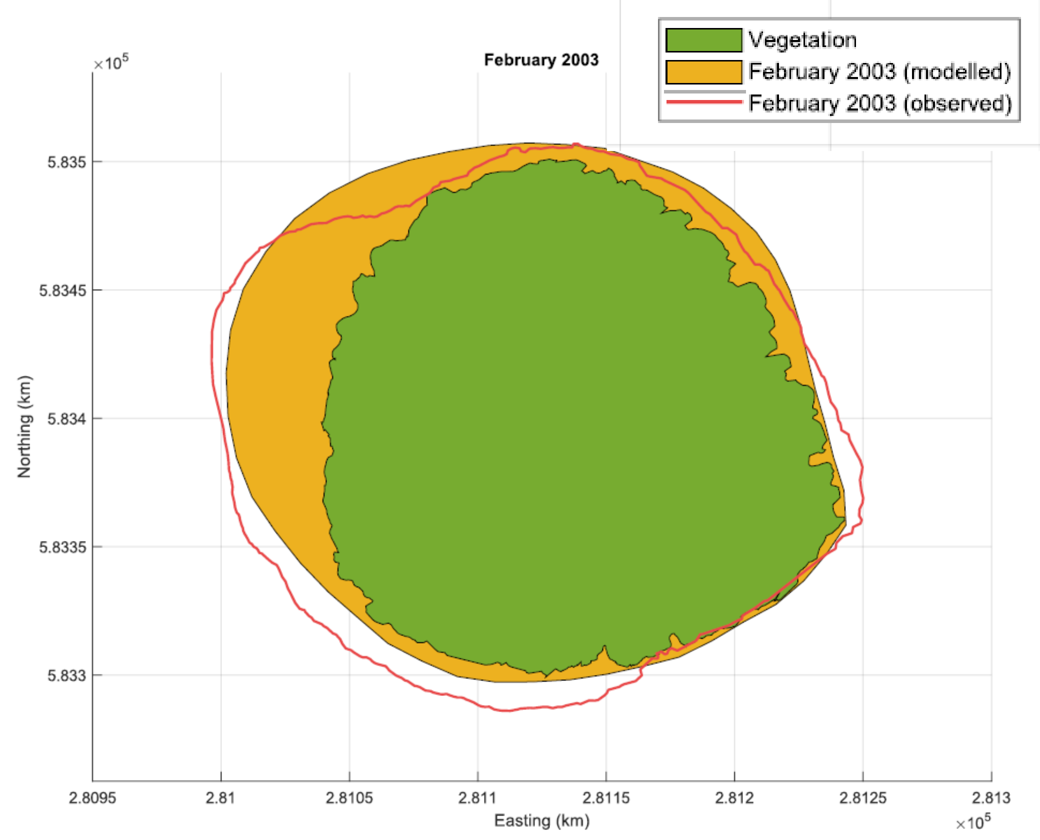

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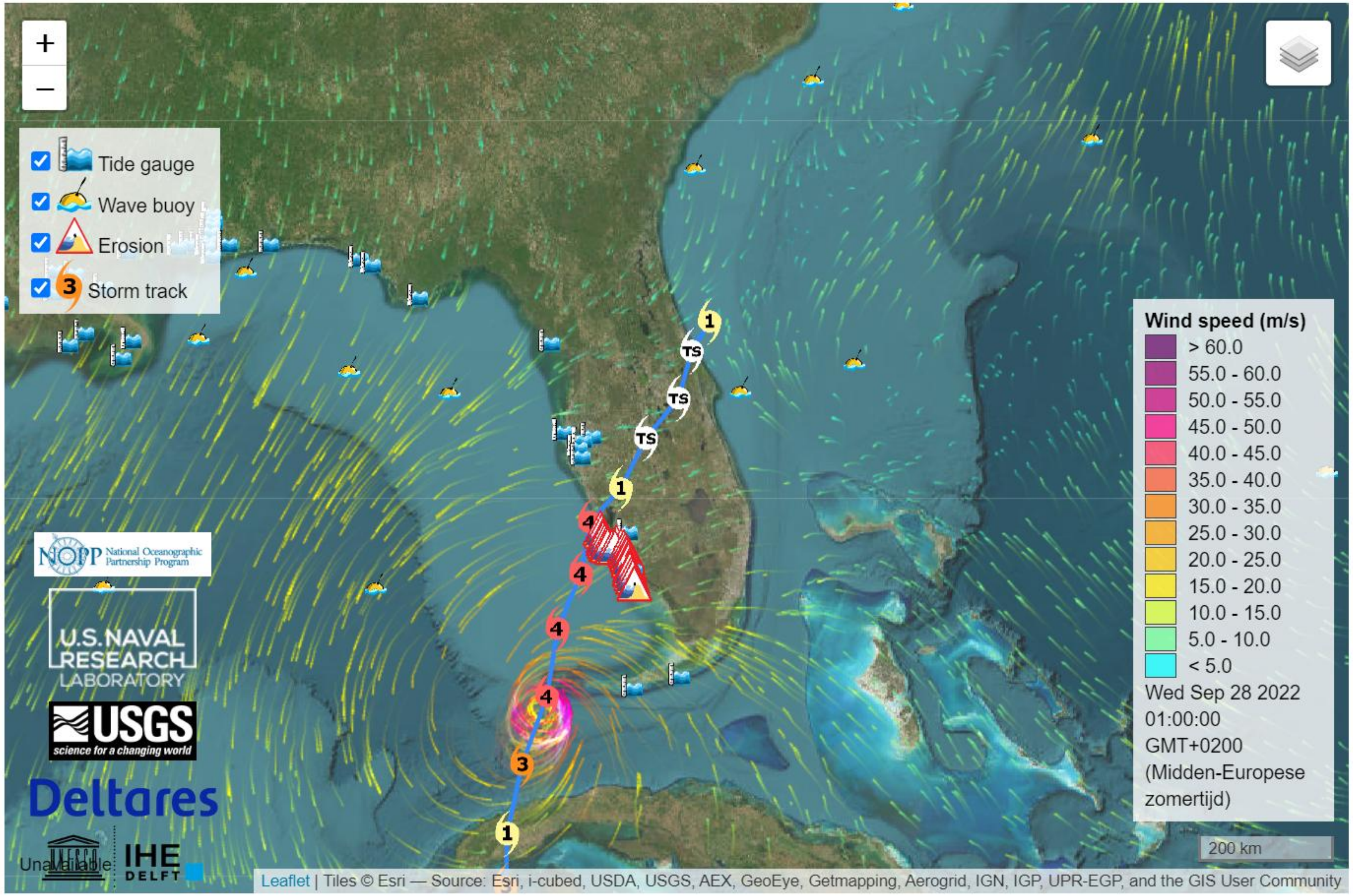
From *anywhere* to *everywhere*

- First step: include SnapWave and ShorelineS in FHICS, for 5,000 km of US coastline
  - Extract coastlines from Global Transect System, at 100 m longshore resolution
  - Digitize coastal structures and put in database
  - Automatically generate unstructured SnapWave grids to go from ERA5 to nearshore
  - Extract beach width, dune height from available DEMs
  - Extract surge and offshore wave height data from GTSM/ERA5 or SFINCS/HURRYWAVE
  - Test what stretches of coastline are feasible to include in one ShorelineS model – probably ~200 km
  - Validate!

FHICS – Forecasting Hurricane Impacts on Coasts

NOPP Event Viewer



Storm Scenario

Hurricane Ian (hindcast)

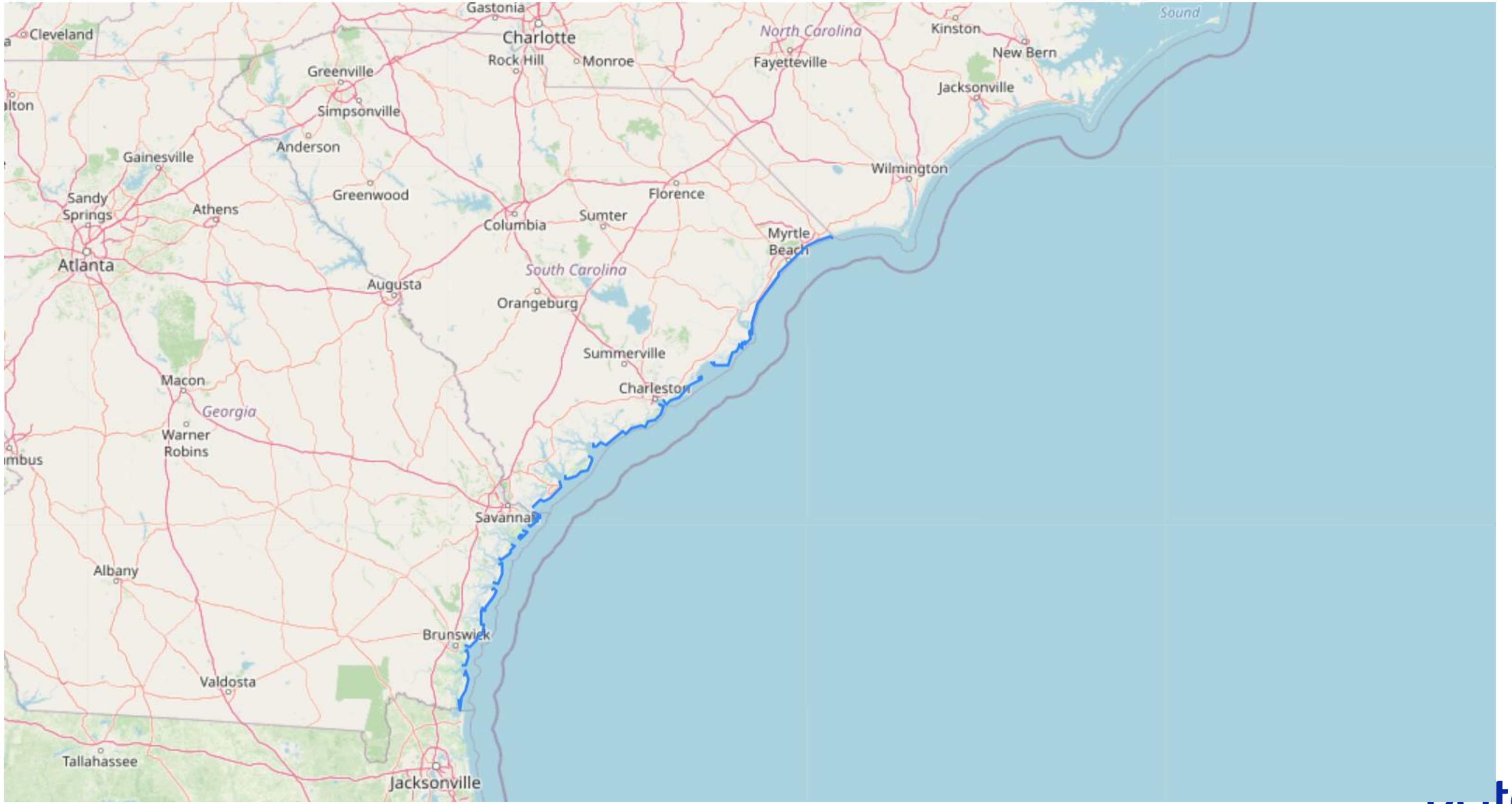
Hindcast of hurricane Ian (2022) using COAMPS-TC

Map layers

- Flood map
- Wave height
- Sedimentation/erosion
- Pre-storm bed level
- Post-storm bed level
- Wind
- Cumulative rainfall

Updated : 2022/10/21 07:36:16 (UTC)

Extracting shorelines at 100m resolution worldwide



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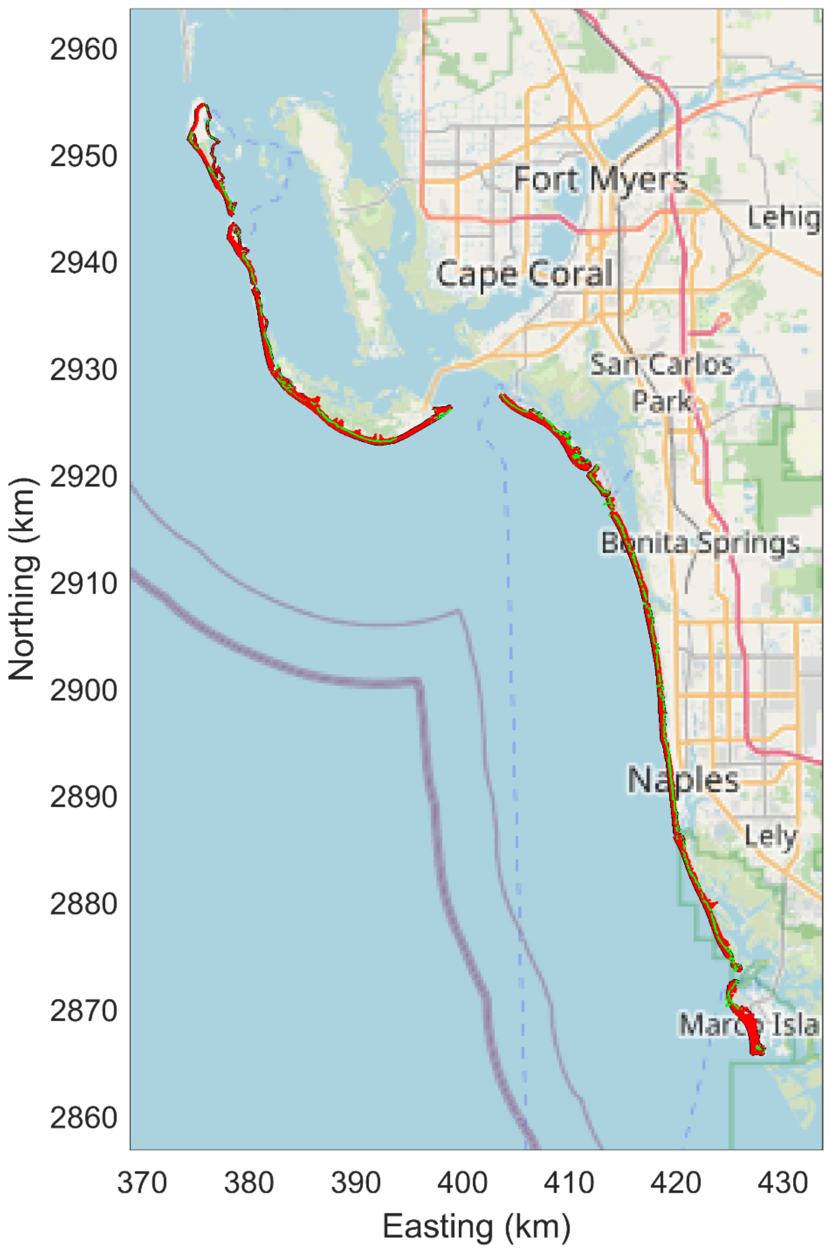
First results Hurricane Ian

- ~150 km of coastline affected
- 5 days hindcast, of which last two relevant
- 9/28 and 9/29/2022
- ShorelineS runtime ~5 min



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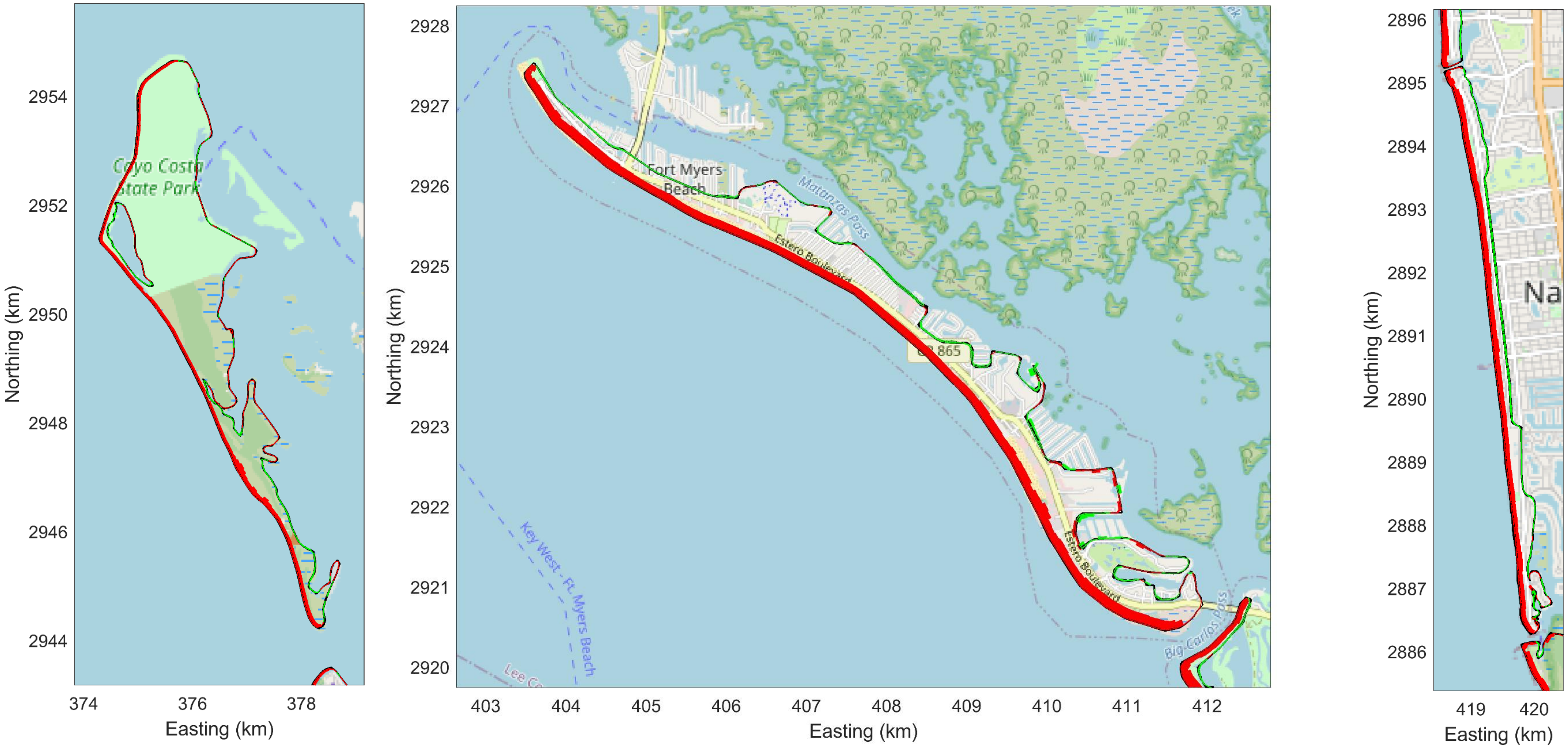

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Conclusions

- First application of ShorelineS for assessing dune erosion and overwashing
- 150 km shoreline assessed for hurricane Ian
- Runtime ~ 5 min for 2 days of actual storm
- Main parameters:
  - SWL+R, offshore wave cond.
  - Dune crest level
  - Coefficients Cs, A
- Effect of longshore transport gradients during storms included, important?

Validation and operationalization

- Check formulations for dune erosion and overwashing vs data and XBeach models of past hurricane impacts
- Develop better (quantitative) predictive capacity
- Develop base coastlines for Gulf and East coasts
- Dune and beach properties
- Develop SnapWave grids
- Integration in FHICS workflows
- Integrate in probabilistic framework

Conclusions so far..

- Promising results for hurricane Ian in SW Florida
- Computation times not prohibitive for 5-day forecast
- Two modes:
  - Short-term hurricane impact forecast based on meteo models
  - Longer-term forecasts based on climatology

Steps towards global application

- Develop robust workflows to extract data on coastlines, structures, bathymetry, waves for bigger regions -> continents
- Invite collaborations, organize hackathons /mapathons to create the databases and models
- Set up a network of institutes responsible for particular regions
- Look for funding possibilities – WMO, EU, World Bank, …