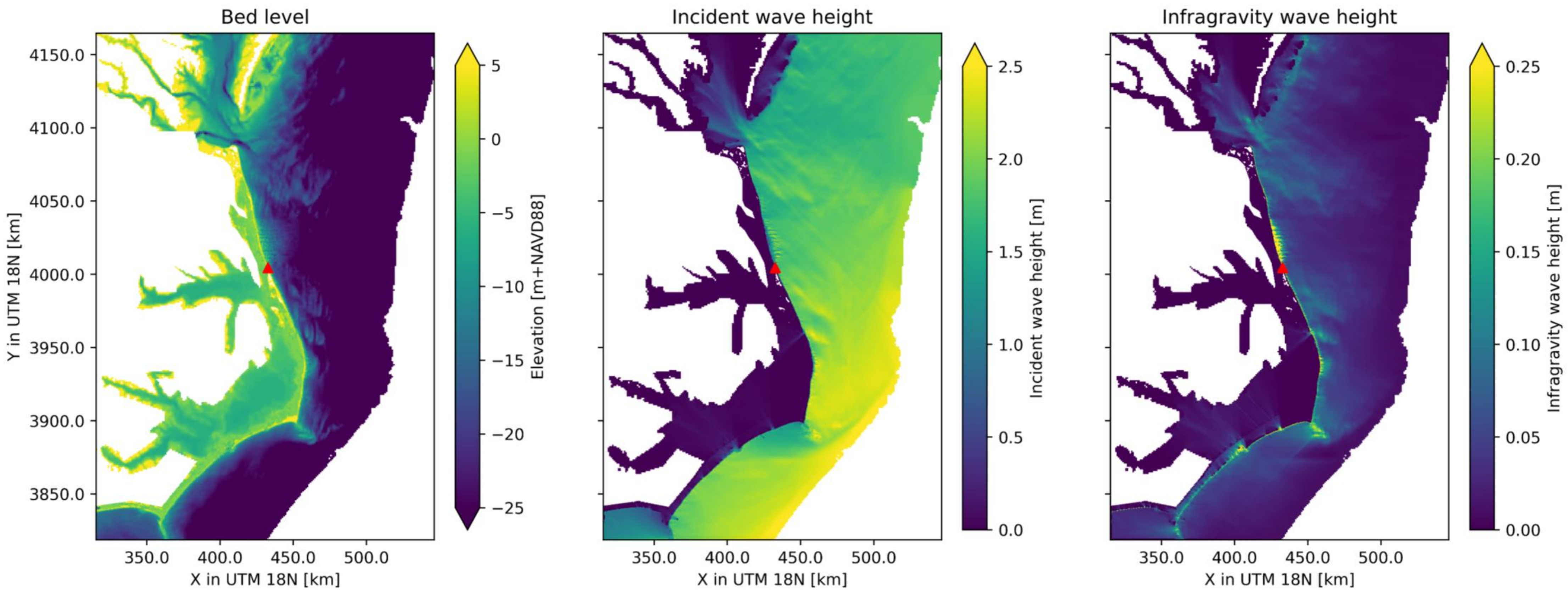
# Deriving a parametrization for estimating nearshore infragravity wave energy for scaling up wave-resolving flood hazard modelling




by Tim Leijnse – PhD Candidate at Vrije Universiteit Amsterdam (IVM) – Product manager SFINCS at Deltares

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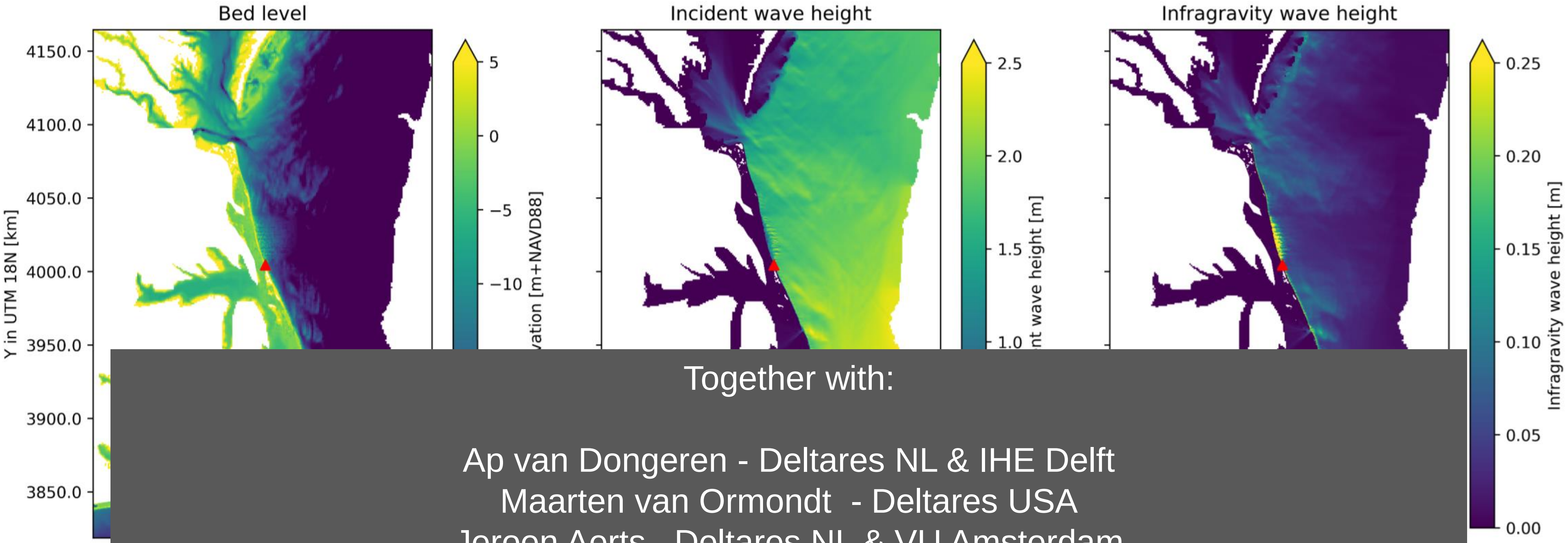


Together with:

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Maarten van Ormondt - Deltares USA
Jeroen Aerts– Deltares NL & VU Amsterdam
Sanne Muis – Deltares NL & VU Amsterdam

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# Problem

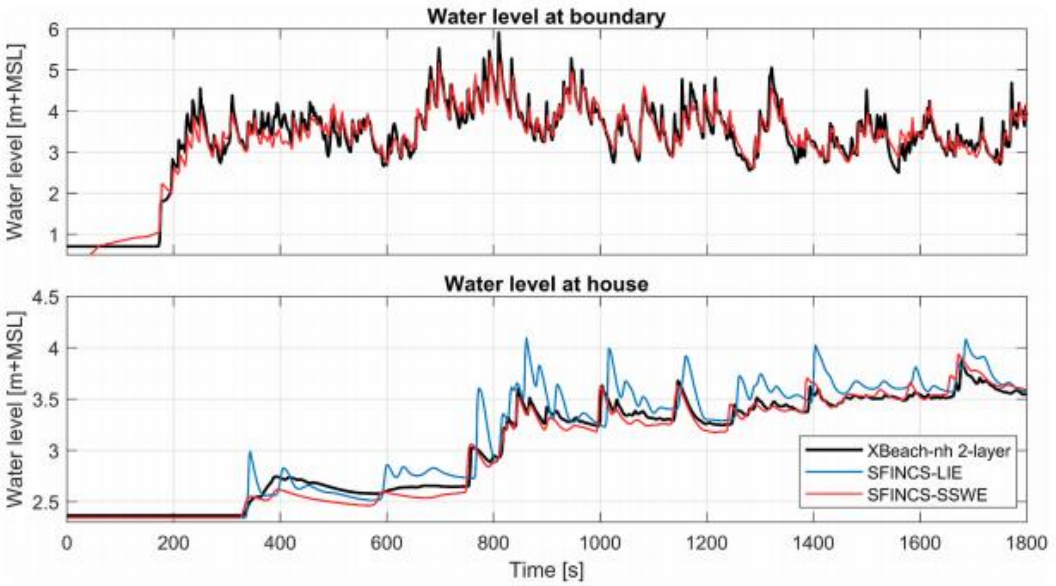
**Problem:** Coastal communities vulnerable to coastal hazards during e.g. hurricanes or king tides, increasingly so with climate change. Dynamic waves can be important too, but its effect on flooding often not (fully) considered

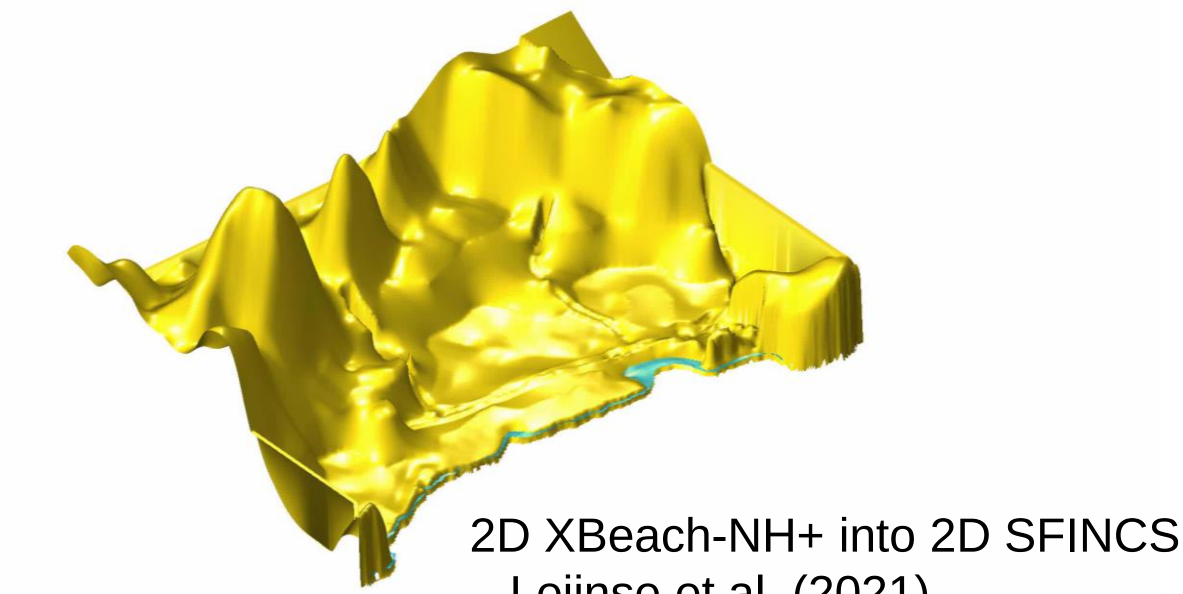
**Challenge:** Including wave-driven flooding in (probabilistic) early warning systems and/or large-scale risk assessments due to very high computational runtimes of numerical models

About Nature

e.g. recent wave-driven flooding in South Africa

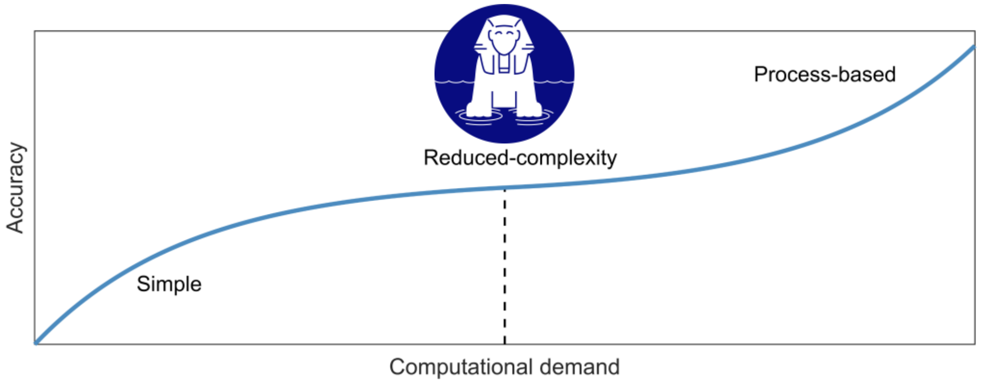
# Why? We can model this…



2D XBeach-NH+ into 2D SFINCS
– Leijnse et al. (2021)

# But too computationally expensive wave models

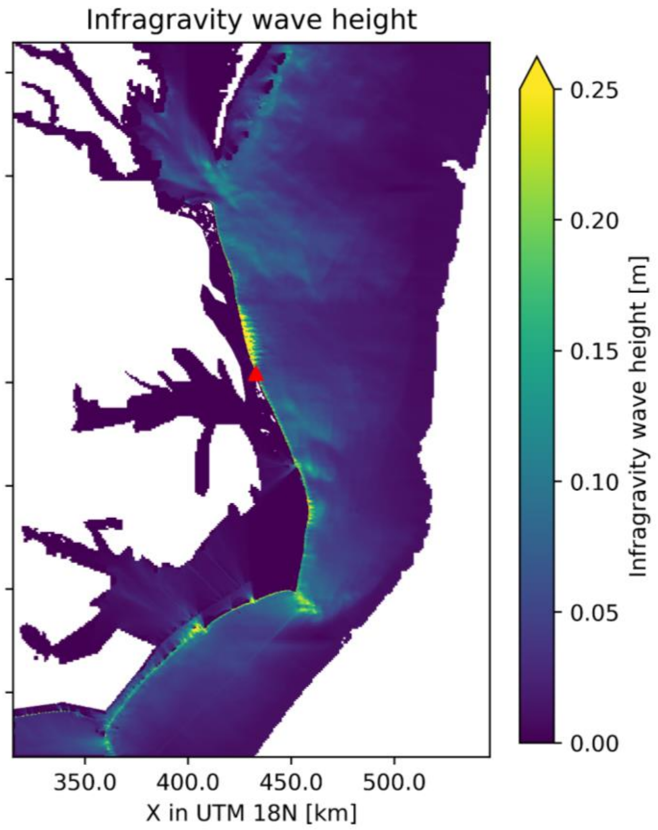



And fast compound flood models like SFINCS still need realistic nearshore IG boundary conditions

These are expensive to generate,
if done using those same advanced models …

# Future goal: fast large scale dynamic wave-resolving compound flood modelling

- Imagine we could give a good estimate of nearshore infragravity wave conditions for 500 km of coastline…
- And that we could calculate that in a matter of seconds…
- Then we could starting taking those IG wave conditions, and force dynamic waves nearshore
- And thereby resolve IG wave runup & overtopping for large scales
- But first we need those nearshore IG wave conditions…

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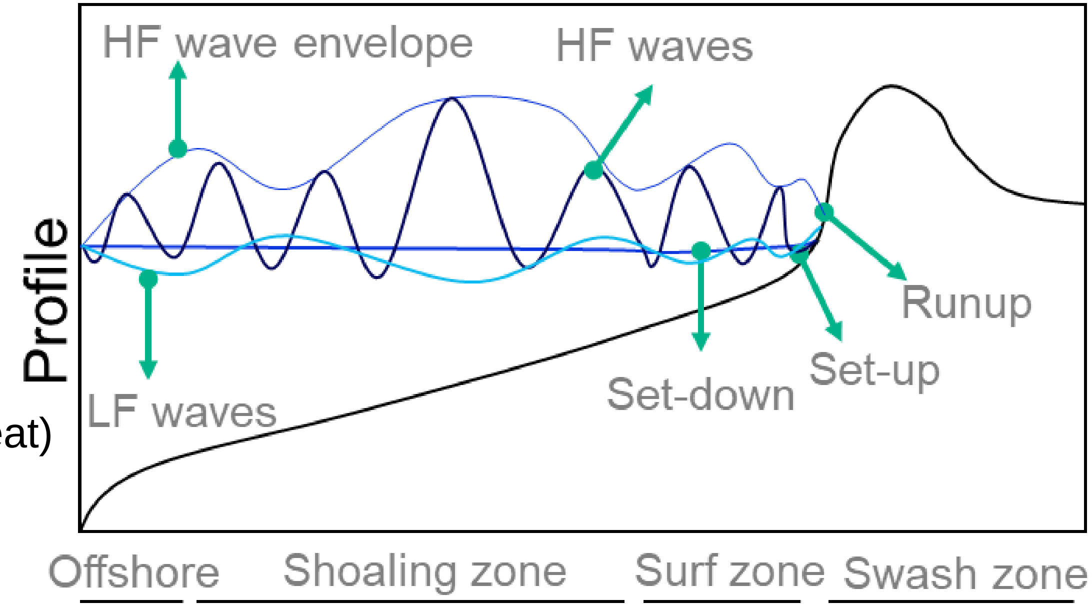
# Objective & challenges

- **Objective:** Efficiently derive nearshore infragravity wave boundary conditions for large scales

- **Challenges**:
  1. Resolve **infragravity** wave heights
  2. Applicable to arbitrary **unseen coastal profiles**
  3. Resolve **alongshore variations**
  4. Resolve wave energy **multi-directional**
  5. Solve **large scales** → be **fast**

  (so order of magnitude faster still than e.g. SWAN 1D Surfbeat)

→ This method is developed in this study




- **How?**

→ Relate infragravity wave growth to incident wave shoaling in a parametrized way

→ Start with sandy coasts under bound wave shoaling

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# Parametrizing infragravity wave growth (1)

- Starting point is standard IG energy balance:

$$\frac{\partial C_g E_{ig}}{\partial x} + U\frac{\partial S_{xx}}{\partial x} = 0 \qquad U = \eta\frac{C_g}{h}$$

- Velocity amplitude ‘U’ → Unwanted dependence on the IG surface elevation wave amplitude $\eta$.
- Estimated as: $\eta = \alpha_{ig}\sqrt{E_{ig}}$
- With shoaling parameter $\alpha_{ig} \sim f(\beta_n)$ as function of normalised local bed slope
- Gives:

$$\frac{\partial C_g E_{ig}}{\partial x} = \alpha_{ig}\sqrt{E_{ig}}\,\frac{C_g}{h}\,\frac{\partial(2n-1/2)E_{inc}}{\partial x}$$

Assumptions:

- From deep water up to the incident wave breaking point, where there is no IG wave breaking or friction dissipation yet
- Only take positive increases of $\frac{\partial S_{xx}}{\partial x}$ for IG shoaling, else only conservative shoaling
- Offshore IG wave height estimated using method of Herbers et al. (1994), as in XBeach

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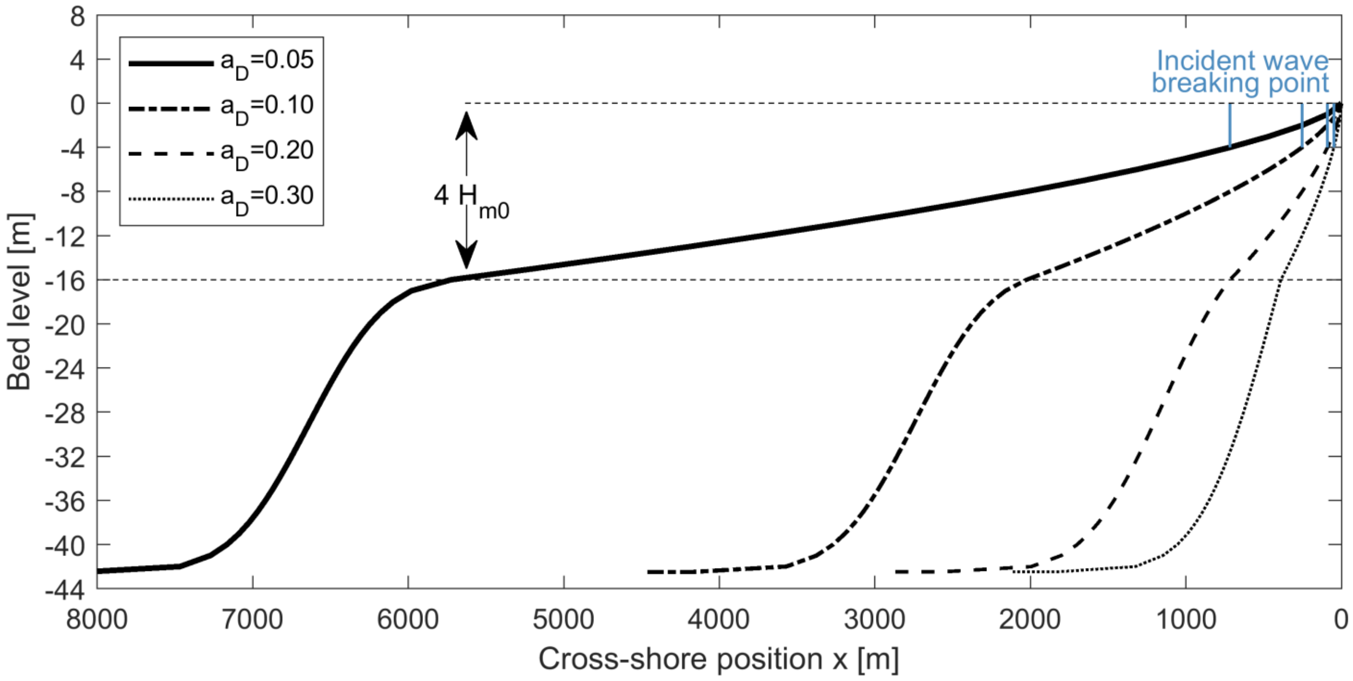
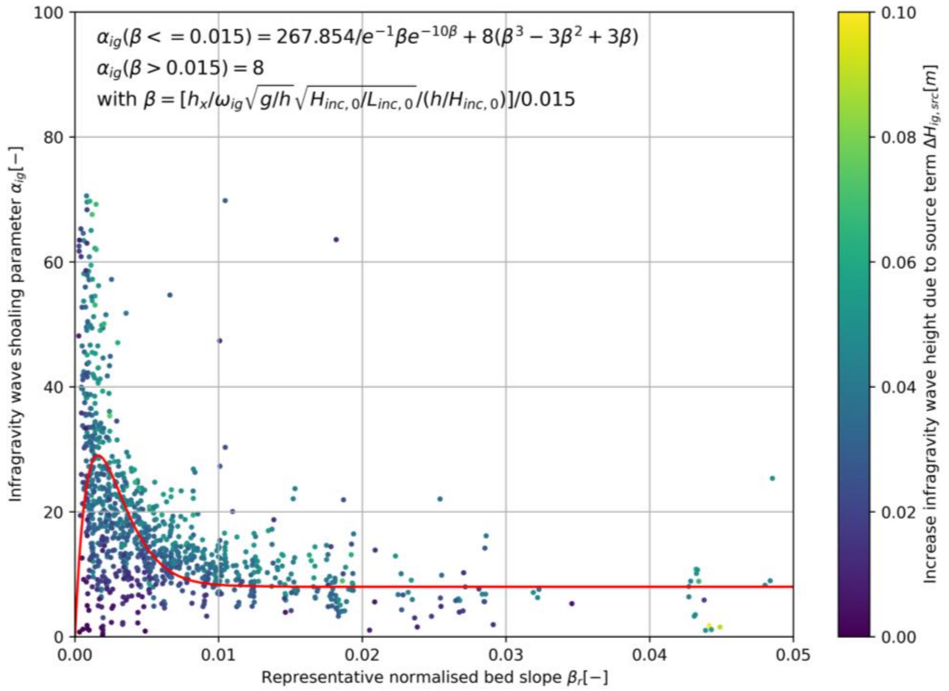
# Parametrizing infragravity wave growth (2)

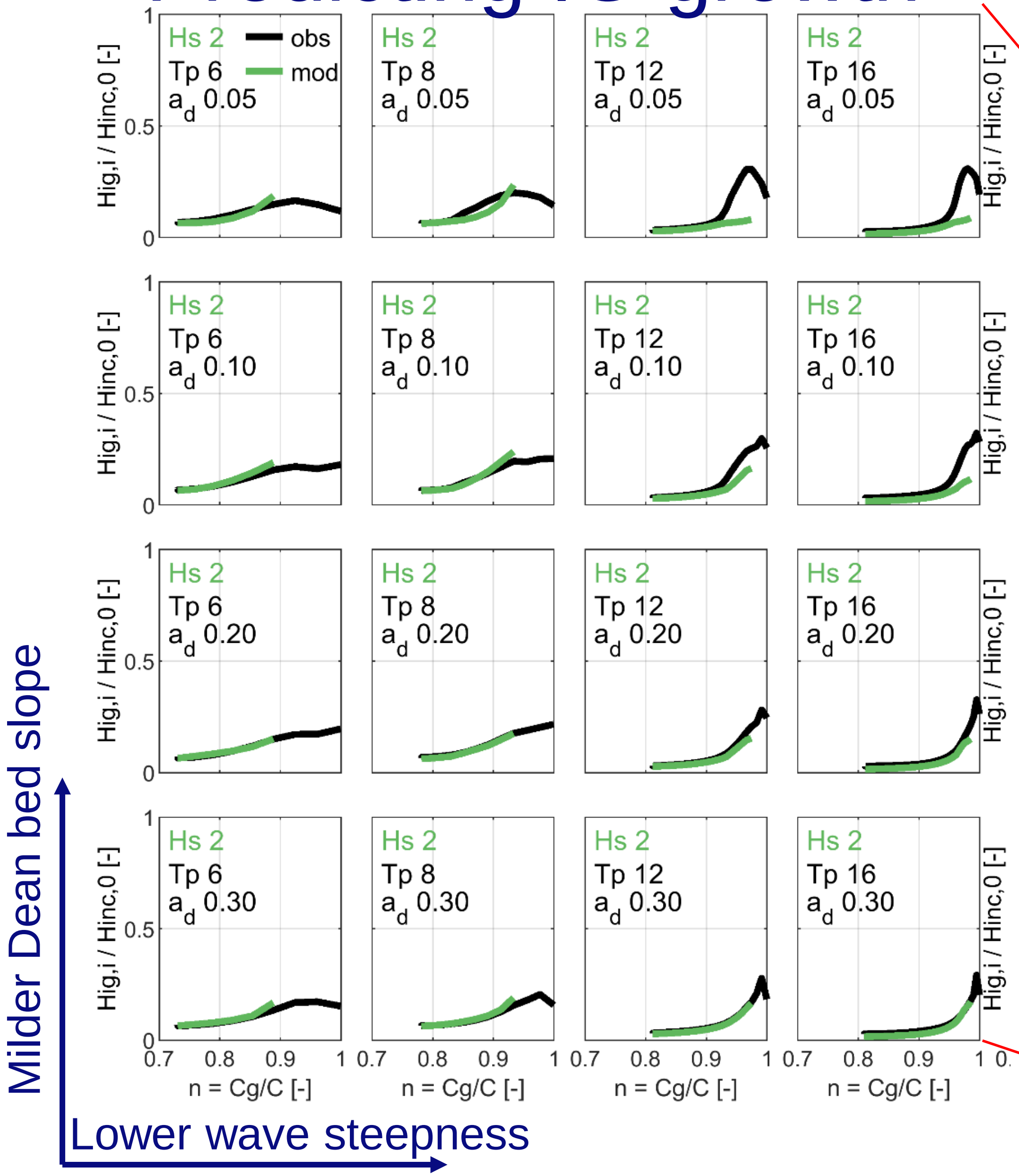
- How to find a relation for shoaling parameter $\alpha_{ig} \sim f(\beta_n)$ as function of the local bed slope?
- Base on dataset of XBeach runs from Van Ormondt et al. (2021) (range of changed Hs, Tp, Dean & beach slope)
- For known results, per grid cell the value of $\alpha_{ig}$ can be calculated > 4441 training data points

- Define representative local, normalised bed slope: $\beta_r = \frac{h_x}{\omega_{ig}} \sqrt{\frac{g}{h}} \sqrt{\frac{H_{inc,0}}{L_{inc,0}}} \frac{H_{inc,0}}{h}$
- Make fit with negative exponential + 3rd order polynome



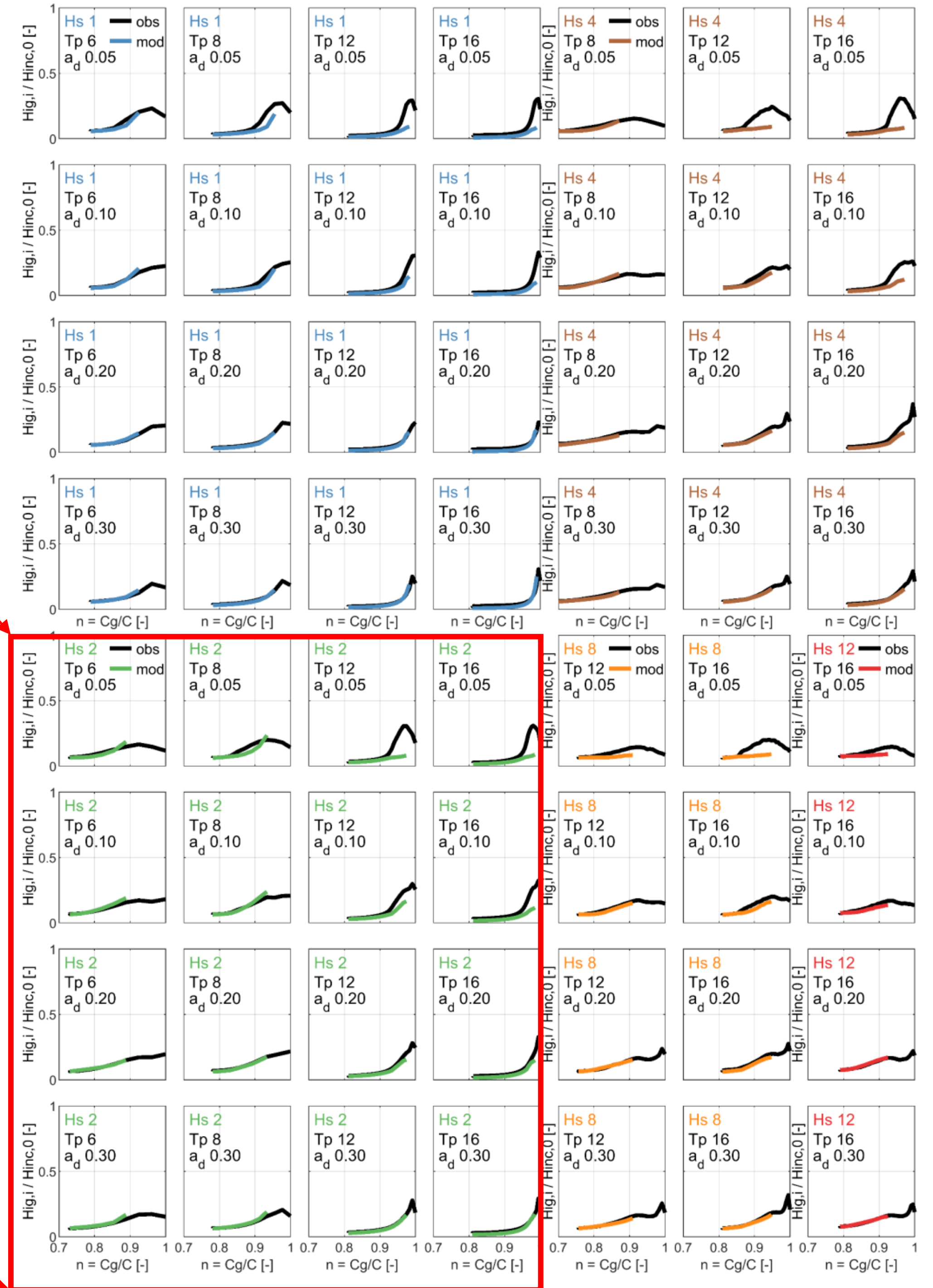



# Predicting IG growth



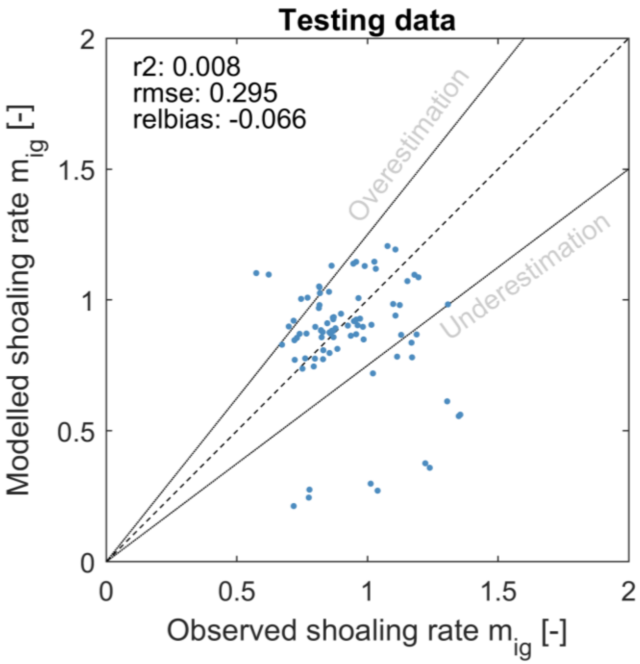

Black is XBeach

Colored is model

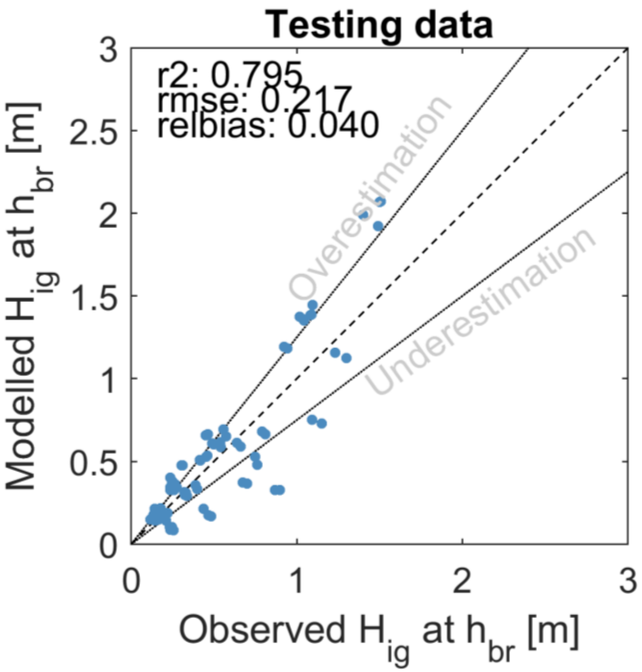


# Validation

- Calculate the shoaling rate as in Van Dongeren et al. (2007), over whole profile, compare for unseen testing profiles:




- Calculate the IG wave height at incident wave breaking point, compare for unseen testing profiles:

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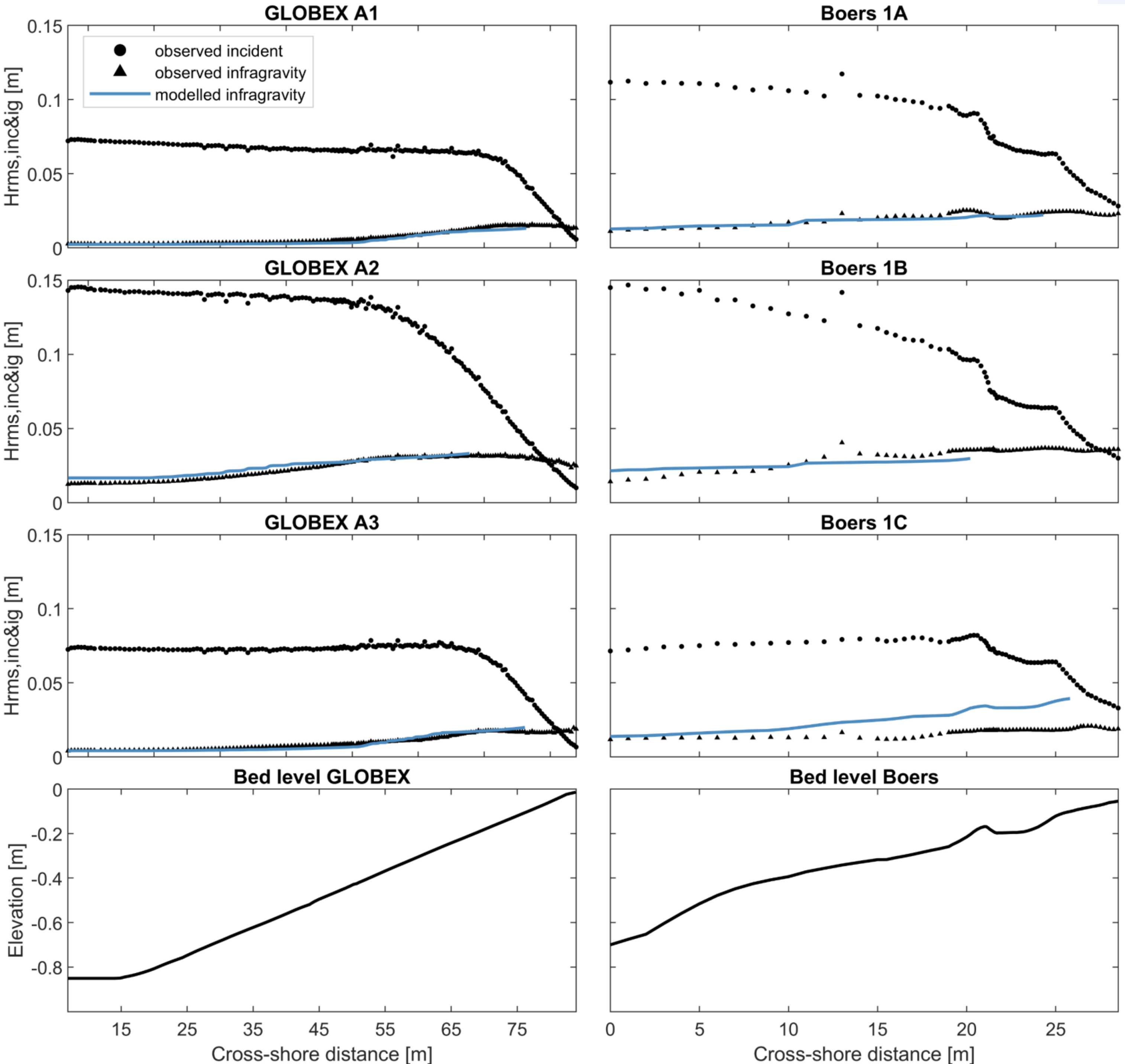
# Verification lab tests

- Compare to observed data for GLOBEX experiments (Ruessink et al. 2013)

- Compare to observed data for Boers experiments (Boers 1996)

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# Verification field case

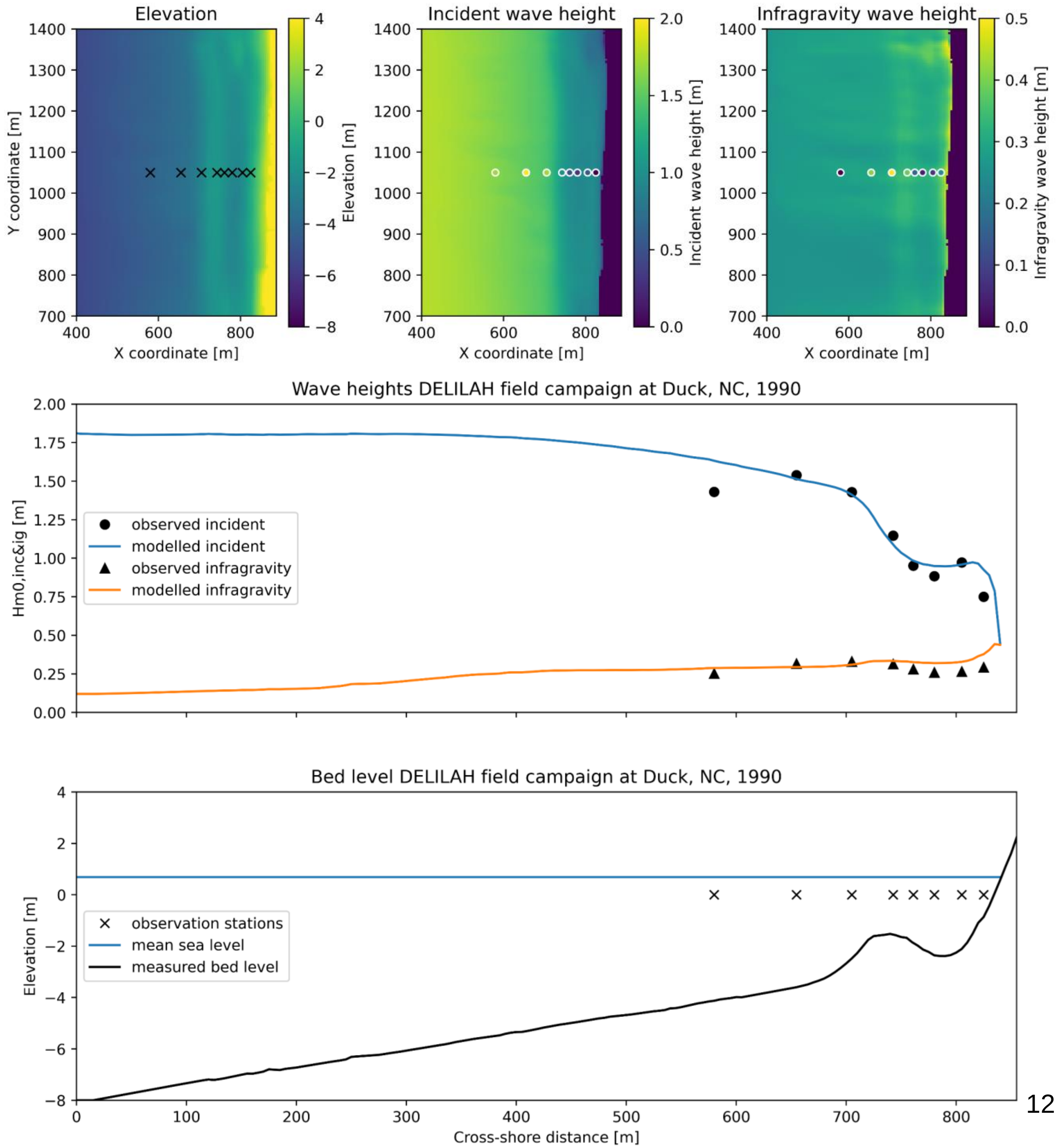
- Duck, NC, DELILAH field data
- Implementation in fast stationary wave energy balance model Snapwave (Dano Roelvink et al.)
- Besides short wave energy, solves same equation for long waves, plus new extra source term
- Solved in 2D, and multi-directional (but 1 frequency bin)

Short waves:

$$\frac{\partial E_{inc}}{\partial t} + \frac{\partial C_g E_{inc}}{\partial s} + \frac{\partial C_\theta E_{inc}}{\partial \theta} + Dw = 0$$

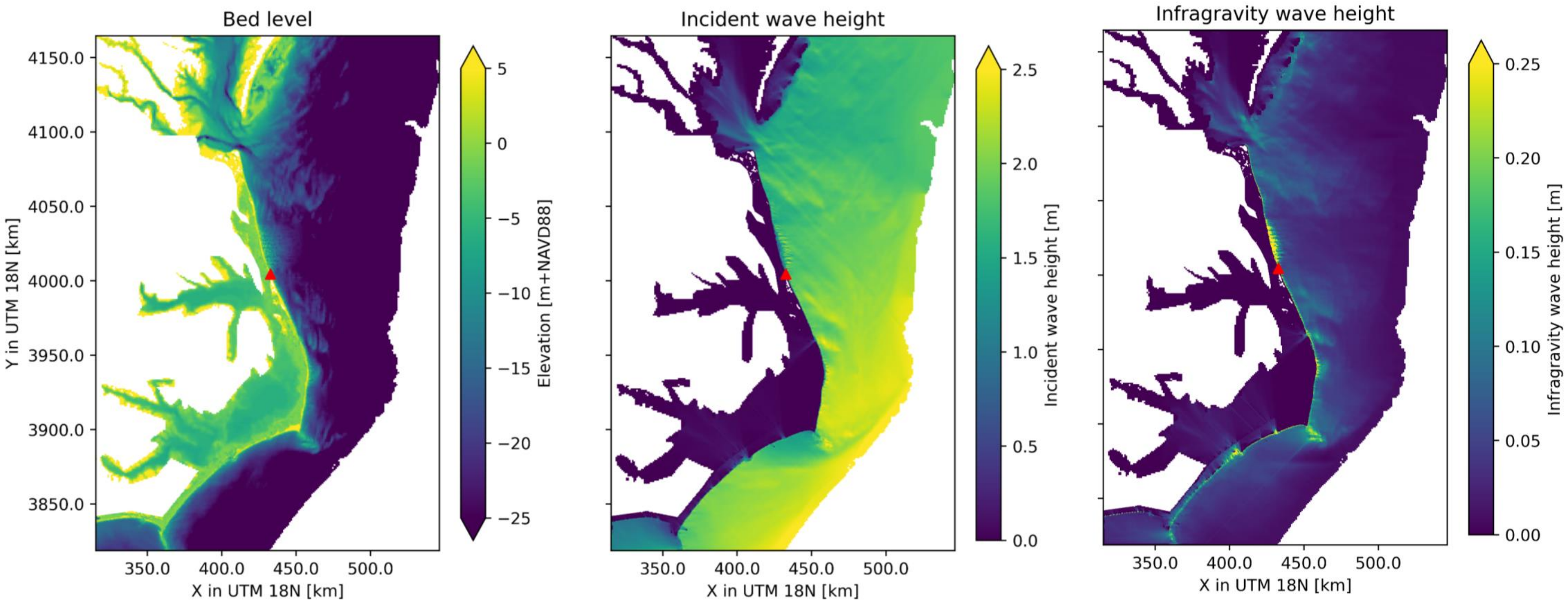
Long waves:

$$\frac{\partial E_{ig}}{\partial t} + \frac{\partial C_g E_{ig}}{\partial s} + \frac{\partial C_\theta E_{ig}}{\partial \theta} + Dw + \alpha_{ig}\sqrt{E_{ig}}\frac{C_g}{h}\frac{\partial S_{ss}}{\partial s} = 0$$



# Upscaling→ demonstration case for Outer Banks, NC

- Large scale model Outer Banks, NC > ~500 km of coastline. Started in 200m water depth at the shelf.
- Variable grid resolution from 1000m offshore up to 20m in surfzone; ~4 million active cells
- 1 timestep of Snapwave (inc+ig) takes **only 10 seconds**!

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# Summary

- Derivation of an **efficient method to estimate IG wave growth** for sandy coasts under bound wave shoaling
- **Very fast, large-scale realistic** estimates possible in **seconds** compared to advanced wave models
- Varying coastlines and wave directions possible
- Not an estimate at 1 point, but describing **development** IG wave heights from offshore to nearshore
- Build into fast stationary wave energy model **Snapwave**, coupled into open source **SFINCS** model

Limitations:

- Derived for (generally) **mild sloping sandy beach** profiles
- You need a (reasonable) estimate for bed profile
- Dependence on **quality short wave** modelling
- No break point forcing yet, as needed for steep profiles/coral reefs (future work…)

Outlook:

- Couple to a wave-resolving compound flood model SFINCS and dynamically force IG waves

→ See also presentation of Maarten van Ormondt LL3, Wed 4.30pm

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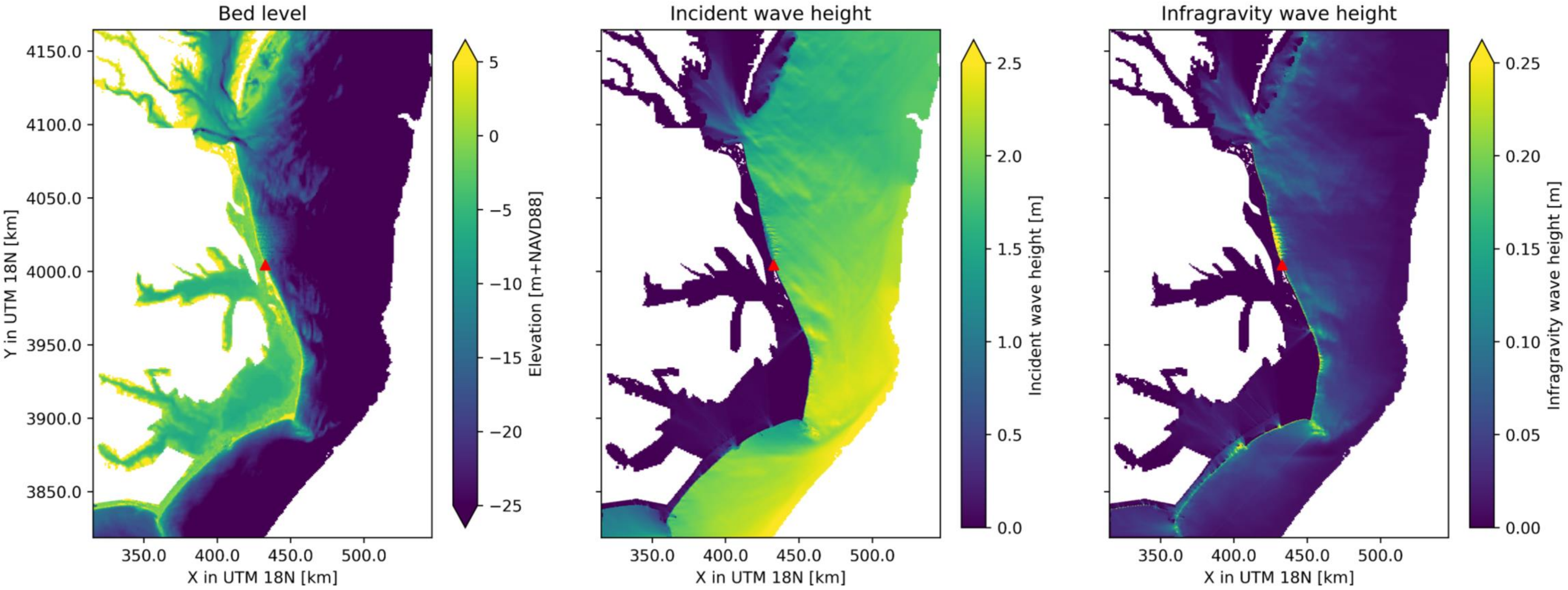



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