Modelling effects of salt marsh vegetation on estuarine hydrodynamics

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SALT MARSHES

- Salt marshes are vegetated intertidal wetlands.
- Increasingly recognized Nature Based Solution:
  - Wave attenuation (e.g. Möller et al, 2014)
  - “Best defences already out there”

Salt marshes in the Taf Estuary, Southwest Wales

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  - Lower waves
  - Strong tidal currents
  - Interaction among features

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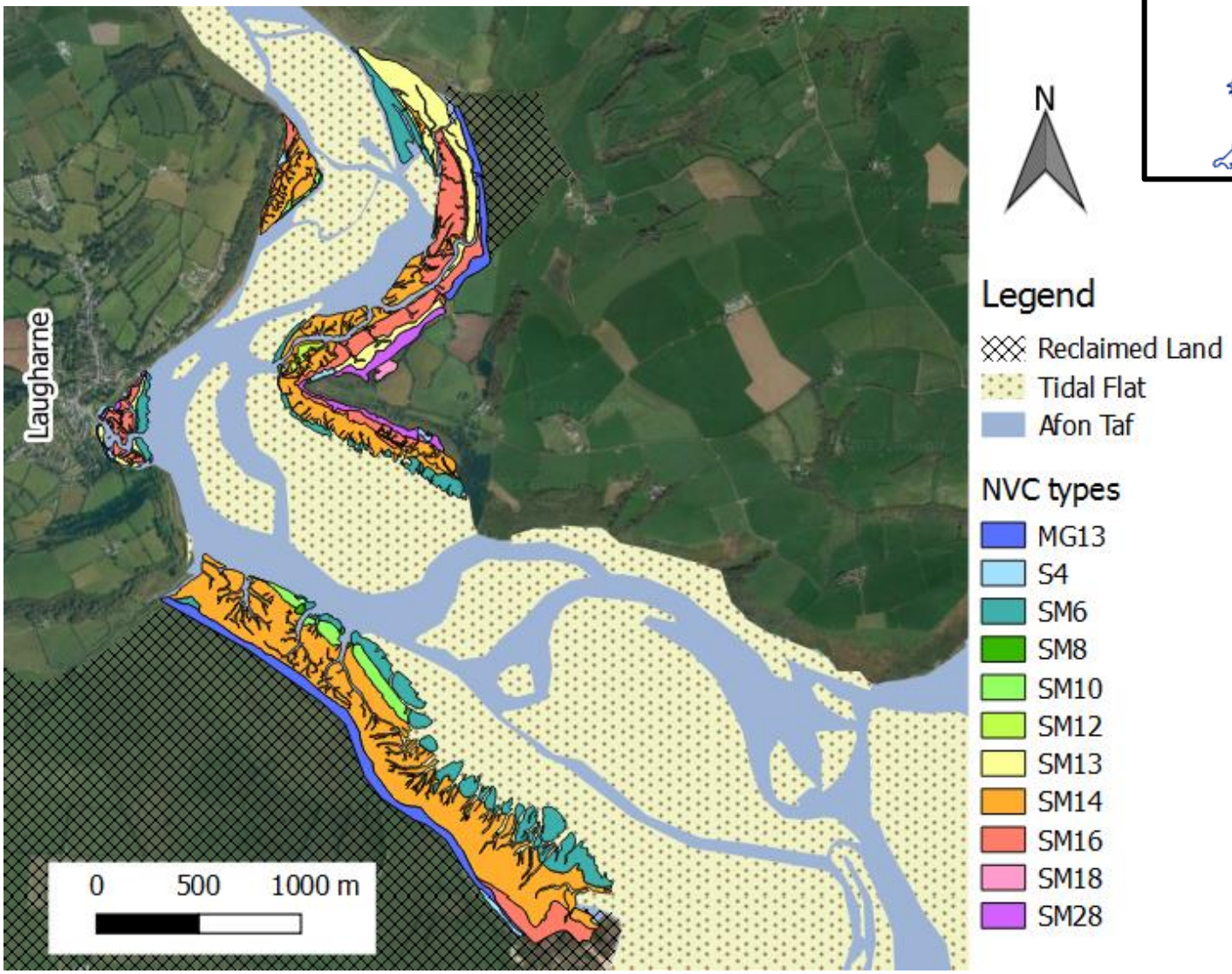
  - Sheltered environments
  - Lower waves
  - Strong tidal currents
  - Interaction among features
- Flood protection requires a broad and estuary-wide approach.

Salt marshes in the Taf Estuary, Southwest Wales

RESEARCH QUESTION

How do salt marshes affect currents and waves in an estuary?

CASE STUDY: TAF ESTUARY



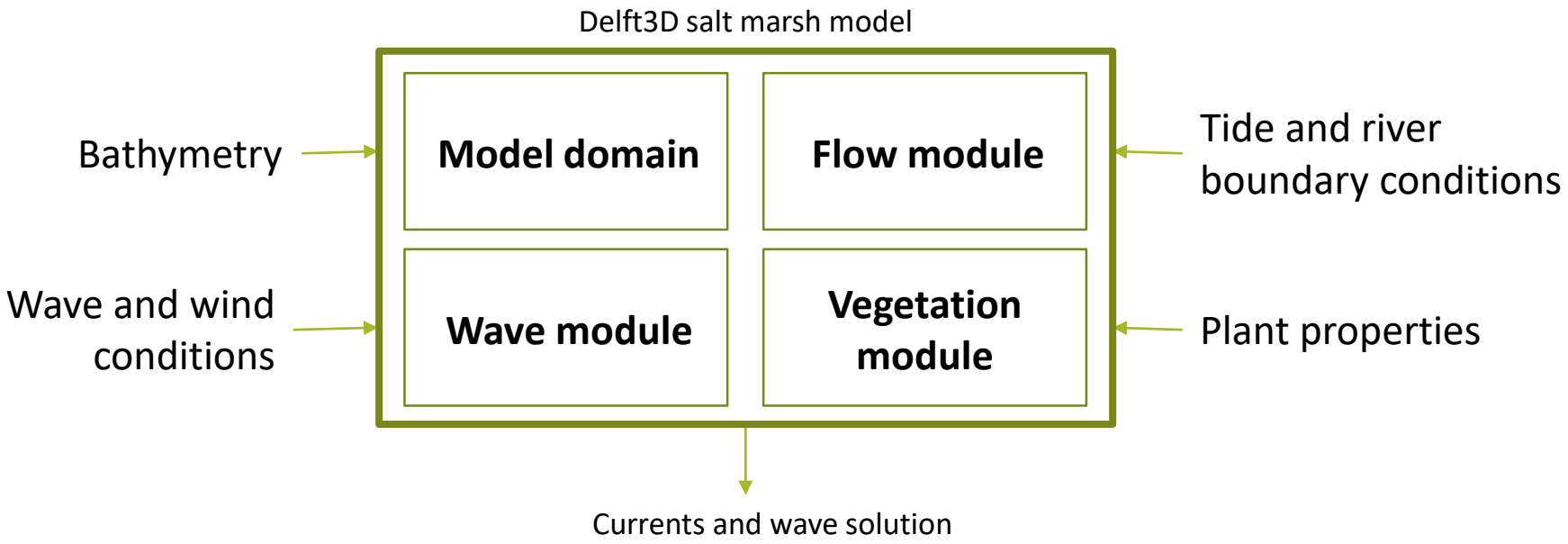
TAF ESTUARY: KEY FACTS

- Macro-tidal estuary, spring tidal range: 7.5m & prism: 18 Mm^3.
- River discharge: 7.5 m^3/s (mean) – 60 m^3/s (extreme)
- Salt marsh area: 279 ha.
- Dominant specie: Atriplex Portulacoides (sea purslane)
- Marshes inundated during spring tides and storms

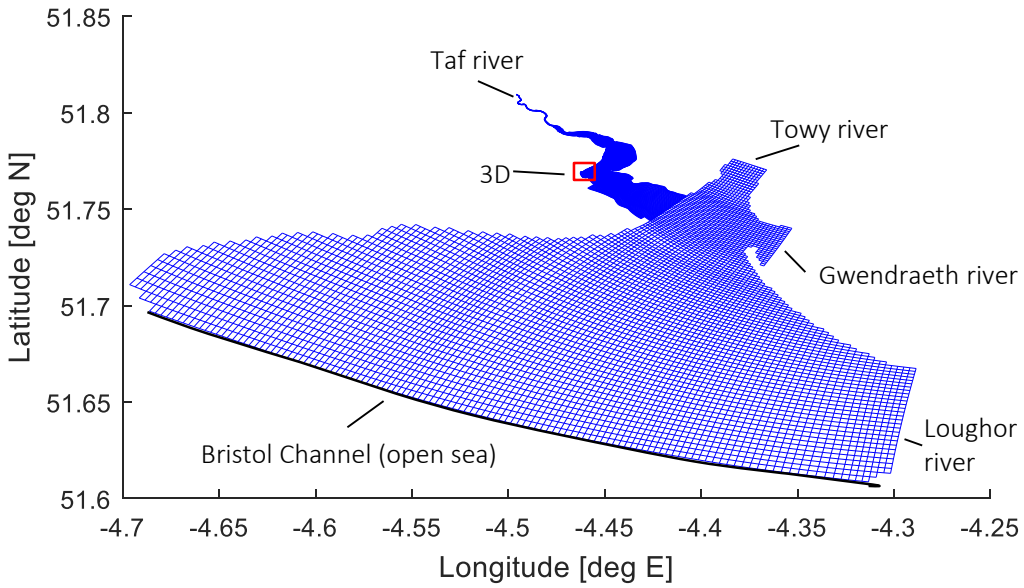
Atriplex Portulacoides, from: Field Studies council (2008)

What is the impact on currents and waves?

- Requires a coupled numerical model (Delft3D) that accounts for:
  - All estuarine features
  - Tide and river forcing
  - Waves
  - Salt marsh vegetation

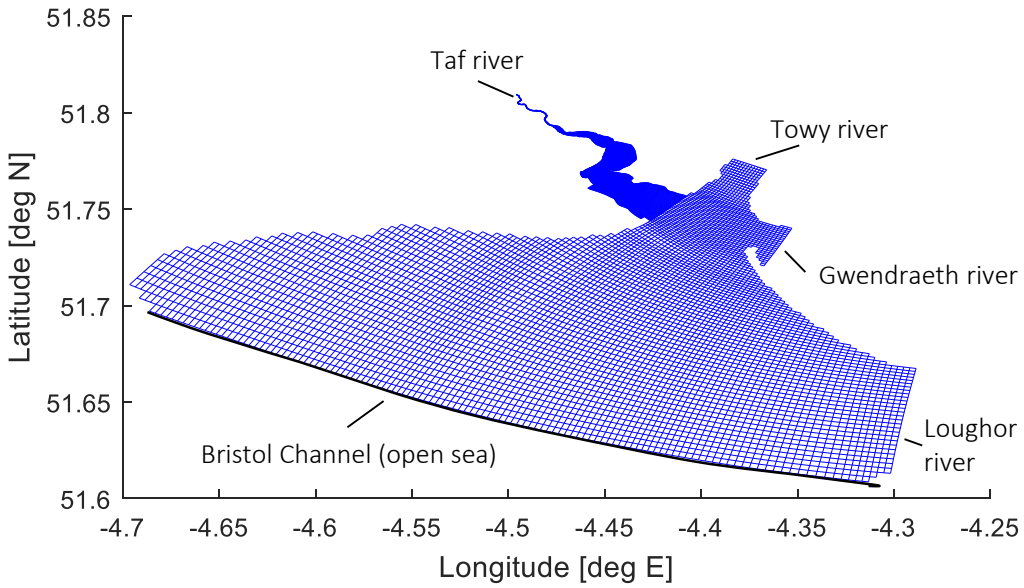


Model domain



- Curvilinear grid with domain decomposition to obtain refinement around salt marshes.
- Resolution: 250x250m at boundary, 10x10m at marshes.
- 3D at Laugharne Marsh, rest 2D (depth-averaged).
- Bathymetry from single-beam sonar survey.

Flow Module



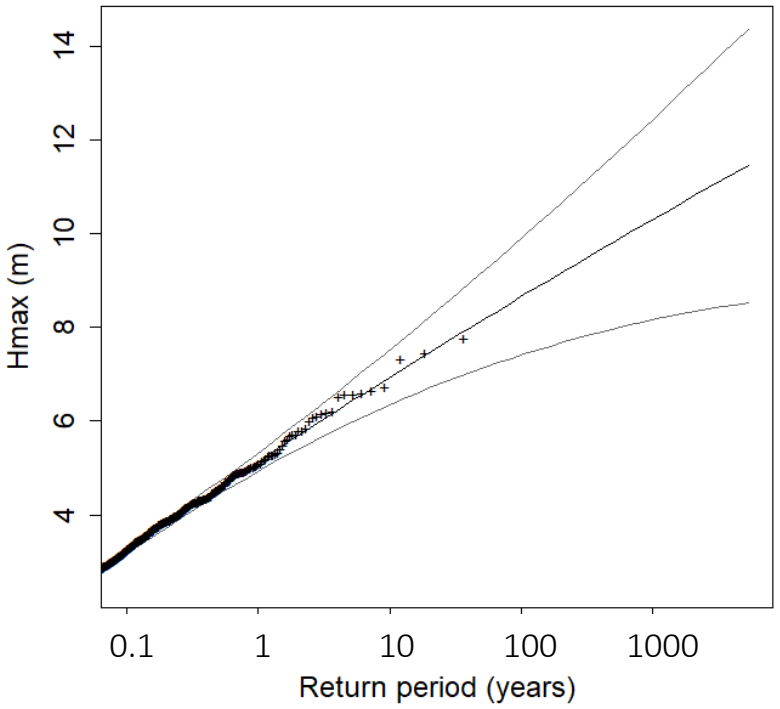
- Delft3D-solver for unsteady shallow water equations.
- Open sea boundary from tidal model for the Bristol Channel.
- River boundary conditions set at mean discharge (7.5 m^3/s – Taf, others 5 – 50 m^3/s).

Wave Module

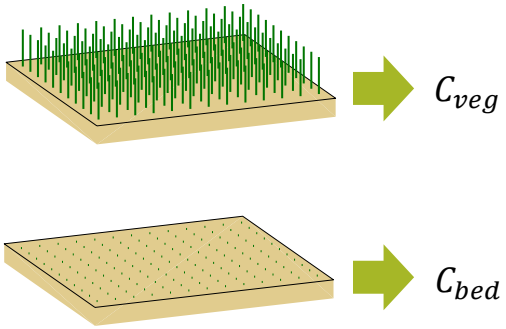
Model domain	Flow module
Wave module	Vegetation module

- SWAN-model.
- Dynamic storm profile of waves and surge applied at open sea boundary.
- Spatially uniform and temporally varying wind forcing.
- Wind, wave and surge conditions derived from extreme value analysis of historical and hindcast data.

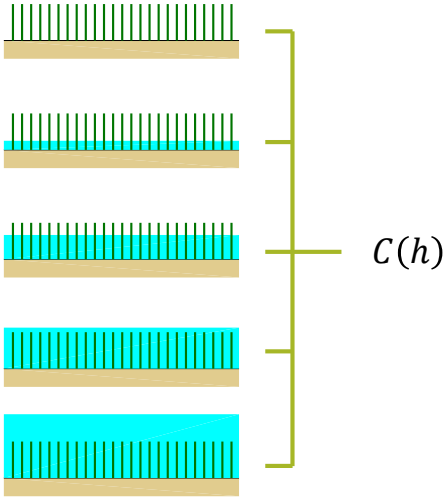
Extreme offshore wave height distribution



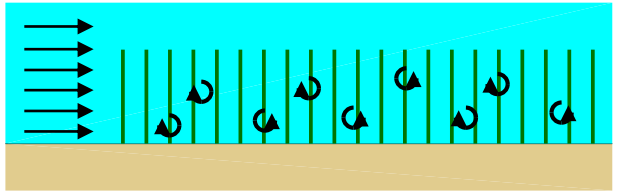
Vegetation Module



1. Fixed increase in bed roughness

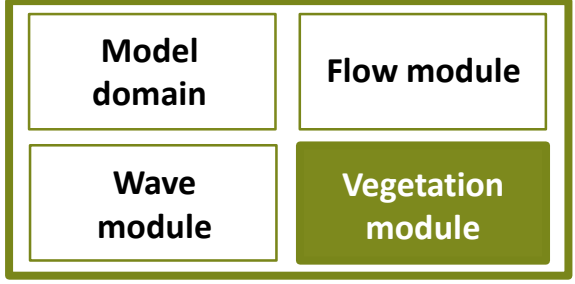


2. Water level-dependent bed roughness (Baptist et al, 2007)



3. Rigid vegetation model (3D momentum approach)

Vegetation Module



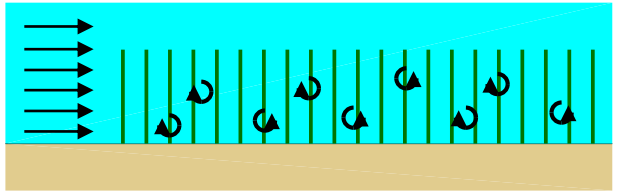
- Extra sink term in 3D momentum equations.

$$F(x,y,z,t) = \frac{1}{2}\rho C_D b_v n|u|u$$

- Valid under the assumption of rigid cylinders as introduced by Dalrympe et al. (1984)
- Wave dissipation is proportional to work done on vegetation (Méndez &Losada, 2004):

$$\frac{\partial E c_g}{\partial x} \sim -Fu$$

- Uniform vegetation (Atriplex P.) cover on platforms. No plants in creeks



3. Rigid vegetation model (3D momentum approach)

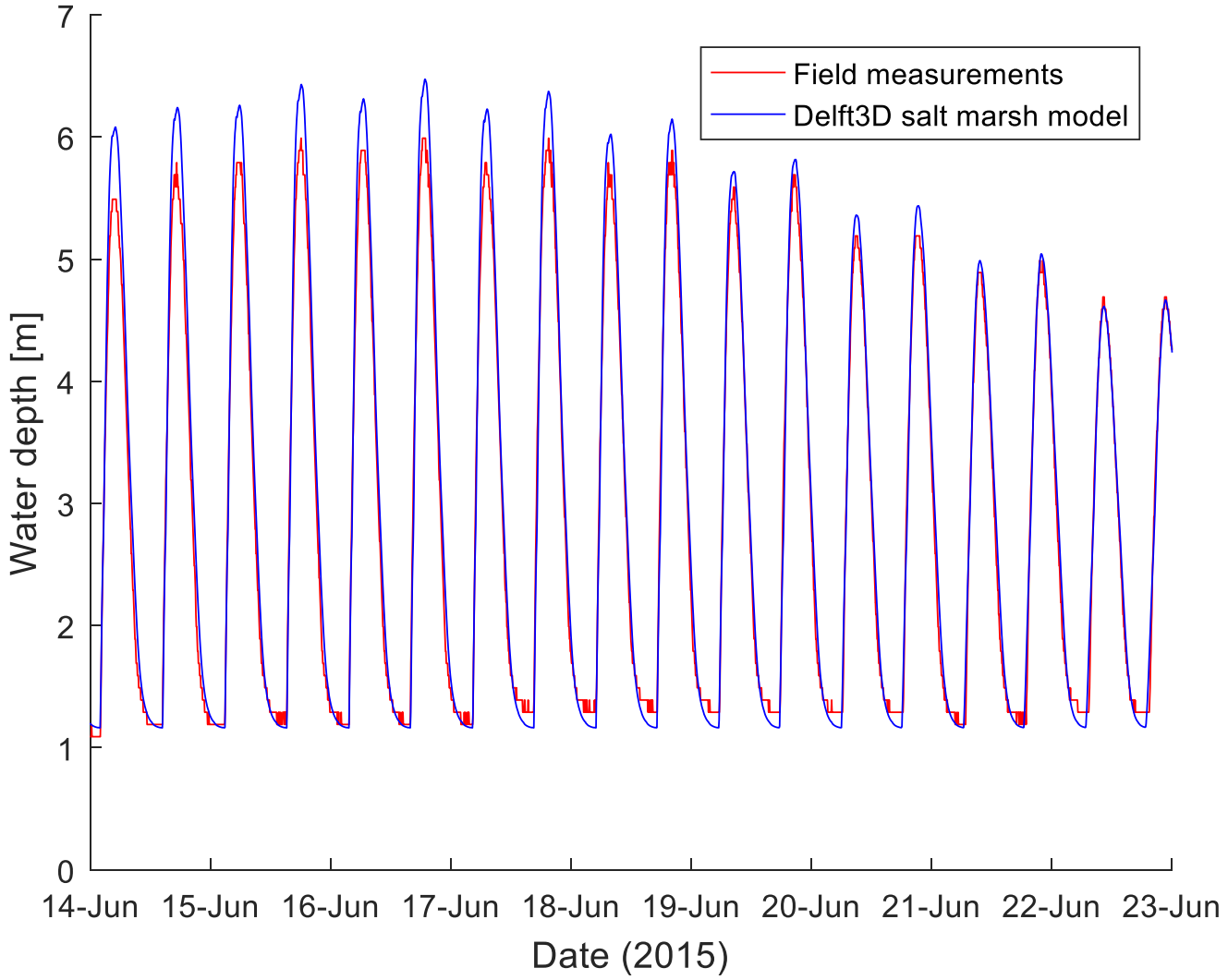
Table 1: Vegetation parameters used in model

Parameter	Symbol	Value	Unit
Drag coefficient	C_d	0.452*	-
Stem diameter	b_v	1.8 - 3.3†	mm
Stem density	n	2275	m^{-2}

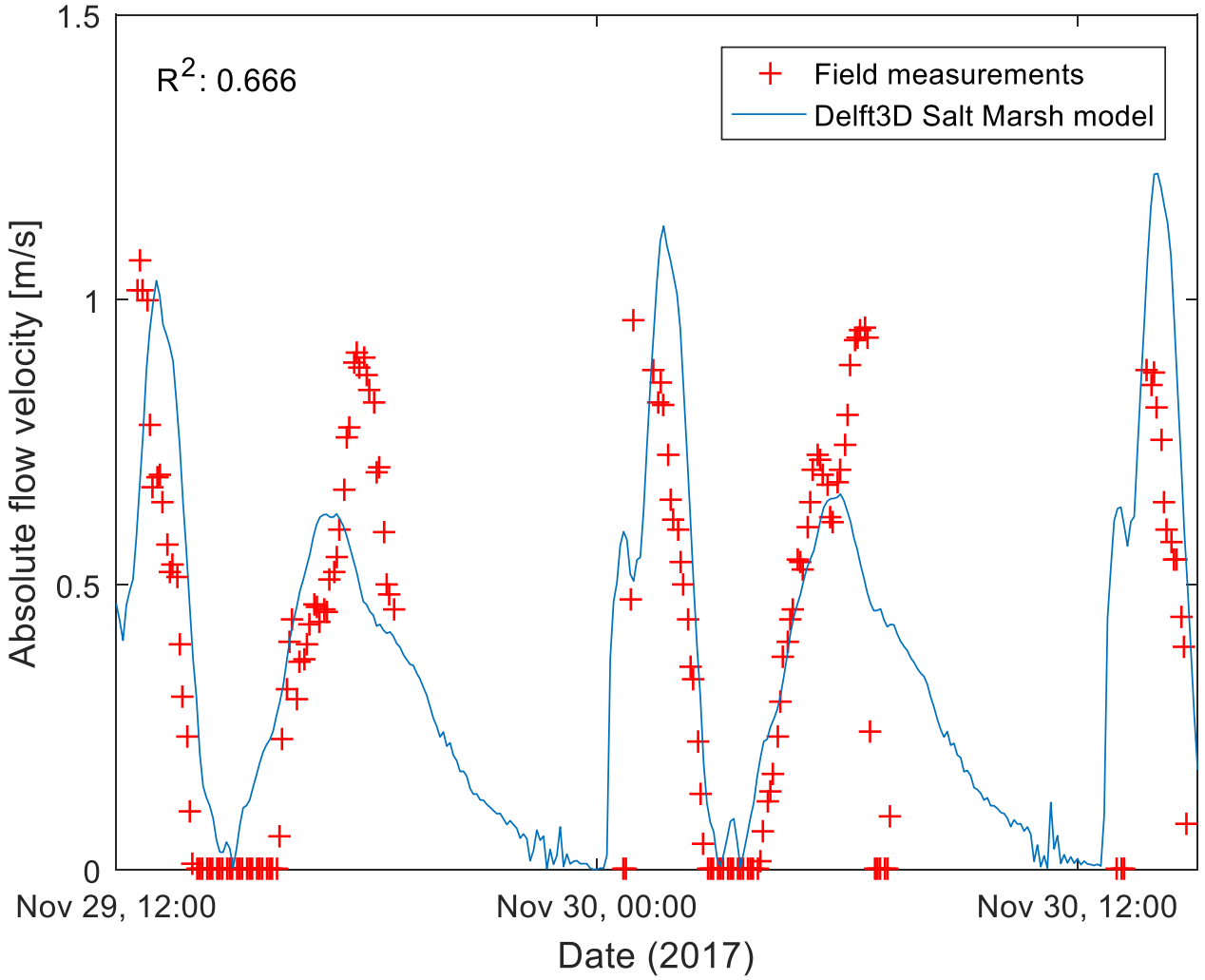
* Based on the work by Möller (2014).

† b_v is a function of z, stems have a width of 3.3 mm at substrate and 1.8 mm at tip.

Model validation: water level



Model validation: flow velocity



What is the impact on flow and currents?

- We have set up and validated a coupled Delft3D salt marsh model.
- Four conditions:
  1. Spring tide, with salt marshes
  2. Spring tide, no salt marshes
  3. 1/10 year storm, with salt marshes
  4. 1/10 year storm, no salt marshes
- No salt marsh cases have vegetation removed. Bathymetry remains unchanged.

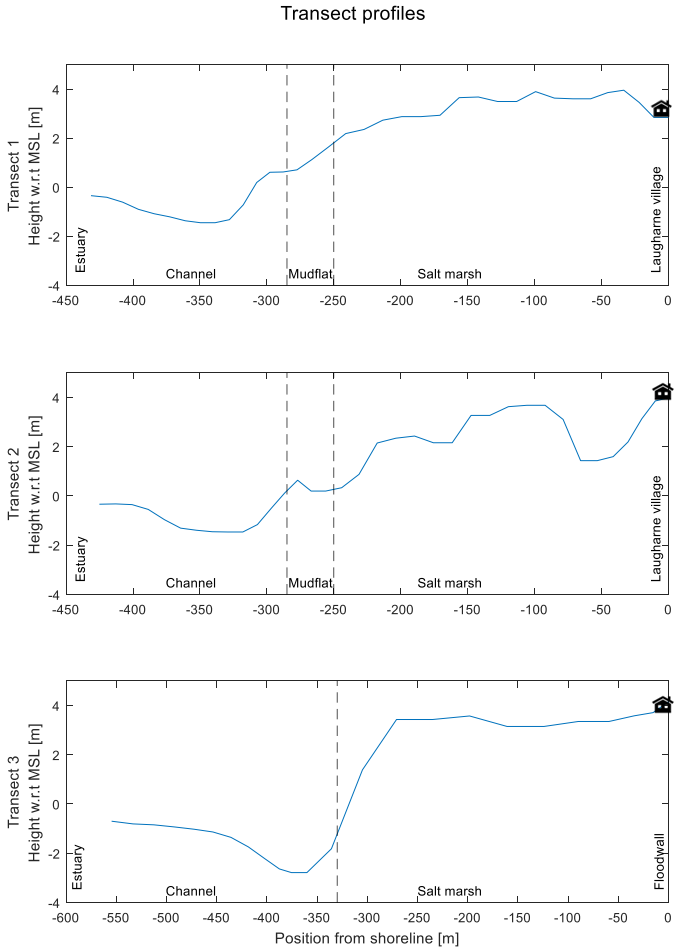
Table 2: Model runs with boundary conditions

Run	Marsh?	h_{max} (m)	H_{max} (m)	U_{wind} (m/s)
1	Yes	4.50	N/A	N/A
2	No	4.50	N/A	N/A
3	Yes	5.30	6.94	26.6
4	No	5.30	6.94	26.6

Transects

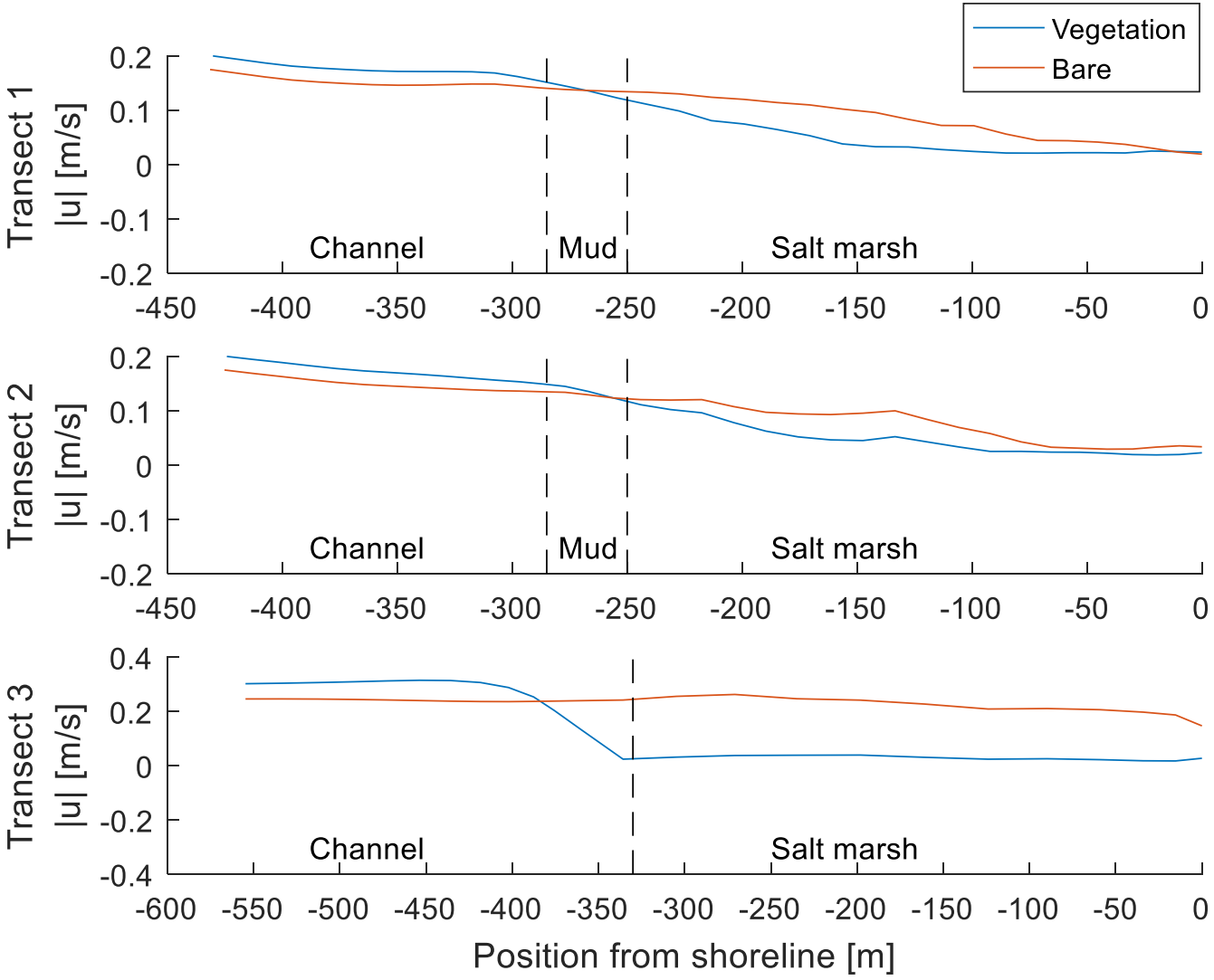
- Three transects selected to compare model outcomes.
  - T1: Laugharne Marsh (3D)
  - T2: Laugharne Marsh (3D)
  - T3: South Marsh (2D)

Transects


Transect profiles
Transect 1
Height w.r.t MSL [m]
Estuary
Channel
Mudflat
Salt marsh
Laugharne village
Transect 2
Height w.r.t MSL [m]
Estuary
Channel
Mudflat
Salt marsh
Laugharne village
Transect 3
Height w.r.t MSL [m]
Estuary
Channel
Salt marsh
Floodwall
Position from shoreline [m]


T1
T2
T3
Image © 2018 DigitalGlobe

Results: spring tide, maximum ebb currents



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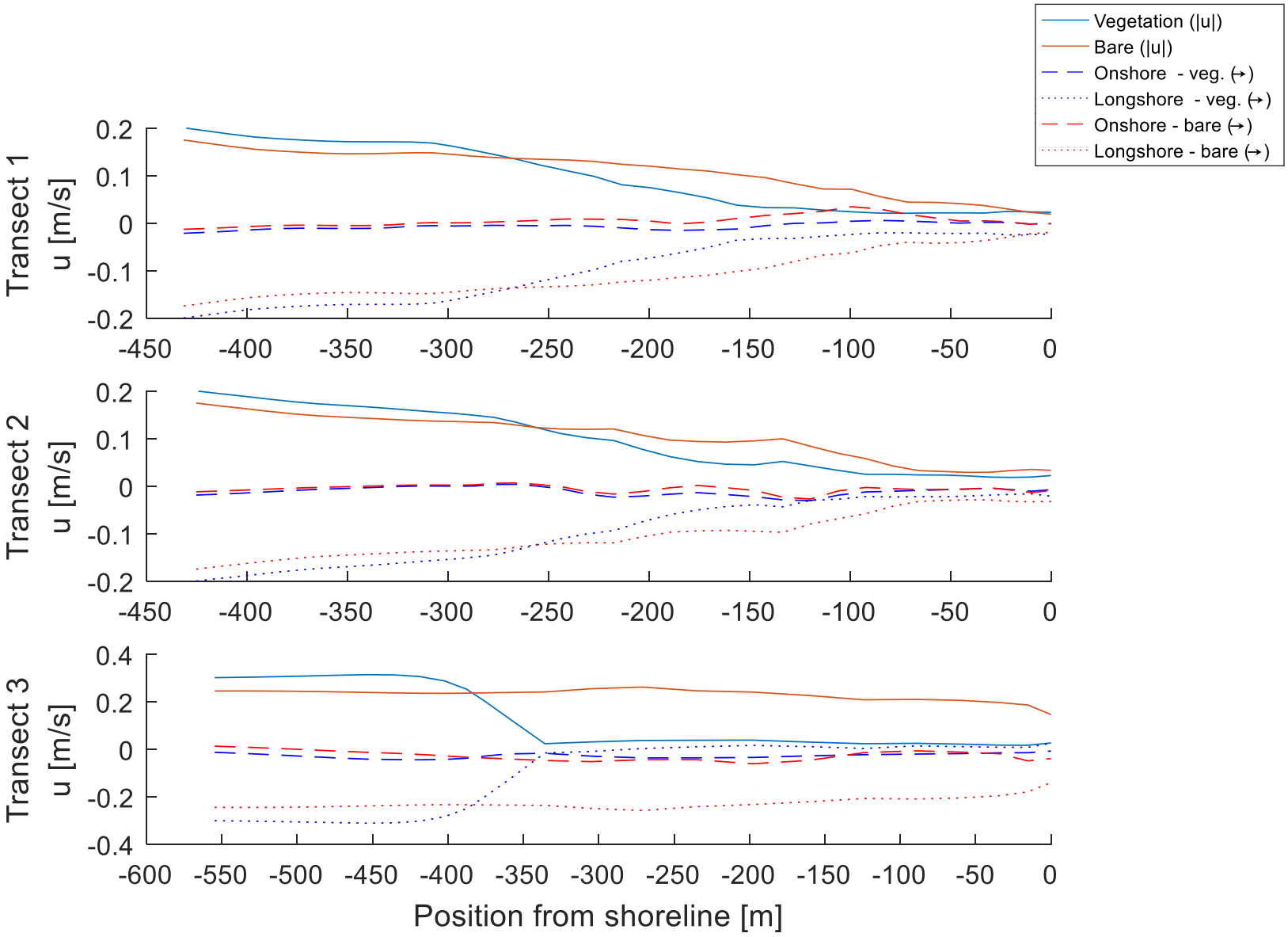

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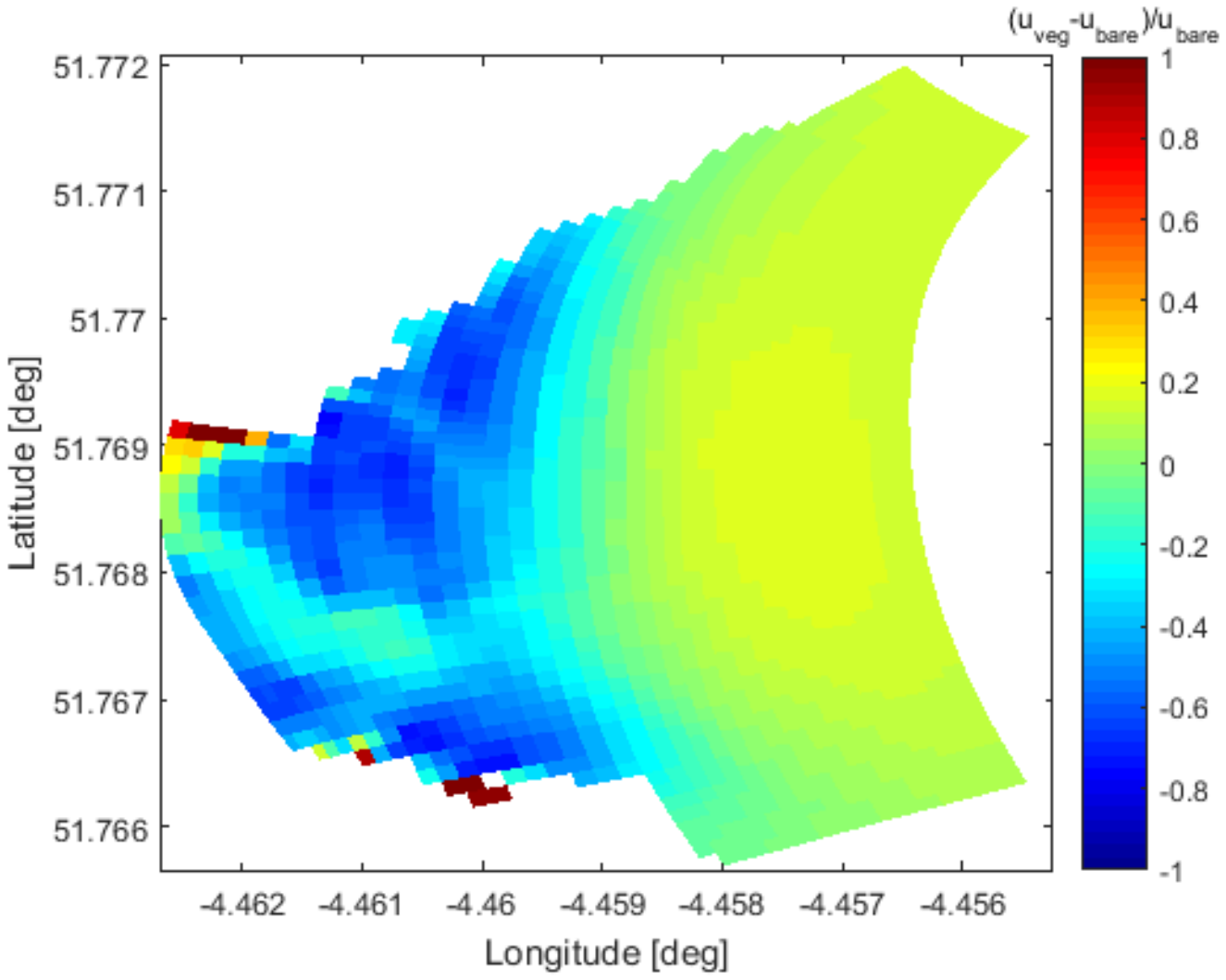

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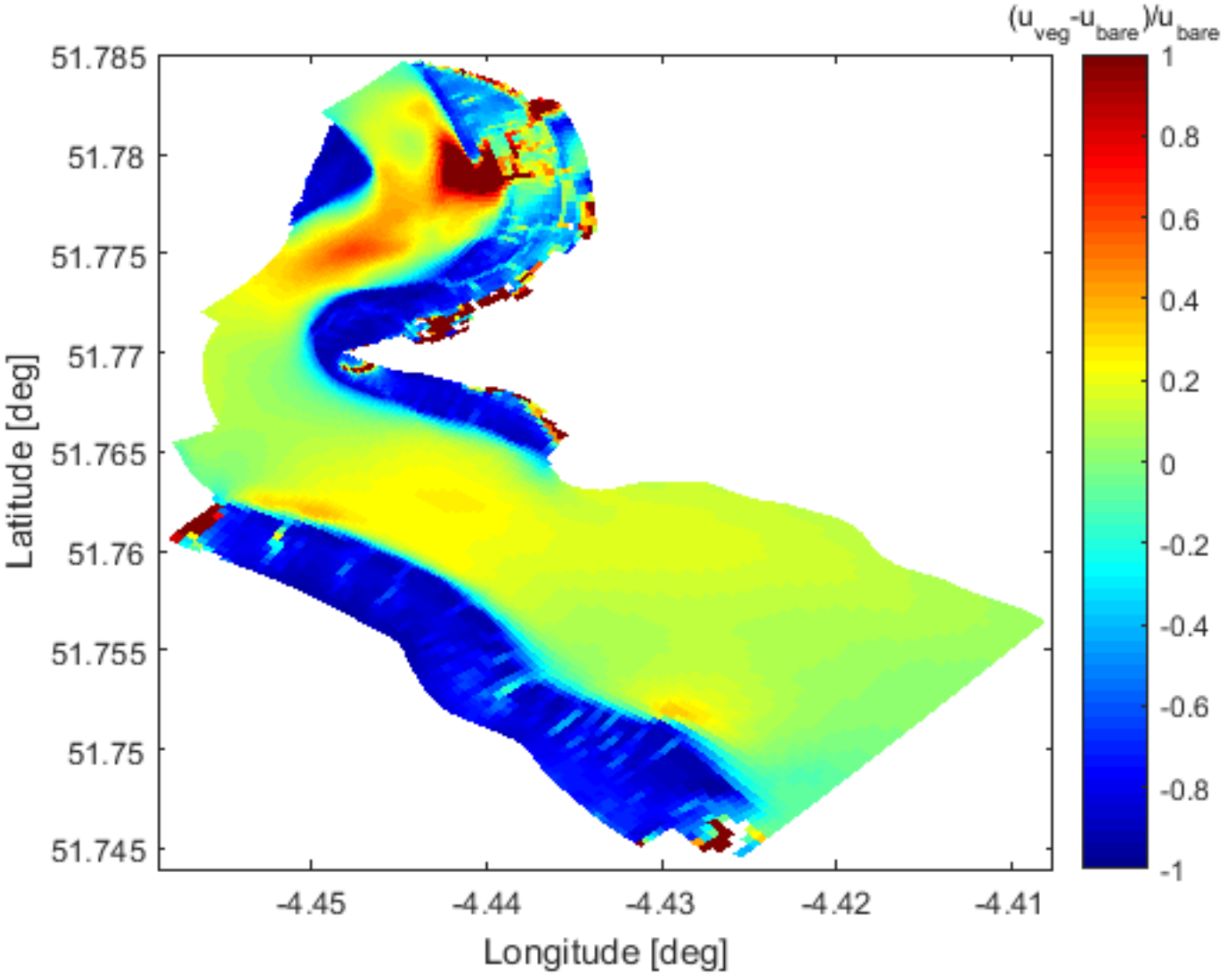
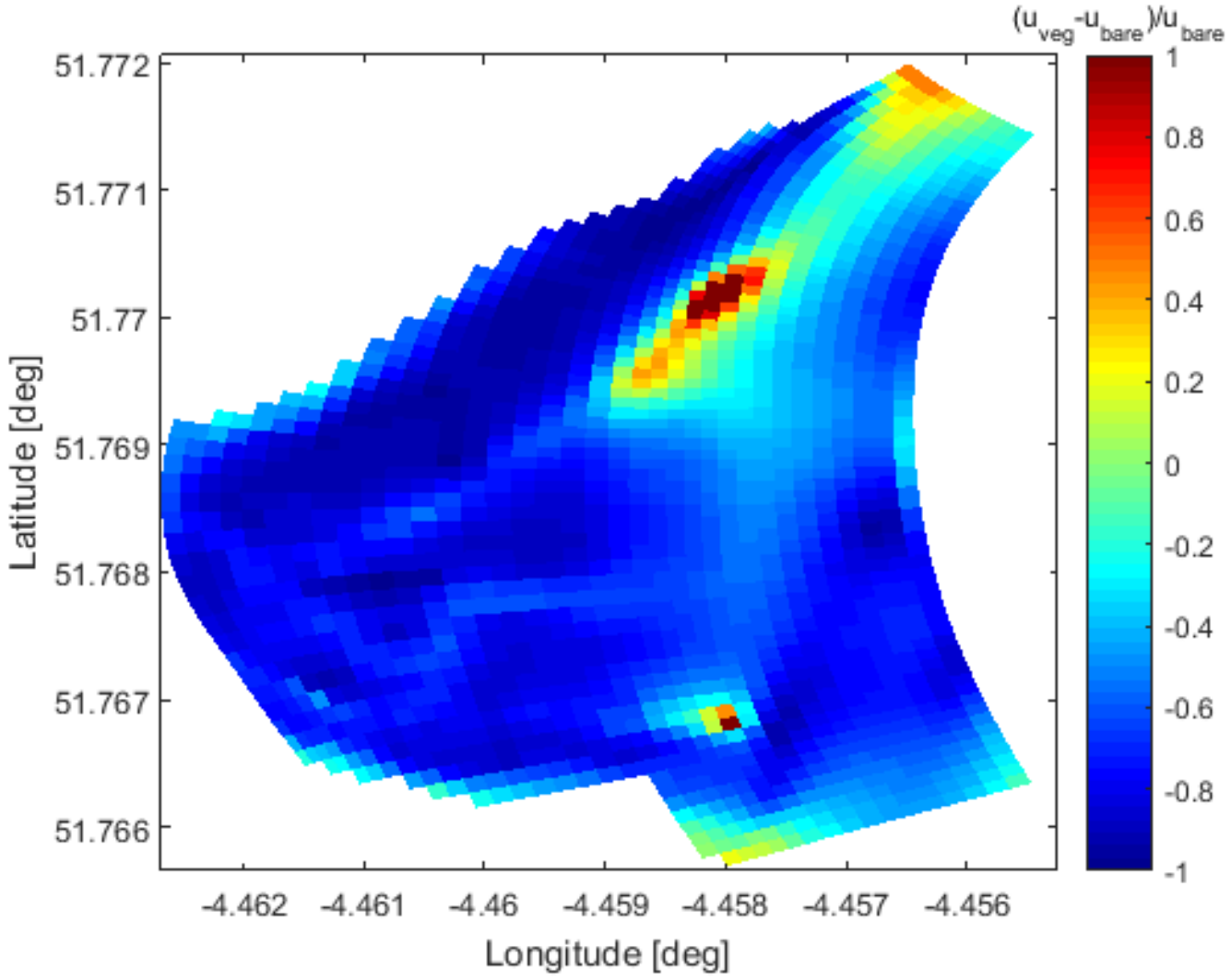
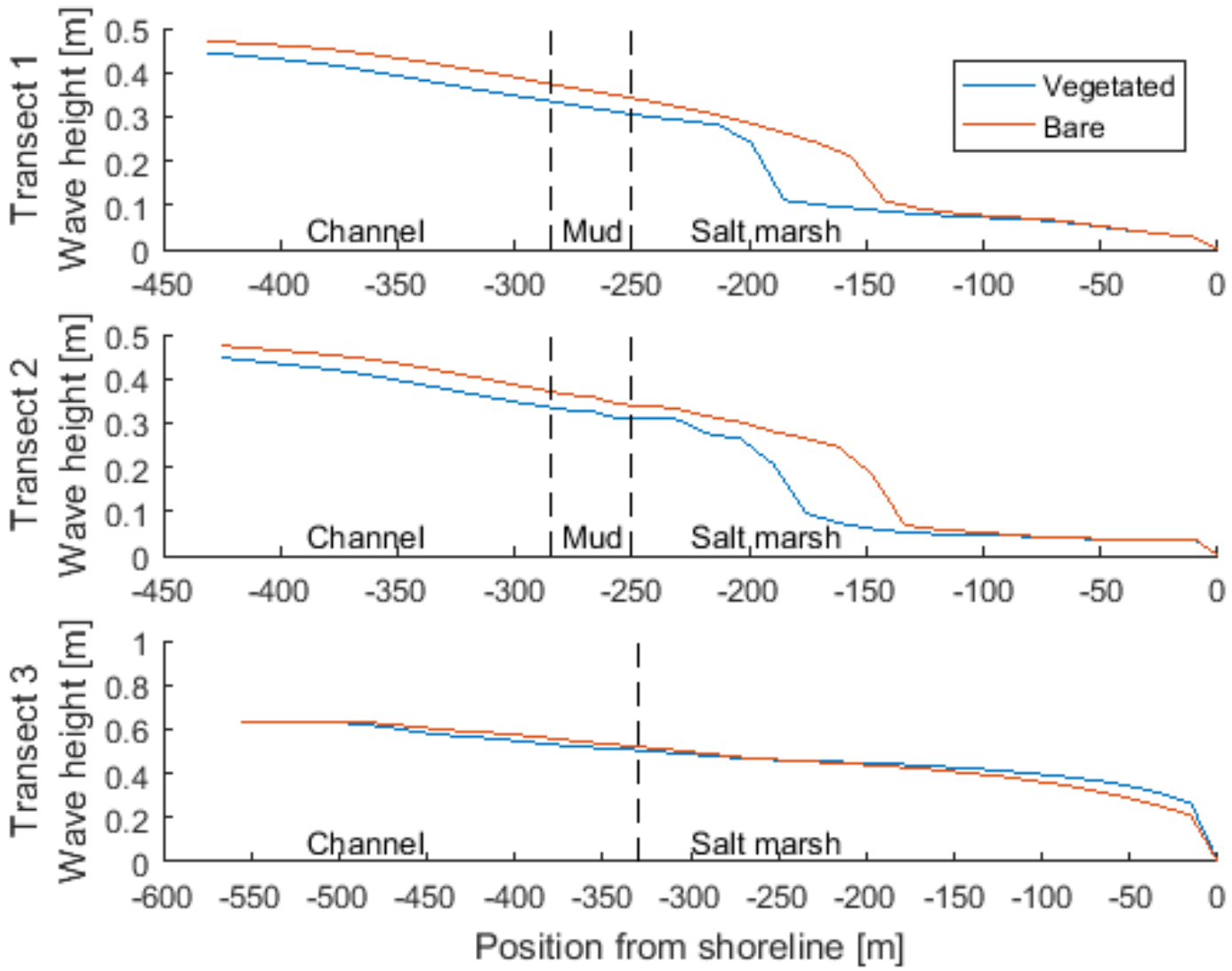


Results: 1/10y storm

Results: 1/10y storm, |u| at max. wave height



Results: 1/10y storm, maximum wave height



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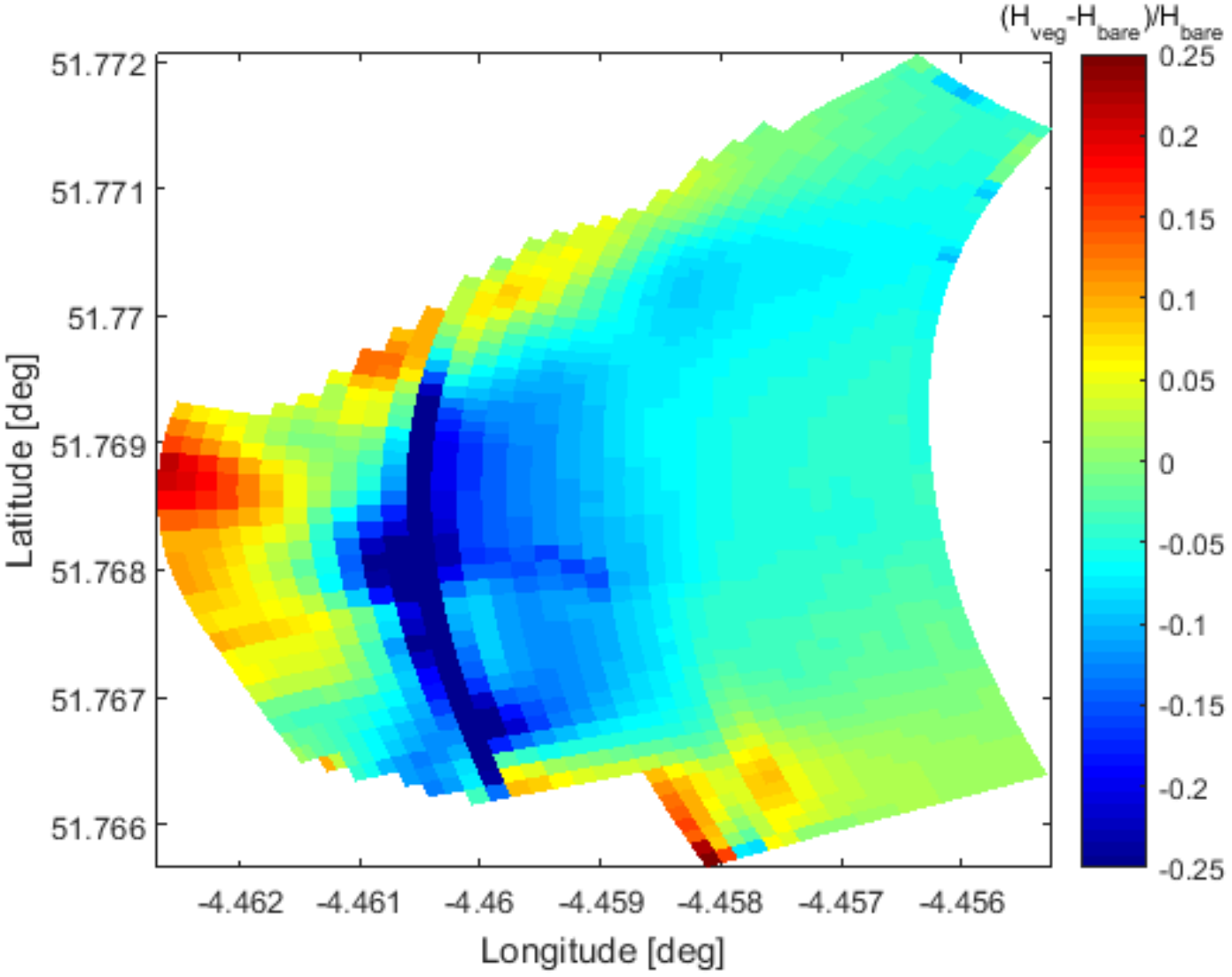

Conclusions

- Successful application of a validated predictive flow-wave-salt marsh model in an estuarine environment.

How do salt marshes affect currents in the estuary?

- Longshore currents are the dominant component of flow over salt marshes in a macrotidal estuary.
- Velocity attenuation by vegetation leads to stronger currents in estuarine channel.

How do salt marshes affect wave height in the estuary?

- Waves are attenuated and break further offshore.

Future work: morphodynamics, more sophisticated plant implementations, other estuaries

Thank you for your attention!

Presenter: Thomas van Veelen
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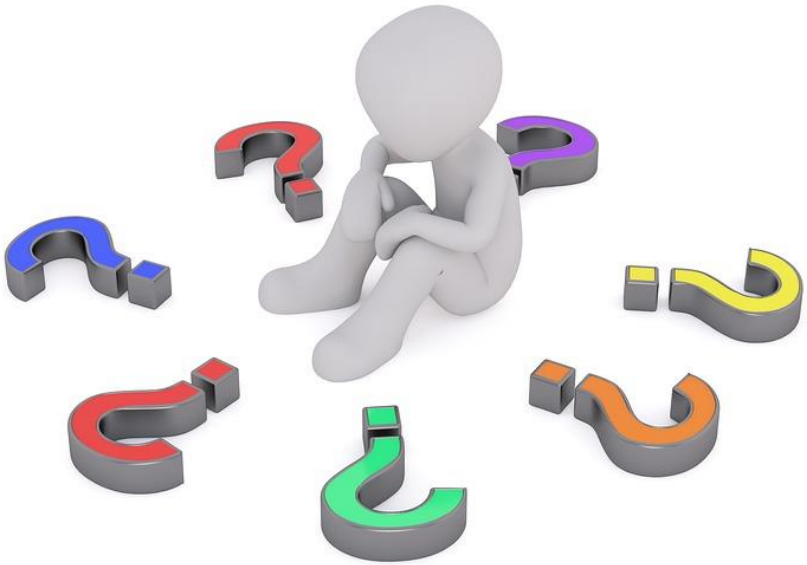

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