Evaluation of seagrass as a nature based solution for coastal protection in the German Wadden Sea

Benjamin Jacob, Joanna Staneva, Tobias Dolch, Andreas Wurpts

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Helmholtz-Zentrum hereon

PILOTS

- Wadden Sea +
- Catalan coast Ebro delta +
- Venice lagoon +
- Vistula lagoon +
- Foros bay +
- Rhone Delta +

Motivation

- Changing extreme weather statistics and global SLR enhance the risk for coastal hazards (land loss, flooding, salt intrusions) and hence the need for coastal protection

- Traditional engineering methods (Dikes, breakwaters, etc.) albeit efficient are costly and represent a strong interference with the system

- Meanwhile Nature based Solutions (NbS) have become increasingly popular as alternative or **supplementation**
  - using natural elements:
    - Sand nourishments
    - Mussel beds
    - Flood plains
    - **Coastal Vegetation**

Source: Ariana E. Sutton-Grier et al. (2015) Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems, Environmental Science & Policy (51) (modified)

  - Interacting with hydro-morphodynamics, effectively attenuating**:**
    - Short term waves events
    - And currents

Motivation

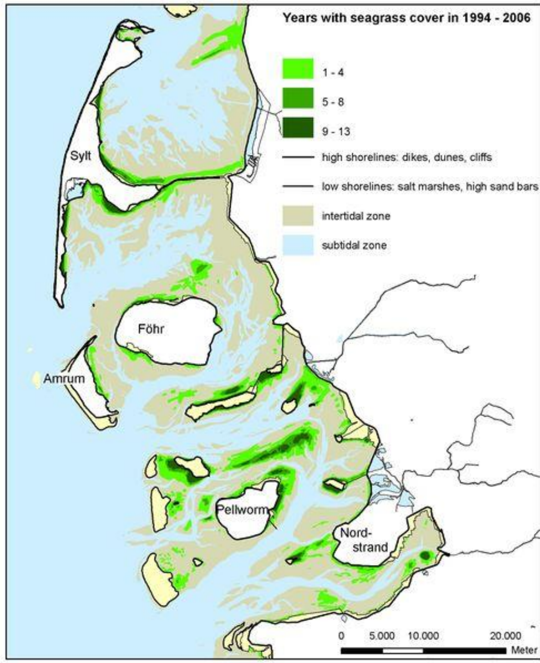
- The German Bight study area
  - Is a high energetic system (tides, wind waves)
  - Contains the valuable Wadden Sea ecosystem,
  - economically important infra structure and large coastal population
  - Is frequently impacted by extreme weather events and traditional coastal protection is a crucial topic for the area

- Coastal sea grass vegetation is sensitive (eutrophication/light/stress)
  - decline in the 1970s
  - rehabilitation at least for NFWS while remaining sparse in EFWS
- However existing literature provides restoration strategies improving patch survival rates under higher energetic conditions (large patch transferal)

Objective:

- By how much could seagrass expansion reduce water levels, current velocities, wave heights and the mobilization of sediments?

- How do the NFWS and EFWS compare in terms of NBS response?

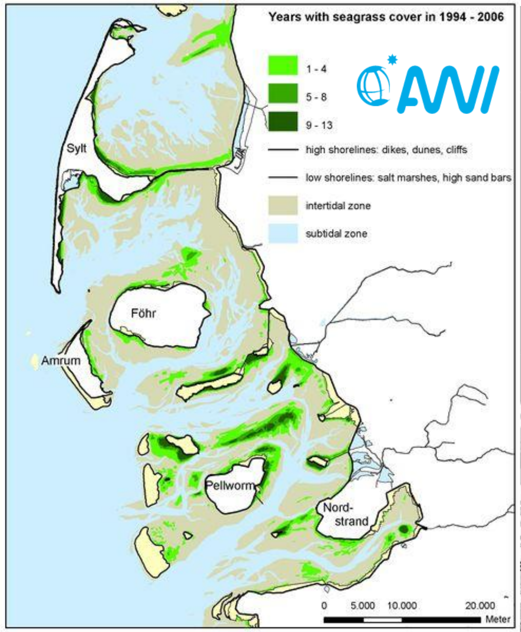


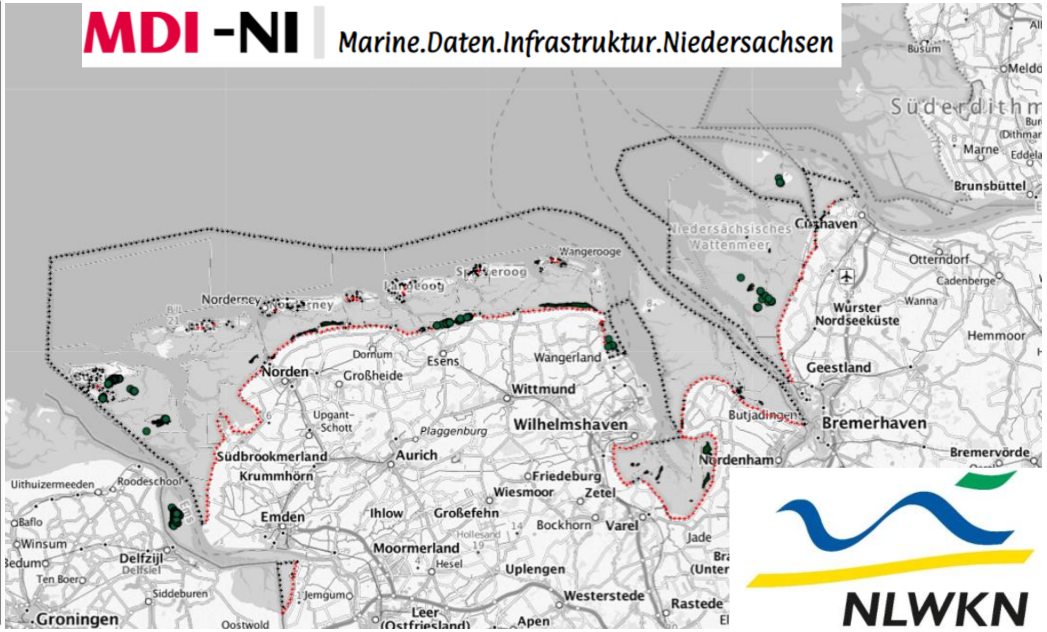
Seagrass Data

- North Frisian Wadden Sea (NFWS): expansion and becoming denser
- East Frisian Wadden Sea (EFWS): only small beds with low shoot densities are found

- Data/sampling (NFWS: T. Dolch (AWI), EFWS: NLWKN) by foot to estimate Summer **Sea Gras Coverage** (plant coverage of meadows, area percentage of meadows to reference area)

- Data was mapped, georeferenced and extrapolated using GIS-techniques and finally binned in 20% coverage intervals





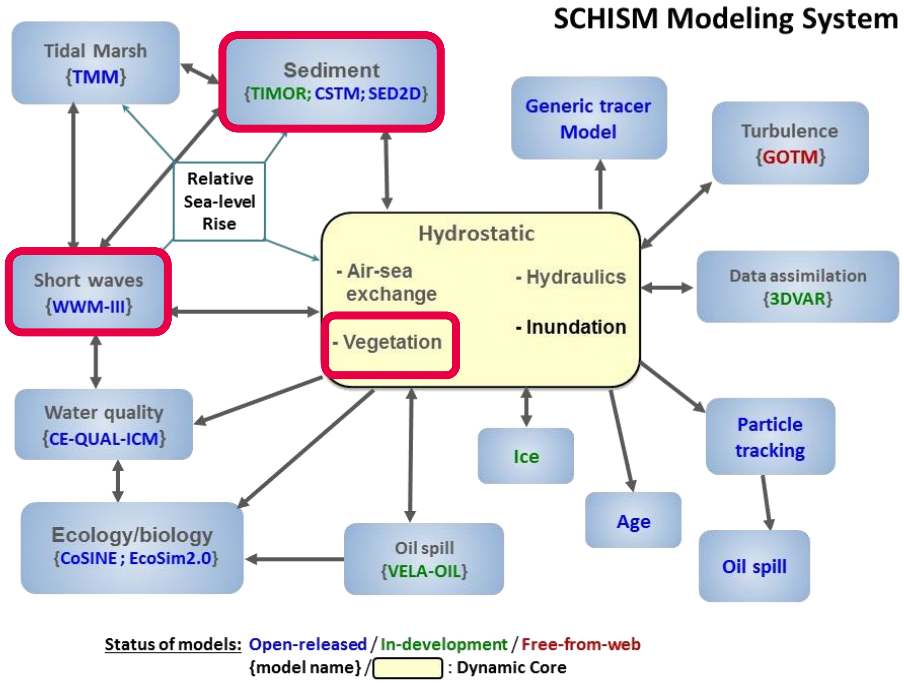
Depth range of Zostera occurrence -4 to 4 m

Observed physiology

leaf height	thickness
19 cm	1.99m
9.8 cm	0.8mm

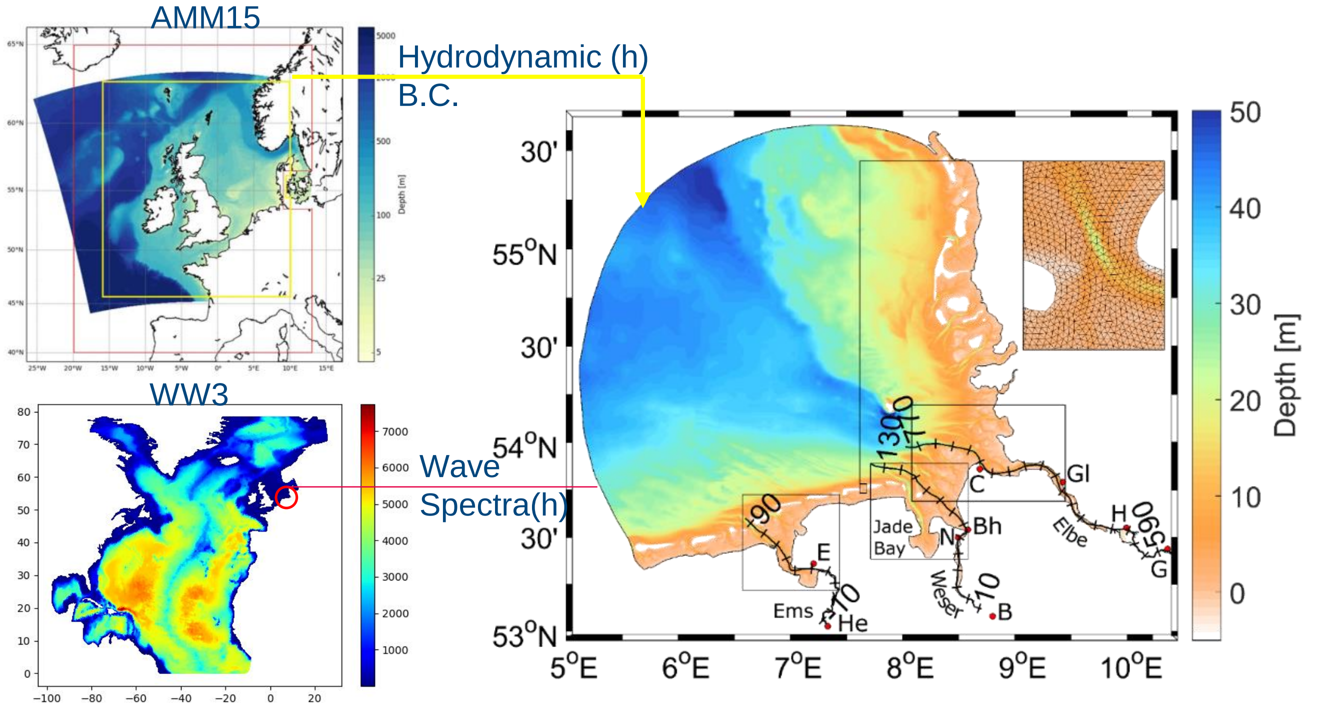
Areal coverage	Density (for model)
areal coverage [%]	Sprouts [1/m2]
5- 19.9	450
20 -39.9	1130
40 59.9	1530
60 - 79.9	3540
80 - 100	7360

Model



source: http://ccrm.vims.edu/schismweb/

German Bight ugrid downscaling configuration



Elements/Nodes
900000/480000
1.5 km - 50 m dx
21 vertical S-layers
90s dt

WWM -III

- Wave Action balance Equation on an unstructured mesh.
- 3rd generation wave model
- ST4 physics Ardhuin et al. (2010)

SCHISM

- 3D, RANS-Equations on unstructured grids
- Robust matrix solver following an efficient semi-implicit time stepping schemes
- Includes Higher-order transport solver: TVD^2
- Includes a variety of functional modules

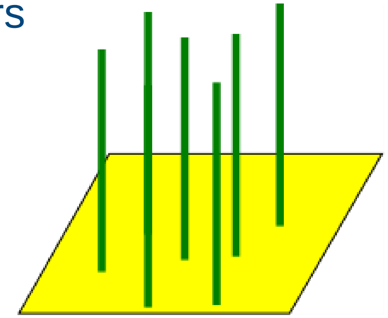
SED3D

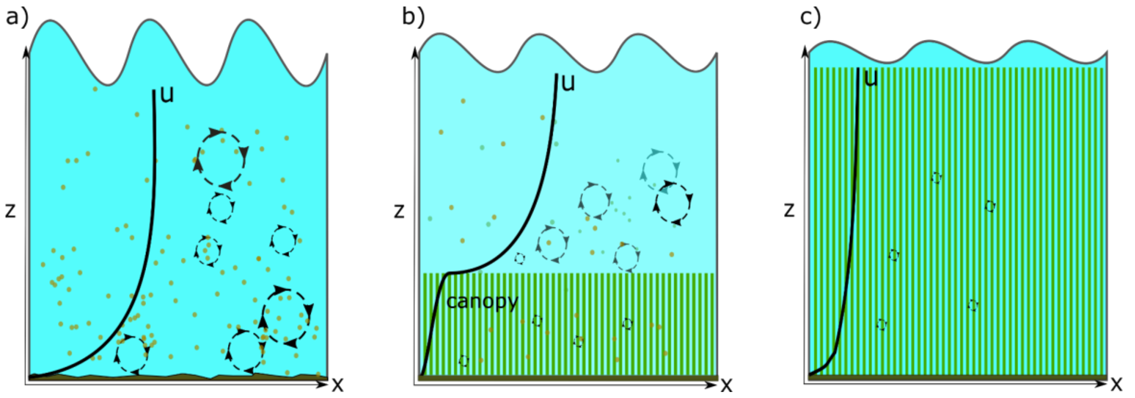
- 3D Sediment model for non-cohesive sediments
- Based on Community Sediment Transport Model (Warner et al., 2008).
- unstructured grid adaption (Pinto et al. (2012)
- Erosion/deposition/bedload of 8 Sediment Classes (0.06-2 mm)

Model - Vegetation

1O approximation as time constant rigid cylinders

1. acting as form drag element in momentum equation
2. Source of turbulent kinetic energy





1. Momentum:

$$\frac{D\mathbf{u}}{dt} = \mathbf{f} - g\nabla\eta + \boldsymbol{m_z} - \alpha|\mathbf{u}|\mathbf{u}L(x,y,z),$$

$$\mathbf{f} = f(v,-u) - \frac{g}{\rho_0}\int_z^{\eta}\nabla\rho d\zeta - \frac{\nabla p_A}{\rho_0} + \alpha g\nabla\Psi + \mathbf{F}_m + other$$

(Explicitly treated terms)

Vegetation density:

$$\alpha(x,y) = D_v N_v C_{Dv}/2$$

→ Scenarios

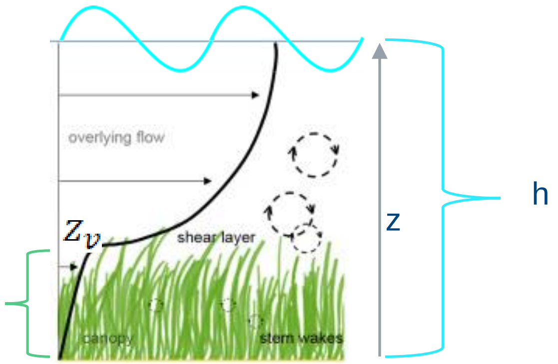
:= diameter x density x drag coeff.

Verticality:

$$L(x,y,z) = \begin{cases}\mathcal{H}(z_v - z), & 3D\\ 1, & 2D\end{cases}$$

$$\mathscr{H}(x) = \begin{cases}1, x \geq 0\\ 0, x < 0\end{cases}$$

$H\alpha$=h+zv



2. TKE/Mixing length

$$\frac{Dk}{Dt} = \frac{\partial}{\partial z}\left(\nu_k^{\psi}\frac{\partial k}{\partial z}\right) + \nu M^2 + \kappa N^2 - \epsilon + c_{fk}\alpha|\mathbf{u}|^3\mathscr{H}(z_v - z)$$

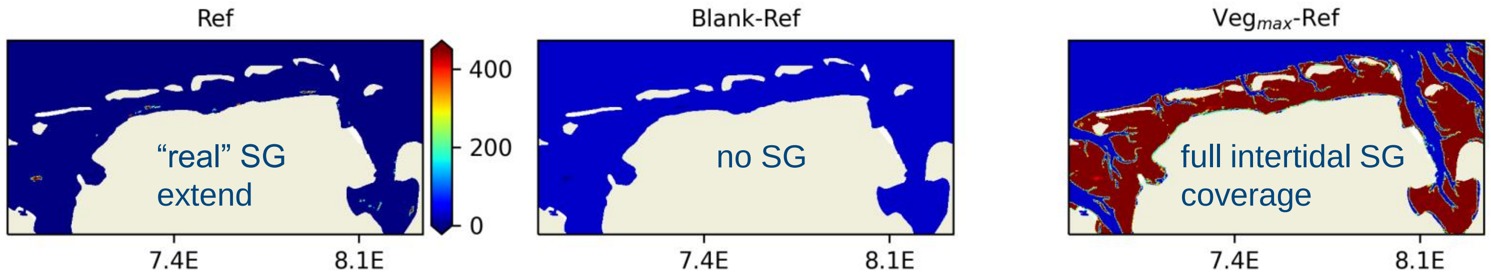
$$\frac{D\psi}{Dt} = \frac{\partial}{\partial z}\left(\mathrm{v}_{\psi}\frac{\partial \psi}{\partial z}\right) + \frac{\psi}{k}\left[c_{\psi 1}\nu M^2 + c_{\psi 3}\kappa N^2 - c_{\psi 2}\epsilon F_{wall} + c_{f\psi}\alpha|\mathbf{u}|^3\mathscr{H}(z_v - z)\right]$$

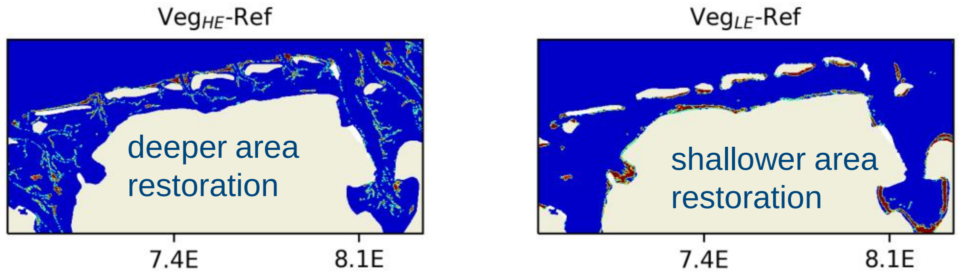
Sea Grass Scenarios

- **Reference**: the present day maximum summer extend/density (data 2019)
- Blank: Control experiment without any sea grass
- Veg_{max}: hypothetical (unrealistic) extreme of fully covered intertidals and maximum dense meadows

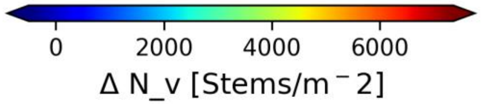
- Veg_{HE}: restoration of deepest 10% of Veg_{max}-coverage area:
  i.e. populating the **high energy** regime near channels
- Veg_{LE}: restoration of shallowest 10% of Veg_{max}-coverage area:
  i.e. populating the **low energy** regime (shallows)

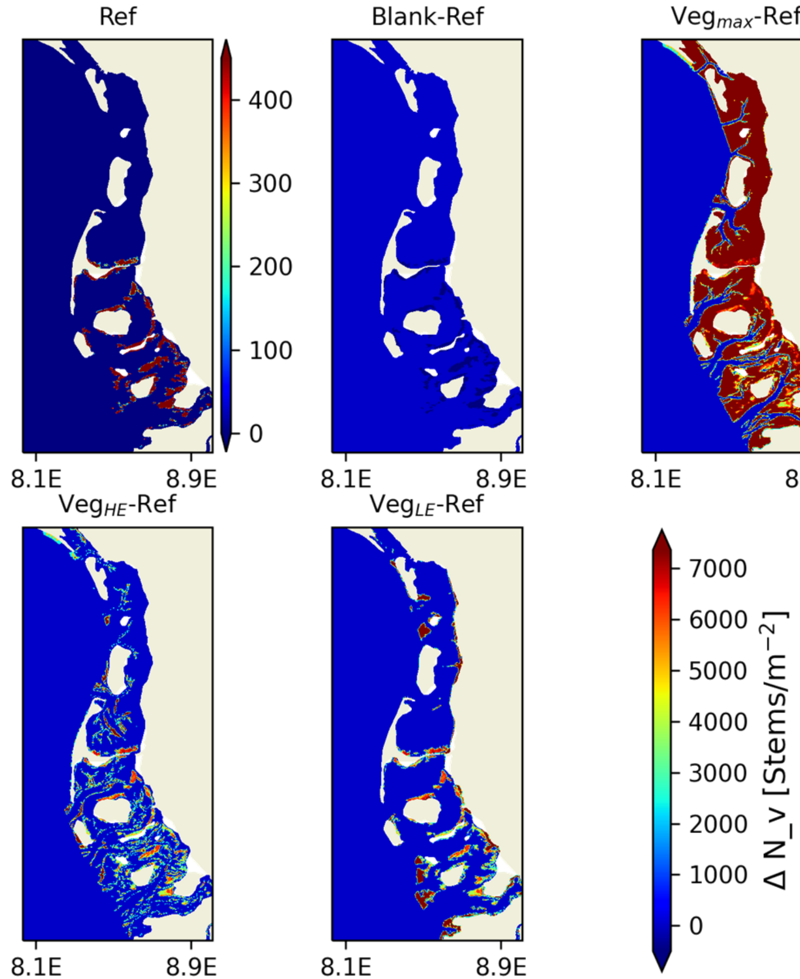
- 1Y simulation for (2017)





Sea grass (stem) density in Reference run and density increase in the different scenarios





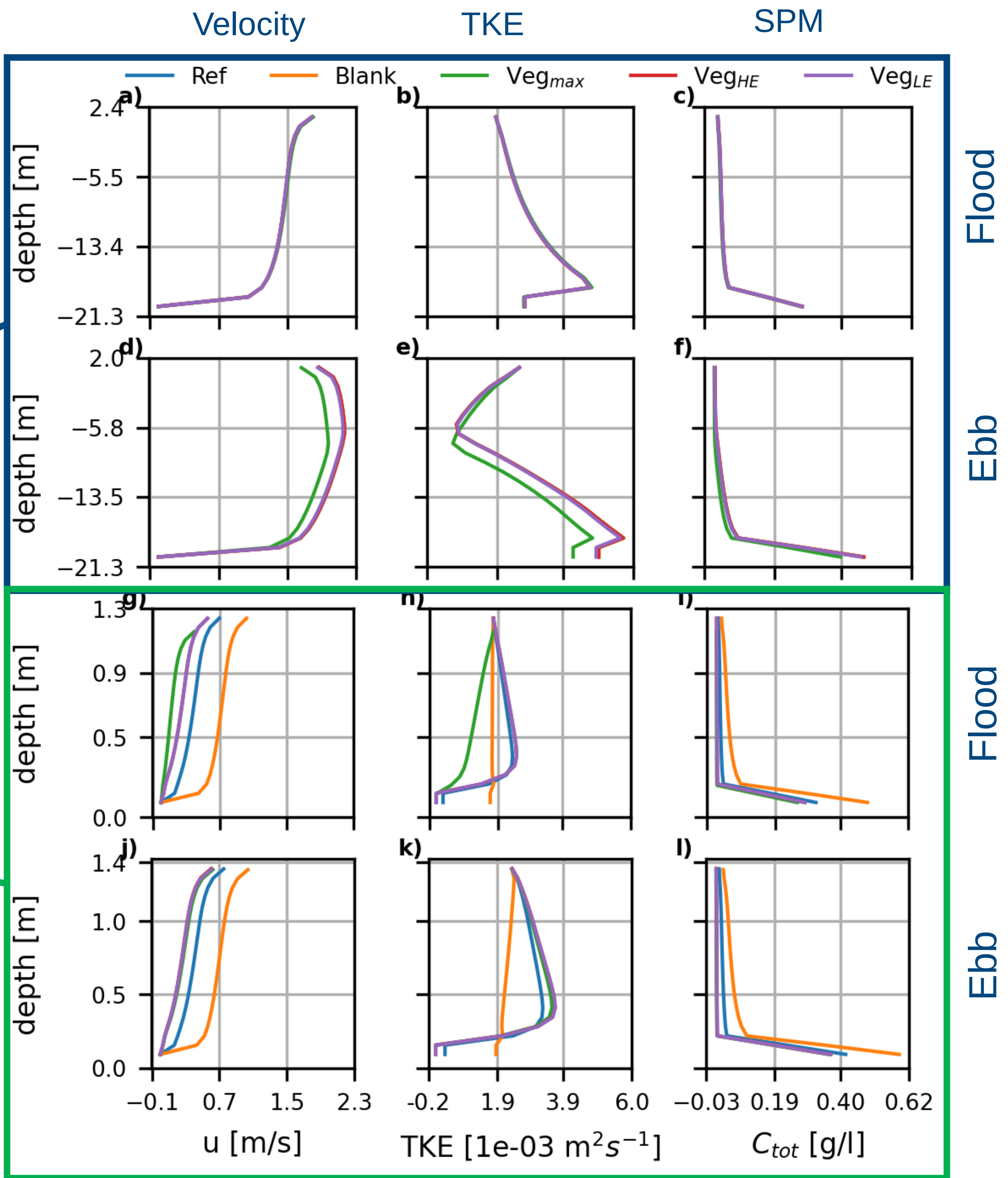
Nr	Name	Sea Grass Cover	Sediment model	Wave model
1	Reference	present day (data) coverage	Yes	Yes
2	Blank	None	Yes	Yes
3	Blank-no-Wave	None	Yes	No
4	Veg-Max	entire WS between -1 and 4 m	Yes	Yes
5	Veg-low-Energy	shallowest 10 % of Veg-Max	Yes	Yes
6	Veg-high-Energy	deepest 10% of Veg-Max	Yes	Yes

Table 2: Caption

Results - Profiles

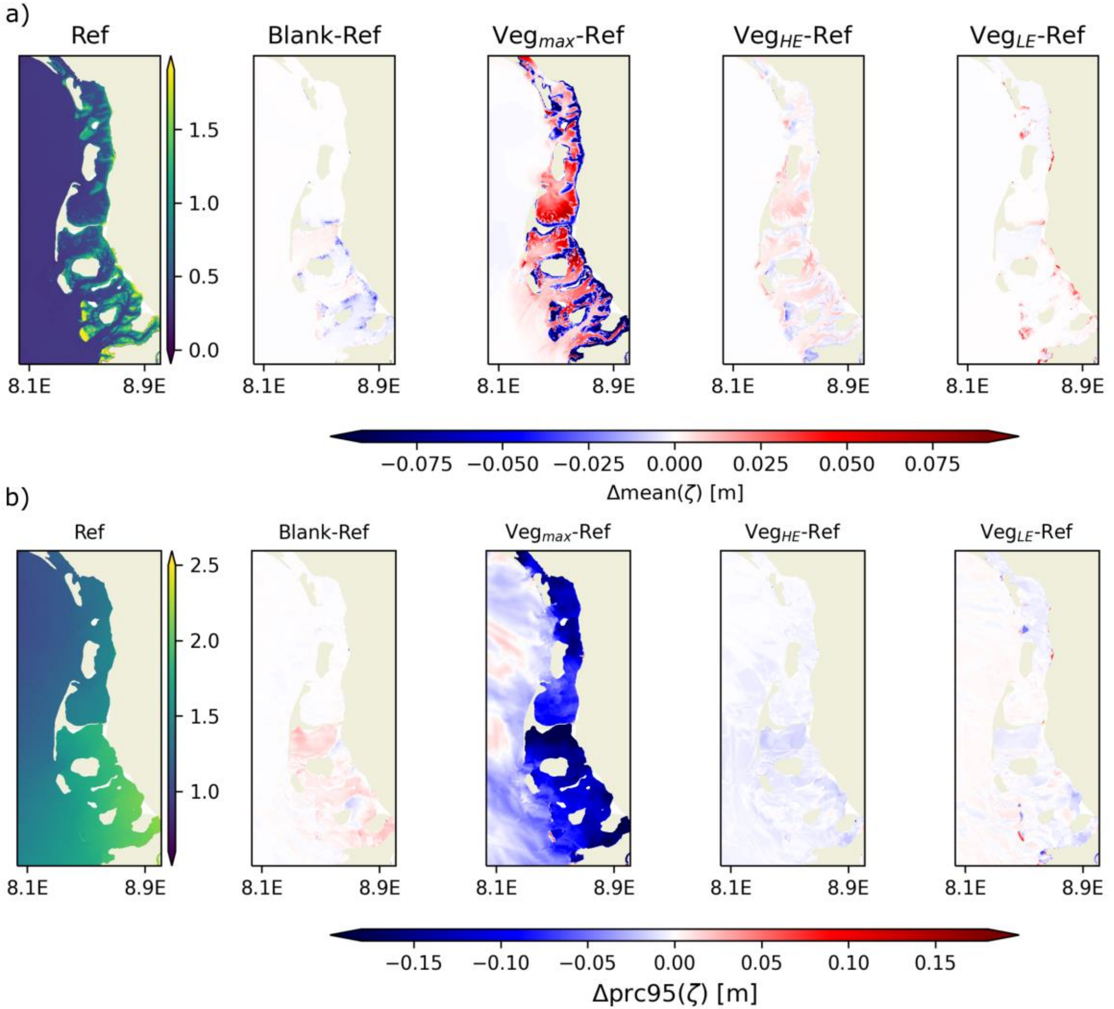
- The presence of a seagrass meadow reduces currents by ~50% and bottom layer SPM ~30%.

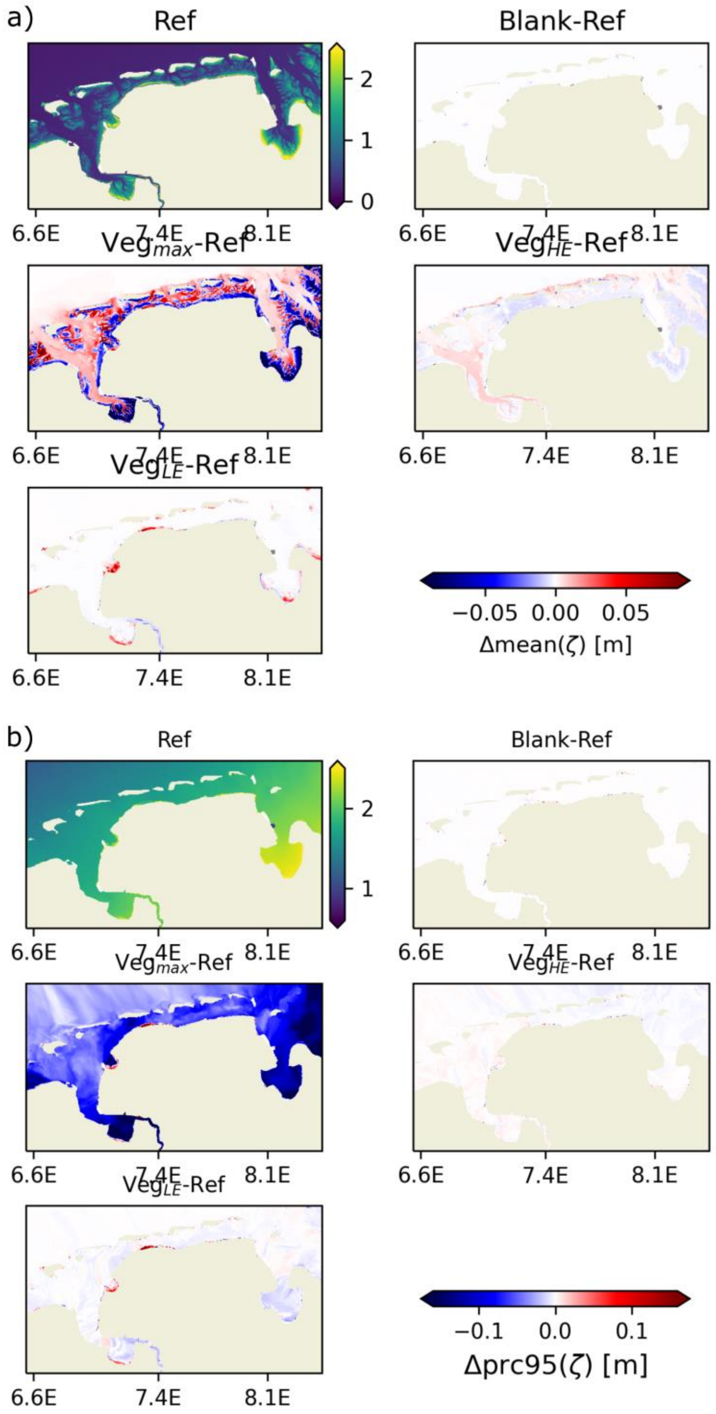
- TKE increases above canopy layer (20 cm)



Results – Elevation

- Weak ssh response (mm-cm)
- Sparse vegetation increase average sea level locally
- Extremes are dampened
- Extensive seagrass meadows are needed to impact sea level



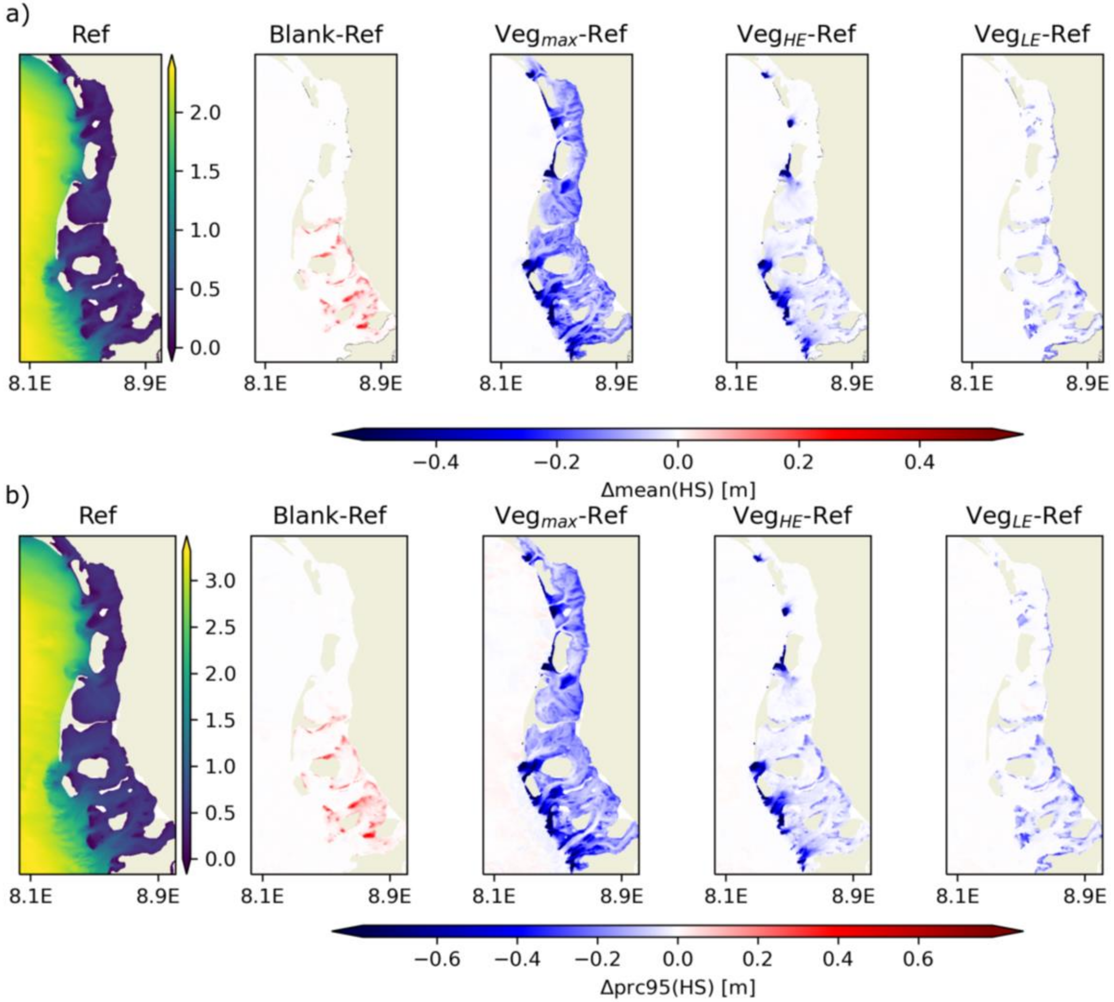


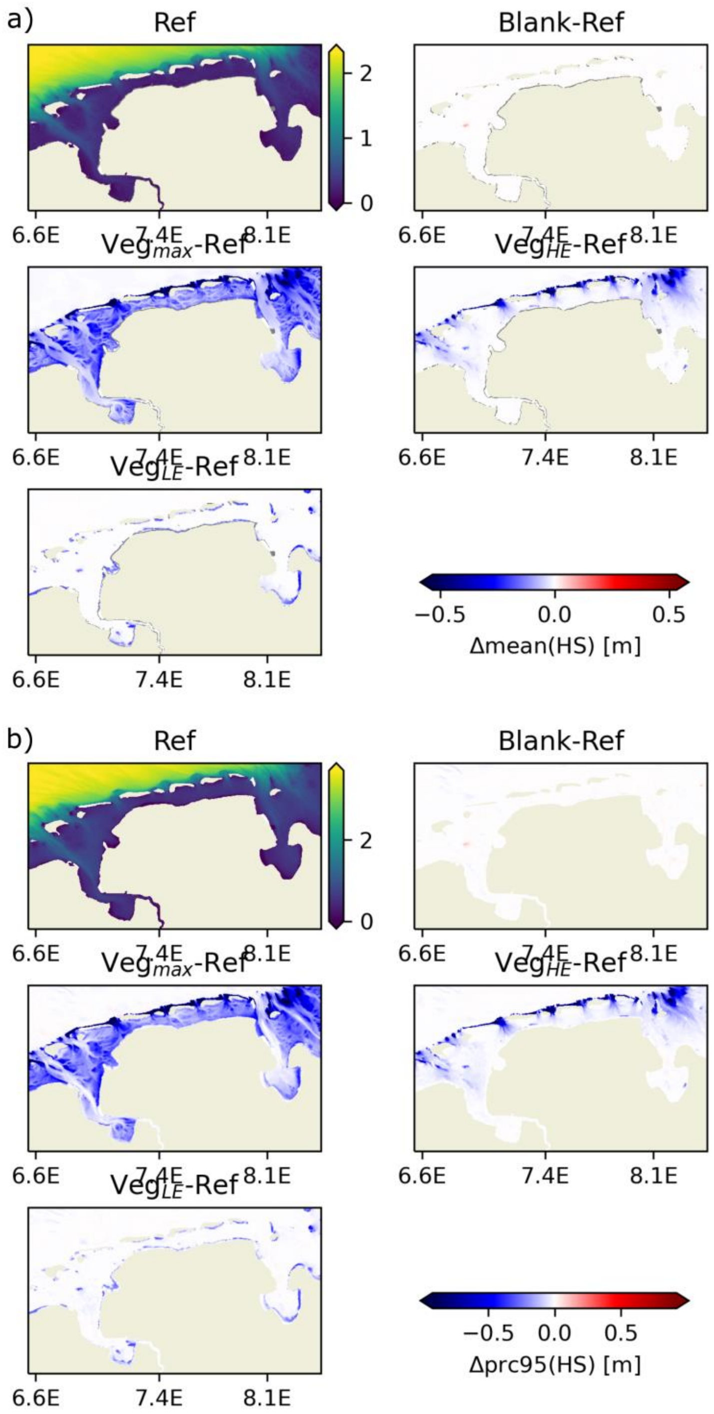
Results – Significant Wave Height

- Seagrass in present day extent scenarios range between 20 to 40cm

- Reductions in HS can succeed 0.5m for seagrass recovery in the deep inter tidal.

- HS reduction reaches 20% in deeper intertidal and over 50% in regions deeper than 1m.

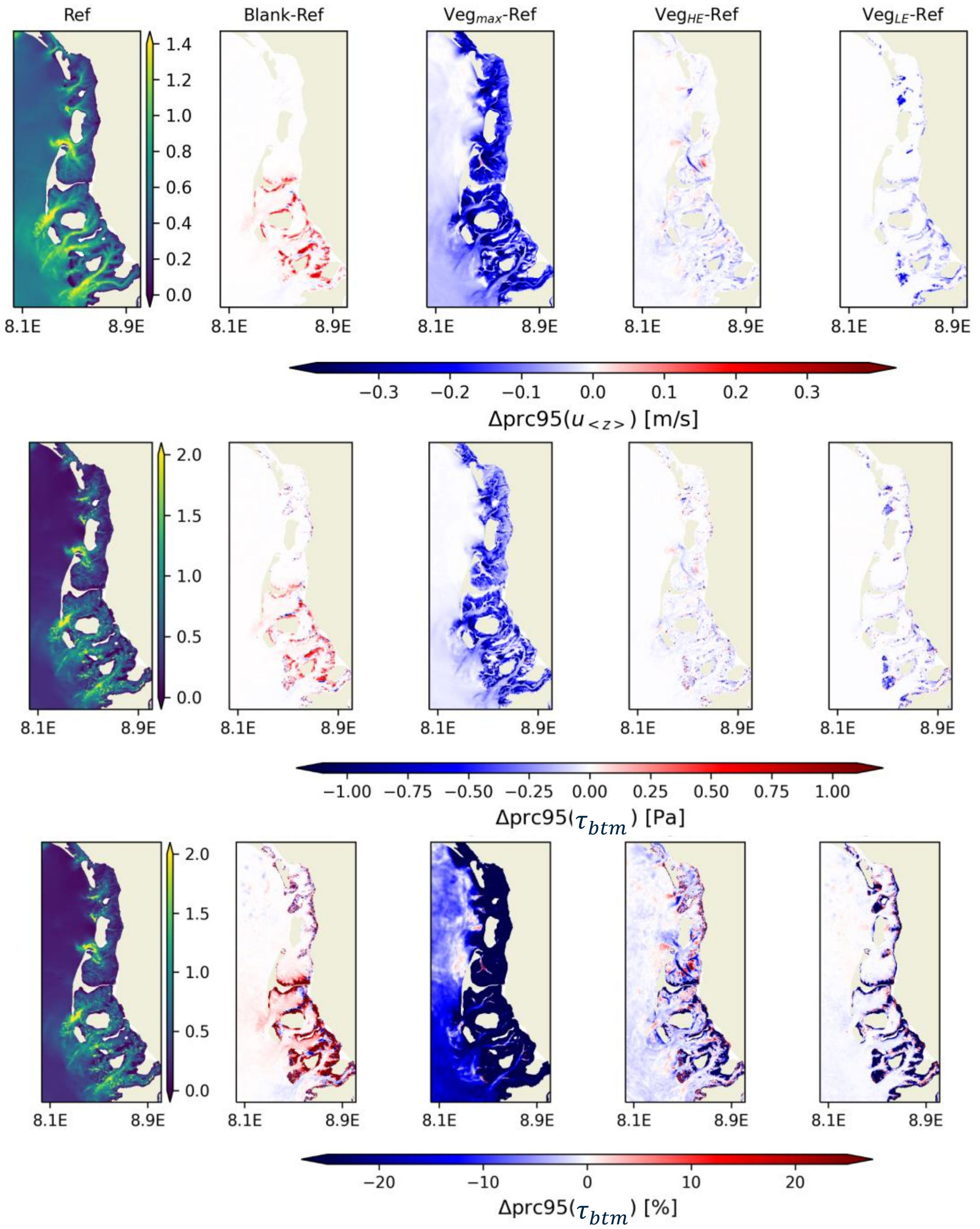


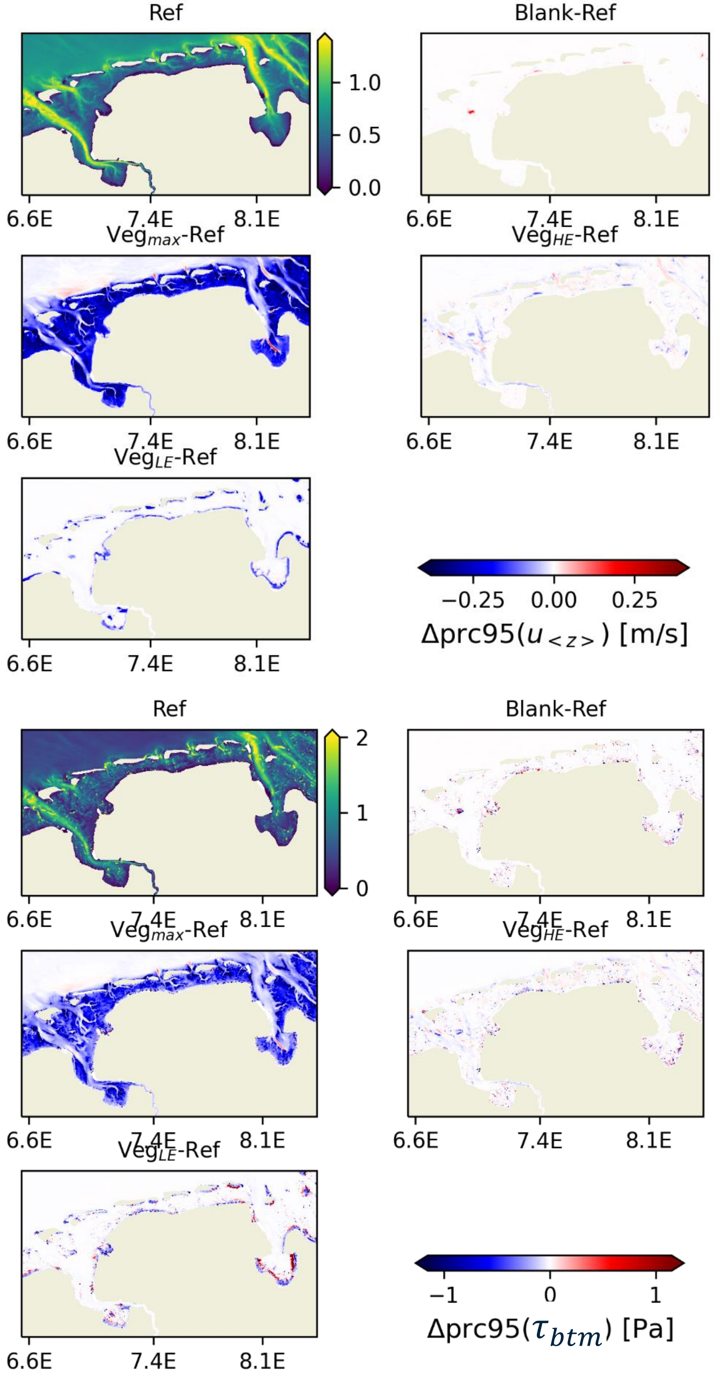


Results – Depth-averaged horizontal velocity

- Effective local attenuation of velocities

- associated bottom stress reduction widely succeeds 20-30% in deeper Wadden Sea area and above 80% in shallow regions.





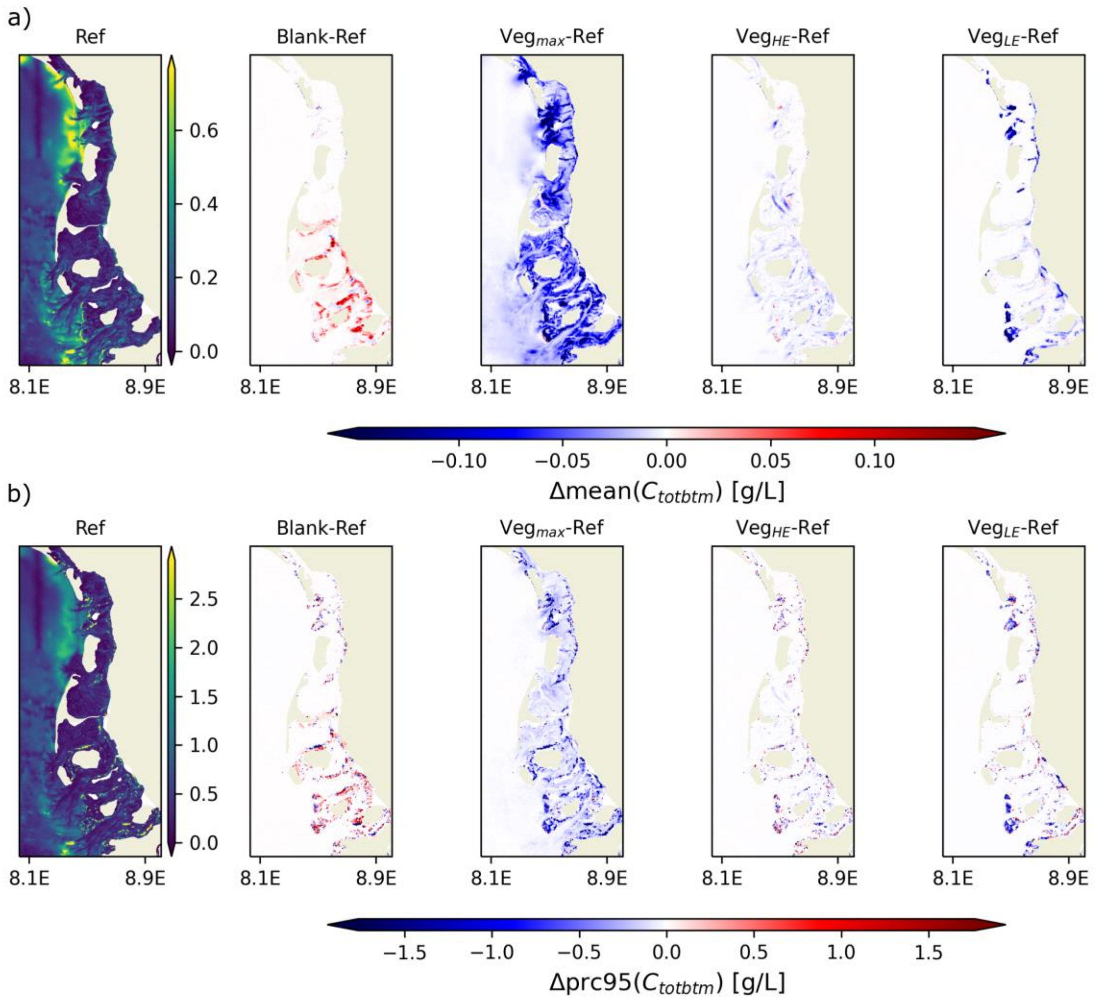
Results – Sediment concentration

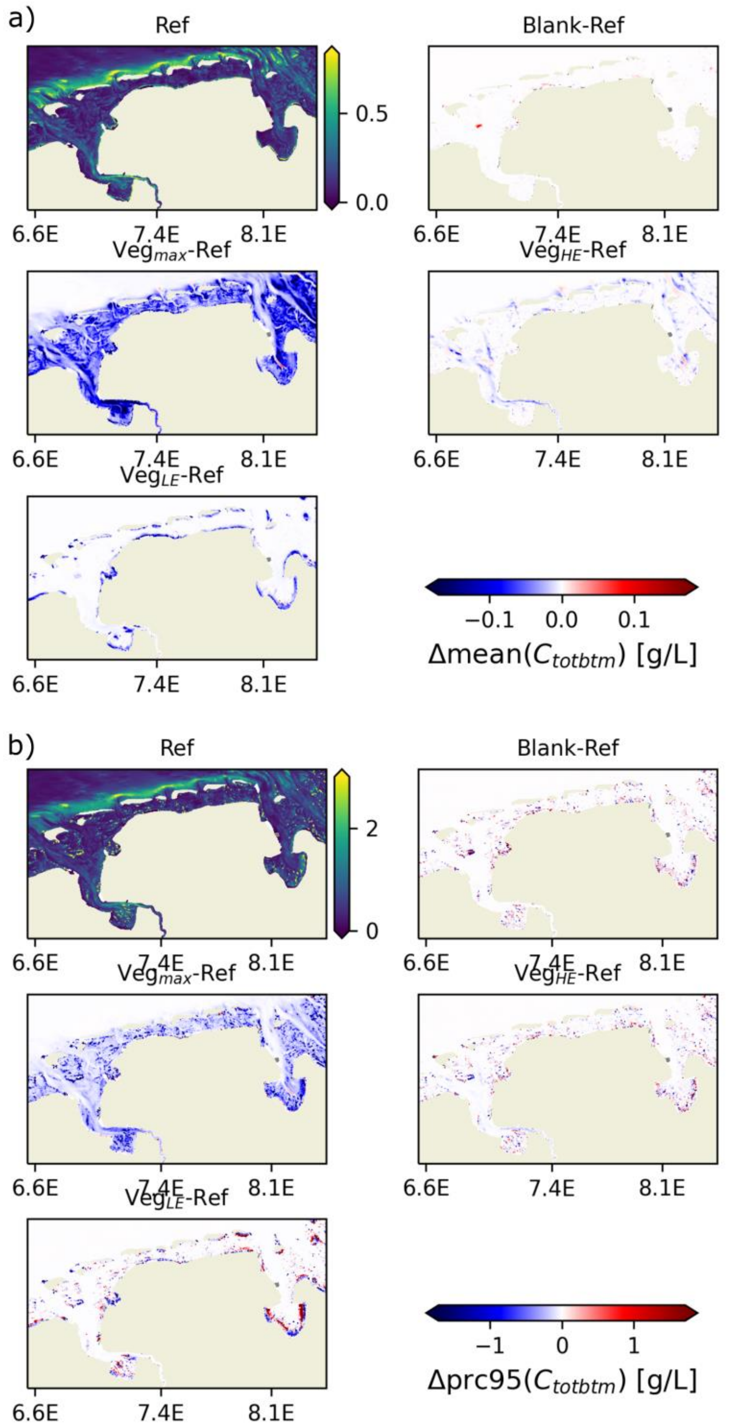
- Reduction in bottom concentrations in the order of a few cg/L - dg/L

- Locally reductions can reach > 1 g/L.

- Depending on depth the attenuation ranges between 20 and 90%.

- Seagrass is most effective in extensive shallow meadows.





Conclusions

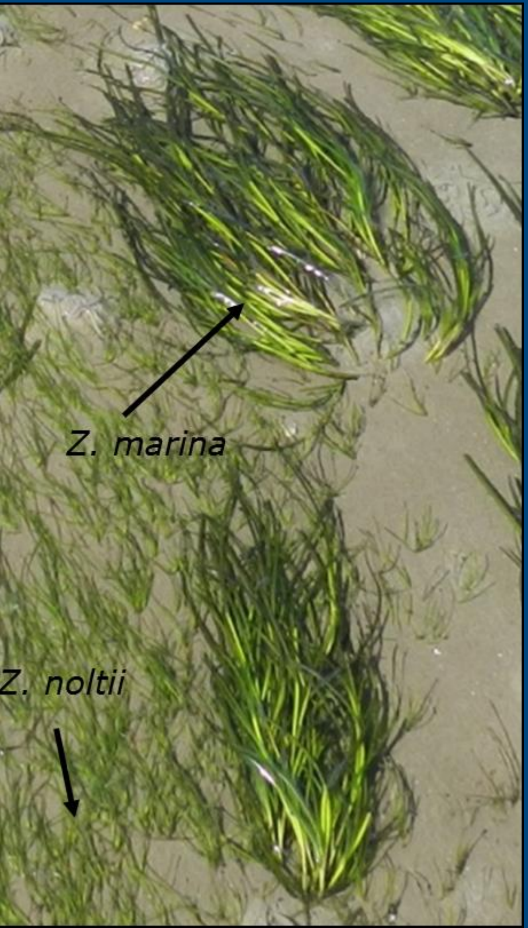
- The impact of expanded coastal vegetation was analyzed using a coupled model for the German Bight. Analysis of monthly average and 95th percentile demonstrated:
    - only a weak impact on sea surface elevation
    - strong attenuation of currents and waves (20-80%).

- Results for EFWS and the NFWS are fundamentally similar, as both systems are subject to similar physical conditions; the higher seagrass coverage in the NFWS already provides already some limited erosion protection.

- The reduction in bottom stress greatly reduced local sediment concentration, suggesting an **effective coastal erosion protection**:

- The potential of seagrass to support the vertical height growth of the Wadden Sea to maintain bathymetric control under future increases in sea level is seen as the major long-term contribution of seagrass to coastal protection.

Thank you for your attention!



We thankfully acknowledge the projects

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Jacob, B., Dolch, T., Wurpts, A., Staneva, S. (2023, under revision). Evaluation of seagrass as a nature based solution for coastal protection in the German Wadden Sea. *Ocean Dynamics*

Benjamin.Jacob@hereon.de