Deltares

Modelling long-term morphological development of the NL Wadden Sea

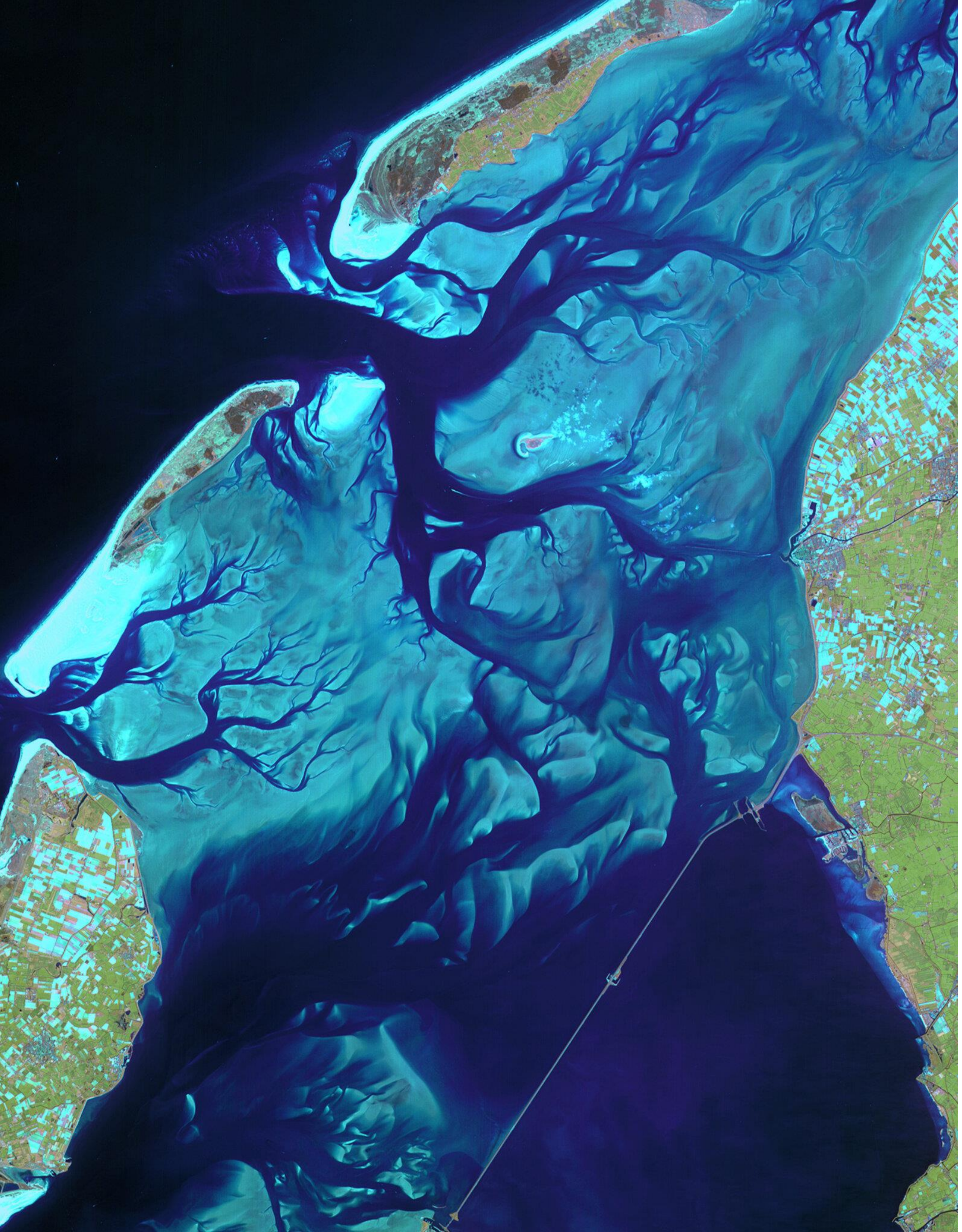
Application and development of the aggregated model ASMITA

Ymkje Huismans, Carola Seyfert, Zheng Bing Wang

Quirijn Lodder, Bert Jagers, Edwin Elias, …

Content

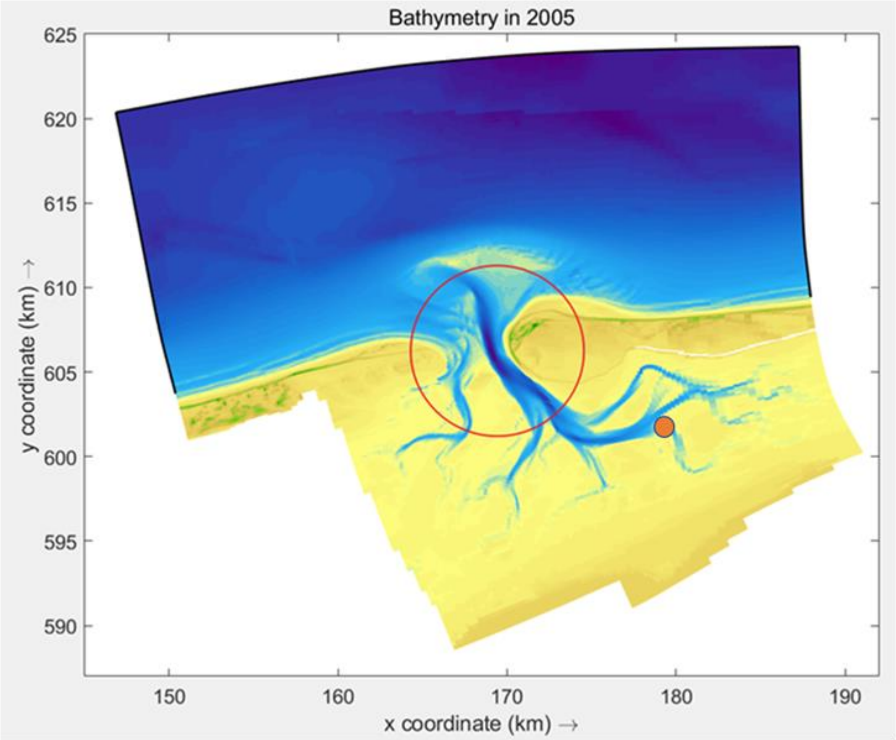
- Introduction various modelling approaches
- Application ASMITA models for the Wadden Sea
- Model development / improvement ASMITA
  - Implementation of mud
  - Extension with saltmarsh element
  - Calibration
- Hybrid model Delft3D-ASMITA
  - Model formulation
  - Implementation
  - First applications
  - Future plan
- Concluding discussions & outlook



Modelling approaches for long-term morphological development in tidal systems

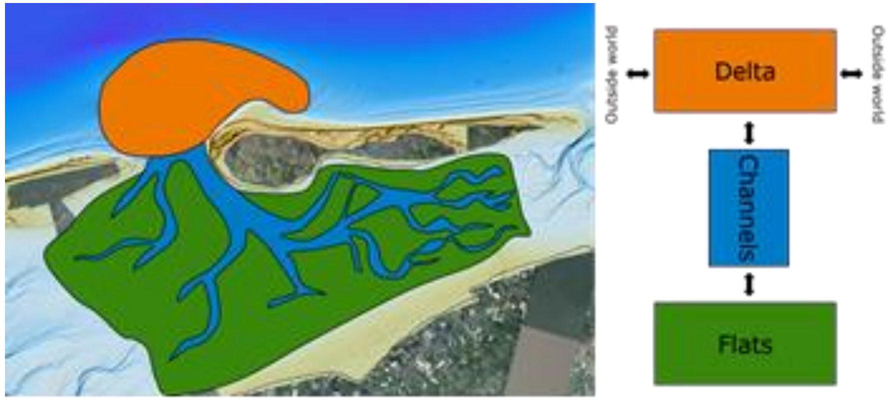
Two existing modelling approaches

Delft3D



ASMITA

(Aggregated Scale Morphological Interaction between Tidal basin and Adjacent coast)

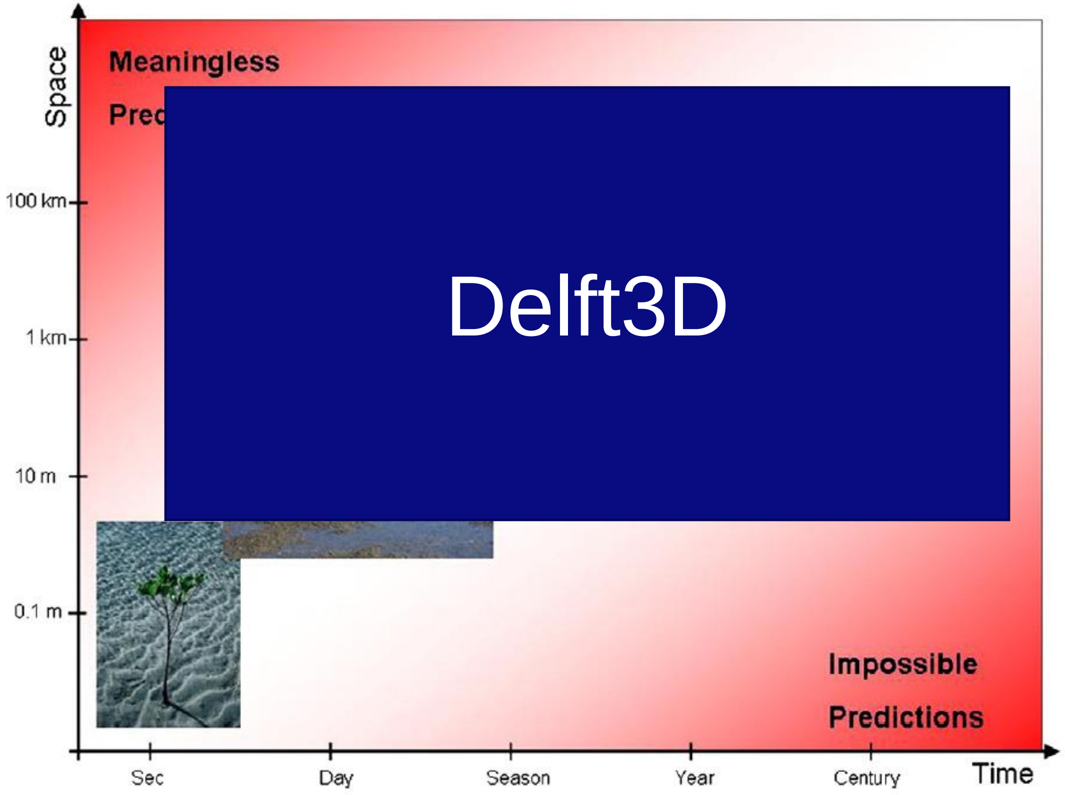


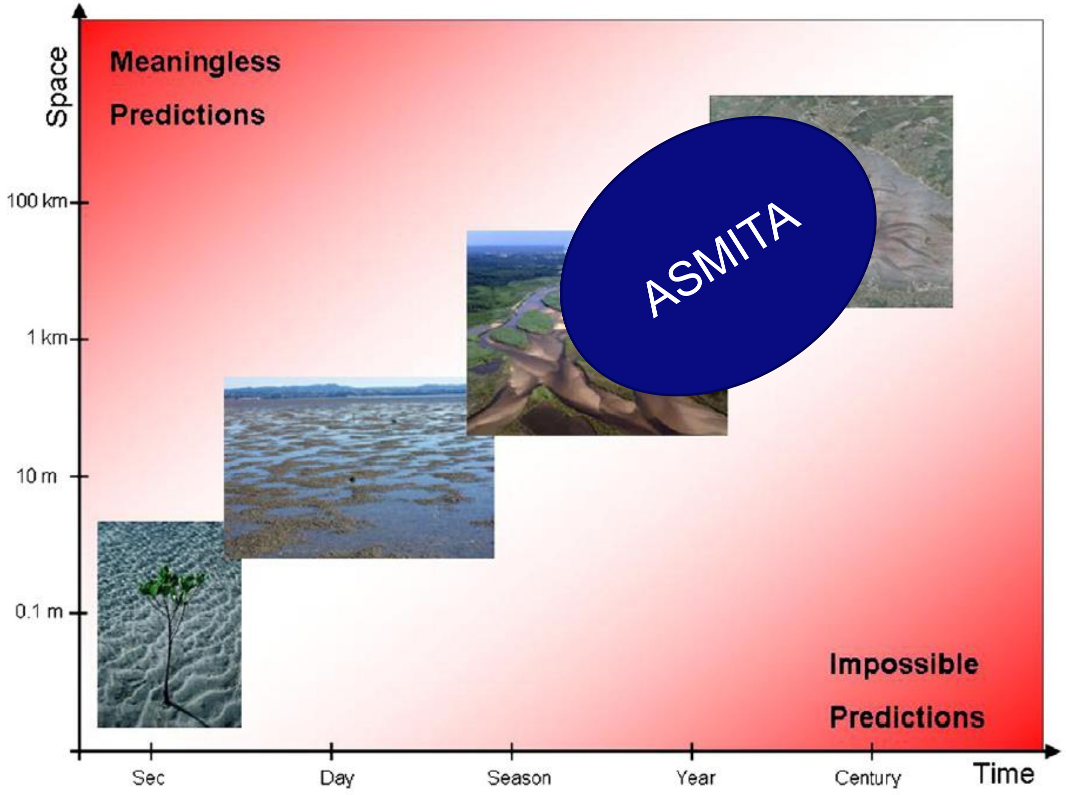
Various types models

- Process-based vs (semi-) empirical
- Detailed vs Aggregated
- Complex vs Reduced complexity

- Realistic vs Idealized

Predictability morphodynamics related to scales & modelling approaches





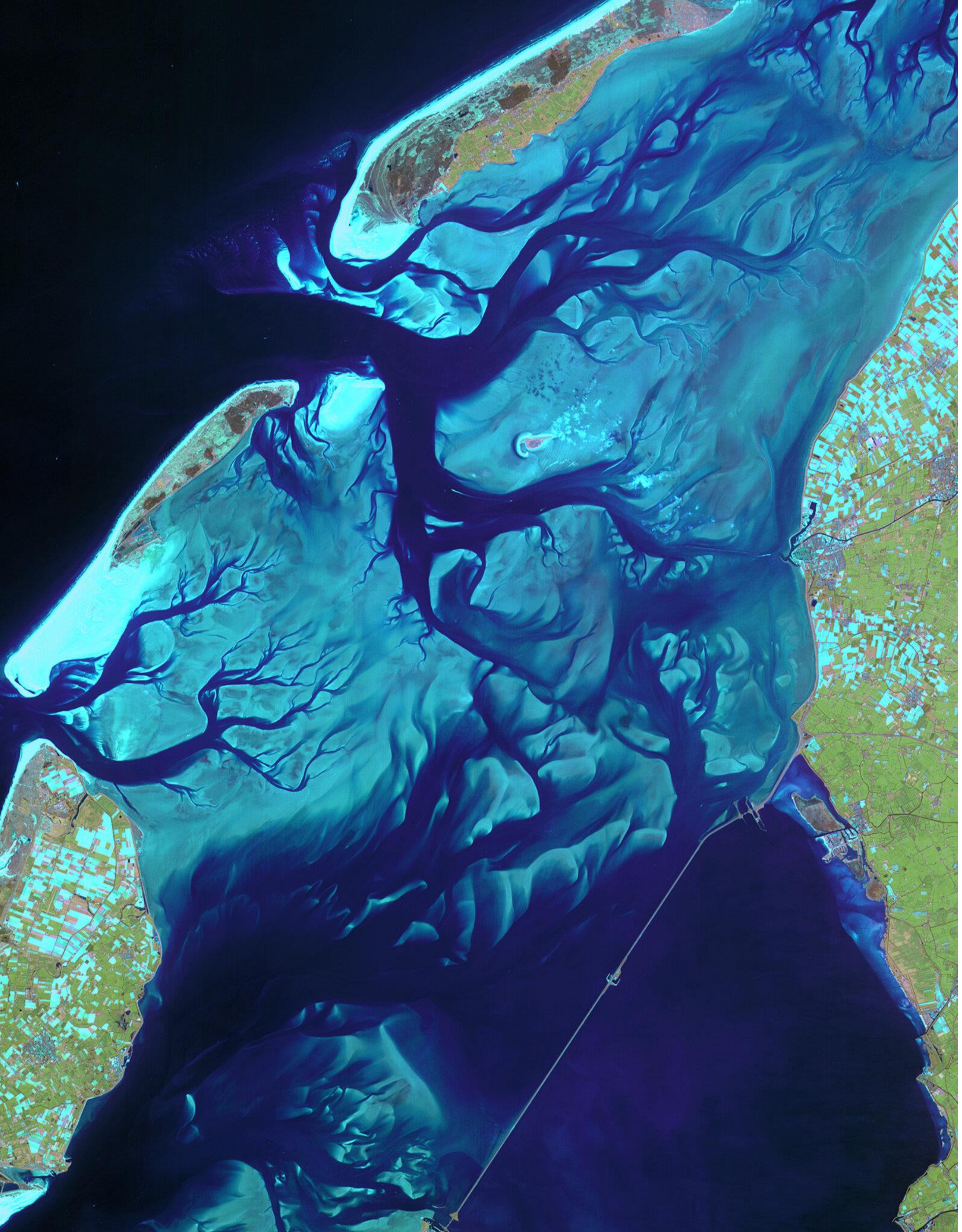
History model development at Deltares (/Delft Hydraulics)

- Morphostatic models based on hydrodynamic model from others
- TRISULA – DelMor
- Delft3D-MOR
- Delft3D-RAM
- Delft3D-SedOnline
- Mormerge
- Delft3D FM / D-Morphology

1989

2024

- EMPREL
- ESTMORF
- ASMITA
- Delft3D-ASMITA



ASMITA
application to Wadden Sea

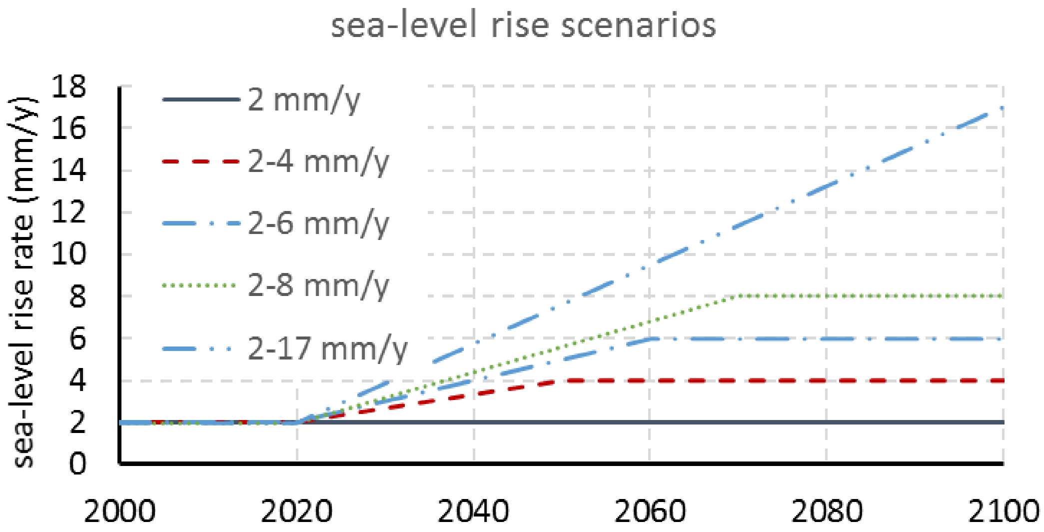
- Sediment exchange between North Sea and Wadden Sea
- Development of intertidal areas under various rates of SLR

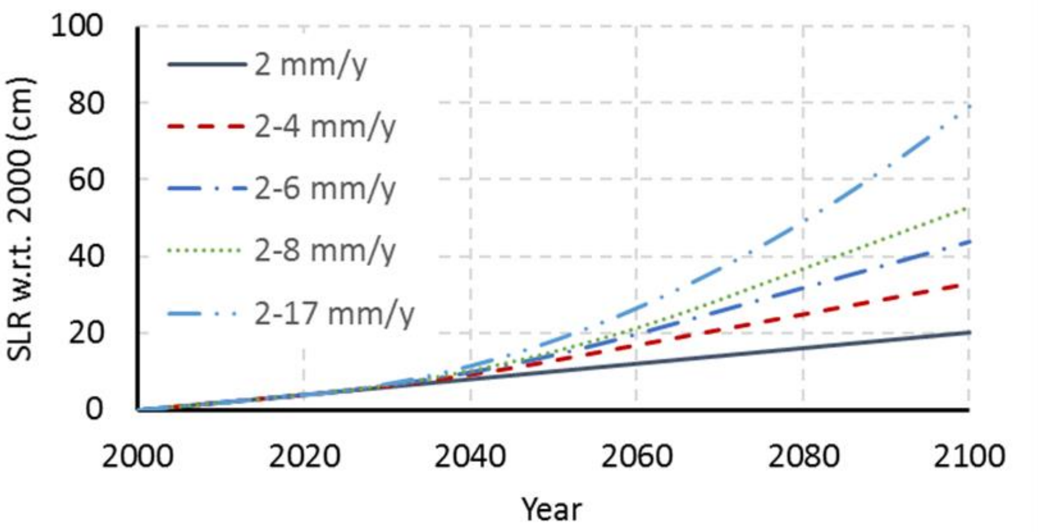
ASMITA history

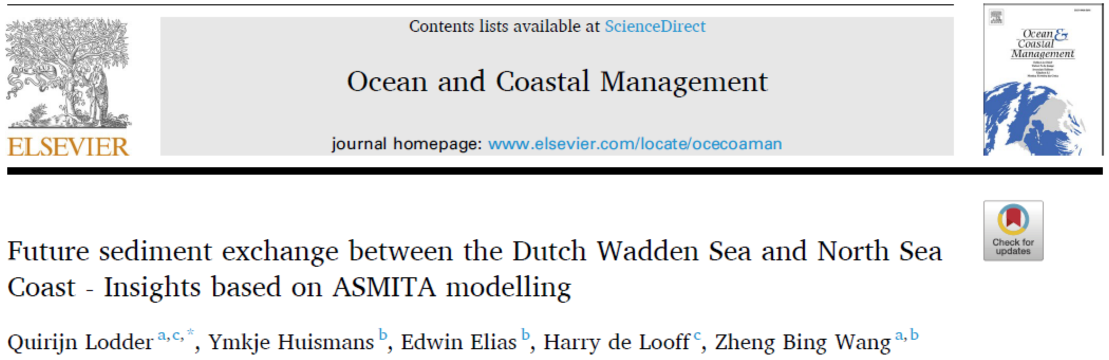
- Developed since end last century
- First applied in the EIA study for gas mining
- Evaluation effect of SLR (van Goor e.a., 2003)
- Morphological time scales (Kragtwijk e.a., 2004)
- Integrale bodemdalingsstudie
- EIA salt mining
- PONTOS-ASMITA
- Applications elsewhere (than NL Wadden Sea)

- Kustgenese 2.0 (Lodders e.a., 2019, 2023; Huismans e.a., 2022)
- ZSS Zandige kust
- …

Response to sea level rise







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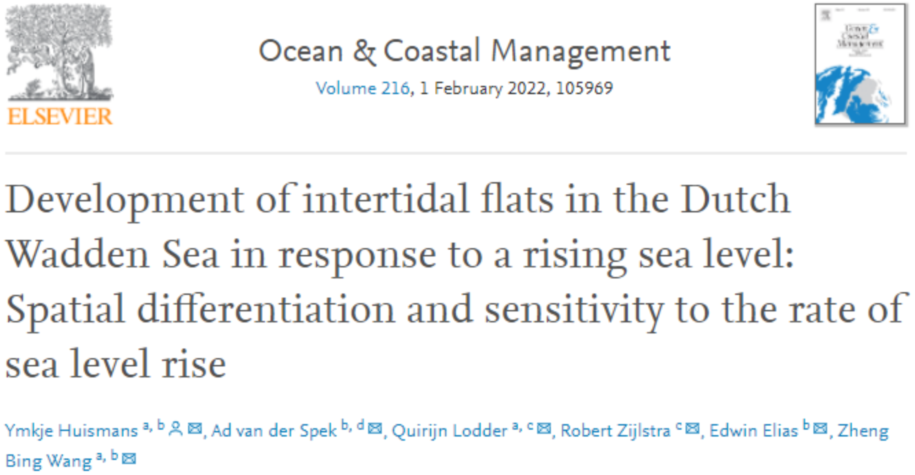
Future sediment exchange between the Dutch Wadden Sea and North Sea Coast - Insights based on ASMITA modelling

Quirijn Lodder [a,c,*], Ymkje Huismans [b], Edwin Elias [b], Harry de Looff [c], Zheng Bing Wang [a,b]



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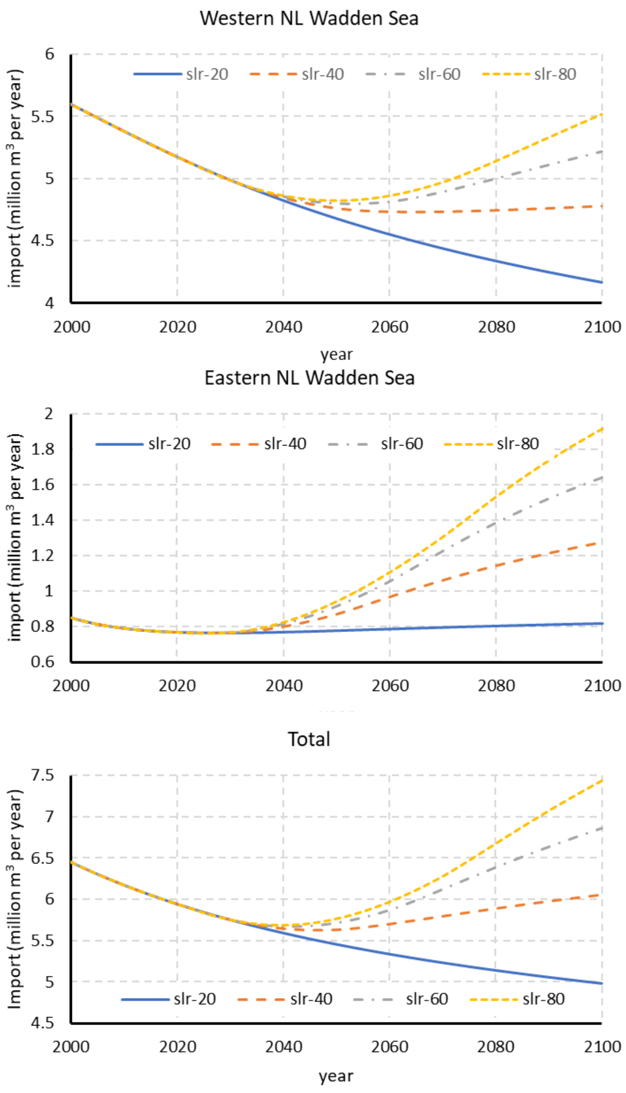
Development of intertidal flats in the Dutch Wadden Sea in response to a rising sea level: Spatial differentiation and sensitivity to the rate of sea level rise

Ymkje Huismans [a, b], Ad van der Spek [b, d], Quirijn Lodder [a, c], Robert Zijlstra [c], Edwin Elias [b], Zheng Bing Wang [a, b]

Modelling for future transport to Wadden Sea
(Lodder e.a., 2023)

- Delayed response to acceleration SLR
- Different responses by the different tidal inlet systems due to
  - Difference in size of the system, thus in morphological time scales
  - Difference in morphological state with respect to equilibrium
- The differences in the projected import rates between the five sea level rise scenarios until 2100 are not as large as the differences in sea level rise rates may suggest.
- The projected increase of the import rate until 2100 with respect to the present situation (2020) is significant but not substantial.



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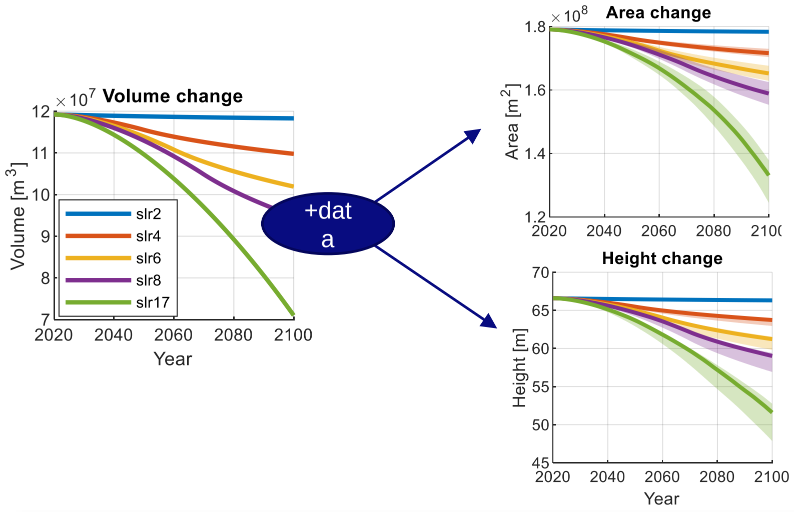
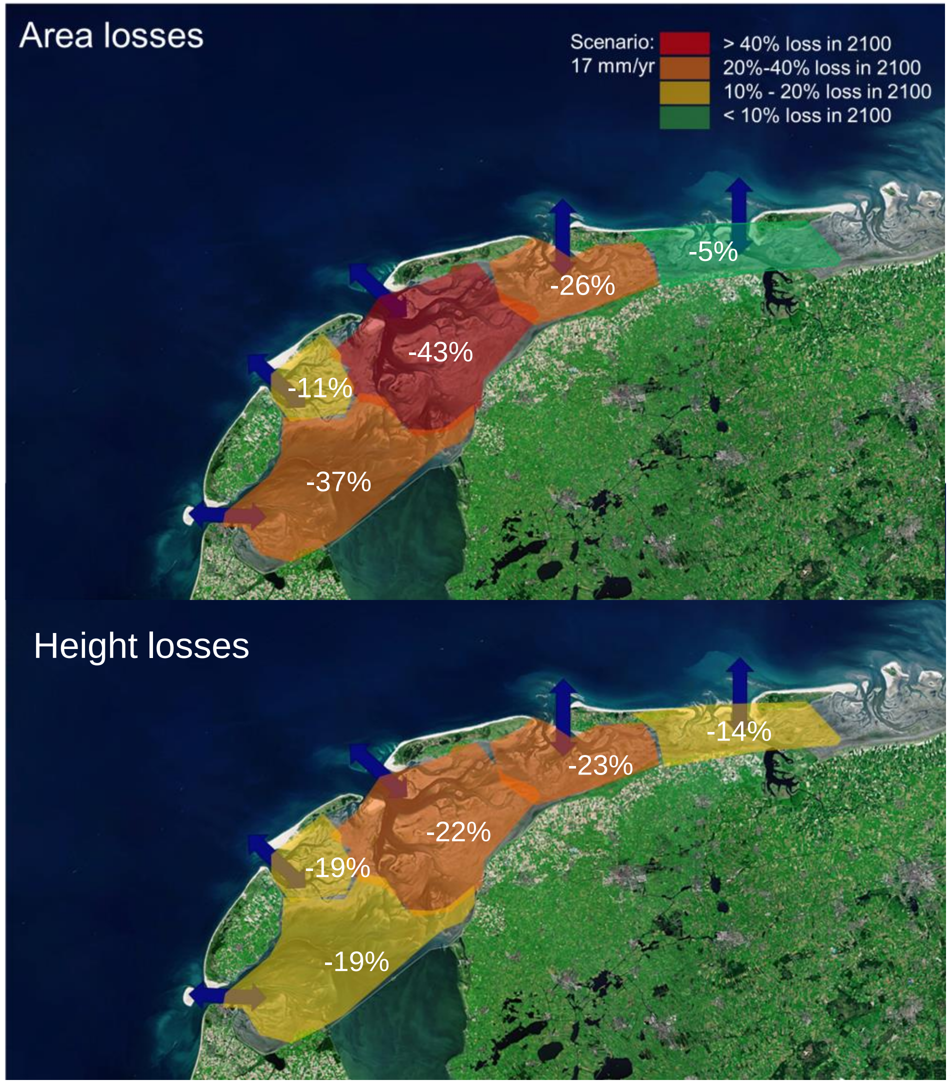
Effect on the tidal flats (Huismans e.a. 2022)





Highlights

- Sensitive to the rate of sea level rise: 2x SLR rate → ~2x losses
- Intertidal flats larger basins most vulnerable.
- Larger basins: area, smaller basins: height.
- Largest losses in areas furthest from inlet.
- Texel and Vlie: 40% loss in area for 17mm/yr in 2100

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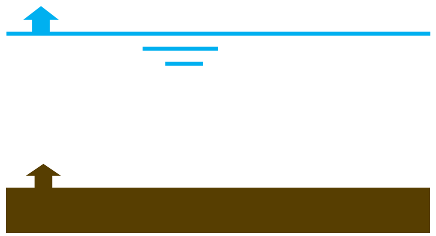
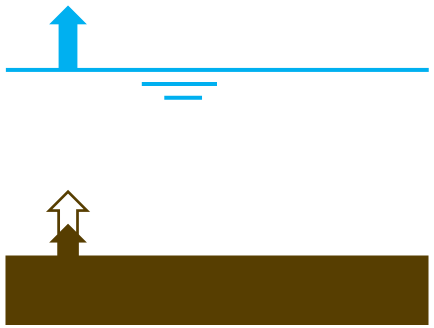
Effect of SLR

Keeping pace
-- No losses



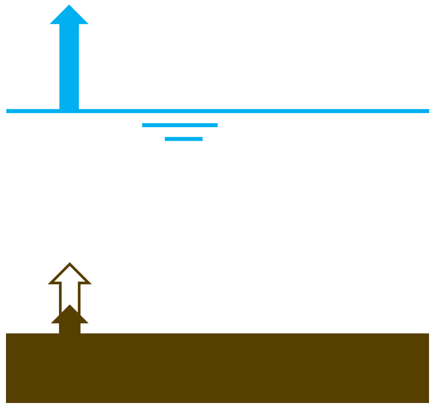
Sea level rise rate ≈
Sedimentation rate

New equilibrium
-- Losses



Sea level rise rate >
Sedimentation rate (initially)

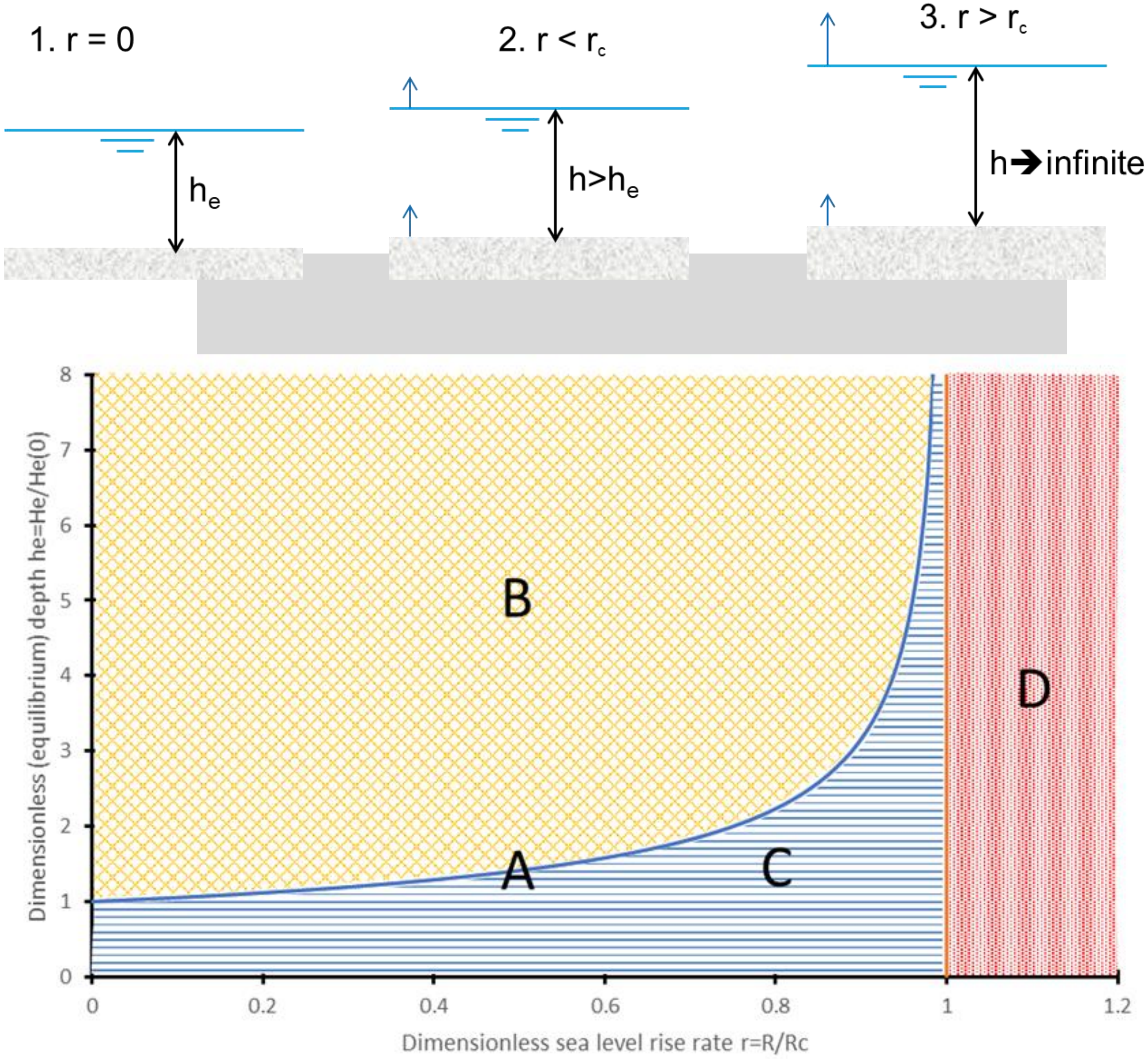
Drowning
-- on the scale of centuries



Sea level rise rate >
Sedimentation rate

Insights from theoretical analysis

- Dynamic equilibrium only if SLR rate lower than a critical level
- Critical SLR rate different for different tidal inlet systems
- Dimensionless SLR rate (= SLR rate / critical SLR rate) determines the development. Different parts of the Wadden Sea will show different response to accelerated SLR
- Time to achieve dynamic equilibrium increases non-linearly with SLR rate
- Similar (drowning) behaviour for SLR rate above ~80% of critical level
- Linear behaviour for SLR rate below ~40% of critical level



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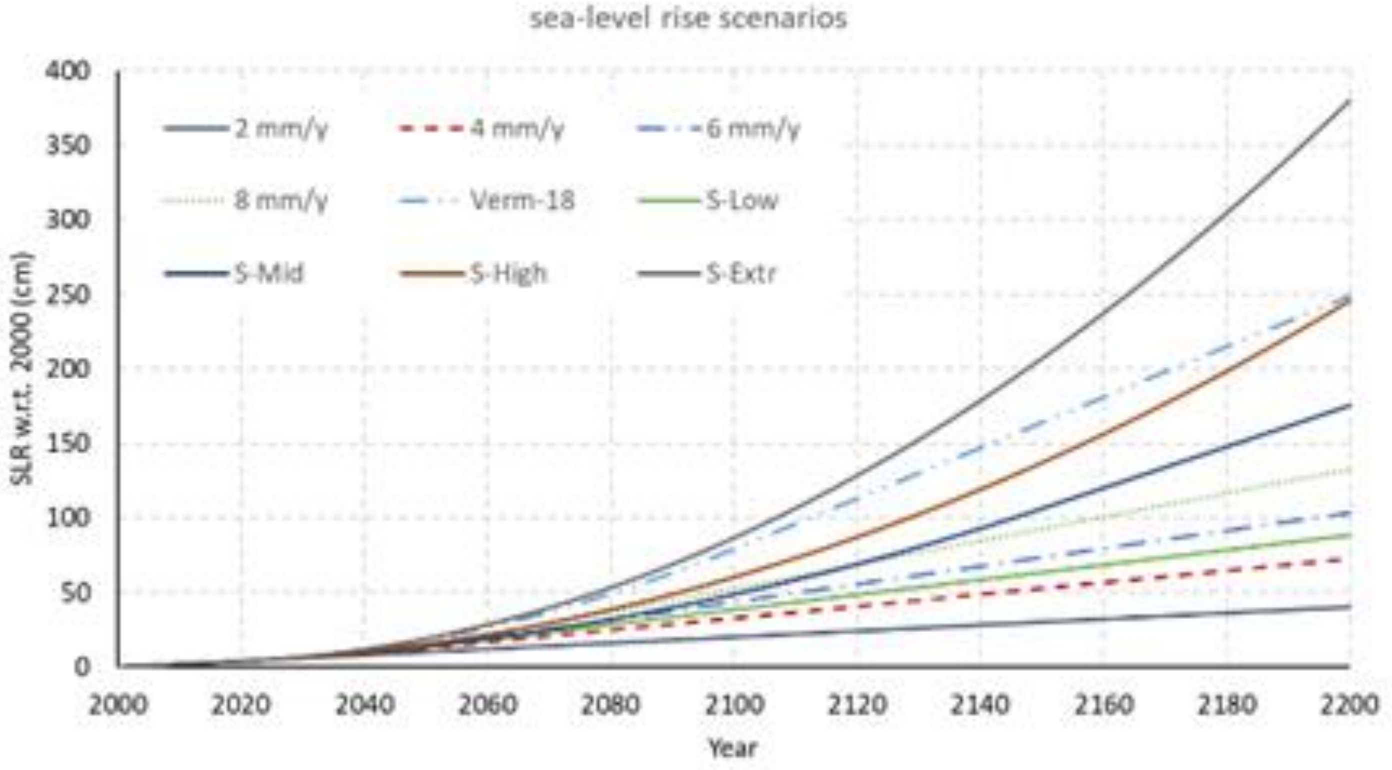
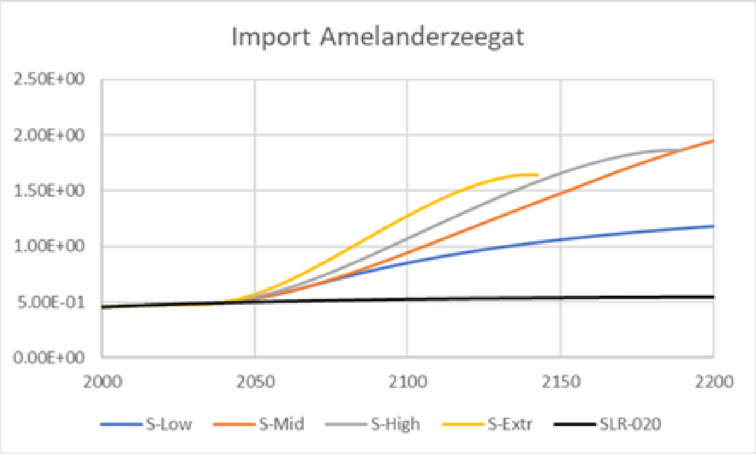
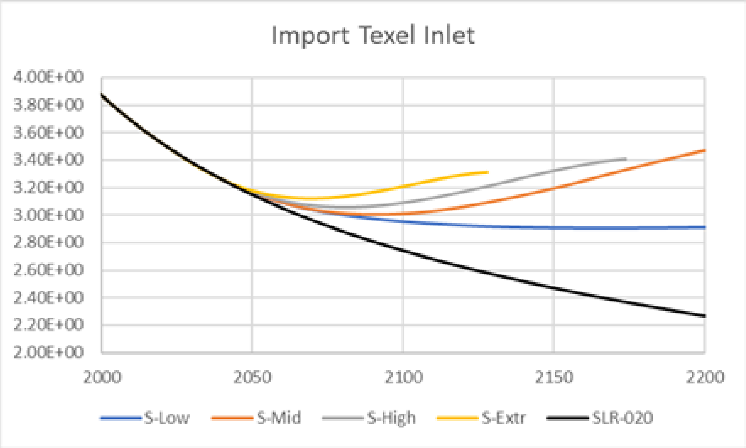
More extreme SLR scenarios & Simulations for new scenarios till 2200

Predict the bathymetry of the Wadden Sea after 1m, 2m and 5m SLR, to determine the hydraulic boudary conditions for flood defense design



Simulated sediment import to Wadden Sea





- The import rate develops to a maximum when drowning occurred.
- The maximum value depends on SLR development. Higher maximum value for lower SLR scenario (causing later drowning)
- The maximum import just before drowning is thus not the transport capacity of the system.

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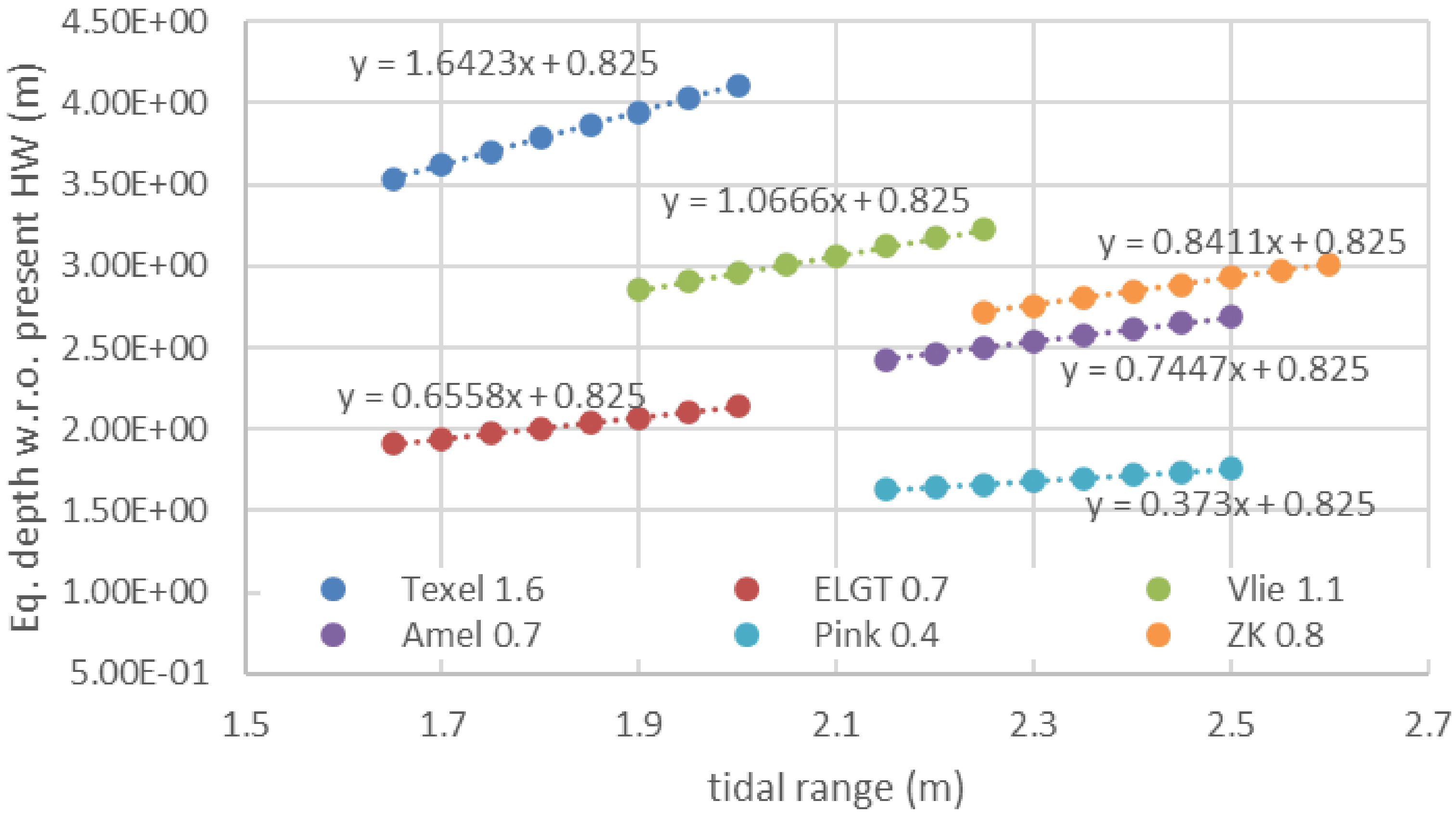
Effect of tidal range change

Increase of tidal range reduces sediment demand in the Wadden Sea



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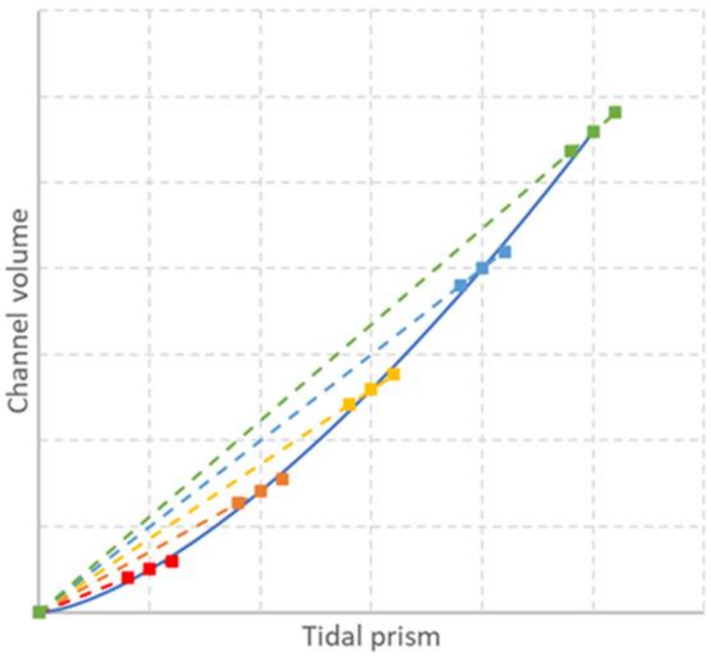
Empirical relation for the equilibrium channel volume What should be used in ASMITA ?

$$V_c = A_c L_c \propto P^{1.5}$$

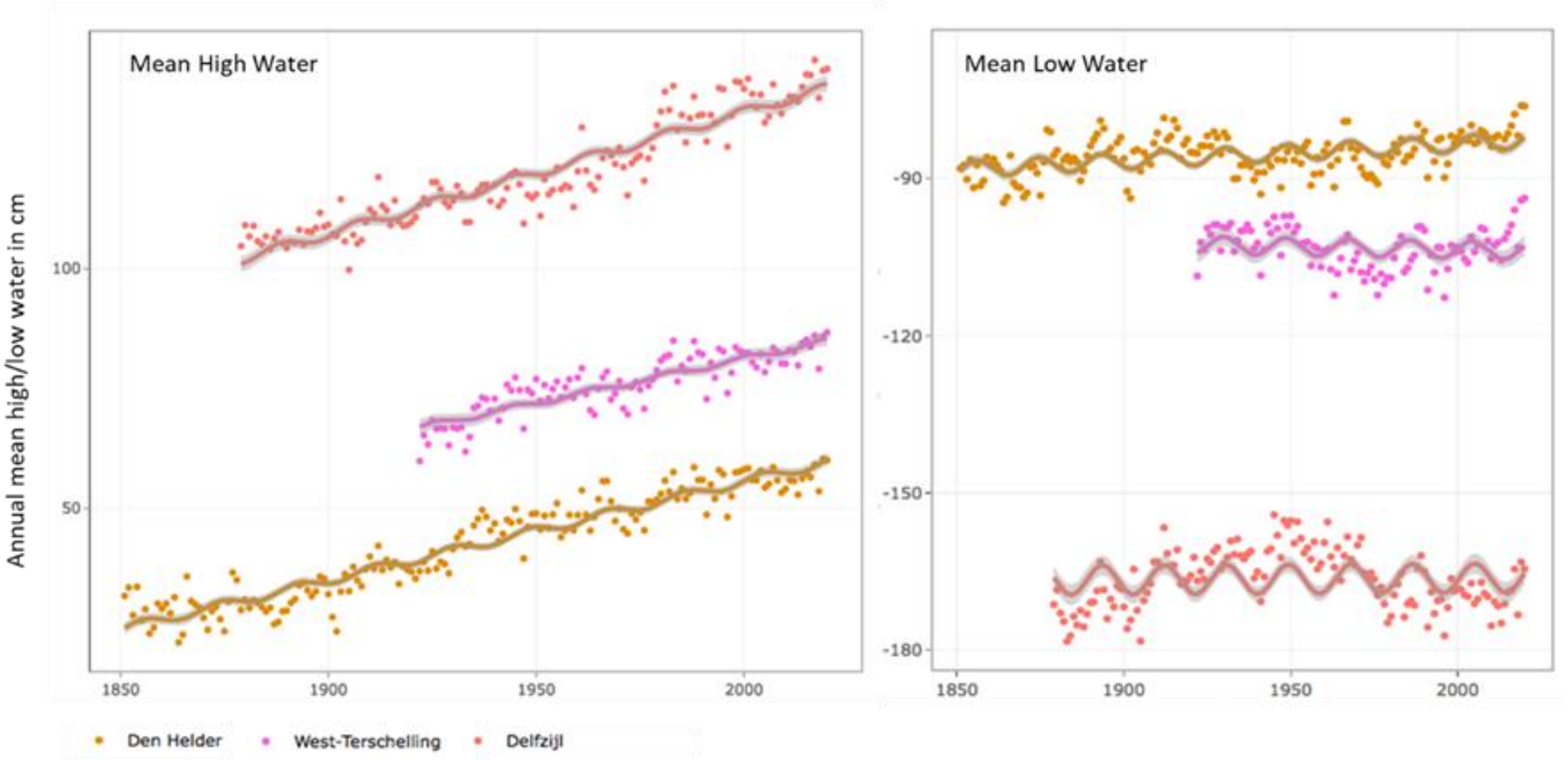
$$A_c \propto P \quad L_c \propto \sqrt{A_b} \propto \sqrt{P}$$

- Channel volume proportional to a power around 1.5 of tidal prism, derived from field data of **various** tidal basins
- The 1.5th power is supported by theoretical consideration based on geometric law

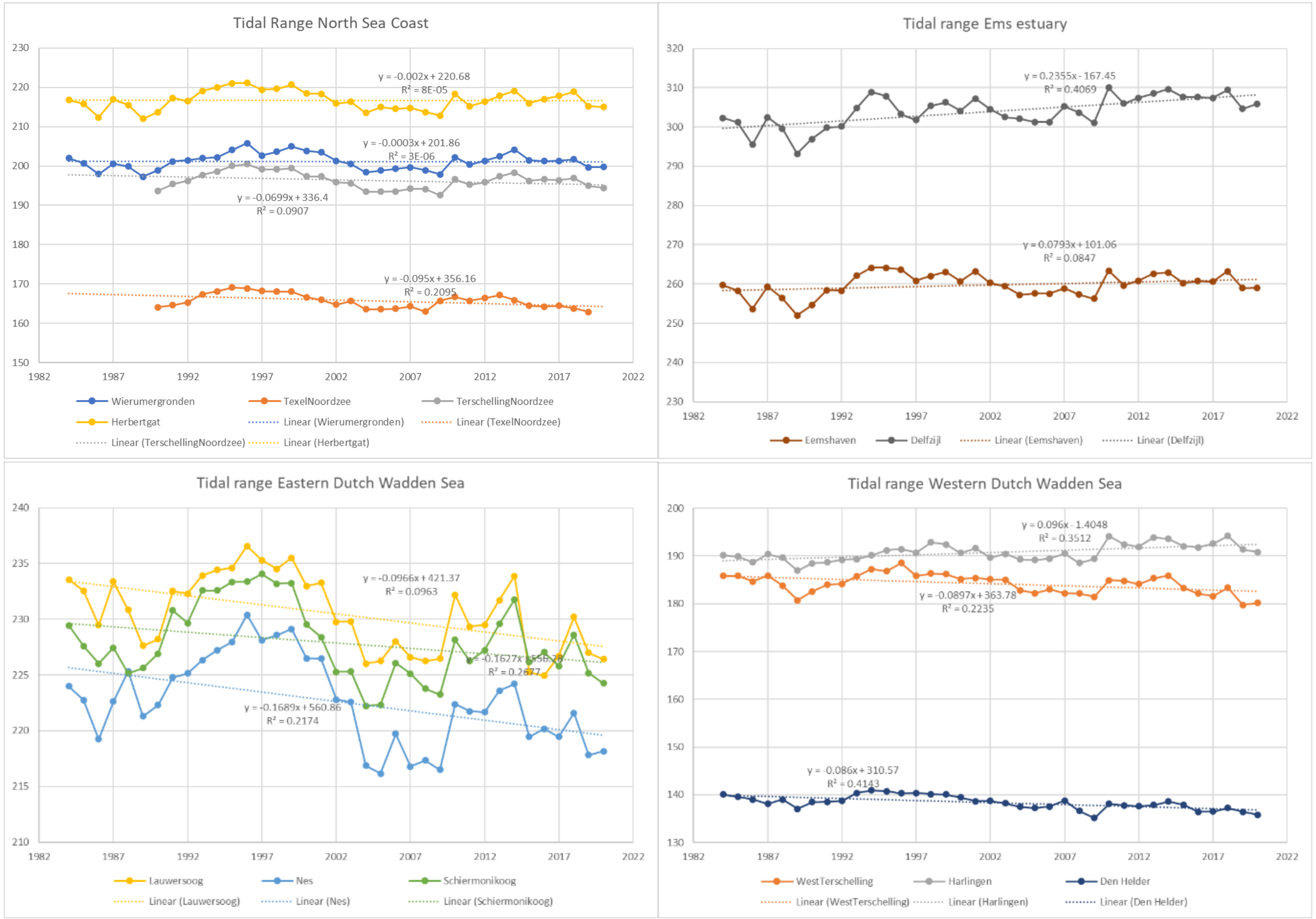
- However, this relation should not be used in the (present) ASMITA models!
- A linear relation between equilibrium channel volume and tidal prism is used.



LT development tidal range



SLR ➔morphological development ⇔ tidal range change



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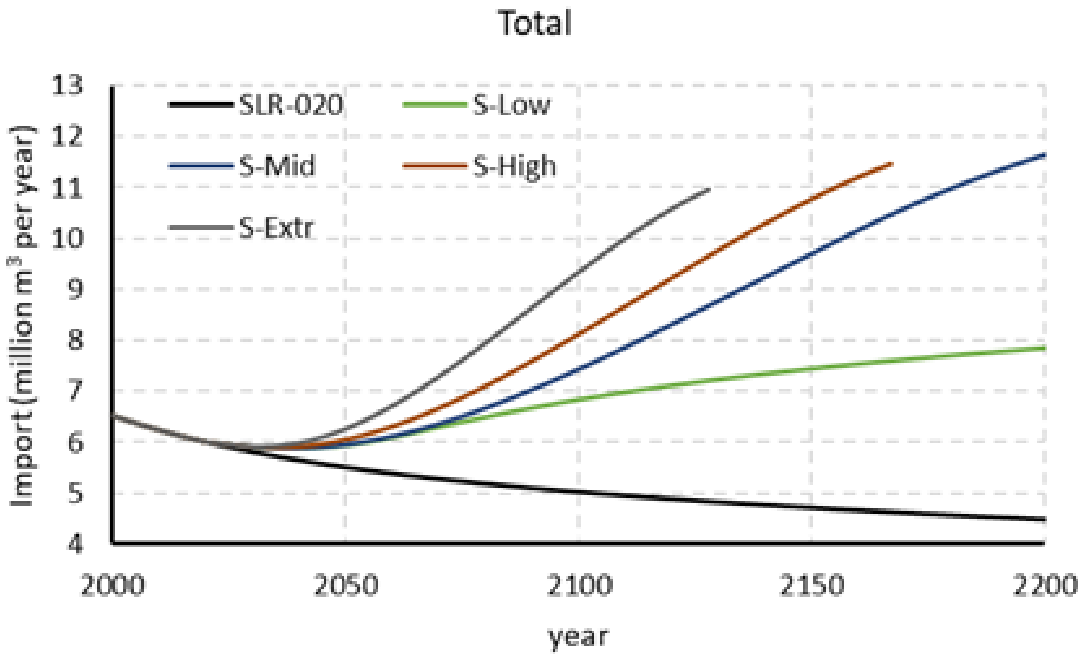
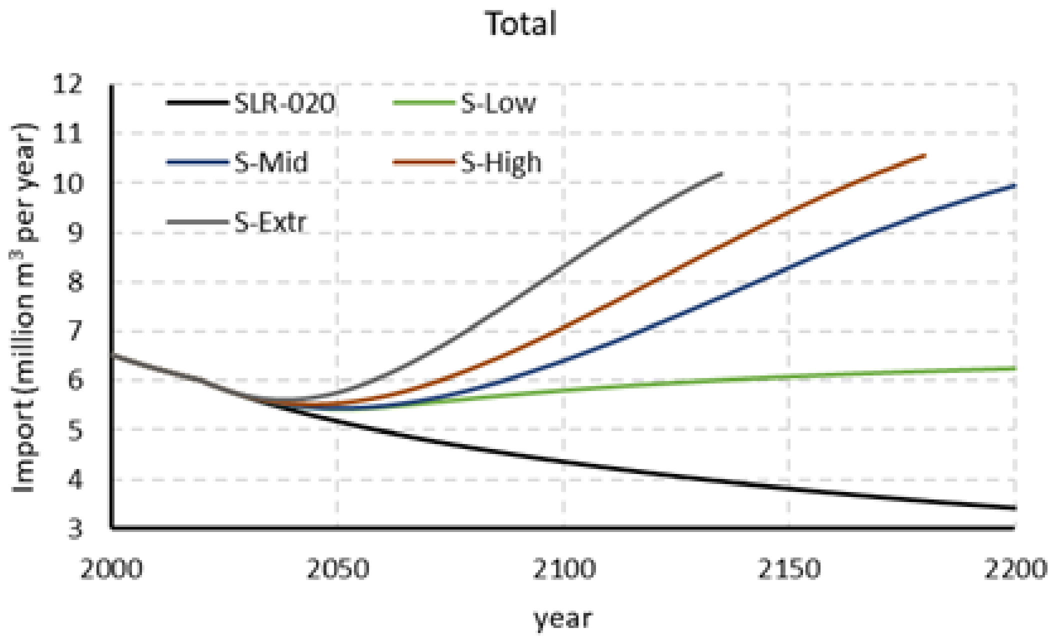
Projected sediment import to NL Wadden Sea



Constant tidal range



Increasing tidal range

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Update critical SLR for drowning

$$R_c = \frac{C_E}{\dfrac{1}{w_{sf}} + \dfrac{S_f + S_c + S_d}{\delta_{od}} + \dfrac{S_f + S_c}{\delta_{dc}} + \dfrac{S_f}{\delta_{cf}}}$$

Bekken	Marsdiep	Eierlandse Gat	Vlie	Amelander Zeegat	Pinkegat	Zoutkamper-laag
C_E (-)	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002
w_{sf}(m/s)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
S_f (km^2)	133	105	328	178	38.1	65
S_c (km^2)	522	52.7	387	98.3	11.5	40
S_d (km^2)	92.53	37.8	106	74.7	34	78
δ_{od} (m^3/s)	1550	1500	1770	1500	1060	1060
δ_{dc} (m^3/s)	2450	1500	2560	1500	1290	1290
δ_{cf} (m^3/s)	980	1000	1300	1000	840	840
R_c (mm/jr)	**7,0**	**18,0**	**6,3**	**10,4**	**32,7**	**17,1**

Wang e.a. (2018)

- Complete model calibration only for Zoutkamperlaag
- Parameter setting revisited based on the theoretical analysis by Wang e.a. (2008), and geometric relations
- ➔ Critical SLR rate less sensitive to basin size than earlier published

$$\delta_{cf} \propto \sqrt{S_b} \qquad \delta_{dc} \propto S_b$$

Bekken	Marsdiep	Eierlandse Gat	Vlie	Amelander Zeegat	Pinkegat	Zoutkamper-laag
δ_{dc} (m^3/s)	7317	1762	7987	3087	673	1290
δ_{cf} (m^3/s)	2001	982	2090	1299	607	840
R_c (mm/jr)	**9,7**	**18,7**	**8,8**	**13,4**	**25,6**	**17,1**

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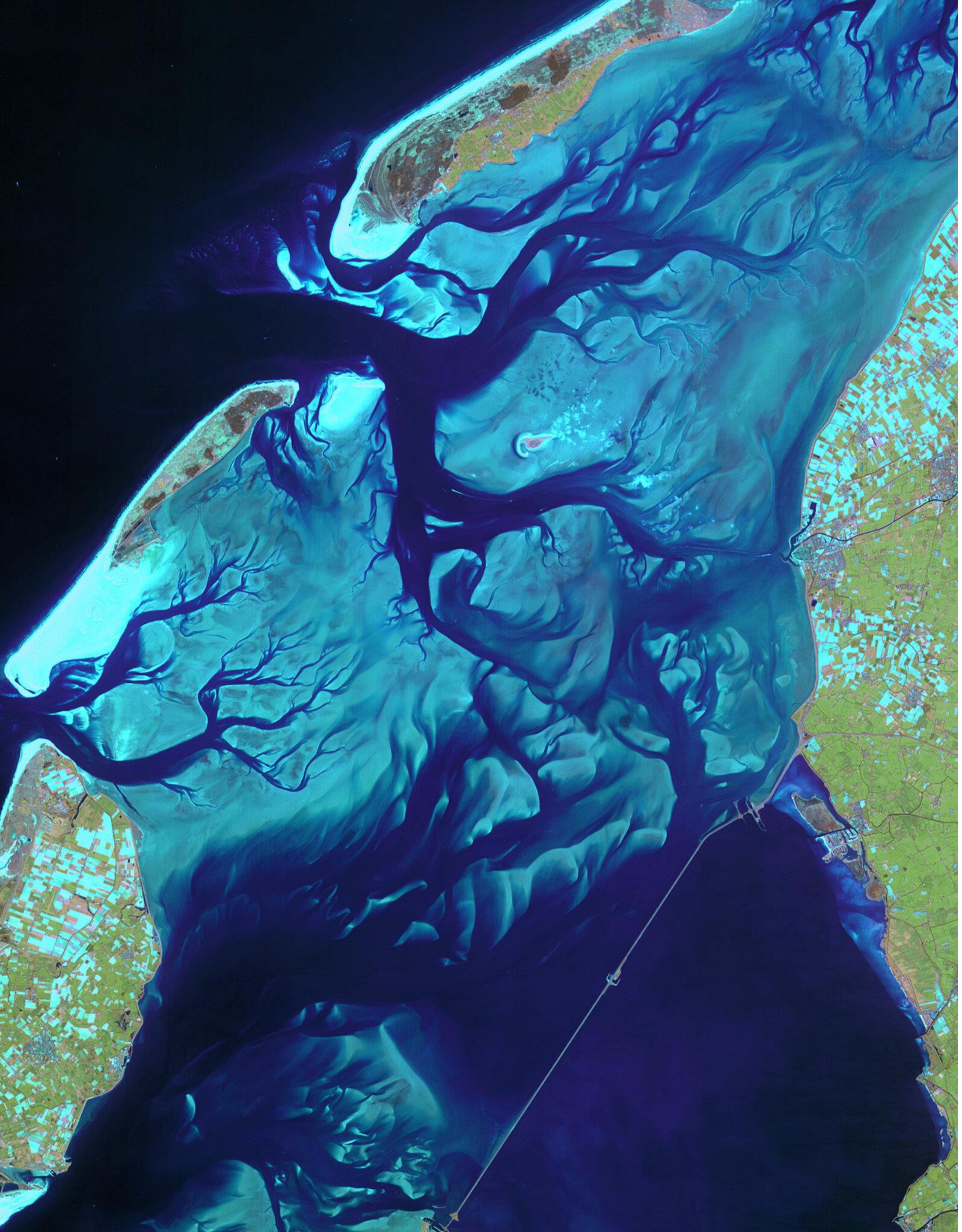
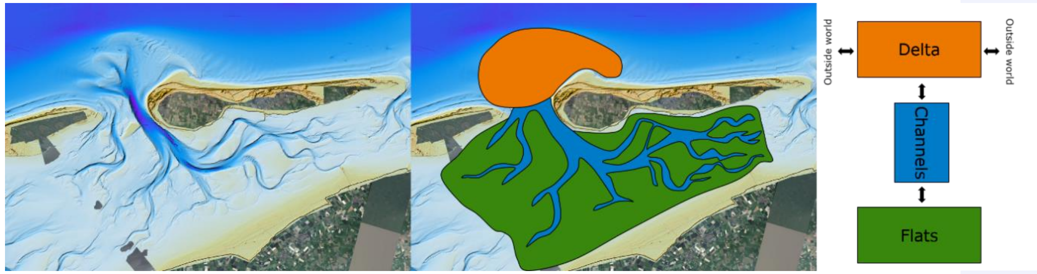


ASMITA model development

1) sand & mud
2) marshes

The computational procedure in ASMITA



0. Bathymetry

1. Hydrodynamic conditions

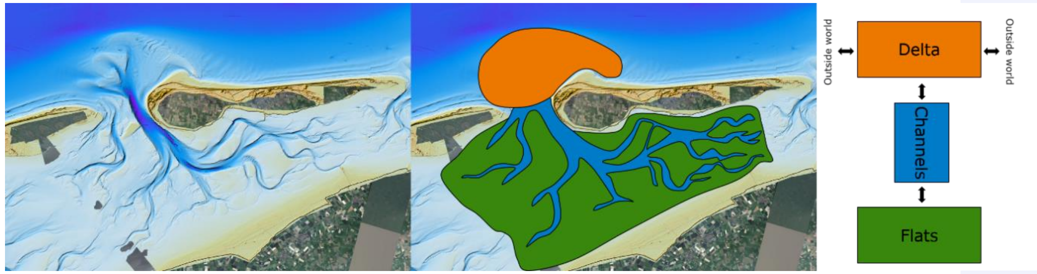
2. Morphological equilibrium

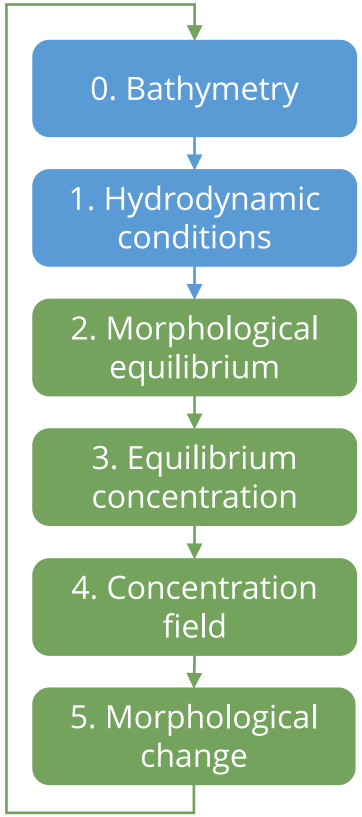
3. Equilibrium concentration

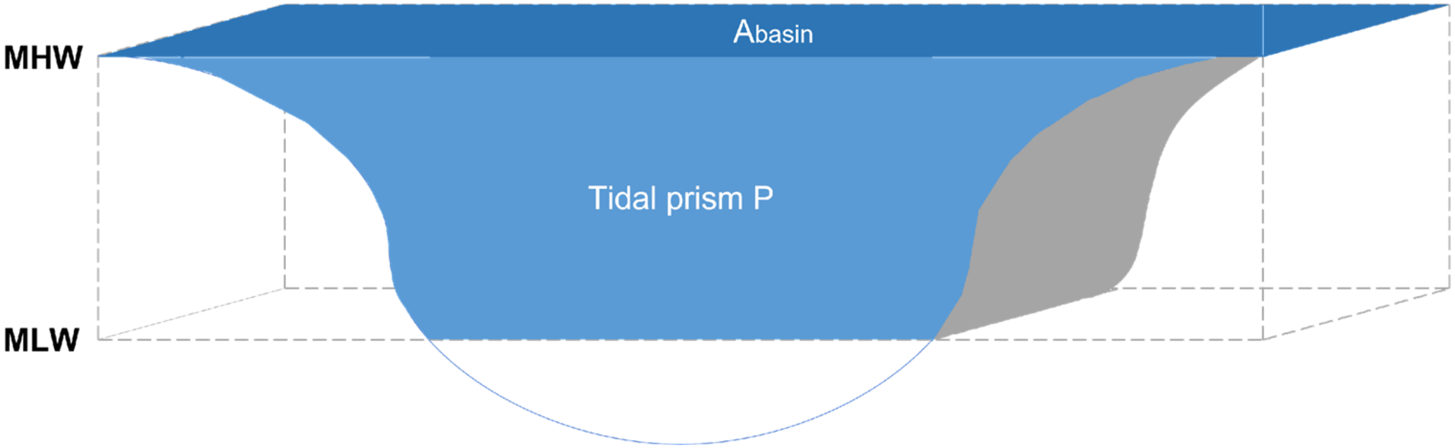
4. Concentration field

5. Morphological change

The computational procedure in ASMITA







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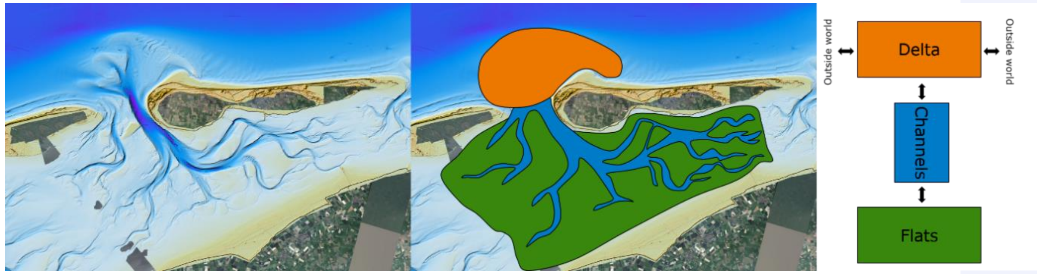
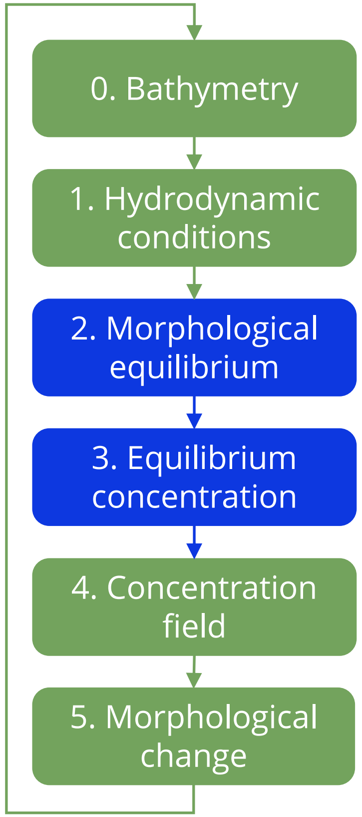
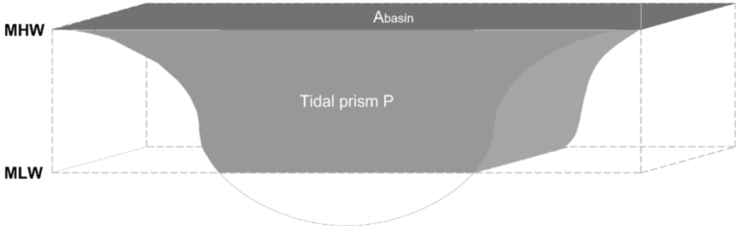


The computational procedure in ASMITA

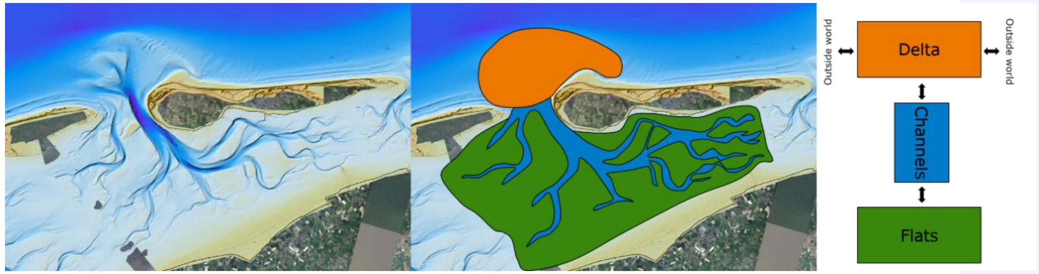


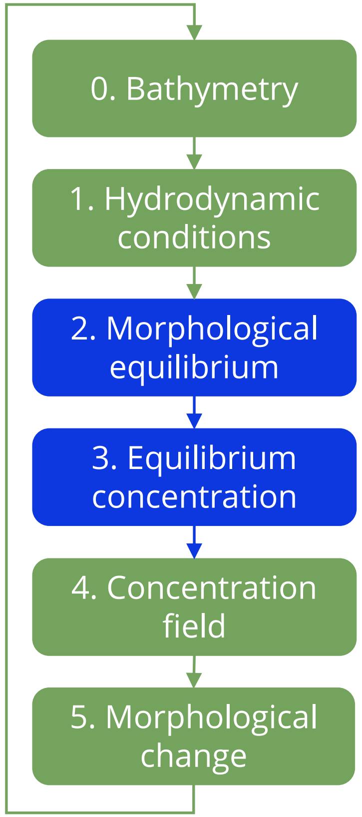


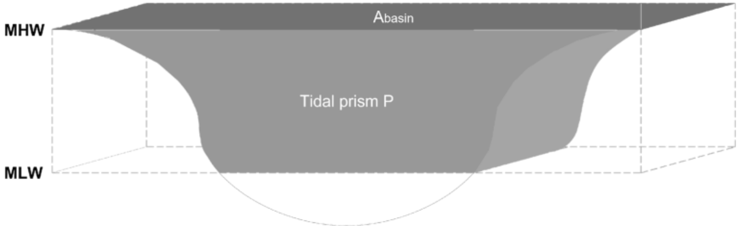
$$V_{equilibrium} = \alpha P^{\beta}$$

$$c_e = c_E \left(\frac{V_{equilibrium}}{V} \right)^n$$

The computational procedure in ASMITA







$$V_{equilibrium} = \alpha P^{\beta}$$

$$c_e = c_E \left(\frac{V_{equilibrium}}{V} \right)^n$$

Large tidal prism **P** vs. basin dimensions

- high flow velocities → **erosion**

Small tidal prism **P** vs. basin dimensions

- low flow velocities → **sedimentation**

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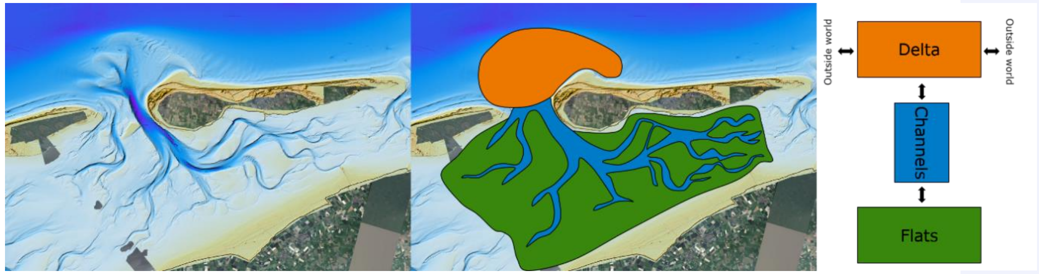
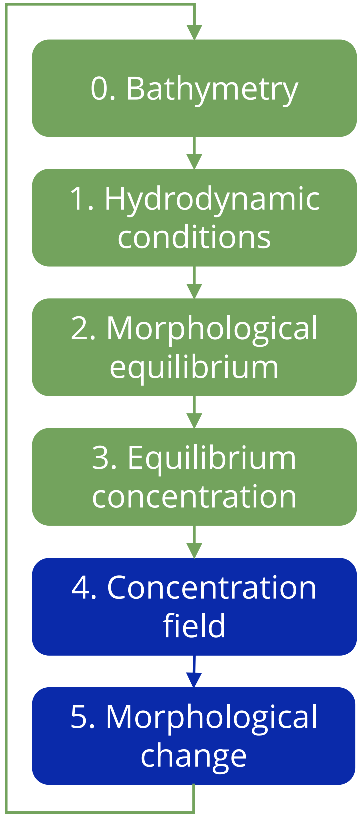
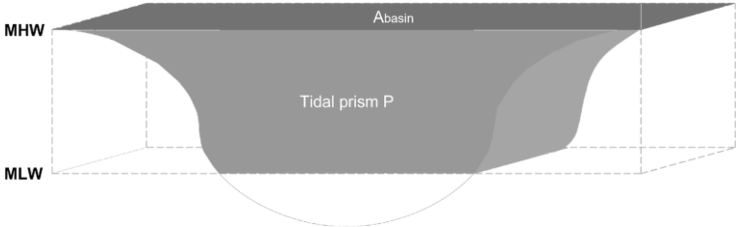
The computational procedure in ASMITA







$$V_{equilibrium} = \alpha P^{\beta}$$

$$c_e = c_E \left(\frac{V_{equilibrium}}{V}\right)^n$$

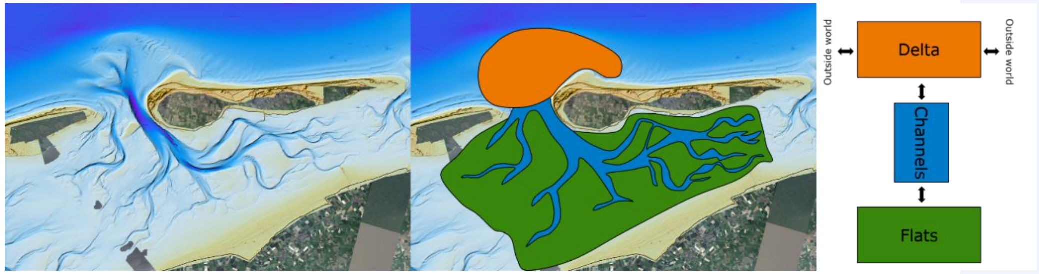
$$wA(c_e - c) = \delta(c - c_E)$$

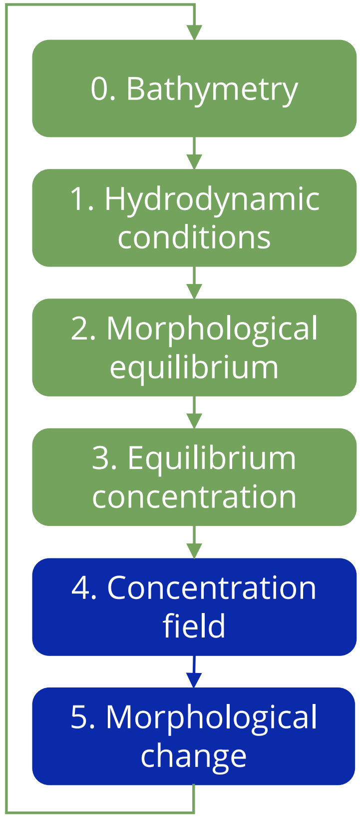
Vertical exchange with the bed

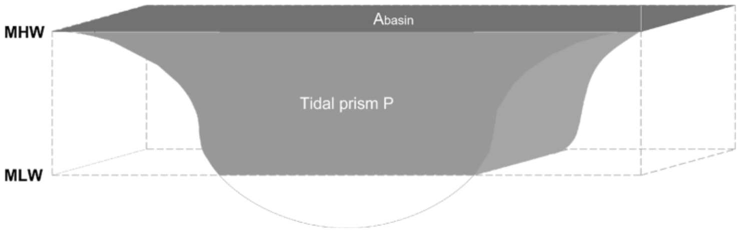
$$\frac{dV}{dt} = w_s A(c_e - c)$$

Horizontal exchange parameter

The computational procedure in ASMITA







$$V_{equilibrium} = \alpha P^{\beta}$$

$$c_e = c_E \left(\frac{V_{equilibrium}}{V} \right)^n$$

$$wA(c_e - c) = \delta(c - c_E)$$

Vertical exchange with the bed

$$\frac{dV}{dt} = w_s A(c_e - c)$$

Horizontal exchange parameter

Multiple sediment fraction implementation follows the same concept as the single fraction implementation

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Validation of mud-implementation

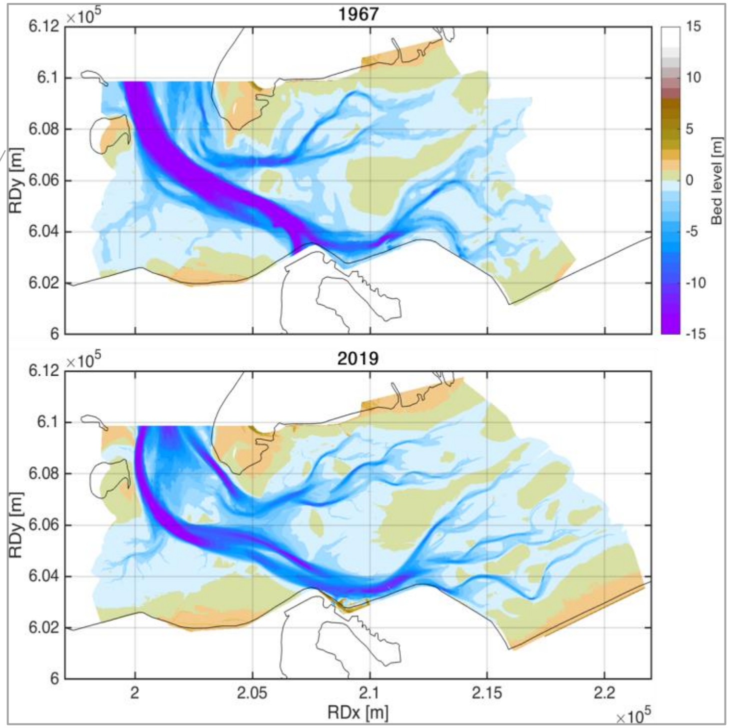
Ana Colina Alonso

Ymkje Huismans

Zheng Bing Wang

+ various others for valuable advice!

Hindcast: case

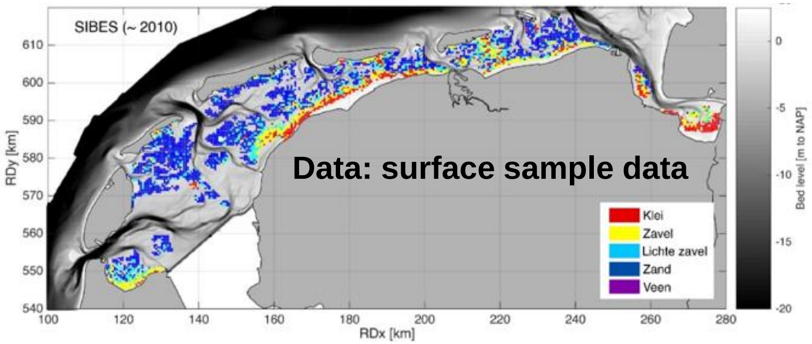


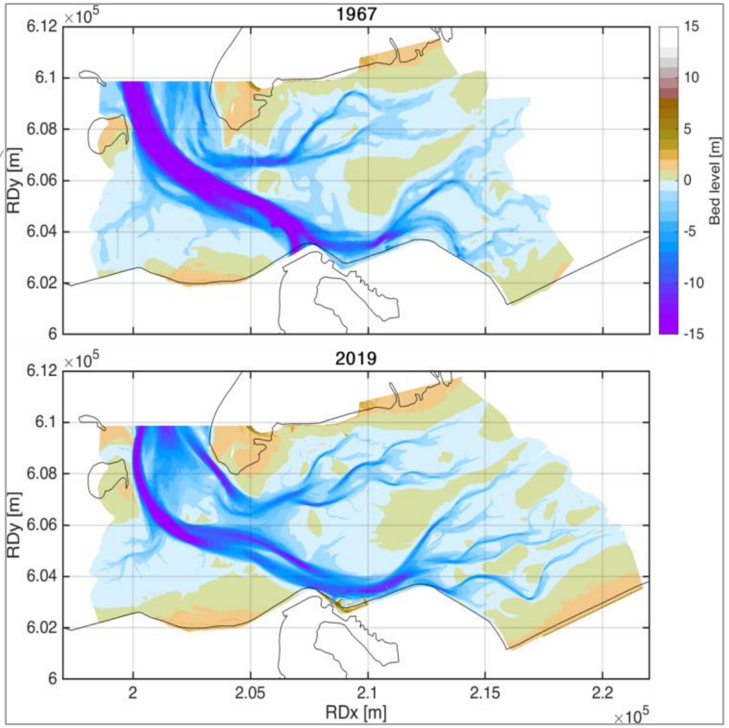
Validation of mud-implementation

Ana Colina Alonso Ymkje Huismans Zheng Bing Wang

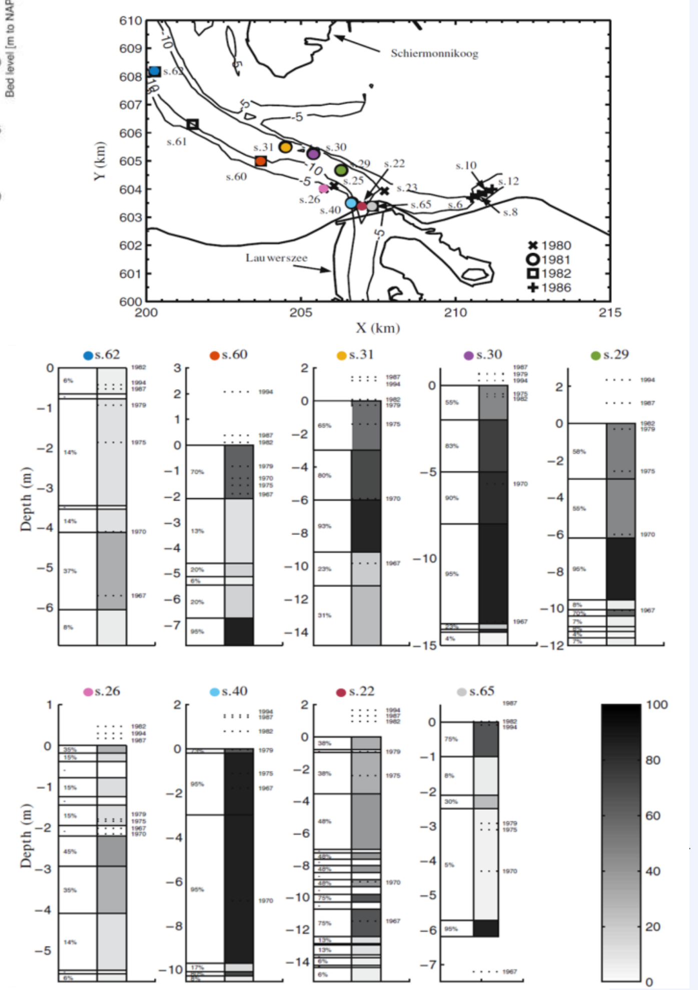
+ various others for valuable advice!

Hindcast: case & data





Data: corings



Parameter choices


Ana Colina Alonso


Ymkje Huismans


Zheng Bing Wang

+ various others for valuable advice!

0. Given Bathymetry — Volume (V)

1. Hydrodynamic conditions — Tidal Prism: $P = 2A_bH - V_f$ with basin area: $A_b = A_c + A_f$

2. Morphological equilibrium — $V = \alpha P^{\beta}$

3. Equilibrium concentration — $c_e = c_E\left(\frac{V_e}{V}\right)^n$

4. Concentration field — $wA(c_e - c) = \delta(c - c_E)$

5. Morphological change — $\frac{dV}{dt} = \frac{1}{c_b}wA(c_e - c)$

Schematization: area and volume of each element

Parameter choices


Ana Colina Alonso


Ymkje Huismans


Zheng Bing Wang


+ various others for valuable advice!

0. Given Bathymetry — Volume (V)

1. Hydrodynamic conditions — Tidal Prism: $P = 2A_b H - V_f$ with basin area: $A_b = A_c + A_f$

2. Morphological equilibrium — $V = \alpha P^{\beta}$

3. Equilibrium concentration — $c_e = c_E \left(\frac{V_e}{V}\right)^n$

4. Concentration field — $wA(c_e - c) = \delta(c - c_E)$

5. Morphological change — $\frac{dV}{dt} = \frac{1}{c_b} wA(c_e - c)$

Schematization: area and volume of each element

Hydrodynamics: tidal range and SLR

Deltares

Parameter choices


Ana Colina Alonso


Ymkje Huismans


Zheng Bing Wang

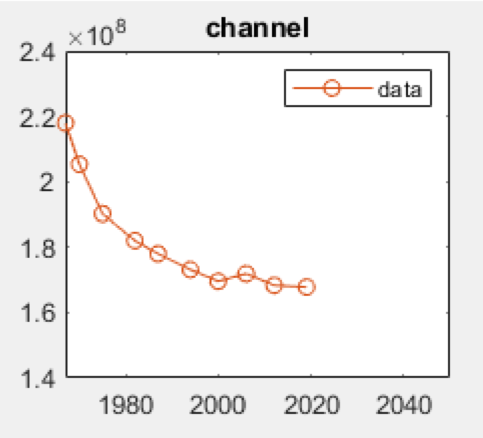

+ various others for valuable advice!

Step	Equation
0. Given Bathymetry	Volume (V)
1. Hydrodynamic conditions	Tidal Prism: $P = 2A_bH - V_f$ with basin area: $A_b = A_c + A_f$
2. Morphological equilibrium	$V = \alpha P^{\beta}$
3. Equilibrium concentration	$c_e = c_E \left(\frac{V_e}{V}\right)^n$
4. Concentration field	$wA(c_e - c) = \delta(c - c_E)$
5. Morphological change	$\frac{dV}{dt} = \frac{1}{c_b} wA(c_e - c)$

Schematization: area and volume of each element

Hydrodynamics: tidal range and SLR

Equilibrium parameters: from literature & hindcast



Parameter choices

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1. Hydrodynamic conditions — Tidal Prism: $P = 2A_bH - V_f$ with basin area: $A_b = A_c + A_f$

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Equilibrium parameters: from literature & hindcast

Sediment concentration: field data & calibration

Deltares

Parameter choices


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Schematization: area and volume of each element

Hydrodynamics: tidal range and SLR

Equilibrium parameters: from literature & hindcast

Sediment concentration: field data & calibration

Sediment size: sand = 100-150 um, mud = 35 um

Deltares

Parameter choices

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0. Given Bathymetry — Volume (V)

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Schematization: area and volume of each element

Hydrodynamics: tidal range and SLR

Equilibrium parameters: from literature & hindcast

Sediment concentration: field data & calibration

Sediment size: sand = 100-150 um, mud = 35 um

Horizontal exchange: from basin dimension & calibration

$$\frac{D}{UH} = \varepsilon\frac{U}{w_s} \qquad \delta = \frac{DA}{L}$$

Validation of mud-implementation

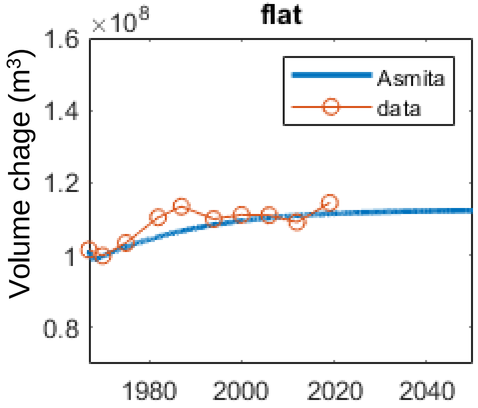

Ana Colina Alonso


Ymkje Huismans

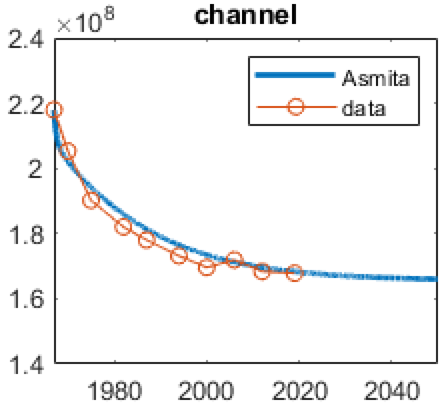

Zheng Bing Wang


+ various others for valuable advice!

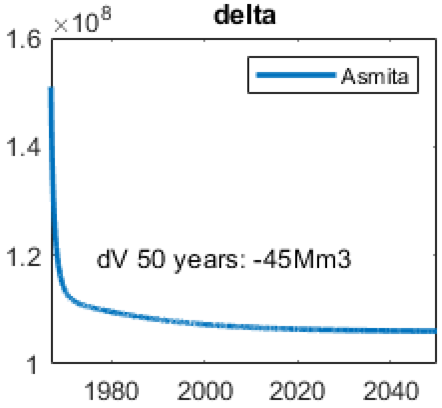
Intertidal flats

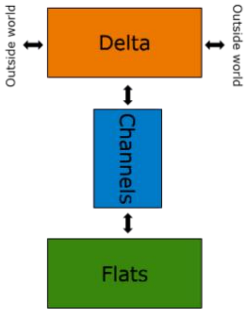


Channels



Delta





Validation of mud-implementation

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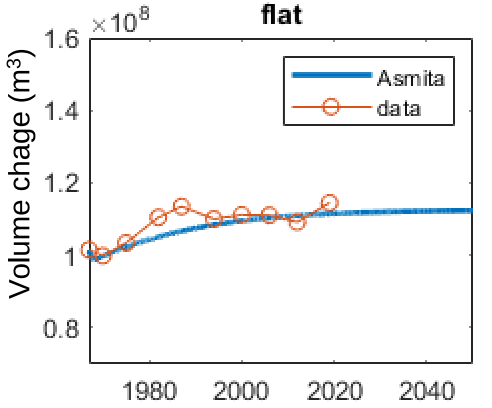
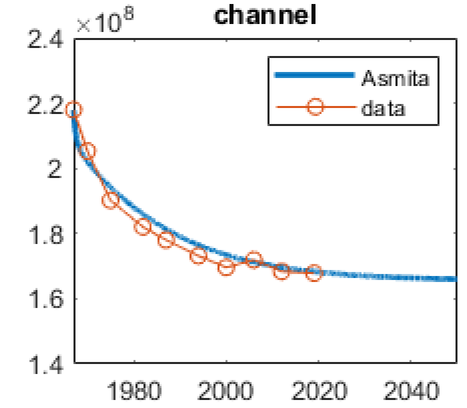
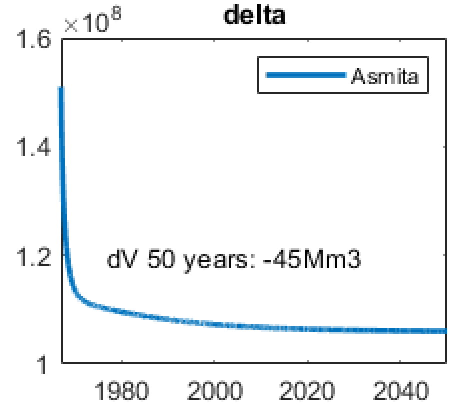
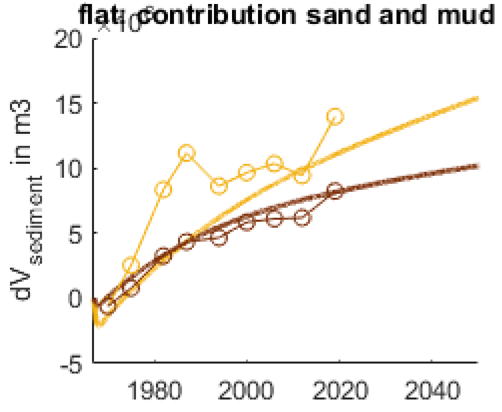
Channels

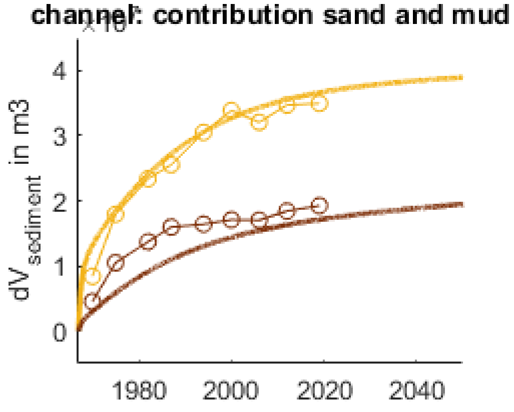
Delta

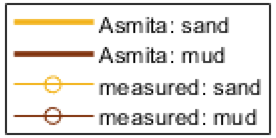


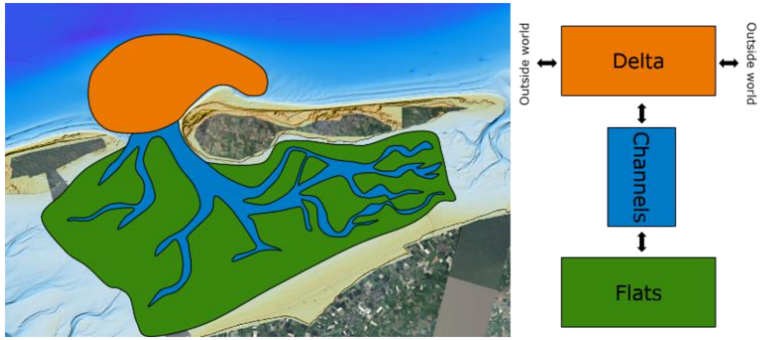








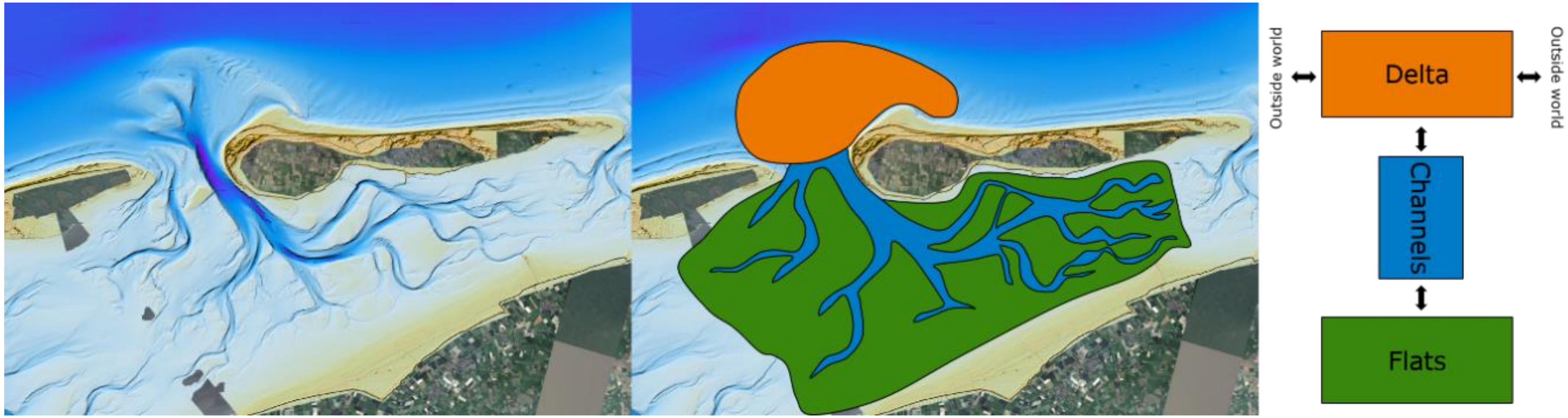




Deltares

Implementation of marshes

Marloes Bonenkamp Master student @ TUD　Ymkje Huismans　Zheng Bing Wang　Jasper Dijkstra　Peter Herman



Implementation of marshes

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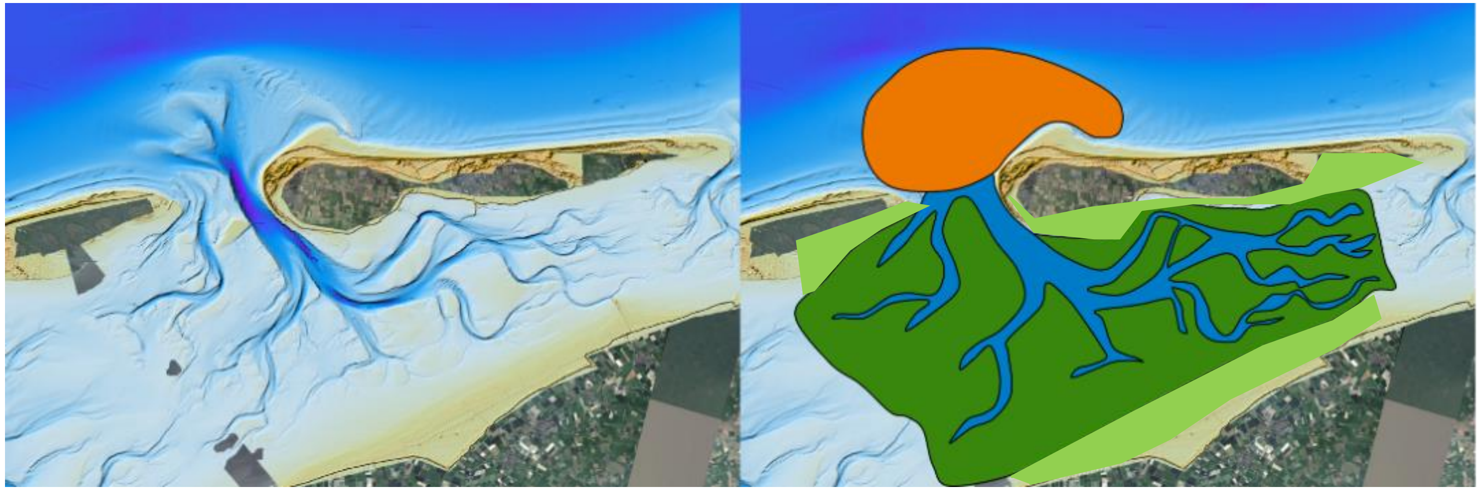
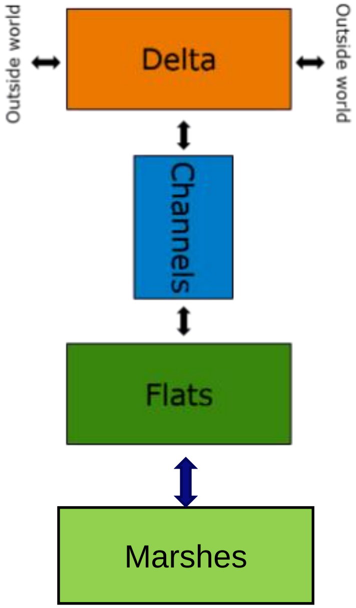
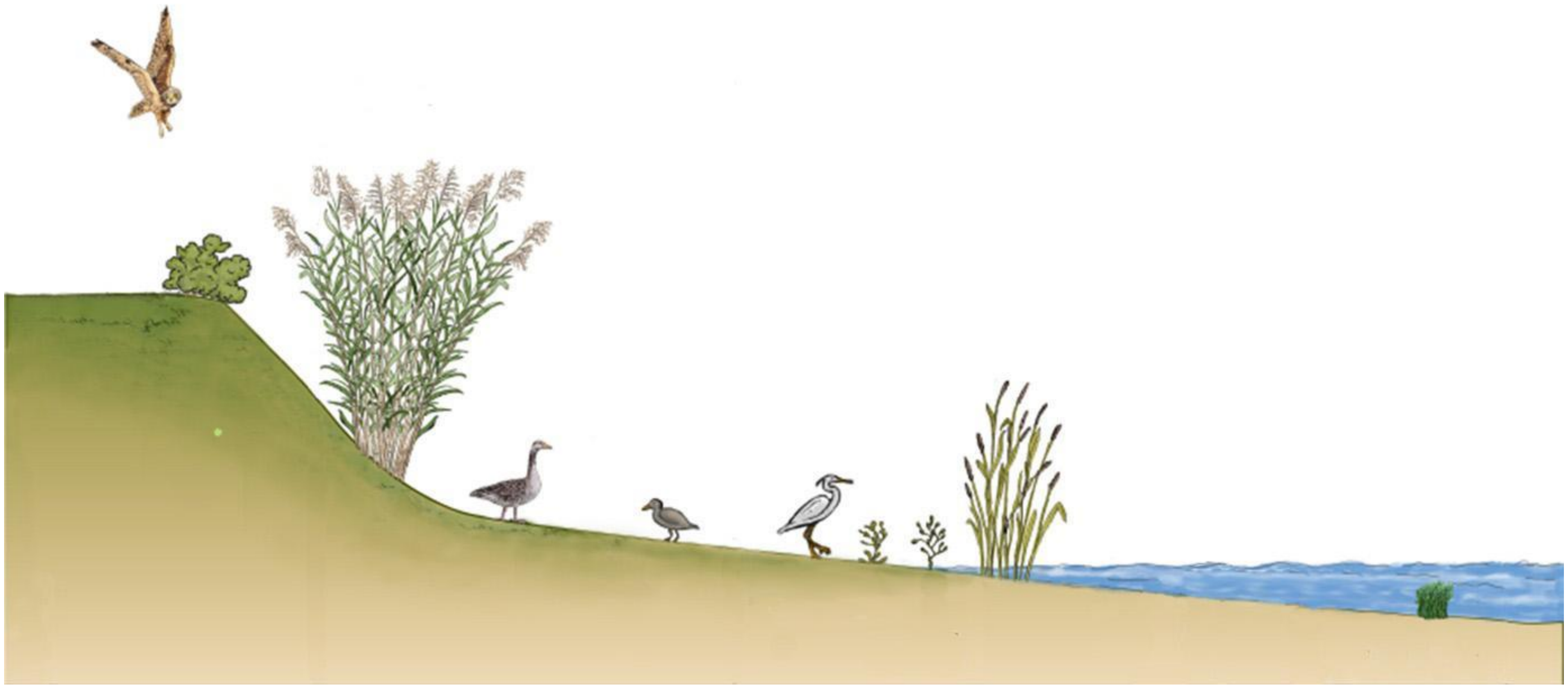
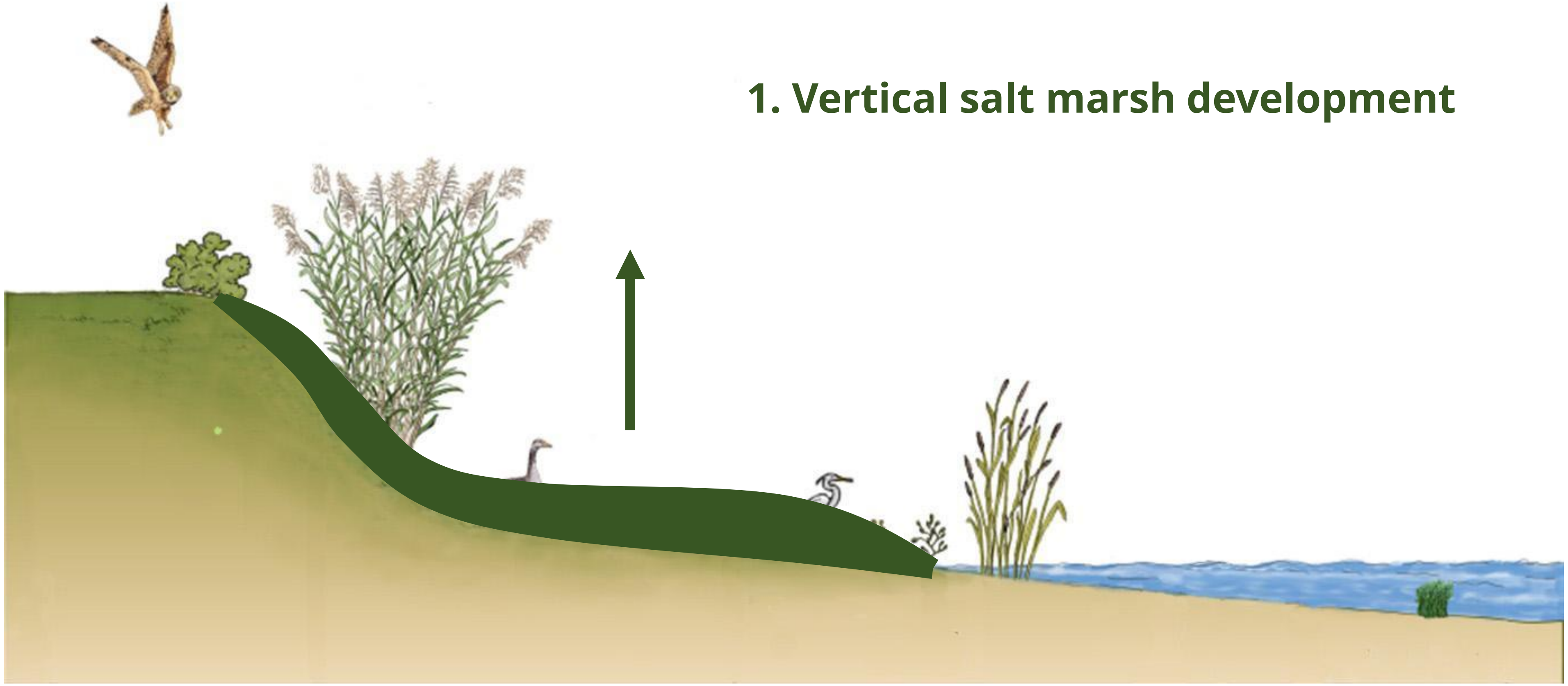




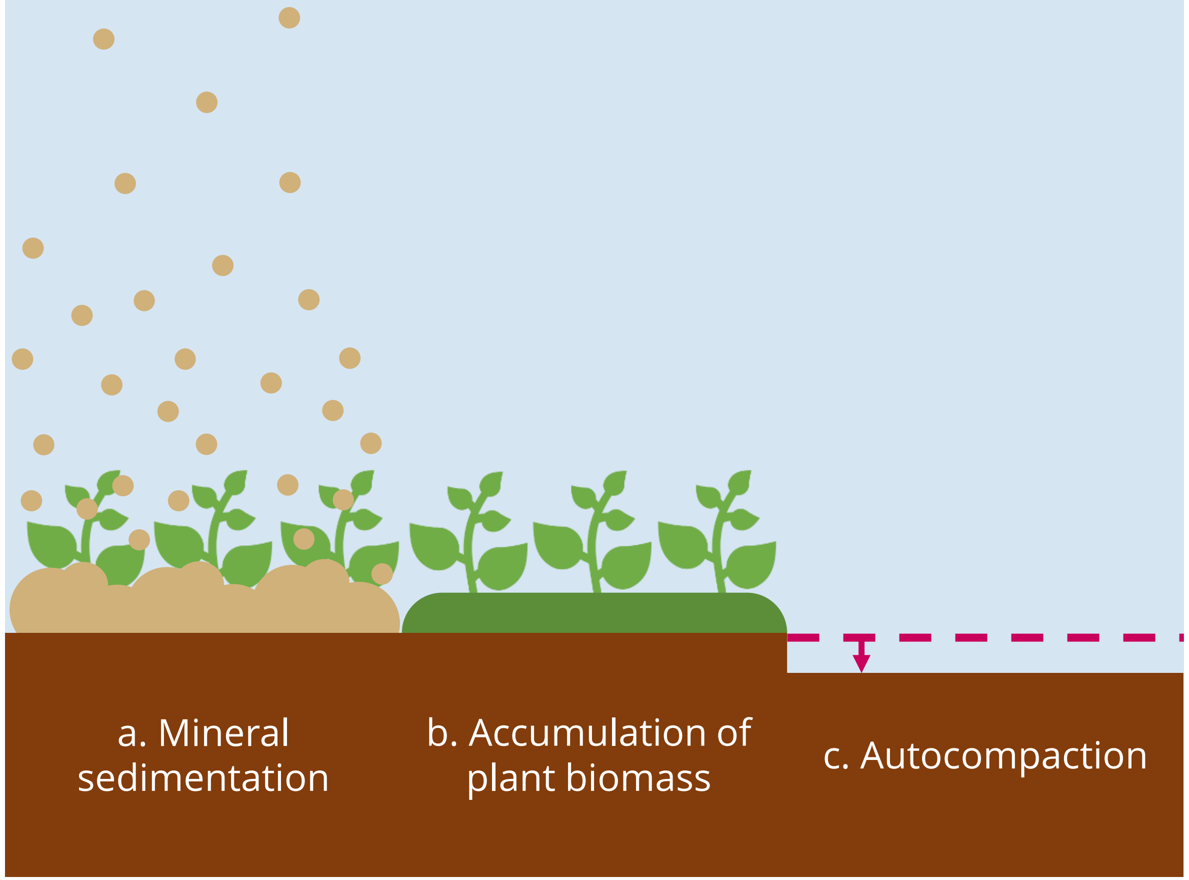
Salt marsh development depends on horizontal and vertical processes.



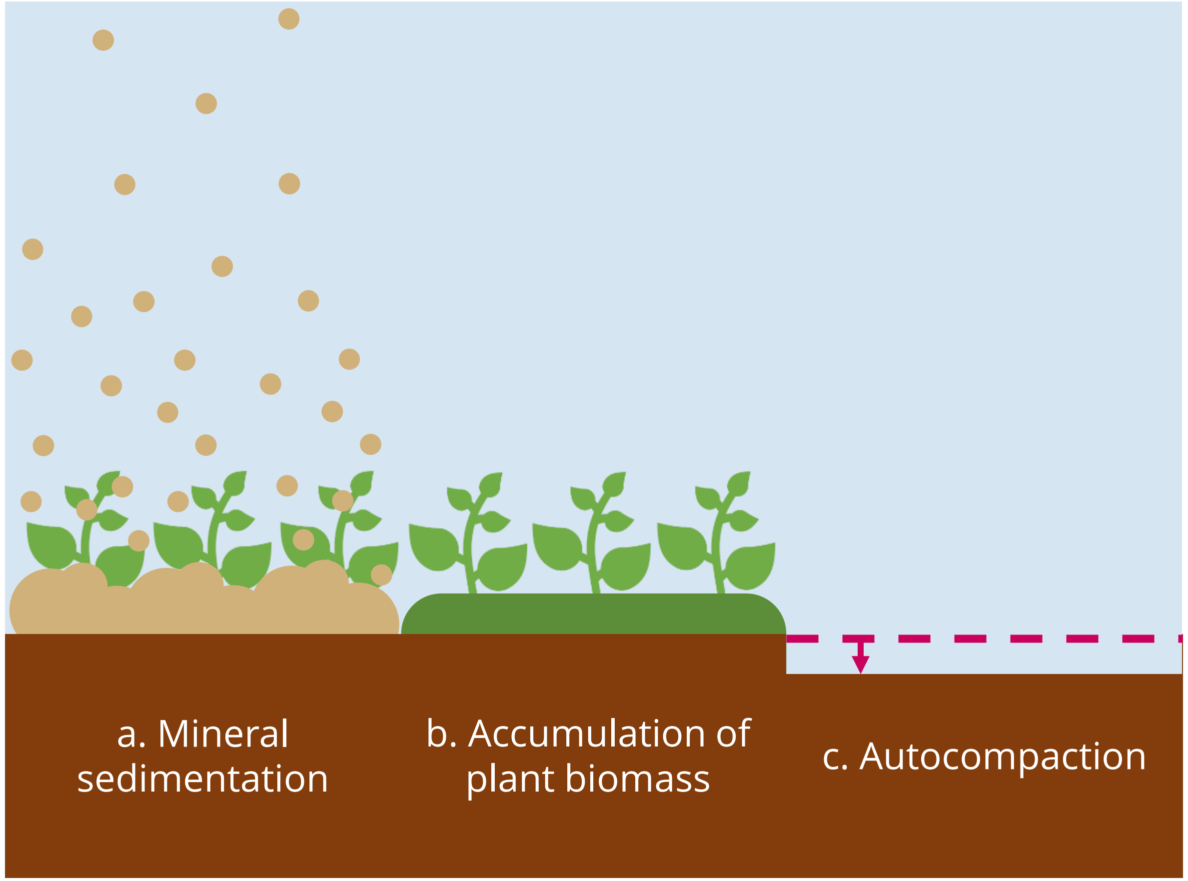
Salt marsh development depends on horizontal and vertical processes.

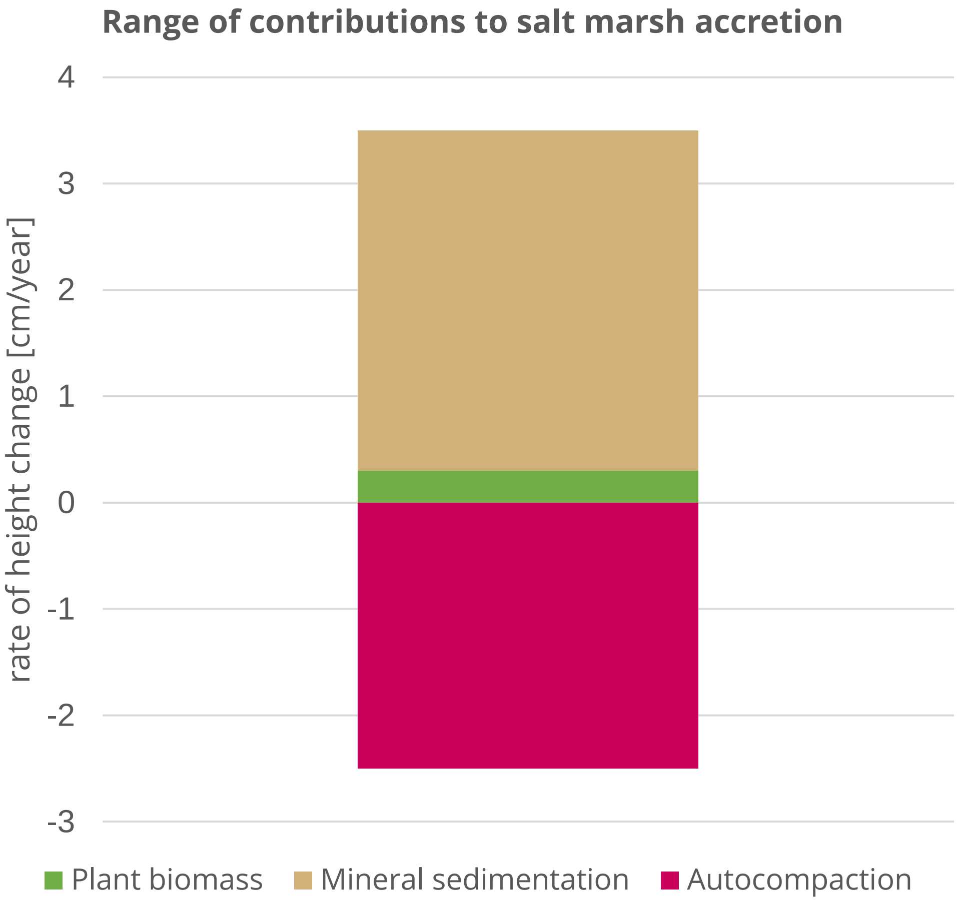


Vertical salt marsh development (accretion) consists of three processes.

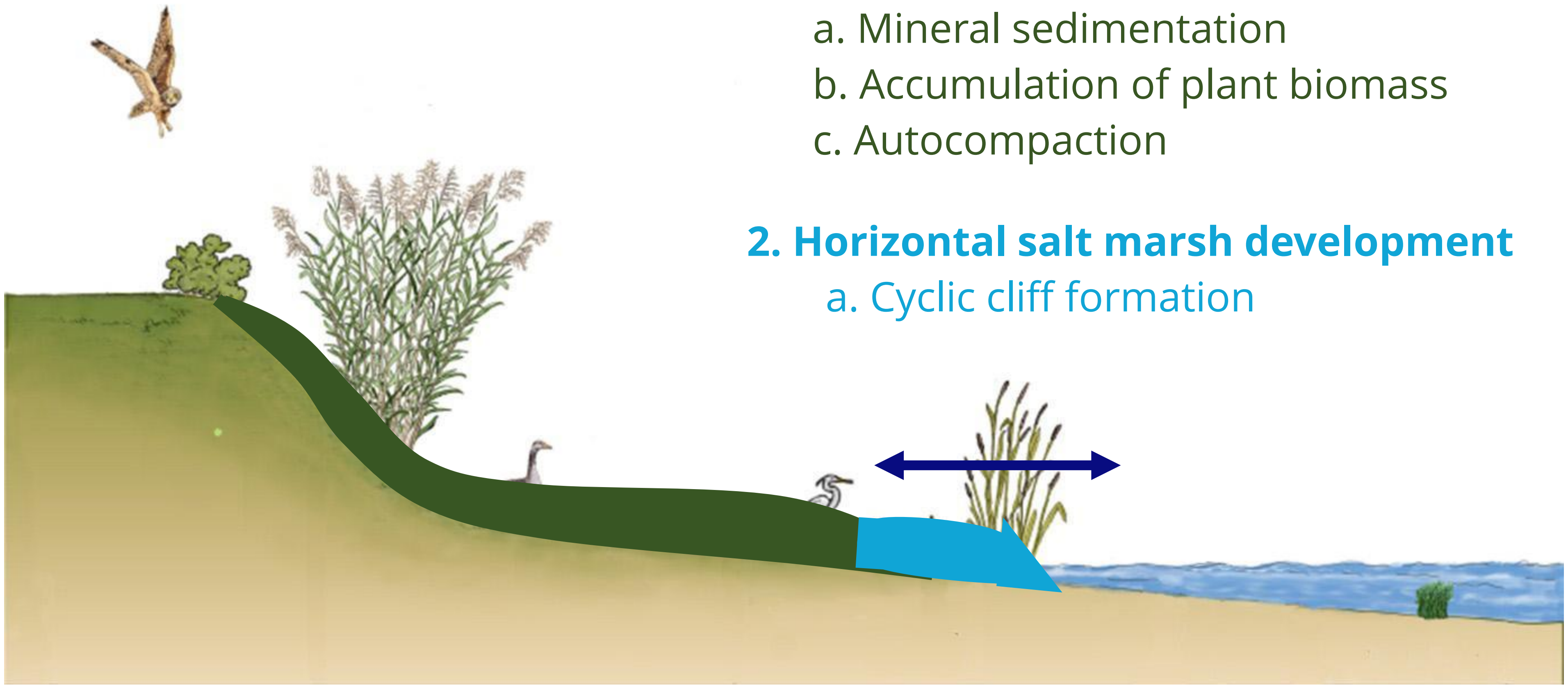


Mineral sedimentation is the largest contributor to accretion.





Salt marsh development depends on horizontal and vertical processes.



1. Vertical salt marsh development
- a. Mineral sedimentation
- b. Accumulation of plant biomass
- c. Autocompaction

2. Horizontal salt marsh development
- a. Cyclic cliff formation

Horizontal salt marsh development is excluded from the ASMITA model extension.

1. Vertical salt marsh development

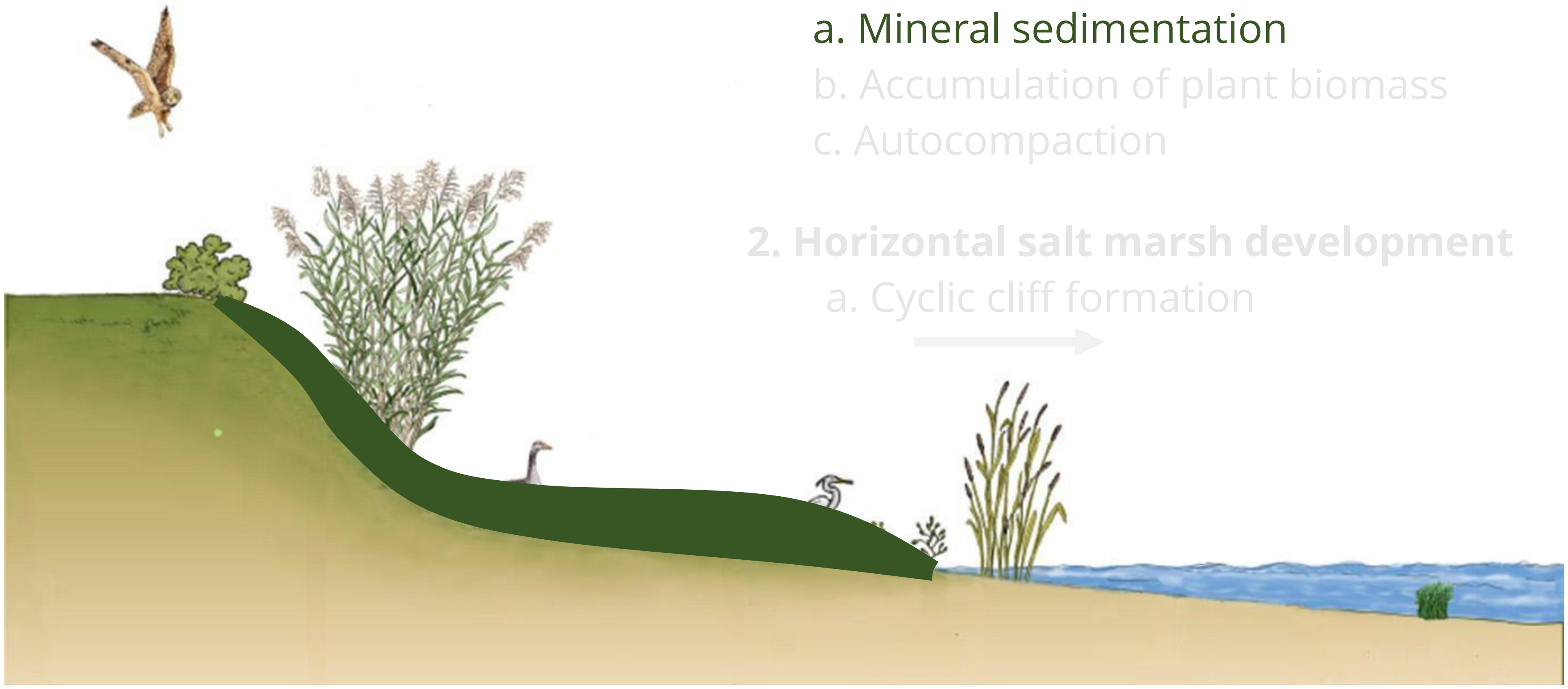
a. Mineral sedimentation

b. Accumulation of plant biomass

c. Autocompaction

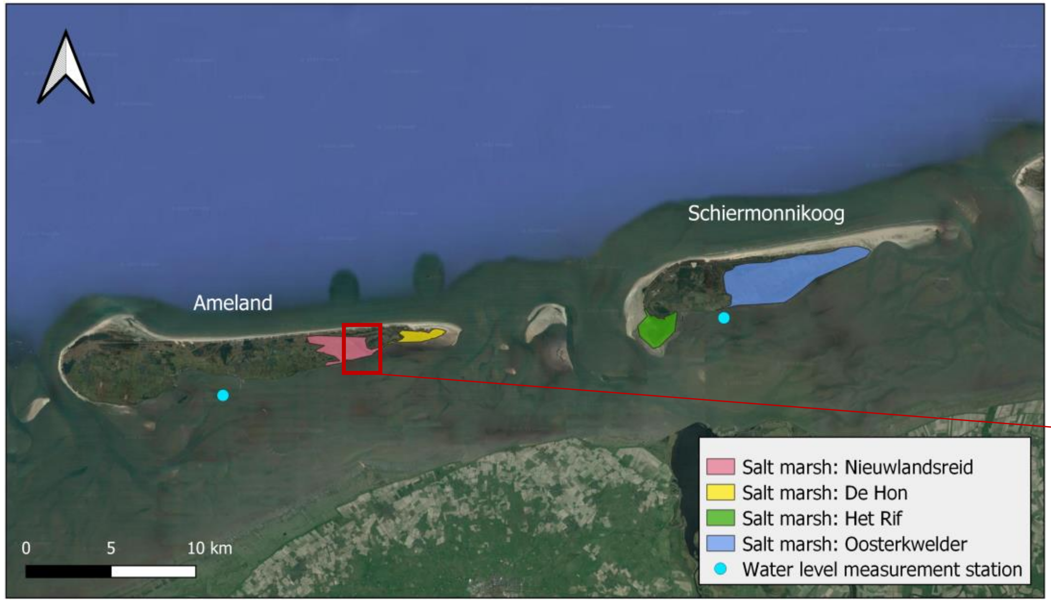
2. Horizontal salt marsh development

a. Cyclic cliff formation



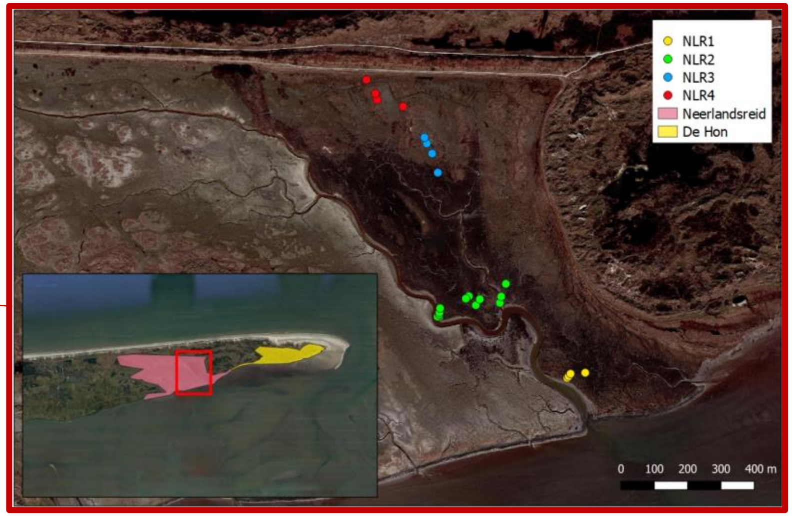
Implementation of marshes

Study-area



Hindcast data ~1995 - present

1. SEB-plots: point measurements for changes in height and sedimentation for period 1995 - present



2. AHN (LIDAR): DTMs for

AHN1: 1997-2004 || AHN2: 2007-2012 || AHN 3: 2014-2019 || AHN 4: 2021-2022

Limited relevance, likely because of poor filtering vegetation height.

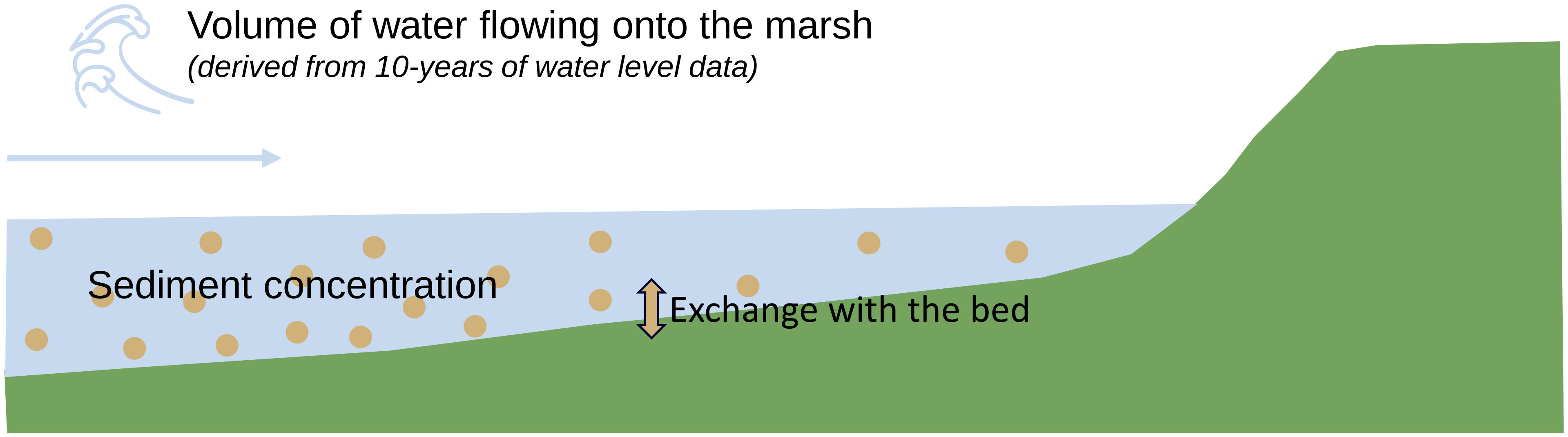
Deltares

1-element model

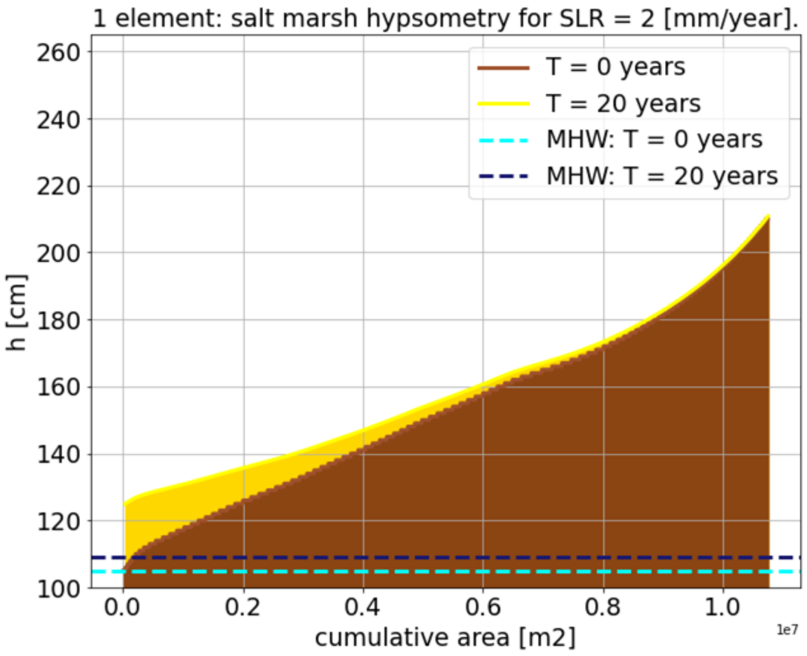
Boundary condition

Salt marshes

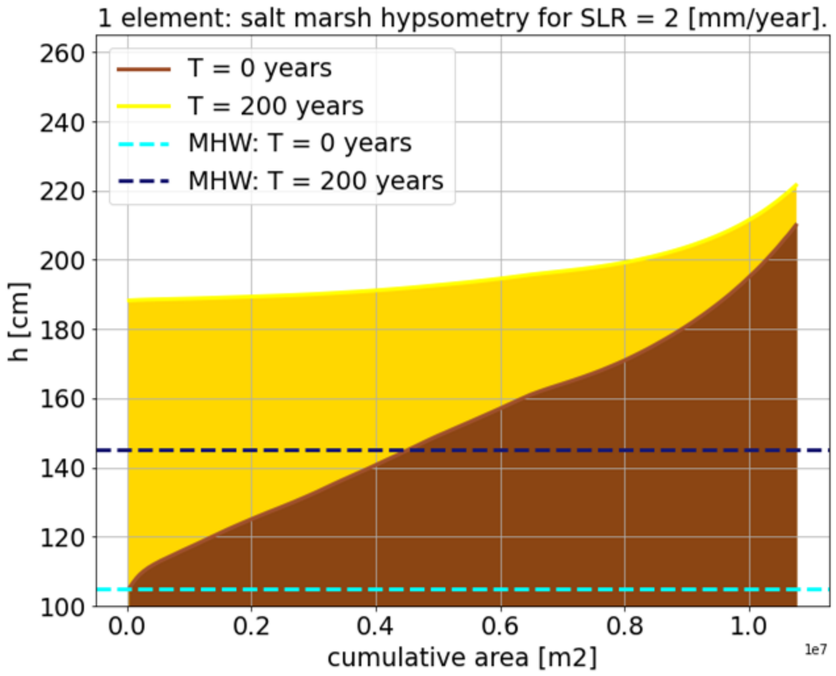
1-element model: background on implementation



1-element model: flattening of the marsh



T = 20 years



T = 200 years

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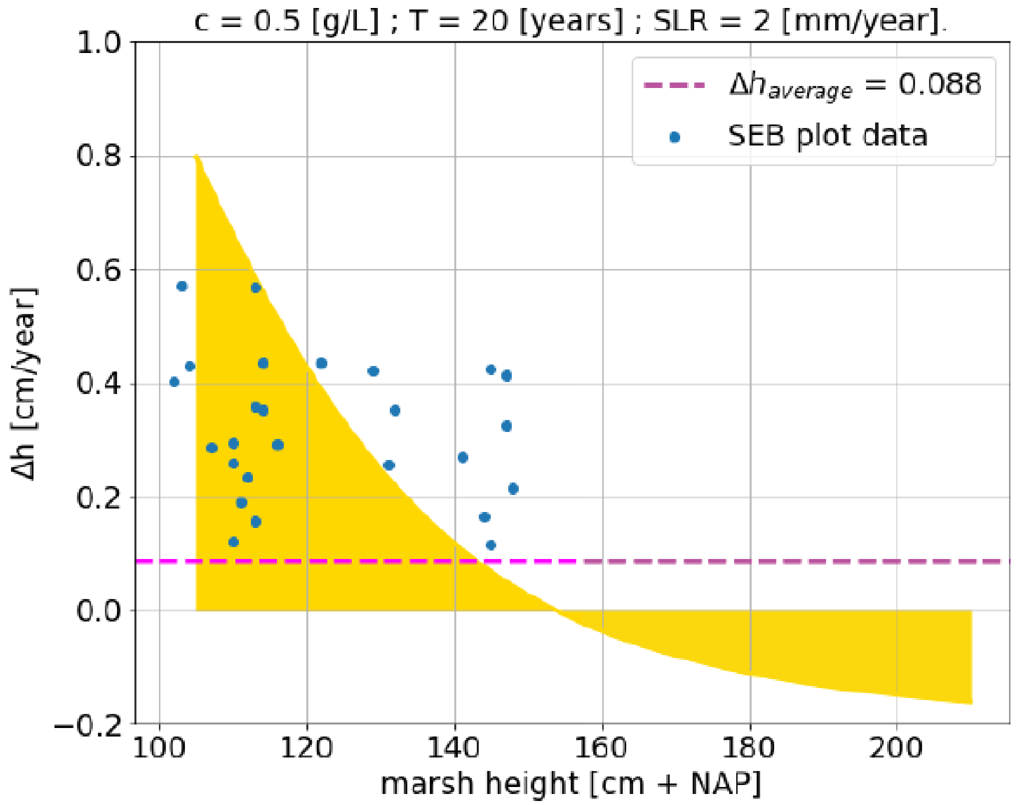
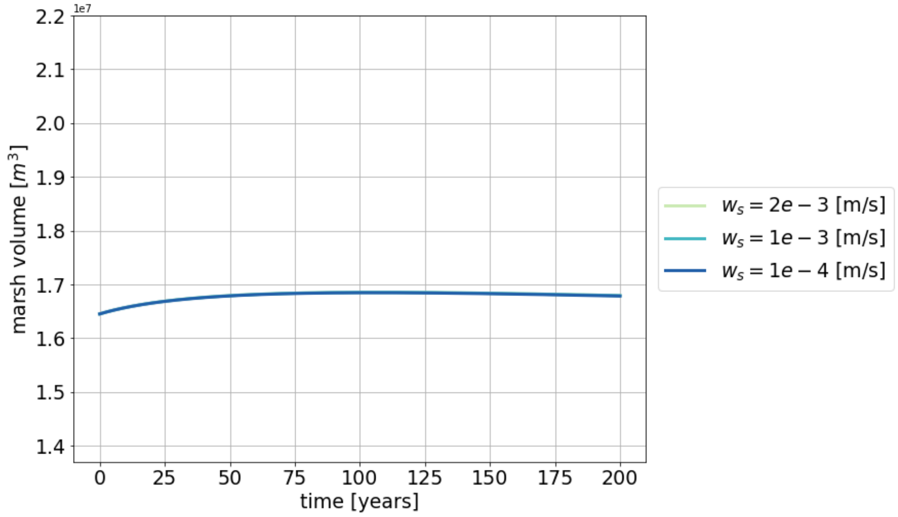
1-element model: Validation

Results for a sediment concentration of fine sediment (mud) of 0.5 mg Cl/l

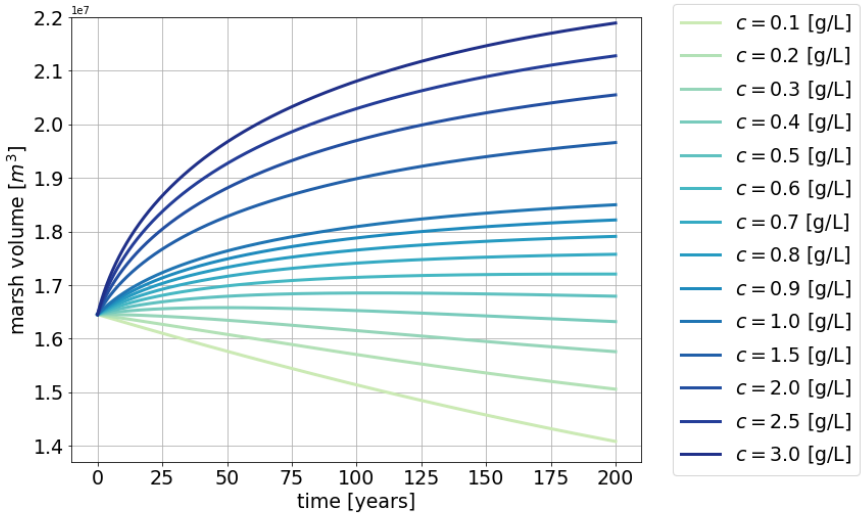


(b) c = 0.5 g/L

1-element model: Sensitivity analysis

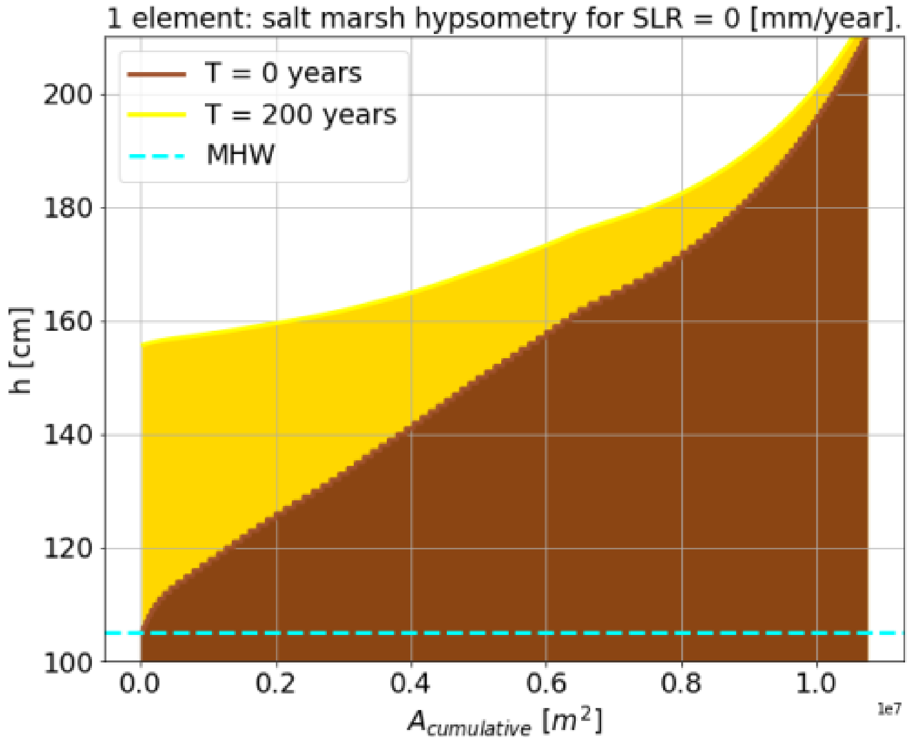


vertical exchange coefficient w_s

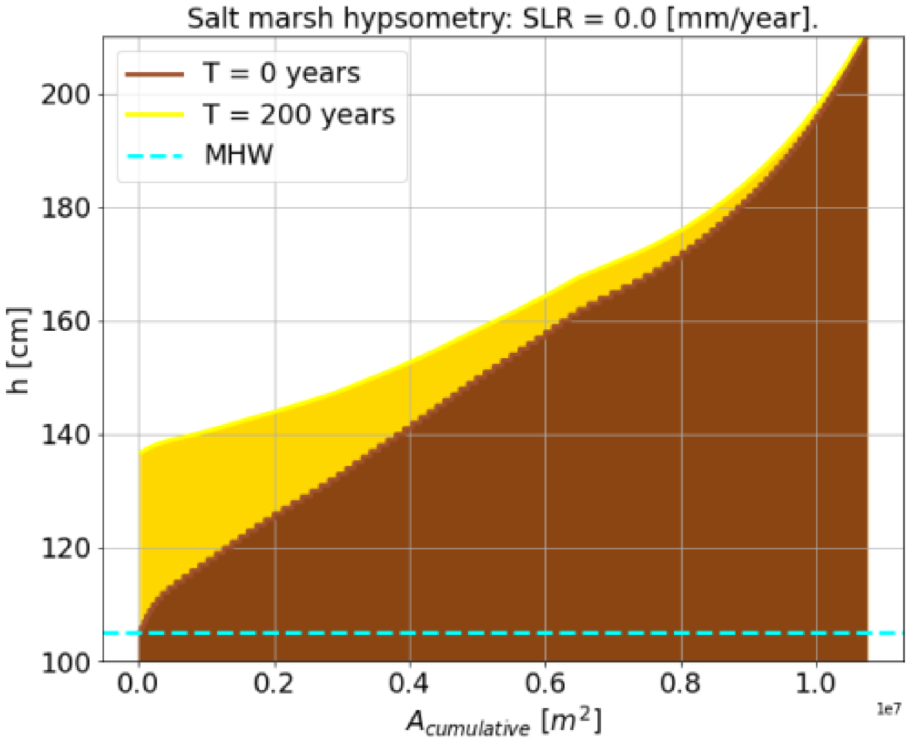


sediment concentration c

4-element model



(a) 1 element.

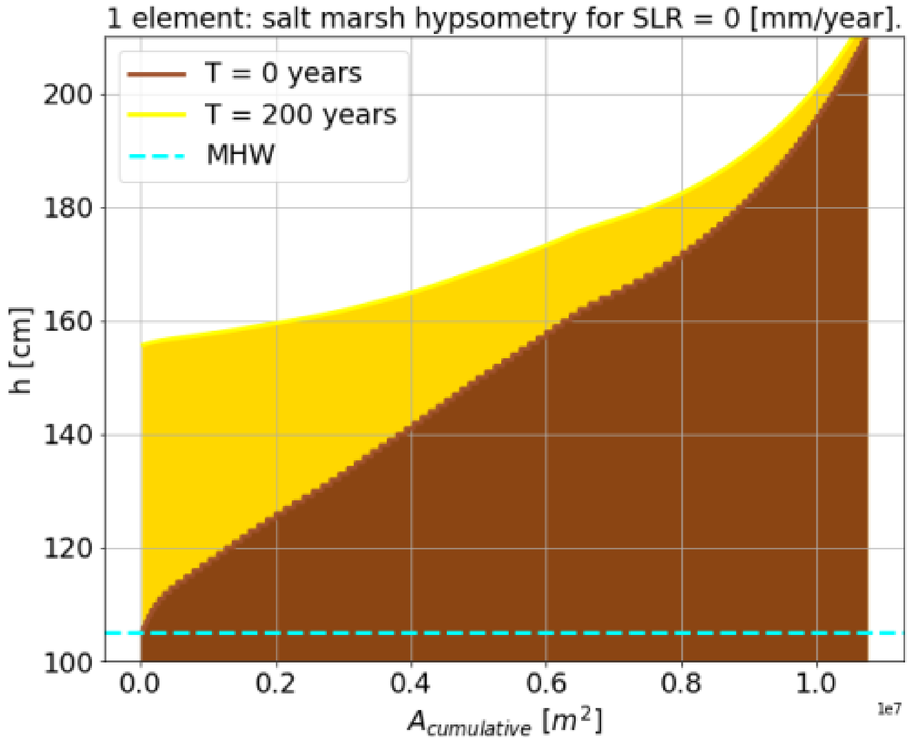


(b) 4 elements.

Deltares

4-element model

A lot less sedimentation?!



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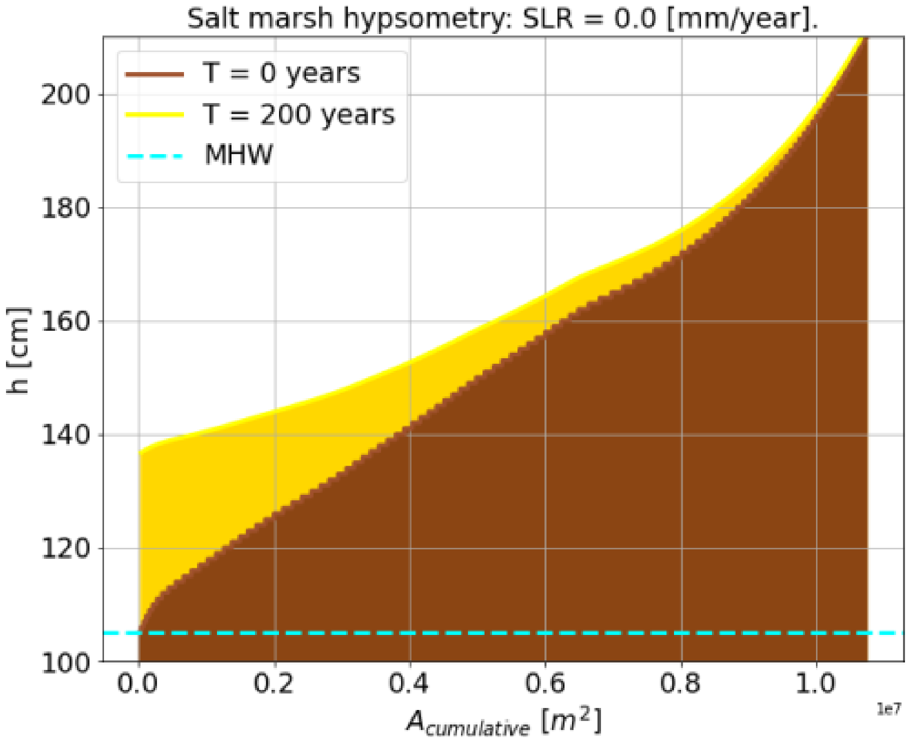

(b) 4 elements.

4-element model

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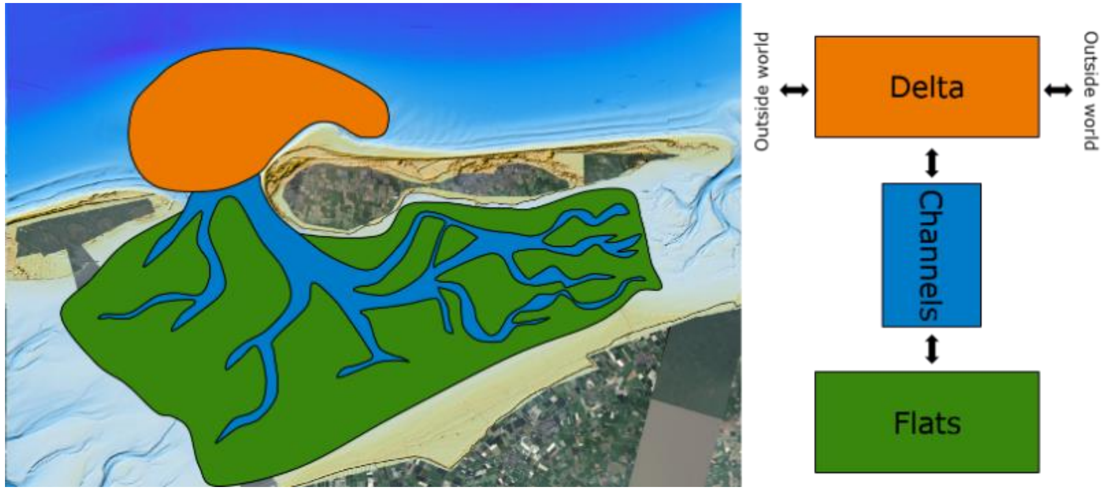
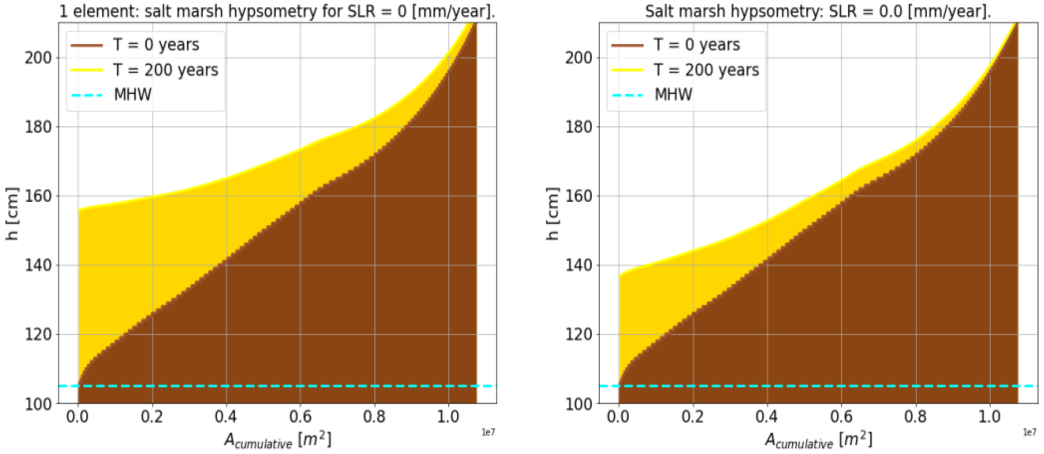


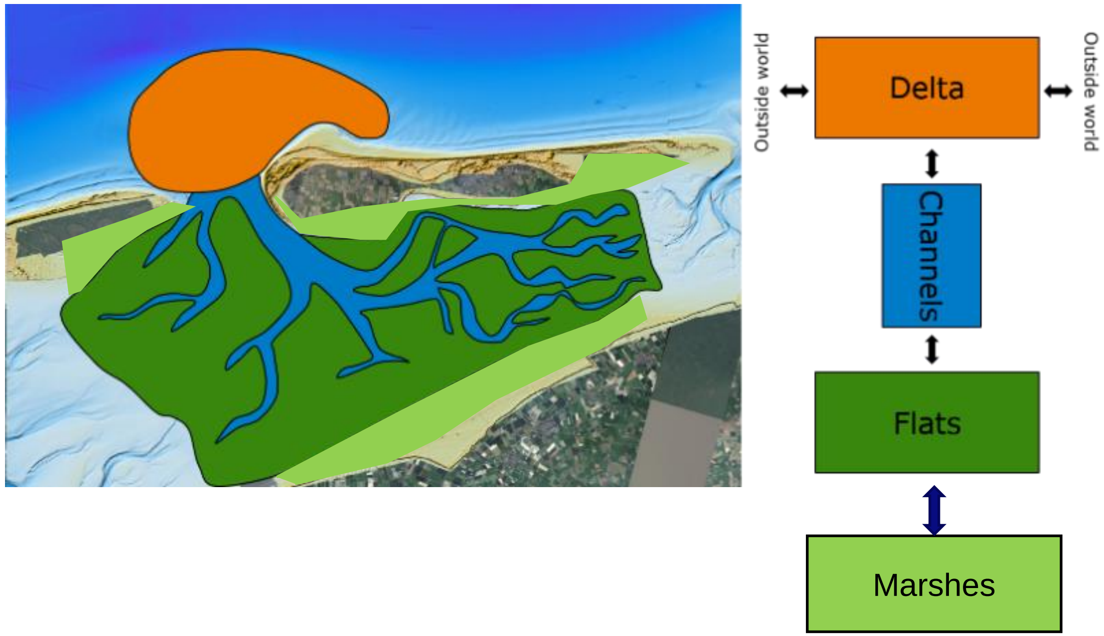


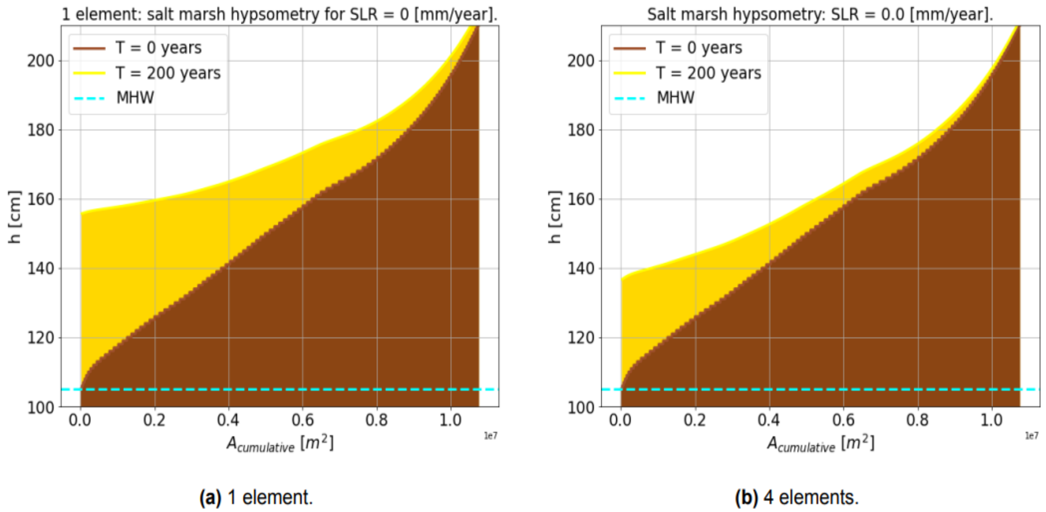
(a) 1 element. **(b)** 4 elements.

In the basin: tidally averaged conditions for sediment concentration

4-element model

A lot less sedimentation?!

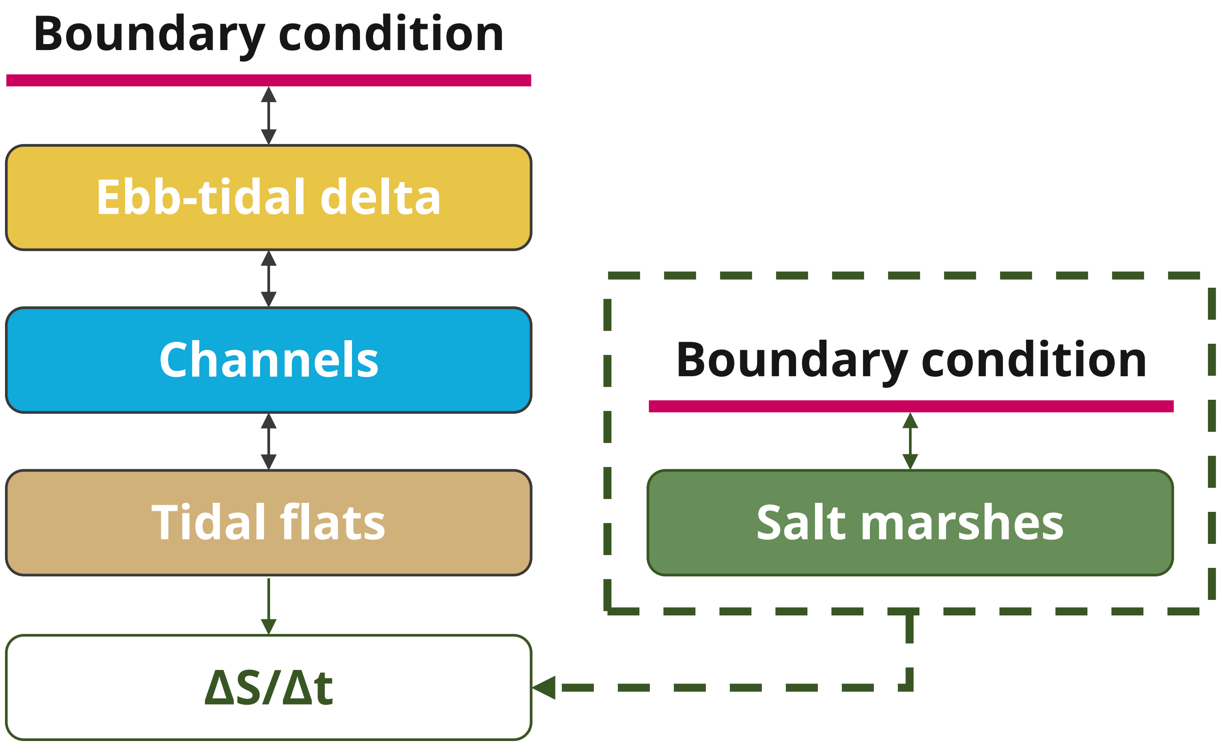




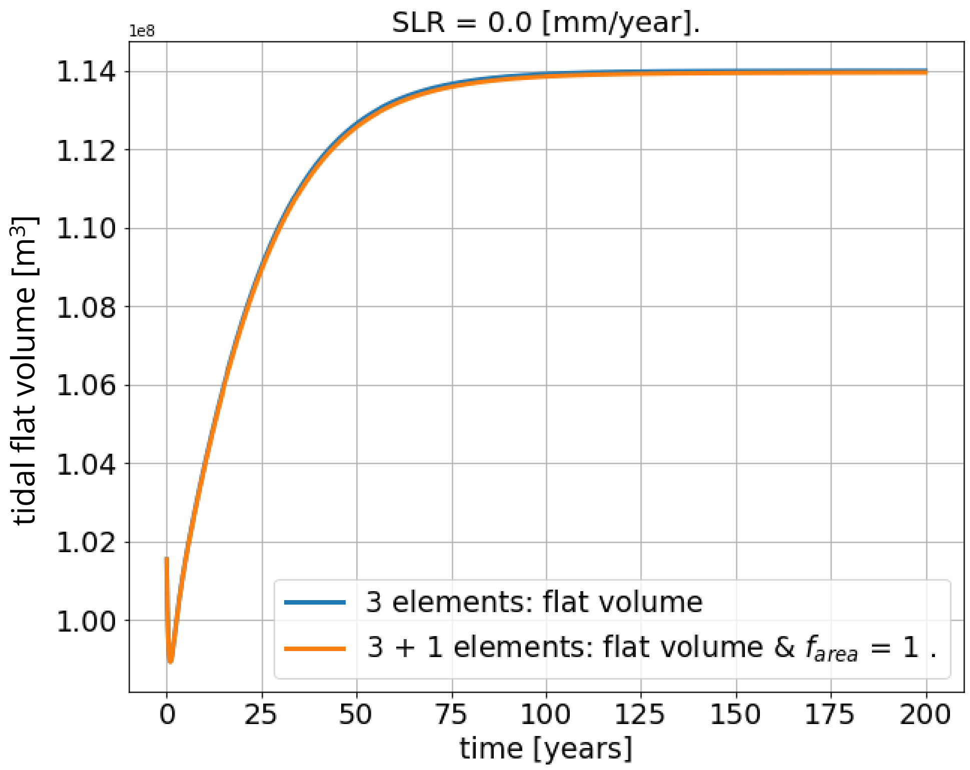
In the basin: tidally averaged conditions for sediment concentration
On the marsh: extreme conditions for sediment concentration

Deltares

3+1 element model



The salt marsh element has a negligible impact on the morphological development in the tidal inlet system.



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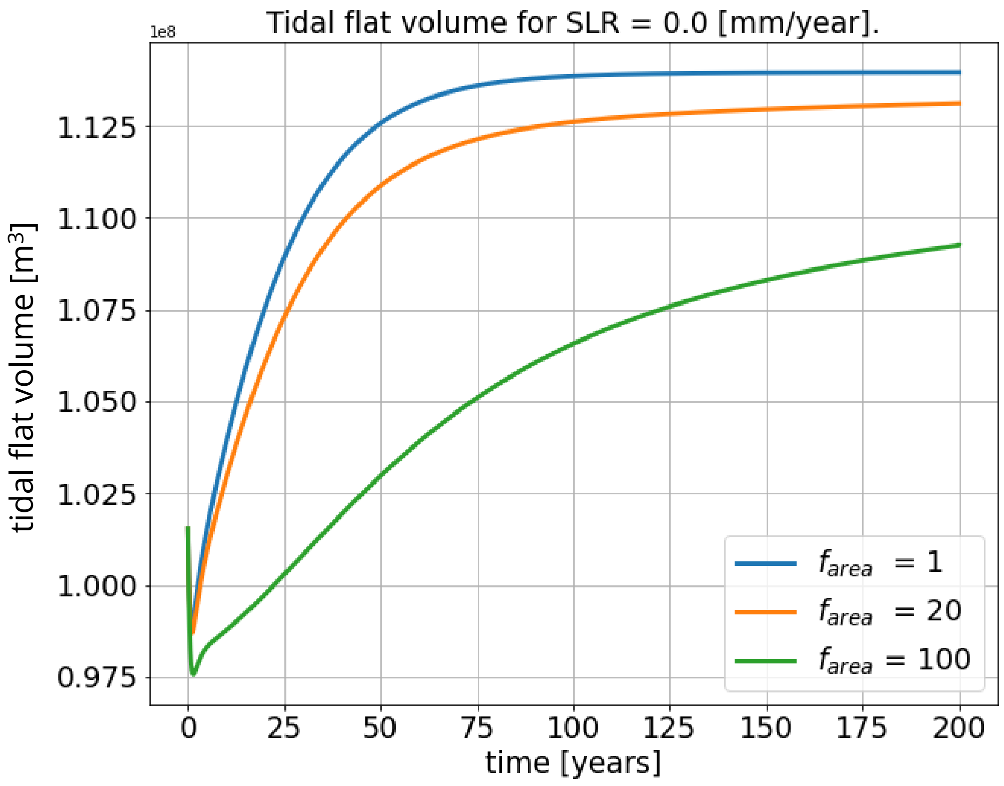
For a larger salt marsh element, the effect of the outgoing sediment flux becomes more evident.



Deltares

Conclusions

1. Salt marsh development by **mineral sedimentation** can be modelled by the ASMITA model, provided that information on the **sediment concentration** is present.

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2. For the **Dutch Wadden Sea**, and limited SLR rates, salt marshes have a **limited impact** on the morphological development in the rest of the tidal inlet system.

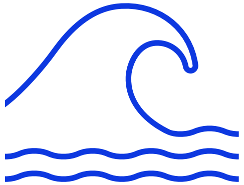
Conclusions

1. Salt marsh development by **mineral sedimentation** can be modelled by the ASMITA model, provided that information on the **sediment concentration** is present.

2. For the **Dutch Wadden Sea**, and limited SLR rates, salt marshes have a **limited impact** on the morphological development in the rest of the tidal inlet system.

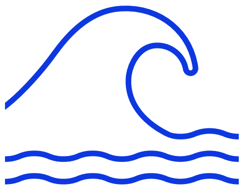
3. The model can be used to gain **quick insight** in **global long-term salt marsh morphodynamics**, but does not provide a detailed description.

Recommendations

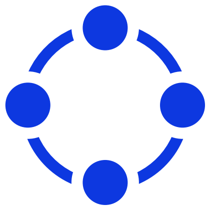


Correlation between water levels and sediment concentration

Recommendations



Correlation between water levels
and sediment concentration



Improve marsh implementation

1) an integrated 4 element model

2) add cliff erosion

Recommendations

Correlation between water levels and sediment concentration

Improve marsh implementation

1) an integrated 4 element model

2) add cliff erosion

Measurements on sediment concentration and marsh elevation

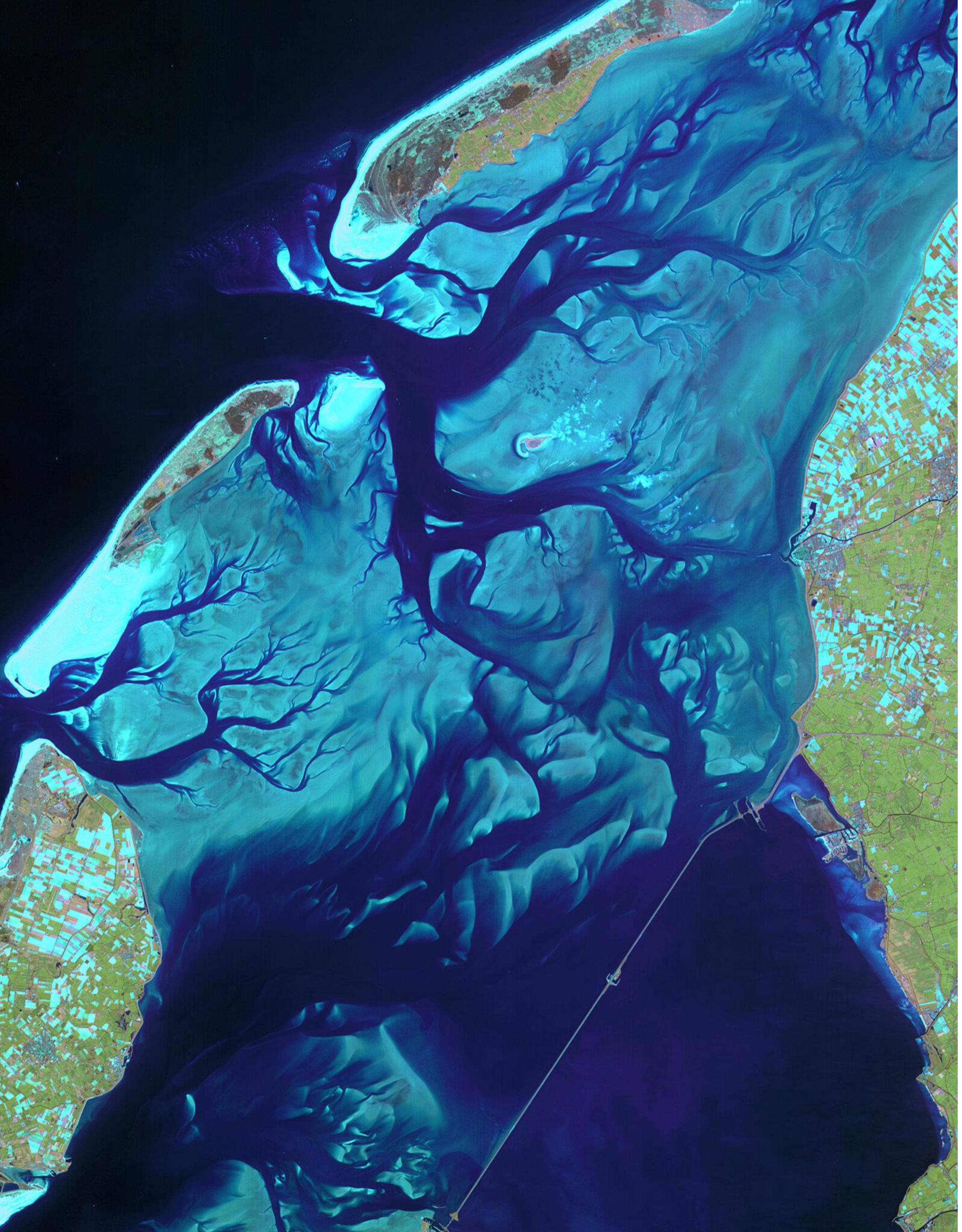
Outlook

2024: Reporting on validation of mud

2024-2028: PhD within WadSed (NWO perspectief).

- Improve processes *river discharge, sediment fractions, marshes, changing basin area, …*
- Higher spatial resolution *Delft3D-Asmita hybrid, more elements Asmita*
- Probabilistic modelling
- International cases *Likely US, collaboration USGS?*
- Coupling with ecology and flood safety

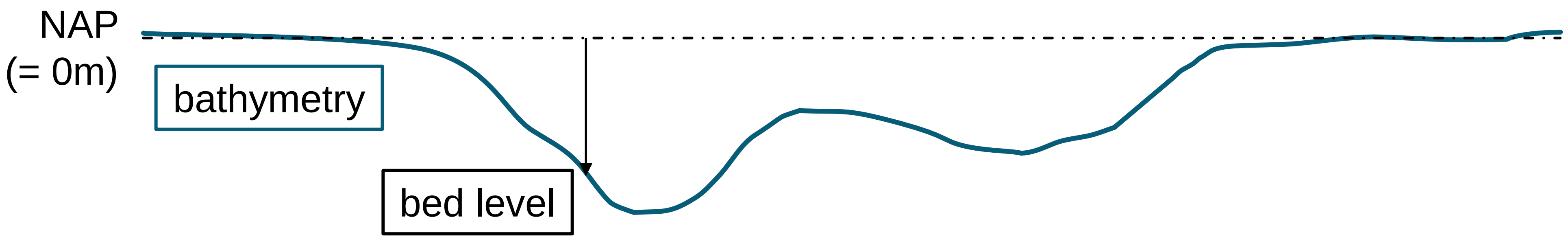
Deltares



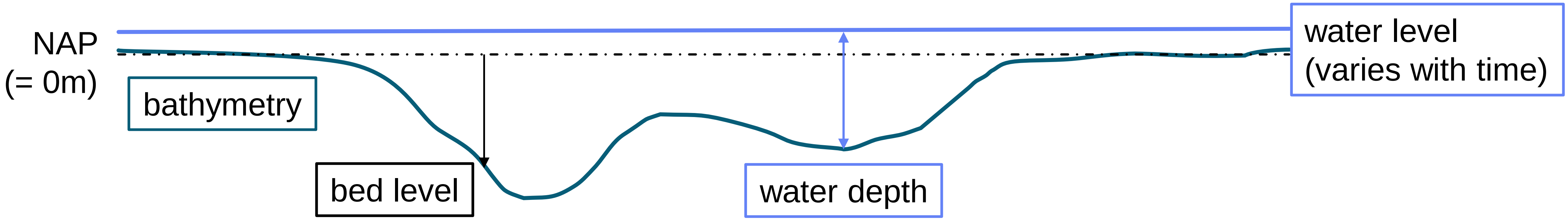
Delft3D-ASMITA hybrid model

- Model principle, formulation & implementation
- Application to the Wadden Sea

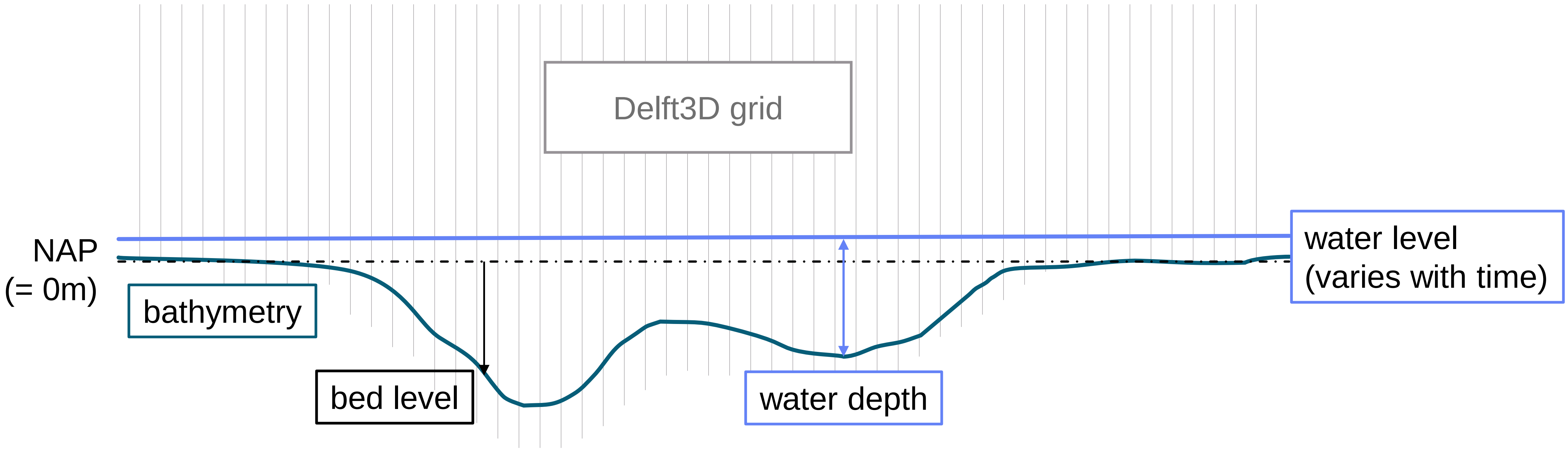
Setting up the hybrid model: start simple



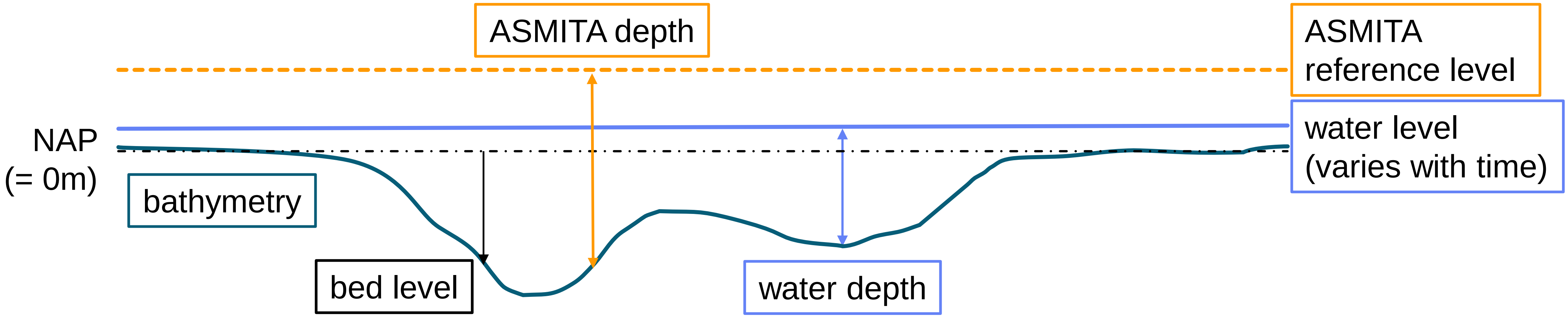
Setting up the hybrid model: start simple, add water



Setting up the hybrid model: add a grid (from Delft3D)

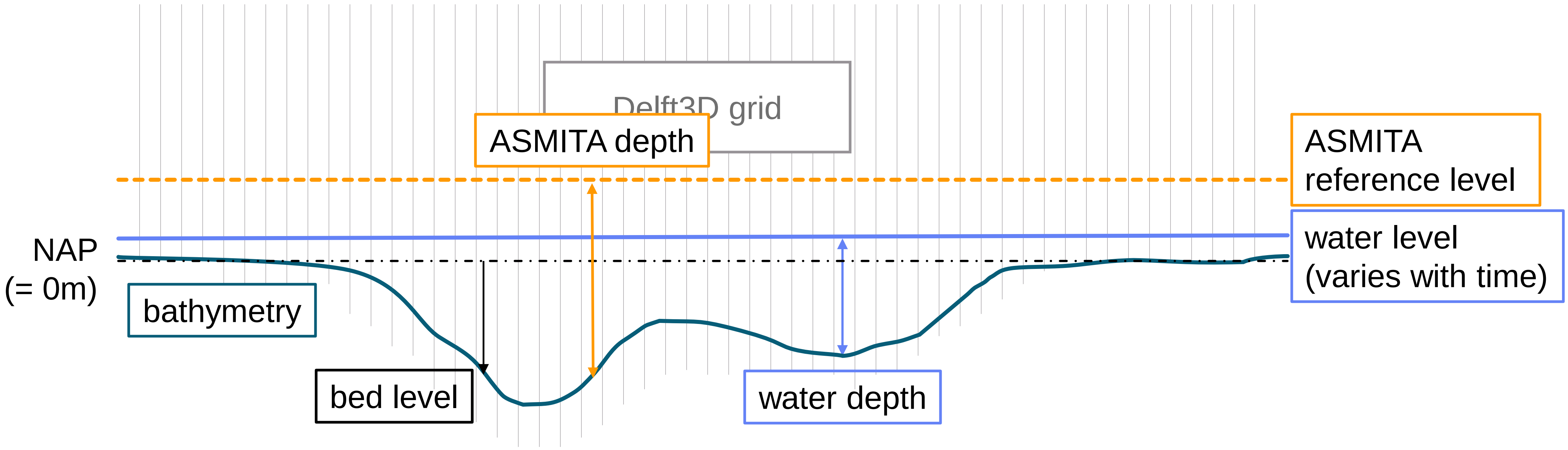


Setting up the hybrid model: introduce equilibrium (from ASMITA)



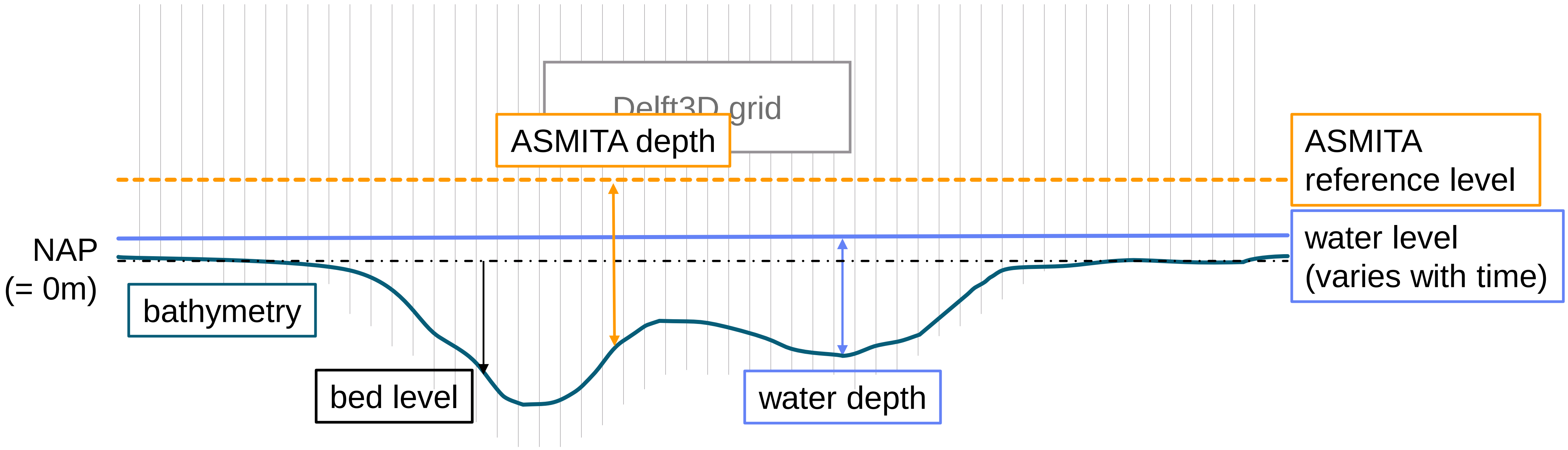
Deltares

Hybrid concept: *equilibrium in grid cells*

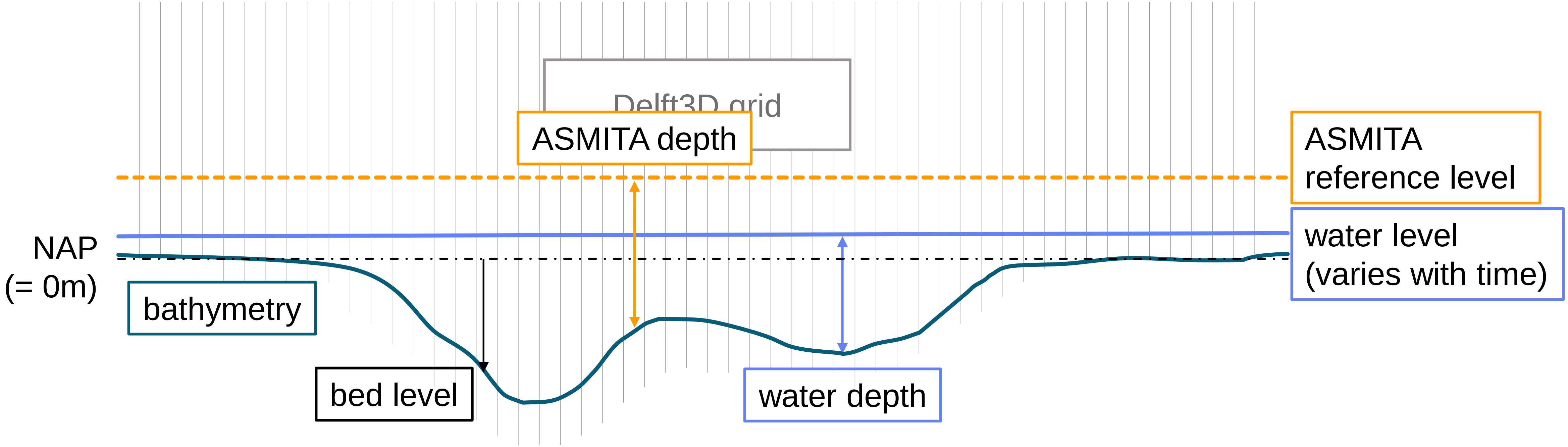


Deltares

Hybrid concept: *equilibrium in grid cells*

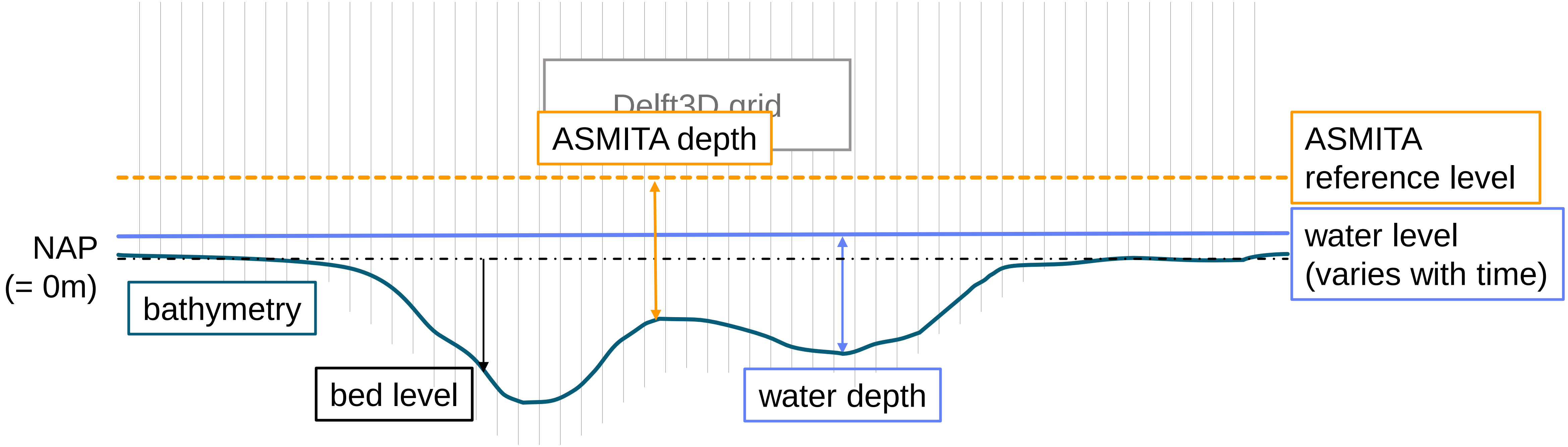


Hybrid concept: *equilibrium in grid cells*



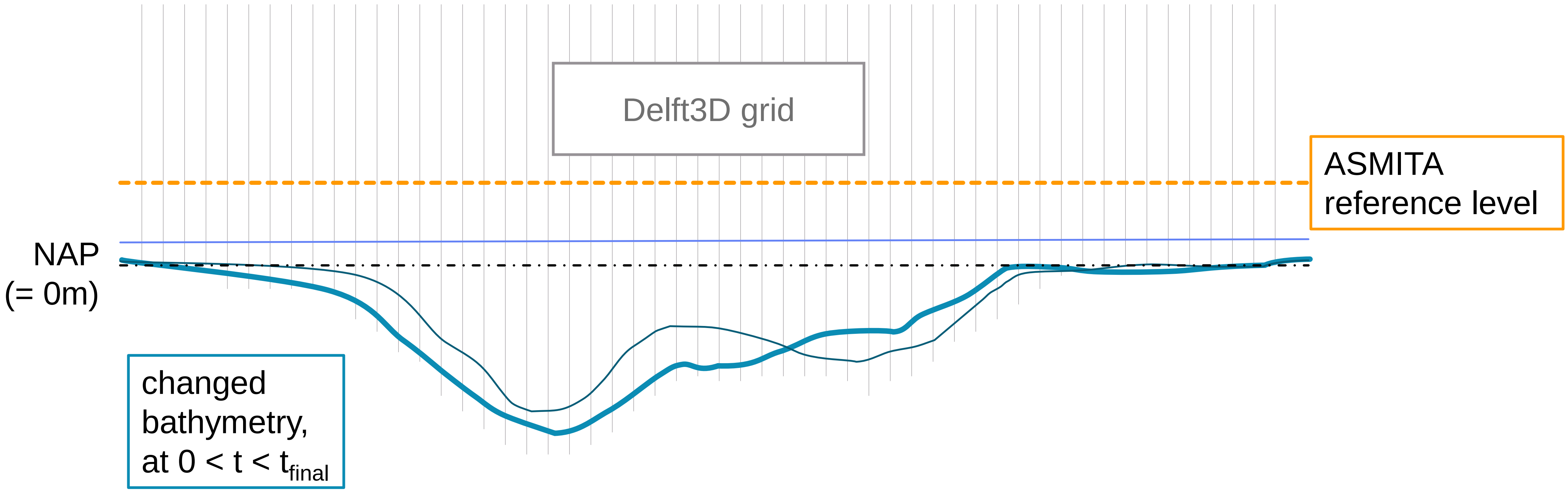
Deltares

Hybrid concept: *equilibrium in grid cells*



Hybrid concept: grid cells *out of* equilibrium

Disturbed equilibrium



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Hybrid concept: grid cells *out of* equilibrium

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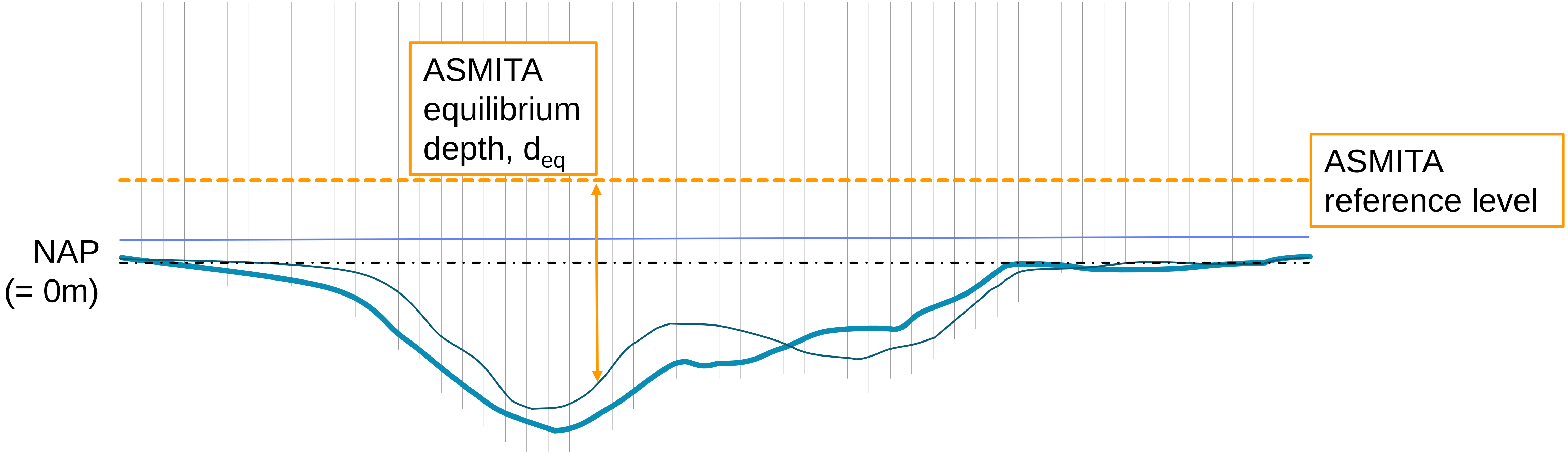

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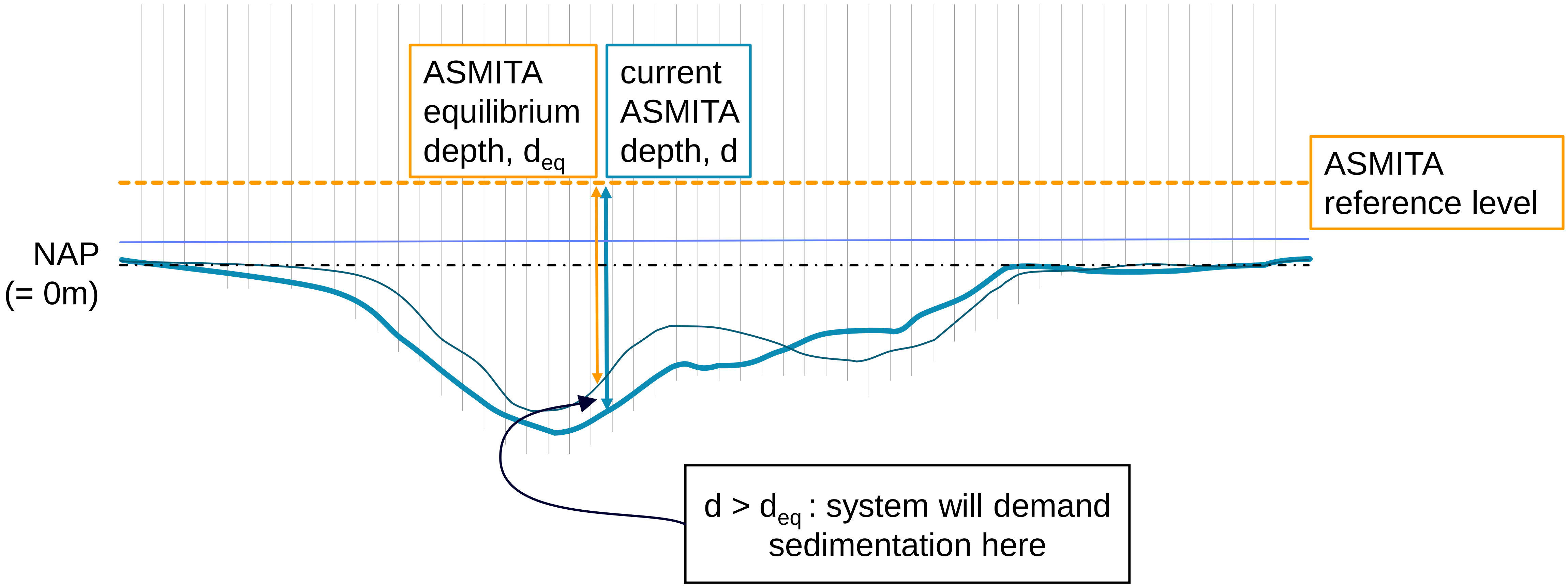
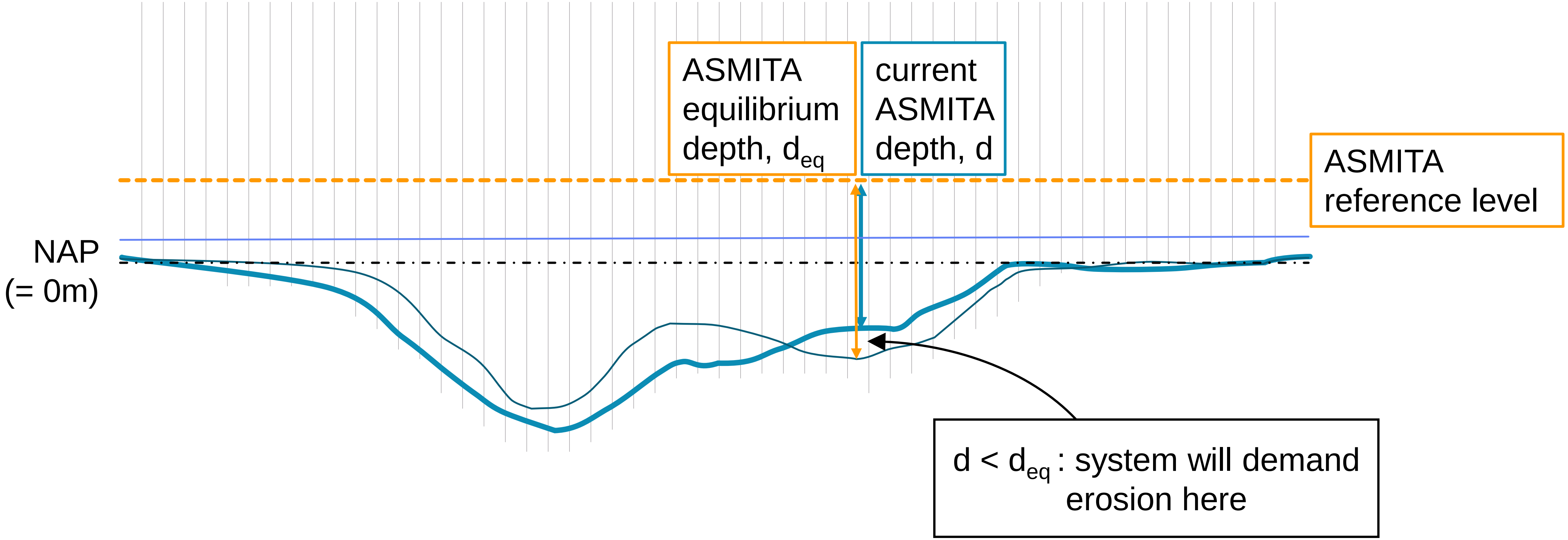
Disturbed equilibrium



Hybrid concept: grid cells *out of* equilibrium

Disturbed equilibrium



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Hybrid model concept
→ combining Delft3D & ASMITA

→ equilibrium bed level for each grid cell: limits applicability, but works very well for e.g. SLR scenarios

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→ Delft3D hydrodynamic module and suspended sediment transport module

$$\frac{\partial h\bar{c}}{\partial t}+\frac{\partial \alpha_x \bar{u} h\bar{c}}{\partial x}+\frac{\partial \alpha_y \bar{v} h\bar{c}}{\partial y}-\frac{\partial}{\partial x}\left(D_x h\frac{\partial \bar{c}}{\partial x}\right)-\frac{\partial}{\partial y}\left(D_y h\frac{\partial \bar{c}}{\partial y}\right)=E \quad \text{with} \quad E=\gamma w_s\left(c_e-c\right)$$

where instead of $c_e = F\left(u, ..., D_{50}, ...\right)$ used for regular Delft3D simulations, we use $c_e = C_E\left(\frac{h_e}{h}\right)^n$

for Hybrid modelling

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Hybrid model concept
→ combining Delft3D & ASMITA

→ equilibrium bed level for each grid cell: limits applicability, but works very well for e.g. SLR scenarios

→ ASMITA formulatio… …lumn: empirical relation based on *morphologi*… …sediment transport capacity

→ Delft3D hydrodyna…

$$\frac{\partial h\bar{c}}{\partial t} + \frac{\partial \alpha_x \bar{u} h\bar{c}}{\partial x} + \ldots \quad \ldots_s \left(c_e - c\right)$$

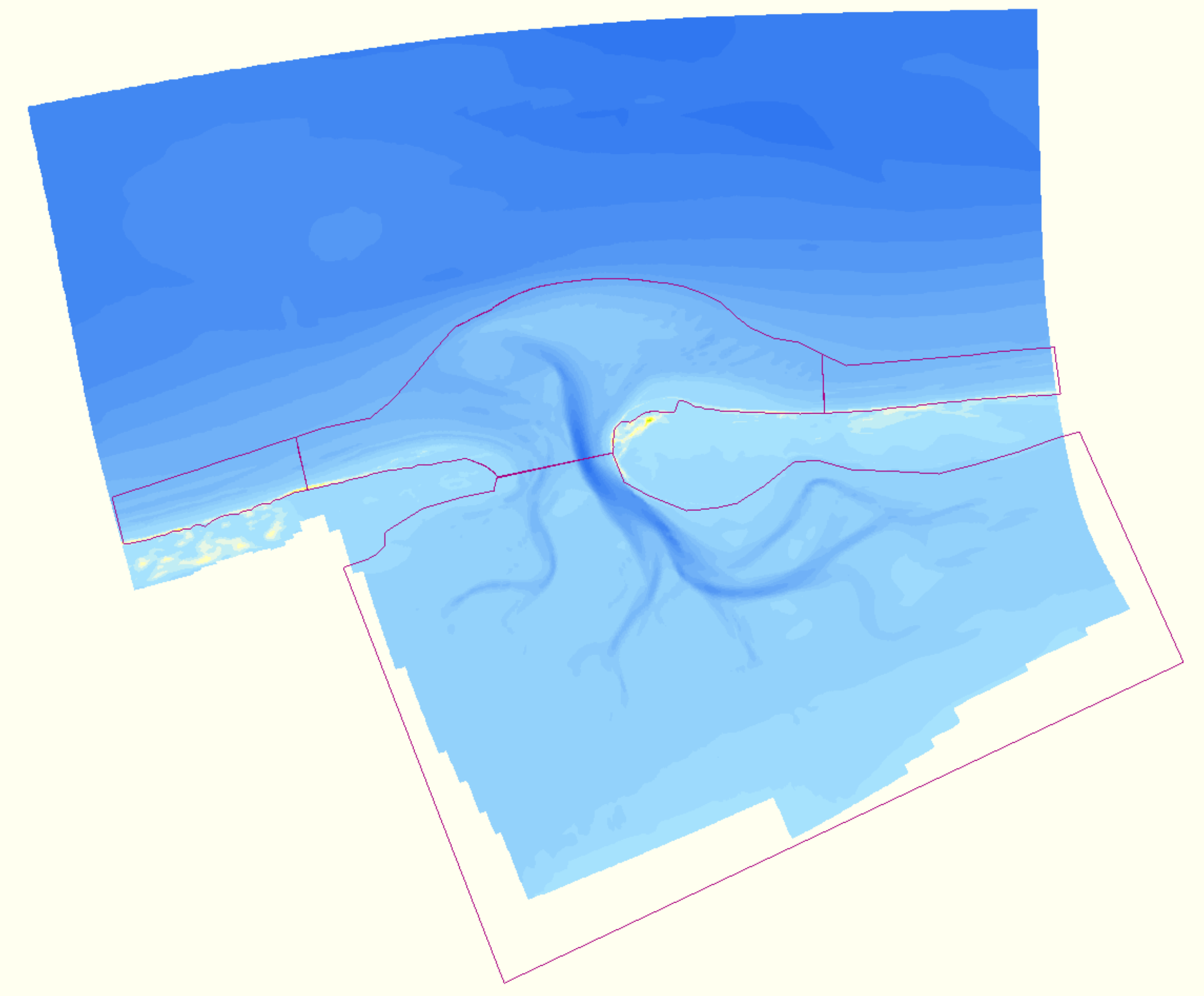
<u>Take-Home message:</u>

Equivalent to running a normal Delft3D simulation

… just using a different transport formula concept

where instead of $c_e = F\left(u, ..., D_{50}, ...\right)$ used for regular Delft3D simulations, we use $c_e = C_E \left(\frac{h_e}{h}\right)^n$ for Hybrid modelling

Hybrid concept: stable SLR implementation



- ASMITA equilibrium relations are only valid in the tidal inlet system.
- Sediment import only happens through open boundaries.
- Raising water levels at boundaries: sediment gets deposited offshore (close to the open boundaries).
- Sea level rise can also be modelled as subsidence: **only apply subsidence where ASMITA is valid**.
- Subsidence in foreshores: smooth transition.
  Nourish in foreshores to counteract SLR.

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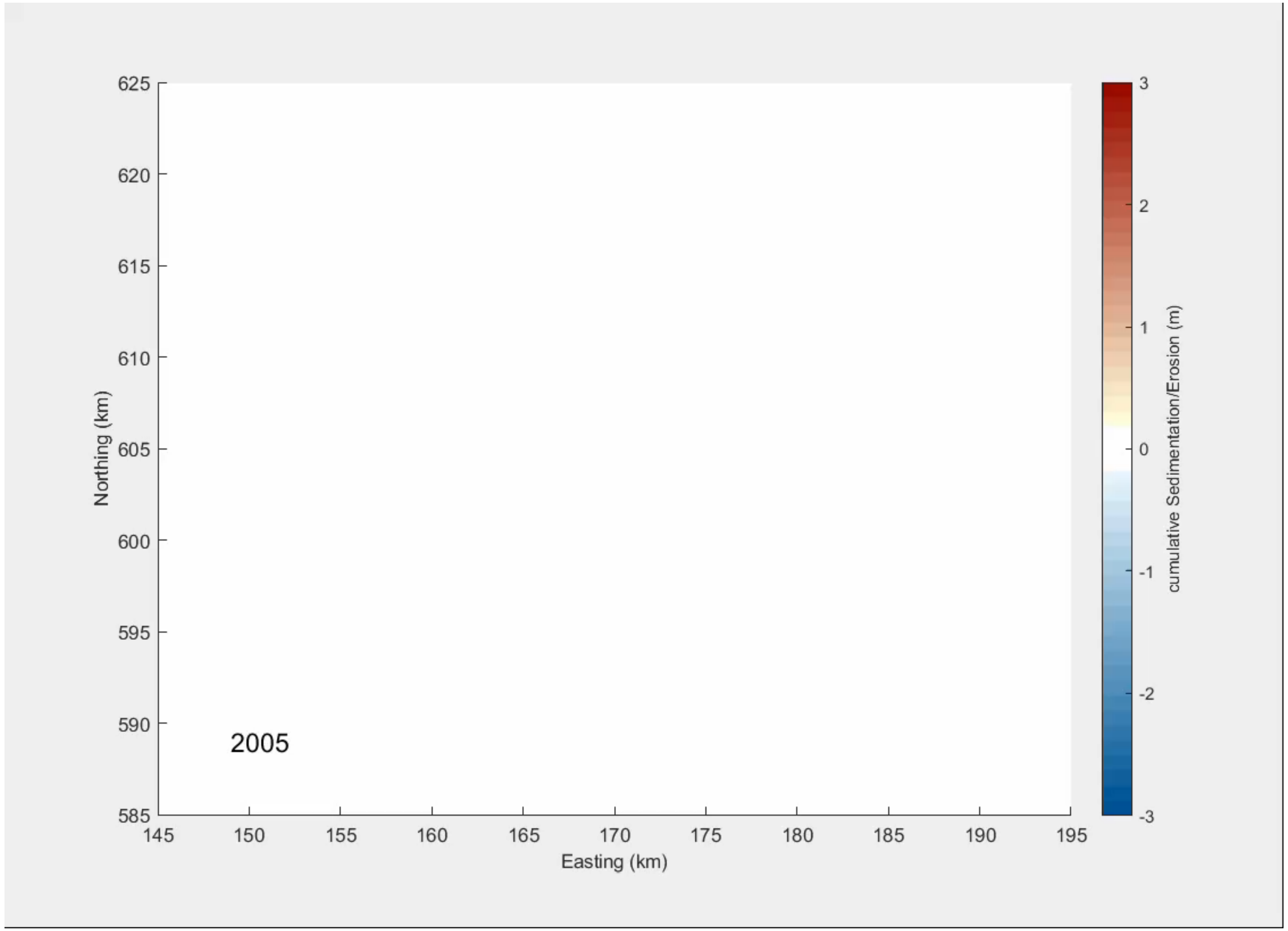
Hybrid model: some results (work in progress)



constant Sea Level Rise:
10.4 mm/y
over two centuries

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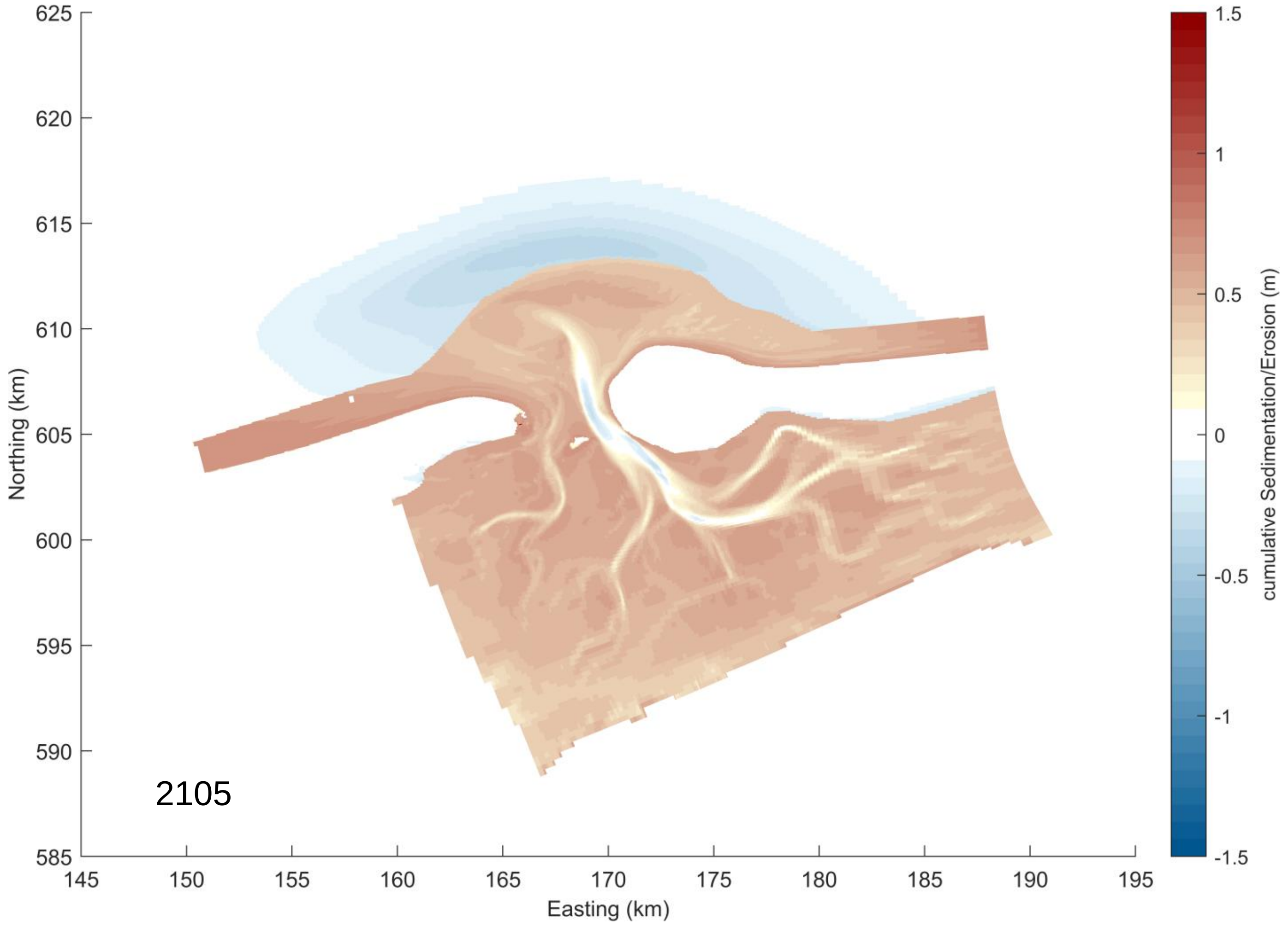
Hybrid model: some results (work in progress)



ramping up SLR:
from 2 mm/y to 10.4 mm/y
(by 2070)
over a century in total

→ 68.5 cm SLR in total

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Functionalities currently under development

Functionality	working	under development	planned
time varying SLR	X		

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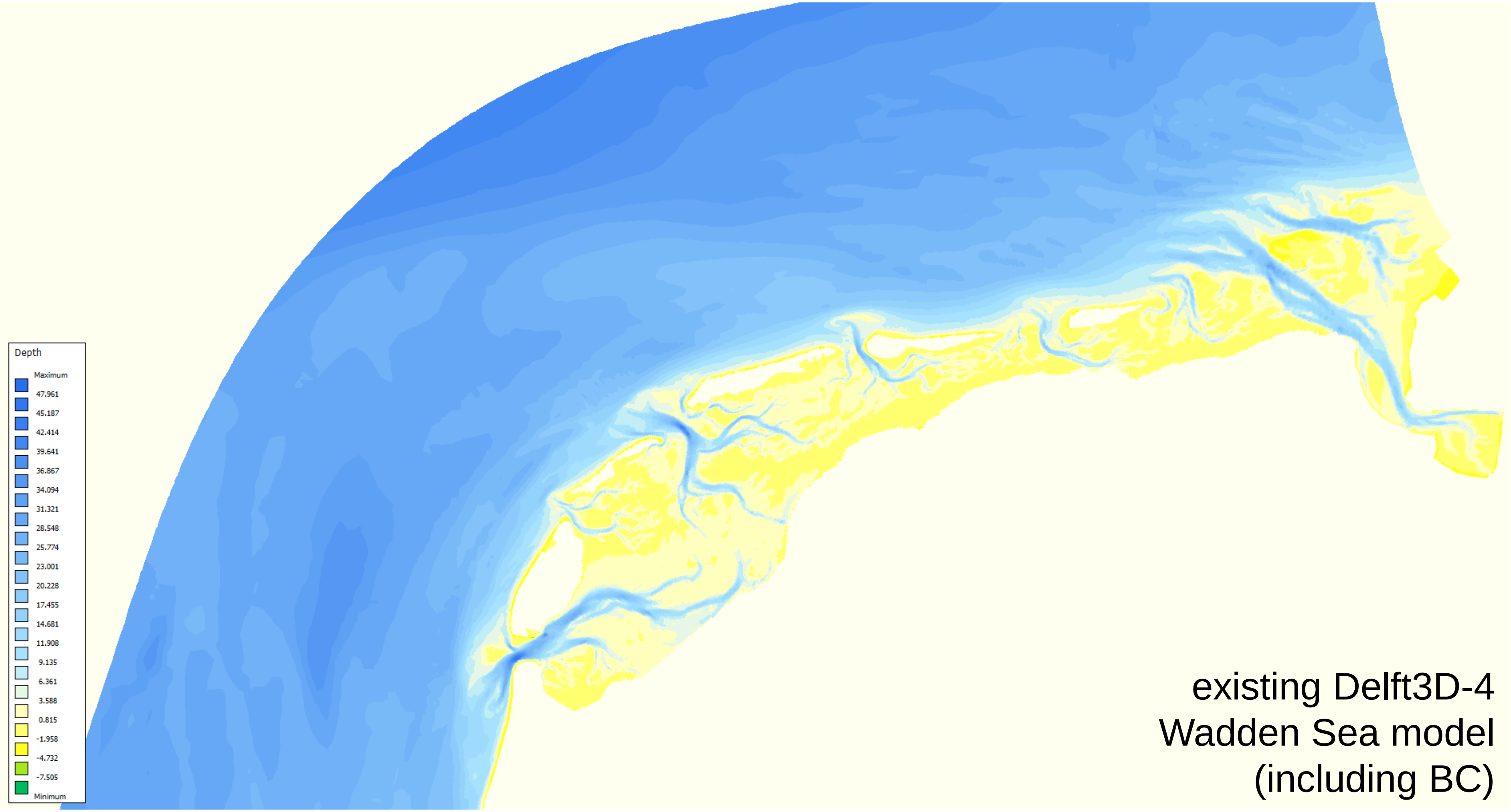
Functionalities currently under development

Functionality	working	under development	planned
time varying SLR	X		
two sediment fractions		X	

Hybrid model: extend to the Wadden Sea



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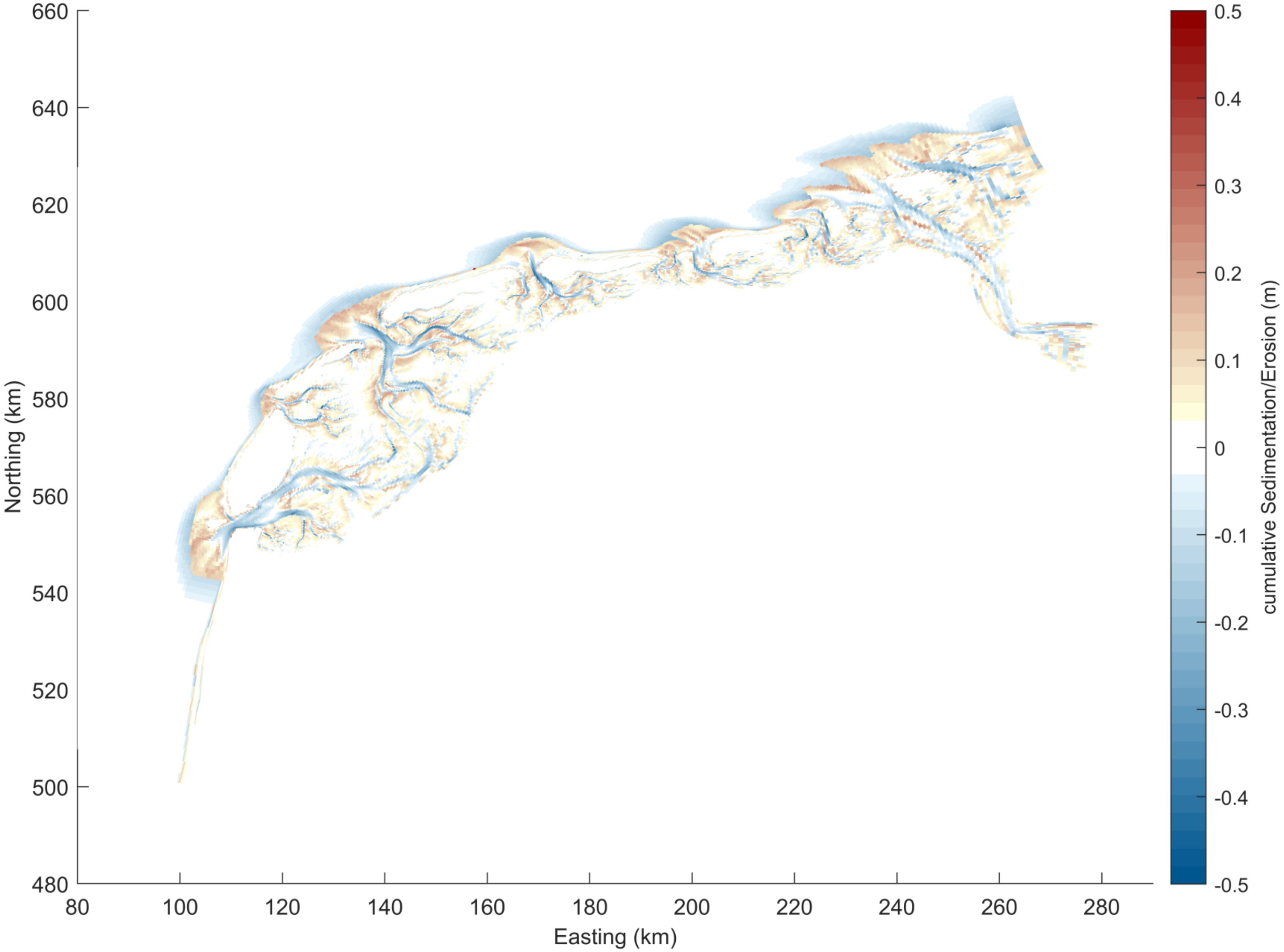
Hybrid concept: first results for the Wadden Sea model

2 mm SLR over two centuries ("business as usual").

Slow sand, settling velocity: 0.1 mm/s

Equilibrium concentration: 320 g/m^3



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Functionalities currently under development

Functionality	working	under development	planned
time varying SLR	X		
two sediment fractions		X	
cross-sectional analysis (watersheds)			X

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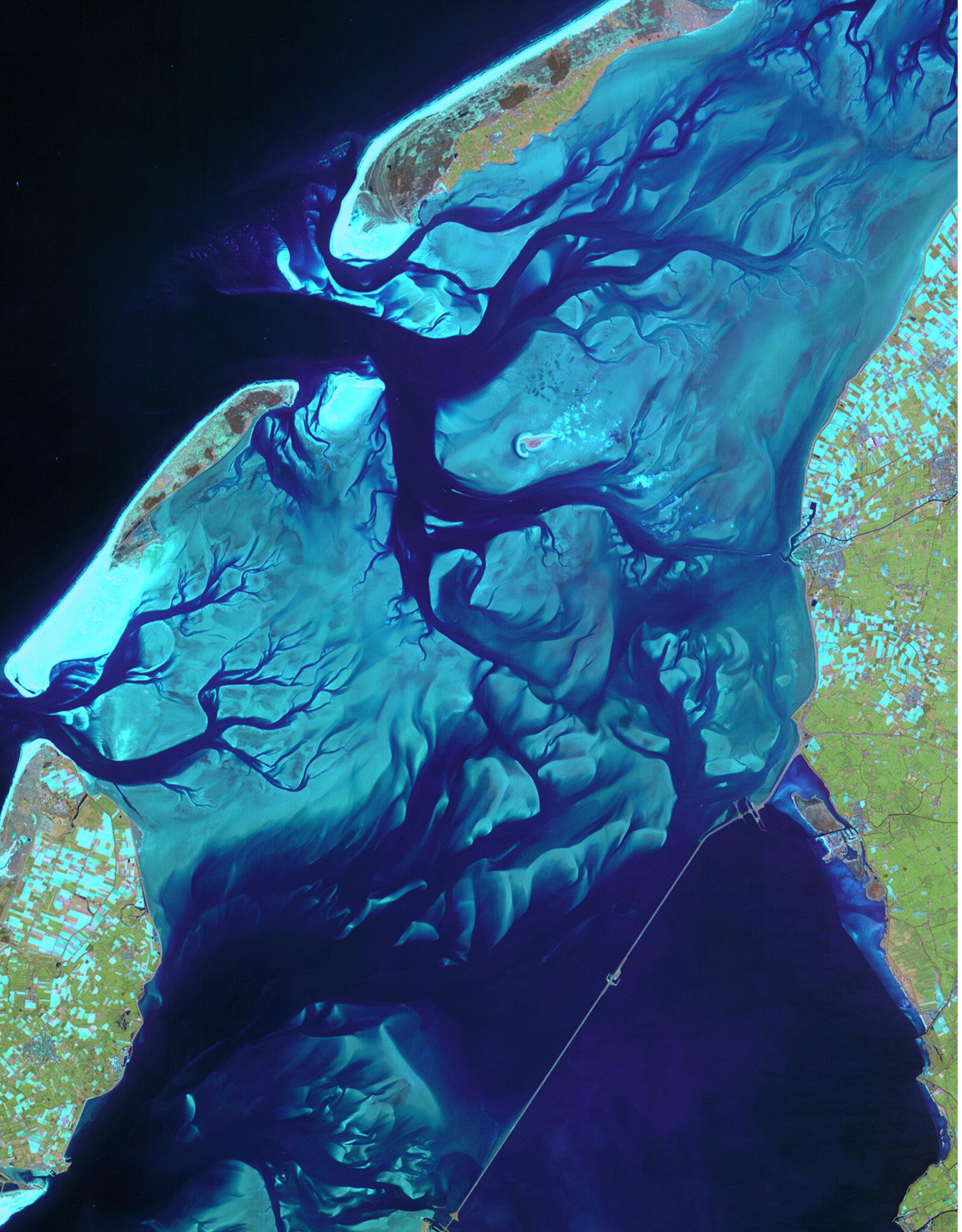
Functionalities currently under development

Functionality	working	under development	planned
time varying SLR	X		
two sediment fractions		X	
cross-sectional analysis (watersheds)			X
spatially varying equilibrium bathymetry			X



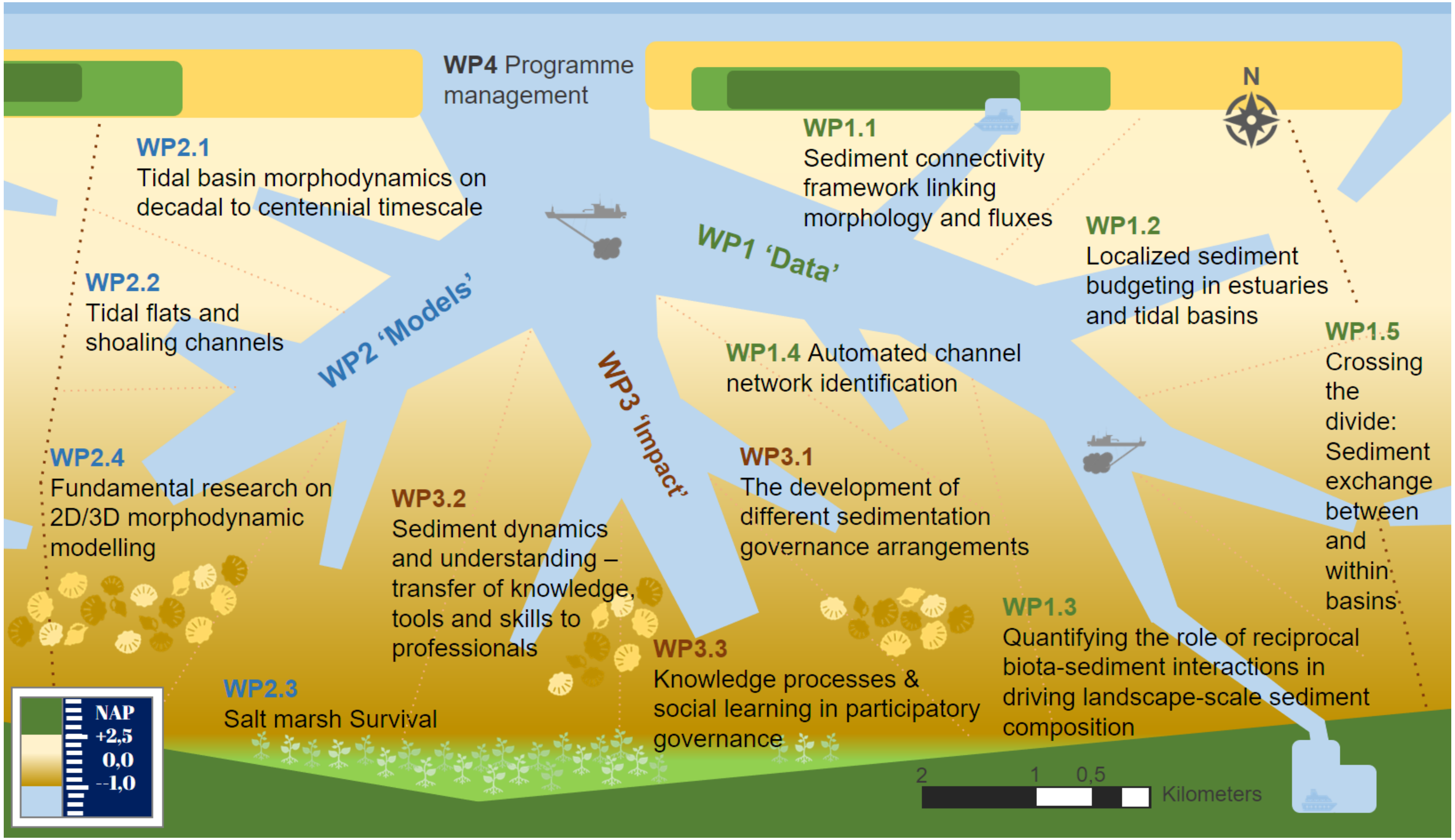
Concluding discussions & outlook

Summary

- Model application
  - Sediment exchange North Sea coast – Wadden Sea ➔ Nourishment requirement & LT strategy
  - Future (e.g. after 2 m SLR) bathymetry of the Wadden Sea ➔ Future flood defense
  - Future development of intertidal flat ➔ ecological value
  - Effects of subsidence due to gas and salt extraction
- Model development
  - Adding functionalities
  - Narrowing the gap with process-based models
- Fundamental research
  - On model concept for supporting model development
  - Obtain system understanding using the model

The aggregated models are competitive but complementary to the process-based models

WadSED



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TU Delft
Delft University of Technology
Delft University of Technology

Pathways for Realising Climate Adaptation in the Wadden Sea - PaRCA

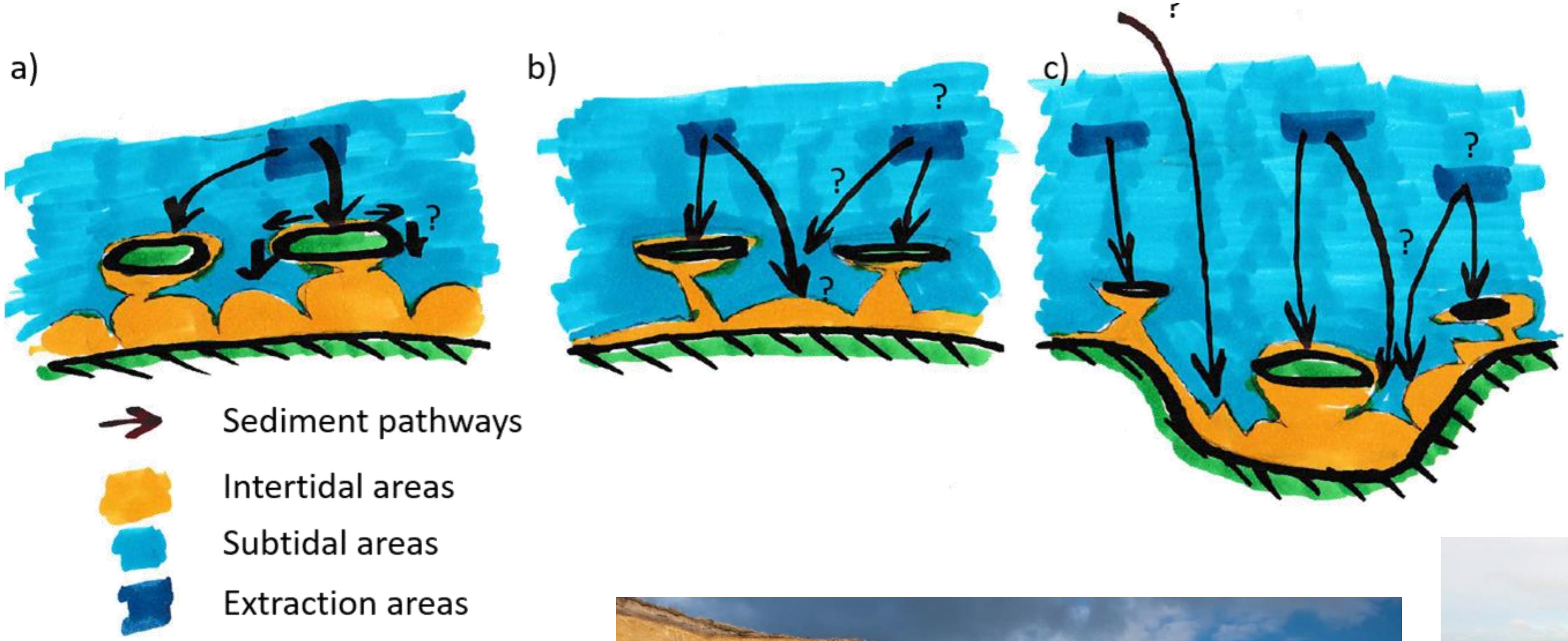
INterventions for a sustainable Wadden Sea

A joint NL-D-DK initiative

BAW Bundesanstalt für Wasserbau | NIOZ Royal Netherlands Institute for Sea Research | SENCKENBERG world of biodiversity | Deltares | TU Delft Delft University of Technology | CAU | Global Climate Forum

Rijkswaterstaat, Staatsbosbeheer, Waddenvereniging, Ecoshape, NLWKN Brake-Oldenburg, NLWKN Norden, LKN.SH, WSA Weser-Jade-Nordsee, GDWS, NPV LS, WWF Wadden Sea Office, WSF, BfG (Federal Institute of Hydrology), Danish Coastal Authority, Uni Rostock

Measures / Interventions



Management Options
a) Indirect nourishments of the tidal flats
b) direct beach and basin nourishments)
c) combination with coastal realignment (islands and mainland).


Thank you!

Concluding discussions & outlook

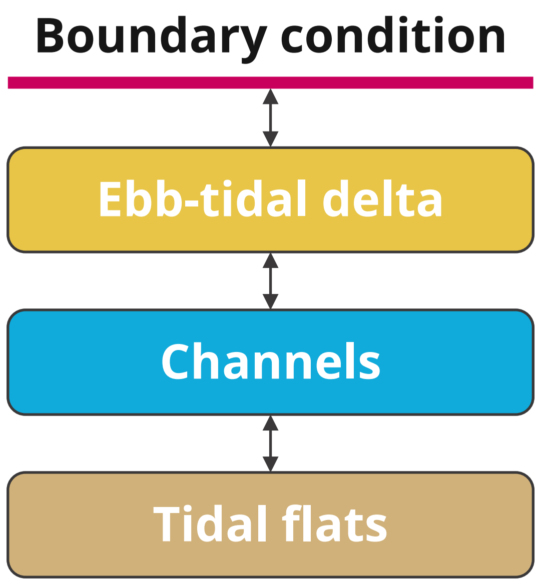
- Extended ASMITA with mud and marshes
- A new LT morphodynamic modelling approach implemented in Delft3D, combining process-based and aggregated (semi-empirical) approaches, meant for studying effects of relative sea-level rise. The first results look promising.
- Advantage & disadvantages
  - Compared to ASMITA: (+) it provide more detailed info concerning e.g. spatial variation of the effect of subsidence caused by gas or salt mining; (-) no ready to use empirical relations for morphological equilibrium available.
  - Compared to (process-based) Delft3D: (+) robustness, saving computational time as coarser grid can be used; (+) no spin-up problem; (-) fixed channel-shoal structure, cannot simulate e.g. channel migration.

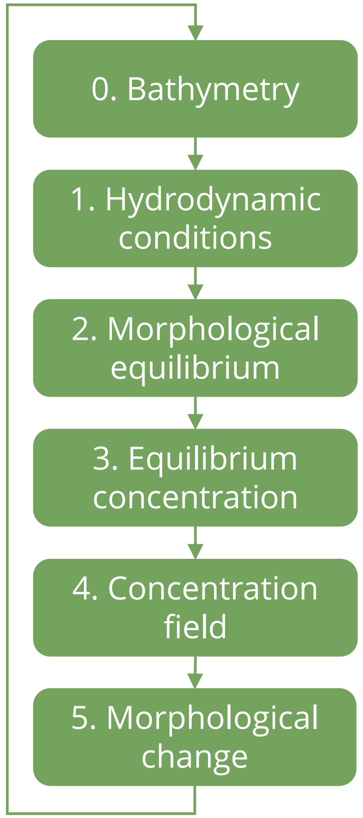
Outlook

- Many things about the new approach still need to be explored
  - Response coastal area (seawards of the inlet) to SLR
  - Influence depth within the basin on response to SLR
  - Multi-fraction sediment
  - Further aggregation in time (tide-averaged mode)
- Studying the relation between Delft3D and ASMITA
  - Determining dispersion coefficient in tide-averaged mode

parameter	value	unit
Δt	3	days
w_s	1e-3	m/s
ρ_s	2650	kg/m^3
n	0.80	-
A_{marsh}	1.01e7	m^2
δ_0	7.60	m^3/s

The salt marsh model extension has a different computational procedure compared to the existing ASMITA model.





The salt marsh model extension has a different computational procedure compared to the existing ASMITA model.

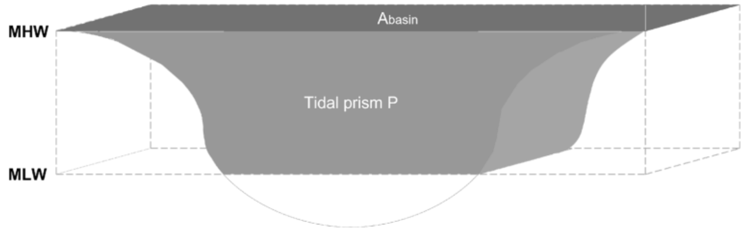
Boundary condition

Ebb-tidal delta

Channels

Tidal flats

0. Bathymetry
1. Hydrodynamic conditions
2. Morphological equilibrium
3. Equilibrium concentration
4. Concentration field
5. Morphological change

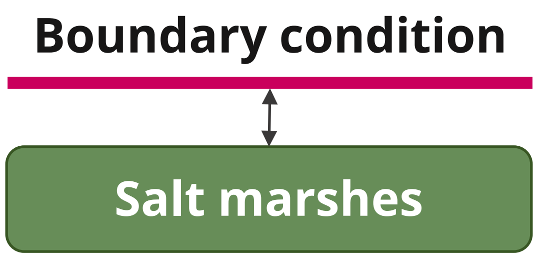


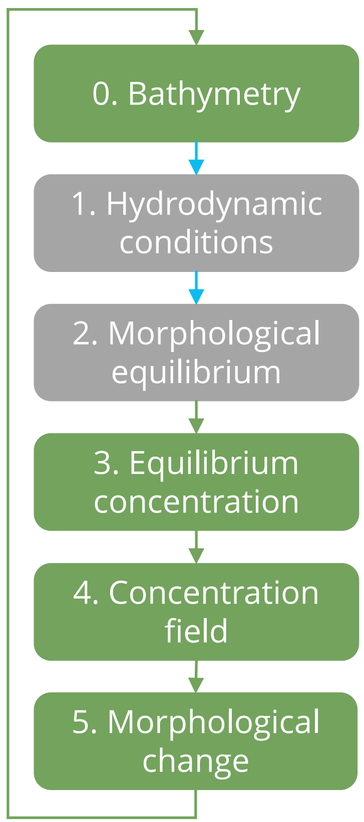
$$V_{equilibrium} = \alpha P^{\beta}$$

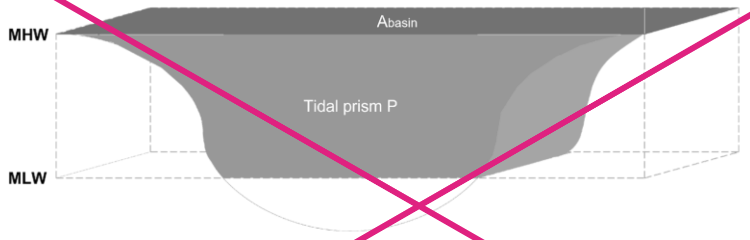
$$c_e = c_E \left(\frac{V_e}{V}\right)^n$$

$$\frac{dV}{dt} = w_s A(c_e - c)$$

For the salt marsh, the tidally averaged hydrodynamic conditions can not be employed for the morphological equilibrium condition.







$$V_{equilibrium} = \alpha P^{\beta}$$

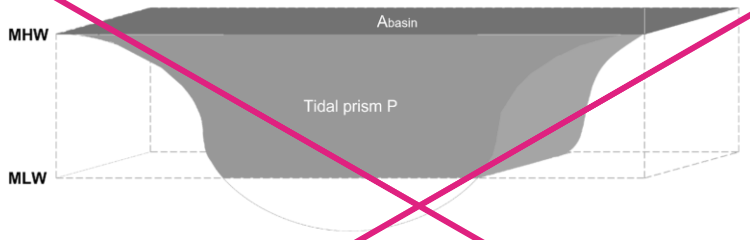
$$c_e = c_E \left(\frac{V_e}{V}\right)^n$$

The model extension is based on $c_e = 0$: all sediment that flows onto the salt marsh is captured.

Boundary condition

Salt marshes

0. Bathymetry
1. Hydrodynamic conditions
2. Morphological equilibrium
3. Equilibrium concentration
4. Concentration field
5. Morphological change



$$\cancel{V_{equilibrium} = \alpha P^{\beta}}$$

$$\cancel{c_e = c_E \left(\frac{V_e}{V}\right)^n}$$

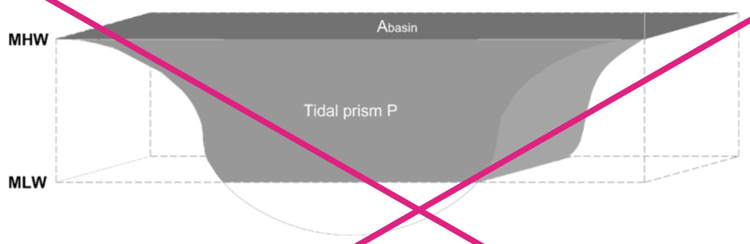
$$c_e = 0$$

The morphological change is calculated based on the aggregated advection-diffusion equation.

Boundary condition

Salt marshes

0. Bathymetry
1. Hydrodynamic conditions
2. Morphological equilibrium
3. Equilibrium concentration
4. Concentration field
5. Morphological change



$$\cancel{V_{equilibrium} = \alpha P^{\beta}} \qquad \cancel{c_e = c_E \left(\frac{V_e}{V}\right)^n}$$

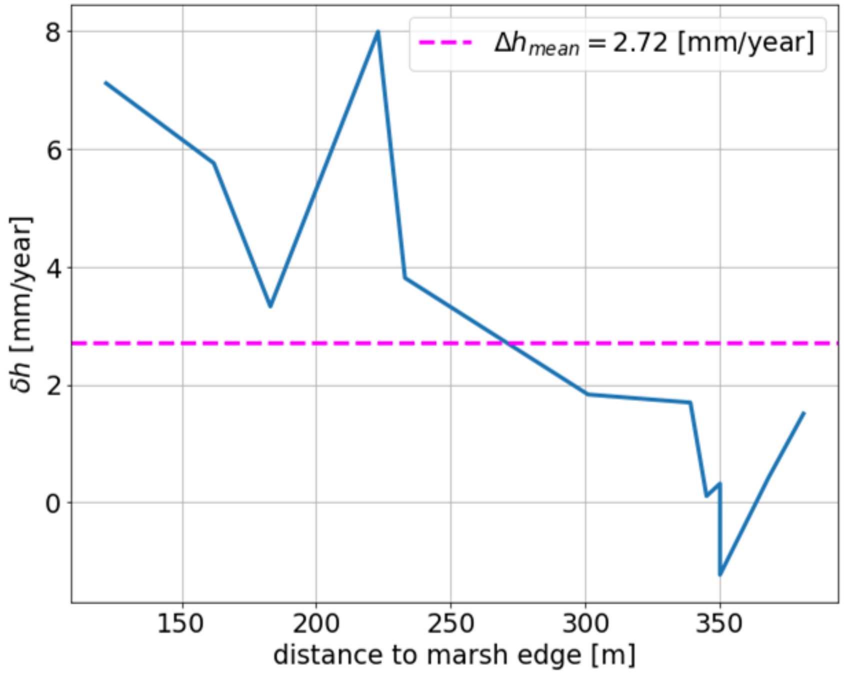
$$\frac{\Delta V_{marsh}}{\Delta t} = \frac{w_s A \delta}{\delta + w_s A} c_E - h_{SLR} A_{marsh}$$

The marsh volume change depends on sedimentation and sea level rise.

$$\underbrace{\frac{\Delta V_{marsh}}{\Delta t}}_{\text{salt marsh volume change}} = \underbrace{\frac{w_s A \delta}{\delta + w_s A} c_E}_{\text{sedimentation}} - \underbrace{h_{SLR} A_{marsh}}_{\text{sea level rise}}$$

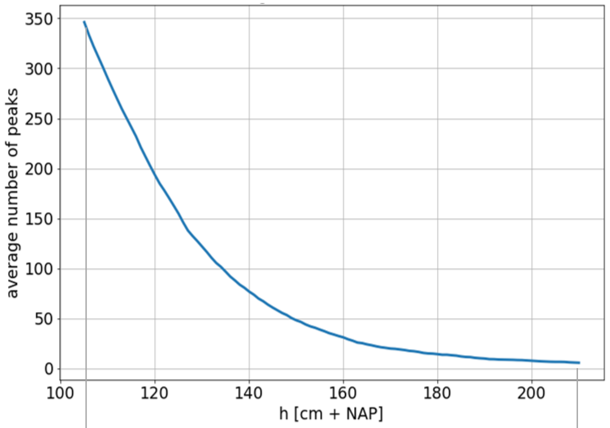
The governing model parameters for sedimentation are δ, w_s and c_E.

$$\underbrace{\frac{\Delta V_{marsh}}{\Delta t}}_{\text{salt marsh volume change}} = \underbrace{\frac{w_s A \delta}{\delta + w_s A} c_E}_{\text{sedimentation}} - \underbrace{h_{SLR} A_{marsh}}_{\text{sea level rise}}$$



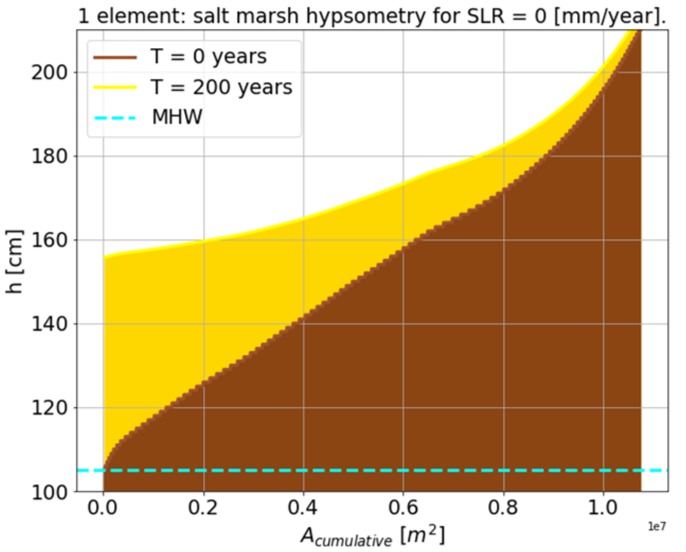
$\Delta h_{mean} = 2.72$ [mm/year]
8
6
4
2
0
δh [mm/year]
150
200
250
300
350
distance to marsh edge [m]

1-element model: how the sediment is distributed over the marsh

ΔV_{marsh} + 

$f_{inundation}$

Marsh edge

= 

Δh_{marsh}

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