The morphodynamics of sandy shorelines and the effects of sand nourishments

FZK Colloquium, Hanover

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Presentation Outline:

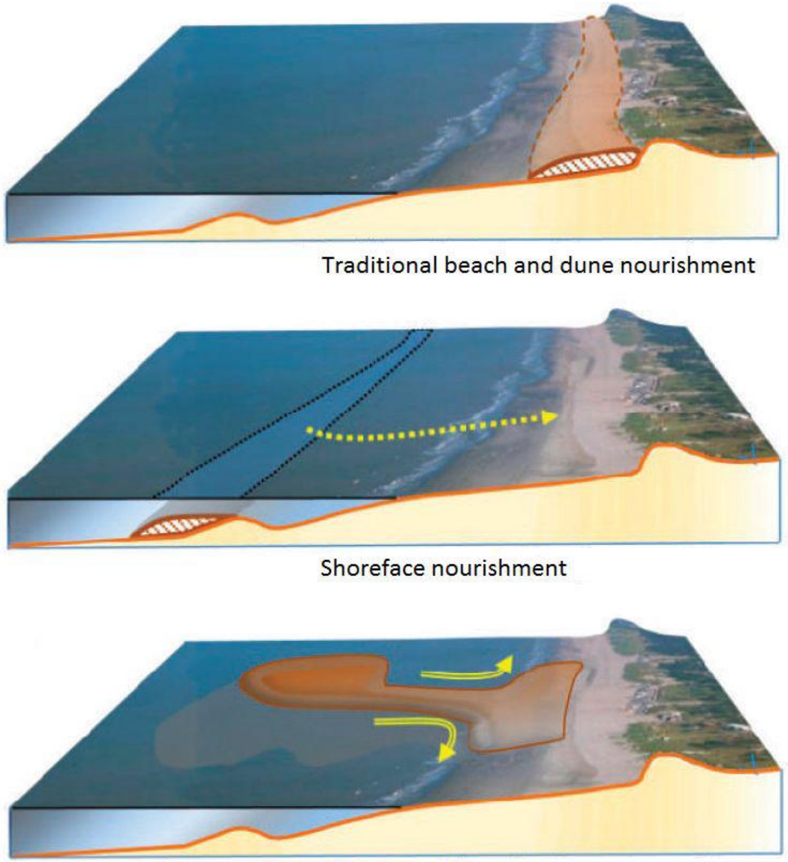
- **Sand nourishments as a 'Building with Nature' solution**
  - Control parameters
- **Identify sandy shoreline dynamics**
  - Comparing two cross-shore profiles
- **Quantify sandy shoreline dynamics with Empirical Eigenfunctions**
  - Academic examples
- **The lifetime of sand nourishments**
  - Two case study applications
- **Conclusions**

Sand nourishments as a 'Building with Nature' solution

- Using environmental values in engineering solutions:
  - Limit the environmental impact
  - Including the natural dynamics

- Control parameters of sand nourishments:
  - Timing
  - Frequency (e.g. volume)
  - Location

- <u>Important to remember for this presentation:</u>
  - Identify the effect of the control parameters of sand nourishments on the lifetime of the sand nourishments
  - Lifetime of the sand nourishment is the period of interruption in the natural morphodynamics of sandy shorelines



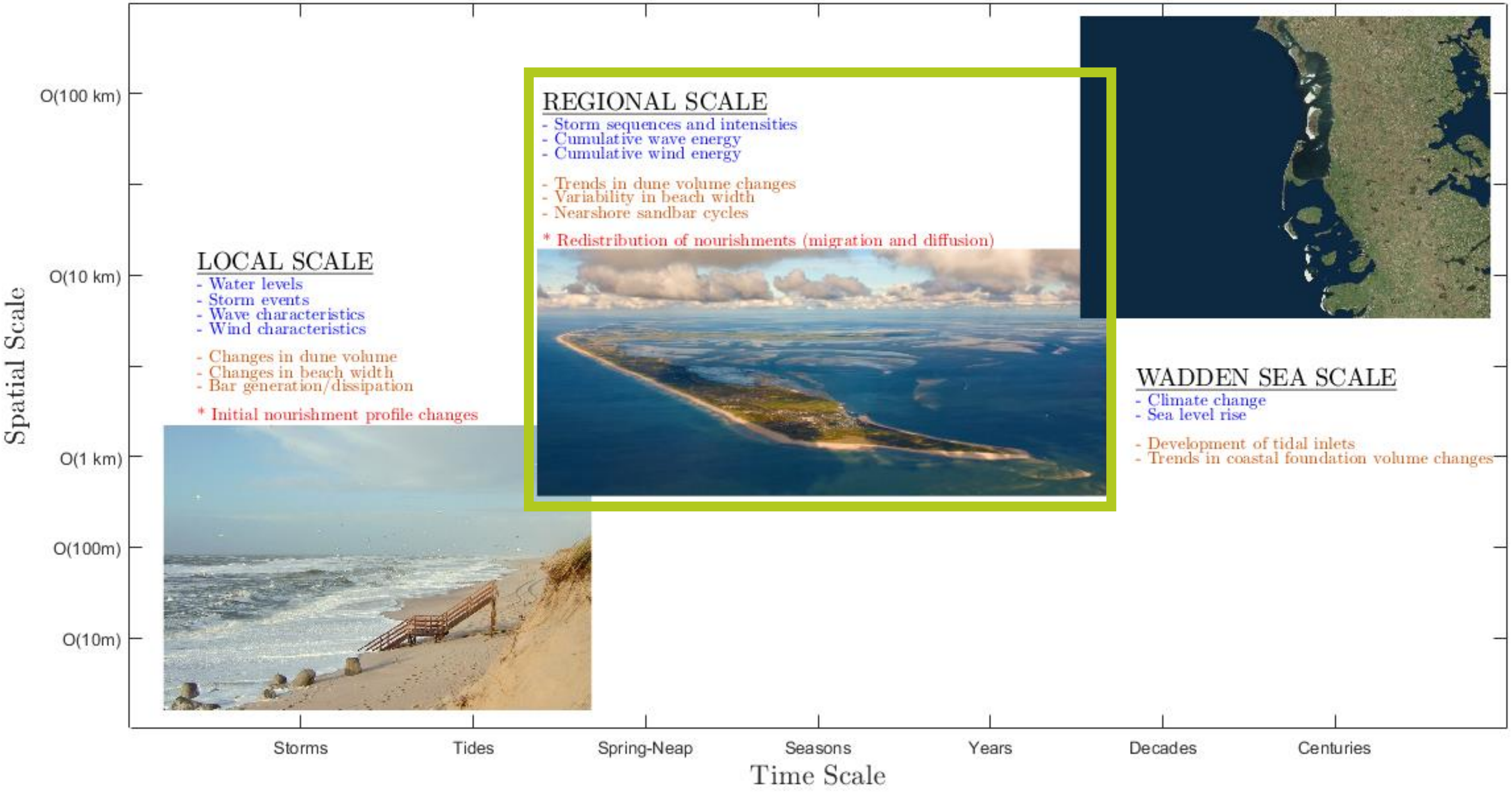
Traditional beach and dune nourishment

Shoreface nourishment

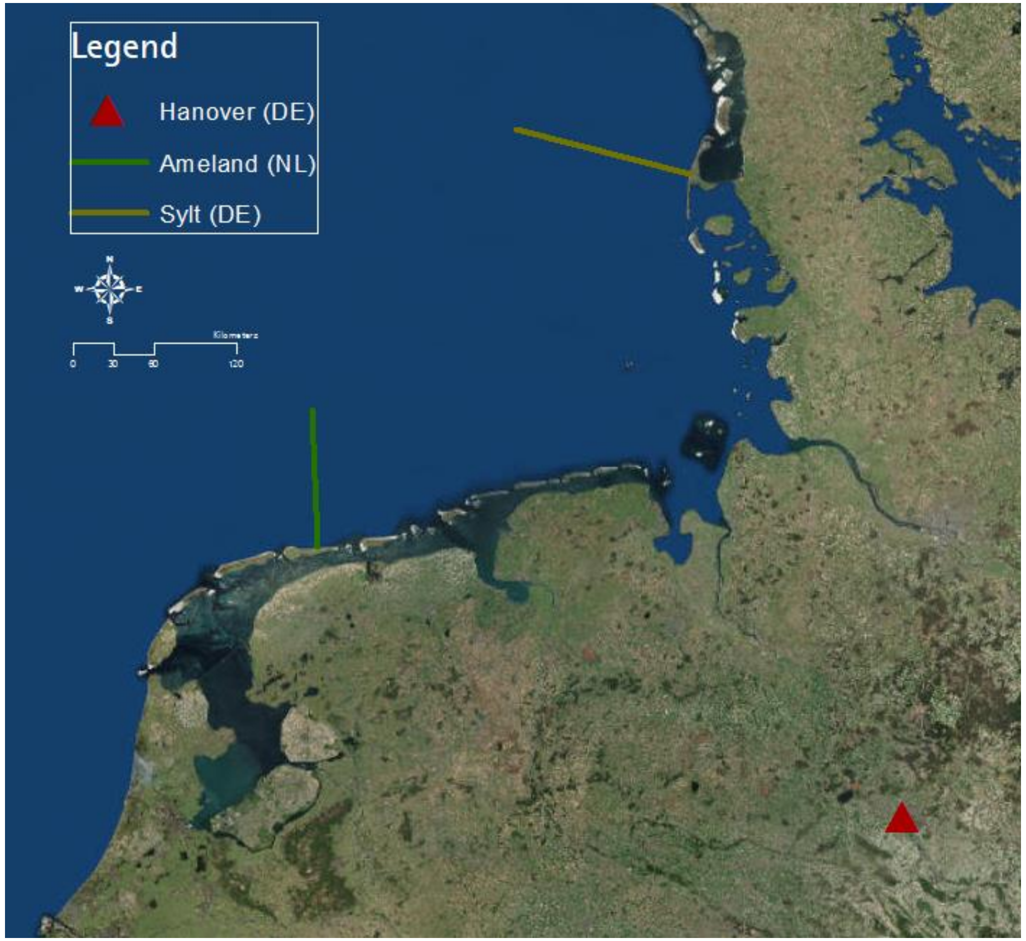
Mega nourishment

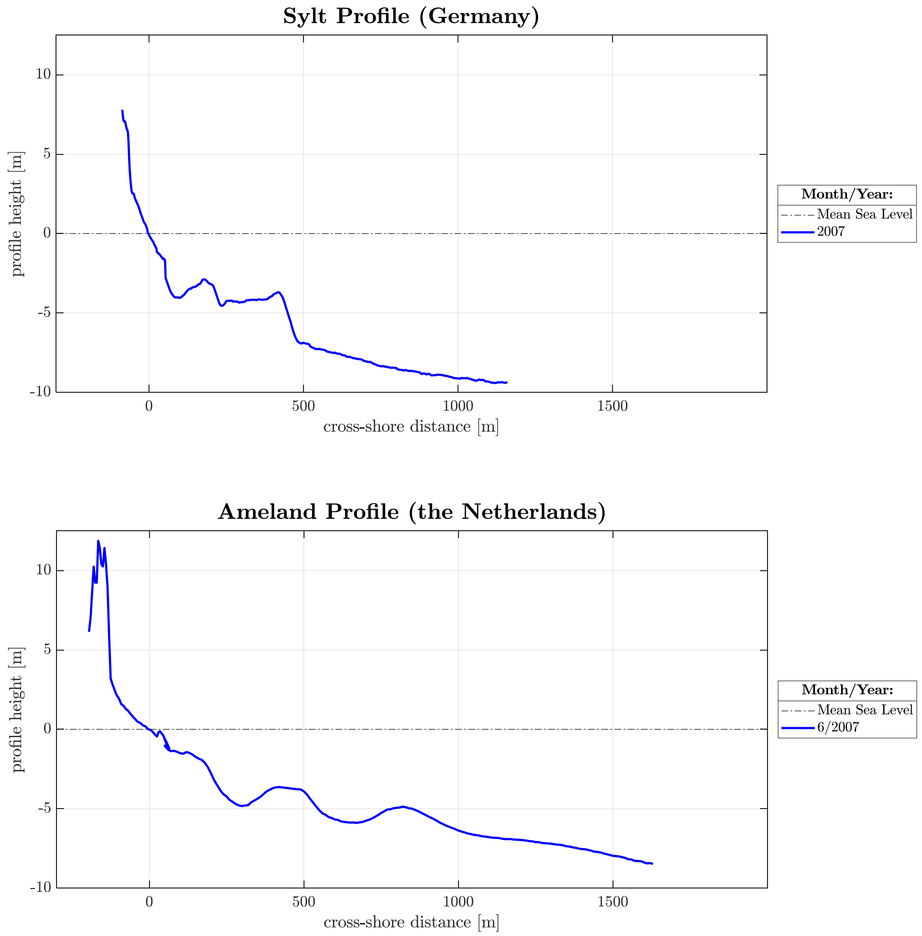
Stive et al., (2013)

Sandy shorelines and its dynamics

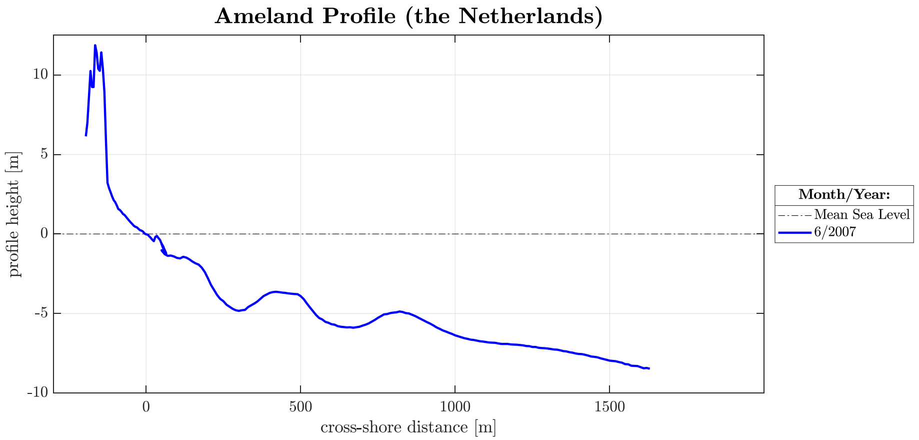


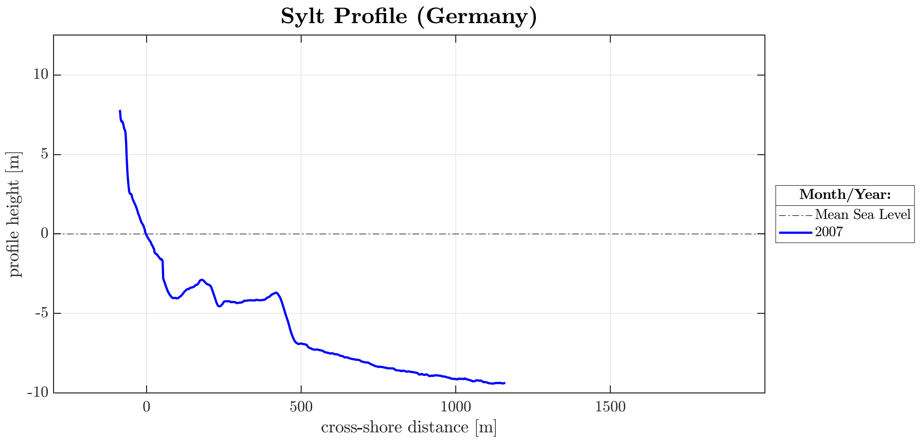
Visual comparison of two coastal profiles





Static comparison coastal profiles 2017





Ameland

Beach characteristics:

- Upper beach slope (~1:50)
- Lower beach slope (~1:80)
- Median grain size ~180 µm

Shoreface characteristics:

- 8 m depth contour ~1500 m offshore
- 3 subtidal sandbars

Sylt

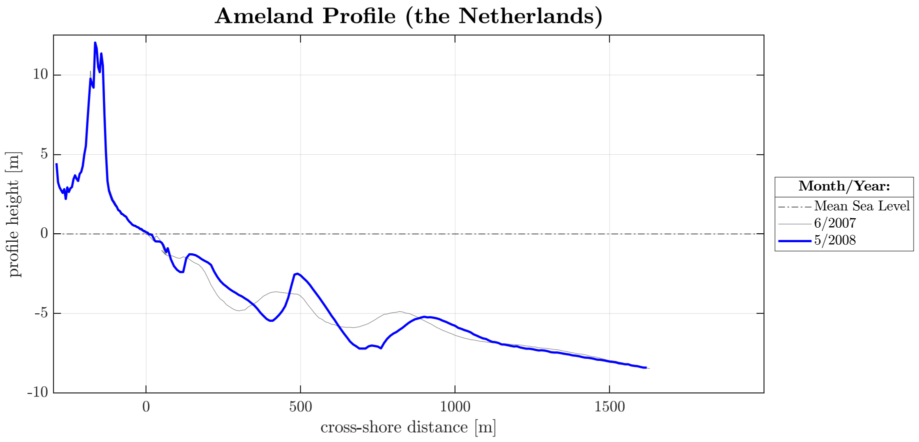
Beach characteristics:

- Upper beach slope (~1:20)
- Lower beach slope (~1:30)
- Median grain size ~300-400 µm

Shoreface characteristics:

- 8 m depth contour ~ 700 m offshore
- 2 subtidal sandbars

2008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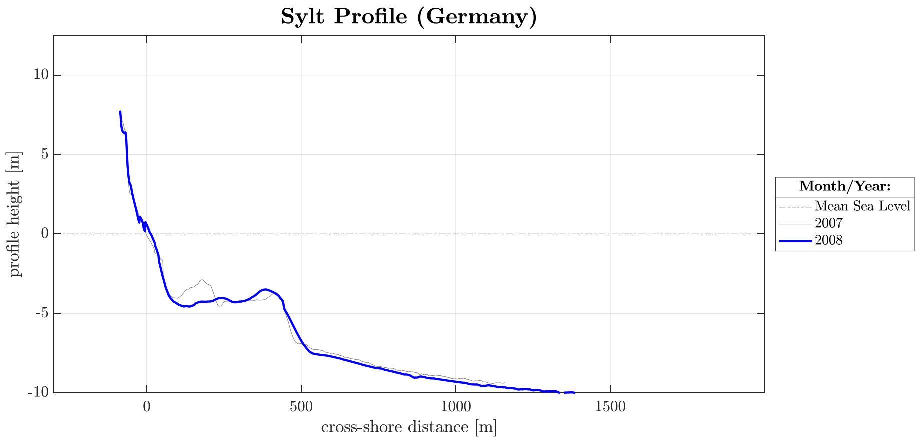
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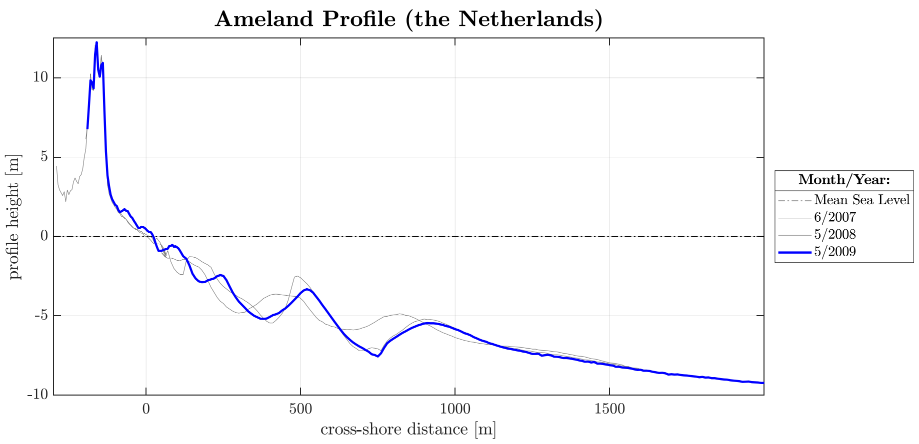
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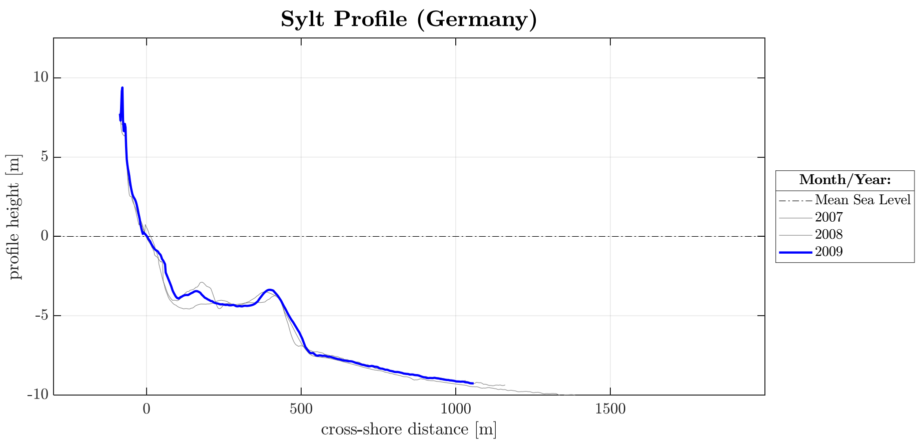
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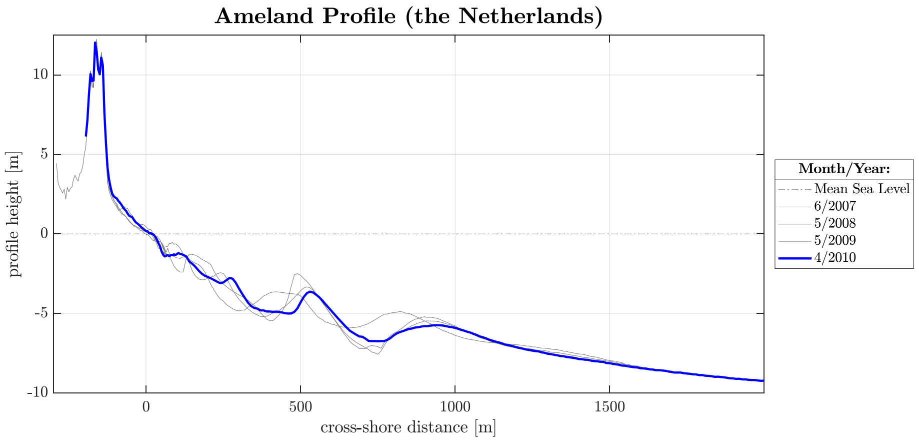
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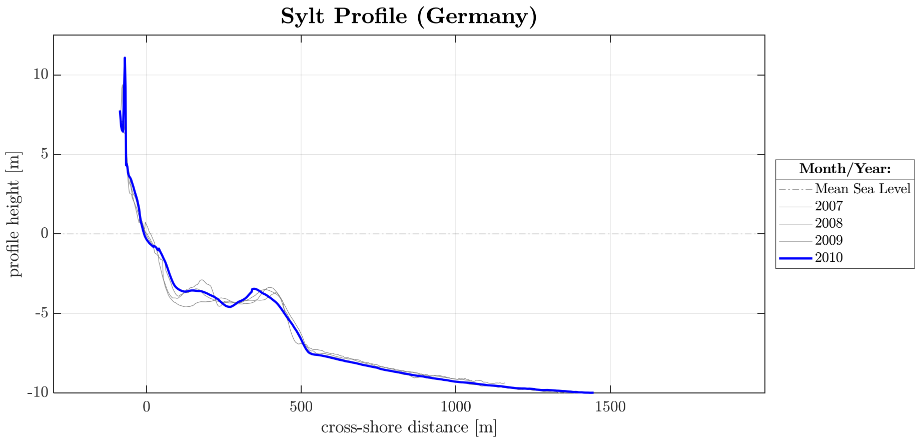
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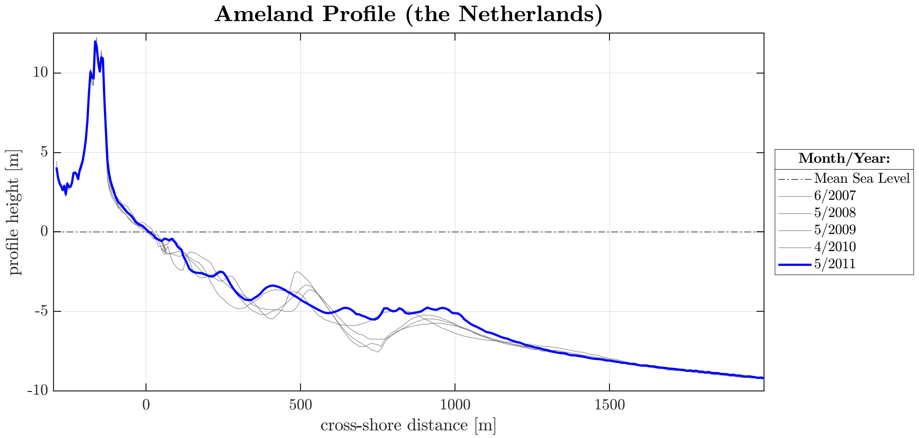
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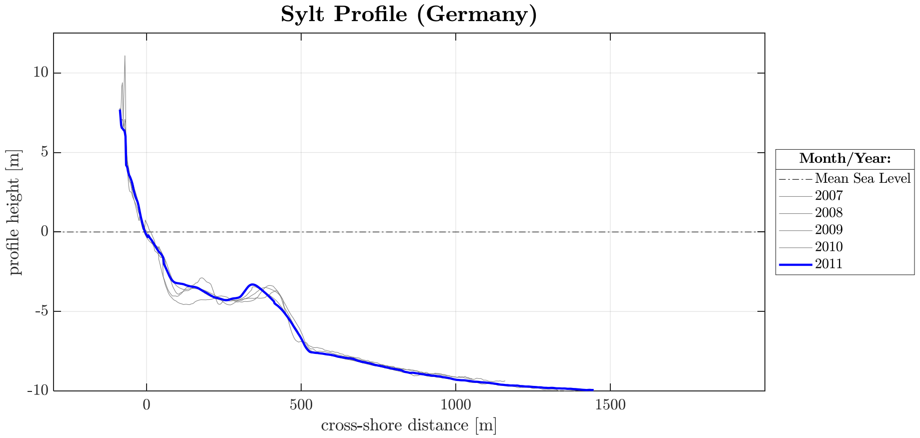
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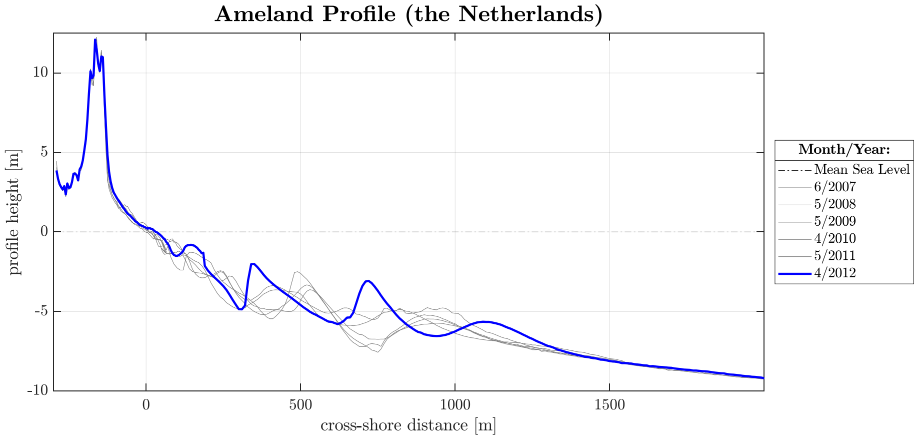
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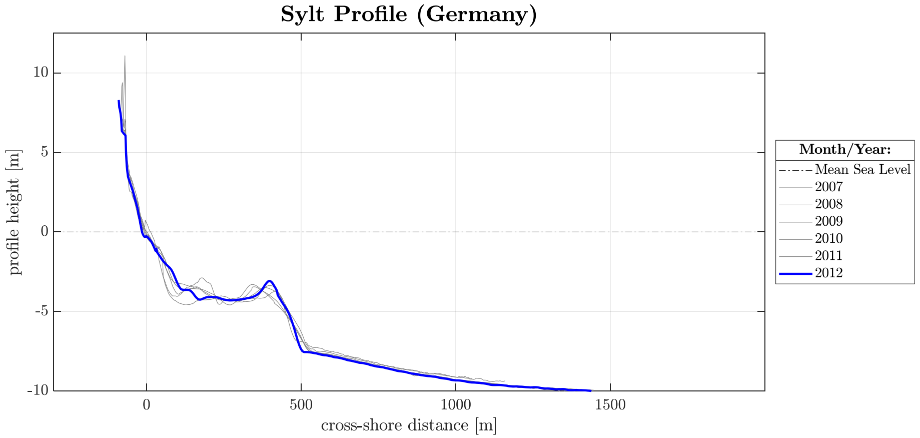
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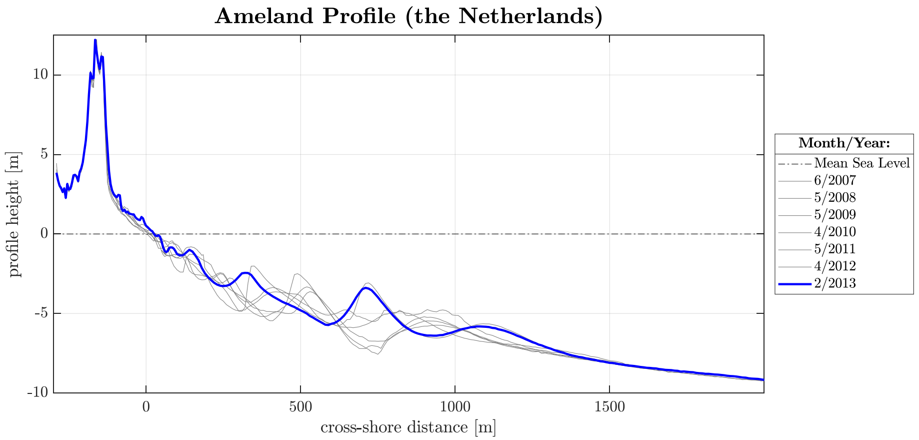
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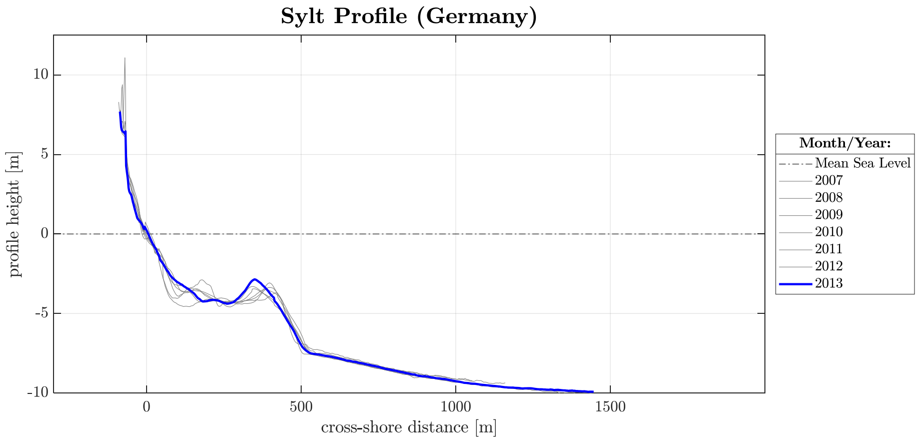
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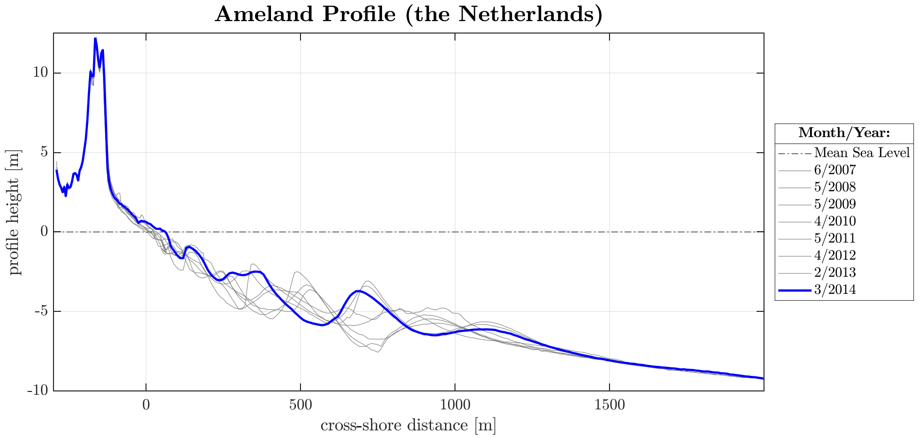
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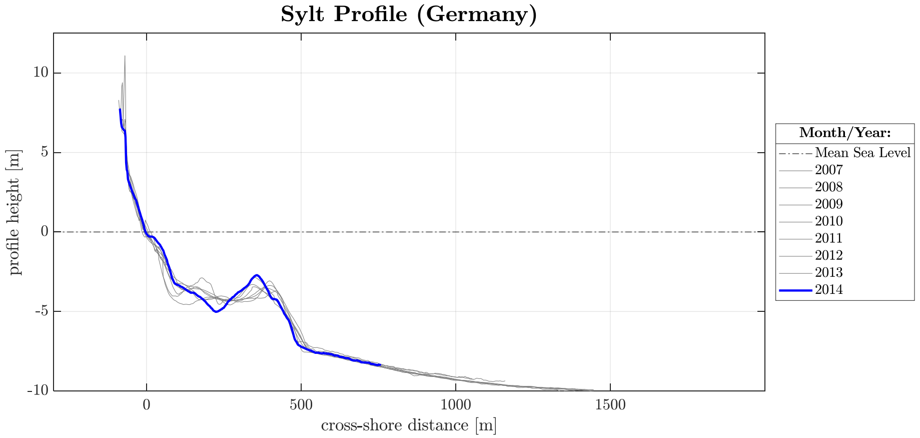
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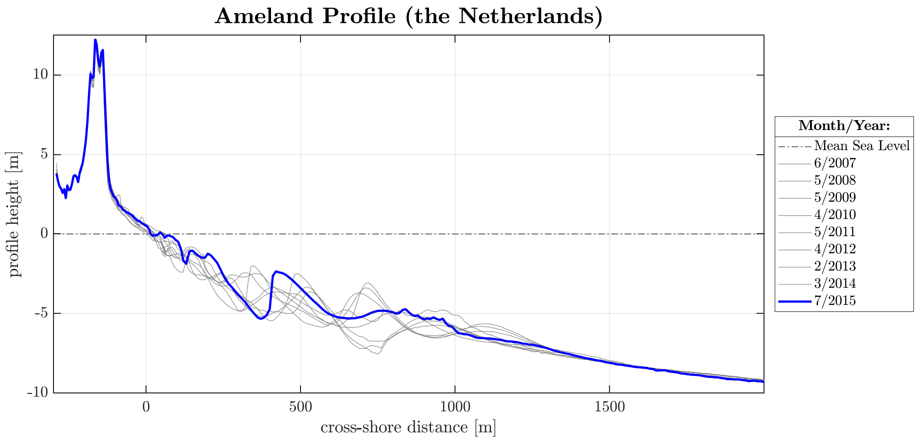
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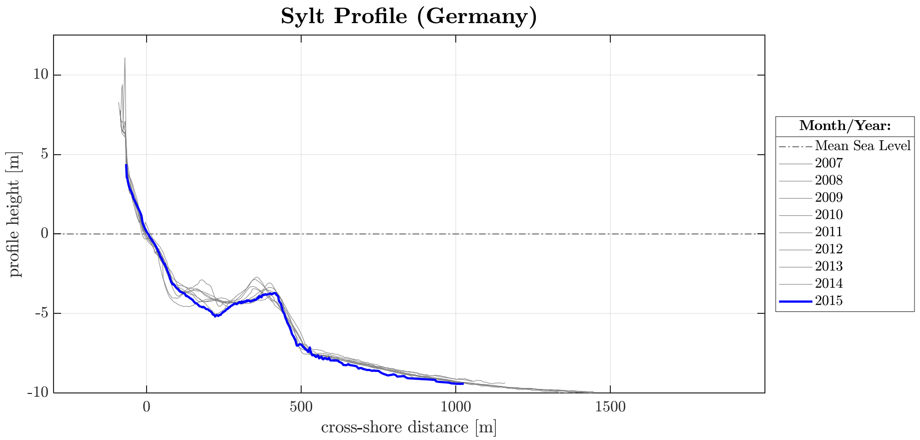
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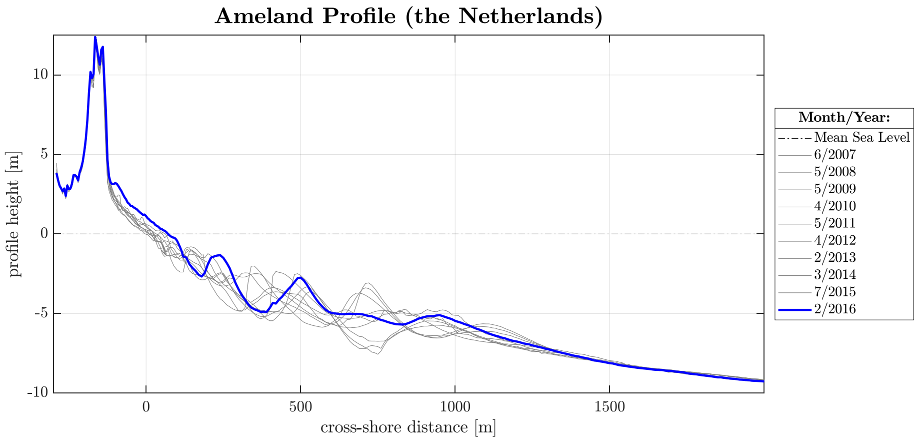
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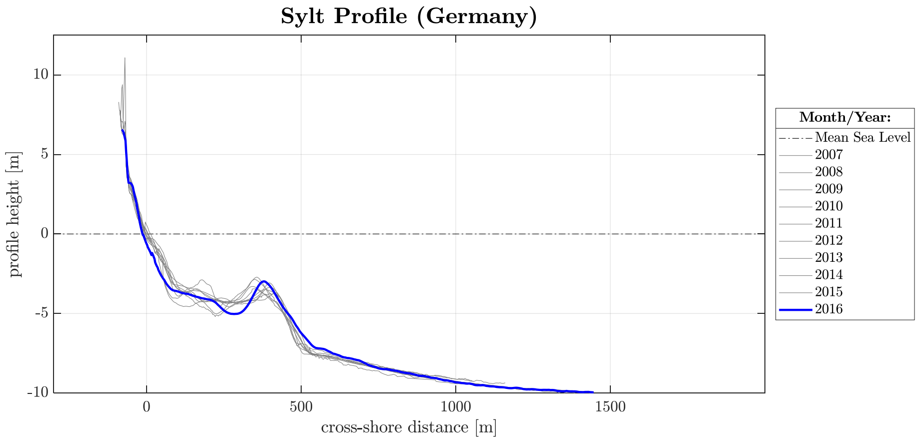
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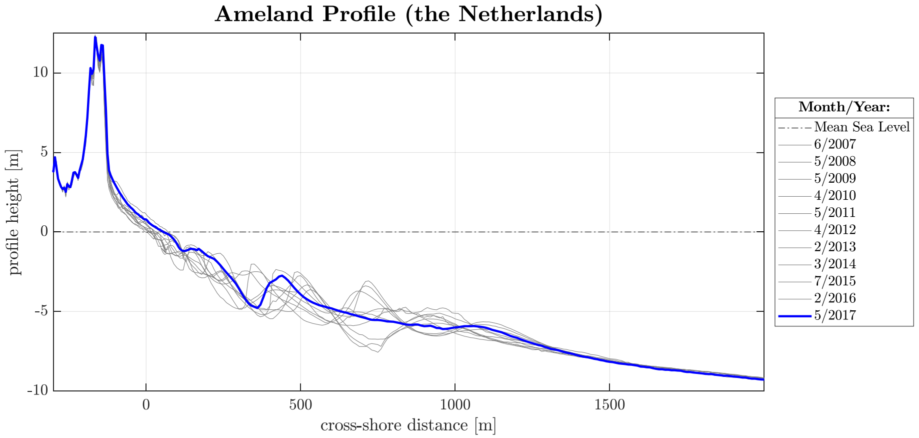
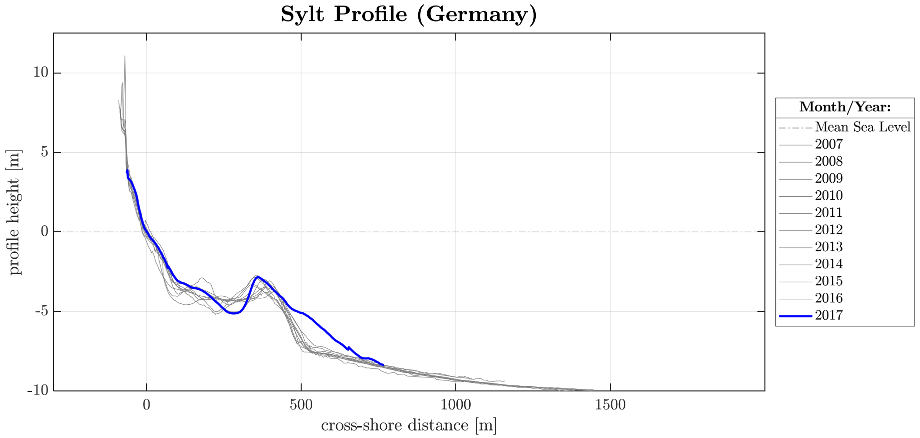
Dynamic comparison coastal profiles





<u>Beach dynamics:</u>
- Stable on the timescale of years

<u>Shoreface dynamics:</u>
- 2-3 migrating sandbars

Dynamic equilibrium (keeps changing)
→ Characteristics of migrating waves

<u>Beach dynamics:</u>
- Stable on the timescale of years

<u>Shoreface dynamics:</u>
- 1-2 stable sandbars

Static Equilibrium (preferred configuration)
→ Characteristics of standing waves

Quantifying the non-stationary dynamics of coastal profiles

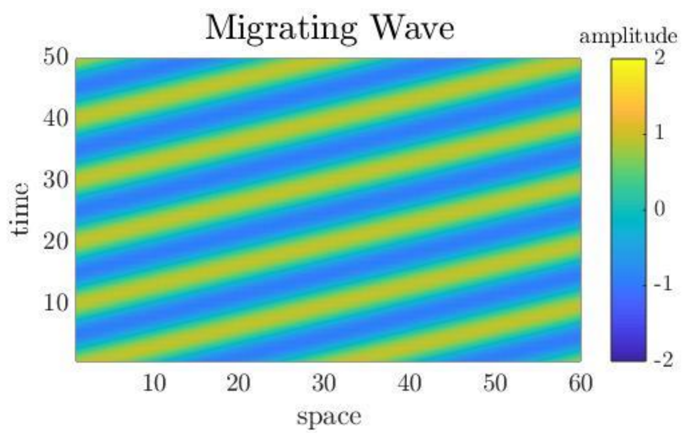
- Mathematical technique to describe:
  - Natural dynamics → Standing or migrating wave signals
    - *E.g. Aubrey (1978), Wijnberg and Terwindt (1995) and Ruessink et al., (2003)*
  - Interrupted natural dynamics → Non-stationary standing or migrating waves

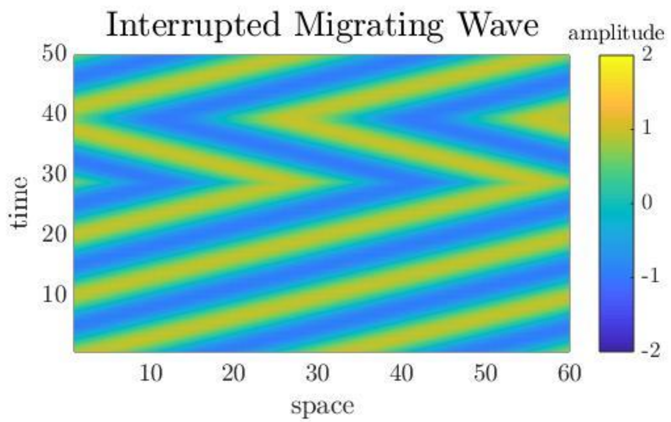
- Empirical Orthogonal Functions (EOF)
  - Reorganises the information in the dataset with new spatial wave signals $f_k(x)$
  - The first new spatial wave signal $f_1(x)$ describes most of the variance (spreading)
  - Temporal weights $w_k(t)$ indicate the presence of the new wave signals in time

$$Z(x,t) = \sum_1^k w_k(t) \cdot f_k(x)$$

- Amplitude and Phase information (Hilbert Transform)
  - Prior to the analysis, temporal phase information is added to the dataset with the Hilbert transform (*E.g. Horel,1983*)

$$Z(x,t) = X(x,t) + i \cdot Y(t)$$

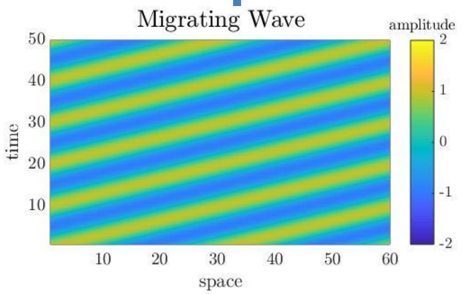


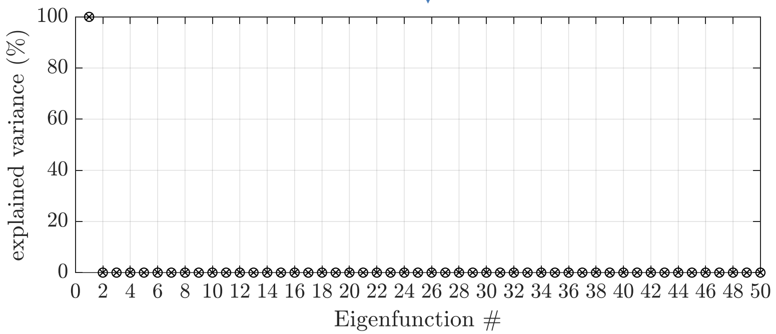


Stationary migrating wave

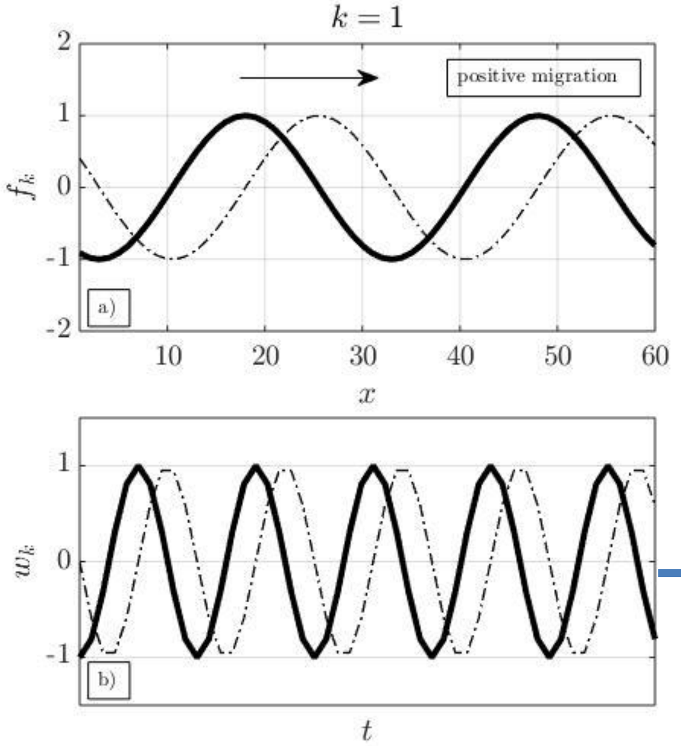
- H = 2 m, L = 30 m and T = 10 years

EOF-analysis

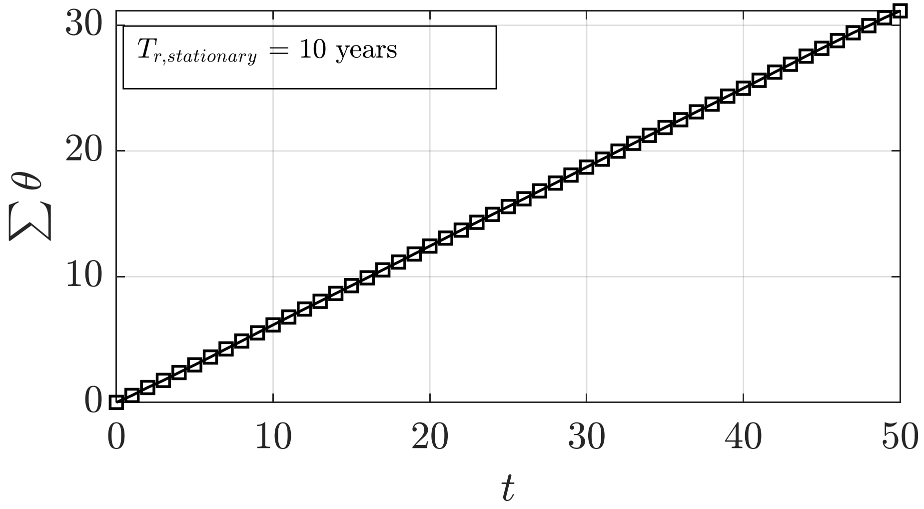




Migrating wave



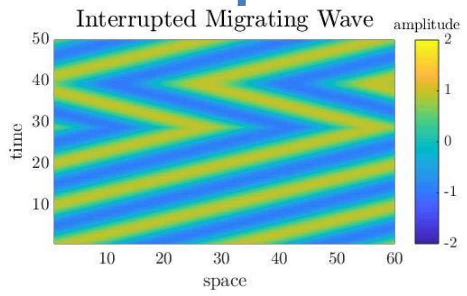
Stationary wave, constant phase

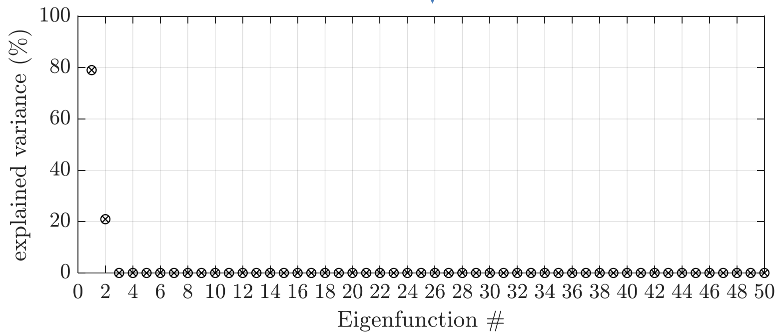


Interrupted migrating wave

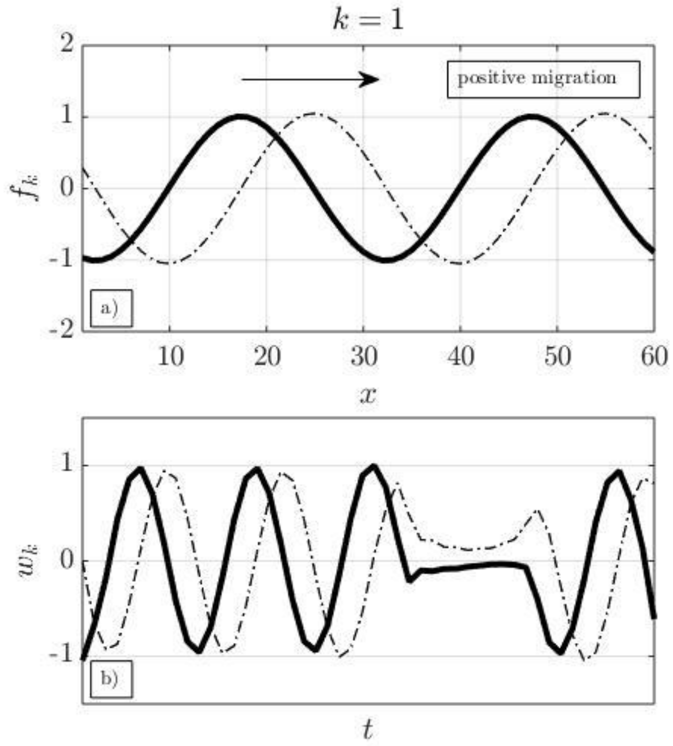
- H = 2 m, L = 30 m and T = 10 years
- Interrupted between t = 30 years and t = 40 years

EOF-analysis

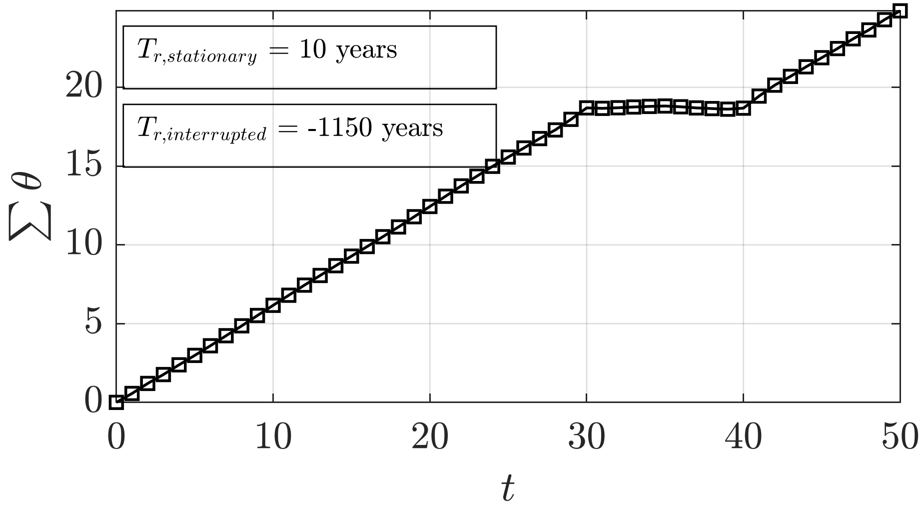




Migrating wave



Non-stationary wave, interrupted phase



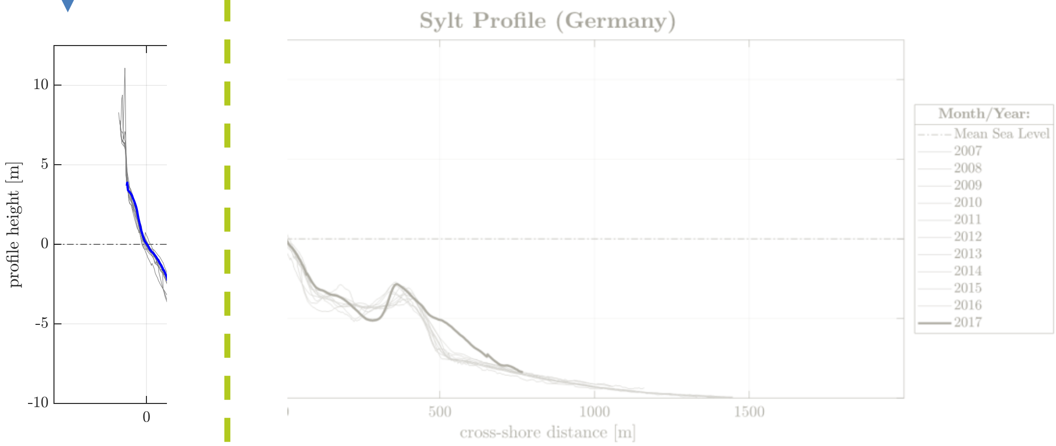
The effects of sand nourishments

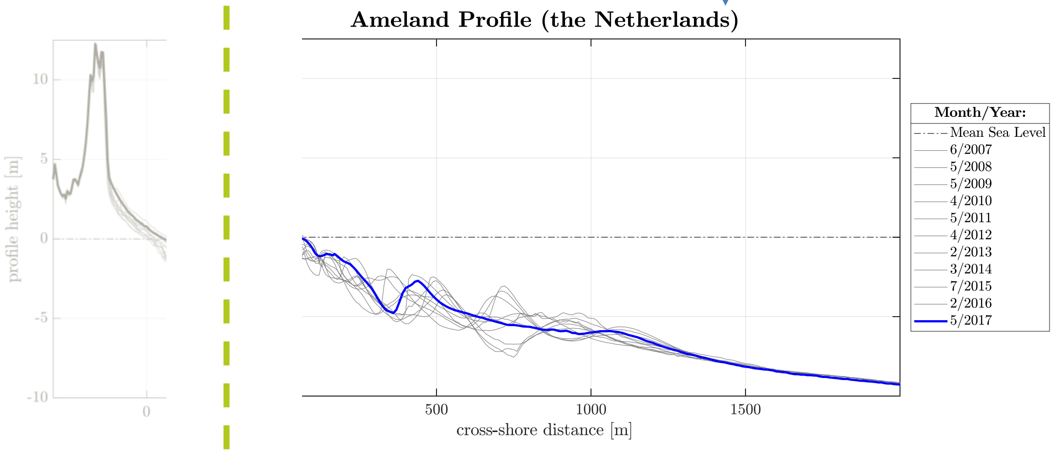
<u>Case study Sylt:</u>

- beach nourishments

<u>Case study Ameland:</u>

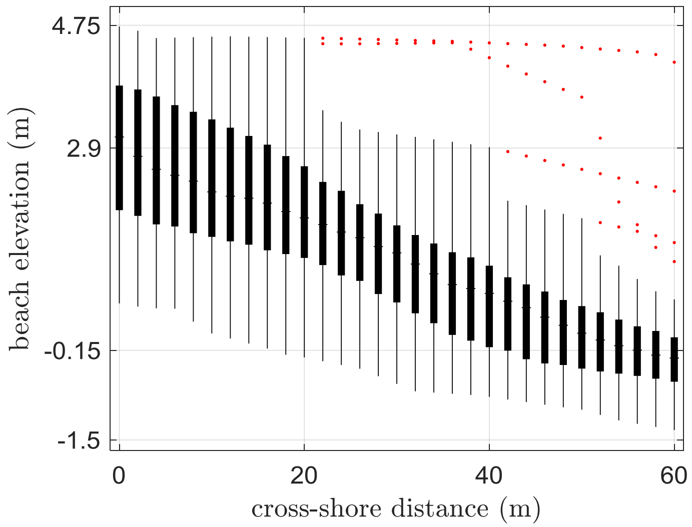
- shoreface nourishments

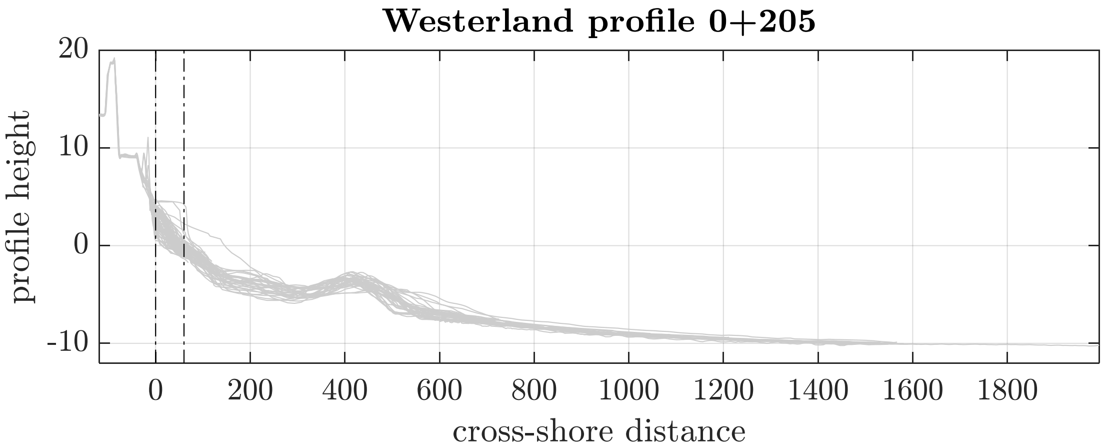


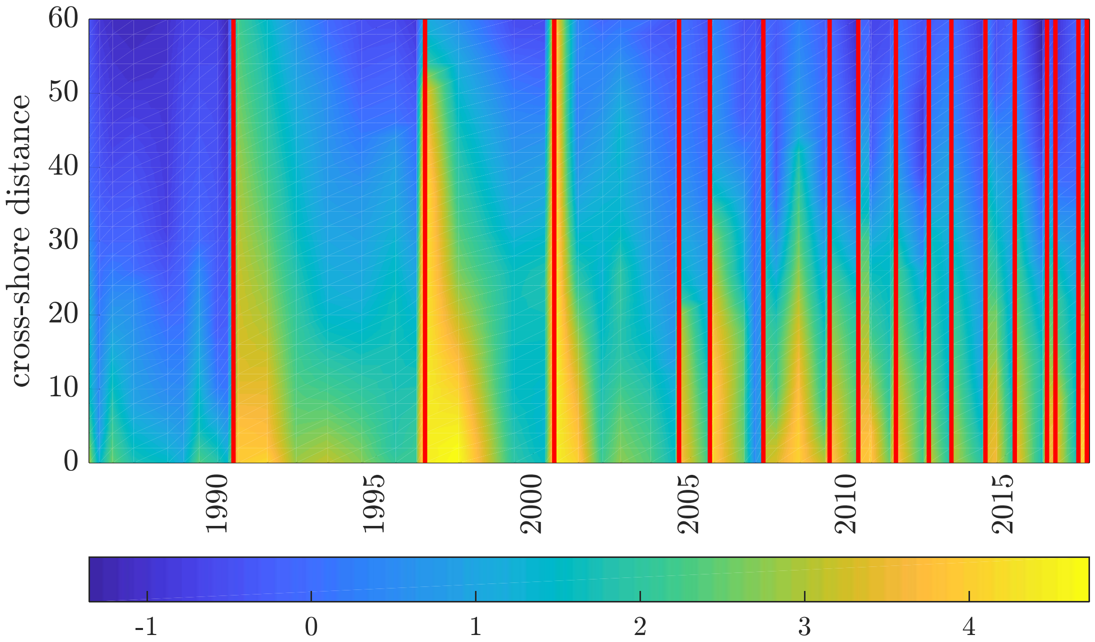


Beach nourishments Sylt

- **Westerland (Sylt)**
  - Beach Profile 0+205
  - Period between 1985 and 2017
    - Between 0 and 4 measurements per year
      - Average 1.9 measurements per year
  - 15 beach nourishments



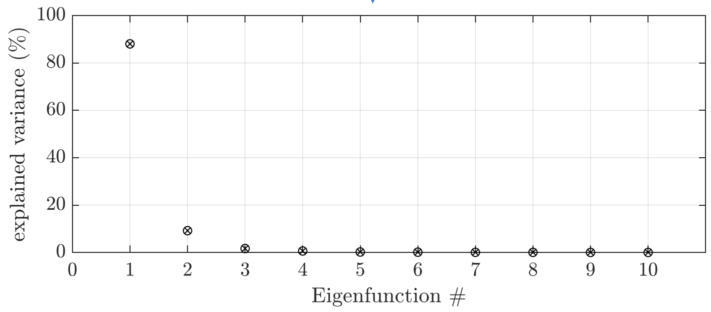


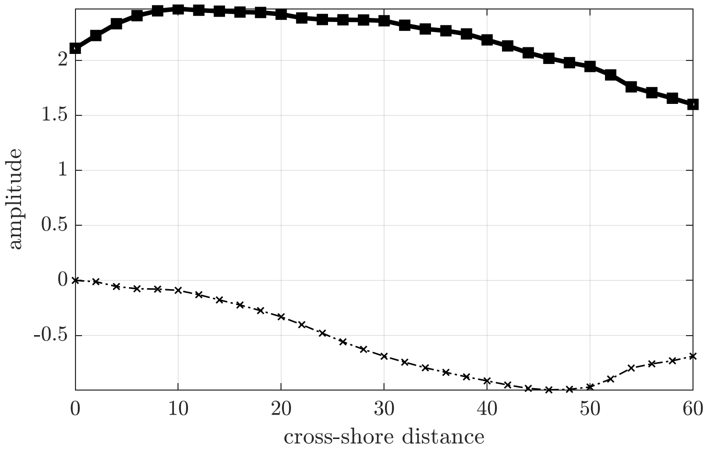


EOF-analysis

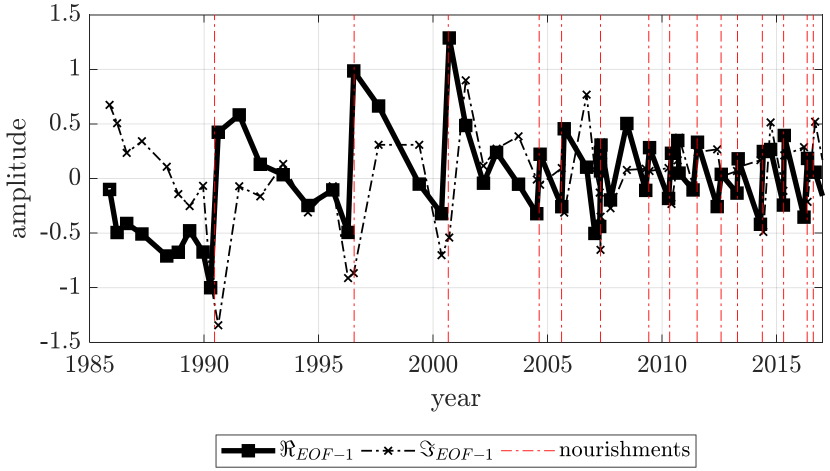
1st New spatial function

- Described variance by EOF-1 (~90%)





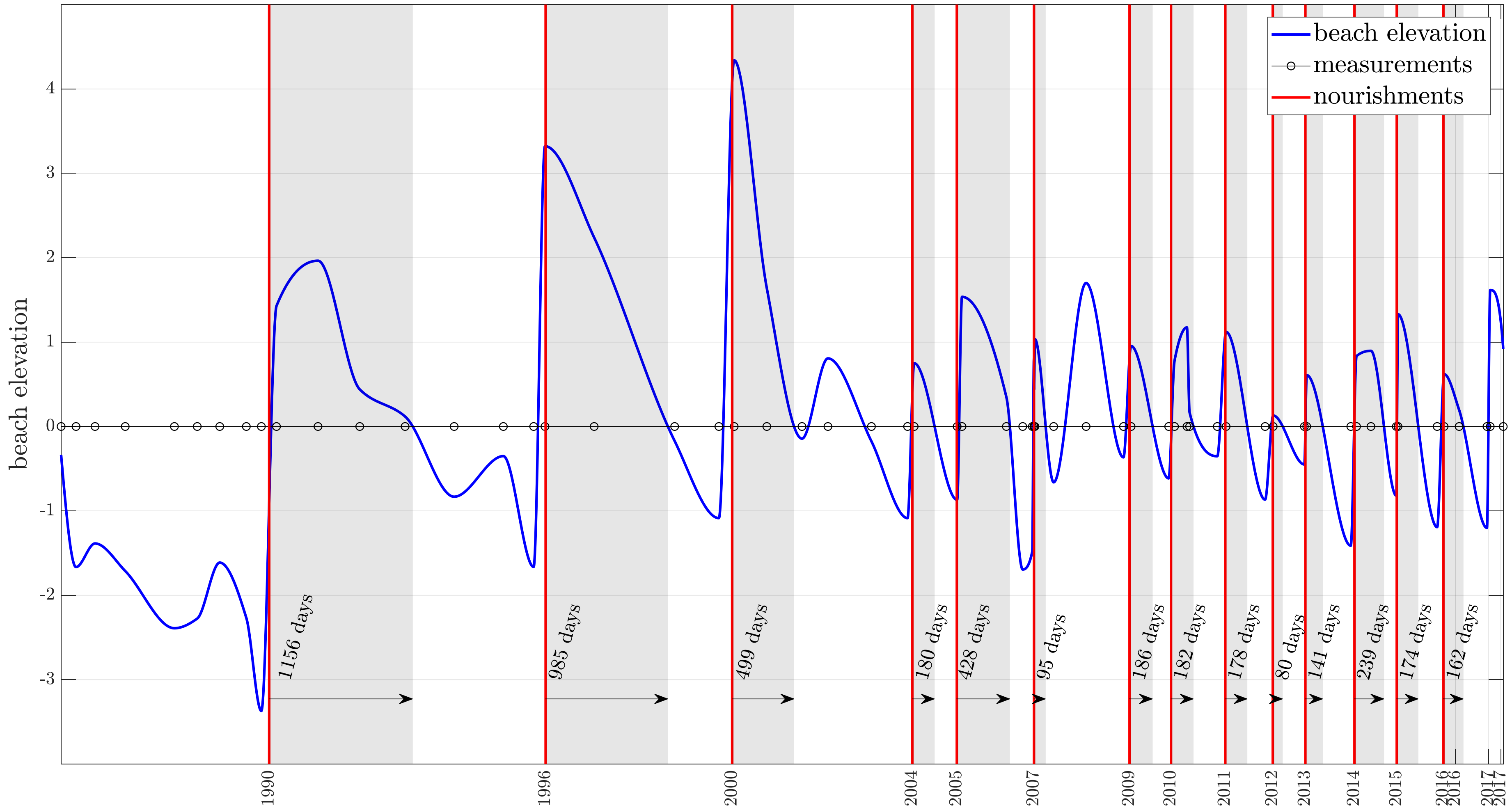
Standing wave



Non-stationary

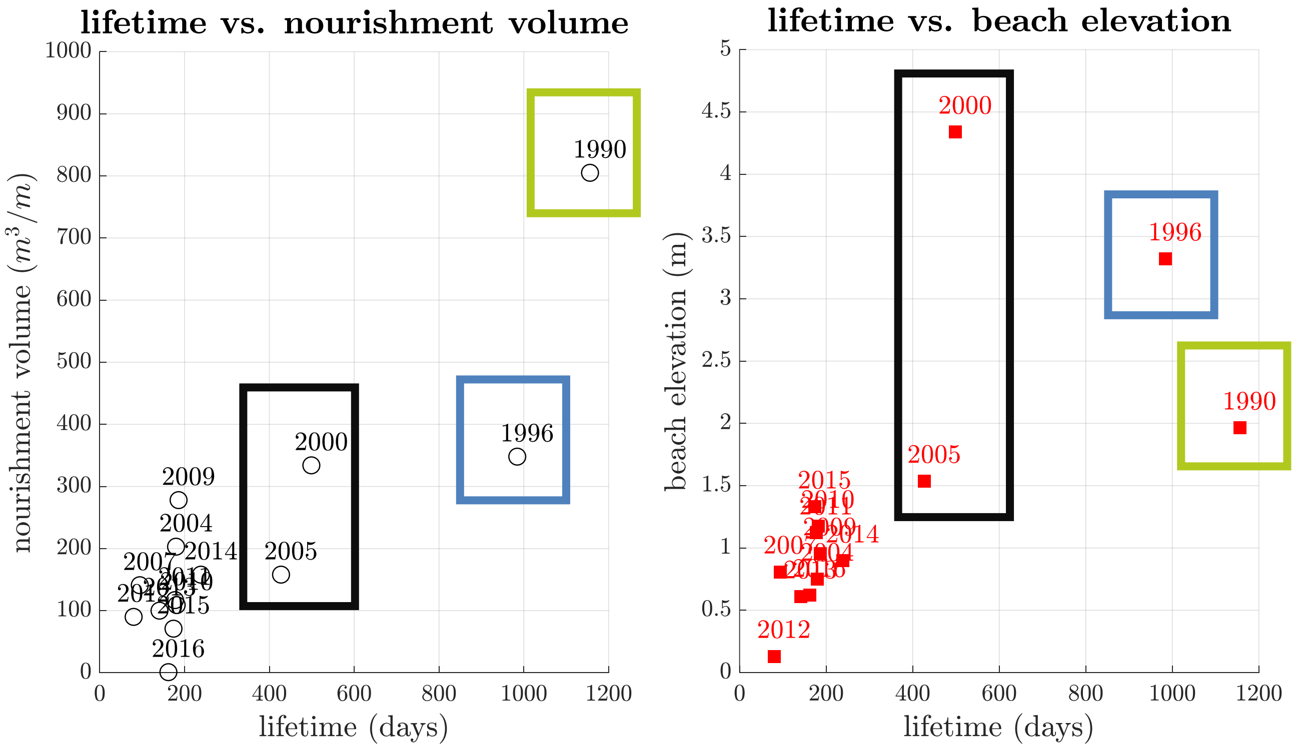
Lifetime of beach nourishments

- Lifetime = time between nourishment and the first time that the profile is back to the average elevation



Relation between lifetime and design of beach nourishments

- Nourishment volume vs. nourishment lifetime
- Beach elevation (after nourishment) vs. nourishment lifetime

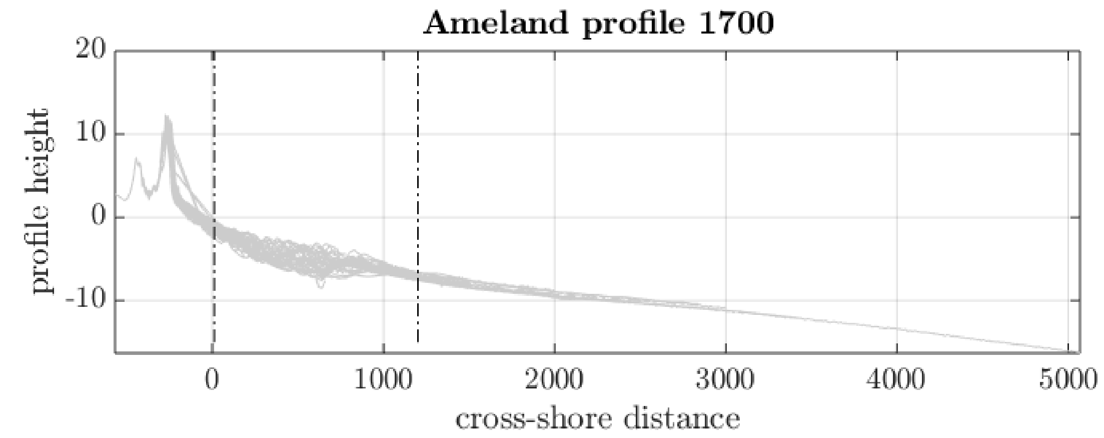


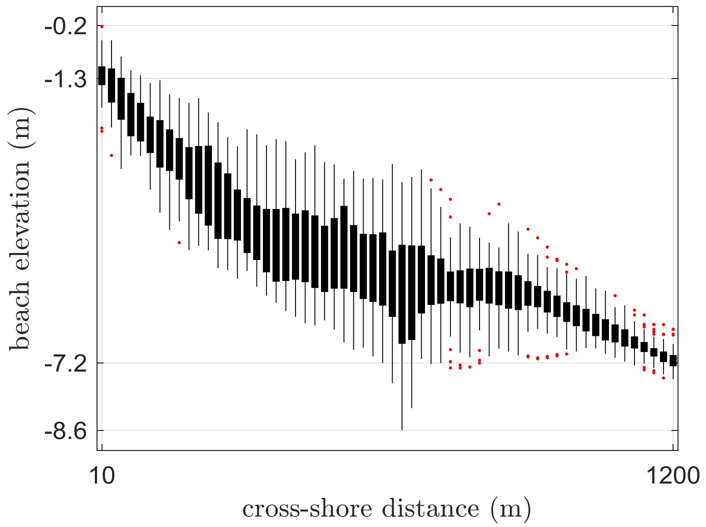
Based on these figure it can be concluded that:

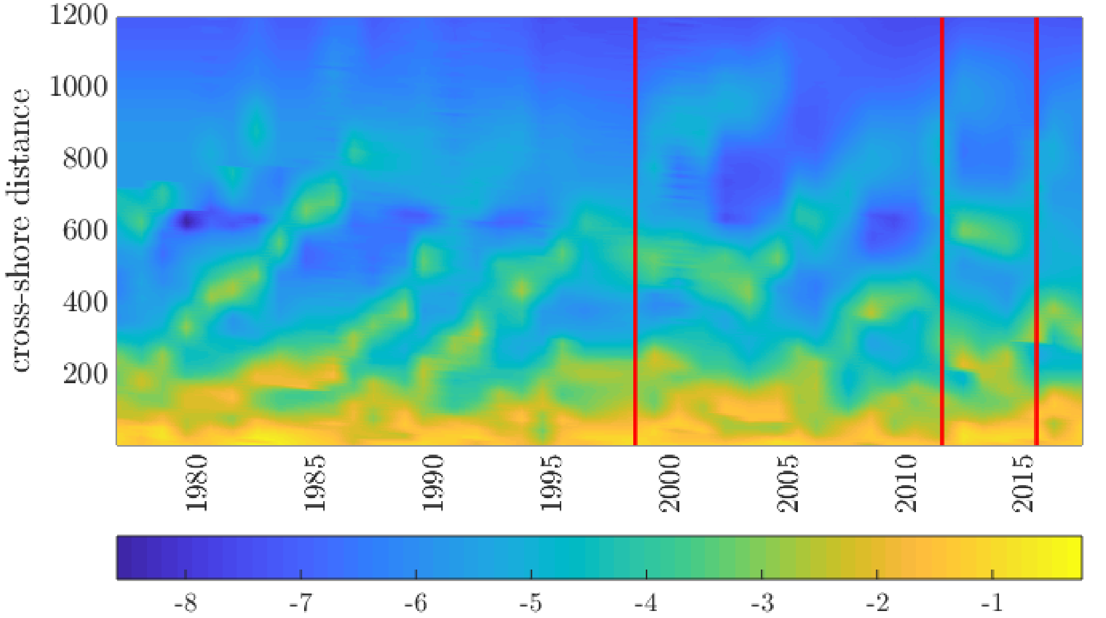
- Lifetime = f(..
  - ✓ Volume
  - ✓ Timing
  - ➢ Others..
    - ○ Hydrodynamics?

Shoreface nourishments Ameland

- **Ameland**
  - Beach Profile 1700
  - Period between 1976 and 2017
    - 1 measurements per year
  - 3 shoreface nourishments



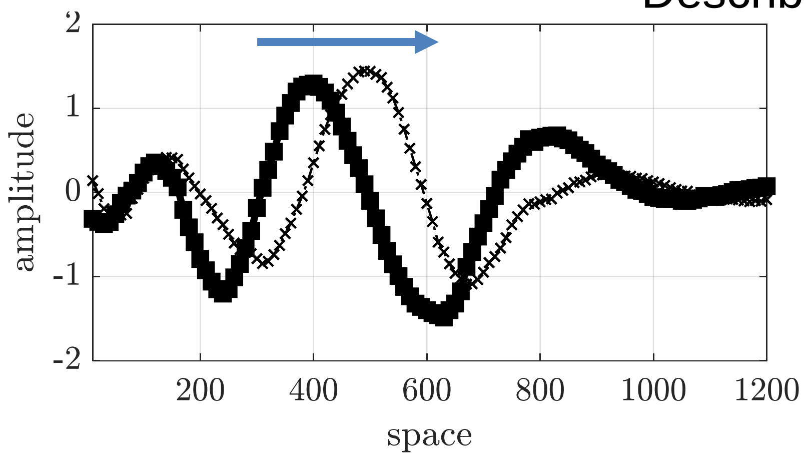


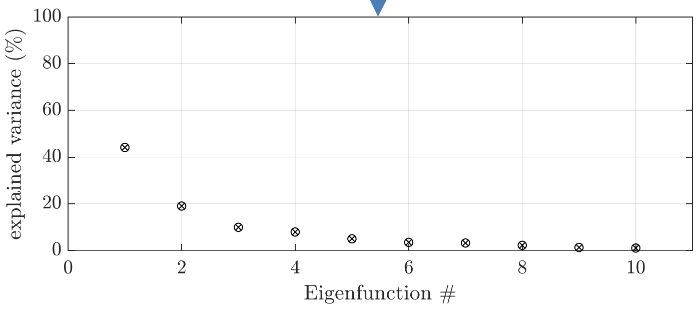


EOF-analysis

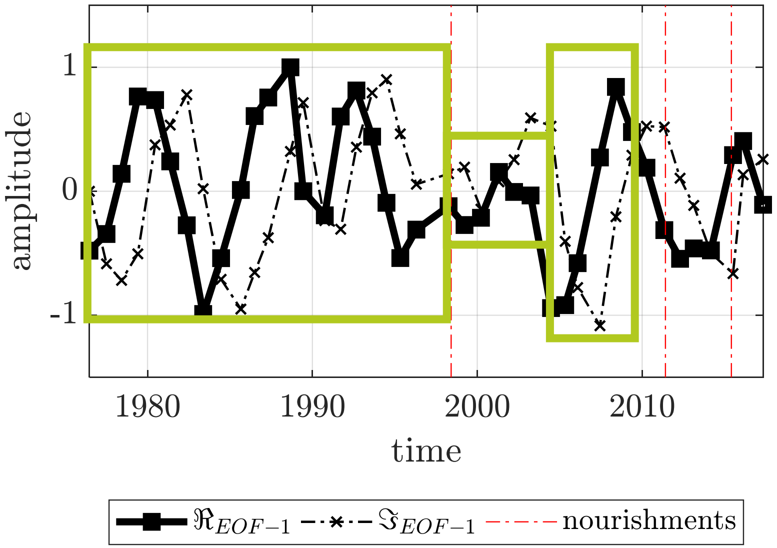
1st New spatial function

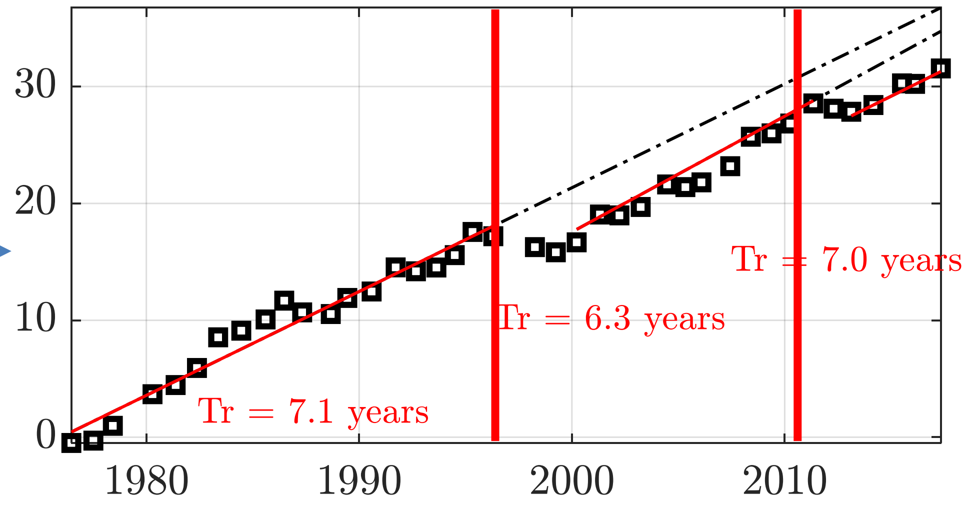
- Described variance by EOF-1 (~45%)





Offshore migrating wave

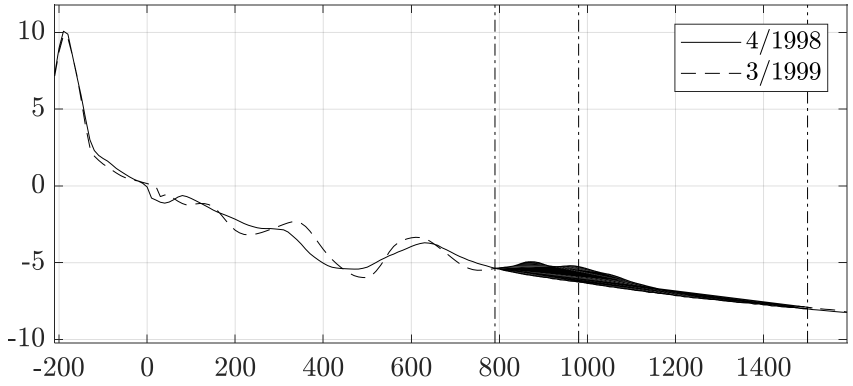




Non-stationary

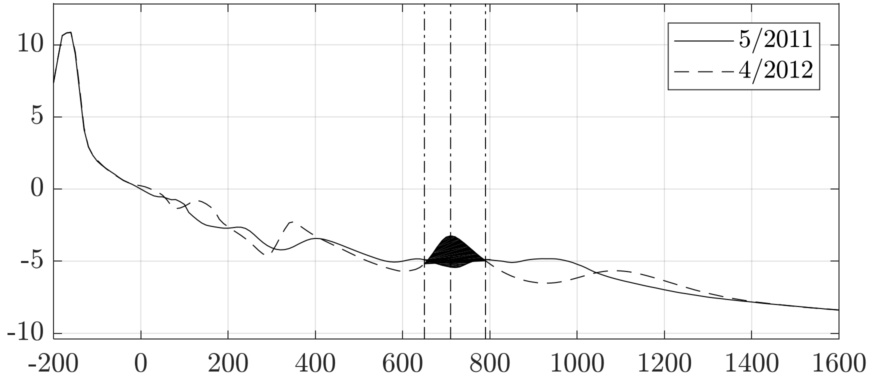
Relation between lifetime and design of shoreface nourishments

- Design of the 1999 shoreface nourishments
- Design of the 2011 shoreface nourishments



Based on these figures it can be concluded that:

- Lifetime = f(..
  - ✓ Location
  - ➢ Others..
    - Timing?
    - Volume?
    - Hydrodynamics?



Conclusions

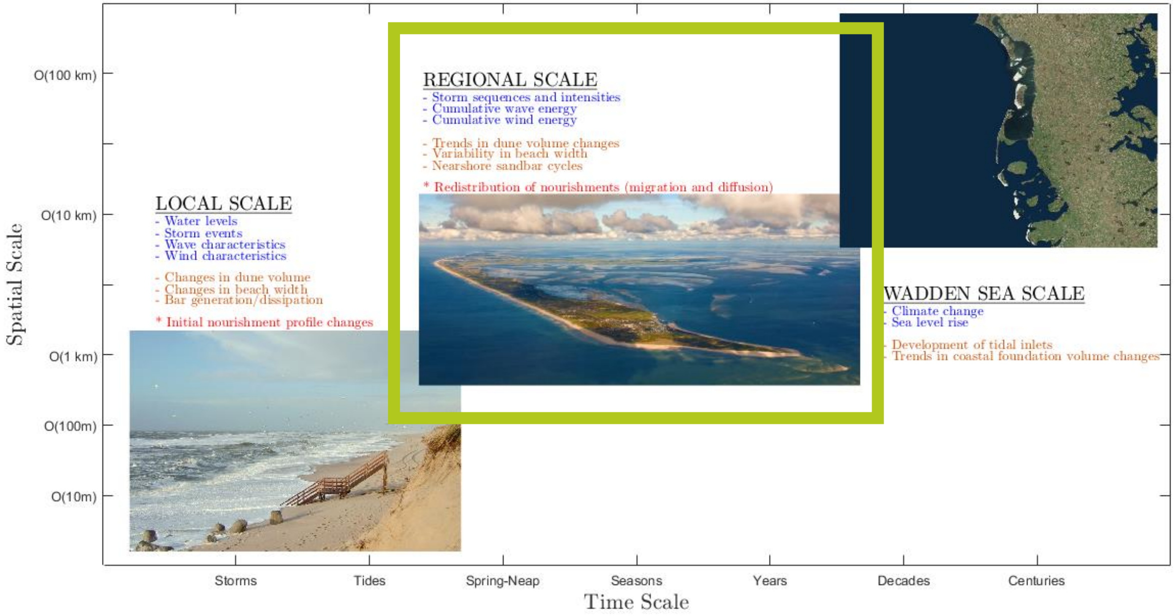
- **Differences in sandy shoreline dynamics**
  - Static and dynamic equilibriums
  - Natural and human induced

- **Empirical Orthogonal Functions**
  - Identify prominent patterns in large datasets
  - Used to quantify natural beach dynamics
  - Potential to identify and even quantify the effects and lifetime of sand nourishments

- **Sylt:**
  - 90% of the beach dynamics can be attributed to structural erosion which is counteracted by beach nourishments
  - Nourishment lifetime depends on, amongst others, the volume and the beach elevation.

- **Ameland:**
  - 45% of the shoreface dynamics can be attributed to offshore migrating sandbars
  - Sand nourishments stop the sandbars from migrating and even reverse the migrating direction during its lifetime
  - Nourishment lifetime depends on, amongst others, the cross-shore location

Discussion



Current limitations:

- No hydrodynamics included yet
- No short term morphodynamics included (e.g. storm impacts or beach recovery processes)
- No long term developments (e.g. profile adaptations to sea level rise)

Outlook:

- Study different designs of sand nourishments in different types of sandy shorelines
- Study scenarios with adapted designs of sand nourishments using numerical modelling

STENCIL

Strategies and Tools for Environment-Friendly
Shore Nourishments as Climate Change Impact
Low-Regret Measures

Federal Ministry
of Education
and Research

KÜNO
Küstenforschung Nordsee-Ostsee

Thank you for your attention!

Any questions or recommendations?