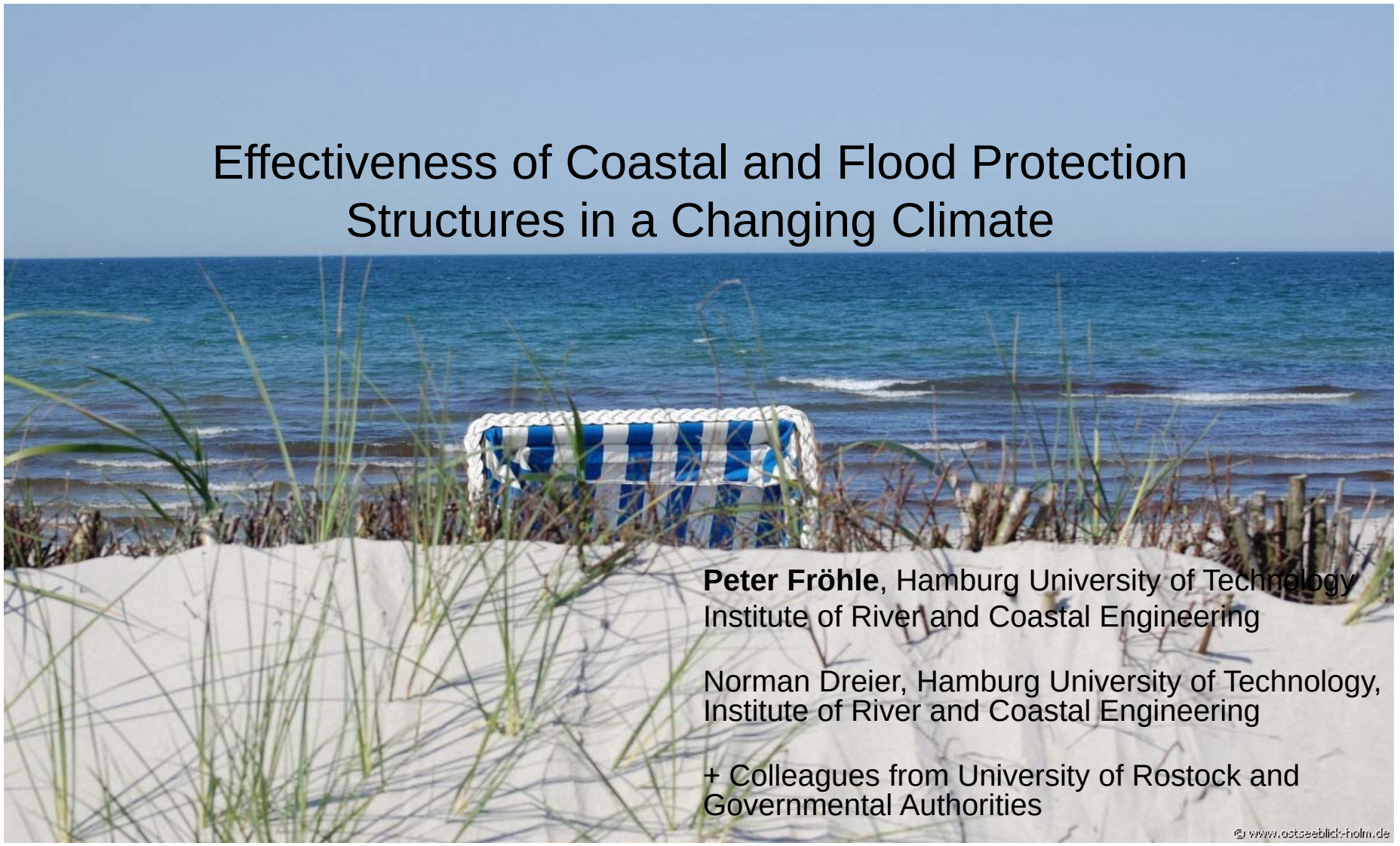
Effectiveness of Coastal and Flood Protection Structures in a Changing Climate



Peter Fröhle, Hamburg University of Technology
Institute of River and Coastal Engineering

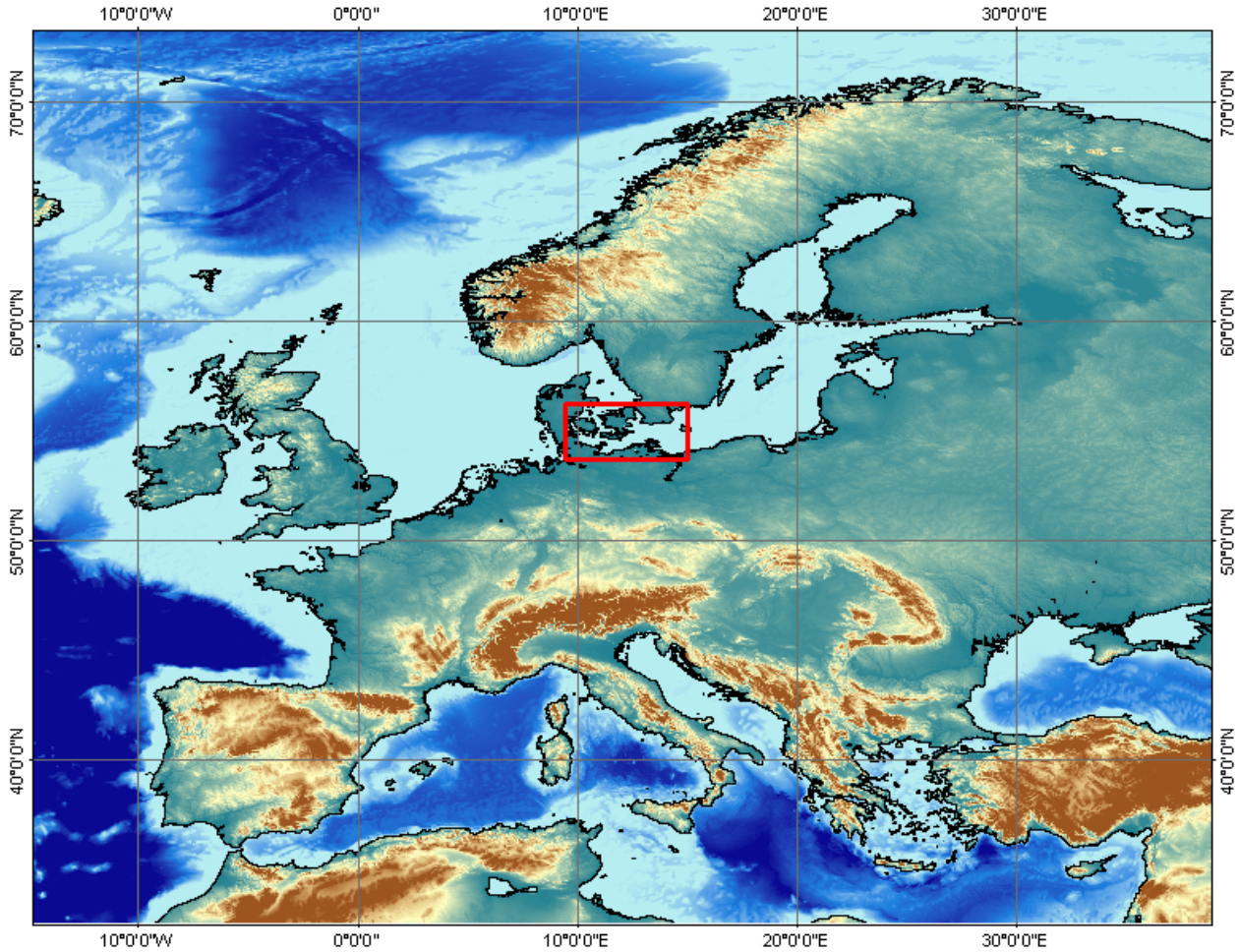
Norman Dreier, Hamburg University of Technology,
Institute of River and Coastal Engineering

+ Colleagues from University of Rostock and Governmental Authorities

Effectiveness of Coastal and Flood Protection Structures in a Changing Climate

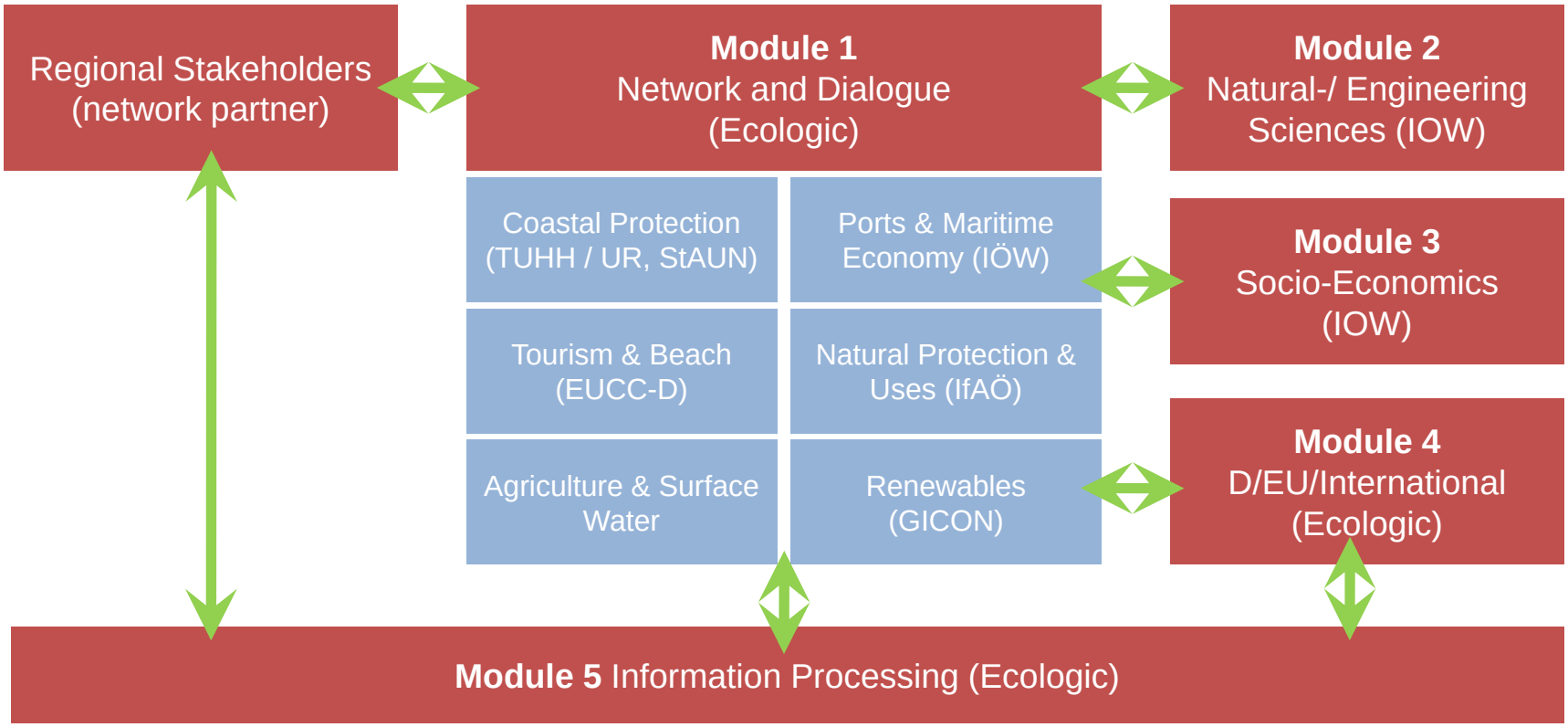
1. Background of Work – Project RAdOst
2. Climate Change – Consequences for Water Levels and Wave Conditions in the Baltic Sea
3. Consequences for Coastal Protection Works
4. Consequences for Sediment Transport and Morphological Development of the Coast
5. Adaptation Strategies and Example Measures for Typical Coastal Protection
6. Conclusions

Study Area: German Part of the Baltic Sea



ETOPO2 [NOAA]

KLIMZUG – Project RADOST (2009 – 2014)



KLIMZUG – Project RADOST (2009 – 2014)

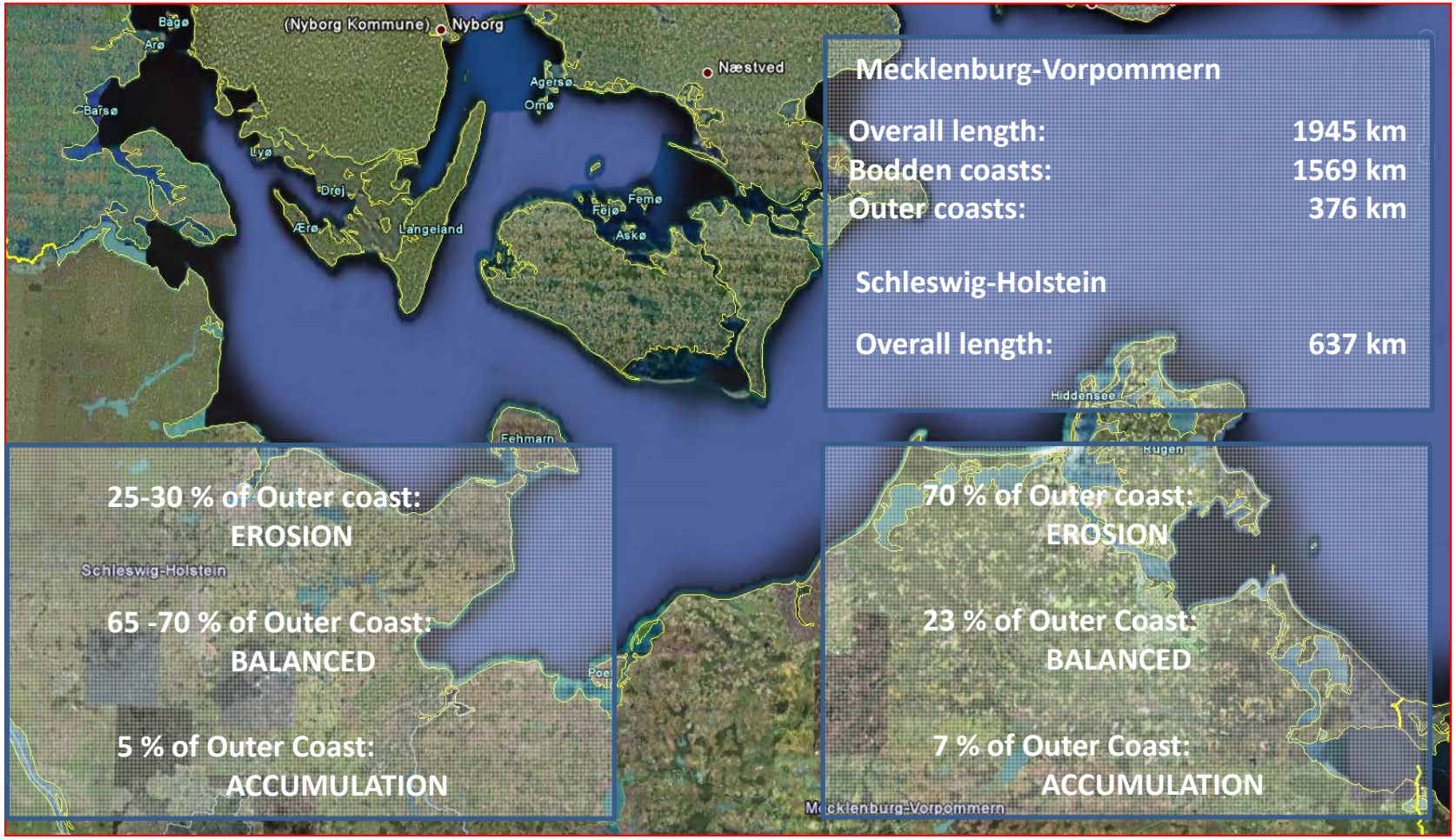
Main Goal (Coastal Protection)

- Develop Adaptation Strategies for Coastal Protection on a Local Scale

Coastal Protection RAdOst Key Questions (2009)

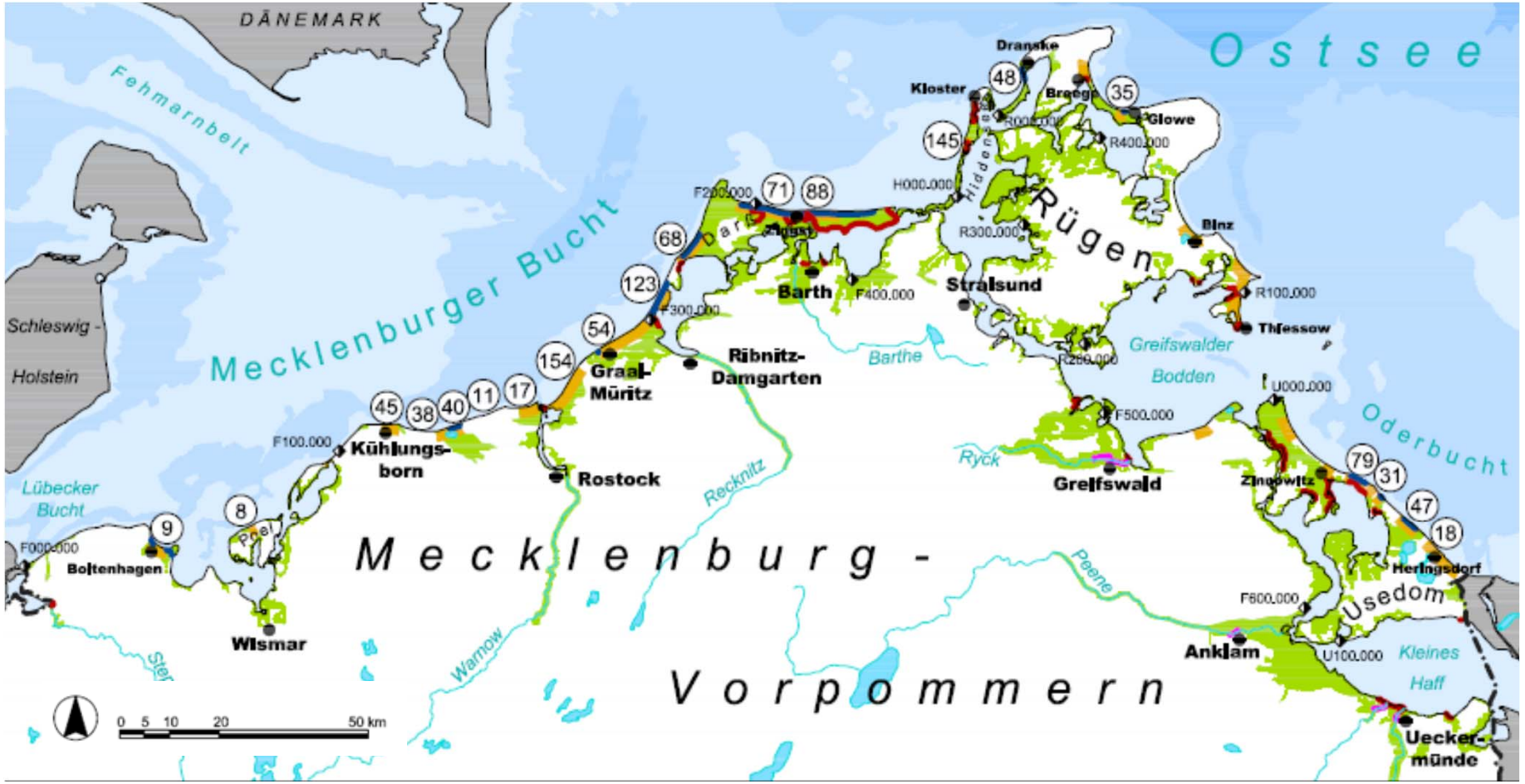
- How may the hydrodynamic conditions develop?
- Do we have to be prepared for changed morphological development? If yes, where?
- Are actual strategies sustainable?
- Do actual coastal protection constructions allow sustainable strategies? Where do we have to react at first?
- How will we protect our coasts in 2050?

Baltic Sea Coast (German Part)



Coastal Erosion in Mecklenburg-Vorpommern (100a)

Baltic Sea Flood Prone Areas



Baltic Sea: Typical Coastal Protection Measures

Coastal Flooding



Erosion of Sandy Coasts



Climate Change and Consequences for Coastal Protection and Structures

Oceanographic Conditions

- Changes of Wind Conditions
  - Average Wind Conditions
  - Strong Winds and Storm Events
- Changes of Water Levels
  - Mean Sea Level
  - Extreme Water Levels

Hydrodynamic Conditions

- Changes of Wave Conditions
  - Average Wave Climate
  - Extreme Wave Conditions
- Changes of Currents
  - Average Flow Velocities
  - Extreme Flow Velocities

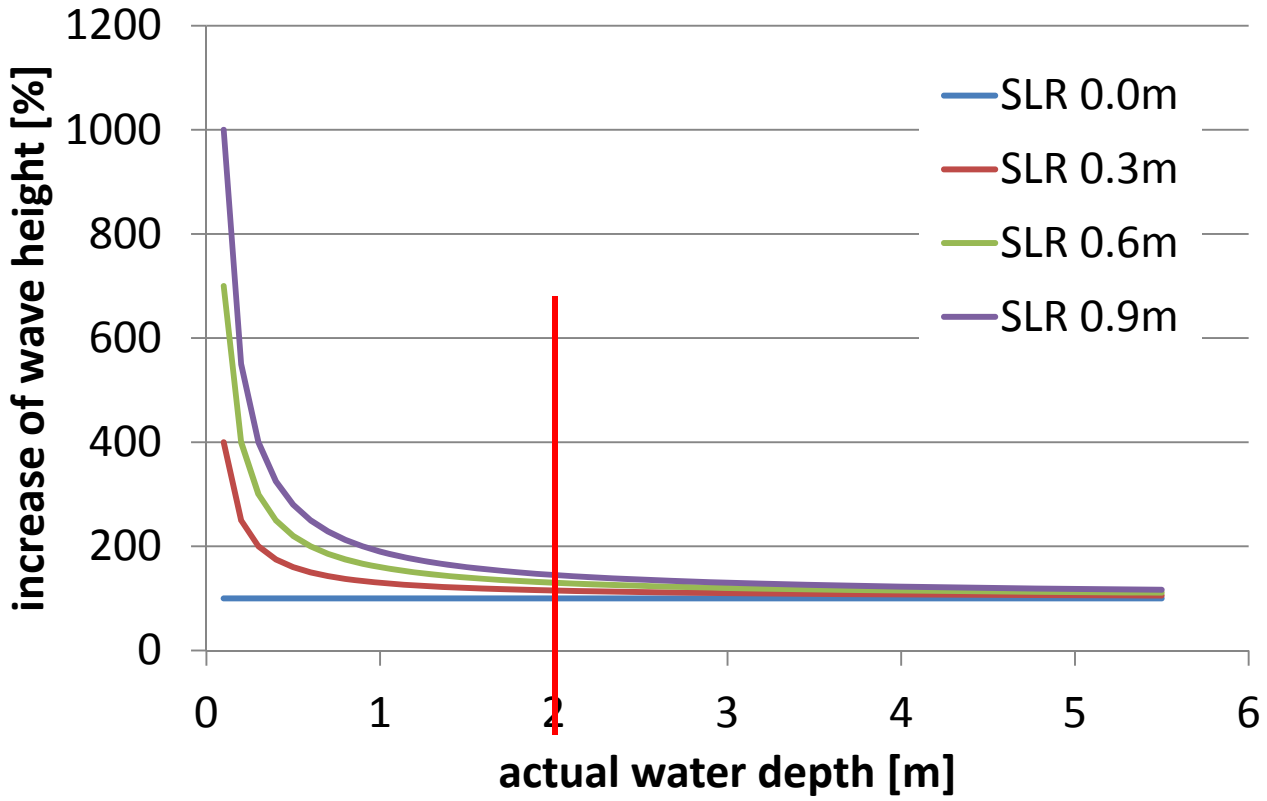
Loads on Structures, Design Conditions, Sediment Transport, …

RadOst - Szenarios 2100 – Offshore Conditions

Szenario	Water Levels	Wave Heights	Coastal Flooding
„moderate“	+ 30 cm	no significant changes	no significant changes
„average“	+ 60 cm	Average Wave Heights + 2% Storm Wave Heights + 10 %, minor changes in wave directions	+ 5 % Energy
„high“	+ 90 cm	Average Wave Heights + 5% Storm Wave Heights + 15 %, significant changes in wave directions	+ 10 % Energy

Details Tuesday by Dreier et al.

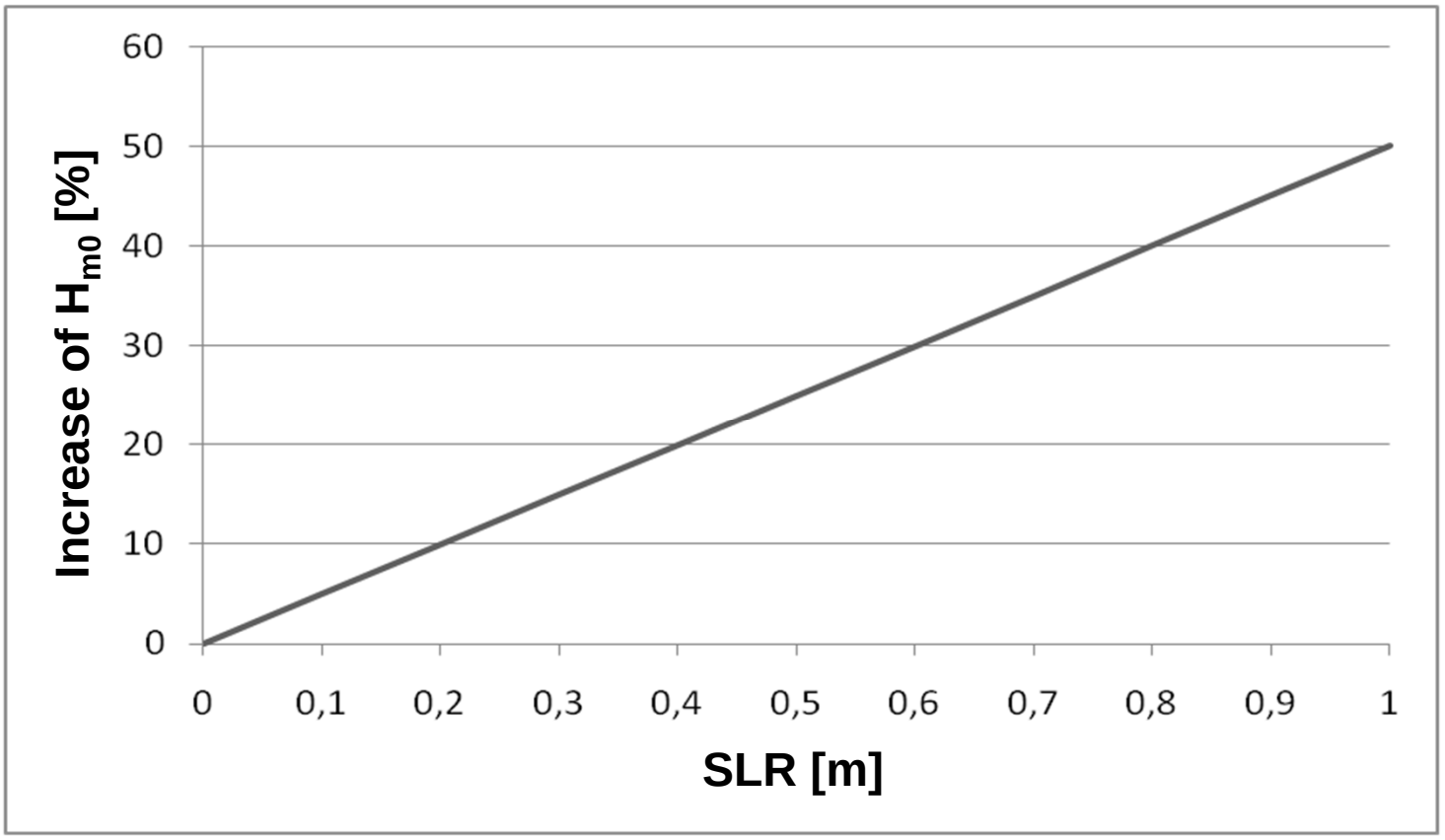
RAdOst Scenarios – Nearshore Conditions



Loads on Structures, Design Conditions, Sediment Transport, …

Increase of Wave Heights at a Construction (d_0=2.0m) Influence of SLR

(Godas Approach)



Consequences for the Coast - Summary

Changes of Water Levels and Wave Conditions

causes

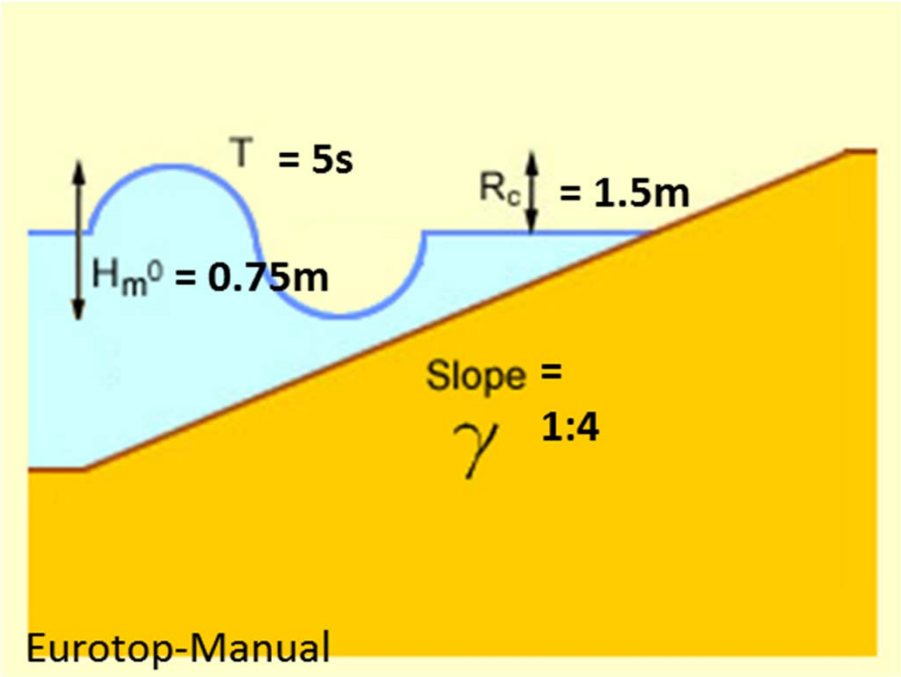
- Consequences for the Coastline, Surf Zone, Beach and Hinterland
- Higher Loads on Coastal Protection Measures
- Reduction of Protection Level of Erosion Protection and Flood-Protection

Quantification of Effects and Consequences

assumption

Reduction of Safety in Erosion- and Flood-Protection
consequently needs an
Adaptation of Coastal Protection Measures and Concets to Climate Change

Influence of Sea Level Rise on Dikes and other Flood Defences



Increase of MSL (m)	Flood Water Level relative to MSL (m)	Wave Overtopping Rates (l/s/m)
0.0	1.5	2.5
0.3	1.5	7.3
0.5	1.5	14.7
0.9	1.5	80.0

Flood Protection Constructions will become **unsafe** in the future

Increase of Wave Heights at a Revetment (d_0=2.0m) Influence on Block Size (Example Hudson Approach)

SLR	ΔH_{m0}	Δ W
0.3 m	+15 %	152 %
0.6 m	+30 %	220 %
0.9 m	+45 %	305 %

All other values constant!

$$W = \frac{\rho \cdot g \cdot H^3}{K_D \cdot (\rho_r/\rho_w - 1)^3 \cdot cot(\alpha)}$$

Revetments wili be unsafe: adaptation to SLR is essential!

Increase of Wave Heights at a Breakwater (d_0=15.0m) Influence on Block Size (Example Hudson Approach)

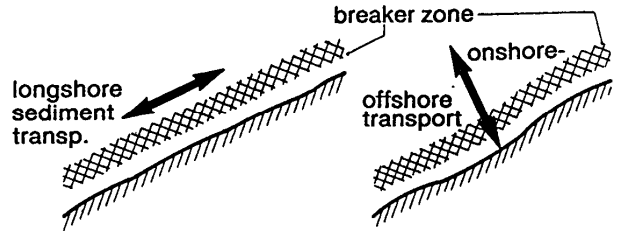
SLR	ΔH_{m0}	Δ W
0.3 m	0 % - 2 %	5 %
0.6 m	0 % - 4 %	10 %
0.9 m	0 % - 6 %	20 %

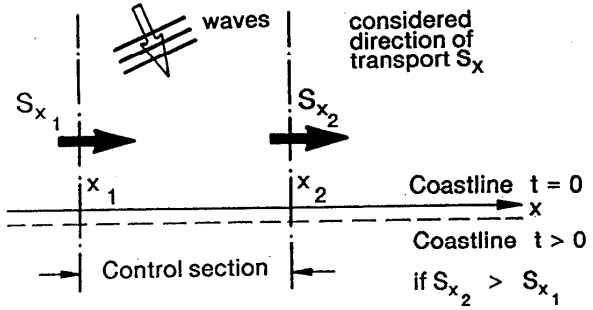
All other values constant!

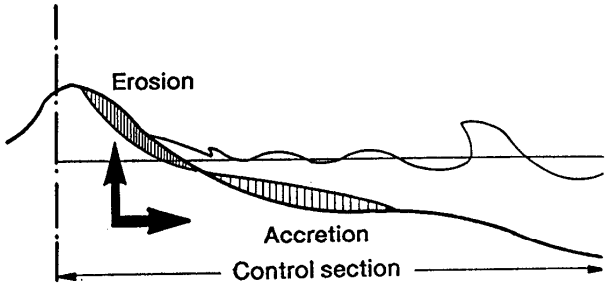
$$W = \frac{\rho \cdot g \cdot H^3}{K_D \cdot (\rho_r/\rho_w - 1)^3 \cdot cot(\alpha)}$$

⇒ Adaptation to SLR is negligible!

Protection of Sandy Coasts - Sediment Transport







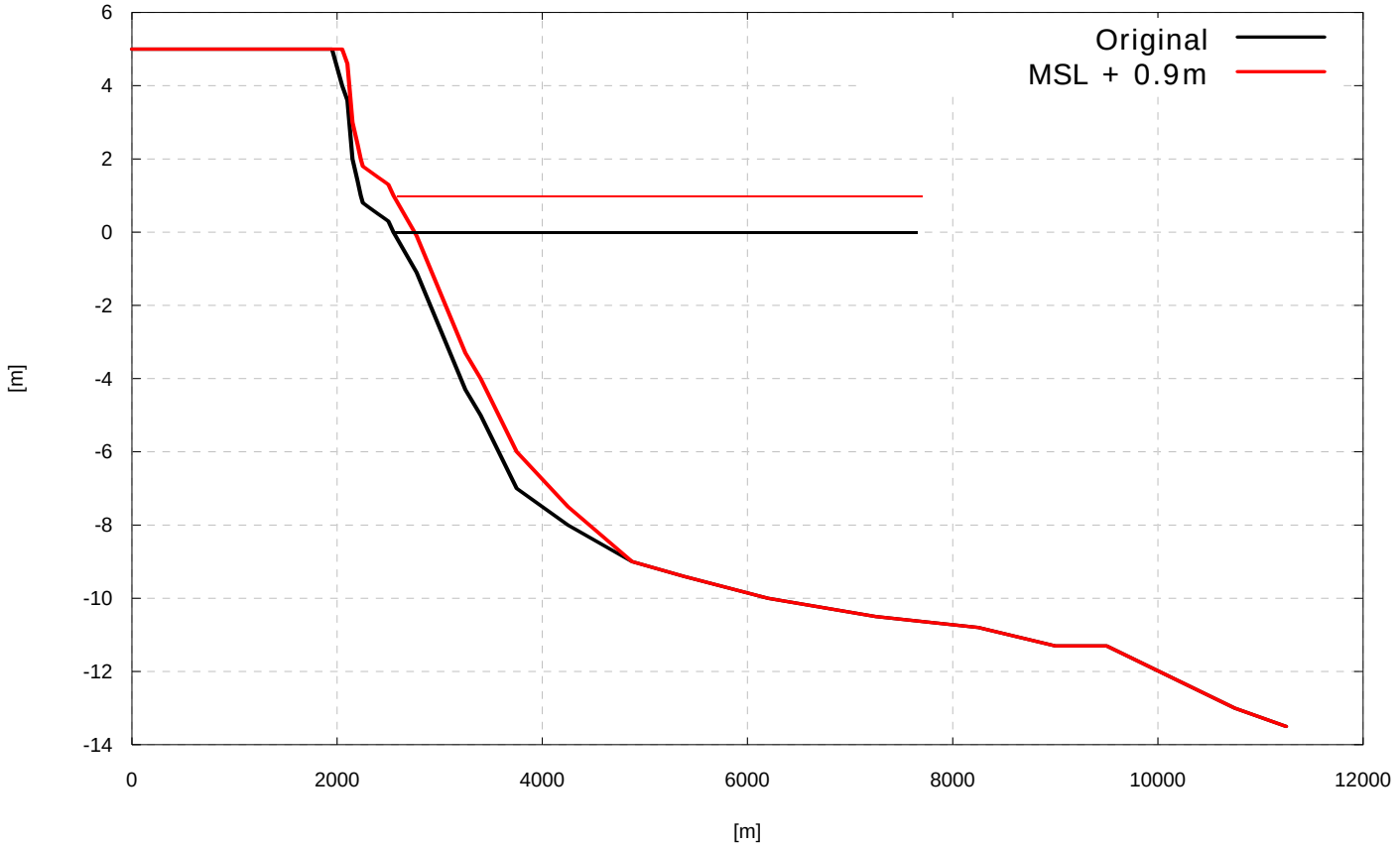
ⓐ "Stable coast" (dynamic equilibrium) : $S_{x_1} = S_{x_2}$

ⓑ Eroding coast : $S_{x_2} > S_{x_1}$ $\left(\frac{dS}{dx} > 0\right)$

ⓒ Accretion : $S_{x_2} < S_{x_1}$ $\left(\frac{dS}{dx} < 0\right)$

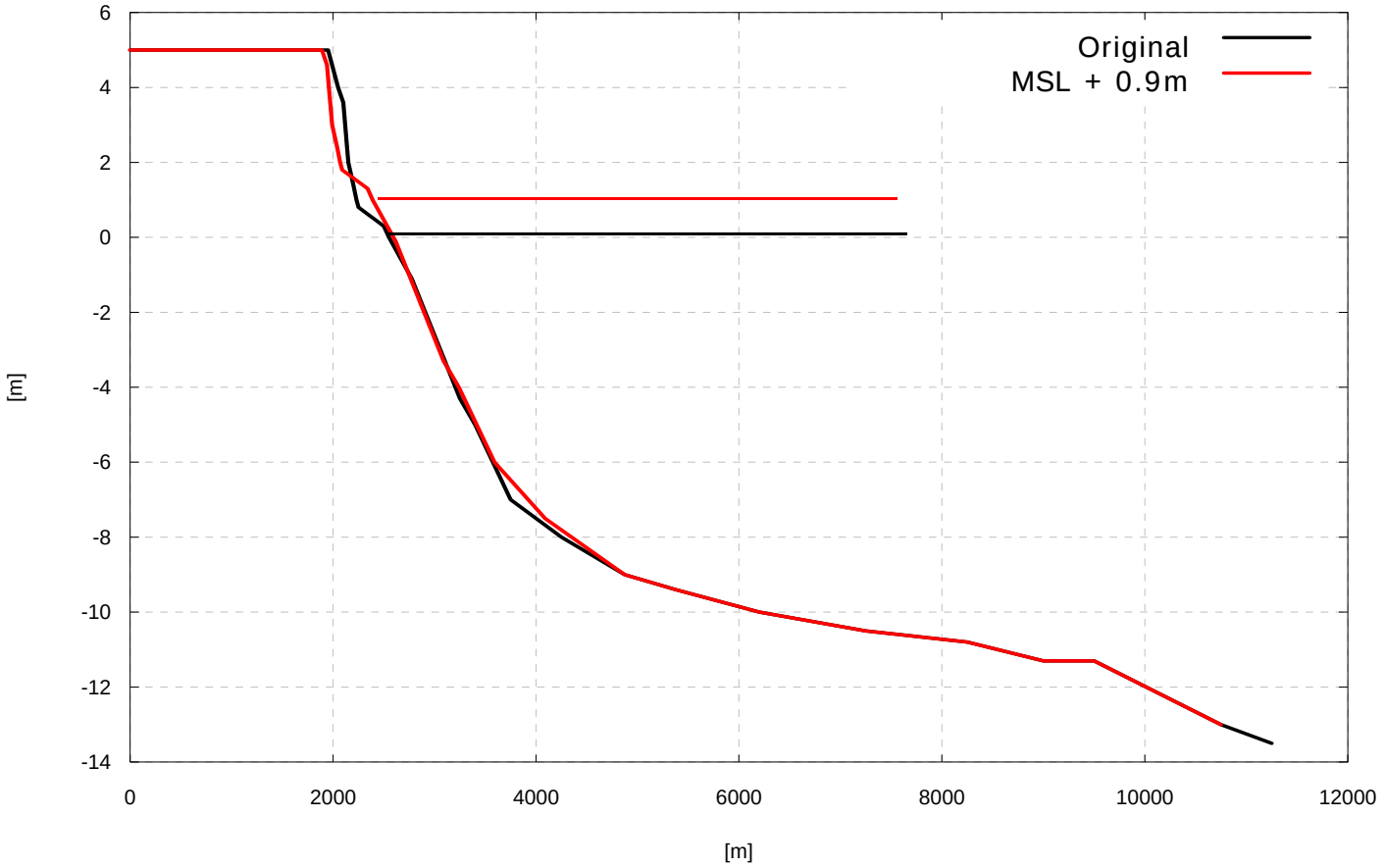
"Dynamic" equilibrium, erosion balanced acc. to
- changing water levels
- changing wave climate
- interactions with sediments

Reaction of a Coastal Profile on Sea Level Rise



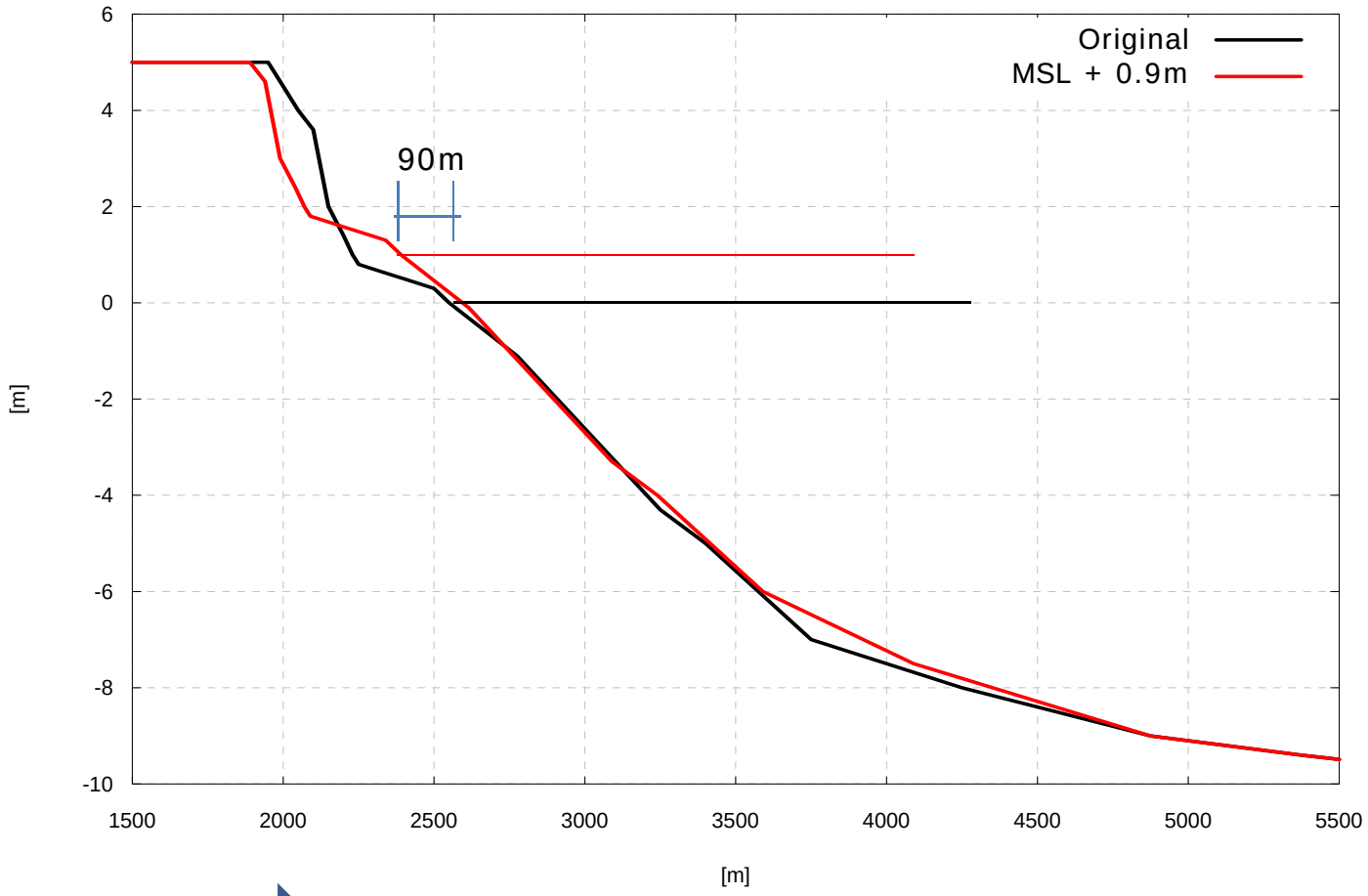
Dynamic Equilibrium Profile

Reaction of a Coastal Profile on Sea Level Rise



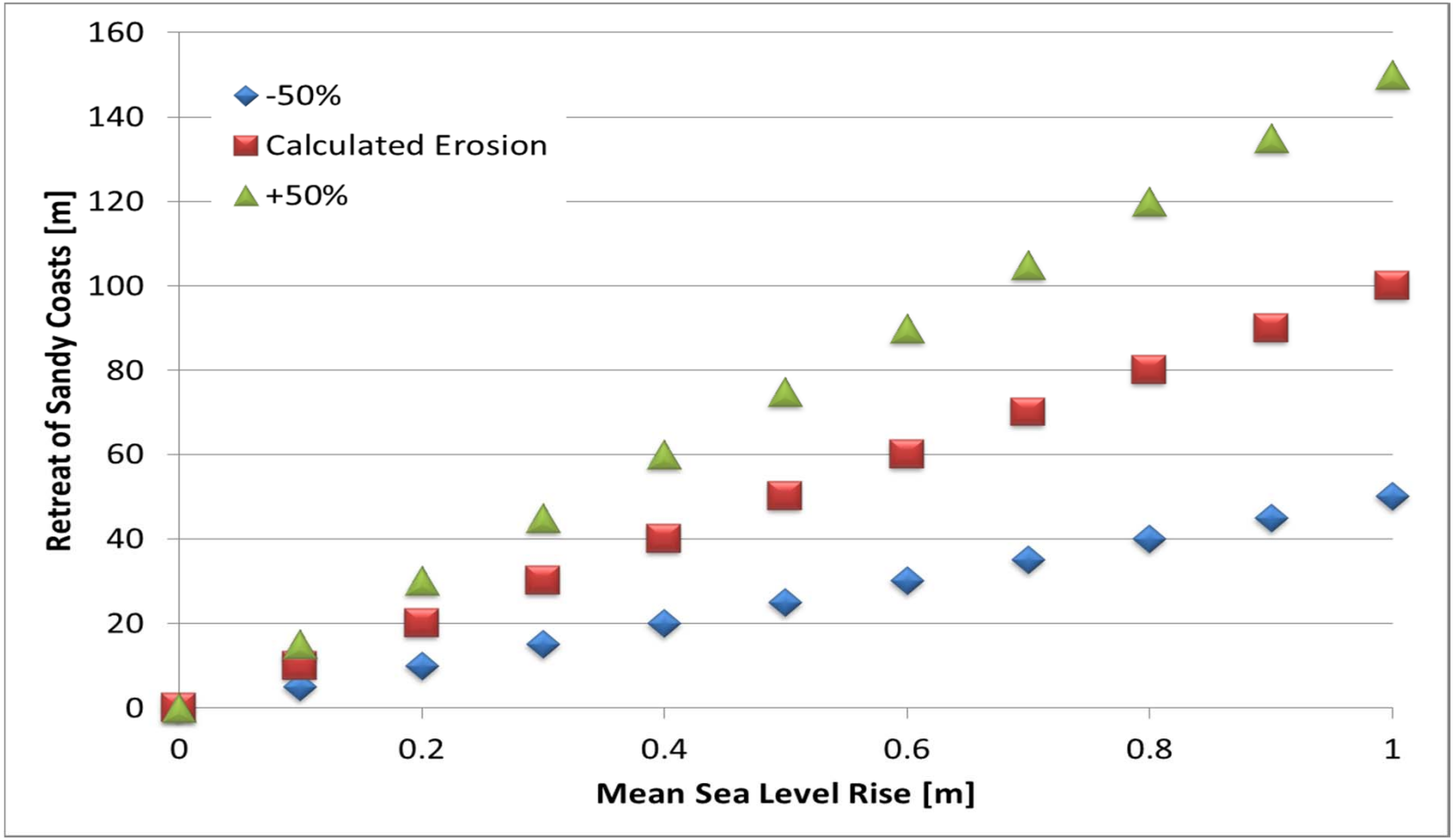
Dynamic Equilibrium Profile

Reaction of a Coastal Profile on Sea Level Rise



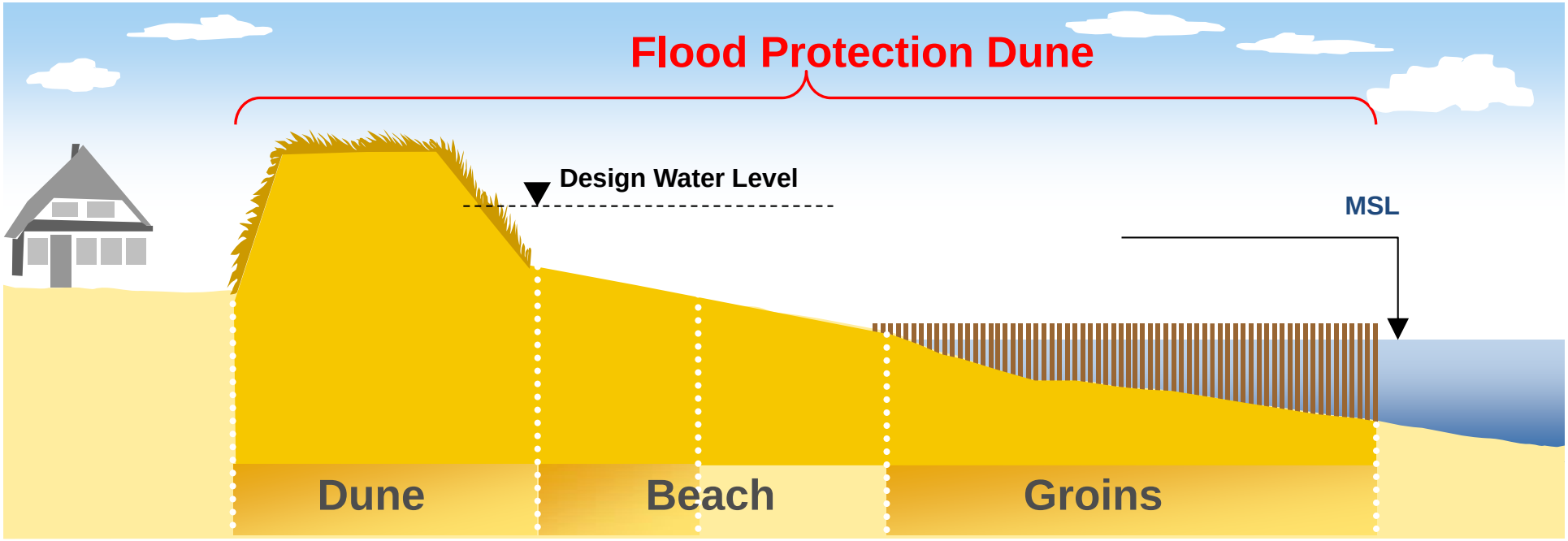
Dynamic Equilibrium Profile

Reaction of Sandy Coasts to Sea Level Rise

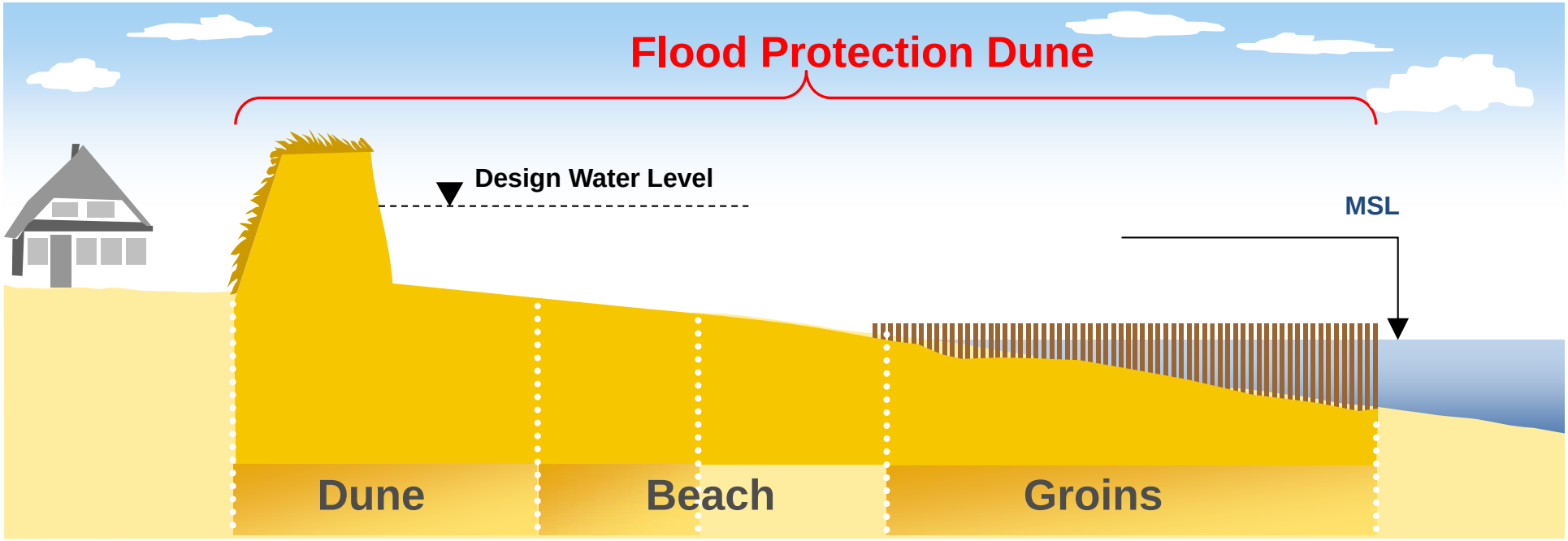


Dynamic Equilibrium Profile

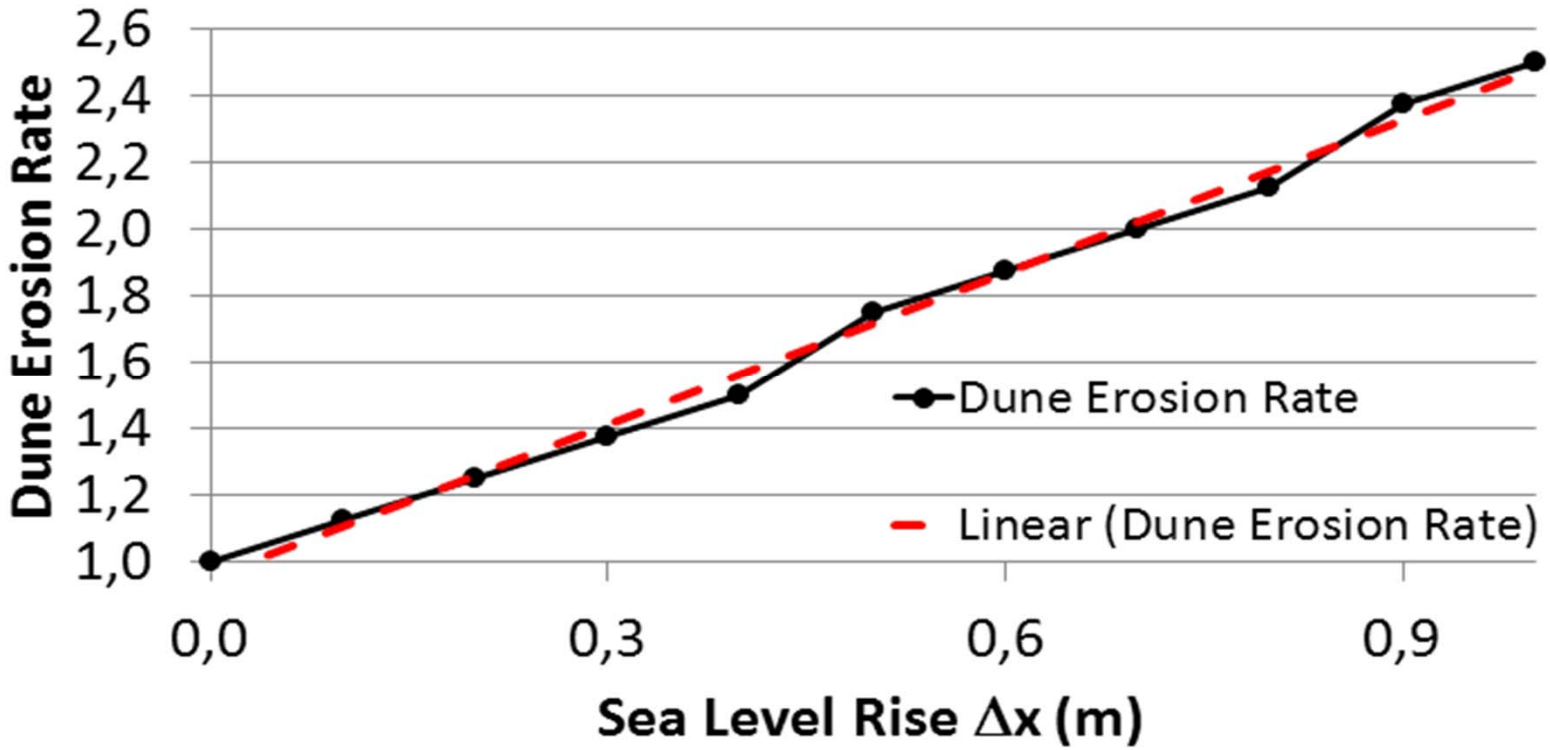
Effects on Coastal Dunes



Effects on Coastal Dunes



Coastal Dunes and Dune Erosion

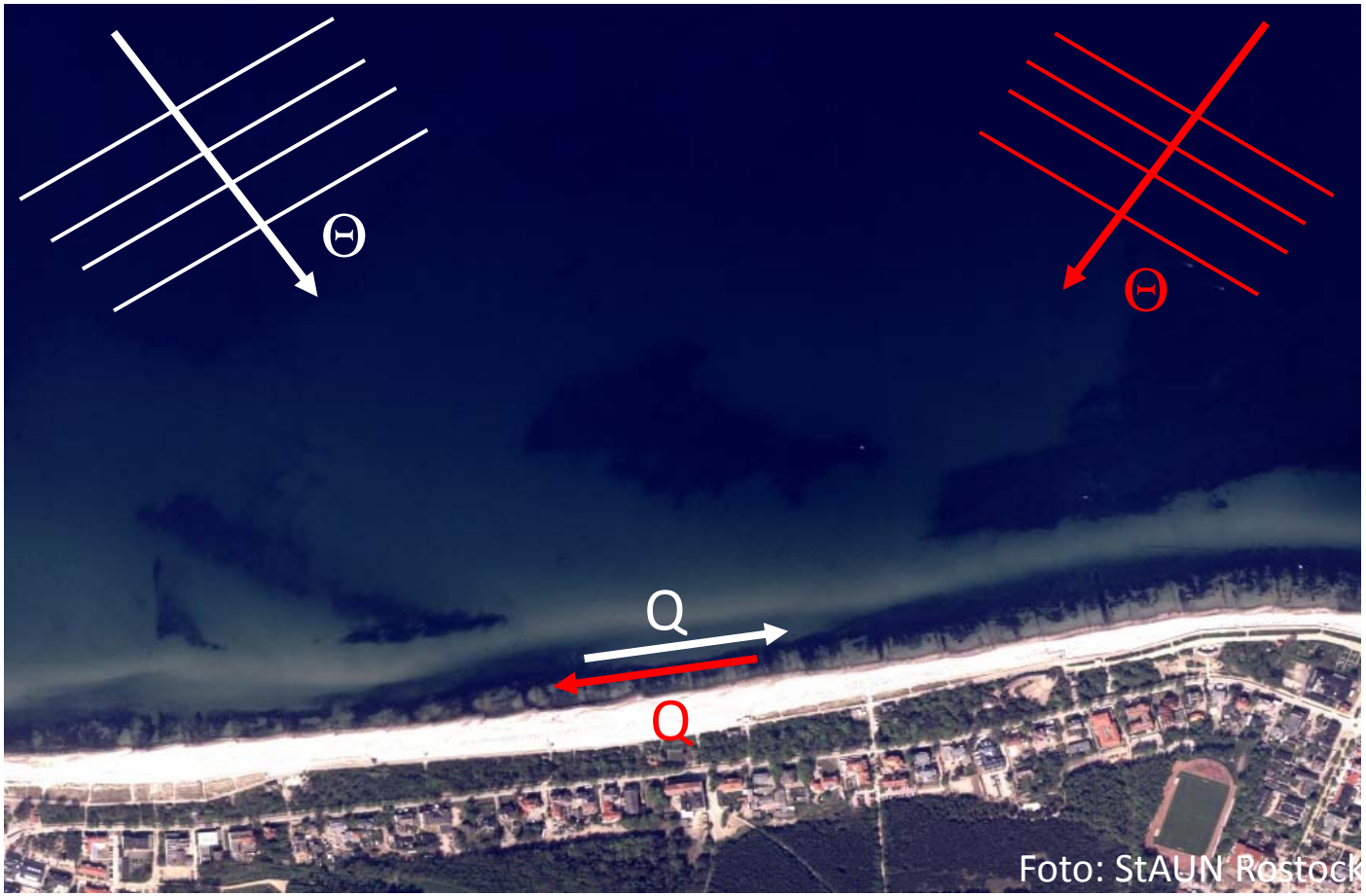


- Decrease of the Dune width

➔ Dune Erosion increases significantly!

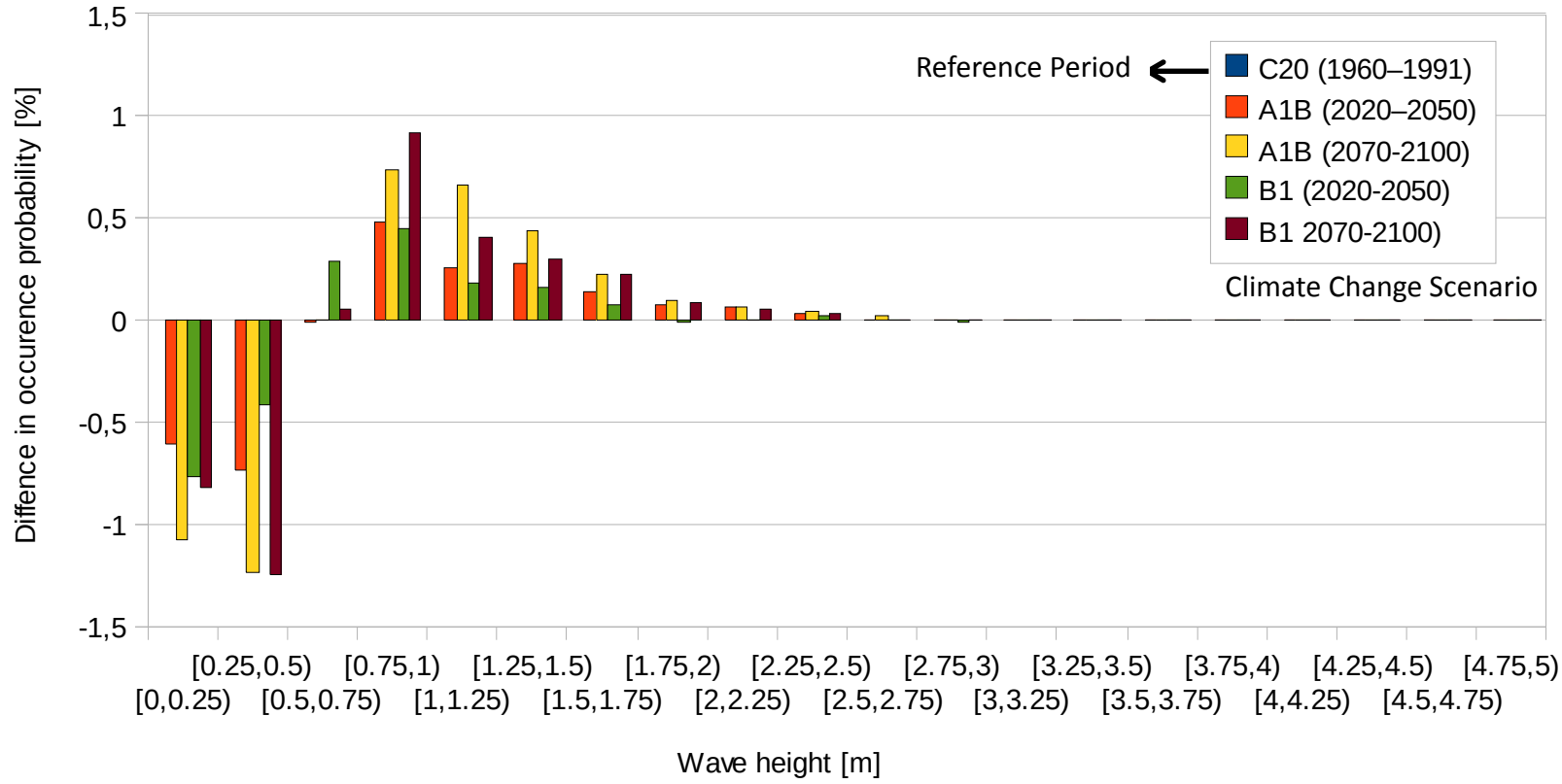
➡ Adaptation is necessary

Influences on the Long-Shore Sediment Transport



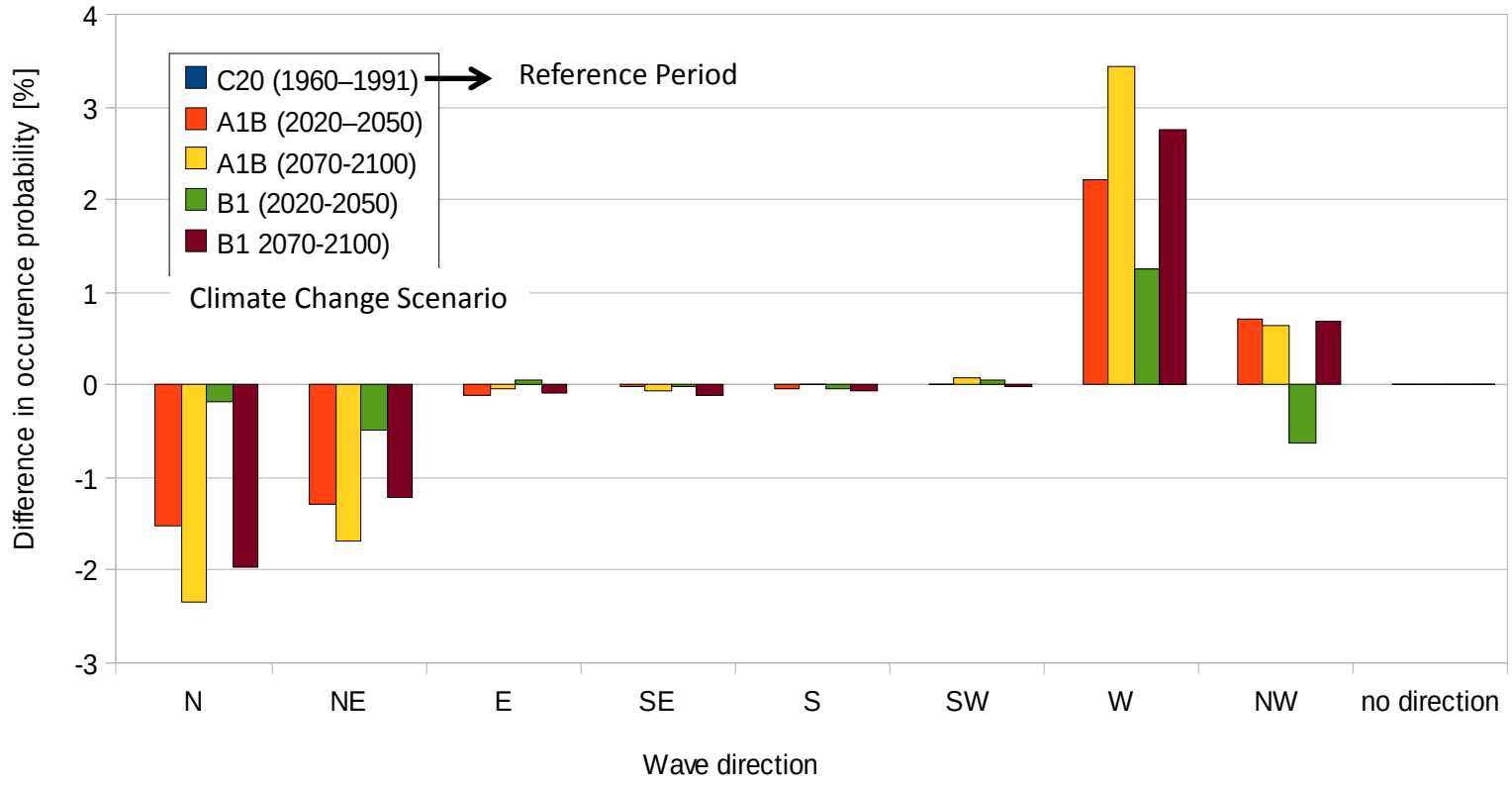
Changes of Wave Directions and/or Current Directions

Changes of the Wave Heights (Warnemünde)



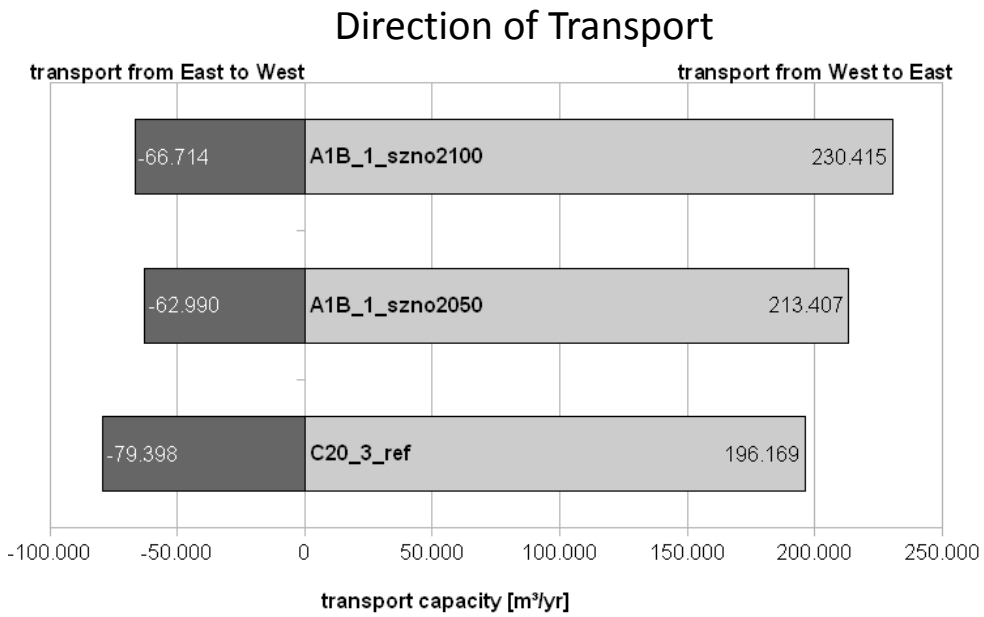
Increase of average significant wave heights up to 4%
(details: see Dreier et al. Tuesday 9.30am)

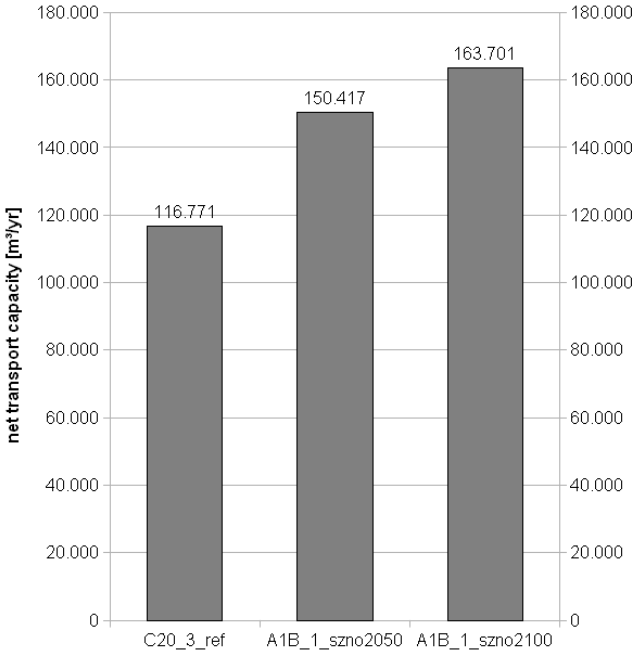
Changes of the Wave Direction (Warnemünde)



Change of mean wave direction of up to 5° in westerly directions
(details: see Dreier et al. Tuesday 9.30am)

Long-shore sediment capacities – Location Warnemünde Baltic Sea





Change of directional transport capacities of up to +20%

Change of net transport capacities of up to +40%

Consequences for the Coast - Summary

Changes of Water Levels and Wave Conditions

causes

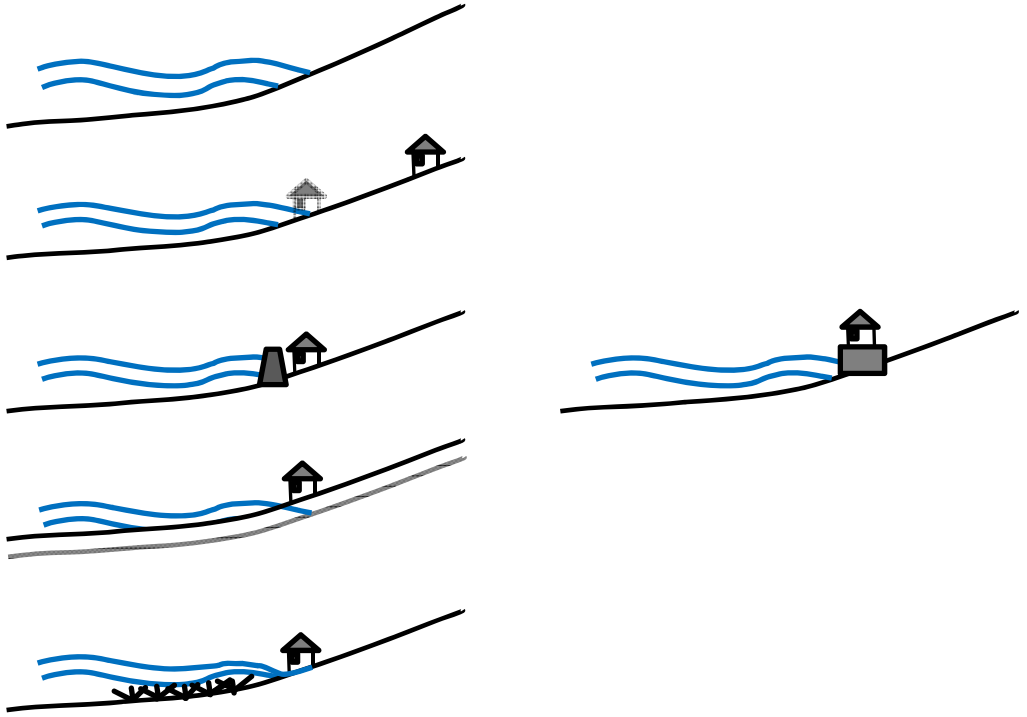
- Consequences for the Coastline, Surf Zone, Beach and Hinterland
- Higher Loads on Coastal Protection Measures
- Reduction of Protection Level of Erosion Protection and Flood-Protection

Reduction of Security in Erosion and Flood Protection
consequently needs an
Adaptation of Coastal Protection Measures and Concets to Climate Change

Policies and Strategies

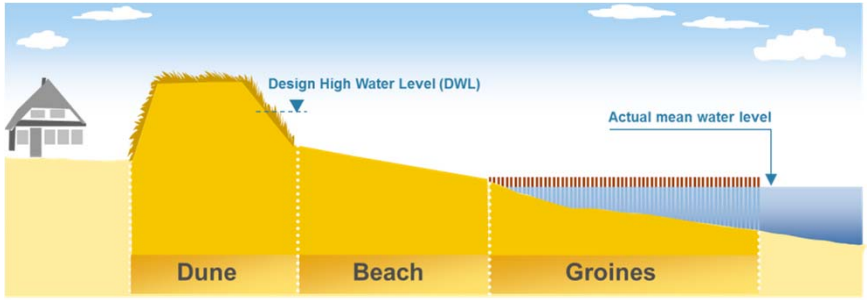
In general, five policies of coastal protection have been developed and applied in coastal engineering. These policies are:

- Do nothing
- Managed realignment
- Hold the line
- Move seaward
- Limited intervention

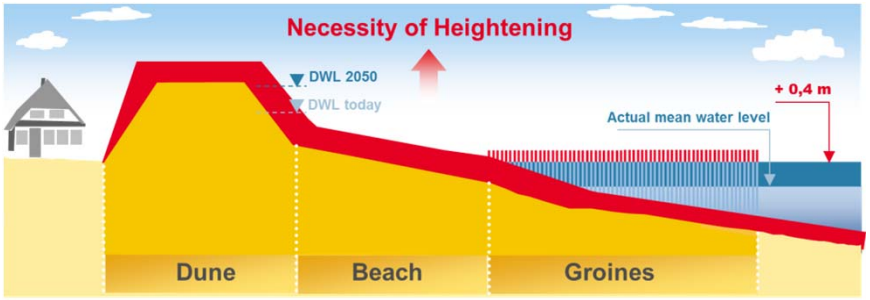


Adaptation of Strategies Example: Flood Protection Dunes

Actual Situation



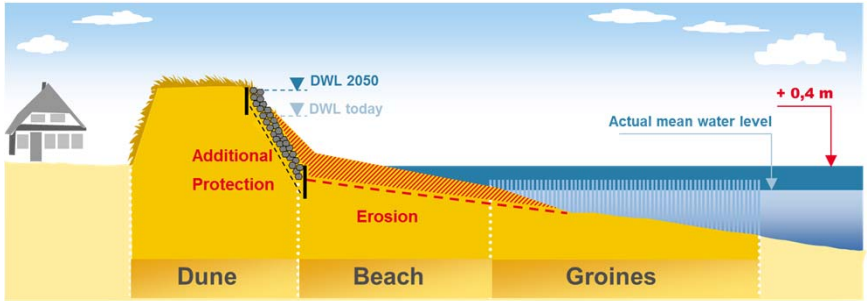
Seeward shift of the Coast



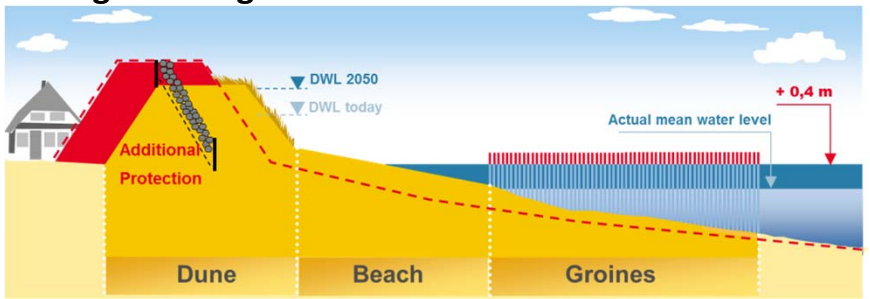
do nothing

Limited Action

Hold the Line

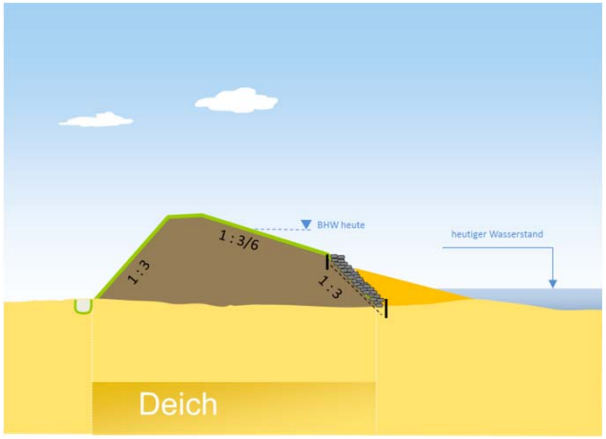


Managed re-alignment + limited action

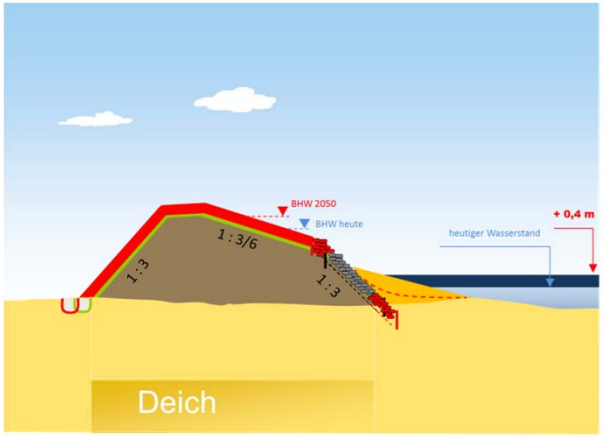


Adaptation of Strategies Example: Dikes I

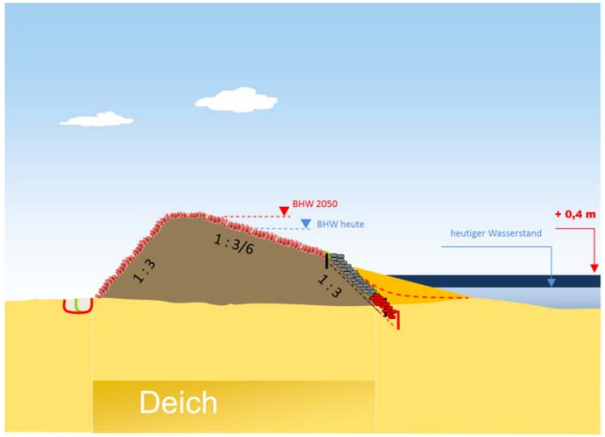
Actual Situation



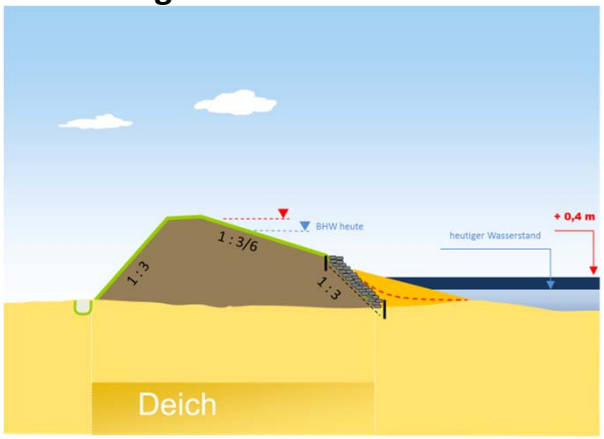
Hold the Line



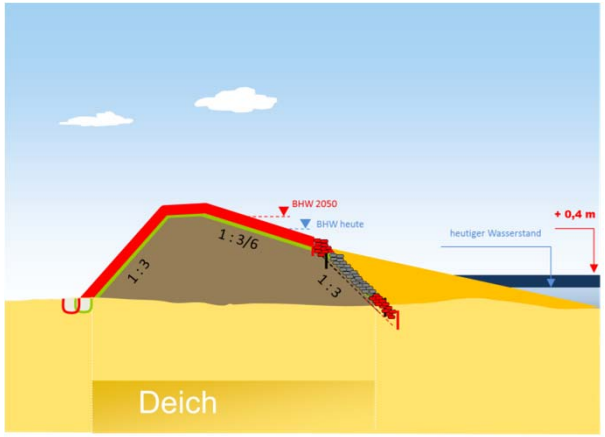
Limited Action



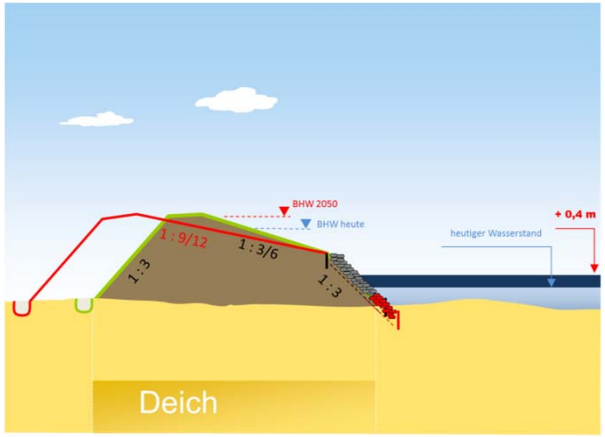
do nothing



Seeward shift of the Coast

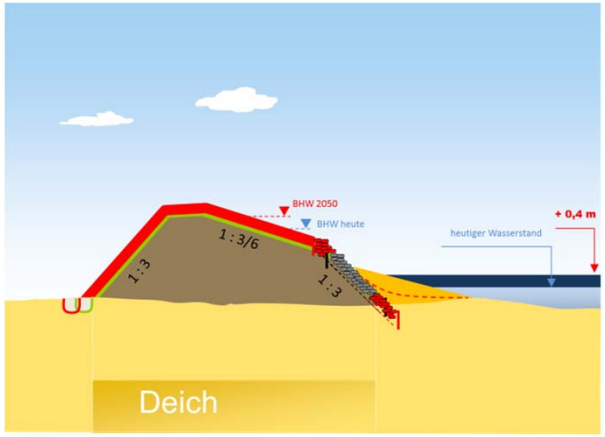


Managed re-alignment + limited action

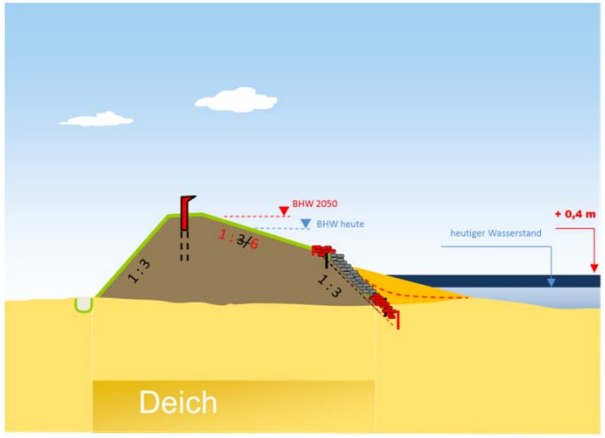


Adaptation of Strategies Example: Dikes II

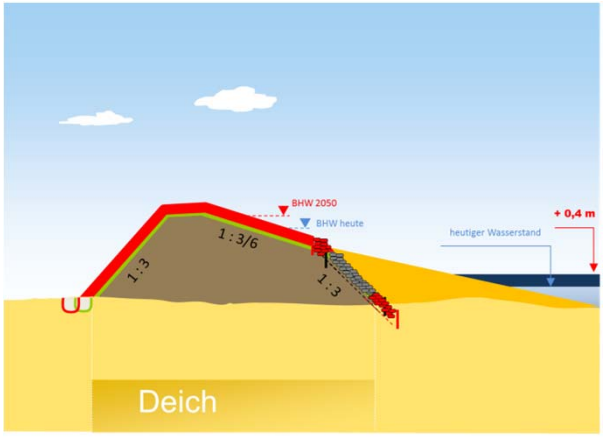
Hold the Line



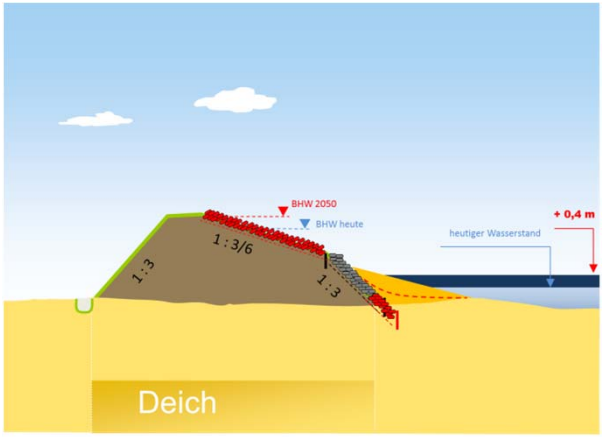
Hold the Line



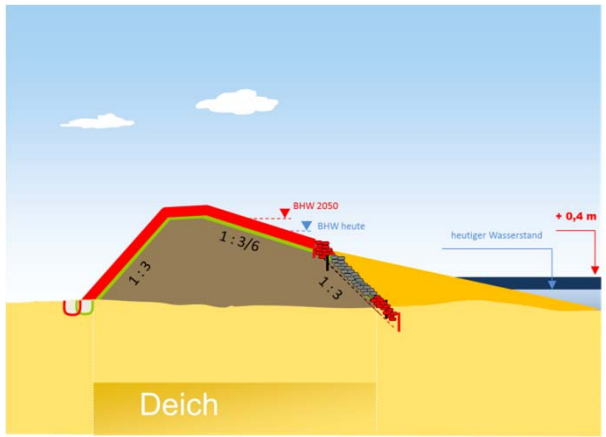
Seeward shift of the Coast



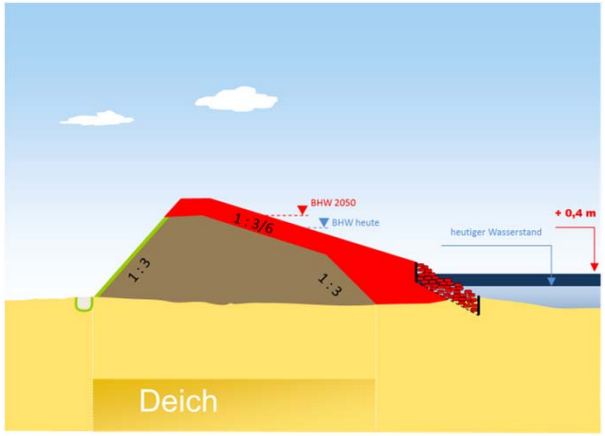
Hold the Line



Seeward shift of the Coast

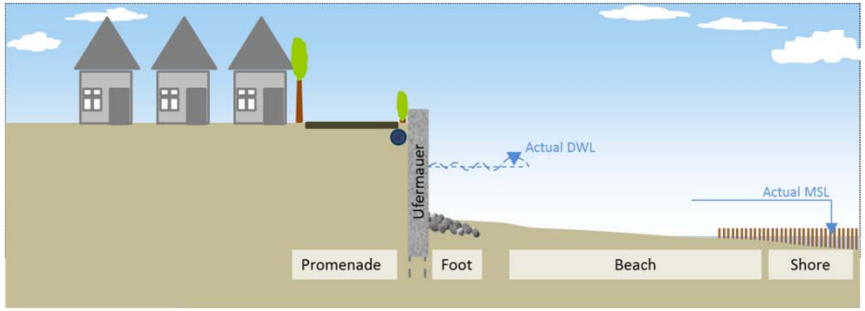


Seeward shift of the Coast

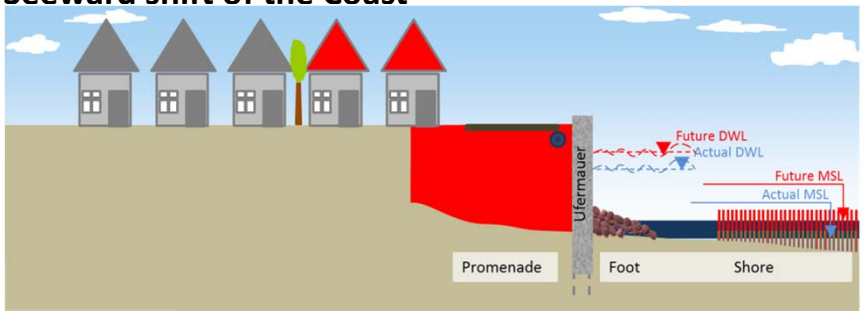


Adaptation of Strategies Example: Beach Walls

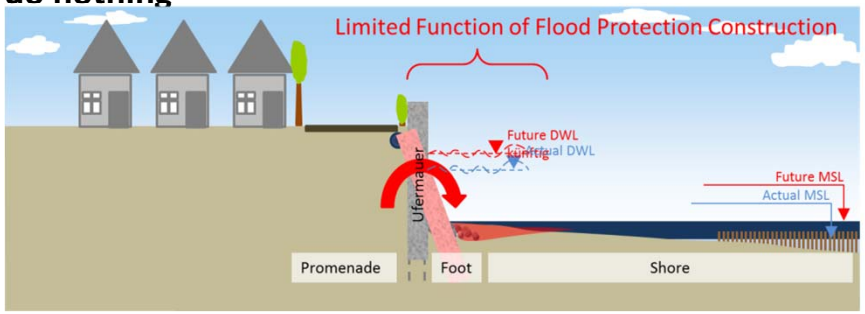
Actual Situation



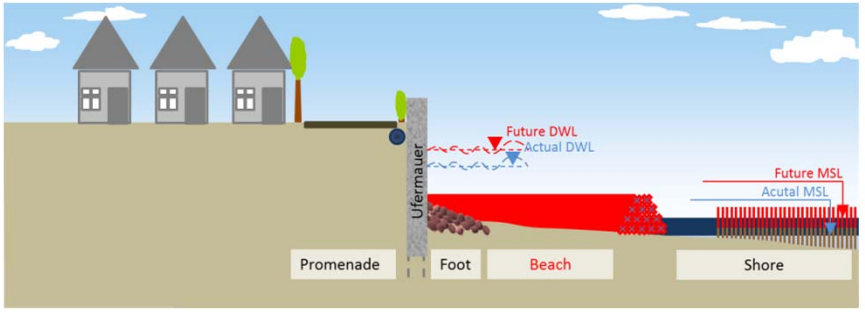
Seeward shift of the Coast



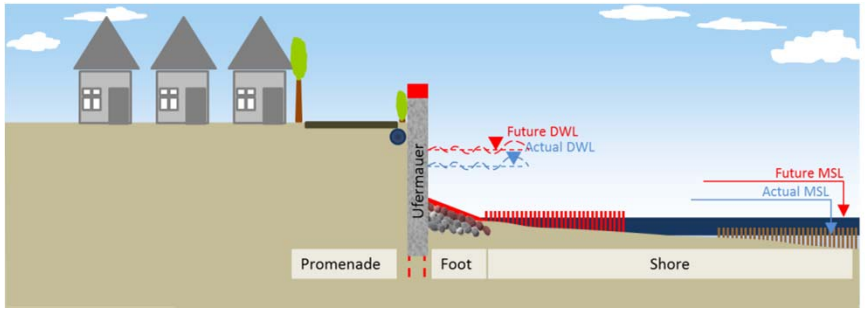
do nothing



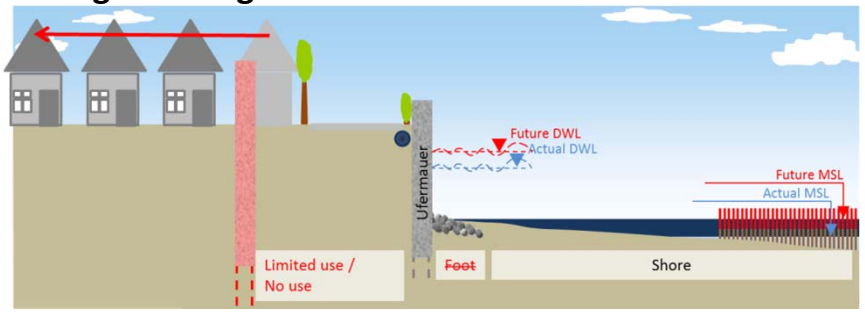
Limited Action



Hold the Line

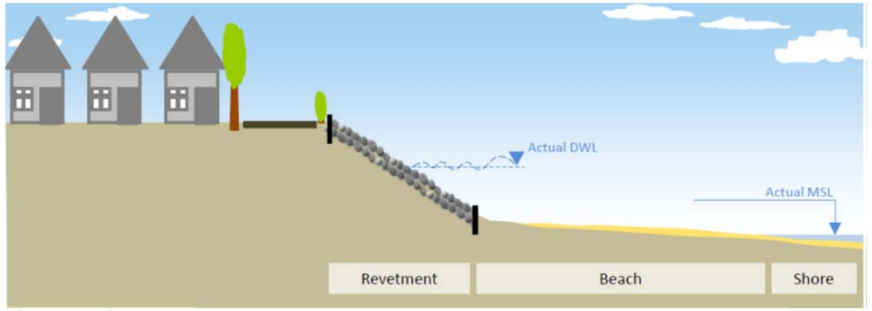


Managed re-alignment + limited action

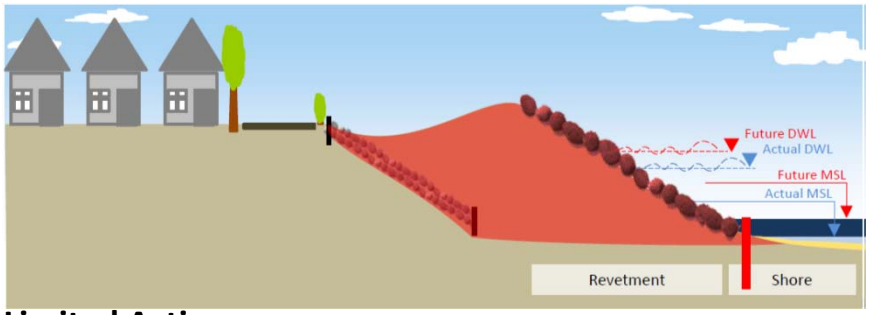


Adaptation of Strategies Example: Revetments

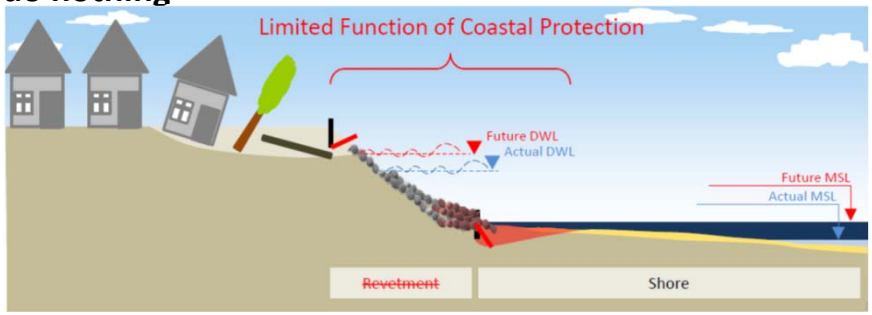
Actual Situation



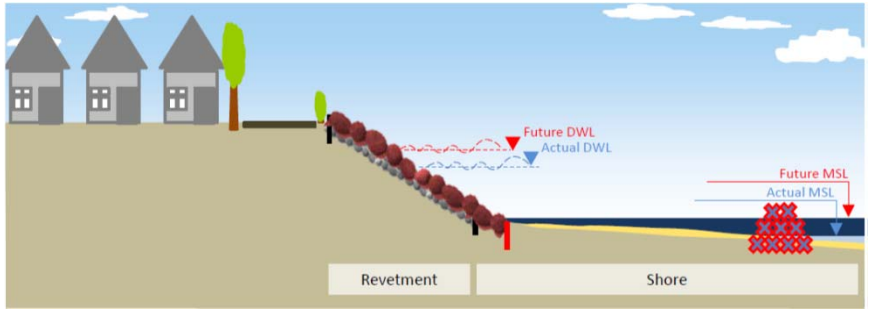
Seeward shift of the Coast



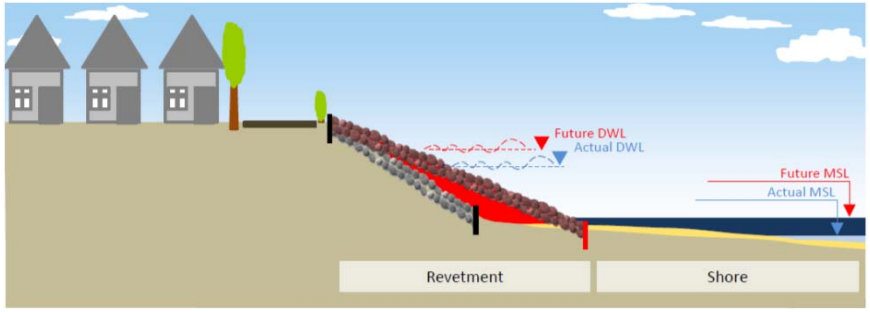
do nothing



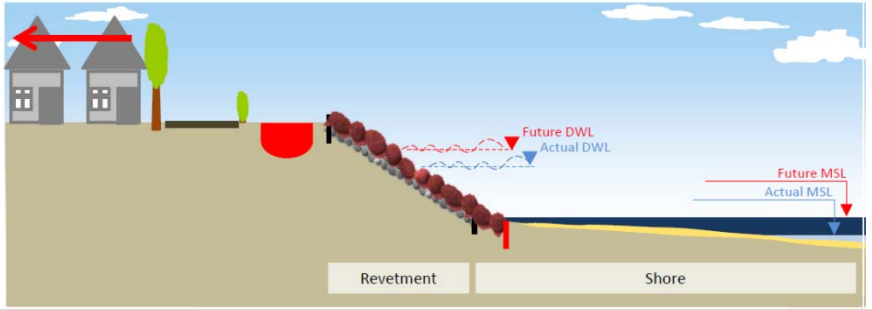
Limited Action



Hold the Line



Managed re-alignment + limited action



Climate Change and Coastal Protection – Baltic Sea

Selected Conclusions

- Climate Change will have direct and indirect effects on Coastal Areas
  - Water levels will increase
  - Wave heights will increase (selected situations)
  - Wave directions may change
  - Frequency and intensity of storms will increase

How to deal with model uncertainties and with bandwidth of model results?

- Higher loads on coastal structures
- Retreat of the coast
- Change in (longshore) sediment transport

} Adaptation strategies for structures

without adaptation:

- Increase in probability of failure of structures
- Increase in flooded area
- Increase of water level in flooded area

} Higher risks in Coastal Areas

Climate Change and Coastal Protection – Baltic Sea

Selected Conclusions (adaptation)

- Adaptation measures may alter general features of the coast
  - Heavily protected coast with hard structures instead of sandy coast
  - Devastation of beaches in front of dikes and other (hard) structures
  - Retreat from coastal areas and / or
  - Change of use of coastal areas

- If the general features of the coast need to be preserved
  - Cross section of the coast must follow the water level within the complete active zone of the beach
  - Working with ‚beach'-nourishment, sand re-fill / replenishment (soft structures) is necessary for coastal protection of sandy coasts
  - Classical protection-structures may support the development and give a local protection

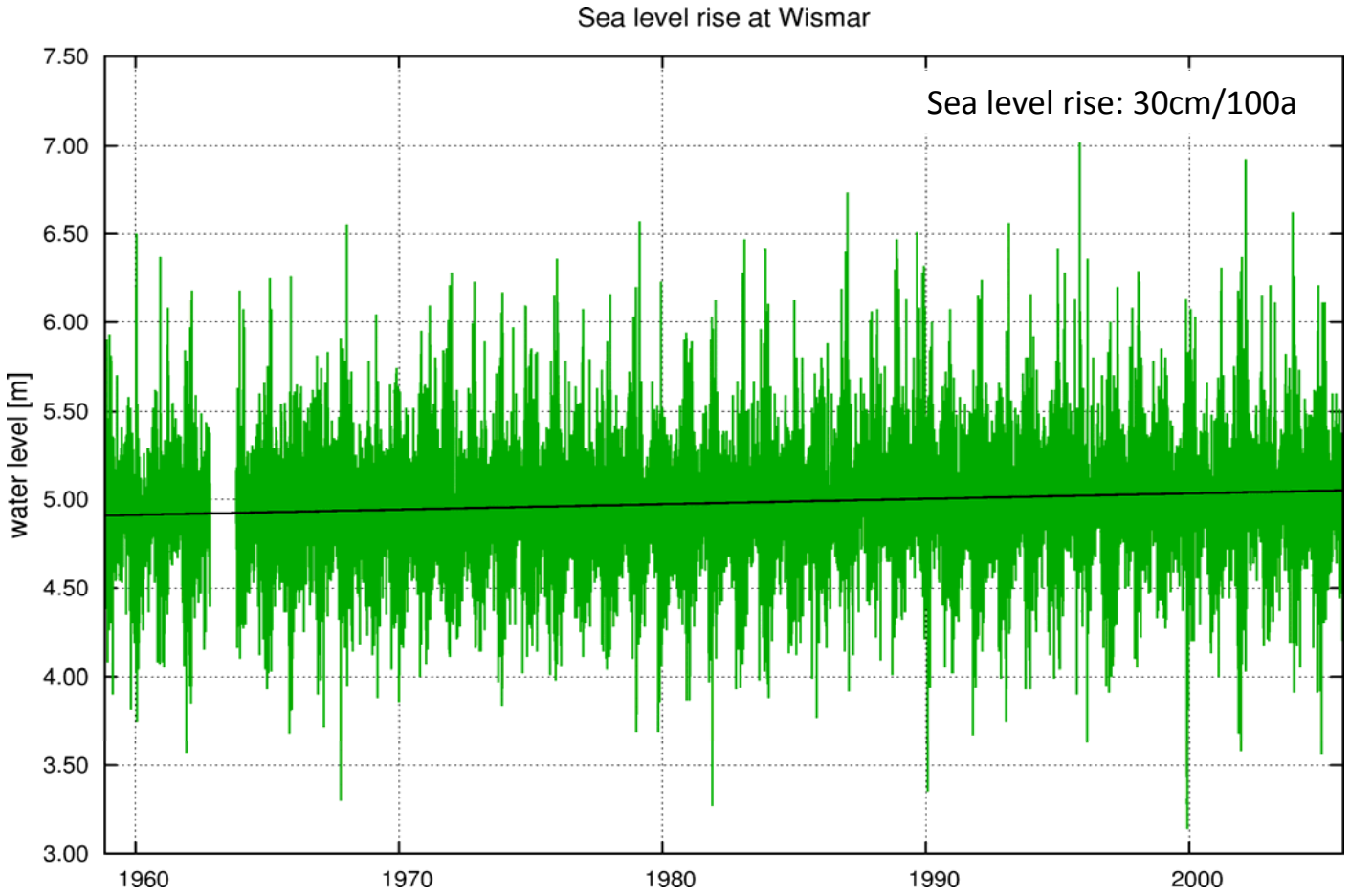
Coastal Protection RAdOst Key Questions

- How may the hydrodynamic conditions develop?
- Do we have to be prepared for changed morphological development? If yes, where?
- Are actual strategies sustainable?
- Do actual coastal protection constructions allow sustainable strategies? Where do we have to react at first?
- How will we protect our coasts in 2050?

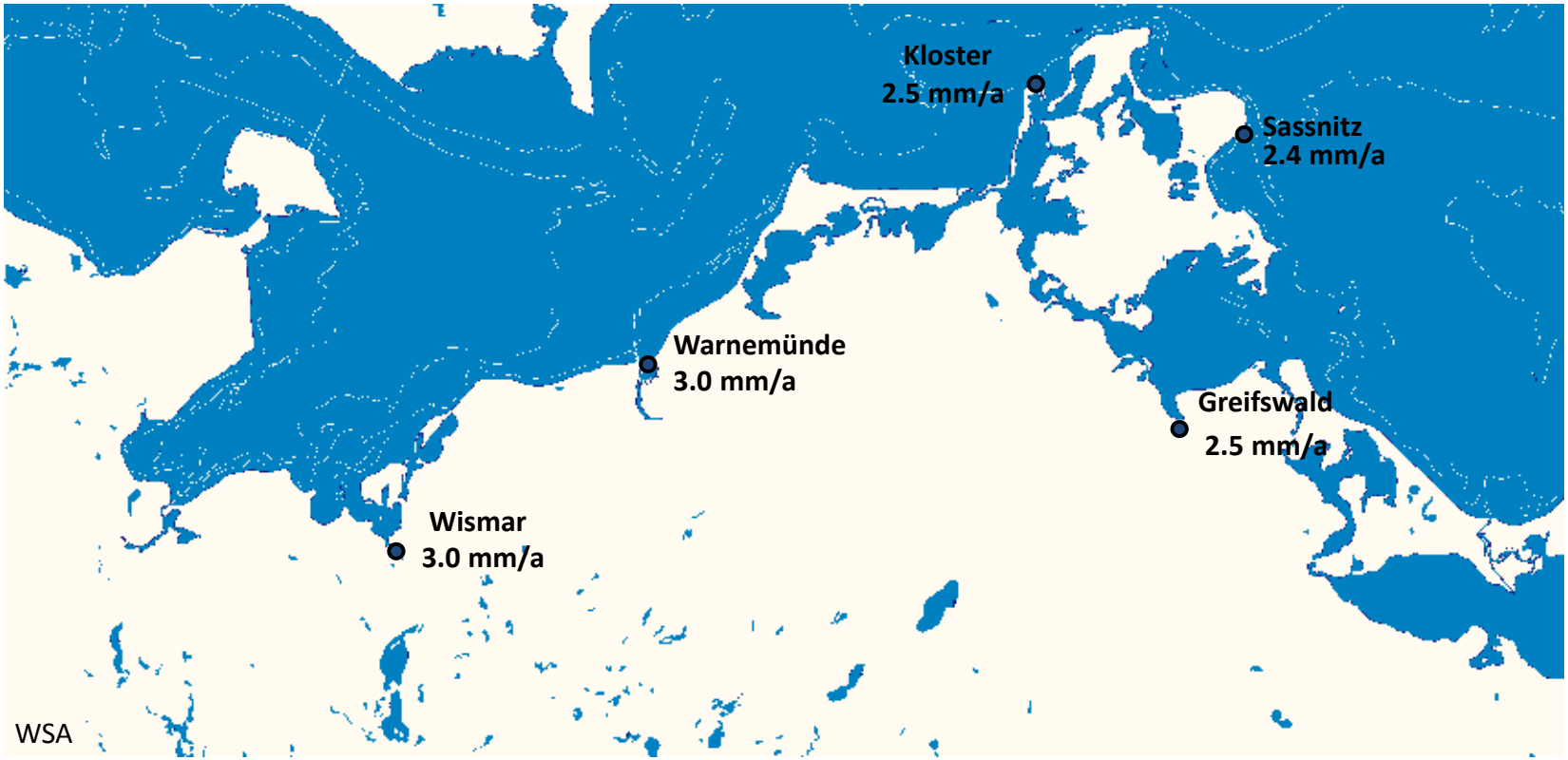
Do we have enough sand?


Thank you for your attention!

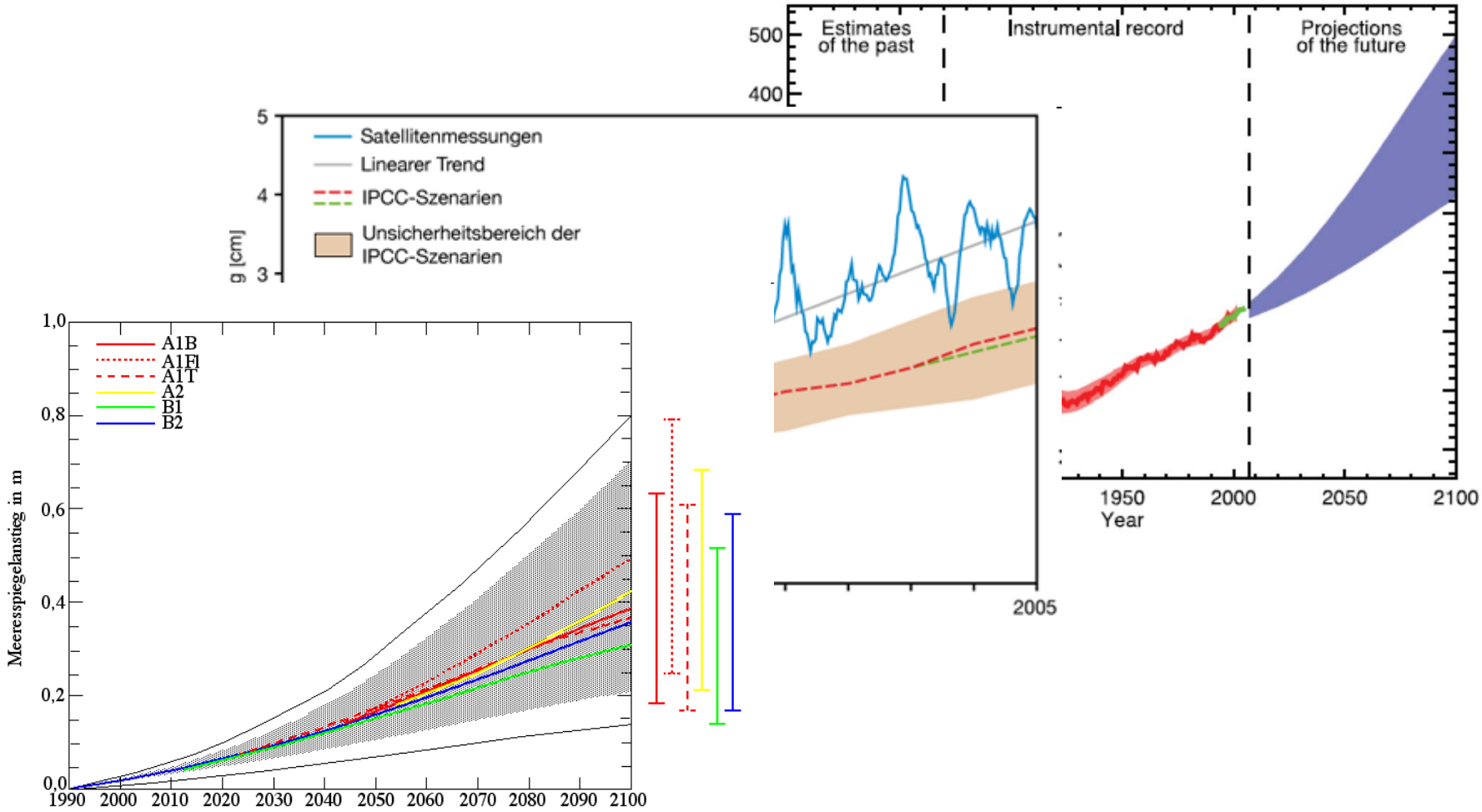
Measured Sea Level Rise Baltic Sea (Gauge Wismar)



Actual rates of Sea Level Rise M-V



Accelerated Sea Level Rise



Future Sea Level Rise (2050 / 2100)

- Observed SLR (actual figures) (measurements)

Ort	2050	2100
Wismar (1958 -2006)	0.12m	0.27m
Warnemünde (1958 -2006)	0.09m	0.20m
Greifswald (1975 -2006)	0.10m	0.23m

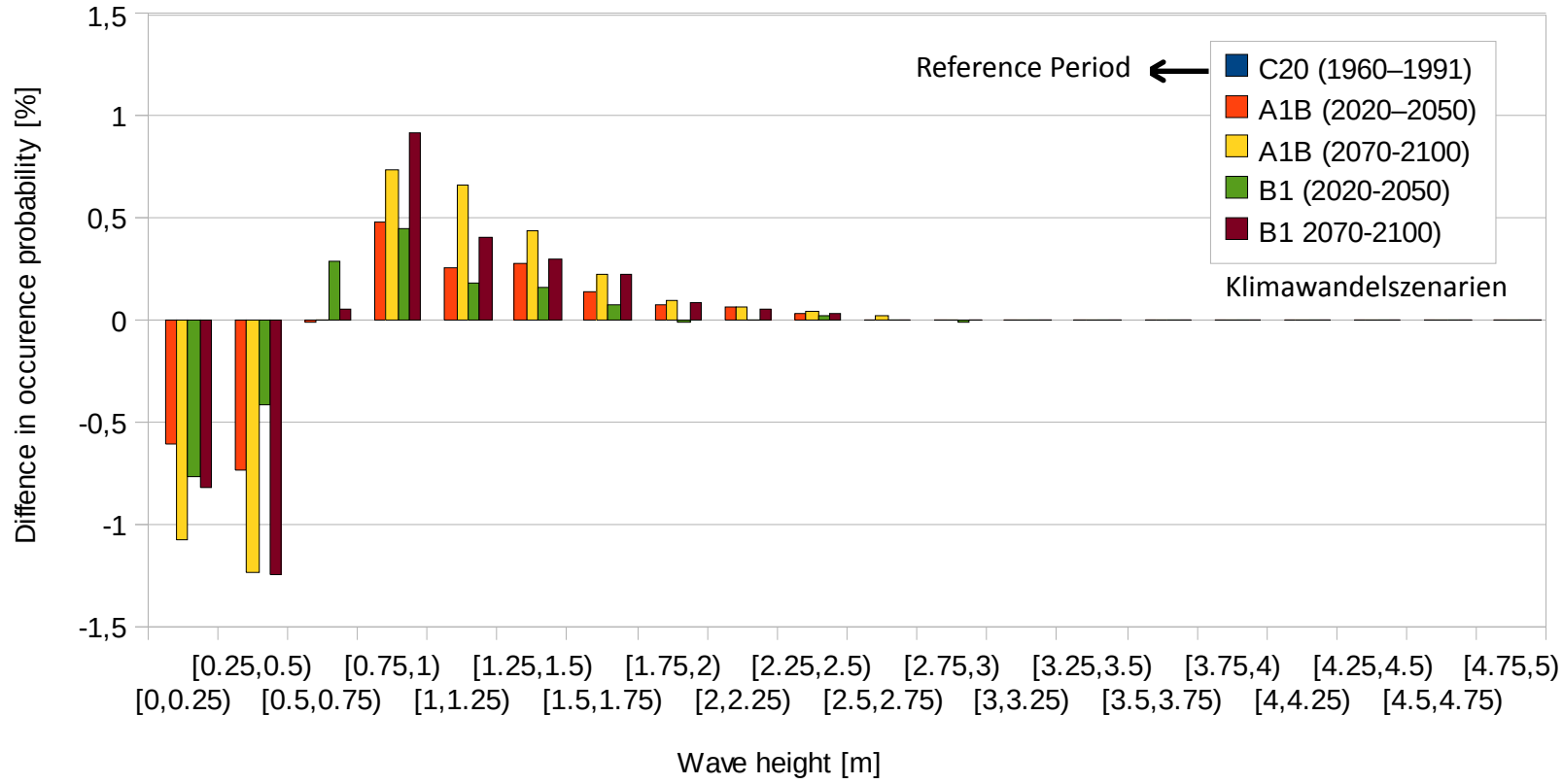
- Global (accelerated) SLR (ICCP / BACC)

	B1 (m)	B2 (m)	A1B (m)	A1T (m)	A2 (m)	A1FI (m)
2050	0.06 - 0.16	0.09 - 0.23	0.09 - 0.25	0.07 - 0.19	0.12 - 0.35	0.12 - 0.40
2100	0.14 - 0.35	0.19 - 0.51	0.19 - 0.55	0.15 - 0.43	0.27 - 0.77	0.27 - 0.88

But Rahmstorf et al. => SLR 1.5m to 2.0m in 2100

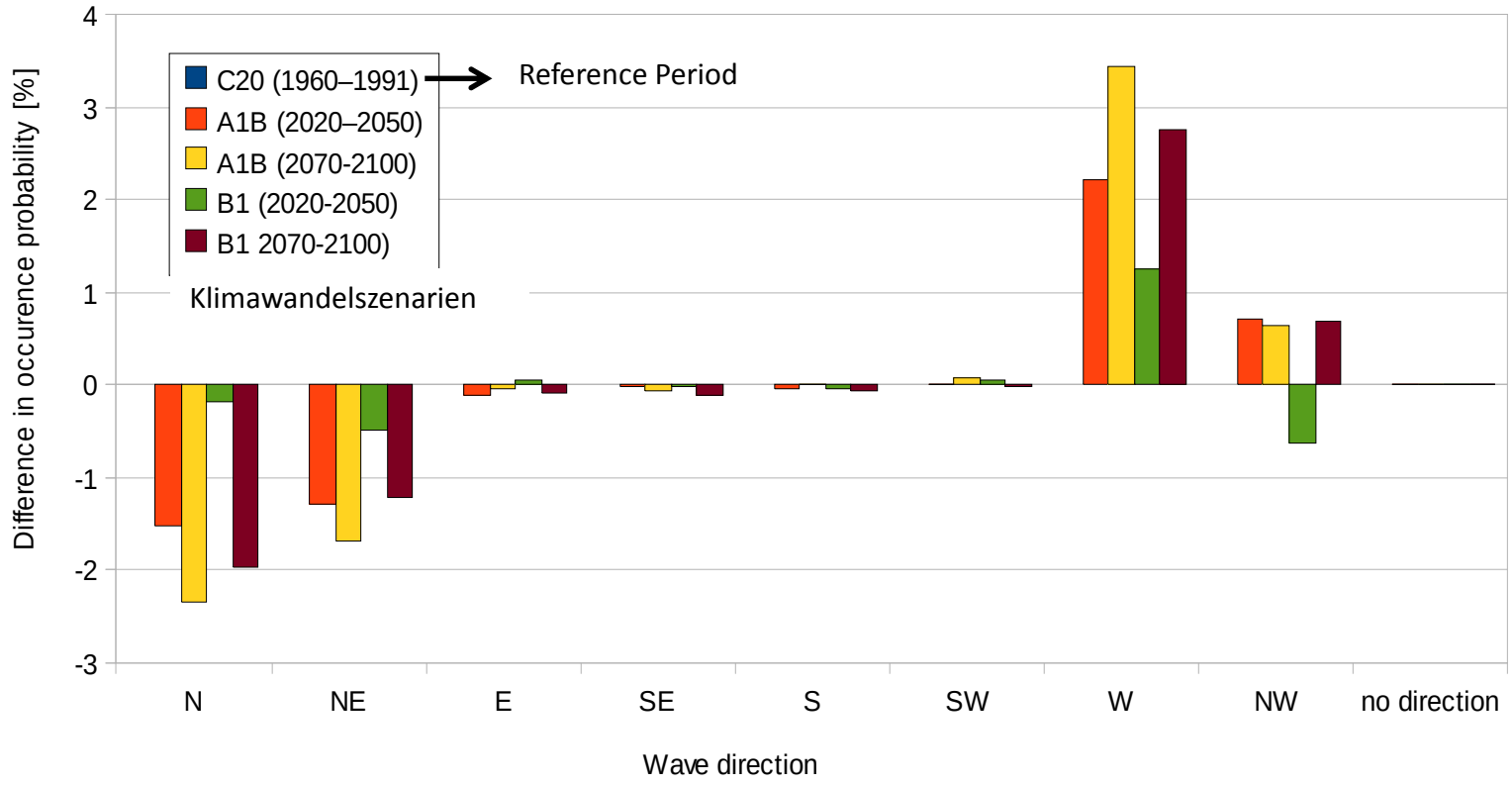
⇒ Implications for Coastal Protection

Changes of the Wave Heights (Warnemünde)



Increase of average significant wave heights up to 4%
(details: see Schlamkow et al. Friday 11.20)

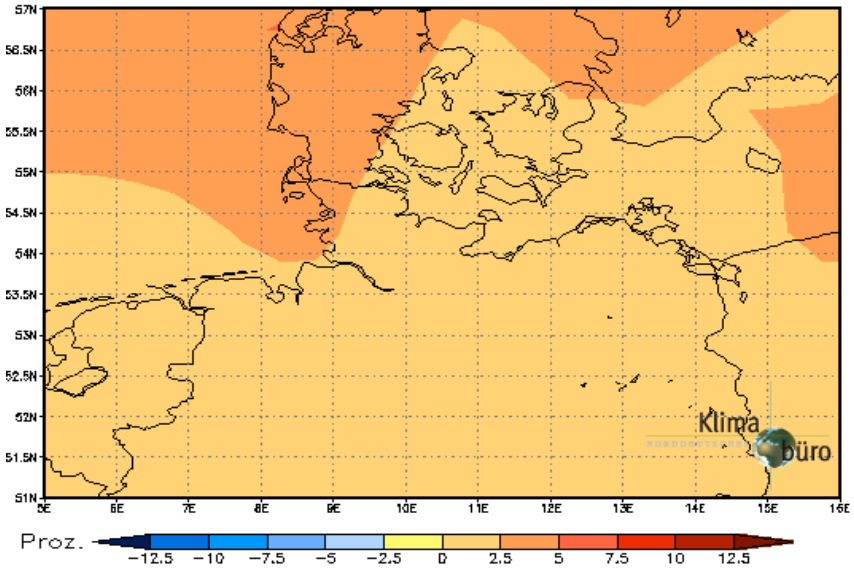
Changes of the Wave Direction (Warnemünde)



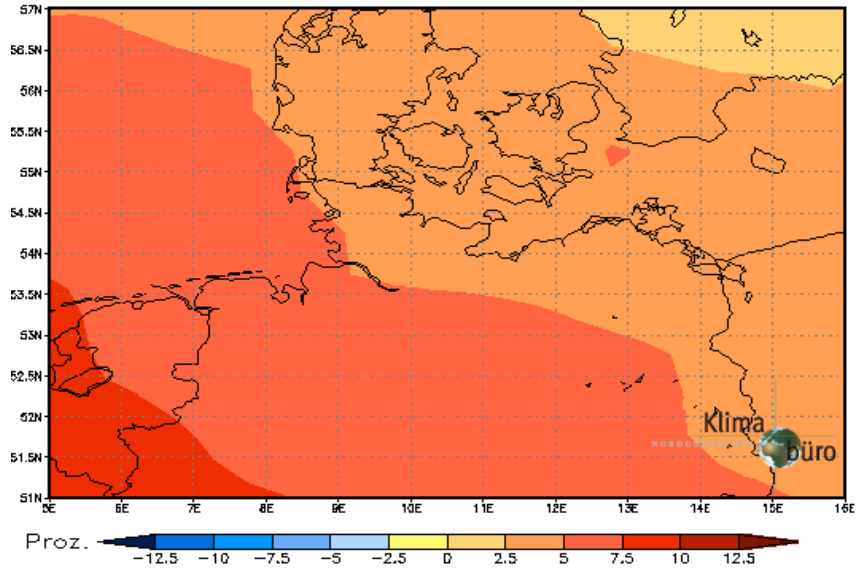
Change of mean wave direction of up to 5° in westerly directions
(details: see Schlamkow et al. Friday 11.20)

Storms and Storm Surges

Source: Norddeutsches Klimabüro



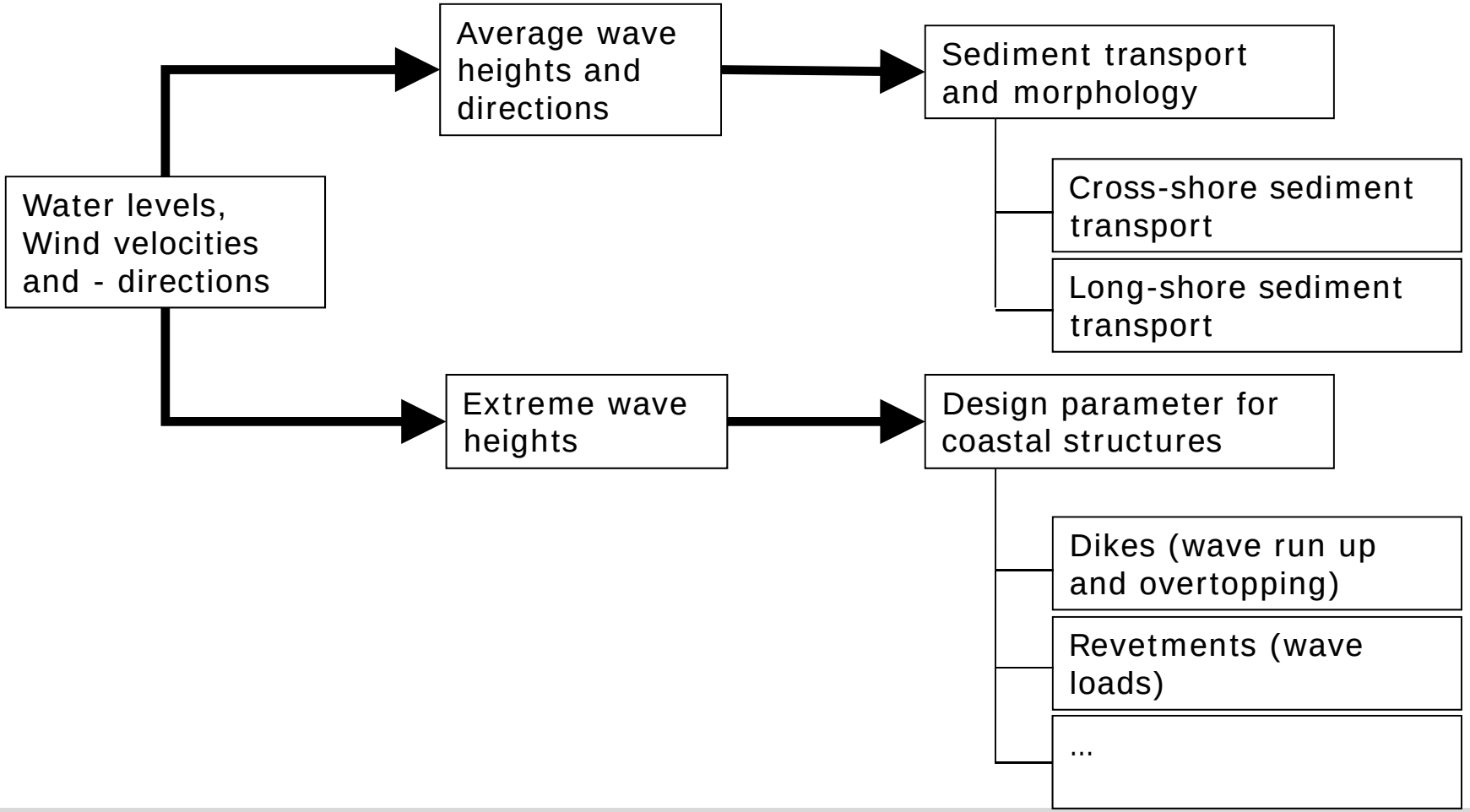
Changes of Storm Intensity
Yearly Average 2070-2100
comp. 1960-1990 (average Scenario)



Changes of Storm Intensity
Winter 2070-2100 comp.1960-1990
(average Scenario)

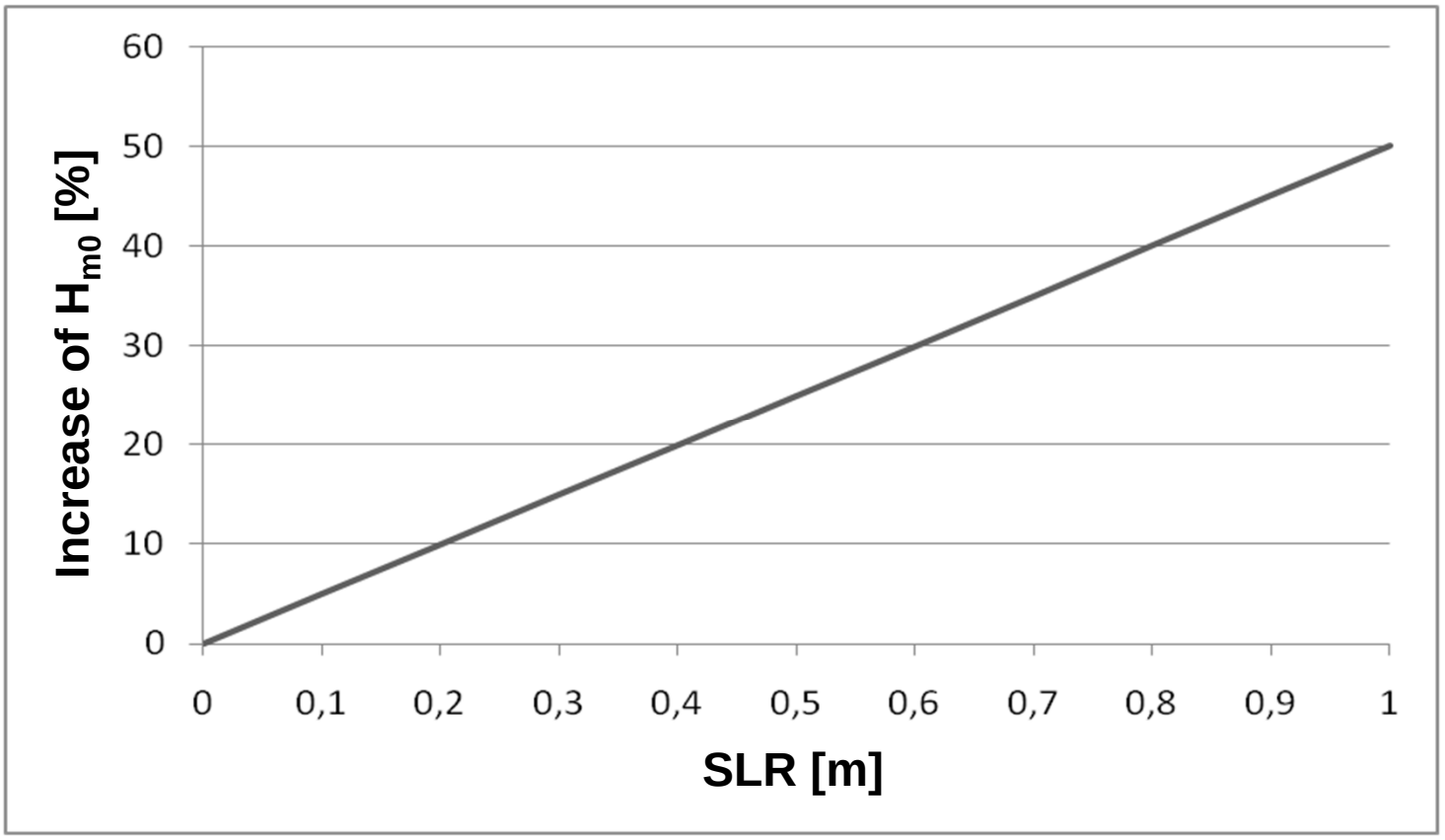
Changes of Extreme Wave Heights by up to 15%
(details: see Schlamkow et al. Friday 11.20)

Changes of Climate and Hydrodynamics and Consequences

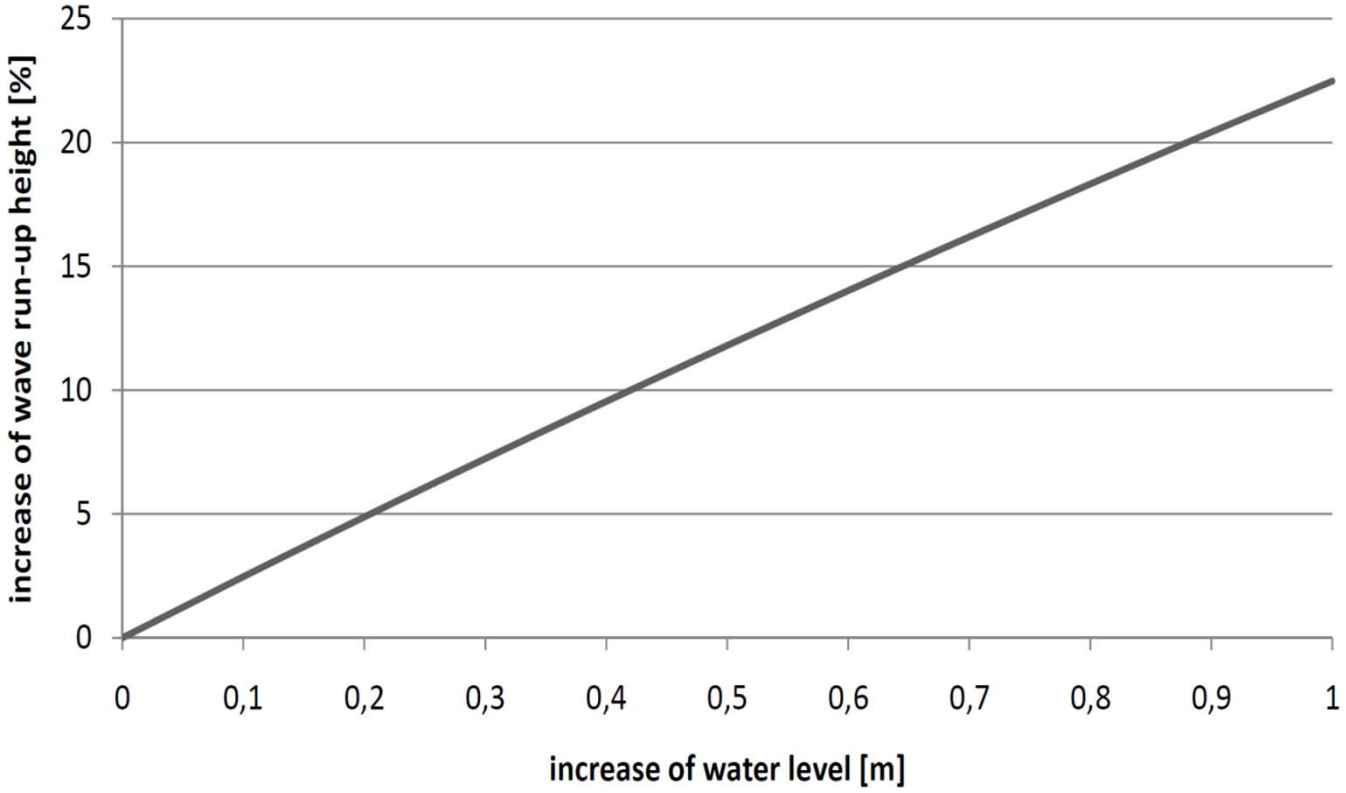


Increase of Wave Heights at a Foot of a Construction (d_0=2.0m) Influence of SLR

(Godas Approach)



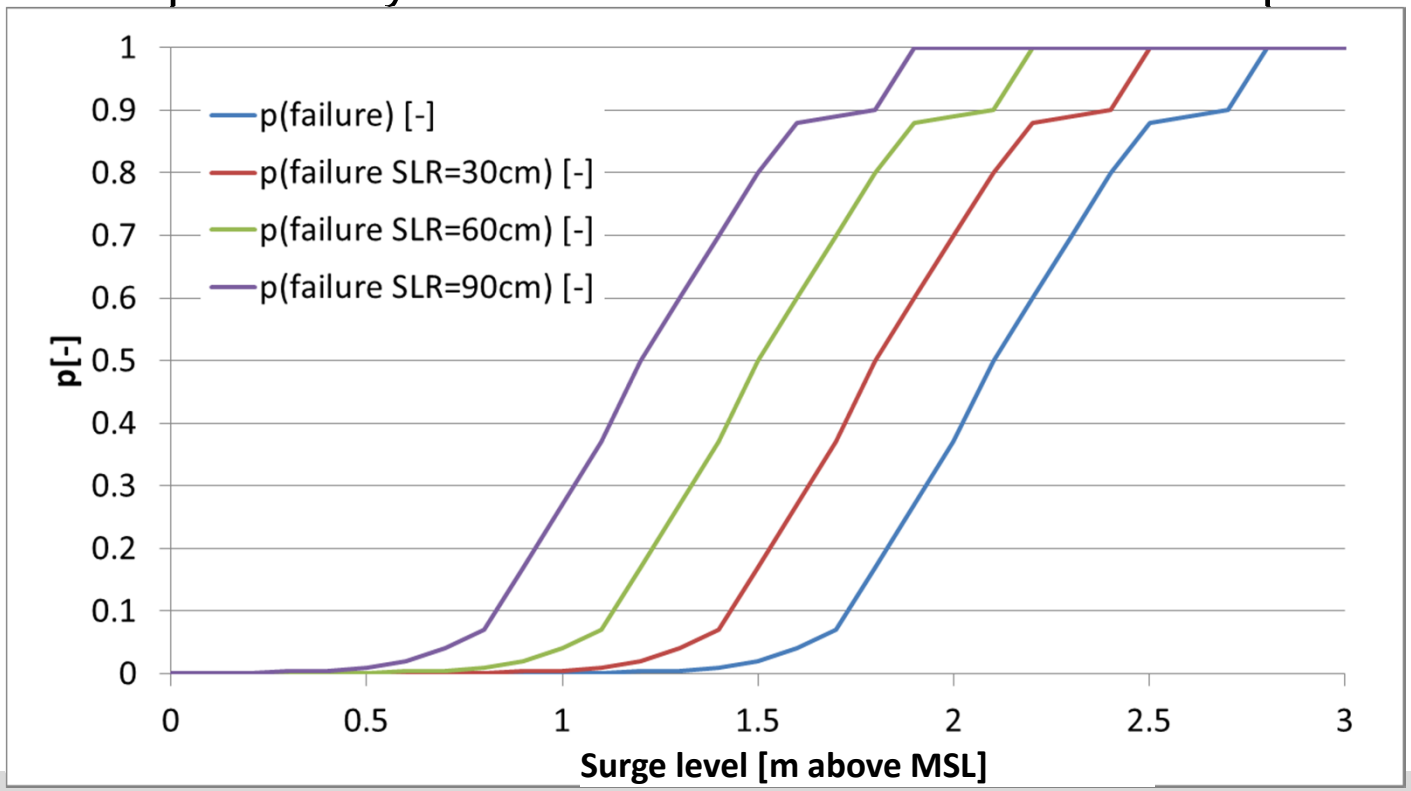
Increase of Wave Run-Up Height at Dykes
Influence of SLR



Climate Change and Risks

Influence of SLR on Fragility Curves (without adaptation of loads)

- Impact – Failure function (fragility curve)
- Failure probability of a construction as a function of impact / load



Climate Change and Risks

Influence of SLR on Fragility Curves (with adaptation of loads)

- Impact – Failure function (fragility curve)
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