Adaptation Pathway Modelling

An Interdisciplinary Endeavor and the Role of Coastal Engineering.

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Agenda

- Introduction and Motivation
- Adaptation Pathways

Theory

- Project: DICES
- Conclusion

Practice

Status Quo

- As of today, the general design guidelines works with the concept of
  - Load or impact (E_d) versus
  - resistance (R_d) and
  - usability (C_d),
- Principle: Resistance must be larger than the impact
  (DIN 1055-100; since 2012 - DIN EN 1990, Eurocode 0 or EC 0):

$$C_d \quad \frac{R_d}{R_k / \gamma_M} > \frac{E_d}{G_k \circ \gamma_F + \Sigma Q_k \circ \gamma_F \circ \psi}$$

Status Quo

$$C_d \quad R_d > E_d$$

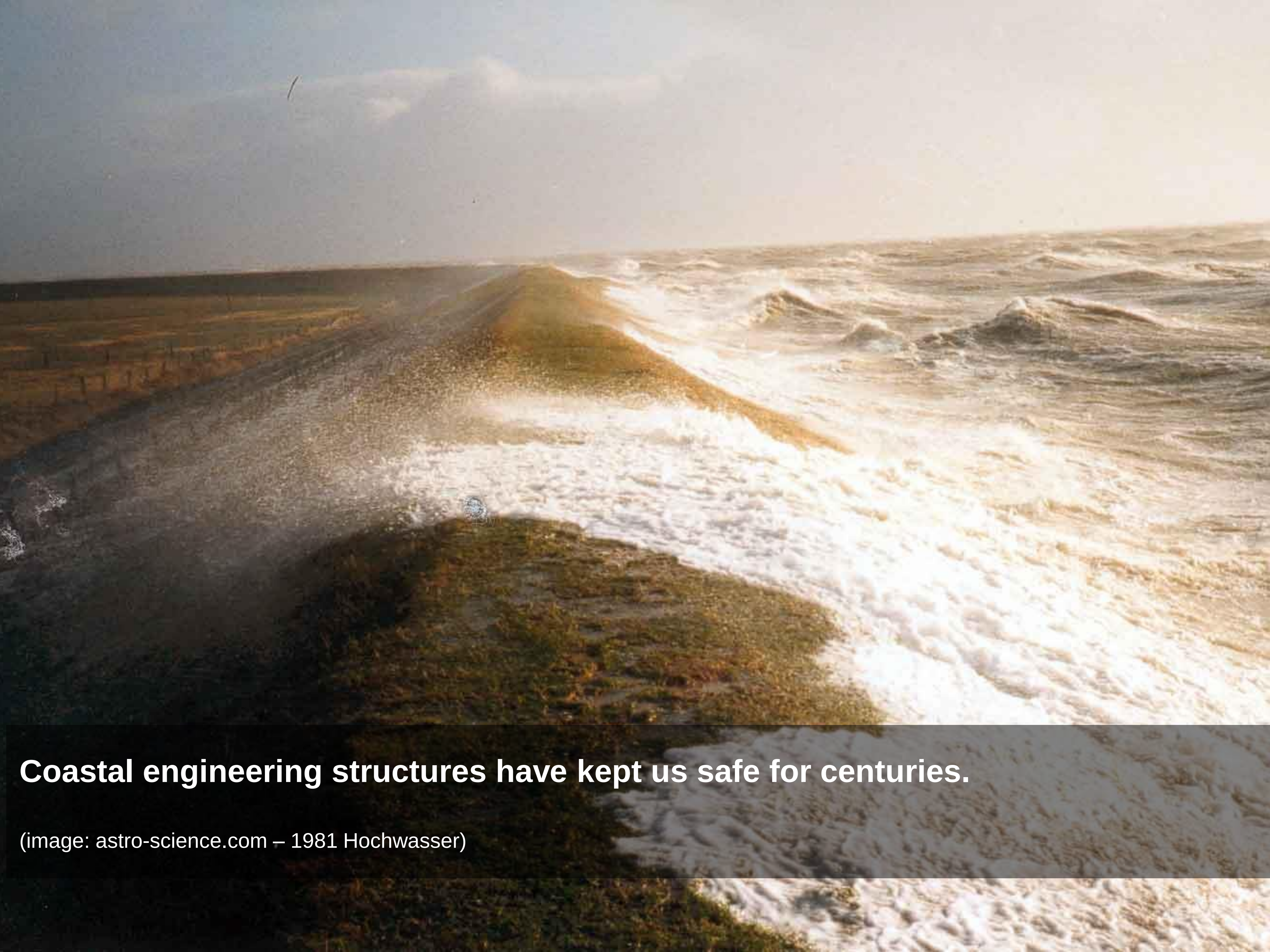
$$R_d = R_k / \gamma_M \qquad E_d = G_k \circ \gamma_F + \Sigma Q_k \circ \gamma_F \circ \psi$$

- Buildings and structures are designed and constructed for a calculated lifetime of several decades (50 / 80 / 100 years).
- Design cases are worst-case-events of a given recurrence (1/10a, 1/100a, etc.).
- This mindset presumes
  - a static behaviour and
  - produces solid and strong buildings and structures,

  that are supposed to resist and withstand these impacts over their lifetime.

Tremendous efforts have been made to invent, design and build coastal engineering structures.

(image: rd.nl - Deltawerke)



Coastal engineering structures have kept us safe for centuries.

(image: astro-science.com – 1981 Hochwasser)

Does *coastal protection* mean *"protect the coastal <u>inhabitants</u>"* or does it imply *the coast as <u>whole</u>*?

(image: serioustravel.com – Male, the Maldives)


Coastal Protection: What is the cost beyond the monetary?
(David 2014, Gili Islands, Indonesia)

Coastal Protection: What is the benefit beyond the monetary?

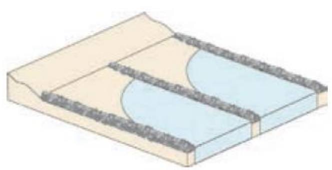
(Source: Cleanmalaysia.com, BioRock Cage)

What are proper means to protect coasts in the face of climate change?

(David, 2017 – Fuvahmulah, the Maldives)

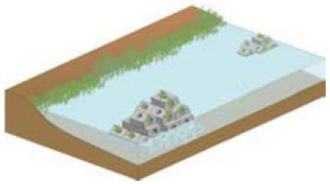
Portfolio of Options (Gray)

Coastal Waters

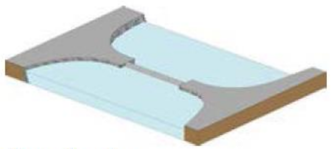


Groins

Breakwaters

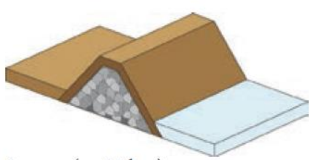


Artificial Reefs

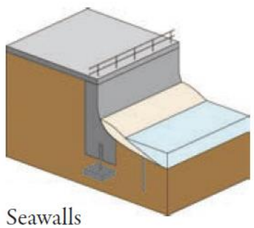


Surge Barriers

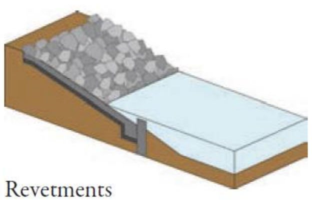
Shoreline



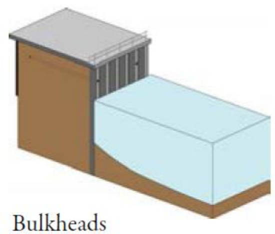
Levees (or Dikes)



Seawalls

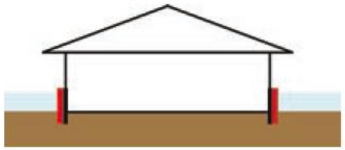


Revetments

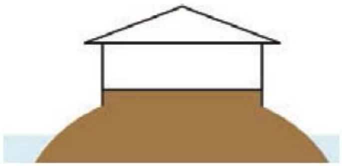


Bulkheads

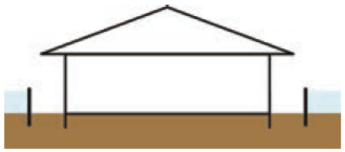
(Infra-) Structural Measures



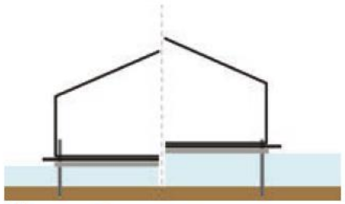
Dry Floodproofing



Elevate on Fill or Mound



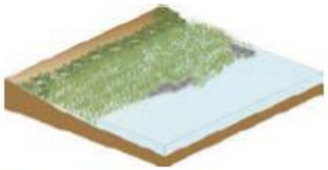
Site Protection



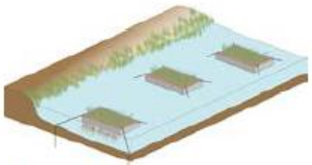
Floating Structures

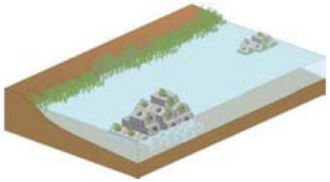
Portfolio of Options (Green)

Coastal Waters


Constructed Wetlands

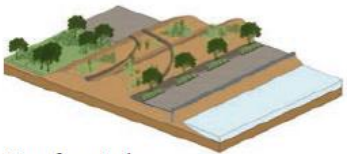

Constructed Breakwater Islands

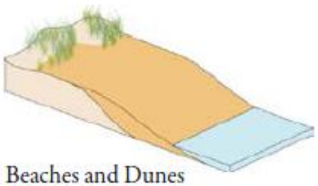

Floating Islands


Artificial Reefs

Shoreline


Living Shorelines

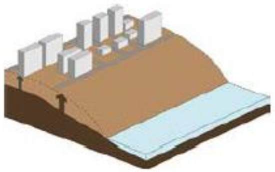

Waterfront Parks


Beaches and Dunes


Multi-purpose Levees

(Infra-) Structural Measures


Strategic Retreat


Elevation of Land and Streets

Status Quo Ecosystem-based Coastal Engineering

Pontee et al. (2016) in NL, UK + USA; David et al. (2016) in Indonesia collect examples of application and implementation of ecosystem-based coastal measures and conclude:

- Existing global trends, to replace or **complement** „hard“ with „soft“ coastal engineering measures, to maintain or support ecosystem services.
- Incentives from international conventions and frameworks (Hyogo Framework of Actions, Sendai, Sustainable Development Goals) and financial support from United Nations Framework Convention on Climate Change, United Nations International Strategy for Disaster Reduction, GAF and World Bank
- Significant potential for wave attenuation $R = 1-(H_i/H_t)$ for NbS of about R = 35-71% (Narayan et al. 2016)

Status Quo Ecosystem-based Coastal Engineering

Deficits, when dealing with Building with Nature:

- No uniform terminology in practice and literature:
  Nature based Solutions (NbS), BwN (Building with Nature), Engineering with Nature (USACE), Eco-DRR, Green Engineering, etc.
- Great uncertainties regarding the design, recommendations, efficiency and durability.
- Guideline gap: False implementation and maintenance is perceived as failure of NbS.
- Measures so far are mostly pilot studies → no direct comparison between „hard“ and „soft“ measures

→ Not enough confidence and trust in NbS

Status Quo

C_d	R_d	$>$	E_d
	R_k / γ_M		$G_k \circ \gamma_F + \Sigma Q_k \circ \gamma_F \circ \psi$

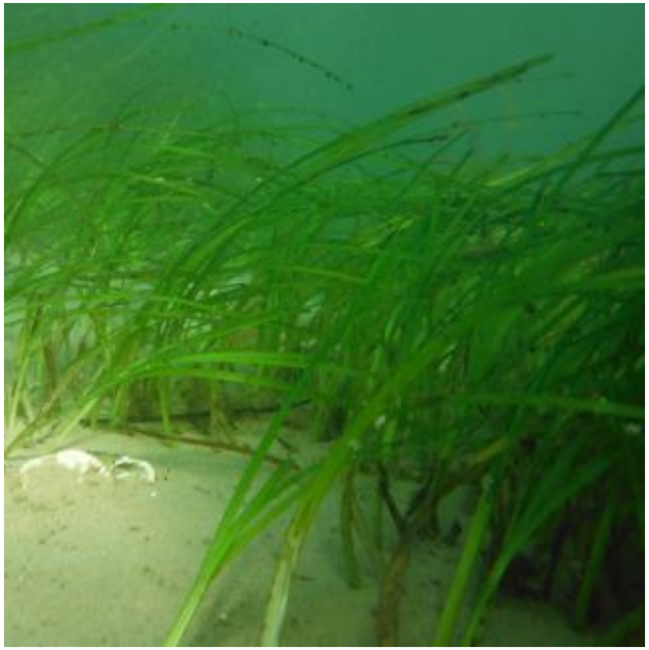
In this sense, the research of **Ludwig-Franzius-Institute** focusses on:

- What is R_D → design guidelines

Status Quo Ecosystem-based Coastal Engineering

- NbS related projects at Ludwig Franzius Institute:

Development of intelligent monitoring techniques and recommendations for green seadikes (EcoDike, WP4)



Artificial, biodegradable seagrass, supporting seagrass reforestation (SeaArt)

Coir fibre geotextile as filter, stabilization and initial shelter for a nature based revetement in Tabanan, Bali, Indonesien (David et al., 2016)

- Questions about appropriateness, social acceptance and implementation (planning) mostly unanswered!

Status Quo

$$C_d \quad R_d > E_d$$

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In this sence, the research of Ludwig-Franzius-Institute focusses on:

- What is R_D → design guidelines
- Appropriateness, social acceptance and implementation?
- What is Resistance and Usability over time ($C_D(t)$, $R_D(t)$)?

- Which mindset is required to put NbS into engineering practice?

→ Adaptation Pathways

(see in: Haasnoot et al. 2013, Kwakkel et al. 2013 and 2016, Ranger et al. 2013)

Status Quo

$C_d(t)$ | $R_d(t)$ > E_d

R_k / γ_M | $G_k \circ \gamma_F + \Sigma Q_k \circ \gamma_F \circ \psi$

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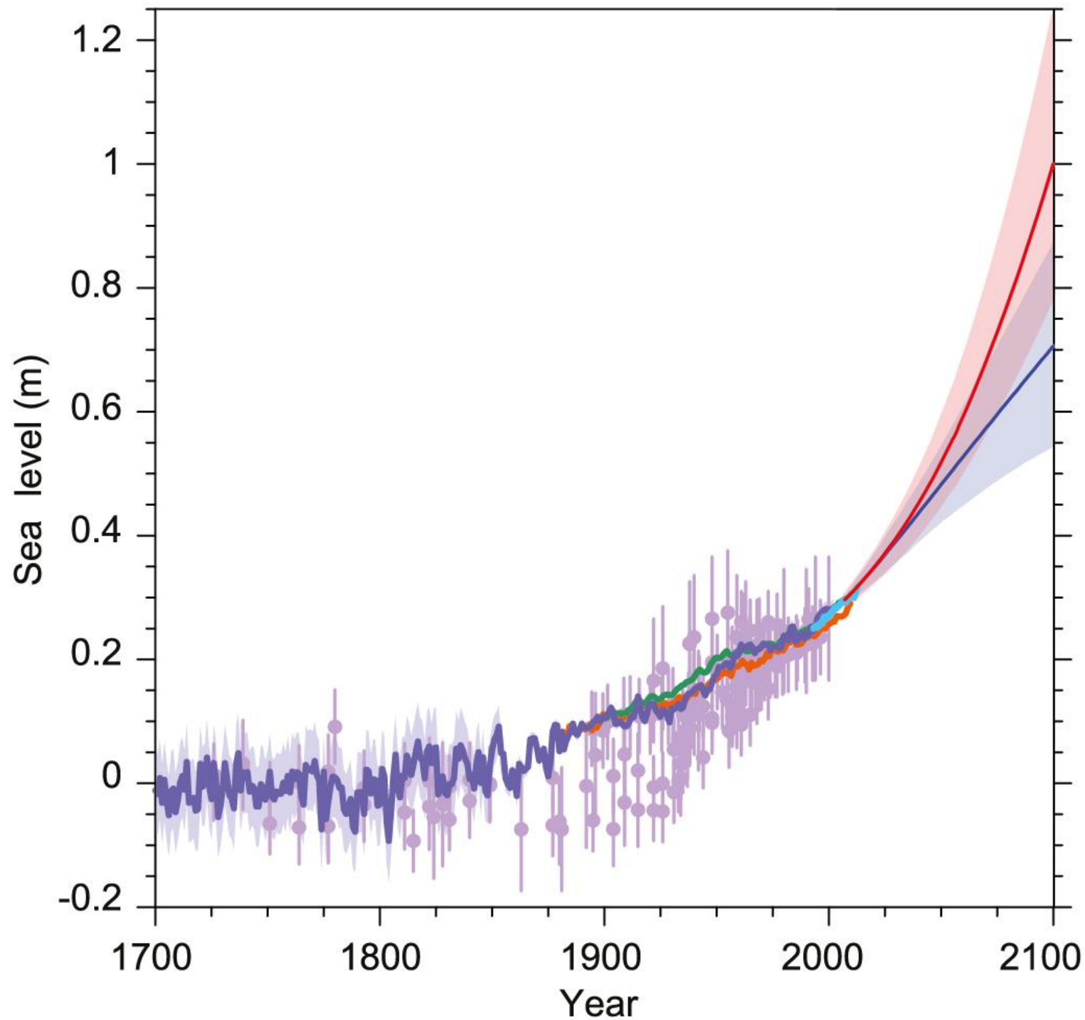

IPCC (2013)

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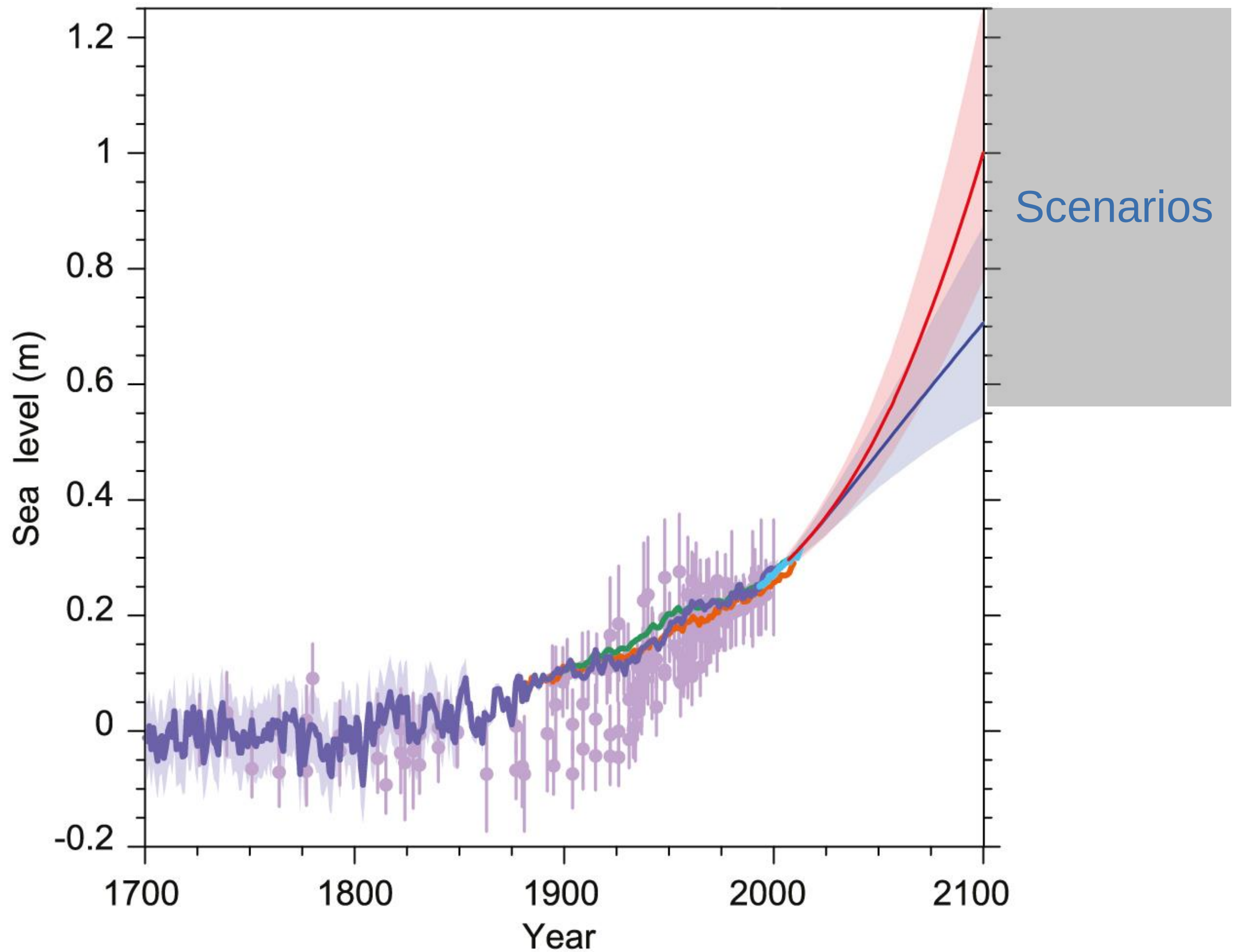

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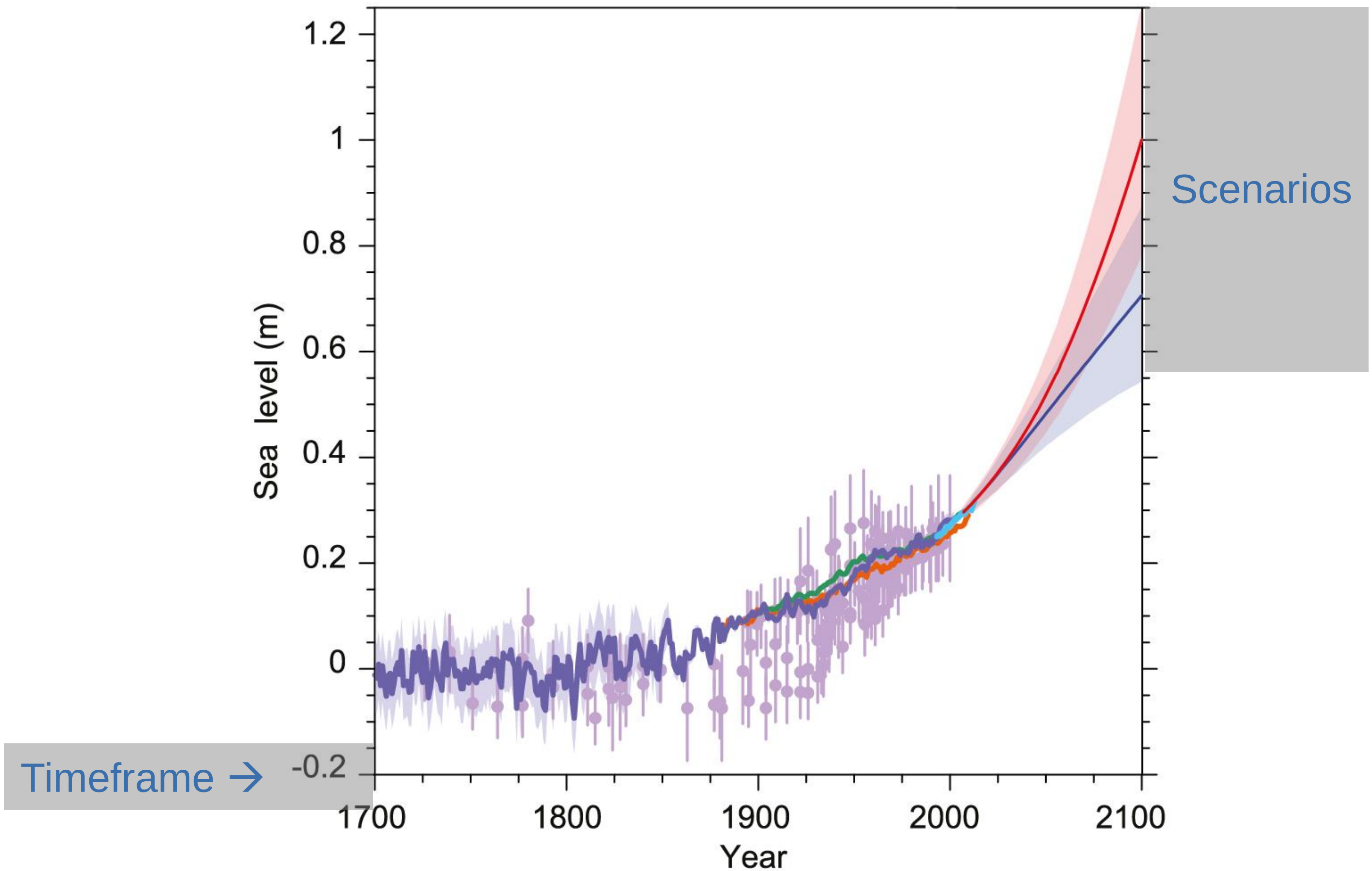

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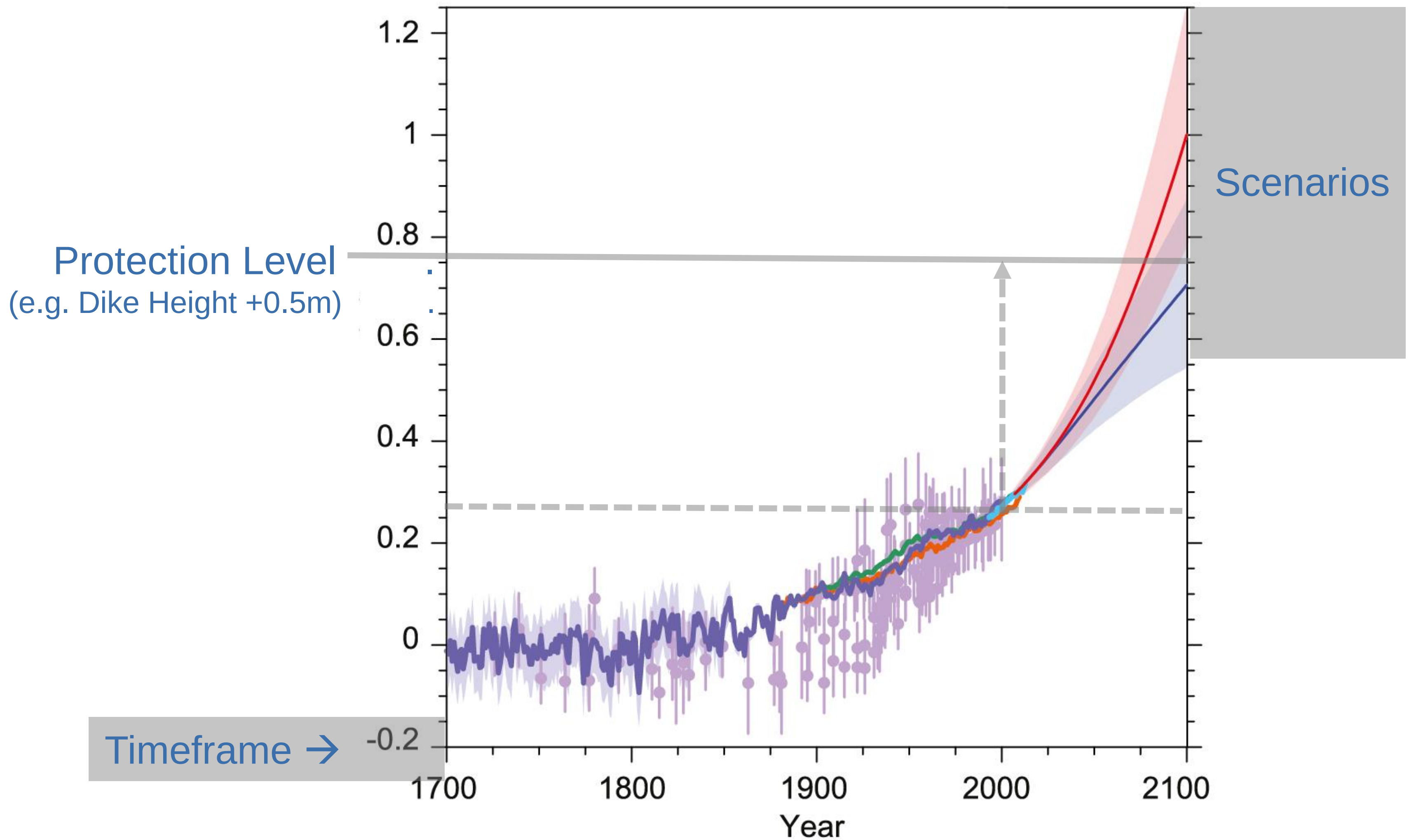

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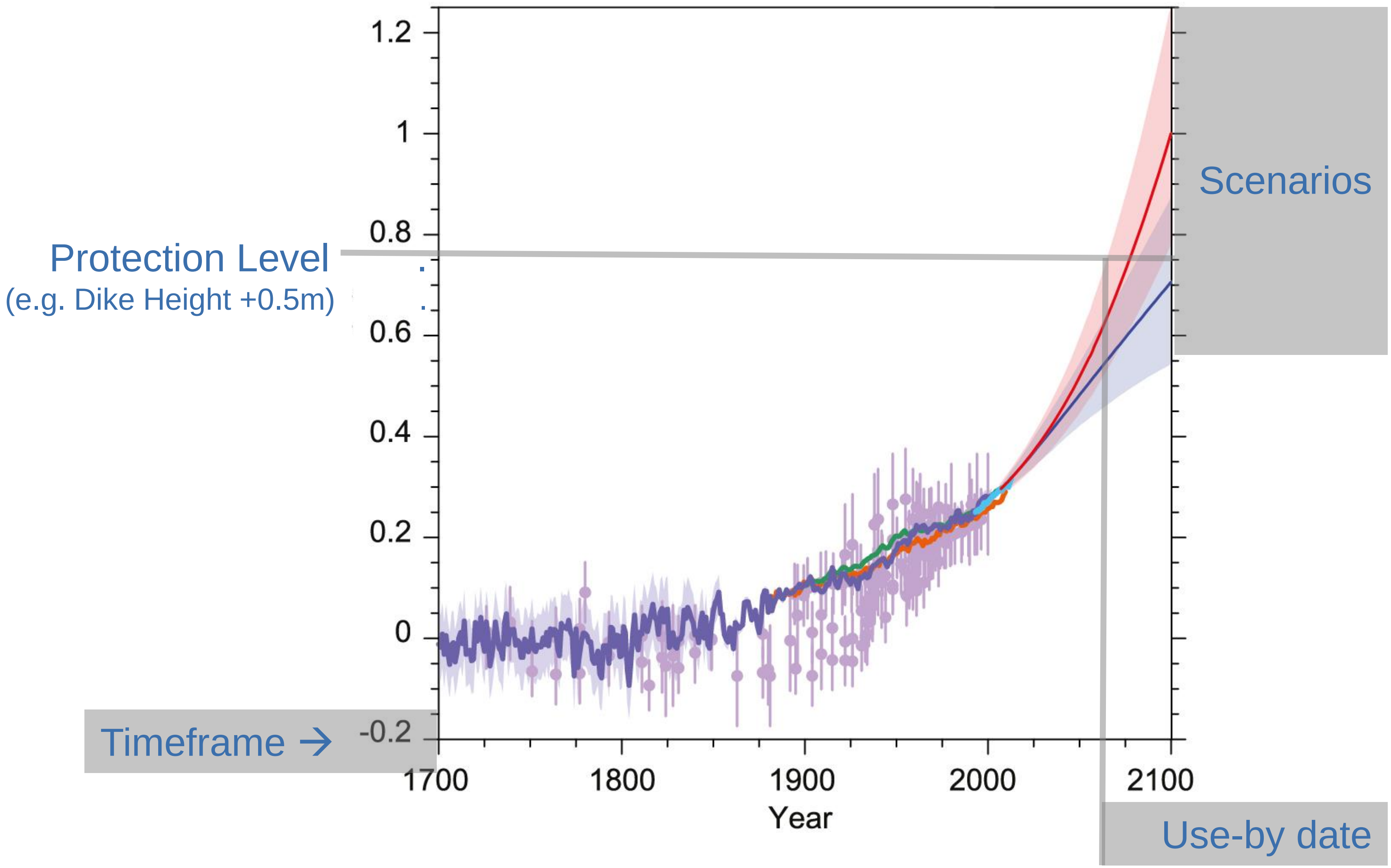

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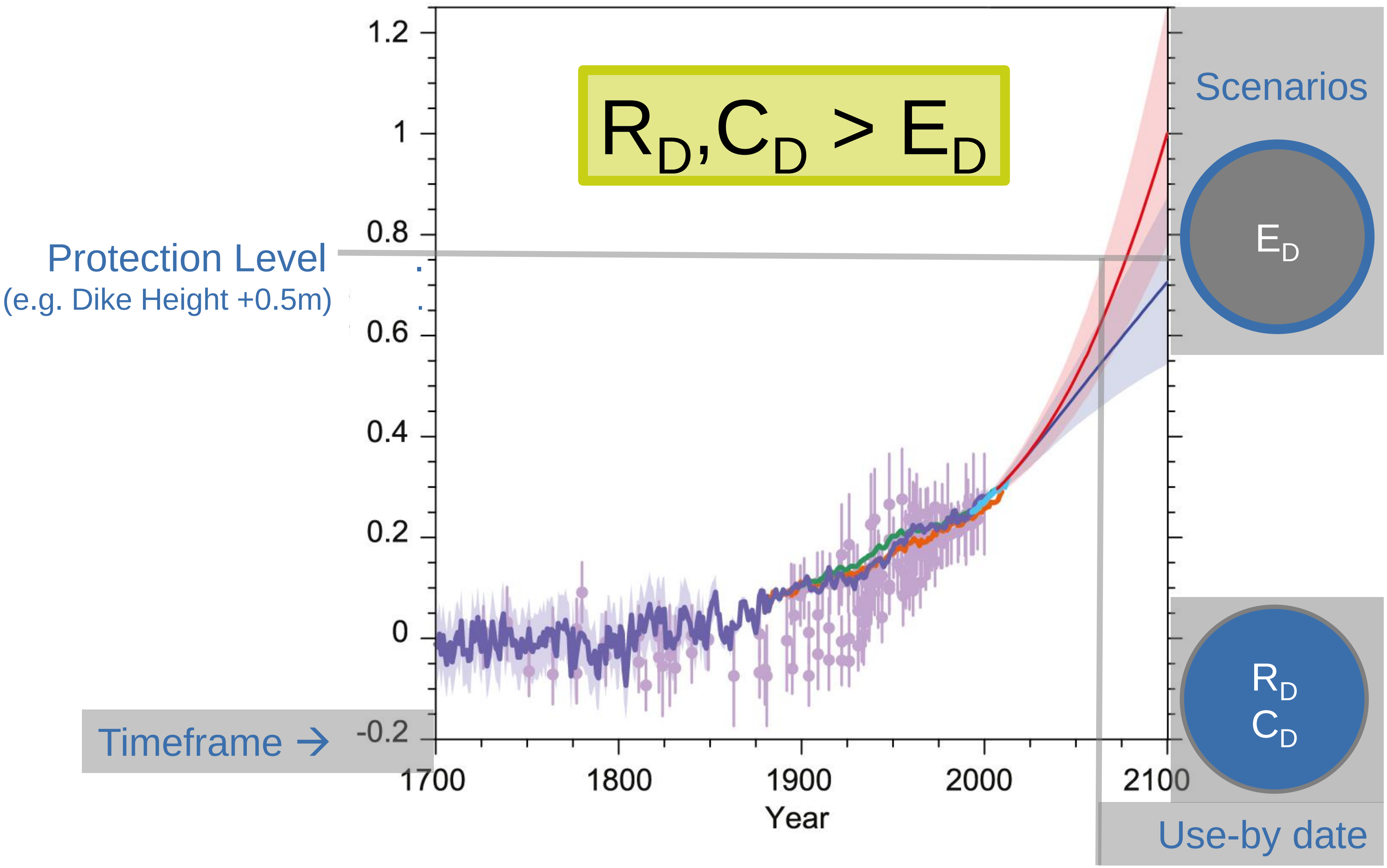

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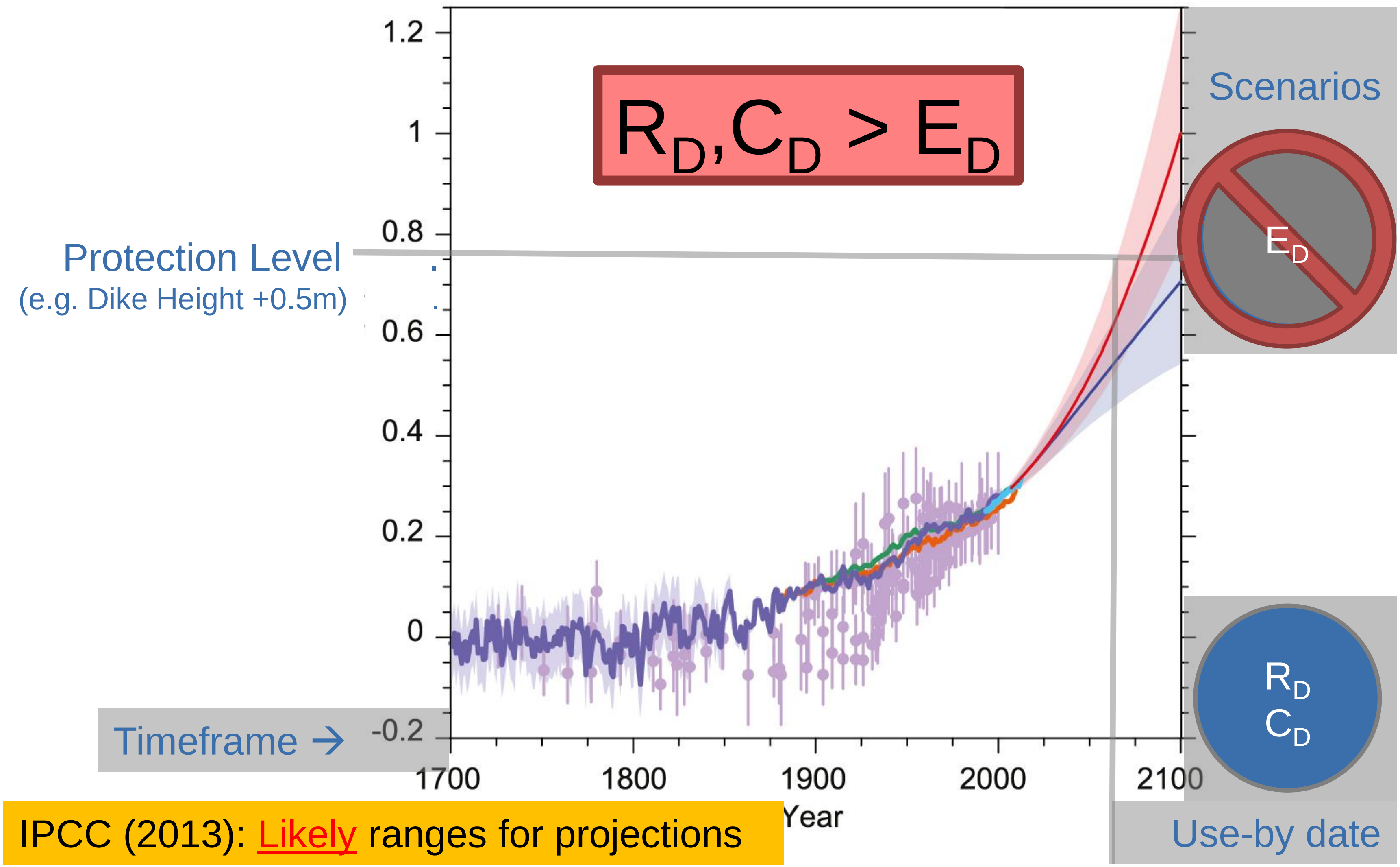


IPCC (2013): Likely ranges for projections

Planning for an Uncertain, Distant Future

Nerem et al. February 12, 2018:

… we estimate the […] global mean sea level could rise 65 ±12 cm by 2100 compared with 2005, [which is] roughly in agreement with the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) model projections. (Nerem et al., 2018)

"This is almost certainly a conservative estimate," Nerem said. *"Our extrapolation assumes that sea level continues to change in the future as it has over the last 25 years. Given the large changes we are seeing in the ice sheets today, that's not likely."*

https://climate.nasa.gov/news/2680/new-study-finds-sea-level-rise-accelerating/

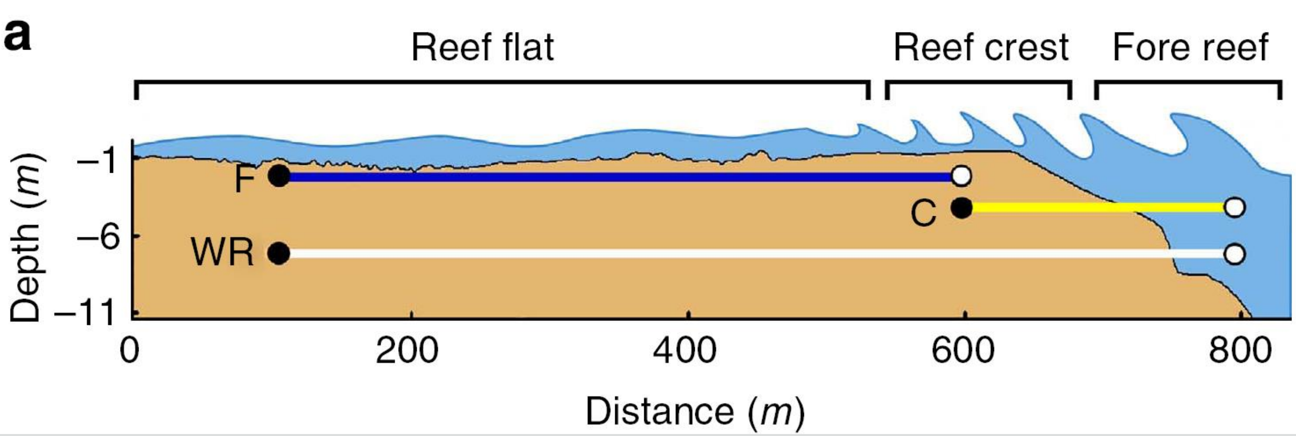
Planning for an Uncertain, Distant Future

Arns et al. **(2017, focus on shallow shelf areas of the German Wadden Sea)**
"Under [climate change induced sea-level rise]*, fewer waves are affected by* [depth induced] *wave breaking facilitating access to the coast"*

Chariton et al. **(2016, focus on reef-island Roi-Namur)**

"… very low-frequency waves (sub-infragravity: 0.004–0.001 Hz) *were the major contributors to run-up at the shoreline."*

Reef / Foreshore dynamics? Ressonances?



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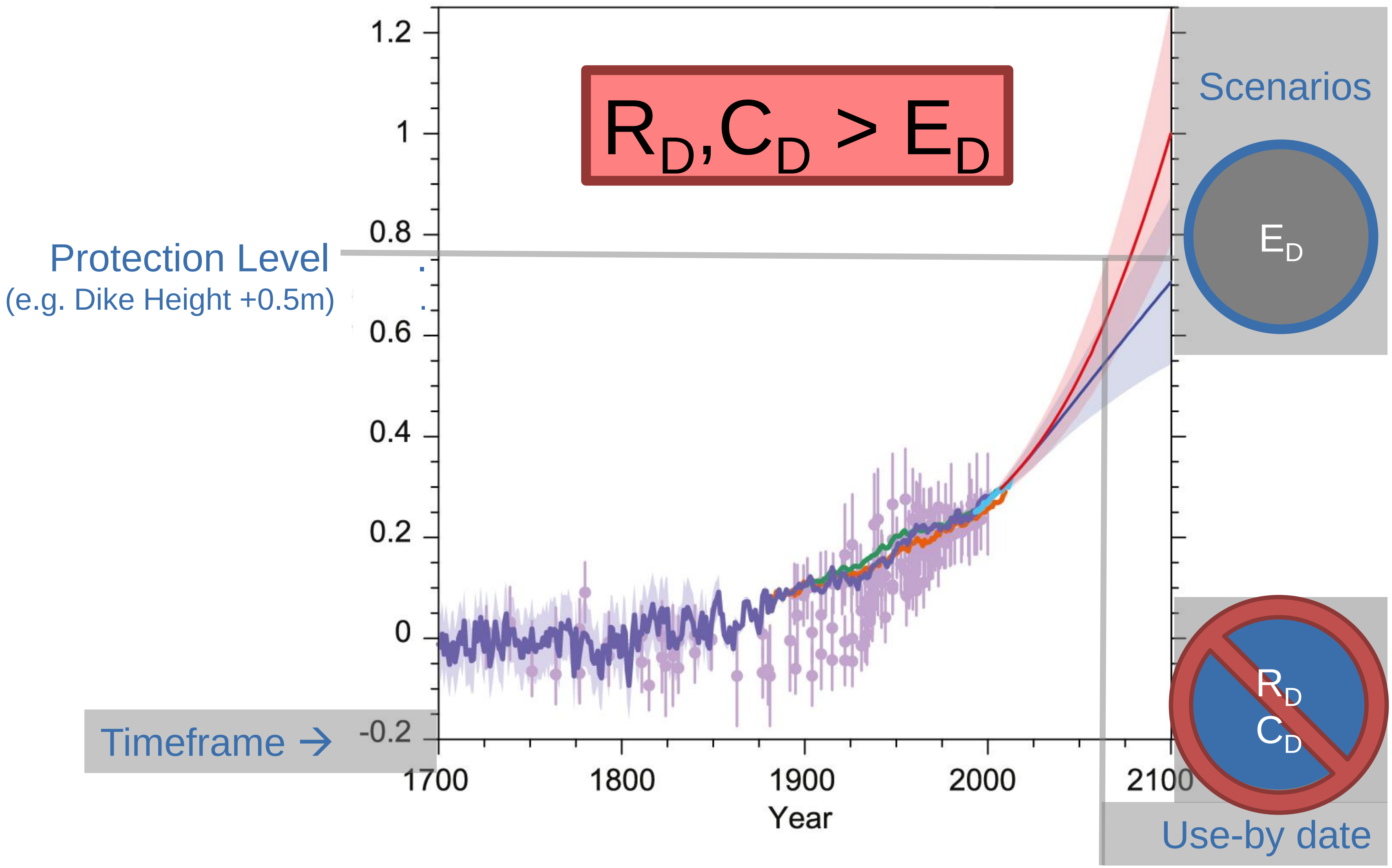


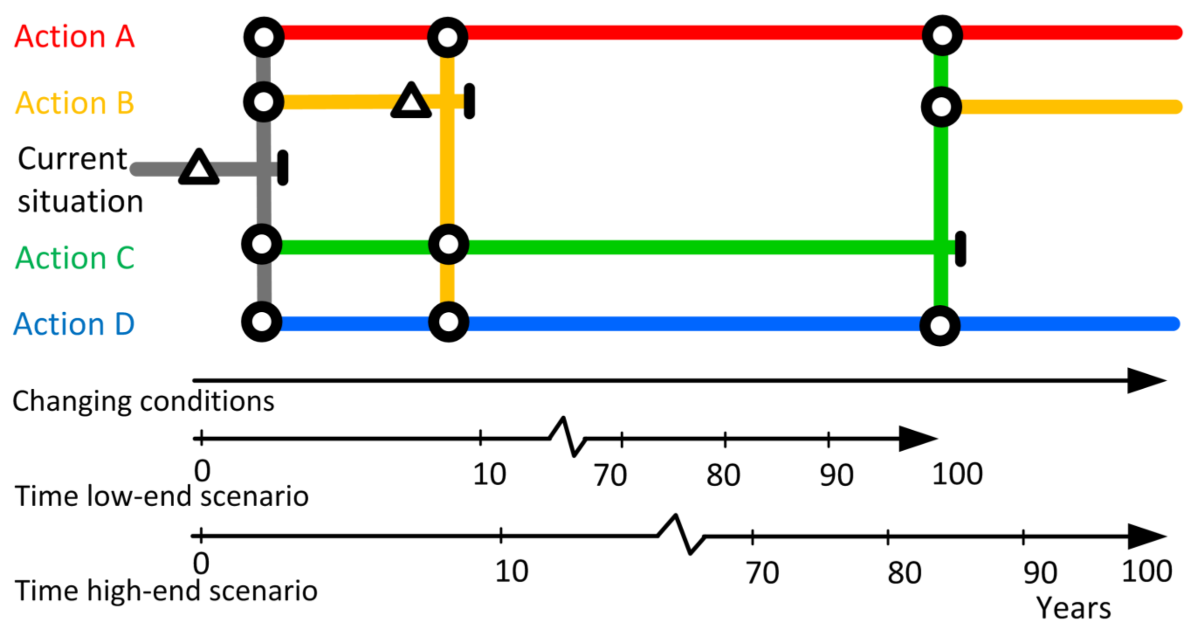
Planning for an Uncertain, Distant Future

Static approach:
(e.g. DIN EN 1990)

$$\cancel{R_D, C_D > E_D}$$

Adaptation Pathways Map

Dynamic Adaptation Pathway Modelling (Haasnot et al. 2013)



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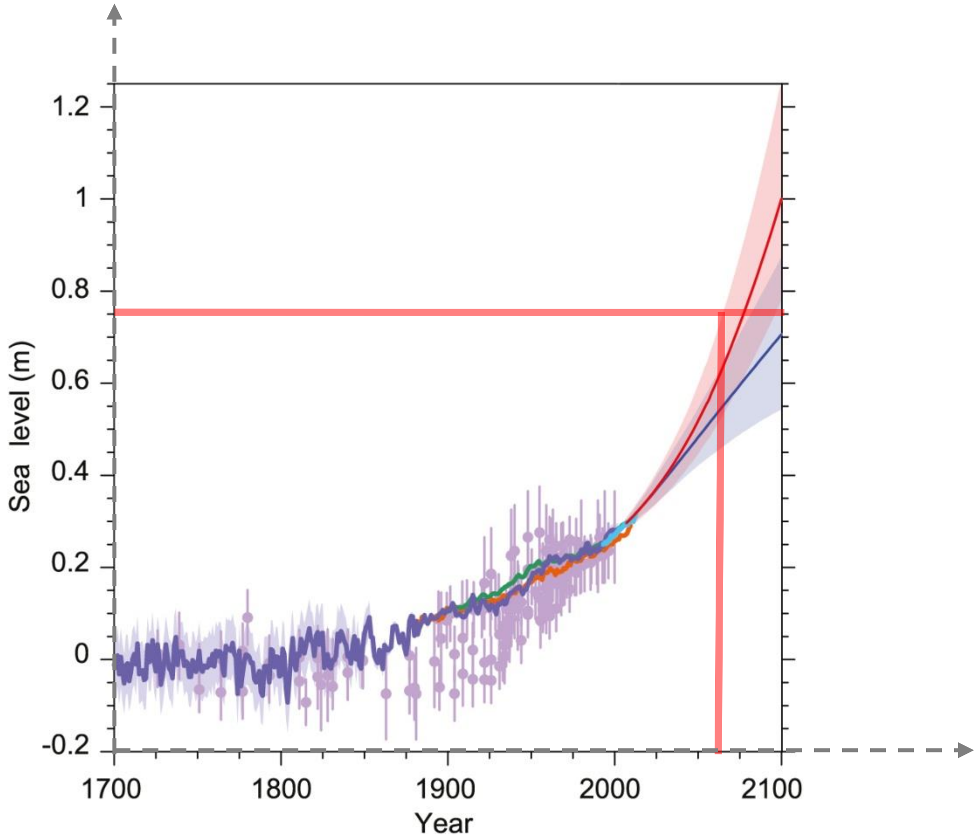

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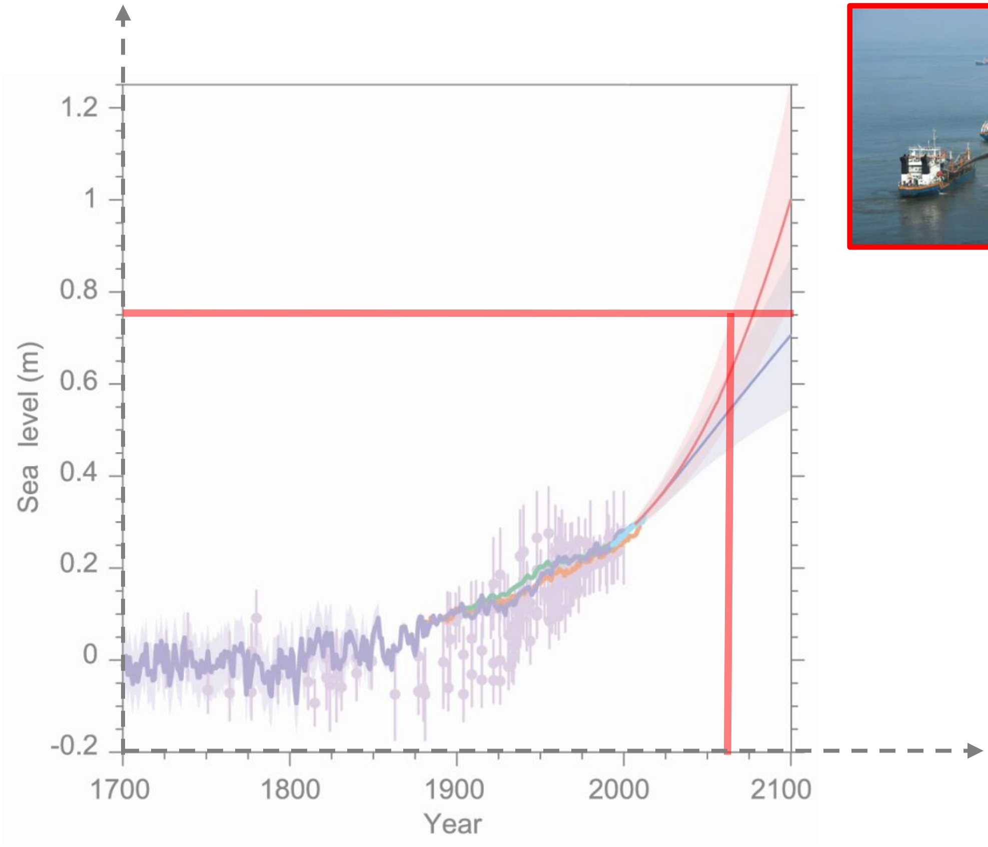
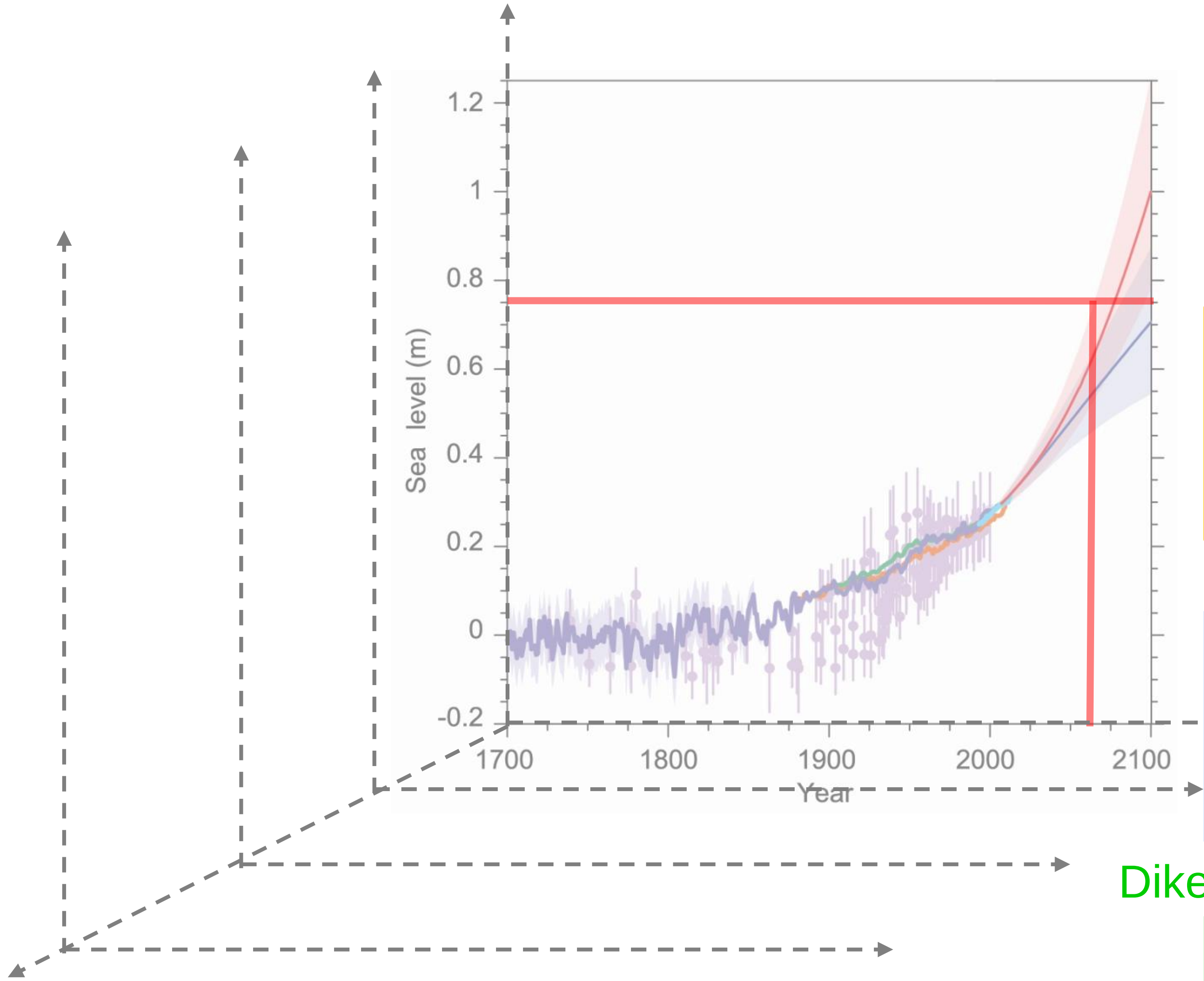


Nourishment

Planning for an Uncertain, Distant Future

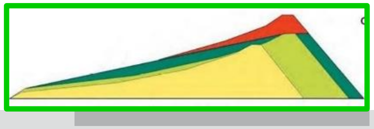


Nourishment

Seagrass

Dike (+0.8m)

Dike (+0.5m) + Buffer



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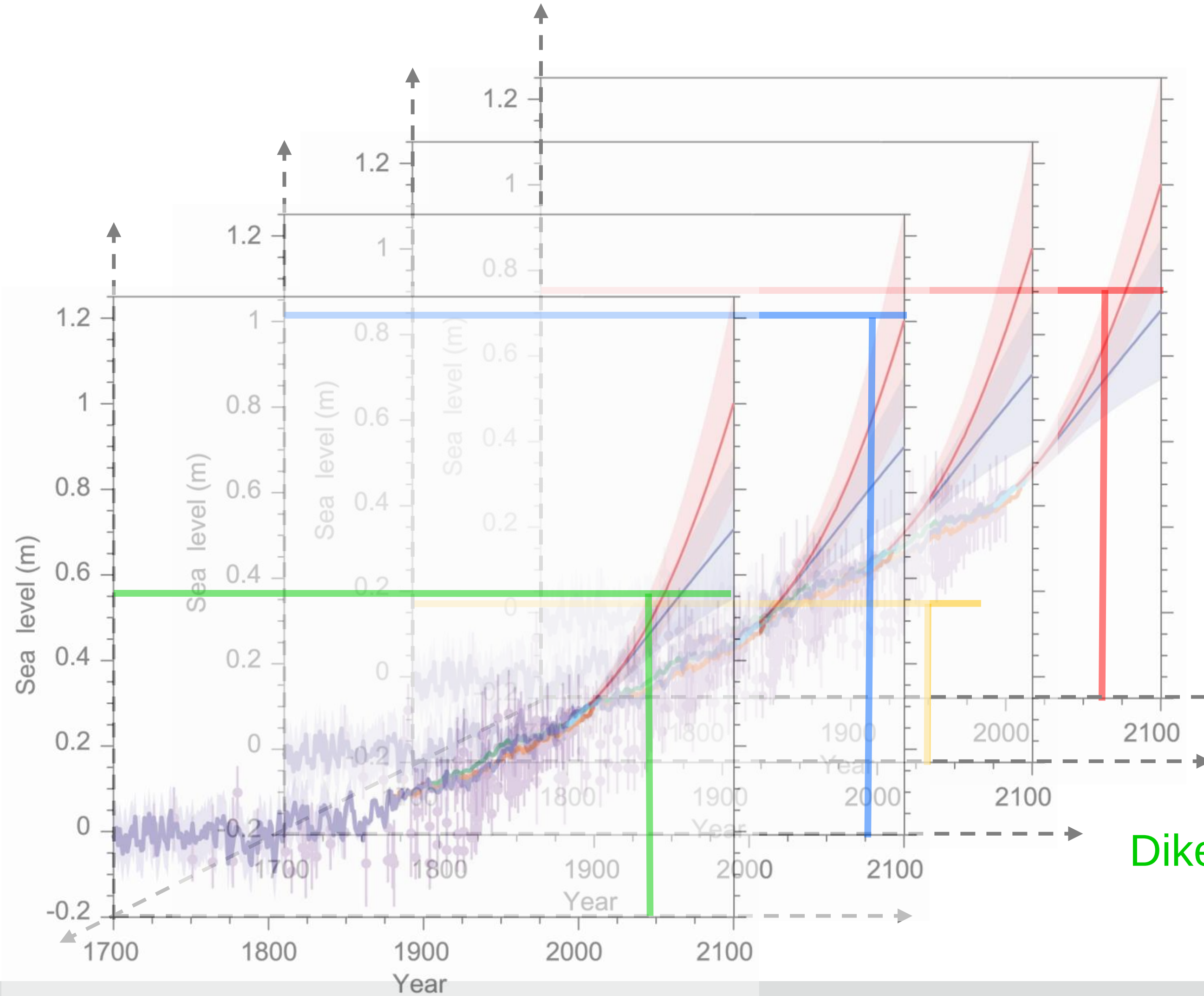

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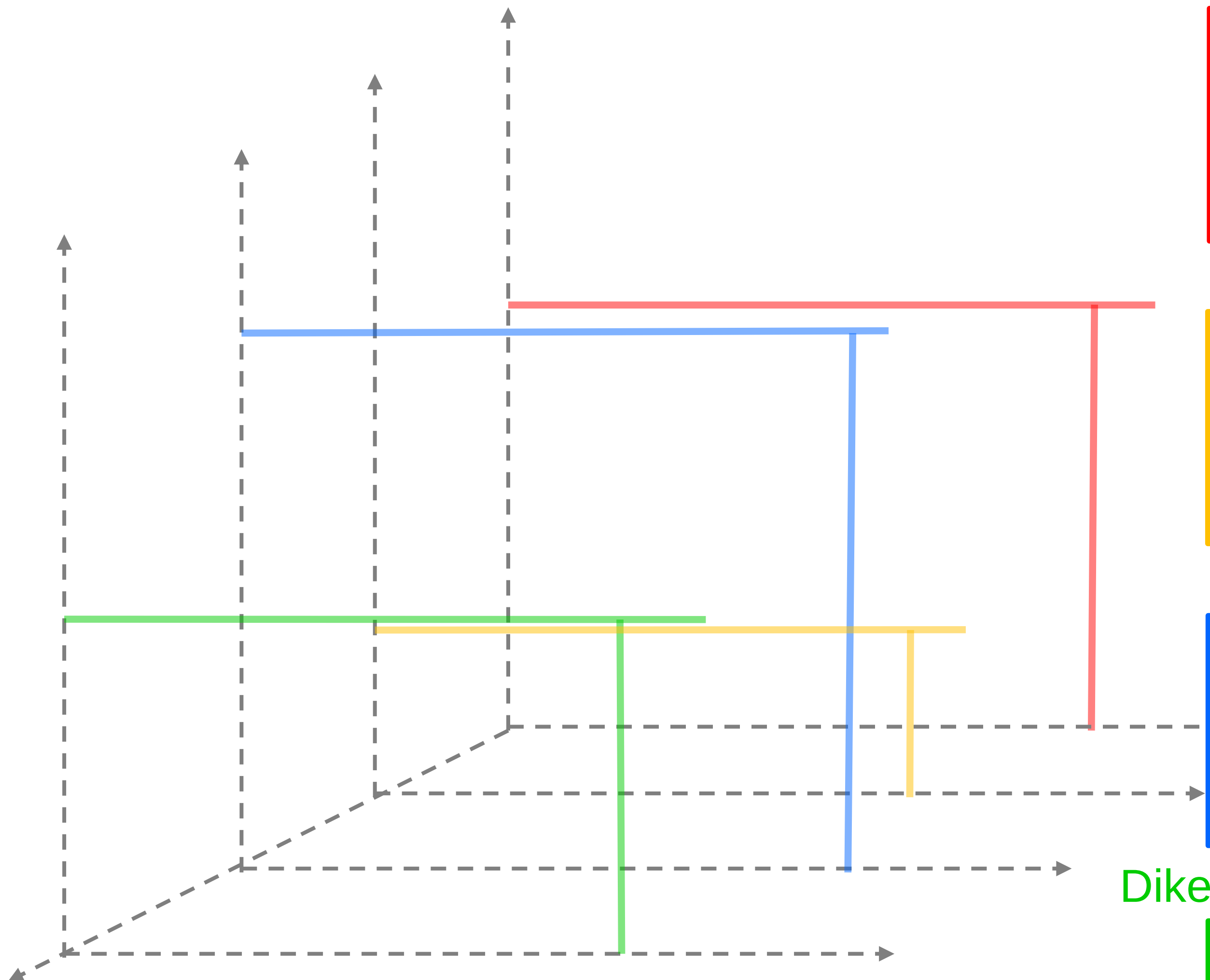

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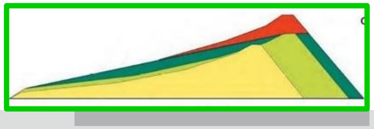

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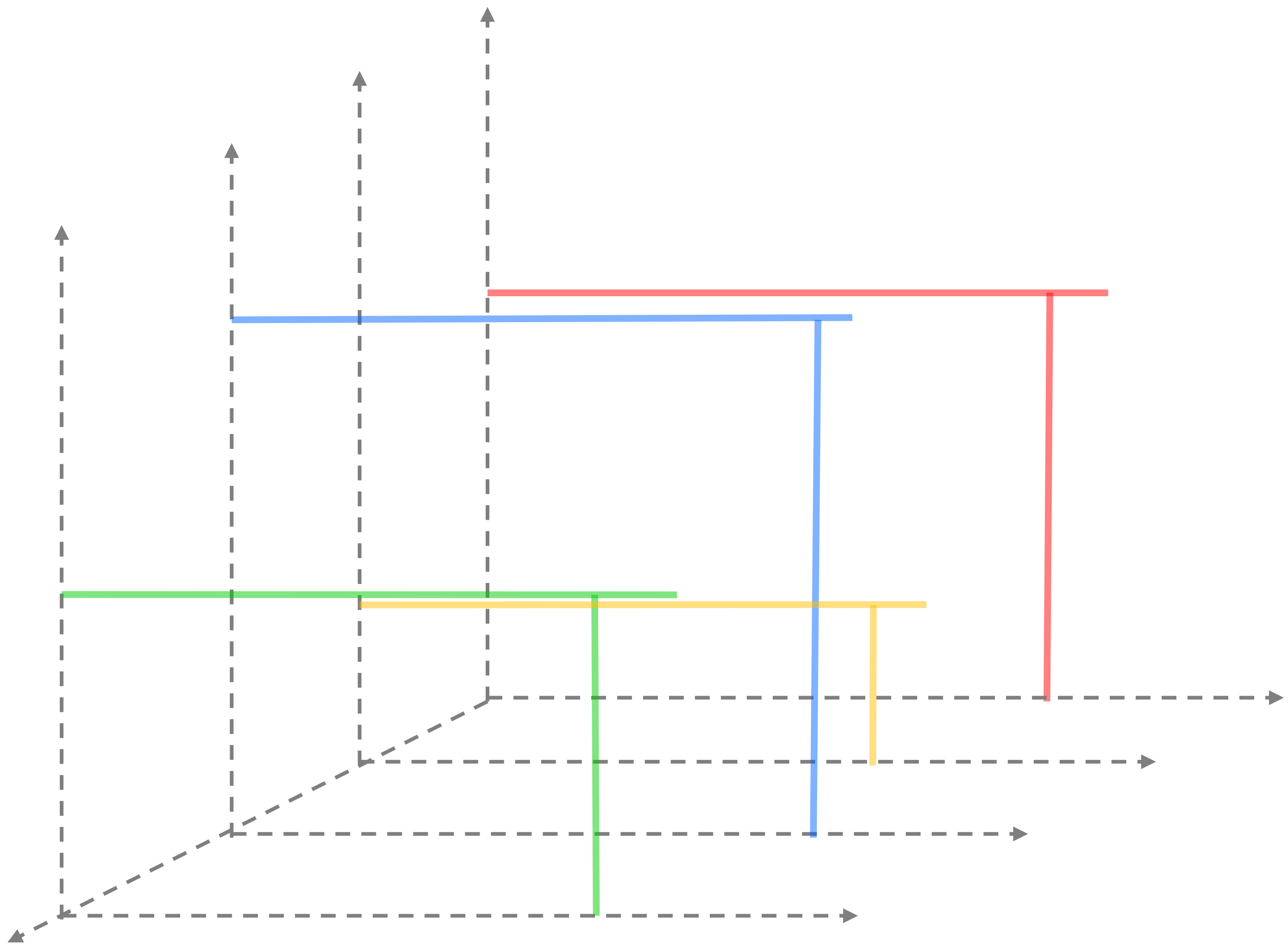

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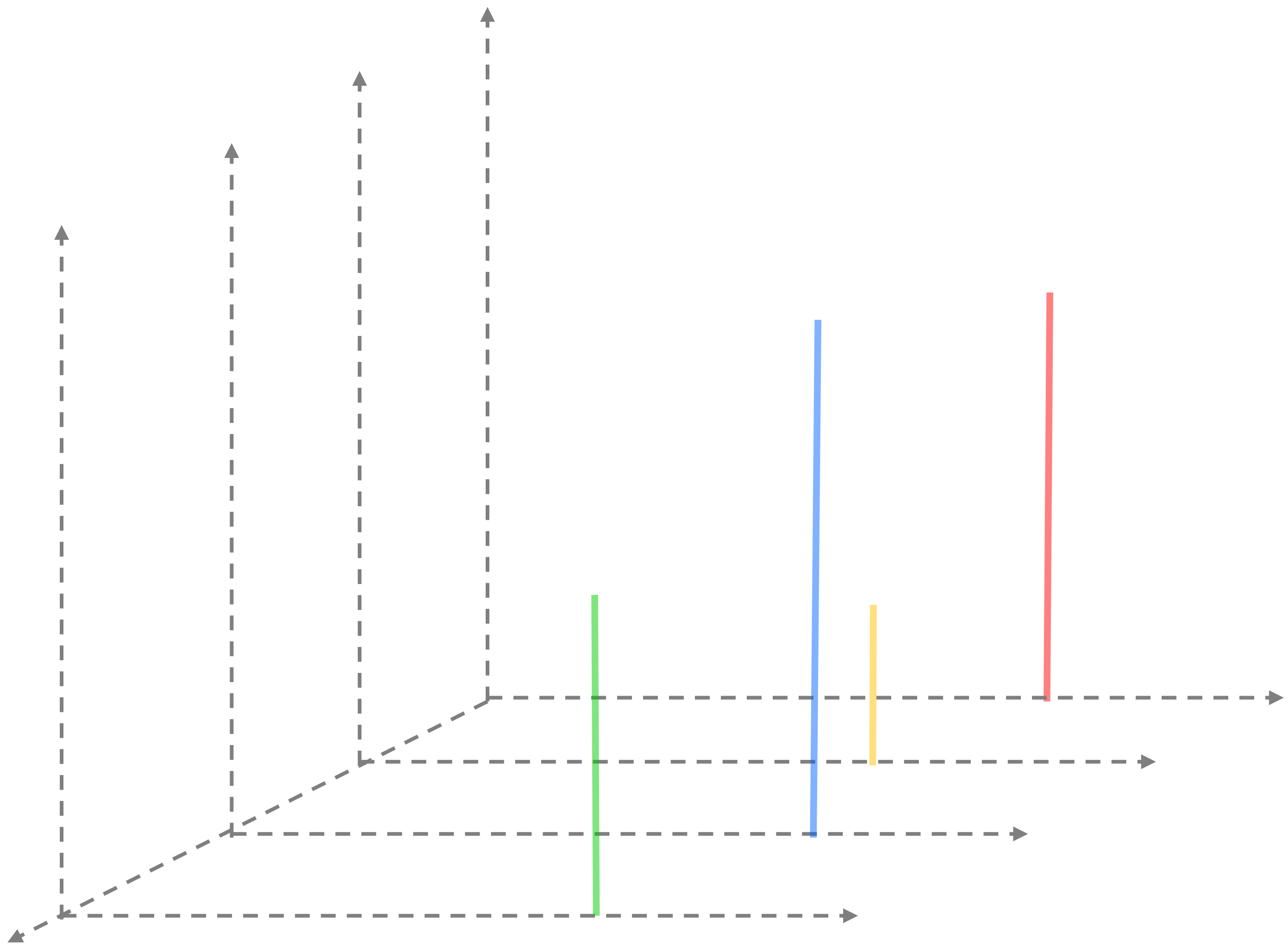

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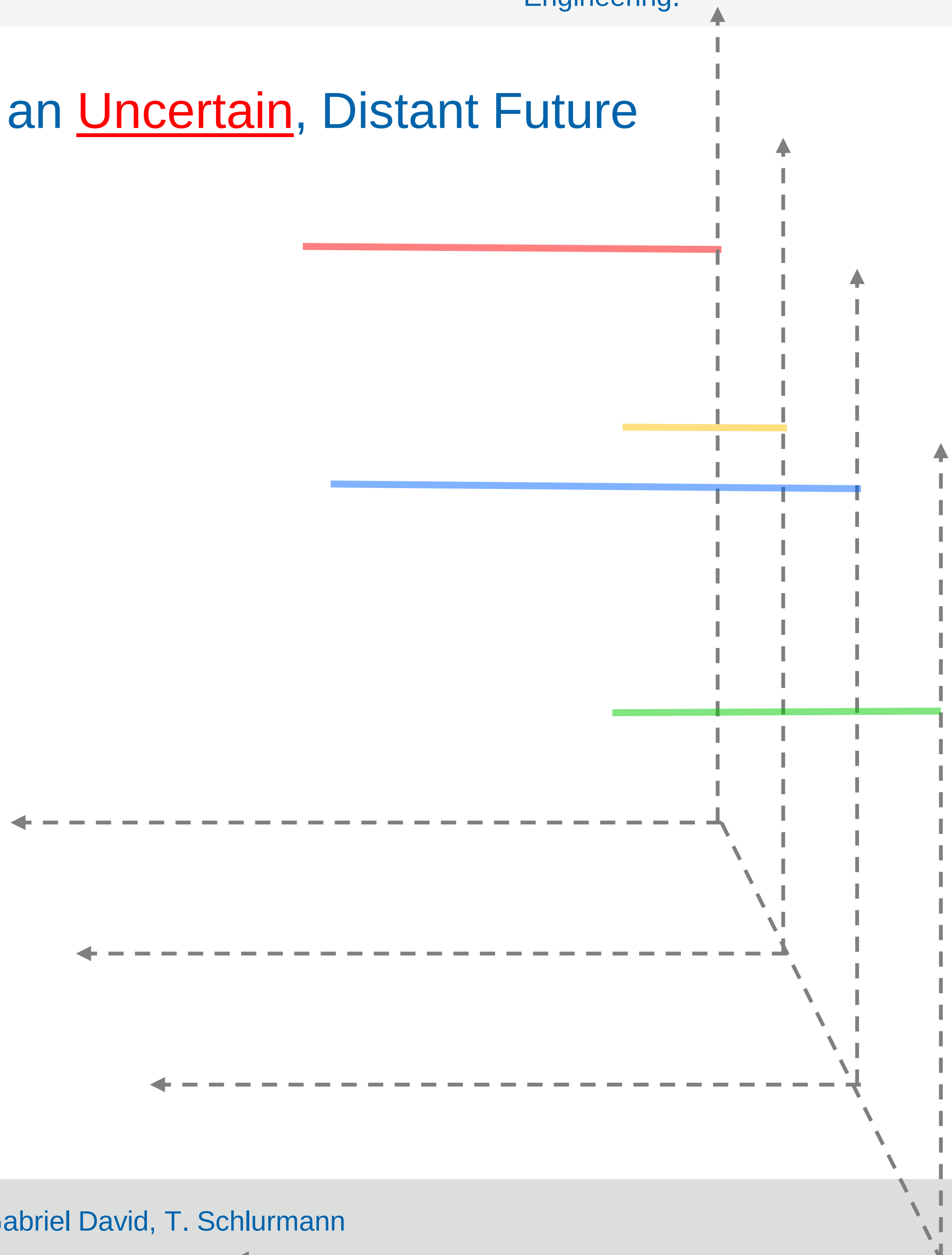
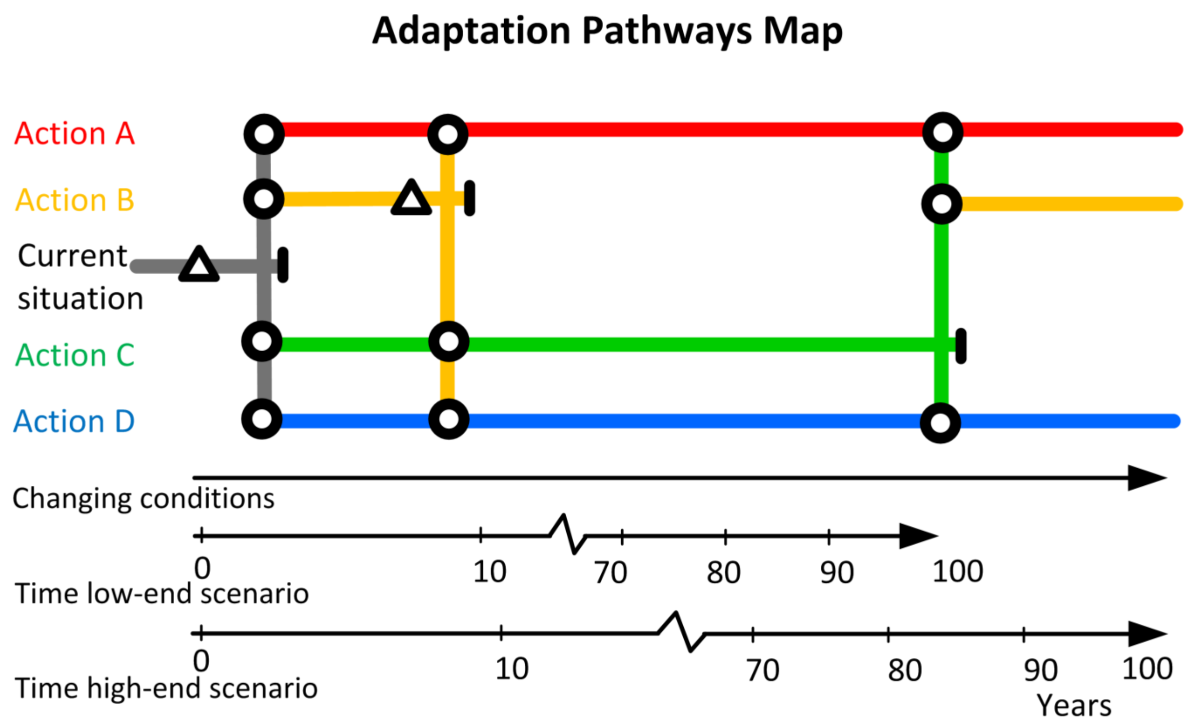


Planning for an Uncertain, Distant Future

Planning for an Uncertain, Distant Future

Planning for an Uncertain, Distant Future:
Dynamic Adaptation Pathway Modelling (Haasnot et al. 2013)

Nourishment →
Seagrass →
Dike (+0.5m) + Buffer →
Dike (+0.8m) →



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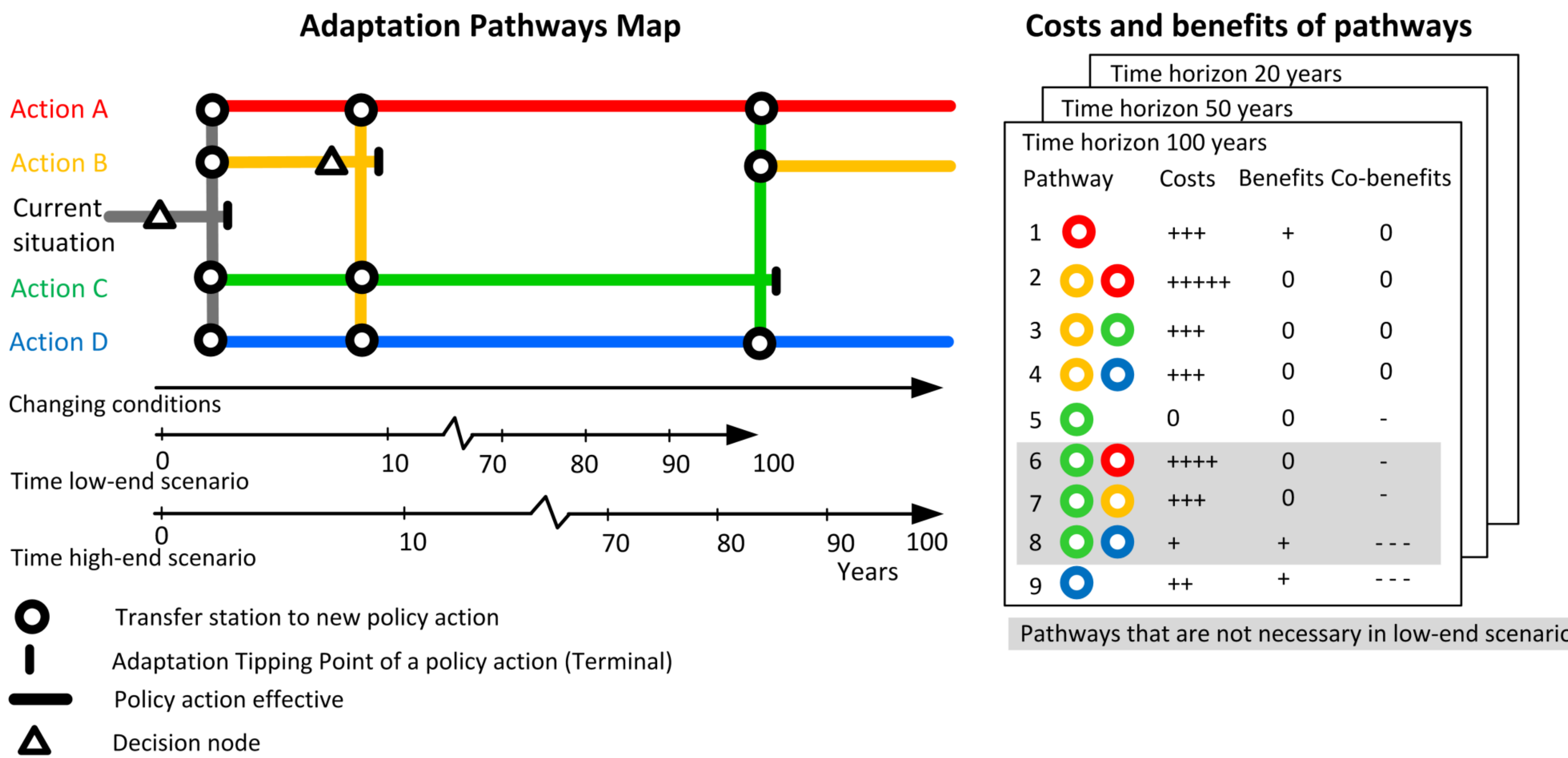

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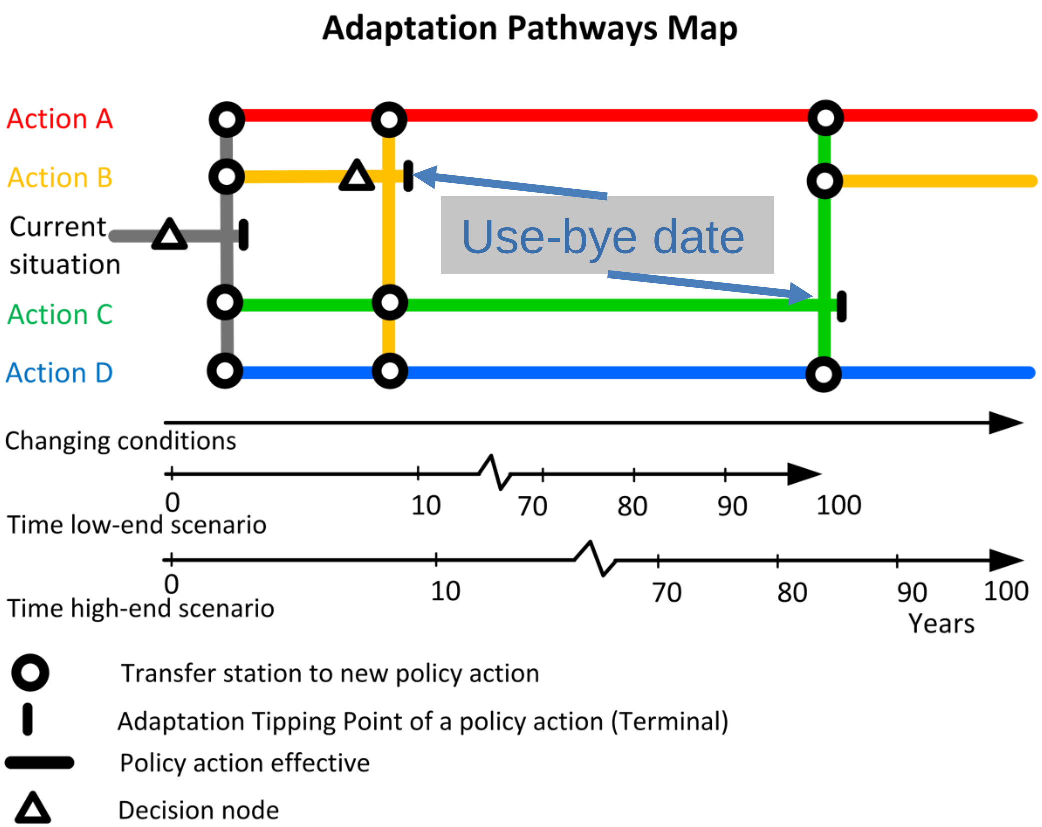

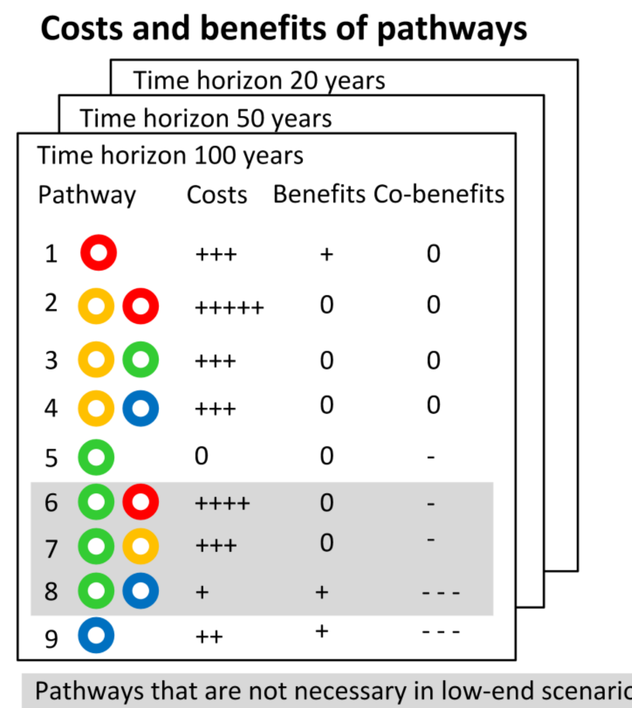

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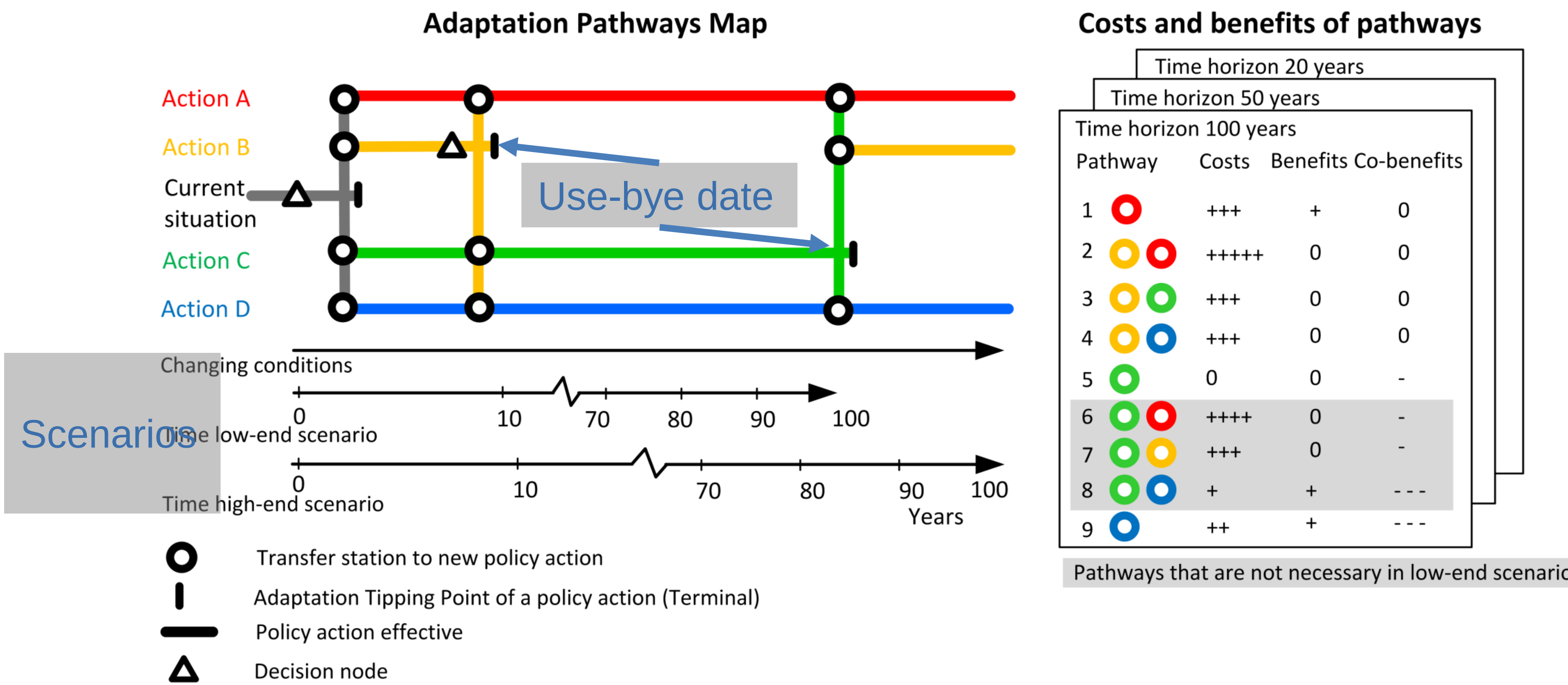

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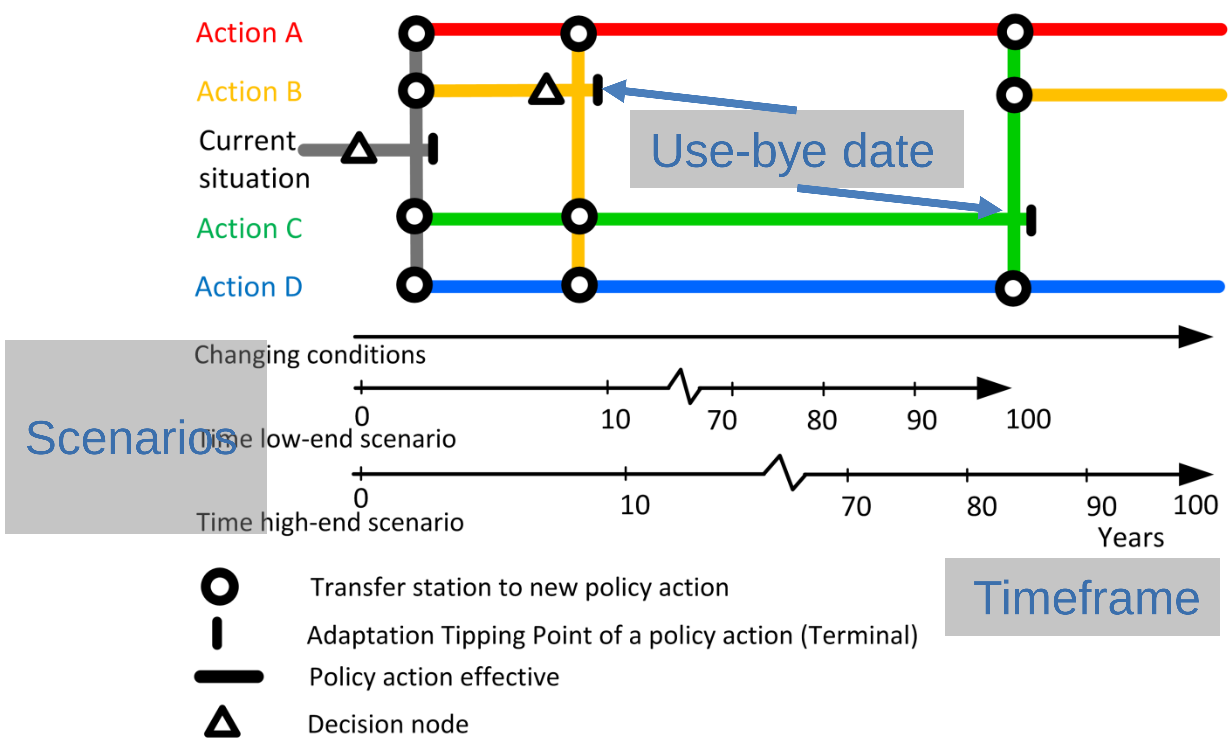
Adaptation Pathways Map



Costs and benefits of pathways

Time horizon 20 years

Time horizon 50 years

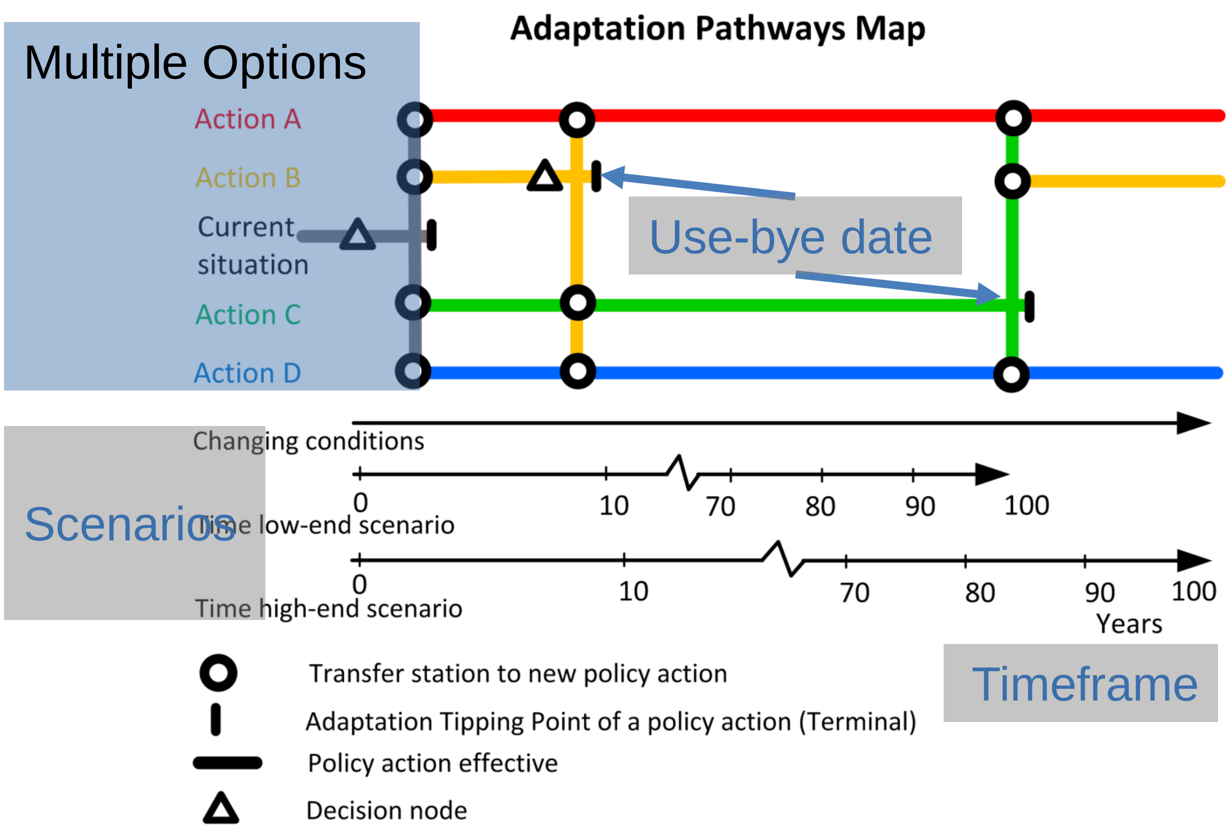
Time horizon 100 years

Pathway	Costs	Benefits	Co-benefits
1	+++	+	0
2	+++++	0	0
3	+++	0	0
4	+++	0	0
5	0	0	-
6	++++	0	-
7	+++	0	-
8	+	+	- - -
9	++	+	- - -

Pathways that are not necessary in low-end scenario

A: Nourishment B: Seagrass C: Dike (0.5m) + Buffer D: Dike (0.8m).

Dynamic Adaptation Pathway Model (Haasnot et al. 2013)



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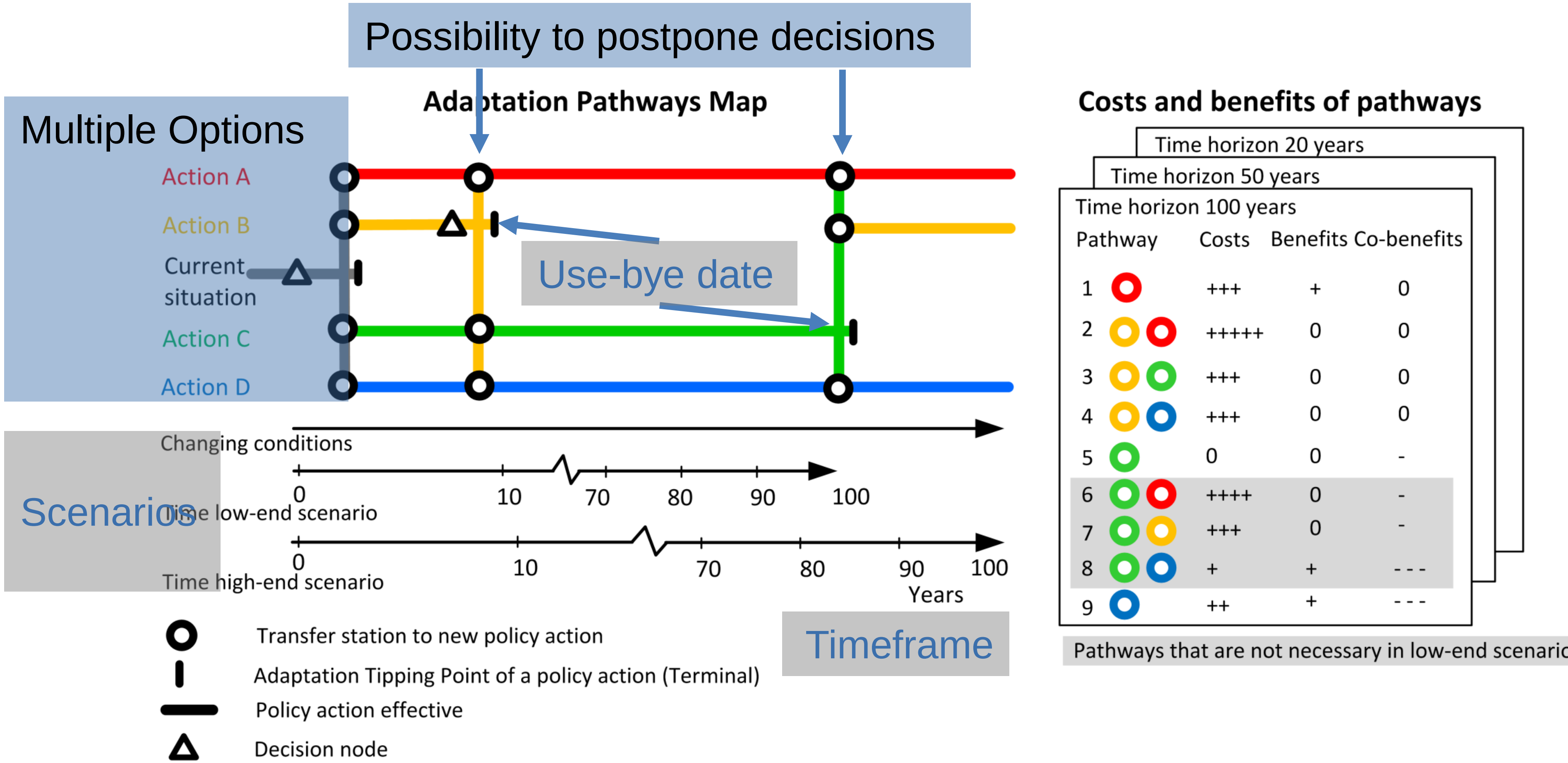
Dynamic Adaptation Pathway Model (Haasnot et al. 2013)



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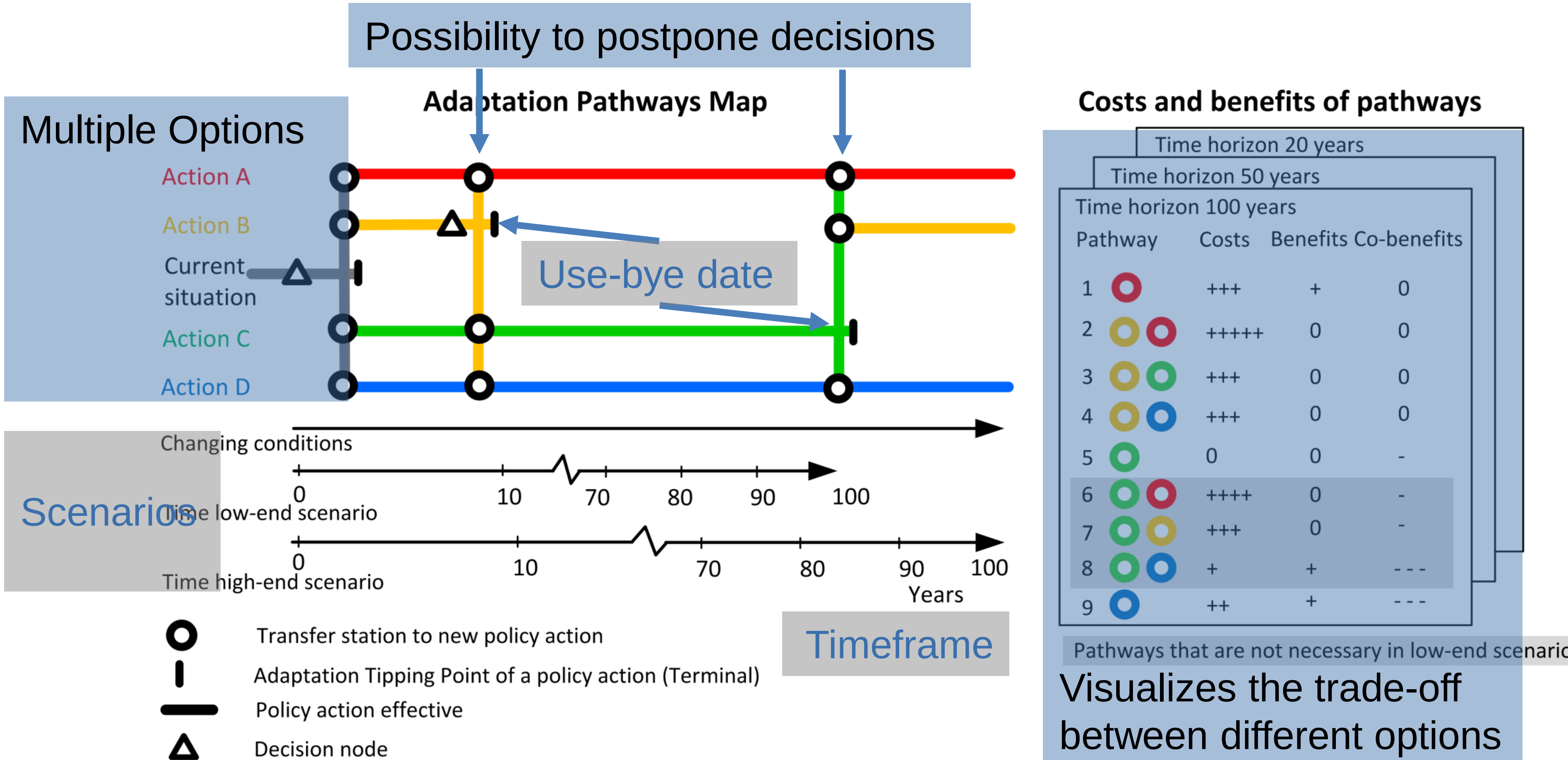


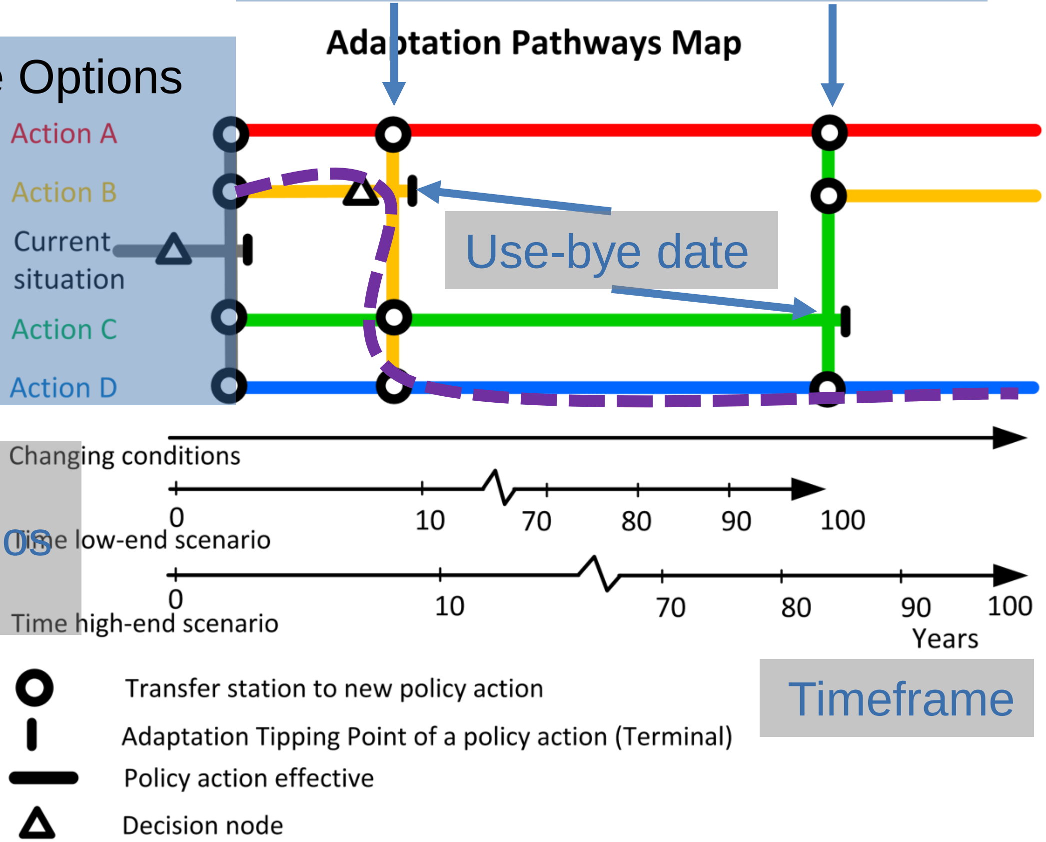
Visualizes the trade-off between different options → <u>different paths for different policies and societies.</u>

A: Nourishment B: Seagrass C: Dike (0.5m) + Buffer D: Di

Dynamic Adaptation Pathway Model (Haasnot et al. 2013)

Possibility to postpone decisions

Multiple Options



Use-bye date

Scenarios

Timeframe

Costs and benefits of pathways

Time horizon 20 years

Time horizon 50 years

Time horizon 100 years

Pathway	Costs	Benefits	Co-benefits
1	+++	+	0
2	+++++	0	0
3	+++	0	0
4	+++	0	0
5	0	0	-
6	++++	0	-
7	+++	0	-
8	+	+	- - -
9	++	+	- - -

Pathways that are not necessary in low-end scenario

Visualizes the trade-off between different options → different paths for different policies and societies.

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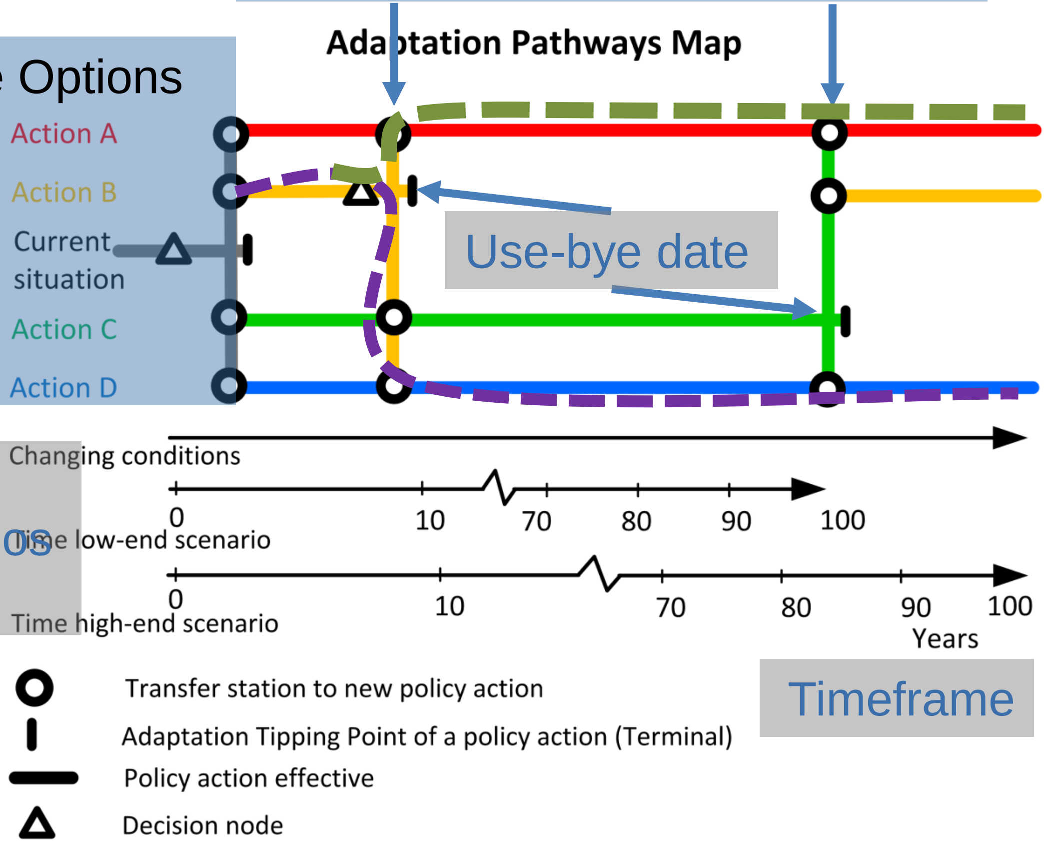

Use-bye date

Scenarios

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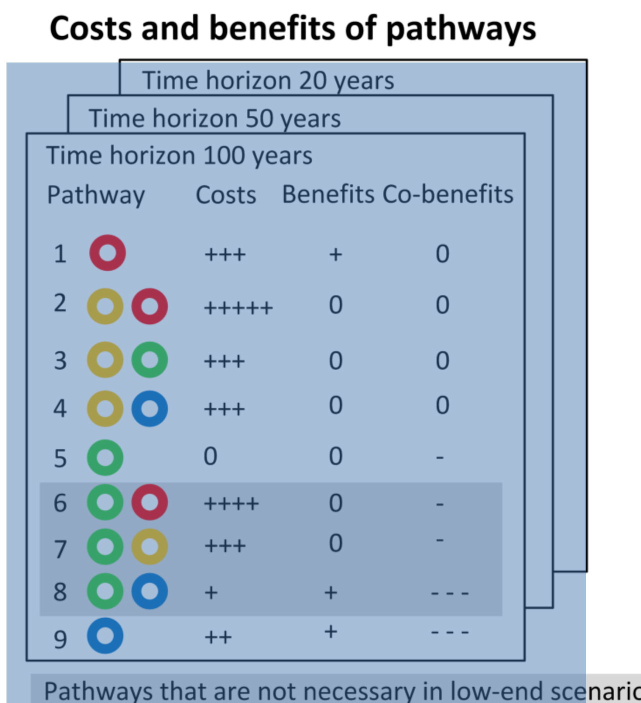

Visualizes the trade-off between different options
→ different paths for different policies and societies.

A: Nourishment B: Seagrass C: Dike (0.5m) + Buffer D: Di

Benefit of Adaptive Planning

- **Expects dynamic C_D, R_D and E_D**
  Implies changes along the way
  Flexible and robust over time

- **Proactive**
  Being prepared, rather than reacting

- **Considers lead-time for implementations**

- **Helps to manage monitoring and focus on relevant parameters**

- **Decision-focused**
  Considers lifetime of decisions / lifetime with decisions:
  Allows changes in policy, society as well as new findings in technology

Dynamic Adaptive Pathway Modelling follows the Principle of small steps, which will lead to smaller impact. By considering different pathways, it helps to plan flexible, dynamic, robust.

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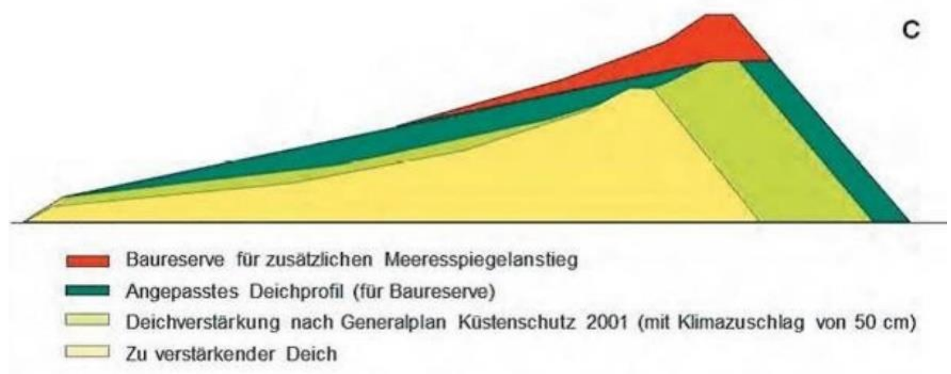
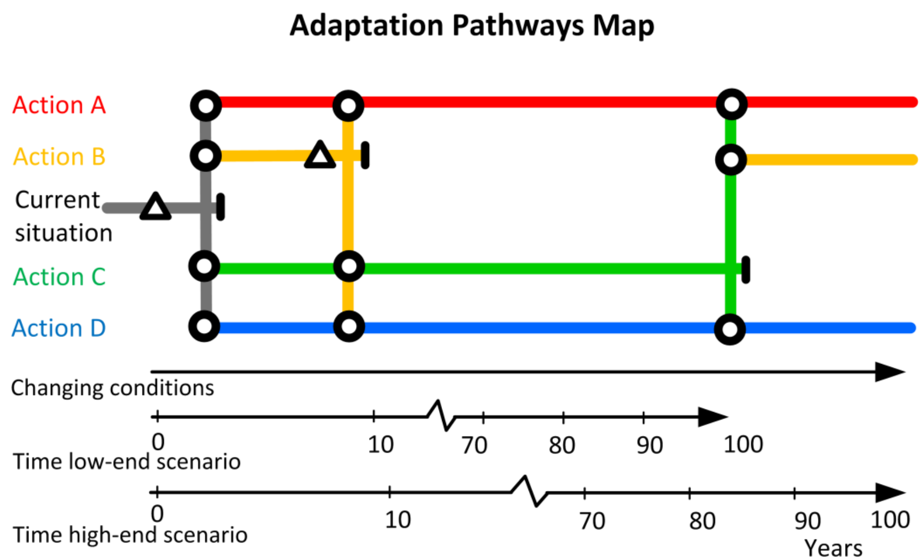
Principle of Small Steps

>> Invest Right Amount at the Right Time! <<

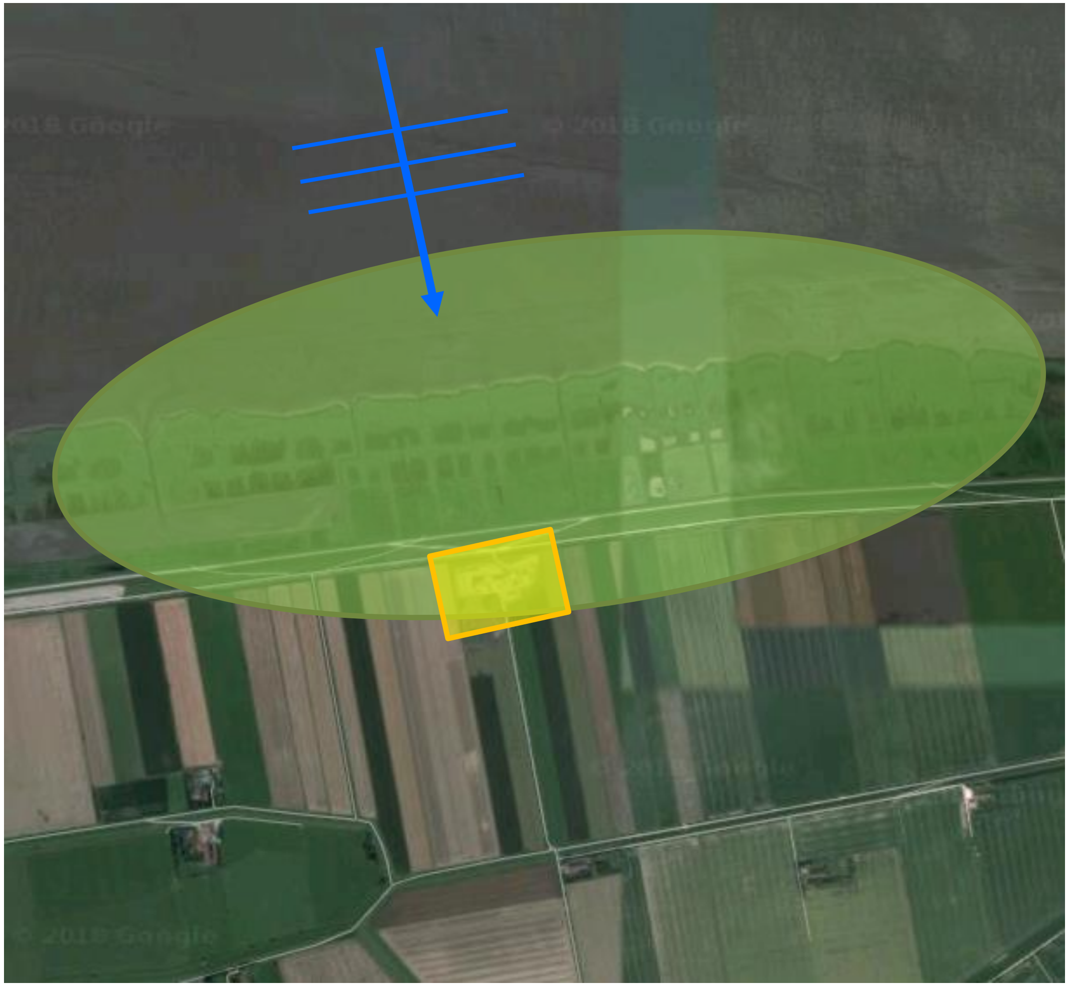
Adaptive Planning - Example



Nourishment →
Seagrass →
Dike (0.5m) + Buffer →
Dike (0.8m) →



Planning for an Uncertain, Distant Future (Status Quo)



Climate change adaptation requires a new mindset:

- Status Quo: Maximin rule (Wald, 1950):
  Consider worst possible outcome of each adaptation option.
  (Prepare for the worst case event in a timeframe or of a given recurrence, see slide 3).

- Dynamic Adaptation Pathway Modelling: Minimax regret rule (Savage, 1954)
  Calculate the maximum regret for each adaptation option, and pick the option that has the smallest (regret) of these
  ("*[avoid] missed opportunities*").

Principle of Small Steps

>> Invest Right Amount at the Right Time! <<

Agenda

- ~~Introduction and Motivation~~
- ~~Adaptation Pathways~~
- Project: DICES
- Conclusion

DICES - Dealing with change in SIDS: societal action and political reaction in sea level change adaptation in Small Island Developing States

A cooperation between:

Universität Hamburg

C | A | U

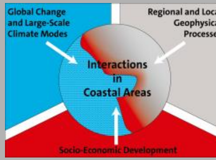
Leibniz Universität Hannover

Funded by:

DFG Deutsche Forschungsgemeinschaft

Carried out within:

Priority Program (SPP) 1889: Regional Sea Level Change and Society



DICES

WP I: Survey design, coordination, synthesis and feed-back

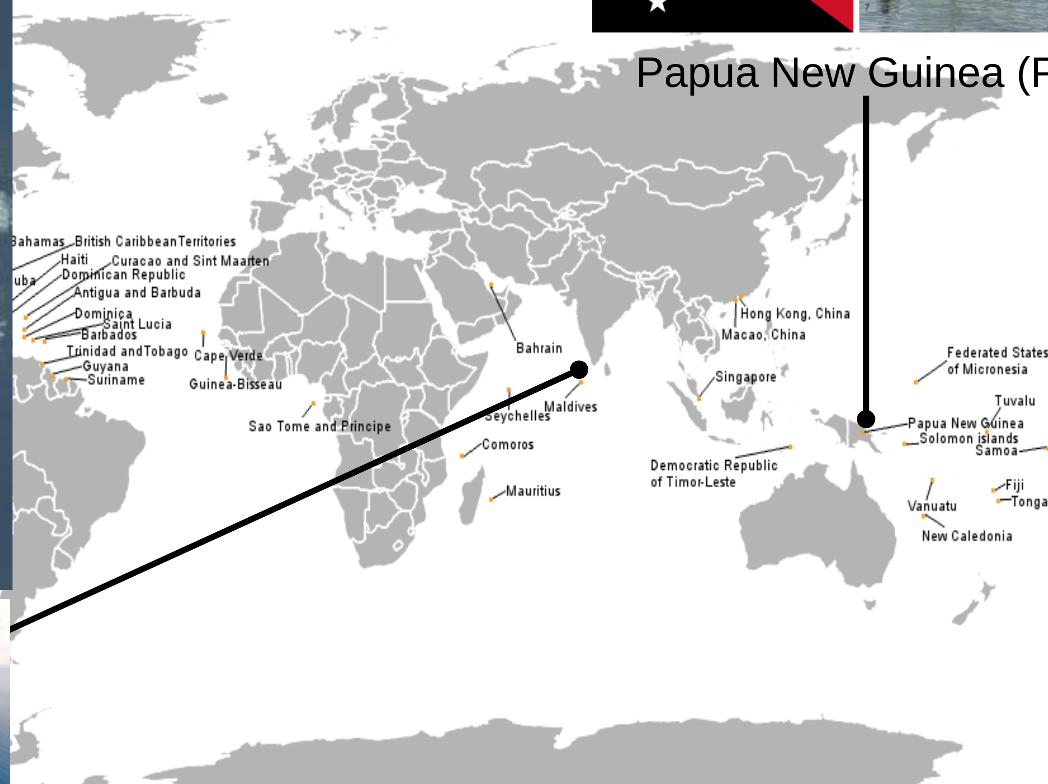
WP II: Probabalistic Pathway Design for Coastal Engineering Strategies

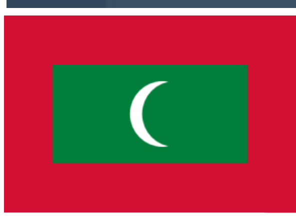
WP III: Perception and Governance Structures

WP IV: Choices and Preference

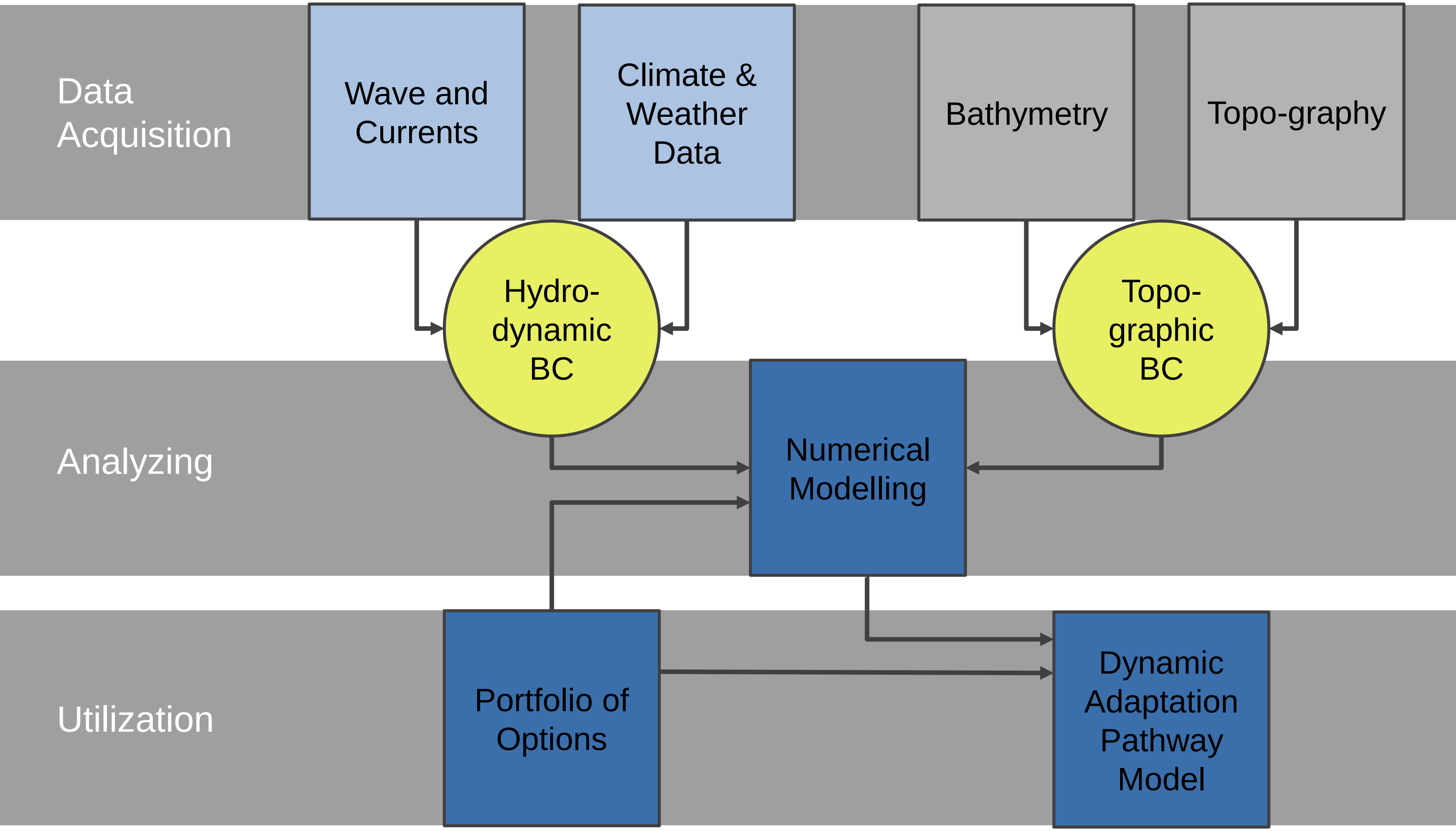
Focus Regions

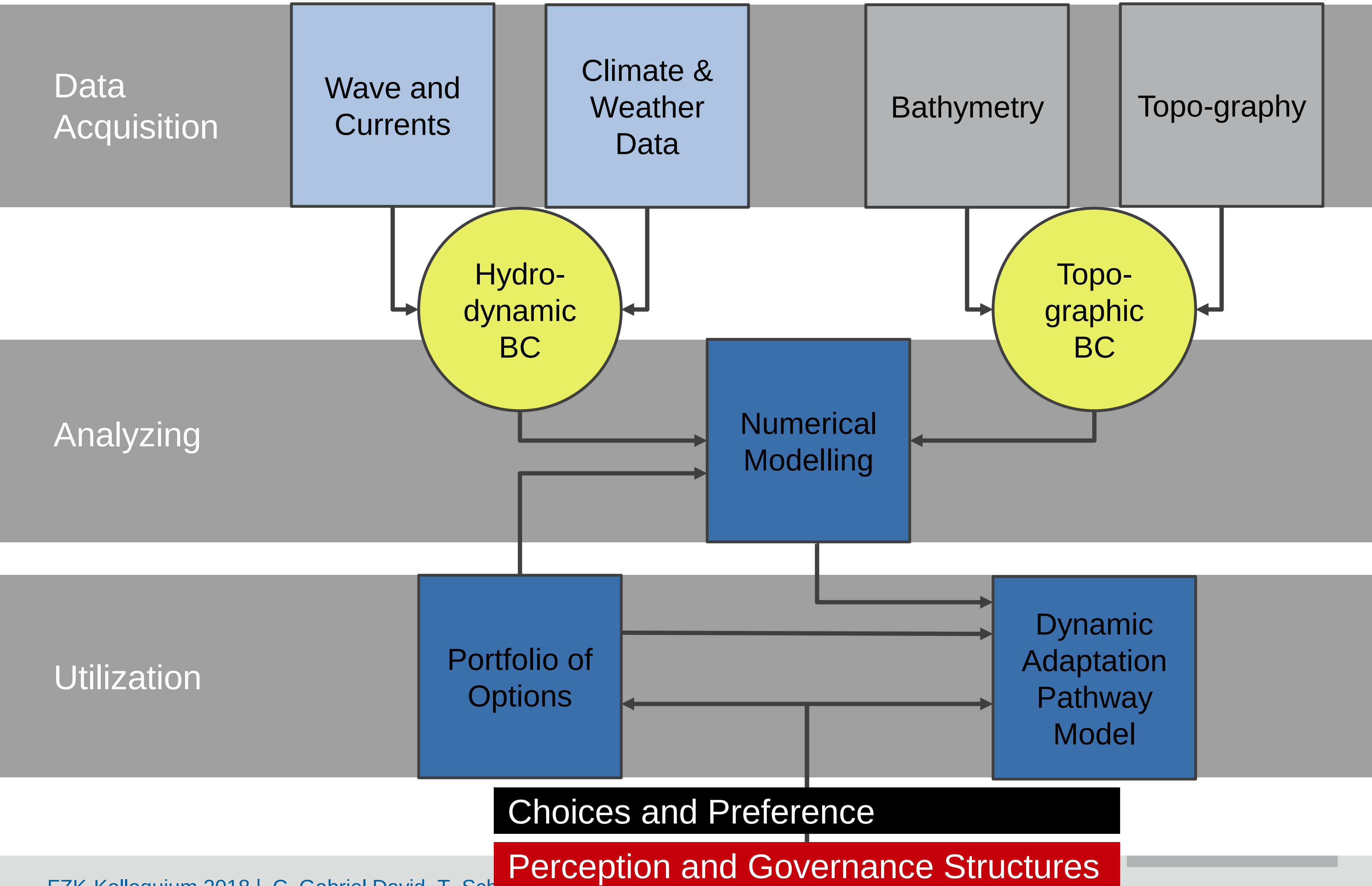
Papua New Guinea (PNG)





Maldives (MDV)


Data Acquisition
Wave and Currents
Climate & Weather Data
Bathymetry
Topo-graphy
Hydro-dynamic BC
Topo-graphic BC
Analyzing
Numerical Modelling
Utilization
Portfolio of Options
Dynamic Adaptation Pathway Model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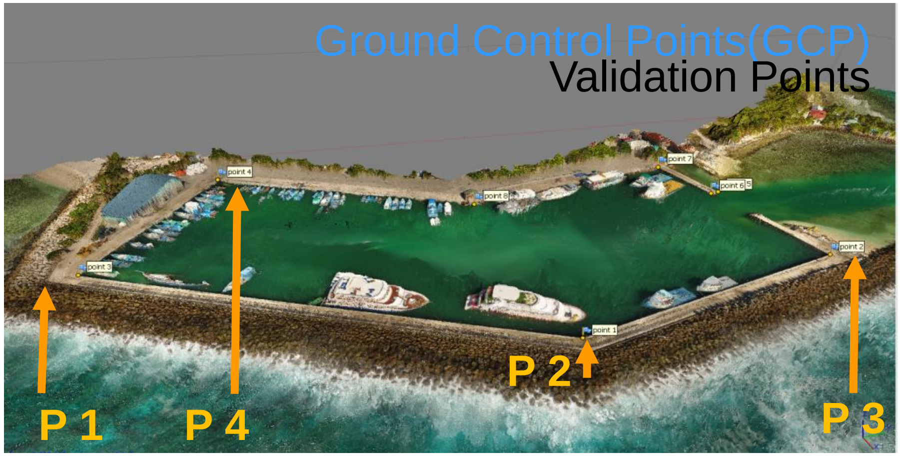
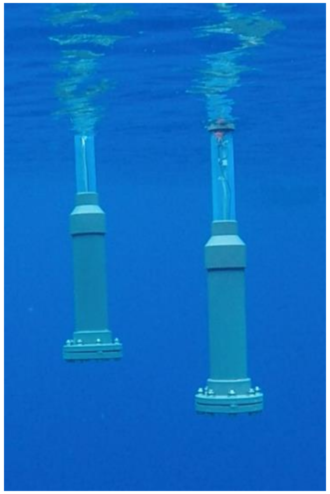
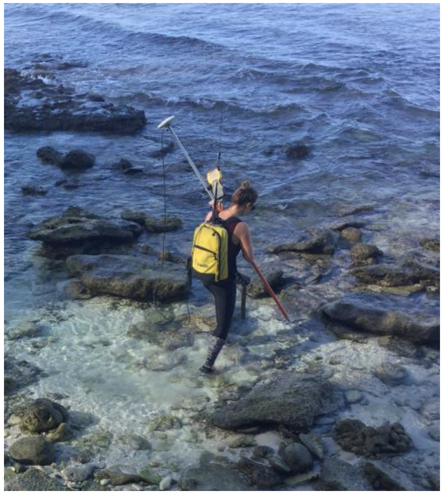
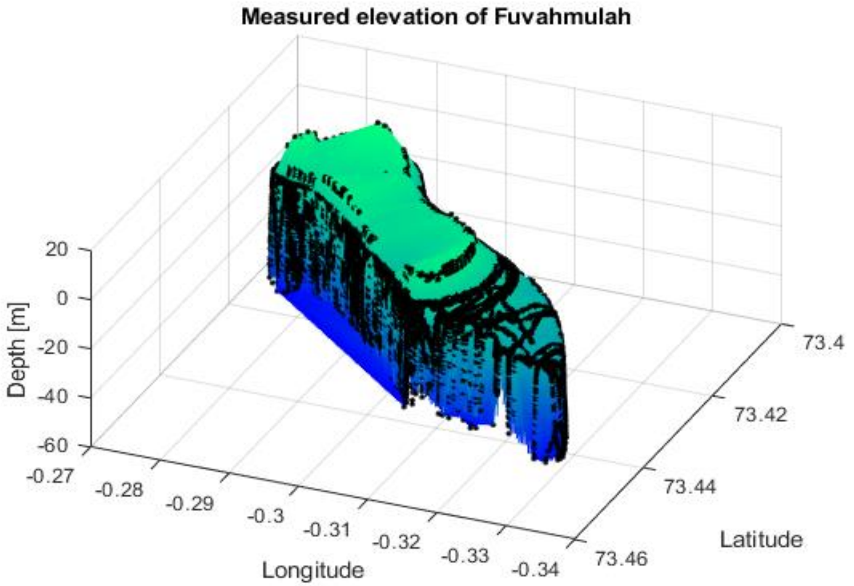
Choices and Preference
Perception and Governance Structures

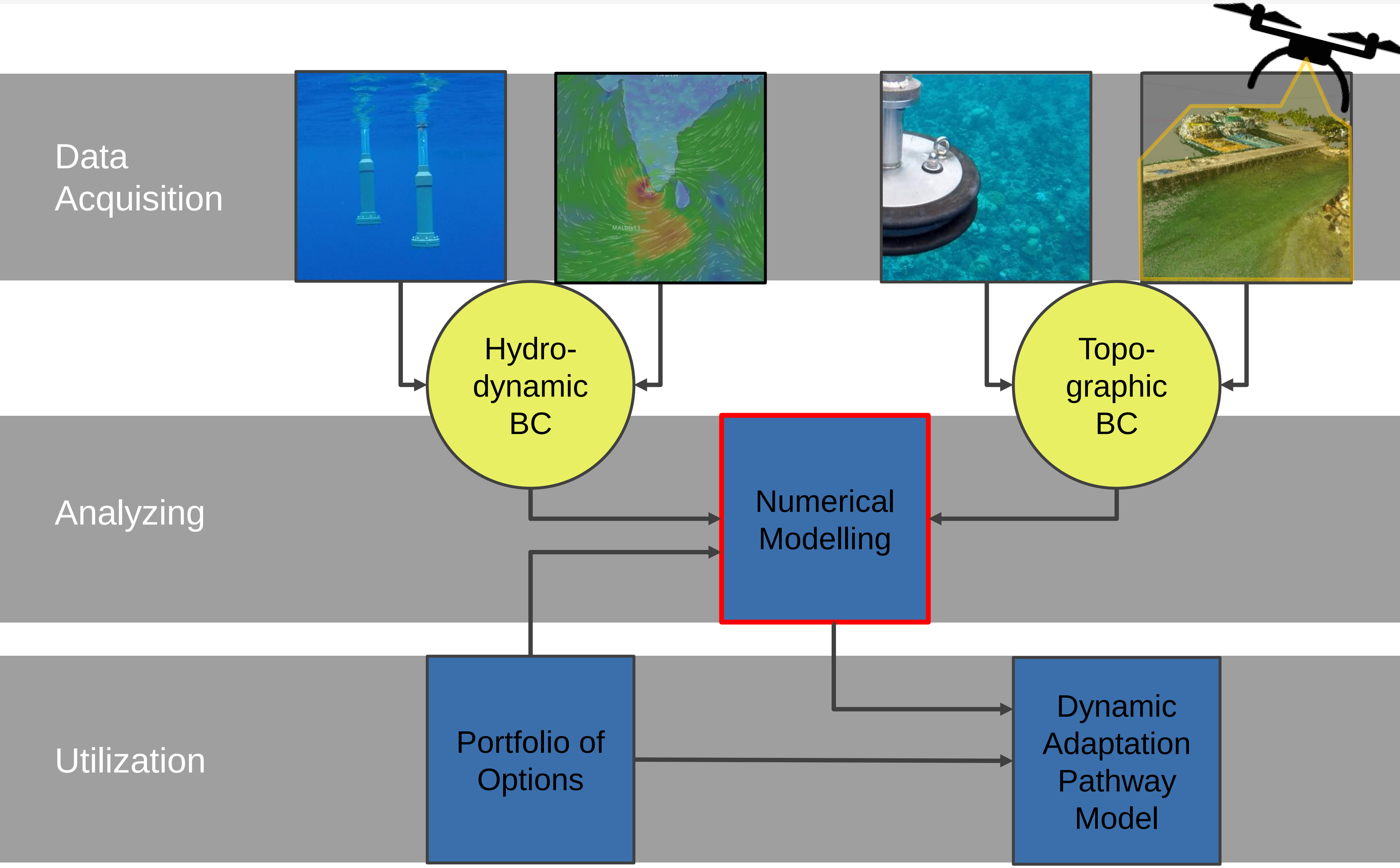
Field Campaign – Impression










Data Acquisition
Hydro-dynamic BC
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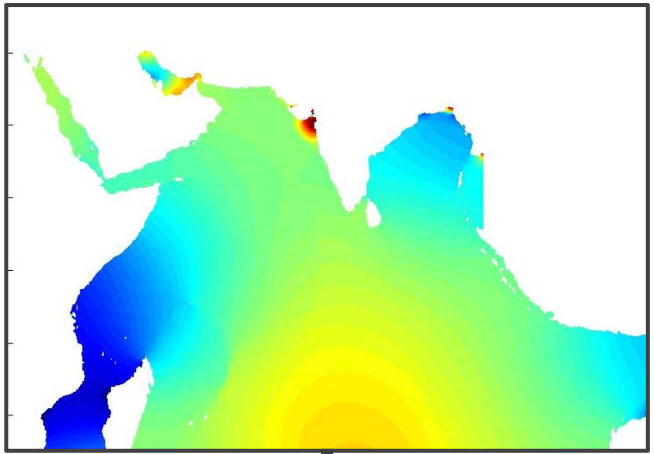
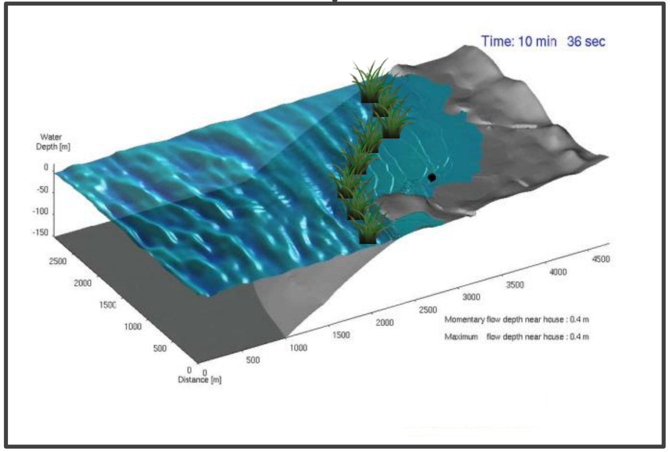
Modelling Cascade

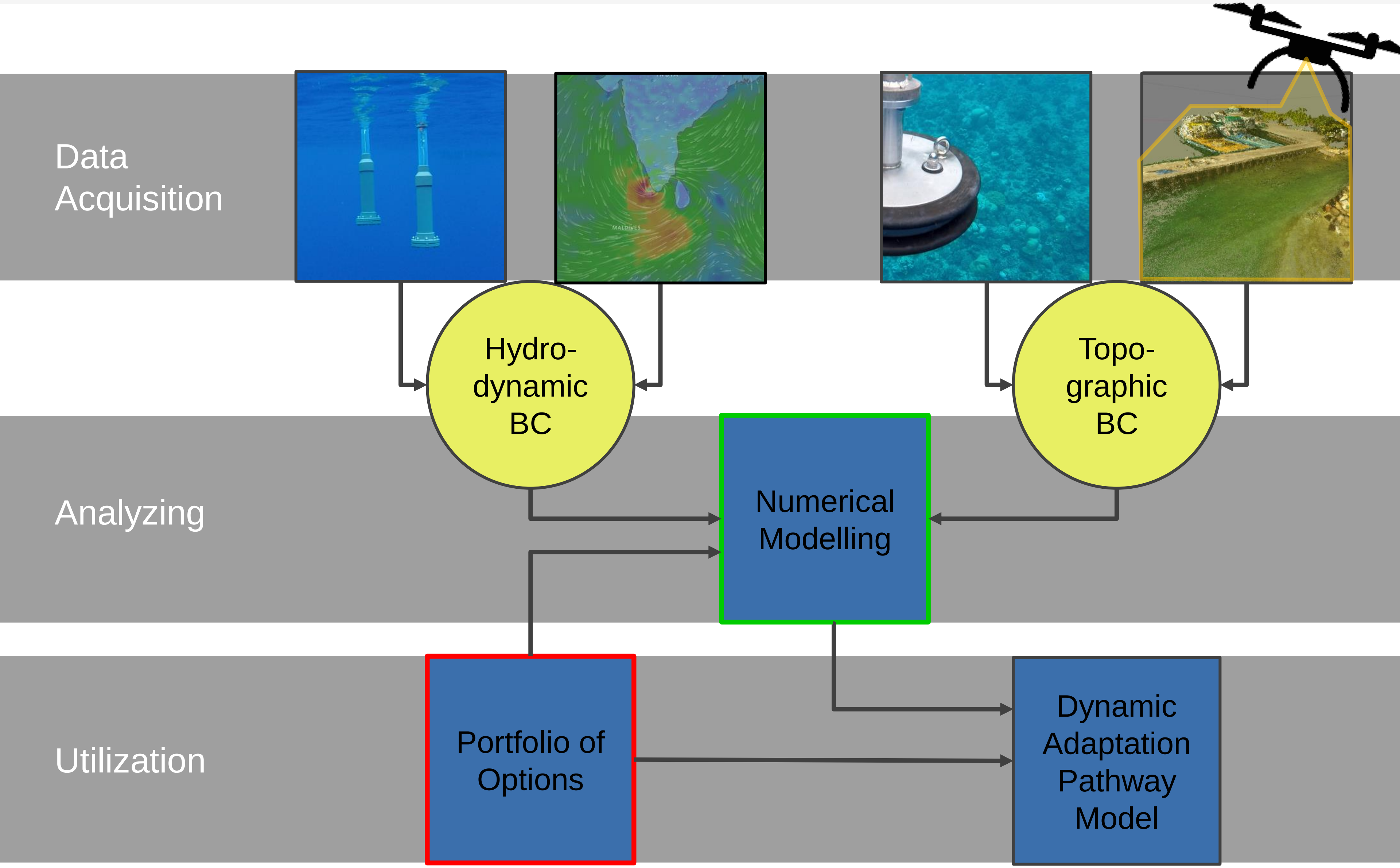


The Indian Ocean Model provides boundary conditions for climate change induced changes in sea level and weather patterns according to different scenarios

Intermediate Cascading

The local model is able to capture near-shore hydrodynamics and thus directly the impact of climate change on the island.




Data
Acquisition
Hydro-
dynamic
BC
Topo-
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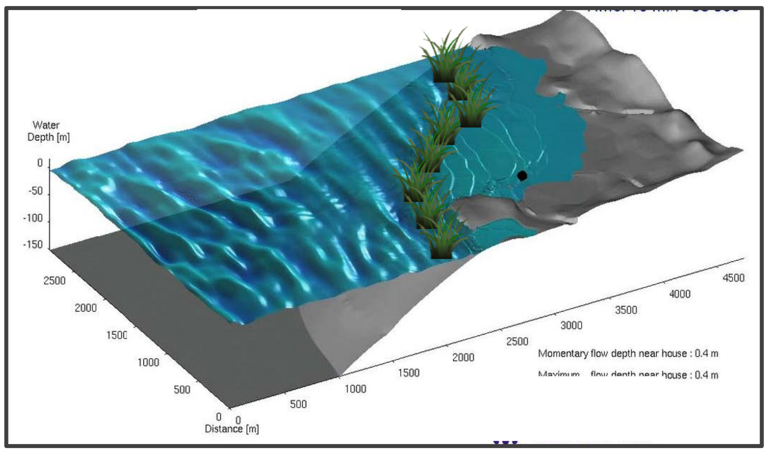
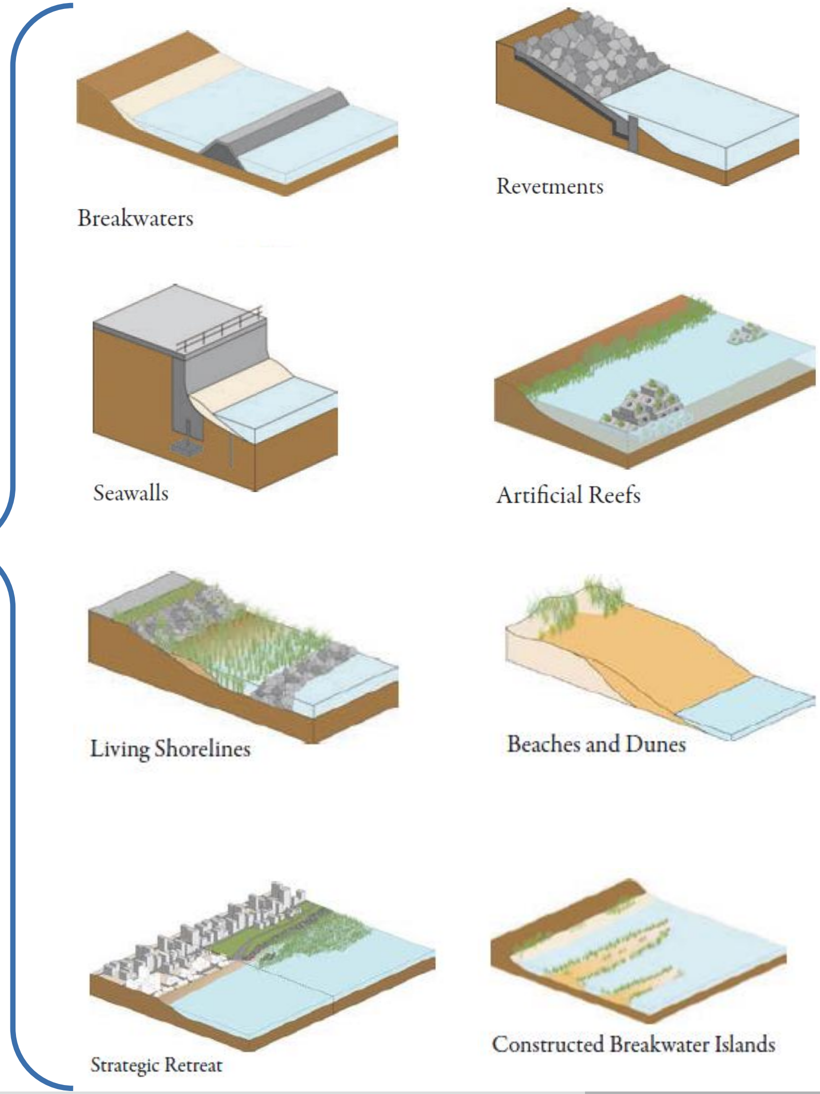
BC
Analyzing
Numerical
Modelling
Utilization
Portfolio of
Options
Dynamic
Adaptation
Pathway
Model

Modelling: Implementing portfolio of options

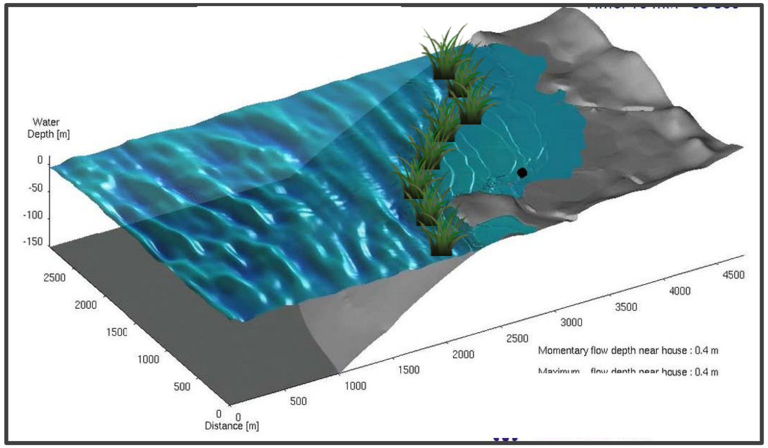




Challenges

Momentum (x):
(Roeber & Cheung , 2012)

$$(Hu)_t + H\left\{\frac{z_\alpha^2}{2}\left[u_{xx}+v_{xy}\right]+z_\alpha\left[(hu)_{xx}+(hv)_{xy}\right]\right\}_t + \left(Hu^2\right)_x + (Huv)_y + gH\eta_x + u\psi_C + H\tau_1 - H\left(\frac{\psi_S}{\rho}\right)_x = 0$$



- Roughness is implemented with *Manning's n* (in x-direction):

$$\tau_1 = gn^2H^{-2/3}u\sqrt{u^2+v^2}$$

- Mendez and Losada (2004): *Manning n* is not sufficient to capture flexible vegetation under flow conditions.
- Losada et al. (2016) presented an improved formulation for flow through vegetation.
- Karambas et al. (2015) implement a sub-module for canopy flow.

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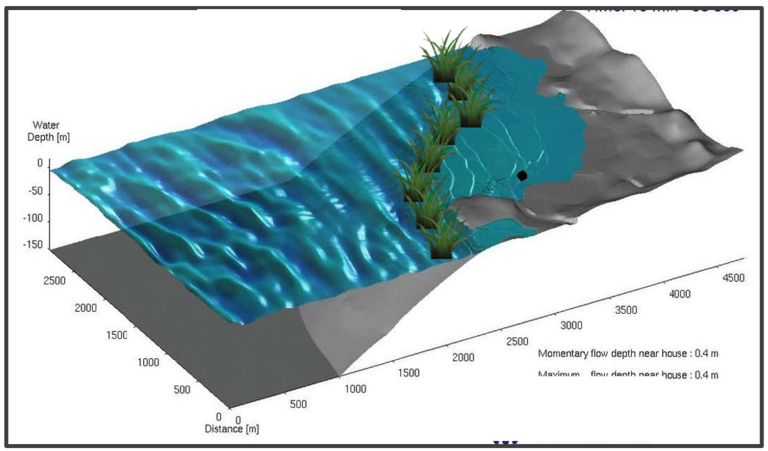

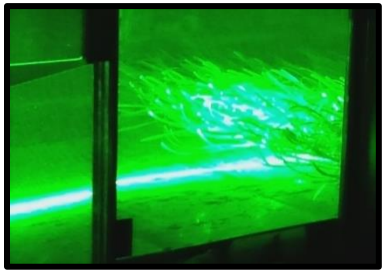

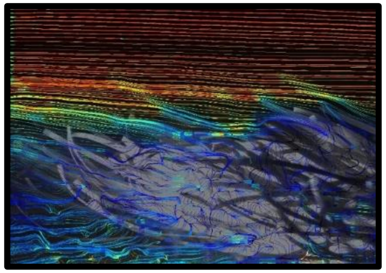

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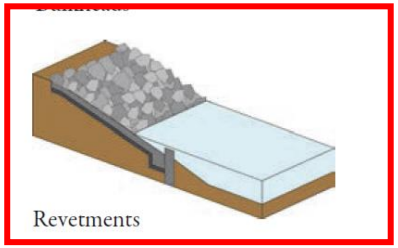
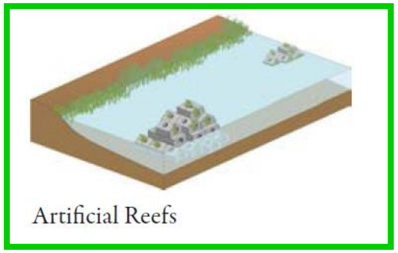
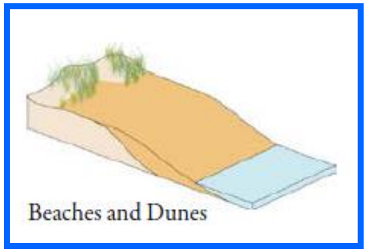
Portfolio of Options → Dynamic Adaptation Pathway Model

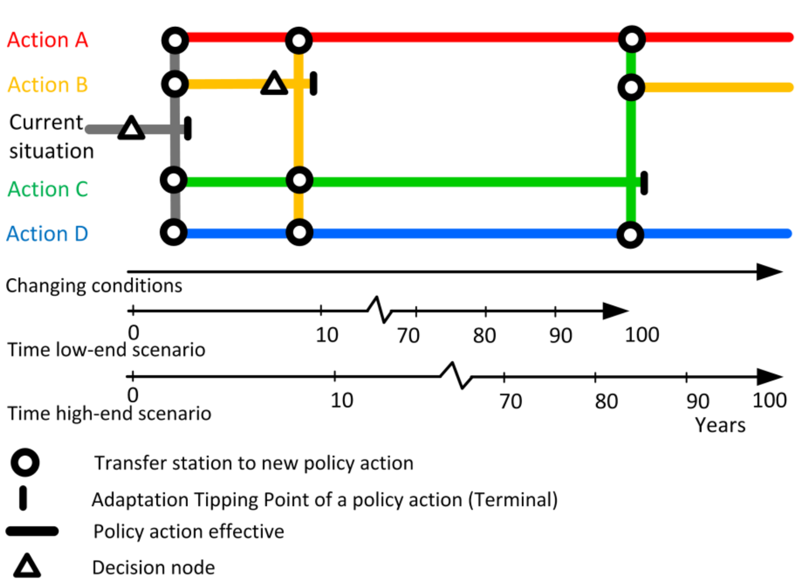






A: Revetment B: Breakwater C: BioRock D: Revetment.

Adaptation Pathways Map



Costs and benefits of pathways

Time horizon 20 years

Time horizon 50 years

Time horizon 100 years

Pathway	Costs	Benefits	Co-benefits
1	+++	+	0
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7	+++	0	-
8	+	+	- - -
9	++	+	- - -

Pathways that are not necessary in low-end scenario

Showcase Example!

Agenda

- ~~Introduction and Motivation~~
- ~~Adaptation Pathways~~
- ~~Project: DICES~~
- Conclusion

Conclusions

- Traditional coastal engineering structures have kept us safe in the past and will be able to keep us safe in the future.

- Nature-based Solutions can complement or replace those traditional solutions and in addition can offer ecosystem-based services.

- Adaptation Pathways are a dynamic and appropriate tool to address an uncertain future and help us to implement NbS in current protection systems or concepts.

- Due to the lack of experience, further research is required to "forecast" the performance of NbS (for example in numerical tools).

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Nicola **Ranger**, Tim Reeder, Jason Lowe **(2013)**: *Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames Estuary 2100 Project* J. EURO J Decis Process 1: 233. https://doi.org/10.1007/s40070-013-0014-5

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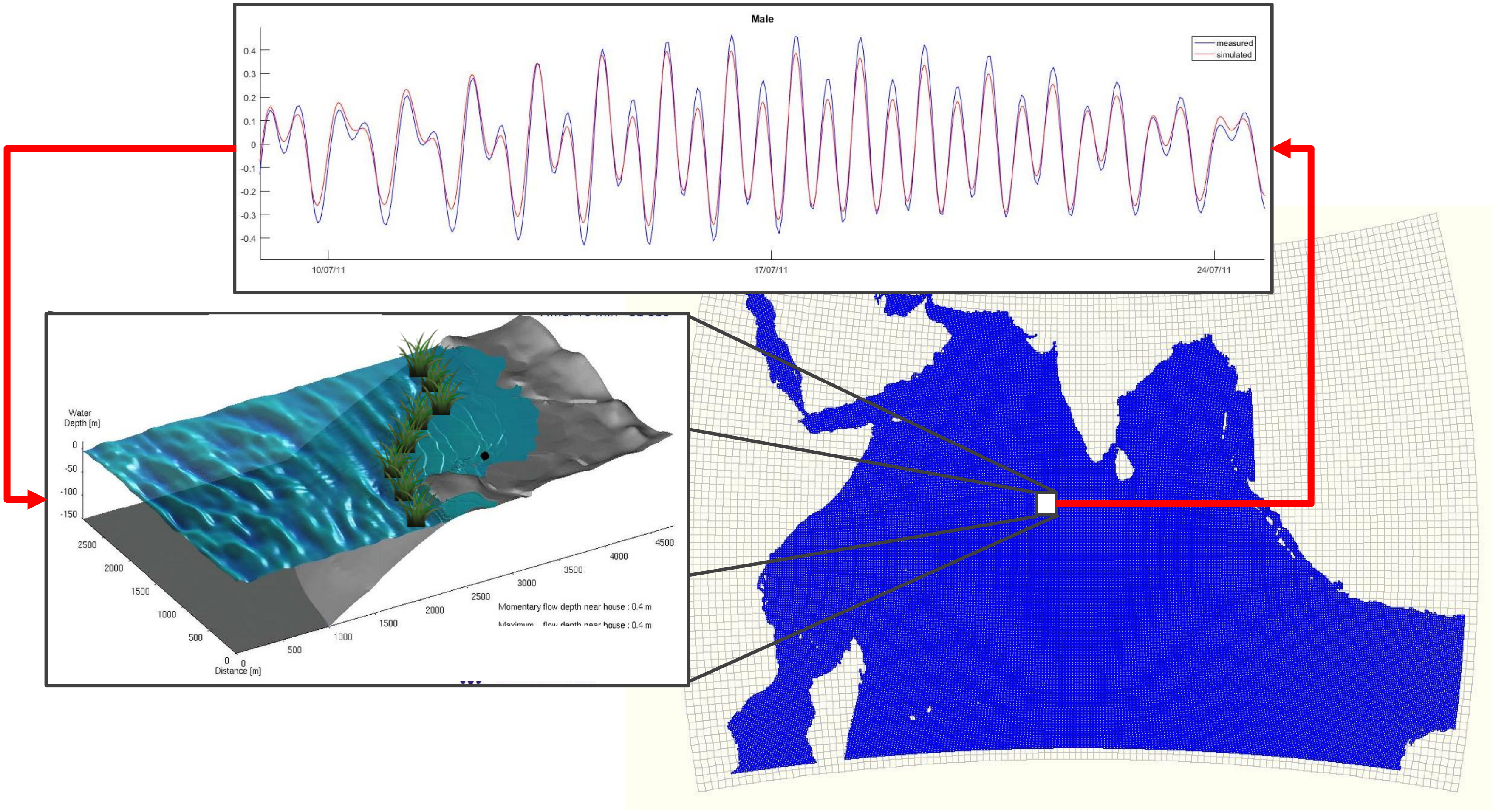
Savage, L. J. **(1954)**: The Foundation of Statistics. New York, Wiley.
Wald, A. **(1950)**: Statistical Decision Functions, Wiley, New York.


Thank you for your attention

Nested Modelling



Why SIDS?

- *"SLR poses one of the most widely recognized climate change threats to low-lying coastal areas on islands and atolls (SIDS)"*

Why project together with social scientists?

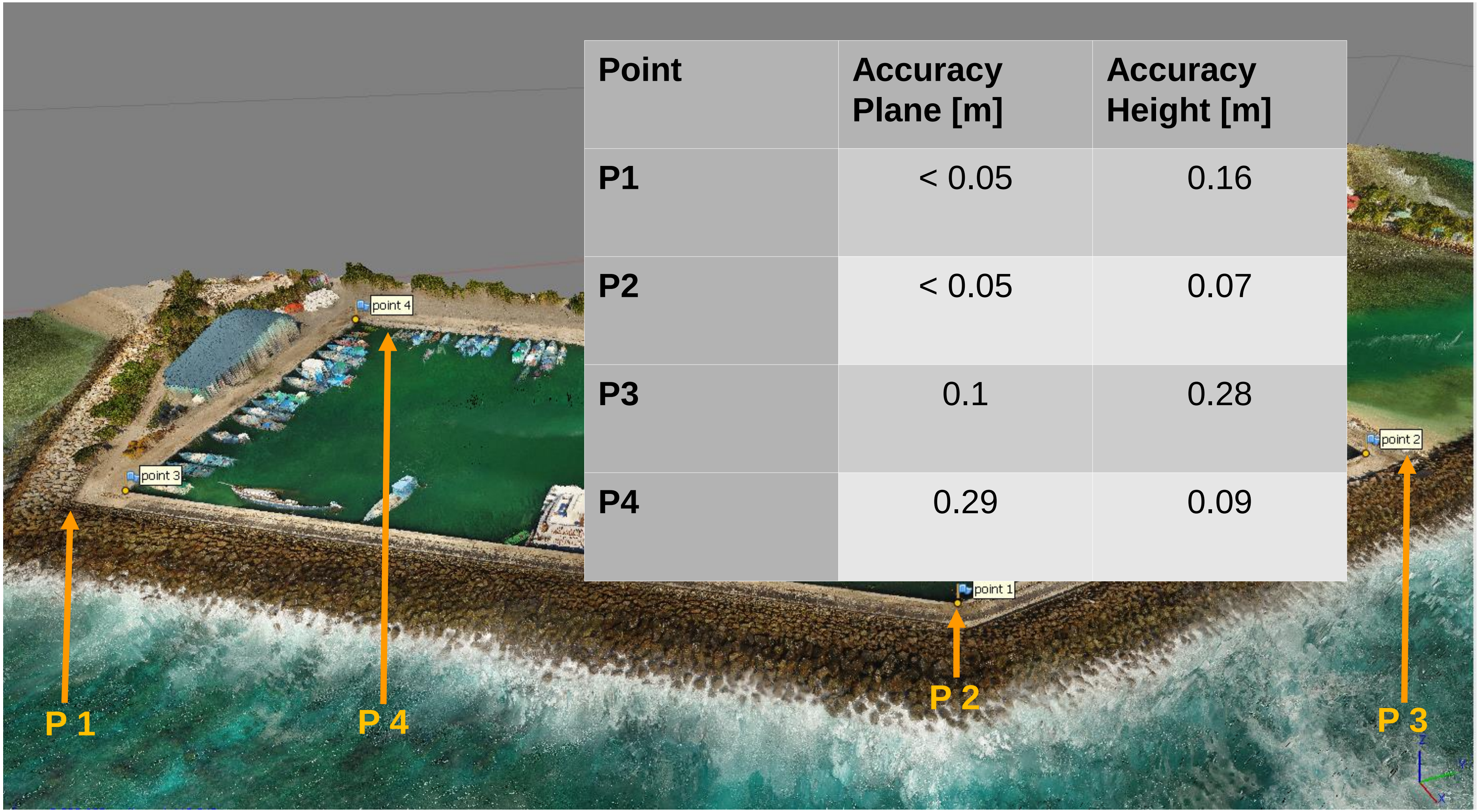
- *"Adaptation to climate change generates larger benefit to small islands when delivered in conjunction with other development activities, such as disaster risk reduction and community-based approaches to development"*

Why these focus areas?

- *"response to climate-related drivers […] climate change impacts, vulnerability, and adaptation will be variable from one island region to another and between countries in the same region."*
  → What are differences and communalities between MDV and PNG?

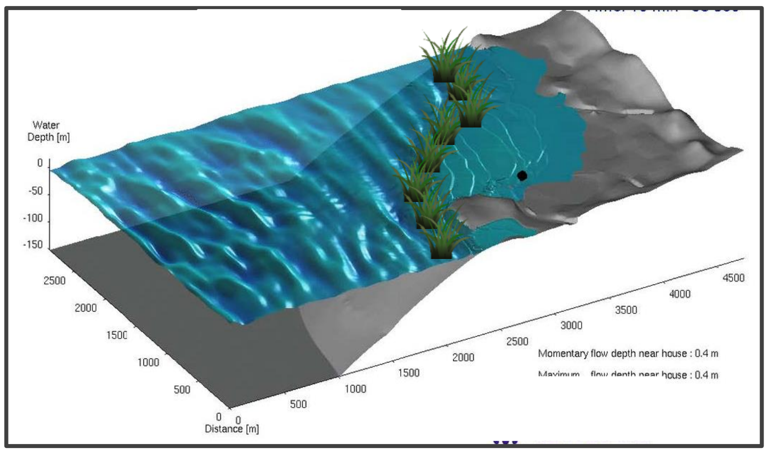
Citation from IPCC Report (2014), Chap. 25 *"Small Islands"*

Topography

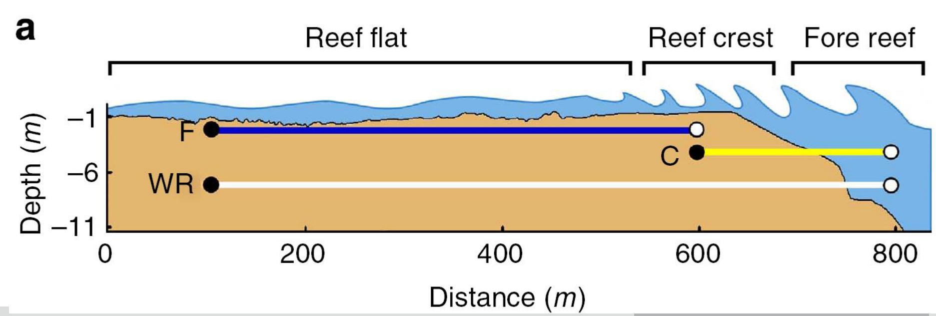


Point	Accuracy Plane [m]	Accuracy Height [m]
P1	< 0.05	0.16
P2	< 0.05	0.07
P3	0.1	0.28
P4	0.29	0.09

Benefits of 2DH Modelling



- Covers wave phenomena and their impacts in much finer temporal and spacial resolution (→ detailled).
- Phase resolving model captures – amongst others – reef dynamics (Roeber et al. 2015)
- Depth averaged model regarding whole island, while keeping computation time acceptable
- Boussensq approaches perform especially well for lower frequencies (kh < 4).



Adaptation (to climate change):
An action to tackle the risk of a certain hazard (of climate change).

Can be a structure, a set of structures (system), a strategy or a modification as well as an improvement of an existing structure, which will decrease the risk of being (negatively) affected by climate change.

Example: Thames Barrier

Example: Climate Change Adaptation of the Thames Barrier (Ranger et al. 2010, 2013):

- *Only in a few cases will a decision-maker be forced to make the difficult choice between potentially 'high regrets'* […] *In many cases a range of 'no-regrets' options are available.*

But this requires a new mindset:

- Status Quo: Maximin rule (Wald 1949) - Consider worst possible outcome of each adaptation option. (Worst case event in a timeframe, see slide 3).
- Dynamic Adaptation Pathway Modelling: Minimax regret rule (Savage 1954) - Calculate the maximum regret for each adaptation option, and pick the option that has the smallest (regret) of these ("*[avoid] missed opportunities*").