**Climate change - The environmental and socio-economic response in the southern Baltic region**

**Szczecin, Poland, 12 – 15 2014**

# A method for estimating coastline recession due to sea level rise by assuming stationary wind-wave climate

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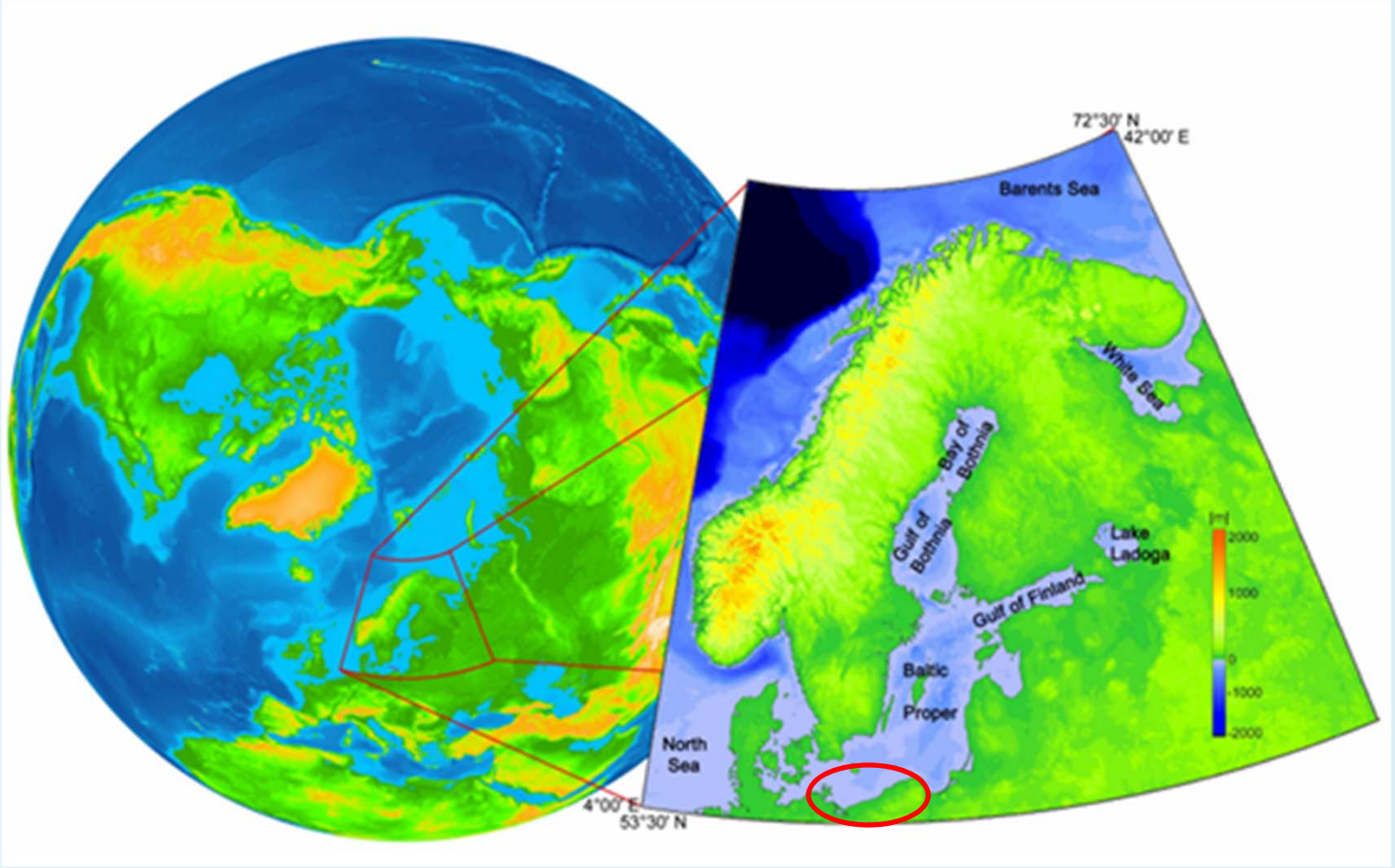
Session E: Changing Baltic Sea coasts and their sustainable protection

WEDNESDAY, 14 May 2014

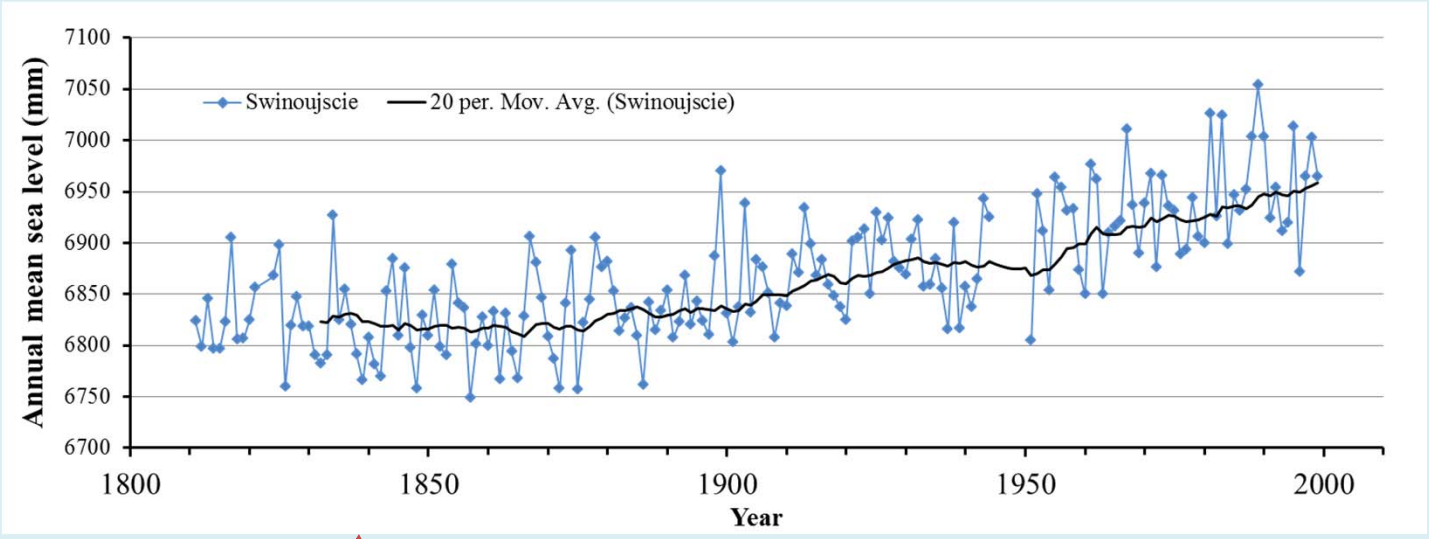
# The Baltic region

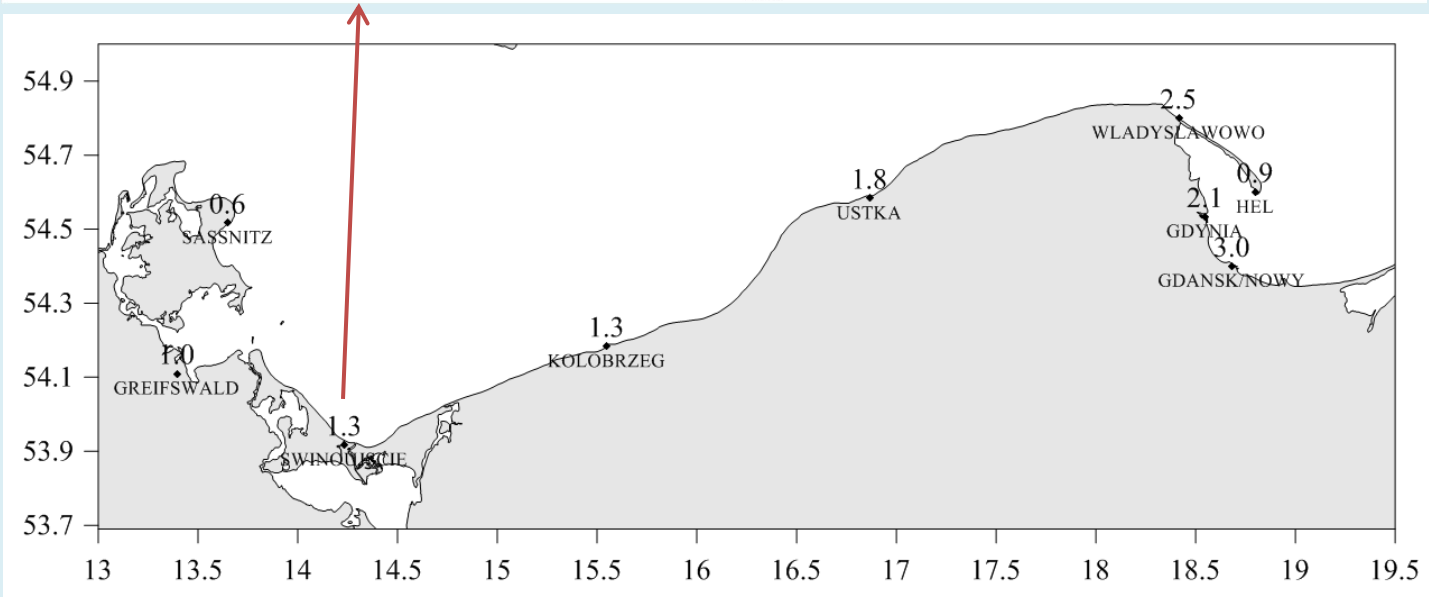


# Coastal erosion during storm surge at Dziwnów on November 4, 1995

Photo: P. Domaradzki

# Relative sea level rise at southern Baltic Sea

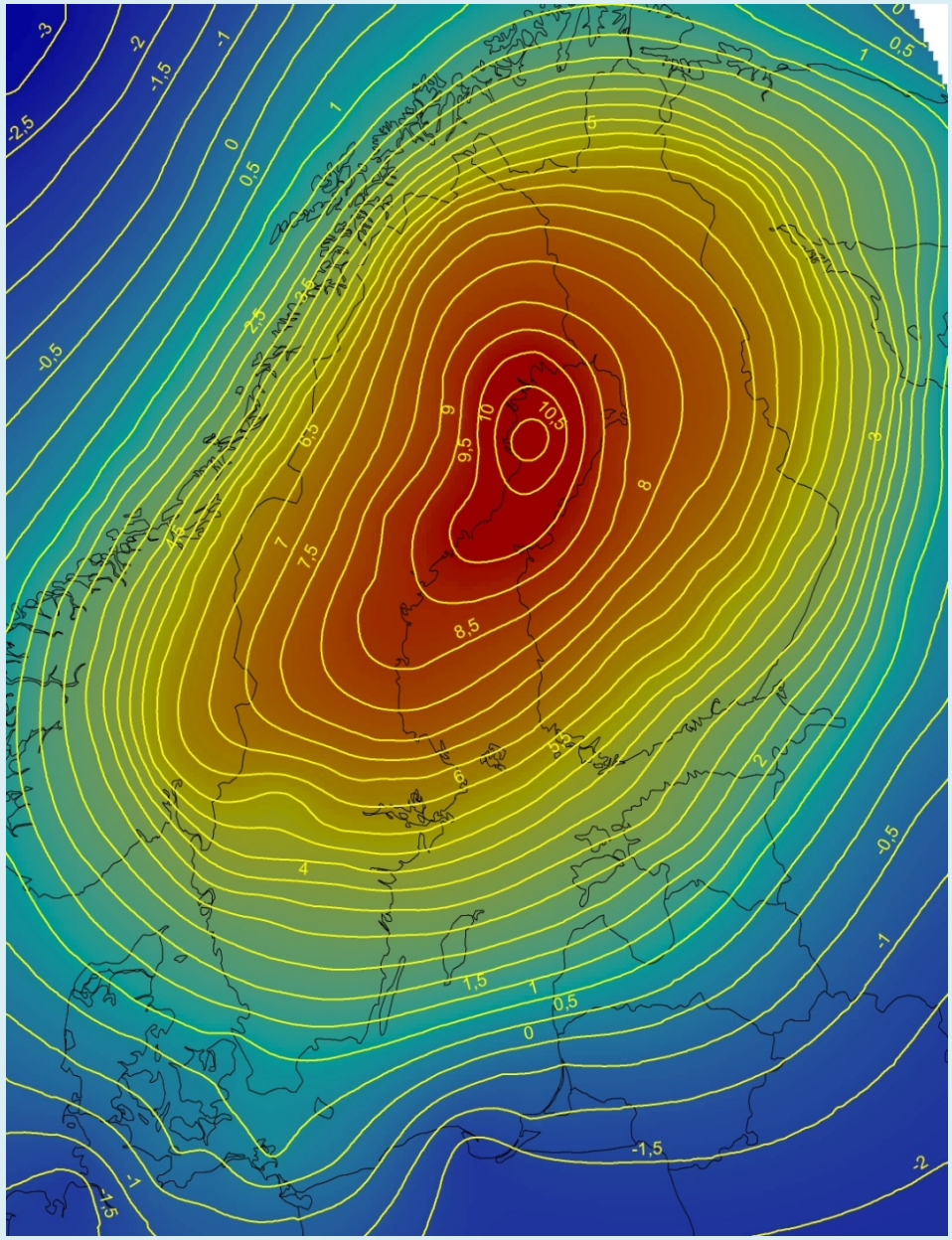



(secular rate: mm/yr)

Groh et al., 2012

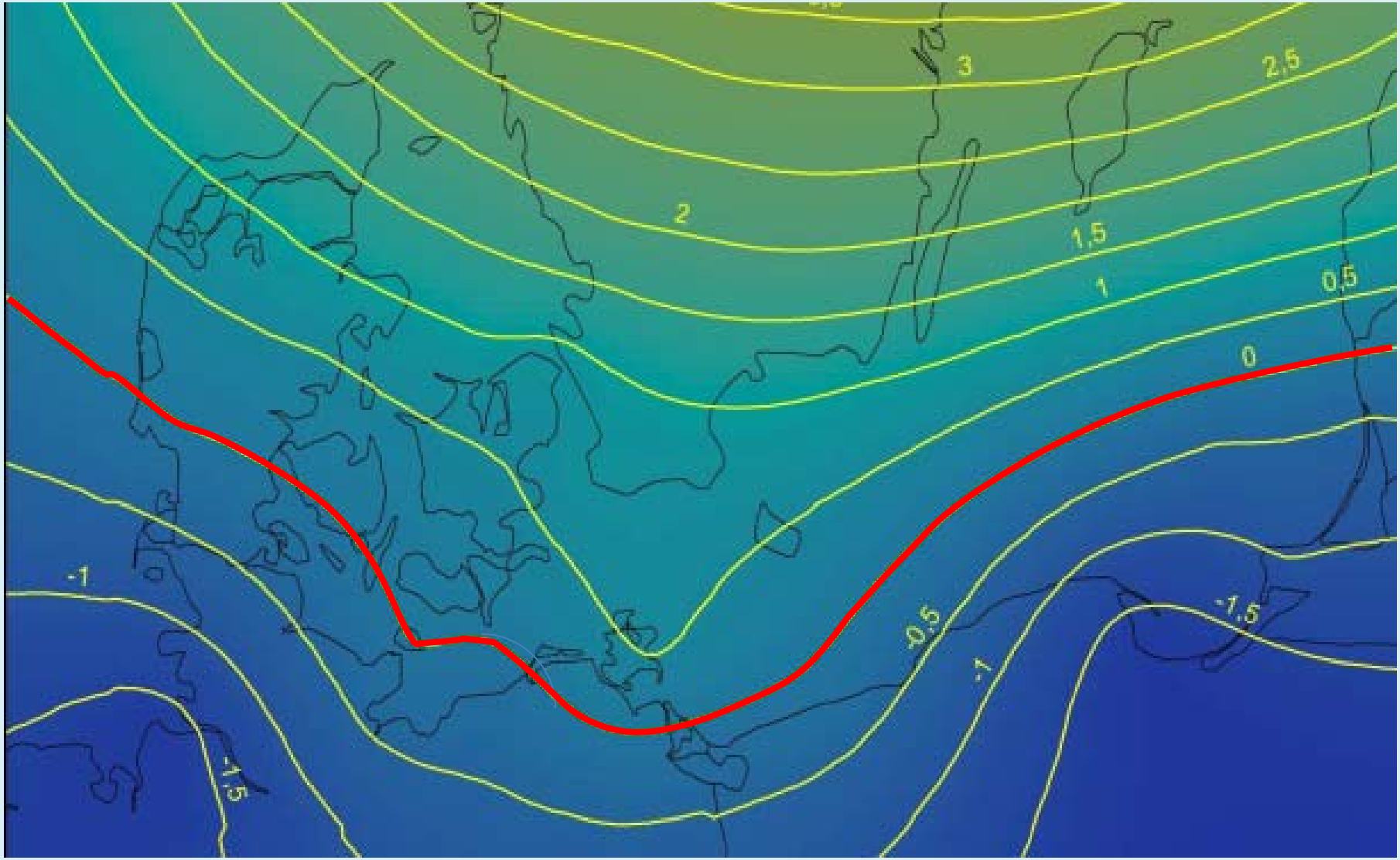
# Glacial Isostatic Adjustments




(unit: mm/yr)

Dudzinska-Nowak et al. (in prep.)

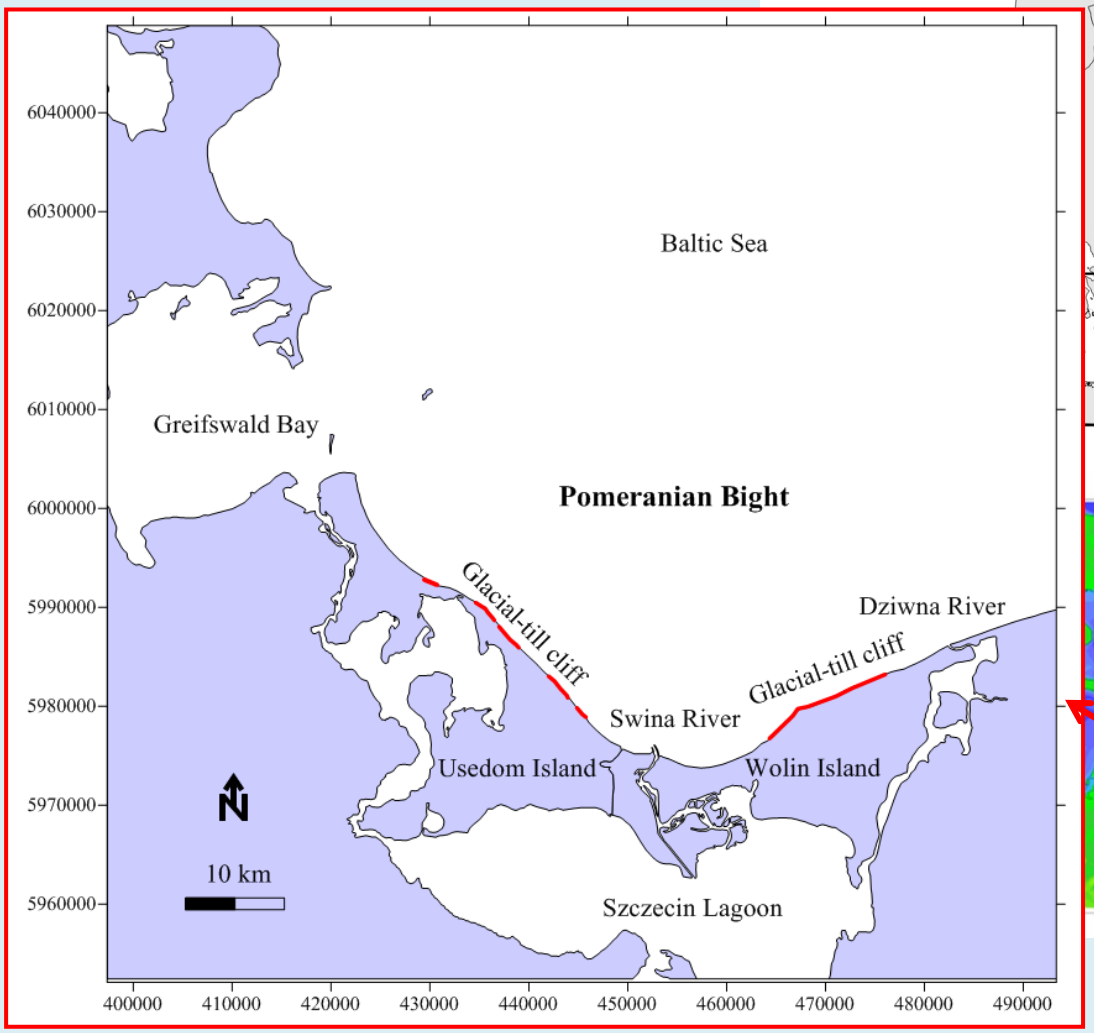
# Glacial Isostatic Adjustments

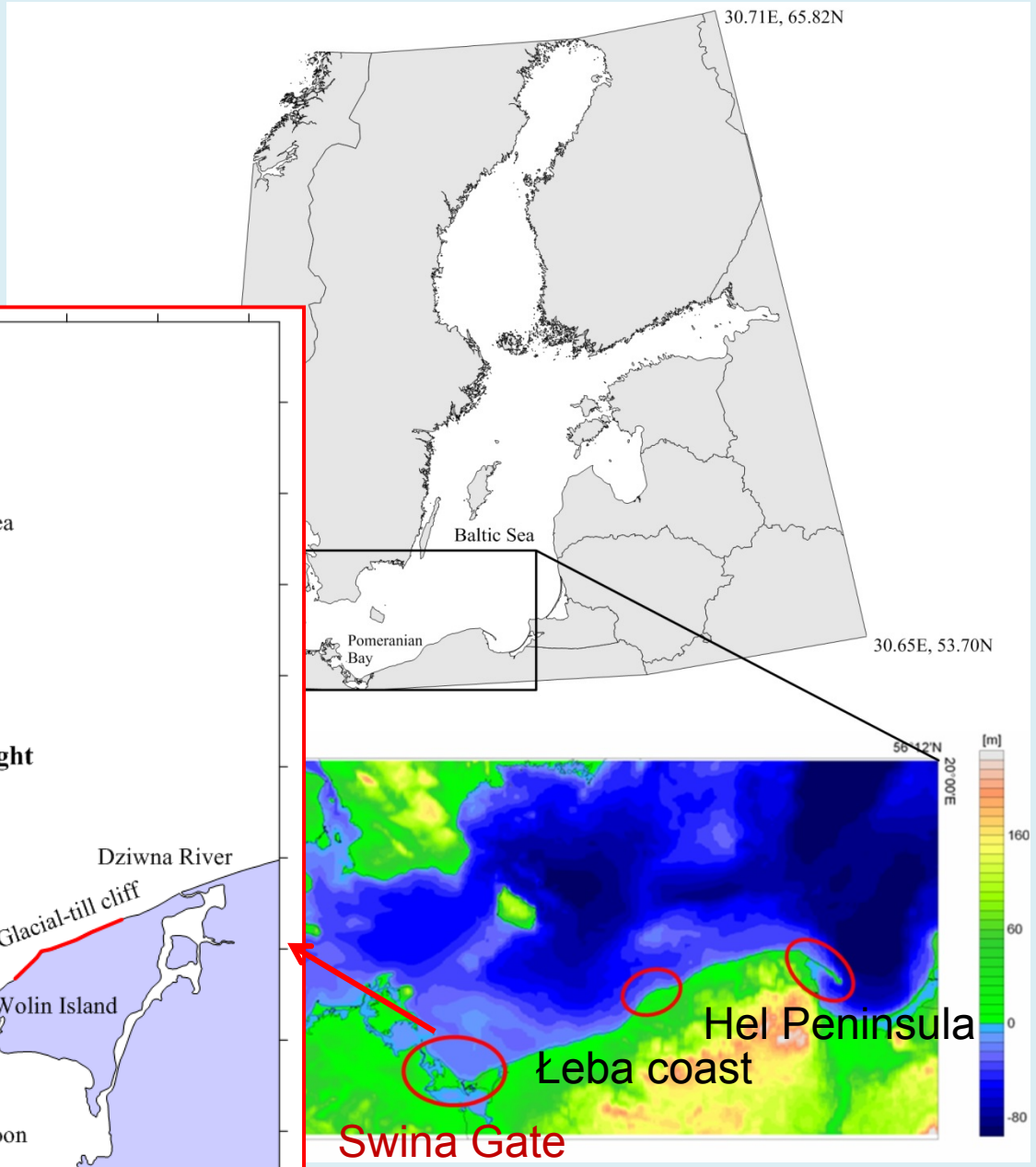



(unit: mm/yr)

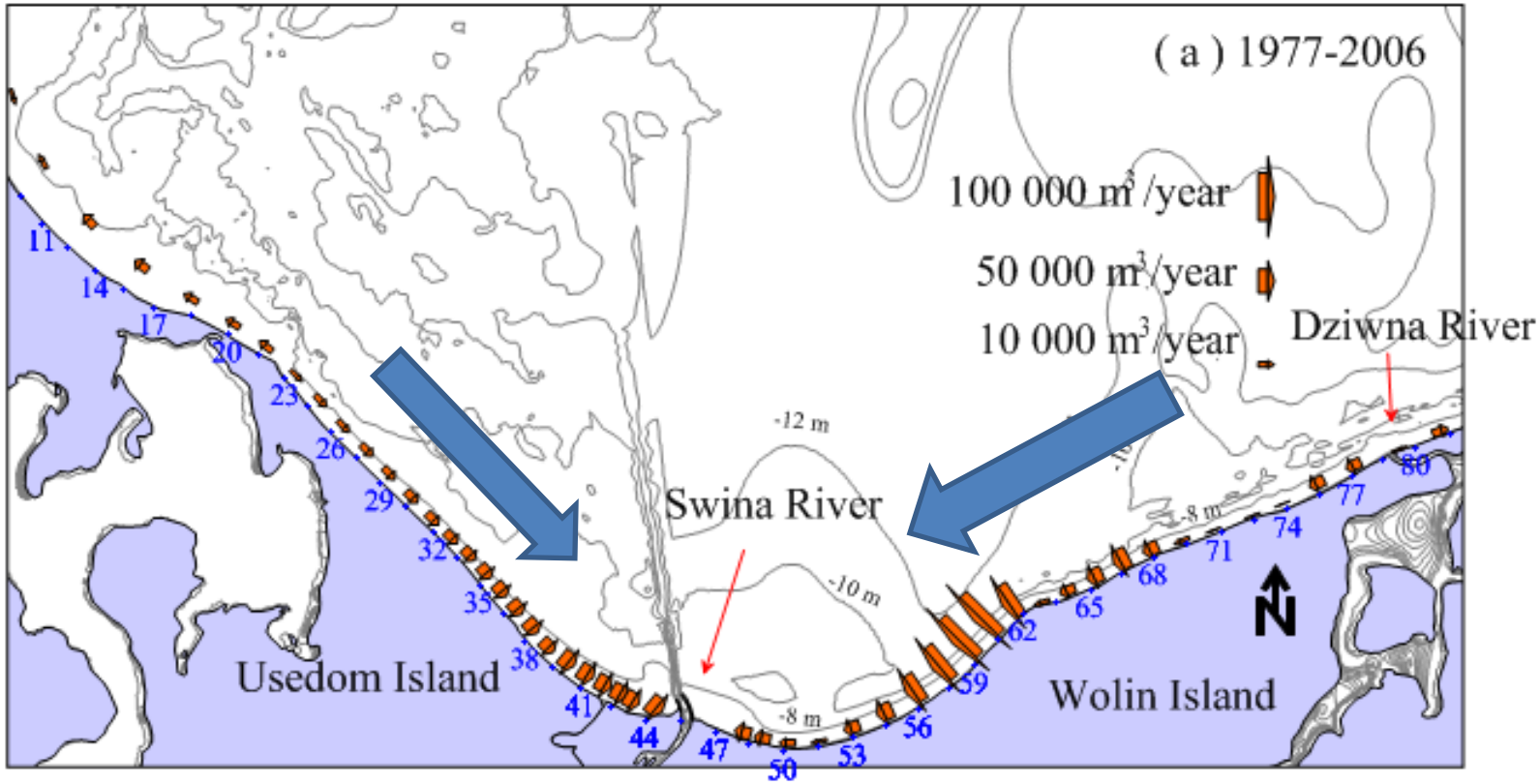
Dudzinska-Nowak et al. (in prep.)

# Swina Gate area, Southern Baltic Sea

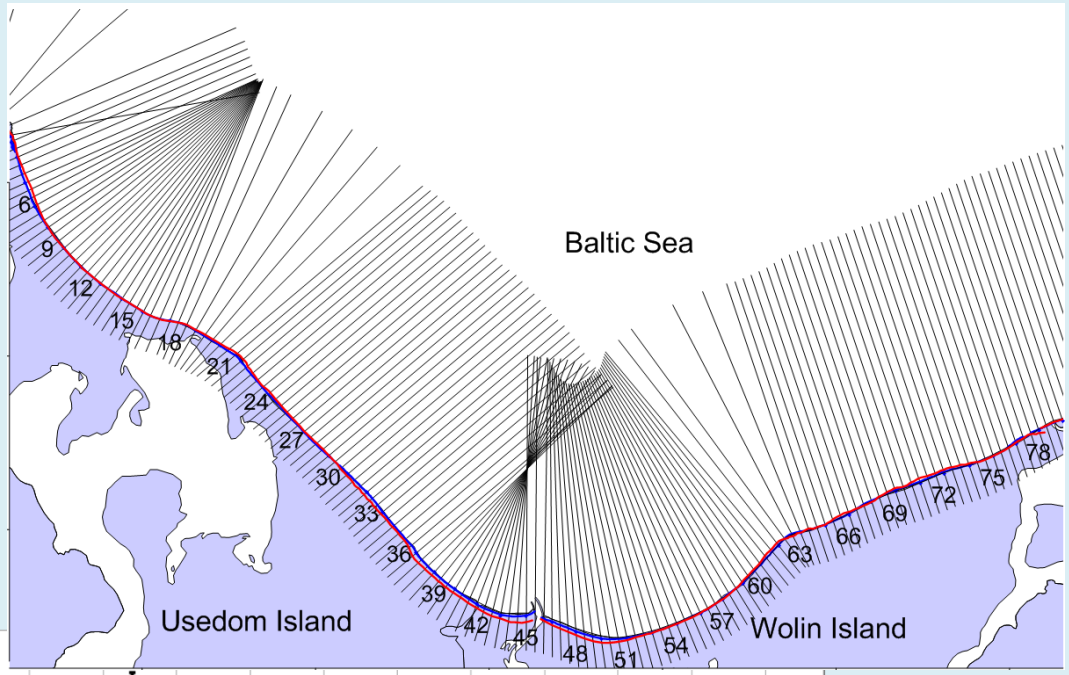


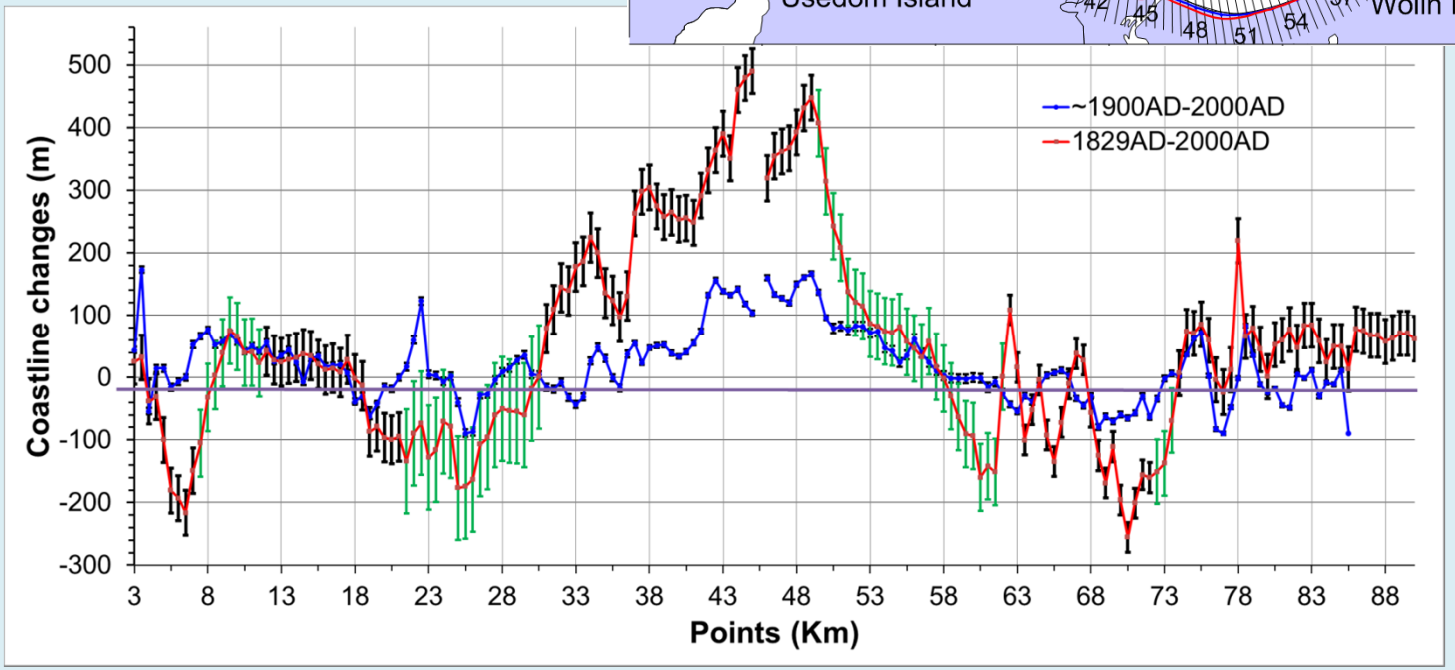



# Long-shore Sediment Transport Capacity by using CERC formula (USACE, 1984):



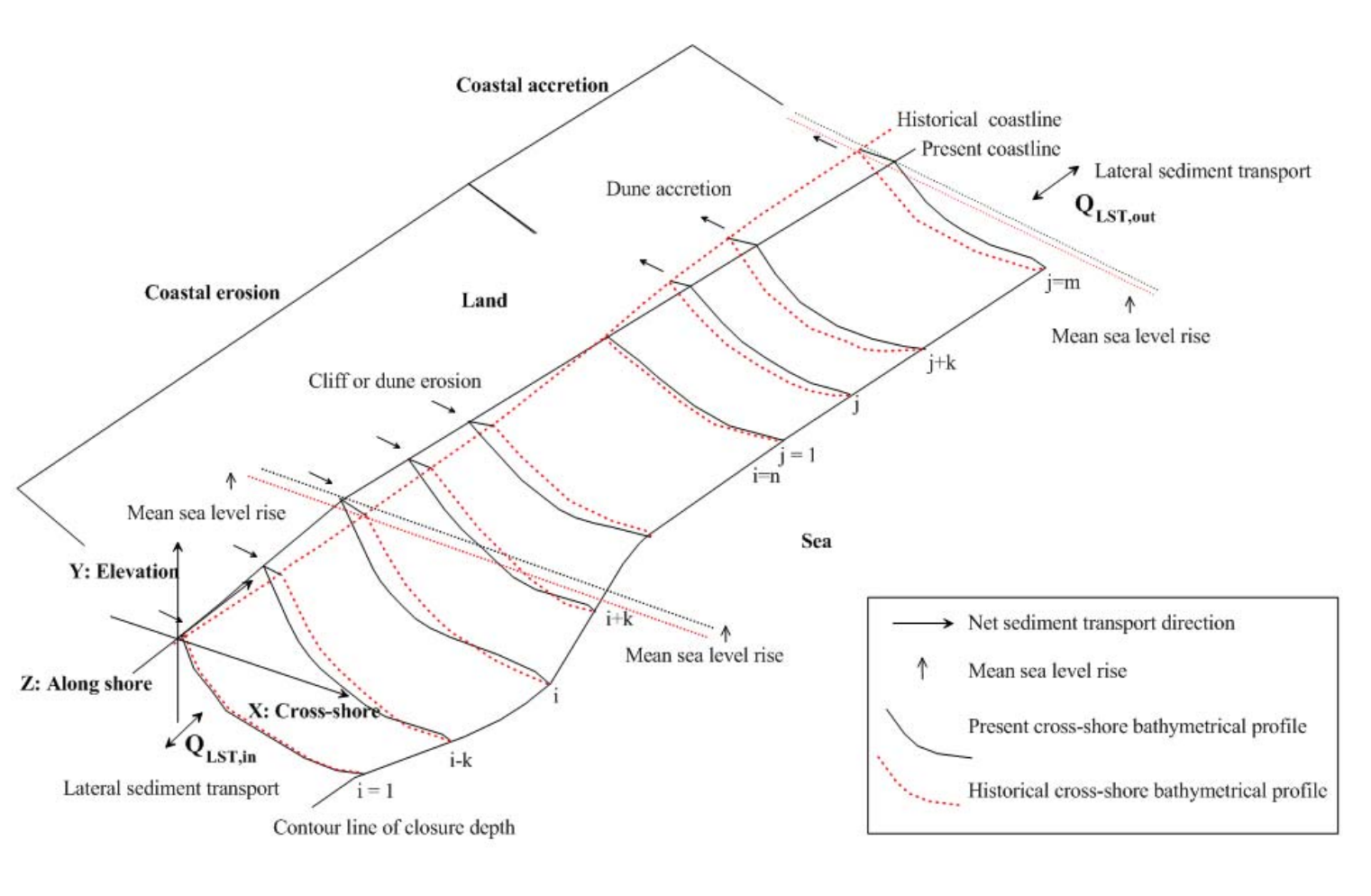
# Historical coastline changes with accuracy error bars



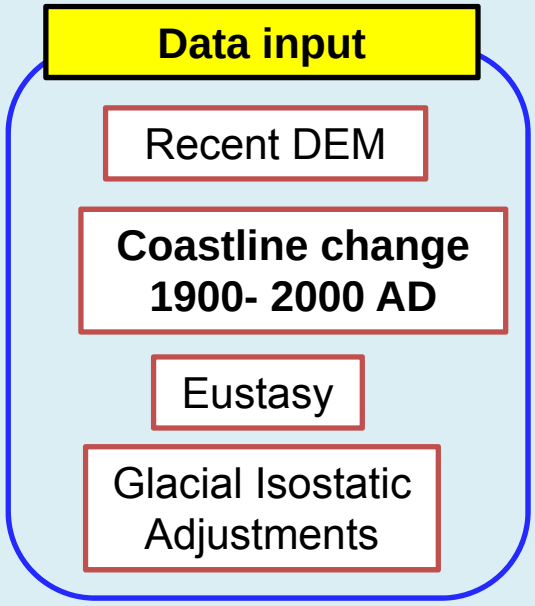
# What's Dynamic Equilibrium Shore Model ?

## Mass-balanced source-to-sink model




Semi-enclosed system: $Q_{LST,in} = Q_{LST,out} = 0$

# Modelling strategy of Dynamic Equilibrium Shore Model (DESM)



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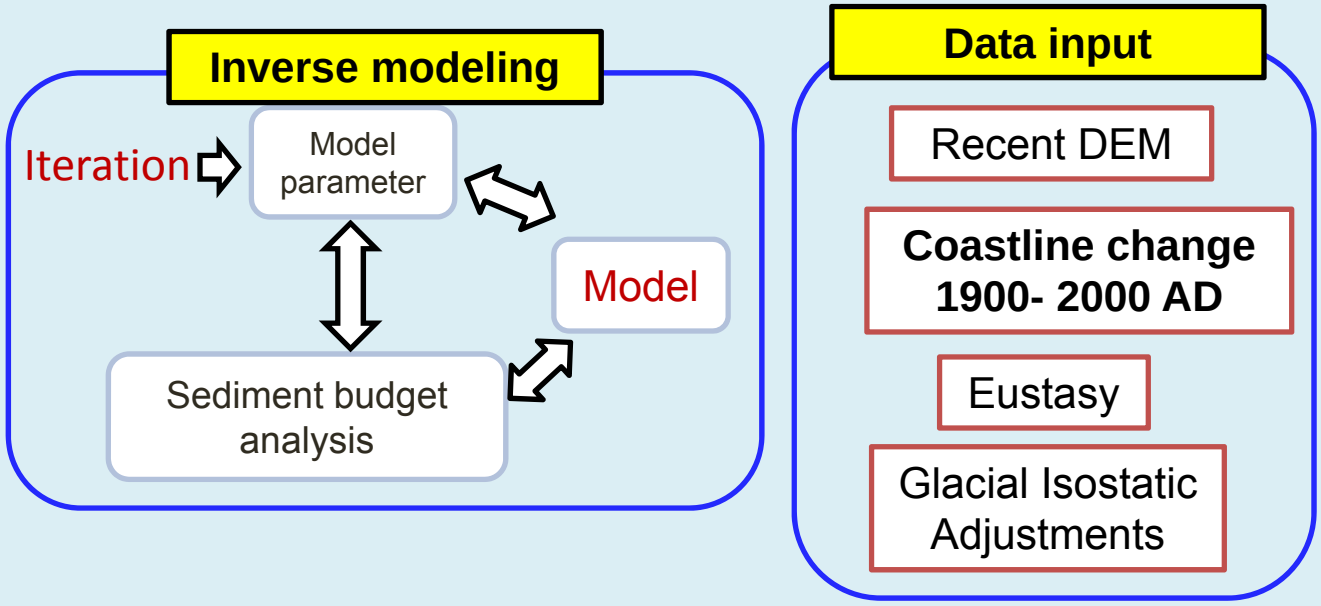

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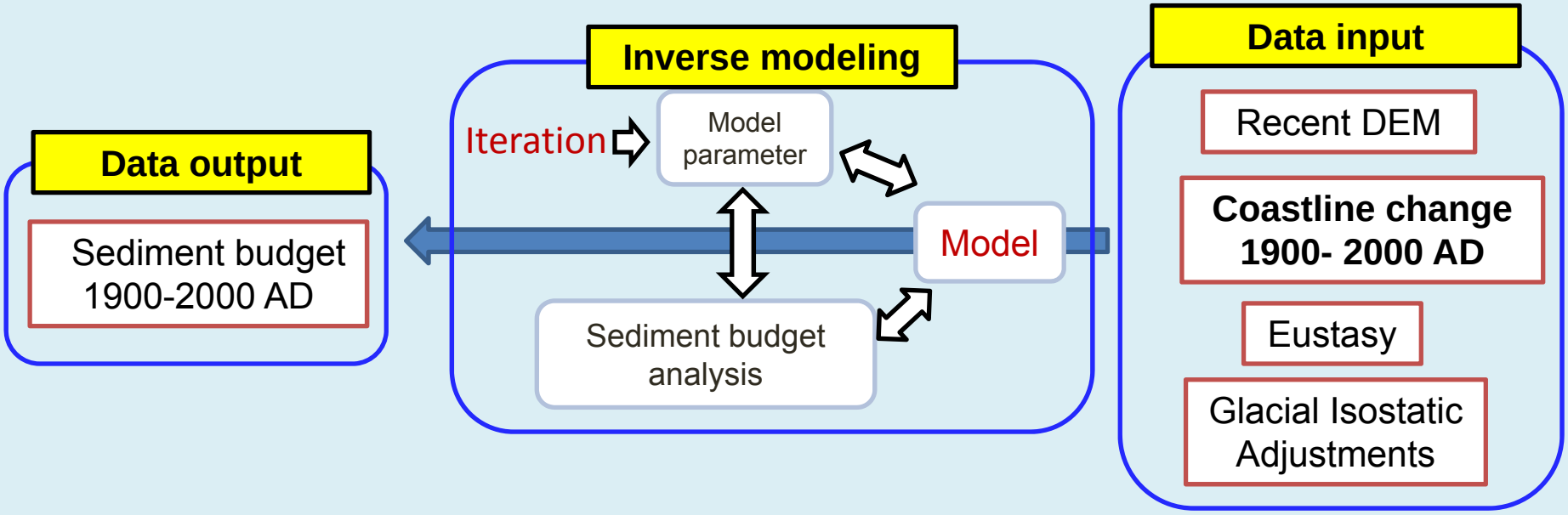

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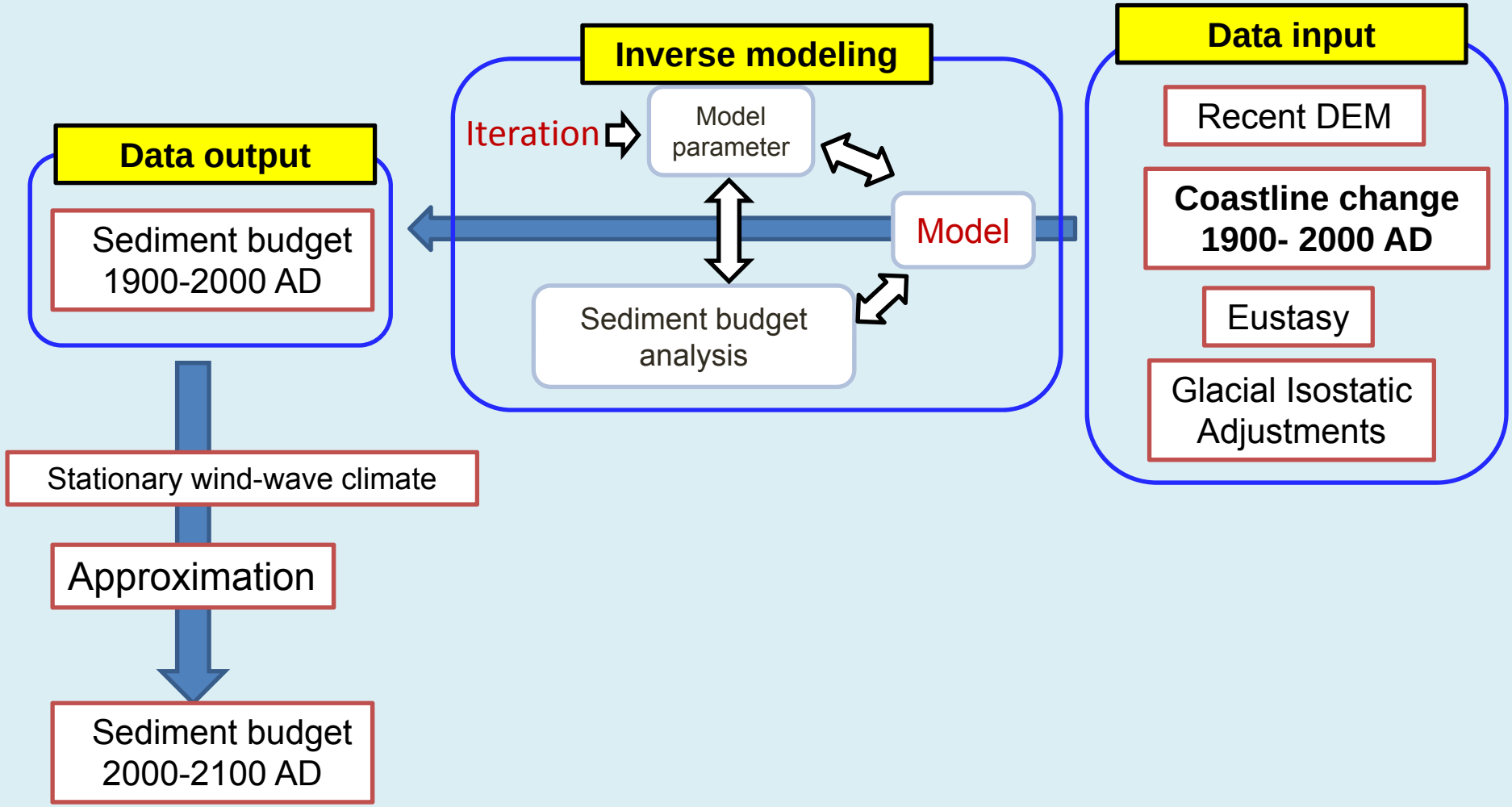

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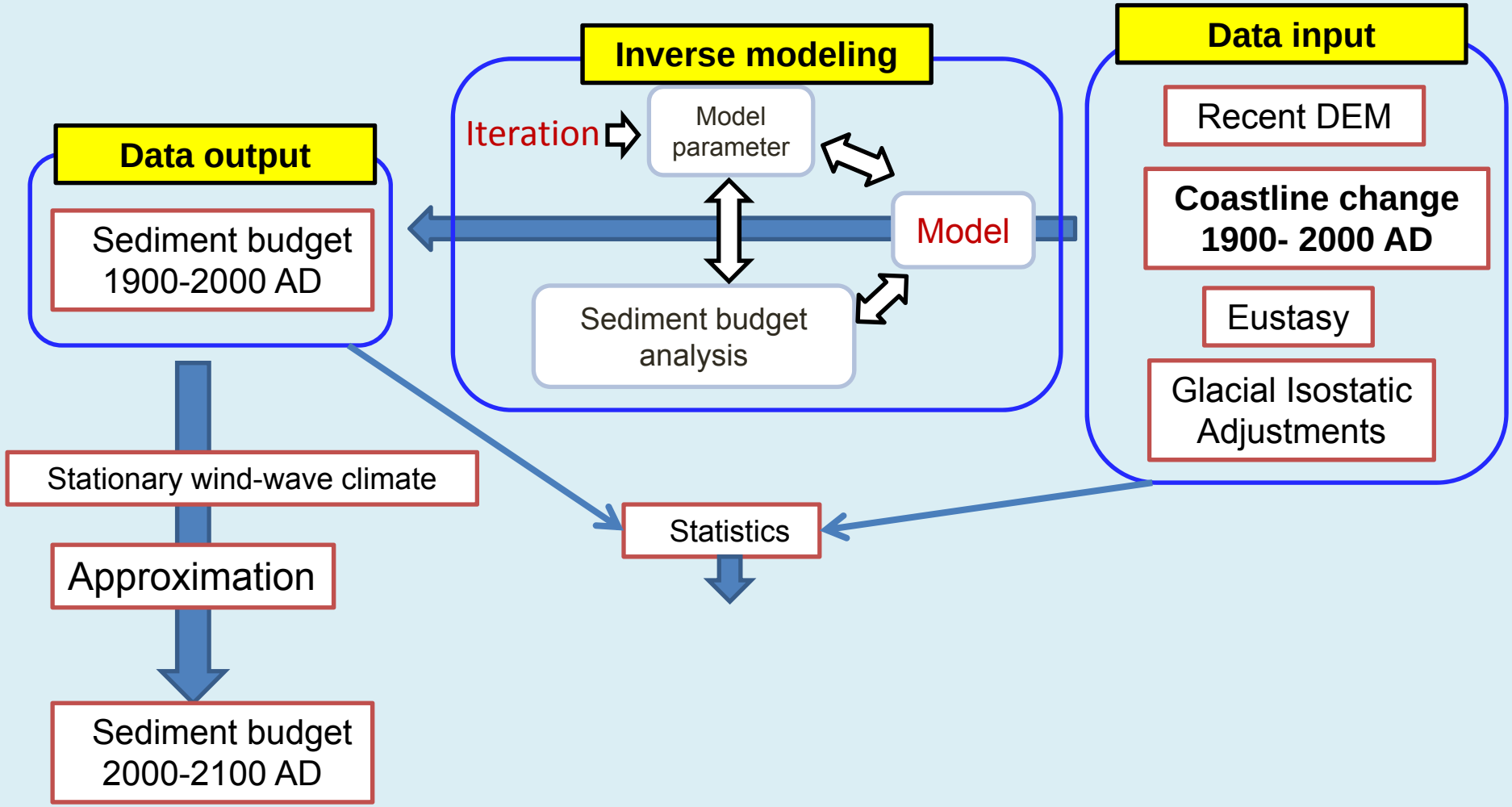

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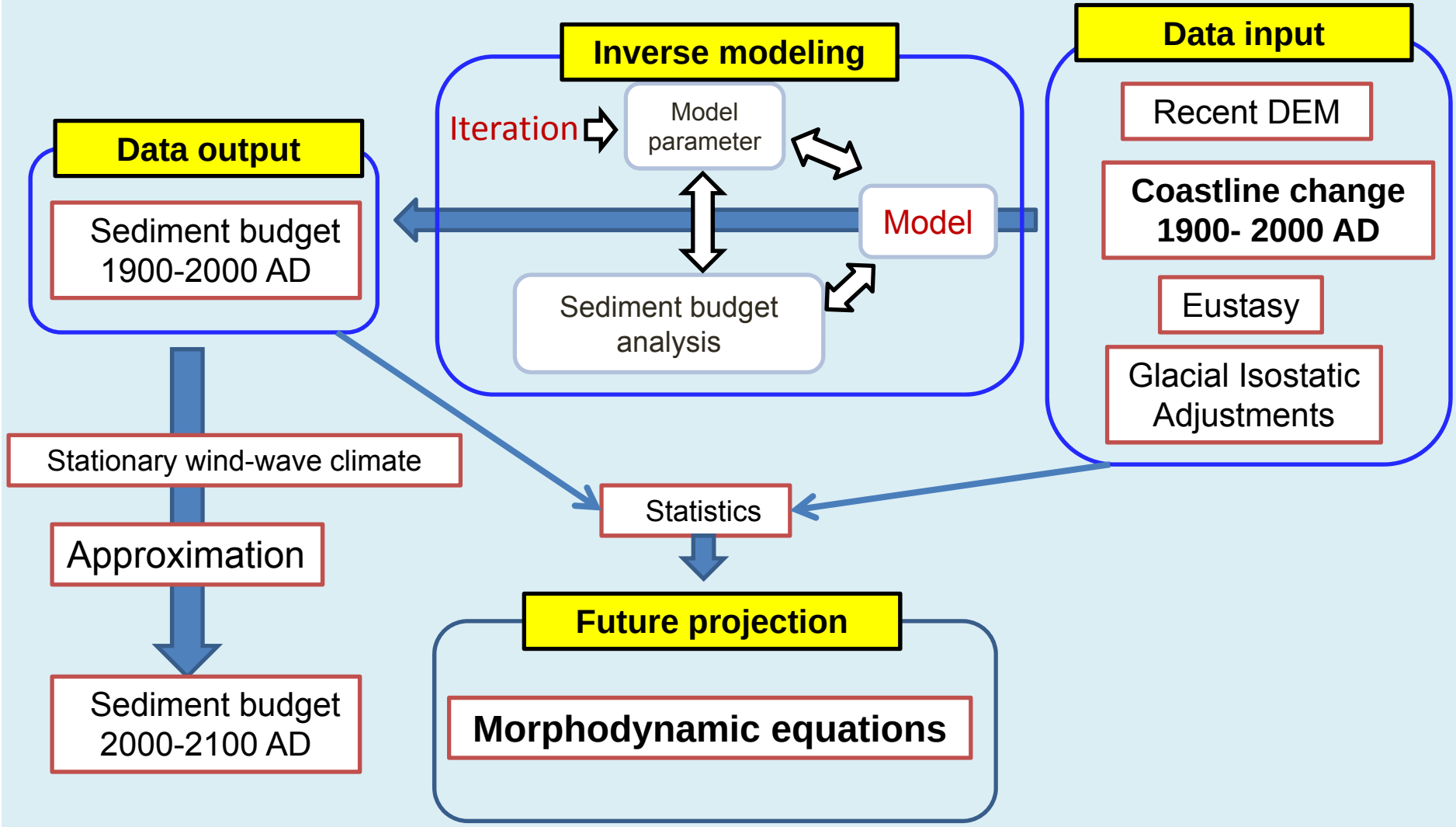
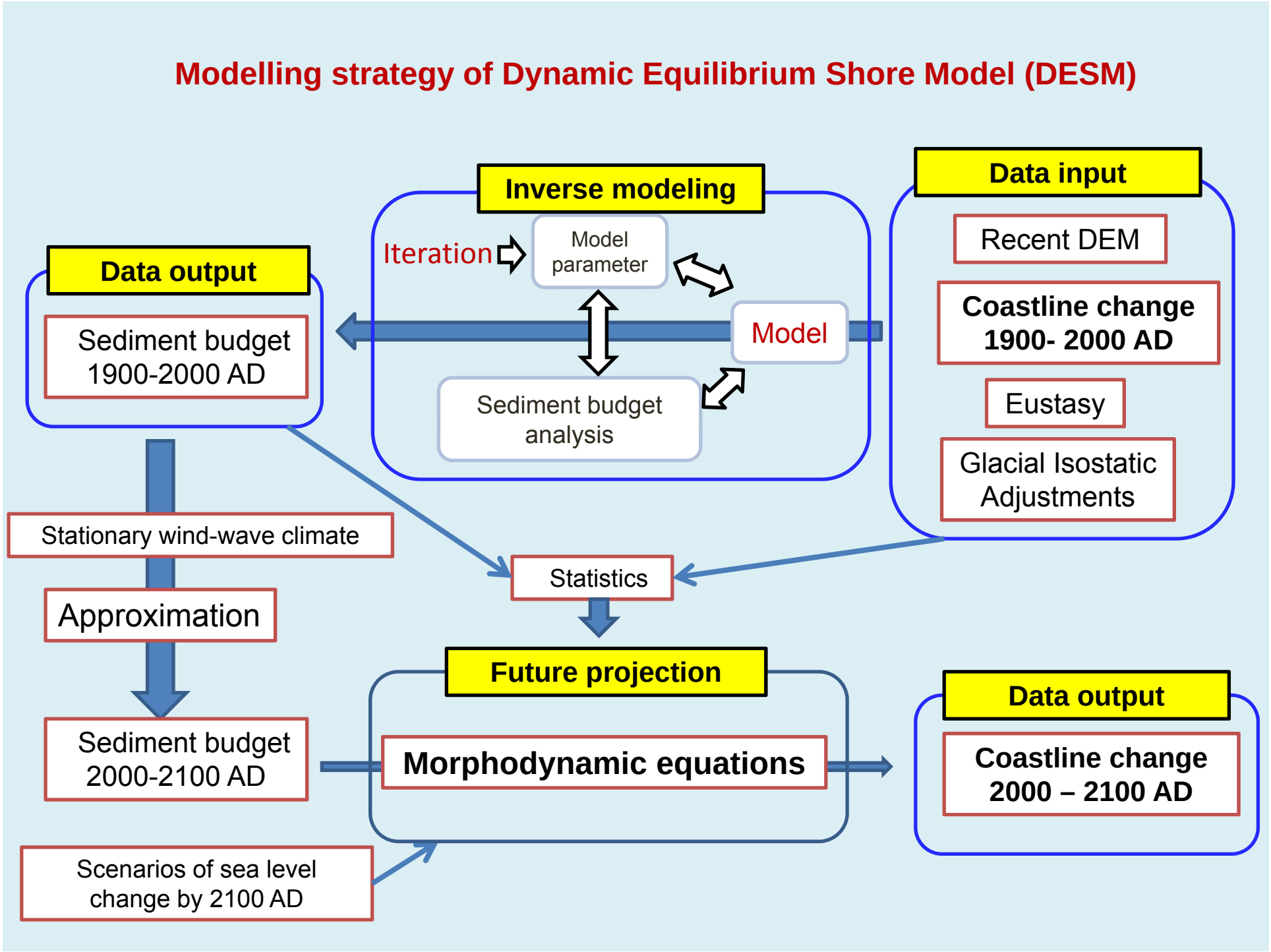



Modelling strategy of Dynamic Equilibrium Shore Model (DESM)
Inverse modeling
Iteration
Model parameter
Model
Sediment budget analysis
Data input
Recent DEM
Coastline change 1900- 2000 AD
Eustasy
Glacial Isostatic Adjustments
Data output
Sediment budget 1900-2000 AD
Stationary wind-wave climate
Approximation
Sediment budget 2000-2100 AD
Statistics
Future projection
Morphodynamic equations
Scenarios of sea level change by 2100 AD
Data output
Coastline change 2000 – 2100 AD

## **Predictive mode** of Dynamic Equilibrium Shore Model

$$(V_{external})_i - Q_x + Q_y = 0$$

## **Predictive mode** of Dynamic Equilibrium Shore Model

**Subaerial** sediment mass volume change

$$(V_{external})_i - Q_x + Q_y = 0$$

**Submarine** sediment mass volume change

Lateral sediment flux

## **Predictive mode** of Dynamic Equilibrium Shore Model

Length of cross-shore coastal profile

Relative sea level rise

$$V'_{external}(c) + s_i * l_i - Q_x + Q_y = 0$$

Coastline retreat distance

# **Predictive mode** of Dynamic Equilibrium Shore Model

Relative sea level rise

Length of cross-shore coastal profile

$$V'_{external}(c) + s_i * l_i - Q_x + Q_y = 0$$

$$V'_{external,i} = E * c_i + F$$

$$c_i (h_{cliff\_foot,i} + h_{cliff,i} + s_i/2)$$

# **Predictive mode** of Dynamic Equilibrium Shore Model

Relative sea level rise

Length of cross-shore coastal profile

$$V'_{external}(c) + s_i * l_i - Q_x + Q_y = 0$$

$$V'_{external,i} = E * c_i + F$$

$$c_i (h_{cliff\_foot,i} + h_{cliff,i} + s/2)$$

Paleo reconstruction by using iterative inverse modelling

## **Predictive mode** of Dynamic Equilibrium Shore Model

$$c_i = \frac{Q_{x,i} - F - s_i l_i}{(E + h_{cliff\_foot,i} + h_{cliff,i} + s/2)}$$

# **Predictive mode** of Dynamic Equilibrium Shore Model

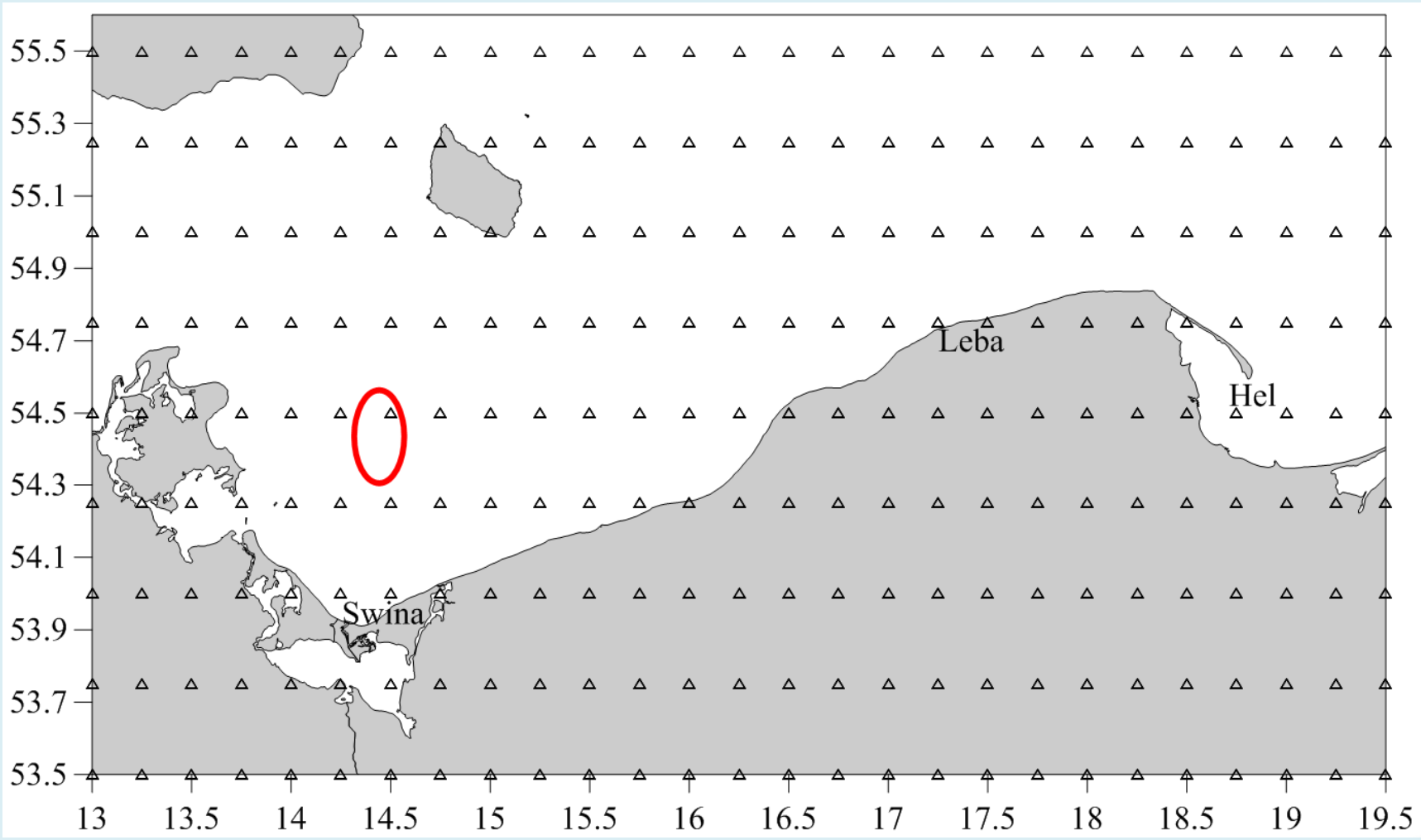
$$c_i = \frac{Q_{x,i} - F - s_i l_i}{(E + h_{cliff\_foot,i} + h_{cliff,i} + s/2)}$$

$|c_i * h_*| = |s_i l_i|$ *Bruun rule model*

**Climate model**:

Swedish Meteorological and Hydrological Institute (SMHI): RCAO

Meier et al. (2011)



**Climate model**:
Swedish Meteorological and Hydrological Institute (SMHI): RCAO
Meier et al. (2011)

| Scenarios | Forcing boundary :GCMs/ERA40 | Emission Scenarios | Time span |
|---|---|---|---|
| 1 | ECHAM5 (MPI-met, Germany) | A1B | 1960-2100 |
| 2 | HadCM3 (Hadley Centre, UK) | A1B | 1960-2100 |
| 3 | ECHAM5(MPI-met, Germany) | A2 | 1960-2100 |

**Climate model**:
Swedish Meteorological and Hydrological Institute (SMHI): RCAO
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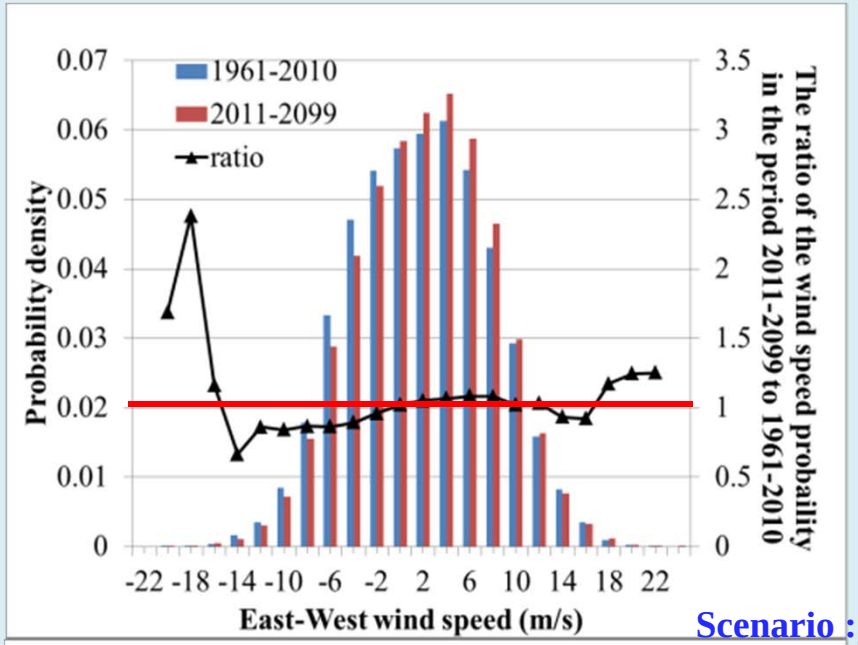
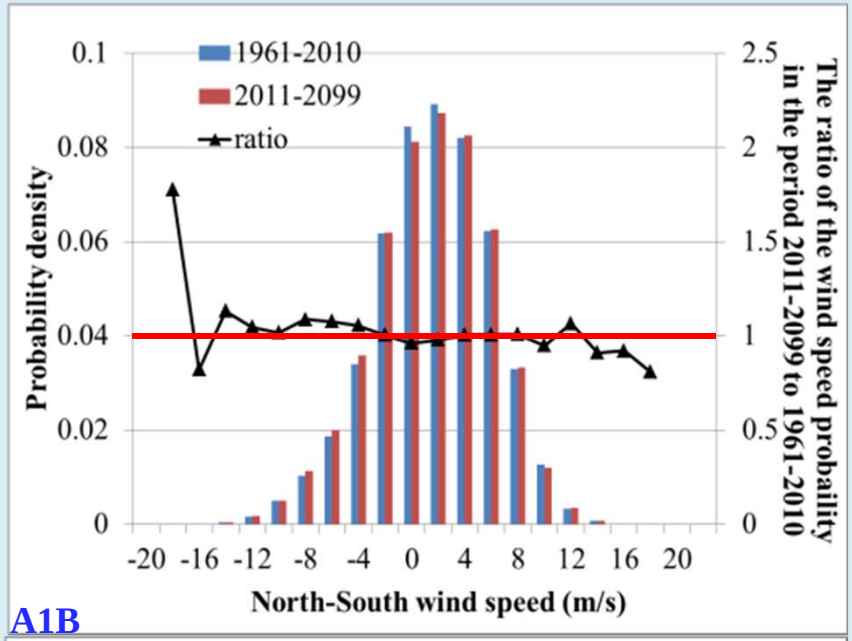
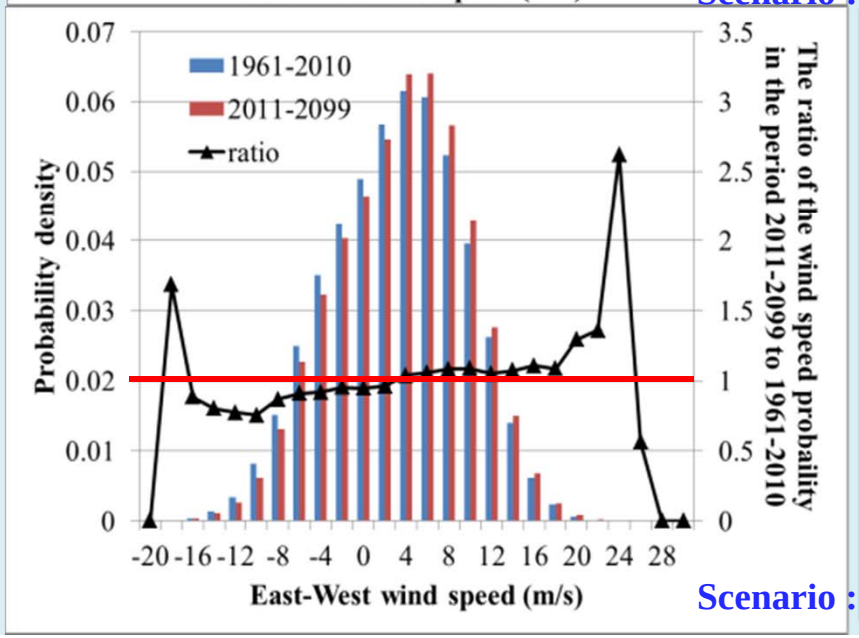
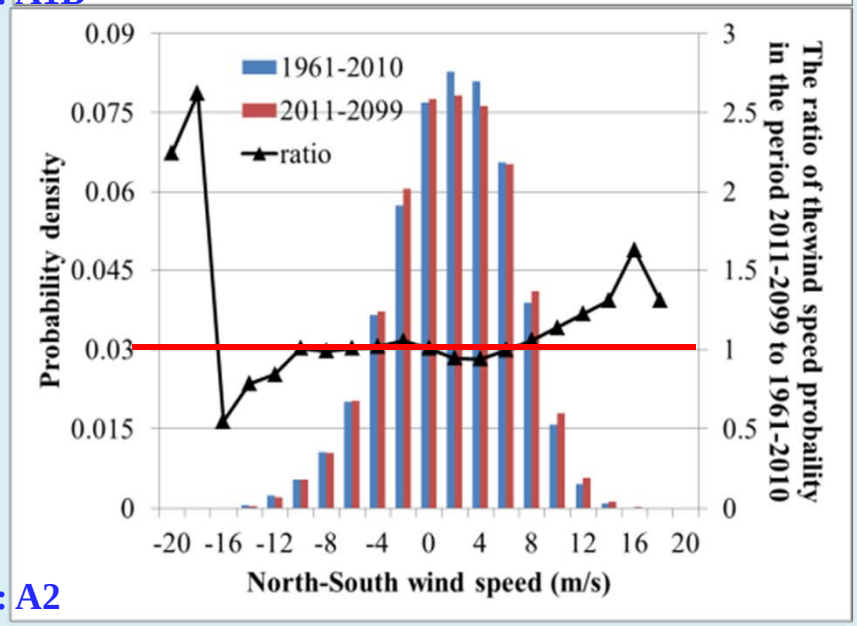
# Future projection of **wind climate change: wind speed**



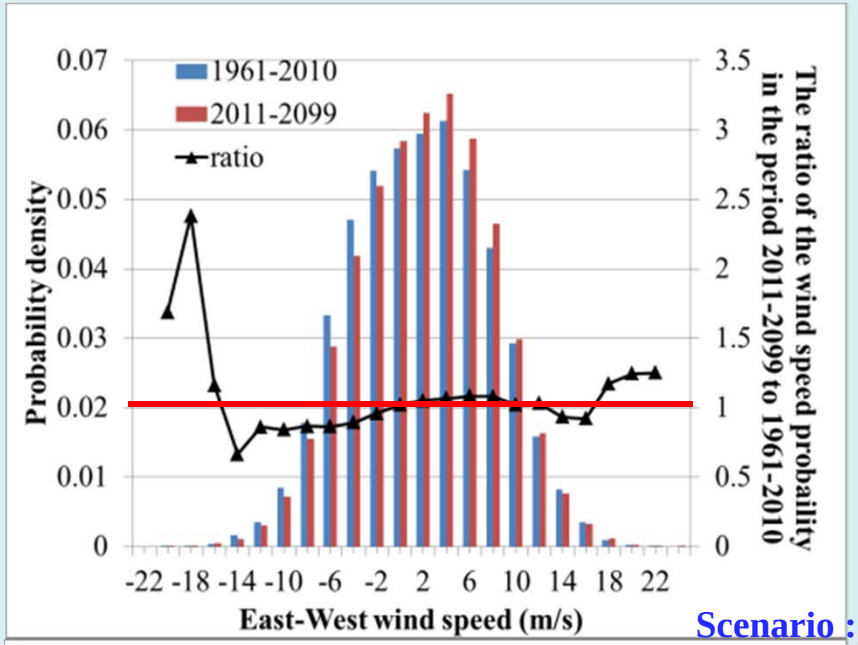

**Scenario : A1B**

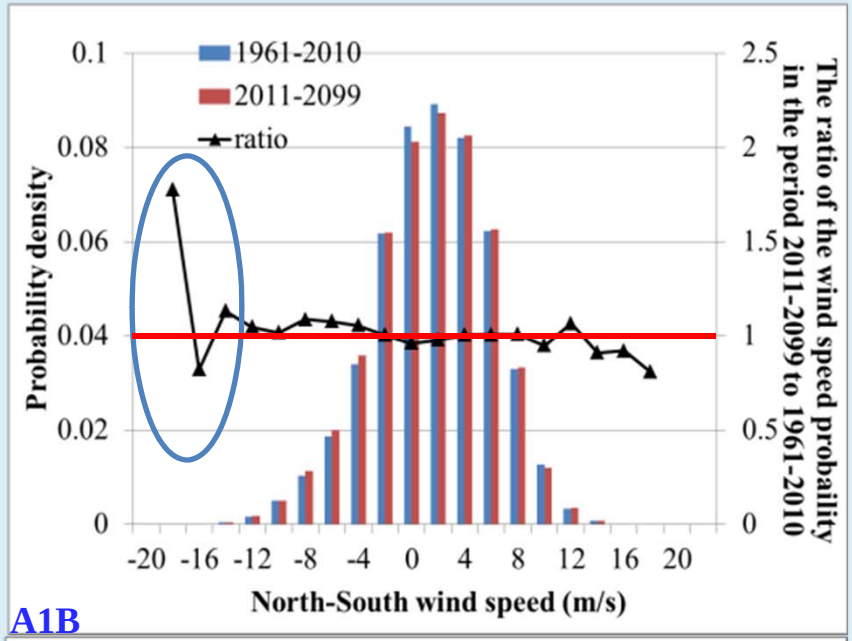


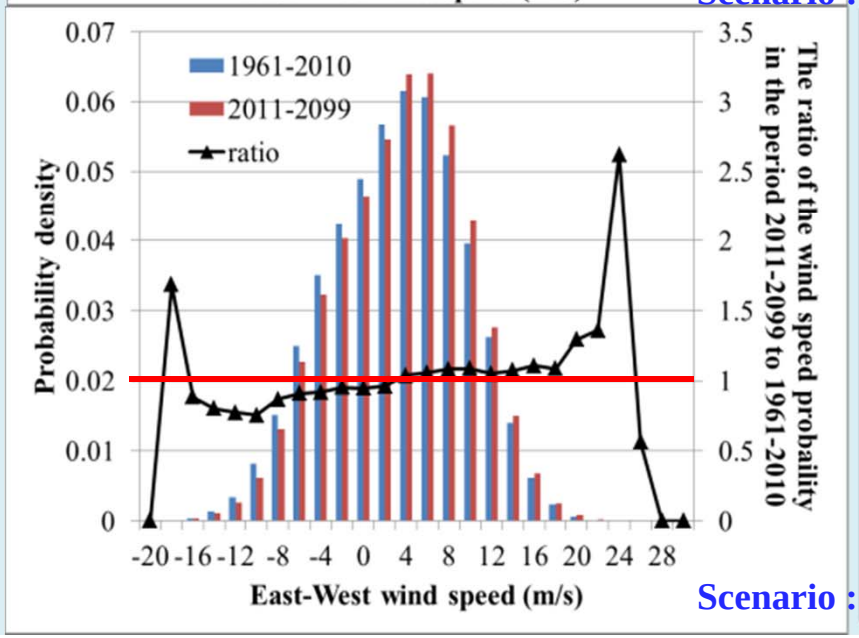

**Scenario : A2**

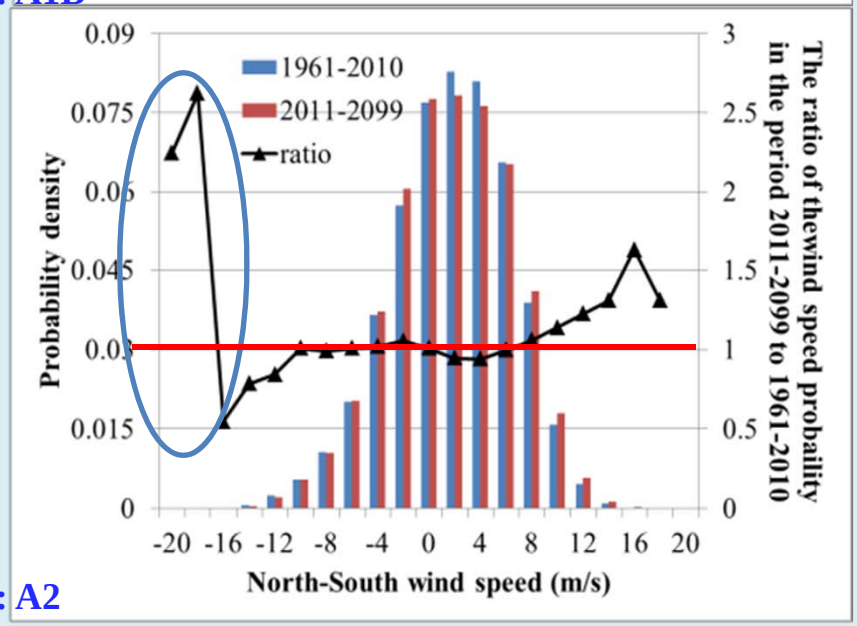
# Future projection of **wind climate change: wind speed**




**Scenario : A1B**



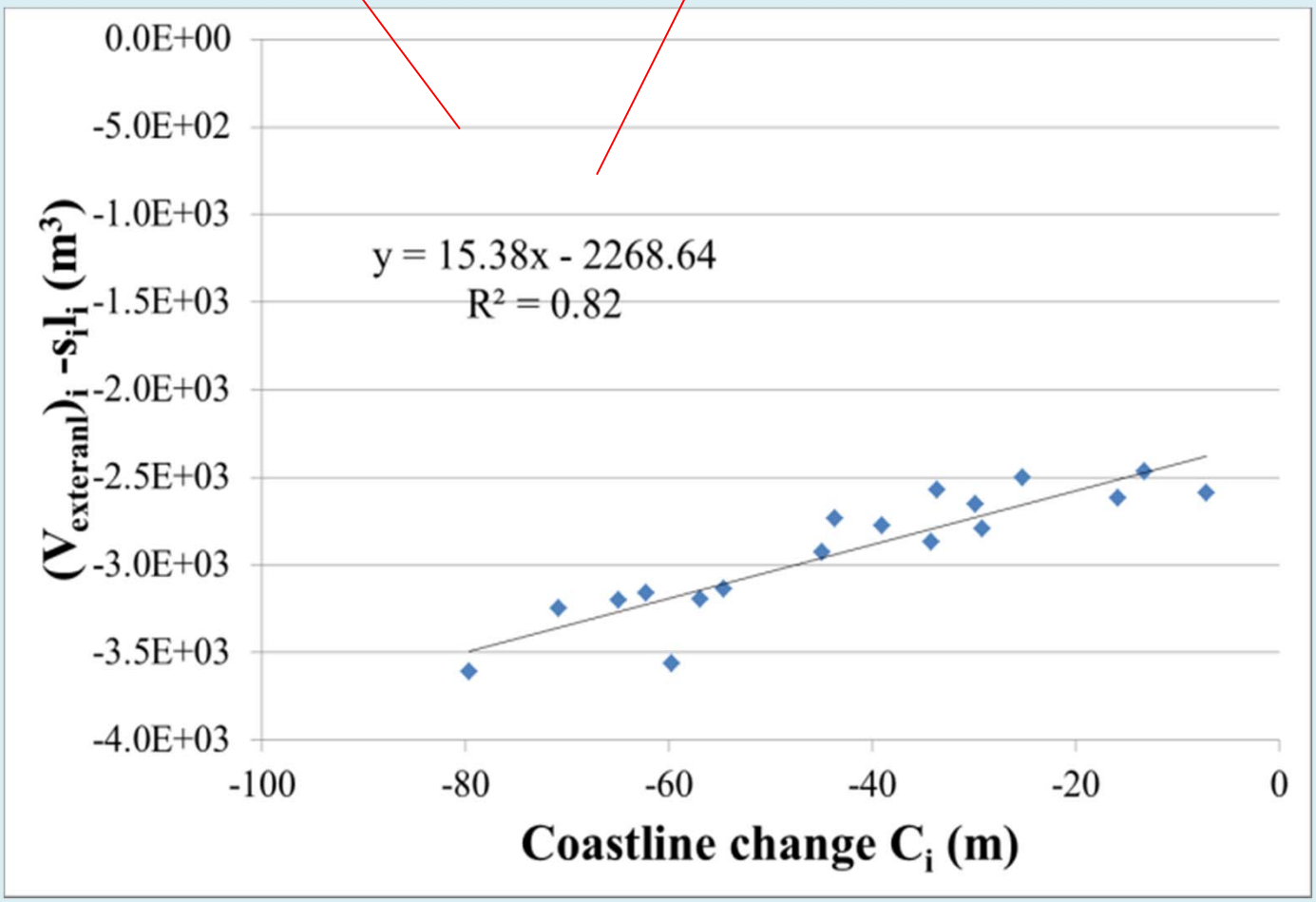

**Scenario : A2**

# For the future projection of coastline changes by 2100 AD

Lateral sediment flux ~1900 – 2000 AD

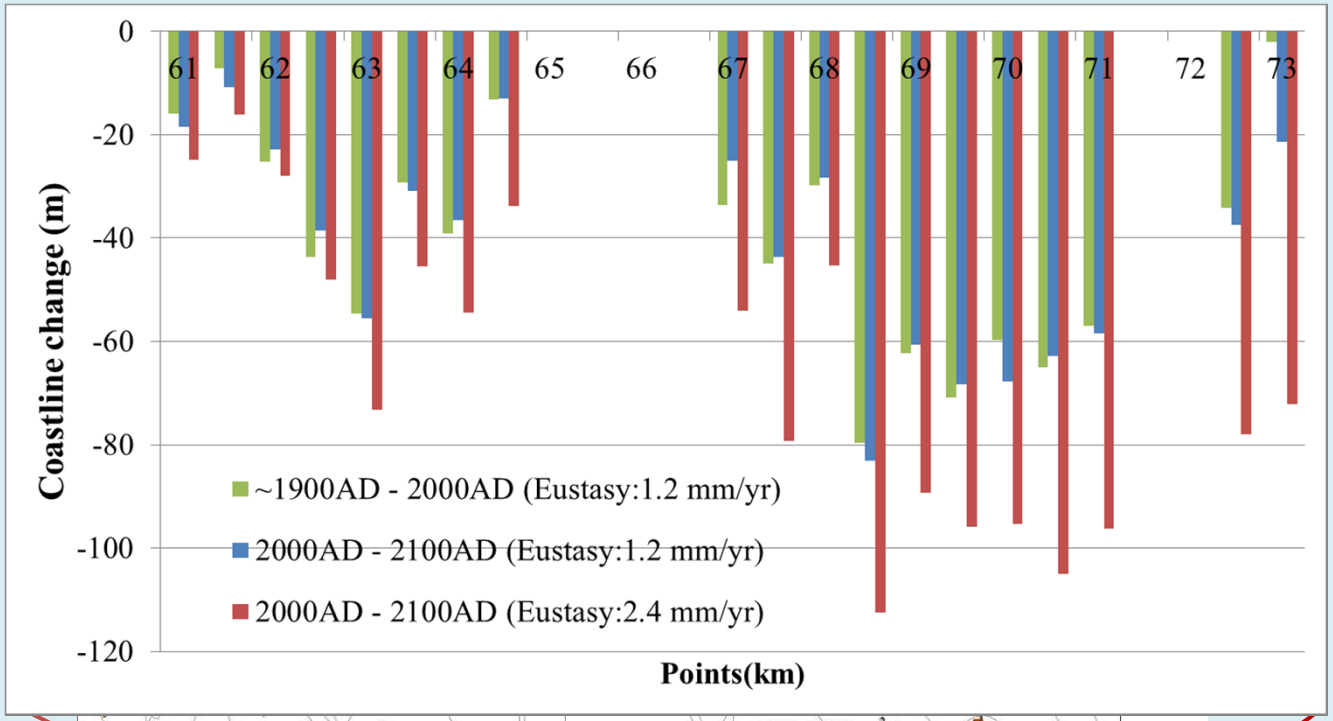
$$c_i = \frac{Q_{x,i} - F - s_i l_i}{(E + h_{cliff\_foot,i} + h_{cliff,i} + s/2)}$$

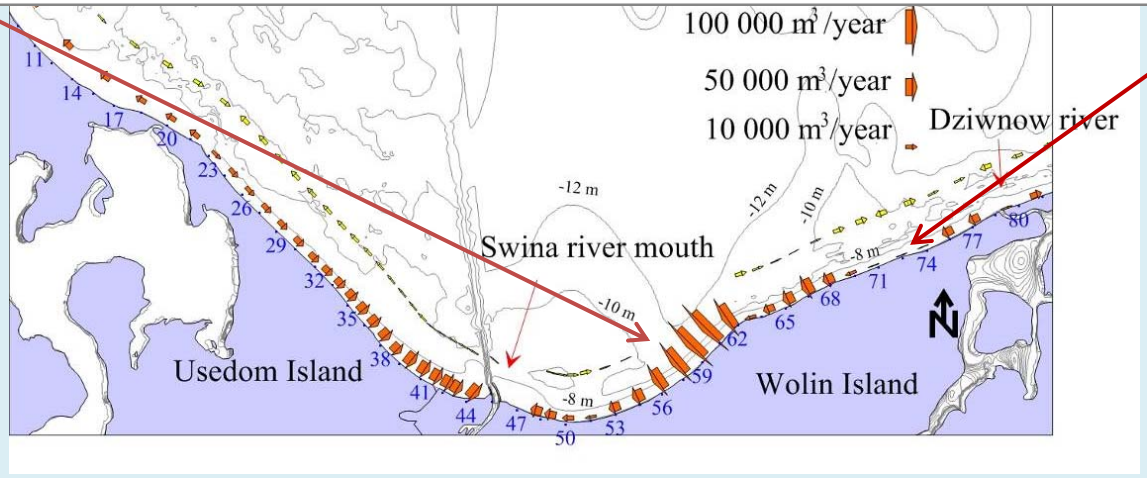
$$c_i = \frac{Q_{x,i} - F - s_i l_i}{(E + h_{cliff\_foot,i} + h_{cliff,i} + s/2)}$$



# Future projection of coastline changes

## 2000AD - 2100AD with eustatic sea level rise of 0.12 m and 0.24m



# Comparison with other equilibrium models

1. Modified Bruun rule model by Bray and Hooke (1997):

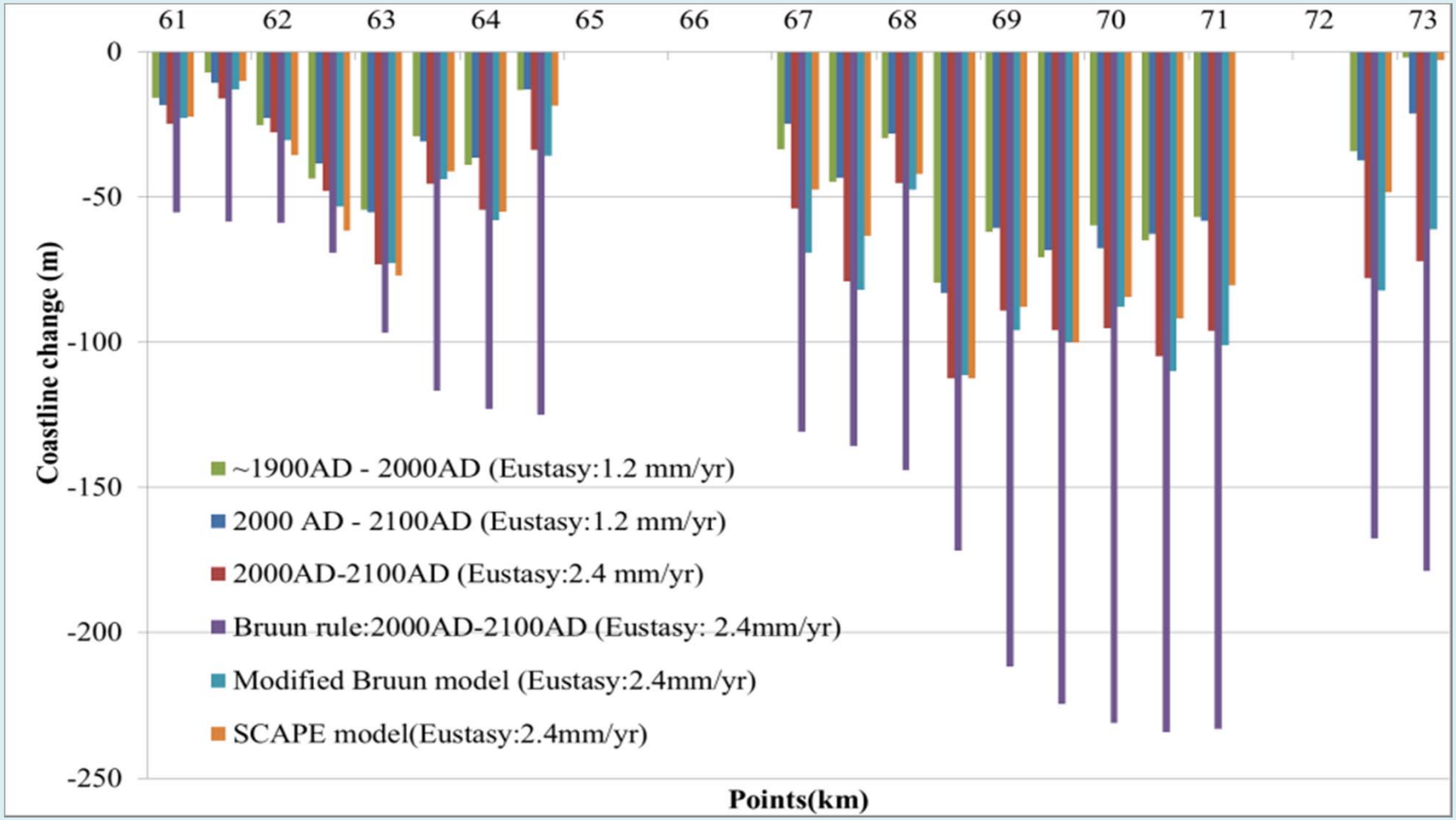
$$R_2 = R_1 + \frac{(S_2 - S_1)L}{P(B + h_*)}$$

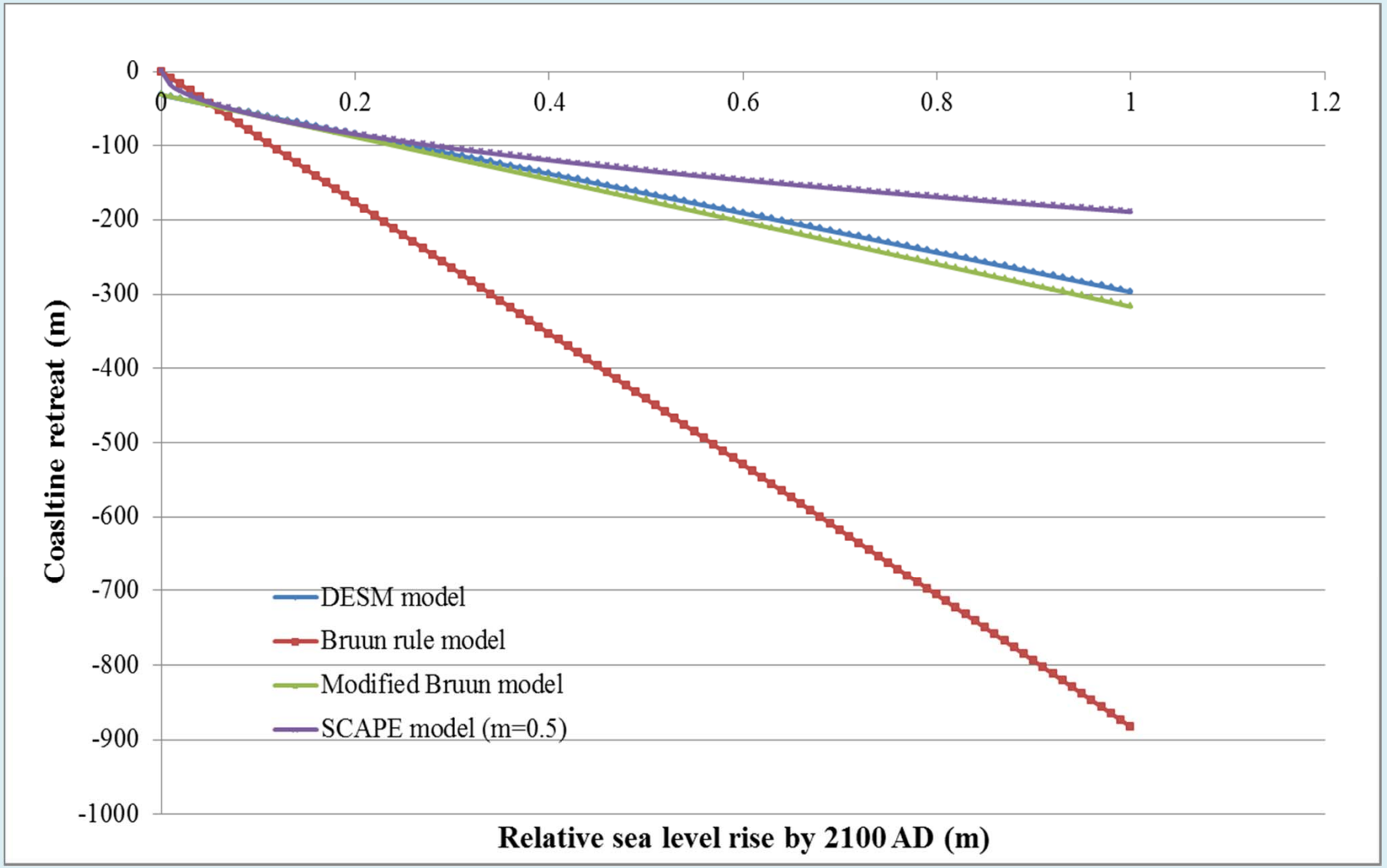
where P is the proportion (here, is 1 ) of cliff sediment that remains within the active profile (% sand and gravel) and B is cliff elevation; $R_1$ is historic retreat rate and $S_1$ is historical relative sea level rise; $R_2$ is future retreat rate and $S_2$ is future relative sea level rise.

2. SCAPE model (m=0.5) by Walkden and Dickson (2008):

$$R_2 = R_1\left(\frac{S_2}{S_1}\right)^m$$

where $R_1$ and $R_2$ are historic and future retreat rates, and $S_1$ and $S_2$ are historical and future relative sea level rises.


61
62
63
64
65
66
67
68
69
70
71
72
73
0
-50
-100
-150
-200
-250
Coastline change (m)
~1900AD - 2000AD (Eustasy:1.2 mm/yr)
2000 AD - 2100AD (Eustasy:1.2 mm/yr)
2000AD-2100AD (Eustasy:2.4 mm/yr)
Bruun rule:2000AD-2100AD (Eustasy: 2.4mm/yr)
Modified Bruun model (Eustasy:2.4mm/yr)
SCAPE model(Eustasy:2.4mm/yr)
Points(km)


0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0
0.2
0.4
0.6
0.8
1
1.2
Coasltine retreat (m)
Relative sea level rise by 2100 AD (m)
DESM model
Bruun rule model
Modified Bruun model
SCAPE model (m=0.5)

# Conclusions

- The model DESM is also capable for the future projection as a first-order three dimensional prediction.
- The predictive mode of the DESM model is developed based on paleo-scenarios reconstructed by the DESM model.
- The predictive mode of the DESM model provides a first-order three dimensional projection of coastline changes. The impact of sea level rise is determined by the ratio between the lateral sediment flux and the ccommodation space evolving from relative sea level rise.
- The result indicates that the impact of accelerated sea level rise is significant especially when thelateral sediment flux is relative small.


University of Szczecin, Co-ordinator: Prof. Dr. Jan Harff (jan.harff@univ.szczecin.pl)

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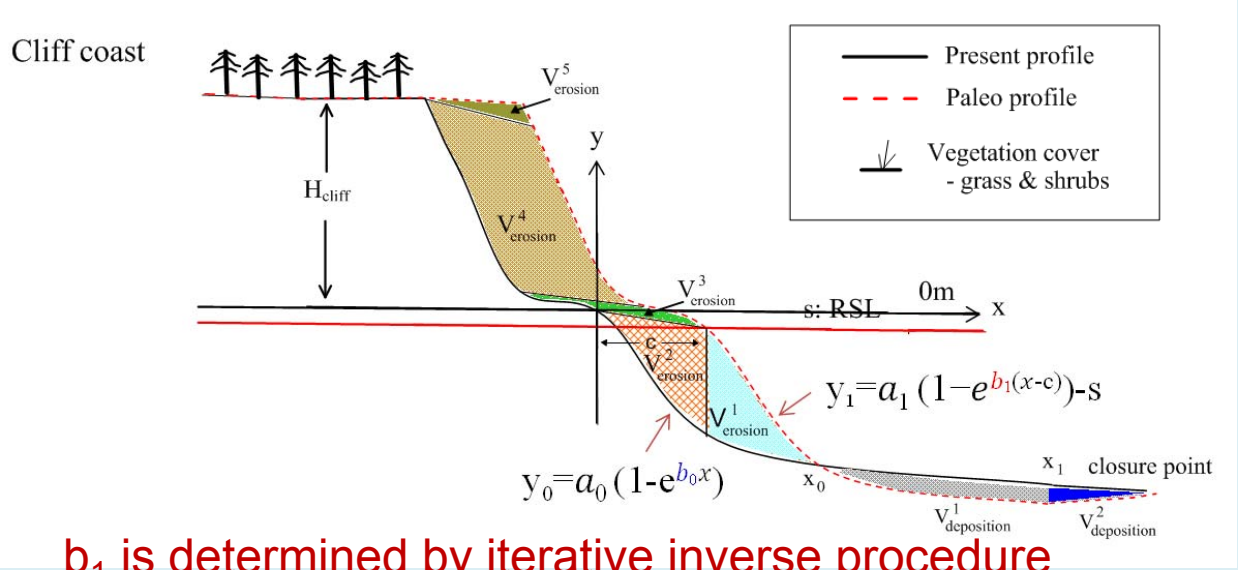
# Thank you !

# Sediment budget estimation




$b_1$ is determined by iterative inverse procedure

Lateral sediment flux

$$Q_{lst} = V^1_{erosion} + V^2_{erosion} + V^3_{erosion} + V^4_{erosion} + V^5_{erosion} - V^1_{deposion} - V^2_{deposion}$$