Submarine Groundwater Discharge (SGD) and its impacts on coastal environments

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Baltic Earth
Earth System Science for the Baltic Sea Region

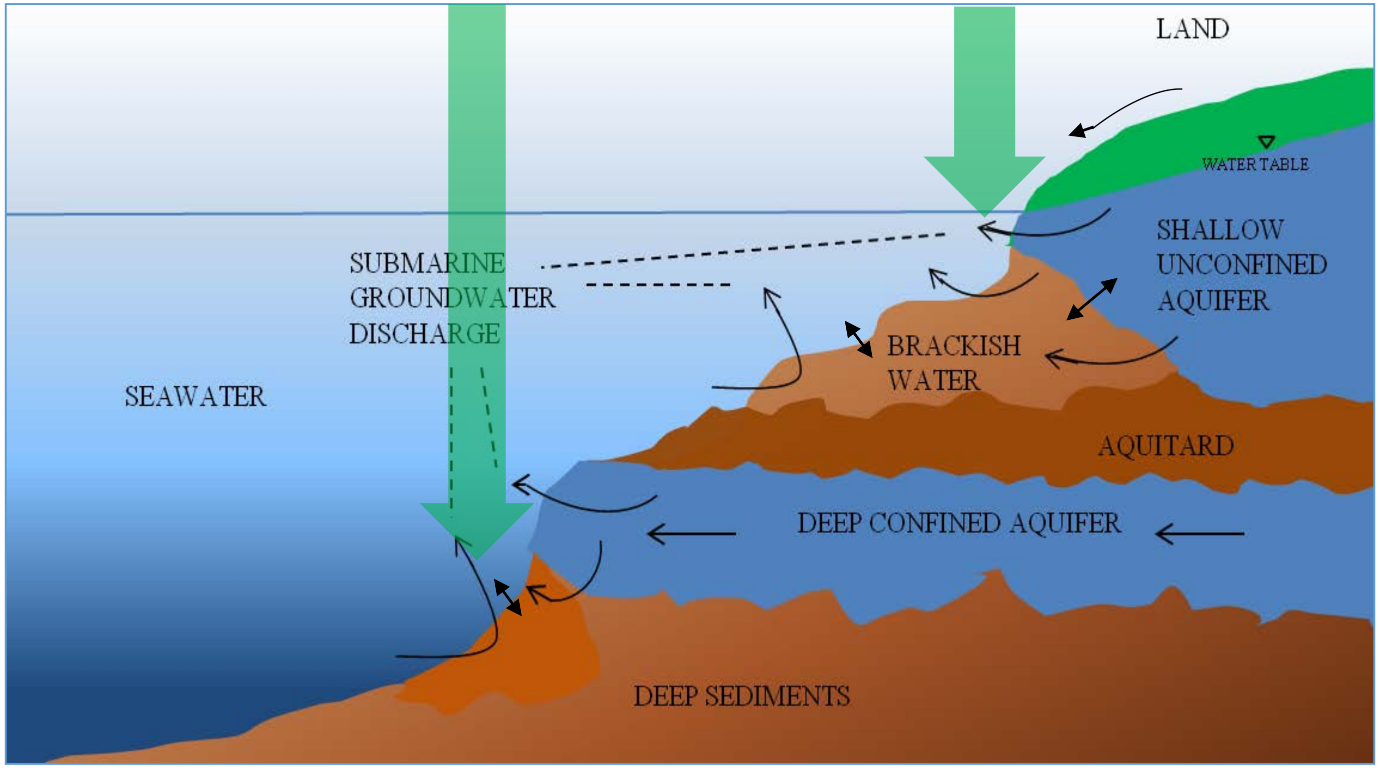
Multiple drivers for Earth system changes in the Baltic Sea region

Tallinn University of Technology, Tallinn, Estonia
26- 27 November 2018

Submarine groundwater discharge SGD

Deep SGD
up to several tens km from the coastline

Coastal SGD
shallow (<20 m) and narrow (<5 km) zones along the coastline



Modified after Burnett, 2006

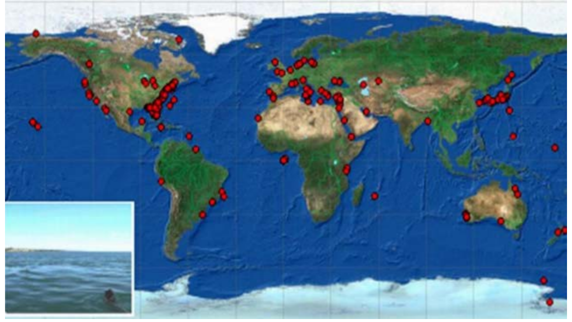
Submarine groundwater discharge SGD - global perspective

SGD source of:

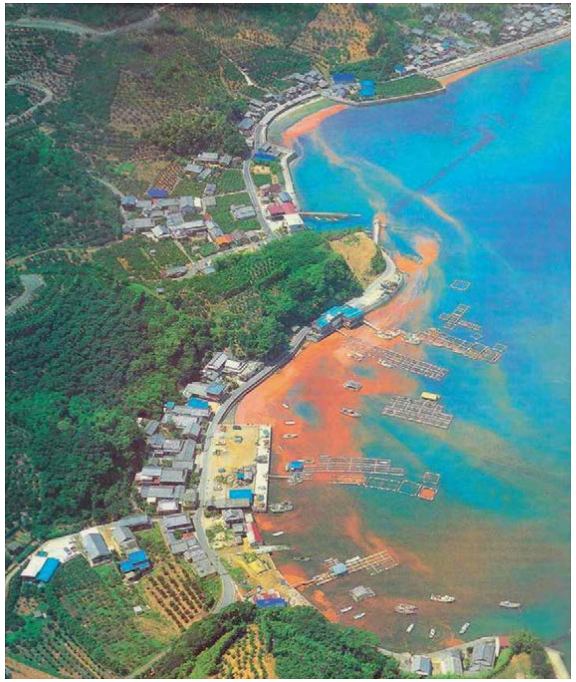
1. Freshwater/Saline water
2. Chemical substances

(nutrients, dissolved carbon, metals, isotopes)

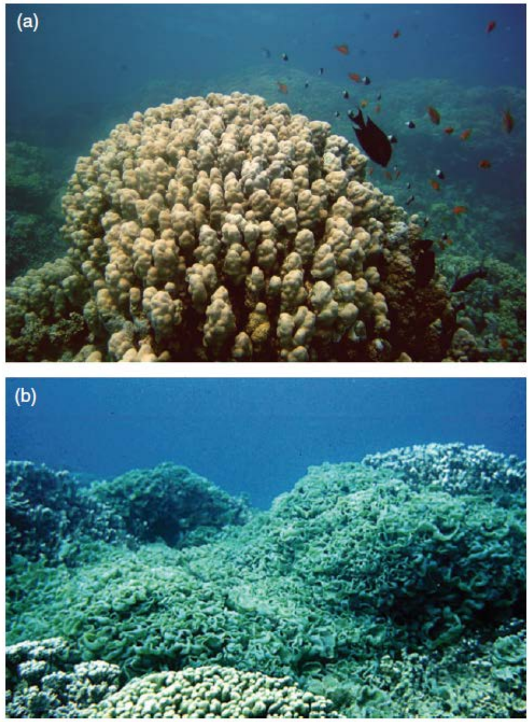
Burnett i in. 2003



www.iaea.org



Knee i Payton, 2011

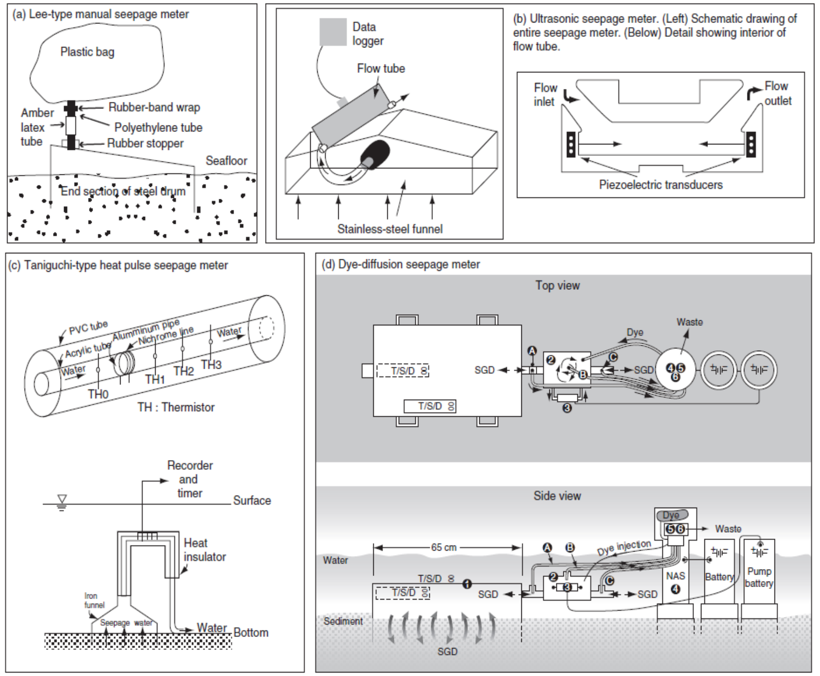


Parsons i in. 2008

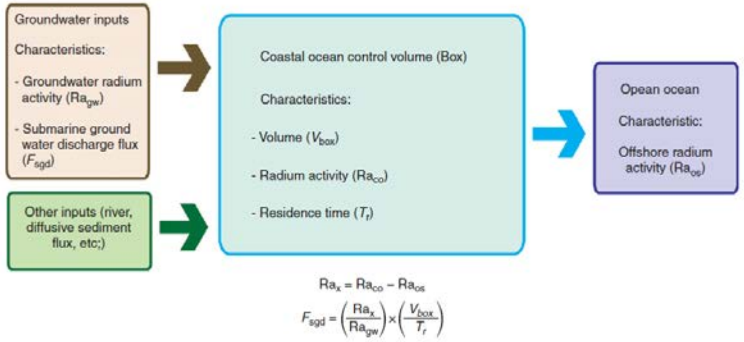
Moosdorf and Oehler 2017

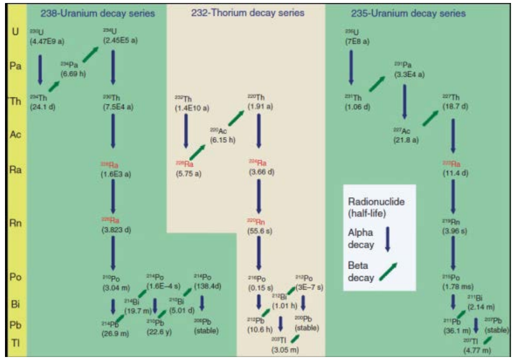
Methods used to measure SGD:

seepage metres, piezometers, natural tracers, infrared imaging, GIS topology, hydrologic approach, mathematical models



Seepage meters





Natural tracers

Mass balance approach

$P = E_T + D_S + D_g + dS.$

where P is precipitation, is E_T evapotranspiration, D_S is surface discharge, D_G is groundwater discharge and dS is the change in water storage

The greatest challenges in SGD research :

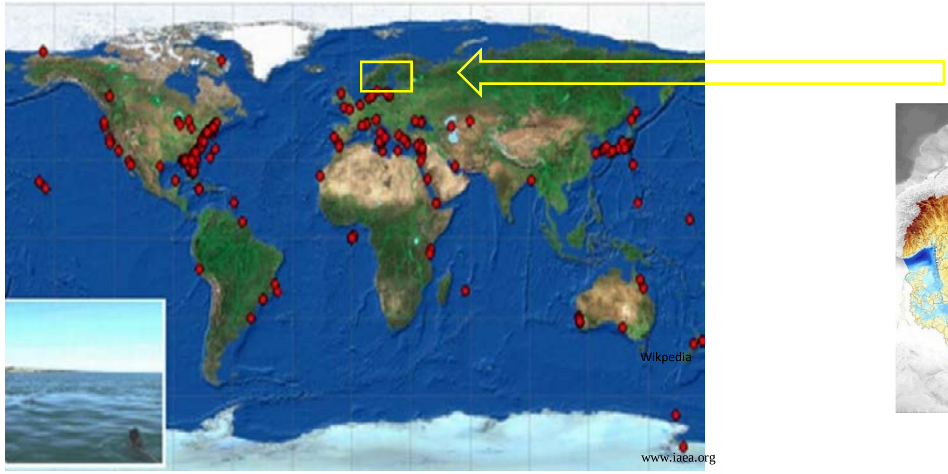
1. reducing the uncertainty in SGD estimates
2. understanding how and why SGD measurement methods differ in order to choose the best method for a particular situation
3. understanding the importance of SGD on a big scale, including spatial variability.

Brief characterization of the Baltic Sea:

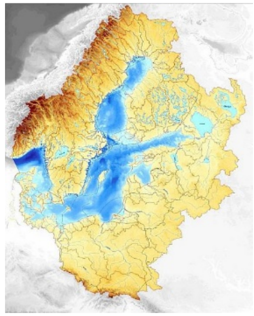
- total surface area - 415,240 km^2 (including the Danish Sounds and Kattegat)
- catchment area - 1,729,000 km^2
- mean runoff (1950-2012)14,204 m^{3}s^{-1}
- severely polluted

SGD $_{fresh}$ 139 m^{3}s^{-1} (Peltonen, 2002)

Total Baltic Sea runoff ~14 232 m^{3}s^{-1} (Helcom, 2016)



Baltic Sea



http://www.baltex-research.eu/

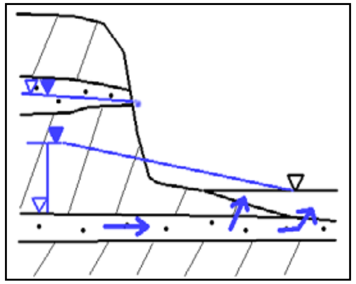
Should we care about SGD in the Baltic Sea?

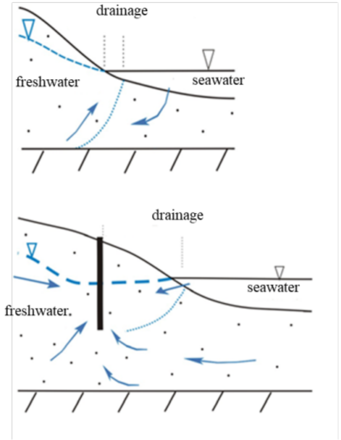
Could SGD be an important driver for ecosytem change in the Baltic Sea?

Coastal SGD- antropogenic impact

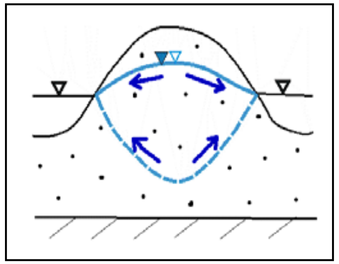
Deep SGD- natural impact

Cliffs

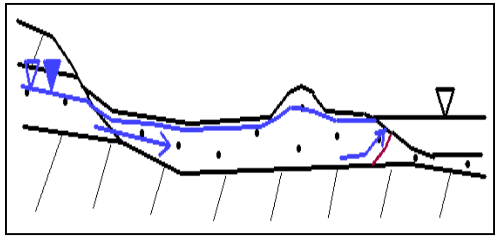


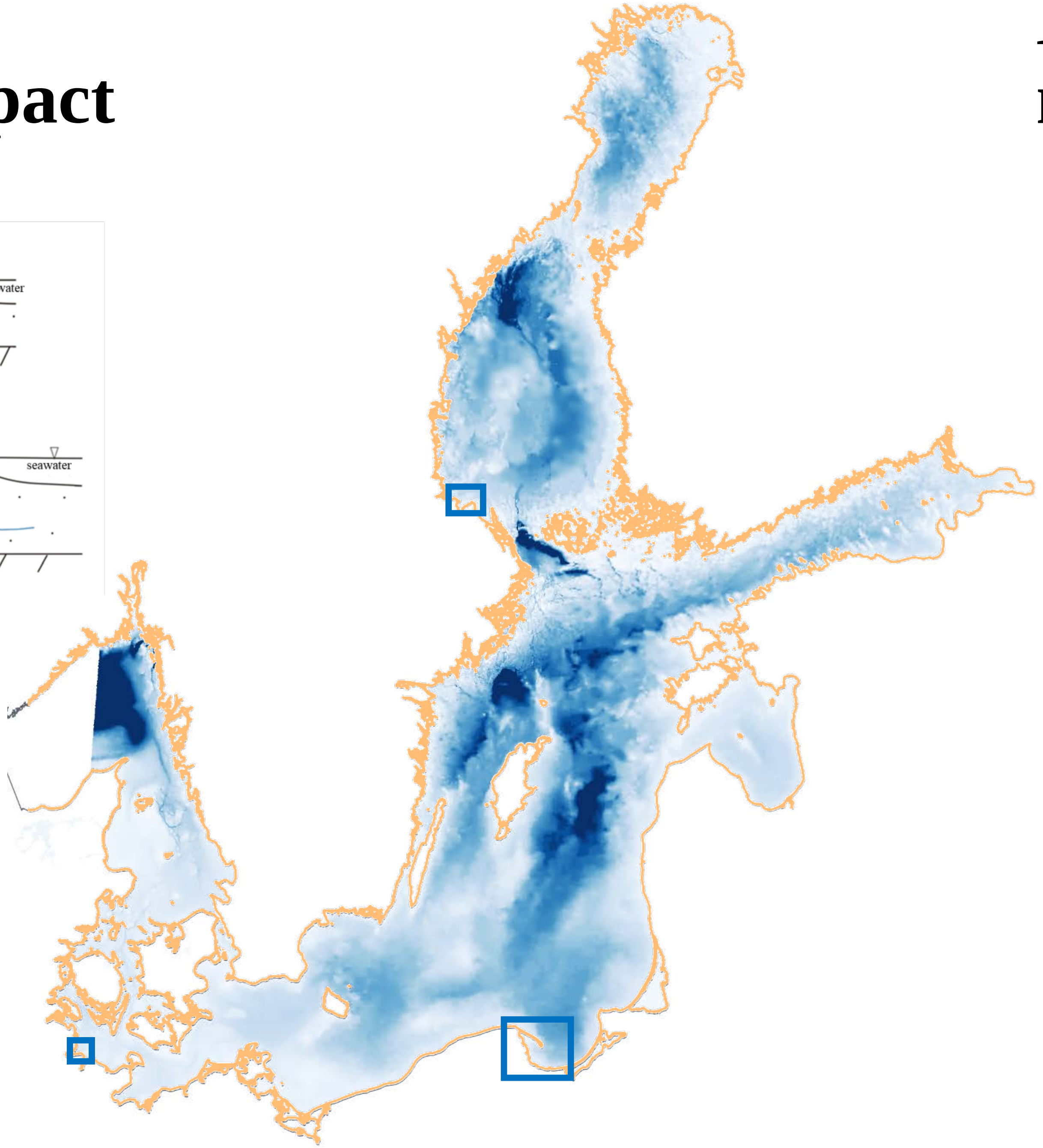


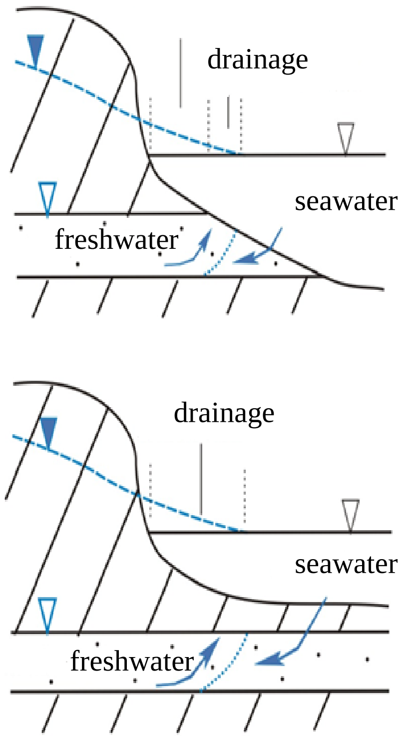
Spits



Lowlands







SGD disharge rates- Bay of Puck example

- **Hydrologic model (Bay of Puck)**

SGD $_{fresh}$ **10^{-5} (m^3 h^{-1} m^{-2})**

Piekarek-Jankowska, 1994

- **Filtrometer and gradientmeter (9 sites within Bay of Puck)**

SGD $_{fresh}$ **0.3-13.5 (m^3 h^{-1} m^{-2}) (???)**

Bublijewska et al., 2017

- **Seepage metre (1 site off Hel)**

SGD $_{fresh\ and\ saline}$ **10^{-4} -10^{-3} (m^3 h^{-1} m^{-2})**

Szymczycha et al., 2012

SGD $_{fresh}$ **10^{-5} -10^{-4} (m^3 h^{-1} m^{-2})**

Szymczycha et al., 2012

SGD disharge rates- Bay of Bothnia/ Forsmark area

- **Hydrologic model (Forsmack area)**

  SGD $_{fresh}$ **10^{-4} (m^3 h^{-1} m^{-2})**

  Jarsjö et al. 2008

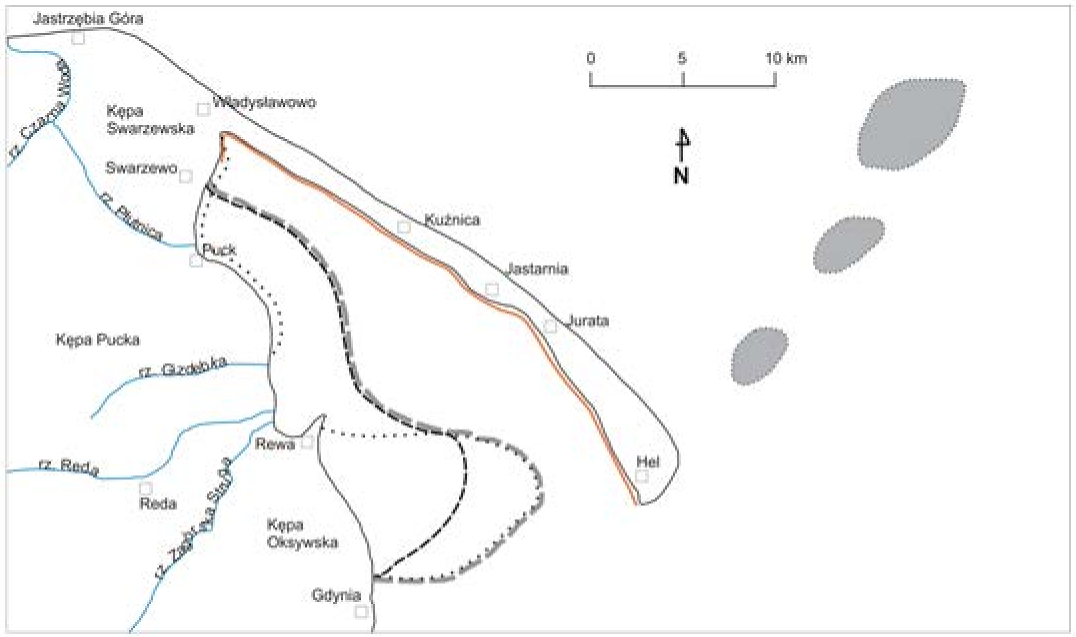
- **Ra isotops (Forsmack area)**

  SGD $_{fresh}$ **10^{-4} (m^3 h^{-1} m^{-2})**

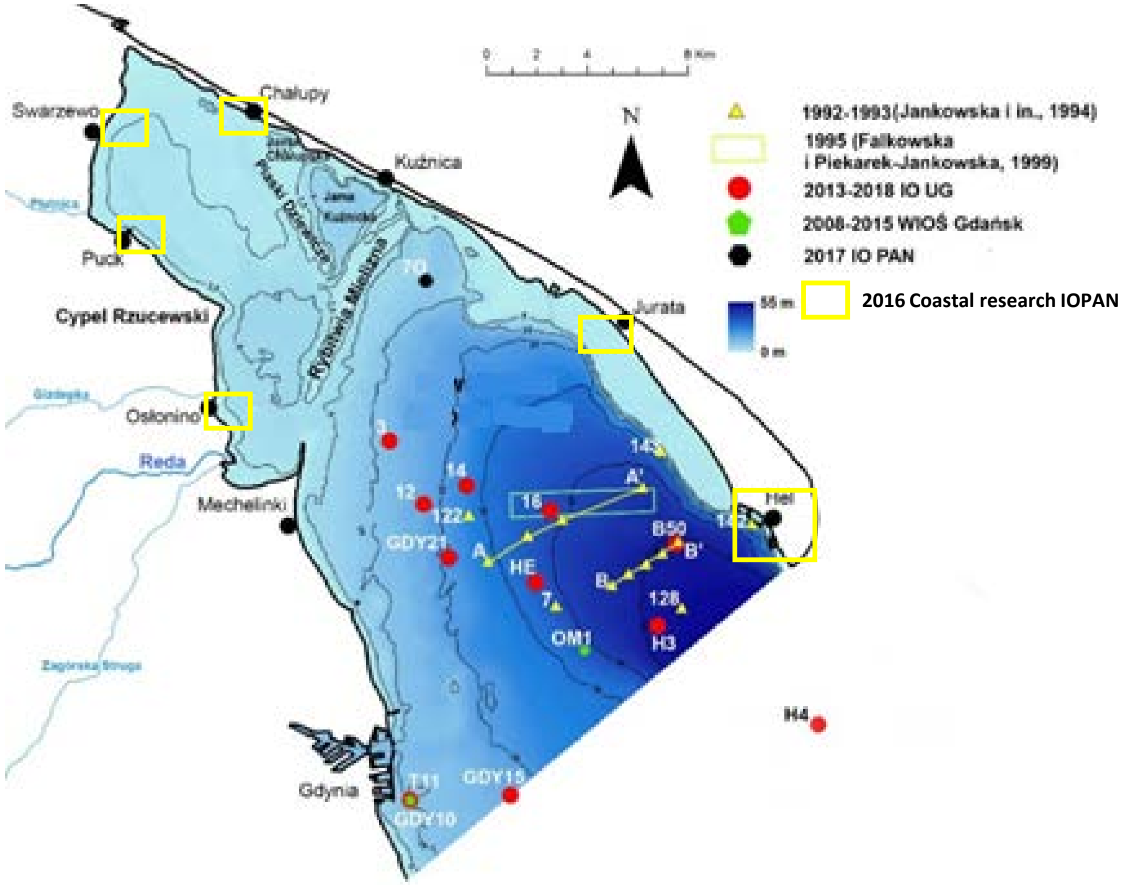
  SGD $_{fresh\ and\ saline}$ **10^{-2} (m^3 h^{-1} m^{-2})**

  Krall et al., 2017

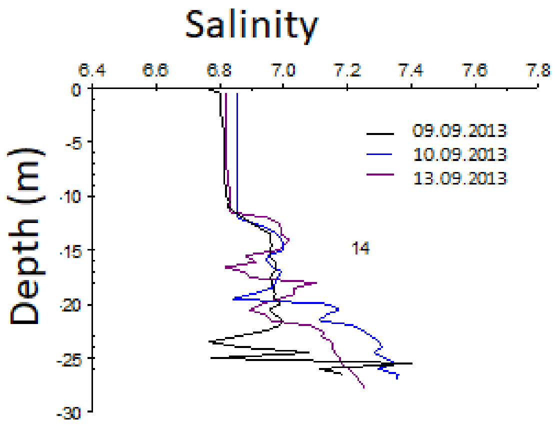
SGD impact on marine ecosytem- Bay of Puck example

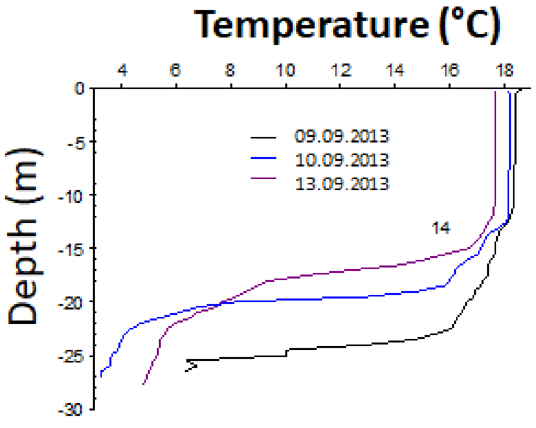


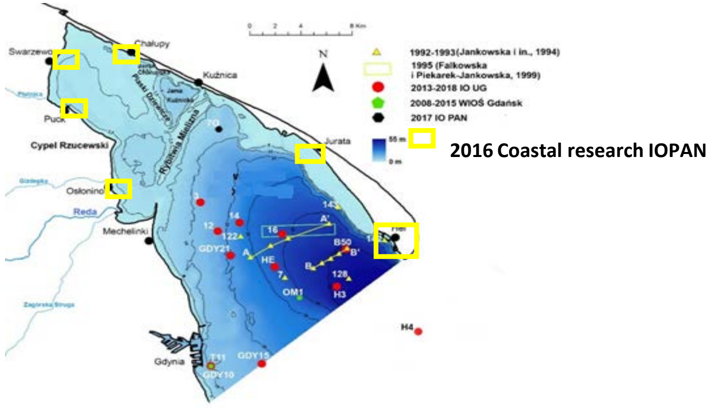
Holocene groundwater
Quaternary groundwater
Oligocene groundwater
Coverege of Oligocene, Miocene and Holocene groundwater
Cretaceous groundwater

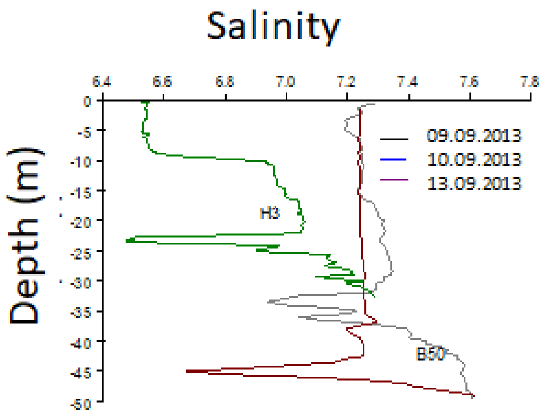


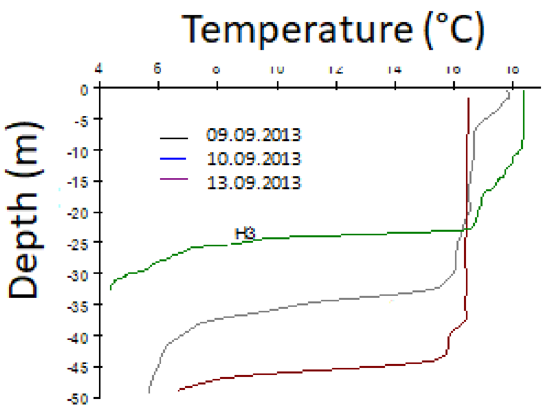
SGD influence on water column- Bay of Puck example

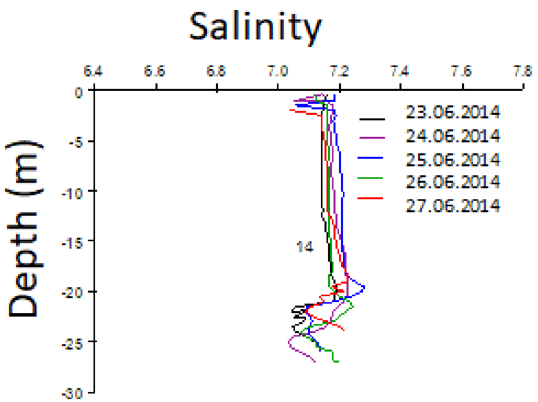


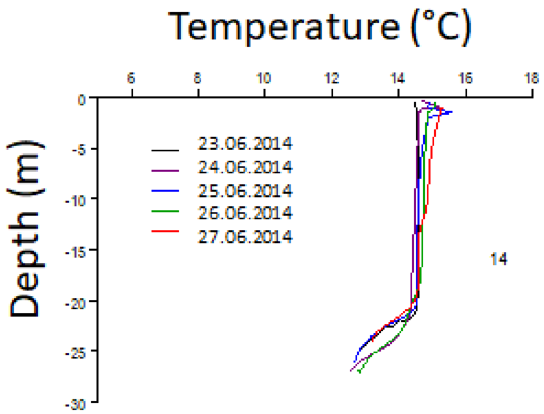












Influence on marine ecosytem

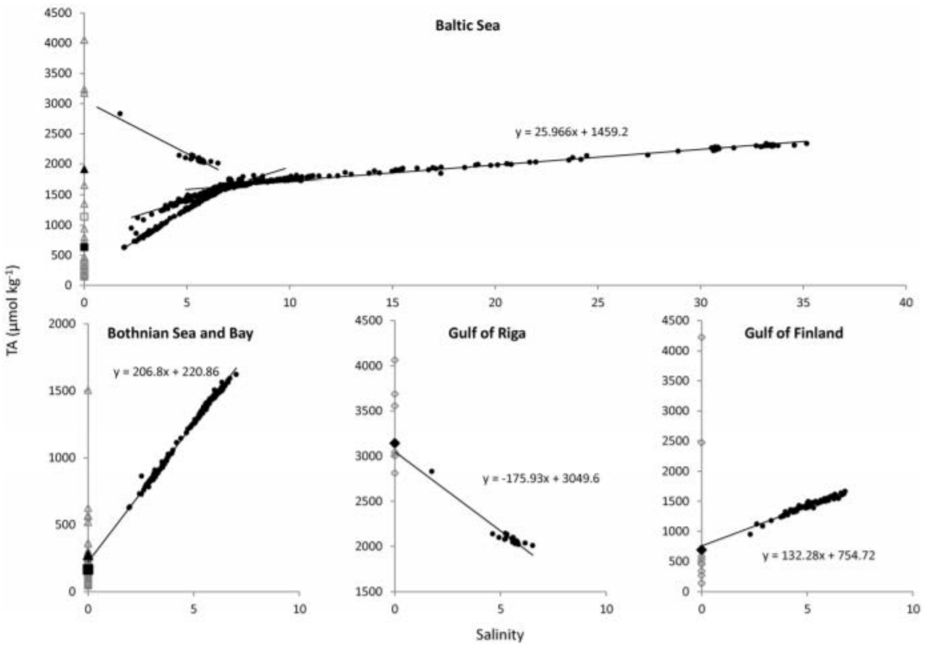


Figure 2. Observed TA (μmol kg^{-1}) and salinity in the water column (depth <70 m) of the Baltic Sea (filled circles). On the vertical axes, open symbols indicate average TA in individual rivers. Filled symbols indicate the average TA on sub-basin level when including not only monitored rivers but also estimates from coastal regions that were not covered by the data sets. In the top panel, triangles and squares correspond to rivers entering the Baltic Proper and Kattegat, respectively. In the bottom left subplot, triangles and squares correspond to rivers entering the Bothnian Sea and Bothnian Bay, respectively.

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1002/2014GB004888

External total alkalinity loads versus internal generation: The influence of nonriverine alkalinity sources in the Baltic Sea

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Key Points:
- Monthly riverine alkalinity loads to the Baltic Sea sub-basins are presented
- External loads alone cannot explain observed alkalinity in the system
- Internal alkalinity generation is similar to river loads in magnitude

Supporting Information:
- Readme
- Figure S1
- Figure S2
- Figure S3
- Figure S4
- Figure S5
- Figure S6
- Figure S7
- Figure S8
- Figure S9
- Figure S10
- Figure S11
- Table S1
- Text S1
- Text S2
- Text S3

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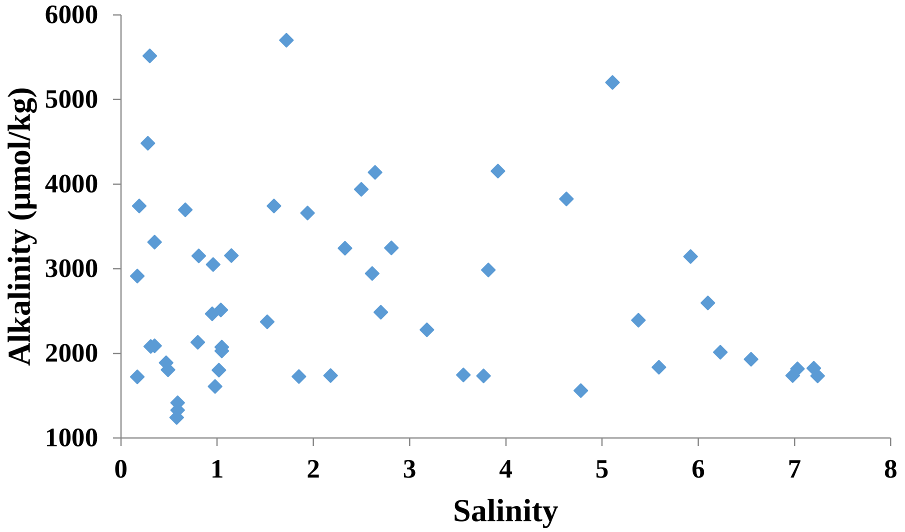
Abstract In this study we first present updated riverine total alkalinity (TA) loads to the various Baltic Sea sub-basins, based on monthly measurements in 82 of the major rivers that represent 85% of the total runoff. Simulations in the coupled physical-biogeochemical BALTSEM (BAltic sea Long-Term large Scale Eutrophication Model) model show that these river loads together with North Sea water inflows are not sufficient to reproduce observed TA concentrations in the system, demonstrating the large influence from internal sources. Budget calculations indicate that the required internal TA generation must be similar to river loads in magnitude. The nonriverine source in the system amounts to about 2.4 mmol m^{-2} d^{-1} on average. We argue here that the majority of this source is related to denitrification together with unresolved sediment processes such as burial of reduced sulfur and/or silicate weathering. This hypothesis is supported by studies on sediment processes on a global scale and also by data from sediment cores in the Baltic Sea. In a model simulation with all internal TA sources and sinks switched on, the net absorption of atmospheric CO_2 increased by 0.78 mol C m^{-2} yr^{-1} compared to a simulation where TA was treated as a passive tracer. Our results clearly illustrate how pelagic TA sources together with anaerobic mineralization in coastal sediments generate a significant carbon sink along the aquatic continuum, mitigating CO_2 evasions from coastal and estuarine systems.



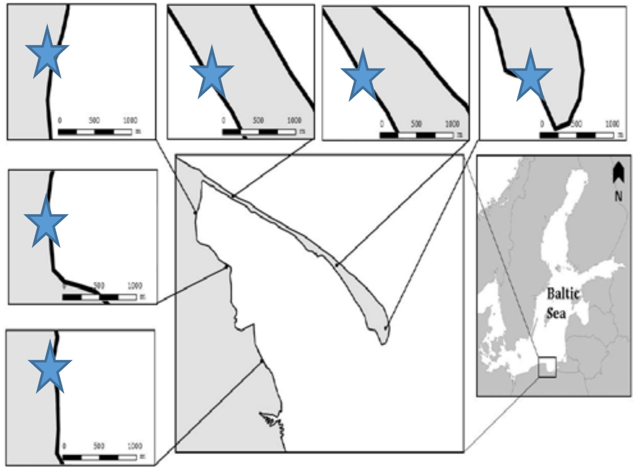
Kłostowska, in prep.

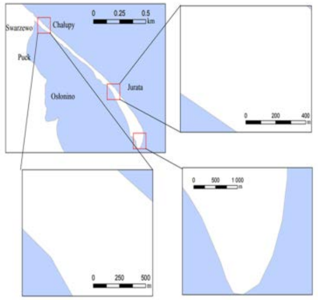
Infuence on water column- Bay of Puck example

Source	Nutrients loads to the Bay of Puck			
	t r^{-1}		kmol r^{-1}	
	P-PO_4^{3-}	N-DIN***	P-PO_4^{3-}	N-DIN
Athmosphere*	18	485	581	34626
Rivers and point sources*	70	220	2260	15706
SGD**	60	30	1911	2118

* Bolałek i in., 1993
** Szymczycha et al., 2012
***DIN= [NO_3^-]+[NO_2^-]+[NH_4^+]

SGD as a source of emerging pollutants





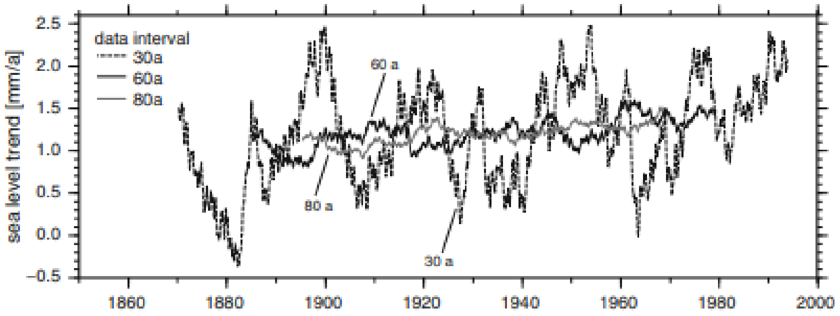
Compound	MDL [ng L^{-1}]	[MQL (ng L^{-1}]	R^2	Precision (%)	Accuracy (%)
Caffeine	0.8	2.5	0.9997	4.9 – 6.8	93.8 – 104.2
Ibuprofen	1.7	5.0	0.9983	1.2 – 7.9	95.5 – 116.2
Naproxen	3.3	10.0	0.9990	3.7 – 9.5	99.7 – 115.0
Carbamazepine	0.3	1.0	0.9985	2.1 – 7.2	84.5 – 113.0
Sulfapyridine	1.7	5.0	0.9989	2.4 – 9.3	88.1 – 105.4
Sulfadiazine	1.7	5.0	0.9993	2.3 – 6.9	92.5 – 106.3
Sulfamethoxazole	1.7	5.0	0.9999	1.6 – 6.0	98.0 – 107.7
Ketoprofen	3.3	10.0	0.9981	2.0 – 9.2	98.4 – 101.4
Sulfamerazine	0.2	0.5	0.9991	4.3 – 9.6	99.3 – 114.8
Sulfamethazine	0.2	0.5	0.9989	3.9 – 9.8	83.5 – 108.7
Trimethoprim	1.7	5.0	0.9985	1.1 – 7.1	99.5 – 104.2
Dicofenac	0.2	0.5	0.9994	2.2 – 9.4	96.2 – 103.6
Acetyl-sulfamethoxazole	1.7	5.0	0.9990	3.7 – 8.3	91.3 – 103.4
Sulfadimethoxine	0.2	0.5	0.9989	1.9 – 8.8	96.2 – 116.9
Enrofloxacin	3.3	10.0	0.9977	0.7 – 6.6	93.1 – 111.3
Tetracycline	3.3	10.0	0.9998	4.1 – 8.8	89.3 – 102.1
Oxytetracycline	3.3	10.0	0.9996	3.5 – 8.9	82.5 – 106.2

	SGD	Seawater SGD
	Concentration [ng L^{-1}]	
Caffeine	**1029.8 ± 58.0**	**-**
Sulfapyridine	**186.1 ± 13.2**	**-**
Diclofenac	**291.3 ± 12.6**	**169.8 ± 16.5**

Borecka, in prep.

SGD / climate change/ antropogenic influence

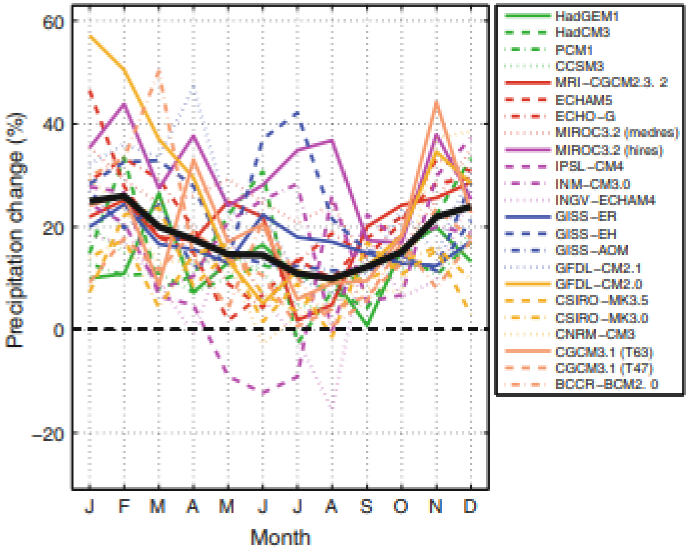
❑ Sea level



Linear trends calculated in sliding windows of fixed length for the annual sea level record in Warnemünde (Germany), a station in the southern Baltic Sea. The three series show the results for different window lengths (redrawn from Richter et al. 2011). From BACCII.

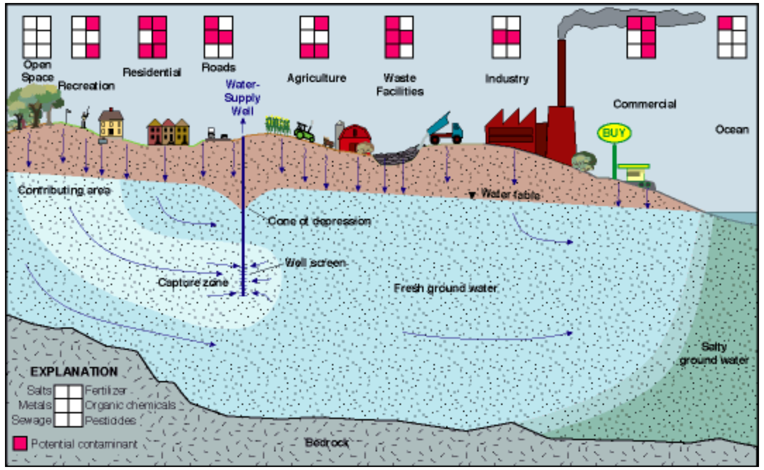
❑ Stroms

❑ Precipitation



Projected change in average monthly precipitation in northern Sweden for 2071–2100 relative to 1961–1990. Results for 23 CMIP3 AOGCM-simulations under the SRES A1B scenario (Lind and Kjellström 2008). The thick black line shows the average of the individual model results and the dashed line indicates no change. Fromm BACC II>

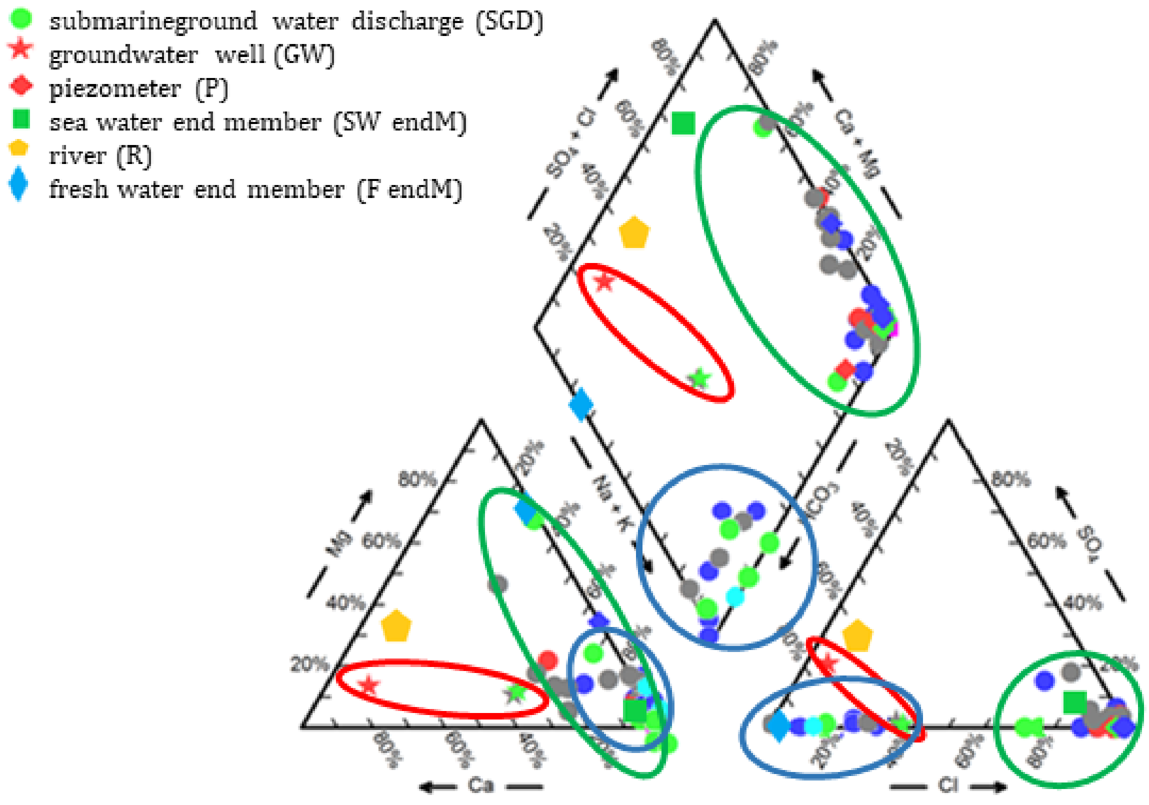
❑ Coastal land use



Thank you for your attention.

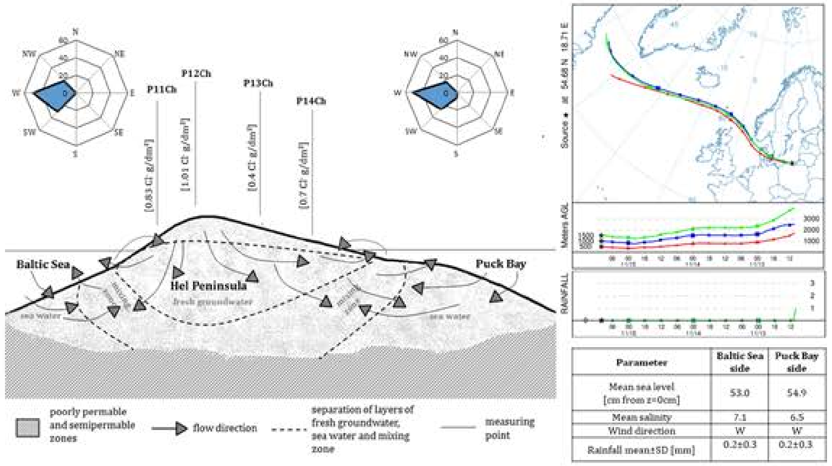
Could SGD be an important driver for ecosytem change in the Baltic Sea?

Infuence on processes taking part in the sediments- Bay of Puck example

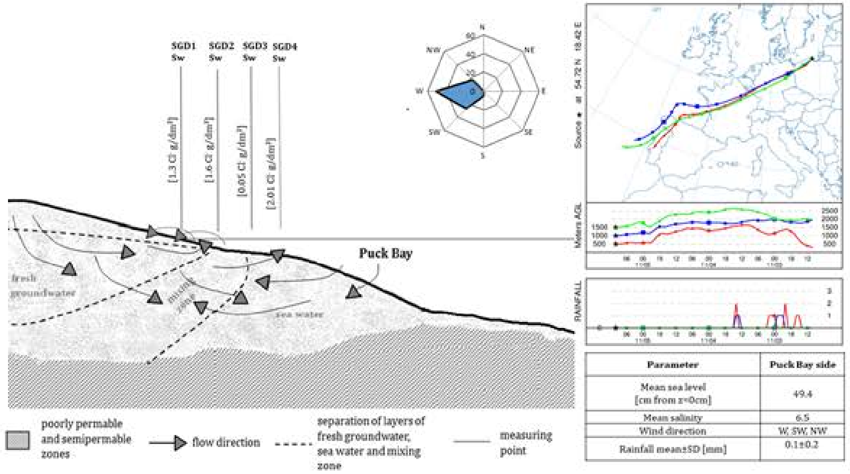


Kłostowska, in prep.

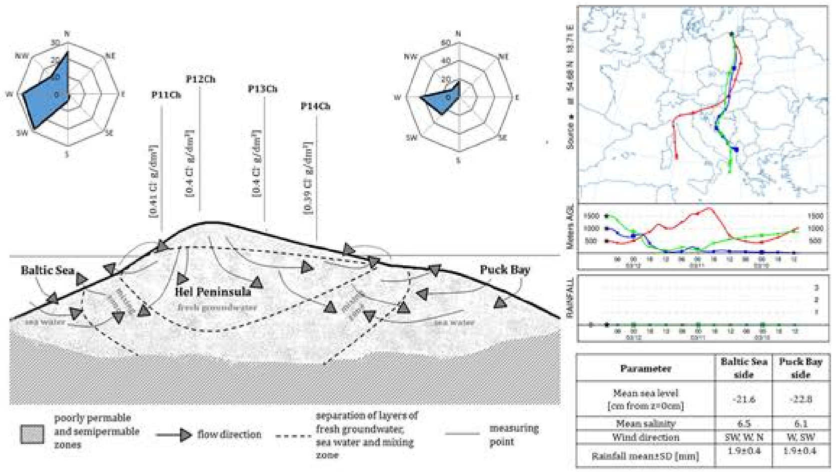
Influence on processes taking part in the sediments- Bay of Puck example



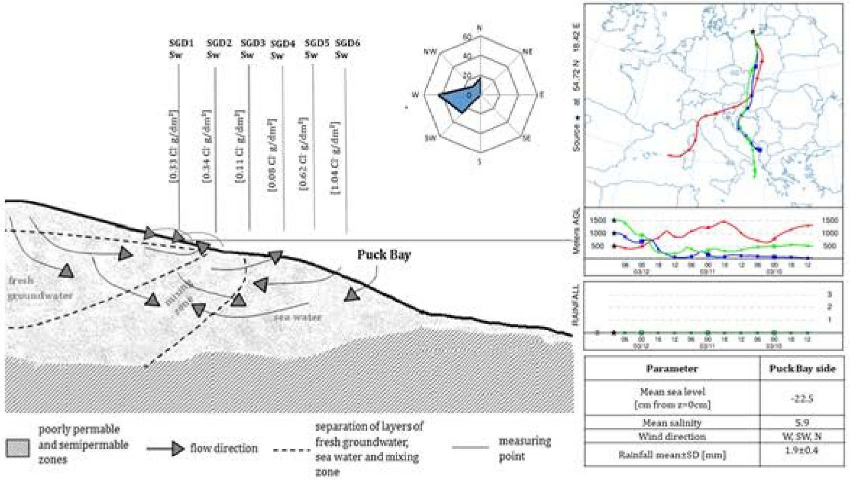
Parameter	Baltic Sea side	Puck Bay side
Mean sea level [cm from z=0cm]	53.0	54.9
Mean salinity	7.1	6.5
Wind direction	W	W
Rainfall mean±SD [mm]	0.2±0.3	0.2±0.3



Parameter	Puck Bay side
Mean sea level [cm from z=0cm]	49.4
Mean salinity	6.5
Wind direction	W, SW, NW
Rainfall mean±SD [mm]	0.1±0.2



Parameter	Baltic Sea side	Puck Bay side
Mean sea level [cm from z=0cm]	-21.6	-22.8
Mean salinity	6.5	6.1
Wind direction	SW, W, N	W, SW
Rainfall mean±SD [mm]	1.9±0.4	1.9±0.4



Parameter	Puck Bay side
Mean sea level [cm from z=0cm]	-22.5
Mean salinity	5.9
Wind direction	W, SW, N
Rainfall mean±SD [mm]	1.9±0.4

Kłostowska, in prep.