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Recently accelerated oxygen consumption rates amplify deoxygenation in the Baltic Sea

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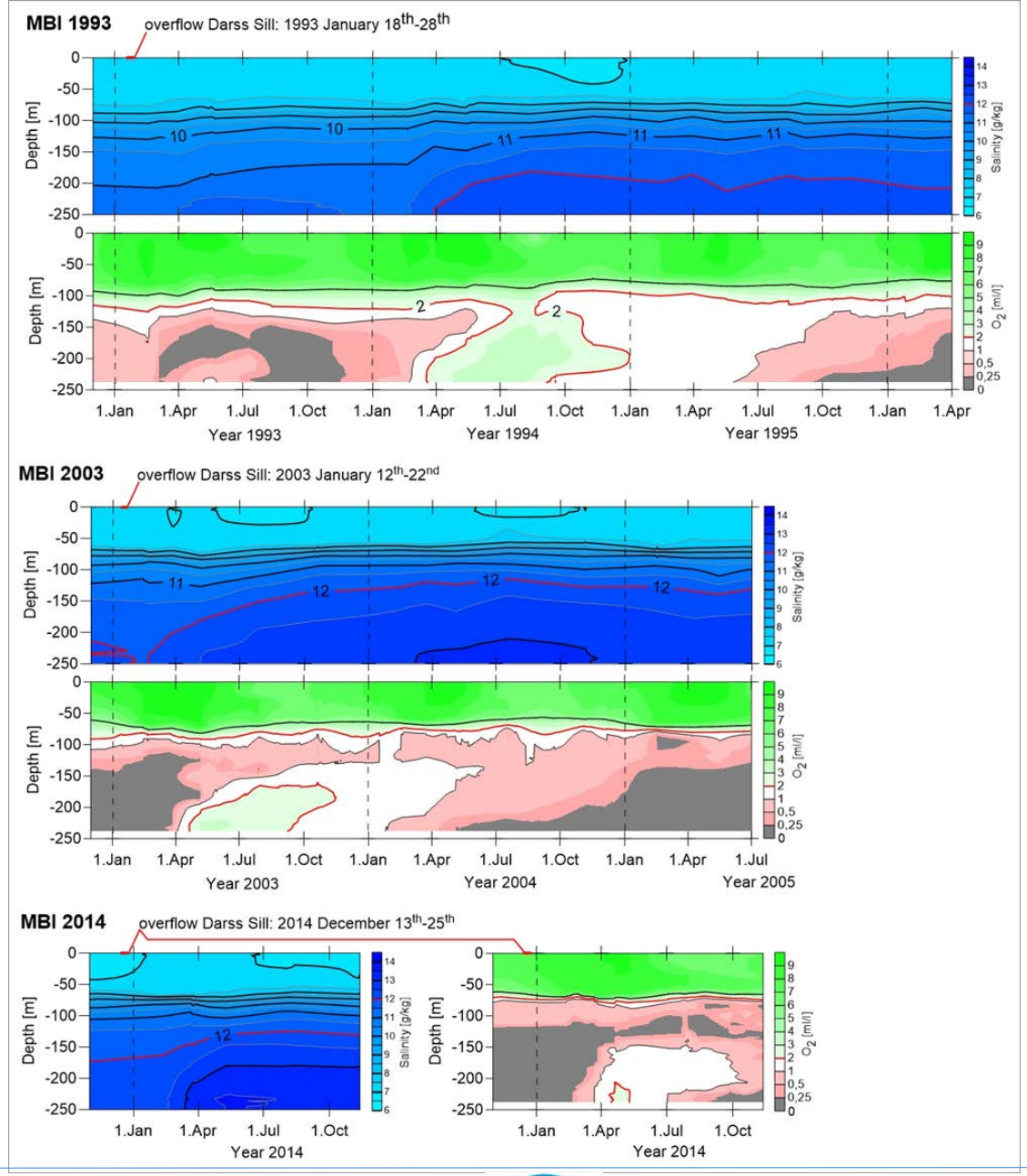
Outline

- Motivation
- Materials and Methods
- Results and discussion
- Conclusions

Motivation

- Exceptionally large inflow 2014
- Are recently observed oxygen consumption rates after the MBI in 2014 unprecedentedly high?
- What might perhaps be the causes for the accelerated consumption?



Materials and Methods: data and model

- Long-term monitoring data since 1900 (IOW and SMHI): 787 oxygen concentration and 1182 salinity quality assured measurements at Gotland Deep from the depth range of 225-235 m

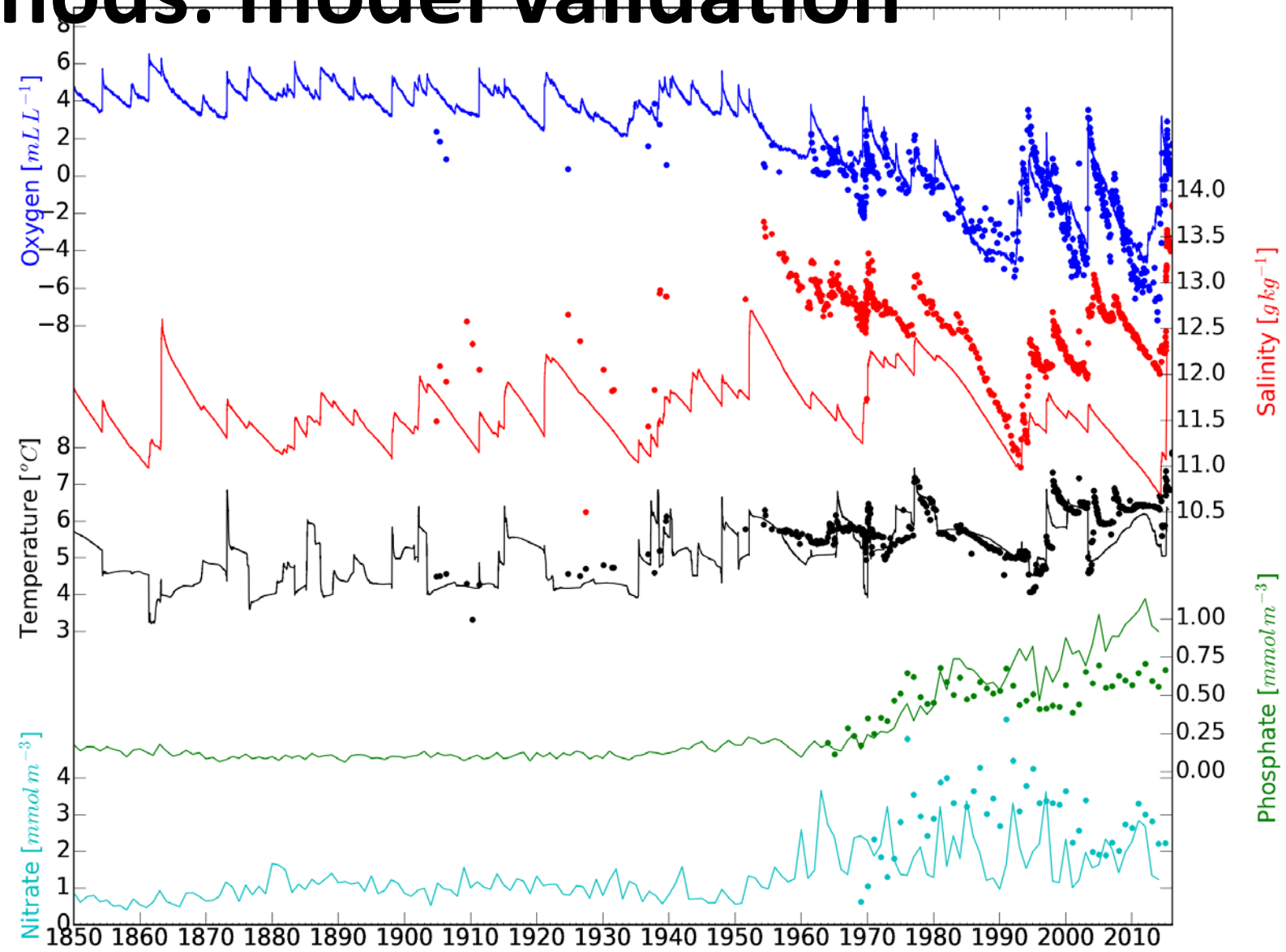
- Baltic Sea model RCO-SCOBI driven with reconstructed forcing for 1850-2015

	1850-2007	2008-2015	
Atmospheric forcing	HiResAFF [Schenk and Zorita, 2012]	Coastdat2 [Geyer, 2014]	
River runoff	Reconstruction [Meier et al., 2012]	2008-2009	2010-2015
		Reconstruction [Meier et al., 2012]	Climatology of 1850-2009
Nutrient loads	Reconstruction [Gustafsson et al., 2012], monthly values of the year 2007 were set to 2006	Monthly values from year 2006	
Sea level at open boundary	Statistical model [Gustafsson et al., 2012]	Daily sea level observations at Smögen	

Materials and Methods: model validation

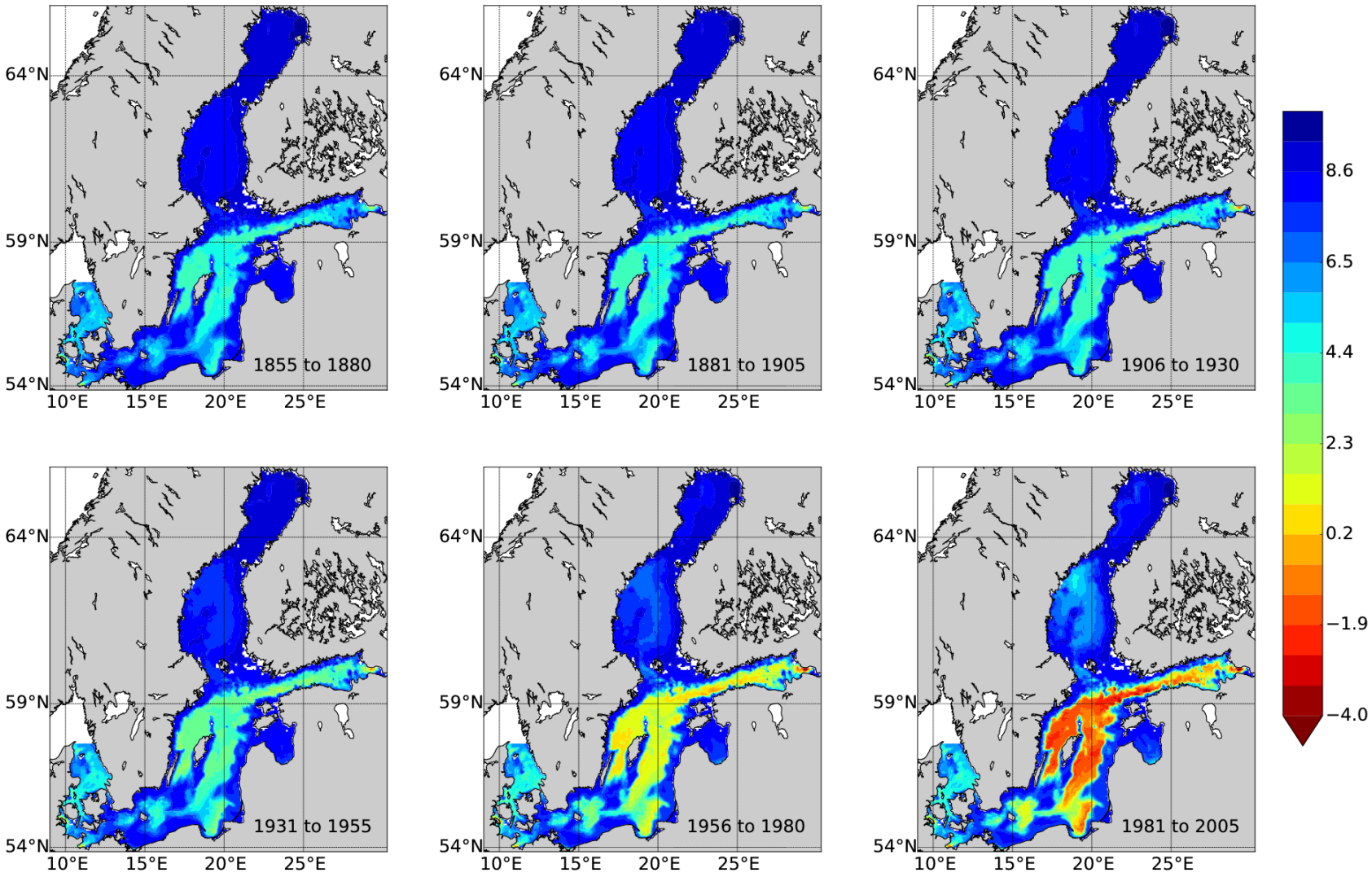
Two-daily temperature (black), salinity (red) and oxygen concentration (blue) at 230 m depth and winter (January, February and March) mean phosphate (green) and nitrate (light blue) concentrations at 1.5 m depth at Gotland Deep (BY15) 1850-2015. Solid lines and dots denote model results and observations, respectively.

- Magnitude and frequency of MBIs well reproduced
- Historical reconstruction consistent and homogenous
- Deep water salinity too low and oxygen before 1950s too high
- Mean surface phosphates after 1990s too high and nitrogen during 1975-2000 too low



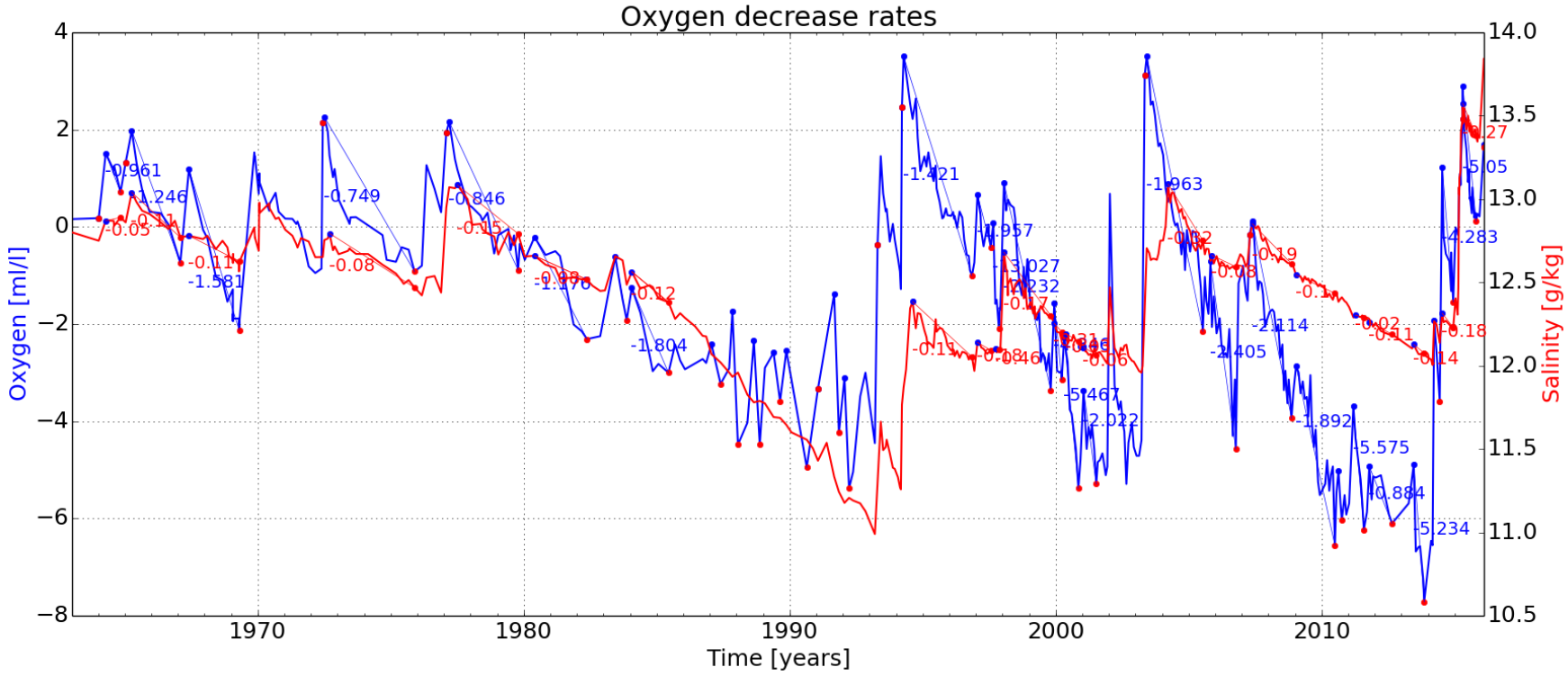
Results and discussion: oxygen concentrations

- Lowest values in the central part of the Baltic Sea
- Significant reduction since the 1950s due to increased eutrophication
- Minima reached in contemporary period



Results and discussion: definition of DR

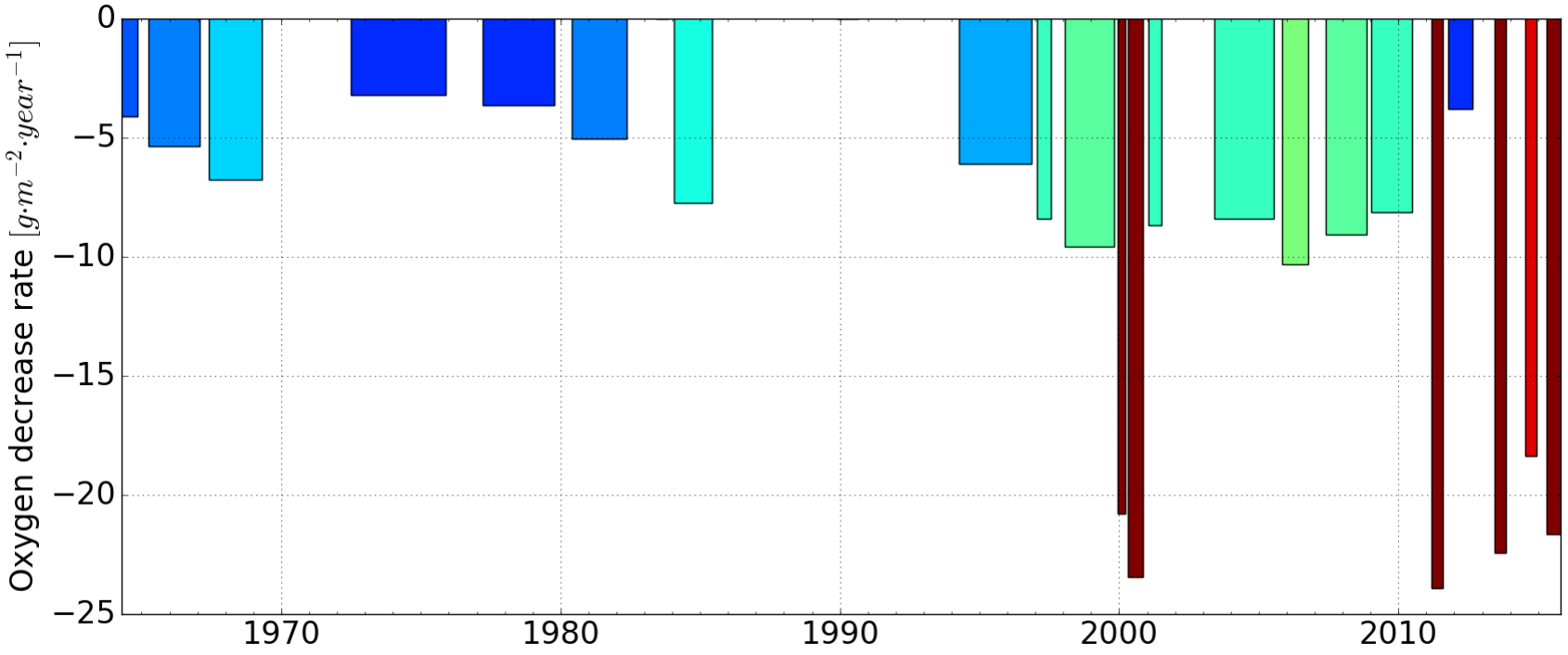
- Time-series of oxygen at BY15 from 230m depth
- Detect inflows from oxygen increase
- Regression slope of reducing oxygen concentration as decrease rate (DR)



Time-series of oxygen (blue) and salinity in the 230 m depth at BY15.

Results and discussion: measured decrease rate

- Moderate oxygen decrease rates before 1990s
- Accelarated oxygen decrease rates, particularly, after 1997
- No significant trend in the salinity decrease rate (not shown)



Oxygen decrease rate expressed as influx (in g m^{-2} yr^{-1}) calculated from observed oxygen concentrations at Gotland Deep (BY15) at 230 m depth for 1964-2015

Results and discussion: comparison

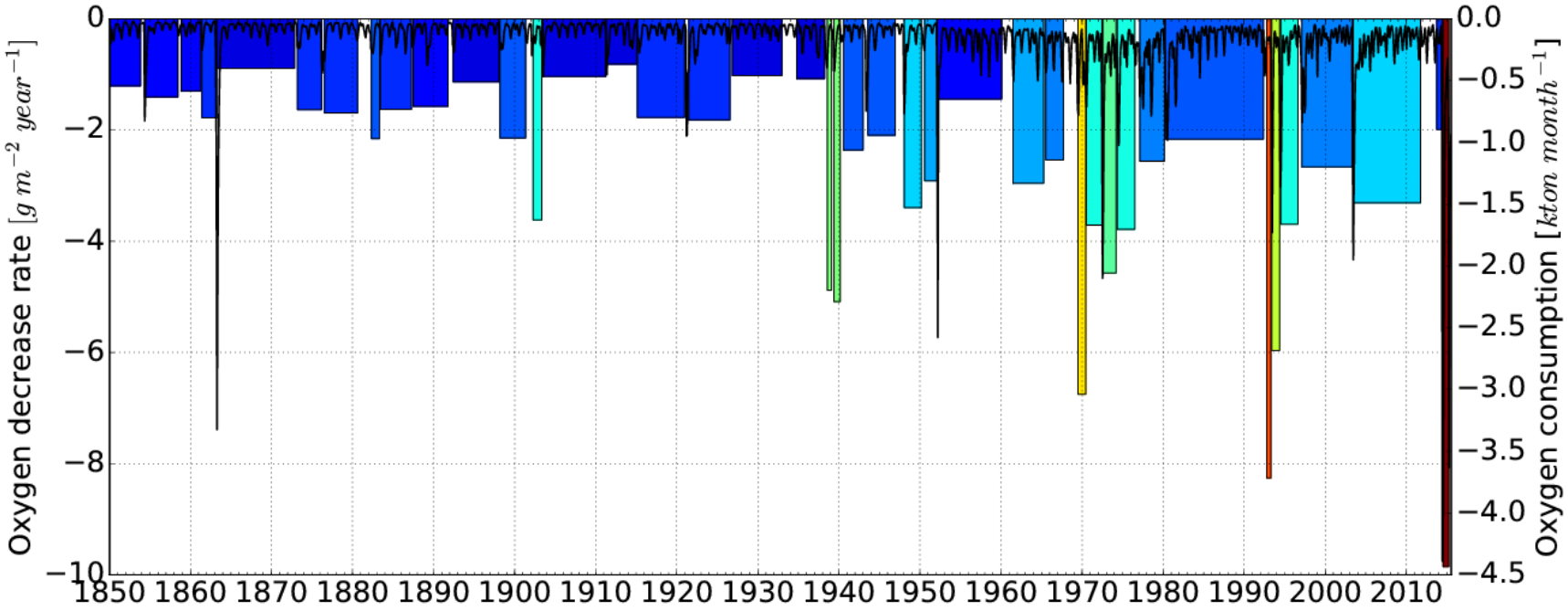
Estimates of Oxygen Consumption Rates (OCRs) From the Literature and This Study

- Doubled due to respiration in the southern Baltic Sea
- Consequence of the eutrophication and increased net production of organic matter in the BS

Reference	Period	Location	Depth (m)	OCR (g m^{-2} yr^{-1})
Rahm (1987)	1957-1982	Eastern Gotland Basin	> 62	71
			> 140	5
Eilola (1998)	1959-1994	Baltic proper	15-50	25
Gustafsson and Stigebrandt (2007)	1965-2005	Eastern Gotland Basin	> 150	44
Stigebrandt and Kalén (2013)	1957-2011	Bornholm Basin	> 65	75
	1970-1979	Bornholm Basin	> 85	27
	2000-2009	Bornholm Basin	> 85	58
This study	1964-2015	Eastern Gotland Basin	> 230	11

Results and discussion: modelled decrease rate

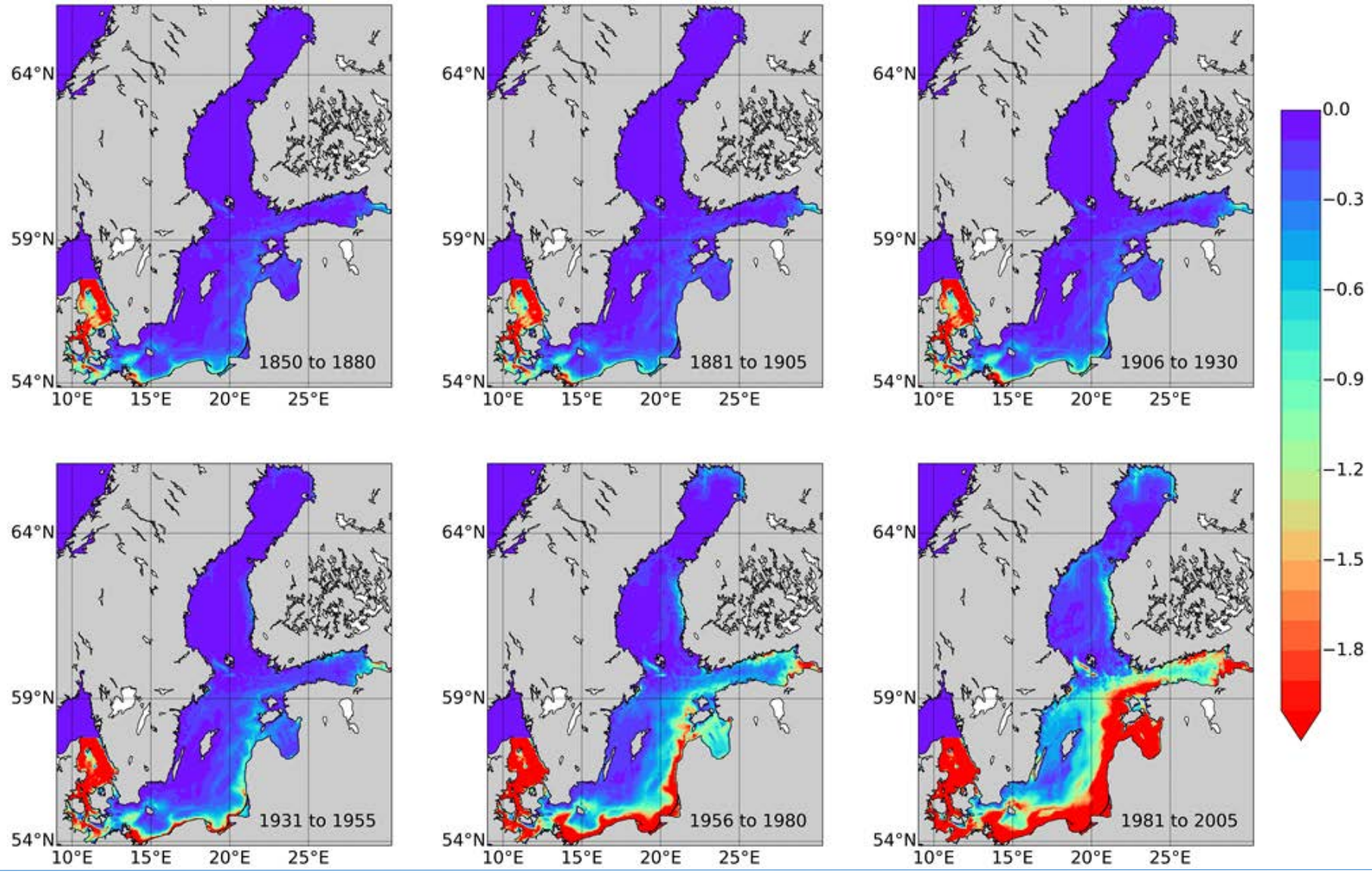
- Relatively constant/low decrease rate before the 1950s, significantly increased decrease rates after 1950s
- Largest decrease rates since 1990s and maxima reached recently
- Values smaller compared to observed decrease rate
- Perfect agreement hardly expected



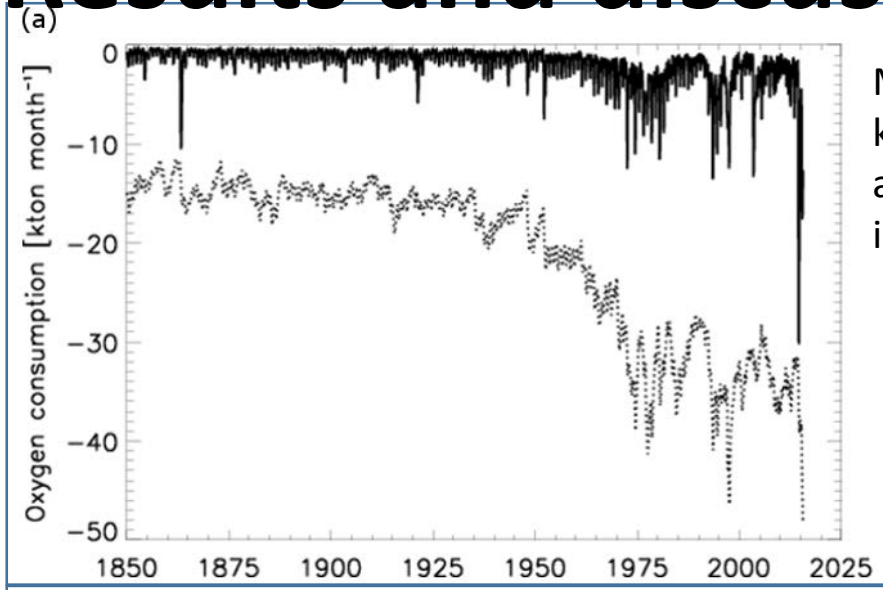
Oxygen consumption rates (in g m^{-2} yr^{-1}, left y-axis) at 230 m depth calculated from simulated oxygen concentrations after saltwater inflows (colored bars) and simulated monthly oxygen consumption rates (in kton $month^{-1}$, right y-axis) between 230 m depth and the bottom from the coupled physical-biogeochemical model (black line) at Gotland Deep (BY15) for 1850-2015

Results and discussion: spatial consumption

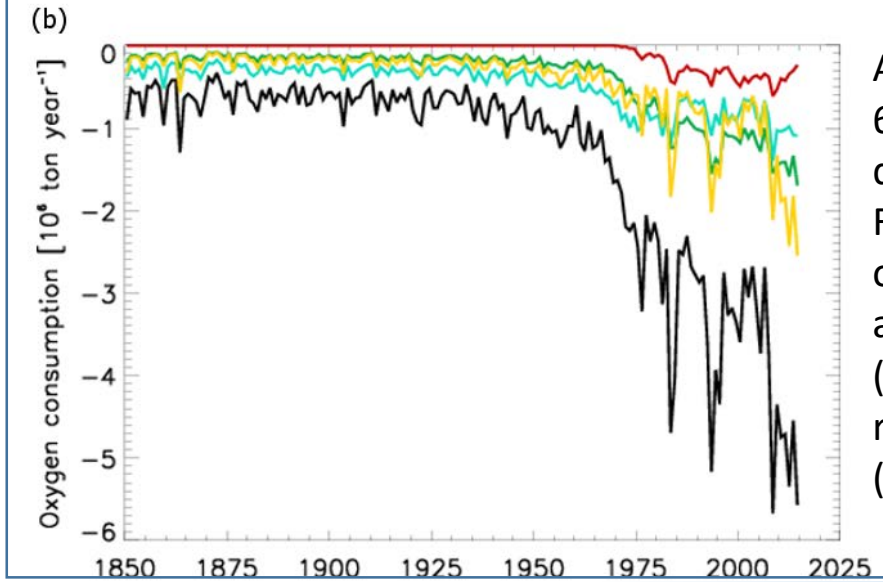
- Increased largest in the coastal zone
- Spreading towards deeper parts with pronounced east-west gradient
- Mostly affected eastern areas of BP and GoF and entire GoR



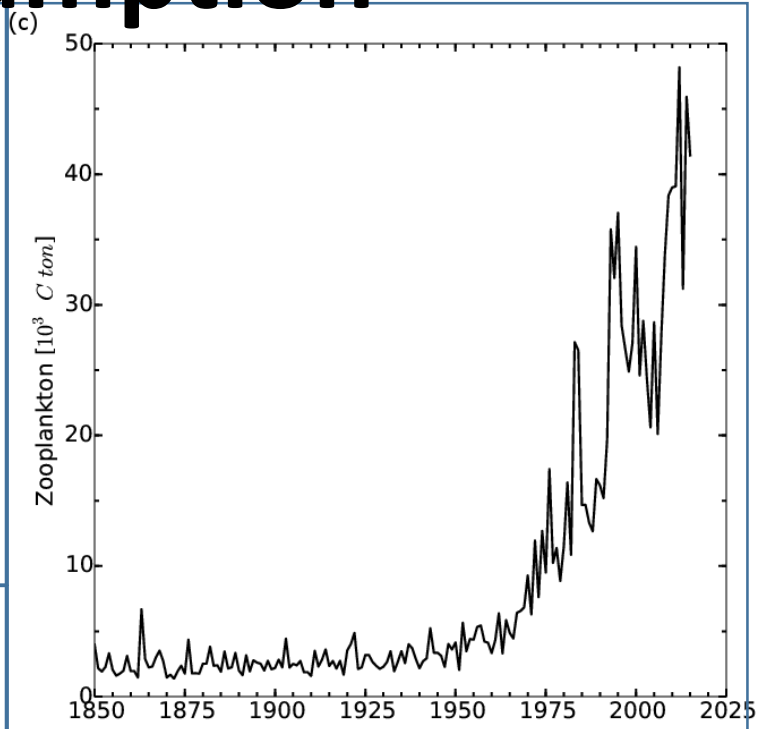
Results and discussion: oxygen consumption



Monthly mean simulated oxygen consumption (in kton per month) in the water column (solid line) and sediment (dotted line) below 150 m depth in the eastern Gotland Basin 1850–2015



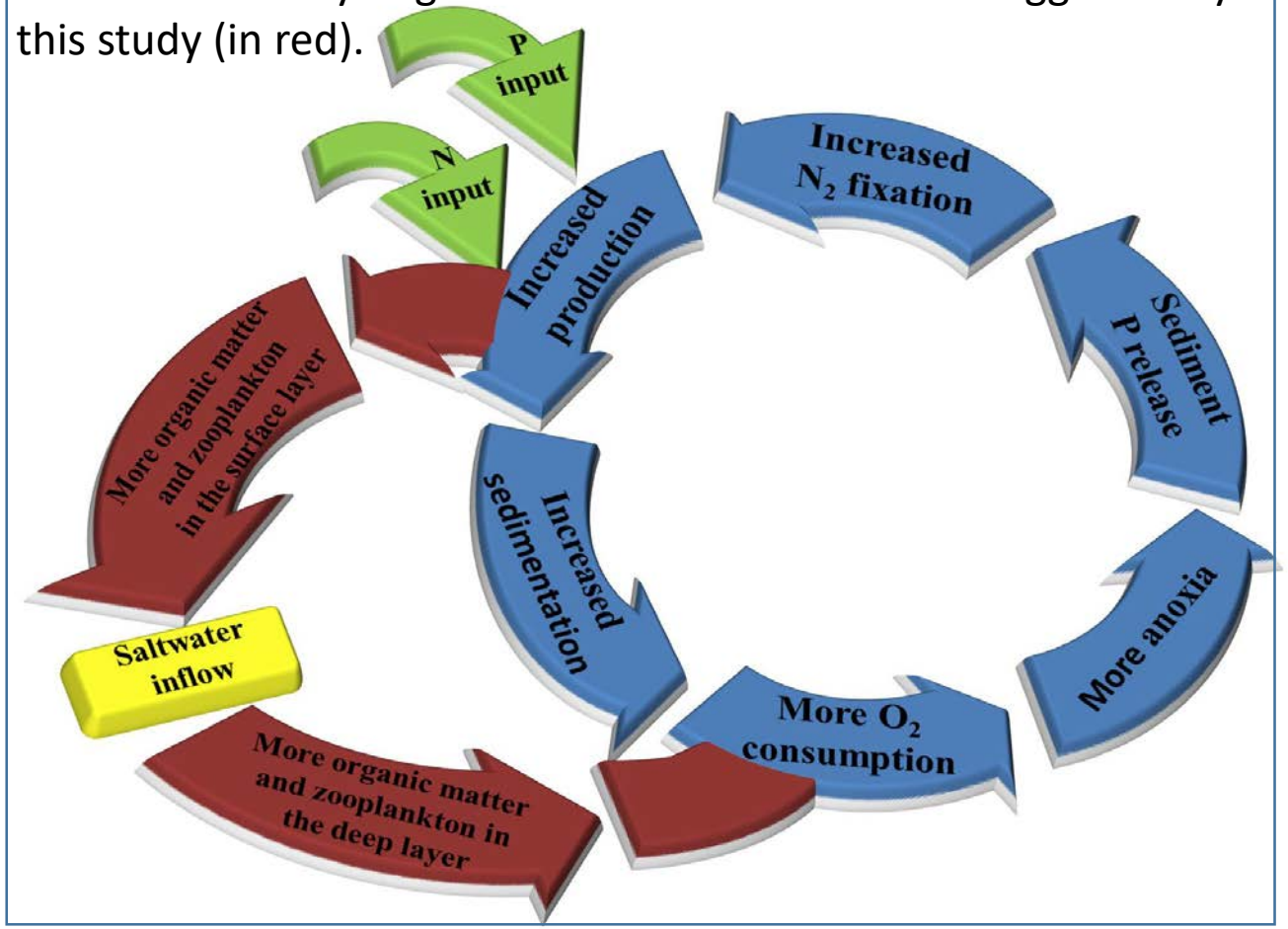
Annual mean simulated oxygen consumption (in 10 6 ton O2 per yr) in the water column below 60 m depth in the Baltic proper, Gulf of Riga, and Gulf of Finland 1850–2015 by process. The curves denote oxygen consumption due to aerobic (cyan) and anaerobic (red) remineralization, nitrification (green), zooplankton and higher trophic level respiration (yellow), and total oxygen consumption (black)

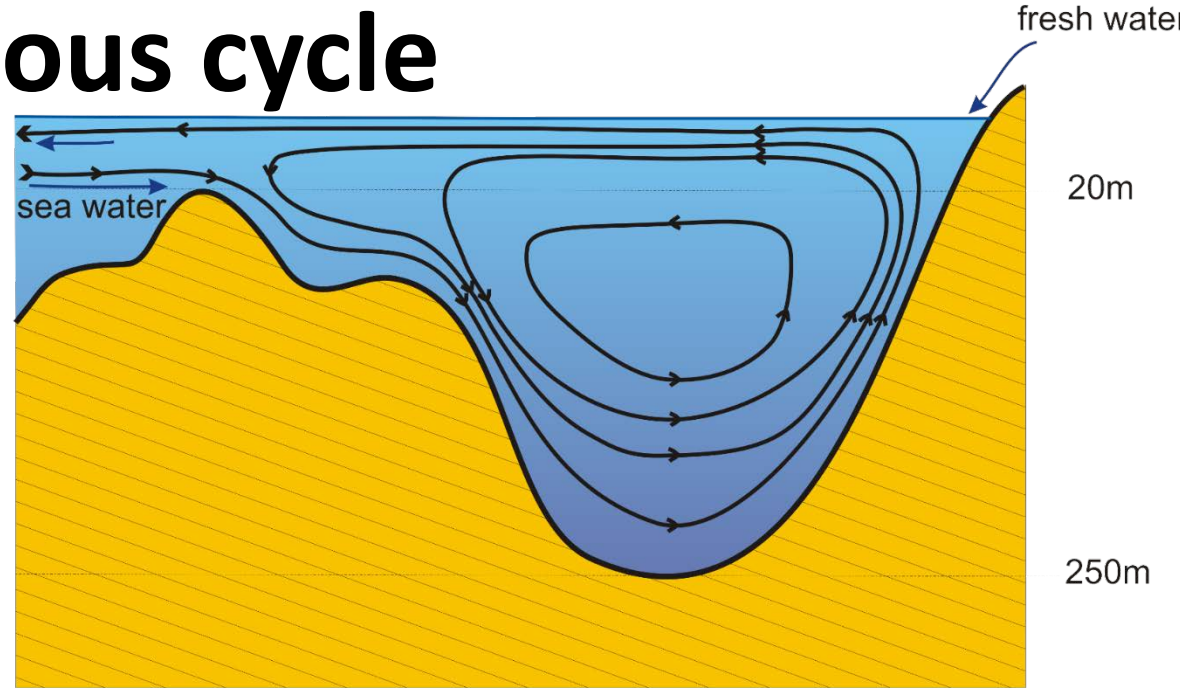


Annual mean simulated zooplankton biomass (in 103 ton C) in the water column below 60 m depth in the Baltic proper, Gulf of Riga, and Gulf of Finland.

Results and discussion: viscous cycle

Schematic view of the ‘‘vicious circle’’ (Vahtera et al., 2007) (in blue) driven by excessive nutrient loads (in green) and reinforced by large saltwater inflow events as suggested by this study (in red).





Schematic view of the estuarian stream function (overturning circulation) on an idealized meridional cross-section from the sills to the north with freshwater supply

Conclusions

- After the MBI in 2014, oxygen consumption rates in the Baltic Sea deep water are unprecedentedly high compared to both modeled rates since 1850 and rates derived from observations since 1964

- Model results suggest that the recent high oxygen consumption rates are explained by aerobic remineralization, nitrification and respiration of zooplankton and higher trophic levels

- Biogeochemical oxygen consumption caused by the transport of organic matter and zooplankton into the deep water counteracts natural ventilation of the Baltic Sea

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Thank You for the attention!