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Baltic Earth Workshop

Climate projections and uncertainties in the northern Baltic Sea region

Helsinki, Finland, 19 - 20 November 2019

Programme, Abstracts, Participants

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Baltic Earth Workshop on

Climate projections and uncertainties in the northern Baltic Sea region

Finnish Environment Institute, Helsinki, Finland

19 - 20 November 2019

Co-organized by
Finnish Environment Institute and Helmholtz-Zentrum Geesthacht
with Baltic Sea Research Institute Warnemünde and Stockholm University

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About the workshop

Scope

Climatic projections for the Baltic Sea have been carried out by numerous models. During the analyses of the results, it was found that the uncertainty of the projections is largest in the northern Baltic Sea and Gulf of Finland. In these areas, the models usually have the lowest skill. Due to these shortcomings in the northern Baltic, it is of vital importance to collect specialists together to discuss the problems.

The climatic projections play an important role in several issues:

1. The adaptation to climate change is a major topic, and advice based on climatic projections is needed for various management issues.

2. Effective mitigation planning is needed e.g. in terms of eutrophication etc.

3. It is necessary to evaluate the role of the northern Baltic Sea in the global carbon balance. Does the northern Baltic Sea act as a strong source (cf. Arctic coastal areas)?

4. The northern Baltic Sea may act as a laboratory for studying climate change mechanisms in northern latitudes by using models as tools.

Representatives of some of the most frequently used biogeochemical models for projections of the Baltic Sea ecosystem such as ERGOM, SCOBI, BALTSEM, BFM, SPBEM, ECOSMO and PROBE-Baltic are invited to discuss the issues above.

We hope and anticipate that this workshop adds to the overall improvement of model development in the Northern Baltic Sea region, but also beyond.

Programme

Tuesday, 19 November 2019

Day 1: Presentations and discussions

09:00	**Welcome by the host** Kai Myrberg
09:05	**Introduction to the Workshop** Kai Myrberg and Markus Meier
09:15	Keynote 1: **Ensemble modelling of the Baltic Sea in past and future climates** H. E. Markus Meier
09:45	Keynote 2: **Biogeochemical cycles of the Gulf of Bothnia** Bo Gustafsson, Erik Gustafsson, Bärbel Müller-Karulis and Oleg Savchuk
10:15	Keynote 3: **Disentangling seston stoichiometry by short-term incubation experiments and hierarchical linear models** Tom Andersen
10:45	**Break** (and Posters)
11:15	Keynote 4: **Structure and variability of the CO_2 system in the Baltic Sea – facts and challenges** Karol Kulinski
11:45	**Open discussion 1**
13:00	**Lunch break**
14:00	**The unique character of the Gulf of Bothnia** Siv Huseby, Joakim Ahlgren and Johan Wikner
14:20	**Some notes on the physics of the Gulf of Finland and its modelling** Pekka Alenius

14:40	**SmartSea scenarios on development of the Gulf of Bothnia area from recent days to 2060** Simo Siiriä, Lars Arneborg, Sam Fredrikson, Jenny Hieronymus, Anders Höglund , Annu Oikkonen, Petra Roiha, Jani Särkkä and Laura Tuomi
15:00	**The Projection Service for Waterways and Shipping (ProWaS) – validation of a NEMO and HBM setup for the northern Baltic Sea** Birte-Marie Ehlers, Janna Abalichin and Frank Janssen
15:20	**The Projection Service for Waterways and Shipping (ProWaS) – first results of model sensitivity studies on the influence of global climate change to the Baltic Sea** Birte-Marie Ehlers, Janna Abalichin and Frank Janssen
15:40	**Break** (and Posters)
16:10	**Consistent changes in a large ensemble of regional climate projections downscaled for the Baltic Sea** Matthias Gröger, Christian Dieterich and H.E. Markus Meier
16:30	**Convective Snow Bands over the Baltic Sea in an Ensemble of Regional Climate Scenarios** Christian Dieterich, Matthias Gröger, Julia Jeworrek, Kirsti Jylhä, Erik Kjellström, H. E. Markus Meier, Taru Olsson, Lichuan Wu and Anna Rutgersson
16:50	**Ecosystem modelling in the Baltic Sea region with ECOSMO in the context of climate change - experiences and perspectives** Johannes Pein, Ute Daewel, Deborah Benkort, Beate Geyer, Emil Stanev and Corinna Schrum
17:10	**Sensitivity of reproduction of the modern climate of the Baltic Sea to external forcing on the example of MITgcm** V. A. Ryabchenko , A.V.Isaev, R.E.Vankevich and D.V.Sein
17:30	**Open Discussion 2 and breakout group definition**
18:30	**End of Day 1**
20:00	**Ice breaker/Joint dinner**

Wednesday, 20 November 2019

Day 2: Breakout group discussions

09:00 **Plenary discussion and allocation to breakout groups**

09:30 **Breakout group discussions 1**

11:00 **Break** (and Posters)

11:30 **Breakout group discussions 2**

13:00 **Closing discussion and future plans**

14:00 **End of Workshop**

Posters

Forecast of socio-economic damage caused by flooding
Alexander Volchek, Dmitriy Kostiuk, Dmitriy Petrov and Nikolay Sheshko

Predicting extreme dry spell risk based on probability distribution in coastal region of Tunisia
Majid Mathlouthi and Fethi Lebdi

Abstracts

(first author alphabetically)

Some notes on the physics of the Gulf of Finland and its modeling

Pekka Alenius, Laura Tuomi, Petra Roiha and Antti Westerlund

Finnish Meteorological Institute, Helsinki Finland (pekka.alenius@fmi.fi)

1. Gulf of Finland's role in the Baltic Sea

The Gulf of Finland (GoF) is an exceptional sub-basin of the Baltic Sea since it is a direct continuation of the Baltic Proper without any sills. The gulf is a large estuary like basin and receives the largest single fresh water supply of the whole Baltic Sea. The gulf has two different parts; narrow western gulf and wider eastern basin. Topographic steering affects currents and circulation in both of these. The internal Rossby-radius is small; a couple of kilometers only, which results in multitude of small and meso-scale features, like eddies and fronts. The western gulf receives deep waters from the Baltic Proper and eastern gulf receives big amounts of fresh water that are mixed with the saltier water in the very eastern part of the gulf.

The Gulf of Finland is very heavily trafficked part of the Baltic Sea. There are big cities around it, and the gulf is both used and affected by people in large extent. A lot of efforts have been put to the research of the GoF including both measurements and modeling of the gulf in the three surrounding countries. The international co-operation is good and solid.

2. The physical state of the Gulf of Finland

The environmental state of the Gulf of Finland in the period 1996 – 2014 was recently assessed in tri-lateral cooperation under The Gulf of Finland Year 2014 project [Raateoja and Setälä eds. 2016]. While the Baltic Sea is located between two major climate zones, the marine temperate and the continental sub-arctic, it is especially vulnerable to climate change. Weather conditions that depend on the climate regulate the water exchange of the Baltic Sea and North Sea and which affects also the Gulf of Finland. As an example the major Baltic inflow of 2014 that was considered the third larges of recorded inflows, could not renew bottom waters markedly in the Gotland basin, and the oxygen conditions in the GoF got worse due to propagation of some of the old stagnant waters from Baltic Proper.

The global sea level rise and the land uplift are presently more or less at balance in the GoF. Some increasing trend was observed in river runoff to the gulf. Annual sea ice extent varies a lot from year to year, but no trends in the assessment were observed there.

Salinity is an issue, because it varies in such a basin a lot in space and time. It has been concluded that there is an increasing trend in deep-water salinity. However, the variability of the deep-water salinity is large and the direction of trends depends on time scale (see Figure 1).

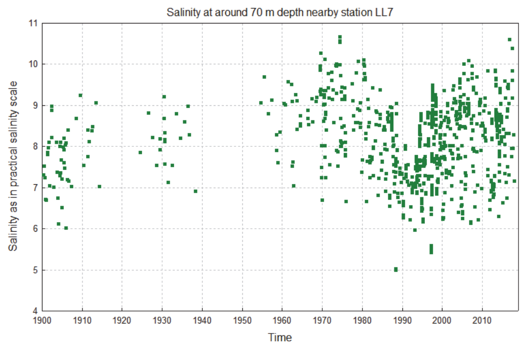

Figure 1. Deep-water (70 m) salinity around station LL7 in the middle of the western Gulf of Finland (HELCOM data, downloadable at www.ices,dk).

3. Challenges in observing the Gulf of Finland

In oceanographic context Gulf of Finland can be considered to be a well-monitored sea area. There are open sea ship observations since 1898. However, there are gaps in WW I and especially in WW II (also seen in Figure 1). The observations are spatio-temporally uneven and mostly temporally biased. The monitoring grid size is big in comparison to internal Rossby-radius, and the temporal coverage may not catch the strong annual cycle. There are some positive exceptions, but generally this is the case for direct observational knowledge. Observational weaknesses will affect the climate studies causing inaccuracies and difficulties.

To understand the response of the sea to climate change we need time-series observations that describe the variability of the annual cycle in a reasonable manner. Such observations would put the sparse open sea observations in right temporal context. Automatic profiling buoys give a promise towards that.

As much as time series, we need means to get simultaneous spatial picture of the gulf. Satellite images give that for the surface for many parameters. Those images can be used as a proxy for estimating the dynamics of the gulf, too. Salinity has so far been a parameter that is not thought when the use of satellite images is spoken about. However, there is ongoing ESA project, Baltic+ Salinity, which aims at developing satellite products for sea surface salinity in the Baltic Sea. Satellites see mainly the surface of the sea and therefore research cruises are needed. E.g. Finland has conducted several cruises that have covered the western gulf in a dense observation site net in comparison to traditional monitoring. Such work should be continued in the future.

Understanding of the dynamic processes needs also specific studies and new technologies. Automatic undersea gliders are a rather new development in the Baltic Sea area. Estonia and Finland have conducted even one month long glider missions, with their gliders. In the future gliders should have a complementary role in monitoring and especially in process research in the area.

4. Numerical circulation modelling

Numerical circulation modeling of the Gulf of Finland has long traditions. Many different models have been applied to the gulf with varying success. Also in modeling international co-operation in GoF area has resulted at least to comparisons of the results of the different models inside the modeler community.

Development in modeling has been fast, but still there are challenges in describing the circulation and especially salinity fields in the gulf. Recently efforts have been put in using pan-European NEMO model to estimate the mean circulation in the gulf (Westerlund et al. 2017). Knowledge on the dynamics and ability to simulate it accurately is vital for practical purposes, but also for climate scenarios.

There are many prominent modeling groups and studies done in the Gulf of Finland, which cannot be mentioned in a short abstract. It can be said that the advances in numerical modeling of the Gulf of Finland have been very important in the last years and there is hope that models can be used to increase the understanding of the behavior of the gulf in changing climate.

5. Conclusions

The Gulf of Finland is a small sea area in the World Ocean, but it is vital for three countries and millions of people. Its environment is vulnerable to human actions and climate change. Luckily this is acknowledged in the society, too. There is lively multidisciplinary scientific community working for the Gulf of Finland. Climatic scenario runs with models are done, which goes hand in hand with model development. Observations methodologies have advanced in recent years and the societal demand for knowledge and information of the response of the sea to changes has increased.

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Disentangling seston stoichiometry by short-term incubation experiments and hierarchical linear models

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Seston samples are known to be complex mixtures of autotrophic, heterotropic, and detrital particles, blurring the interpretation of the underlying stoichiometric signal. The autotrophic component of seston stoichiometry may be isolated by using chlorophyll or other proxies for algal biomass as covariate in regression analysis. We analyze a large seston data set from the NE Baltic Sea, where individual samples are organized as more than 170 factorial, short-term incubation experiments, distributed across sites and seasons over 3 years. The data set consists of over 3500 samples of chlorophyll a (Chla) and particulate organic C, N, and P (POC/N/P). Using hierarchical linear models, we can identify strongly constrained population-level parameters representing average concentrations of non-autotrophic POC/N/P, as well as average POC/N/P to Chla ratios of autotrophs. Population-level effects of nutrient addition treatments indicate that N addition has only minor effects on both autotrophic and non-autotrophic stoichiometry, while P addition has dramatic effects on both the non-autotrophic POP concentration (intercept), as well as the chlorophyll-specific P content of autotrophs (slope). The P addition effect on the intercept could indicate temporary decoupling between P uptake and autotroph growth, either by autotrophic luxury P uptake, competitive P uptake by heterotrophic bacteria, or rapid nutrient tunneling to higher trophic levels.

Deeper insights into the validation of hydrodynamic models using a synergy of remote sensing data

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[2] Department of Civil Engineering and Architecture, Tallinn University of Technology, Tallinn, Estonia

1. Introduction

Sea surface heights(SSH) derived from hydrodynamic models (HDM) are often utilized for climate studies to estimate sea level changes, circulation patterns, volume fluxes etc. There exist however two very important but hidden issues with respect to SSH derived from HDM. Firstly, in most cases SSH derived from hydrodynamic models are often validated by land bounded tide gauges (Elken et al. 2006; Hordoir et al. 2019). Thus there exist very few studies dealing with initial validation of the SSH offshore. The second issue is that the modelled sea level may have a bias relative to a geodetic reference system datum. In many cases this bias can change both spatially and temporally (Lagemaa et al. 2011). This study now displays a methodology that utilizes a synergy of other sensors for validation of offshore points and the utilization of a more stable vertical reference frame such as a high resolution marine geoid.

2. Method

The methodology displayed in figure 1 involves (i) comparison of the SSH from tide gauges (whose zero is fitted to the geoid surface) and HDM. This allows determination of the dynamic bias that exists in the models; (ii) Once this dynamic bias is known it can then be applied to the HDM model at offshore points using an interpolated approximation. This yields Dynamic Topography (DT) estimates.

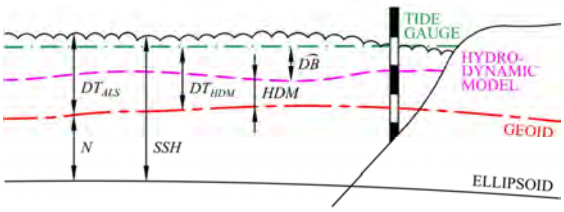

Figure 1. Derivation of Dynamic Topography (DT) with respect to participating reference surfaces. Note that the airborne laser scanner (ALS) and satellite altimetry data are referenced to the ellipsoid, whilst the Hydrodynamic models (HDM) may have a dynamic bias (DB). By utilizing the geoid, it is possible to obtain DT.

The SSH data from remote sensors such as satellite altimetry (SA) and airborne laser scanner (ALS), are usually referenced to an ellipsoid. These sensors in conjunction with the high-resolution EST-GEOID2017 geoid model (Ellmann et al. 2019) were employed in the present study. Thus, by correcting HDM to the geoidal reference datum an inter-comparison can be made with respect to the HDM data points. In this study two different hydrodynamic models are utilized. First, the three-dimensional High-Resolution Oceanographic Model of the Baltic Sea, HIROMB (Funkquist and Kleine, 2007) along with the Baltic Sea Physical Analysis and Forecasting model, computed at the Copernicus Marine Environment Monitoring Service (CMEMS), were employed. Comparisons were made with SA and ALS data.

3. Results

Inter-comparison between HIRMOB and satellite altimetry data showed root mean square errors that varied from 99−115 mm. Interestingly figure 2 shows that comparison between different satellite passes and cycles allowed deeper insights into spatial and temporal deficiencies either with HDM or with the satellite data. Results for inter-comparison between the SA and ALS and also shows discrepancies which may be related to the HDM but can also give different characteristics such as wave properties.

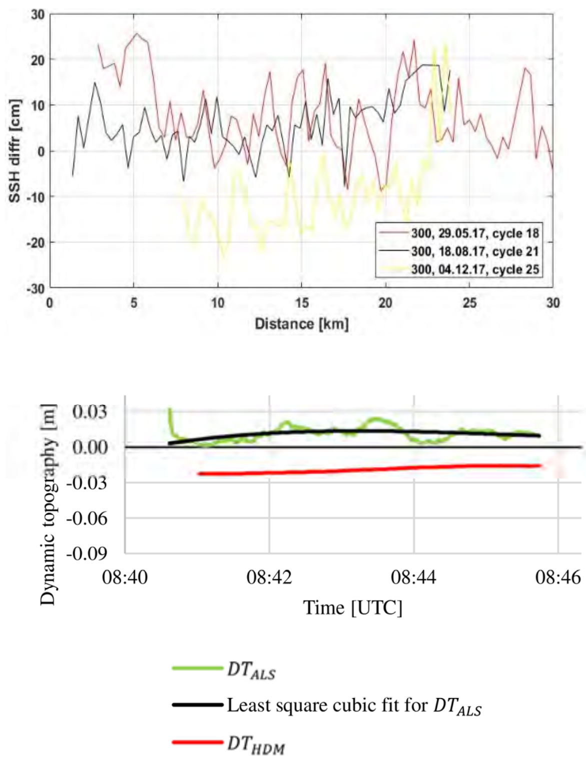

Figure 2. (Top) an example of the differences between the Dynamic Topography (DT) derived HIROMB hydrodynamic model(HDM) and satellite altimetry data (SA). By examining different satellite cycles it is possible to obtain discrepancies in

the HDM or SA. (Bottom) an example of the DT from airborne laser scanning (ALS) and CMEMS hydrodynamic model.

4. Summary

Thus the methodology applied shows by utilizing a common reference datum such as the high resolution marine geoid along with other sensors allows the possibility to identify problem areas and their spatial and temporal characteristics.

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Convective Snow Bands over the Baltic Sea in an Ensemble of Regional Climate Scenarios

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1. Introduction

Snow bands are a type of extreme precipitation event that occurs in the northern Baltic Sea in the cold season. Cold air that moves over open sea can lead to convection through sensible and latent heat fluxes. Strong winds may arrange the convection cells into wind parallel snow bands. When these snow bands approach a coast heavy precipitation can occur. Coastal areas in Sweden and Finland are regularly hit by these snowfall events (e.g. Jeworrek et al. 2017, Olsson et al., 2017) that can lead to problems for traffic and infrastructure.

Under projected climate change we expect strong warming in the northern Baltic Sea region, amplified by the ice-albedo feedback. The Bothnian Bay and Bothnian Sea are projected to become ice free more often (Höglund et al., 2017). An ice free Baltic Sea is a requirement for snow bands to develop, so that the atmosphere can take up moisture and heat from the sea and start convection. The hypothesis is that the northern Baltic Sea should show snow bands more often under future climates, since the ice free period is prolonged into the winter season.

2. Methods

We use a coupled regional atmosphere-ice-ocean model to downscale different general circulation models (GCMs) from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al., 2012). Using three different representative concentration pathways (RCPs, van Vuuren et al., 2011) of the CMIP5 models allows us to generate a small ensemble of regional climate scenarios for the North Sea and Baltic Sea region (Table 1).

	RCP8.5	RCP4.5	RCP2.6
MPI-ESM-LR	1961-2099	1961-2099	1961-2099
EC-EARTH	1961-2099	1961-2099	1961-2099
HadGEM2-ES	1961-2099	1961-2099	1961-2099
IPSL-CM5A-MR	1961-2099	1961-2099	
GFDL-ESM2M	1961-2099	1961-2099	1961-2099
CanESM2	1961-2099	1961-2099	
NorESM1-M	1961-2099	1961-2099	1961-2099
MIROC5	1961-2099	1961-2099	1961-2099

Table 1. Ensemble of regional climate scenarios downscaled with RCA4-NEMO.

The analysis of snow band conditions follows Jeworrek et al. (2017). They have shown that the coupled model RCA4-NEMO that we use here shows the effects of snow bands, even though the horizontal resolution of 0.22° is rather coarse. RCA4-NEMO tends to underestimate the amount of snowfall and the timing and precise location of the events is not accurately reproduced. The aim of this study is not the analysis of dynamical and thermodynamical processes for snow band formation. We rather focus on how the statistics of snow bands, as they are represented in the regional climate model, change with changing climatic conditions in the northern Baltic Sea.

3. Preliminary Results

Fig. 1 shows the time series of occurrence of moderate conditions (Jeworrek et al., 2017, see Appendix) for snow bands on the Swedish east coast. Contrary to the initial hypothesis that warmer and ice free conditions in the northern Baltic Sea would favor the formation of snow bands, snow band frequency tends to decrease towards the end of the century. For the RCP8.5 scenario the change between the far future (2070 to 2099) and the recent past (1970 to 1999) is significant at the 95% level.

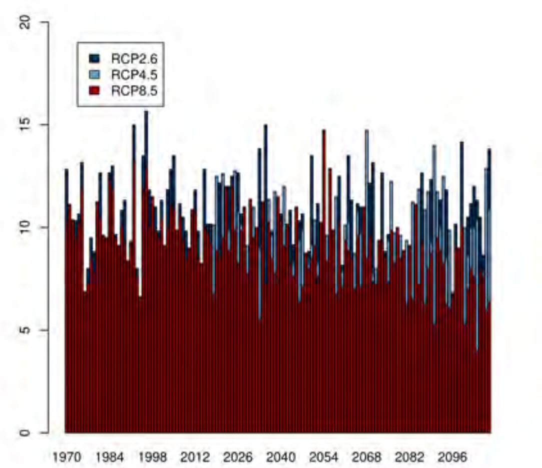

Figure 1. Number of days per year with moderate atmospheric conditions for convective snow bands on the Swedish east coast in the ensemble mean of three different RCP scenarios.

There is combination of interdependent, changing conditions that lead to an overall decrease of snow band occurrences. The atmospheric boundary layer height increases together with the number of days for heavy precipitation. At the same time, surface temperature strongly decreases and days with a mean temperature of 8° C or less become less frequent. This also leads to a reduction of days where the vertical temperature gradient is sufficiently large for snow bands to occur. Together with increasing temperatures the number of days where precipitation occurs as snow fall reduces.

As shown by Jeworrek et al. (2017) and reproduced in our analysis the peak month for snow bands in the recent past (1970 to 1999) on the Swedish east coast is November (Fig. 2). In the course of the century the month with the highest number of snow band conditions shifts to December in the near future (2020 to 2049) and in the far future (2070 to 2099) there are almost as many events in January as in December. This effect is caused primarily by warm surface temperature extending further into the cold season.

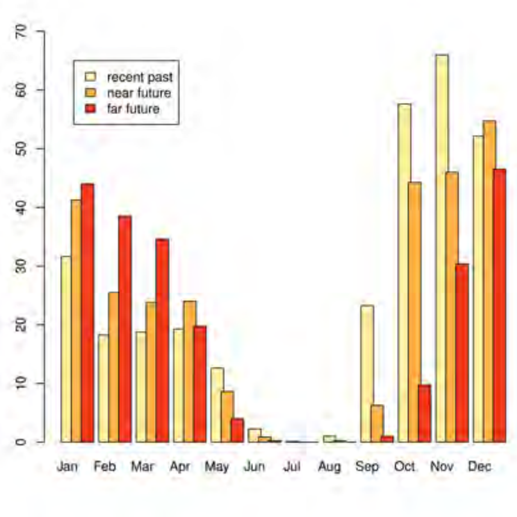

Figure 2. Number of days per month with moderate atmospheric conditions for convective snow bands on the Swedish east coast in the ensemble mean of the RCP8.5 scenarios.

4. Discussion

We have downscaled a number of CMIP5 scenarios with the coupled atmosphere-ice-ocean model RCA4-NEMO to produce regional climate scenarios for the North Sea and Baltic Sea region. These scenarios show strong signals in surface fluxes (Dieterich et al., 2019) and surface conditions (Gröger et al., 2019, Meier et al., 2019) due to climate change. In this study we have analyzed how atmospheric conditions for the formation of snow bands change under projected climate change. Snow bands occur less often in a warmer climate. The single strongest stressor is the increase in atmospheric surface temperature. During the recent past 300 days per year would qualify for a daily mean temperature of less than 8° C. In the far future there are on average only 230 days per year that are below 8° C. This also causes the seasonal maximum of snow band occurrence to shift from November towards December and January.

Additional analysis is necessary to identify the sensitivity of our conclusions against the criteria of the conditions for convective snow bands. We have applied those that have been developed by Jeworrek et al. (2017), see Appendix.

We plan further analysis to identify whether the changing snow band signal is related to changes in atmospheric circulation patterns.

Appendix

parameter	criteria
max 10m wind speed	> 10 m/s
mean 2m temperature	< 8° C
max temperature difference between surface and 850 hPa	> 13° C
mean wind shear between 700 and 975 hPa	< 60°
mean wind direction at 900 hPa	> 0° and < 90°
max boundary layer height	> 1000 m
max precipiation	> 0.5 mm/h
max snow fall	> 1.5 mm/d

Table 2. Criteria for days with moderate atmospheric conditions for convective snow bands. The precipitation parameters are evaluated along the Swedish east coast. The other parameters are evaluated over the Baltic Sea, north of 56° N. Reproduced from Jeworrek et al. (2017).

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The Projection Service for Waterways and Shipping (ProWaS) – first results of model sensitivity studies on the influence of global climate change to the Baltic Sea

Birte-Marie Ehlers[1], Janna Abalichin[1] and Frank Janssen[1]

[1] Federal Maritime and Hydrographic Agency, Rostock, Germany (birte-marie.ehlers@bsh.de)

1. Introduction

The “German Strategy for Adaptation to Climate Change” (DAS) is established as the political framework to climate change adaption in Germany. One task of the “Adaption Action Plan of the DAS“ is the installation of a permanent service on seamless climate prediction. The pilot project “Projection Services for Waterways and Shipping” (ProWaS) prepares an operational forecasting and projection service for climate, extreme weather and coastal and inland waterbodies. The target region is the North Sea and Baltic Sea with focus on the German coastal region and its estuaries, but for validation reasons also results for the northern Baltic Sea and the Gulf of Finland are analyzed.

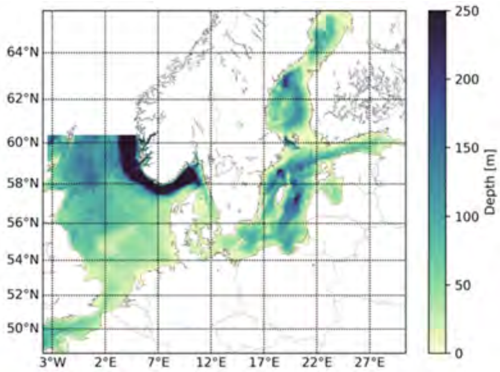

Figure 1: Bathymetry of model setup used for a 20year hindcast simulation.

2. Model setup

ProWaS provides regional model setups for the North and Baltic Seas (Figure 1). To figure out model technical issues and to validate the model setup a 20year hindcast simulation forced with a regional reanalysis (COSMO-REA6 (Bollmeyer et al., 2015) was carried out.

3. Sensitivity studies

This simulation is used as basis for sensitivity studies with reference to different global climate change scenarios. To evaluate the effect of global climate change on the coastal regions especially in the North and Baltic Seas, model studies regarding global sea level rise (Figure 2) and changes in global ocean temperature have been performed. Therefore boundary conditions of a hindcast simulation are adapted to different climate change conditions.

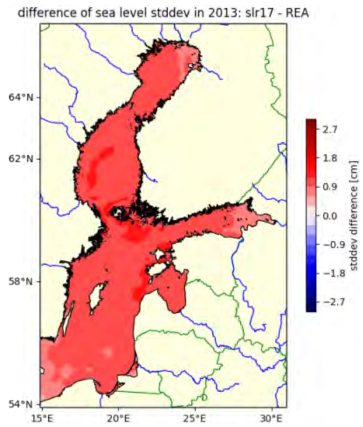

Figure 2: Example for a sensitivity study for a global sea level rise of 1.7m for 2013: difference of sea level standard deviation for the sensitivity study example and the hindcast run.

With focus on the northern Baltic Sea and the Gulf of Finland we will present first results of the performed sensitivity studies and draw conclusions from the changed boundary conditions to the reference hindcast run. In addition further product examples for the climate projection service will be presented (Figure 3).

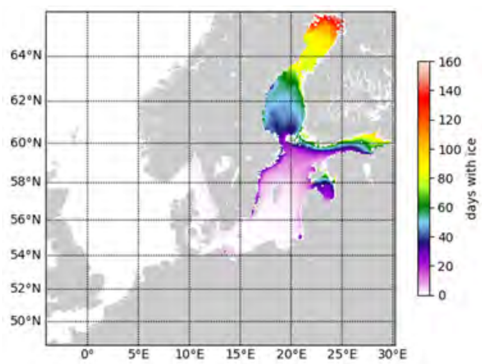

Figure 3: Multi-year mean of number of days with sea ice per year as product example for the climate projection service.

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The Projection Service for Waterways and Shipping (ProWaS) – validation of a NEMO and HBM setup for the northern Baltic Sea

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1. Introduction

The "German Strategy for Adaptation to Climate Change" (DAS) is established as the political framework to climate change adaption in Germany. One task of the "Adaption Action Plan of the DAS" is the installation of a permanent service on seamless climate prediction. The pilot project "Projection Services for Waterways and Shipping" (ProWaS) prepares an operational forecasting and projection service for climate, extreme weather and coastal and inland waterbodies. The target region is the North Sea and Baltic Sea with focus on the German coastal region and its estuaries, but for validation reasons also results for the northern Baltic Sea and the Gulf of Finland are analyzed.

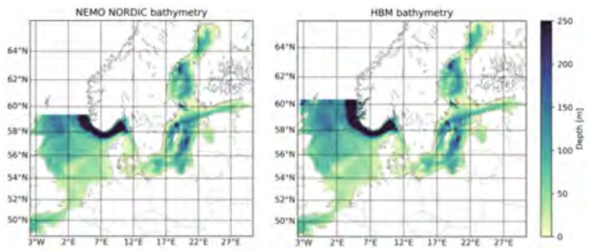

Figure 1: Bathymetry for modelled region for NEMO Nordic v3.3 and HBM model setups.

2. Model setup

With the aim of finding the most suitable ocean component for a coupled model system, two 20-year hindcast simulations (Figure 1, Table 1) covering the North Sea / Baltic Sea region are performed. The ocean model codes NEMO Nordic v3.3 and the HIROMB-BOOS Model (HBM) run with similar setups and identical prescribed atmospheric forcing from COSMO-REA6 (Bollmeyer et al., 2015).

	NEMO Nordic v3.3	HBM BSH
hindcast run	06/1996 – 12/2015	06/1996 – 12/2015
atmospheric forcing	COSMO-REA6	COSMO-REA6
horizontal resolution	2sm	3sm / 0.5sm
nesting	no	yes
wetting & drying	no	yes
minimum water depth	10m	-
boundary conditions for sea level	monthly	15 min

Table 1: model setup NEMO Nordic v3.3 and HBM

3. Results

Important model output variables such as sea level, sea surface temperature (Figure 2), salinity and ice cover are validated. A special focus is set to the comparison of the models and the validation with observation data in the northern Baltic Sea and the Gulf of Finland.

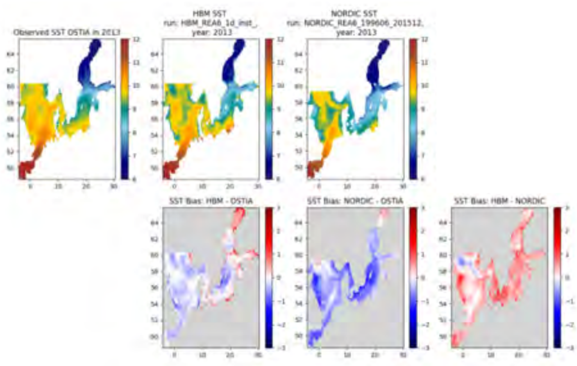

Figure 2: Data example for the mean sea surface temperature in 2013. Top: observation, NEMO Nordic v3.3, HBM; Bottom: Bias of HBM – observation, NEMO Nordic v3.3 – observation and HBM – NEMO Nordic v3.3.

References

Bollmeyer, C., Keller, J. D., Ohlwein, C., Wahl, S., Crewell, S., Friederichs, P., Hense, A., Ekune, J., Kneifel, s., Pscheidt, I., Redl, S. and Steinke, S. (2015) Towards a high-resolution regional reanalysis for the European CORDEX domain, Quarterly Journal of the Royal Meteorological Society, 141, Pp 1-15.

Consistent changes in a large ensemble of regional climate projections downscaled for the Baltic Sea

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1. Introduction

Reliable information about future Baltic Sea hydrography is a prerequisite for simulating future changes in biological productivity, carbon exchange with the atmosphere as well as the potential acidification of the water body. We here present physical hydrographic results from from an ensemble from a regional coupled ocean-atmosphere model (Gröger et al. 2015; Dieterich et al., 2019; Gröger et al., 2019) to elaborate consistent changes along the ensemble. In particular we show the likely future changes in the large scale circulation and changes in stratification in the Baltic Sea as well as mean extreme changes in the atmospheric forcing.

2. Results

2.1 Ocean

In all scenarios so far analyzed the Baltic Sea shows a widespread freshening mainly due to increased yearly total rainfall over the Baltic Sea. Additionally a 10 % increase of river discharge around the Bothnian Sea contributes to the freshening in the northern Baltic. Beside these large scale changes local circulation driven large scale atmospheric changes promote strongest salinity changes in the Skagerrak where the cyclonic circulation strengthens.

In regard to start to stratification both, increased atmospheric freshwater flux as well as warming of the near surface layer stabilize the water column. The summer pycnocline, in most areas reflecting the thermal stratification, intensifies in the course of the century especially in the high emission scenario RCP8.5.

Finally, assuming todays tolerance ranges for temperature and salinity of many species presently found in the Baltic Sea imply large changes in the future biology in response to climate change.

2.2 Atmosphere -preliminary results

Some scenarios, especially those carried out under the high emission climate scenario RCP8.5 show an increased likelihood for heat waves at the end of the 21st century (Fig. 1). Here the uncertainty to the chosen scenario is quite larger than the uncertainty due to the choden model. First analysis point to a sporadic events of elongated presence of high pressure fields as main factor rather than the change in the mean climate. However, further analysis is necessary to figure out robust causal relationships.

Despite most ensemble members show increased moisture convergence over northern Europe together increased yearly mean rainfall, summer conditions in the southern Baltic Sea become dryer during summer. In the strongest warming scenario the Baltic Sea is affected by a rise of dry periods with at least five days with less than 1mm/day precipitation is registered. Impacts of those short term instances on marine biogeochemical cycles are fairly unknown so far.

Further analysis reveals changes in storm track intensity. This has been investigated using an established approach following Blackmon (1976). Preliminary results indicate at least 5 out of 9 ensemble significantly increased storm track intensity over the center part of Europe. However, so far high uncertainties related to the choice of the global model mkaeit difficult to come to robust conclusions.

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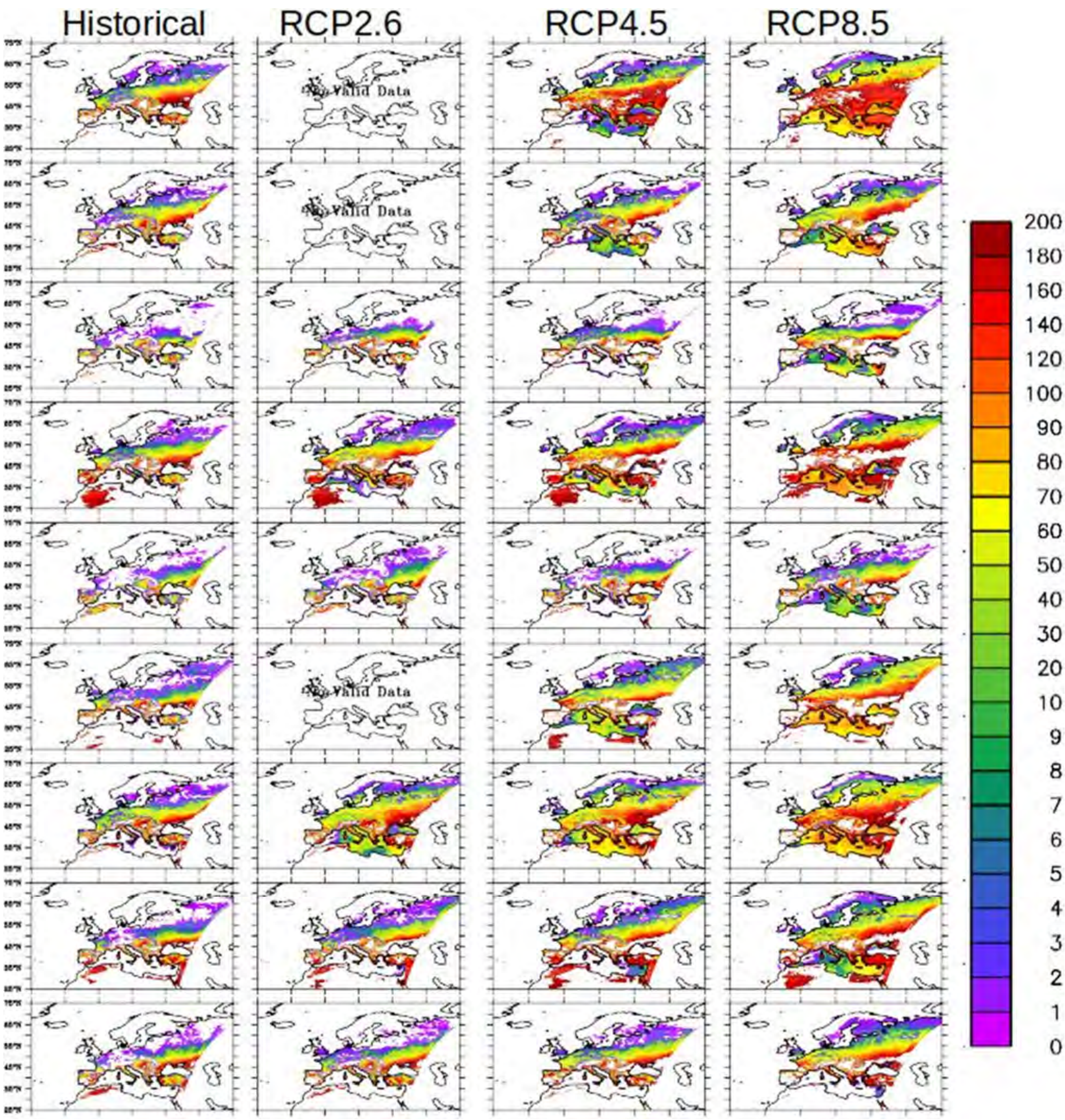

Figure 1: Number of periods of at least 5 consecutive days within a 30-year period.Historical=1970-1999; RCPs=2070-2099.

Biogeochemical cycles of the Gulf of Bothnia

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Highlights of the talk will be

a) the large contrast in nutrient cycling in the two sub-basins of Gulf of Bothnia,

b) a presentation of the recent trends in nutrient concentrations in the seas as well as inputs of nutrients,

c) a discussion of causes for these trends,

d) a presentation of recent advances on the knowledge of the sediment processes, and

e) a discussion of the importance and possible ways forward for improving the modelling of nutrient/biogeochemical cycles in these basins

The unique character of the Gulf of Bothnia

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The Bothnian Bay show different characters when it comes to hydrography, chemistry and biology compared with the Baltic Proper. Heterotrophic production is of higher importance for fueling the food web, as compared to autochthonous autotrophic production. The phytoplankton community consists of a higher amount of mixotrophic organisms in the Gulf of Bothnia. It is therefore important to include terrestrial organic matter, heterotrophic bacteria and mixotrophs in models accounting for biogeochemistry and climate change scenarios. Data suggests that dissolved organic compounds and humic substances are of vital importance for understanding the Gulf of Bothnia now and in the future.

Here we present time series from the Gulf of Bothnia and discuss its implications for understanding the potential effects of climate change.

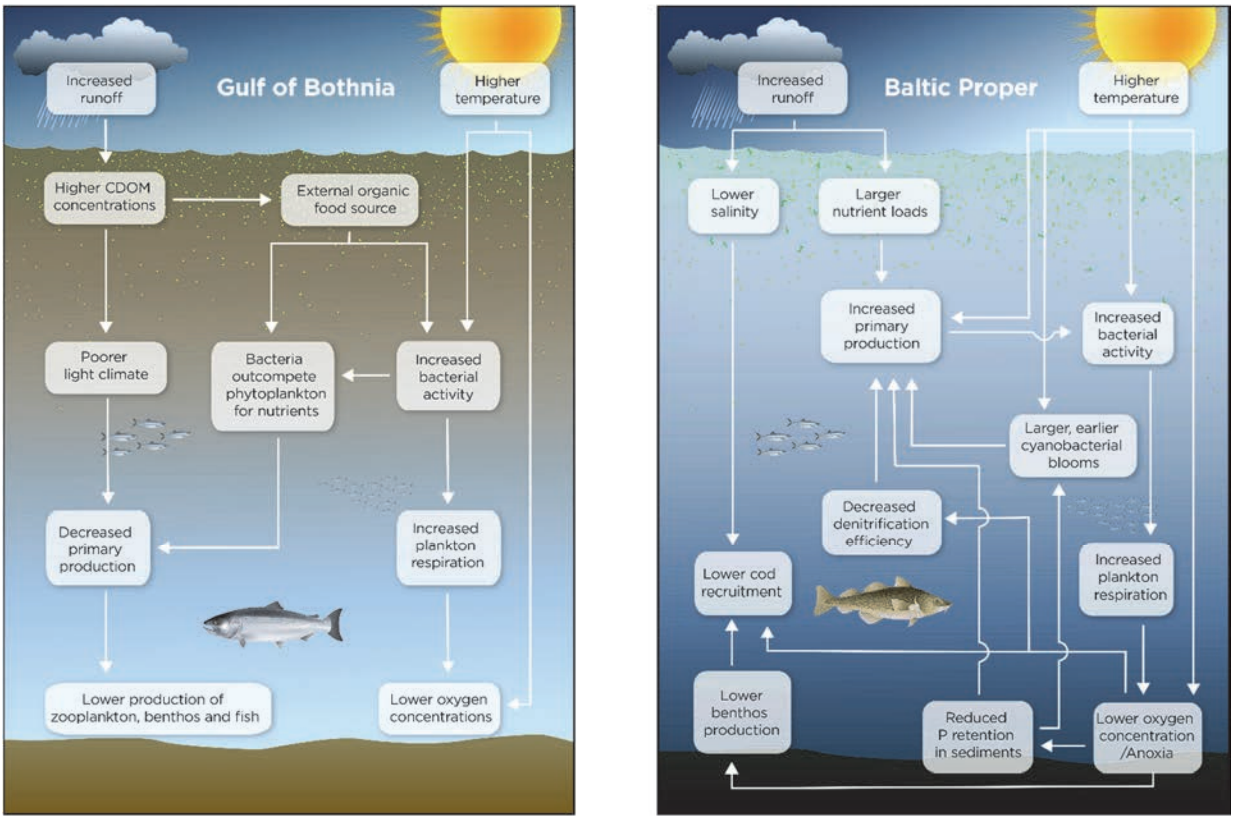

Figure 1. General characteristics of the Gulf of Bothnia and the Baltic Proper (Figure: Kristina Viklund)

Structure and variability of the CO_2 system in the Baltic Sea – facts and challenges

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1. CO_2 system in the Baltic Sea

Spatial and temporal variability of the CO_2 system in the Baltic Sea is driven by a number of processes among which the seasonal changes in the mixed layer depth and in production/respiration as well as input of different carbon species from land play the most important role. The seasonality of the CO_2 partial pressure (pCO_2) in the surface waters shows typical pattern with maximum values observed in winter due to the predominance of respiration over production and deepening of the mixed layer depth, which brings to the surface deeper waters enriched in CO_2. In spring along with the production increase and formation of the thermal stratification the pCO_2 drops and surface seawater becomes undersaturated with CO_2. Second minima in pCO_2 appears in summer as a consequence of usually intense cyanobacteria bloom. Although, the net ecosystem production, and thus also pCO_2 variability, is relatively well understood and quantified in the Baltic Sea still significant knowledge gaps exist. The most important are: (i) identification the source of nitrogen in the post-spring production period in the central Baltic Sea and (ii) understanding the C:N:P stoichiometry in the production in the northern part of the Gulf of Bothnia.

The Baltic Sea, and especially its northern part, is under high influence of terrestrial input. According to Kuliński and Pempkowiak (2011) rivers the Baltic Sea receives about 4.1 mln tones of organic carbon annually. As some fraction of that load is bioavailable the remineralization of terrestrial organic carbon contributes to pCO_2 fields and thus can shape the CO_2 exchange through the air/sea interface (Kuliński et al., 2016). However, still the fate and pathway of terrigenous organic carbon in the Baltic Sea is not well understood yet.

Another important feature conditioning structure and variability of the CO_2 system in the Baltic Sea is total alkalinity (A_T) (Kuliński et al., 2017). As A_T is a measure of buffer capacity, it controls also the large scale variability of pH. The importance of A_T for controlling the seawater pH has been documented in the Baltic Sea studies by Omstedt et al. (2010) and Kuliński et al. (2017) (Fig. 1). They showed that when the Baltic Sea surface water is at equilibrium with the atmosphere, the pH varies spatially between 7.7 and 8.3 purely due to the large variability in A_T distribution. The range of A_T in the Baltic Sea surface waters is due to different riverine forcing. Rivers draining the granite-dominated Scandinavian Peninsula contain little A_T, meaning that in the northernmost part of the Baltic Sea (the Bothnian Bay) A_T does not exceed 800 μmol kg^{-1}. Continental rivers, on the other hand, are draining limestone-rich catchments which mean that near the mouth of these rivers A_T can be as high as 3200 μmol kg^{-1}. Generally, due to the low salinity and thus also lower A_T, the Baltic Sea water should be more sensitive to the OA than oceanic waters. However, it was reported that A_T in the Baltic Sea change over time. The statistical analysis performed by Müller et al. (2016) showed that A_T continuously increases in the Baltic Sea in the recent decades. They found that the highest trend of about 7 μmol kg^{-1} yr^{-1} observed for the northern part of the Baltic Sea (the Gulf of Bothnia) mitigates almost entirely the pH decrease that would occur due to atmospheric CO_2 increase. In the Baltic Proper, the A_T increase is smaller (3.4 μmol kg^{-1} yr^{-1}). The most probable explanations of the difference assume that it is caused by the increased weathering of carbonate and silicate rocks in the catchment or by internal generation of A_T (Müller et al., 2016). Both hypotheses are theoretically plausible, although not yet confirmed by the experimental data for the Baltic Sea. It is also plausible that both these processes act simultaneously.

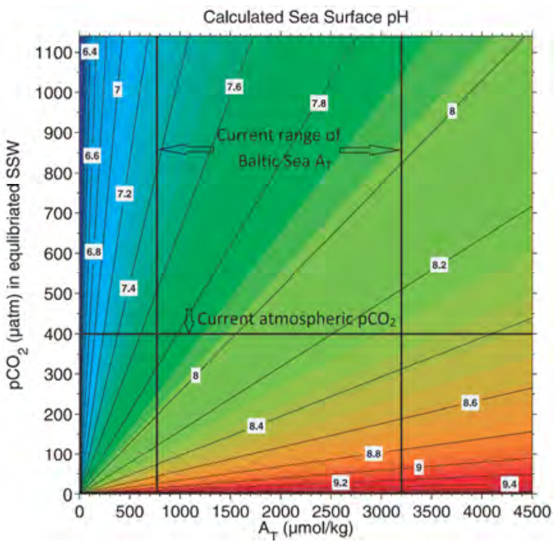

Figure 1. *Distribution of pH on the total scale (pH_{tot}) in the Baltic Sea as a function of A_T and pCO_2 at a salinity of 7.5 and a temperature of 0°C (Kuliński et al., 2017, modified after Omstedt et al., 2010). The A_T range represents findings by Beldowski et al. (2010). SSW is an abbreviation for surface seawater.*

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Predicting extreme dry spell risk based on probability distribution in coastal region of Tunisia

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Abstract Climate variability and climate change in the longer term consequences of economic, social and environmental. It is likely that climate change increases the frequency and duration of droughts. Event based analysis of dry spell phenomenon, from series of daily rainfall observations was conducted in order to predict extreme dry-spell risk. The case study is a coastal region northern Tunisia of Mediterranean climate. A dry period is defined as a series of days with daily rainfall less than a given threshold. For analysis carried out to provide data for water resources development studies, the rainfall event has been defined even more restrictively by omitting daily rainfall below a certain threshold value. As this limit 3.5 mm j^{-1} has been selected, since this amount of water corresponds approximately to the expected daily evaporation rate, thus marking the lowest physical limit for considering rainfall that may produce utilizable surface water resources. Dry events are considered as a sequence of dry days separated by rainfall events from each other. Thus the rainy season is defined as a series of rainfall and subsequent dry events. Rainfall events are defined as the uninterrupted sequence of rainy days, when at last on one day more than a threshold amount of rainfall has been observed. The evolution of dry events and longest spells in duration and frequency in the region under the influence of a changing climate was studied. The identification of the longest dry and wet events on the history was carried out. For planning purposes, the longest dry spells associated with various statistical recurrence periods are derived on the basis of the fitted GEV type probability distribution functions. Dry spell lengths for return periods of 2, 5, 10, 25 and 50 years indicate the areas where drought phenomena might be more severe, as well as how often they might occur. This analysis is used to calibrate precipitation models with little rainfall records, the study of the effects of climate change on water resources and crops. The results reported here could be applied in estimating climatic drought risks in other geographical areas.

Key words: climate change, extreme dry event, risk analysis.

1. Introduction

Dry spell can be defined as a sequence of dry days including days with less than a threshold value of rainfall. A practical procedure to analyze rainfall event time series under semi-arid climatic conditions is the event-based concept. This design of analysis is favored over continuous type data generation method. It is to simulate wet and dry spells separately by fitting their durations to an appropriate probability distribution such as the negative binominal or geometric distribution (Semenov *et al.*, 1998; Mathlouthi & Lebdi, 2008), or empirical distribution (Rajagopalan and Lall, 1999). The characteristics of multi-day wet and dry spells is often important for investigating likely scenarios for agricultural water requirements, reservoir operation for analyses of antecedent moisture conditions (Mathlouthi & Lebdi, 2008), and runoff generation in a watershed. In virtue, this paper is focused on the modelling of rainfall occurrences under climate Mediterranean by wet-dry spell approach for operation dam with basis different from that of observations carried out with regular time's intervals. The event-based concept allow the synthetic rainfall data generation. This used, for example, for reservoir simulation studies, the estimation of irrigation water demand and the study of the effects of a climatologically change. This paper concentrates solely on the characterization of the events of the dry spell in a Dam North of Tunisia.

2. Data and method

The data used in this analysis are the daily precipitation records at coastal region Northern Tunisia. The rainy season starting at September and lasting until the beginning of May. The mean of annual rainfall is 680 mm. Except in occasional wet years, most precipitation is confined to the winter months in this basin. The dry season lasts from May to August. Daily values of precipitation are quite variable.

A rainfall *event* is an uninterrupted sequence of wets periods. The definition of event is associated with a rainfall threshold value which defines *wet*. As this limit 3.5 mm d^{-1} has been selected. This amount of water corresponds to the expected daily evapotranspiration rate, marking the lowest physical limit for considering rainfall that may produce utilizable surface water resources. In this approach, the process of rainfall occurrences is specified by the probability laws of the length of the wet periods (storm duration), and the length of the dry periods (time between storms or inter-event time). The rainfall event *m* in a given rainy season *n* will be characterized by its duration $D_{n,m}$, the temporal position within the rainy season, the dry event or inter-event time $Z_{n,m}$ and by the cumulative rainfall amounts of Hn,m of Dn,m, rainy days in mm:

$$H_{n,m} = \sum_{i=1}^{Dn,m} h_i \qquad (1)$$

Where h_i is positive and represent the daily precipitation totals in mm. Note that for at least one *hi* >3.5 mm.

3. Results and concluding remarks

Independent events are separated by a time period t which follows an exponential distribution (Fogel and Duckstein, 1982):

$$f(t) = b.e^{-bt} \qquad t > 0 \qquad (2)$$

where *b* parameter of the exponential distribution, can be estimated as the reciprocal mean *t* of the sample of times observed:

$$b = \frac{1}{t} \qquad (3)$$

If the waiting time is measured in days, the exponential distribution can be replaced by the equivalent discrete distribution, namely the geometrical distribution:

$$f(n) = p.q^{n-1} \qquad \text{for n = 1, 2, …} \qquad (4)$$

where the *p* parameter is estimated by the reverse of the expectation of the average duration n of waiting between two successive events.

$$p = \frac{1}{n} \quad ; \qquad \text{and} \quad q = 1 - p \qquad (5)$$

However, if the series of successive precipitations do not form independent events, the waiting time follows a gamma distribution with two parameters instead of an exponential distribution (Fogel and Duckstein, 1982). Consequently, if the time is discretized in days, the distribution of time separating two events is represented by the negative binomial distribution (Mathlouthi and Lebdi, 2008) which is the equivalent discrete distribution of the gamma distribution:

$$f(n) = \frac{(r + n - 1)}{n!(r - 1)!} . p^r . q^n \qquad (6)$$

where *n* = 0, 1, 2, … , and *r* et *p* are estimated by the variance and mean of the dry event duration.

Approximately 33% of the events last at most one day. The persistence of uninterrupted sequences of rainy days sometimes lasting nearly two weeks (the maximum observed duration is 13 days). However, the frequency of such long-duration events decreases rapidly with increasing duration. An arithmetic mean of 2.79 days and a standard deviation of 1.87 were obtained. The geometric pdf appears most adequate for the fitting.

The regression analysis display that the dry event can be assumed to be independent from the rainfall event and the rainfall depth per event. Thus the distribution of the dry event (interevent time), which can only assume integer values, follows an unconditional probability distribution function. The negative binomial pdf has been found as best fitted to describe the distribution of the dry event (Fig. 1). The shortest interruption (one day) is the most frequent one. Almost a fifth of the observed dry events are only one day long. Dry periods up to 30 or even more days may be recorded (a 56 days maximum is recorded). The arithmetic mean and the standard deviation for the dry event are respectively 7.3 days and 7.9; for the longest dry event there are 30.2 days and 3.6.

Figure 2 shows the best fitting of the beginning of the first rainfall event during rainy season. It was concluded that the first rainfall event occurs in the mid-September, whereas the probability of surpassing this value is 0.52 (a biennial return period). For extreme case, the hydrological year starts about the first decade of October.

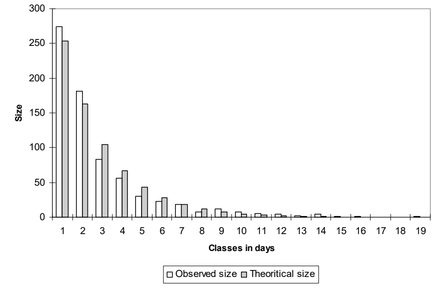

Figure 1. Distribution of the time elapsed between rainfall events (dry events).

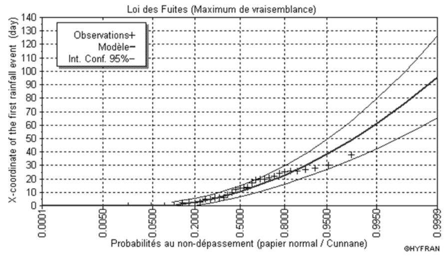

Figure 2. Fitting leaks law for the chronological position of the first rainfall event in rainy season.

The case study confirms the concept of the independence of rainfall and dry event duration. The dry spell phenomenon in this region seems to be particularly well described by fitting a pdf to the length of the interevent time. The negative binomial pdf provides an excellent fit for the prolonged dry periods between subsequent rainfall events. Conceptually, in a true Poisson process, the time “without event” should follow the exponential pdf or, in a discrete case, the geometric pdf (Fogel and Duckstein, 1982). It is relevant to note that this “flaw” could be eliminated by defining the interevent time as the dry event. Consequently, the present role of the interevent time would be taken over by the rainfall events duration. The theoretical requirements of the fitted geometric pdf are satisfied.

Event-based analysis has been used to generate synthetic rainfall event time series. By coupling this with a rainfall-runoff model, one obtains synthetic streamflow series to be used for reservoir simulation studies and design flood estimations. As another application, the study of the effects of a climatologically change.

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Ensemble modelling of the Baltic Sea in past and future climates

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1. Recent achievements

Regional climate system models are powerful tools to explain and to project past and future changes in Baltic Sea climate (Meier and Saraiva, 2019). Applying the so-called dynamical downscaling approach, climate variability during periods longer than the period of available instrumental data can nowadays be regionalized. These simulations cover both the past 1000 years (e.g., Börgel et al., 2018) and the coming 100 years (e.g., Meier et al., 2011; Höglund et al., 2017; Dieterich et al., 2019; Gröger et al., 2019). Coupled climate-environmental modelling allowed to disentangle the impact of multiple drivers on the marine ecosystem (e.g., Meier et al., 2019a; 2019b).

However, climate simulations suffer from uncertainties such as model biases, unknown external drivers and natural variability. To improve the predictive capacity of regional climate models, an international Baltic Sea Model Intercomparison Project (BMIP) was initiated by Baltic Earth[1]. First results suggested that the mean circulation in hindcast simulations differs considerably among various circulation models although simulated temperatures and salinities agree relatively well with observations (Placke et al., 2018). As differences in barotropic ocean currents were explained by the usage of different atmospheric forcing datasets, in BMIP simulations will be driven by the same atmospheric and hydrological forcing.

To investigate natural climate variability while neglecting the impact of anthropogenic changes, a pre-industrial period covering approximately the last 1000 years was simulated. It was shown that the Atlantic Multidecadal Oscillation (AMO) influences the low-frequency variability of temperature and salinity in the Baltic Sea and consequently the marine ecosystem (Börgel et al., 2018; Kniebusch et al., 2019a; 2019b). Further, new projections and sensitivity studies were analysed to investigate Baltic Sea climate variability (Saraiva et al., 2019a; 2019b). Using a coupled physical-biogeochemical model, the impact of past and accelerated future global mean sea level rise (GSLR) upon water exchange and oxygen conditions in the Baltic Sea was investigated (Meier et al., 2017). In future high-end projections (> ~ 1 m), the impact of GSLR is projected to become important by reinforced saltwater inflows causing increased vertical stratification, expanded anoxic bottom areas and increased risk for cyanobacteria blooms compared to present-day conditions.

Within Baltic Earth an international working group assessed the impact of the implementation of the Baltic Sea Action Plan (BSAP) on the future environmental status by analyzing multi-model ensemble simulations for the 21st century (Meier et al., 2018; 2019c). A substantial spread in projections was found. As example, changes in bottom oxygen concentrations are shown (Fig. 1).

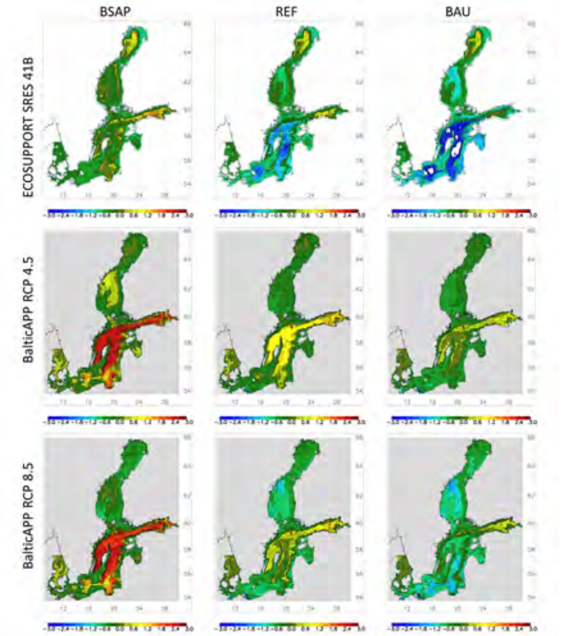

Figure 1. Ensemble mean summer (June – August) bottom dissolved oxygen concentration changes (mL L^{-1}) between 1978-2007 and 2069-2098. From left to right results of the nutrient load scenarios Baltic Sea Action Plan (BSAP), Reference (REF) and Business-As-Usual (BAU) are shown. From top to bottom results of the ensembles ECOSUPPORT (white background), BalticAPP RCP 4.5 (grey background) and BalticAPP RCP 8.5 (grey background) are depicted. ECOSUPPORT and BalticAPP were two BONUS projects (Source: H. E. Markus Meier, IOW and SMHI)

The biggest uncertainties were identified to be (1) unknown current and future bioavailable nutrient loads from land and atmosphere, (2) the experimental setup, (3) differences between the projections of global and regional climate models, in particular, with respect to the global mean sea level rise and regional water cycle, (4) differing model-specific responses of the simulated biogeochemical cycles to long-term changes in external nutrient loads and climate of the Baltic Sea region, and (5) unknown future greenhouse gas emissions. Nevertheless, it was found that the implementation of the BSAP will lead to a significant improvement of the environmental status of the Baltic Sea.

In summary, the analysis of climate simulations suggested that Baltic ecosystem changes significantly depend on

[1] https://baltic.earth/organisation/bewg_BMIP/index.html

natural and externally forced variations in the large-scale atmospheric circulation and that changing climate has to be considered for marine management. Further, the results emphasized the need for investigating ensembles of climate simulations with many members and rigorous assessments of models' performance. As marine ecosystems are often more vulnerable to changing extremes than to changing means, climate models should be able to simulate extremes realistically (Meier et al., 2019d).

2. Challenges

Uncertainties of projections both for physical and biogeochemical variables are largest in the northern Baltic Sea and Gulf of Finland (Meier et al., 2018). In these areas, the models usually have the lowest skill compared to observations (Eilola et al., 2011; Placke et al., 2018). Reasons might be the insufficient process descriptions of, *inter alia*, bioavailable fractions of external nutrient loads (e.g., Eilola et al., 2011), non-Redfield stoichiometry (e.g., Fransner et al., 2018), the microbial loop (e.g., Wikner and Andersson, 2012), sediment-water fluxes (e.g., Eilola et al., 2009), and the lacking top-down cascade in the food web including the impact of fishing (e.g., Bauer et al., 2018).

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Ecosystem modelling in the Baltic Sea region with ECOSMO in the context of climate change - experiences and perspectives

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The ECOSystem MOdel is a N(utrient) P(hytoplankton) Z(ooplankton) D(etritus) model developed for the use in fully-coupled physical-biological 3D modelling frameworks (Schrum et al. 2006). The basic version of ECOSMO comprises lower trophic level interactions between two phyto- and two zooplankton components, where phytoplankton growth is controlled by the availability of the macronutrients nitrogen, phosphate and silicate as well as light. Since the basic configuration, ECOSMO has been able to identify zones of high productivity and zooplankton growth, such as ocean fronts. Further development including a bottom sediment pool for nutrients and dynamics of cyanobacteria have resulted in ECOSMO2 (Daewel and Schrum, 2013). Applied to the coupled North Sea and Baltic Sea system, this model has been used to provide long-term hindcasts of the ecosystem dynamics revealing long-term changes in primary and secondary production. Further applications of the coupled modelling framework comprise sensitivity of the Baltic ecosystem to atmospheric forcing as well as effects of artificial deep-water oxygenation (geo-engineering) on oxygen and nutrient levels in the deep Baltic basins. More recent developments of ECOSMO2 aim at expanding trophic interactions towards fish and lower trophic and nutrient dynamics in sea ice. Coupling of ECOSMO2 to an unstructured model, SCHISM (Zhang et al. 2016), is the basis for ongoing works on simulating various ecosystems such as the Arctic shelf and Elbe estuary.

Sensitivity of reproduction of the modern climate of the Baltic Sea to external forcing on the example of MITgcm

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1. Purpose of the study

The purpose of this work is to show that adequate reproduction of the modern climate of the Baltic Sea, including not only average values of climatic characteristics, but also extreme events, is possible not with any forcing set on the basis of scenario runs with global climate models.

2. Model and forcing

Reproduction of the modern climate of the Baltic Sea was carried out using the hydro-thermodynamic model of the Massachusetts Institute of Technology MITgcm (http://mitgcm.org/). A hydrostatic version of the model complex was used, including parametrizations of vertical turbulence, spreading of bottom waters, isopycnic mixing, and sea ice module. When adapting the model to the conditions of the Baltic Sea, the values of the coefficients were adjusted in a number of parameterizations used.

The boundary conditions were the atmospheric fields (shortwave and longwave incoming radiation, temperature, pressure, wind velocity components, humidity, precipitation rate), river discharge, sea level, temperature and salinity at the liquid sea boundary.

The calculations were performed on a spherical grid with a horizontal resolution of 2 nautical miles and a vertical resolution of 3 meters from the surface to the bottom. The depth field used is shown in Figure 1.

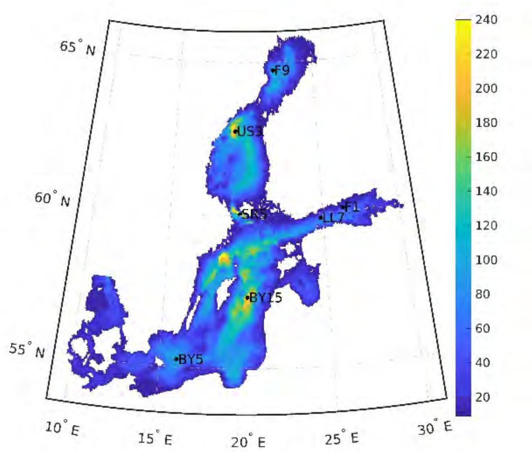

Figure 1. Baltic Sea bottom depths and the position of the analyzed hydrographic stations.

To reproduce the modern climate considering the period from 1966 to 2005, we performed 2 runs with different sets of boundary conditions. The first run (Reanalysis) was performed when setting the atmospheric forcing from regional reanalysis of the Swedish Meteorological and Hydrological Institute (https://www.smhi.se/en/research/research-departments/meteorology/reanalyses-for-climate-1.132240). The river flow was set as monthly average values from the available data. At the liquid boundary in the straits, hourly values of the level and monthly climatic average values of temperature and salinity were set. In the second calculation (called MPIOM), initial conditions, conditions at the open borders and atmospheric forcing (with one-hour resolution) and river flow (monthly average values) were specified according Sein et al. (2015) from the run of the model ROM for the period 1920-2005 according to the AR5 IPCC scenario.

3. Results

Simulated temperature and salinity of the Baltic Sea in the period 1966-2005 are in a good agreement with the observational data in the “Reanalysis” run. In the MPIOM run, despite the average sea surface temperature is in good agreement with the observations in the Baltic Proper, it strongly (by several degrees) underestimates the data at stations F1, LL7 in the Gulf of Finland, station F9 in the Bothnia Bay and stations SR5 and US3 in the Bothnia Sea. Worse, in this run, the standard deviation of the sea surface temperature at all the stations under consideration turned out to be greatly underestimated (by 1.3–1.7 ° C).

There are also the unobserved trends of decreasing surface and bottom salinity over time. Moreover, the number of years with extreme summer temperatures at HELCOM stations BY5, BY15 and LL7 for this period in the “Reanalysis” run turned out to be close to the estimation from observational data, while according to the MPIOM run, a specified threshold of extreme temperature was not reached. The MPIOM run also showed a complete absence of the events of the inflow of the North Sea waters into the Baltic Sea, whereas in reality there were 6, and in the “Reanalysis” run, 4 such events during the period considered.

4. Conclusions

Thus, the MPIOM run did not reproduce the extreme phenomena causing the eutrophication of the Baltic Sea. Hence, we should carefully choose external forcing when we want to reproduce not only average climatic characteristics, but also extreme climate changes.

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SmartSea scenarios on development of the Gulf of Bothnia area from recent days to 2060

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1. Overview

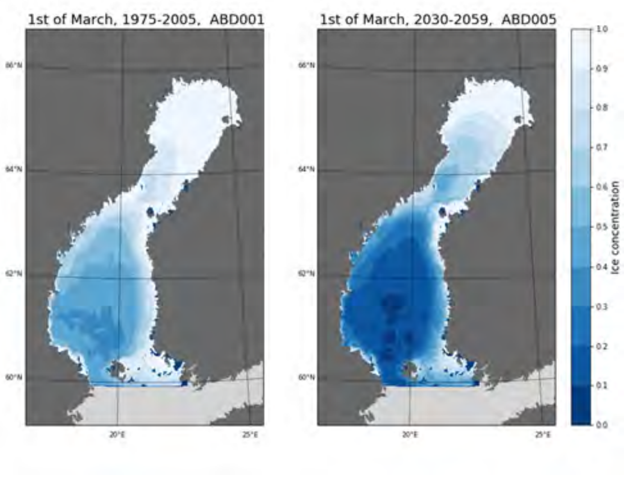

Figure 1. Change of average ice volume, March, during studied period.

Future changes in the Gulf of Bothnia will impact both the biology of the area as well as the human activities. For example the conditions for fishing, aquaculture and wind parks will change.

The SmartSea project aims to predict the changing conditions of the Gulf of Bothnia from recent days to 2060. For this purpose we have conducted numerical model experiments using NEMO-SCOBI with 4 different atmospheric models and with two different RCP scenarios (4.5 and 8.5).

2. Model setup

We used NEMO 3.6 with 1 NM resolution to simulate the hydrodynamic conditions in the Gulf of Bothnia. NEMO 3.6 was coupled with SCOBI biogeochemical model and with LIM3 sea ice model.

For atmospheric forcing four different models were chosen. A: MPI-ESM-LR, B: EC-EARTH, C: IPSL-CM5A-MR and D: HadGEM 2-ES.

3. Changes on ice conditions

Our preliminary results show considerable changes in several sea ice variables by 2060. The length of ice season continues shortening with a comparable rate that has been observed during the past few decades (-6 days/decade). The annual maximum ice volume in the Bothnian Bay shows a clear decrease: -50% and -60% for RCP 4.5 and 8.5, respectively, when comparing periods 1975-2005 and 2030-2059. Also, the timing of the annual maximum ice volume shifts to earlier. The extent of ice cover decreases with the most prominent change around the time of the annual maximum coverage (March, Figure 1) and in the end of the ice season (May).

4. Changes in temperature and salinity

All the simulations indicate gradual rise of temperature on the area, however the actual rise varies from simulation to simulation considerably.

For salinity the general trends is downwards in all simulations, but is much less systematic, even reserving for long periods in some simulations. There is lot of difference between various runs.

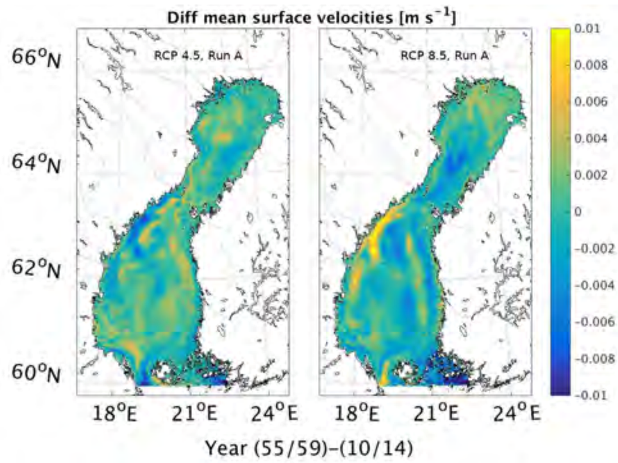

Figure 2. Images show the difference of mean surface flow speed for the last 5 years of the scenario runs, in comparison to the current averages at the start of the time period. Left side shows the development in RCP 4.5, and right one on RCP 8.5 for run A.

5. Changes in current patterns

The maximum and mean local surface flow speeds have been studied in the different scenarios. The results are both compared to present conditions and within the different scenarios. It can be seen that there are both horizontal variability for the maximum mean flow speed within a certain period as well as between different climate scenarios.

Forecast of socio-economic damage caused by flooding

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Flood damage forecasting issues are particularly relevant for highly anthropogenic transformed territories. In relation to the Baltic Sea basin, an increase in world ocean level and, as a result, a possible change in the boundaries of the water area increases the importance of this task. This also applies to flooding in the floodplains of the rivers of this region, which, being hydraulically connected to the Baltic basin, clearly respond to the above changes.

Moreover, flooding is already a frequent guest in a number of river systems of the Baltic basin. In particular, in accordance with the assessment of the flood situation within the Pripyat River, published in the Republican Program by Decree of the Council of Ministers of the Republic of Belarus (2009), during the spring flood, this territory and settlements in its floodplain are subjected to flooding almost every year, resulting in significant economic damage.

If we consider the period of existence of this territory, in which there was a slight technological integration in the domestic and industrial sectors, dangerous meteorological and hydrological phenomena did not cause significant material and social damage. This consisted in the use of devices of labor and home life that do not have energy-dependent mechanisms. A similar situation was observed in the field of agricultural production, the lack of significant mechanization made it possible to transfer such natural phenomena less painfully.

With the constant deepening of the technogenic transformation of natural landscapes, the problem of their protection from natural climatic phenomena becomes more and more significant. Measures to protect against flooding of the territory are generally understood as technical (hydraulic) structures that manage water masses in time and space. At the same time, no less important element is forecasting the development of natural and climatic phenomena, their economic and social consequences.

Methods of geographical analysis and forecasting have found wide application in almost all areas of economic activity, and in particular in predicting the occurrence and development of dangerous hydrological phenomena (flooding of the territory). Many scientists are developing methods and algorithms for calculating the boundaries and zones of flooding. So from the point of view of a compromise between accuracy (taking into account the natural relief and technogenic elements of the territory) and the use of computing resources, we can distinguish the algorithm described in detail by Volchak et al. (2010, 2015). As a result of applying this algorithm and the currently existing digital elevation models (DEM), it is possible to obtain not only the area of flooding of the territory, but also its isobaths (contours of equal depths). This will make it possible to classify the territory according to different depths of flooding and thus create polygons for geographic information systems (GIS) corresponding to them. The application of this kind of approach makes it possible to assess the economic and social consequences of flooding the territory more accurately. The work by Mironchik & Sayechnikov (2009) describes a software package that allows you to evaluate the flood zone, as well as calculate the economic damage. The GIS-based geographic analysis approaches described in it quite fully take into account the main types of technogenic landscapes subject to flooding, however, when assessing economic damage, the depth (level) of flooding of the territory and the period of exposure to dangerous hydrological phenomena are not taken into account.

Economic damage caused by hazardous hydrological phenomena can be estimated using the ArgGIS Spatial Analyst calculation algorithm package, designed to work with raster maps of various types of geographical phenomena. First, it is necessary to prepare thematic layers of GIS (digital layers) of territories with different levels of economic efficiency, book value and social significance. Thus, it is possible to generalize the study area from a socio-economic point of view. In turn, the approach used in [4] requires a complete and detailed GIS with technical and technological parameters of technogenic objects, which is currently not possible for large areas due to the lack of such an integrated system, and the accuracy of the estimates will not increase significantly. This is due to the fact that enlargement and generalization when performing such estimates makes it possible to smooth out the forecast errors of the flood zone. To represent such an effect, one can conduct a mental experiment: the forecast of the flood zone was made with an accuracy of 100-500 m [4], while within the limits of the forecast accuracy there is an object with great economic efficiency, in which case the economic damage will be significantly overstated. The overestimation of economic damage will be proportional to the ratio of economic efficiency (or cost, or social significance) of the considered individual object to its average value over the territory of flooding.

The next issue that needs attention is the depth of the water within the flood zone. Depending on the depth of water, the magnitude of socio-economic damage per unit area is estimated. To take into account these features, weights can be used, obtained from preliminary physical, technical and economic analysis of the effect of the water depth of the territory in question on the amount of damage. At the same time, the application of expert estimates method for determining the weight coefficients is quite effective.

The duration of flooding (or flooding) of the territory can be taken into account in the same way as in the case of the depth of water in the territory in question, based on weighting factors.

Thus, we can present an equation for assessing the damage from flooding (flooding) of the j-th type of land in general:

$$E_j = \sum_{i=1}^{n} k^h_{i,j} \cdot k^t_{i,j} \cdot F_i \cdot e_j ,$$

where E_j is the amount of damage to the j-th type of land, in monetary units; $k^h_{i,j}$, $k^t_{i,j}$ - respectively, weight coefficients taking into account the depth of water standing and its duration for the i-th plot of the j-th type of land, dimensionless; F_i is the area of the i-th section formed by the intersection of the geometric polygon of the j-th type of land and the flooding polygon classified by depth and duration of standing water, in units of area; e_j - specific efficiency (or cost, or social significance) of the j-th type of land, in monetary units per unit area.

Weights can be determined through the signal functions as follows:

$$k^h = 0.5\left(\frac{e^{2(h \cdot a_h + b_h)} - 1}{e^{2(h \cdot a_h + b_h)} + 1} + 1\right),$$

$$k^t = 0.5t\left(\frac{e^{2(t \cdot a_t + b_t)} - 1}{e^{2(t \cdot a_t + b_t)} + 1} + 1\right),$$

where a_h, b_h, a_t, b_t are the parameters of the function determined based on the inflection points of the hyperbolic tangent (Fig. 1).

Using the example of determining the flooding time weight coefficient, we define the parameters of the function as follows

$$\begin{aligned} &at\ t = t_1,\ \frac{dk^t}{dt} \to 1 \\ &at\ t = t_{2+1},\ \frac{dk^t}{dt} \to 1 \end{aligned} \Rightarrow \begin{cases} a_t \\ b_t \end{cases}$$

It should also be noted that there are differences in the equations for determining the weight coefficient of the depth of flooding and its duration. In the case of a relationship between the depth of flooding, when a certain level is exceeded, the damage stops growing almost completely. However, considering the time of flooding, from a certain moment only fixed costs can be considered as damage, the amount of which is directly proportional to the time of flooded territories exclusion from economic operation.

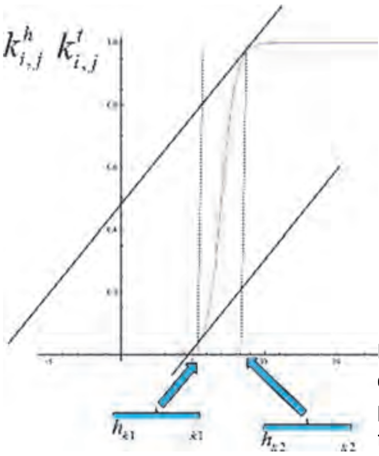

Figure 1. The scheme for determining the parameters of the signal function

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