Climate Change in the Baltic Sea region -

What do we know?

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Abstract

Knowledge about current and future climate change in the Baltic Sea region is scattered in various scientific publications which are mostly not usable for non-scientists. Nevertheless, trustworthy scientific information on the effects of regional climate change is necessary for decision makers. In the BACC assessments (BALTEX Assessment of Climate Change for the Baltic Sea basin), more than 100 experts from the entire Baltic Sea region summarize the currently available published knowledge of climate change and its impacts in the Baltic Sea region. Observed changes are described, scenarios of possible future changes are presented and observed and estimated impacts on the environment are discussed. The assessments encompass the knowledge about what scientists agree on but also identify cases of disagreement or knowledge gaps. The assessments are evaluated by independent scientific reviewers. The BACC assessments of 2008 (BACC I) and 2013/14 (BACC II) are used by HELCOM, the intergovernmental Baltic Marine Environment Protection Commission, as a basis for future deliberations on regional climate change.

According to BACC I, a warming is going on in the Baltic Sea region presently, and is expected to continue throughout the 21st century. So far, and in the next few decades, the signal is limited to temperature and directly related variables, such as ice conditions. Later, changes in the water cycle are expected to become obvious. This regional warming will have a variety of effects on terrestrial and marine ecosystems – some predictable such as the changes in the phenology others so far hardly predictable. BACC II confirms BACC I results. Some aspects are treated in more detail in the new assessment, or are completely new. The issue of multiple drivers on ecosystems and socio-economy is recognized, but more efforts are needed. In many cases, the relative importance of different drivers next to climate change needs to be evaluated.

1. Global and regional climate change assessments

Why do we care about regional climate change? Climate does not change uniformly at different locations around the world, and the impacts of the changes also differ greatly. Moreover, relevant political decisions are taken locally, and policy makers and the public need sound and accessible scientific information. While regional aspects are also treated in the global assessments of the Intergovernmental Panel on Climate Change (IPCC 2007), they are not sufficiently detailed and lack the local expertise. So dedicated regional climate change assessments, compiled by a team of local researchers, are needed as a scientifically comprehensive and sound information source. In the Baltic Sea region, the BACC Team was installed in 2005 to prepare a regional climate change assessment for the Baltic Sea region. BACC, the "BALTEX Assessment of Climate Change for the Baltic Sea Basin" is an endeavor of BALTEX (now: Baltic Earth), the research network for the Baltic Sea catchment basin (Reckermann et al. 2011). The report was published in 2008 as a textbook (BACC 2008), and the update (BACC II 2014) is published in early 2014. The BACC reports summarize the currently available knowledge on climate change and its environmental and socio-economic impacts in the Baltic Sea region, based solely on scientifically legitimized literature, encompassing the knowledge about what scientists agree or disagree on. Both BACC reports are accompanied by Thematic As-

[1] www.baltic-earth.eu/BACC2

sessment Reports by HELCOM (the intergovernmental Baltic Marine Environment Protection Commission), based on the BACC material (HELCOM 2007, HELCOM 2013).

This chapter is based on the material assembled by the BACC II Team (www.baltic-earth.eu/BACC2); for a full and extensive description of the topic, please refer to the book (BACC II 2014).

2. The climate of the Holocene - A geo-historical perspective

The Baltic Sea was formed after the glaciers that covered this area for over 100,000 years began to recede about 18,000 years ago, mainly as a result of changes in the orbital configuration of the Earth´s rotation around the sun. In the Baltic Sea area, this last glaciation ended about 11,000 years ago. After the melting of the remnants of the Fennoscandian ice sheets, a relatively stable period occurred around 7,000 years ago, with higher summer temperatures than at present. Thereafter, a continued decreasing summer solar insolation, due to astronomical factors, resulted in a more unstable climate and a progressive millennial cooling. A reconstruction of mean annual air temperature of the past 10,000 years from pollen data is shown in Figure 1.

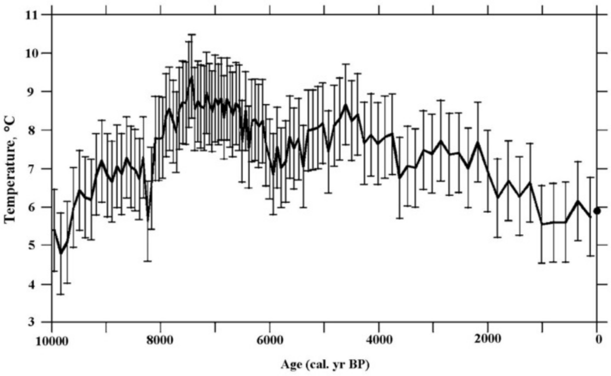

Figure 1: Mean annual temperature reconstructed from pollen data of the lake Flarken (south-central Sweden) during the last 10,000 years (black line) (Seppä et al. 2005). Present day annual temperature (5.9°C) is marked by a dot.

The temperature during the last 1,000 years did not change as drastically as during the previous millennia, but showed a pronounced variability on centennial and decadal time scales. Relatively stable climate conditions prevailed during the Medieval Warm Period (MWP) between 900 and 1100, typified by warm, dry summers, with temperatures exceeding the contemporary warming at the end of the 20th century by about 0.5 °C. An exceptionally warm period also occurred from 1220 to 1250. In the second half of the 16th century, temperatures dropped and the Little Ice Age started. The longest consecutive cold period occurred from the late 16th century until the middle of the 18th century, with the period from 1630 to 1700 being the coolest during the entire past millennium in the Northern Hemisphere. Thus, the climatic history of the Baltic Sea region was dominated by a postglacial warming until about 8,200 years ago, followed by a long lasting cooling until about 1,000 years ago. The last millennium was characterized by a succession of relatively stable and variable periods, and warmer and cooler phases than today, respectively.

3. The climate of the past 200 years

In contrast to the previous periods, instrumental measurements of temperature and other meteorological phenomena such as precipitation and wind were made with increasing accuracy during the past 200 years.

Despite the large inter-annual variability, a clear increase in surface air temperatures in the Baltic Sea region could be shown since the beginning of the record in 1871 (Figure 2). The warming was more pronounced in the northern part of the Baltic Sea region (north of 60°N) than in the south: From 1871 to 2011, the north warmed by 0.11 °C, per decade and by 0.08 °C per decade in the south.

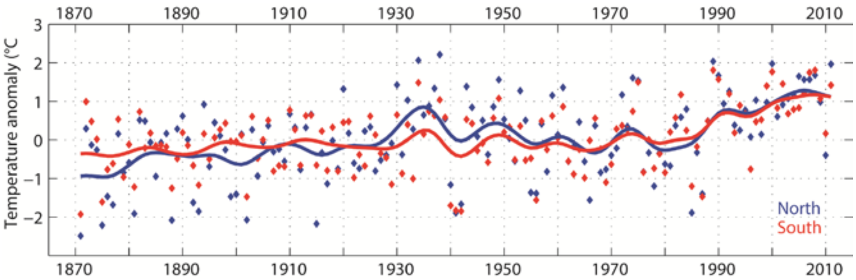

Figure 2. Annual mean surface air temperature anomalies (compared to the 1960-1991 period) for the Baltic Sea basin from 1871 to 2011, calculated from 5° by 5° latitude, longitude box average taken from the CRUTEM3v dataset (Brohan et al. 2006) based on land stations The blue colour relates to the Baltic Sea basin north of 60°N and the red colour to the south of that latitude. The dots represent individual years, and the smoothed curves (Gaussian filter, σ = 3) highlight variability on time scales longer than ten years.

Looking at more recent periods, we see stronger signs of warming. An analysis of temperature trends from 1970 to 2008 shows the strongest increase in the Gulf of Bothnia in autumn and winter (+0.5 to 0.6 °C/decade), while significant changes also occurred during spring and summer in the central and southern parts of the Baltic Sea region (+0.2 to 0.3 °C/decade). During the past decade, the warming has continued during spring and summer in the southern parts, and during autumn and spring in the northern parts, but the recent winters of 2009/2010 and 2010/2011 were very cold.

The amount of precipitation in the Baltic Sea area during the past century has varied between regions and seasons, with both increasing and decreasing precipitation. A tendency of increasing precipitation in winter and spring has been detected during the second half of the 20th century. The mean cloudiness and duration of sunshine have shown large long-term fluctuations over the Baltic Sea basin during the 20th century.

The wind climate is generally related to large-scale variations in the atmospheric circulation of the North Atlantic, including the North Atlantic Oscillation (NAO) in winter. Decadal variations can be detected but no trend towards more or less wind.

No significant long-term change has been detected in the total river runoff to the Baltic Sea during the past 500 years. Still, a marked difference was observed in the runoff patterns between the northern and southern parts of the catchment basin. While northern catchments generally have shown increased stream flow, a decrease was observed over the past century for the southern part. Although regional variations exist, a pronounced downward trend is evident in river ice extent and duration, which is considered to be a sensitive climate change indicator. The same is true for annual snow cover, and also for permafrost soils.

In the Baltic Sea itself, an increase in annual mean sea surface temperature of up to +1 °C/decade from 1990 to 2008 has been measured, with the greatest increase in the northern parts of the Baltic Sea. A climate reconstruction of Baltic Sea water temperature and sea ice conditions from 1500 to 2001 suggests that the current warmer temperatures are within the range of changes during the past 500 years. Nonetheless, the 20th century can be interpreted as the warmest for water temperatures, except for the warm anomaly around the 1730s. A reconstruction of annual maximum sea ice extent, based on various observational methods, shows a significant decreasing trend of 20% over the past 100 years (Figure 3). A clear trend in salinity cannot be detected.

Due to postglacial rebound of the Earth´s crust, the maximum uplift is approximately 10 mm/year in the Gulf of Bothnia but subsides in parts of the southern Baltic Sea by about 1 mm/year. Thus, relative sea level is decreasing in the northern Baltic Sea region where the continental crust is rising, while sea level is rising in the southern Baltic Sea region where the continental crust is sinking. Finnish and Estonian tide gauges show a rise in sea level maxima in the order of 2 to 4 mm/yr.

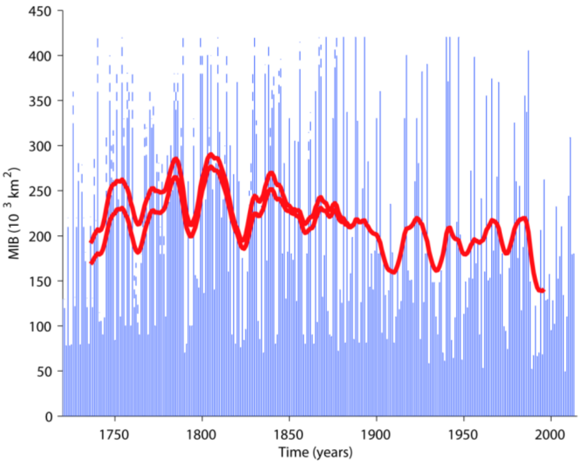

Figure 3. The maximum extent of ice cover in the Baltic Sea 1720 to 2012. The dashed bars represent the error range of the early estimates. The 30-year moving average is indicated by two lines representing the error range early in the series, converging into one line when high-quality data are available (data source: Finnish Meteorological Institute).

4. Future climate change

Regional Climate Model (RCM) ensembles of climate projections represent a range of different possible futures which are based on different plausible greenhouse gas scenarios for the future. They may serve decision makers for operating with a variety of perspectives for further planning.

Although there is a large spread between different models, there is a clear increase in air temperature in all seasons. The pattern of highest warming in the northern Baltic Sea basin in winter is similar in all models (Figure 4). Warm extremes in summer are also expected to become more pronounced than at present. Precipitation is projected to increase in the entire Baltic Sea region during winter. For summer, increases are mainly projected for the northern half of the basin (Figure 5). For the southern part of the Baltic Sea, there is a large spread between the different models with both increases and decreases. Extremes of precipitation are projected to increase. For wind speed, the models show a large spread so that no clear trends can be given.

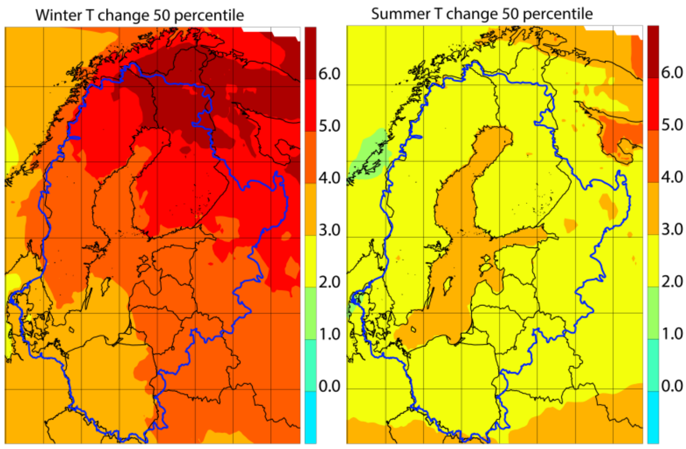

Figure 4. Surface air temperature change (°C) between 1961-1990 and 2071-2099, according to SRES A1B as simulated by 13 RCM models from the ENSEMBLES project, shown are only point-wise median results. Left: Winter (DJF), right: Summer (JJA). The Baltic Sea catchment is indicated by the blue colored line.

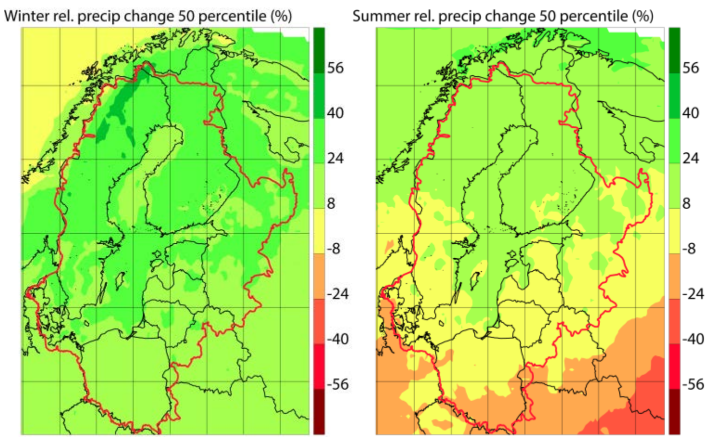

Figure 5. Precipitation change (%) between 1961-1990 and 2071-2099, according to SRES A1B as simulated by 13 RCM models from the ENSEMBLES project, shown are only point-wise median results. Left: Winter (DJF), right: Summer (JJA). The Baltic Sea catchment is indicated by the red colored line.

The annual cycle of runoff is expected to change considerably. In areas that presently receive spring floods owing to the melting of snow, the floods in the future are projected to generally occur earlier and to be smaller due to less snowfall and a shorter period of snow accumulation. In the southern part of the Baltic Sea region, increasing precipitation in winter is expected to result in increased river discharge, while in summer, decreasing precipitation and increasing temperatures and evapotranspiration would result in drying. Especially the southern half of the Baltic Sea catchment area is projected to experience significant reductions in the amount of snow, with median reductions of about 75%.

By the end of the century, the summer sea surface temperature is expected to increase about 2 °C in the southern parts of the Baltic Sea and about 4 °C in the northern parts. Most simulations indicate a decrease in salinity, and changes in sea surface salinity would be largest in the region of the Danish straits, and small in the northern and eastern Baltic Sea. A decrease in vertical stratification across the permanent halocline between the surface and deeper water layers is expected but is still uncertain due to biases in the hydrology cycle. Simulations indicate a drastic decrease in sea ice cover in the Baltic Sea in the future. There is considerable uncertainty in projections of sea level rise over the 21st century, and projections range between 0.6 m and 1.1 m sea level rise for the Baltic Sea. This is partly compensated by vertical land movement which varies between 0 m/century in Denmark and 0.8 m/century in the Bay of Bothnia.

5. Impacts of current and future climate change in association with non-climatic drivers

There are many non-climatic changes going on such as pollution, eutrophication, fishery, river regulation or land use, which make a clear attribution of observed changes difficult and which may have a stronger impact on the environment than climate change.

5.1. Impacts on the environment

For changes in atmospheric chemistry, climatic factors are generally considered less important than emission changes, with the conclusion that future emissions are considered the dominant source of uncertainty when attempting to predict future deposition amounts. However, ammonia emissions which are dominated by agricultural sources are highly dependent on climate variables, especially temperature.

Coastal areas are often densely populated, so a large variety of impacts are exerted from various sources on the coastal ecosystems. Land use varies greatly within the Baltic Sea drainage basin, with the most notable contrast between the agricultural south and the forested north. Climate change may affect coastal and archipelago ecosystems by warming the coastal sea water, changing runoff, changing river borne sediments and nutrient loads. The biodiversity is particularly sensitive to changes in salinity, which can have a cascading effect on food webs and interactions between aquatic and terrestrial ecosystems. Climate change can also facilitate the invasion of non-indigenous species, a northward migration of terrestrial and aquatic species, changes in species composition and ecosystem functions, and a reduction and fragmentation of benthic and littoral habitats.

Agricultural practices and urban sources have significantly increased nitrogen and phosphorus concentrations in the rivers draining the cultivated watersheds of the southern Baltic Sea catchment. A slight decrease is visible in recent years only in phosphorus loads, probably as a result of improved sewage treatment from urban areas, especially in Poland. First studies indicate that nitrogen fluxes to the Baltic Sea may increase between 2 and 70% as a result of changes in water discharge and lifestyle.

Reduction measures of nutrient loads since about 1980 have resulted in reduced nitrate concentrations in the winter surface water of the Baltic Proper, but not for phosphate concentrations, which can be partly explained by the enhanced recycling of phosphate due to increased areas of anoxic water. In marine systems, the increase in atmospheric CO_2 concentrations since the pre-industrial era is expected to cause a decrease in the pH by 0.15 units; however, the increase in alkalinity in the central parts of the Baltic Sea over the past 60 years has diminished this decrease by roughly 0.03 units.

Changes in precipitation and runoff patterns may influence the inputs of nutrients, alkalinity and organic matter to the Baltic Sea. Future warming is expected to increase hypoxia (given that temperature controls the stratification of the water column), the respiration of organisms, and the solubility of oxygen. Simulations of the Baltic Sea biogeochemistry in a warmer climate indicate an increase in anoxic bottom waters areas and a significant decrease in pH by the end of this century.

For phytoplankton, a temperature increase could result in an increasing proportion of dinoflagellates in spring and cyanobacteria in summer. Warmer and possibly less saline surface waters could alter the composition of the zooplankton community, with potentially negative consequences for the food conditions and growth of the main plankton-eating fish, namely, Baltic Herring and Sprat. A possible decrease in salinity would also have a negative influence on Cod.

A projected salinity decline would result in geographical shifts in the distribution of species in both deep and shallow water communities. The loss of marine benthic fauna would have profound effects on the functional diversity. Reduced sea ice could result in a loss of habitat for ice-dwelling organisms. Furthermore, human-induced pressures including overfishing and eutrophication may erode the resilience of the ecosystem, making it more vulnerable to climatic change impacts. The influence of climate change on eutrophication and productivity of the Baltic Sea is not clear at this time and will probably vary in the different basins of the sea. Acidification associated with high levels of CO_2 in the sea may have severe implications for calcifying organisms such as bivalves (shellfish).

5.2. Socio-economic impacts

Climate change may have direct or indirect effects on the managed environment. It may alter the way agriculture or forests are managed, or cities are planned. Visible changes may thus be direct consequences of human activities, indirectly induced by climate change.

Climate change affects the vulnerability and productivity of agricultural and forestry systems, predominantly through changes in precipitation and temperature patterns, and by increased stress periods such as droughts, floods, storms and biotic disturbances like pest infestations. Changing energy policies could also influence the systems through changes in biomass demand. Effects of climate change on growth conditions differ with location, with conditions generally tending to improve in the northern zone, while reduced precipitation and increasing temperatures tend to deteriorate growth conditions in the south. Changing growth conditions would cause shifts in forest structure and diversity.

For urban complexes in the Baltic Sea catchment, several climate change impacts are expected in very different fields such as on urban services and technical infrastructure, on buildings and settlement structures, on the urban economy and the urban population. The impacts differ due to the location of the urban complexes, be they in the northern or southern part of the catchment, directly at the Baltic Sea coast or more inland.

The Baltic Sea features a large variety of shorelines, each responding differently to climate change. In a warmer climate, coastal interaction with sea ice may become less important while the impact of wave energy may become more important. These changes would have a significant impact on coastal morphodynamics and ecosystems. The low coasts of the southern Baltic Sea will be strongly affected by sea level rise.

6. Detection and attribution on the regional scale

A key question of regional climate change is whether there is evidence that the recent change is beyond natural variation, so that we have to conclude that external drivers are at work (“detection”); and if so, which mix of such external drivers is most plausibly responsible for this change (“attribution”).

There is evidence that summertime near-surface warming in northern Europe exceeds the natural internal variability of the climate system (“detection”), and that the observed warming cannot be explained without human influence (in particular the warming effect of increasing atmospheric greenhouse gas concentrations; “attribution”). Precipitation changes in northern Europe have been found to exceed natural internal variability (“detection”); however, a plausible attribution to causes has not yet succeeded. Currently there is no direct evidence for an impact of aerosols or land use change on the regional climate of the Baltic Sea, although they are plausible.

7. Key findings

In general, the new BACC assessment (BACC, 2014) considers the findings of BACC (2008) valid. So in summary we can say that a climate warming has been observed in various variables, from temperatures, precipitation, runoff patterns to ice regimes. This warming has just begun to emerge from the variability of the past millennium, and is expected to continue. Although many changes in the natural and managed environment have been observed, a clear attribution of any of these changes to climate is difficult due to the presence of many other drivers. Compared to BACC (2008), the following key findings, including gaps in the current knowledge, can be summarized as follows:

- Significant additional material was found and assessed in more detail. Some contested issues are now reconciled (e.g. sea surface temperature trends).
- The ability to run multi-model ensembles to simulate future changes seems a major improvement. First detection studies are now available, but the attribution of observed changes to certain causes is still weak.
- Regional climate models still suffer partly from severe biases related to the heat and water balances, and the effect of certain drivers (aerosols, land use change) on regional climate statistics cannot be described by these models.
- Data homogeneity, which is required for comparing observations over long time periods, is still a problem and sometimes not taken seriously enough.
- The issue of multiple drivers acting on ecosystems and socio-economy is recognized, and more efforts to are needed to deal with this problem. In many cases, the relative importance of different drivers, not only climate change, needs to be evaluated.
- Estimates of future deposition and concentrations of substances like sulphur and nitrogen oxides, ammonium, ozone and carbon dioxide depend on future emissions and climate conditions. Atmospheric factors seem relatively less important than emission changes. The specification of future emissions is plausibly the biggest source of uncertainty when attempting to estimate future deposition or marine acidification.
- In the narrow coastal zone where climate change and land uplift act together, plant and animal communities have to adapt to changing environment conditions.

- Climate change is a compounding factor to major drivers of freshwater biogeochemistry, but often the available evidence is still based on small scale studies in both time and space. The effect of climate change cannot be quantified yet on a Baltic Sea basin-wide-scale.
- Climate change projections show a tendency towards reduced salinities in the Baltic Sea in the future, but due to the large bias in the water balance it is still uncertain whether the Baltic Sea will become less or more saline.
- Climate change projections suggest that the Baltic Sea will most probably become more acid in the future. Increased oxygen deficiency, increased temperature, changed salinity and increased acidification are expected to have impacts on the marine ecosystem in several ways and may erode its resilience.
- There is an increasing need for adaptive management strategies in the Baltic Sea basin (e.g. for forestry, agriculture, urban complexes and the marine environment), which deal with both climate change but also with emissions of nutrients, aerosols, carbon dioxide and other substances.

8. Literature

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