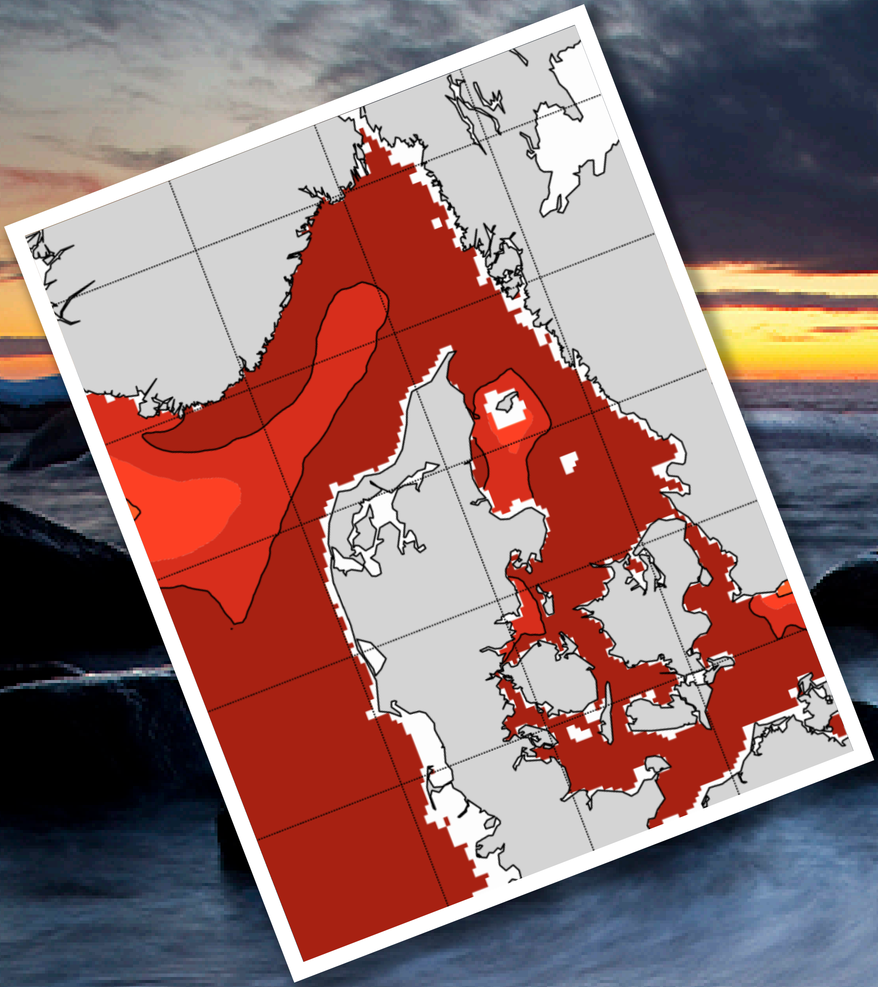

# Framtidens Kattegatt och Skagerrak – temperatur, salt och havsvattenstånd

## En ny havsmodell för klimatmodellering

Rapport från projekt Hav möter Land

Hav møter Land

**Klima vatten samfundsplanlæging sammen**

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Författare: Robinson Hordoir, Germo Väli och Karin Borenäs, SMHI
Utgivare: Hav möter Land, Länsstyrelsen i Västra Götalands län
Omslagsfoto: Claes Hillén
Ämnesord: havsmodellering, Östersjön-Västerhavet, klimatscenarier

Rapporten finns på www.havmoterland.se

# Sammanfattning

## Ny modell

I projektet Hav möter Land har vi tagit fram en havsmodell för Östersjön-Kattegatt-Skagerrak-Nordsjön för att kunna studera havets nuvarande tillstånd och hur förhållandena kan förändras i ett framtida klimat.

## Beräknat för tre perioder

Modelleringen har utförts för tre 30-årsperioder: 1970-1999, 2020-2049 samt 2070-2099. Vi har använt ett utsläppsscenario som innebär snabb befolkningstillväxt och intensiv energianvändning.

Temperatur, salthalt och havsvattenstånd har beräknats för respektive period och resultaten presenteras här i form av kartor och tvärsnitt. Figurerna visar dels absoluta värden, dels förändringen jämfört med den historiska perioden 1970-1999.

## Temperatur, salthalt och havsvattenstånd i framtiden

I Kattegatt-Skagerrak-området ger modellen en ökning av ytvattentemperaturen på 2 till 3 grader till slutet av århundradet, med lokala variationer. Största ökningen fås oftast för vinterperioden december-februari.

Förändringen i ytsalthalten blir inte så stor i simuleringen, vilket hänger samman med att tillrinningen ges av klimatologiska värden som inte ändras under modellkörningen. Från tvärsnitten kan man se att den modellerade skiktningen blir starkare.

Lokala effekter beräknas leda till en höjning av havsnivån, dels på grund av den lokala uppvärmningen och dels som en följd av ökade västvindar. Till den lokalt betingade höjningen ska den globala förändringen adderas, liksom landhöjning respektive landsänkning.

## Ett scenario av många – men någorlunda generella trender

De resultat som redovisas i rapporten är baserade på *ett* utsläppsscenario och *en* modellkörning. Andra scenarier och andra uppsättningar av globala såväl som lokala modeller skulle ge andra resultat, men trenderna är någorlunda generella.

# Innehåll

Engelsk del 🇬🇧 English section

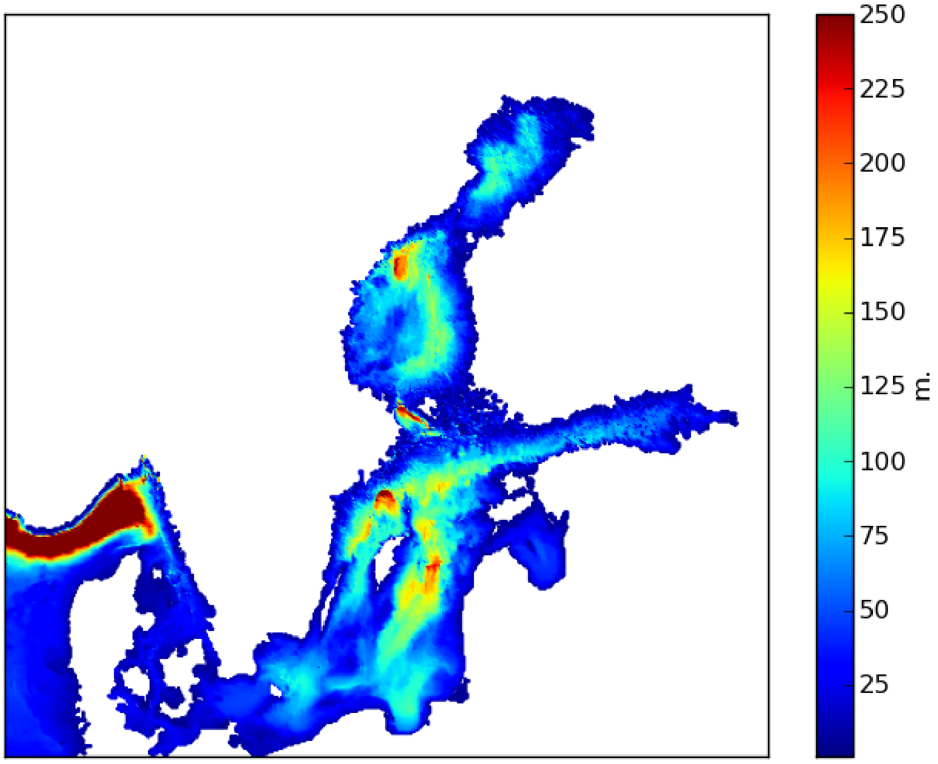
# Havsmodellen

Vi har utvecklat en havsmodell för Östersjön-Kattegatt-Skagerrak-Nordsjön för att kunna studera havets nuvarande tillstånd, men också förhållandena i ett framtida klimat. I denna rapport presenteras resultat för temperatur, salthalt och vattenstånd.

Havsmodellen heter numera NEMO-Nordic, men kallades tidigare BaltiX. I den engelska delen av denna rapport används namnet BaltiX.

## Modellområdet, horisontell och vertikal upplösning

Modellområdet, samt den bottentopografi som används i modellen, visas i Figur 1. Den horisontella upplösningen är 2 nautisk mil (cirka 3.7 km) och modellen utför beräkningar på 56 vertikala nivåer. De olika lagren varierar i tjocklek, det översta är 3 meter för att sedan succesivt öka till 22 meter. Höjden på det nedersta lagret kan anpassas till den rådande bottentopografin.



Figur 1: Bottentopografin som används i modellen.

## Modellens fysik, drivning och randvillkor

De scheman för advektion, diffusion och turbulens som används i modellen beskrivs i detalj i rapporten samt i Hordoir et al., 2013. En is-modell är också kopplad till NEMO-Nordic.

För modellering av tillståndet i havet fram till idag drivs NEMO-Nordic med ERA-40 (ECMWF 40 Year Re-analysis) som skalats ned till det aktuella området med hjälp av Rossbycentrets atmosfärsmodell RCA. Tillrinningen är baserad på klimatologiska värden men även andra dataset kan användas.  Vid ränderna utnyttjas klimatologiska värden för salt och temperatur.

För klimatsimuleringarna används en lågupplöst global klimatmodell som ger randvärden till den regionala mer högupplösta modellen som i sin tur tillhandahåller drivningen till havsmodellen NEMO-Nordic.

## Modellvalidering

Modellen har testats mot historiska mätningar av temperatur, salt och vattenstånd. De resultaten redovisas i Hordoir et al., 2013.

# Framtidsscenarier

En första klimatkörning har utförts för perioden 1961-2099. Här har utsläppsscenario A2 använts, vilket bland annat innebär snabb befolkningstillväxt och intensiv energianvändning.

## Globala effekterna ska adderas till resultaten

I rapporten redovisas de *lokala* framtida förändringar som klimatmodellen beräknar. Det innebär att de *globala* effekterna av en klimatförändring inte finns med utan ska adderas. Tillrinningen ges även i framtidsscenarierna av klimatologiska värden.

## Förändringar i temperatur och salt

Kartor över ytvattentemperaturen för den historiska 30-årsperioden 1970-1999, samt för de två framtida perioderna 2020-2049 och 2070-2099, visas i avsnitt 4.1. Först visas kartor för årliga medelvärden och därefter kartor för årstiderna vinter, vår, sommar och höst. Motsvarande kartor för ytsalthalten återfinns i avsnitt 4.2.

För att se hur temperatur och salt varierar i djupled har två sektioner valts ut, en i ost-västlig riktning (längs breddgrad 57° N) och en i nord-sydlig riktning (längs längdgrad 10° E). Återigen har årliga medelvärden för temperatur och salt beräknats för de tre 30-årsperioderna samt för de olika årstiderna. Resultaten presenteras i avsnitt 4.3.

## Förändringar i havsvattenstånd

Havsvattennivån har studerats i området utanför tre orter, Falkenberg, Henån och Larvik. I fallet Henån är det havsvattennivån i den öppna vattenmassan utanför Orust som avses.

Resultaten från studien redovisas i kapitel 5 i rapporten för de tre 30-årsperioderna. I figurerna 5.1–5.3 kan man se att medelvattennivån ökar (kurvornas topp förskjuts åt höger). Detta kan kopplas till två olika processer. Den första är en effekt av att temperaturen ökar varvid tätheten minskar och vattnets volym ökar. Den andra är kopplad till en ökning av västvindarna vilket skulle innebära en ackumulering av vatten längs den svenska kusten.

Här ska man notera att det är endast den lokala effekten som beräknats i rapporten, varken en global höjning på grund av högre vattentemperatur eller en höjning orsakad av smältande glaciärer finns med. Hur stor den globala höjningen kan bli är mycket osäkert (se till exempel Bergström, 2012) men ett värde runt 1 meter används ofta. Förutom den globala höjningen måste man även ta med effekten av landhöjning alternativt landsänkning.

Förutom att figurerna 5.1–5.3 visar på en förändring av den lokala havsvattennivån så kan man också lägga märke till att medelvärdet inträffar mer sällan
vilket innebär att variabiliteten ökar och att sannolikheten för mer extrema händelser ökar.

# Osäkerheter

De resultat som redovisas i rapporten är baserade på *ett* utsläppsscenario och *en* modellkörning. Andra scenarier och andra uppsättningar av globala såväl som lokala modeller skulle ge andra resultat. Trenden med ökande temperaturer och att sannolikheten för extrema händelser ökar är dock generell, däremot kan styrkan hos förändringarna skilja sig mellan olika klimatsimuleringar.

# Referenser

Bergström, S. Framtidens havsnivåer i ett hundraårsperspektiv - kunskapssammanställning 2012. SMHI, Klimatologi nr 5, 2012.

R. Hordoir, B. W. An, J. Haapala, C. Dieterich, S. Schimanke, A. Höglund and H.E.M. Meier, 2013. BaltiX A 3D Ocean Modelling Configuration for Baltic & North Sea Exchange Analysis. SMHI, Report Oceanography (RO) No. 48, 2013

Dessa rapporter kan hämtas på SMHI:s hemsida www.smhi.se.

# English section

# 1. Background

The Kattegat/Skagerrak area is a transition zone between two regional seas – the North Sea and the Baltic Sea. This area is critical for the Baltic Sea and the West Coast of Sweden, with strong salinity and temperature gradients and high variability. It is therefore important to study this area in a climate change context in order not only to provide predictions of the evolution of sea surface height on the Swedish Western Coast, but also in order to predict how the exchanges between the North Sea and the Baltic Sea could evolve in a future climate.

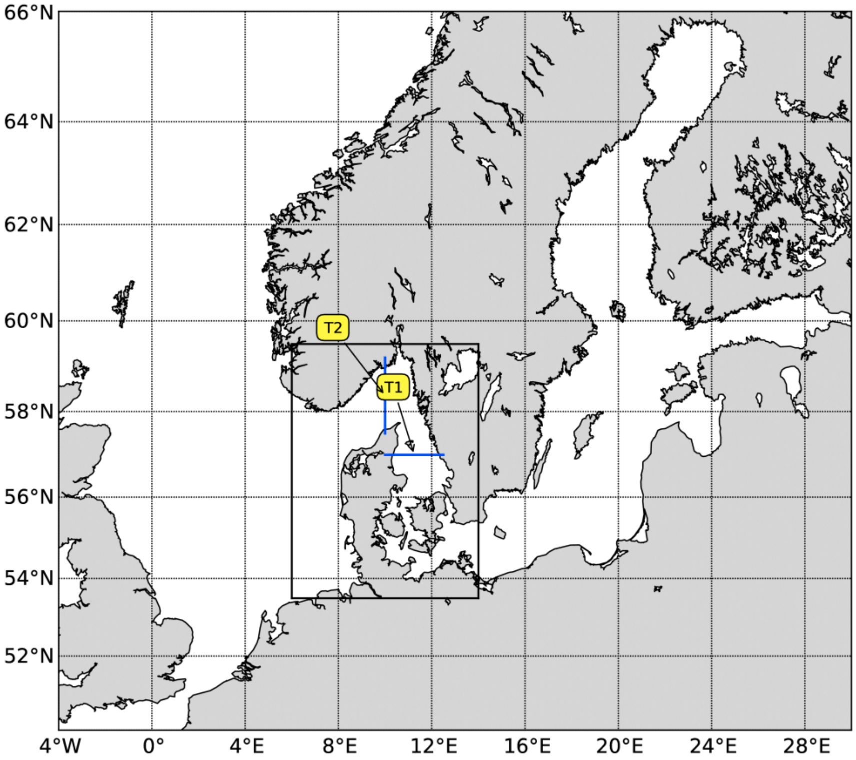


Figure 1.1 The area of model domain with the area of interest and the location of the two transects used in the study.

# 2. Model description

BaltiX is a Baltic & North Sea configuration based on the NEMO (Madec, 2010) ocean engine. Its development started in 2011 at SMHI (Swedish Meteorological & Hydrological Institute, Norrköping, Sweden). It follows closely the development of the NEMO ocean engine, and BaltiX is updated each time an update is done in it.

The computational domain of BaltiX covers the entire Baltic Sea, the English Channel and the North Sea, with open boundary conditions between Cornwall and Brittany (meridional), and between Hebride Islands and Norway (zonal). The reference bathymetry comes from the HIROMB model (Funkquist and Kleine, 2007), except for the Danish Straights where the IOW bathymetry is used and either averaged over each grid cell, or taken as the maximum value. The domain is therefore the same as that of the HIROMB configuration, with a resolution of approximately 2 nautical miles (≈ 3700 m), and a vertical resolution of 3 m close to the surface, decreasing to 22 m at the bottom of the deepest part of the domain, that is the Norwegian trench. The vertical grid has a total of 56 levels and uses VVL (Variable Volume Layer) coordinates (Adcroft and Campin, 2004) with an explicit free surface. Partial steps are used in order to reach a good consistency between the input bathymetry and that actually used by the numerical model configuration.

From a barotropic point of view, open boundary conditions are defined using the Oregon State University Tidal Inversion Model (Egbert et al., 1994; Egbert and Erofeeva, 2002) with 13 tidal harmonics defining both sea surface height (SSH) and velocities. From a baroclinic point of view, Levitus (Levitus and Boyer, 1994) is used for temperature and salinity with a sponge layer, and simple radiation conditions are used for baroclinic velocities. The surface boundary condition uses a bulk formulation based on Large and Yeager (2004), and in addition the LIM3 ice model (Vancoppenolle et al., 2008) is used with a fixed ice salinity equal to $10^{-3}$ PSU. A climatological runoff is used based on different databases for the Baltic and the North Seas, and the runoff salinity is also set to $10^{-3}$ PSU which is enough to avoid any negative salinity values close to river mouths even when the runoff is rejected on a single grid cell, as it is the case in this configuration. In addition to the TVD scheme mentioned later in the present report, the version of the NEMO Ocean Engine that is used (version 3.3.1) allows rejecting runoff as a lateral boundary condition, which produces an estuarine-like baroclinic circulation close to river mouths, bringing enough salt to ensure a stable positive salinity even in the very low saline areas of the domain, such as the Gulf of Finland or the Bothnian Bay.

A quadratic friction formulation is applied at the bottom, and the drag coefficient is computed for each bottom grid cell based on a classical law-of-the-wall, with a constant bottom roughness of 3 cm.

A time splitting method is used, and a modified leapfrog method is implemented in order to ensure conservation (Leclair and Madec, 2009). A TVD scheme is used for tracer advection. A Laplacian diffusion scheme is applied, and a Smagorinsky method (Smagorinsky, 1963) has been implemented in order to lower as much as possible the value of the diffusion coefficient into the two very different dynamical systems that are the North Sea and the Baltic Sea: one which is very dynamic and mixed, the other less dynamic and more stratified.

A k − vertical turbulence model is used, and a parameterization of the bottom boundary layer (Beckmann and Döscher, 1997; Campin and Goosse, 1999) is included both from an advective and a diffusive point of view. The advective part is included to help dense water flows across the Danish straights, which is mostly a high frequency wind driven circulation process driven both by barotropic and baroclinic currents (Gustafsson and Andersson, 2001). In addition, it is important for dense water inflows to be able to reach the centre of the Baltic proper, which is a lower frequency process (Meier et al., 1999). This process requires several weeks or months during which it is important that bottom dense water flows follow the bathymetry, and that the z system coordinates do not induce artificial mixing.

The atmospheric forcing comes from a downscaled run of ERA40 (used at the open boundaries) using Rossby Centre Atmosphere model, RCA, (Samuelsson et al., 2011) for the period 1961-2007. The resolution of the atmospheric model is 50 km but depends in terms of variability on the one degree horizontal resolution ERA40 re-analysis run that is applied at the open boundaries.

The model has been first validated from a barotropic perspective, and shown to be able to represent the sea surface height, SSH, tidally induced and/or wind driven. This is especially true for critical measurement stations such as Landsort Deep (Baltic Sea) for which variability is highly correlated with the total Baltic Sea volume, and the deep salt inflows.

The model was also shown to provide realistic sea surface temperatures, SSTs, and ice covers, and the variability of the deep water salinity at Gotland Deep in the Baltic Sea is also realistic. Some tuning is still being done in order to achieve a better representation of the halocline which appears still to be too stiff and too high.

Further documentation and validation examples can be found online
(Hordoir et al., 2013).

# 3. Scenario simulation

A future projection for the Skagerrak/Kattegat area up to 2100 has been made using the downscaled emission scenario A2 for atmospheric forcing. However, the open boundary conditions at the Channel and North Sea boundaries remain based on a climatology for the Skagerrak/Kattegat simulations, meaning that the temperature increase in the configuration, as well the SSH changes can only be related with the influence of the atmospheric forcing on the configuration, and no outside oceanic change. This means that these simulations concentrate on the influence of local effects on the SSH and temperature changes, and do not include for example global sea level rise. In addition, no runoff change scenario has been used for any part of the simulation, due to the high degrees of uncertainty in hydrological scenarios.

# 4. Results from scenario simulation

In this section projections for temperature and salinity are presented in various ways. Maps of sea surface temperature and sea surface salinity are found in subsection 4.1 and 4.2 for three time periods: 1970-1999, 2020-2049 and 2070-2099. Both annual and seasonal means are provided. In subsection 4.3 temperature and salinity are given for two cross sections (T1 and T2 in Figure 1.1), again for three time periods and for annual and seasonal means.

In Appendix A the corresponding figures are presented for the difference between the periods 2020-2049 and 2070-2099, respectively, and the historical period 1970-1999.

## 4.1. Sea surface temperature

### *4.1.1. Annual means*

The climatological mean sea surface temperature (1970-1999) and corresponding projections (2020-2049, 2070-2099) are shown on figures 4.1.1 and 4.1.2.

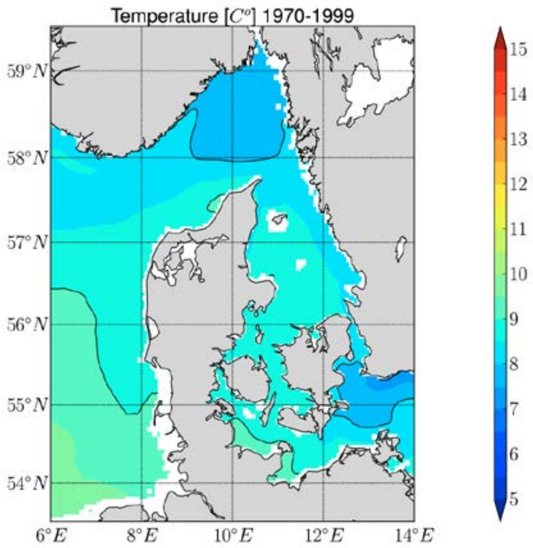


Figure 4.1.1 The climatological SST (sea surface temperature) for 1970-1999.

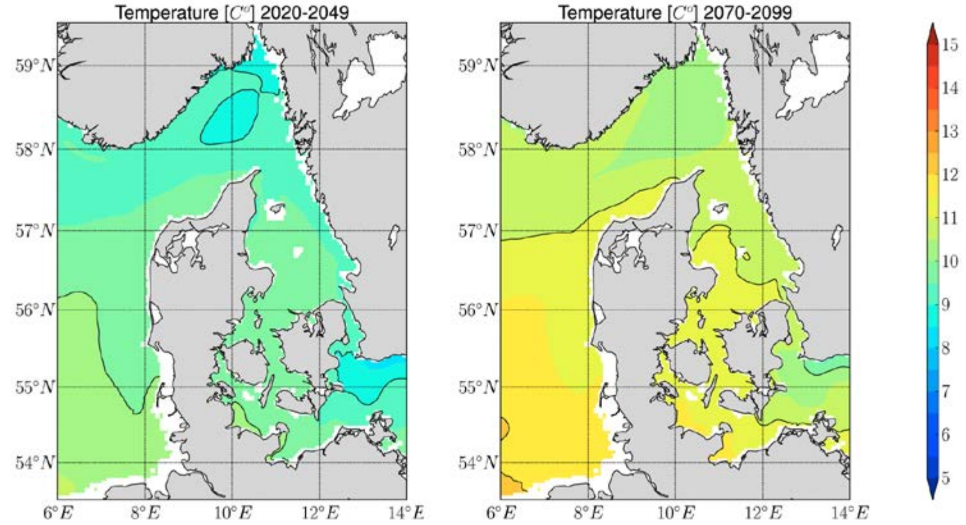
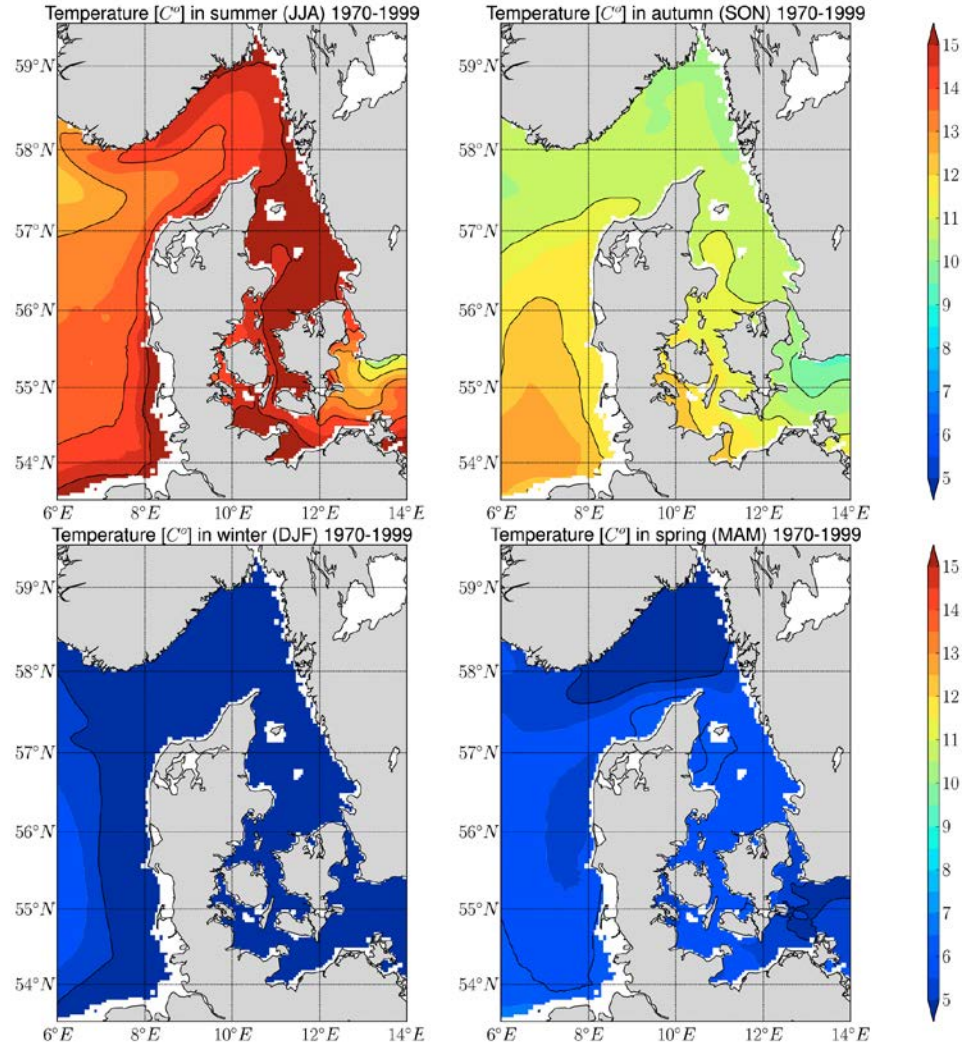


Figure. 4.1.2 The SST (sea surface temperature) projection for 2020-2049 (left) and 2070-2099 (right).

### *4.1.2. Seasonal cycle*

The climatological seasonal cycles of the sea surface temperature respectively for the 1970-1999, 2020-2049, 2070-2099 periods are shown in Figures 4.1.3 to 4.1.5.


Temperature [$C^o$] in summer (JJA) 1970-1999

Temperature [$C^o$] in autumn (SON) 1970-1999

Temperature [$C^o$] in winter (DJF) 1970-1999

Temperature [$C^o$] in spring (MAM) 1970-1999

Figure 4.1.3 The climatological seasonal mean SST (sea surface temperature) for 1970-1999.

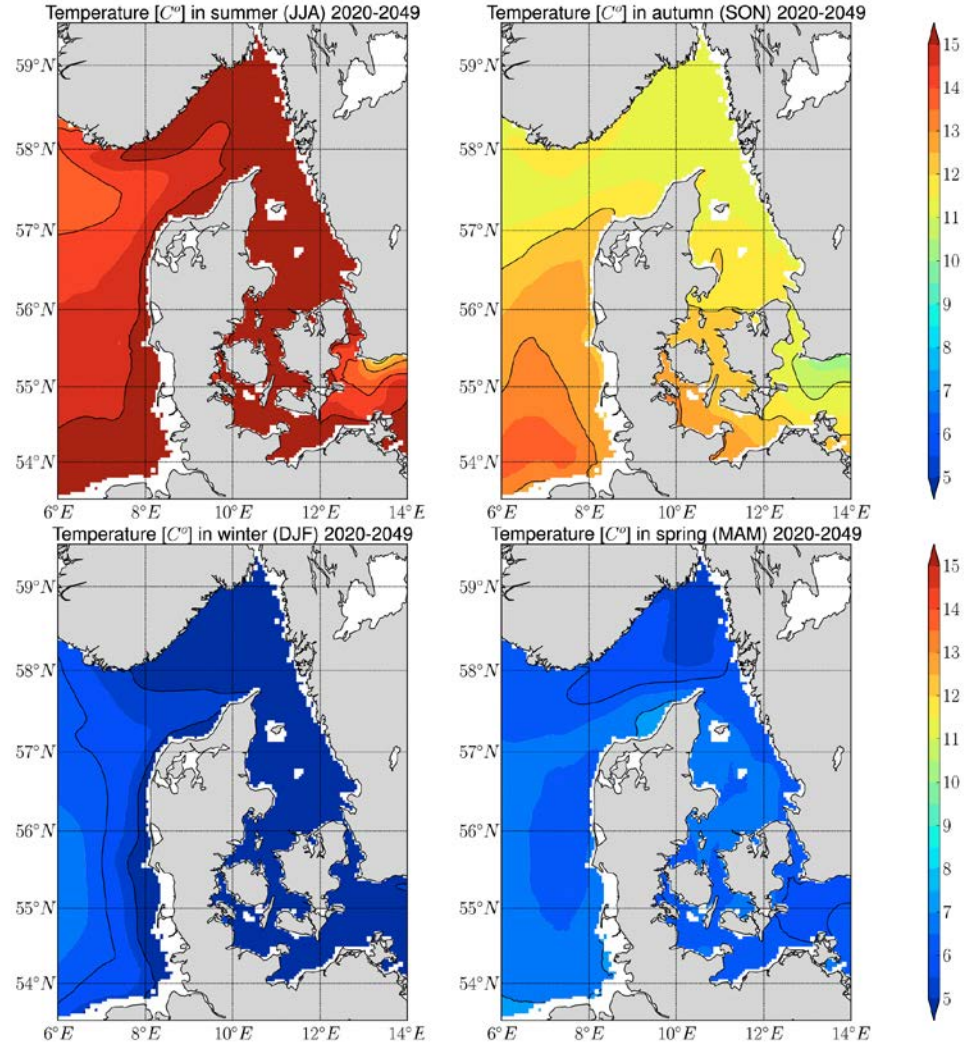


Figure 4.1.4 The projected seasonal mean SST (sea surface temperature) for 2020-2049.

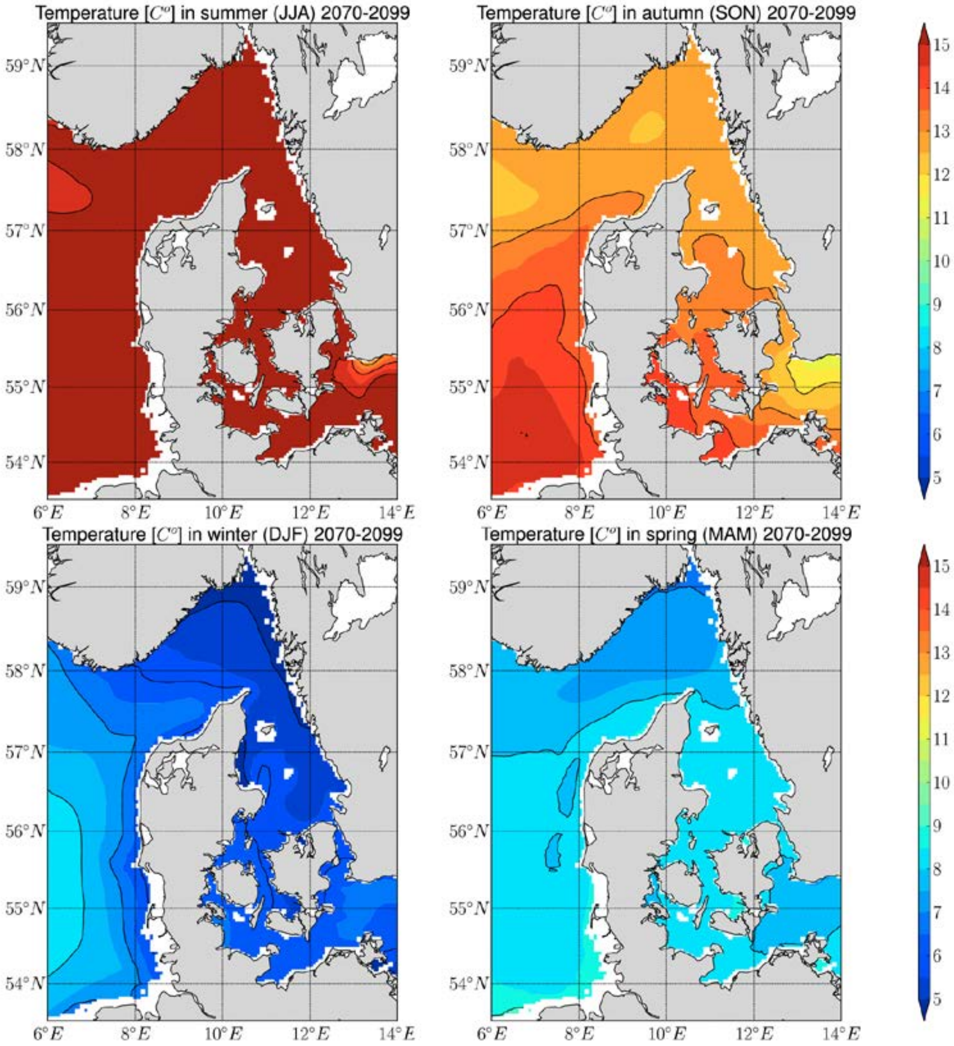


Figure 4.1.5 The projected seasonal mean SST (sea surface temperature) for 2070-2099.

One can observe a radical increase in temperature over the Kattegat/Skagerrak. This increase is consistent with the temperature increase of the atmospheric forcing: a 2 to 3 degree increase is predicted for the end of the 21th century. This increase is not homogeneous, but depends on the stratification structure of the location, and as we shall see later, has a direct impact on salinity stratification.

## 4.2. Sea surface salinity

### *4.2.1. Annual means*

The climatology of mean sea surface salinity and corresponding projections for the future are shown in figures 4.2.1 and 4.2.2.

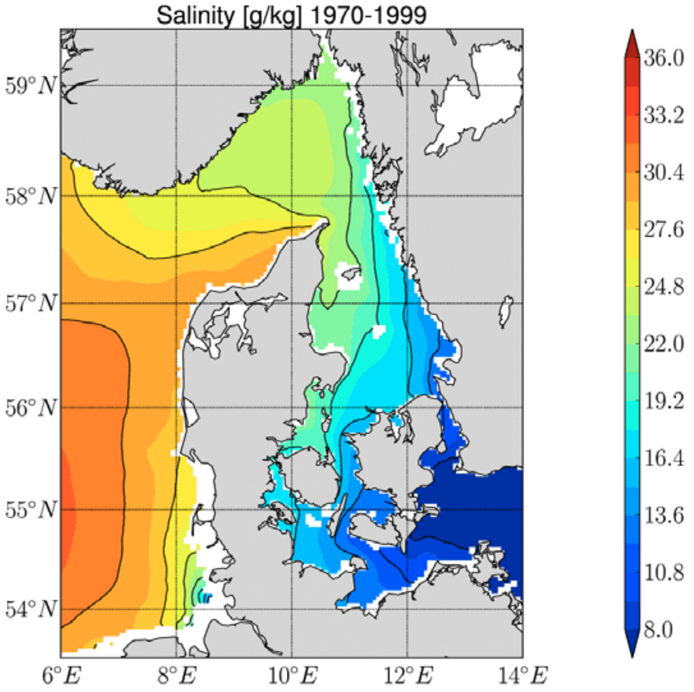


Figure 4.2.1 The climatological SSS (sea surface salinity) for 1970-1999.

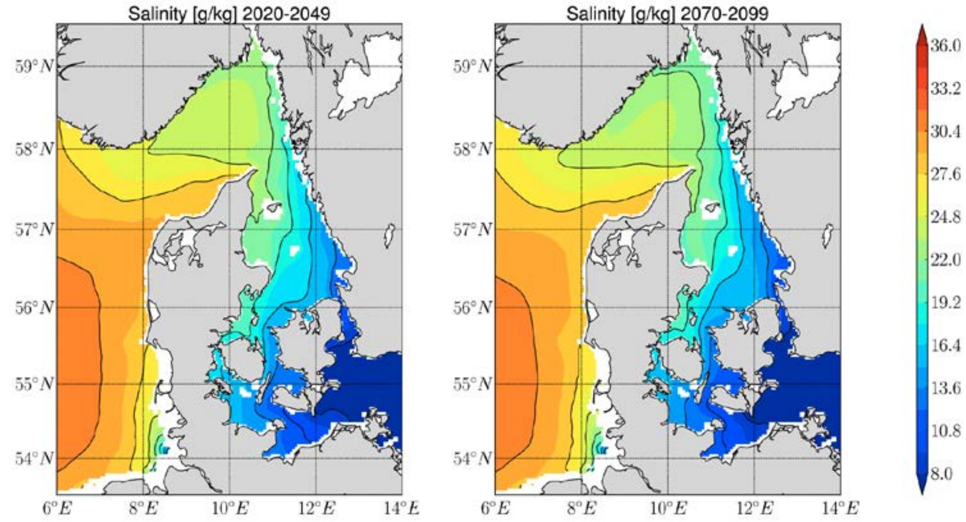
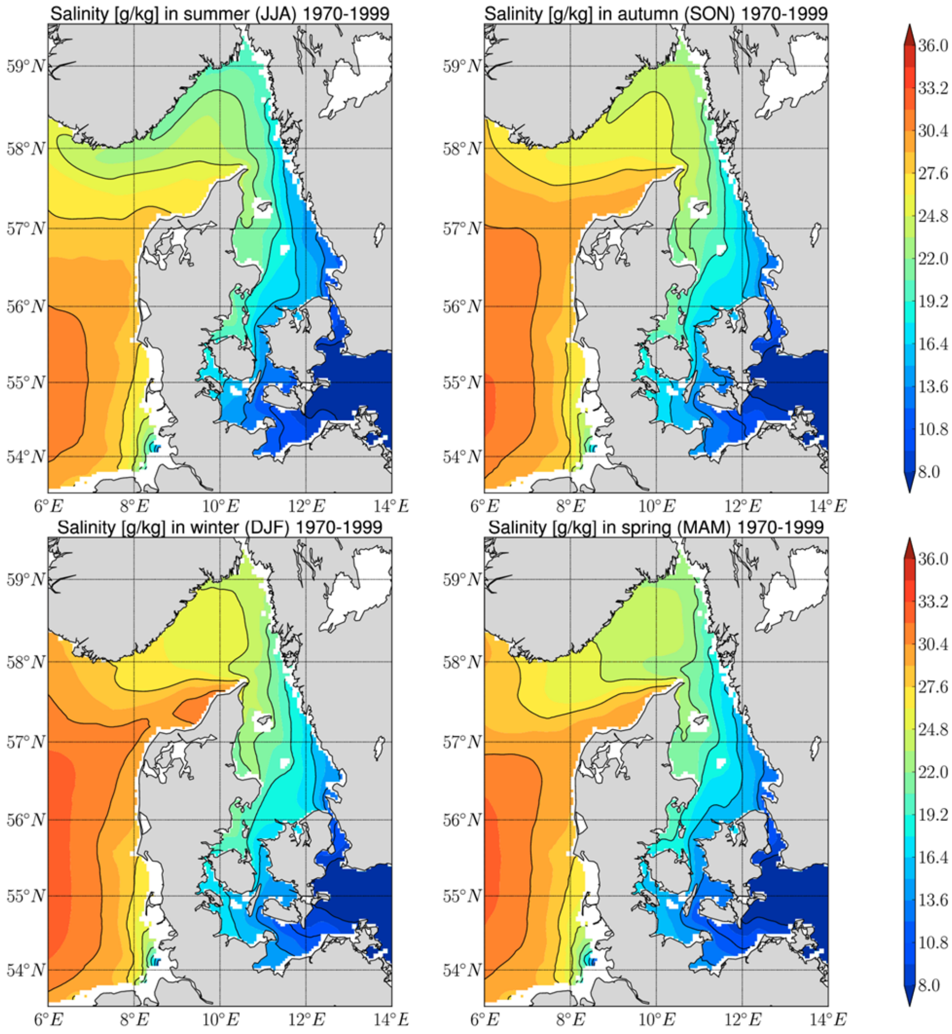


Figure 4.2.2: The mean SSS (sea surface salinity) projection for the 2020-2049 (left) and 2070-2099 (right).

### *4.2.2. Seasonal cycle*

The climatology of mean sea surface salinity and corresponding projections for the future are shown in Figs. 4.2.3 to 4.2.5.

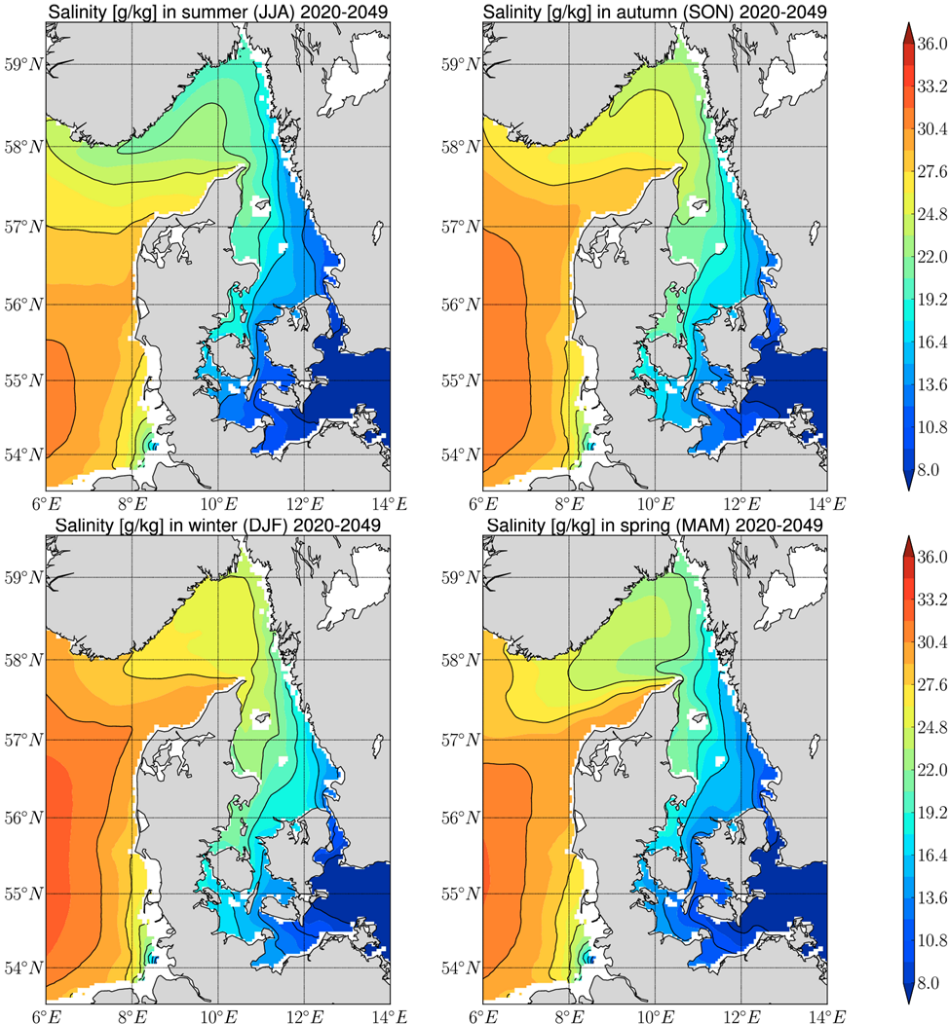

Salinity [g/kg] in summer (JJA) 1970-1999

Salinity [g/kg] in autumn (SON) 1970-1999

Salinity [g/kg] in winter (DJF) 1970-1999

Salinity [g/kg] in spring (MAM) 1970-1999

Figure 4.2.3 The climatological seasonal mean SSS (sea surface salinity) for 1970-1999.



Salinity [g/kg] in summer (JJA) 2020-2049

Salinity [g/kg] in autumn (SON) 2020-2049

Salinity [g/kg] in winter (DJF) 2020-2049

Salinity [g/kg] in spring (MAM) 2020-2049

Figure 4.2.4 The projected seasonal cycle of SSS (sea surface salinity) for 2020-2049.

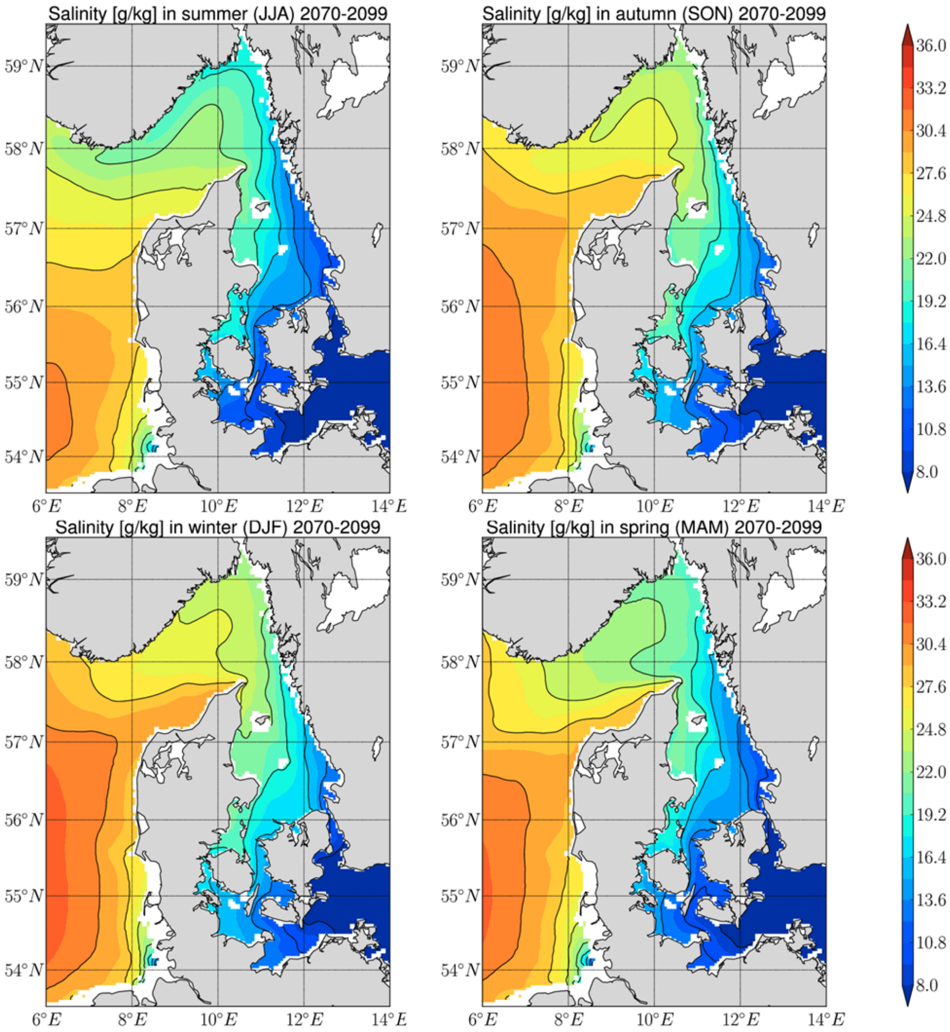


Figure 4.2.5 The projected seasonal cycle of SSS (sea surface salinity) for 2070-2099.

The surface salinity plots do not show a major salinity difference, which is consistent with the fact that the runoff to the Baltic Sea is not modified in the simulation. However, one can spot an increased advance of the freshwater tongue in the Kattegat region. This effect may prove that the increased temperature related stratification maintains the freshwater outflow closer to the surface, resulting into a higher salinity stratification as well.

## 4.3. Cross sections in the Skagerrak/Kattegat

### *4.3.1. Annual means*

Two cross-sections were selected in the Skagerrak/Kattegat area to analyze the changes in the stratification in the future. The climatological temperature and salinity for the period 1970-1999 are shown in the Figs. 4.3.1 and 4.3.2. The projections are presented in Figs. 4.3.3 and 4.3.4 for the period 2020-2049 and in Figs. 4.3.5 and 4.3.6 for the period 2070-2099.

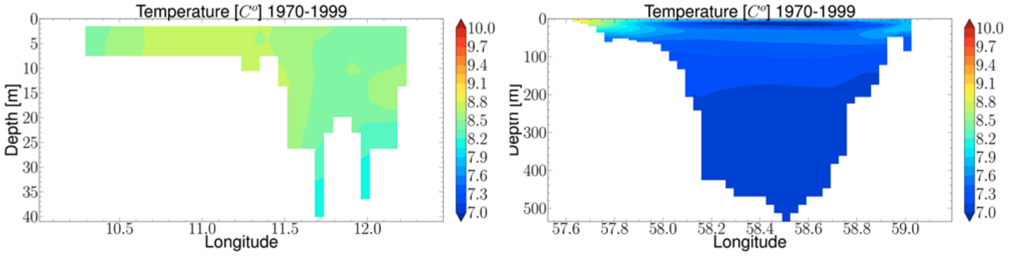


Figure 4.3.1 The climatological temperature for 1970-1999 along transect T1 (left) and T2 (right).

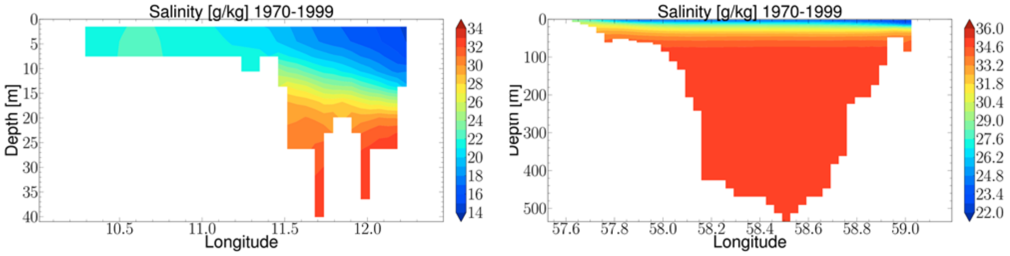


Figure 4.3.2 The climatological salinity for 1970-1999 along transect T1 (left) and T2 (right).

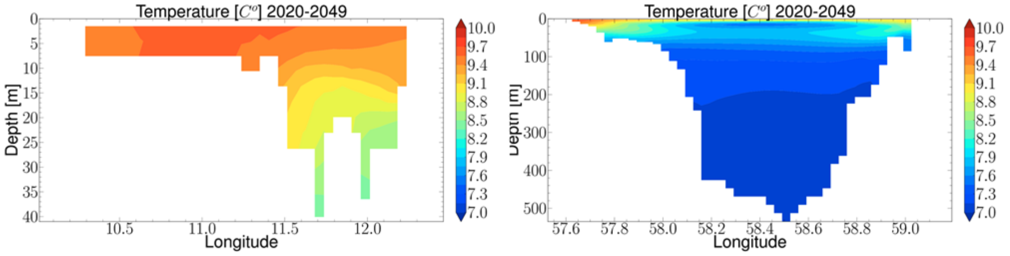


Figure 4.3.3 The temperature projections for 2020-2049 along transect T1 (left) and T2 (right).

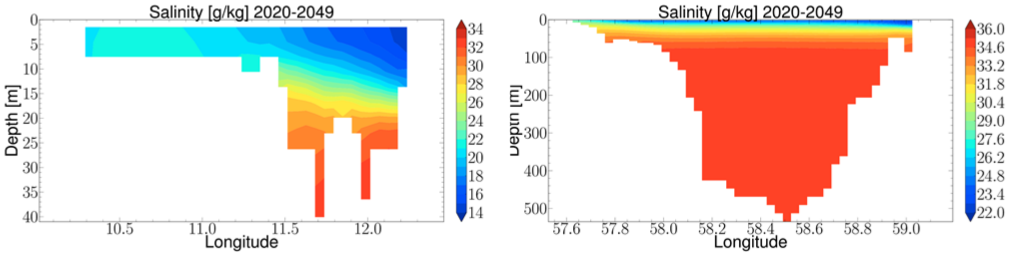


Figure 4.3.4 The salinity projections for 2020-2049 along transect T1 (left) and T2 (right).

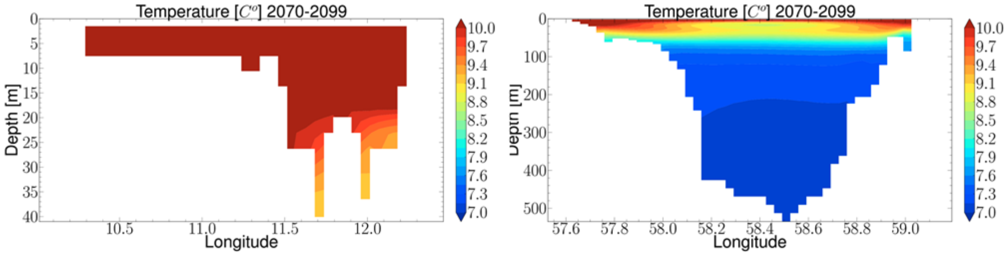


Figure 4.3.5 The temperature projections for 2070-2099 along transect T1 (left) and T2 (right).

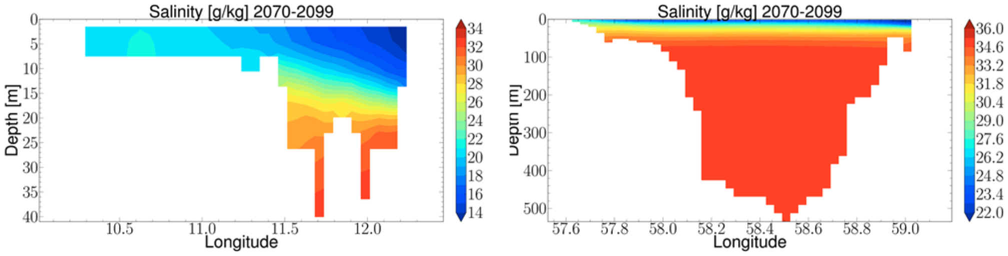


Figure 4.3.6 The salinity projections for 2070-2099 along transect T1 (left) and T2 (right).

The cross-sections of temperature and salinity show, of course, the temperature increase previously observed on SST maps. However, these cross-sections also demonstrate the increased stratification. This increased stratification is naturally observable from a temperature point of view, but also and this is more disturbing, from a salinity point of view. This stratification increase is also confirmed by the seasonal means shown in the later section.

### *4.3.2. Seasonal means*

The climatological seasonal cycles for salinity and temperature are shown in Figs. 4.3.7 to 4.3.10. The projections for the 2020-2049 and 2070-2099 periods are shown in Figs. 4.3.11 to 4.3.18.

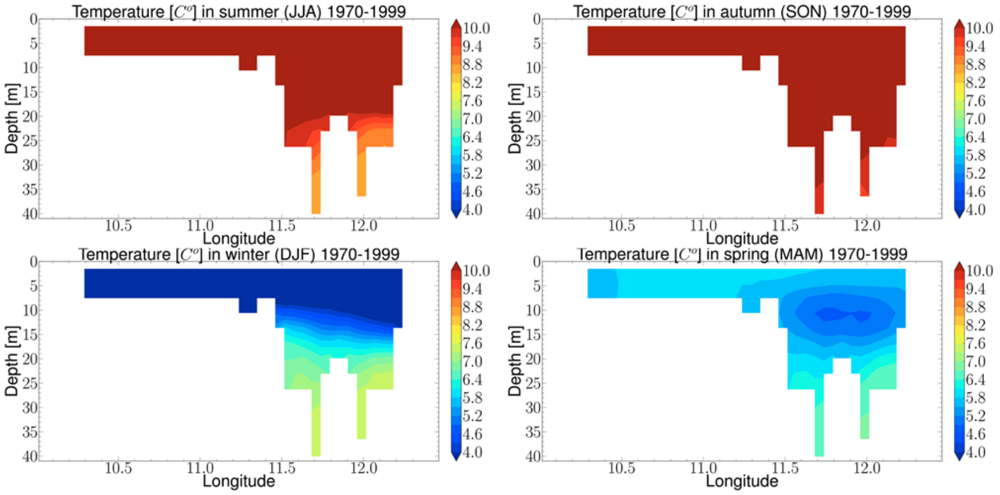


Figure 4.3.7 The climatological seasonal cycle for temperature during 1970-1999 along transect T1.

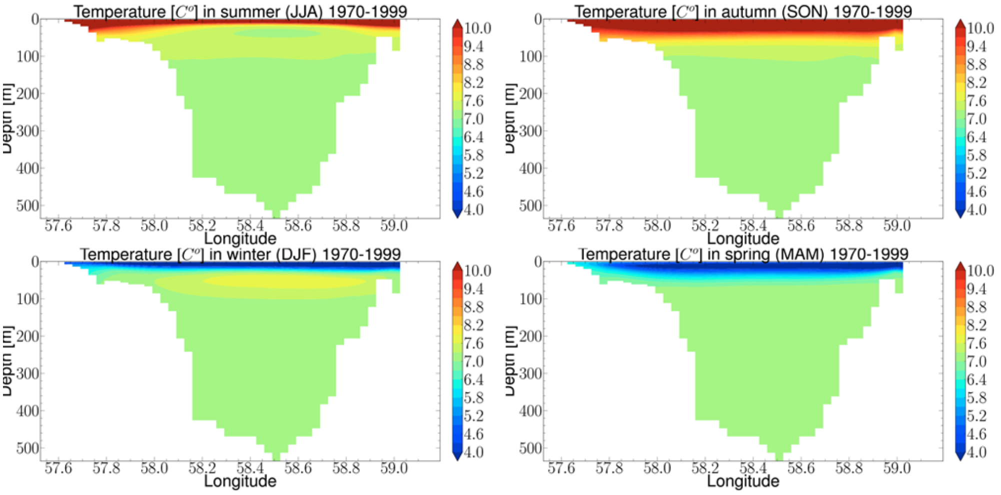


Figure 4.3.8 The climatological seasonal cycle for temperature during 1970-1999 along transect T2.

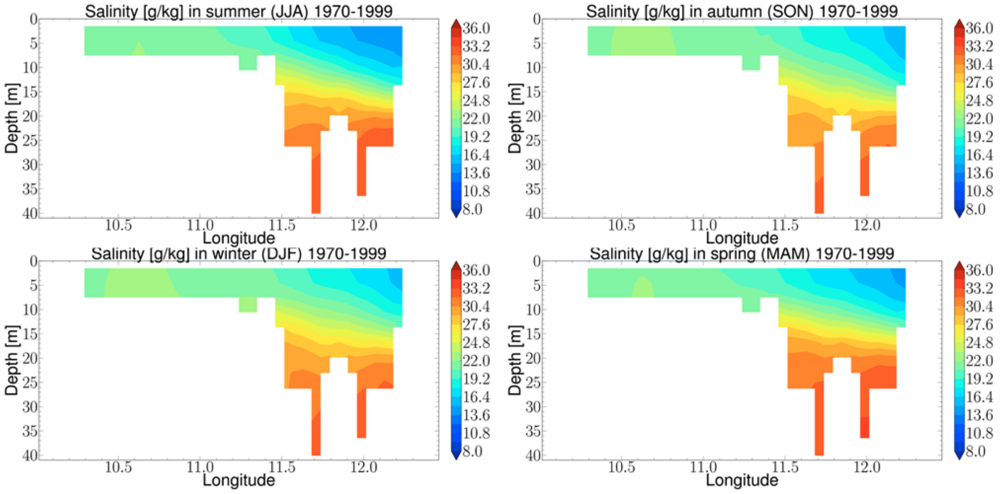


Figure 4.3.9 The climatological seasonal cycle for salinity during 1970-1999 along transect T1.

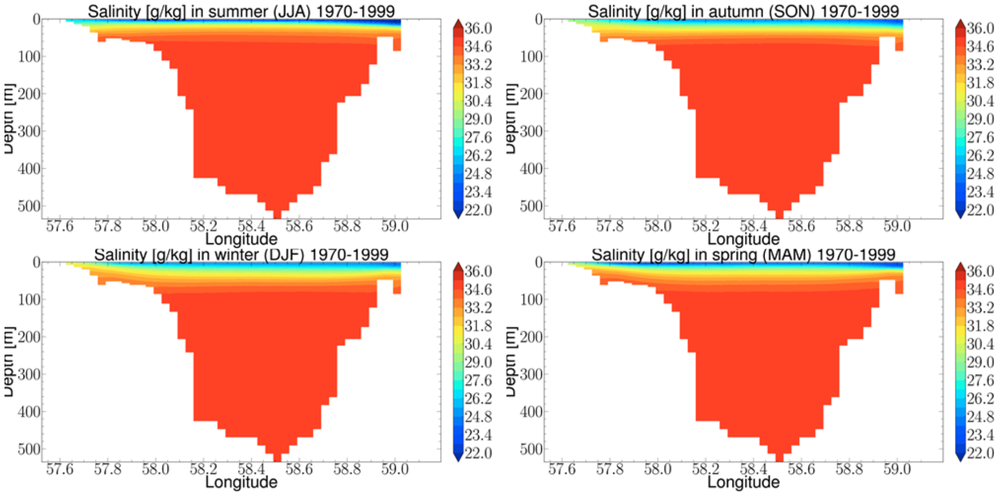


Figure 4.3.10 The climatological seasonal cycle for salinity during 1970-1999 along transect T2.

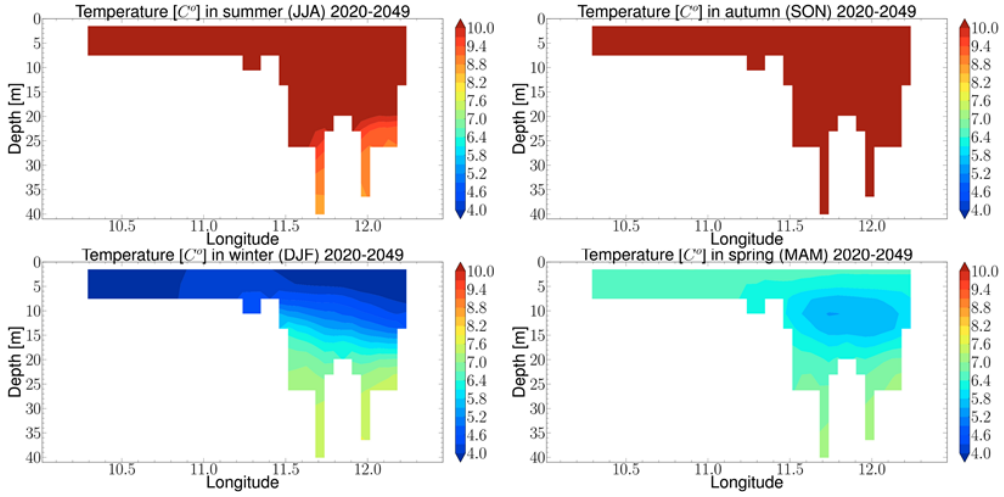


Figure 4.3.11 The projection of seasonal cycle of temperature for 2020-2049 along transect T1.

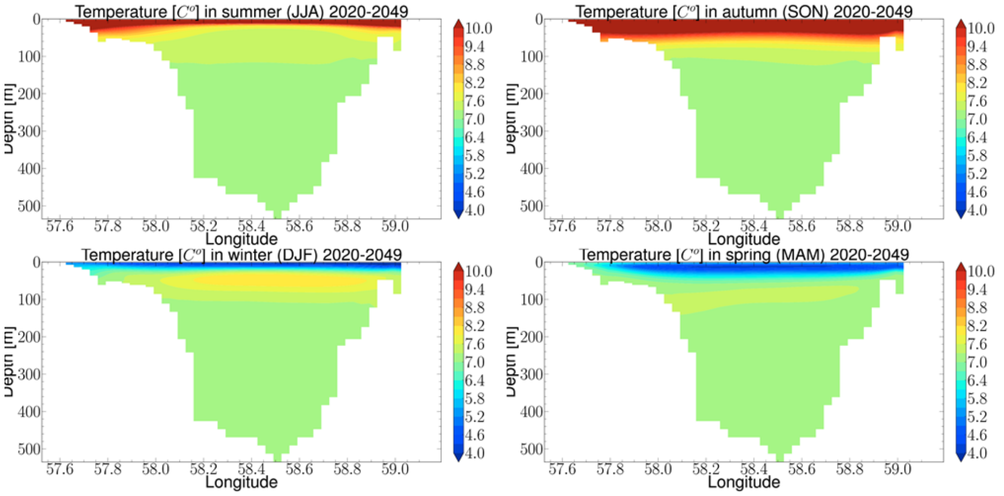


Figure 4.3.12 The projection of seasonal cycle of temperature for 2020-2049 along transect T2.

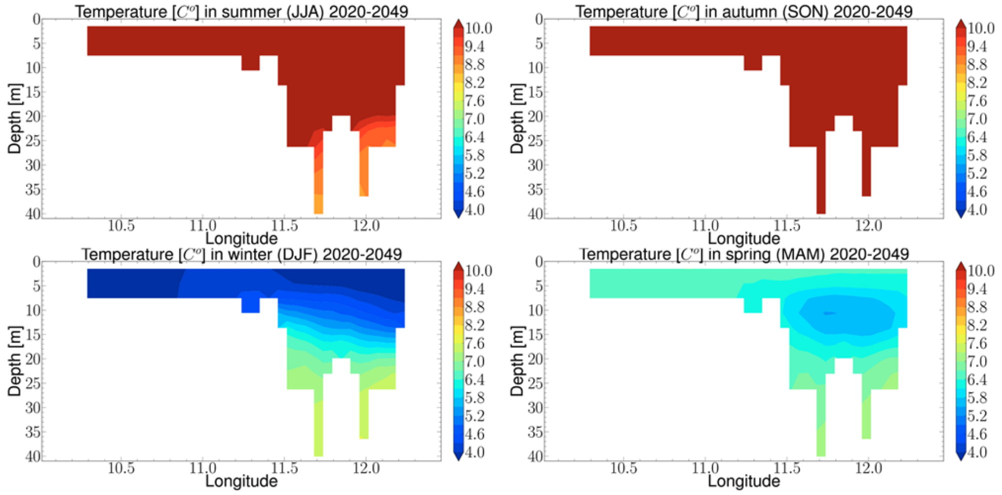
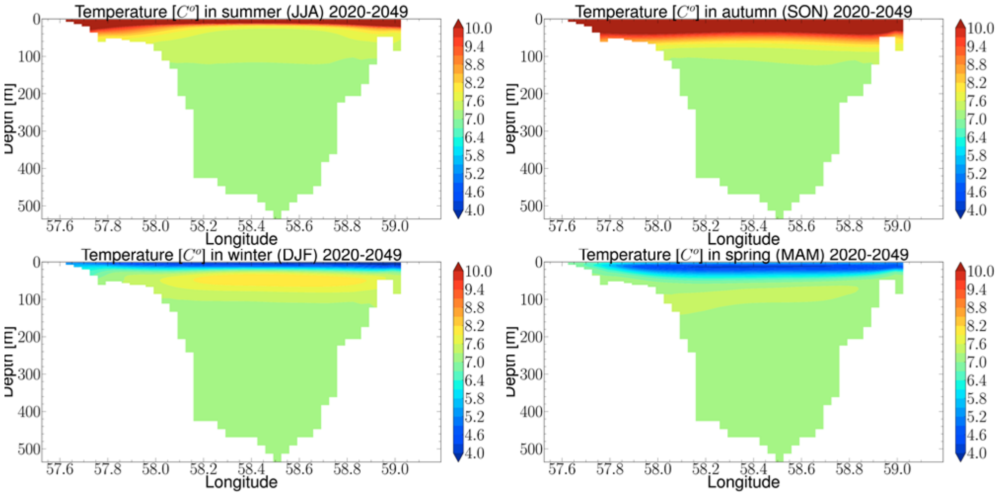
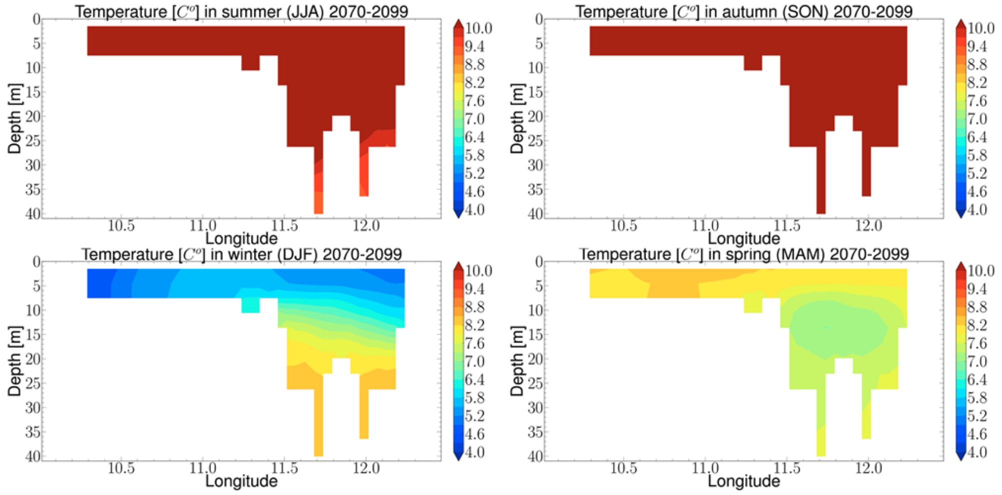


Figure 4.3.13 The projection of seasonal cycle of salinity for 2020-2049 along transect T1.



4.3.14 The projection of seasonal cycle of salinity for 2020-2049 along transect T2.



4.3.15 The projection of seasonal cycle of temperature for 2070-2099 along transect T1.

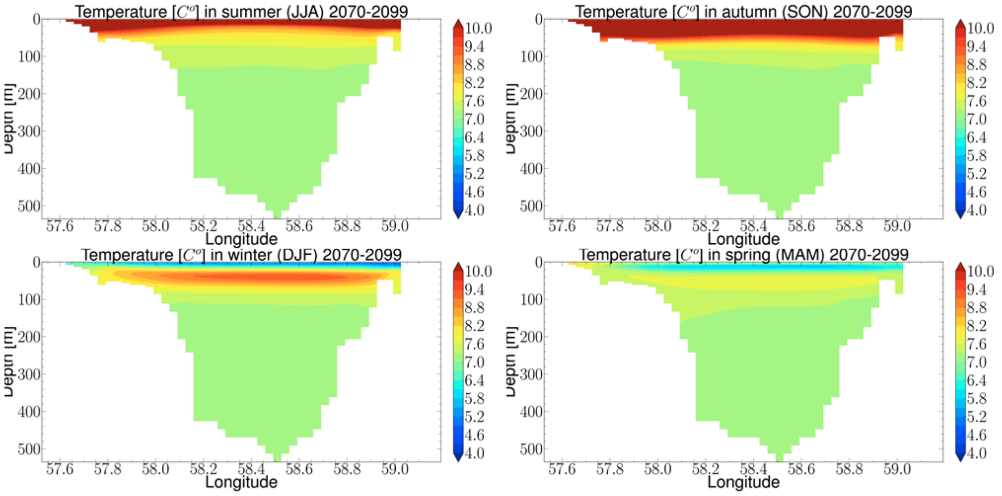


Figure 4.3.16 The projection of seasonal cycle of temperature for 2070-2099 along transect T2.

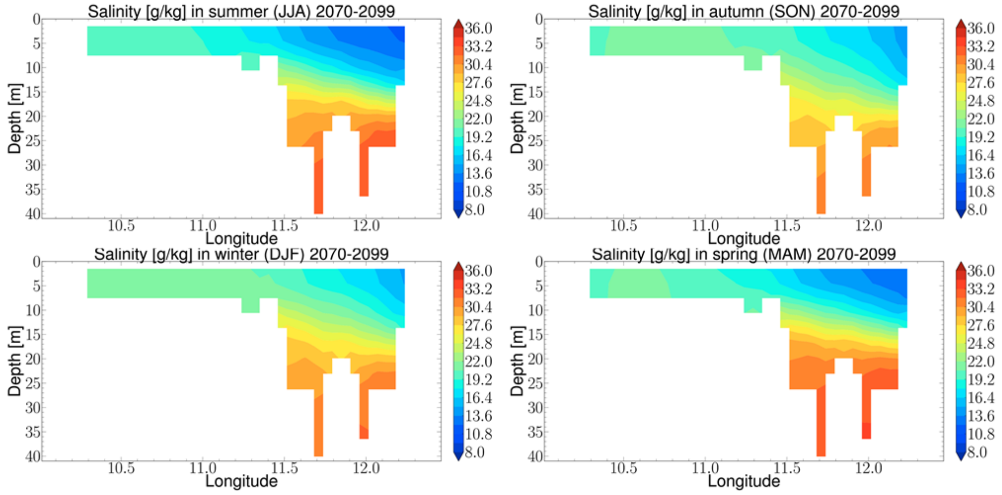


Figure 4.3.17 The projection of seasonal cycle of salinity for 2070-2099 along transect T1.

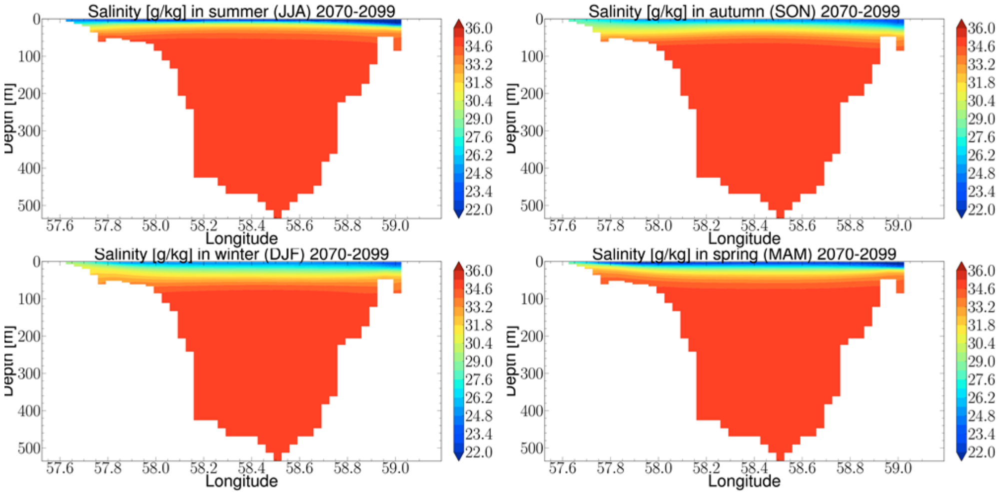


Figure 4.3.18 The projection of seasonal cycle of salinity for 2070-2099 across transect T2.

# 5. Three study cases

An analysis of the evolution of the sea surface height (SSH) is provided for Falkenberg, Henån and Larvik , for the 3 time periods previously mentioned and here represented in black, blue and red, respectively.

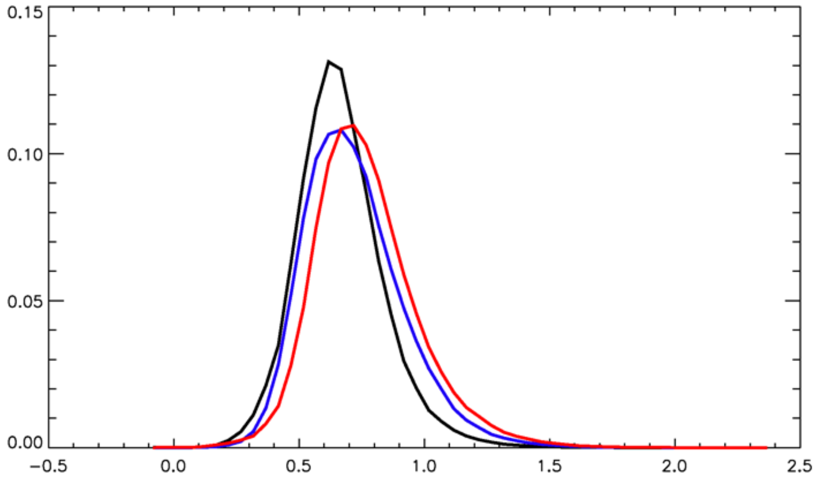


Figure 5.1. Distribution of the SSH (sea surface height) at Falkenberg for three time periods 1970-1999 (black line), 2020-2049 (blue line) and 2070-2099 (red line).

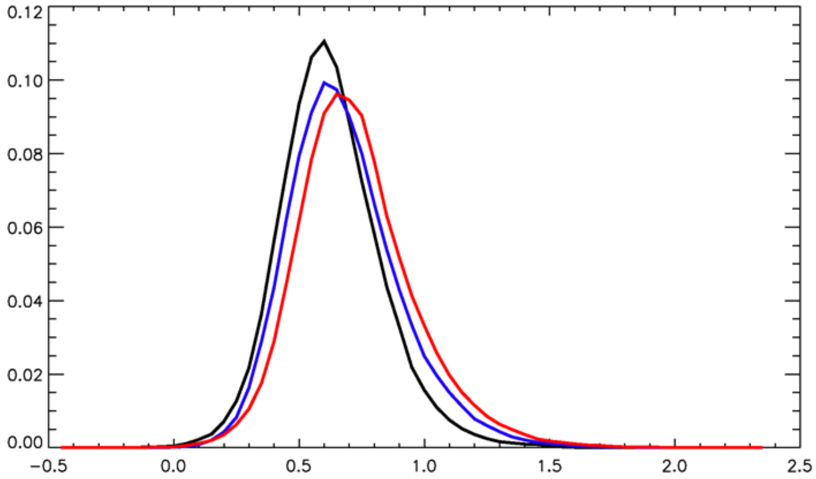


Figure 5.2 Distribution of the SSH (sea surface height) at Henån for three time periods 1970-1999 (black line), 2020-2049 (blue line) and 2070-2099 (red line).

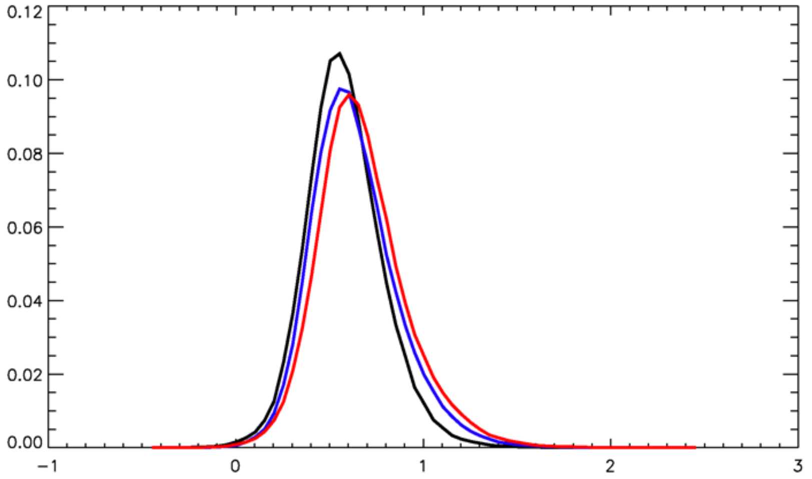


Figure 5.3. Distribution of the SSH (sea surface height) at Larvik for three time periods 1970-1999 (black line), 2020-2049 (blue line) and 2070-2099 (red line).

Based on the probability density function of the SSH, one can observe two similar processes occurring, regardless of the locations.

1. There is a clear increase of mean SSH (the peak of the probability density function) of 10 to 20 cm. This effect can be related with two different things. First, the warming effect that creates a decrease of water density and hence an increase of volume for each water column. Second, most climate scenarios predict an increased westerly flux which will most likely accumulate more water along the western Swedish coast. One should, however, keep in mind that this sea level rise increase reflects only the local effects of the ocean modeling configuration, refereed usually as steric effect. In this case, it is a local steric effect only, because the global steric effect is ignored. So is the sea-level-rise due to glacial melt. Both global steric effects and glacial melts present a degree of uncertainty which is important and for which reason they have been ignored from the simulations presented in this report. Adding the two effects leads to an increase of about 1m.

2. There is a clear shift in the density function, apart from the sea-level-rise signal. The “mean value” occurs less often, which means the SSH variability is increased. This effect is consistent with all climate scenarios available. The negative extremes do not occur more, but the probability that a major event occurs is increased by 15%, which, in combination with sea level rise, leads to a much higher probability for storm surges along the Swedish Western Coast.

# 6. Conclusions

The present study gives an estimate of the size of the local influence in changes in temperature and sea-surface-height, in a climate change scenario. The high-resolution BaltiX configuration identifies the local influence of climate change, which could not be seen in a global climate model for which the resolution is too coarse. This is especially true for the evolution of the sea surface height for which the grid cell of most climate models cannot represent the complex bathymetry and thermo-haline structure of the Kattegat/Skagerrak area. One has to keep in mind, however, that this study does not include global effects, although it is consistent to think one can just add them from a linear perspective.

The results confirm a temperature increase for the entire area that results into a higher thermal stratification, but also haline stratification. This effect can be explained by the fact that the thermal stratification has an important effect that brings up the freshwater mass exiting from the Baltic Sea towards the surface layers . Further analysis is required to show this effect, but one can think that the surface salinity of the Kattegat/Skagerrak area will decrease in a future climate, regardless of any increase in runoff in the Baltic Sea.

Of course, one should always be very cautious with such results and consider the high degree of uncertainty. In the present simulation, no runoff scenario has been used. This permits to focus more on the effects of wind pattern and strength changes in the Kattegat/Skagerrak area. However this should not take out of the spirit of that survey, that an increase of 5 to 10% of runoff into the Baltic Sea would decrease a lot more the surface salinity than what can be observed in this study, and which is mostly related with stratification increase. Another degree of uncertainty comes from the fact that only one climate scenario has been used, and other more or less extreme climate scenarios may produce trends which differ in strength. However, if it is certain that there is a difference in the strength of trends from one scenario to one another, they all predict similar trends, linked with higher temperatures and an increase of extreme events such as storm surges, emphasized in the present report.

The main results of this study, apart from the increased temperature and stratification, are related with the sea-surface-height behavior in future climate. A sea-level-rise can be noticed, even when one neglects global effects, but also the probability for extreme events is increased by a factor that cannot be neglected in any planning of coastal structure.

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# Appendix

Figures for the difference between the periods 2020-2049 and 2070-2099, respectively, and the historical period 1970-1999.

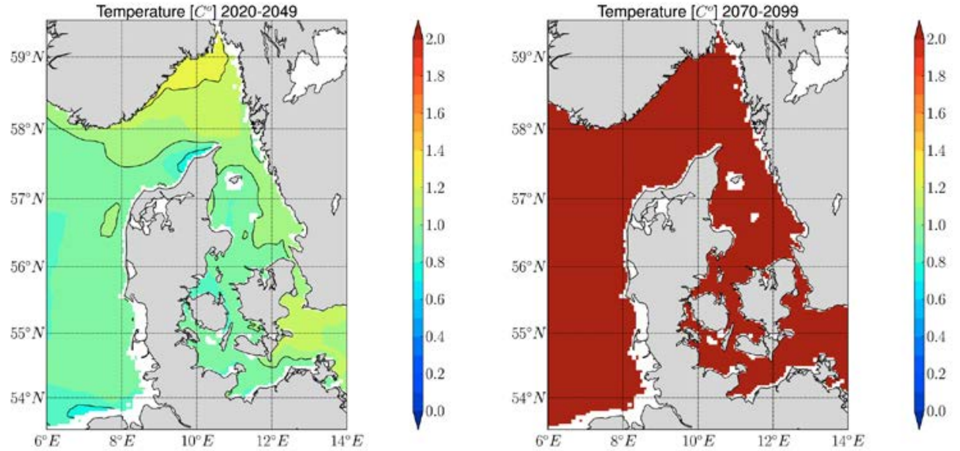

Figure A1. Sea surface temperature change between the periods 1970-1999 and 2020-2049 (left); 1970-1999 and 2070-2099 (right).

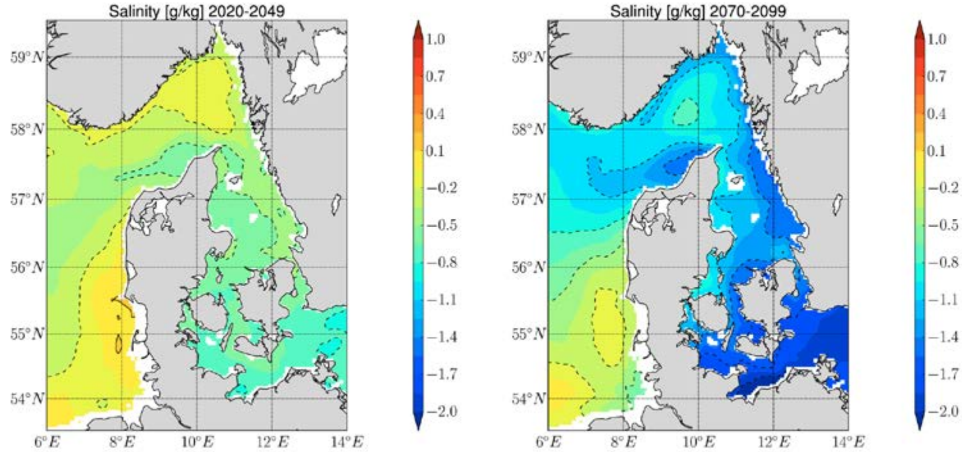

Figure A2. Sea surface salinity change between the periods 1970-1999 and 2020-2049 (left); 1970-1999 and 2070-2099 (right).

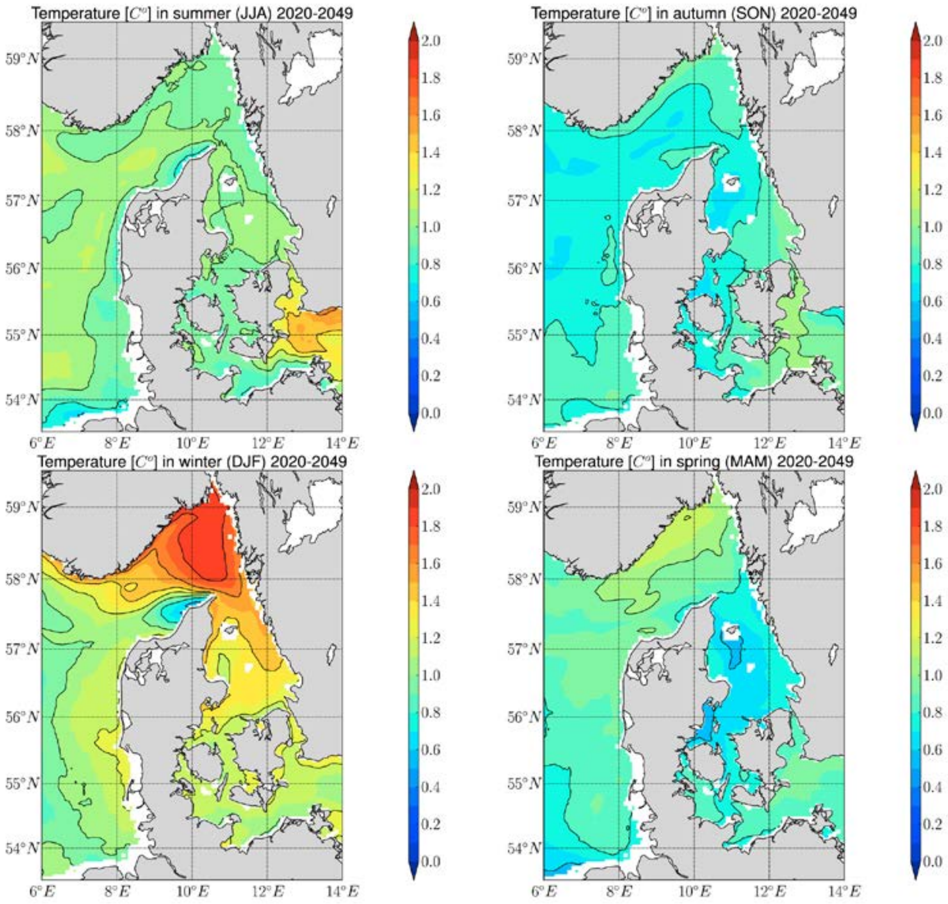

Figure A3. Sea surface temperature change between the periods 1970-1999 and 2020-2049, for different seasons.

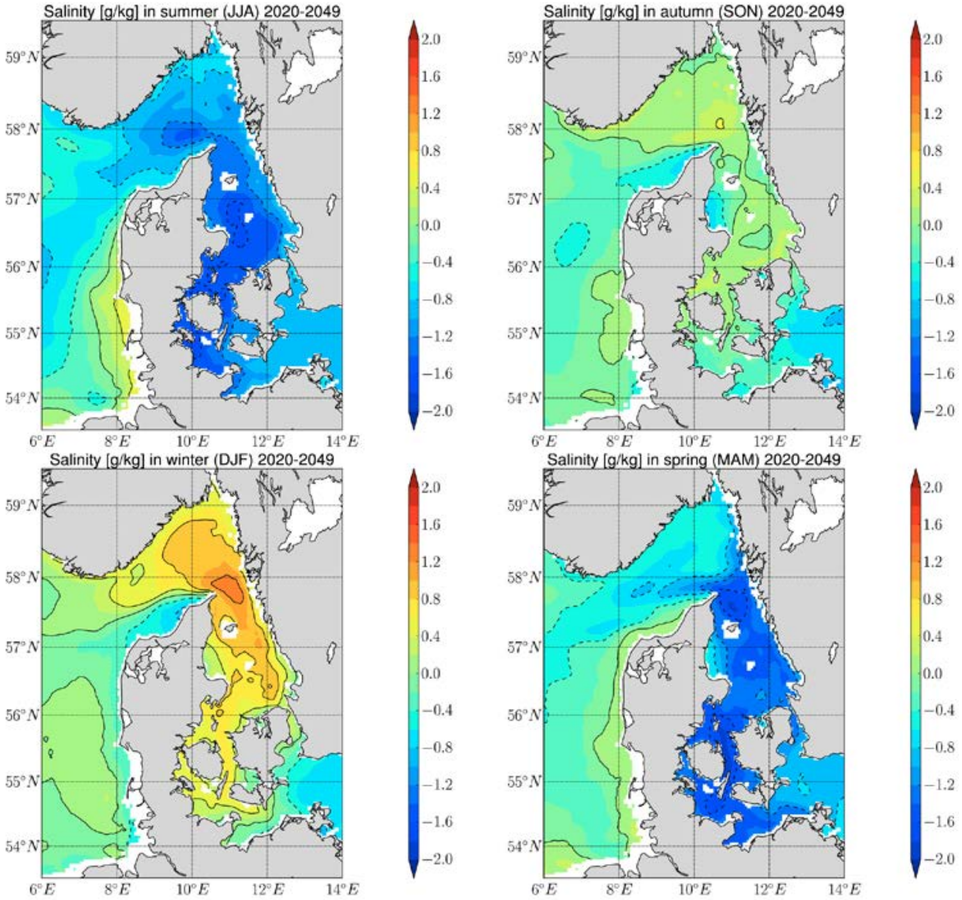

Figure A4. Sea surface salinity change between the periods 1970-1999 and 2020-2049, for different seasons.

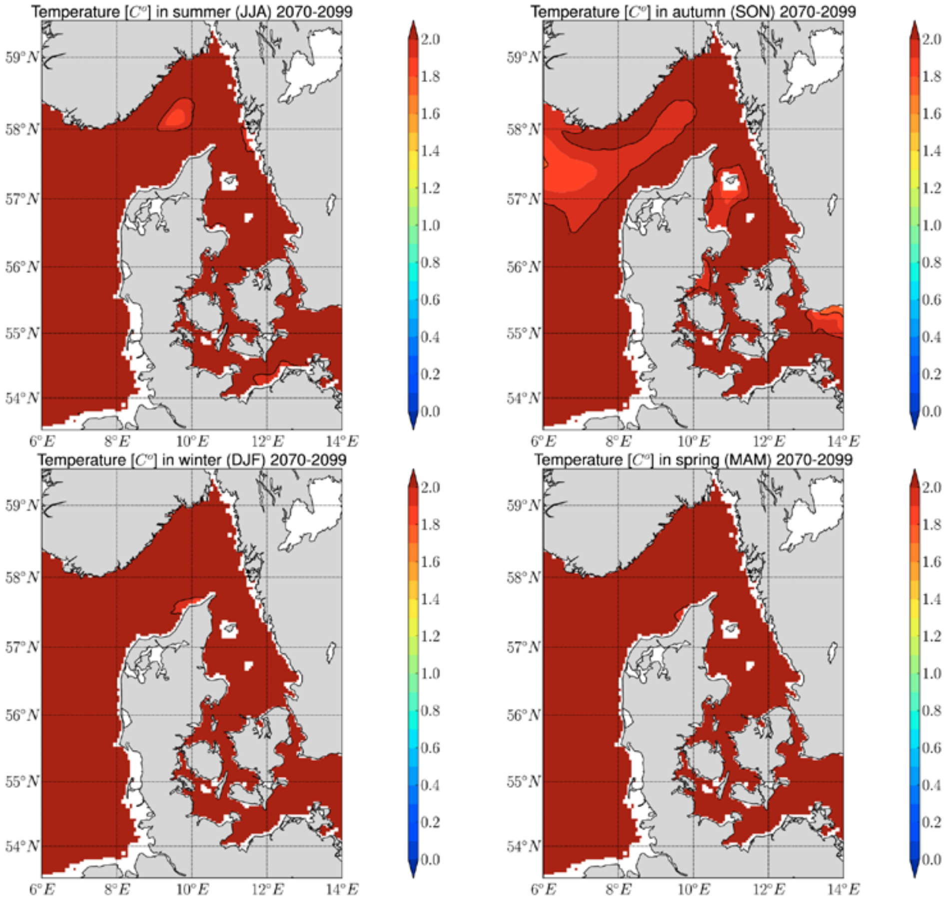

Figure A5. Sea surface temperature change between the periods 1970-1999 and 2070-2099, for different seasons.

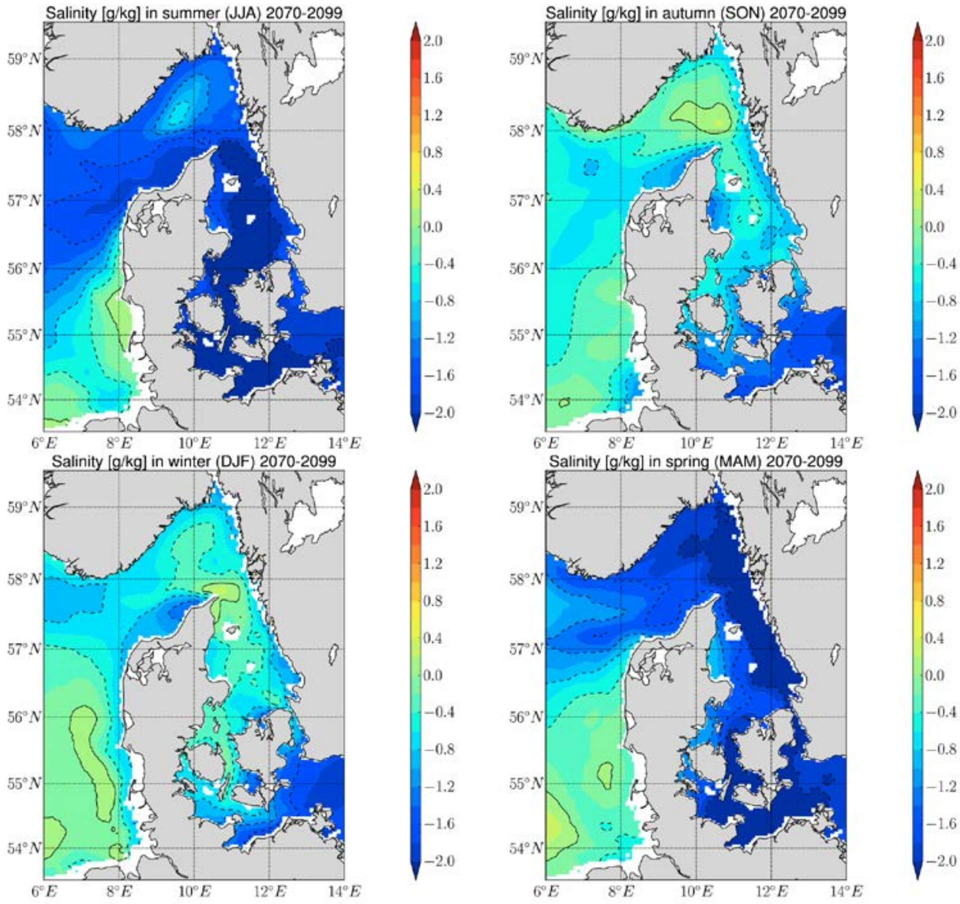

Figure A6. Sea surface salinity change between the periods 1970-1999 and 2070-2099, for different seasons.

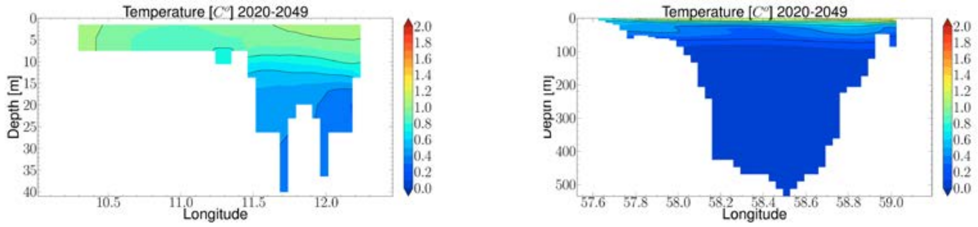

Figure A7. Temperature change between the periods 1970-1999 and 2020-2049, for transect T1 (left) and T2 (right).

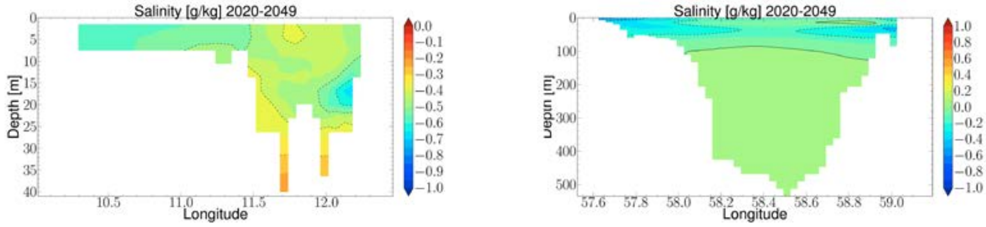

Figure A8. Salinity change between the periods 1970-1999 and 2020-2049, for transect T1 (left) and T2 (right).

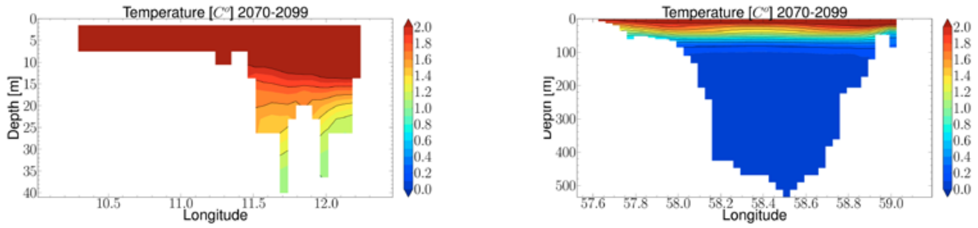

Figure A9. Temperature change between the periods 1970-1999 and 2070-2099, for transect T1 (left) and T2 (right).

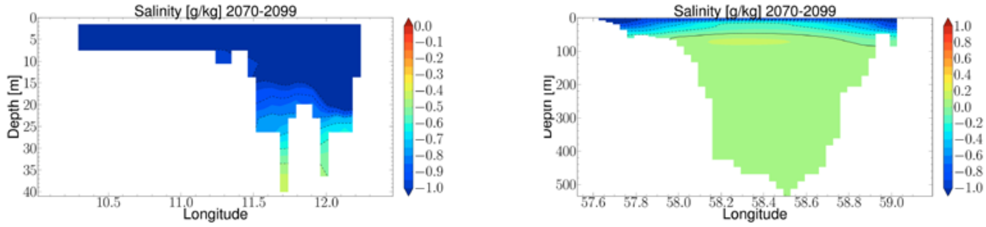

Figure A10. Salinity change between the periods 1970-1999 and 2070-2099, for transect T1 (left) and T2 (right).

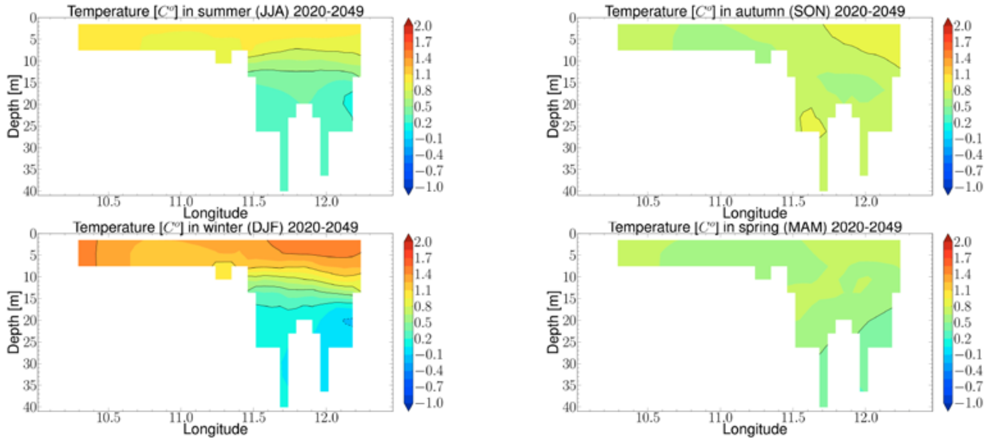

Figure A11. Temperature change between the periods 1970-1999 and 2020-2049, for different seasons. Transect T1.

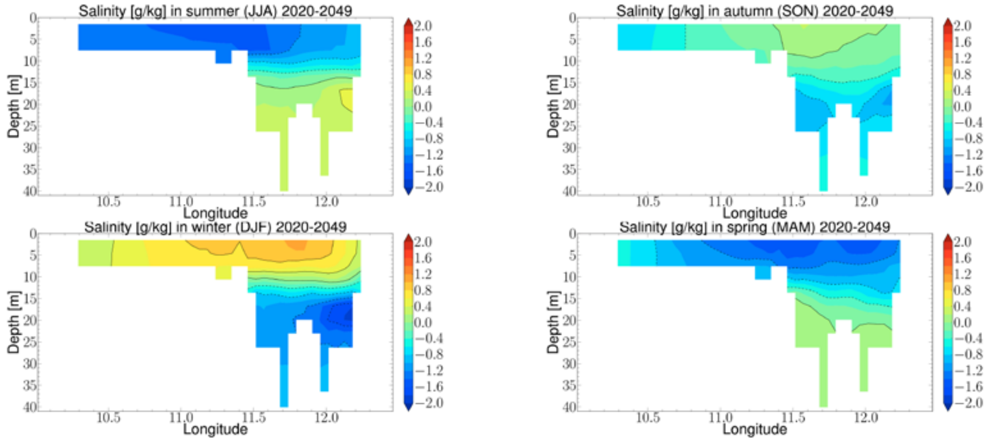

Figure A11. Salinity change between the periods 1970-1999 and 2020-2049, for different seasons. Transect T1.

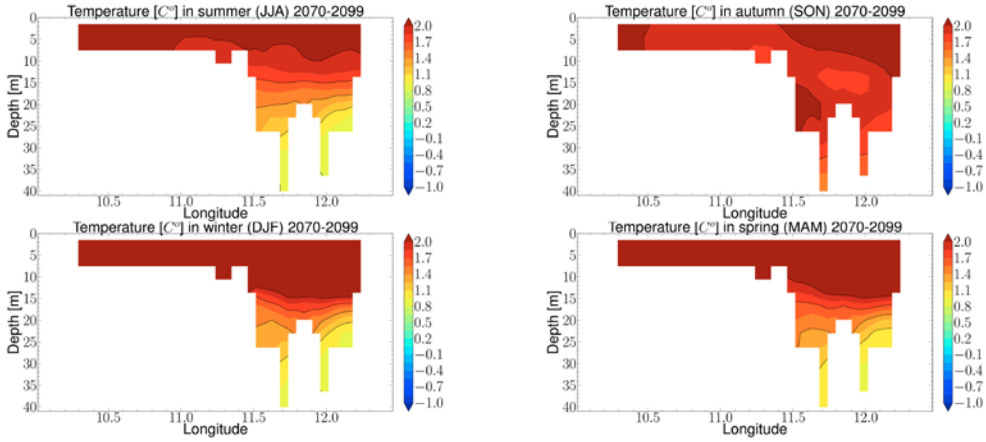

Figure A12. Temperature change between the periods 1970-1999 and 2070-2099, for different seasons. Transect T1.

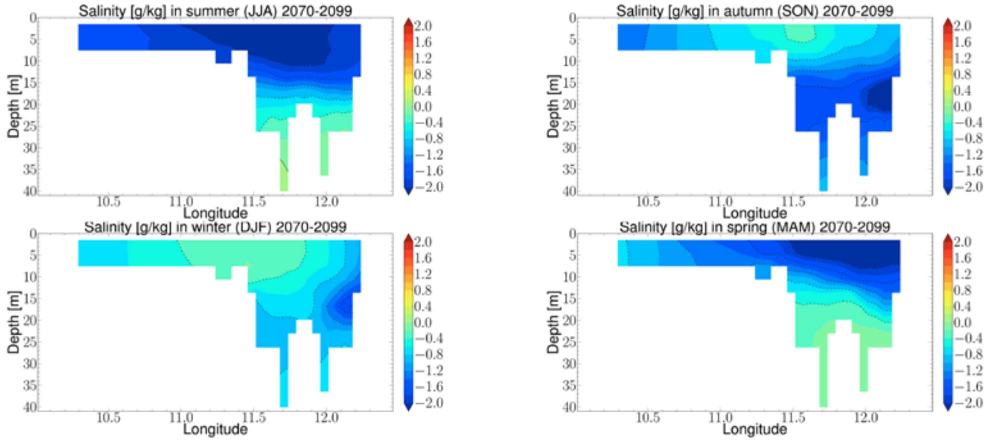

Figure A13. Salinity change between the periods 1970-1999 and 2070-2099, for different seasons. Transect T1.

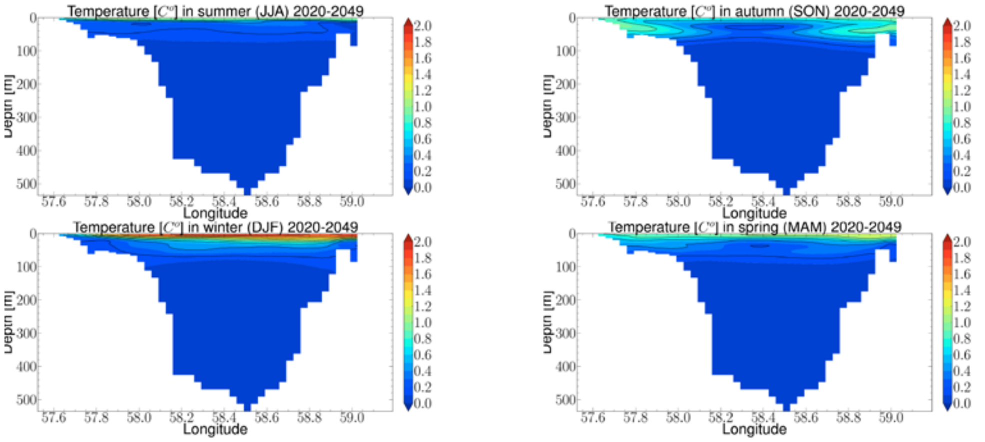

Figure A14. Temperature change between the periods 1970-1999 and 2020-2049, for different seasons. Transect T2.

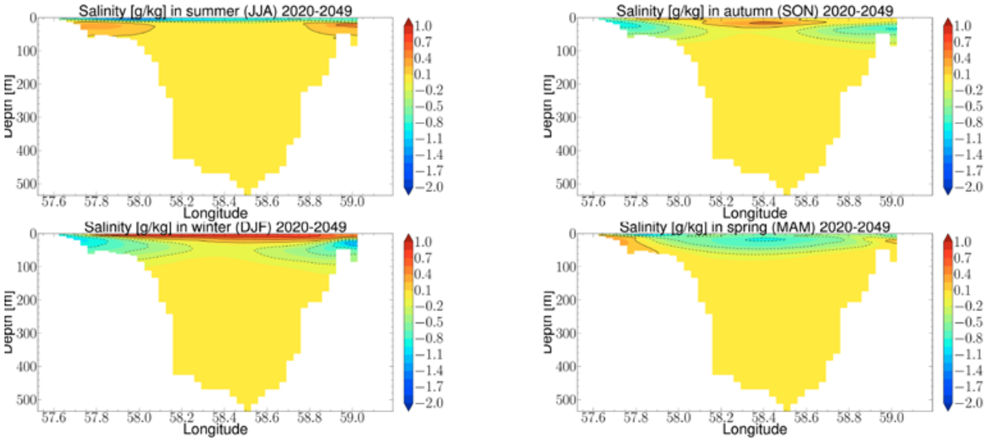

Figure A15. Salinity change between the periods 1970-1999 and 2020-2049, for different seasons. Transect T2.

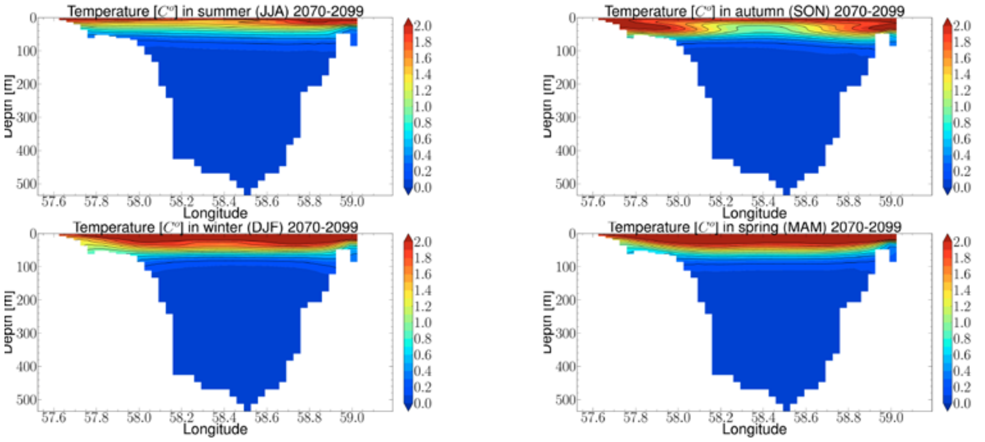

Figure A16. Temperature change between the periods 1970-1999 and 2070-2099, for different seasons. Transect T2.

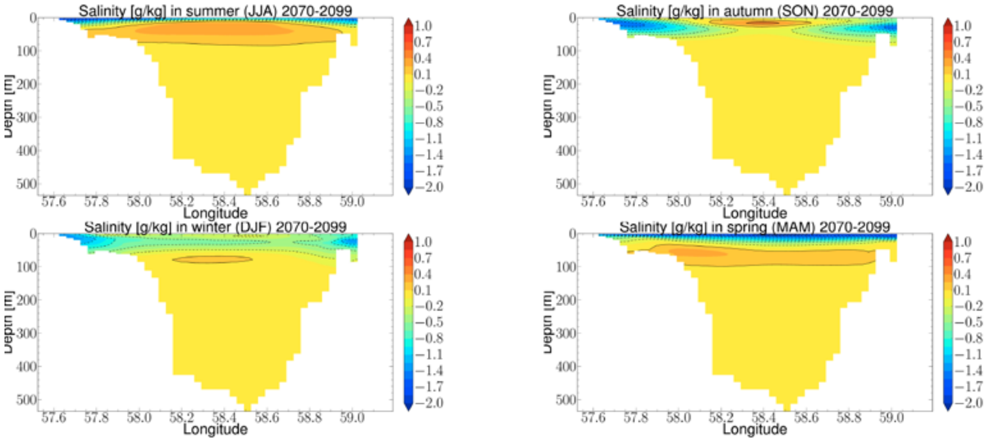

Figure A17. Salinity change between the periods 1970-1999 and 2070-2099, for different seasons. Transect T2.

# Om projekt Hav möter Land

## Klimat, vatten, samhällsplanering tillsammans

Hav möter Land samlar 26 organisationer i Sverige, Norge och Danmark. Vi samarbetar om klimat, vatten och samhällsplanering för Kattegat och Skagerrak.

Våra resultat är användbara för beslutsfattare, planläggare, forskare och förvaltare av naturresurser.

Klimatet förändrar våra möjligheter att bo och livnära oss här. Vi tar fram gemensam kunskap för gemensam beredskap.

I projektet arbetar kommuner, regioner, universitet och statliga myndigheter tillsammans. EU är med och finansierar projektet genom Interreg IVA.

Hjälp gärna till på www.havmoterland.se.

## Partners

Länsstyrelsen i Västra Götalands län
Østfold fylkeskommune
Artdatabanken
Aust-Agder fylkeskommune
Buskerud fylkeskommune
Falkenbergs kommun
Fylkesmannen i Aust-Agder
Fylkesmannen i Buskerud
Fylkesmannen i Telemark
Fylkesmannen i Vestfold
Fylkesmannen i Østfold
Göteborgs universitet
Havs- och vattenmyndigheten
Kungsbacka kommun
Larvik kommune
Lysekils kommun
Länsstyrelsen i Hallands län
Nøtterøy kommune
Orust kommun och projekt 8 fjordar
Region Halland
SMHI
Sotenäs kommun
Telemark fylkeskommune
Vestfold fylkeskomune
Västra Götalandsregionen
Århus Universitet

## Framtidens Kattegatt och Skagerrak – temperatur, salt och havsvattenstånd

Vi har tagit fram en ny havsmodell för Östersjön-Kattegatt-Skagerrak-Nordsjön för att kunna studera havets nuvarande tillstånd och hur förhållandena kan förändras i ett framtida klimat.

Temperaturen i ytvattnet ökar med 2 till 3 grader i Kattegatt-Skagerrak till slutet av århundradet, enligt beräkningarna, med lokala variationer. Ökningen blir oftast störst på vintern. Skiktningen kan också komma att bli starkare.

Räknar man bort en global förändring av havsnivån, landhöjning respektive landsänkning så kan havsnivån höjas på vissa platser, dels på grund av lokal uppvärmning och dels som följd av ökade västvindar. Sannolikheten för mer extrema händelser ökar. I beräkningarna har vi använt ett utsläppsscenario med snabb befolkningstillväxt och intensiv energianvändning.

### Hav möter Land

Projekt Hav möter Land samlar 26 kommuner, regioner, universitet och statliga myndigheter i Sverige, Norge och Danmark. Vi samarbetar om klimat, vatten och samhällsplanering för Kattegat och Skagerrak. Våra resultat är användbara för beslutsfattare, planläggare, forskare och förvaltare av naturresurser. Klimatet förändrar våra möjligheter att bo och livnära oss här. Vi tar fram gemensam kunskap för gemensam beredskap. EU är med och finansierar projektet genom Interreg IVA.

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