

FUTURE SEA ICE IN THE BOTHNIAN BAY OR (FUTURE SEA ICE CONDITIONS FOR MARITIME TRAFFIC IN THE NORTHERN BALTIC SEA)

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Objectives/Background

SMHI

Assess changes in future ice conditions in the Baltic Sea from a **maritime traffic perspective**. (For reinvestment of Swedish icebreaker fleet.)

We focus on changes in Swedish waters and northern Baltic Sea.

We analyze observations and model data in a historical period to assess **near-recent changes** and judge model data quality.

Future changes are analyzed from dynamically downscaled CMIP5 scenarios comparing a historical and two future 30-year periods.

We use an **extended set of indicators** compared previous assessments BACC, BACC-II and BEARs.

Results summarized in Pemberton et al, (2021); Höglund et al, (2017); Pemberton et al, (2017).

Baltic Sea ice conditions

Seasonal (November–May)

Average extent $\sim 170\,000\text{ km}^2$ (**40%** of Baltic Sea)

Winters classified as mild/average/severe

Minimum in 2020: $37\,000\text{ km}^2$

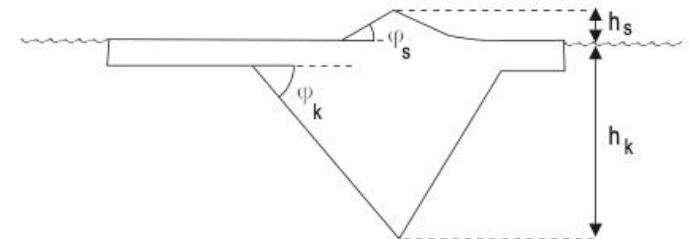
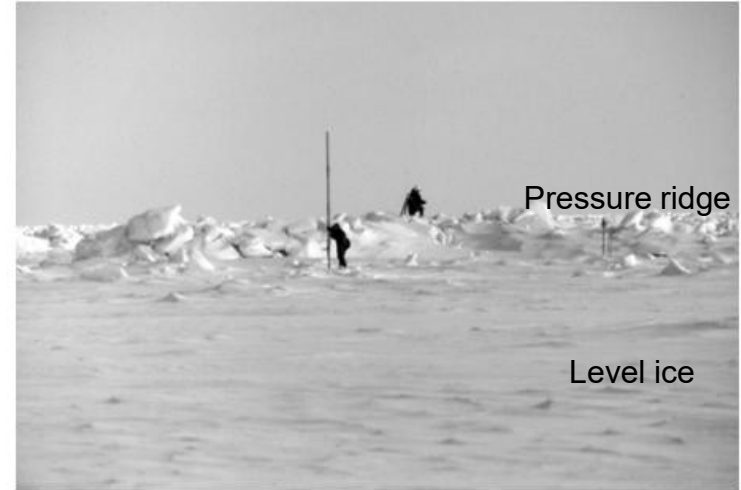
Undeformed ice thickness $< 1\text{ m}$

Deformed ice thickness $< 30\text{ m}$

Deformed ice = Pressure ridges, rafted ice and rubble fields.

Internal loads can build up ice pressure

Ice pressure and **ridges** impact traffic



Source: Leppäranta (2011)

Wintertime maritime traffic

SMHI

Baltic Sea has 15 % of the world's cargo transportation and is one of the seas with heaviest maritime traffic in the world (HELCOM, 2009).

To maintain the maritime traffic during winter the SMA offers **icebreaking assistance**. SMA also **imposes traffic restrictions** to all winter navigation to improve safety. The restrictions are based on the Finnish-Swedish ice classes which are defined based on ice thickness and tonnage of the vessels.



Source: www.sjofartsverket.se

Indicators

Seven sea ice indicators selected based on their **relevance for maritime traffic** and icebreaking operations. The indicator were **identified jointly with SMA**.

Indicator	Description [unit]
Maximum sea ice extent	Total area [1000 km ²] maximum ice extent during a season
Ice season	Number of [days] a region is ice covered
Undeformed ice thickness	Thickness [cm] of thermodynamically grown ice
Deformed ice concentration	Fraction of ice [%] grown due to dynamical processes (ridging and rafting)
Ice thickness distribution	Areal distribution [%] of ice in a given thickness interval
Ice drift	[cm/s]
Ice class based traffic restrictions	Time period [days] when different Finnish-Swedish traffic restrictions are imposed

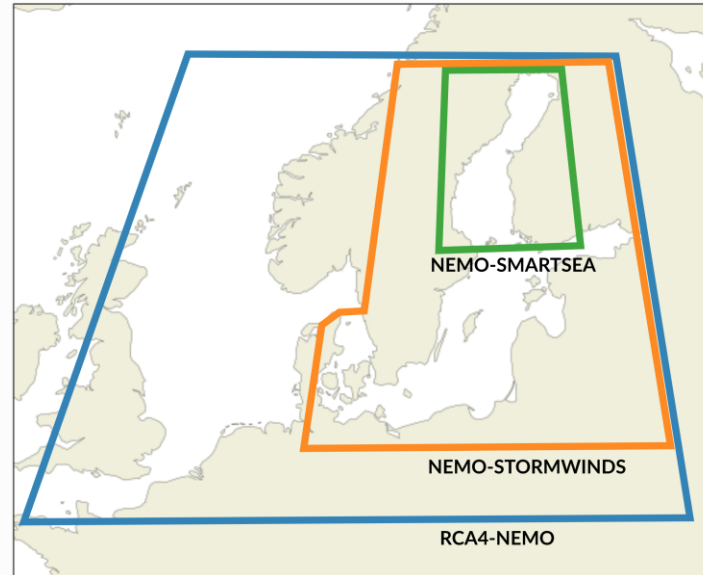
Data

We use historical **observations** (ice extent, ice charts, coastal observations) from SMHI, FMI, and SMA.

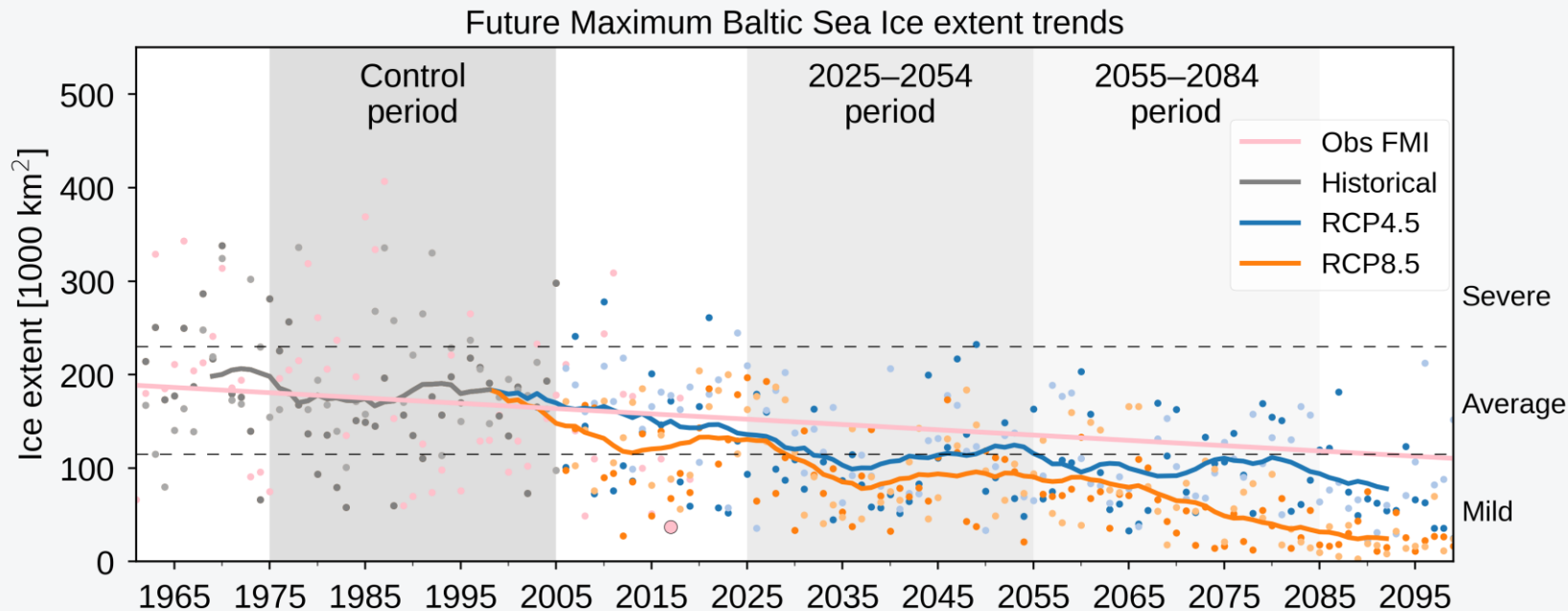
Downscaled climate (CMIP5) scenarios for **RCP4.5** and **RCP8.5** (**RCP2.6** are unfortunately absent in existing datasets), for **3 GCMs** and **2 RCMs**.

Downscaling chain and Simulations

GCM (RCP)	→	RCM	→	High res. ocean-sea ice model
1 EC-Earth (RCP4,5)	→	RCA4-NEMO	→	NEMO-STORMWINDS
2 EC-Earth (RCP8,5)	→	RCA4-NEMO	→	NEMO-STORMWINDS
3 MPI (RCP4,5)	→	RCA4-NEMO	→	NEMO-STORMWINDS
4 MPI (RCP8,5)	→	RCA4-NEMO	→	NEMO-STORMWINDS
5 EC-Earth (RCP4,5)	→	RCA4-NEMO	→	NEMO-SMARTSEA
6 EC-Earth (RCP8,5)	→	RCA4-NEMO	→	NEMO-SMARTSEA
7 MPI (RCP4,5)	→	RCA4-NEMO	→	NEMO-SMARTSEA
8 MPI (RCP8,5)	→	RCA4-NEMO	→	NEMO-SMARTSEA
9 HadGEM2 (RCP4,5)	→	RCA4-NEMO	→	NEMO-SMARTSEA
10 HadGEM2 (RCP8,5)	→	RCA4-NEMO	→	NEMO-SMARTSEA



Maximum ice extent



Observed trend: $-2\ 000$ to $-6\ 000$ km²/decade.

Future trends: $-9\ 000$ and $-14\ 000$ km²/decade for RCP4.5 and RCP8.5.

No ice-free winters for 21st century, **no severe winters** after ~2050.

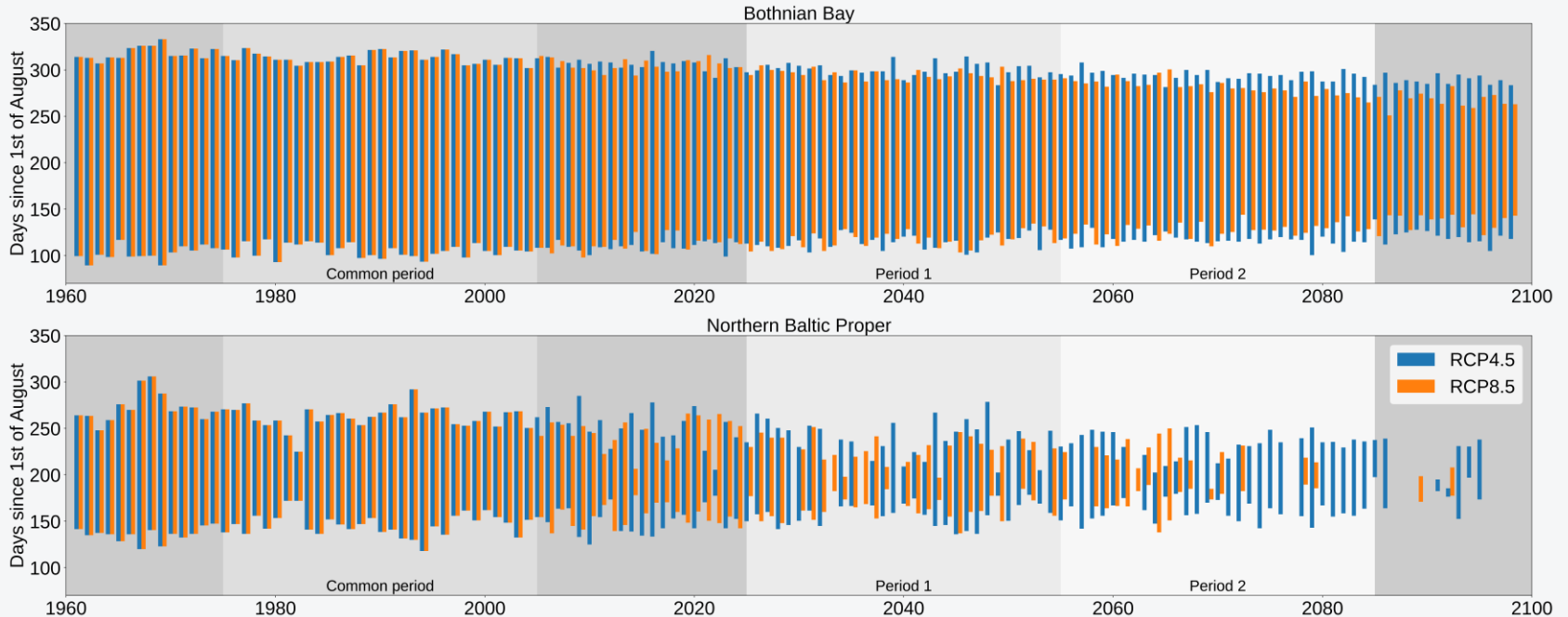
Decreased variability and shift of distribution towards mild/average winters.

Ice season

General decrease 4–11 days/decade. Change at the end of ice season is more pronounced than start of season, 2–4 days/decade vs 1–3 days/decade.

Sharper decreasing trend in the south.

Observations at coastal stations also show strongest change in end of season.



Ice thickness (undeformed ice)

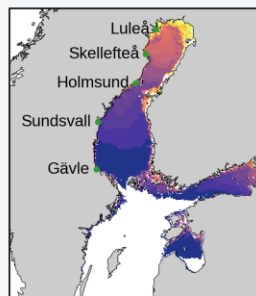
For ice breaking operations only ice thickness above 10–20 cm is relevant.

Northward shift, only Bothnian Bay has ice thickness > 10 cm.

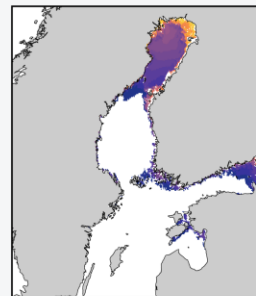
Decreasing trends of 2–4 cm/decade.

Station	Max. ice thickness trend [cm/decade]	
	RCP 4.5	RCP 4.5
Luleå	-2	-4
Skellefteå	-3	-4
Holmsund	-3	-4
Sundsvall	-3	-4

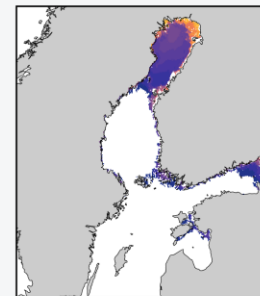
Historical 1975–2004



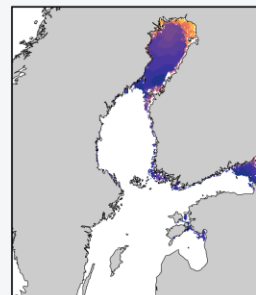
RCP4.5 2025–2054



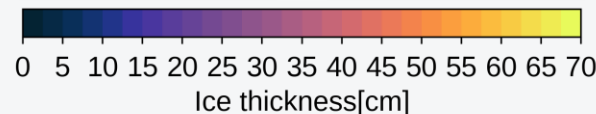
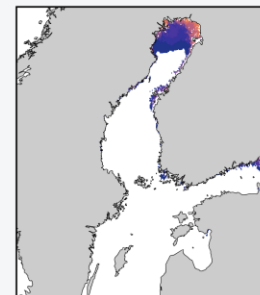
RCP4.5 2055–2084



RCP8.5 2025–2054



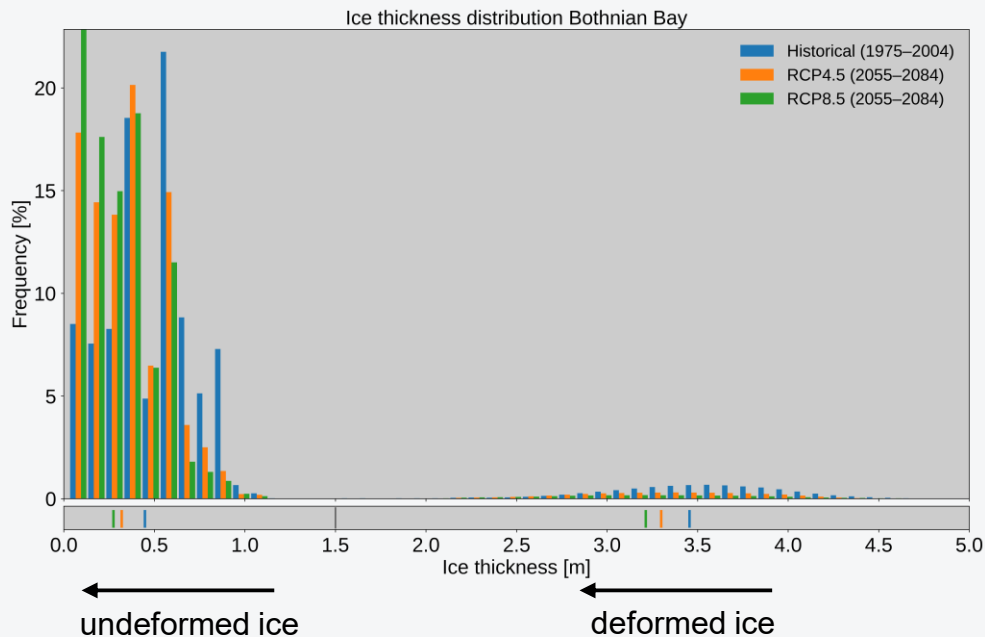
RCP8.5 2055–2084



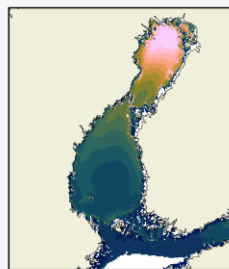
Deformed ice and ice thickness dist. SMHI

A decrease in areas with deformed ice, and a northward shift.

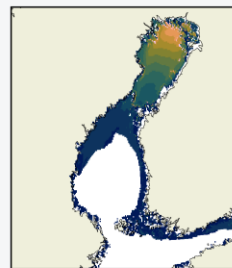
Both undeformed ice and deformed ice thickness decrease.



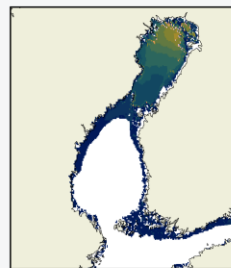
Historical 1975–2004



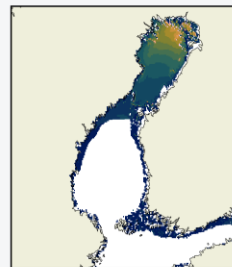
RCP4.5 2025–2054



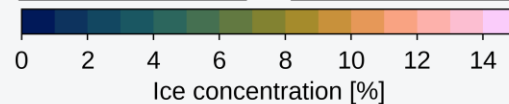
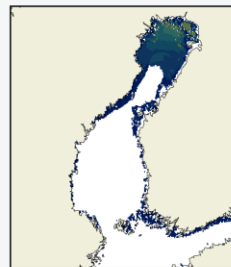
RCP4.5 2055–2084



RCP8.5 2025–2054



RCP8.5 2055–2084

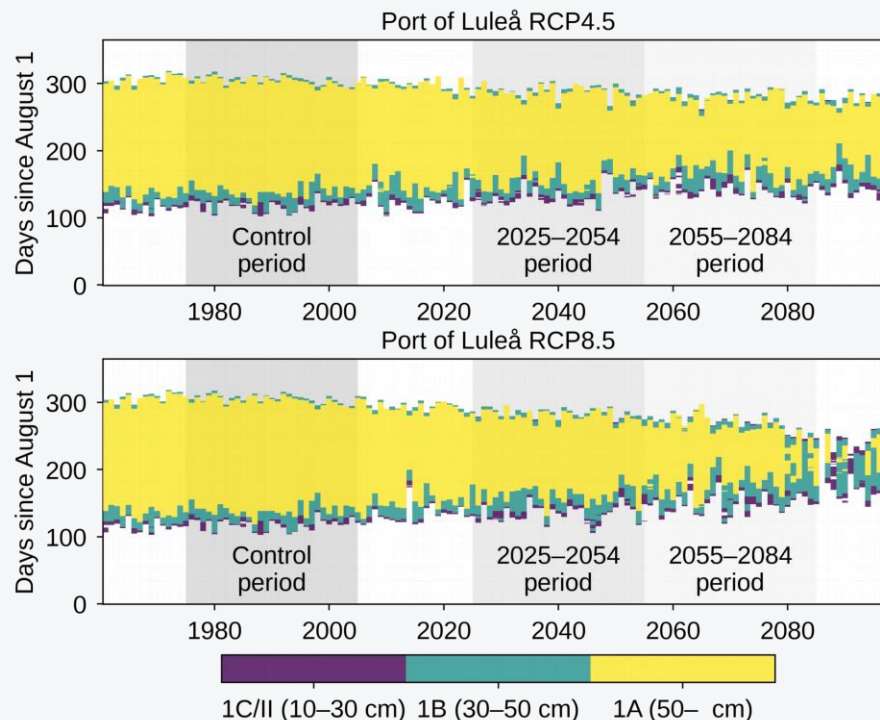


Ice class based traffic restrictions

This indicator integrates changes both in season length and ice thickness. Traffic restrictions in a selected number of Swedish ports where analyzed.

Finnish-Swedish ice class

Class	Thickness [cm]	Traffic conditions
II	10–15	extremely mild
1C	15–30	mild
1B	30–50	average to severe
1A	>50	severe to extremely severe

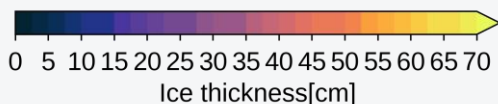
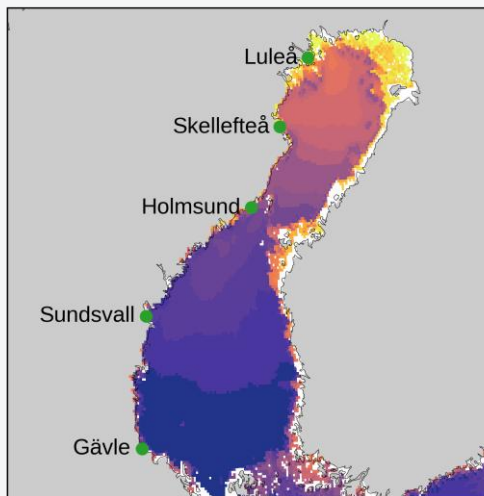


Ice class based traffic restrictions

There is a general decrease in number of days for all ice classes in the south.

In the north there is a shift decrease of stricter classes and increase of less strict classes.

Ports and mean ice thickness 1975–2004



Class	Luleå	Skellefteå	Holmsund	Sundsvall	Gävle
1C/II	24 (32/42)	40 (47/ 43)	34 (28/ 17)	42 (35/ 23)	40 (9/ 4)
1B	38 (48/ 44)	58 (41/ 16)	43 (22/ 9)	32 (13/ 6)	16 (0/ 0)
1A	113 (58/ 23)	50 (6/ 1)	41 (7/ 2)	48 (13/ 5)	2 (0/ 0)
Total	175 (138/109)	148 (94/ 60)	118 (57/ 28)	122 (61/ 34)	58 (9/ 4)

Blue (red) means decreased (increased) number of days.

Changes in indicators and confidence SMHI

Estimated changes between 1975–2004 and 2055–2084.

The confidence estimated based on number of available observations and model–obs misfit.

Indicator	Change	Confidence
Maximum sea ice extent	Decrease 41–63%	High
Ice season	Decrease 26–48 days	High
Undeformed ice thickness	Decrease 14–17 cm	Medium
Deformed ice concentration	Decrease in all areas and remains only in Bothnian Bay	Low
Ice thickness distribution	Decrease of both undeformed ice and thick deformed ice	Low
Ice drift	Small increase in ice drift (not shown)	Low
Ice class based traffic restrictions	Decrease in days with restrictions and shift in northern BB from stricter to milder	Medium

Summary and conclusions

We have assessed near-recent and future changes in northern Baltic Sea ice conditions, analyzed from a maritime traffic perspective.

Like previous assessments we find that future winters will **gradually have a smaller maximum ice extent, thinner undeformed ice and a shorter ice season**, with the largest differences in the southern areas.

We also find that the **fraction and thickness deformed ice will decrease**, and only be present in the northern parts of Bothnian Bay.

No assessment for milder scenarios (e.g RCP2.6) which is worst-case scenario for maritime traffic.

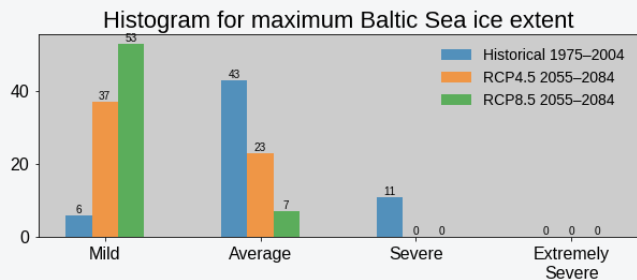
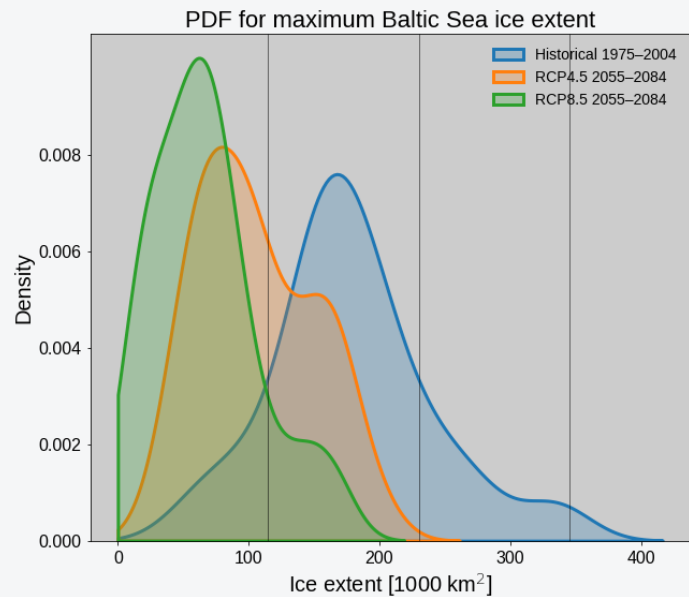
The assessment uses a limited number of downscaling models (only 3 GCMs and 2 RCMs), **a larger ensemble with more models might reduce uncertainties**.

More observational data on sea ice deformation and ice drift needed.

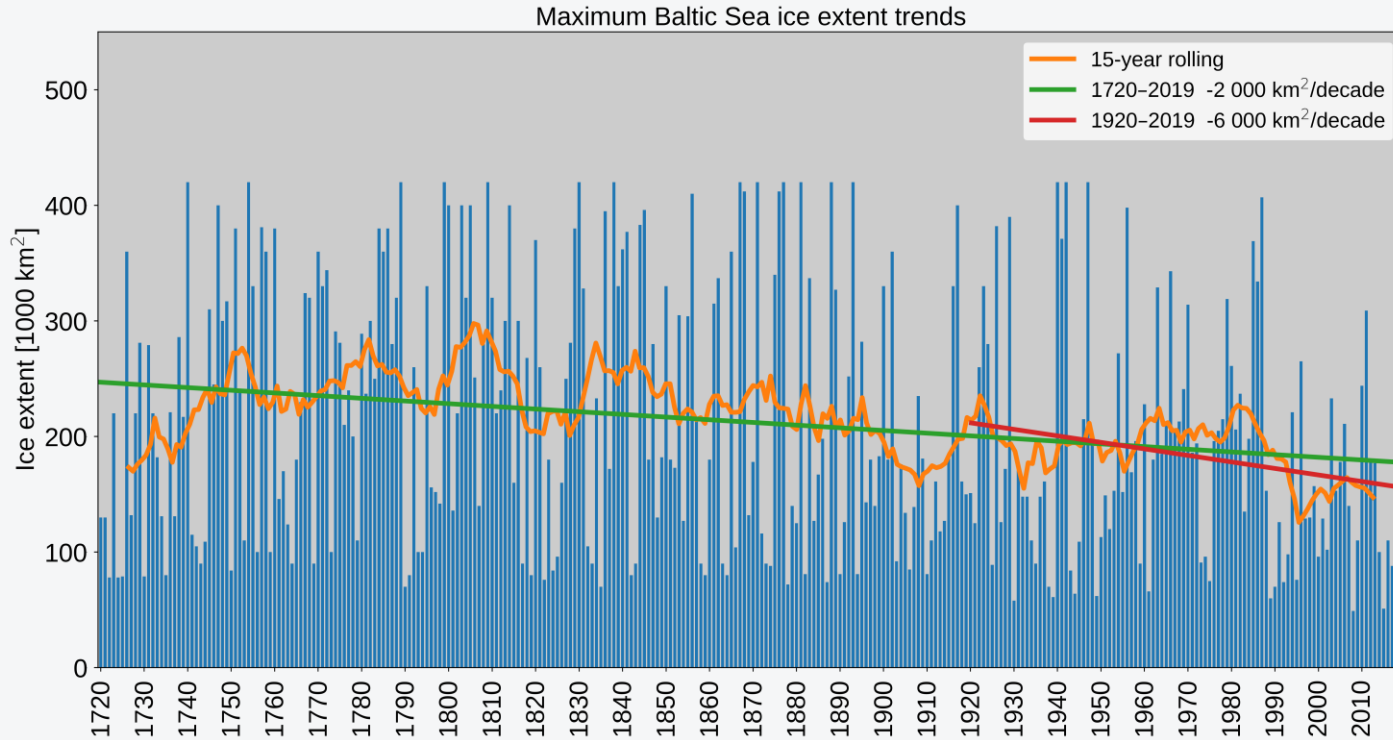
An aerial photograph of a vast, flat, light blue landscape, possibly a frozen body of water or a salt flat. The surface is marked by numerous dark blue, winding paths or channels that meander across the terrain. The overall color palette is dominated by various shades of blue, from pale to deep navy. The text "Thank you!" is centered in the middle of the image.

Thank you!

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Observed maximum ice extent



Observed trends: $-2\ 000$ and $-6\ 000$ km²/decade for 1720–2019 and 1920–2019.
Large natural variability driven by large scale atmospheric variability.