Sea ice – Ocean interactions in the Arctic


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European Marine Board Science Webinar
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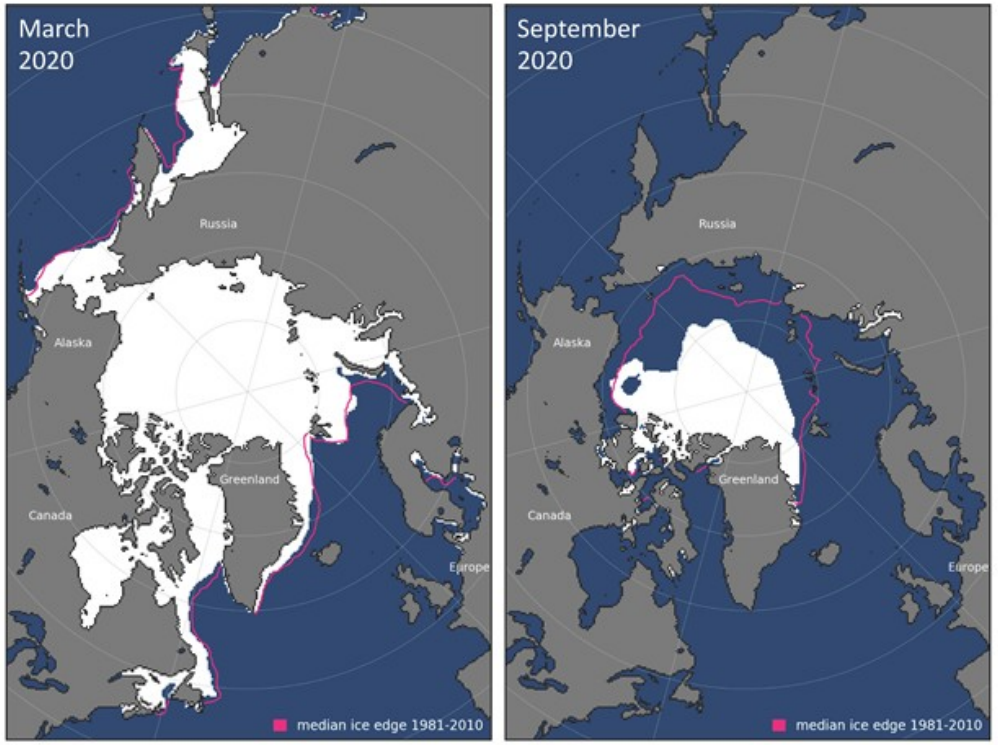
Plan

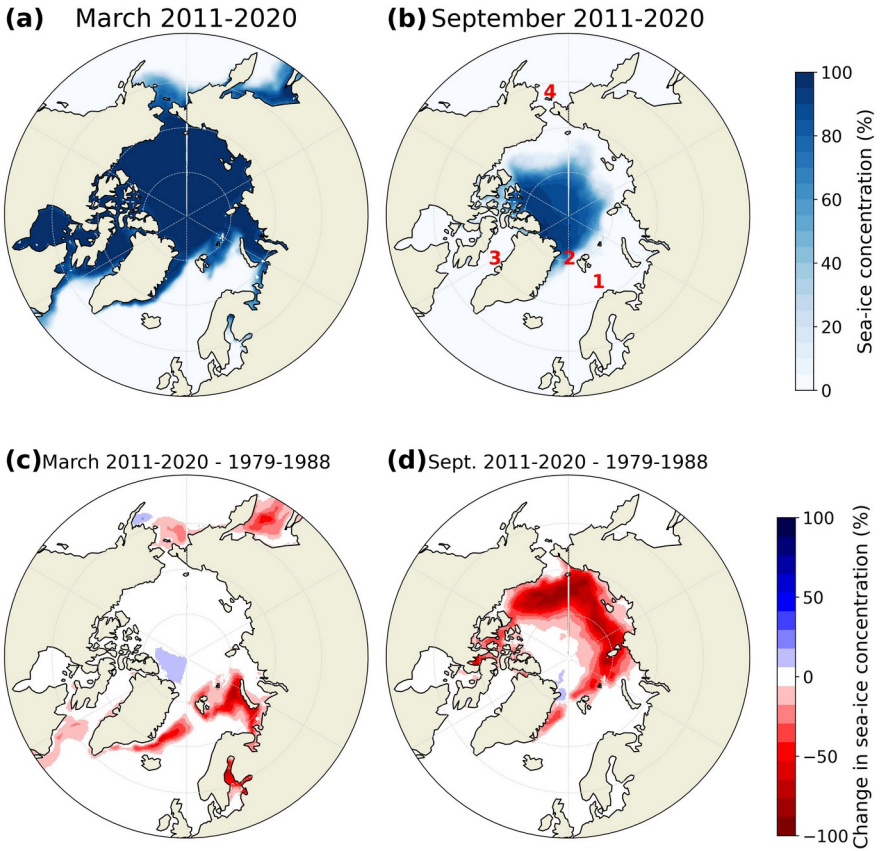
1) Recent and future changes in Arctic sea ice
2) Causes of Arctic sea-ice loss
3) **Influence of the ocean on Arctic sea ice → MAIN PART**
4) Influence of Arctic sea ice on the ocean
5) Causal analyses
6) Research gaps
7) Conclusions

Recent changes in Arctic sea ice

Satellite observations



Perovich et al. (2020)

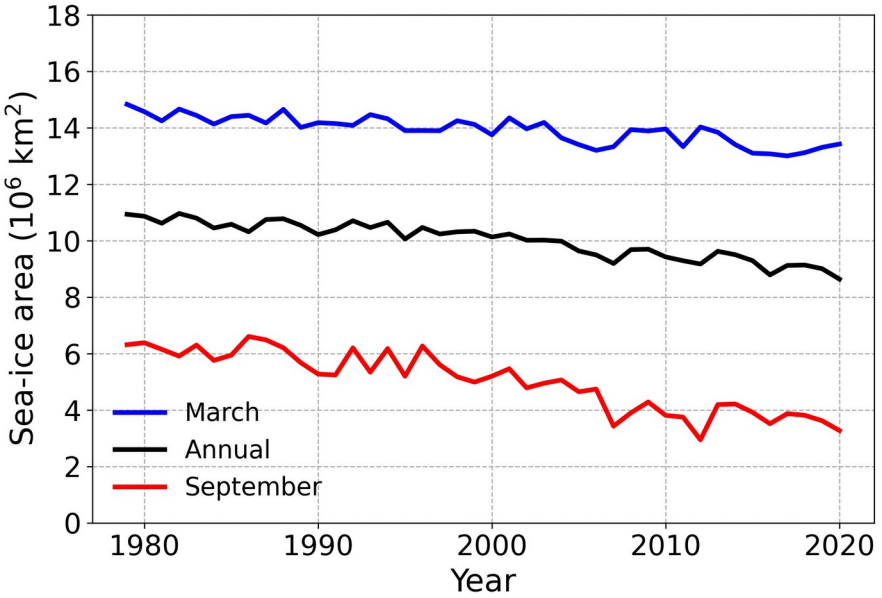


Docquier & Koenigk (2021)

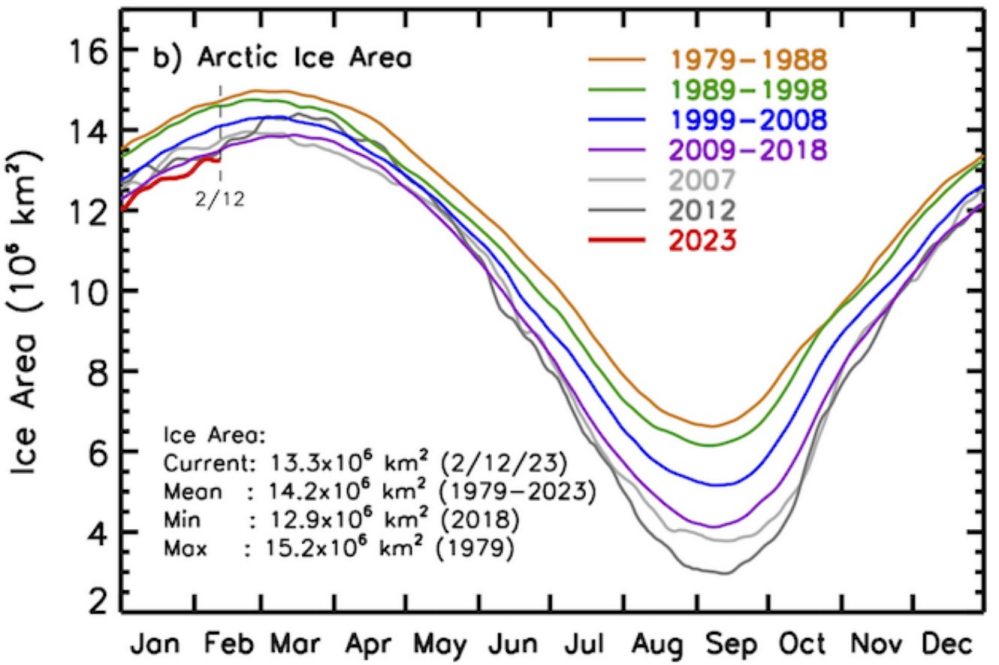
Recent changes in Arctic sea ice

Satellite observations

- Strong decline since 1979
- More pronounced in summer



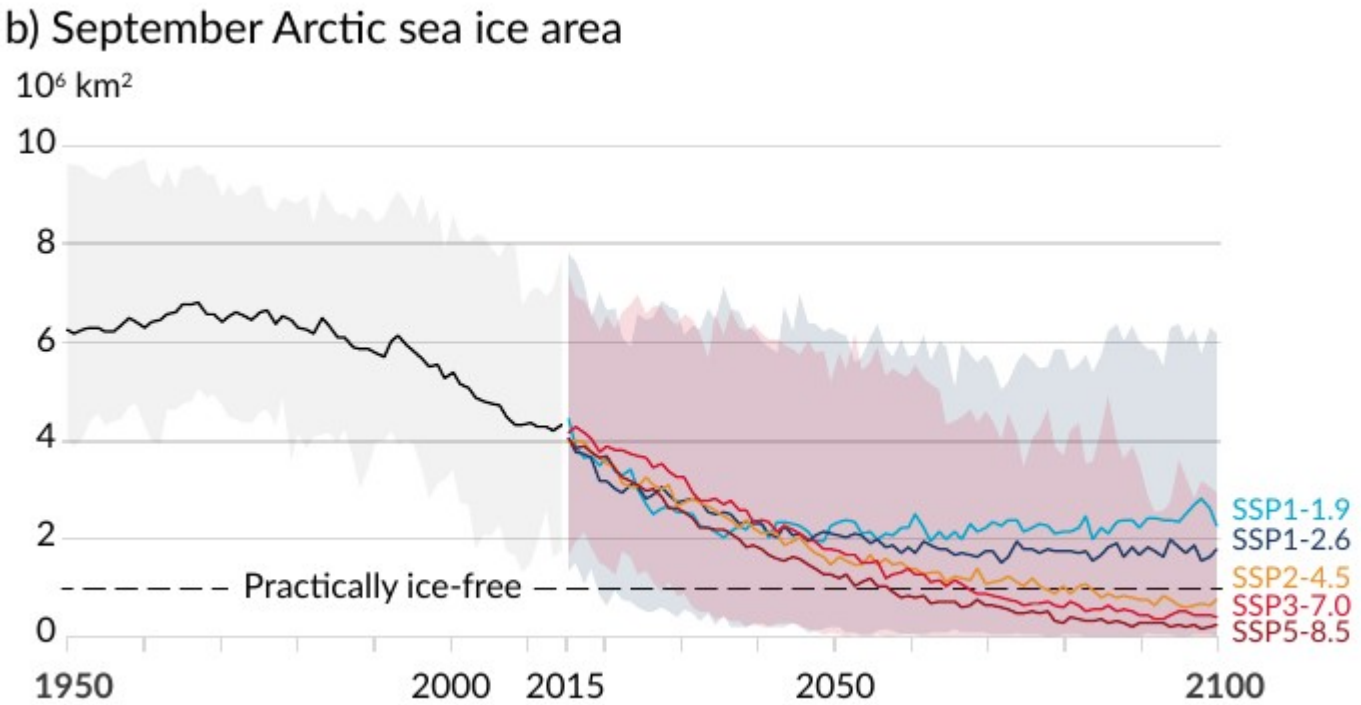
Docquier & Koenigk (2021)



NASA; Comiso et al. (2023)

Future loss of Arctic sea ice

CMIP6 models

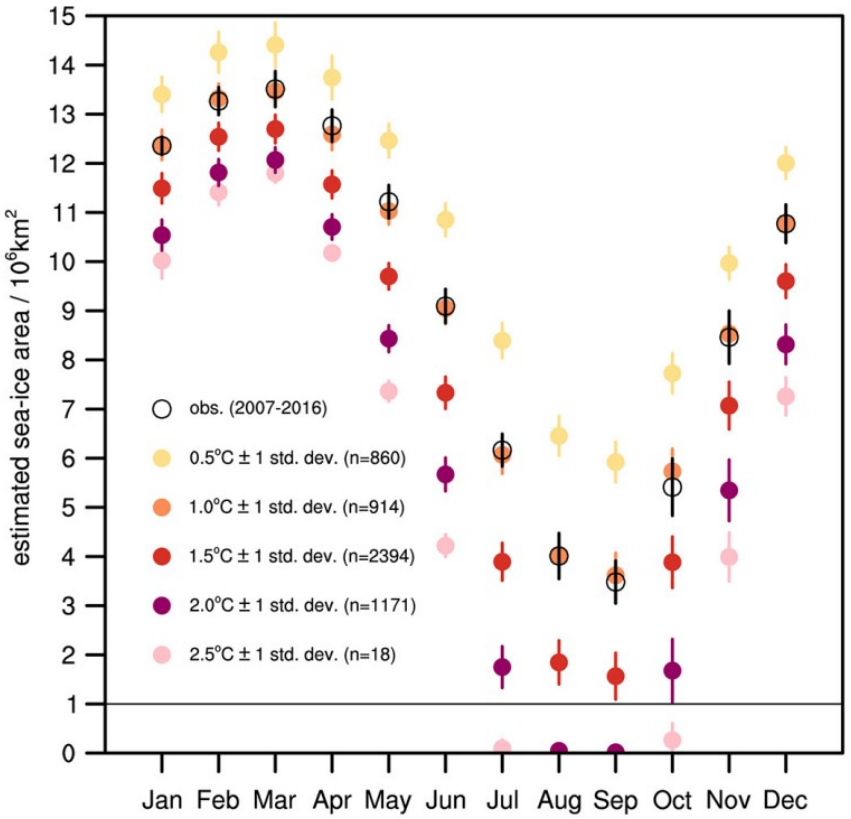


IPCC (2021)

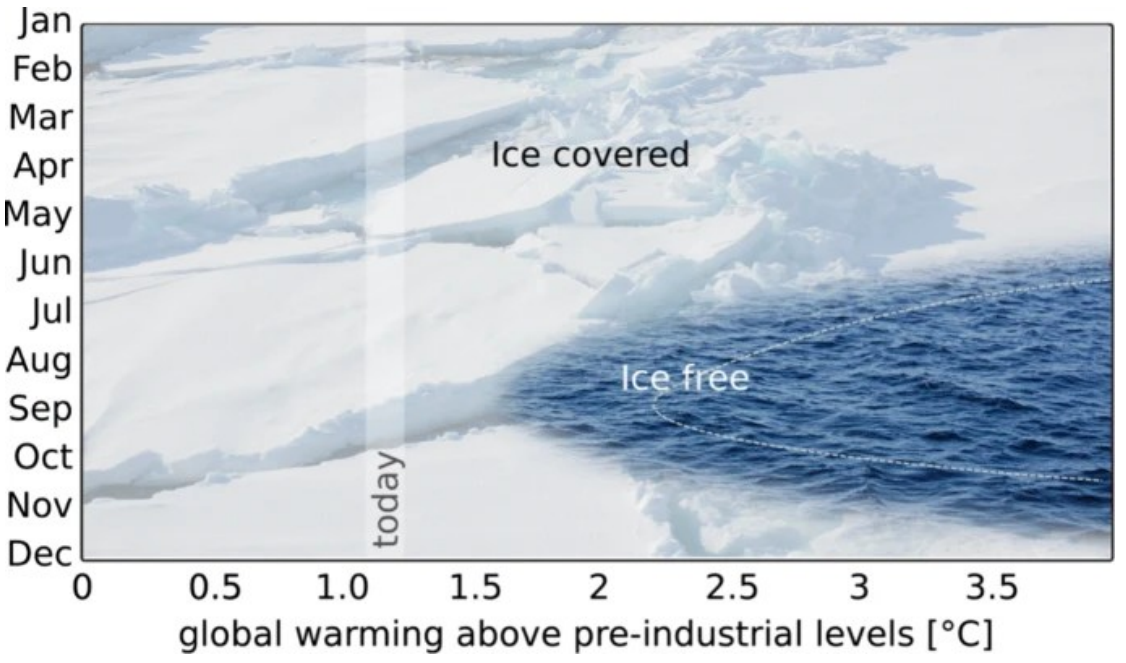
- The Arctic could be almost ice-free in summer at least once before 2050
- Future changes in Arctic sea-ice area strongly depend on the greenhouse gas emission scenario

Future loss of Arctic sea ice

Observational extrapolation



Niederdrenk & Notz (2018)

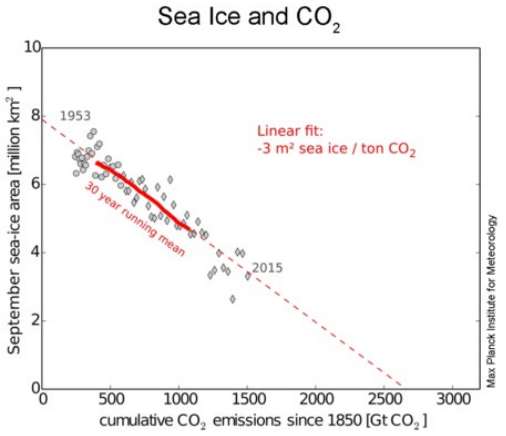


Notz & Stroeve (2018)

Causes of Arctic sea-ice loss

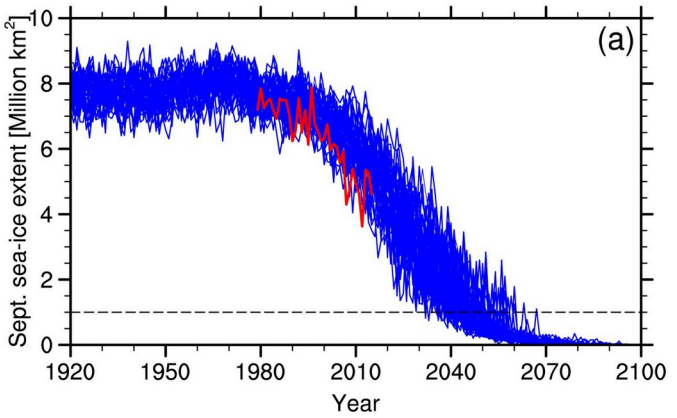
Forcing

1. External forcing



Notz & Stroeve (2016)

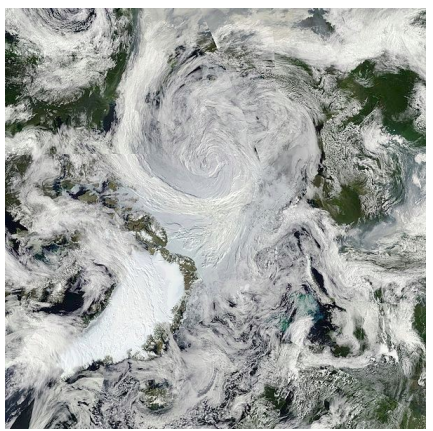
2. Internal variability



Jahn et al. (2016)

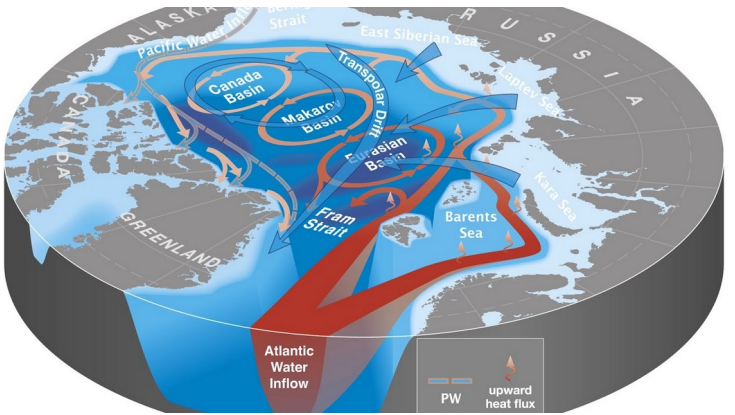
Processes

1. Atmosphere



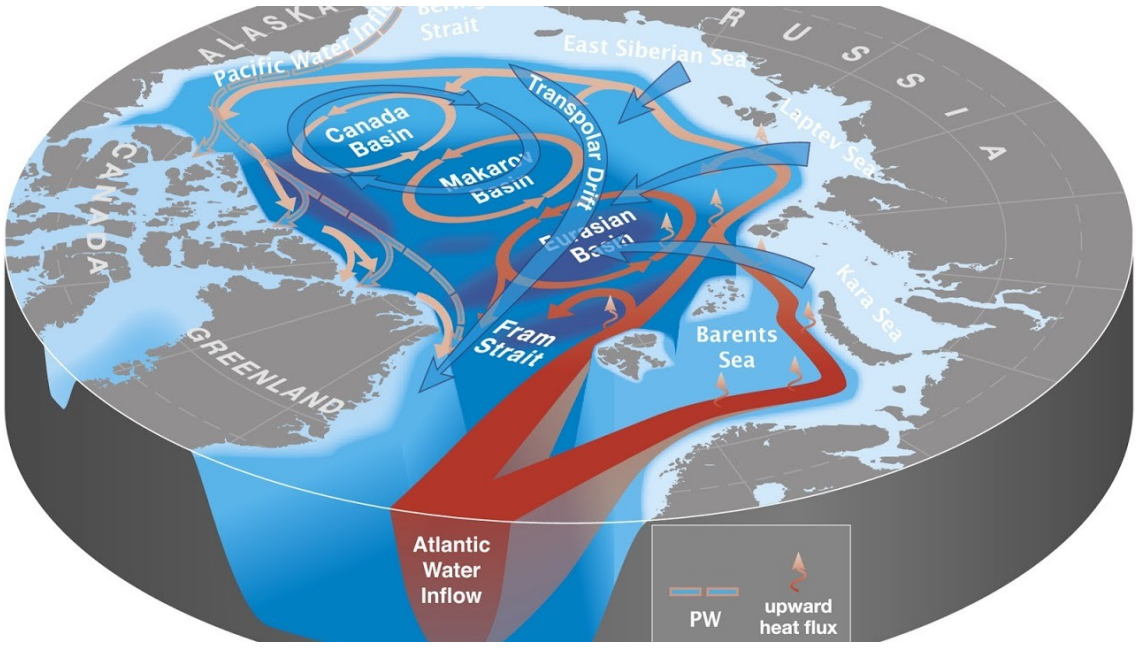
NASA

2. Ocean

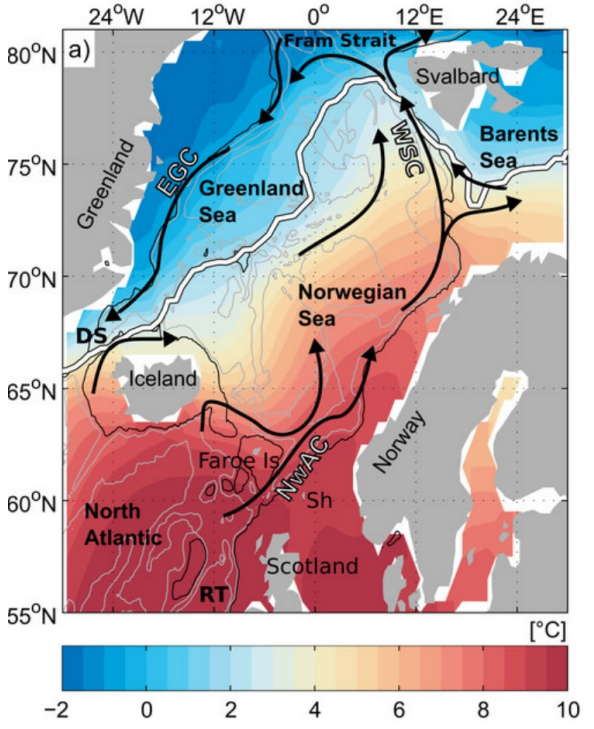


Carmack et al. (2015)

Influence of ocean heat transport on Arctic sea ice



Carmack et al. (2015)

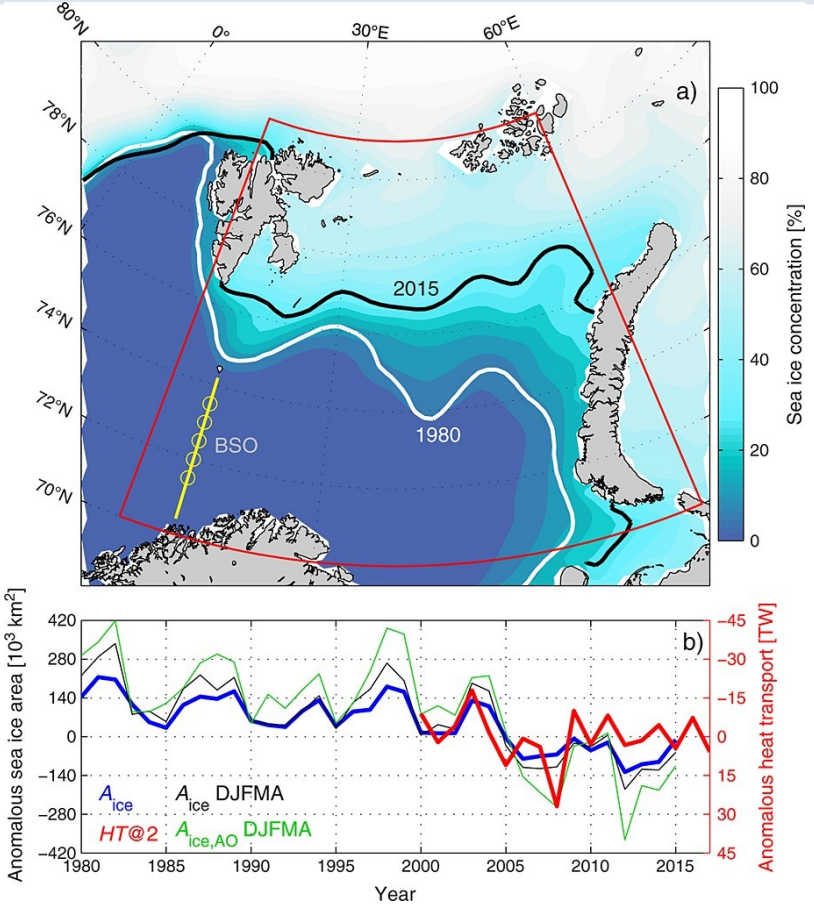


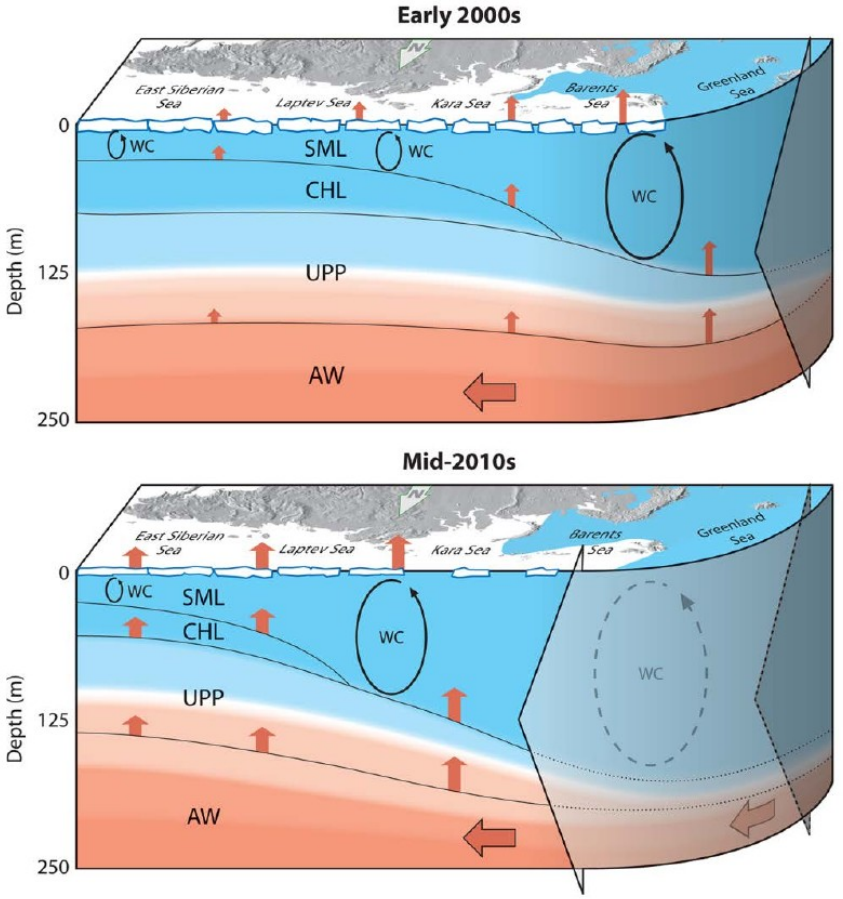
Arthun & Eldevik (2016)

Influence of ocean heat transport on Arctic sea ice

Observations

Onarheim et al. (2015)

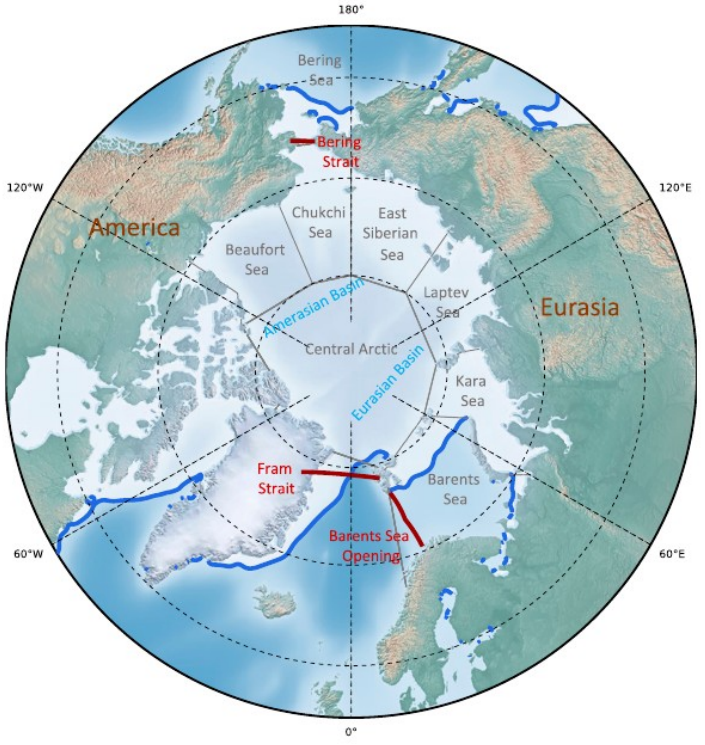




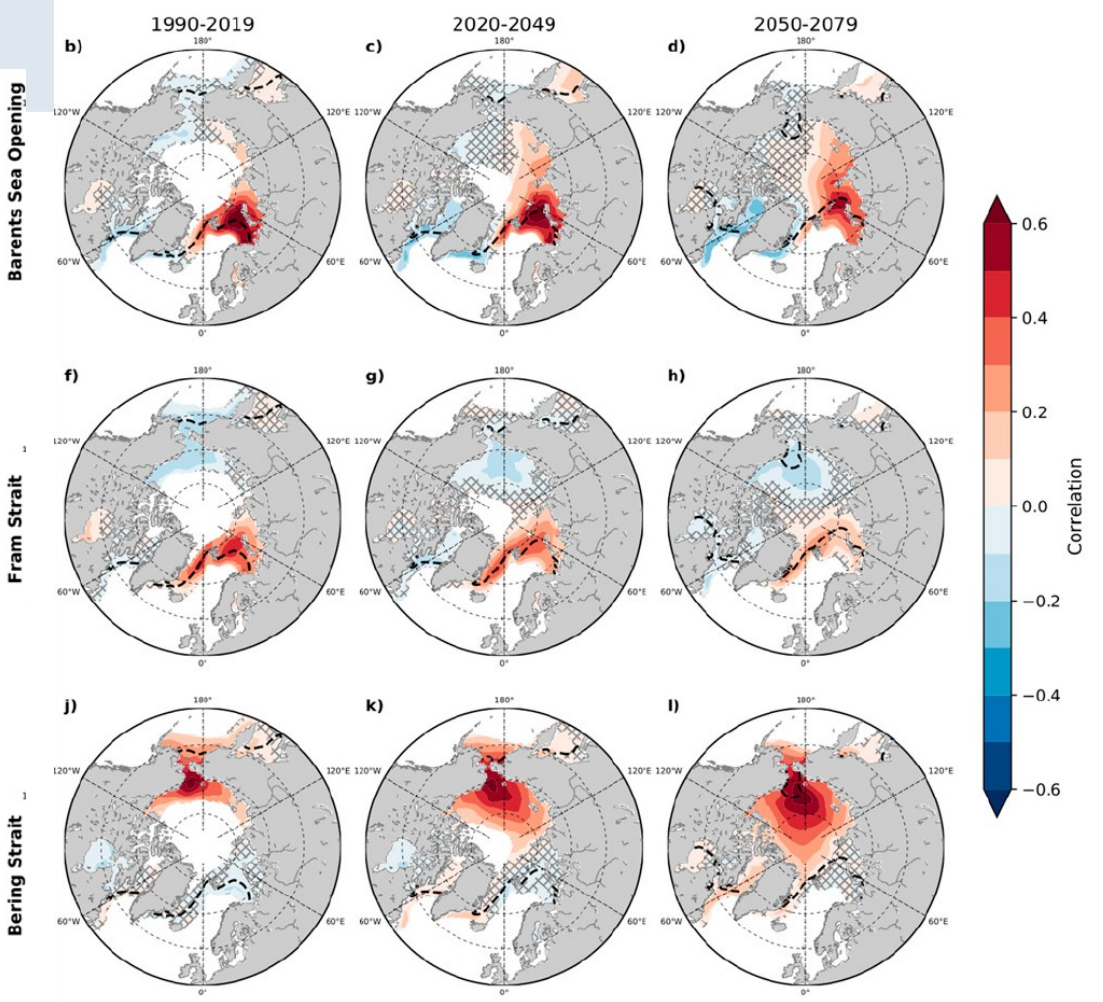
Polyakov et al. (2017)

Influence of ocean heat transport on Arctic sea ice

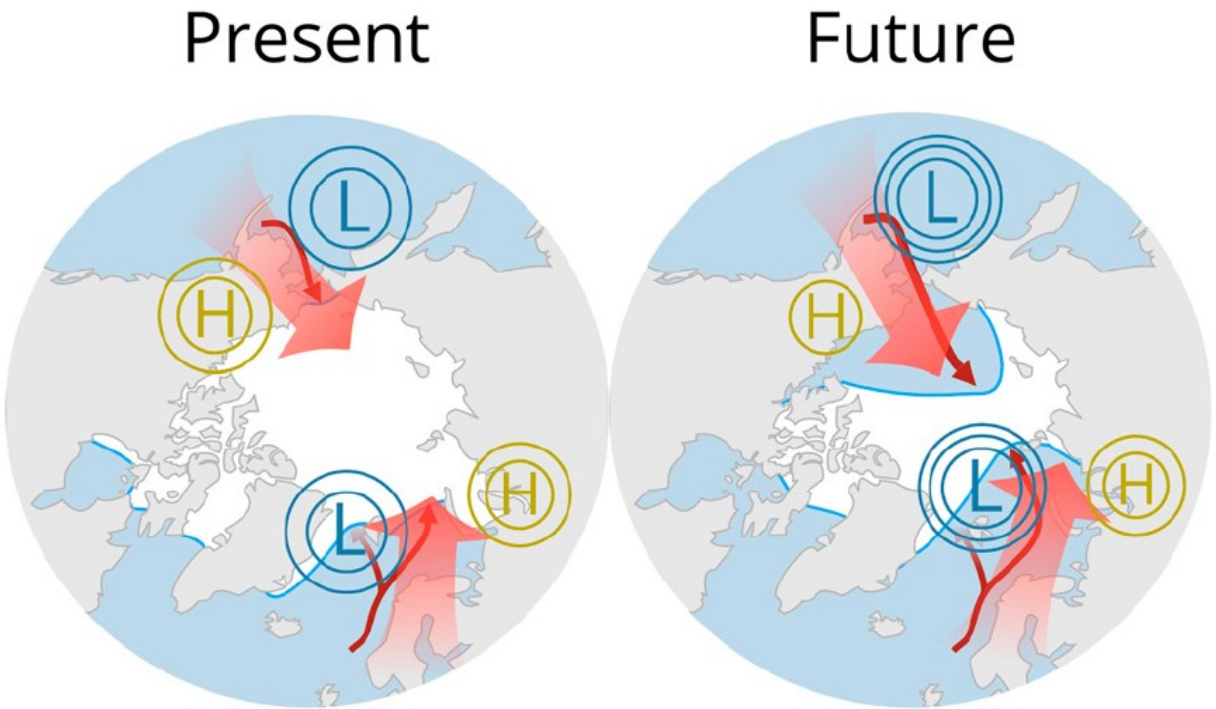
CESM-LE model



Dörr et al. (2021)



Influence of ocean heat transport on Arctic sea ice



CESM-LE model Dörr et al. (2021)

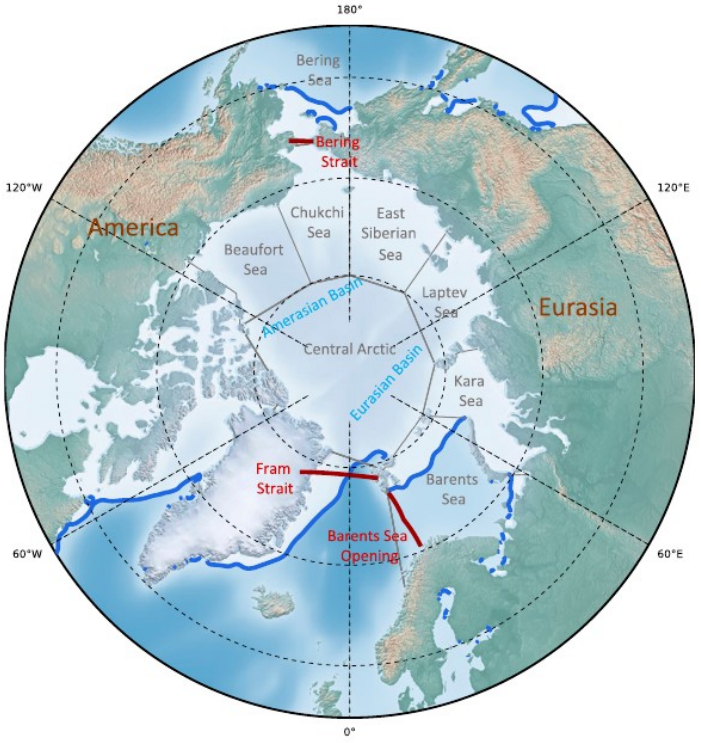
CMIP6 models

Model	max $r(\mathrm{OHT}, \phi_i)$ ϕ_0	r
ACCESS-CM2	58	+0.86
ACCESS-ESM1-5	69	+0.94
CAMS-CSM1-0	65	+0.89
CanESM5	59	+0.88
CanESM5-CanOE	58	+0.91
CESM2	55	+0.73
CESM2-FV2	69	+0.59
CESM2-WACCM	56	+0.55
CESM2-WACCM-FV2	69	+0.82
CNRM-CM6-1-HR	62	+0.98
CNRM-ESM2-1	62	+0.98
HadGEM3-GC31-LL	58	+0.84
HadGEM3-GC31-MM	68	+0.94
IPSL-CM6A-LR	58	+0.94
MPI-ESM-1-2-HAM	50	+0.69
MPI-ESM1-2-HR	70	+0.90
MPI-ESM1-2-LR	51	+0.77
MRI-ESM2-0	69	+0.72
NorCPM1	51	+0.59
UKESM1-0-LL	57	+0.89

Aylmer et al. (2022)

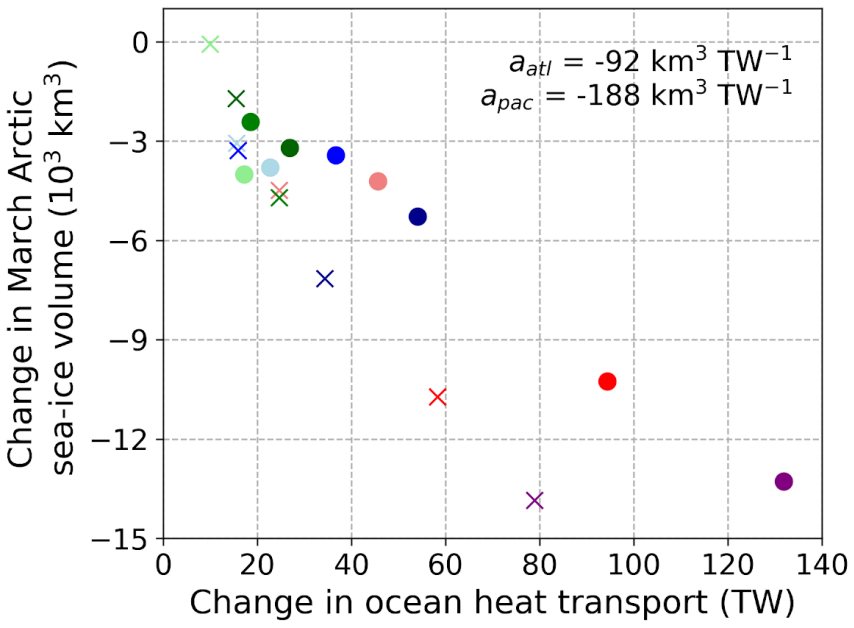
Influence of ocean heat transport on Arctic sea ice

EC-Earth3 model



Dörr et al. (2021)

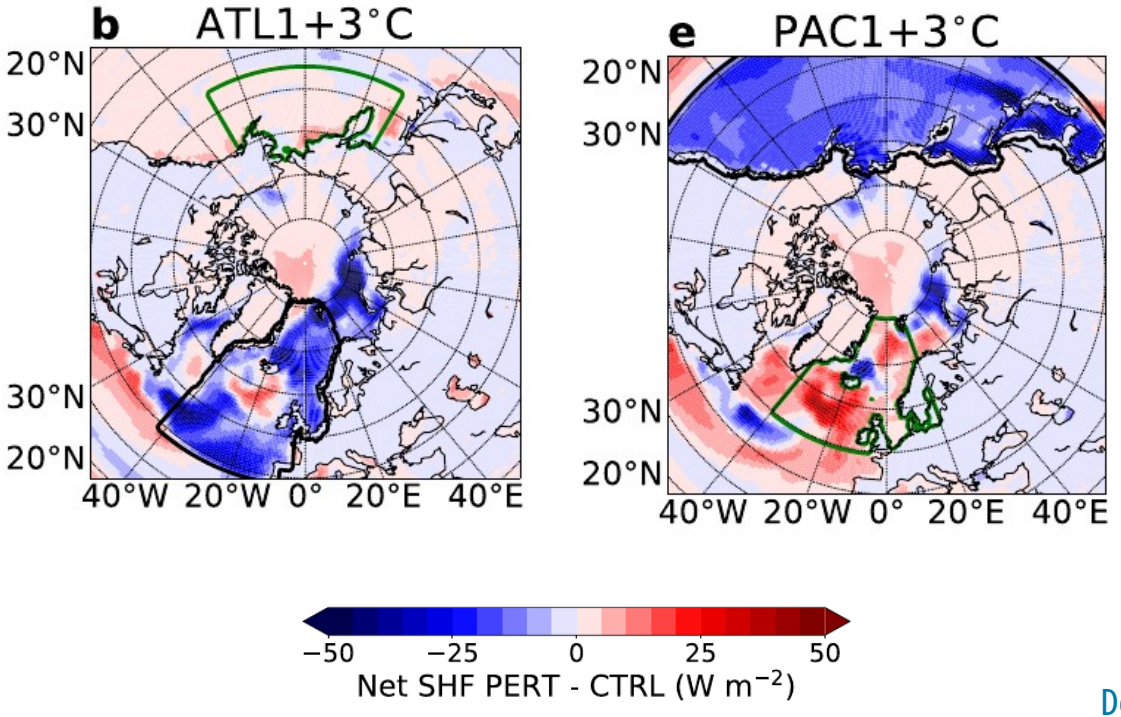
Dots: Atlantic experiments
Crosses: Pacific experiments



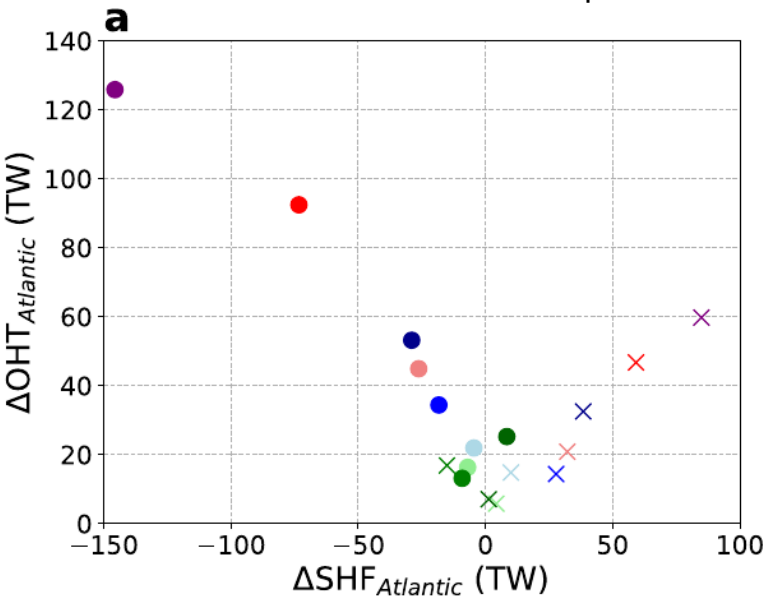
Docquier et al. (2021)

Influence of ocean heat transport on Arctic sea ice

EC-Earth3 model



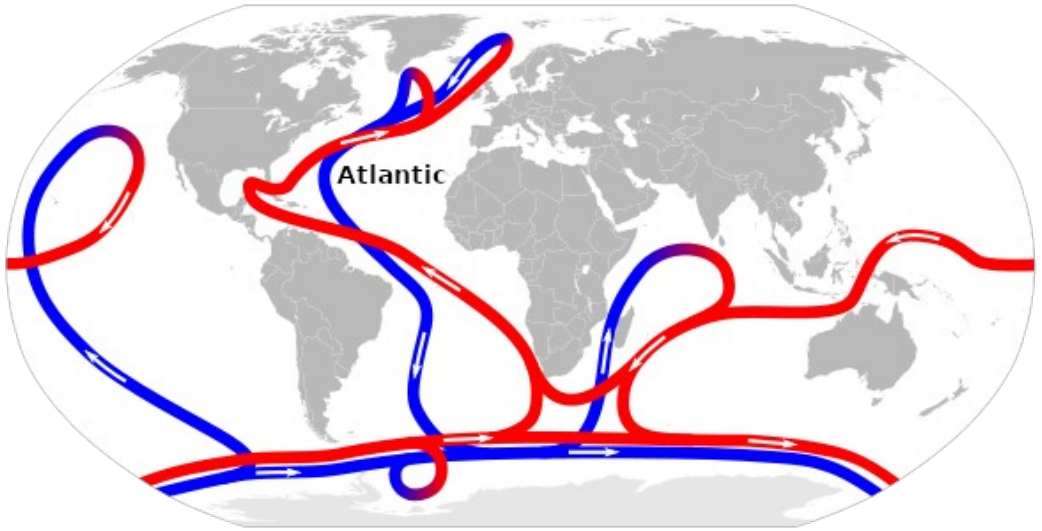
Dots: Atlantic experiments
Crosses: Pacific experiments



Docquier et al. (2021)

Influence of AMOC on Arctic sea ice

CCSM4 model



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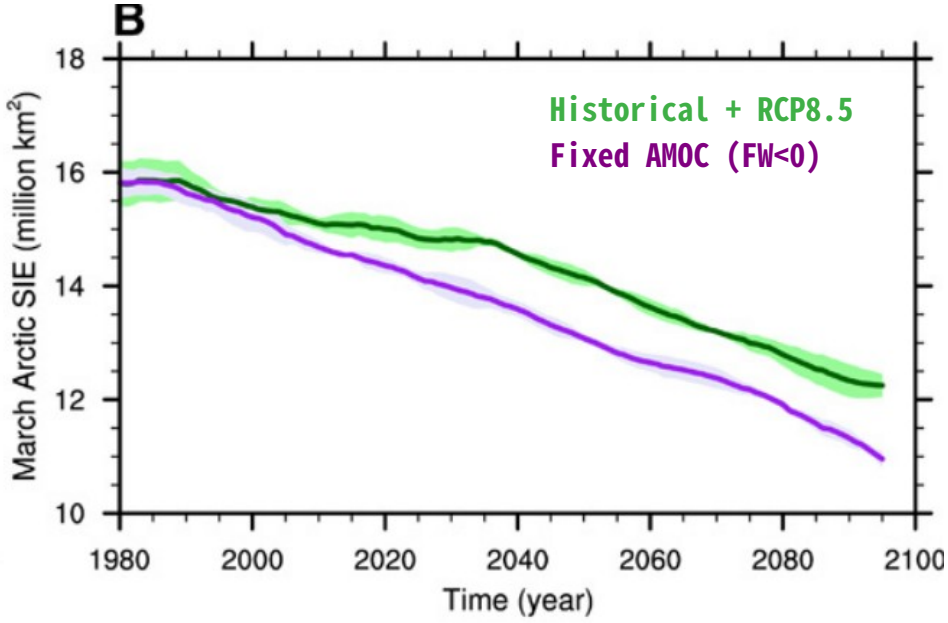
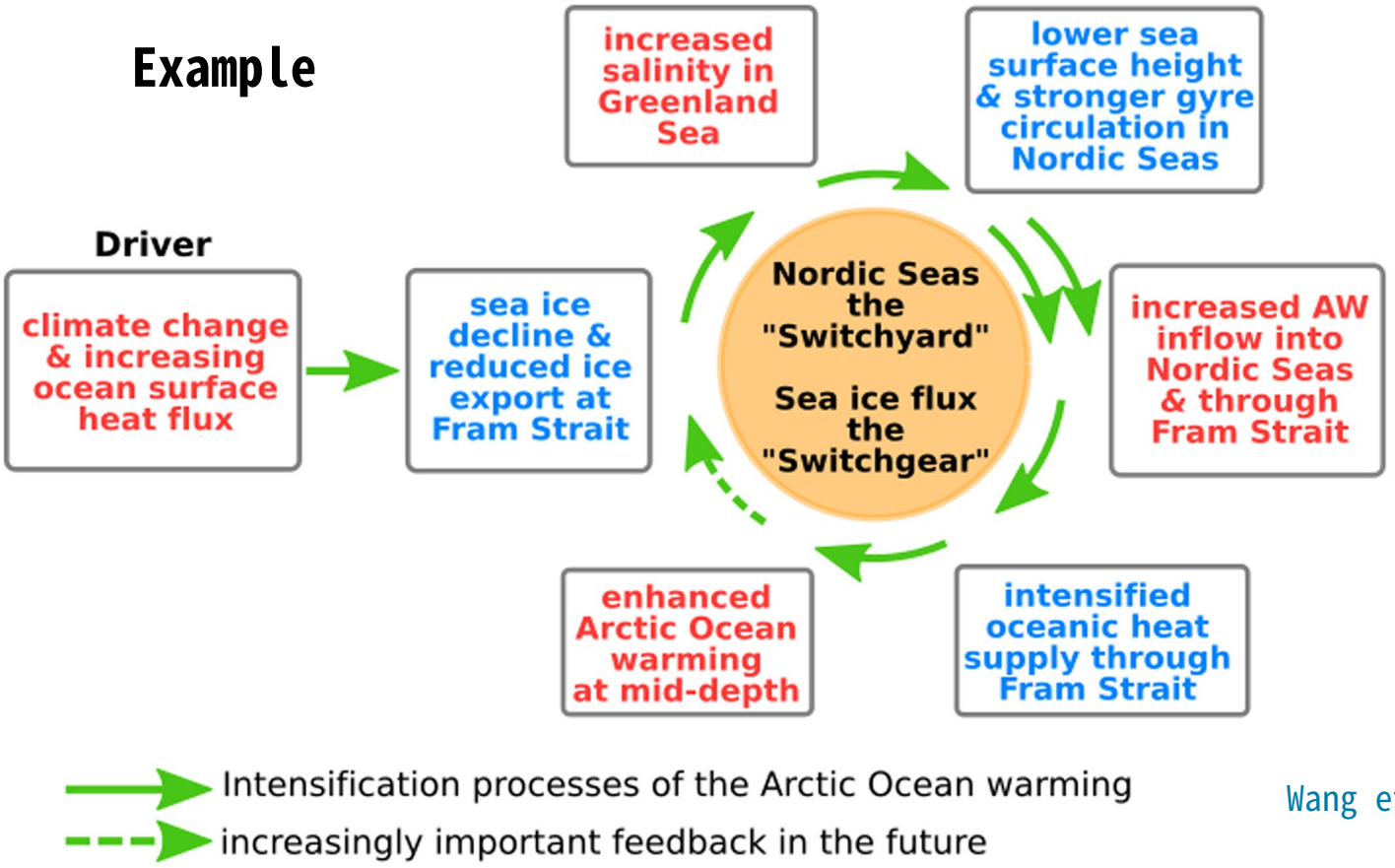


Liu et al. (2020)

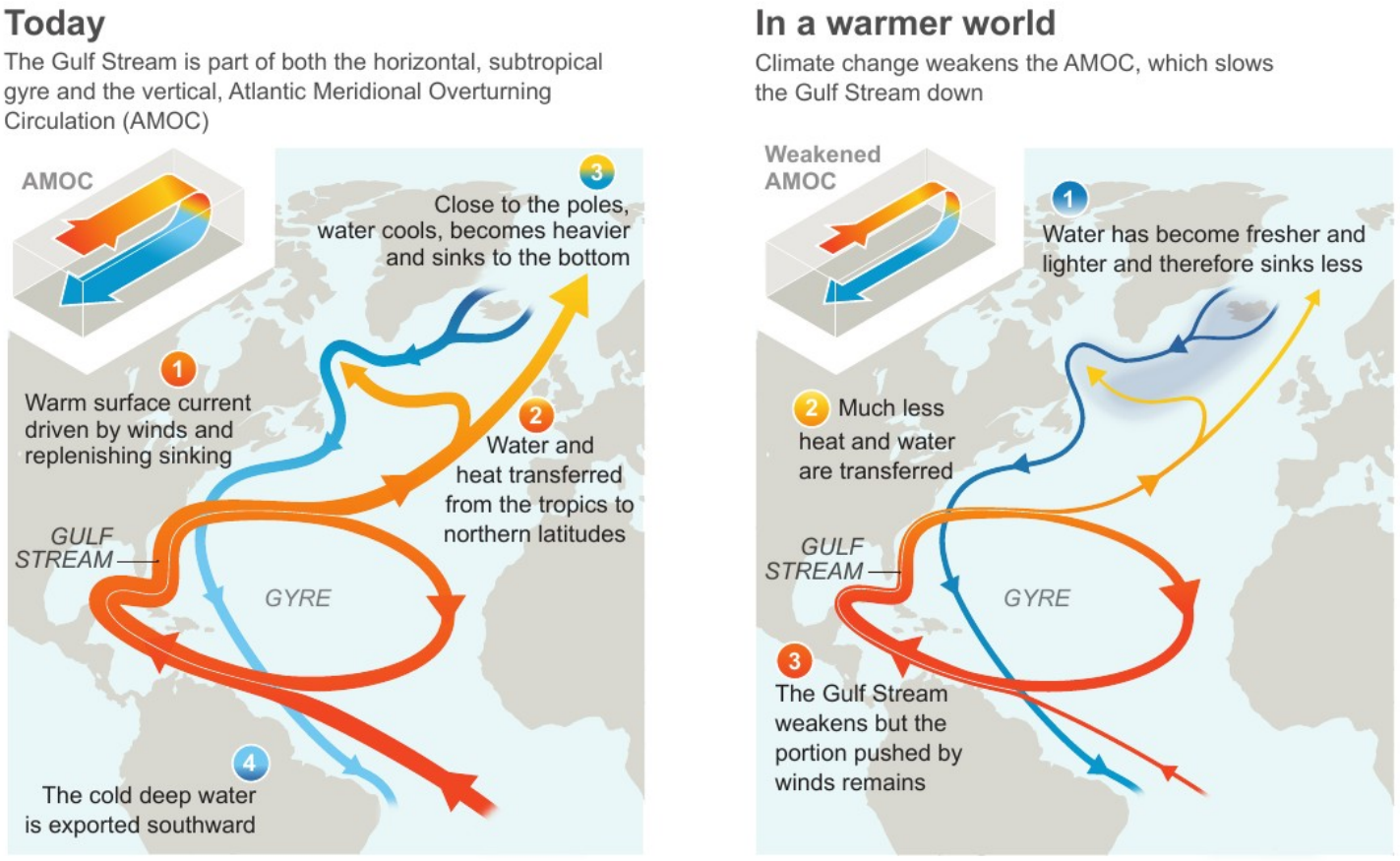
Arctic sea ice also influences the ocean



Wang et al. (2020)

Potential future impact of sea-ice melting:

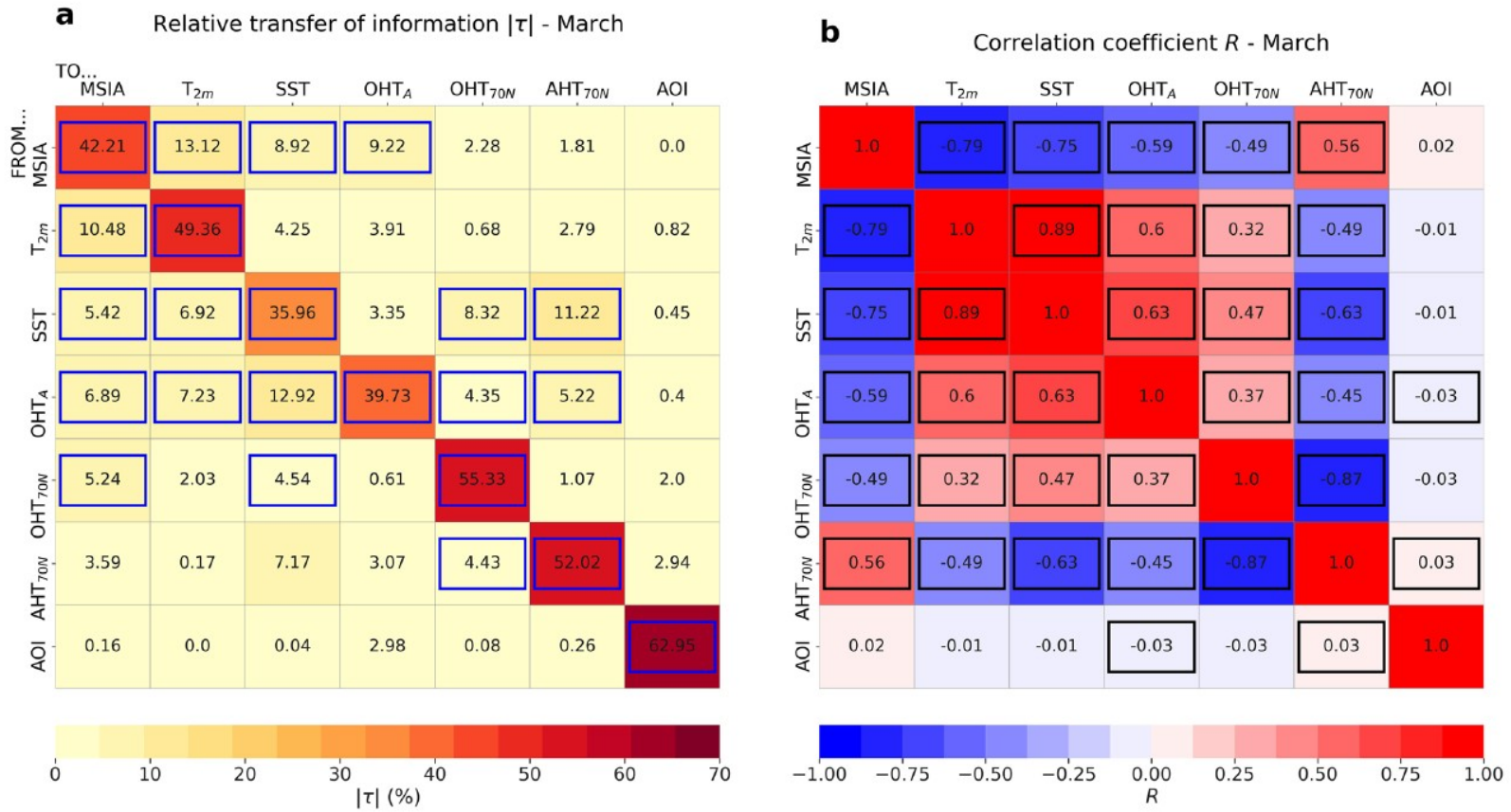
Atlantic Meridional Overturning Circulation (AMOC) weakening



IPCC (2021)

Two-way causal links between Arctic sea ice and ocean/atmosphere variables

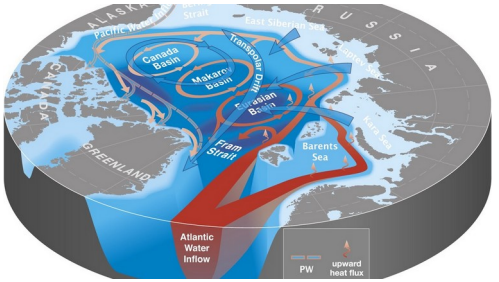
EC-Earth3 model



Docquier et al. (2022)

Examples of research gaps (1)

- Need to **improve observations**
  - Large uncertainties in sea-ice thickness coming from satellites
  - Better understand the pathways of ocean heat entering the Arctic
    → important to monitor under sea ice
    → better quantify risk of large amounts of inflowing warm water to come into contact with Arctic sea ice in the near future



Carmack et al. (2015)

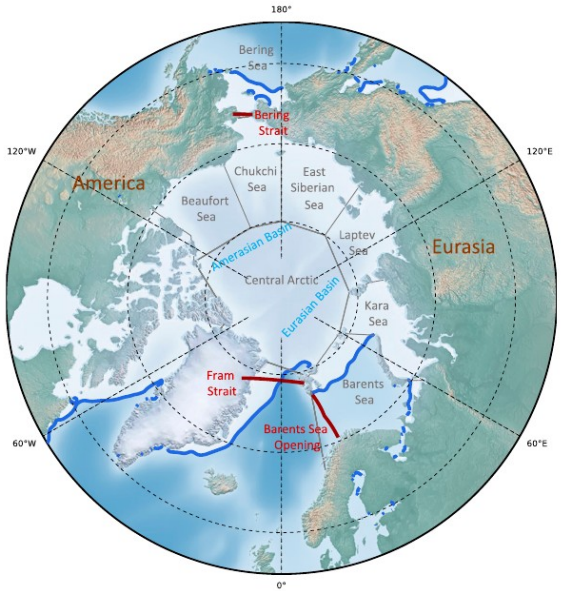
- Need to **improve climate models**
  - More realistic description of ocean current system
  - Finer model resolution
    → gain precision into ocean and sea-ice processes
  - Combination of 3 approaches: multi-model comparison, sensitivity experiments, large model ensemble simulations

DKRZ

Examples of research gaps (2)

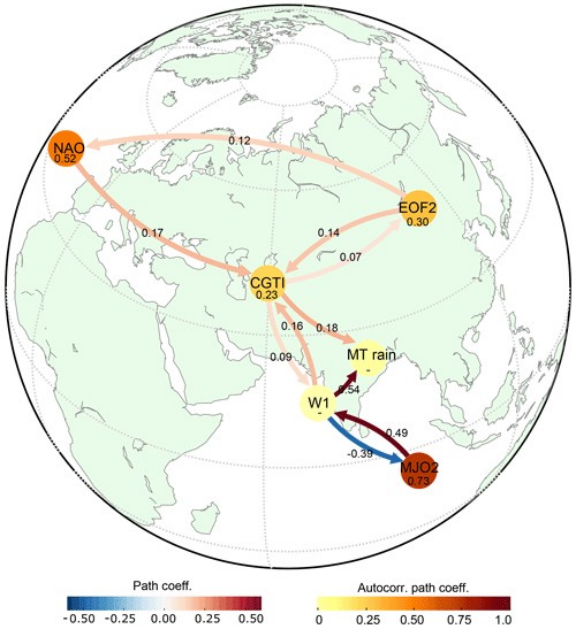
- More **emphasis on regions and processes that are less studied**
  - Pacific side of the Arctic
  - Influence of sea ice on the ocean

Dörr et al. (2021)



- Need to **improve techniques to evaluate and analyze observations and models**
  - e.g. use of causal methods

Di Capua et al. (2020)



Conclusions

- Large decrease in Arctic sea-ice area and volume in the past 40 years, due to both anthropogenic global warming and internal variability → projected to continue in the future
- Major influence of ocean heat transport on Arctic sea ice
- Influence of the AMOC on Arctic sea ice
- Arctic sea ice also influences the ocean
- Causal methods help in identifying causes of recent climate changes
- Need to improve observations, models and techniques to analyze them, as well as focus on less studied regions/processes

Further reading

- **Arctic freshwater**
  - Solomon et al. (2021). Freshwater in the Arctic Ocean 2010-2019. *Ocean Science*.

- **Ocean heat transport – Arctic sea ice**
  - Carmack et al. (2015). Towards quantifying the increasing role of oceanic heat in sea ice loss in the New Arctic. *Bulletin of the American Meteorological Society*.
  - Docquier & Koenigk (2021). A review of interactions between ocean heat transport and Arctic sea ice. *Environmental Research Letters*.
  - Smesdrud et al. (2022). Nordic seas heat loss, Atlantic inflow, and Arctic sea ice cover over the last century. *Reviews of Geophysics*.

- **Ocean circulation – Arctic sea ice**
  - Timmermans & Marshall (2020). Understanding Arctic Ocean circulation: A review of ocean dynamics in a changing climate. *Journal of Geophysical Research Oceans*.
  - Wang & Danilov (2022). A synthesis of the upper Arctic ocean circulation during 2000-2019: Understanding the roles of wind forcing and sea ice decline. *Frontiers in Marine Science*.

- **Arctic Atlantification and Pacification**
  - Polyakov et al. (2020). Borealization of the Arctic Ocean in response to anomalous advection from sub-Arctic seas. *Frontiers in Marine Science*.
  - Ingvaldsen et al. (2021). Physical manifestations and ecological implications of Arctic Atlantification. *Nature Reviews Earth & Environment*.

- **Research Topic** on Sea Ice – Ocean Interactions in *Frontiers in Marine Science*
  - Editors: D. Docquier, L. Ponsoni, A. Simon, A. Piola
  - Manuscript deadline: 15/03/2022