Arctic sea ice and the Atlantic meridional overturning circulation (AMOC) in a warming climate

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Arctic sea ice decline and AMOC weakening

Data from National Snow and Ice Data Center (NSIDC)

(c) 85% EXTENT, 50% EXTENT, 15% EXTENT, NET TOTAL

Sévellec, Fedorov & Liu (2017)
Scientific Questions

• Are the two phenomena of Arctic sea ice decline and AMOC slowdown related (Does Arctic sea ice decline drive a slowdown of the AMOC)?

• If it does drive, what is the physical mechanism?

• With the induced AMOC slowdown, how will Arctic sea ice loss affect will global climate?
  Liu & Fedorov (2019) GRL
Adjoint analysis: AMOC sensitivity to global surface heat and freshwater fluxes

Sévellec, Fedorov & Liu (2017)
CESM1 experiments: forcing Arctic sea ice decline

Arctic sea ice decline drives a slow-down of the AMOC.

Liu, Fedorov & Sévellec (2019)
Mechanisms

Liu, Fedorov & Sévellec (2019)
Climate response to Arctic sea ice loss: a two-time-scale story

Fig. 2 Changes in annual mean (a) surface air temperature (in unit of K) and (b) precipitation (in unit of mm/day) during the first 15 years of the experiment to a 50-year man of the control run.

Note: The extreme increase of the warming hole and globally cold region in (c) and the ITCZ southward shift in (d). Ensemble-mean values are shown.
Changes of energy fluxes at the top of atmosphere (TOA) and surface

(a) $\Delta F_{\text{TOA}}$ (Yr 1-15)
(b) $\Delta F_{\text{SFC}}$ (Yr 1-15)
(c) $\Delta F_{\text{TOA}}$ (Yr 151-200)
(d) $\Delta F_{\text{SFC}}$ (Yr 151-200)
(e) (c)-(a)
(f) (d)-(b)

Fast response

Slow response

Difference

Liu and Fedorov (2019)
Changes in atmospheric energy

Fast response

90°S  |  90°N

-0.03PW

0.07W/m²  0.03W/m²  1.07W/m²

The ITCZ shifts northward

Slow response

90°S  |  90°N

+0.12PW

0.13W/m²  0.35W/m²  1.21W/m²

The ITCZ shifts southward

Liu and Fedorov (2019)
Conclusion

• Sea ice decline warms and freshens the upper Arctic ocean, generating positive buoyancy anomalies that spread to the North Atlantic and weaken the AMOC on multi-decadal timescales.

• Climate response to Arctic sea ice loss is of two time scales. During the first two decades, when atmospheric processes dominate, sea ice decline induces a “bipolar seesaw” pattern in surface temperature and a northward ITCZ shift.

• On multi-decadal and longer timescales, the weakening of the AMOC mediates direct sea-ice impacts and nearly reverses the original response pattern outside the Arctic. The Southern Hemisphere warms, a Warming Hole emerges in the North Atlantic and the ITCZ shifts southward.
Thank you!
Simulated sea ice retreat (spatial pattern)

(a) SIC (NSIDC, 1979-1988)  
(b) SIC (NSIDC, 2005-2014)  
(c) (b)-(a)

Observation

(a) CTRL (ann)  
(b) SW (ann)  
(c) (b)-(a)

Model
Surface buoyancy flux (BF) change

Density Flux

\[ DF = -\alpha \frac{SHF}{C_p} - \rho(0,SST)\beta \frac{SFWF \cdot SSS}{1 - SSS} \]

(a) \( \Delta DF \)
(b) \( \Delta TF \)
(c) \( \Delta SF \)

+ BF (- DF, blue): make surface water lighter, more buoyant
- BF (+ DF, red): make surface water heavier, less buoyant
From the Arctic to the North Atlantic

March mixed layer depth (MLD)
Deep late winter-time MLD indicates the formation area of North Atlantic Deep Water (NADW) -> AMOC strength
Propagation of T & S signals (I)
Propagation of T & S signals (II)
Changes in Atmospheric temperature and Hadley cell

(a) $\Delta T$ (Yr 1-15)

(b) $\Delta T$ (Yr 151-200)

(a) $\Delta \Psi_A$ (Yr 1-15)

(b) $\Delta \Psi_A$ (Yr 151-200)