Regime Shift in Arctic Ocean Sea-Ice Extent

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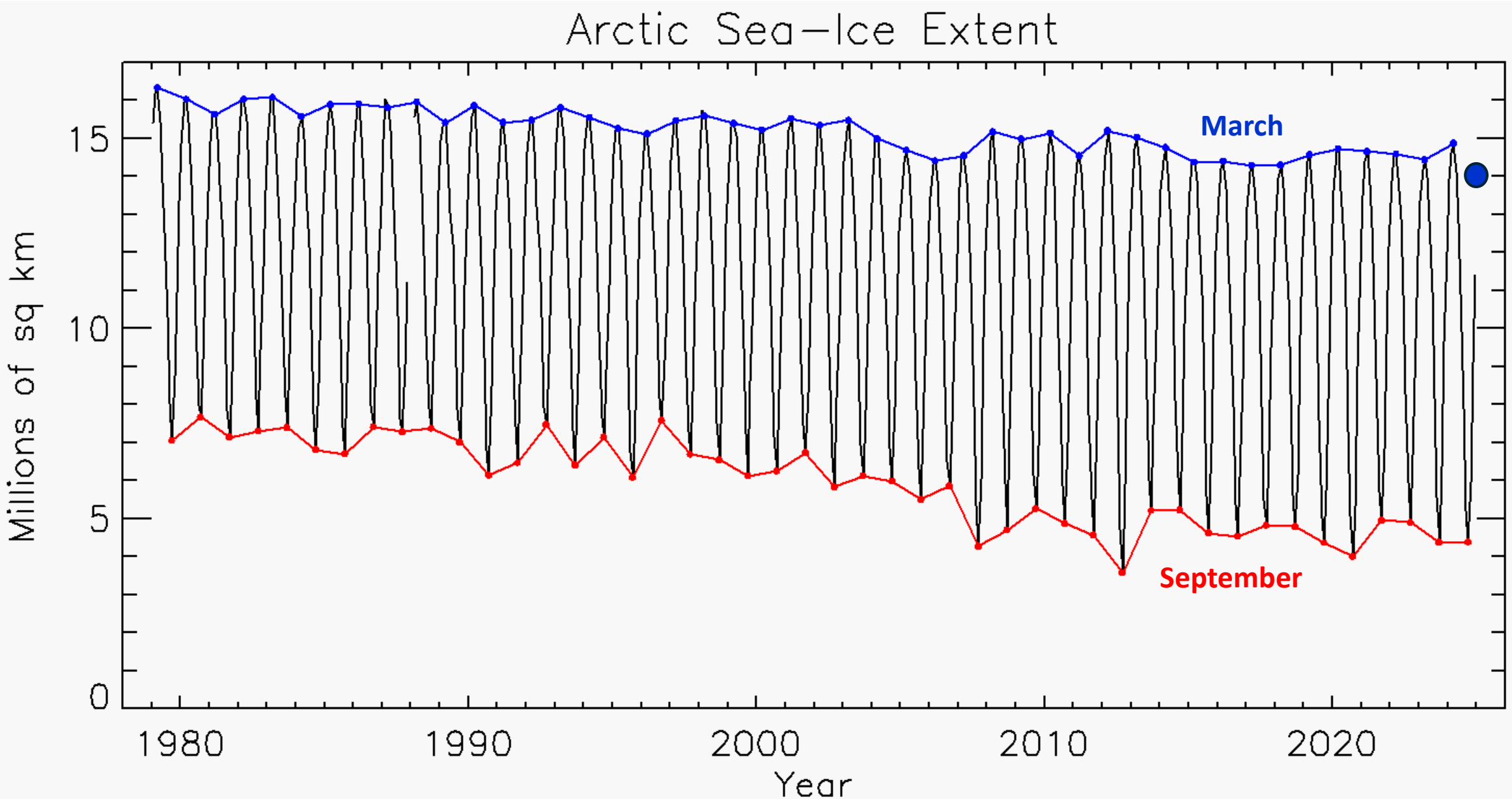
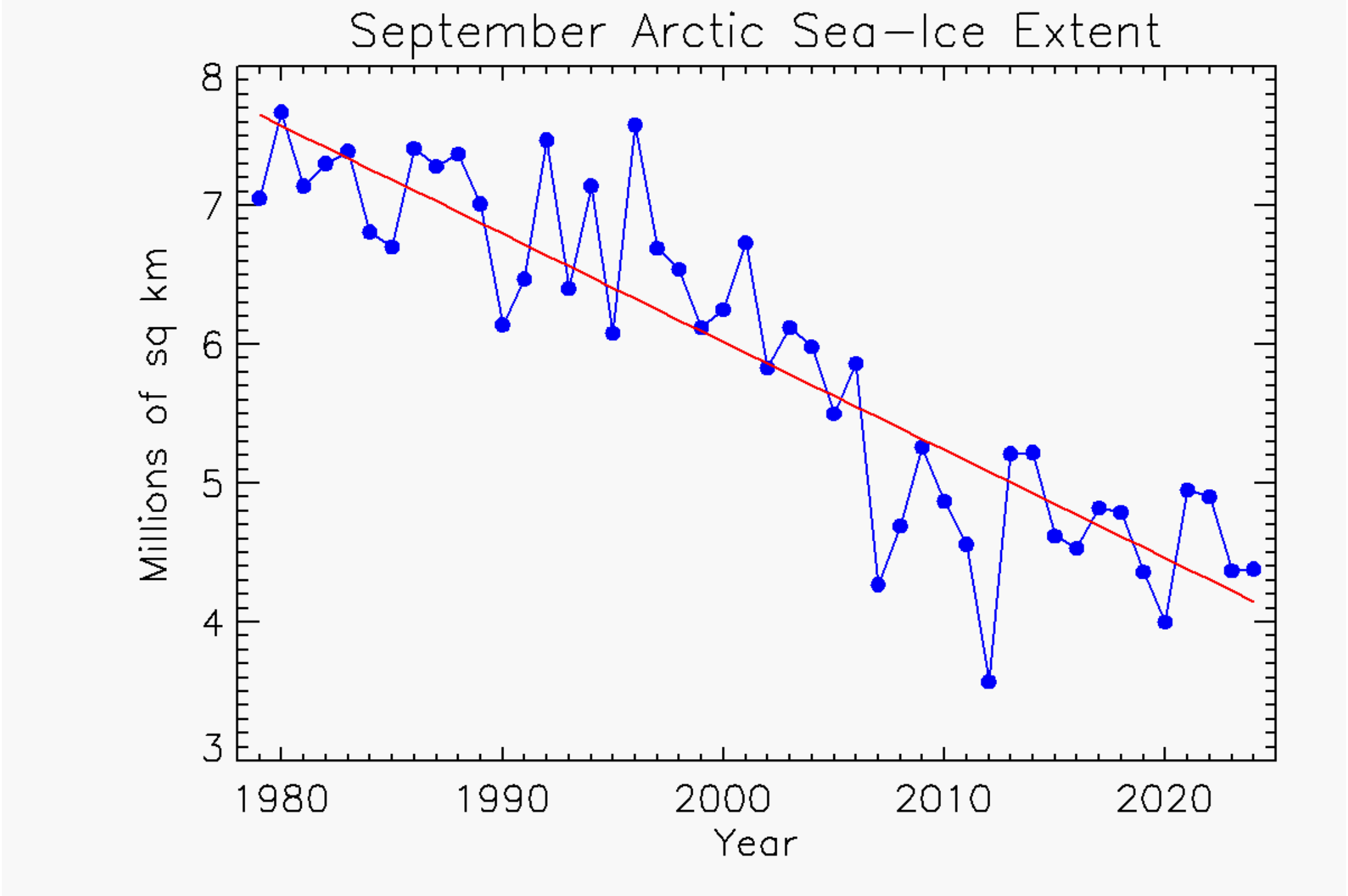
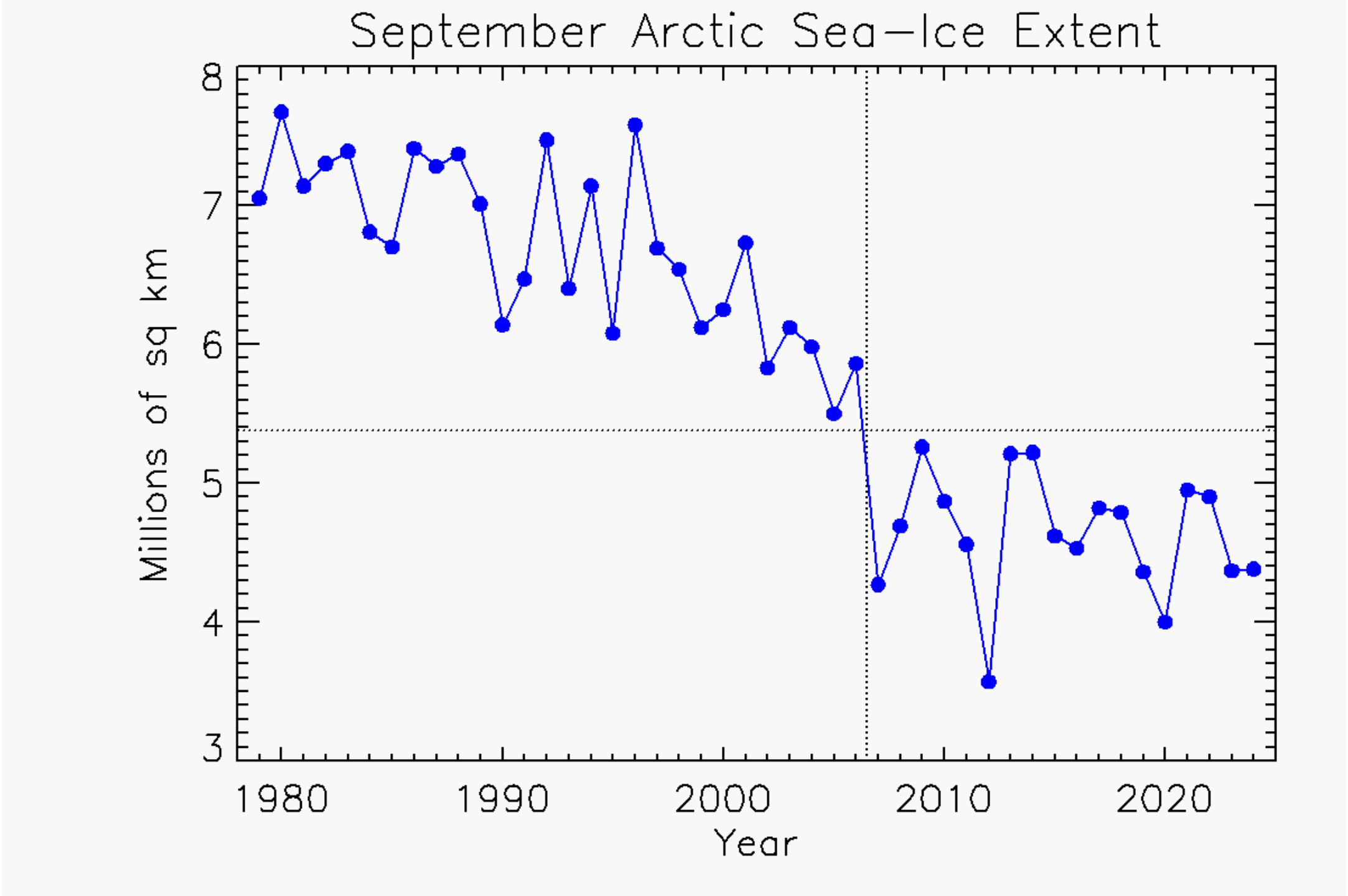
Geophysical Research Letters, in press

A **regime shift** is an abrupt, substantial, and persistent change in the state of a system (Reid et al., *Global Change Biology*, 2015)


Arctic Sea–Ice Extent
Millions of sq km
0
5
10
15
1980
1990
2000
2010
2020
Year
March
September


September Arctic Sea–Ice Extent
Millions of sq km
8
7
6
5
4
3
1980
1990
2000
2010
2020
Year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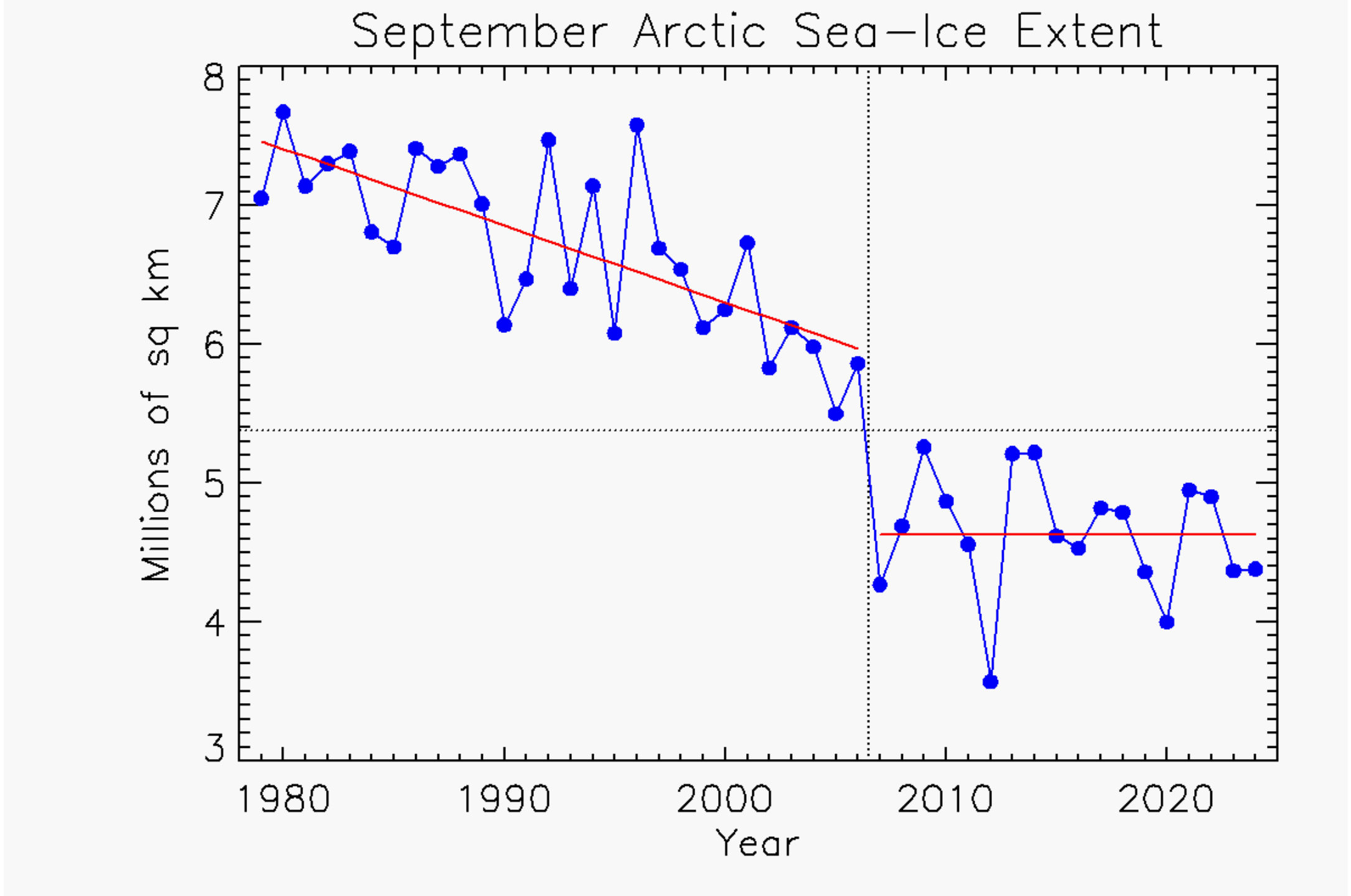
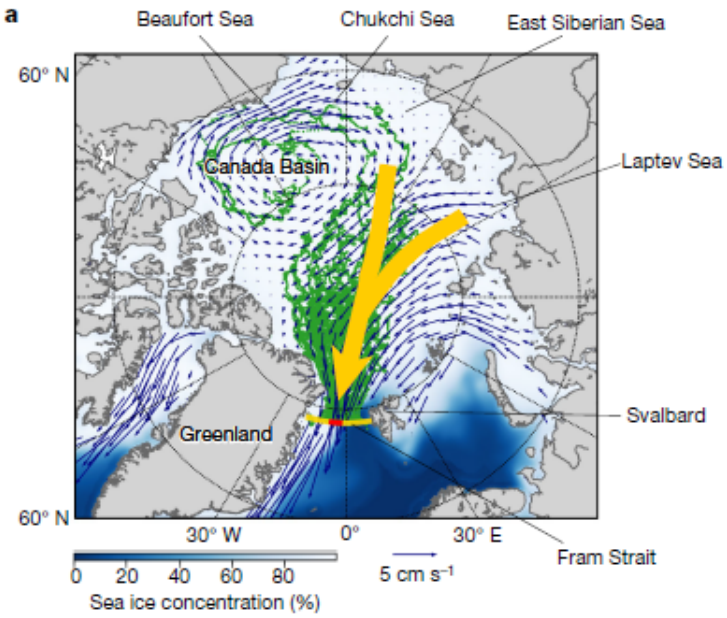
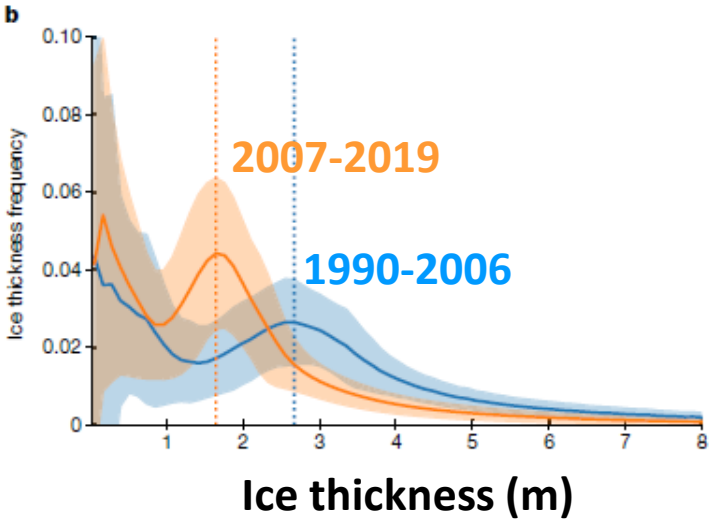
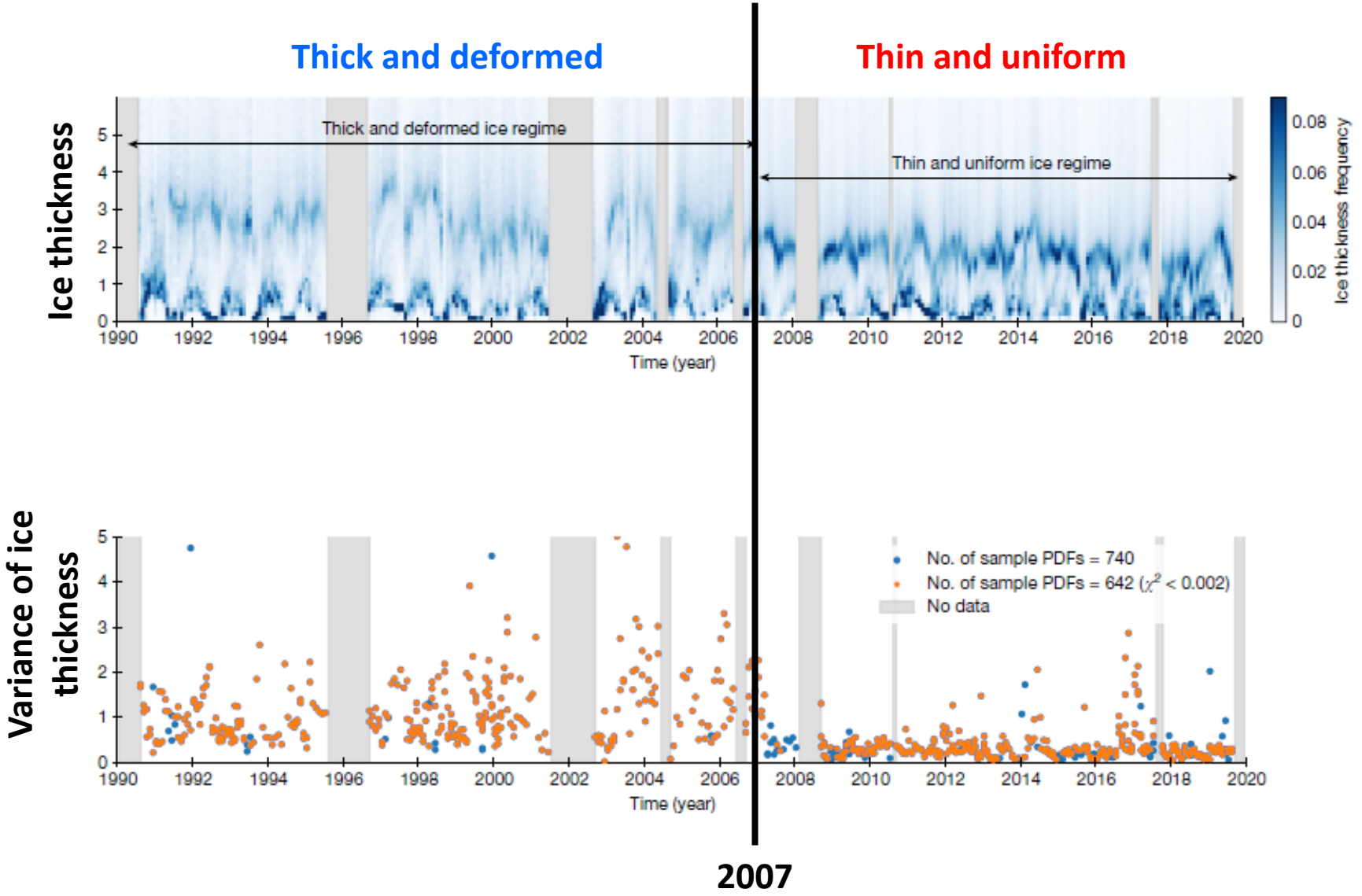

September Arctic Sea-Ice Extent
Millions of sq km
8
7
6
5
4
3
1980
1990
2000
2010
2020
Year

Regime shift in Arctic Ocean sea ice thickness

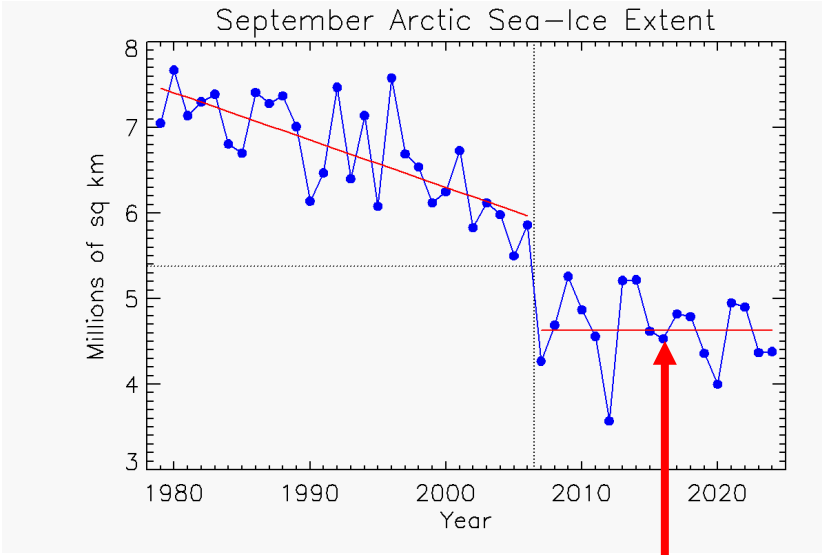
Hiroshi Sumata, Laura de Steur, et al. (2023), *Nature*



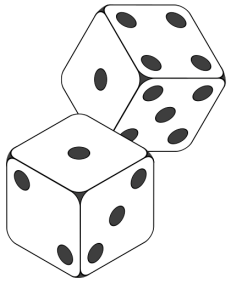




Why has there been no trend in September Arctic sea-ice extent since 2007?



1. Random variability



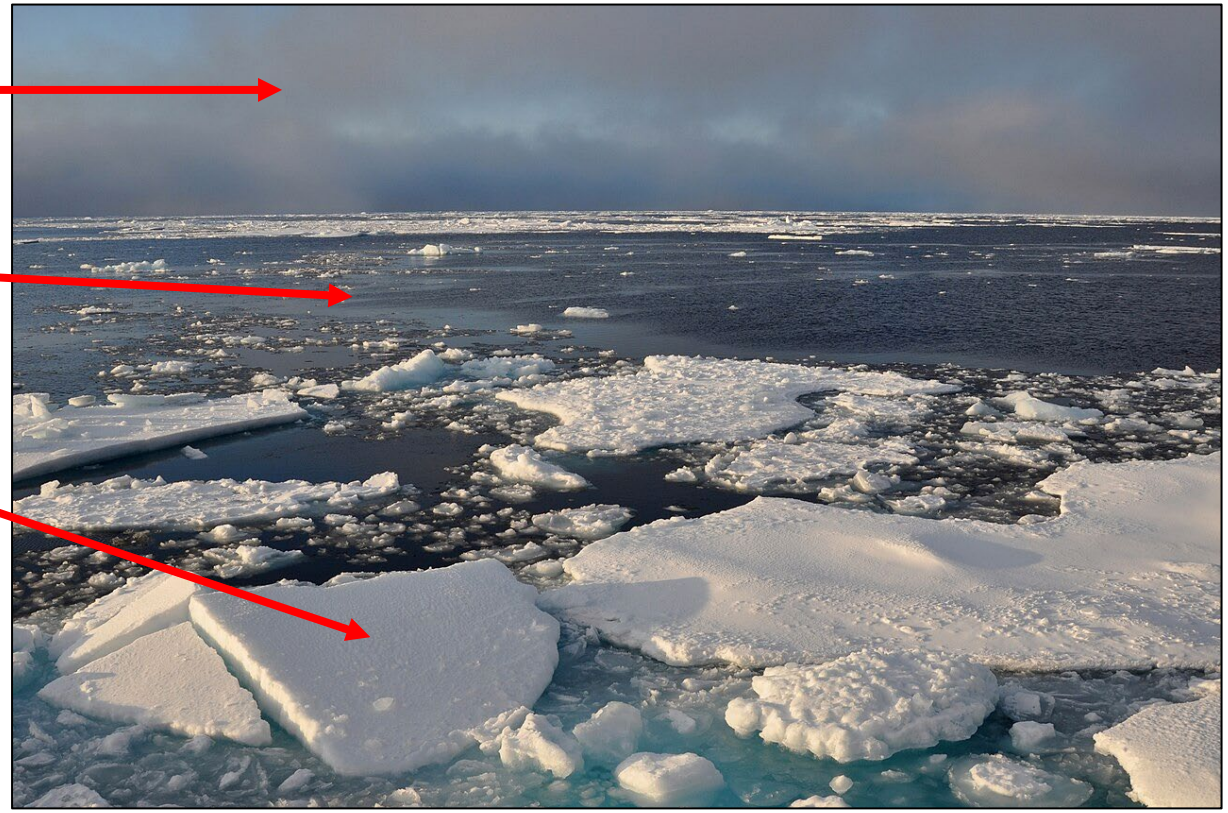
2. Physical processes in the:

Atmosphere

Ocean

Sea ice

and feedbacks between them



no trend

By Patrick Kelley - https://www.flickr.com/photos/usgeologicalsurvey/4370267907/in/set-72157623467470824

Random variability

Baxter et al (2019). How tropical Pacific surface cooling contributed to accelerated sea ice melt from 2007 to 2012 as ice is thinned by anthropogenic forcing
Journal of Climate

"observational and model evidence shows that the changes in summer sea ice since the 2000s reflect a continuous anthropogenically forced melting masked by **interdecadal variability of Arctic atmospheric circulation**" which "has contributed to … slower declines in recent years, **resulting in the appearance of a slowdown over the past 11 years**."

England et al (2025). Surprising, but not unexpected, multi-decadal pause in Arctic sea ice loss
Submitted to *Geophysical Research Letters*

- Climate models from CMIP5 and CMIP6 simulate such pauses relatively frequently (about a 20% chance).
- Therefore, we can't rule out random internal variability in the climate system.
- The pause may plausibly continue for 5 to 10 more years.

Atmosphere

Francis and Wu (2020). Why has no new record-minimum Arctic sea-ice extent occurred since September 2012? *Environmental Research Letters*

Early spring snowmelt across high-latitude land areas → abrupt atmospheric shift in late summer →
low sea-level pressure and reduced transport of sea ice through Fram Strait → slowdown in loss of sea ice.

Blanchard-Wrigglesworth et al (2025). Increasing boreal fires reduce future global warming and sea ice loss *Preprint*

More forest fires → more aerosols in the atmosphere → more scattering of incoming solar radiation →
reduced warming → reduced sea-ice loss.

CMIP6 models used future boreal emission scenarios with unrealistic near-zero trends.
Based on observed boreal emission trends, Arctic warming and sea-ice loss are reduced.

Ocean

Yeager et al (2015). Predicted slowdown in the rate of Atlantic sea ice loss
Geophysical Research Letters

- Skillful predictions of decadal trends in Arctic winter sea ice extent are possible, esp. in the Atlantic sector.
- The accuracy is greatly enhanced by more realistic representation of **ocean heat transport anomalies**.
- Recent forecasts indicate that a spin-down of the thermohaline circulation that began near the turn of the century will continue, and this will result in **near-neutral decadal trends in Atlantic winter sea ice extent in the coming years**.

Lee and Liu (2023). Weakened Atlantic Meridional Overturning Circulation Diminishes Recent Arctic Sea Ice Loss
Geophysical Research Letters

Weakened AMOC → decelerates ocean circulation → reduces northward Atlantic heat transport →
less basal melting of sea ice → less sea-ice loss

Atmosphere / Ocean

Polyakov et al (2023). Fluctuating Atlantic inflows modulate Arctic atlantification
Science

- Explicitly recognized the regime shift in September Arctic sea-ice extent in 2007.
- Positive "Arctic Dipole" (2nd mode of SLP) → transfer of freshwater from Siberian shelves to Amerasian Basin → increased stratification in the ocean → suppressed upward heat flux → sea ice grows thicker.
- These conditions were maintained by the persistence of +AD during 2007-2021.

Arctic Oscillation (AO)

- In the past decade, winter +AO has set up cyclonic circulation in the Arctic Ocean (**Morison et al, 2021**)
- In the 1980s, winter +AO drove sea-ice loss (**Rigor et al, 2002**)
- But the connection between +AO and sea-ice loss weakened in the 2000s (**Rigor and Wallace, 2004**)
- Maybe the persistence of the present cyclonic mode is contributing to the steady state of Sept sea-ice extent

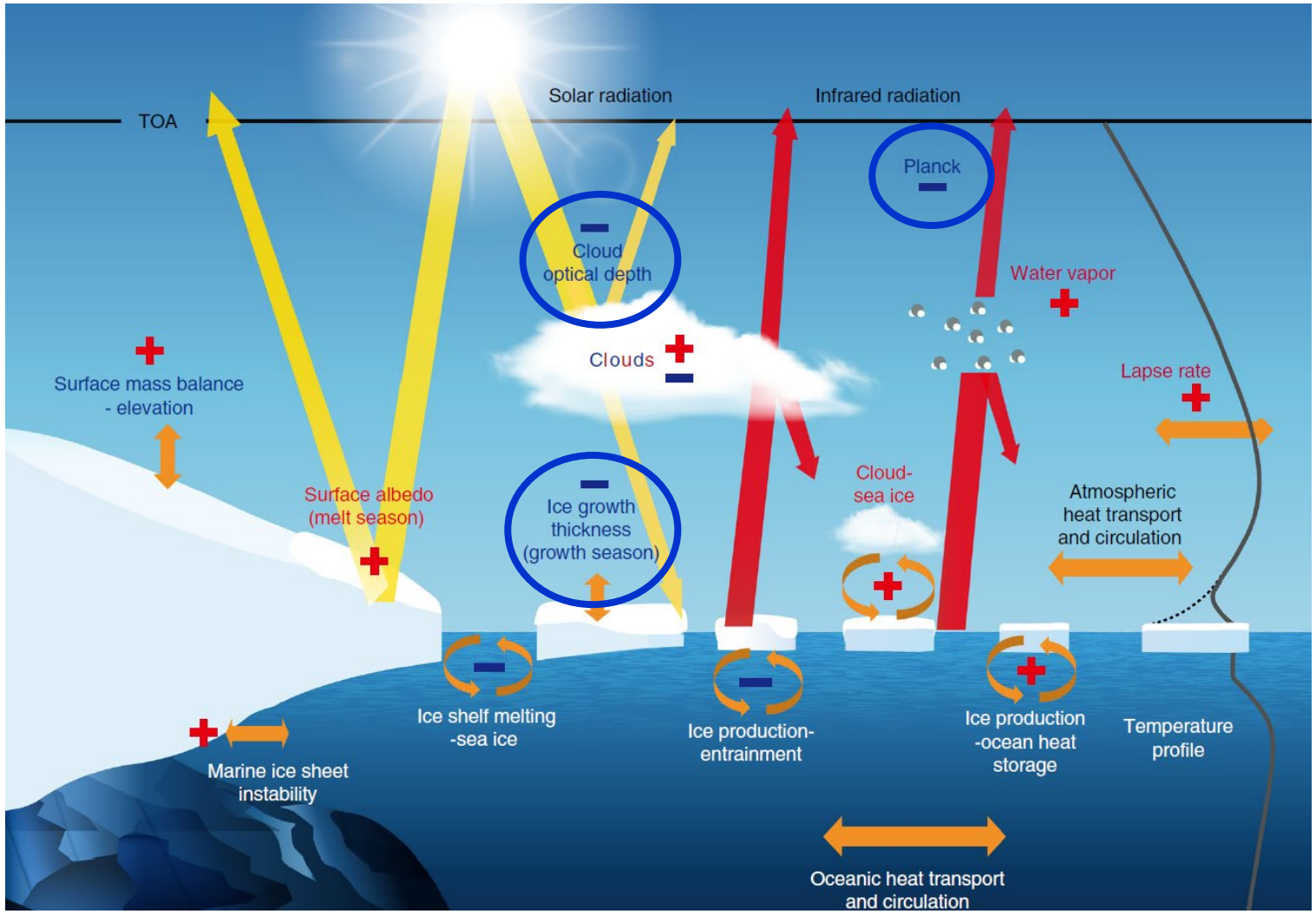
Sea Ice

Zhang (2021). Recent Slowdown in the Decline of Arctic Sea Ice Volume
Geophysical Research Letters

The decline of Arctic sea ice volume (SIV) slowed down during 2007–2020

- Strong decrease in ice export
- But only a weak decrease in net ice production because:
  * Thinner ice grows faster than thicker ice **(Bitz and Roe, 2004)**
  * Thinner ice diverges more easily → more open water created in the ice pack → more ice production

Feedbacks



Lindsay and Zhang (2005) framework:

- Pre-conditioning thins the sea ice
- Trigger (AO) flushes out thick ice
- Ice-albedo feedback amplifies shift

But since the regime shift in 2007, could the ice-albedo feedback be neutralized by negative feedbacks?

"A lasting impact of the ice-albedo feedback is not possible because the large-scale heat fluxes quickly adapt to release the excess oceanic heat from the Arctic." (Tietsche et al, 2011, *Geophysical Research Letters*).

Goosse et al. (2018). Quantifying Climate Feedbacks in the Polar Regions, *Nature Communications*

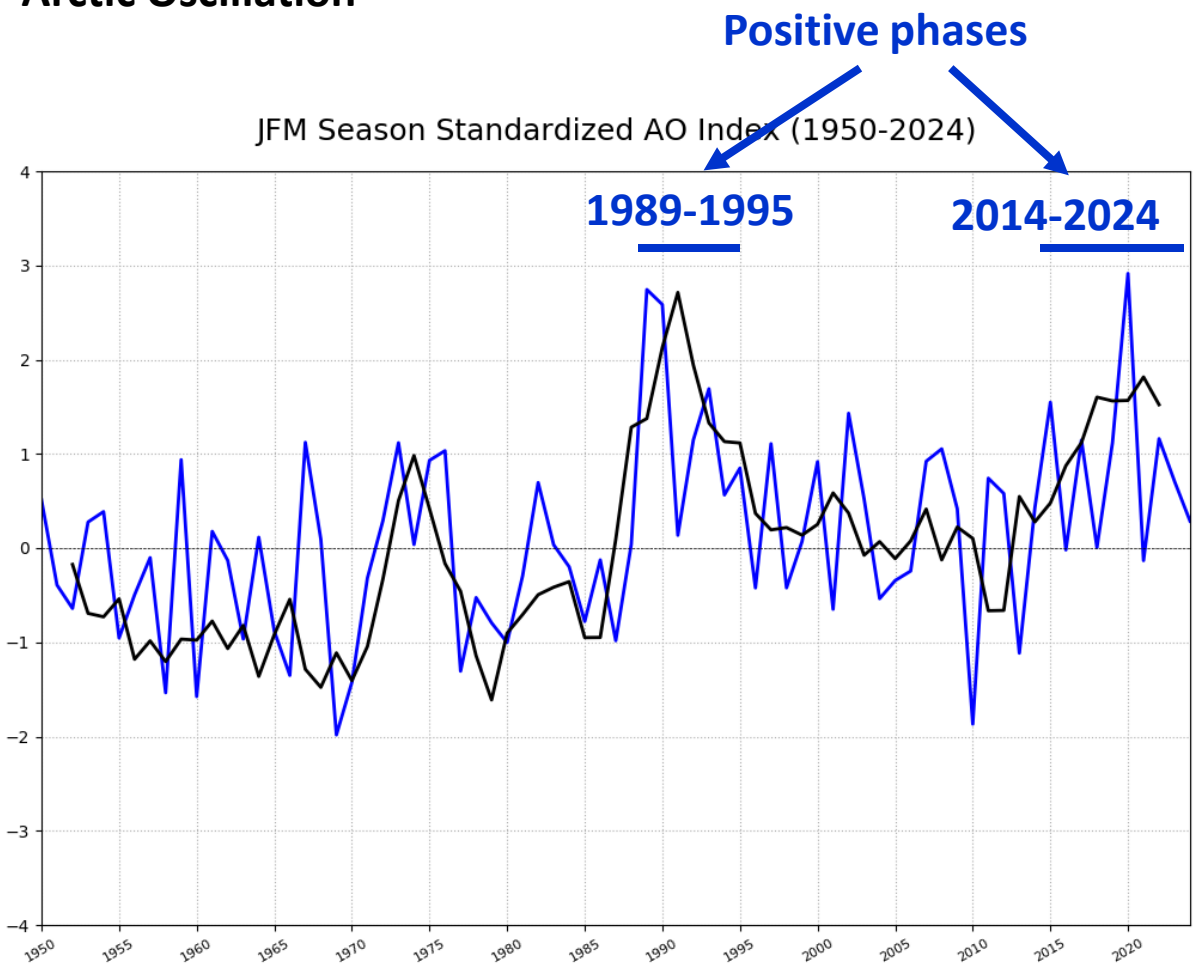
Conclusions

- A regime shift occurred in 2007 in the September Arctic sea-ice extent
- There is no long-term trend over the last 18 years (2007-2024)
- It could be due to natural variability
- It could be due to processes and feedbacks in the atmosphere, ocean, and/or sea ice

Further notes from England et al (submitted to GRL)

- The slowdown in September sea ice loss mainly occurs in the Pacific and Eurasian sector, from the Beaufort Sea westward to the Barents Sea.
- The current pause in Arctic sea ice loss is seen in every single month throughout the year.
- Therefore, the underlying mechanism(s) must explain not just summer trends or winter trends but sea ice trends throughout the entire year.

Arctic Oscillation

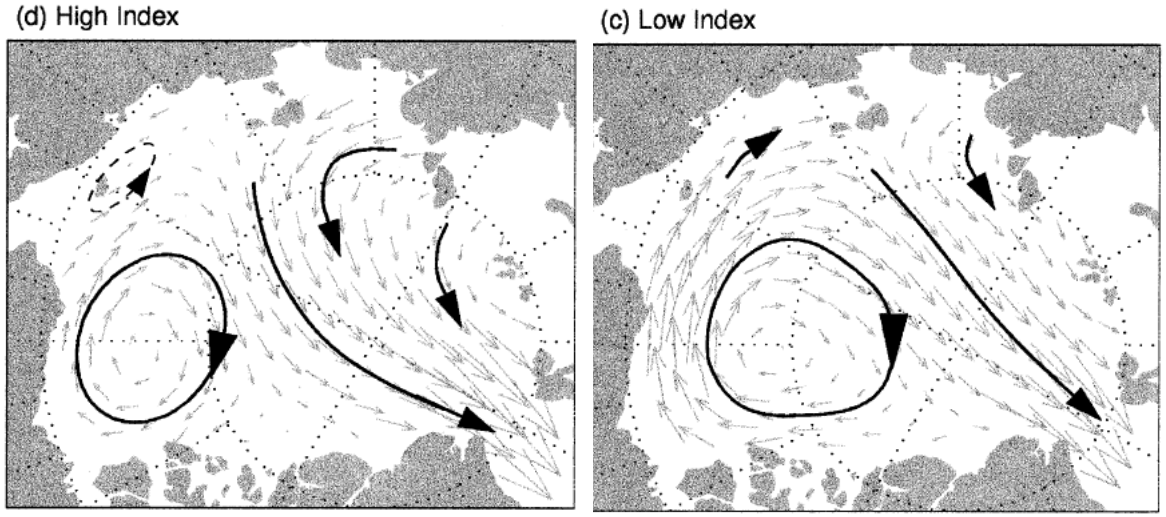


https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/JFM_season_ao_index.shtml

The standardized seasonal mean AO index during cold season (blue line) is constructed by averaging the monthly AO index for January, February and March for each year.
The black line denotes the standardized five-year running mean of the index.
Both curves are standardized using 1950-2000 base period statistics.

Positive winter AO
Negative SLP anomalies
Cyclonic circulation
Smaller Beaufort Gyre
More ice export
Less summer sea ice

Negative winter AO
Positive SLP anomalies
Anti-cyclonic circulation
Larger Beaufort Gyre
Less ice export
More summer sea ice



Rigor et al. (2002) *Journal of Climate*

But in the 2000s the connection between winter AO and summer sea-ice extent weakened because younger and thinner ice that recirculated in the BG north of Alaska no longer survived the summer melt.

Rigor and Wallace (2004). *Geophysical Research Letters*