Do Models Capture the Observed Regime Shift in Arctic Sea-Ice Extent and Thickness?

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CAMAS is the Consortium for the Advancement of Marine Arctic Science

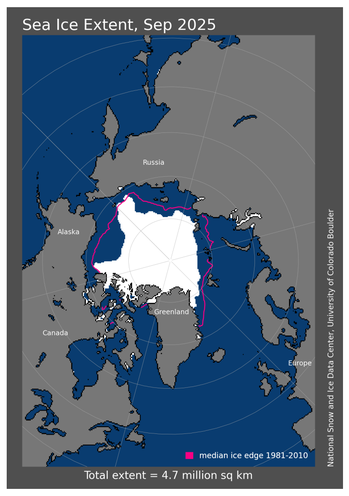
A **regime shift** is an abrupt, substantial, and persistent change in the state of a system (Reid et al., 2015).

Documented Regime Shifts in the Arctic Ocean

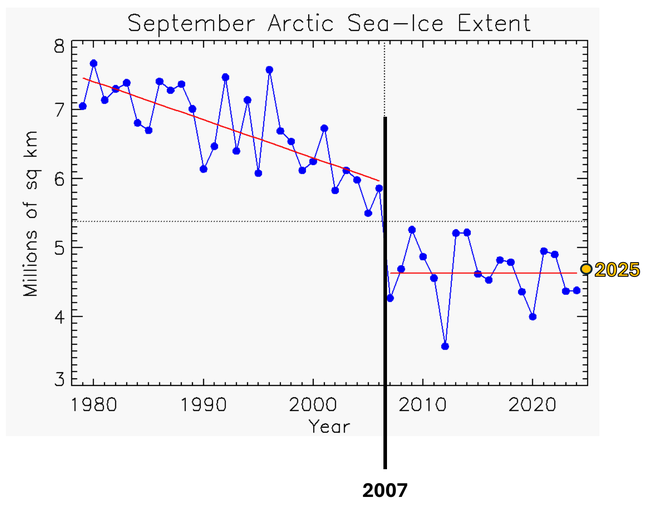
Property	Location	Year(s) of shift	Data used	References
Sea-ice extent in September	Arctic-wide	2007	Satellite passive microwave sea-ice con., 1979-2024	Polyakov et al. (2023); Stern (2025)
Sea-ice thickness distribution	Arctic-wide	2007	Upward-looking sonar in Fram Strait, 1990-2019	Sumata et al. (2023)
Area of multiyear sea ice	Arctic-wide	1989, 2006-2008	Sea-ice age via Lagrangian tracking of parcels, 1980-2021	Babb et al. (2023)
Freshwater volume	Beaufort Gyre and Russian Shelf	2007	ECMWF Ocean Reanalysis System 5, 1979-2018	Hall et al. (2023)

Regime Shift in Arctic Ocean Sea-Ice Extent

Stern (2025)



Data: Sea Ice Index (Fetterer et al., 2017), September average sea-ice extent
Temporal coverage: 1979-2024
Spatial coverage: Northern Hemisphere

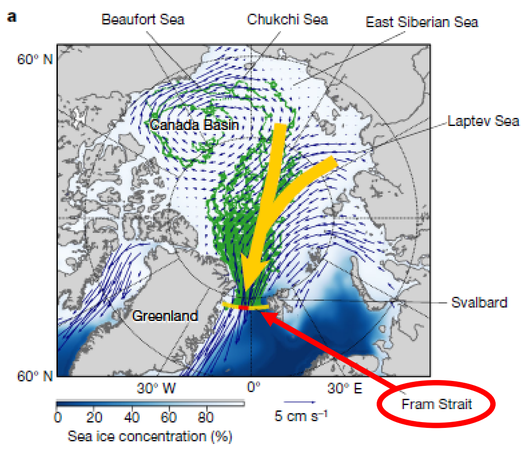


Results

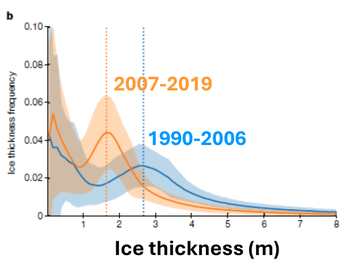
- Decline 1979-2006
- Severe drop in 2007
- No trend since 2007
- Regime shift in 2007

Regime Shift in Arctic Ocean Sea-Ice Thickness

Sumata et al. (2023)

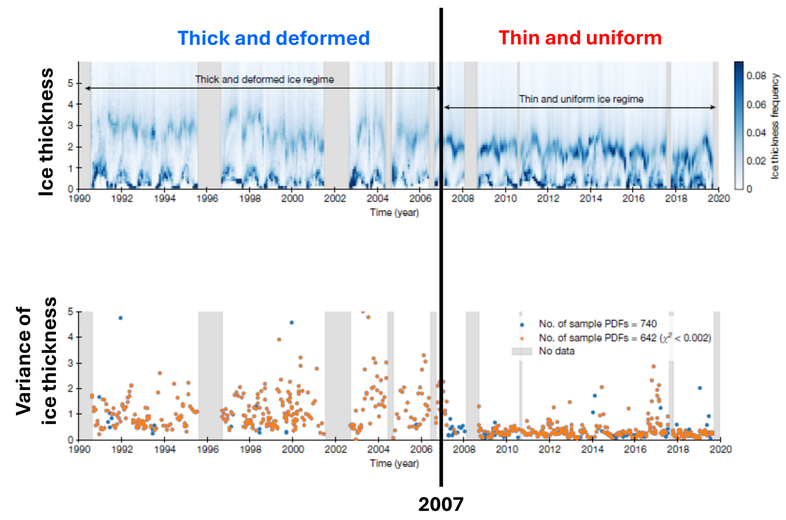


Data: Upward-looking sonar
Temporal coverage: 1990-2019
Spatial coverage: Fram Strait



Results

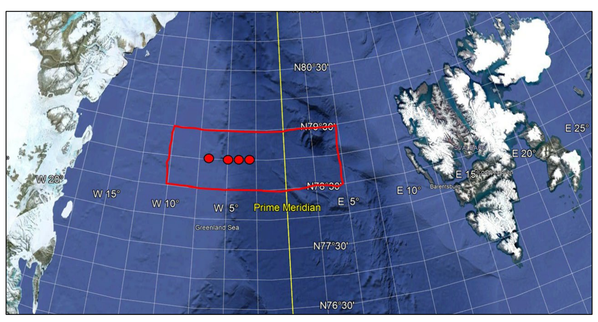
- Modal ice thickness declined between **1990-2006** and **2007-2019**
- Distribution became more compact
- Variance of ice thickness decreased
- Ice pack shifted in 2007 from **thick and deformed** to **thin and uniform**



Model – Data Comparisons

Model Runs

- Calculate monthly average sea-ice extent over the entire Northern Hemisphere
- Calculate monthly average sea-ice thickness distributions within **red outline** in the figure



Fram Strait region between Greenland (left) and Svalbard (right).
Red dots: locations of ULS moorings used by Sumata et al. (2023).
Red outline: domain for model sea-ice thickness calculations.

Sea-Ice Extent Comparison

- Plot model September sea-ice extent and Sea Ice Index data (1979-2025) for visual comparison
- Calculate root-mean-square difference between model and data sea-ice extent (1979-2025)
- Test model times series for regime shift in 2007 using the method of Rodionov (2004)

Sea-Ice Thickness Comparison

- Plot model sea-ice thickness distributions for visual comparison with Sumata et al. (2023)
- For each monthly sea-ice thickness distribution:
  - Find minimum thickness between 0 and mode
  - Fit lognormal distribution to values > minimum
  - Calculate mode, modal peak height, variance
- Calculate average of distributions over 1990-2006 and 2007-2019, and compare to Sumata et al.
- Plot time series of modal thickness, modal peak height, variance, and test for regime shifts using the method of Rodionov (2004)

References

Babb, D. G., R. J. Galley, S. Kirillov, J. C. Landy, S. E. L. Howell, J. C. Stroeve, W. Meier, J. K. Ehn, and D. G. Barber (2023). The stepwise reduction of multiyear sea ice area in the Arctic Ocean since 1980. *Journal of Geophysical Research: Oceans*, 128, e2023JC020157. https://doi.org/10.1029/2023JC020157

Fetterer, F., Knowles, K., Meier, W. N., Savoie, M. & Windnagel, A. K. (2017). Sea Ice Index. (G02135, Version 3). Boulder, Colorado USA. National Snow and Ice Data Center. https://doi.org/10.7265/N5K072F8

Hall, S. B., Subrahmanyam, B., & Steele, M. (2023). The role of the Russian Shelf in seasonal and interannual variability of Arctic sea surface salinity and freshwater content. *Journal of Geophysical Research: Oceans*, 128, e2022JC019247. https://doi.org/10.1029/2022JC019247

Polyakov, I. V., Ingvaldsen, R. B., Pnyushkov, A. V., Bhatt, U. S., Francis, J. A., Janout, M., et al. (2023). Fluctuating Atlantic inflows modulate Arctic atlantification. *Science*, 381(6661), 972–979. https://doi.org/10.1126/science.adh5158

Reid, P. C., Hari, R. E., Beaugrand, G., Livingstone, D. M., Marty, C., Straile, D., et al. (2015). Global impacts of the 1980s regime shift. *Global Change Biology*, 22(2), 682–703. https://doi.org/10.1111/gcb.13106

Rodionov, S. N. (2004). A sequential algorithm for testing climate regime shifts. *Geophysical Research Letters*, 31(9), L09204. https://doi.org/10.1029/2004GL019448

Stern, H. L. (2025). Regime shift in Arctic Ocean sea-ice extent. *Geophysical Research Letters*, 52, e2024GL114546. https://doi.org/10.1029/2024GL114546

Sumata, H., de Steur, L., Divine, D. V., Granskog, M. A., & Gerland, S. (2023). Regime shift in Arctic Ocean sea ice thickness. *Nature*, 615 (7952), 443–449. https://doi.org/10.1038/s41586-022-05686-x

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