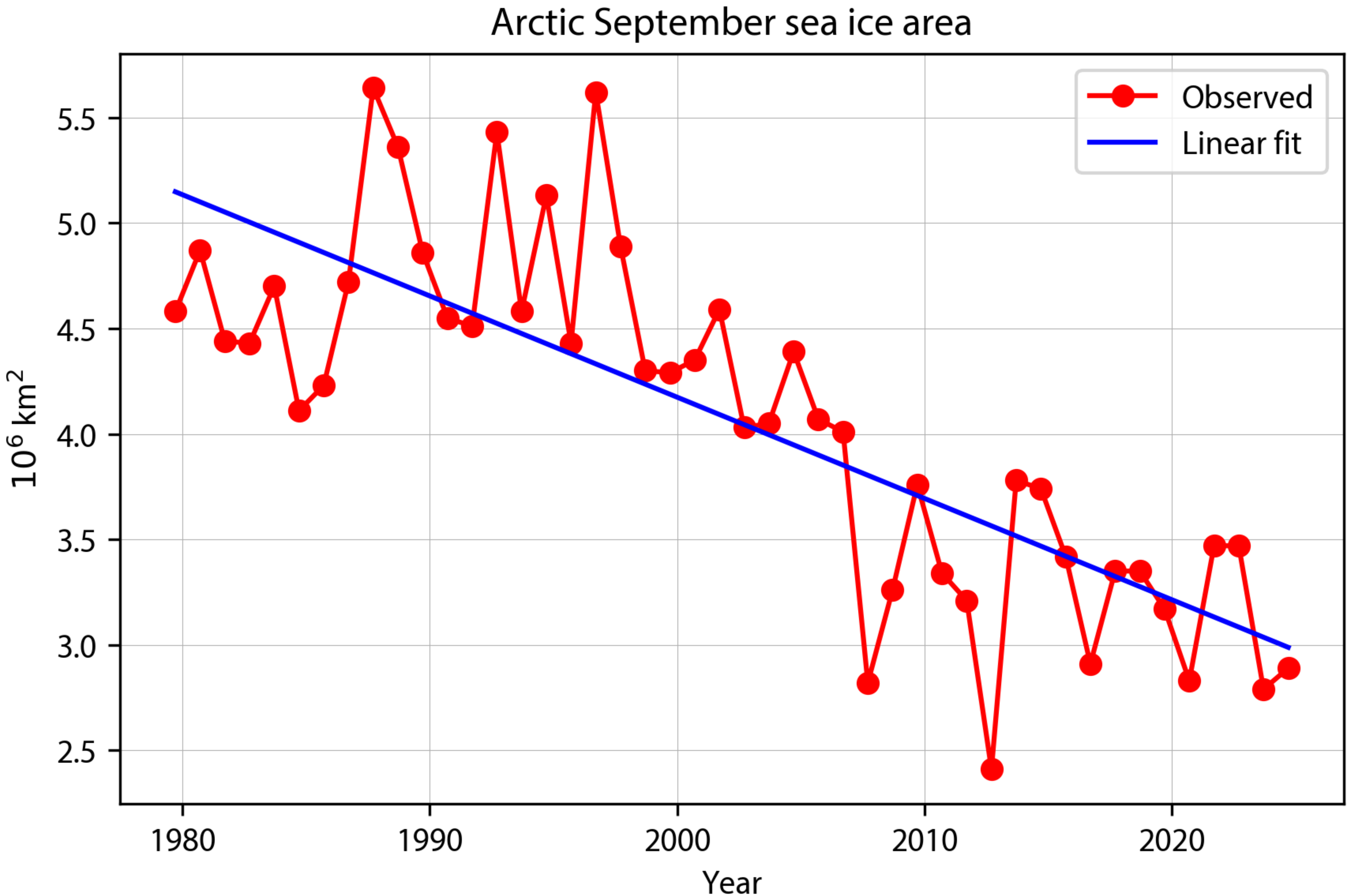
Sea ice

Global Warming Science, EPS101

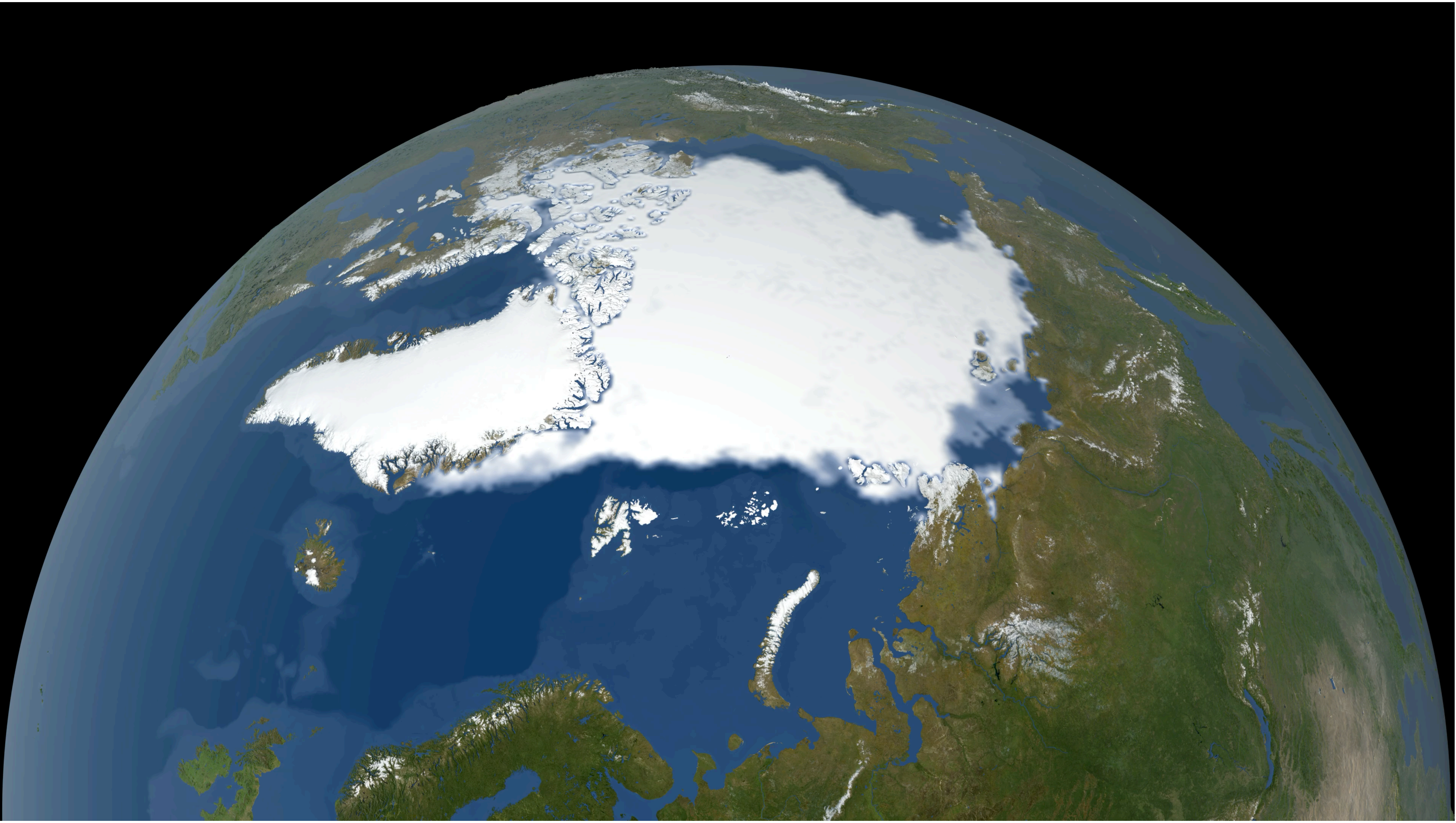
Eli Tziperman

https://courses.seas.harvard.edu/climate/eli/Courses/EPS101/

September Arctic sea ice record over past decades



Arctic sea ice minimum over past decades



https://svs.gsfc.nasa.gov/vis/a000000/a005100/a005170/sea_ice_min_w_graph_2023_2160p30.mp4

NASA

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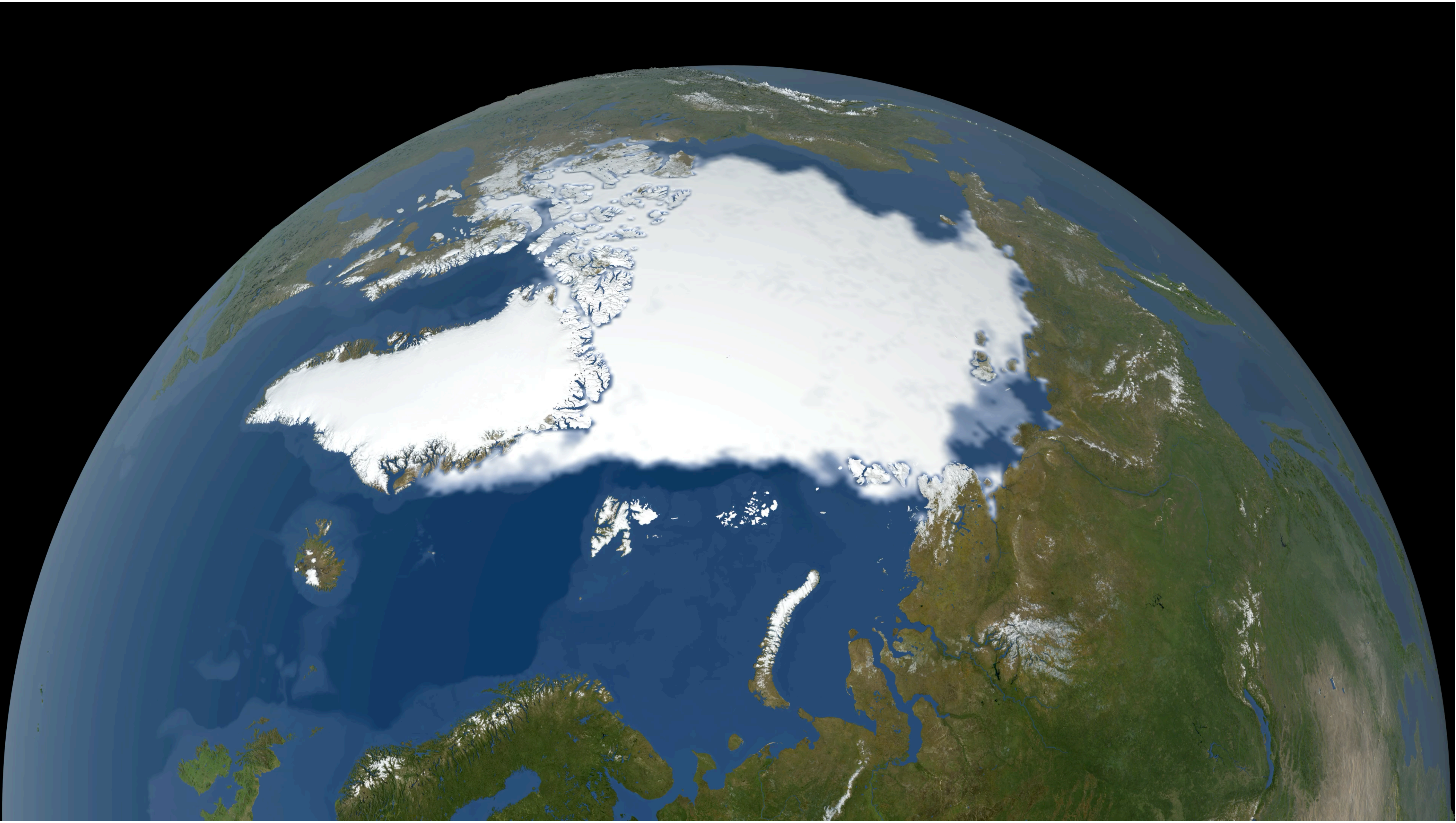

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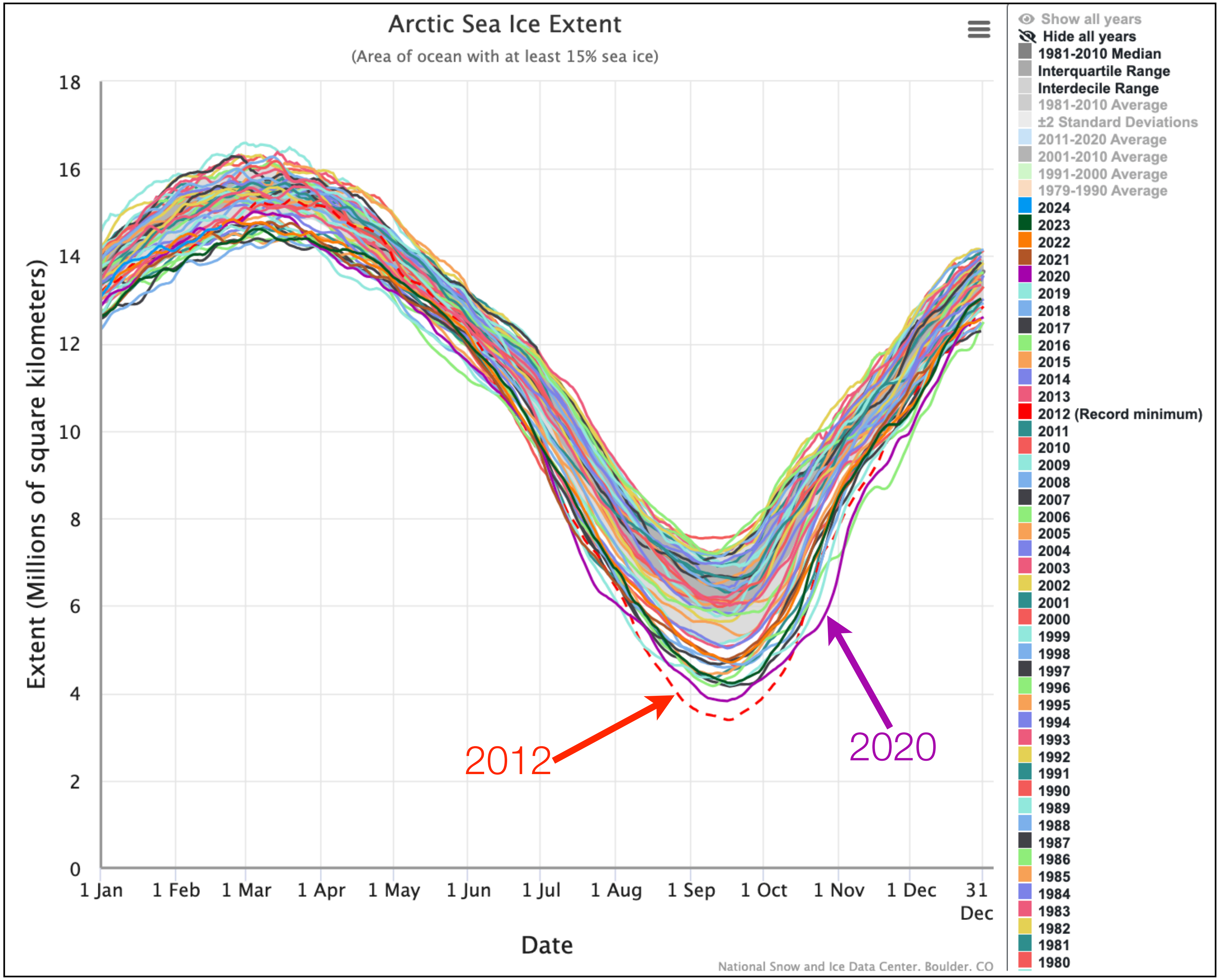
NASA

Sea ice seasonal cycle over past decades



http://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/

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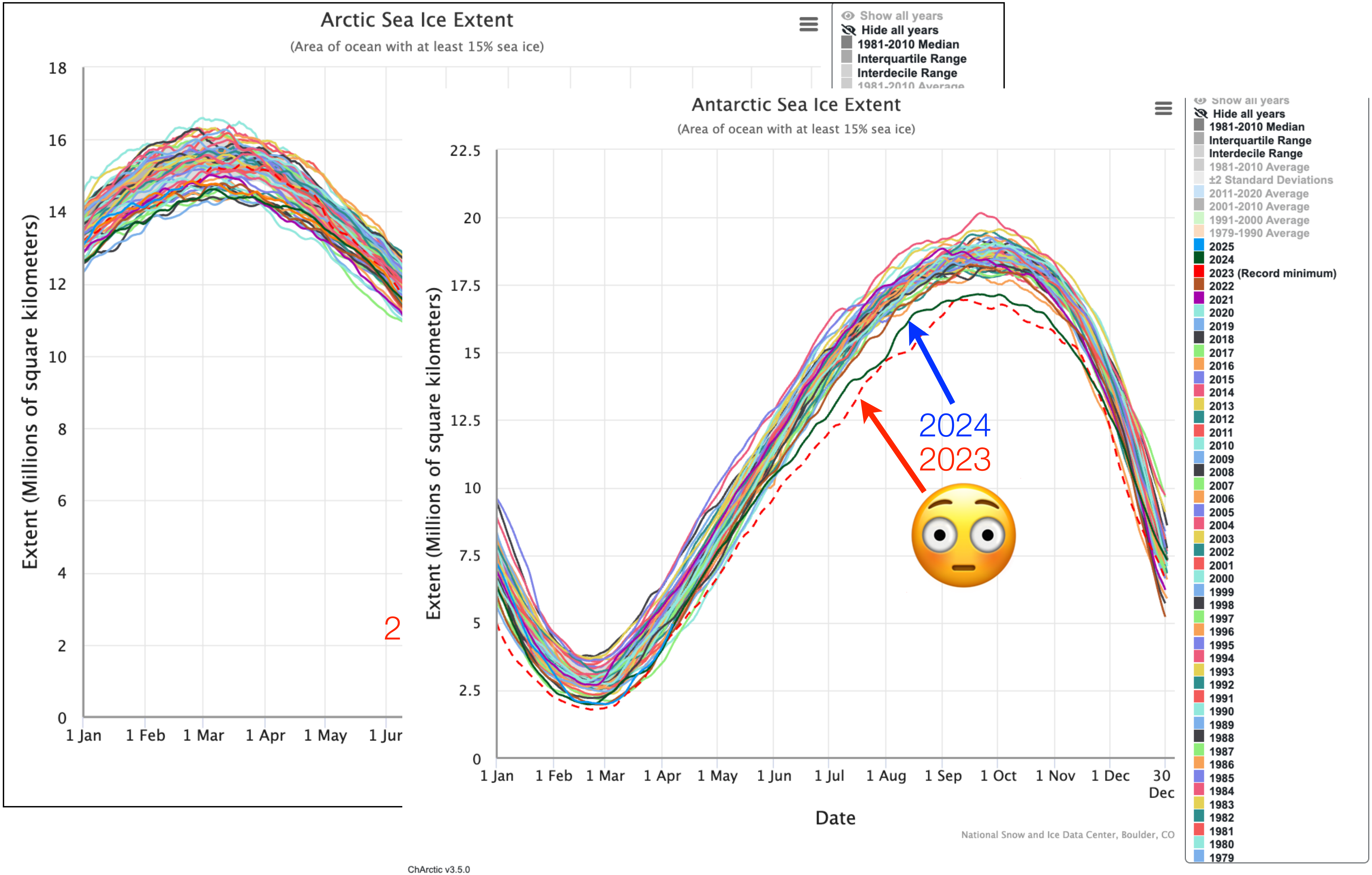

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And now it's global COOLING! Return of Arctic ice cap as it grows by 29% in a year

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- **BBC reported in 2007 global warming would leave Arctic ice-free in summer by 2013**
- **Publication of UN climate change report suggesting global warming caused by humans pushed back to later this month**

By DAVID ROSE FOR THE MAIL ON SUNDAY
PUBLISHED: 00:37 GMT, 8 September 2013 | **UPDATED:** 15:58 GMT, 11 October 2014

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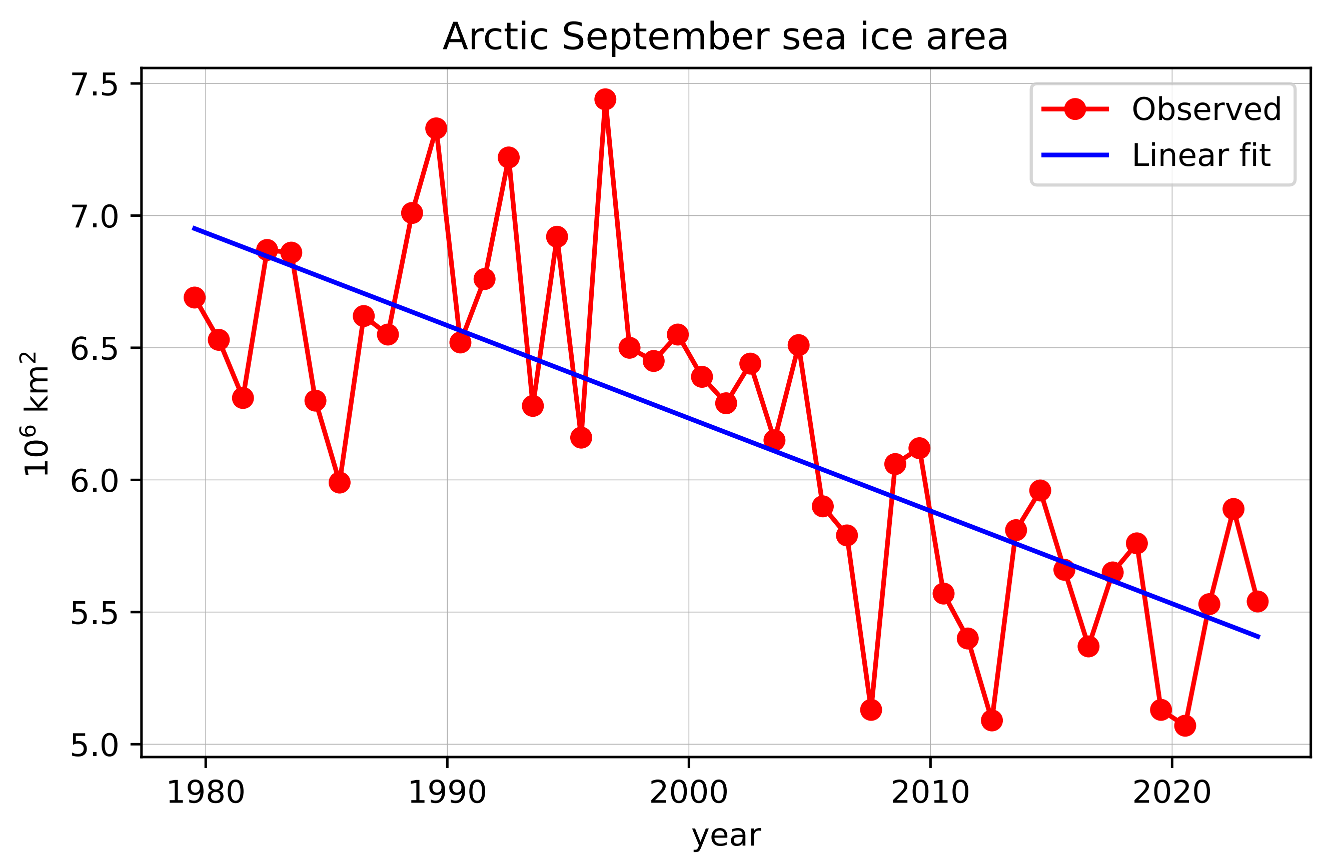

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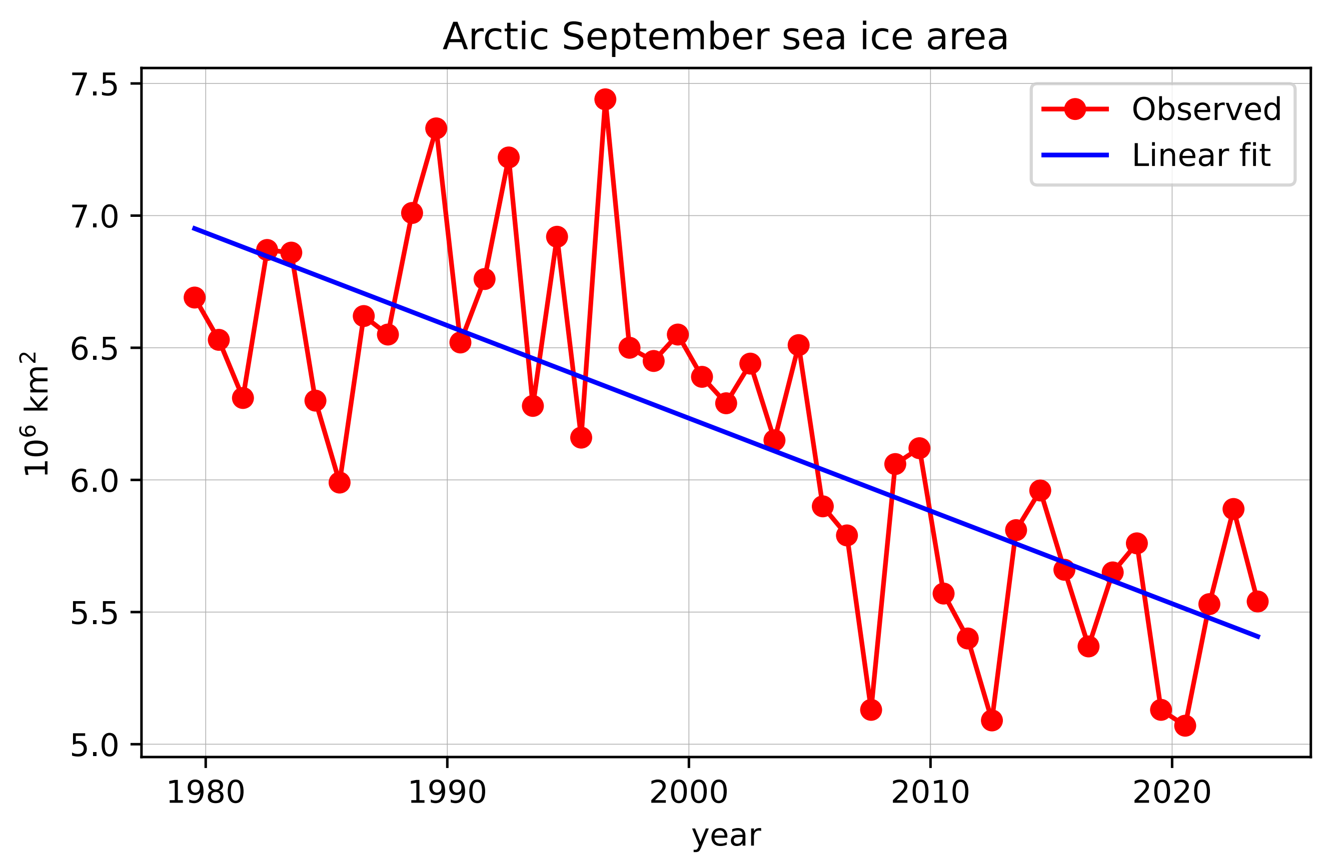

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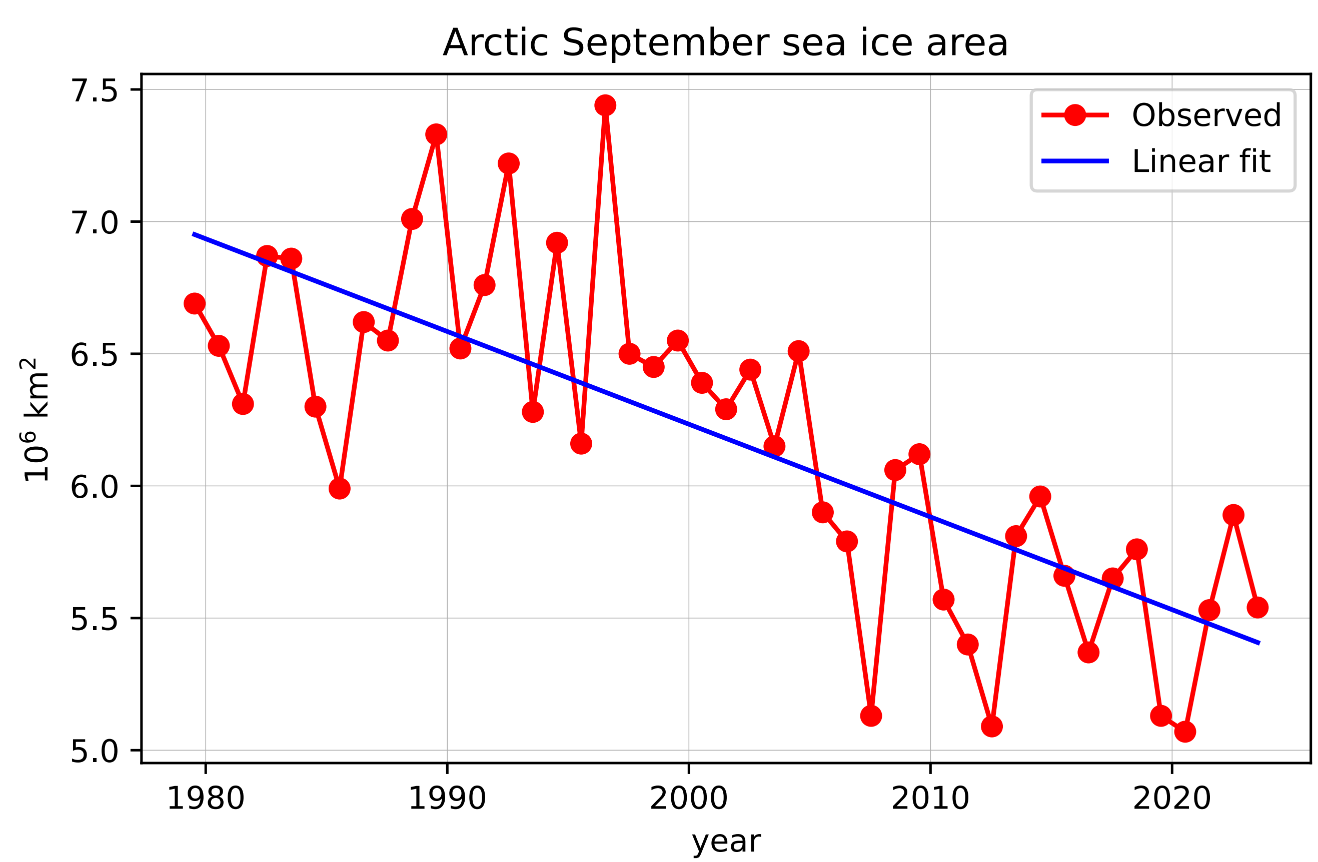

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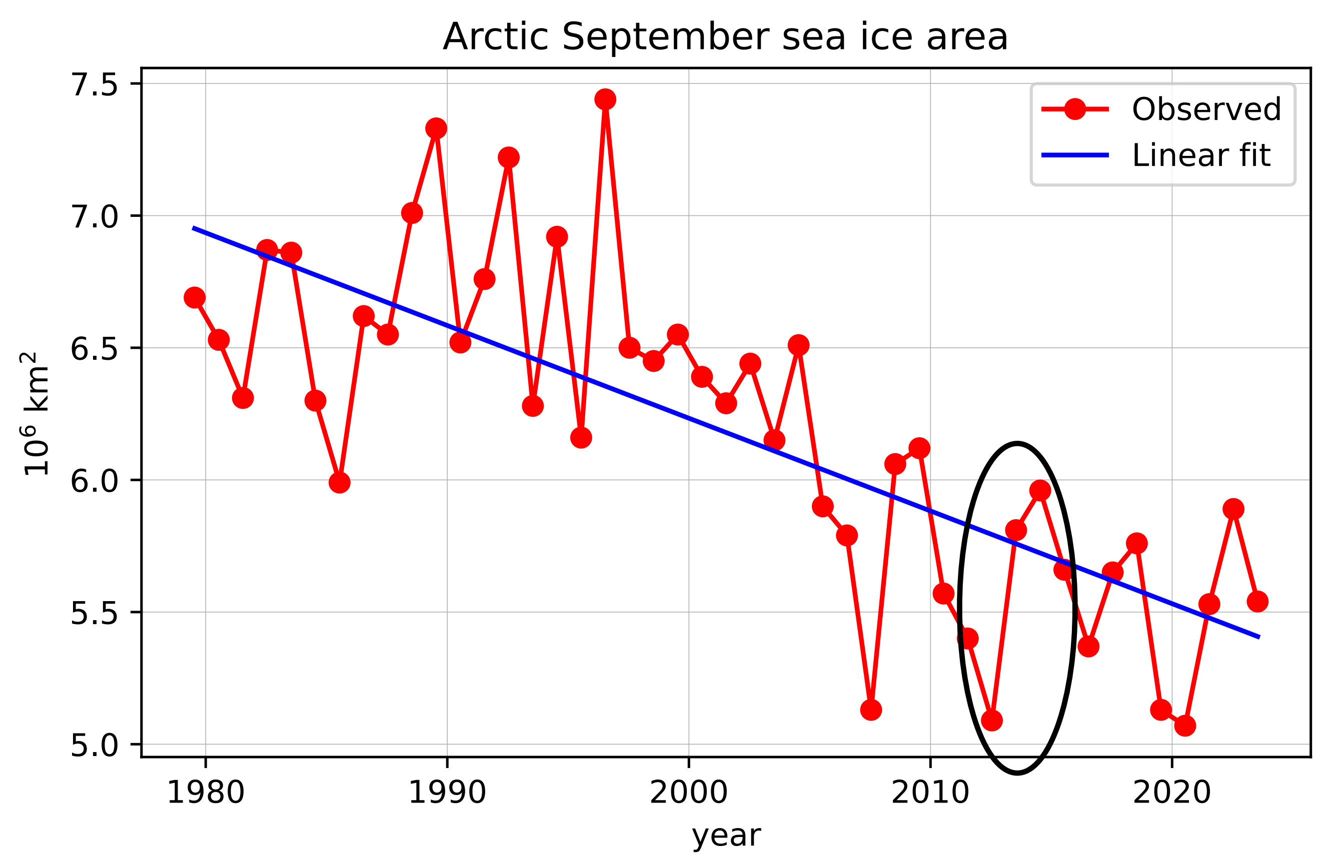

The adventures of Kevin: bad day on the sea ice

https://www.youtube.com/watch?v=K16lZU0agbg

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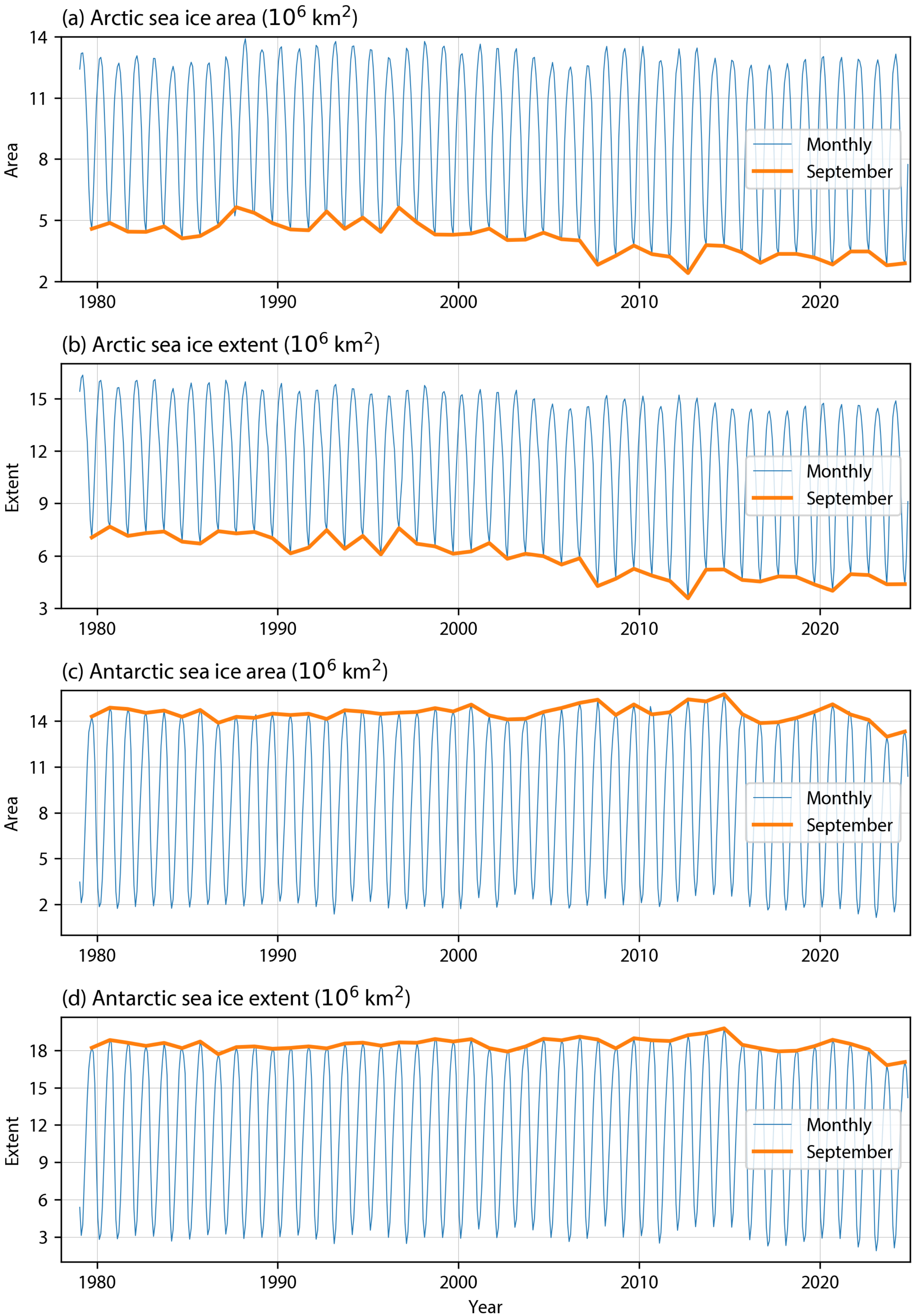
sea ice floes

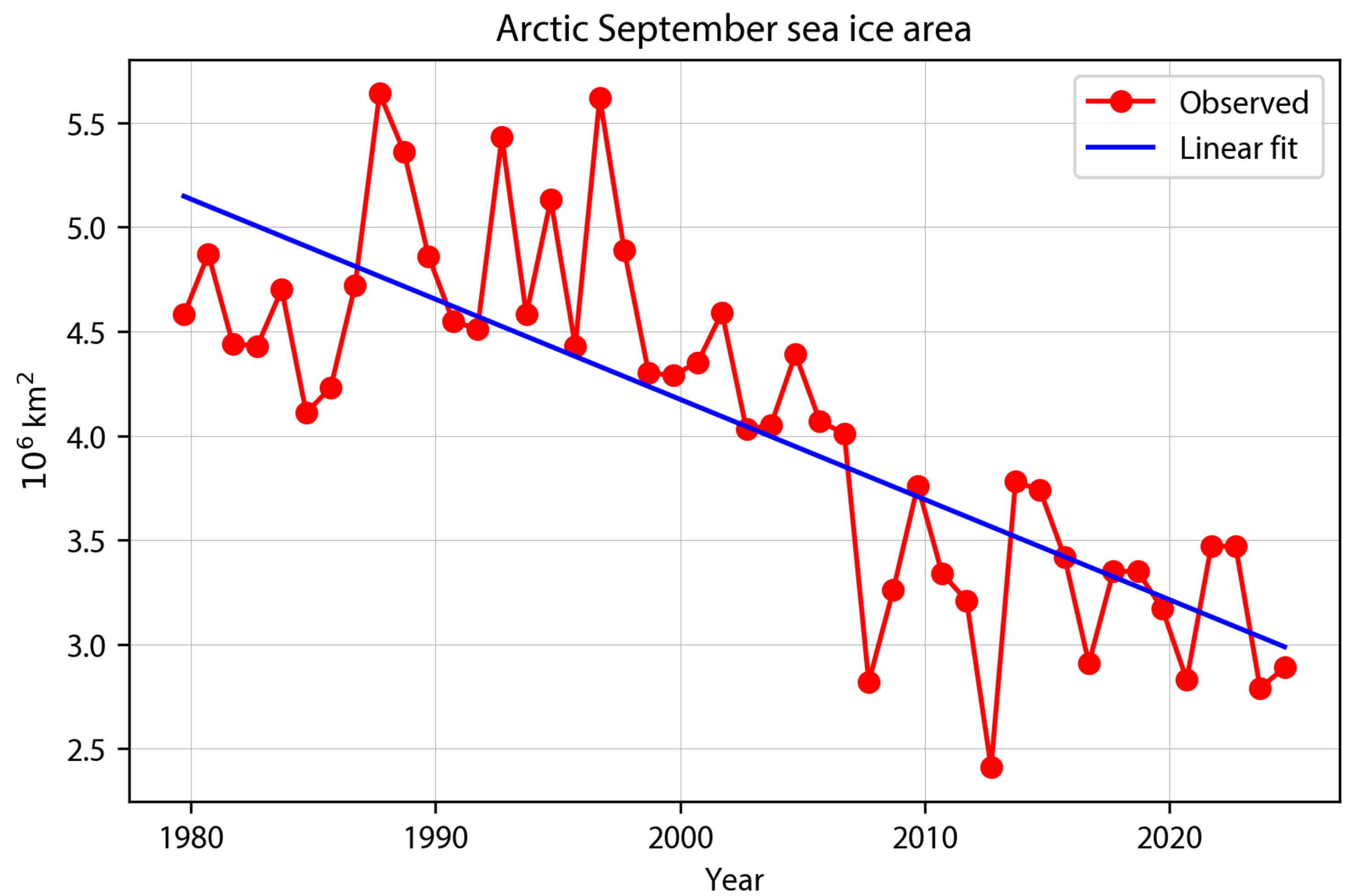
https://www.shutterstock.com/video/clip-22833073-breaking-melting-ice-floes-arctic-circle-perfect

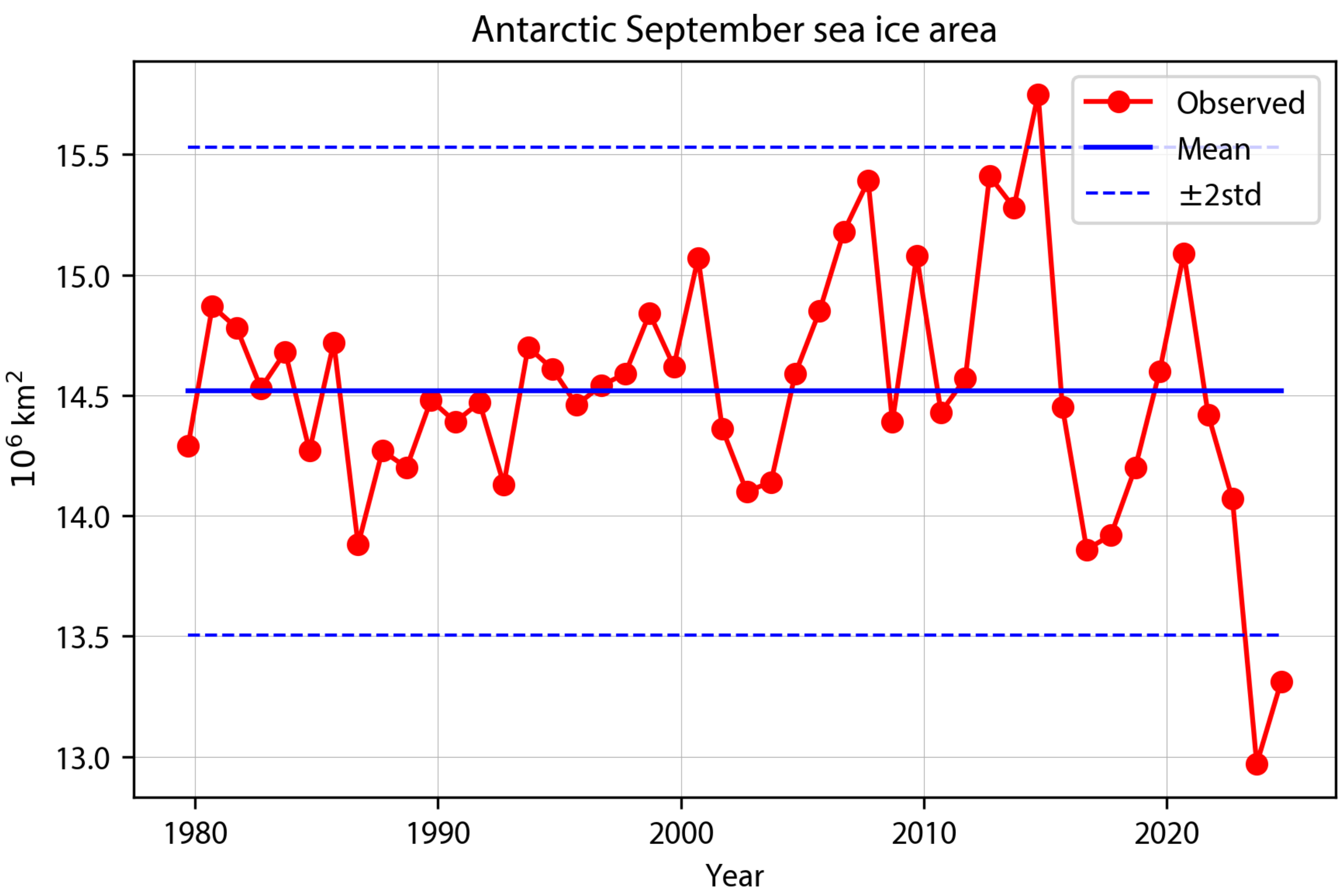
Notes: chapter introduction paragraphs
Quantifying the state of sea ice:
area, concentration, extent (=area of concentration>15%), age, thickness.

workshop #1a, b: characterizing observed changes in sea ice
(leave c, d, e for HW)

Arctic & Antarctic sea ice trends

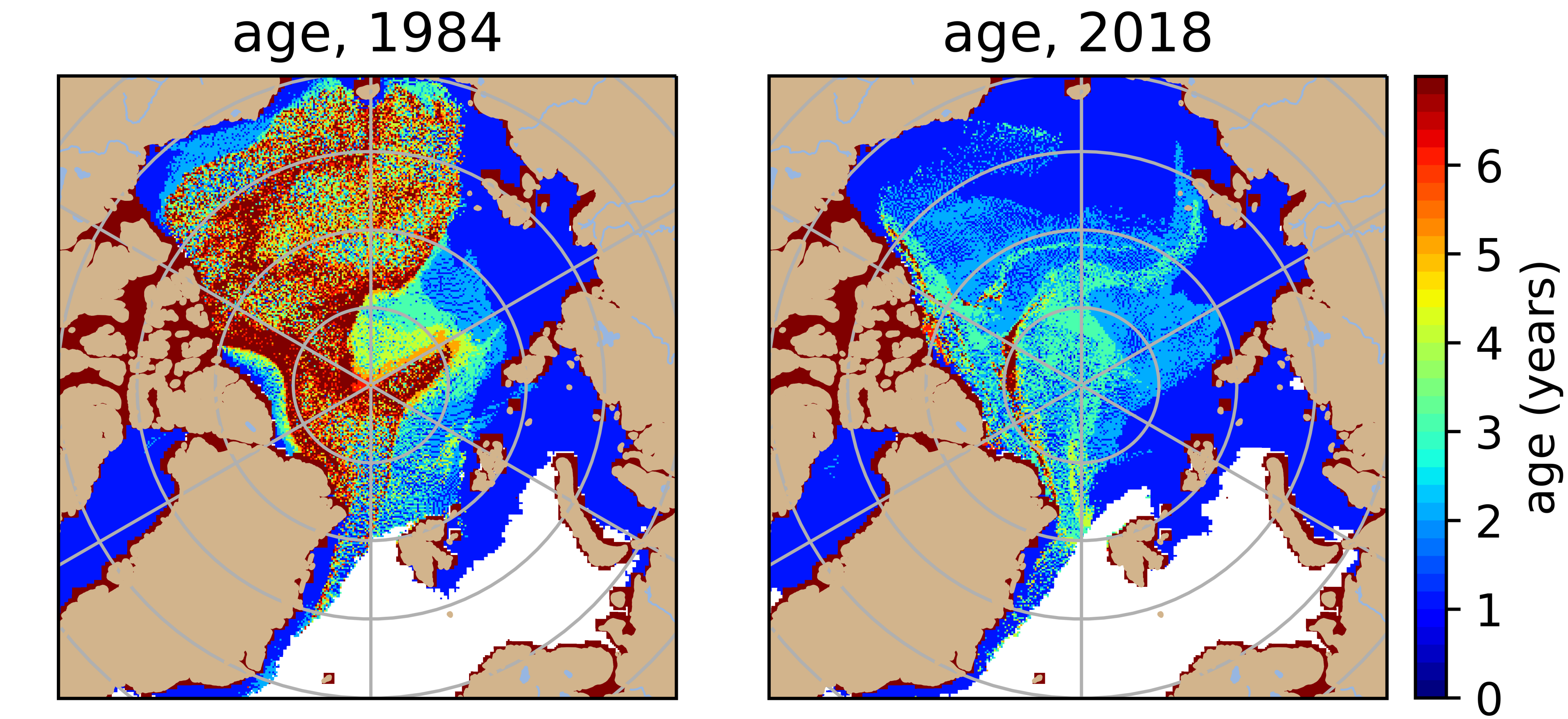




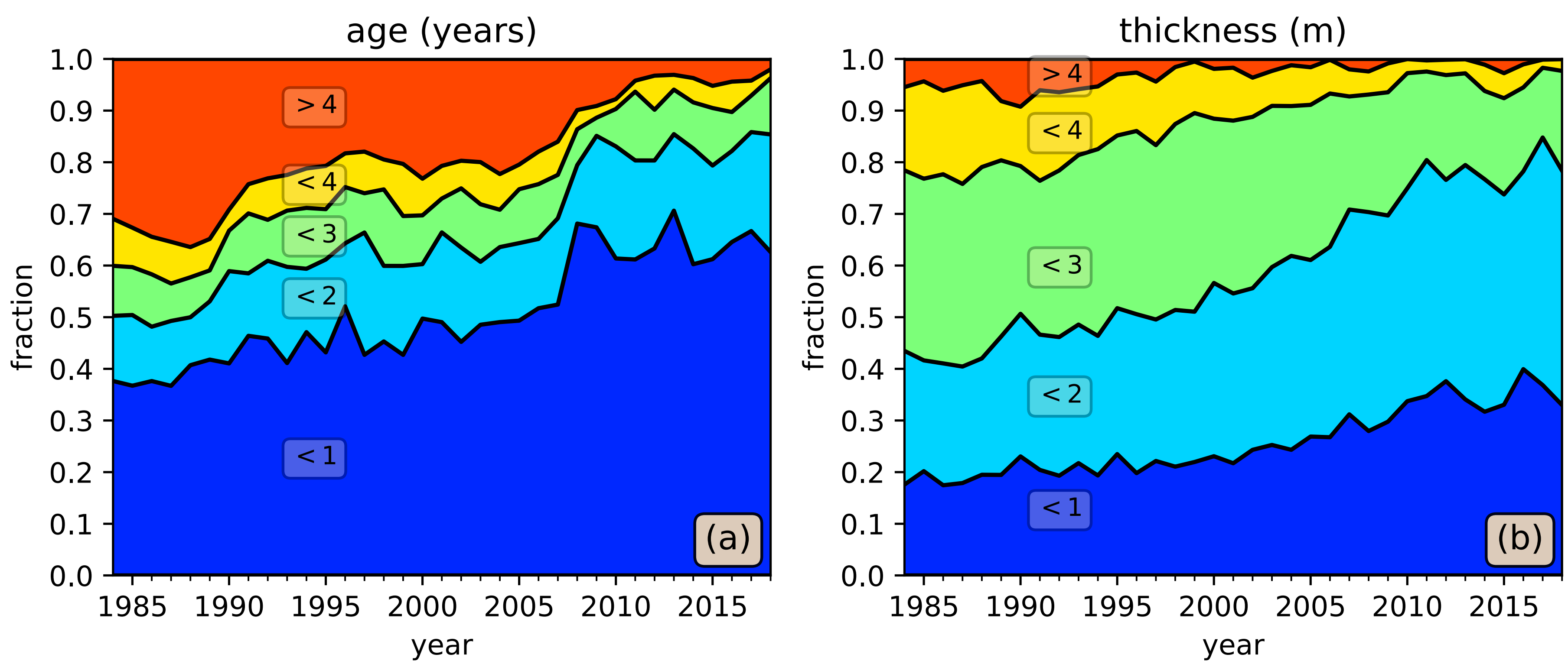


Arctic minimum & Antarctic maximum sea ice trends

Arctic sea ice record over past decades



Sea Ice Age
1985-2019



data from http://nsidc.org/

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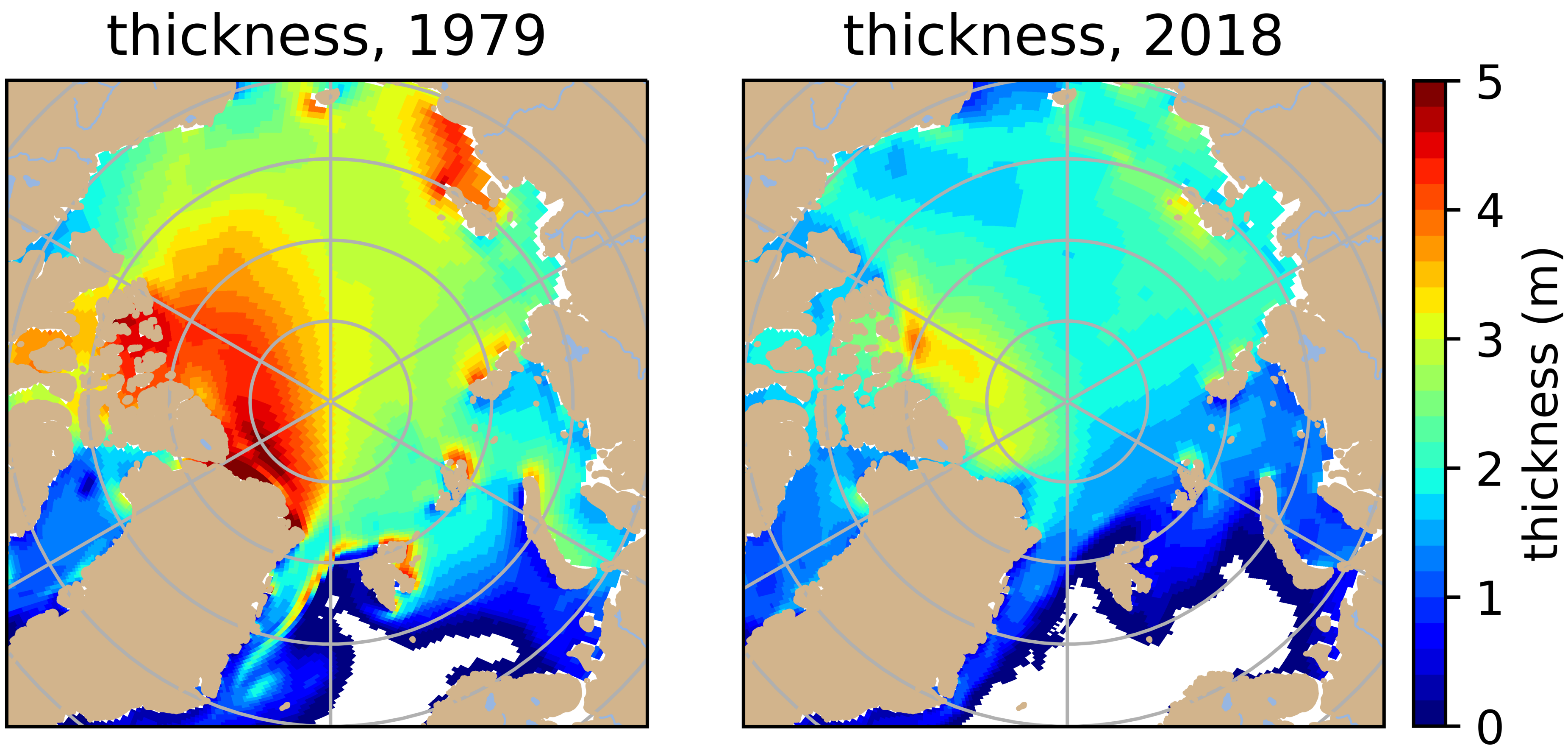
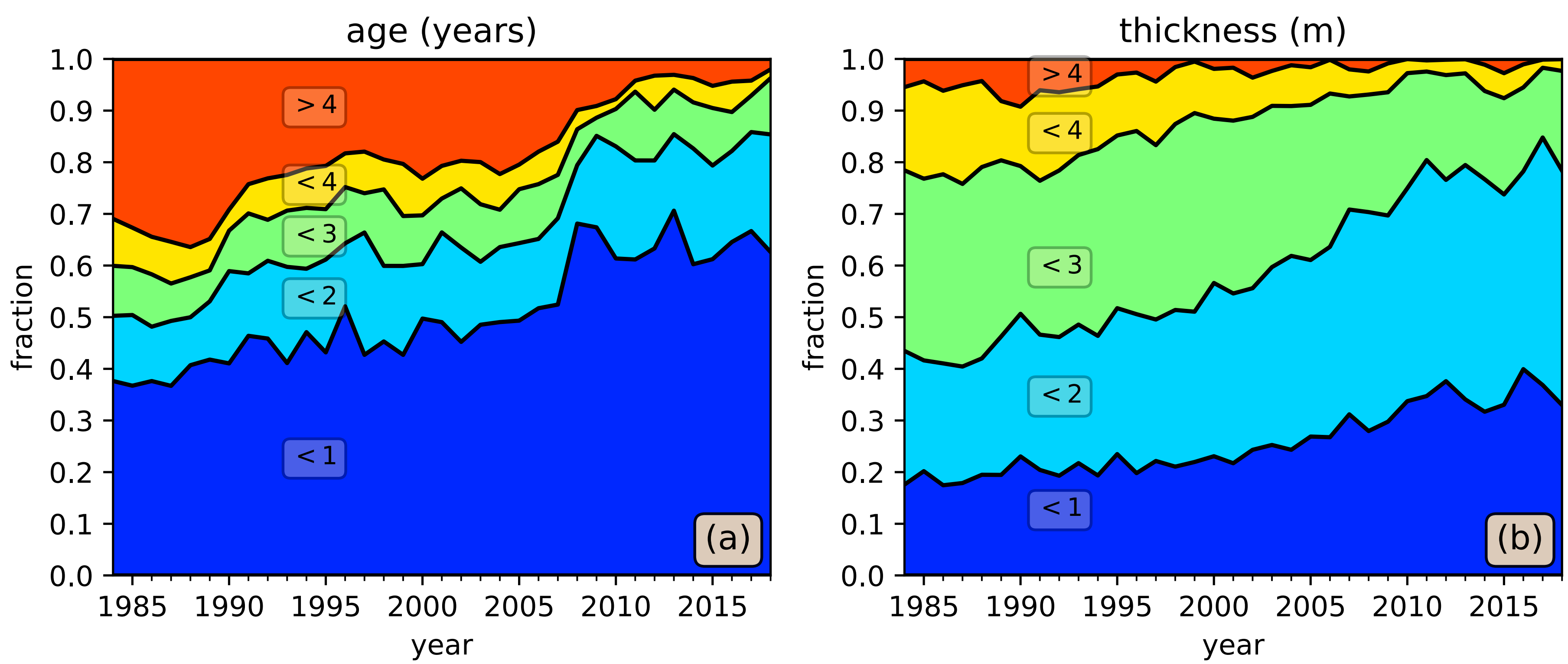


Sea Ice thickness 1985-2019



[data from http://nsidc.org/](http://nsidc.org/)

Sea ice formation: frazil to pancakes to new ice

Frazil ice, Grease ice, Pancake ice, First-year ice, Old ice, multi-year ice

http://www.antarctica.gov.au/about-antarctica/environment/sea-ice/development-of-sea-ice

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http://www.antarctica.gov.au/about-antarctica/environment/sea-ice/development-of-sea-ice

pancake ice

https://blogs.egu.eu/divisions/cr/2018/04/27/image-of-the-week-making-pancakes/

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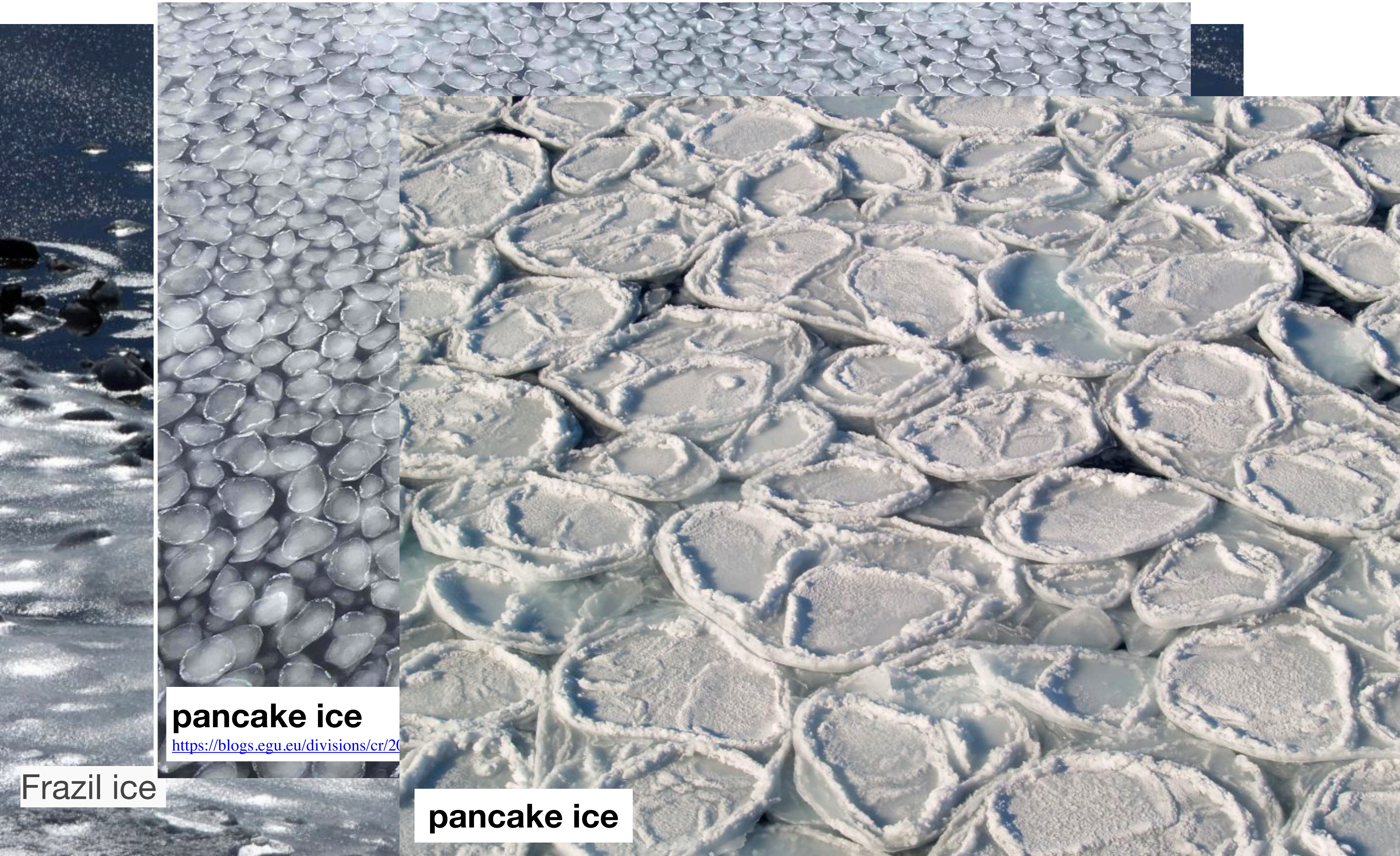

Maturing sea ice: rafting, ridging

1 m by 3 m rafted ice
Stephen F. Ackley, Peter Wagner, Hongjie Xie 2007

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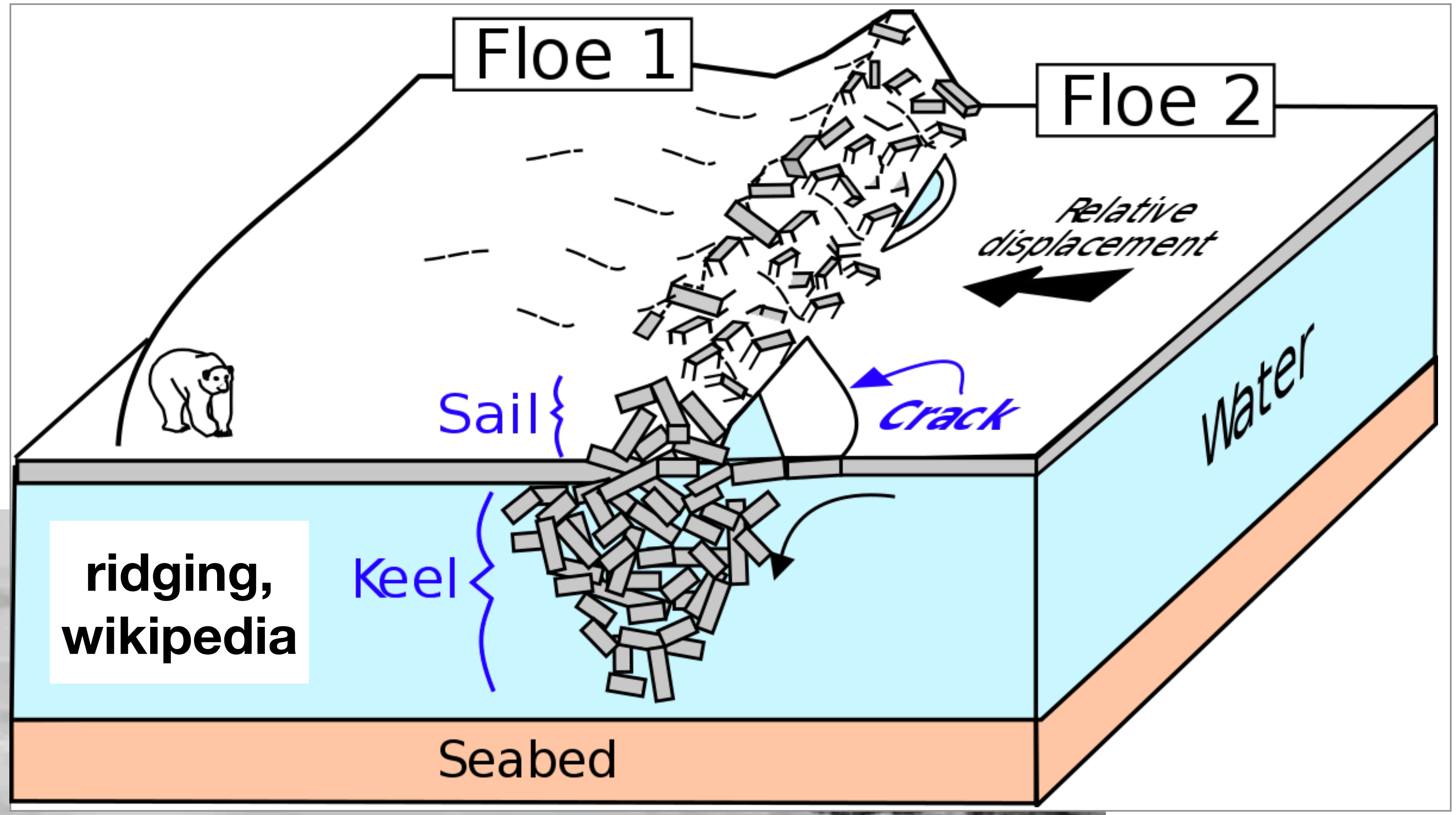
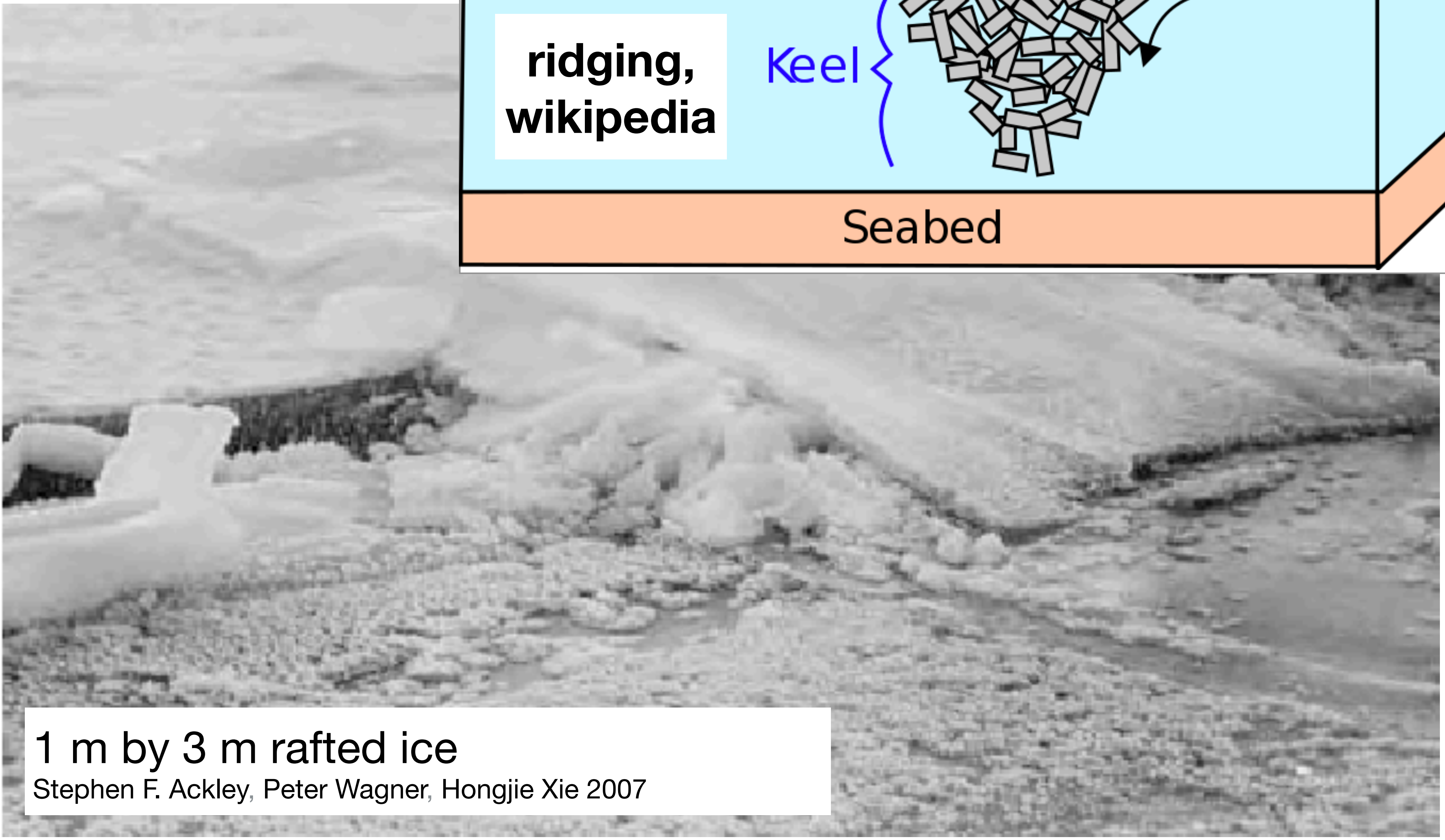


ridging, wikipedia



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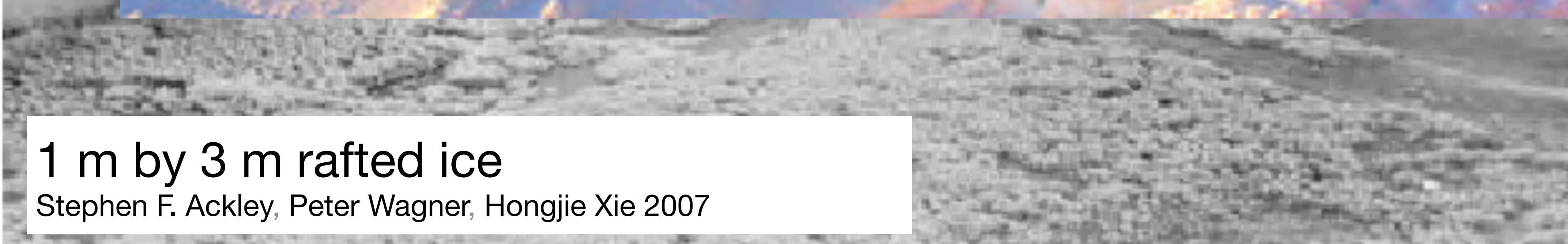
Maturing sea ice: rafting, ridging

ridging, https://earthobservatory.nasa.gov/features/SeaIce



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Observed sea ice records since 1980/1900

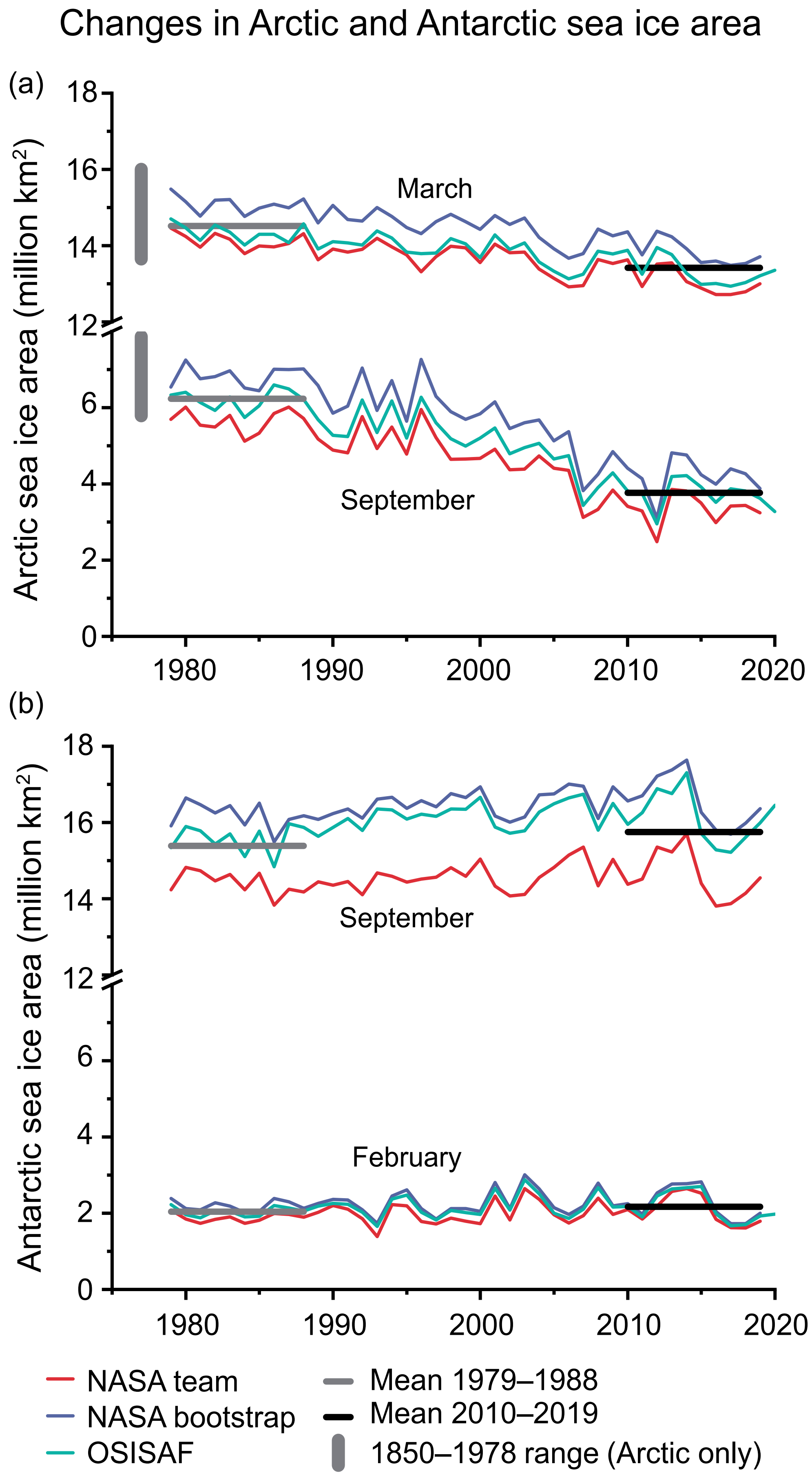

Figure 2.20 | Changes in Arctic and Antarctic sea ice area. (a) Three time series of Arctic sea-ice area (SIA) for March & Sept, 1979–2020 (passive microwave satellite era). SIA range for 1850–1978 indicated by vertical bar on left. **(b)** Three time series of Antarctic sea ice area for Sept & February (1979–2020). In (a & b), decadal means for the first and most recent decades of obs shown by horizontal grey (1979–1988) and black (2010–2019) lines. SIA values have been calculated from sea ice concentration fields.

IPCC, AR6 2022

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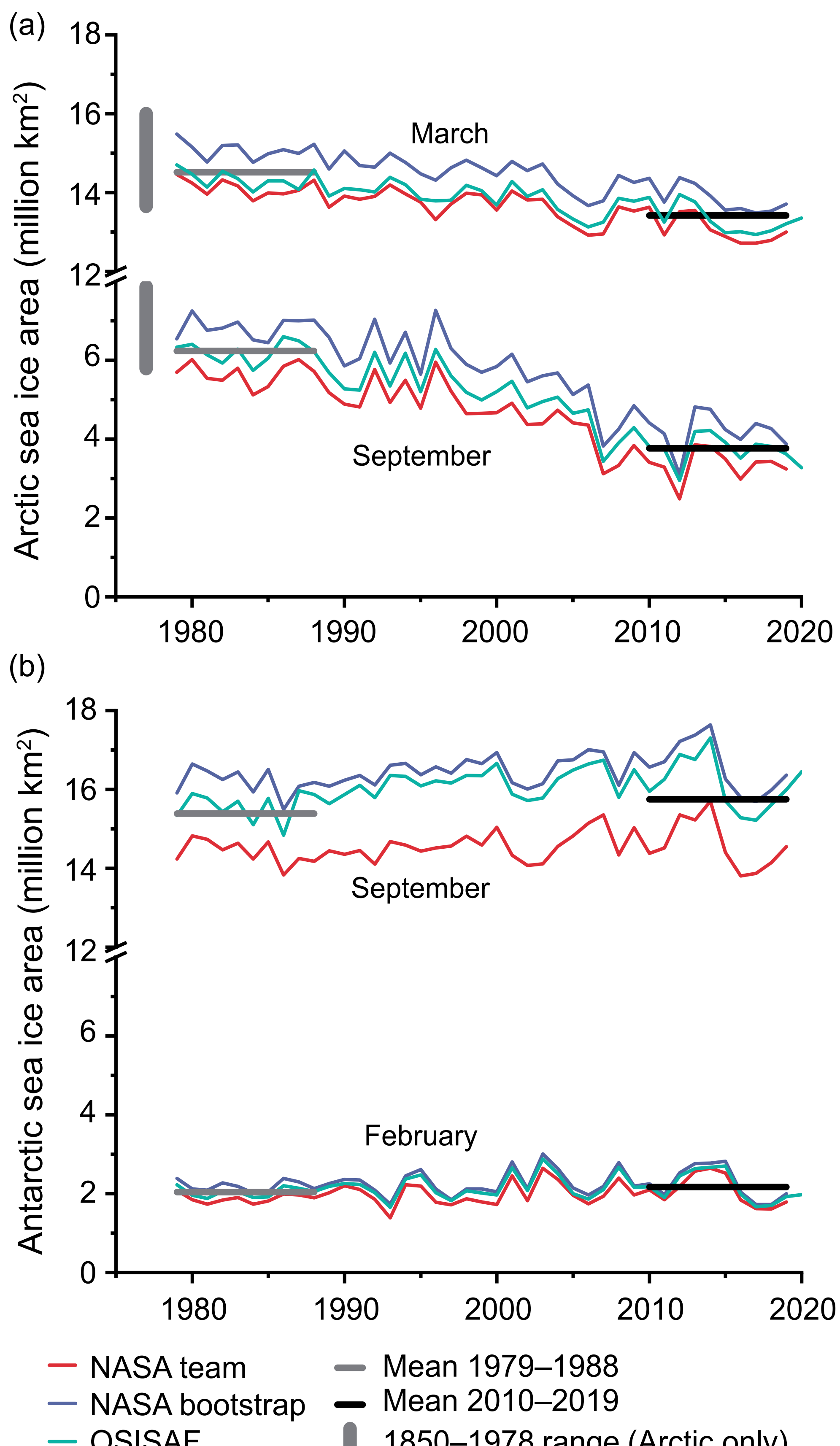

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IPCC, AR6 2022

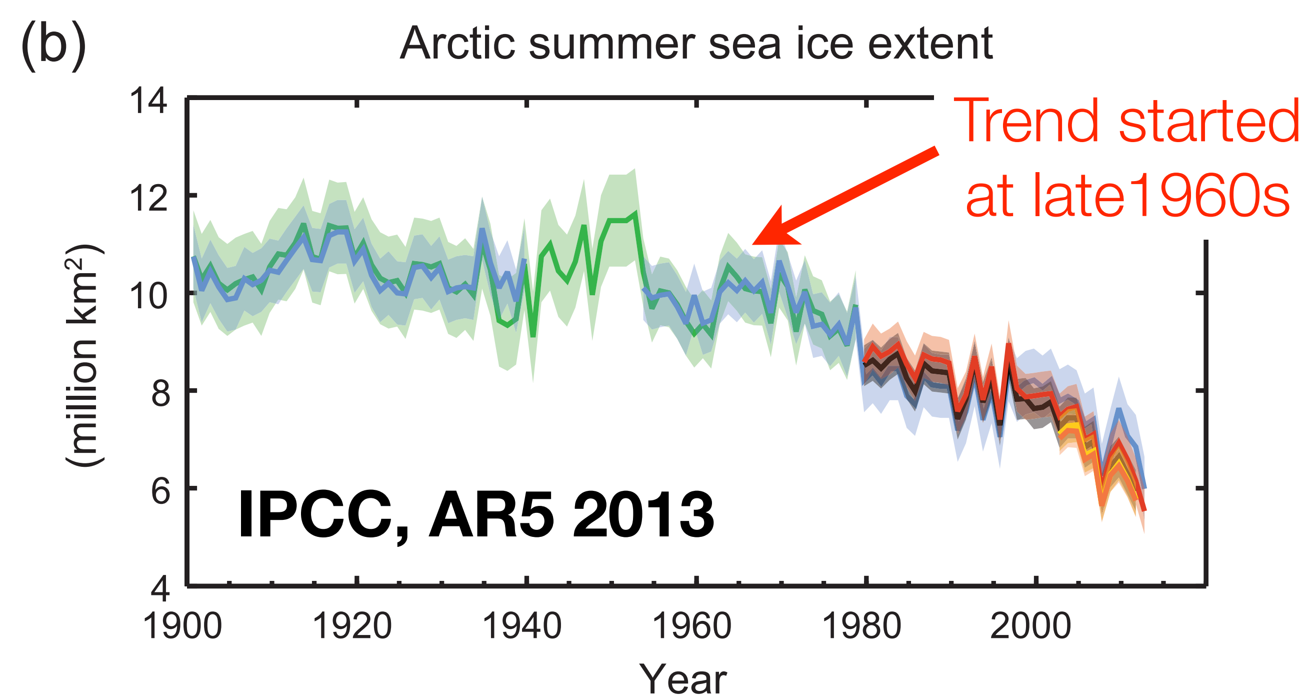

Figure SPM.3 | extent of Arctic July-August-September (summer) average sea ice; (colored lines indicating different data sets)

Notes: section 9.1

Sea ice feedbacks:
albedo, age-roughness-albedo, thickness-mobility, thickness-insulation
(use following slide)

Sea ice feedbacks

(1) Albedo feedback:

Smaller sea ice area ➨ more SW absorption by ocean near sea ice ➨ ocean warming ➨ increased melting ➨ a powerful positive feedback that can accelerate melting.

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Melt ponds accumulate in sea ice depressions, have a lower albedo than ice, and absorb more SW, warm, & further melt ice underneath. ➨ Older sea ice has a rougher surface, smaller & deeper melt ponds and a higher effective albedo.

Ice age declines ➨ surface becomes less rough ➨ shallower & larger-area melt ponds ➨ a smaller effective albedo ➨ further melting and to an even lower ice age area.

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(3) Ice thickness and insulation feedback:

Upward diffusive heat flux through the ice: $$F = -\kappa \frac{\partial T_{\text{ice}}}{\partial z} = -\kappa \frac{T_{\text{surface}} - T_f}{h}$$

as a result, sea ice thickness equation: $$\rho_{ice} L_f \frac{dh}{dt} = \kappa \frac{T_f - T_{\text{surface}}}{h}$$

thicker ice ➨ slower growth ➨ negative feedback.

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thicker ice ➨ slower growth ➨ negative feedback.

(4) Thickness-mobility feedback:

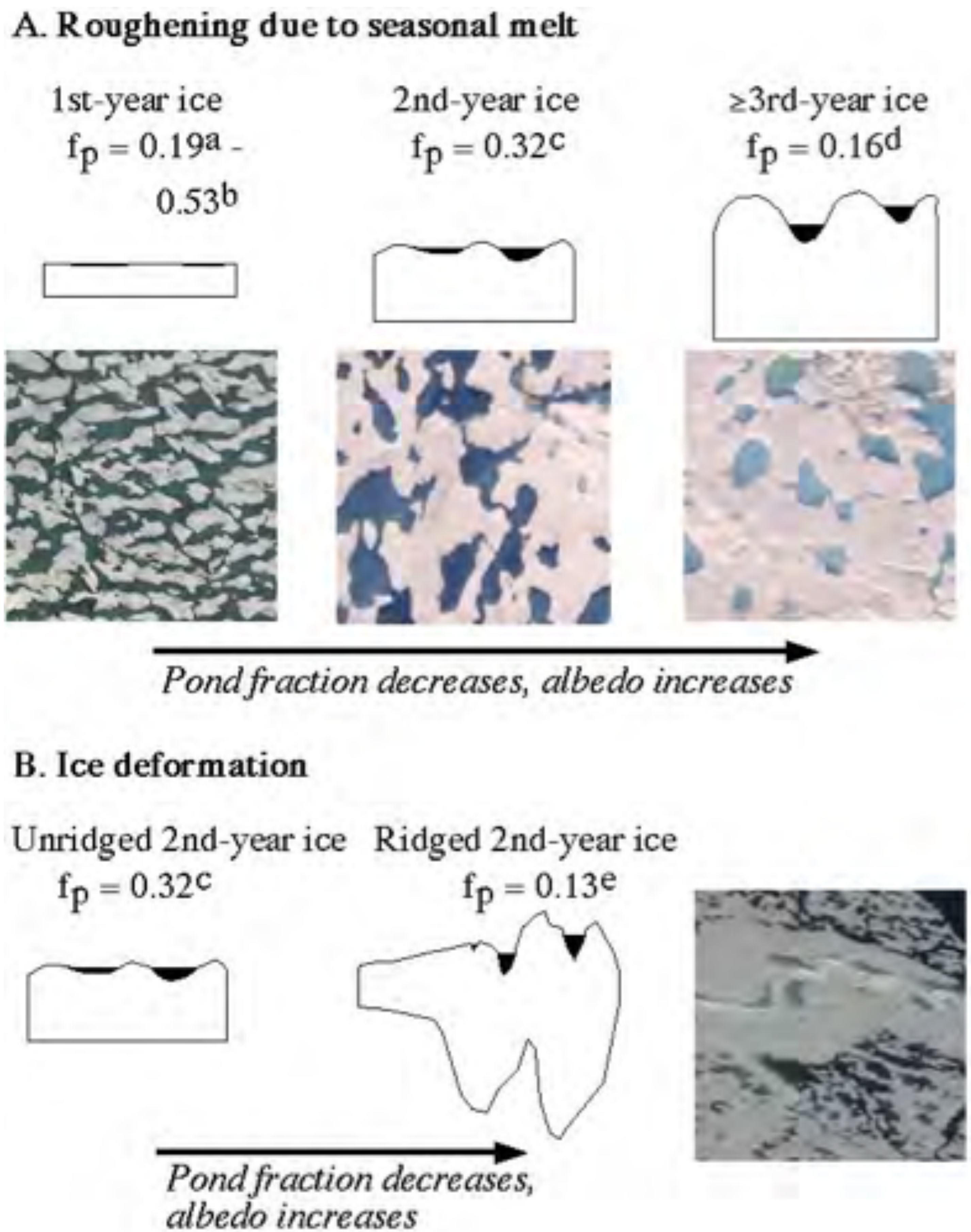
Thinner sea ice ➨ can be broken by wind & waves & transported out of Arctic by winds/currents ➨ thinner new ice in following year workshop 2: how much heat is needed to melt sea ice workshop 3: thickness-insulation feedback

leave for HW

Seasonal reduction of ice albedo due to melt ponds

- Surface consists of bare, white ice and melt ponds
- White ice surface shows stable albedo
- Areal fraction (and type) of melt pond determine large-scale ice albedo

Ice roughness and ponding

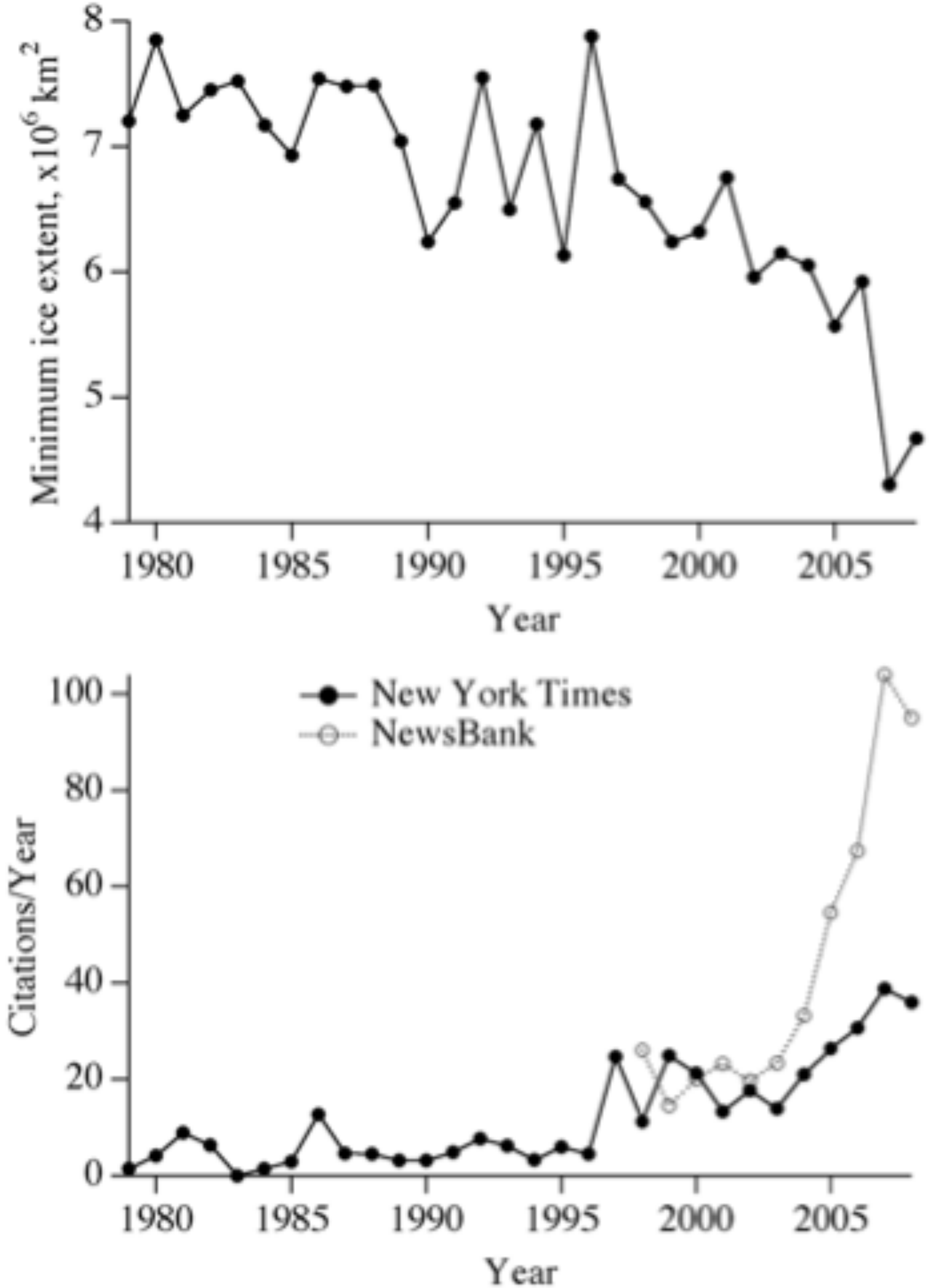


- Pond shrinkage and albedo increase with age
- Pond shrinkage and albedo increase with roughening through deformation

Hajo Eicken

workshop 4:
Sea ice age, roughness, melt ponds and albedo

Gauging societal interest



Citations (normalized) of “sea ice” in news media related to coverage of climate change, polar bears, access to the Arctic.

Hajo Eicken

Impacts of sea ice changes

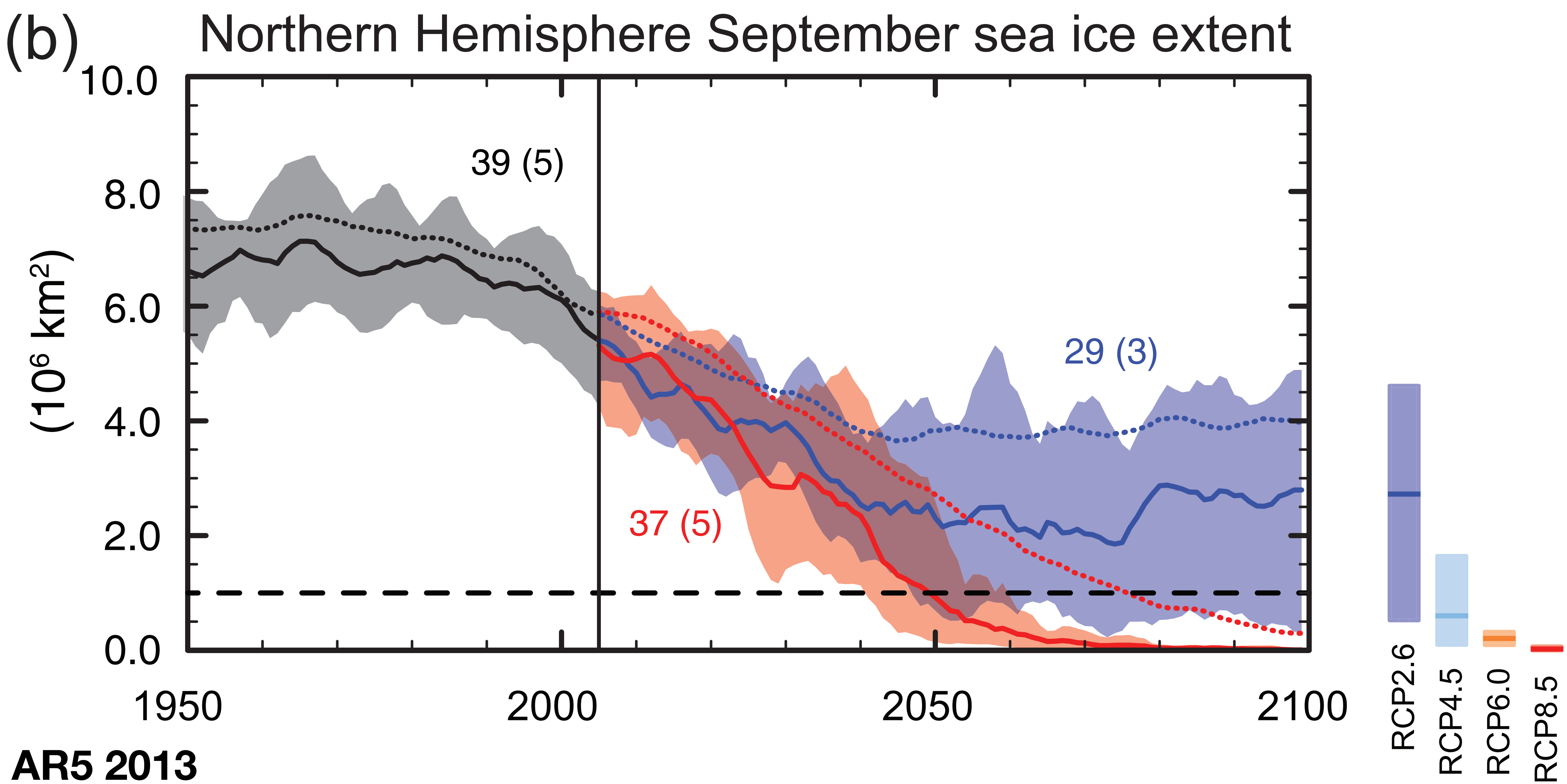
- Use of sea ice as platform by marine mammals (walrus, seals)
- Use of sea ice as a platform for hunting by Iñupiaq & Siberian Yupik hunters

Hajo Eicken

Polar bear making its way across the Arctic sea ice floe © MARTIN JAKOBSSON

workshop 5: future projections

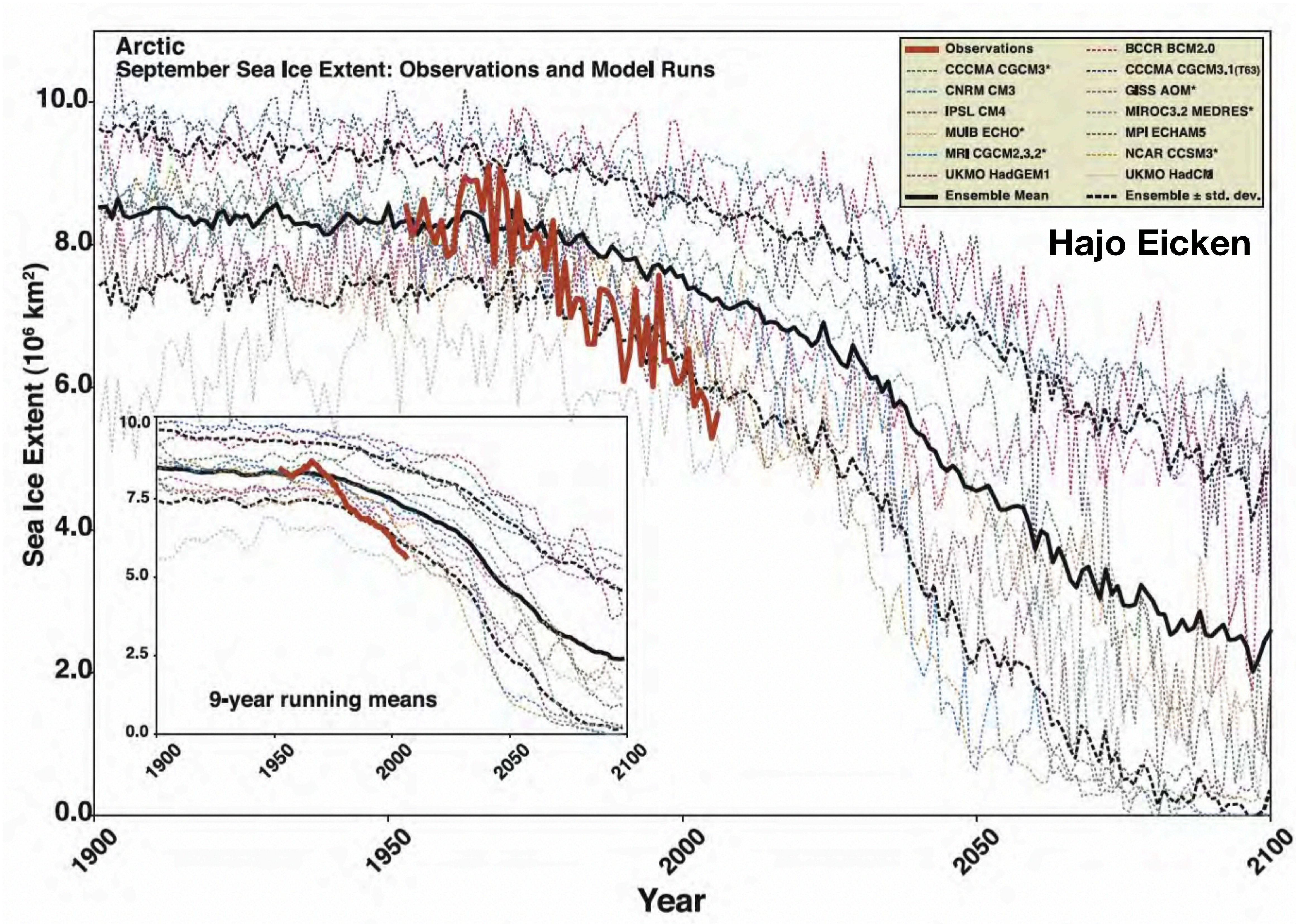
RCP projections to 2100



IPCC, AR5 2013

Northern Hemisphere September sea ice extent (5-year running mean)

The Arctic sea-ice cover: Model projections



Hajo Eicken

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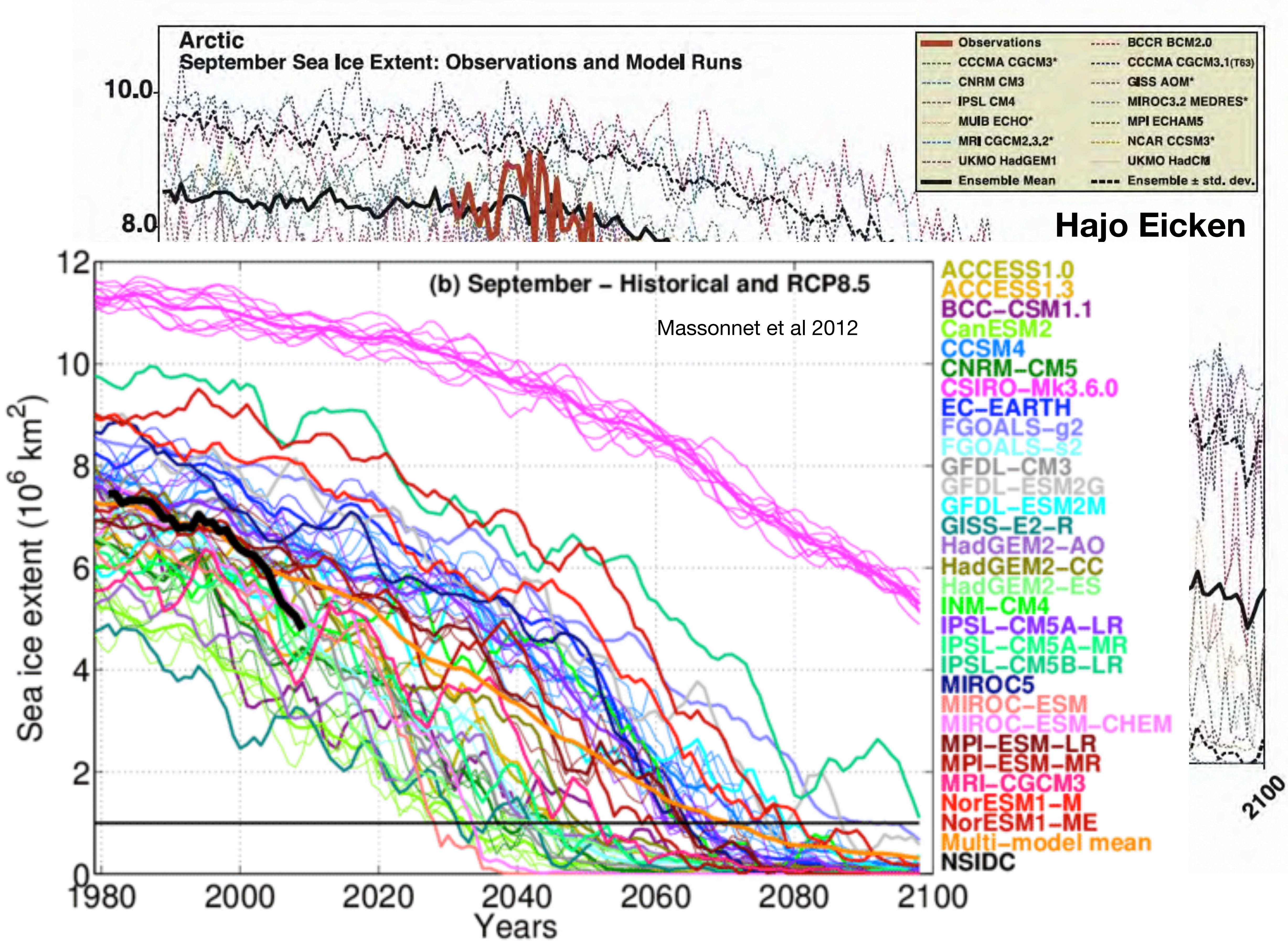

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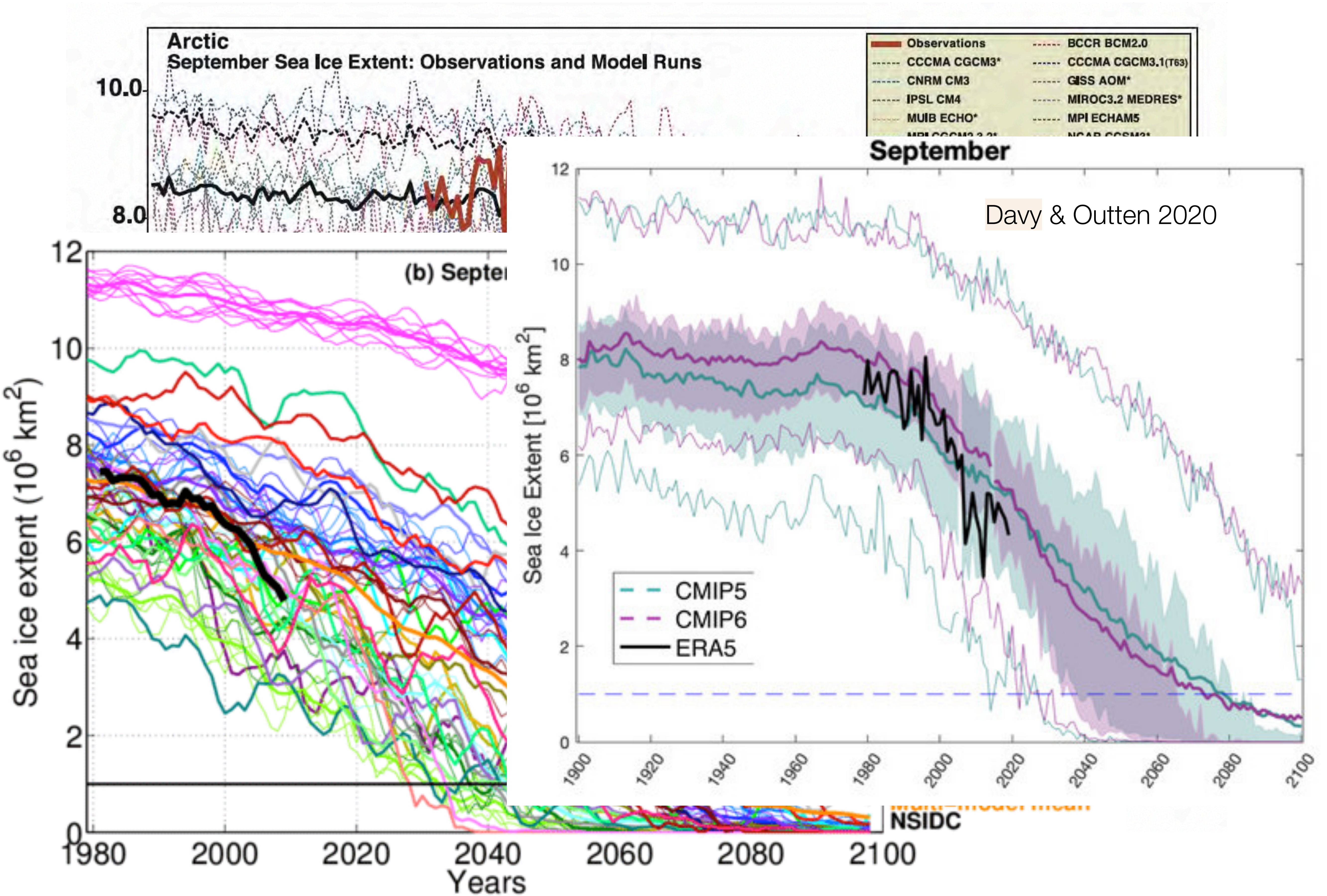


RCP projections to 2100

IPCC, AR5 2013

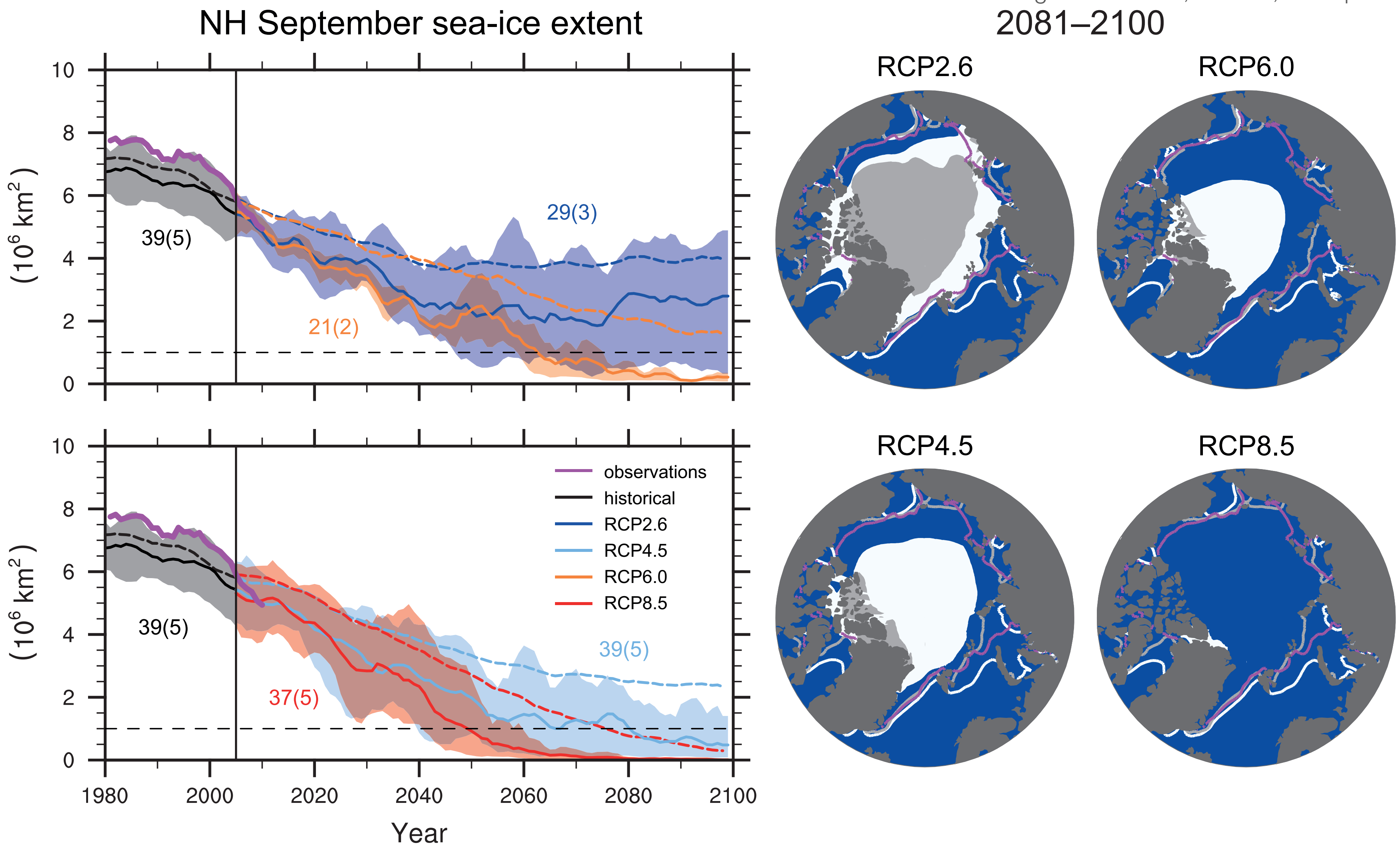
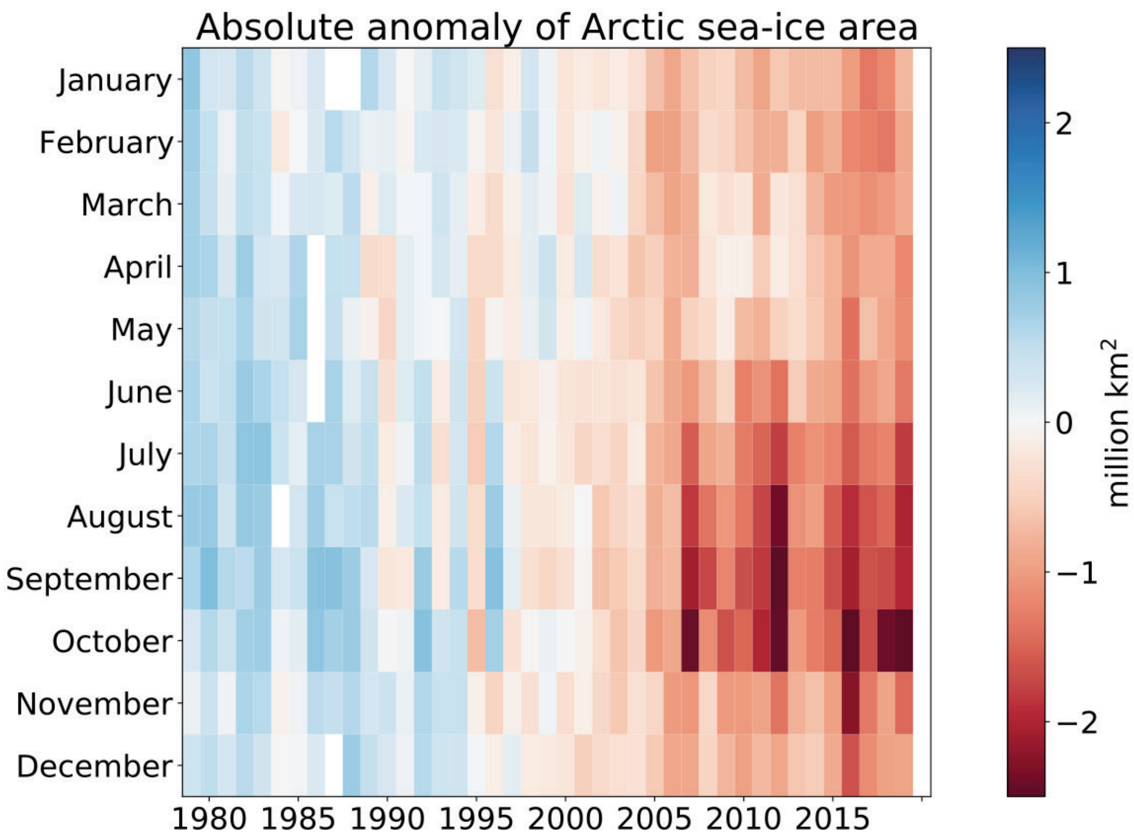


Figure TS.17 | Northern Hemisphere (NH) sea ice extent in September for RCP2.6, RCP4.5, RCP6.0, and RCP8.5 in CMIP5, and corresponding maps of multi-model results in 2081–2100 of NH September sea ice extent. In the time series, the number of CMIP5 models used to calculate the multi-model mean is indicated (subset in brackets). Time series are given as 5-year running means. The projected mean sea ice extent of a subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea ice is given (solid lines), with the minimum to maximum range of the subset indicated with shading. Black (grey shading) is the modeled historical evolution using historical reconstructed forcings. The CMIP5 multi-model mean is indicated with dashed lines. In the maps, the CMIP5 multi-model mean is given in white and the results for the subset in grey. Filled areas mark the averages over 2081–2100, lines mark the sea ice extent averaged over 1986–2005. The observed sea ice extent is in pink as a time series and averaged over 1986–2005 as a pink line in the map.

Observations and RCP projections

Arctic sea-ice historical records and CMIP6 projections

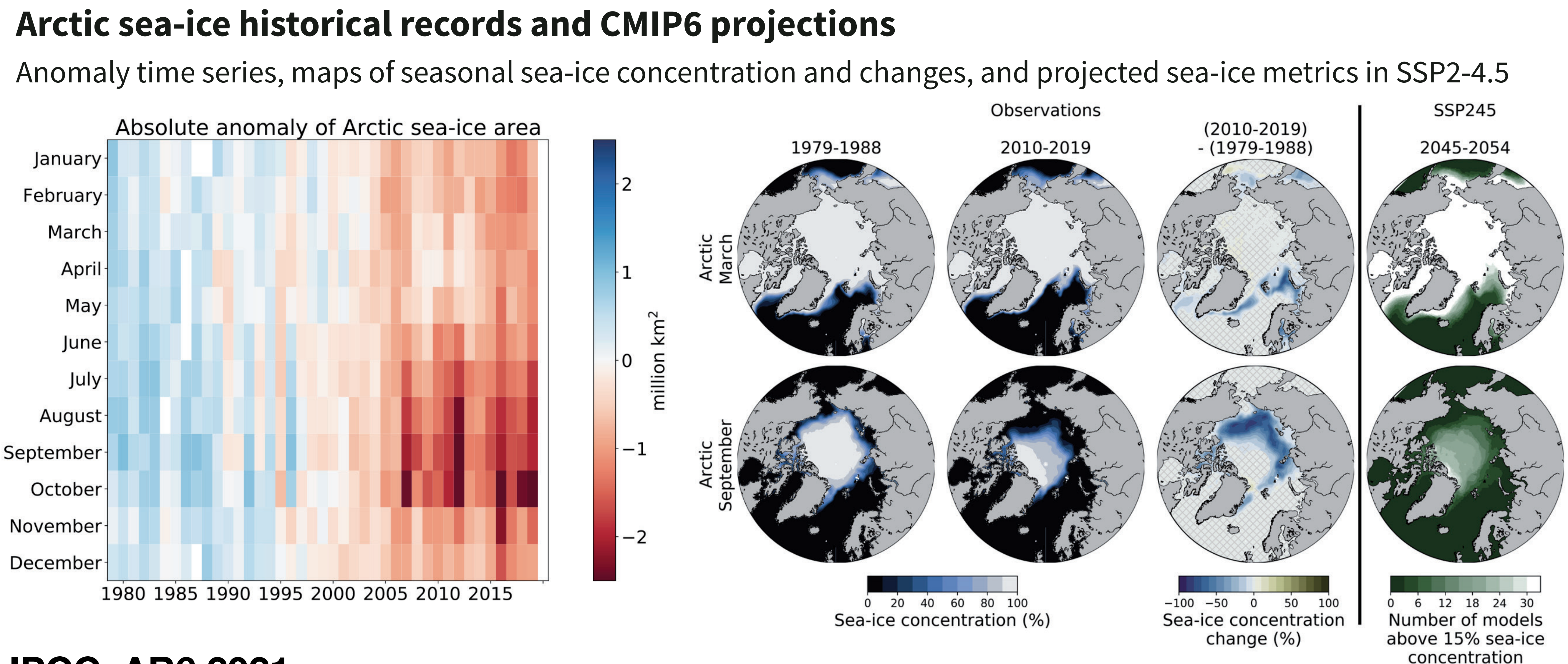
Anomaly time series, maps of seasonal sea-ice concentration and changes, and projected sea-ice metrics in SSP2-4.5



IPCC, AR6 2021

Figure 9.13 | Arctic sea ice historical records and CMIP6 projections. (Left) Absolute anomaly of monthly-mean Arctic sea ice area during the period 1979 to 2019 relative to the average monthly mean from 1979 to 2008. **(Right)** Sea ice concentration in the Arctic for March and September, which usually are the months of maximum and minimum sea ice area, respectively. First column: Satellite-retrieved mean sea ice concentration during 1979–1988. Second column: Satellite-retrieved mean sea ice concentration during 2010–2019. Third column: Absolute change in sea ice concentration between these two decades, with grid lines indicating non-significant differences. Fourth column: Number of available CMIP6 models that simulate a mean sea ice concentration above 15 % for 2045–2054.

Observations and RCP projections



IPCC, AR6 2021

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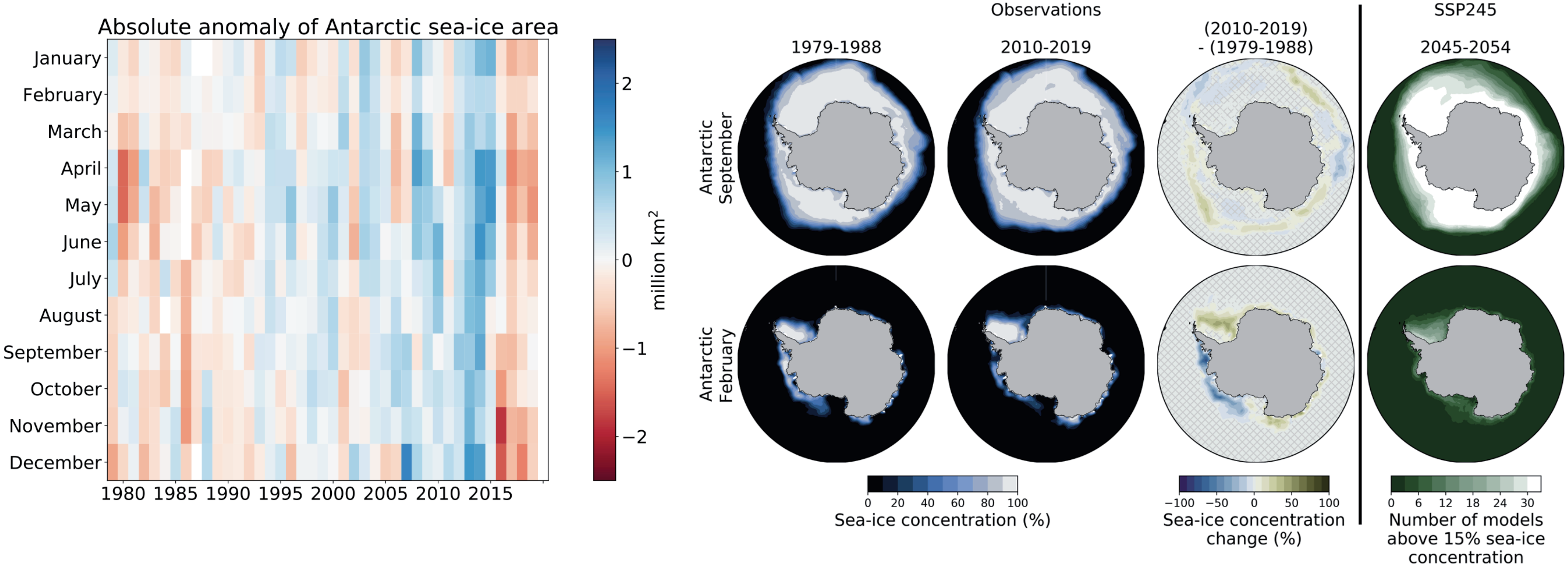

IPCC, AR6 2021

Figure 9.15 | Antarctic sea ice historical records and CMIP6 projections. (Left) Absolute anomaly of observed monthly mean Antarctic sea ice area during 1979–2019 relative to the average monthly mean during 1979–2008. **(Right)** Sea ice coverage in the Antarctic as given by the average of the three most widely used satellite-based estimates for September and February (usually the months of maximum and minimum sea ice, respectively). First column: Mean sea ice coverage during 1979–1988. Second column: 2010–2019. Third column: Absolute change in sea ice concentration between these two decades, with grid lines indicating non-significant differences. Fourth column: Number of available CMIP6 models that simulate a mean sea ice concentration above 15% for 2045–2054.

Notes: section 9.2, detection of climate change
(use following three slides)

Anthropogenic climate change detection

- Specify N: sea ice area time series segment-length in years.

Anthropogenic climate change detection

- Specify N: sea ice area time series segment-length in years.

- Scan a long model sea ice area time series, calculate trends by a linear fit to September area time series in each N-year interval: $area = a \times year + b$.

Anthropogenic climate change detection

- Specify N: sea ice area time series segment-length in years.
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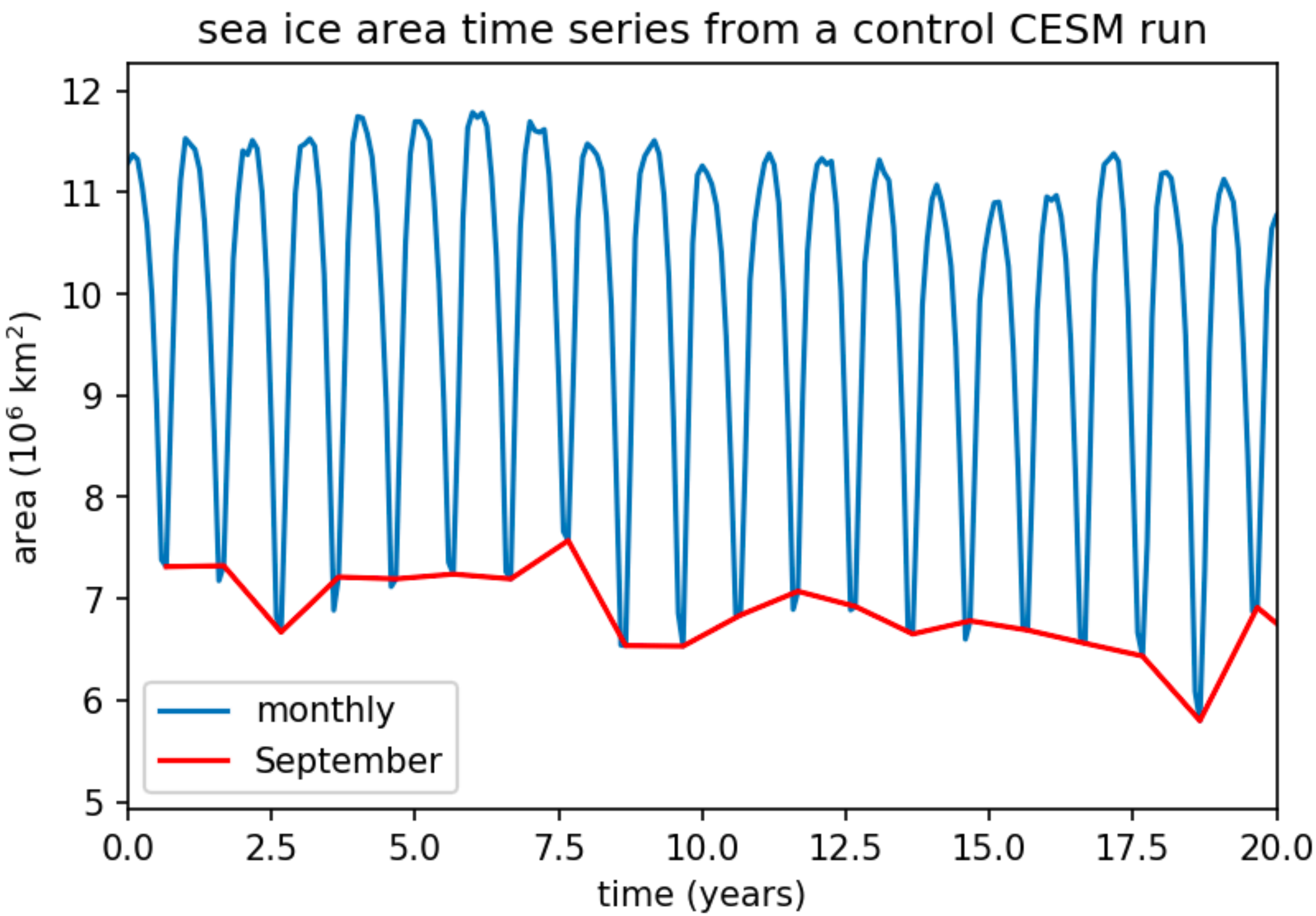
- Repeat for different time intervals N, from two to a hundred years, to find the PDF as a function of time interval N and trend amplitude T: $PDF(N, T)$.

Climate change detection



Sea ice area time series from a “control” run of a climate model, using a fixed preindustrial CO_2, showing 3 example four-year trends.

Trends are calculated as the least-square line fit to the points in the year-range in question.

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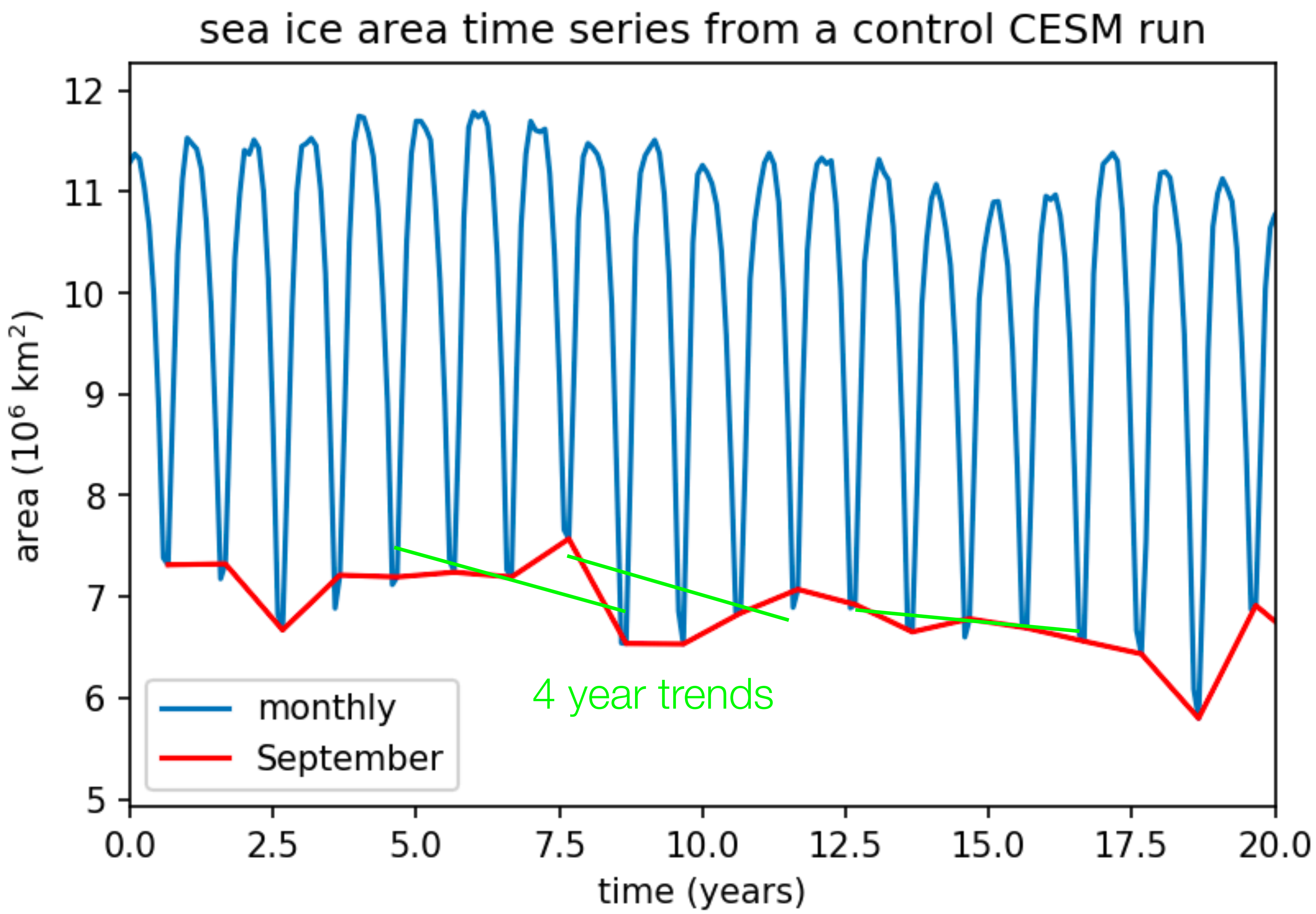

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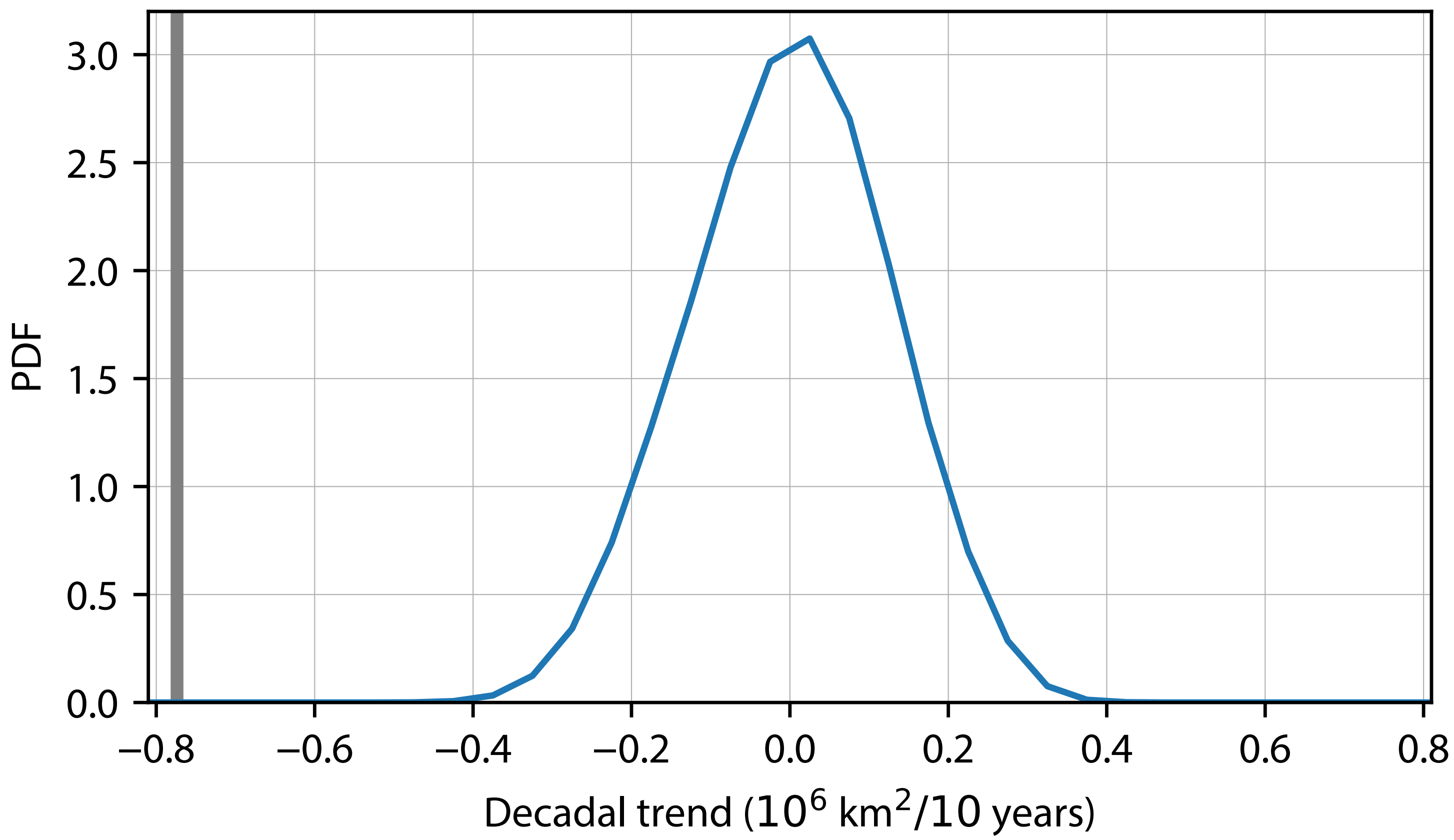

Figure 9.7: Detection and attribution of sea ice trends. The probability density function of multi-year trends in the annual minimum sea ice area, as a function of the trend magnitude, when examining intervals of 41 yr in a long run of a climate model. The observed trend, over a similar interval, is marked by the vertical gray bar.

[Following Vinnikov et al 1999 Fig 3]

The probability of encountering a trend in $(T, T + \Delta T)$ over a 40-yr period in the absence of Anthropogenic climate change, is $PDF(T)\Delta T$. The PDF at the observed trend (vertical bar) is ≈ zero ➡ the observed trend is not due to natural variability.

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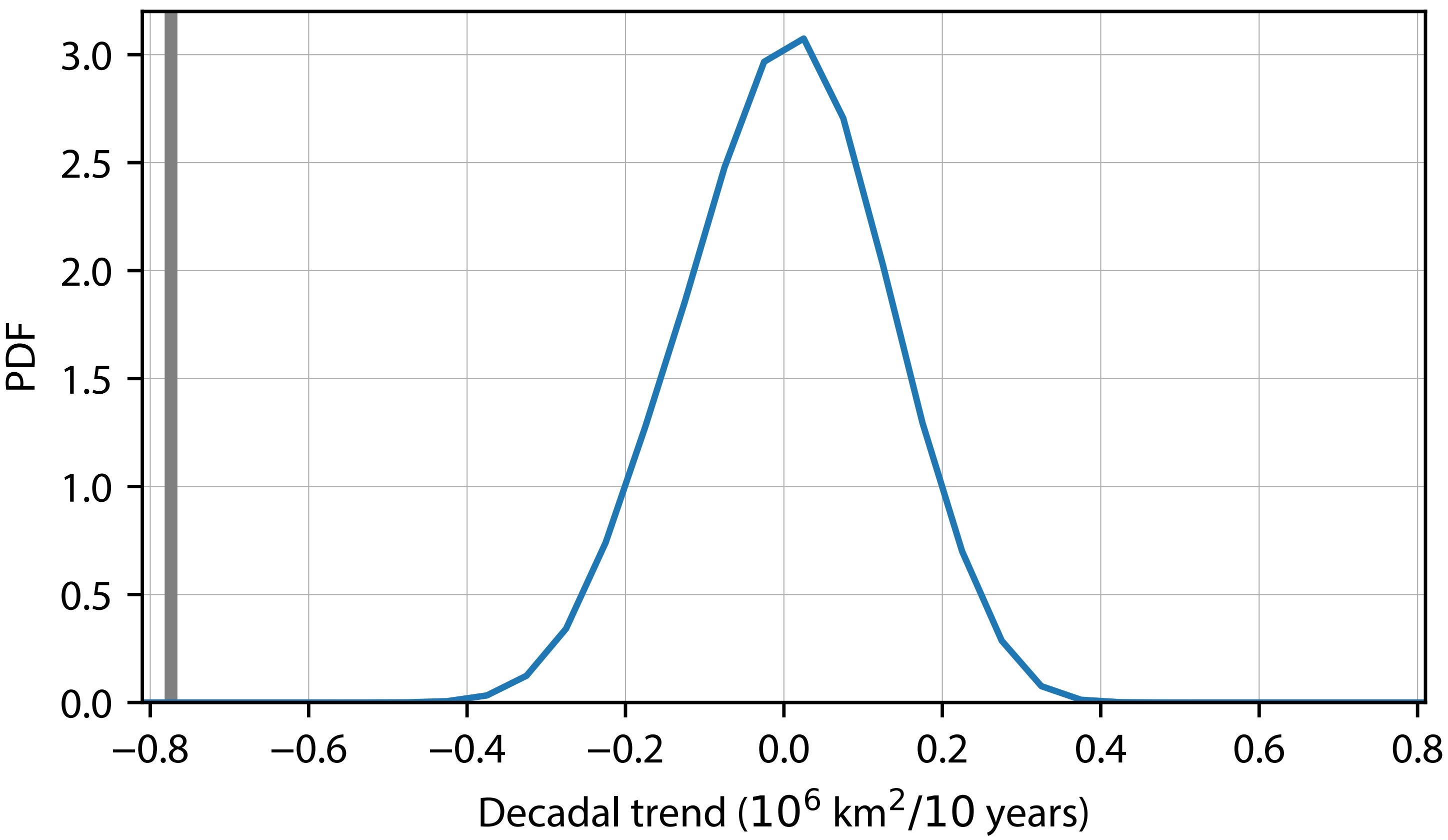

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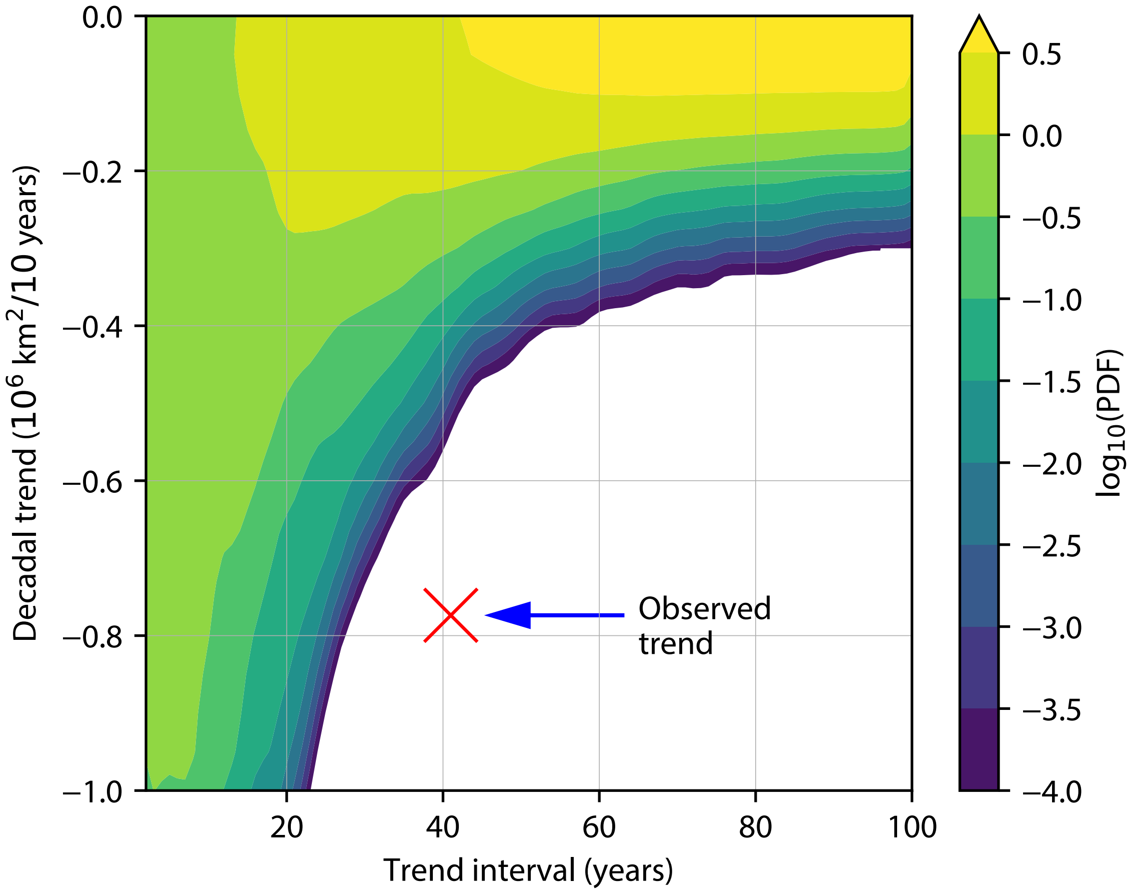

Figure 9.8: Detection and attribution of sea ice trends. The probability density function of multi-year trends in the annual sea ice minimum area, as a function of the trend magnitude (showing only trends that correspond to sea ice decline) and the interval length, in a long run of a climate model. The observed trend is marked by a red symbol.

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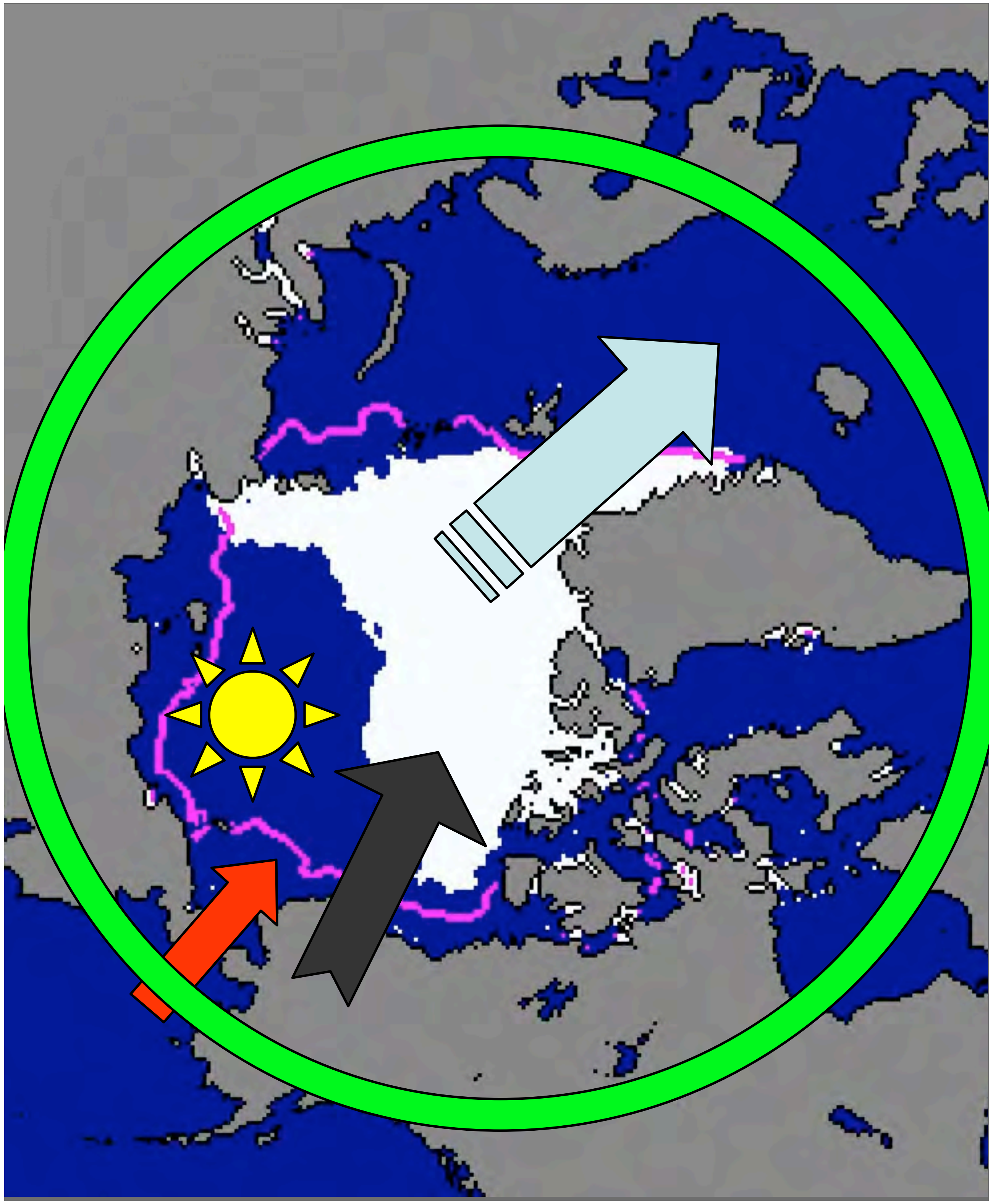
workshop 6: detection of climate change

Processes leading to 2007 Arctic sea ice minimum



Hajo Eicken

(1) Unusual weather pattern: persistent southerly winds brought warm air and moved ice towards North Pole in 2007
(2) Submarine data indicate 40% reduction in ice thickness between 1950s & 1990s ➡ Long-term ice thinning in line with Arctic warming driven by impact of greenhouse gases on longwave radiation balance
(3) Thinner, more mobile ice cover more susceptible to extreme summer retreat
(4) Warming of water north of Alaska as a result of thinned & reduced ice cover melts back ice from below in summer (>2 m of summer bottom melt north of Alaska!); less clouds in 2007
(5) Warm inflow of water through Bering Strait(?)

workshop #7: animation…!

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5. Climate change detection/attribution using a long model run shows Arctic trend is impossible without Anthropogenic change

The End