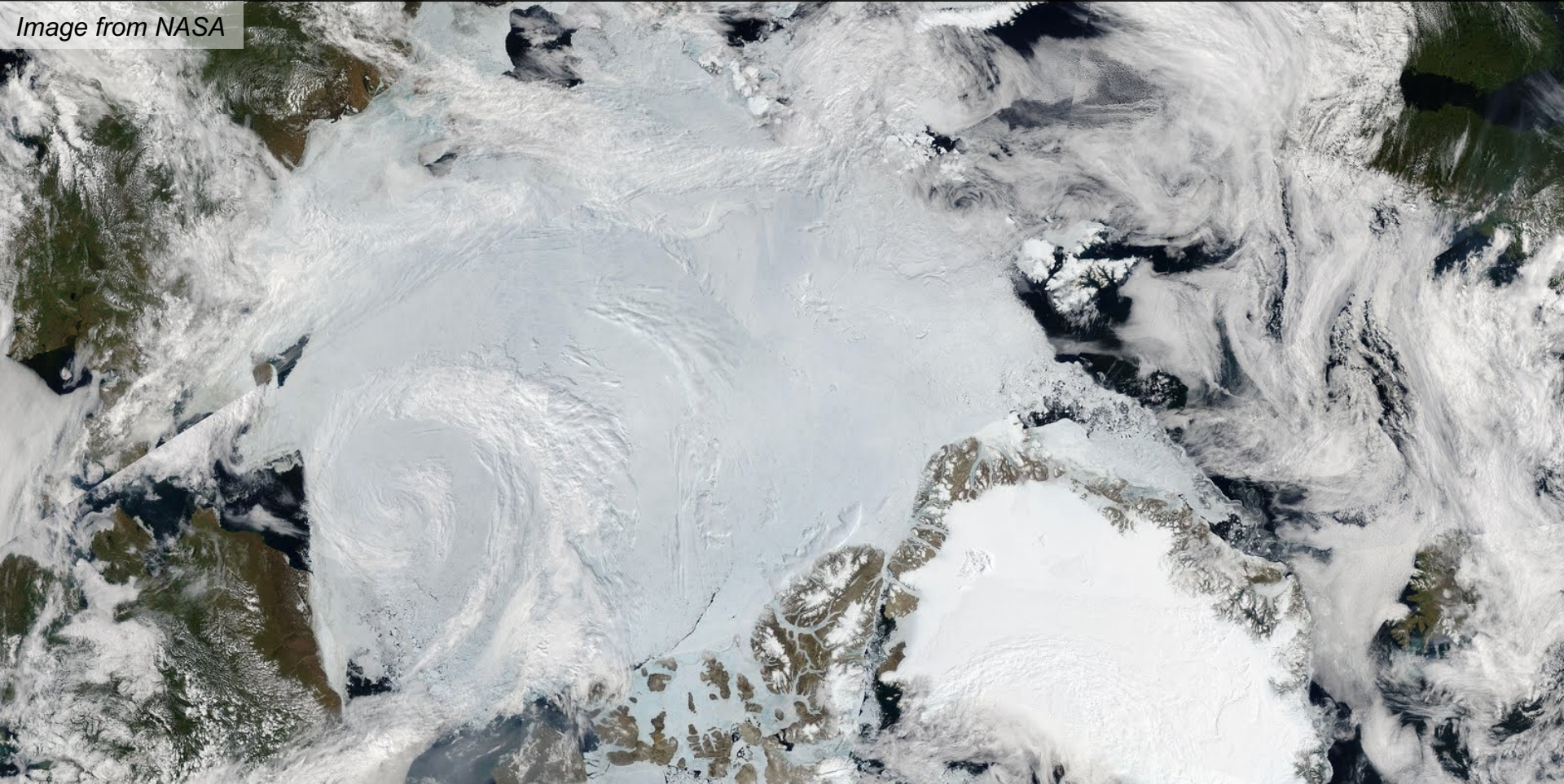


Modeling climate extremes in the new Arctic and the possible impacts on vessel traffic

AGCI Arctic Climate and Weather Extremes – May 20, 2022

Image from NASA



Alice DuVivier - duvivier@ucar.edu
Laura Landrum, Marika Holland, and many others



NCAR

Science Questions



Photo: Greenland Adventure Tours

1) What is an extreme in the “new Arctic” climatologically speaking?

2) What are some human impacts of this “extreme” new state?

The Arctic as we know it is changing rapidly



Photo: Greenland Adventure Tours

1) What is an extreme in the “new Arctic” climatologically speaking?

Photo: Steffen Olsen, Danish Met Institute, June 2019



What does it mean to be “extreme” in a changing climate?

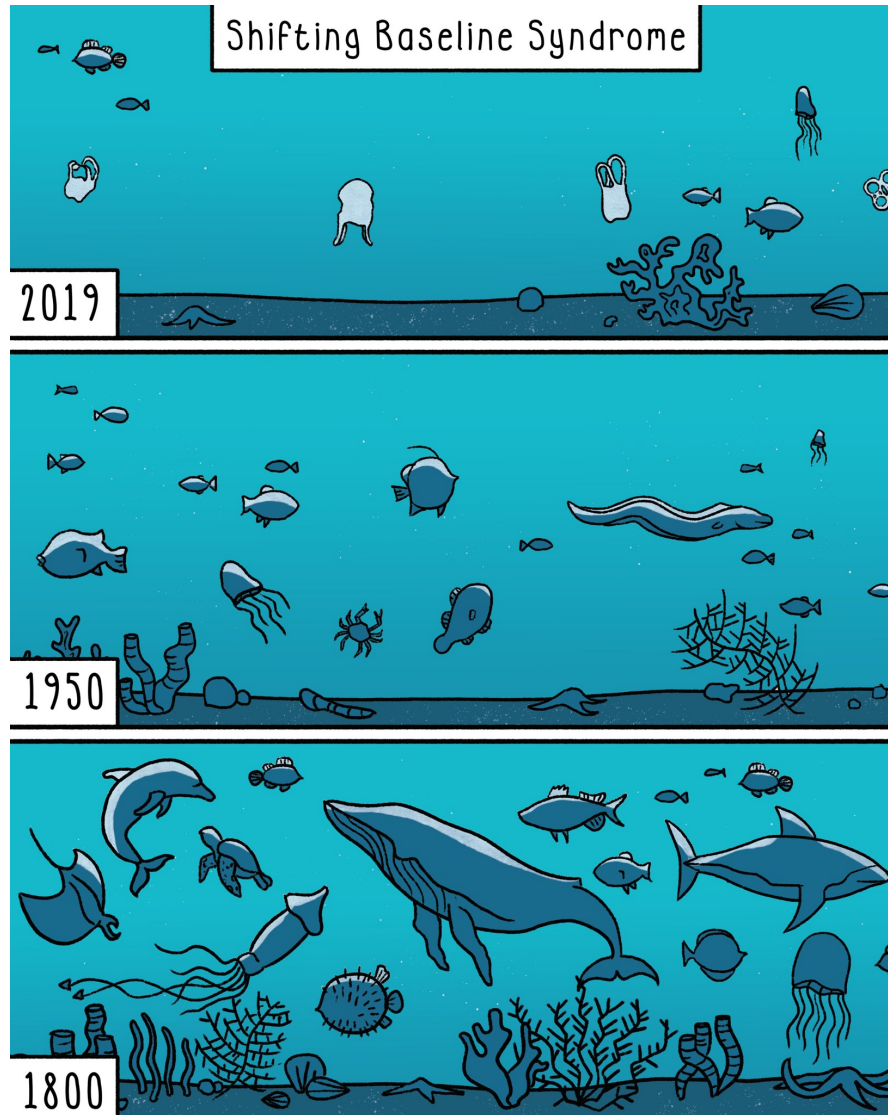


Image: Cameron Shepherd



Arctic temperatures are increasing fastest over the globe.

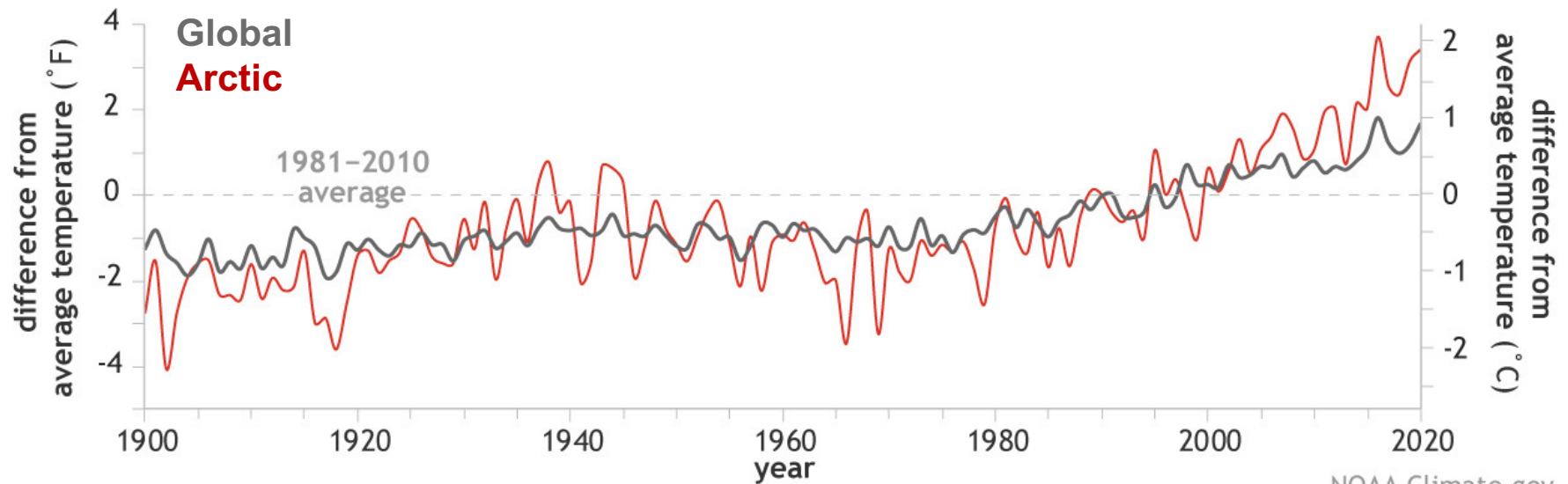


Figure: Climate.gov

NOAA Climate.gov
Data: ARC 2020

Arctic temperatures are increasing fastest over the globe.

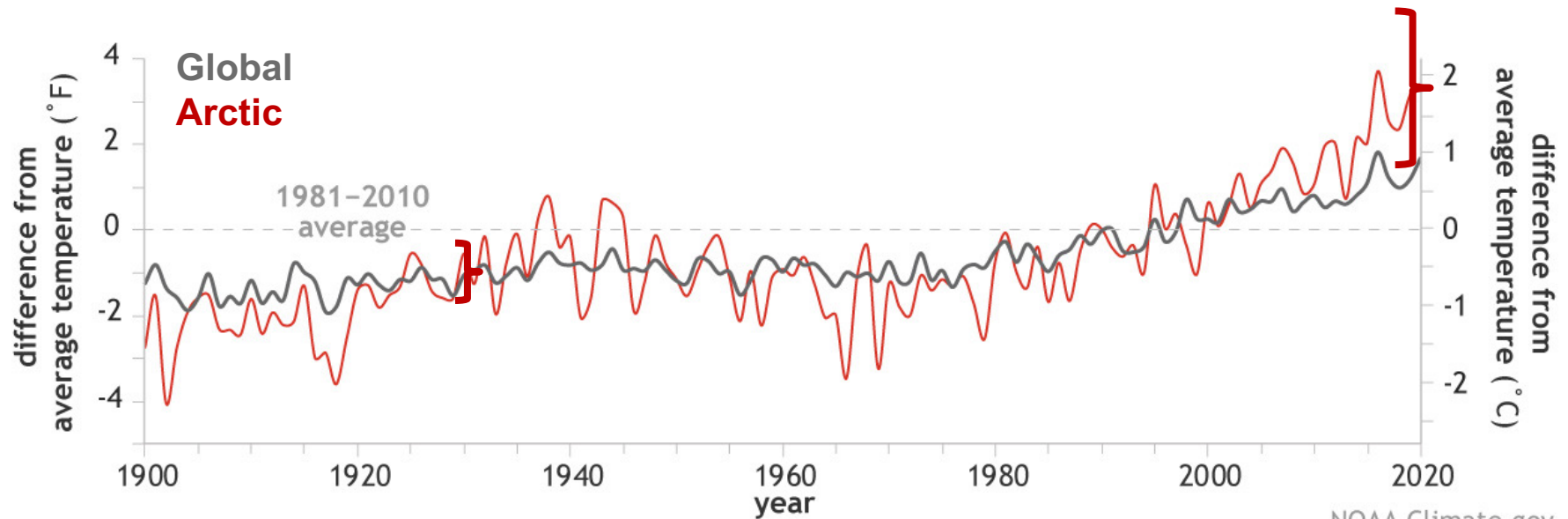


Figure: Climate.gov

NOAA Climate.gov
Data: ARC 2020

Both the mean and the spread can change.

Coupled Earth System Model Large Ensembles are crucial for understanding statistics of climate change.

Preindustrial Control Simulation

- 100's – 1000's of years
- Constant forcing



Coupled Earth System Model Large Ensembles are crucial for understanding statistics of climate change.

Historical + Future radiative forcing

- 1850-2100
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Introduce Perturbation

- Same Model
- Same forcing
- $1e-14$ K in initial atmospheric temperature



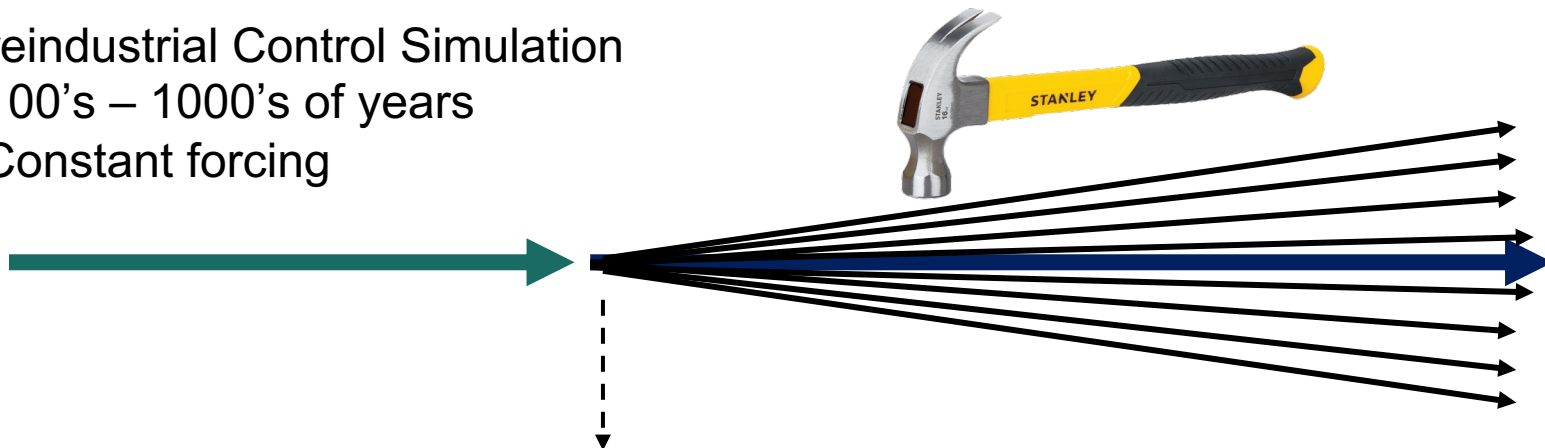
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Introduce Perturbation

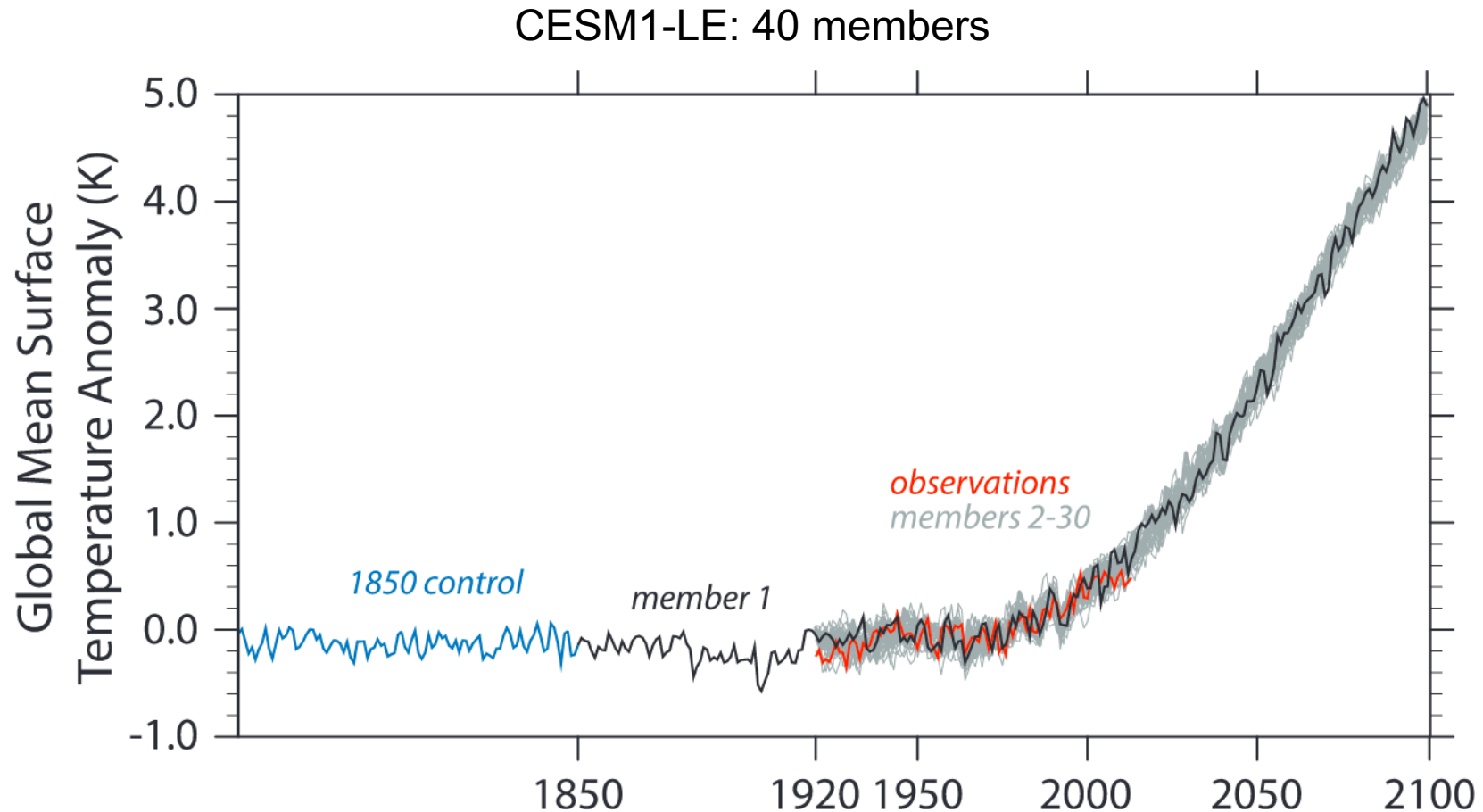
- Same Model
- Same forcing
- $1e-14$ K in initial atmospheric temperature



$t = 0$

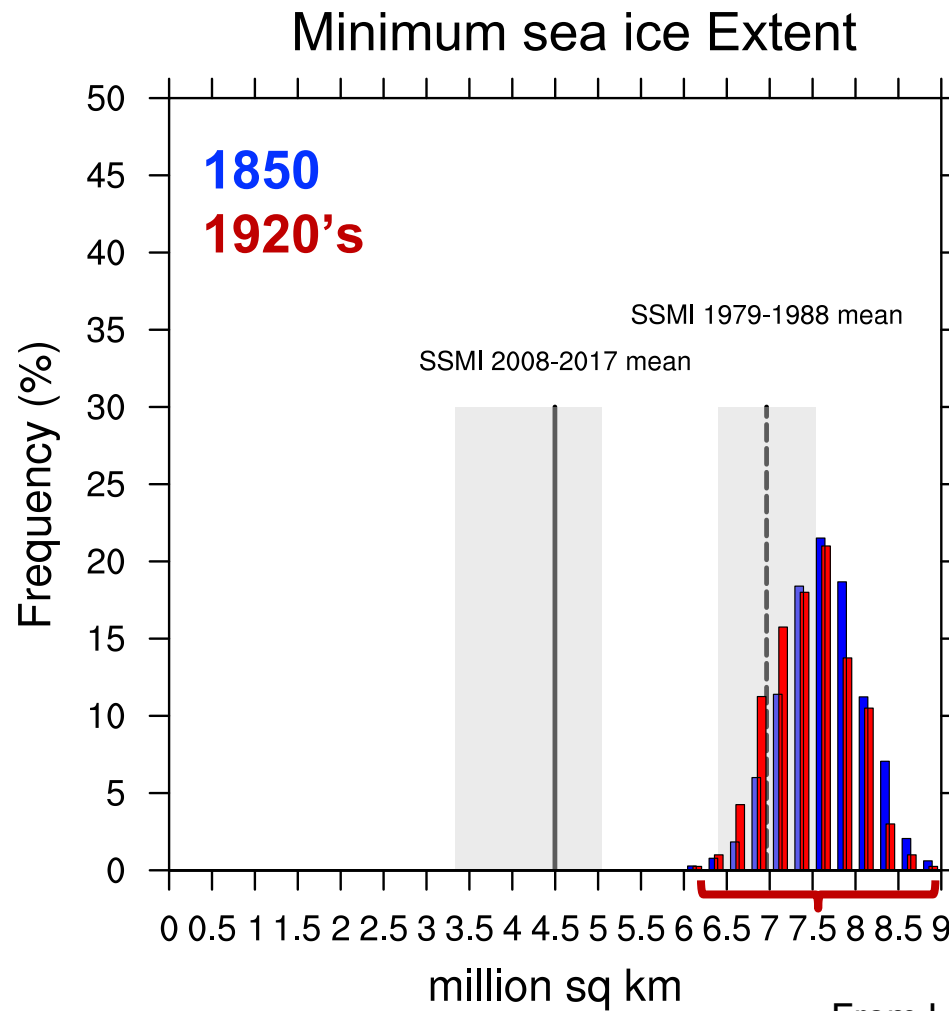
From: Twitter @fermatslibrary

Large Ensembles provide sufficient samples help constrain what is normal or extreme in a changing climate.



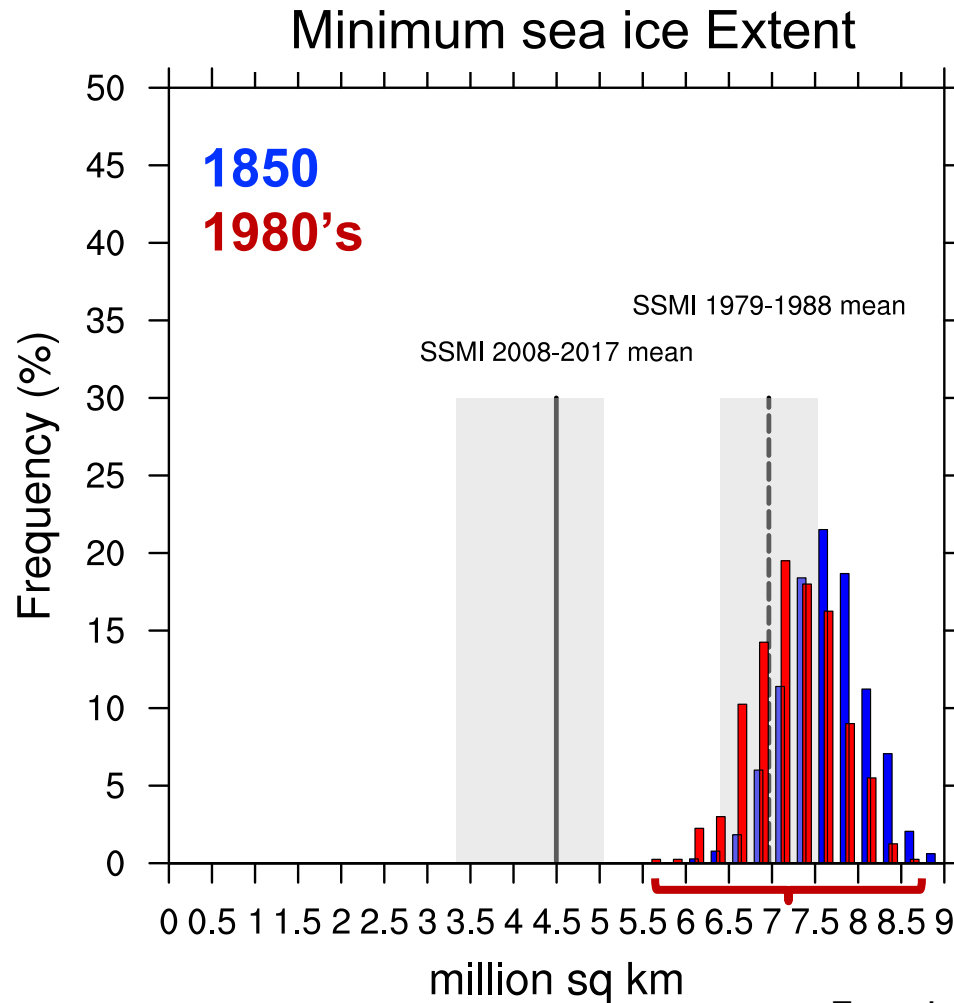
From Kay et al. 2015

What is “normal” minimum sea ice in the future?



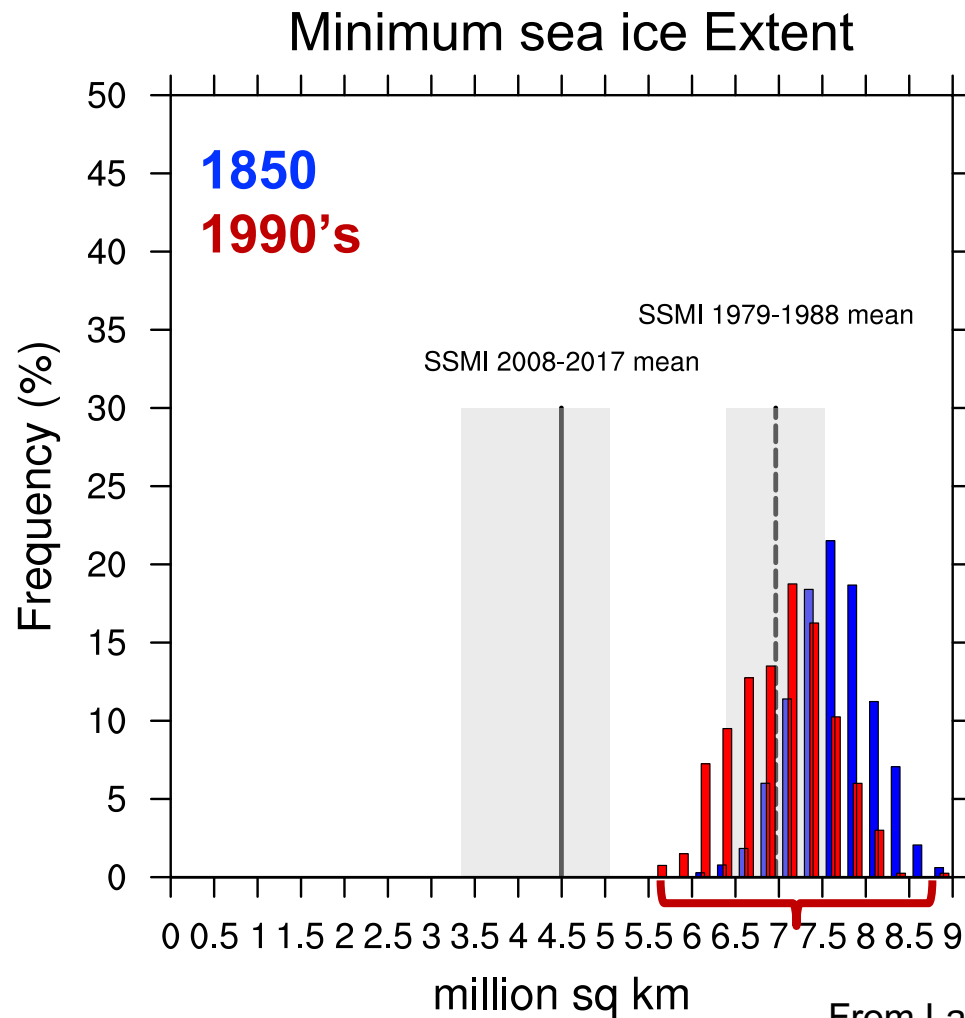
From Landrum and Holland 2020

What is “normal” minimum sea ice in the future?



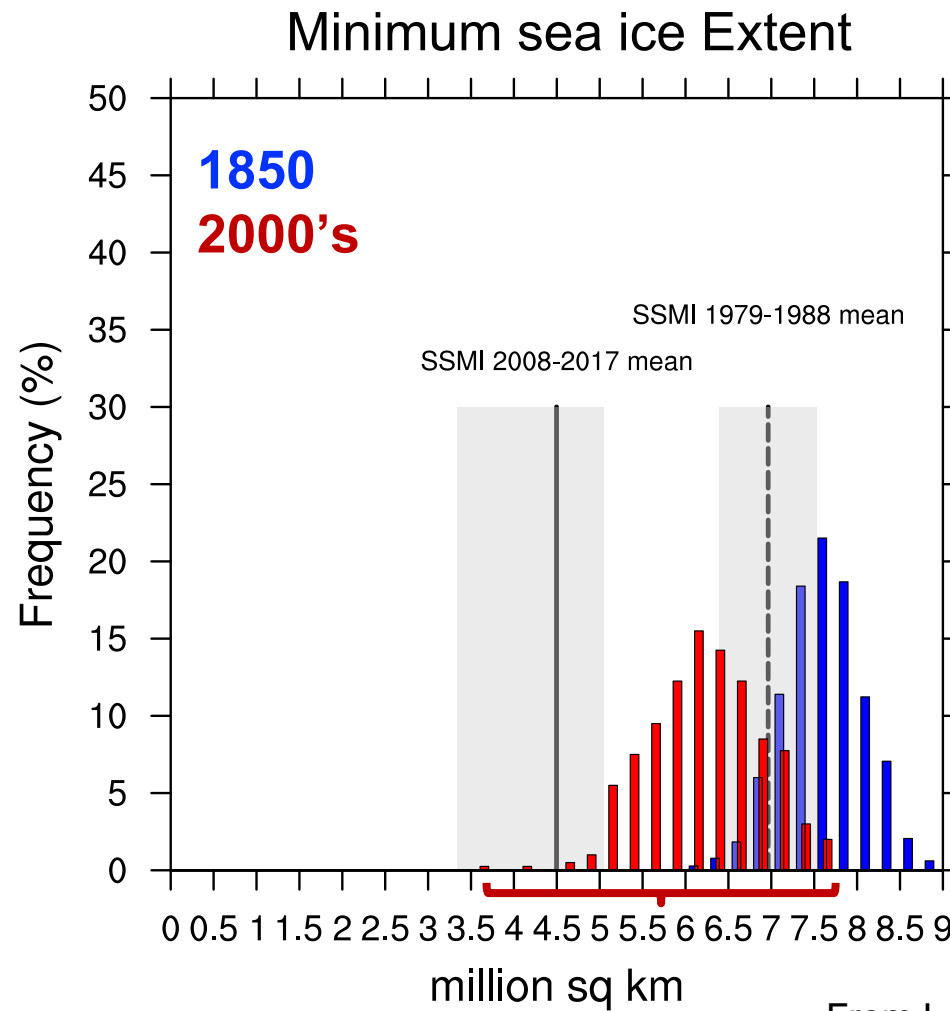
From Landrum and Holland 2020

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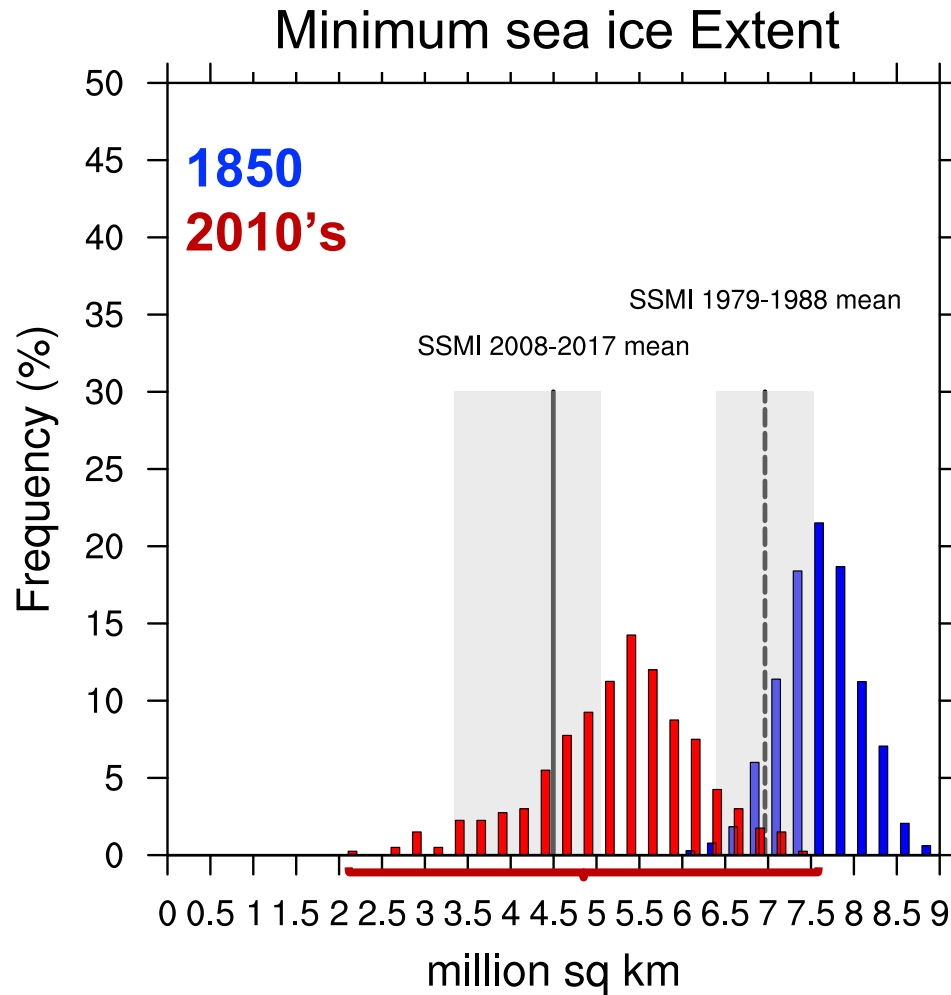
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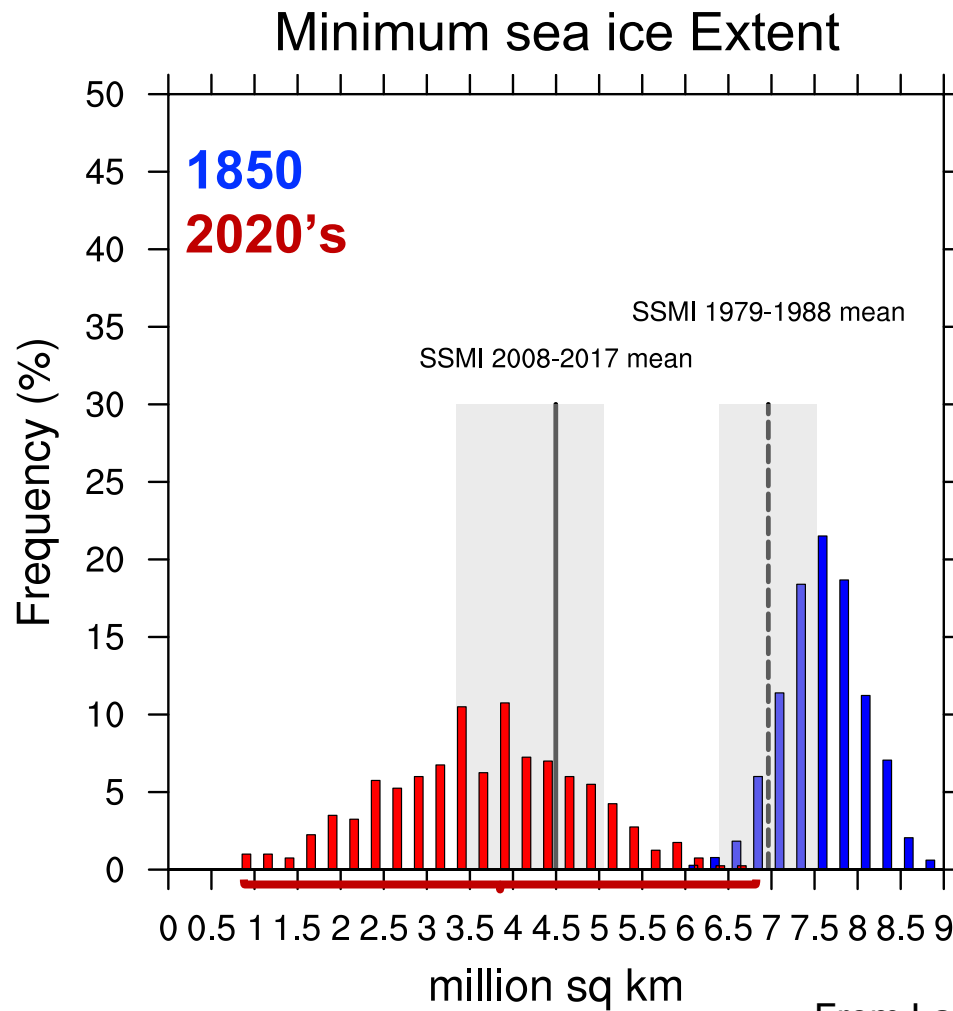
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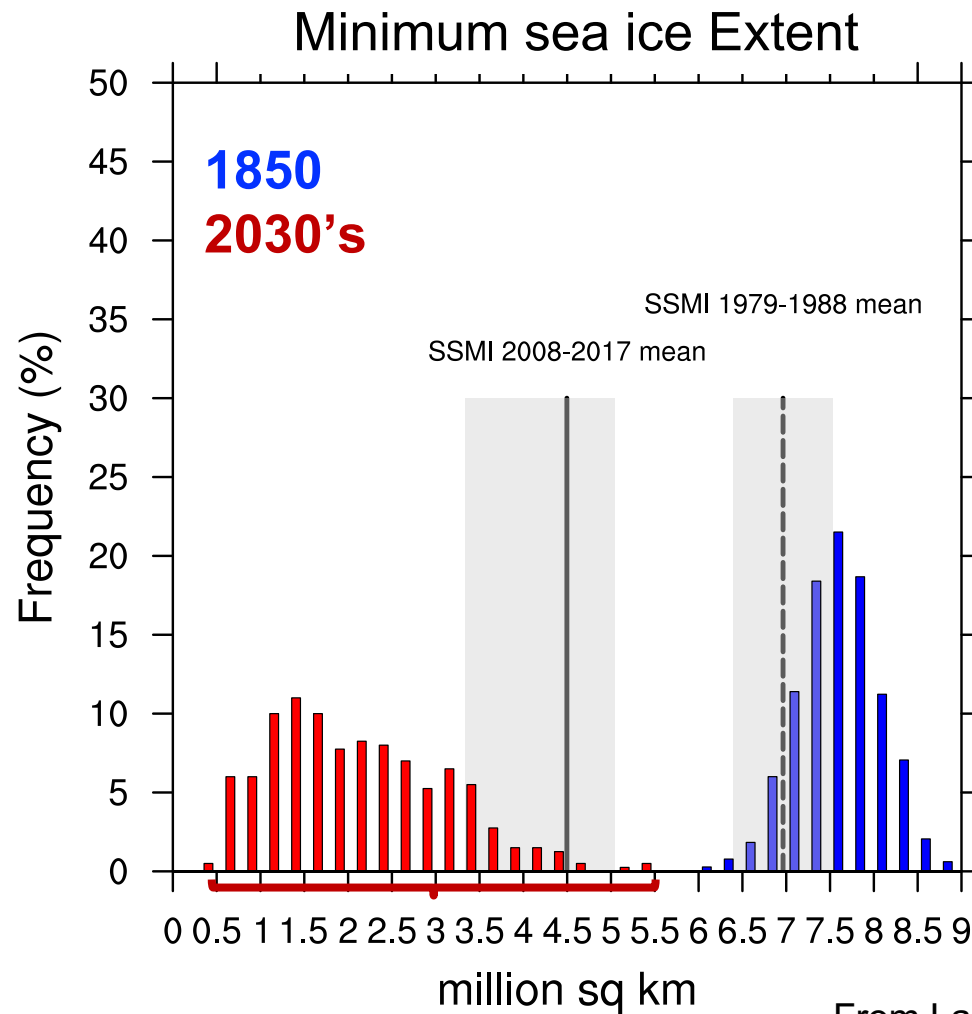
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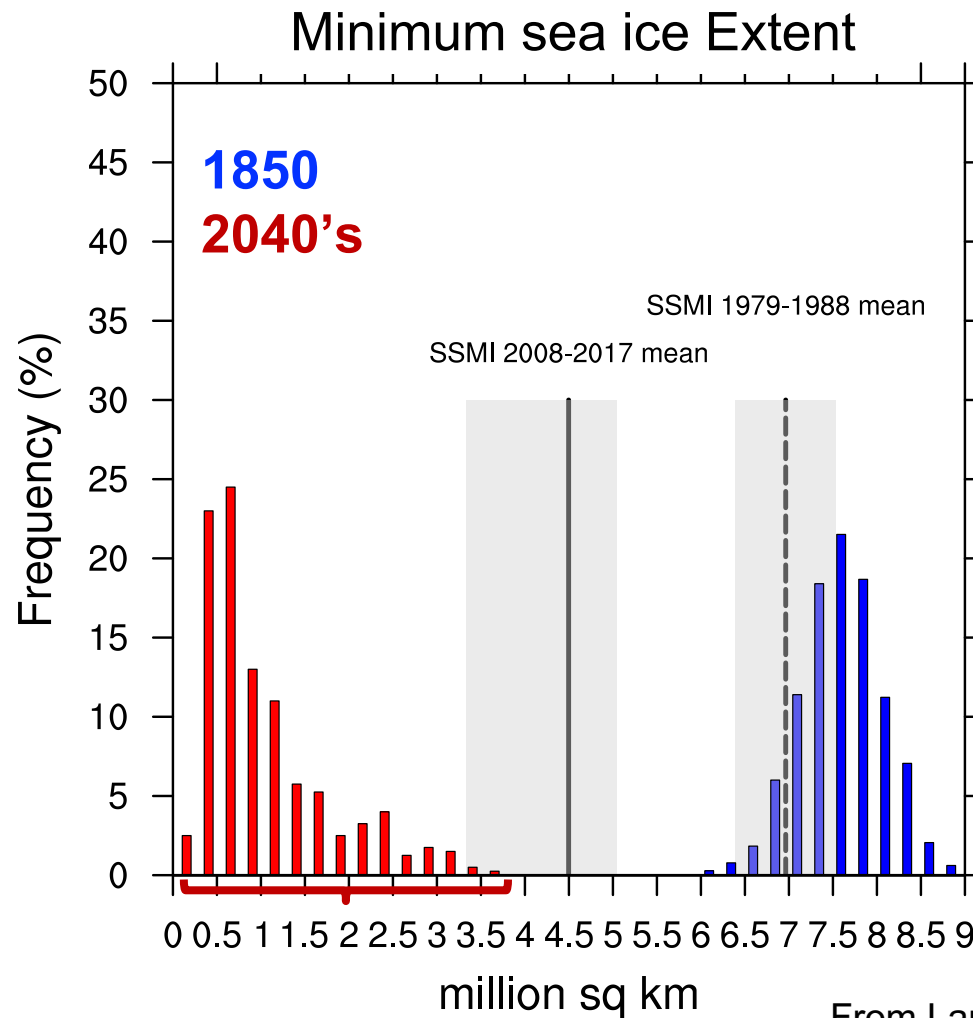
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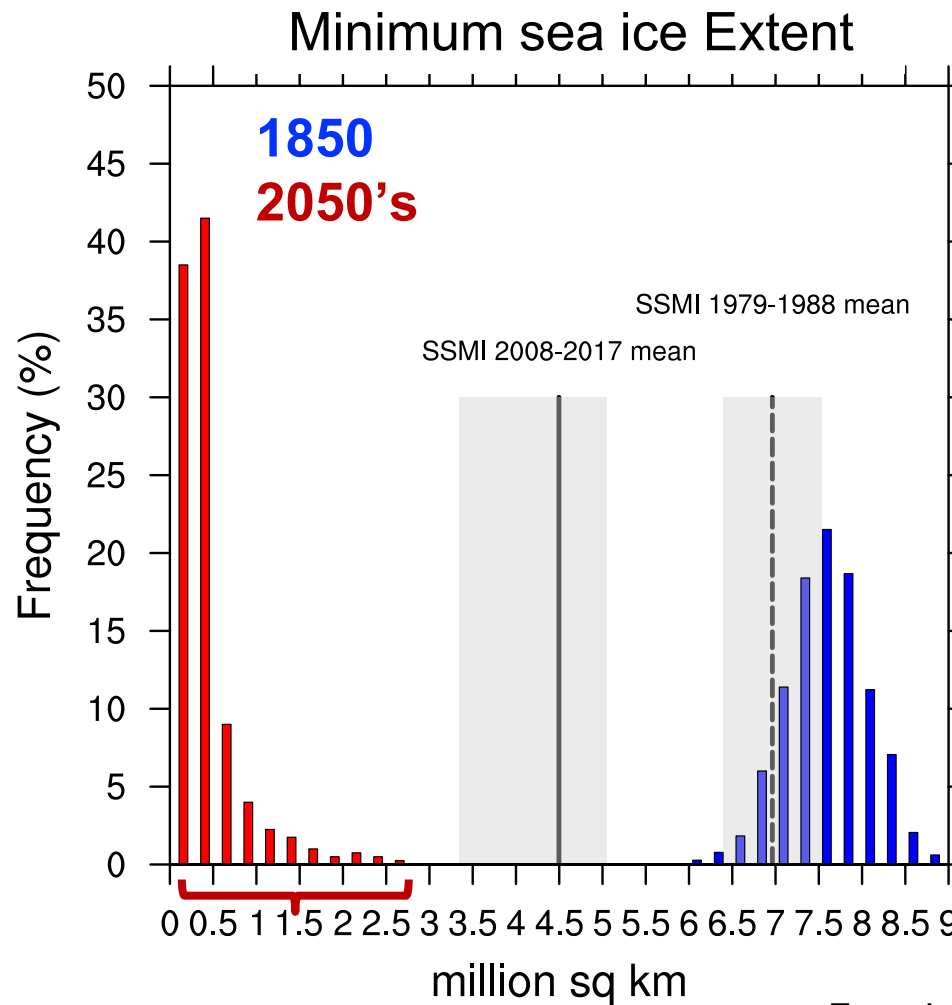
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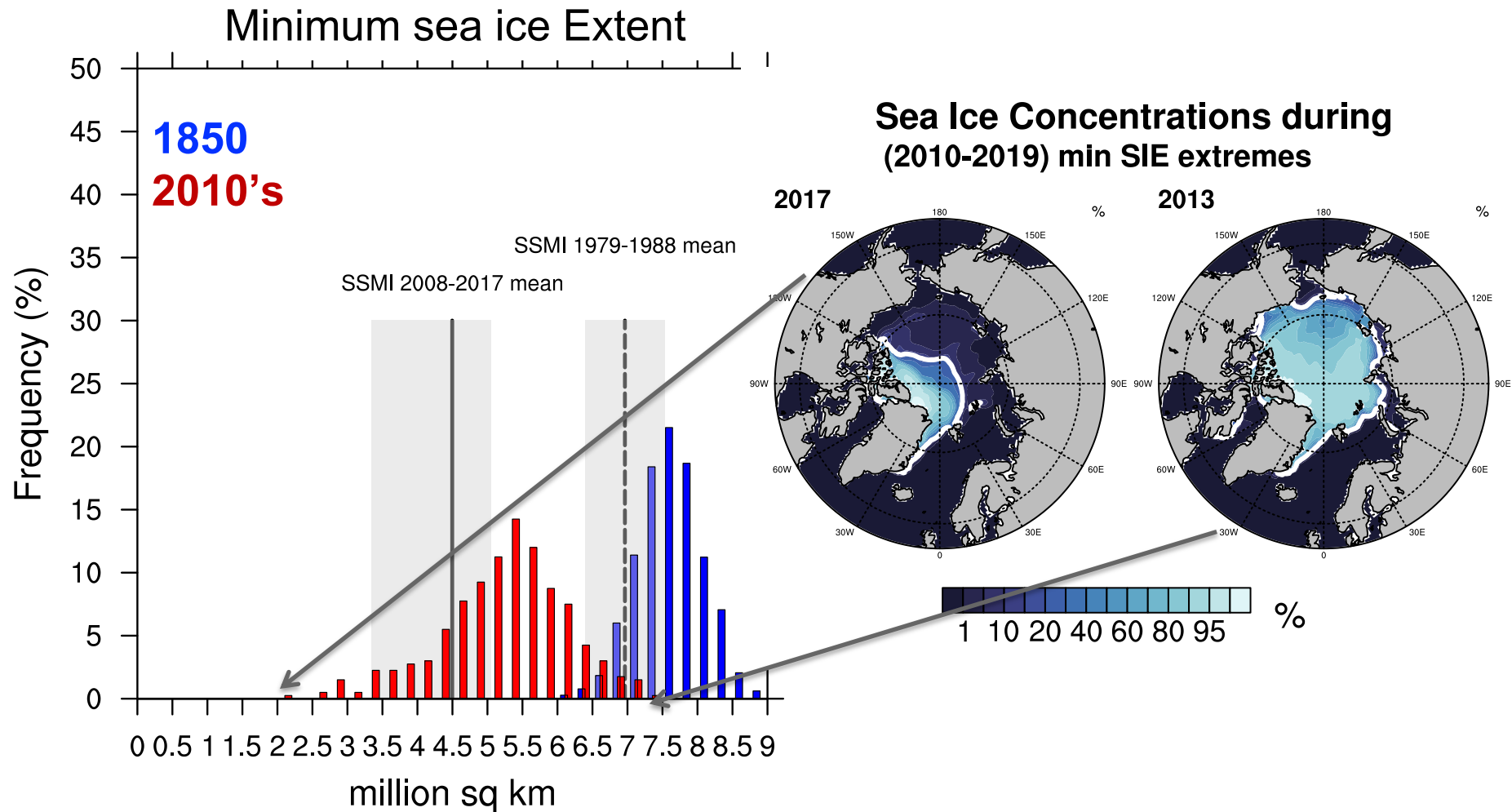
From Landrum and Holland 2020

What is “normal” minimum sea ice in the future?



From Landrum and Holland 2020

What do “extreme” ice extent look like with wider distribution?

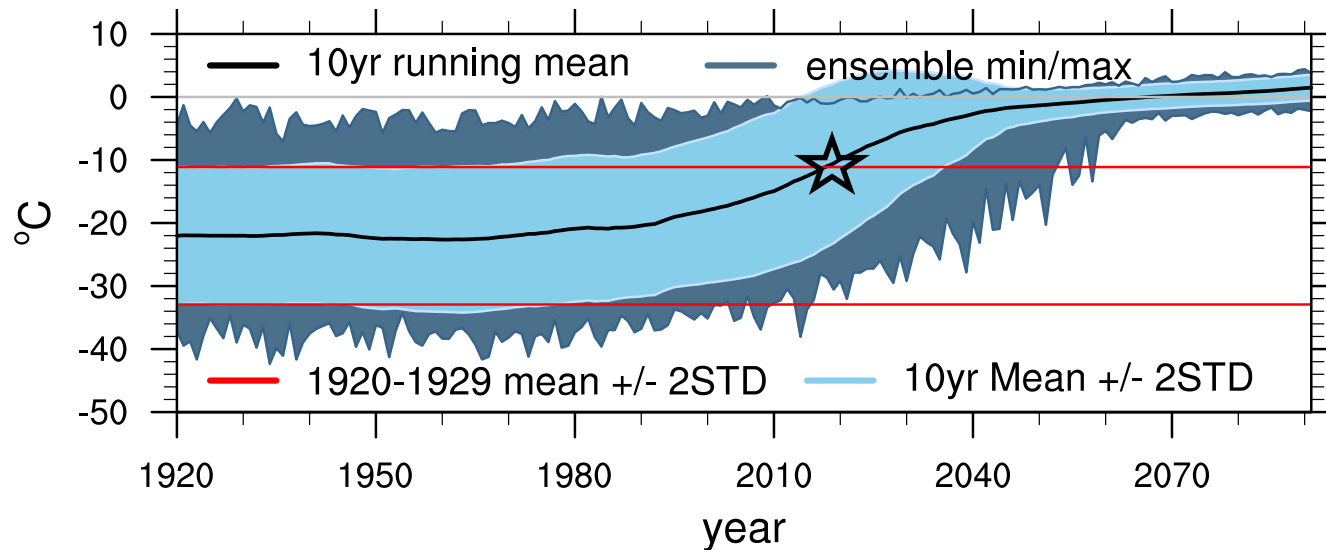


From Landrum and Holland 2020

So when do “extremes” become “normal”?

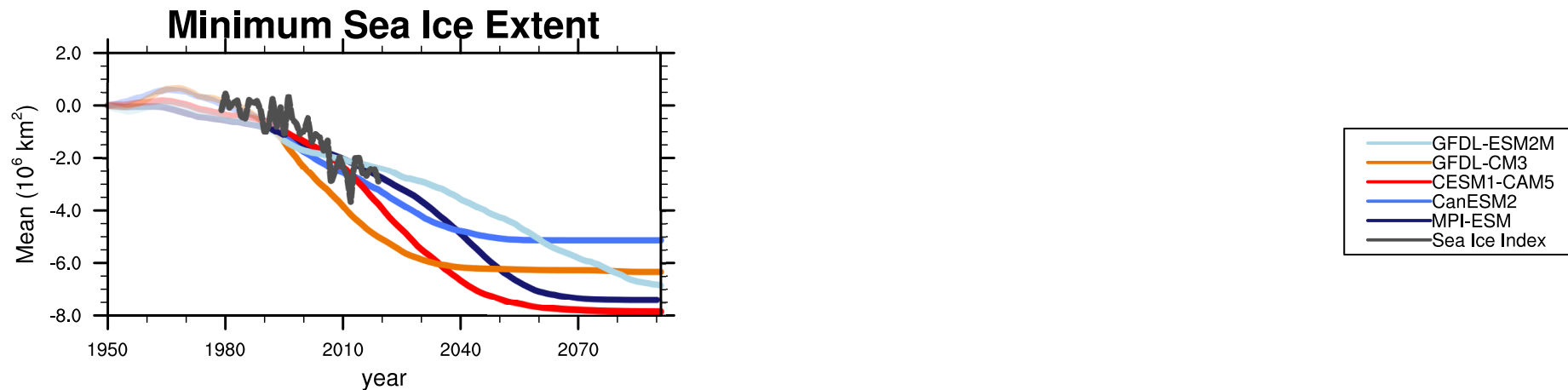
Time of Emergence (ToE):

The year when the ensemble mean exceeds the reference decadal mean (1920's) by 2 standard deviations



From Landrum and Holland 2020

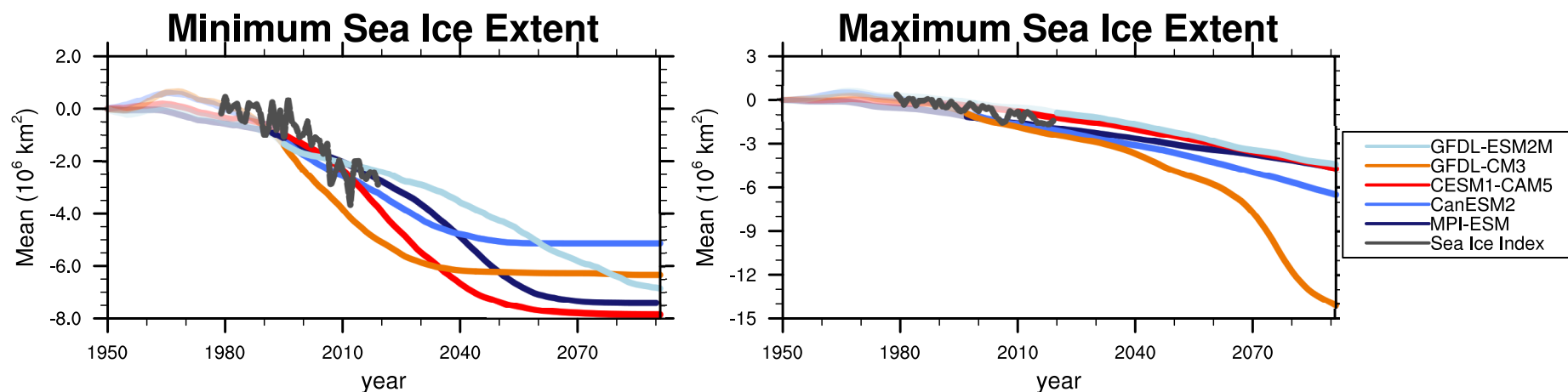
Time of Emergence for minimum sea ice extent: In the past - climate change has already happened!



Large Ensemble	ToE for Minimum Extent	
CanESM2	1996	
CESM1-LE	1995	
GFDL-CM3	1995	
GFDL-ESM2M	1995	
MPI-ESM	1992	

From Landrum and Holland 2020

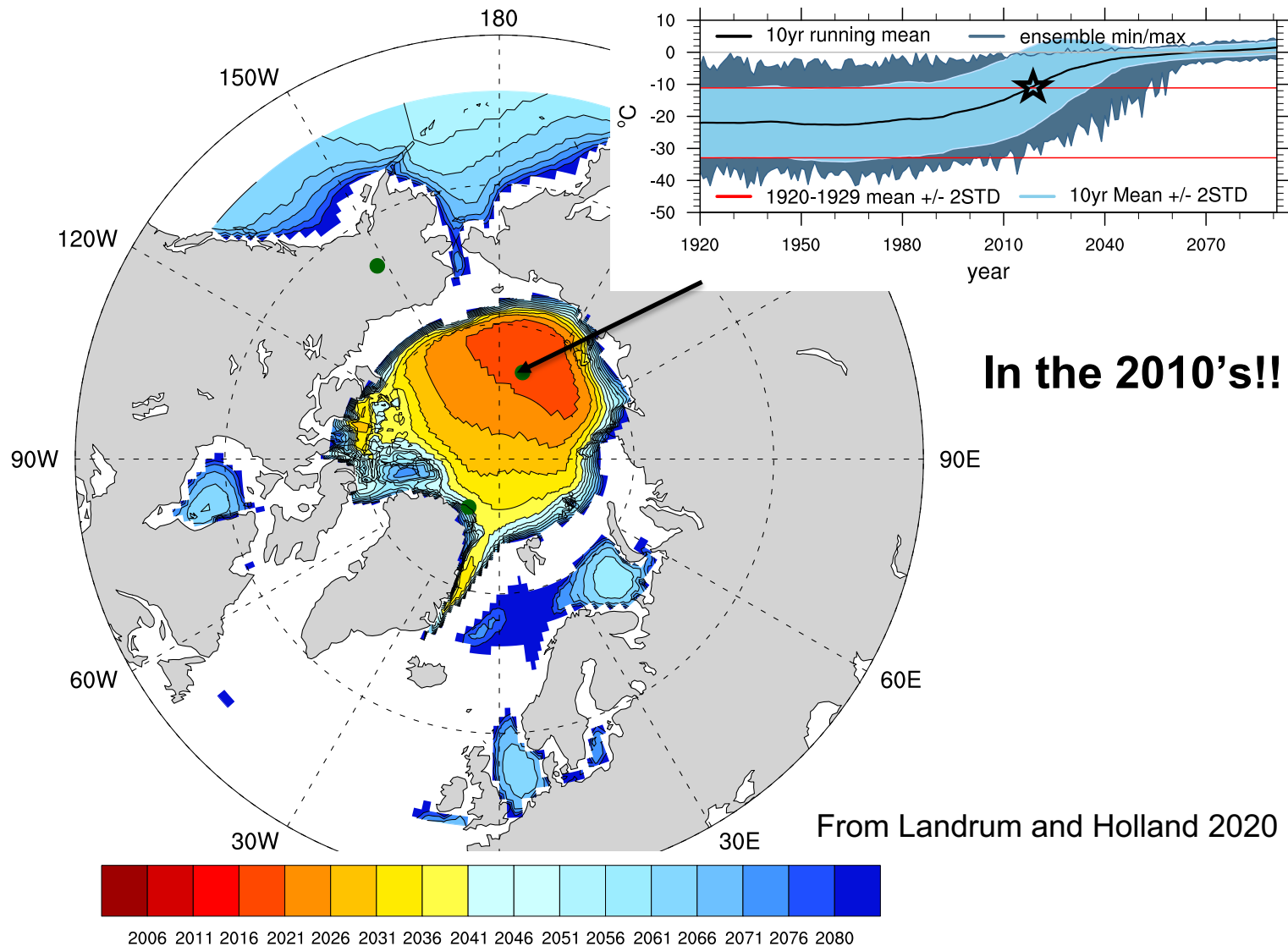
Time of Emergence for maximum sea ice extent is a bit more uncertain.



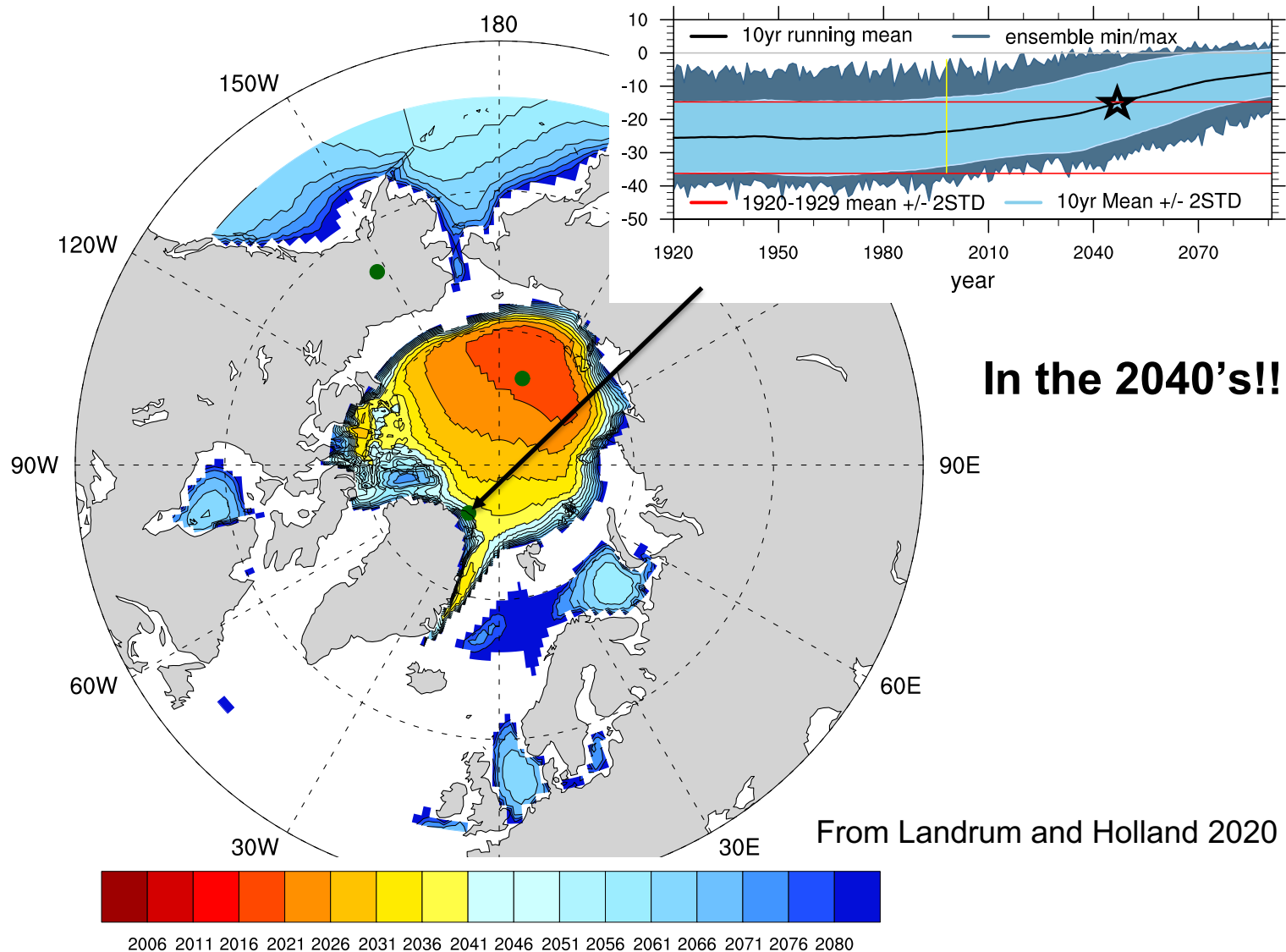
Large Ensemble	ToE for Minimum Extent	ToE for Maximum Extent
CanESM2	1996	2000
CESM1-LE	1995	2010
GFDL-CM3	1995	1997
GFDL-ESM2M	1995	2020
MPI-ESM	1992	1997

From Landrum and Holland 2020

Time of Emergence for temperatures is spatially heterogeneous.



Time of Emergence for temperatures is spatially heterogeneous.



How might people experience the “new” normal?



Photo: Greenland Adventure Tours

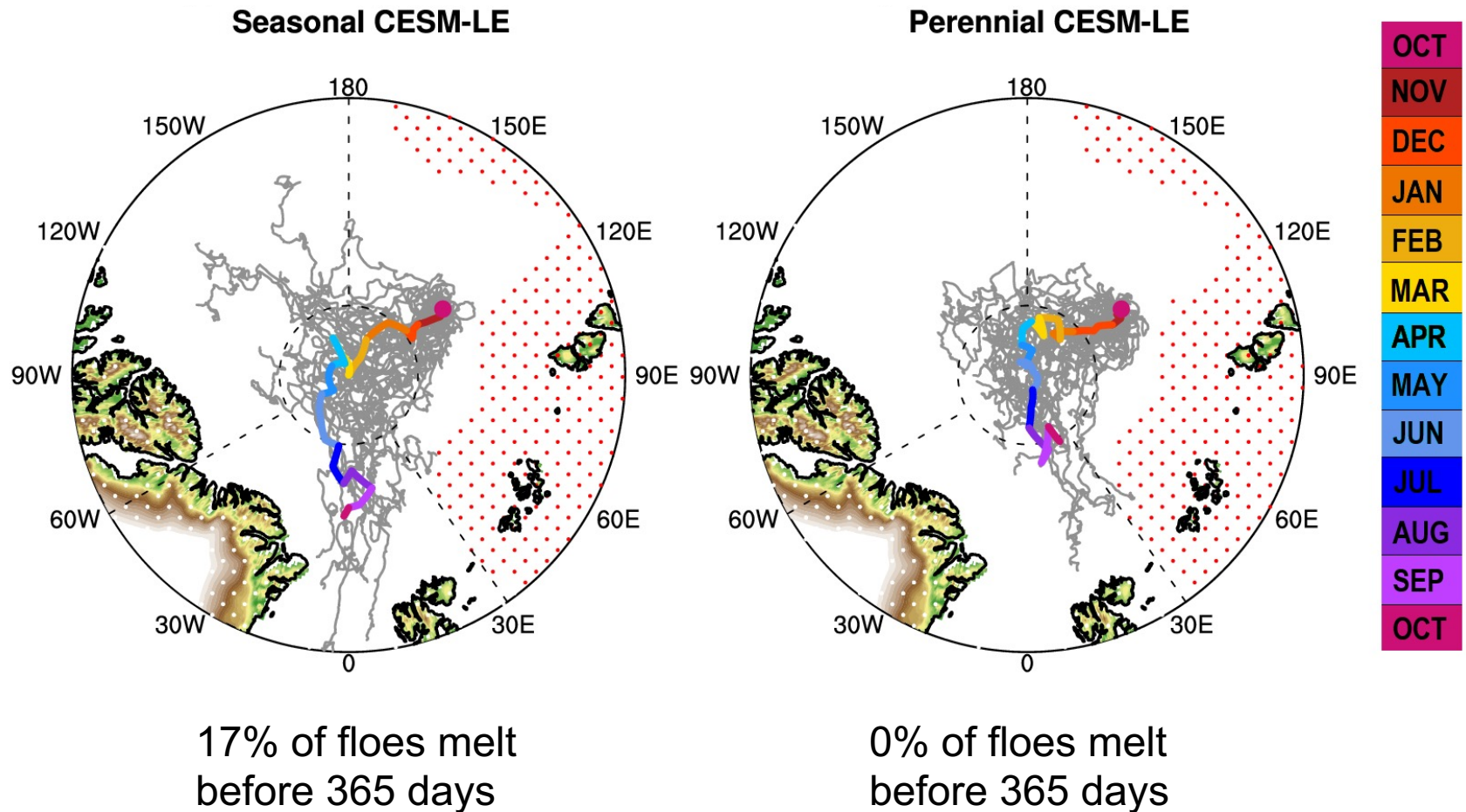
1) What is an extreme in the “new Arctic” climatologically speaking?

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Photo: Steffen Olsen, Danish Met Institute, June 2019



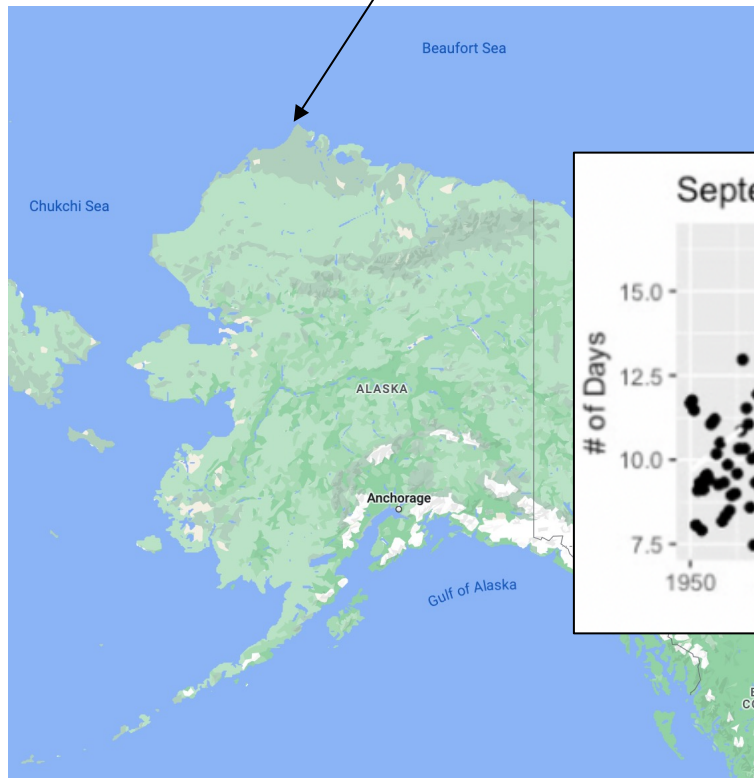
Model can provide statistics about outlier events



From DuVivier et al. 2020

Changing ice and wind conditions are likely to impact fall whale hunting success.

Utqiagvik, AK



Number of **Unsafe** hunting days for **small boats**

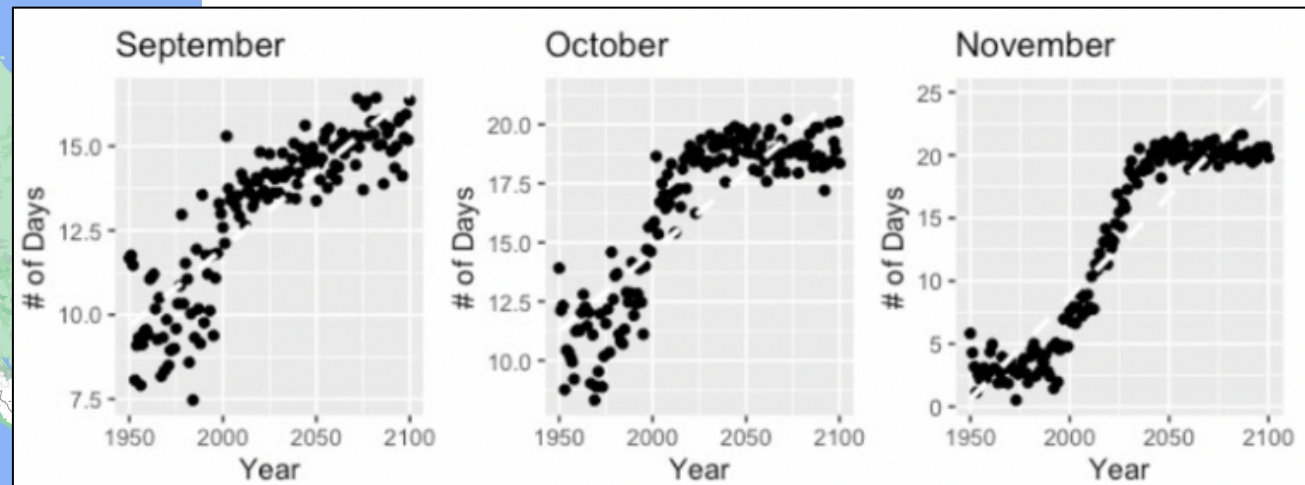
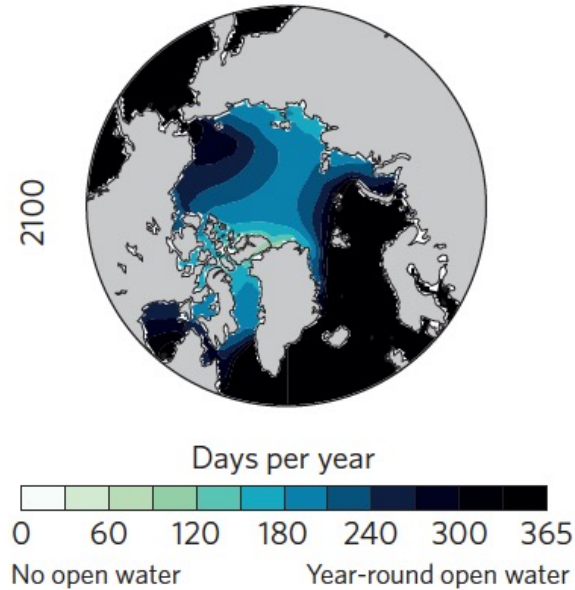


Figure from 'Ana Stringer and Ralf Bennartz, Vanderbilt University

* Ongoing work

Changing Ice and wind conditions

Longer ice-free season



From Barnhardt et al. 2016

Increasing Wind Speed Trend: 2006-2100

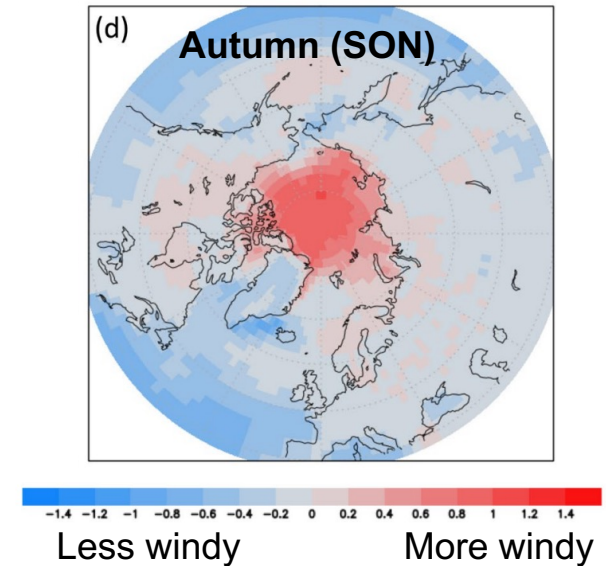
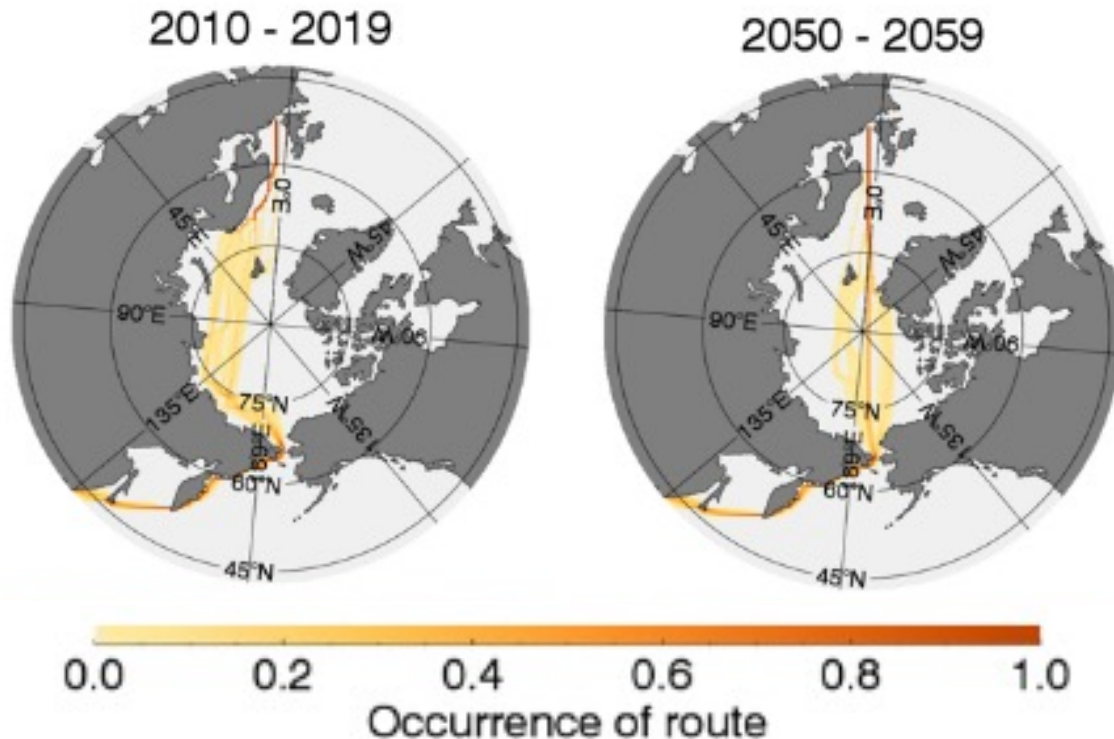


Figure from Vavrus and Alkama 2021



Changing atmospheric and sea ice conditions affect shipping risk

September shipping route availability

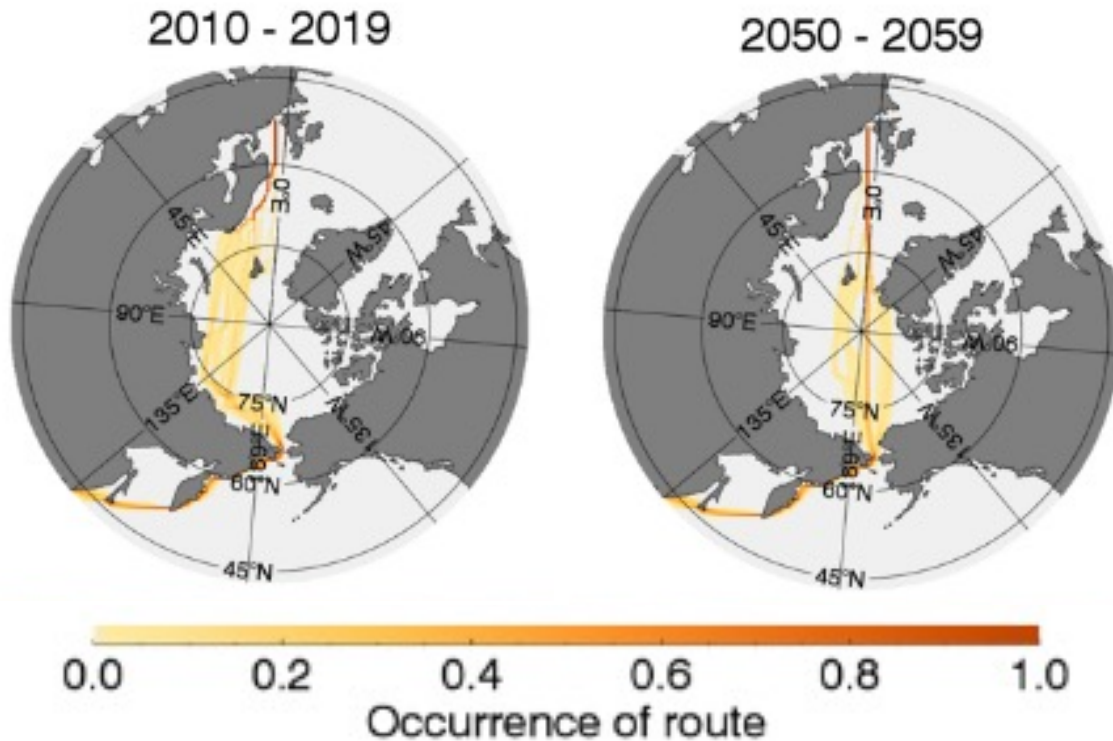


Figures from Ralf Bennartz

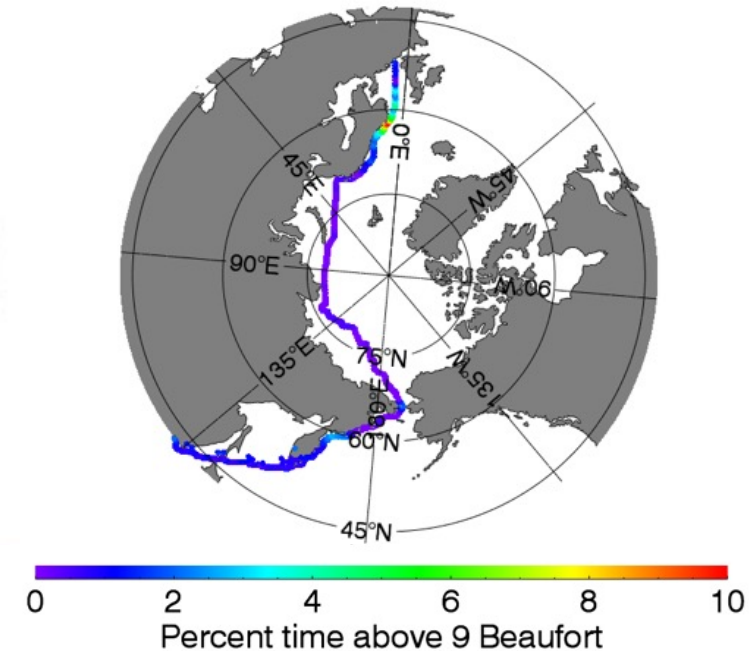
* Ongoing work

Changing atmospheric and sea ice conditions affect shipping risk

September shipping route availability



Modeled frequency of Beaufort Level 9 (strong gale) along shipping route



Figures from Ralf Bennartz

* Ongoing work

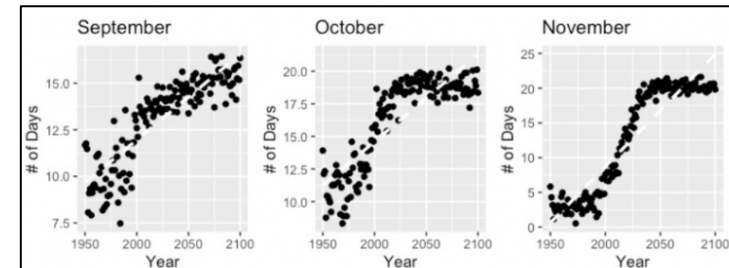
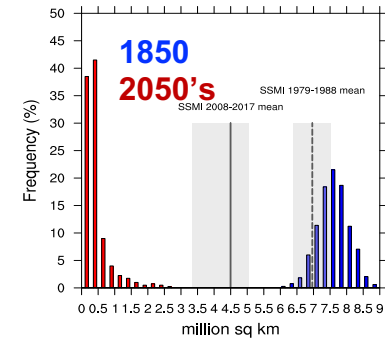
Conclusions

1) What is an extreme in the “new Arctic” climatologically speaking?

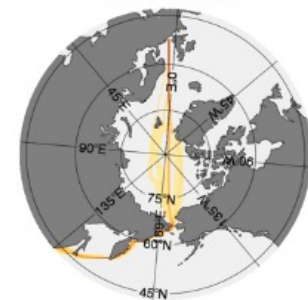
- Coupled large ensembles are essential for determining changing extremes.
- Time of emergence to a new, “extreme” climate has already happened in many instances.
- Changing variance and regional time of emergence impacts our ability to plan.

2) What are some human impacts of this “extreme” new climate state?

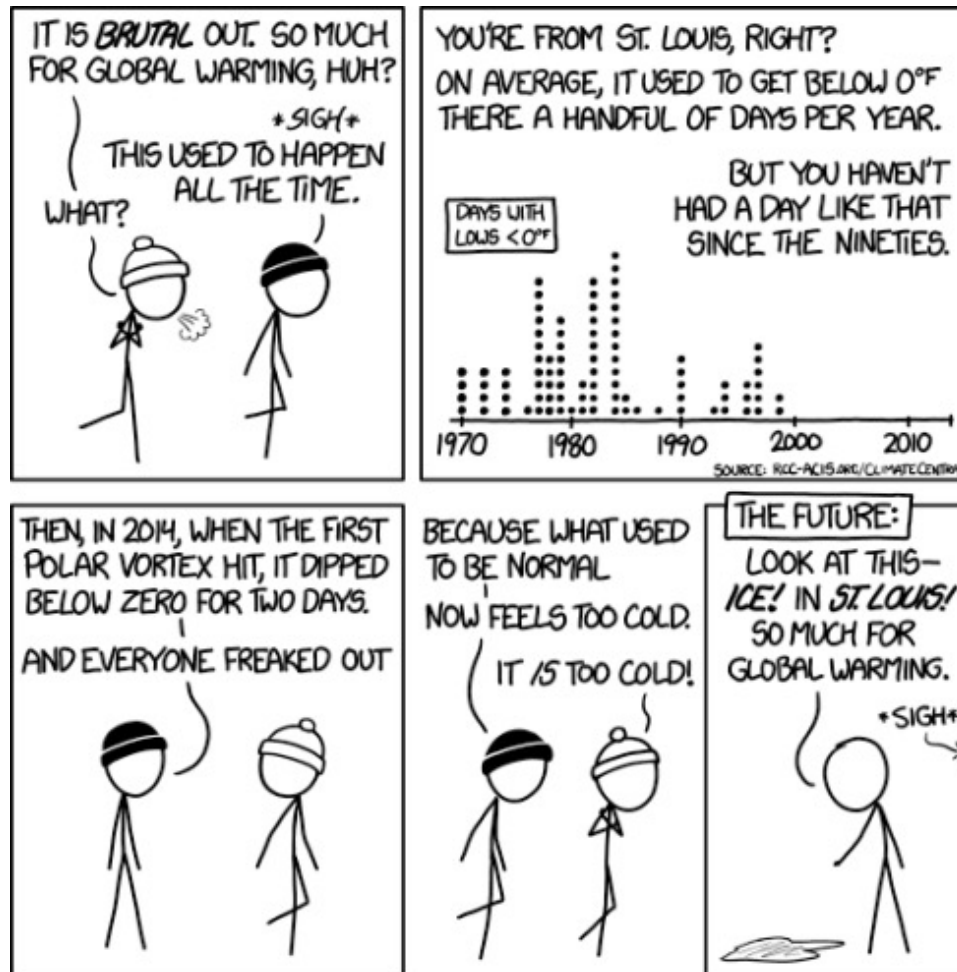
- Open ocean routes increase
- Unclear if ocean transport is more accessible depending on boat size, wave height, and other risk factors.



2050 - 2059



What we experience and perceive as extreme is shifting dramatically.



Comic: XKCD

Thank you!

Questions?
Please email me!!
duvivier@ucar.edu



Image by Laura Keene — National Geographic Your Shot

This project is primarily supported by the National Science Foundation (NSF) award 2043727.

The CESM project is supported primarily by NSF. This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the NSF under Cooperative Agreement No. 1852977. Computing and data storage resources, including the Cheyenne supercomputer (doi:10.5065/D6RX99HX), were provided by the Computational and Information Systems Laboratory (CISL) at NCAR.





Map of today's talk

- Definition of extremes change in time
- Human experience vs. statistics. 2deg doesn't matter to a human...How we as humans notice extremes.
- Ice extremes vs become normal (PDFS) extremes
- Changing climate is more than just changing mean. Also changes variability and distribution. Or combo of both!
- When is it going to be ice free? Can't answer this (Alex's work).
- Question: when do extremes now become "normal"?
- Climate change is in the past, not the future!
- Approach could be more relevant for policy makers. New port? What might we encounter and how fast will this be obsolete?
- Changing baselines or frog in a pot
- Include:
 - Navigation: Brown work, Vandy work, Steve Vavrus
 - MOSAIC: melting out possibility
 - Wildlife: polar bear habitat/penguins
- Clara seminar: think about change in mean state but also variability. Widening of extremes and extremes are more extreme (Re-watch seminar)
- Ice free season length (Barnhardt)

How will the Arctic change in the future?



June 2019

Steffen Olsen, Danish Met Institute

Coupled Earth System Models provide means for statistical analysis.



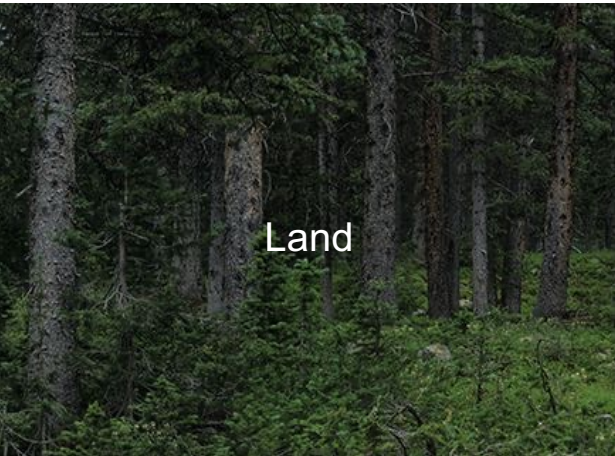
Atmosphere



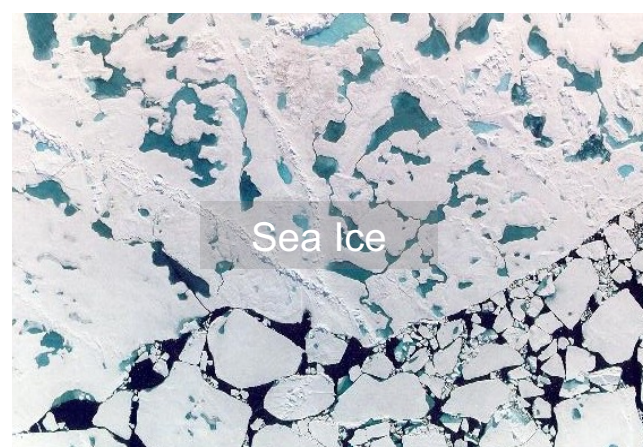
Ocean



Land Ice



Land



Sea Ice



Land



Ecosystems

Ocean

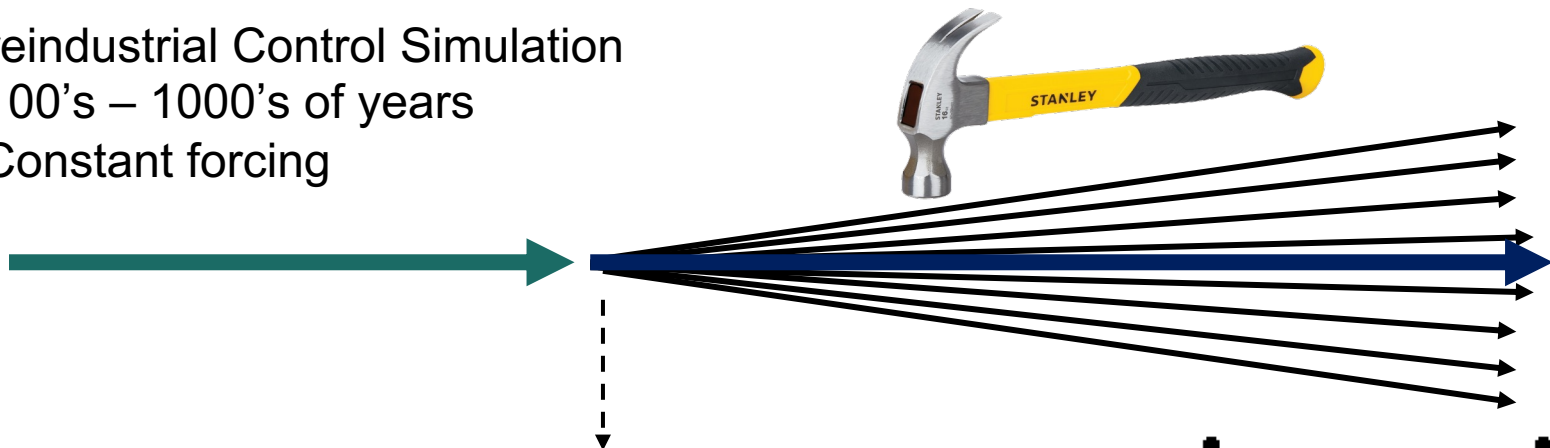
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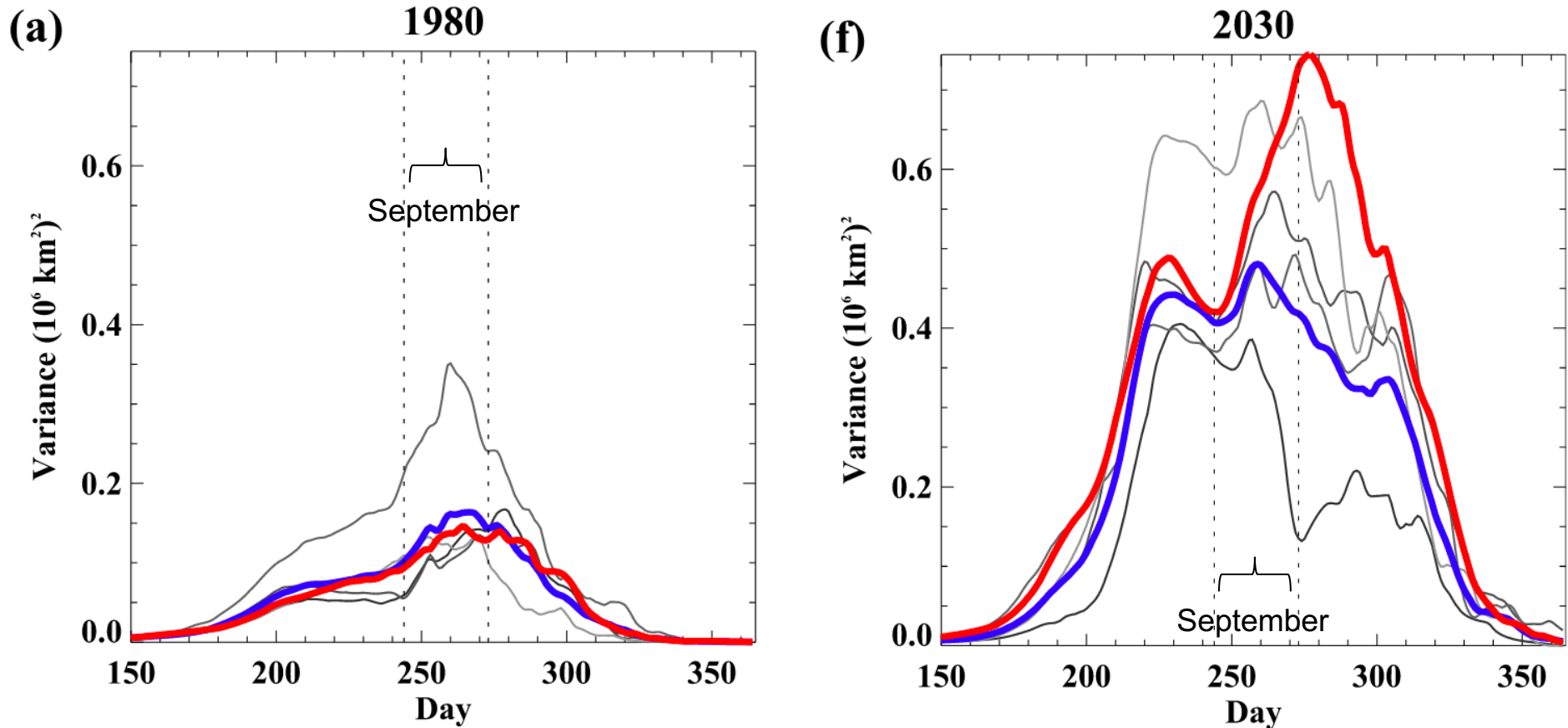
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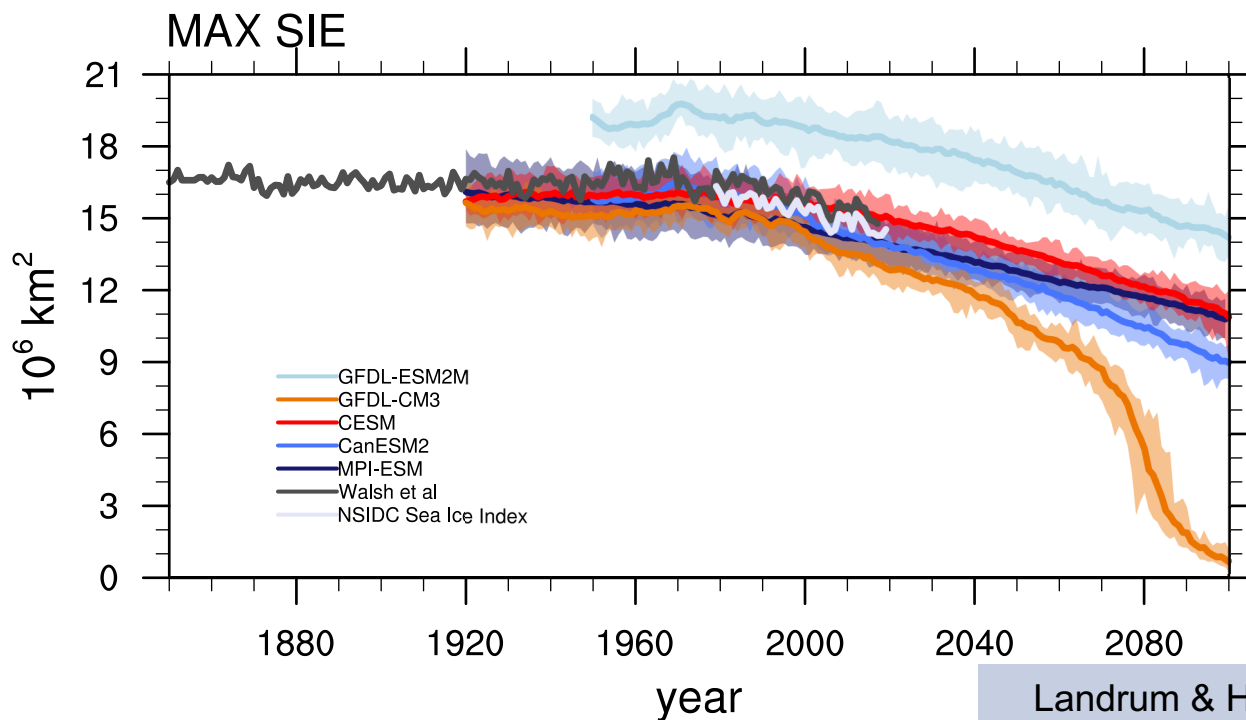
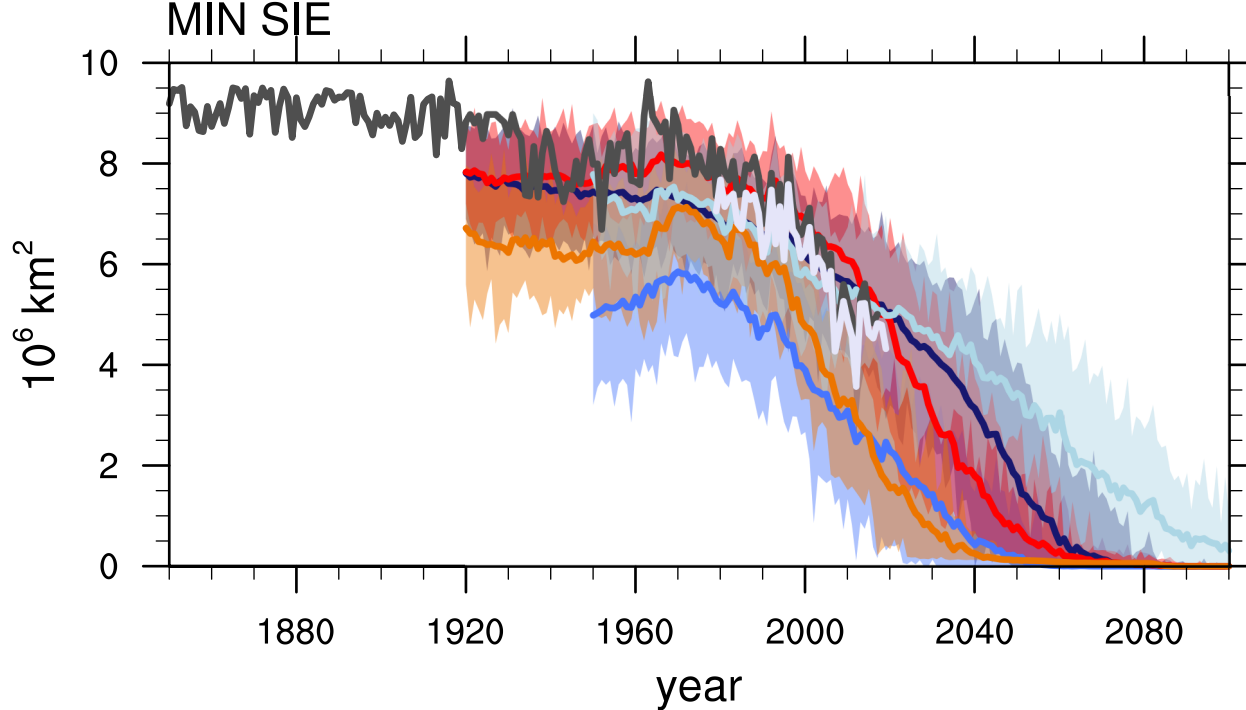


Sea ice extent variance increases during the transition to “seasonal” Arctic.

CESM1-LE



From Holland et al. 2019



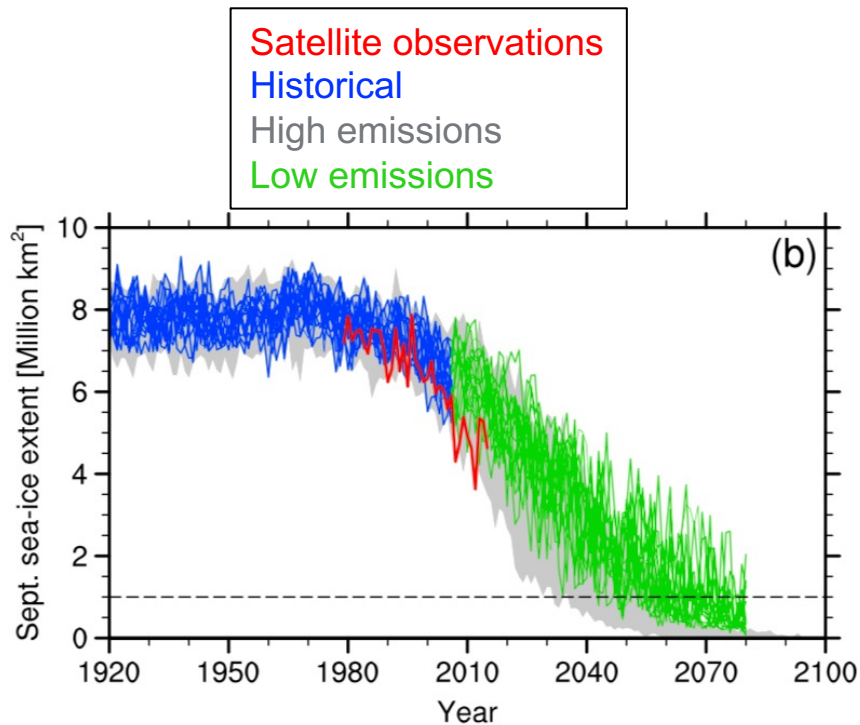
“Time of Emergence” (ToE)

The year when the decadal mean of an ensemble exceeds the reference decade by 2 standard deviations (based on reference decade variability)

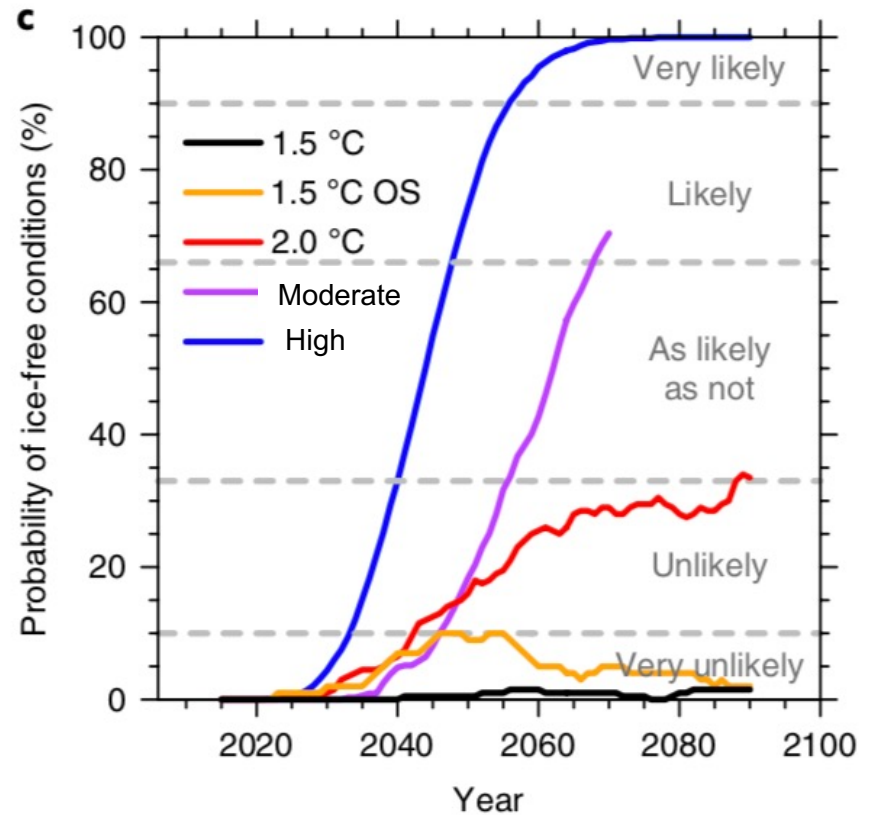
**Reference decade
1950-1959**

(year refers to the first year of the decadal mean – e.g. “1980” refers to 1980-1989 decadal mean)

The choices we make determine whether and when the Arctic ocean might be sea ice free.

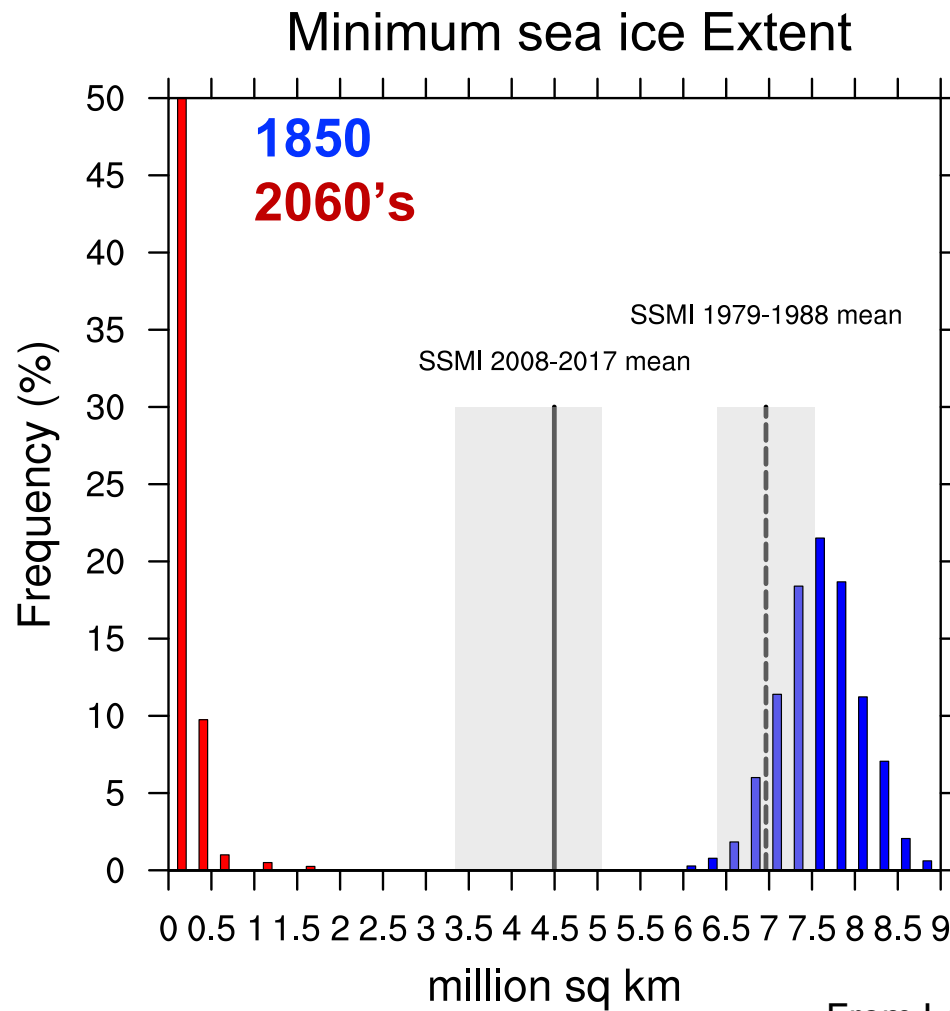


Jahn et al., 2016



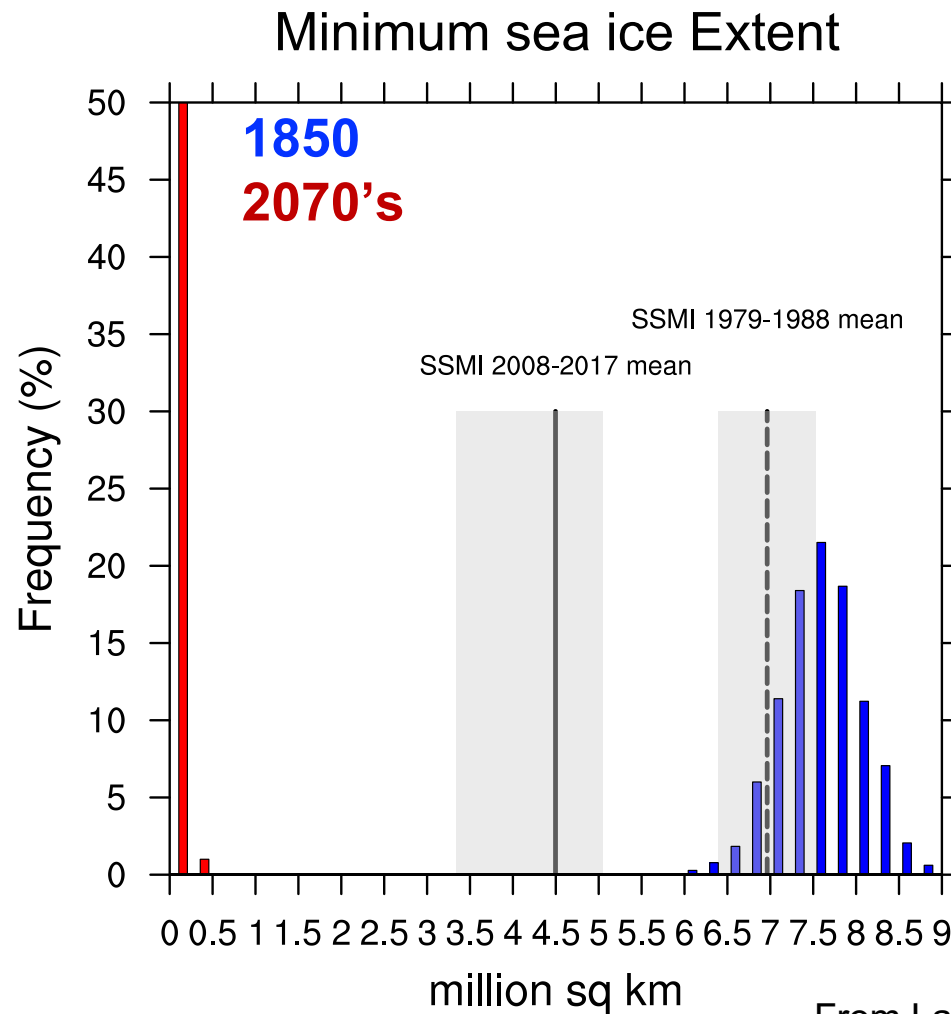
Jahn 2018

How do distributions change in future decades?



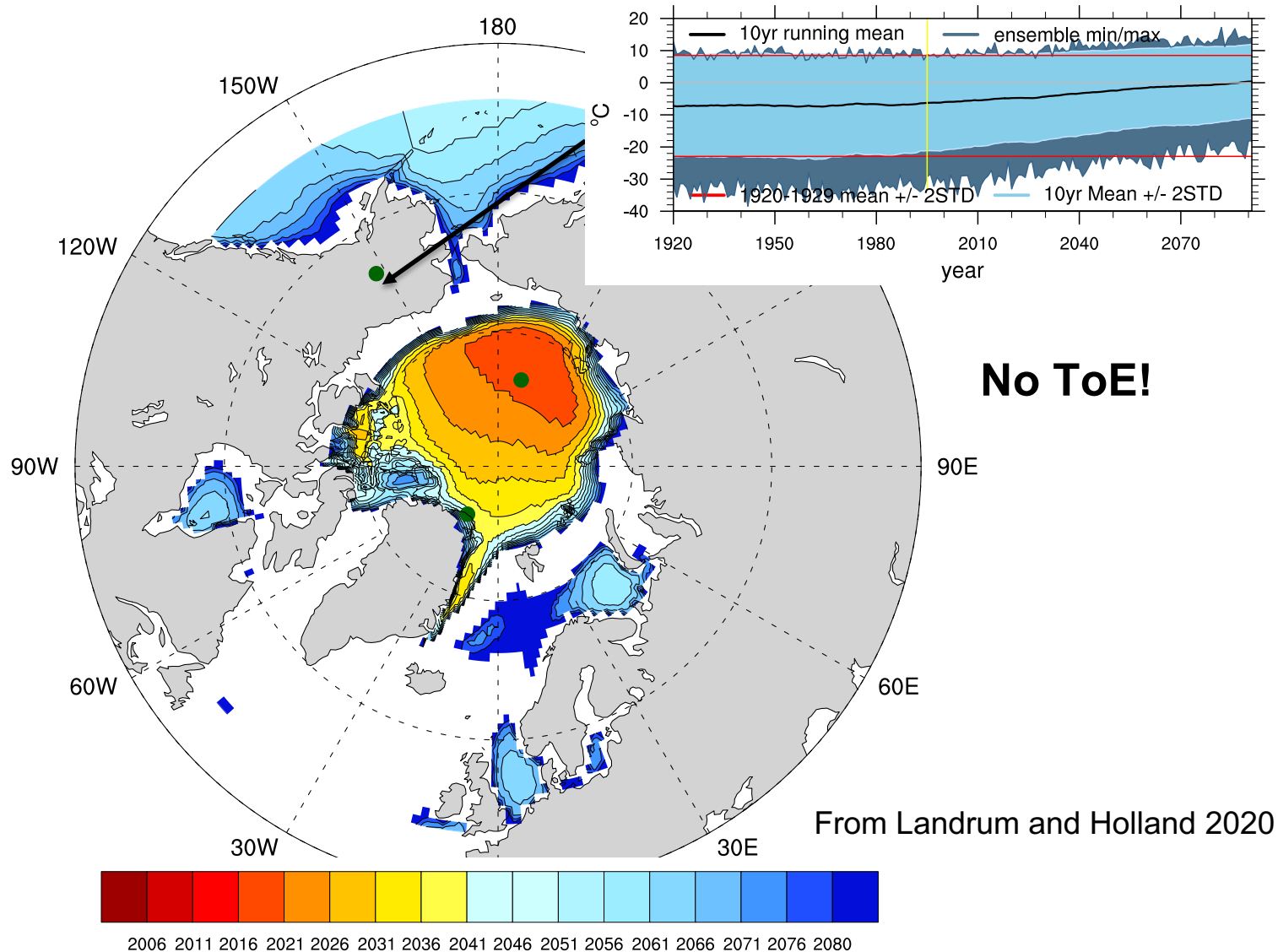
From Landrum and Holland 2020

How do distributions change in future decades?



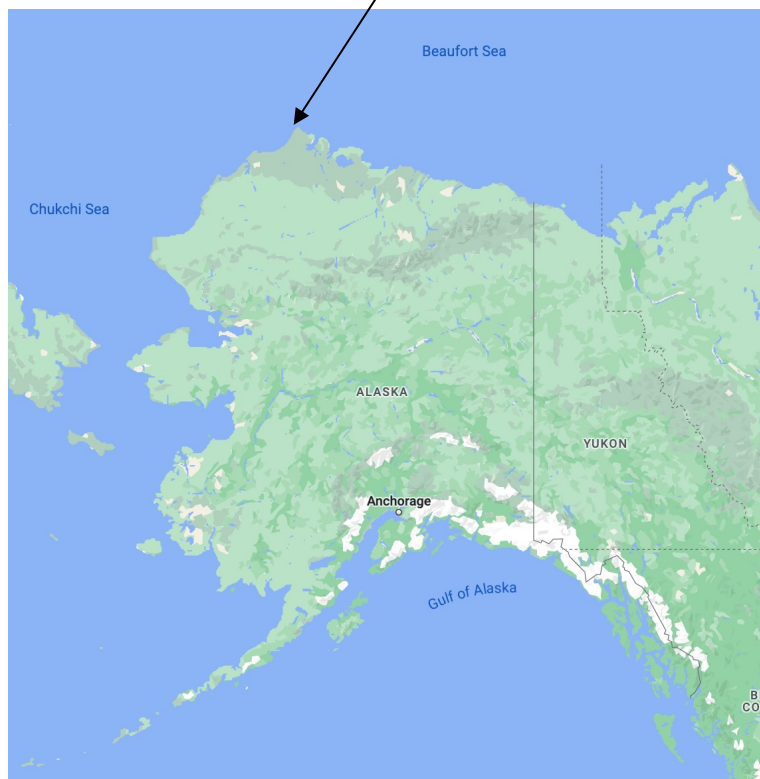
From Landrum and Holland 2020

Time of Emergence for October surface temperatures: Cape Morris Jesup



Tails of wind distribution are also likely to increase.

Utqiagvik, AK



Annual 99th and 95th wind speed event

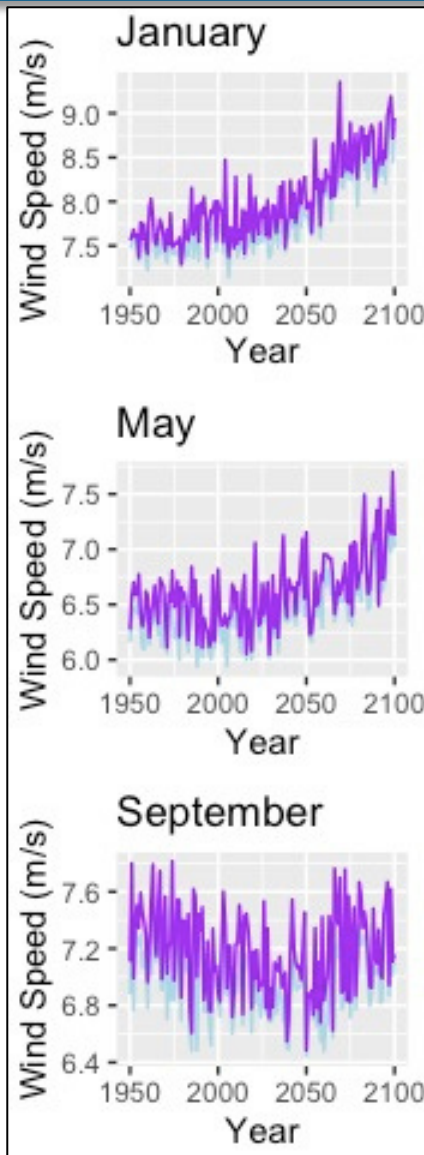
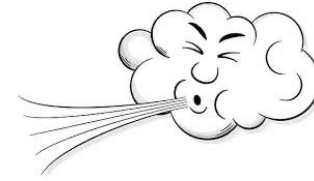


Figure from 'Ana Stringer and Ralf Bennartz, Vanderbilt University

More open ocean and stronger winds will impact waves.



Seawall planned for Utqiagvik will help protect the Arctic Alaska city

By Alena Naiden
Published: December 12, 2021

ANCHORAGE DAILY NEWS



Photo from: National Snow and Ice Data Center

Helicopters rescue Norway cruise ship passengers amid storm

By JARI TANNER Associated Press
March 23, 2019, 9:05 PM • 4 min read



Photo from: ABC News

Combination of decreasing ice and increasing wind lead to large waves at Drew Point.

Drew Point, AK

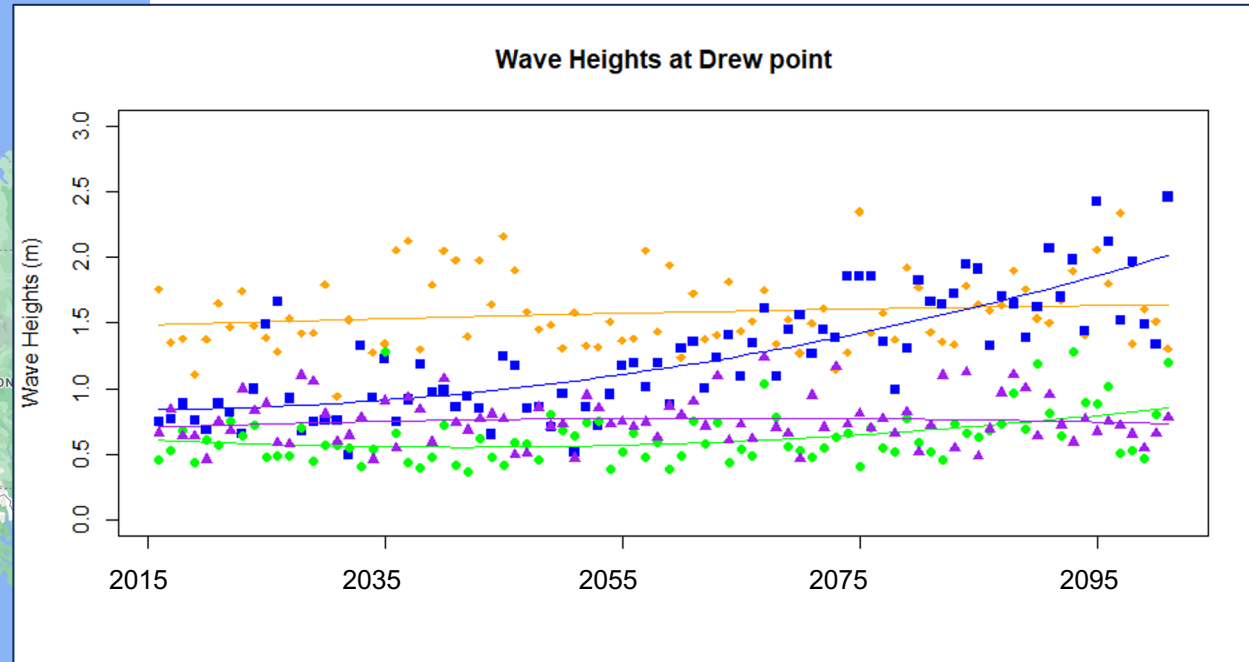
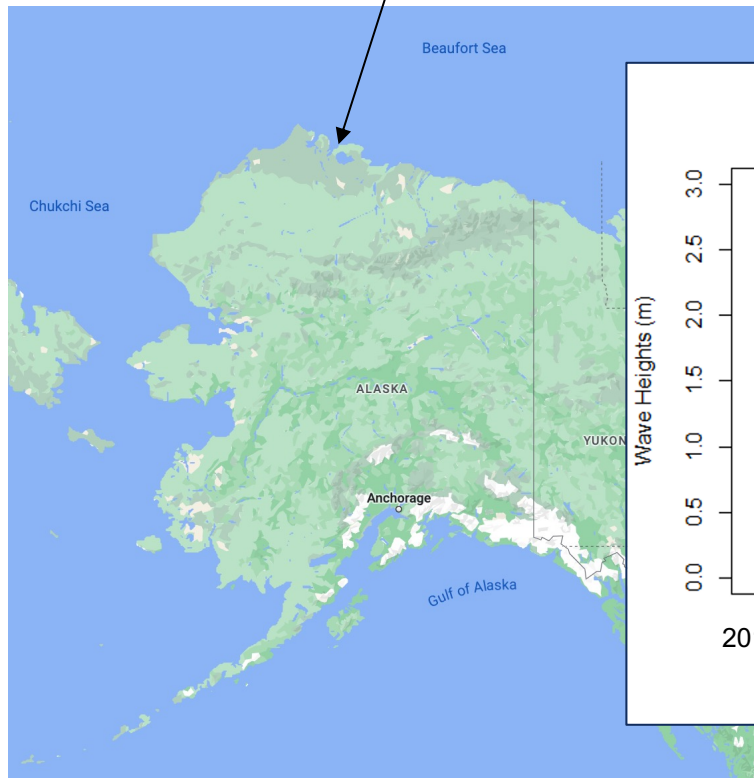
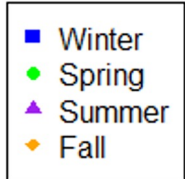


Figure from Ian Franda and Steve Vavrus,
University of Wisconsin

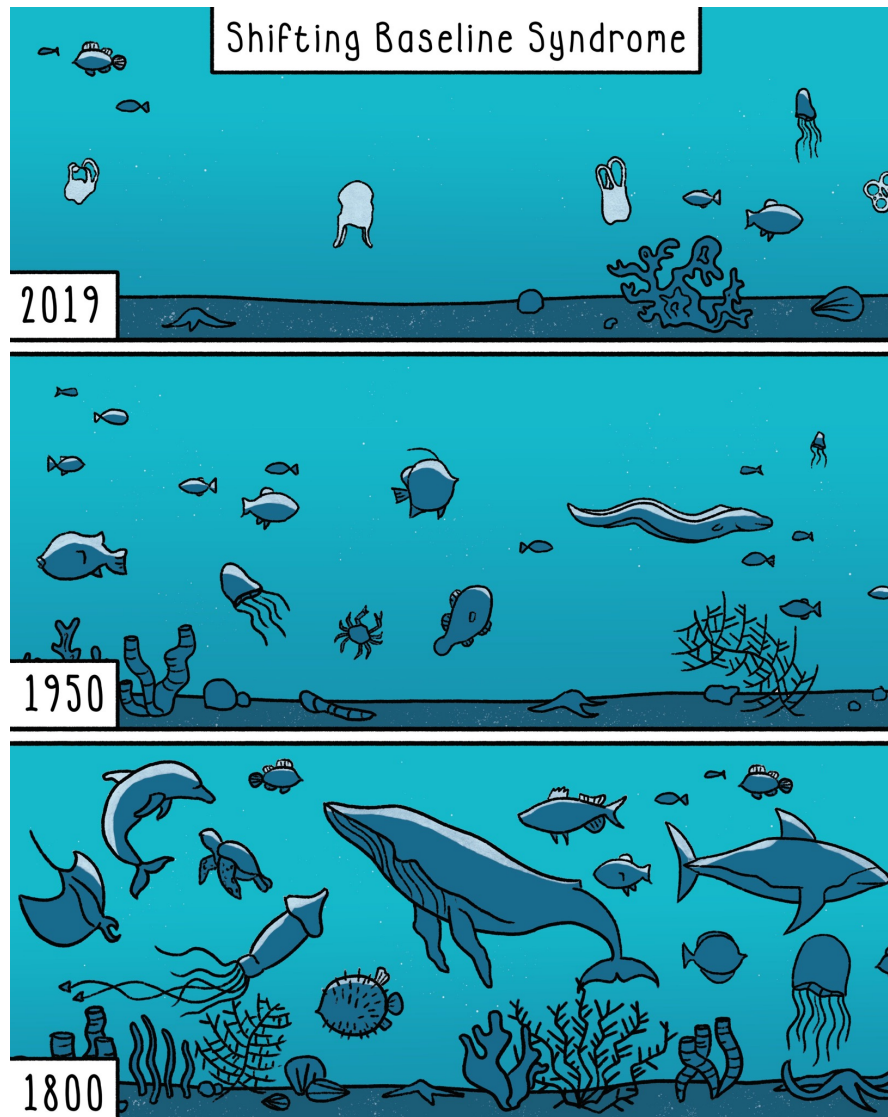
* Ongoing work



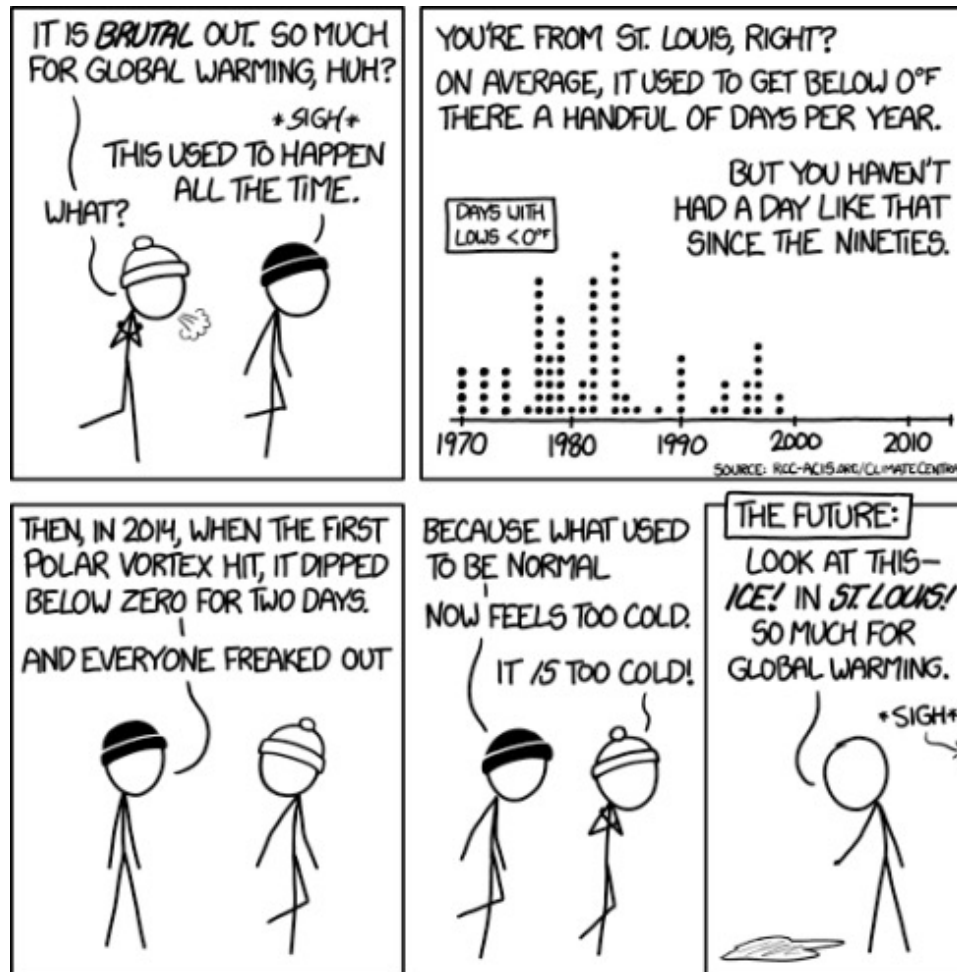
Map of today's talk



The landscape of “normal” is shifting.



What does it mean to be “extreme” in a changing climate?



Comic: XKCD