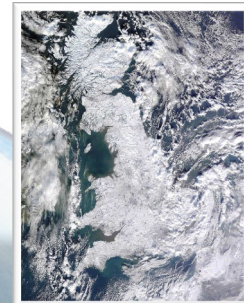


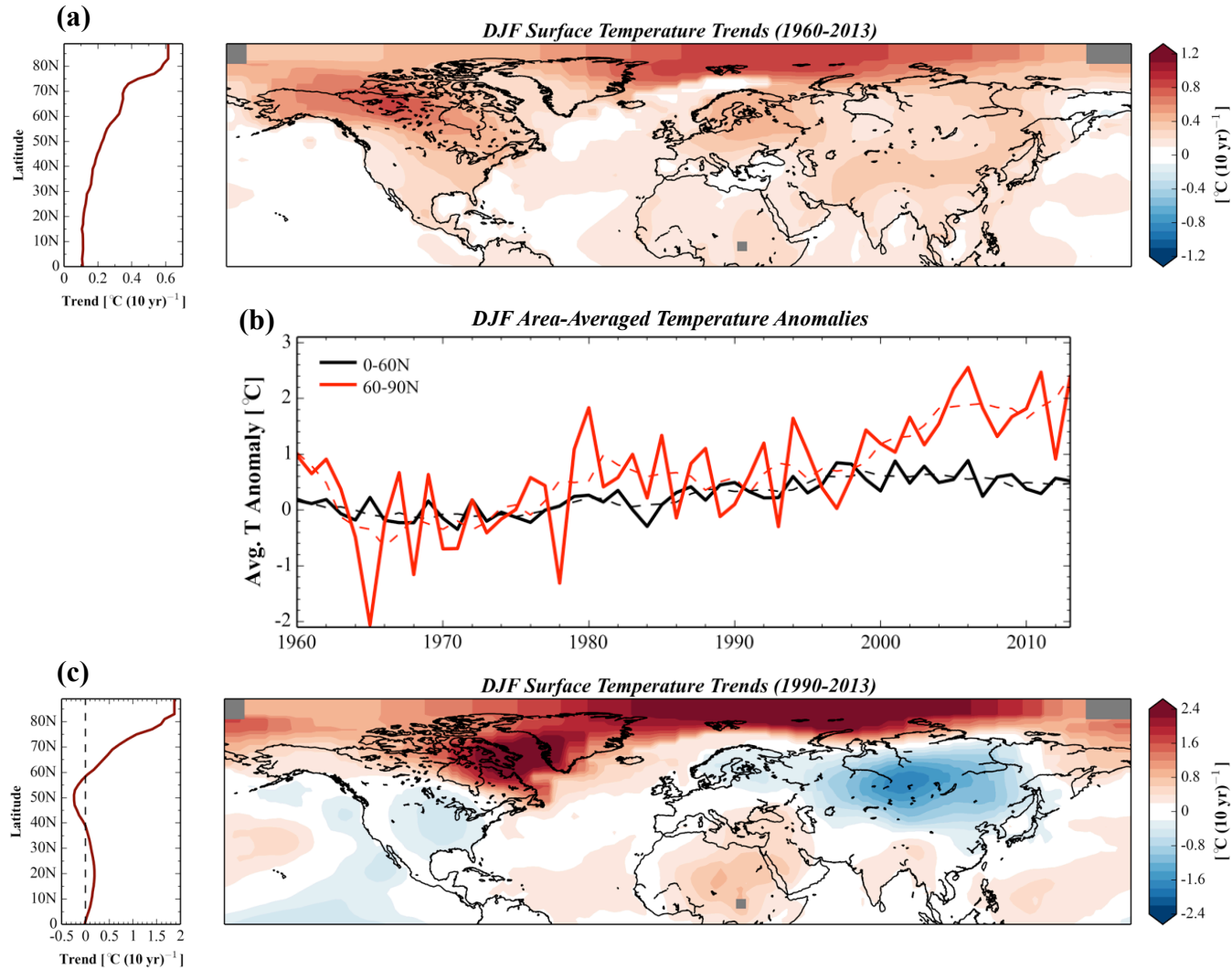
# Linking Arctic variability and change with extreme winter weather in the US

Laurie Agel & Mathew Barlow @UMass, Lowell  
Chaim Garfinkel & Ian White @Hebrew University

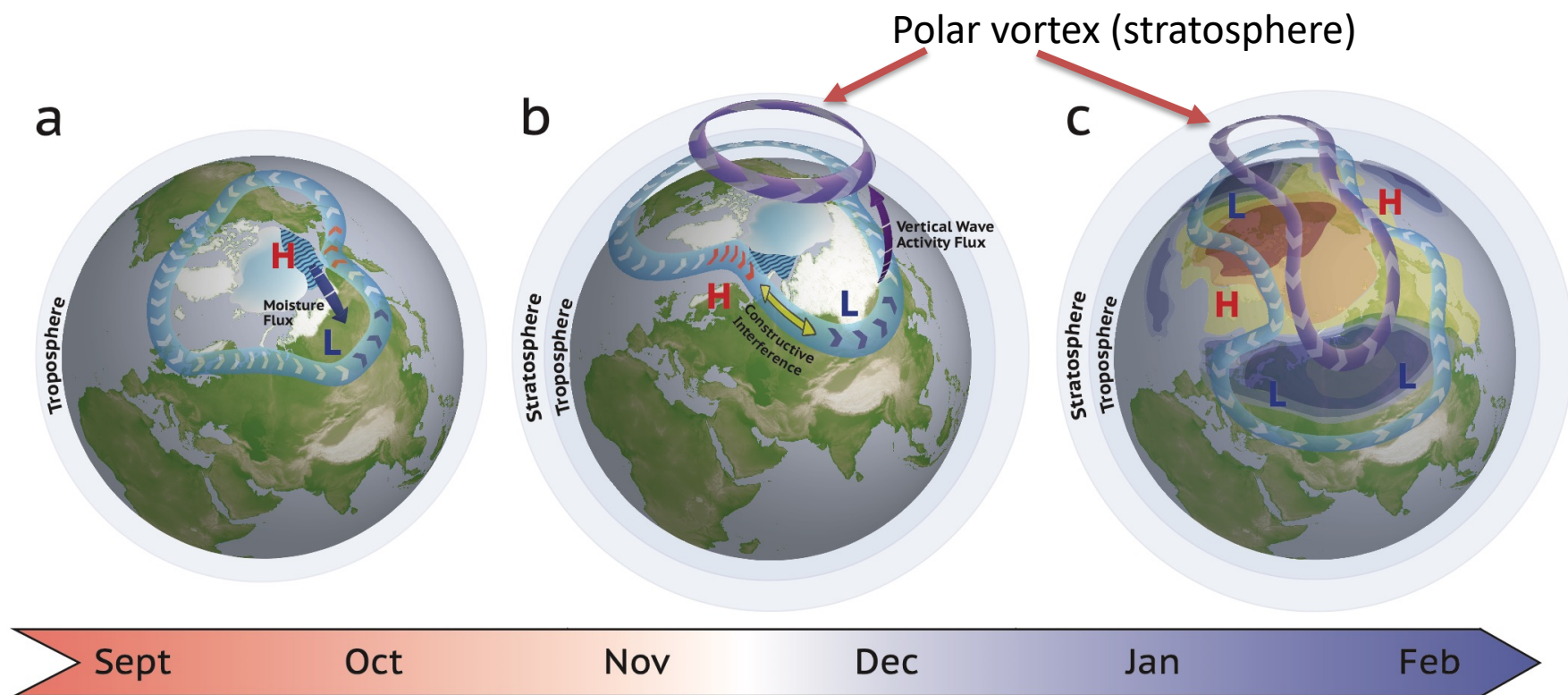
**Judah Cohen**  
**AER/Dept CEE MIT**  
**May 18, 2022**



# Arctic Amplification



# How Accelerated Arctic Warming Impact the Polar Vortex



# Brrr: US shivered through its coldest February in more than 30 years

**Doyle Rice** USA TODAY

Published 1:23 p.m. ET March 8, 2021 | Updated 9:37 a.m. ET March 10, 2021

## ENERGY

### How Unprecedented Was the February 2021 Texas Cold Snap?

#### WINTER STORM 2021

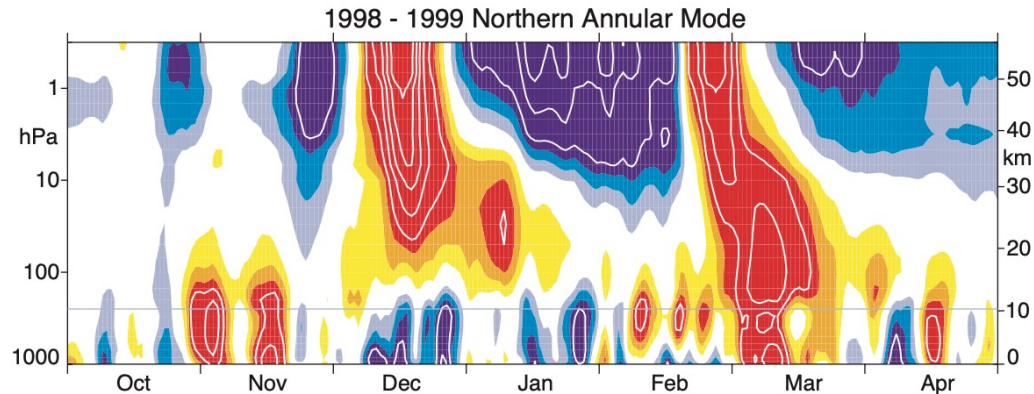
## Texas leaders failed to heed warnings that left the state's power grid vulnerable to winter extremes, experts say

Texas officials knew winter storms could leave the state's power grid vulnerable, but they left the choice to prepare for harsh weather up to the power companies — many of which opted against the costly upgrades. That, plus a deregulated energy market largely isolated from the rest of the country's power grid, left the state alone to deal with the crisis, experts said.

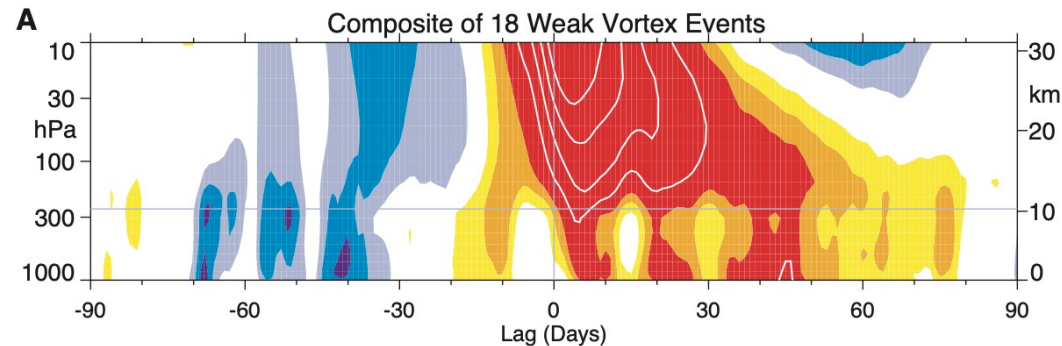
BY **ERIN DOUGLAS**, **KATE MCGEE** AND **JOLIE MCCULLOUGH** FEB. 17, 2021 15 HOURS AGO



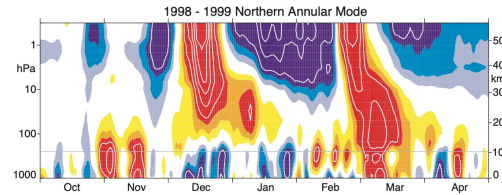
# Climate change contributed to Texas February 2021 Freeze through a classical SSW



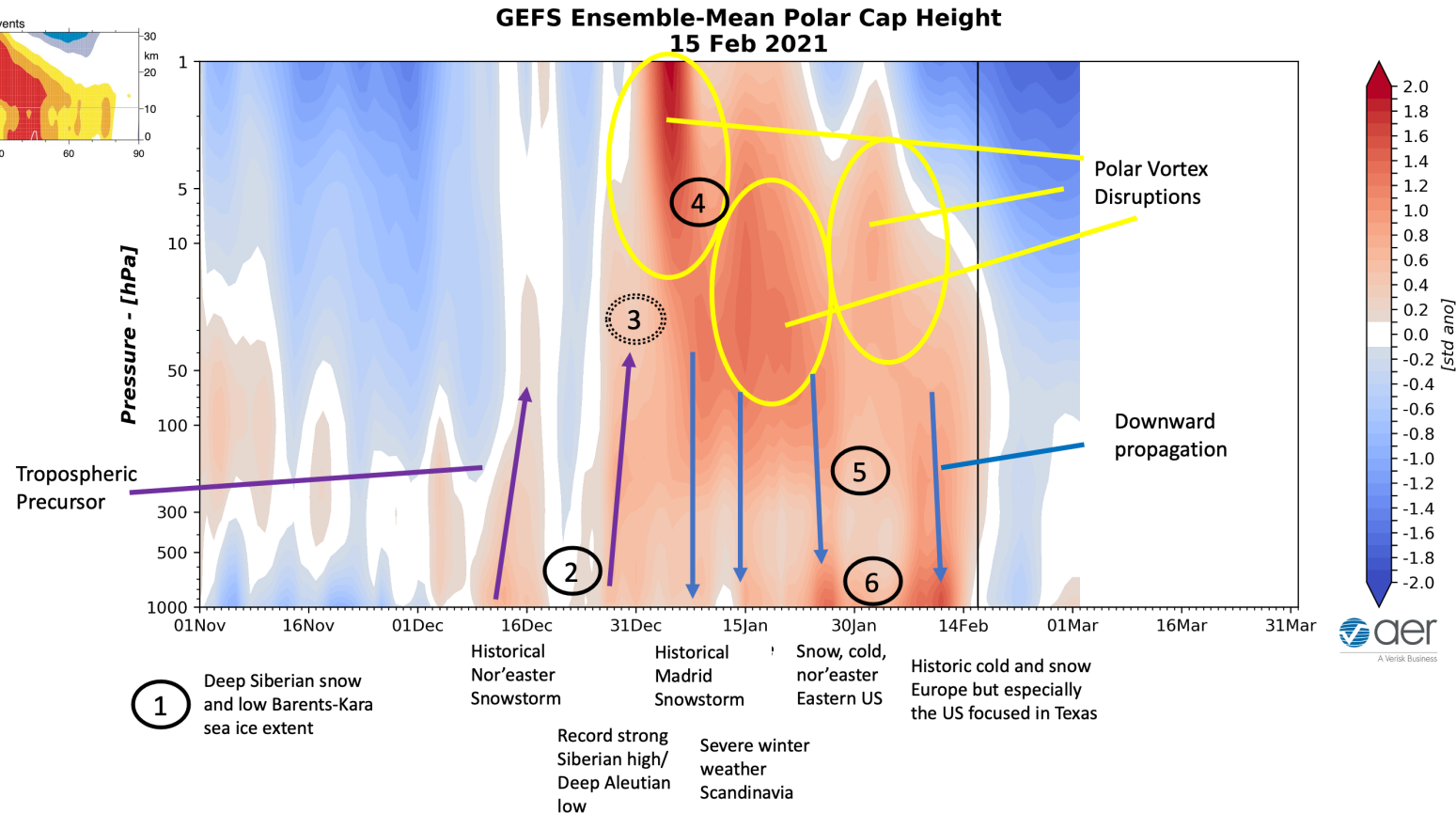
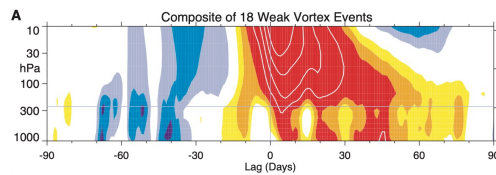
**Fig. 1.** Time-height development of the northern annular mode during the winter of 1998–1999. The indices have daily resolution and are nondimensional. Blue corresponds to positive values (strong polar vortex), and red corresponds to negative values (weak polar vortex). The contour interval is 0.5, with values between  $-0.5$  and  $0.5$  unshaded. The thin horizontal line indicates the approximate boundary between the troposphere and the stratosphere.



# Climate change contributed to Texas February 2021 Freeze through a classical SSW

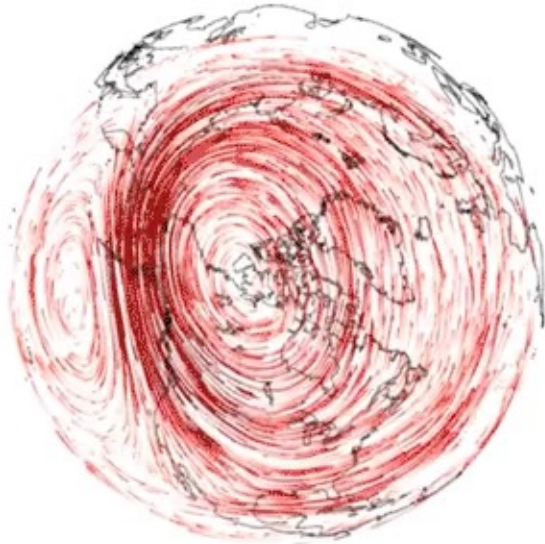


**Fig. 1.** Time-height development of the northern annular mode during the winter of 1998–1999. The indices have daily resolution and are nondimensional. Blue corresponds to positive values (strong polar vortex), and red corresponds to negative values (weak polar vortex). The contour interval is 0.5, with values between  $-0.5$  and  $0.5$  unshaded. The thin horizontal line indicates the approximate boundary between the troposphere and the stratosphere.

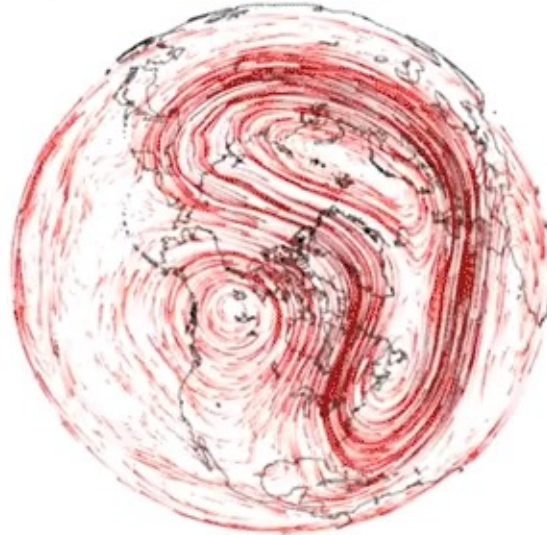


# Polar vortex disruptions Jan-Feb 2021

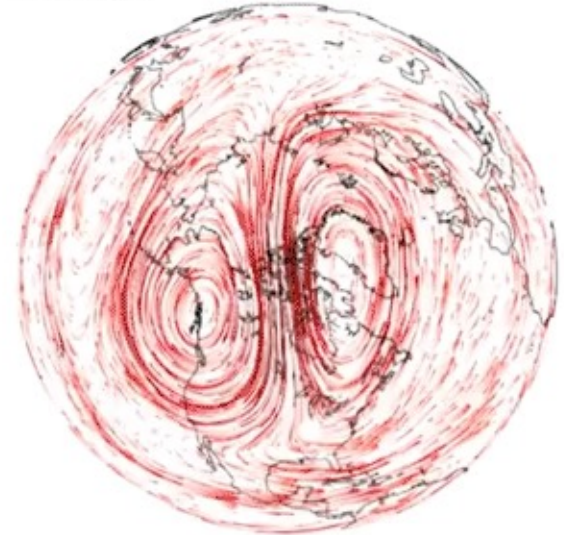
1 Dec 2020



15 Jan 2021



1 Feb 2021



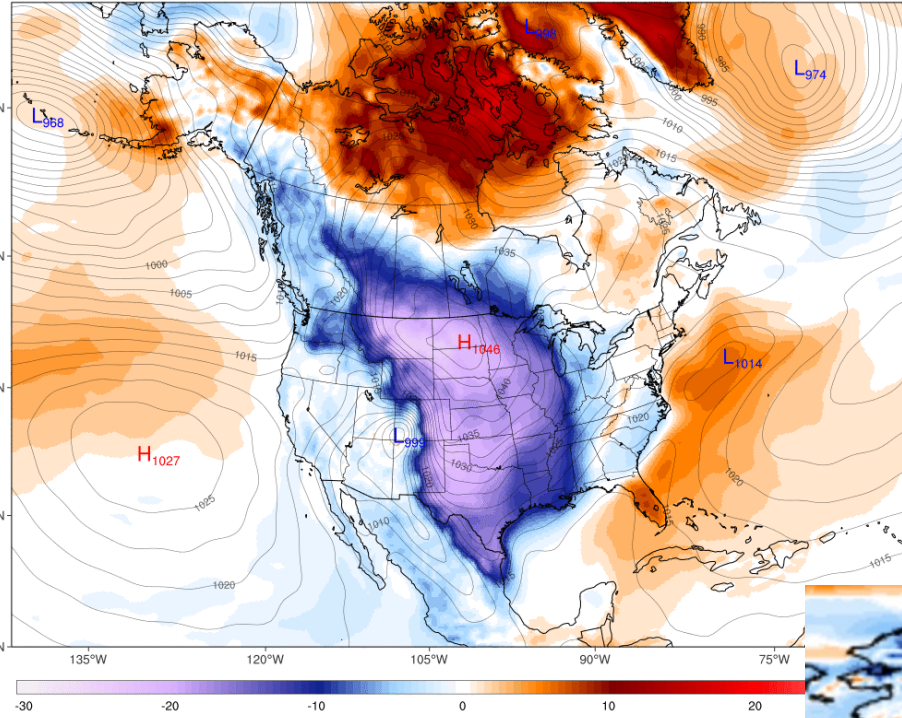
The Stratospheric Polar Vortex During Winter 2020-2021



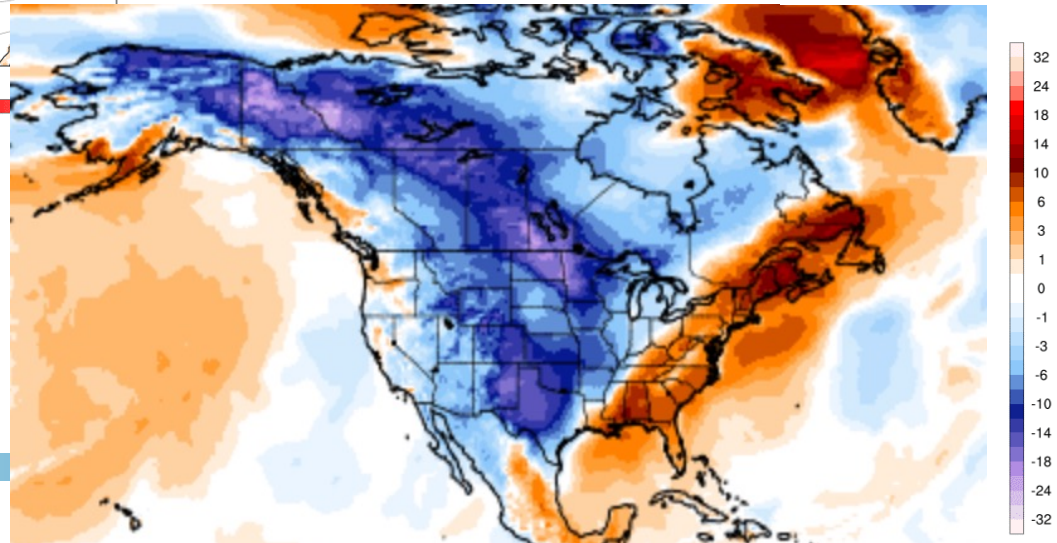
# Temperatures 2021 and 2022

CFSV2 2m T Anomaly (°F) [1979-2000 base], MSLP (hPa)  
Sun, Feb 14, 2021

ClimateReanalyzer.org  
Climate Change Institute | University of Maine



2m T Anomaly (°C)  
Thursday, Feb 03, 2022

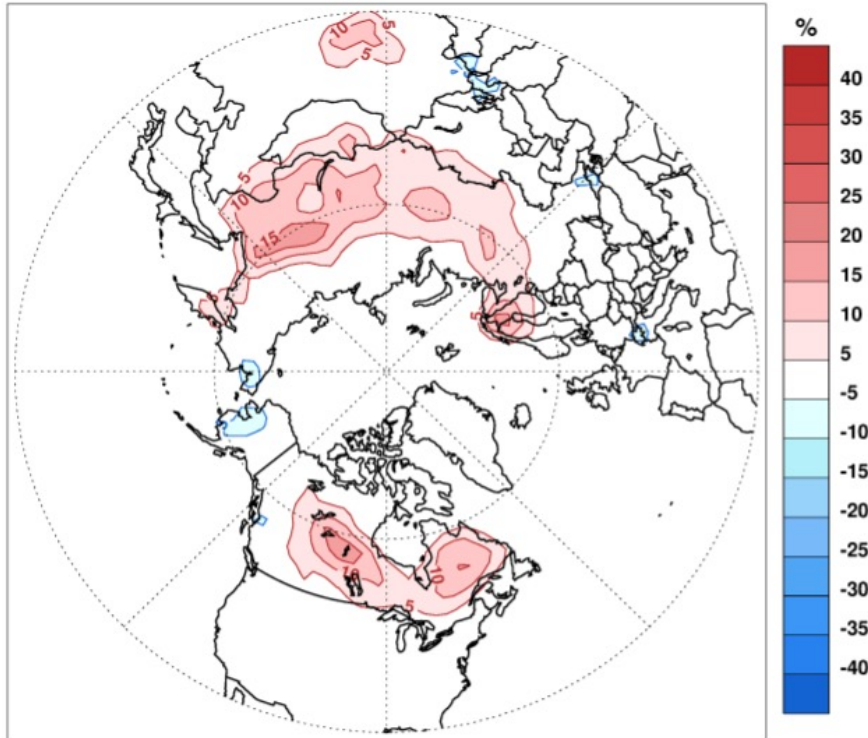




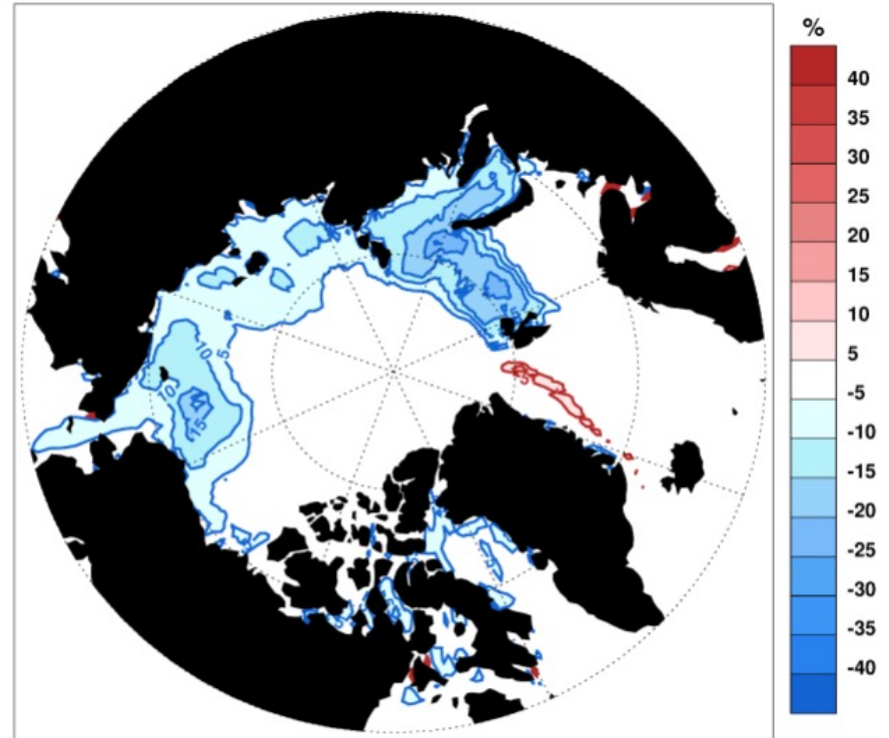
# **ARCTIC AMPLIFICATION AND ITS IMPACTS ON TRENDS**

# Snow and Sea Ice Trends during Era of Arctic Amplification

A October 1990-2020 SCE Trend

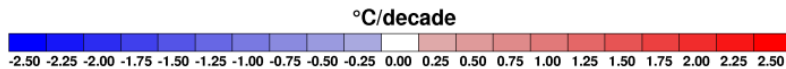
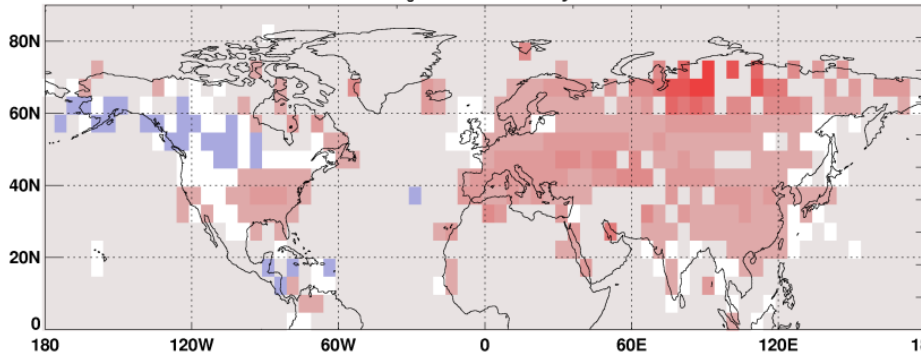


B Oct-Nov-Dec 1990-2020 SIC Trend

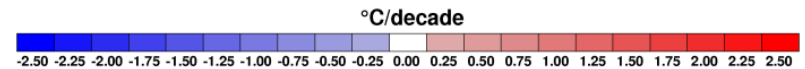
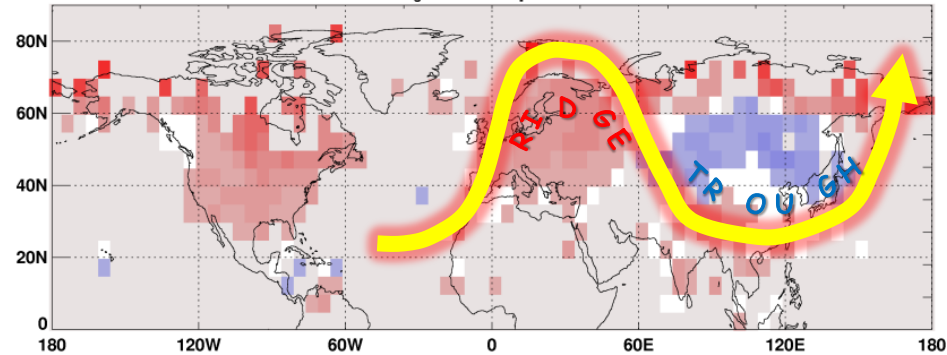


# Seasonal Trends

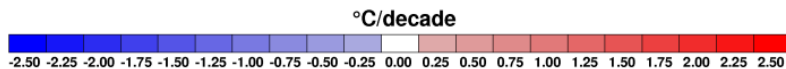
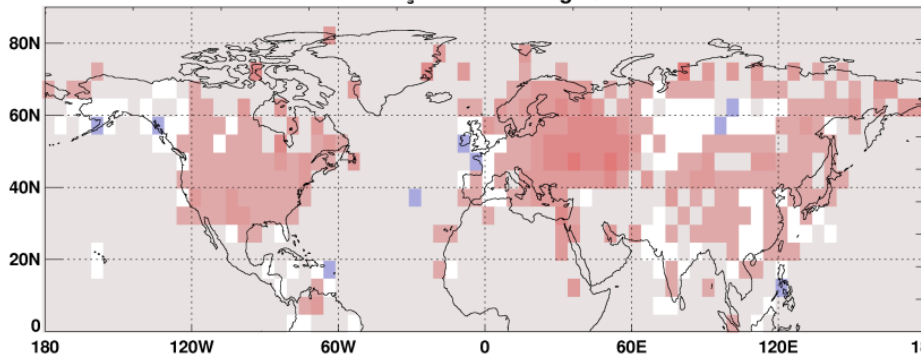
Observed  $T_s$  Trend Mar-May 1988-2015



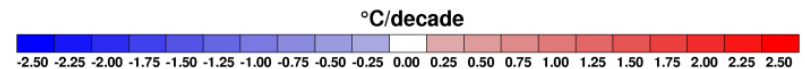
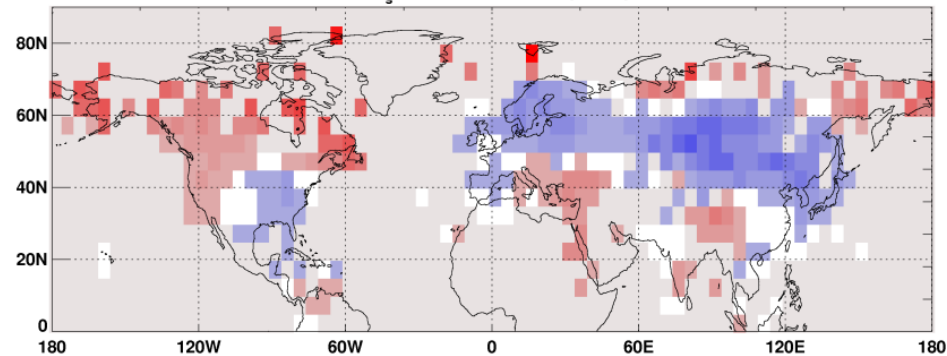
Observed  $T_s$  Trend Sep-Nov 1988-2015



Observed  $T_s$  Trend Jun-Aug 1988-2015



Observed  $T_s$  Trend Dec-Feb 1988/89-2015/16

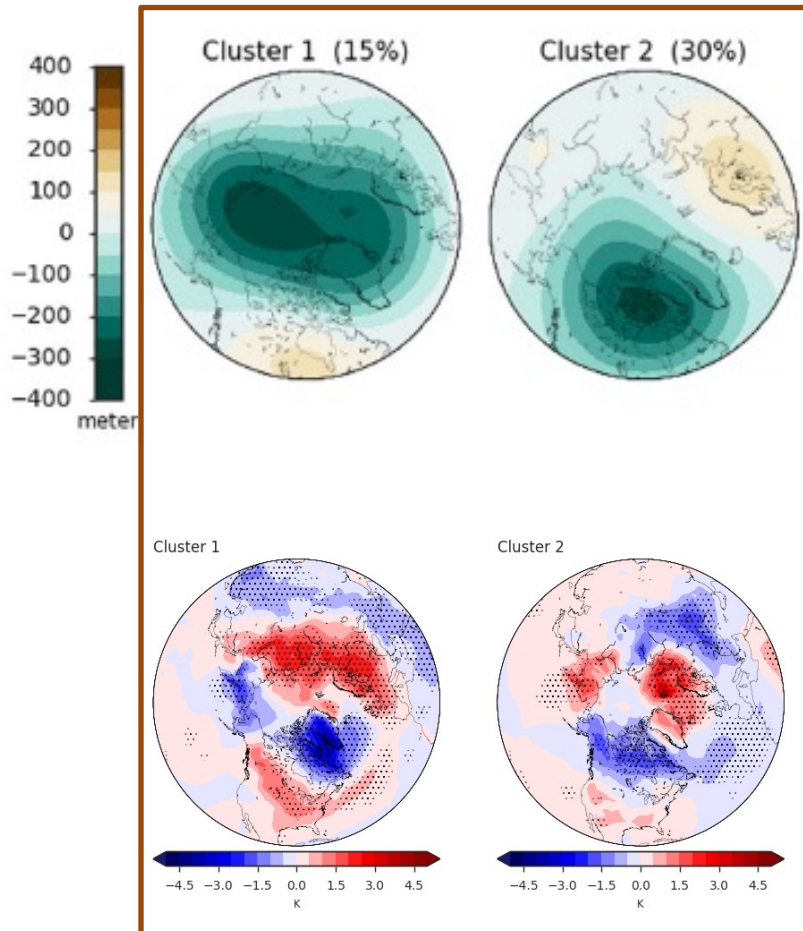


# STRETCHED POLAR VORTEX

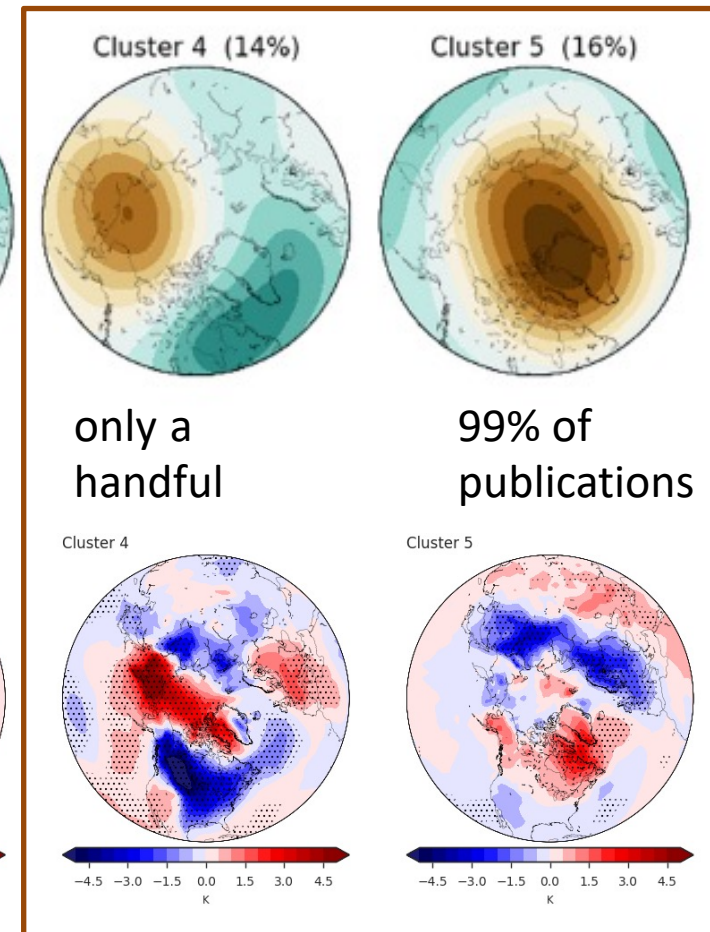


# Cluster Analysis of Polar Vortex and Trends

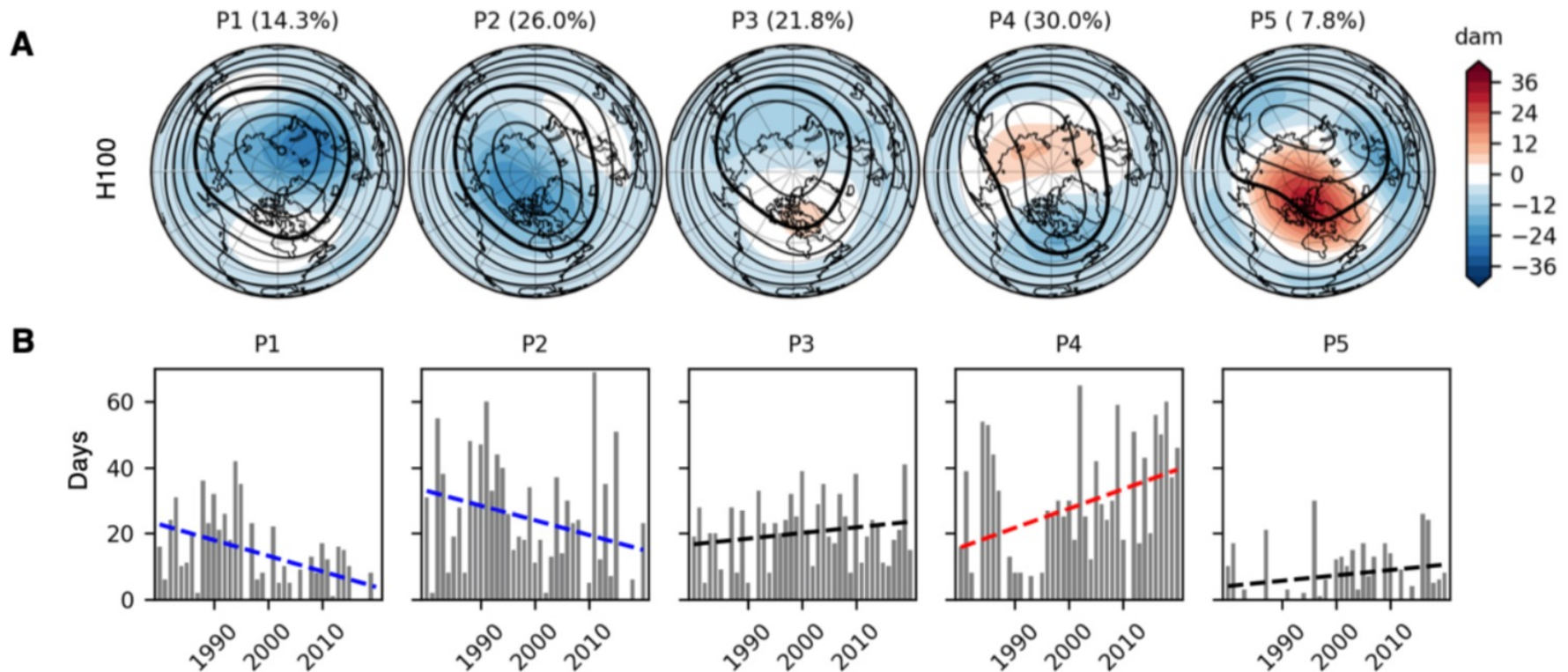
## Strong Polar Vortex States



## Weak Polar Vortex States



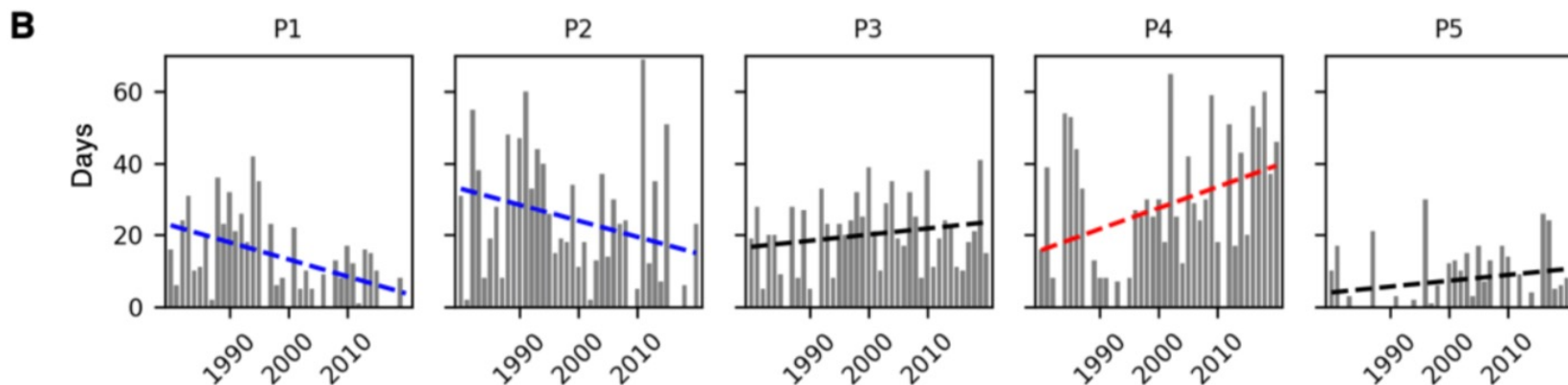
# Trends of five clusters over reanalysis



Cluster 4 shows strongest increasing trend

# Increasing trends have shifted

Previously SSWs showed the fastest increasing trend but now it is SPV stretching events.



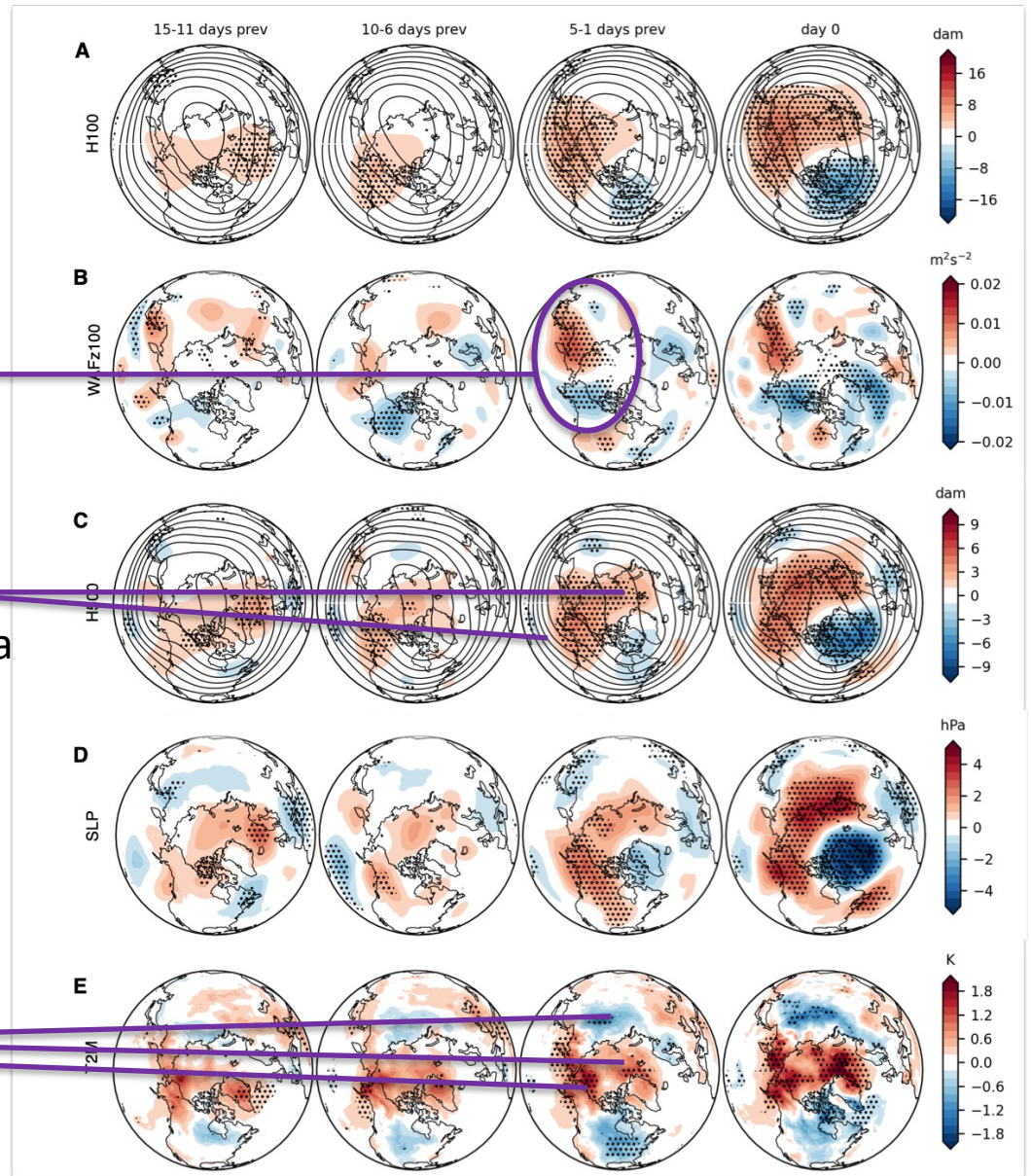


# Precursors

Dipole in vertical wave energy

Ridging in B-K Seas & Alaska with  
Troughing in East Asia & East N America

Warming B-K Seas & Alaska with  
Cooling East Asia & East N America

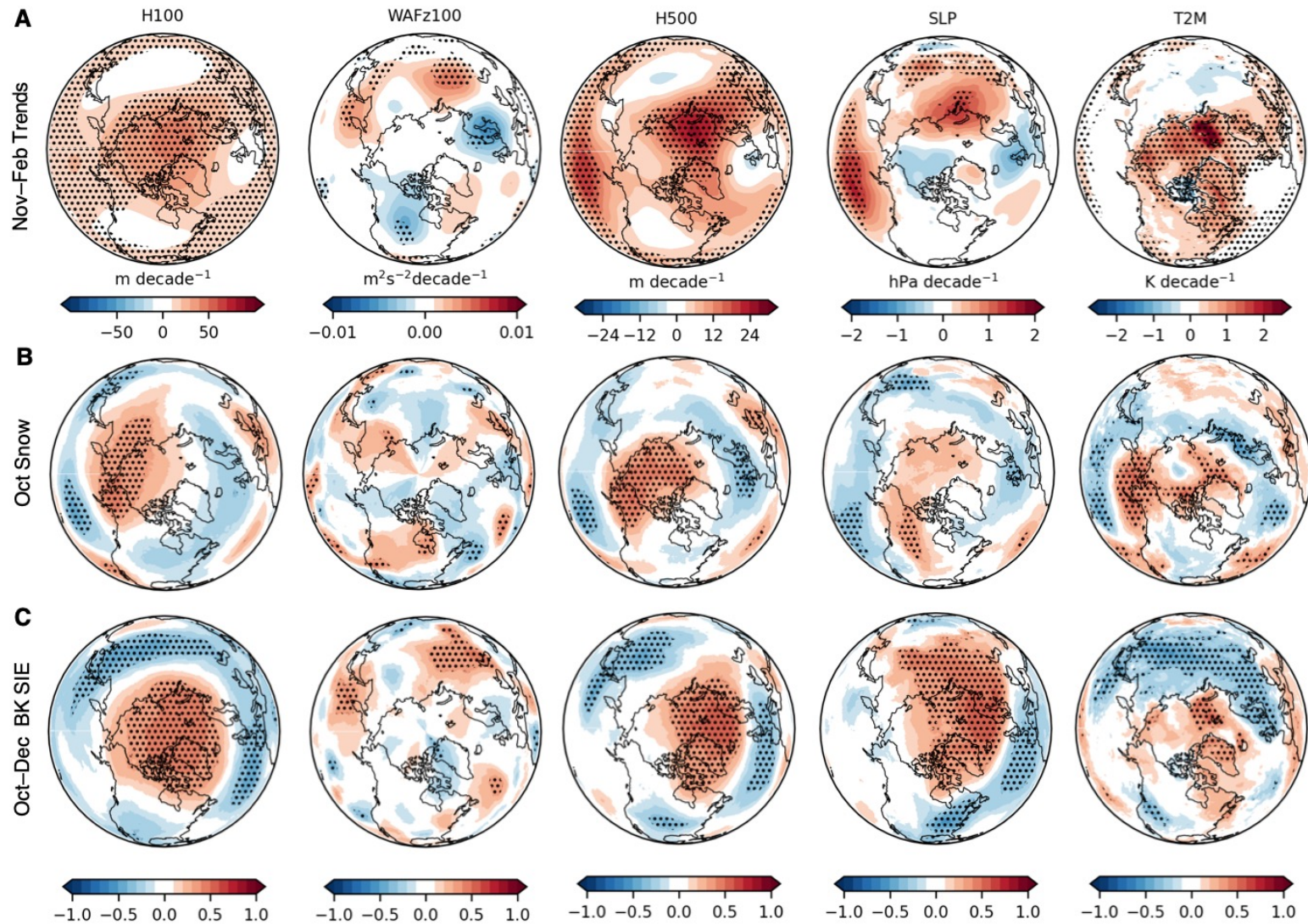




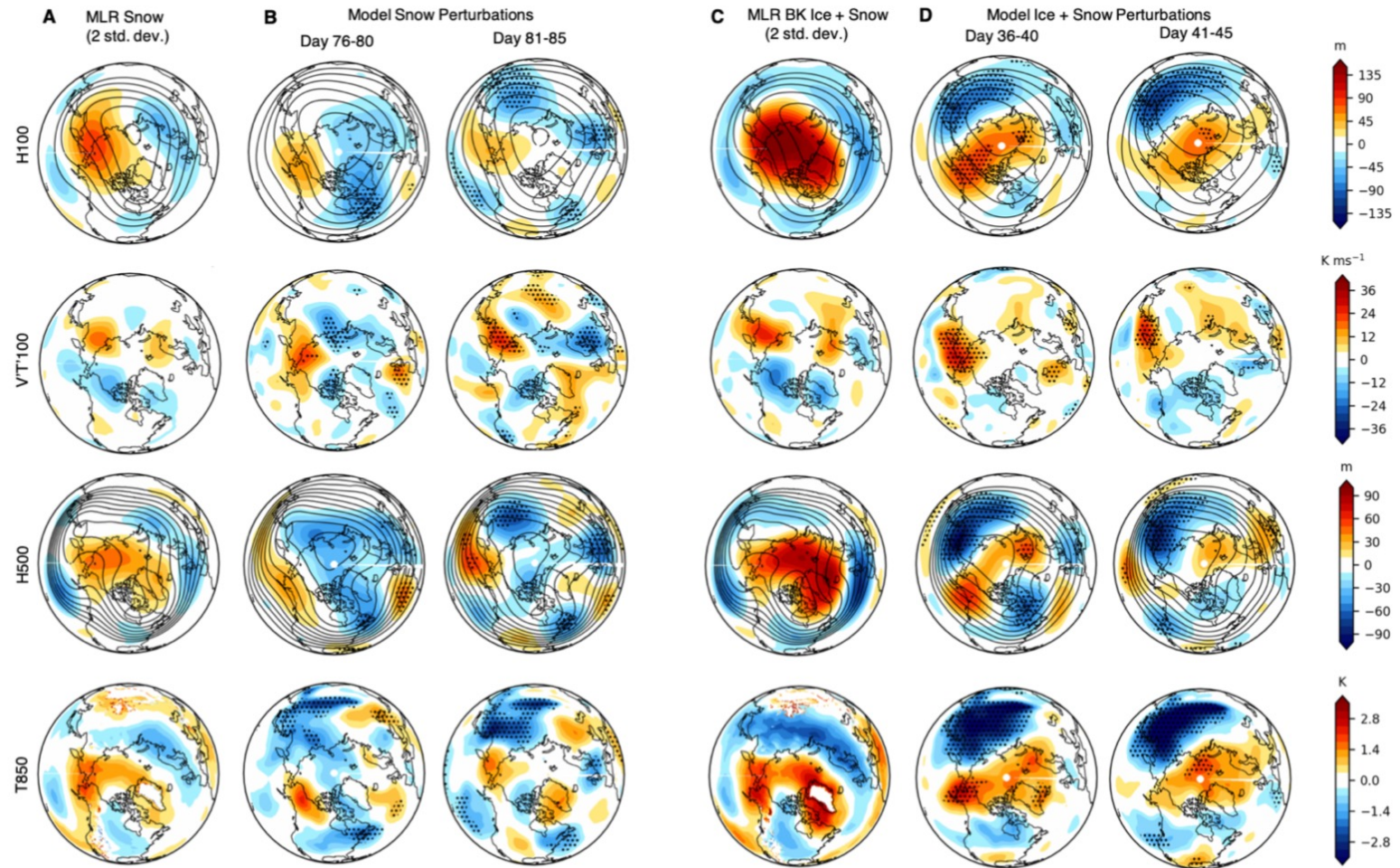
Trends in  
circulation  
anomalies are  
consitent with  
precursors to a  
disrupted PV

Snow resembles  
SPV stretching  
And NPO-

Sea Ice resembles  
SSW and NAO-

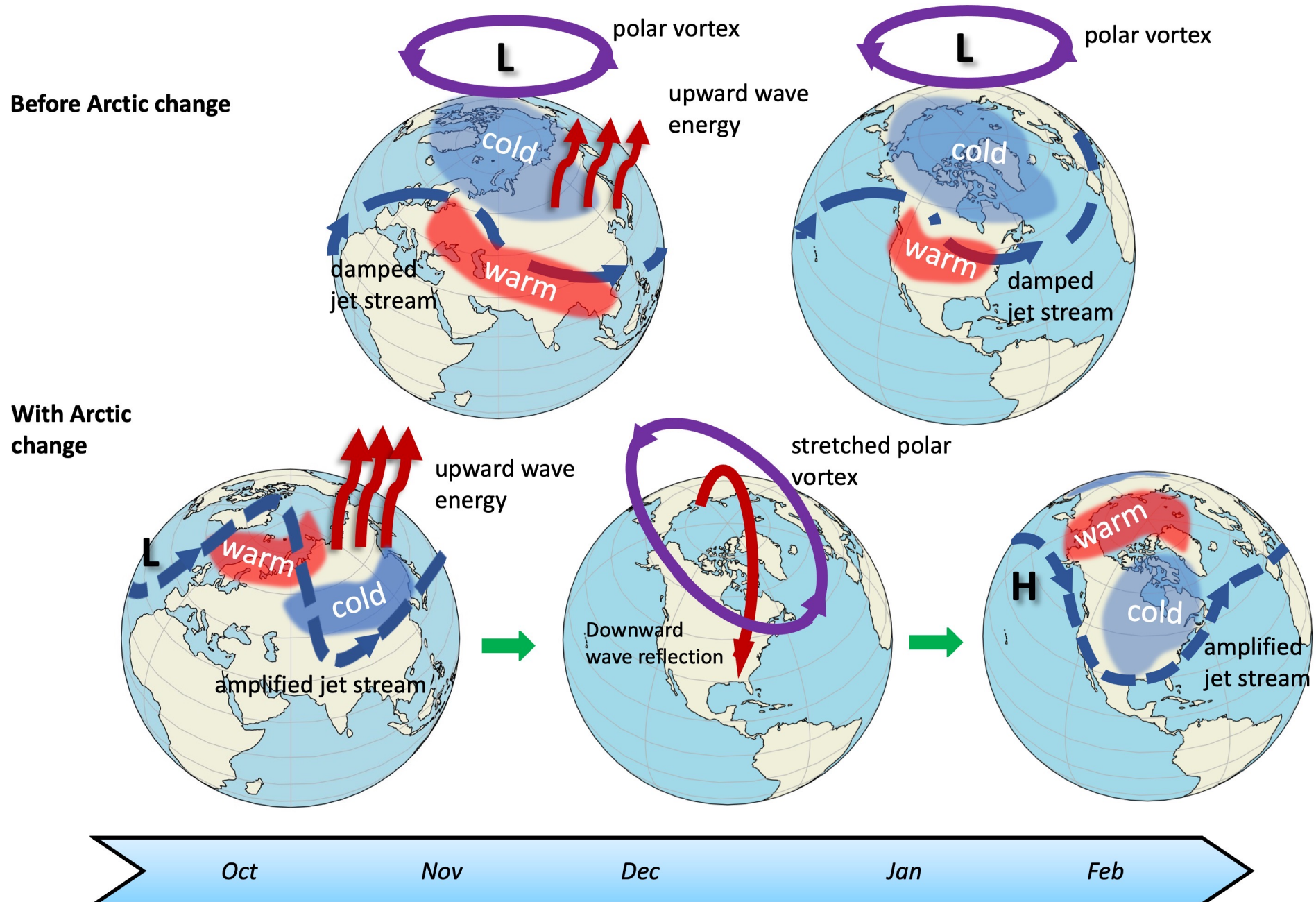


# Observational and modeling support





Late fall to early-winter Arctic amplification amplifies the natural standing wave over Eurasia, which leads to mid- to late-winter wave amplification over North America. Wave amplification on both continents favors extreme winter weather.

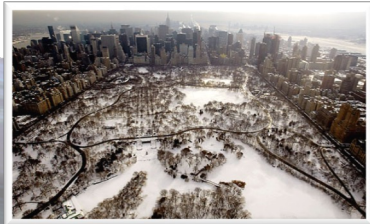


# Summary

- The globe is warming and our climate system is much warmer than even a few decades ago.
- Global warming is not equal everywhere. Over the past three decades the Arctic has been warming the fastest while the mid-latitudes have cooled/no trend (in winter).
- Studies strongly suggest that the warming in the Arctic is related to the cooling in the mid-latitudes and the dynamical link is through the “polar vortex.”
- A rather esoteric behavior of the polar vortex is related to extreme winter weather east of the Rockies including Texas where the polar vortex becomes elongated or stretched.
- Winter days where the polar vortex “stretches” have been increasing during the period of accelerated Arctic warming, which can contribute to more severe winter weather.

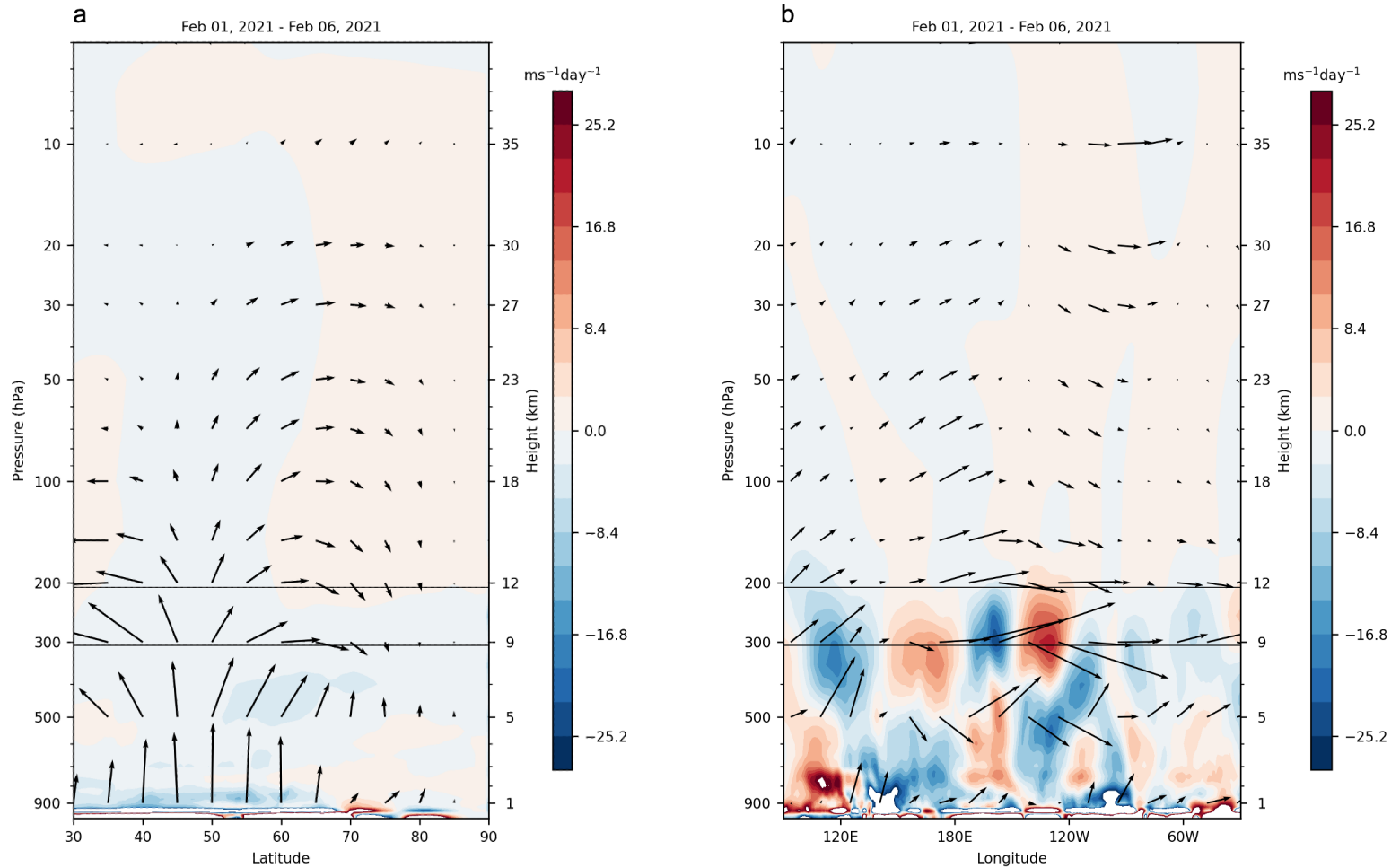


**Cohen, J., L. Agel, M. Barlow, C. I. Garfinkel, I. White. 2021: Linking Arctic variability and change with extreme winter weather in the US, *Science*, 373 (6559), 1116–1121, DOI: [10.1126/science.abi9167](https://doi.org/10.1126/science.abi9167).**



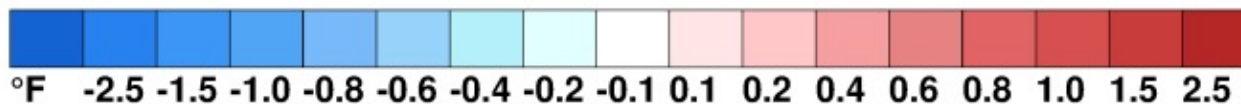
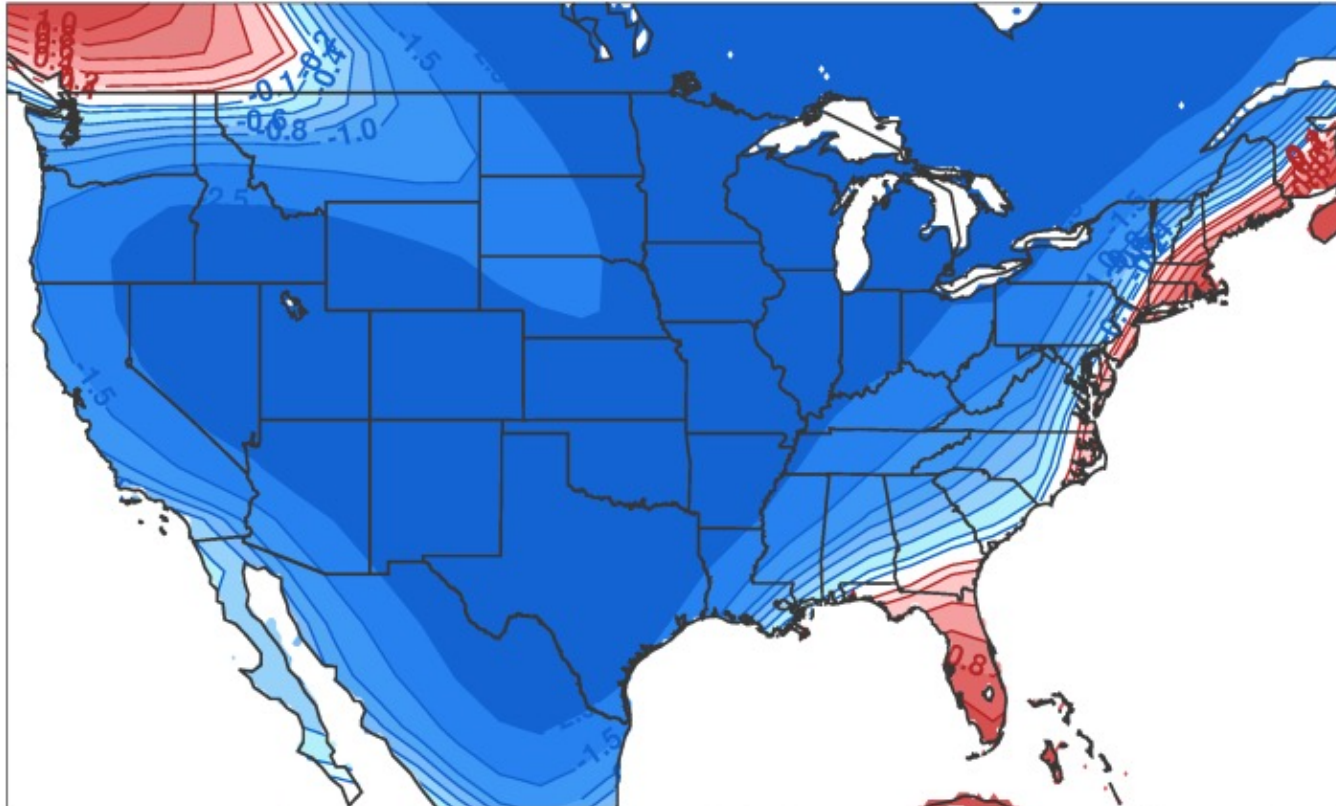
**Thank you!**

# Davis et al. 2022

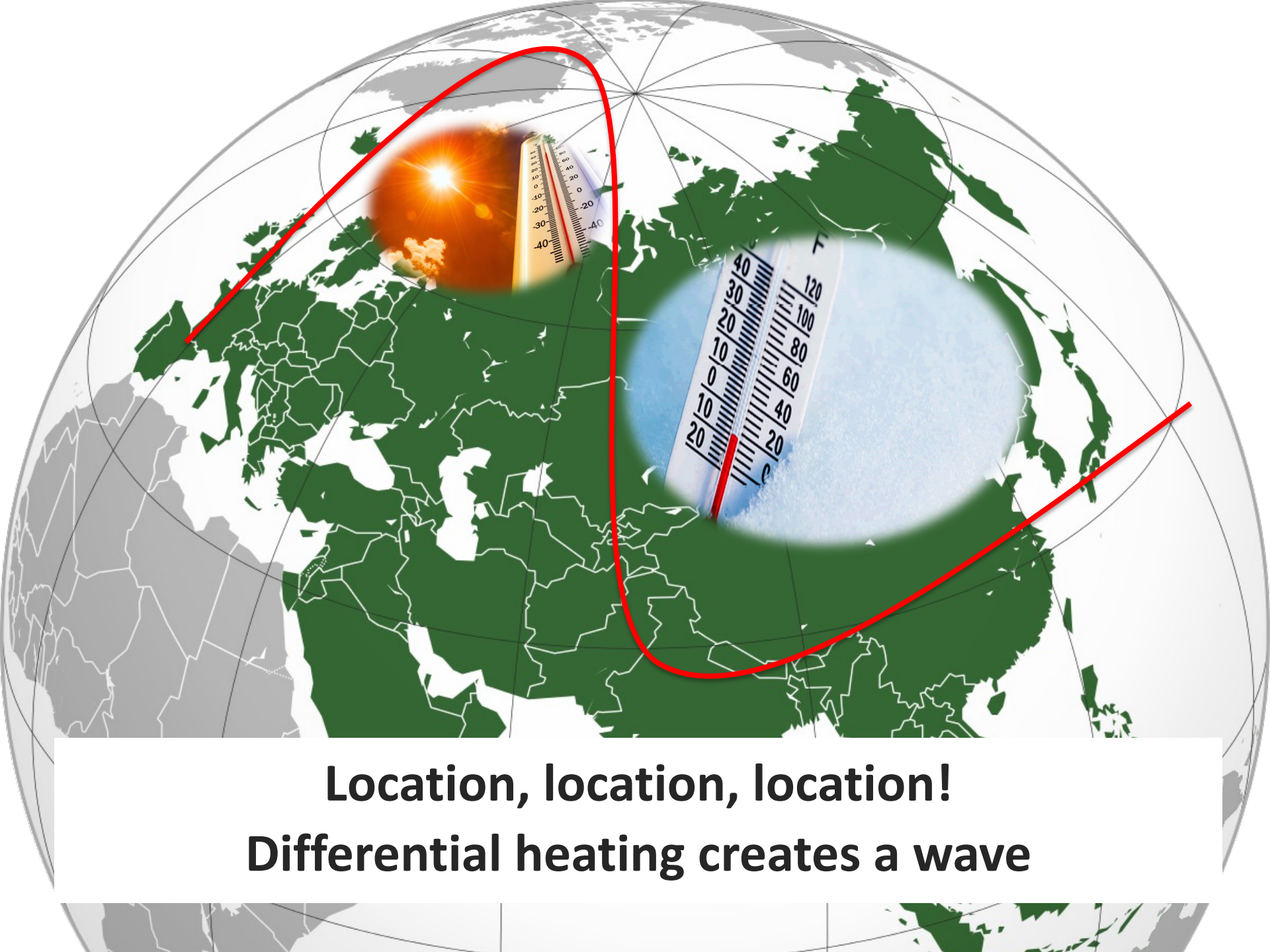


# Surface temperature anomalies winter 2022

Observed Temperature Anomaly Jan-Feb-Mar 2022



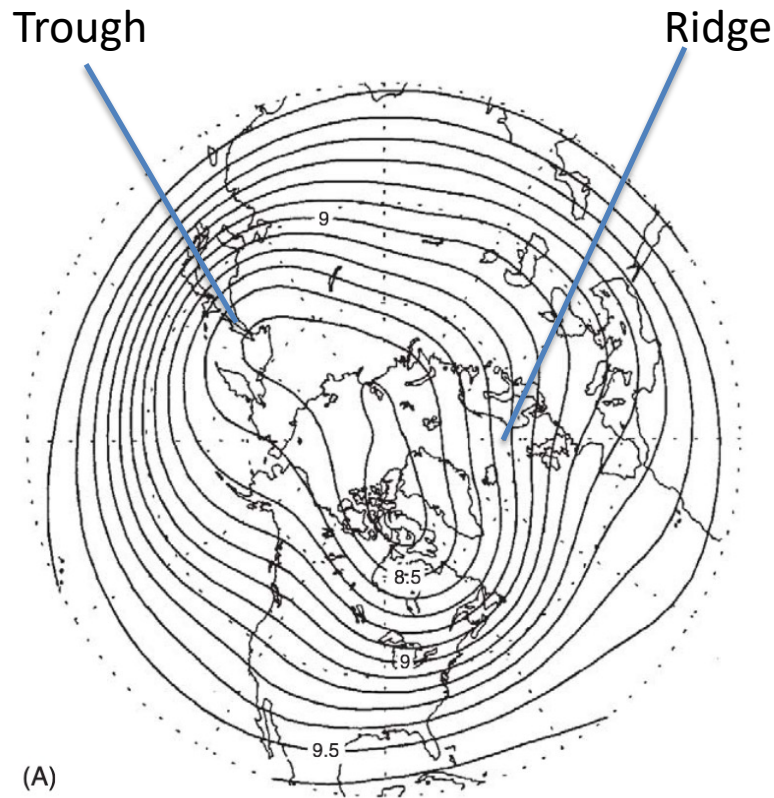




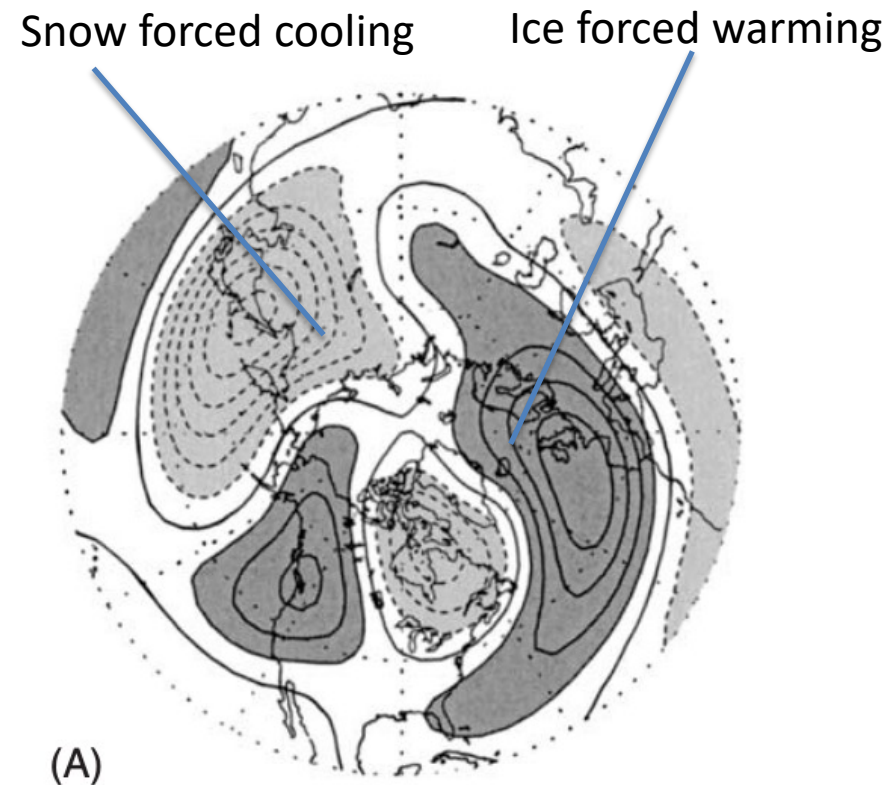
**Location, location, location!**  
**Differential heating creates a wave**



# Location, location, location - Atmospheric stationary waves (orographically & thermally forced)



Standing or planetary waves

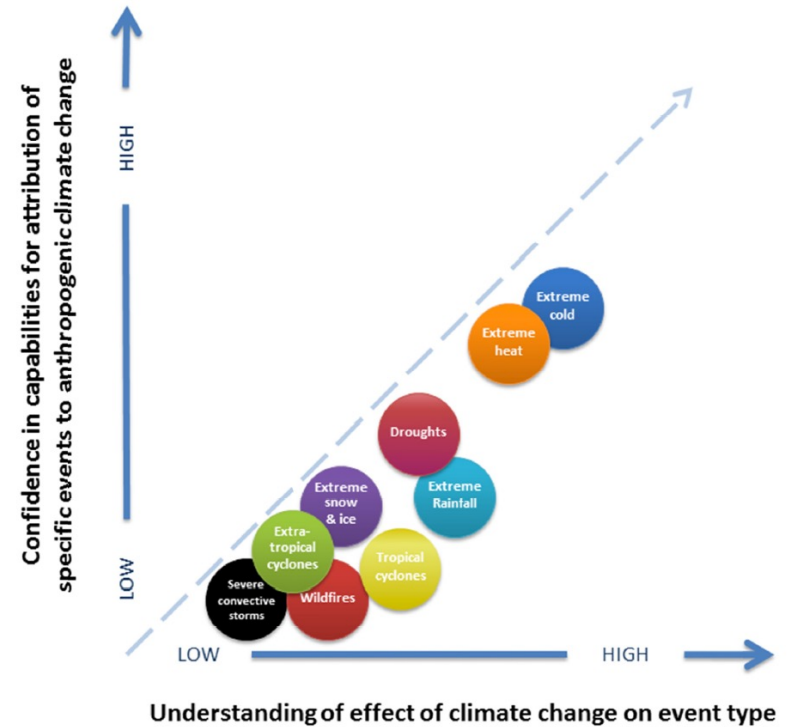
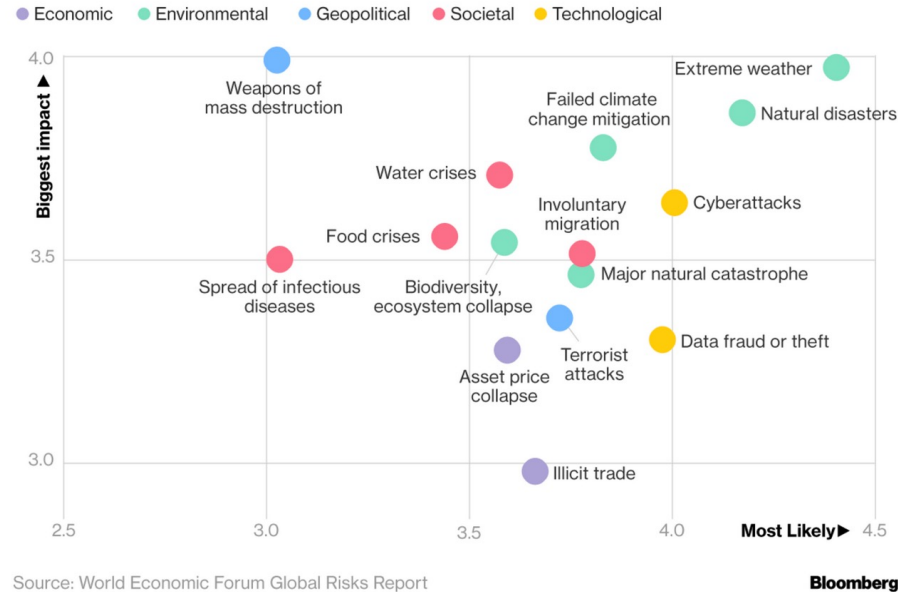


zonal anomalies

# Extreme Weather

## These Are the Biggest Global Risks for 2018

The World Economic Forum's top 10 risks, ranked by likelihood and impact



- Extreme weather is considered by economists to be the biggest global risk
- The extreme weather climate scientists are most confident will change due to climate change is a decrease in extreme cold

# Record snow cover extent in 2021

