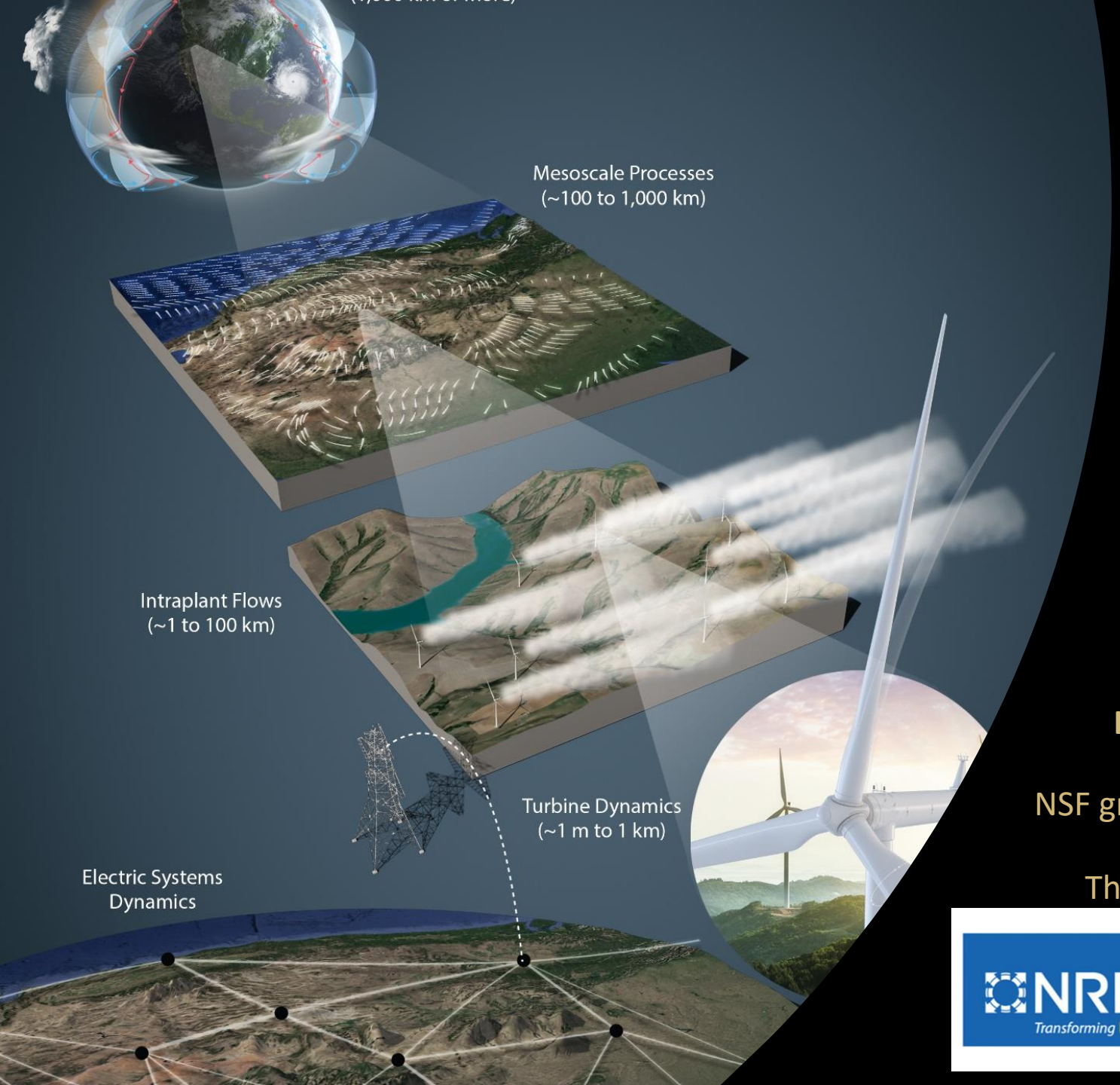


The Texas Event: What Does Atmospheric Science Tell Us?

Julie K. Lundquist [1,2]
[1] University of Colorado Boulder,
[2] National Renewable Energy Laboratory

ESIG Meteorology & Market Design Workshop
26 May 2021 Keynote

NSF grants AGS-1554055 (CAREER) and AGS-1565498

Thanks to Andrew Winters[1] for helpful discussions!

NREL Transforming ENERGY

University of Colorado Boulder

NSF

Climate variability is highlighted in the "atmospheric science" grand challenge for wind energy

REVIEW

RENEWABLE ENERGY

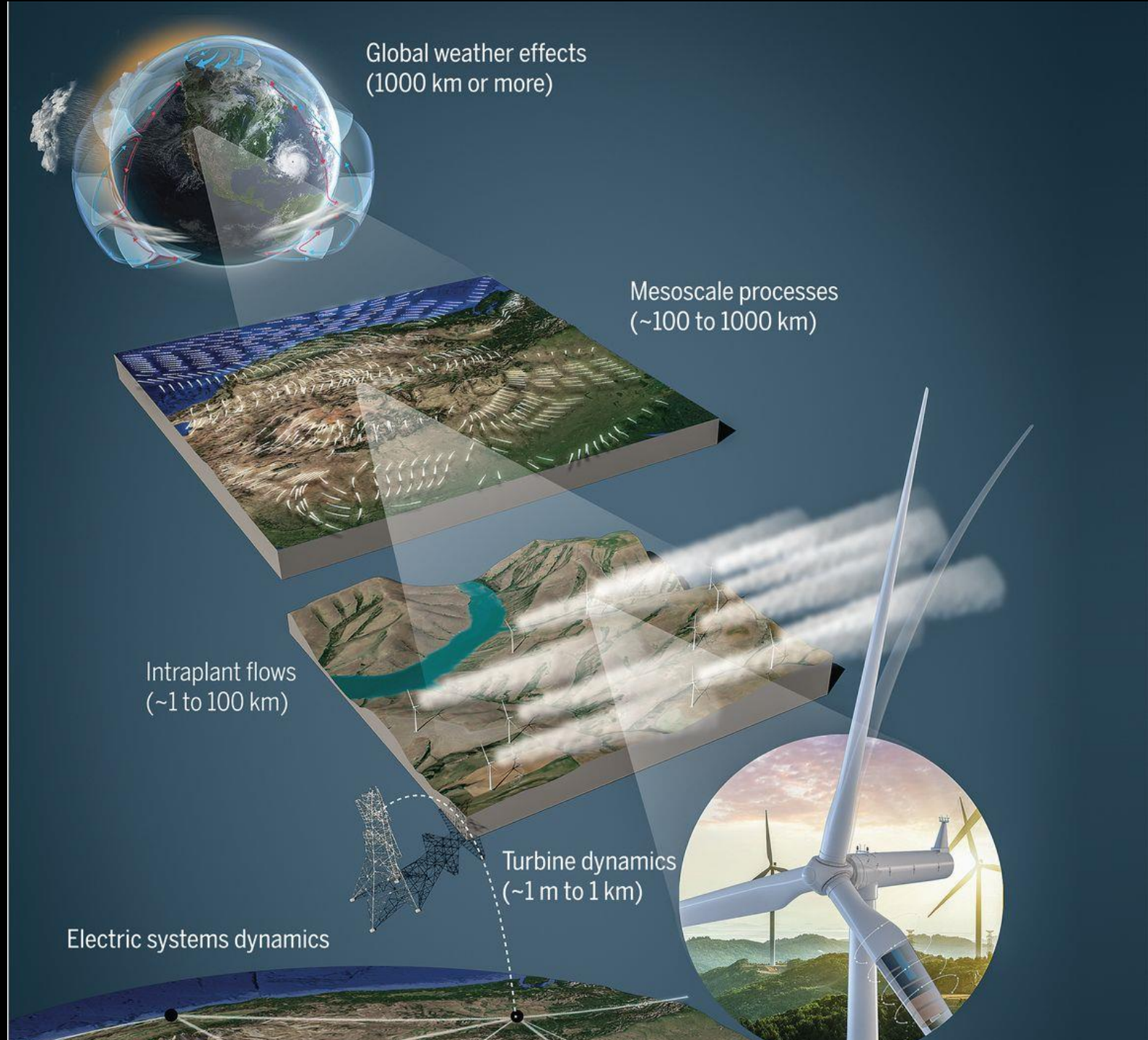
Grand challenges in the science of wind energy

Paul Veers[1]*, Katherine Dykes[2]*, Eric Lantz[1]*, Stephan Barth[3], Carlo L. Bottasso[4], Ola Carlson[5], Andrew Clifton[6], Johney Green[1], Peter Green[1], Hannele Holttinen[7], Daniel Laird[1], Ville Lehtomäki[8], Julie K. Lundquist[1,9], James Manwell[10], Melinda Marquis[11], Charles Meneveau[12], Patrick Moriarty[1], Xabier Munduate[13], Michael Muskulus[14], Jonathan Naughton[15], Lucy Pao[16], Joshua Paquette[17], Joachim Peinke[3,18], Amy Robertson[1], Javier Sanz Rodrigo[13], Anna Maria Sempreviva[2], J. Charles Smith[19], Aidan Tuohy[20], Ryan Wiser[21]

Harvested by advanced technical systems honed over decades of research and development, wind energy has become a mainstream energy resource. However, continued innovation is needed to realize the potential of wind to serve the global demand for clean energy. Here, we outline three interdependent, cross-disciplinary grand challenges underpinning this research endeavor. The first is the need for a deeper understanding of the physics of atmospheric flow in the critical zone of plant operation. The second involves science and engineering of the largest dynamic, rotating machines in the world. The third encompasses optimization and control of fleets of wind plants working synergistically within the electricity grid. Addressing these challenges could enable wind power to provide as much as half of our global electricity needs and perhaps beyond.

Veers *et al.*, *Science* **366**, eaau2027 (2019) 25 October 2019

Wind originates from global meteorology, but is affected by phenomena at a range of scales

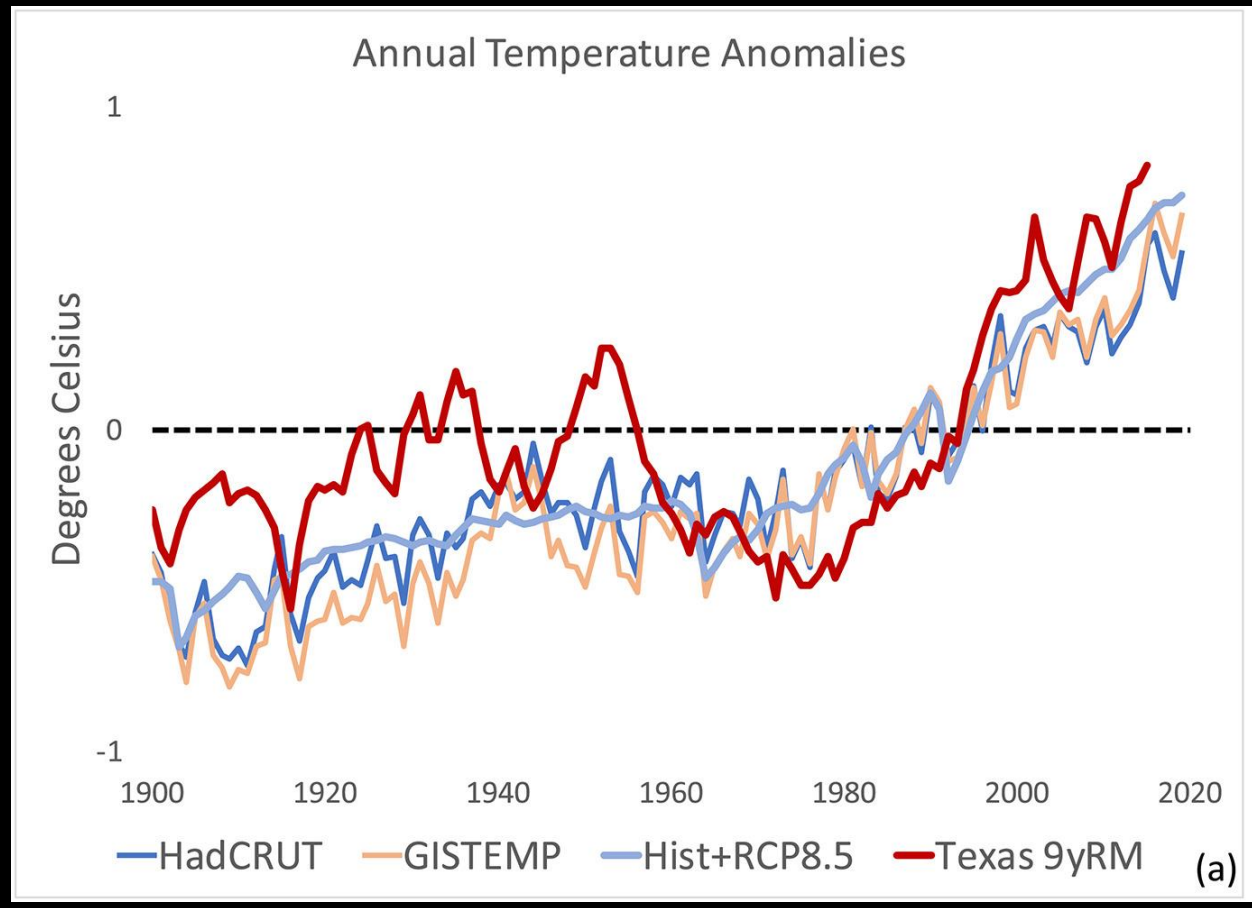


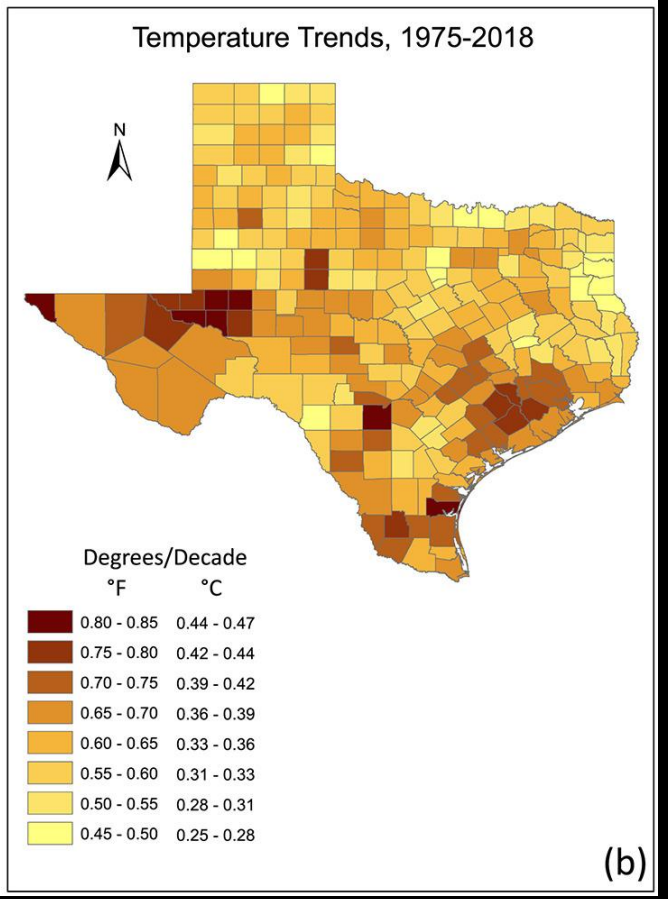
There is no scientific consensus on whether extended anomalous winter cooling, such as experienced in Texas, is caused by global warming, especially Arctic warming

Today's discussion:

- Review recent decades' temperature changes in Texas and in the Arctic
- Demonstrate rapid sea ice loss and Arctic warming
- Explain Arctic Amplification (AA)
- Delineate the proposed mechanism for how AA might affect jet stream and blocking frequency
- Highlight analysis that show if there is a relationship between AA and extreme winter events in mid-latitudes, it is a complex one mediated by internal climate variability
- Set the stage for Dr. Sharp's discussion of the meteorology of this particular event

In Texas, historic air temperatures trends variations broadly match global air temperature trends: general increase during the first part of the twentieth century, decline between ~ 1955 - 1975, and increase thereafter.





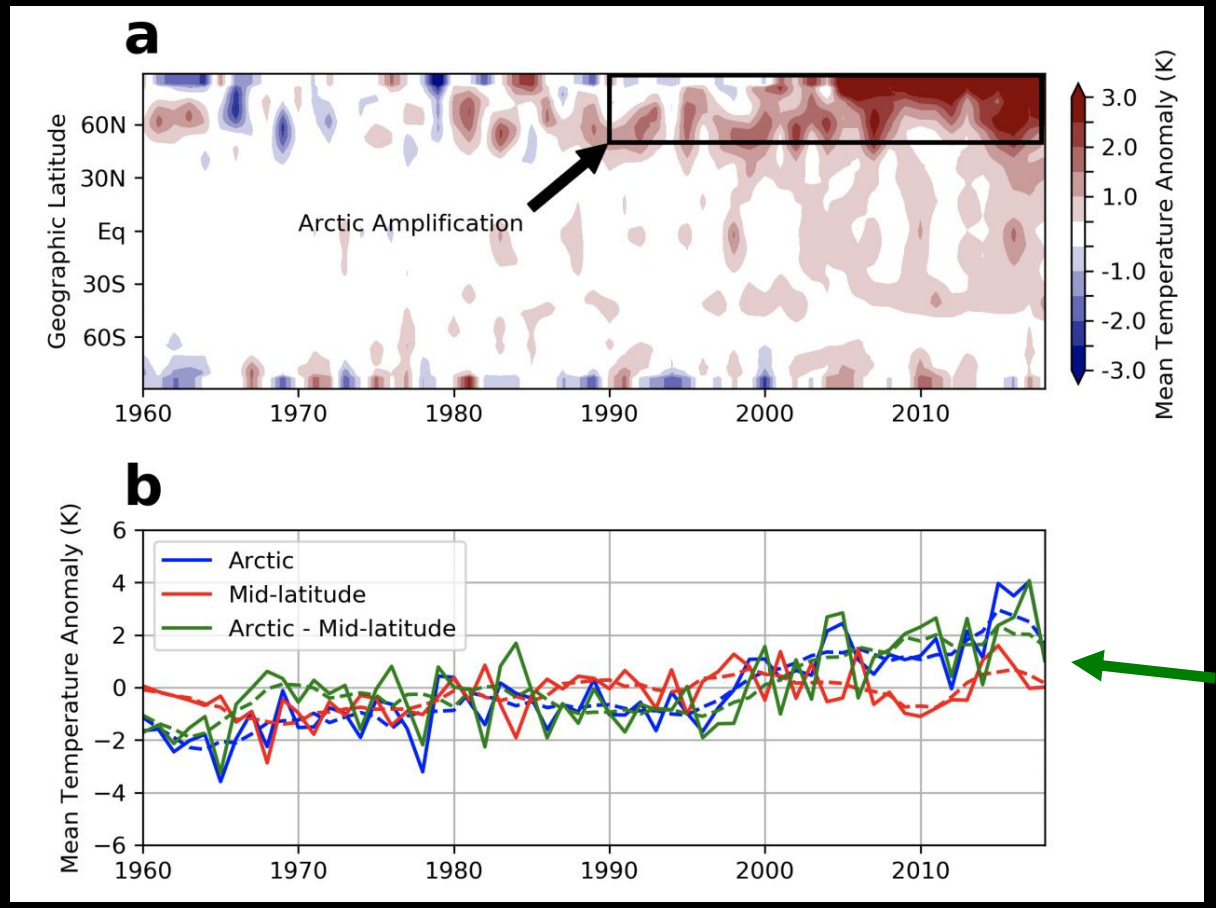
Temperature is expected to continue increasing in Texas at or greater than the global mean rate of increase

University of Colorado Boulder

Nielsen-Gammon et al. 2020 *Earth's Future,* https://doi.org/10.1029/2020EF001552

The Arctic has warmed more than twice as fast as the global average since the late twentieth century

AA is strongest over the Arctic Ocean in autumn and winter, whereas during the summer it is weaker and shifted over land and the Greenland ice sheet

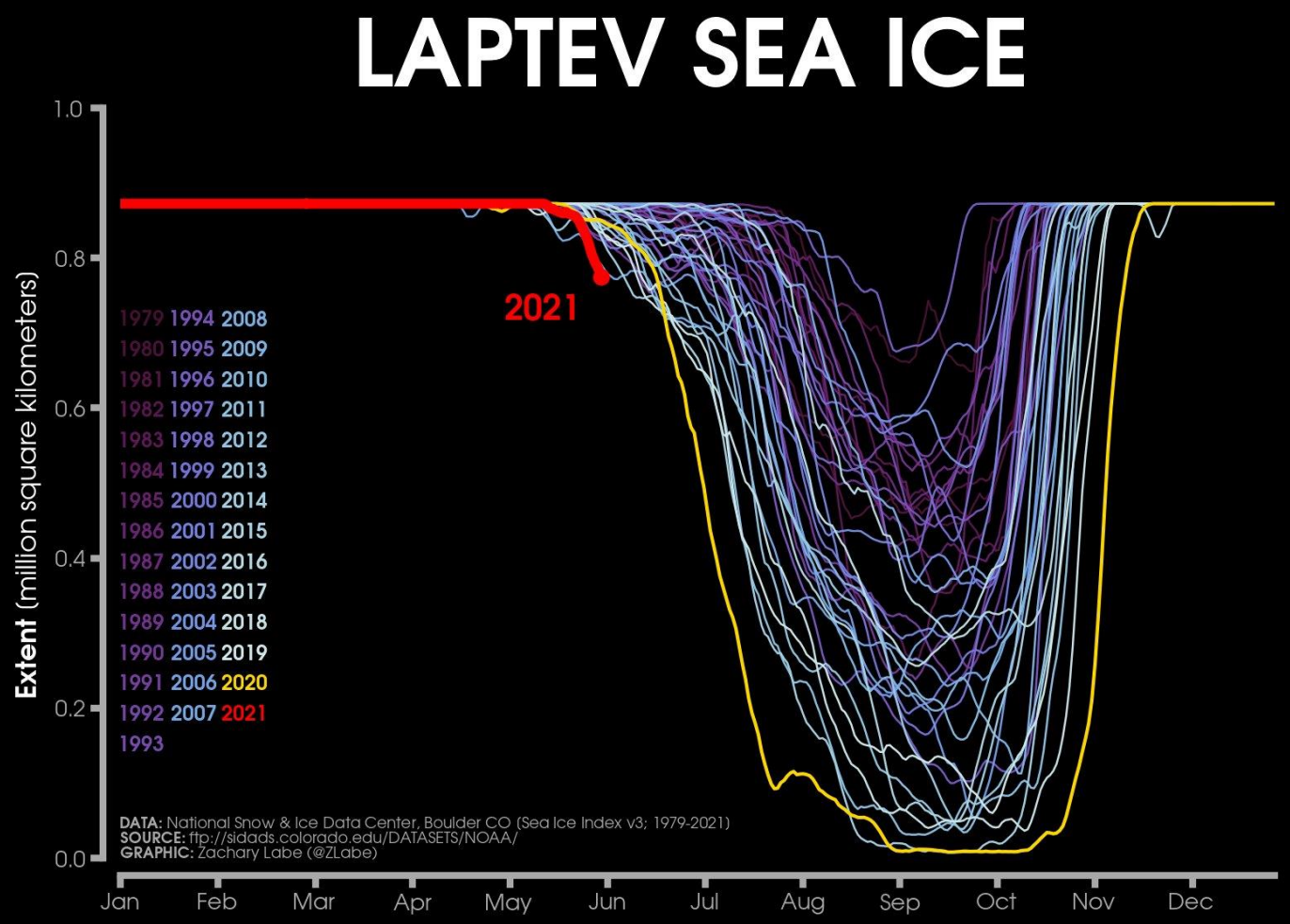


Note the divergence of Arctic and mid-latitude temperature trends

Cohen, J. *et al.* Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10,** 20–29 (2020). https://doi.org/10.1038/s41558-019-0662-y

Rapidly declining sea ice extent in summer and early autumn demonstrates climate change in the Arctic

(Laptev Sea is in the Siberian Arctic)

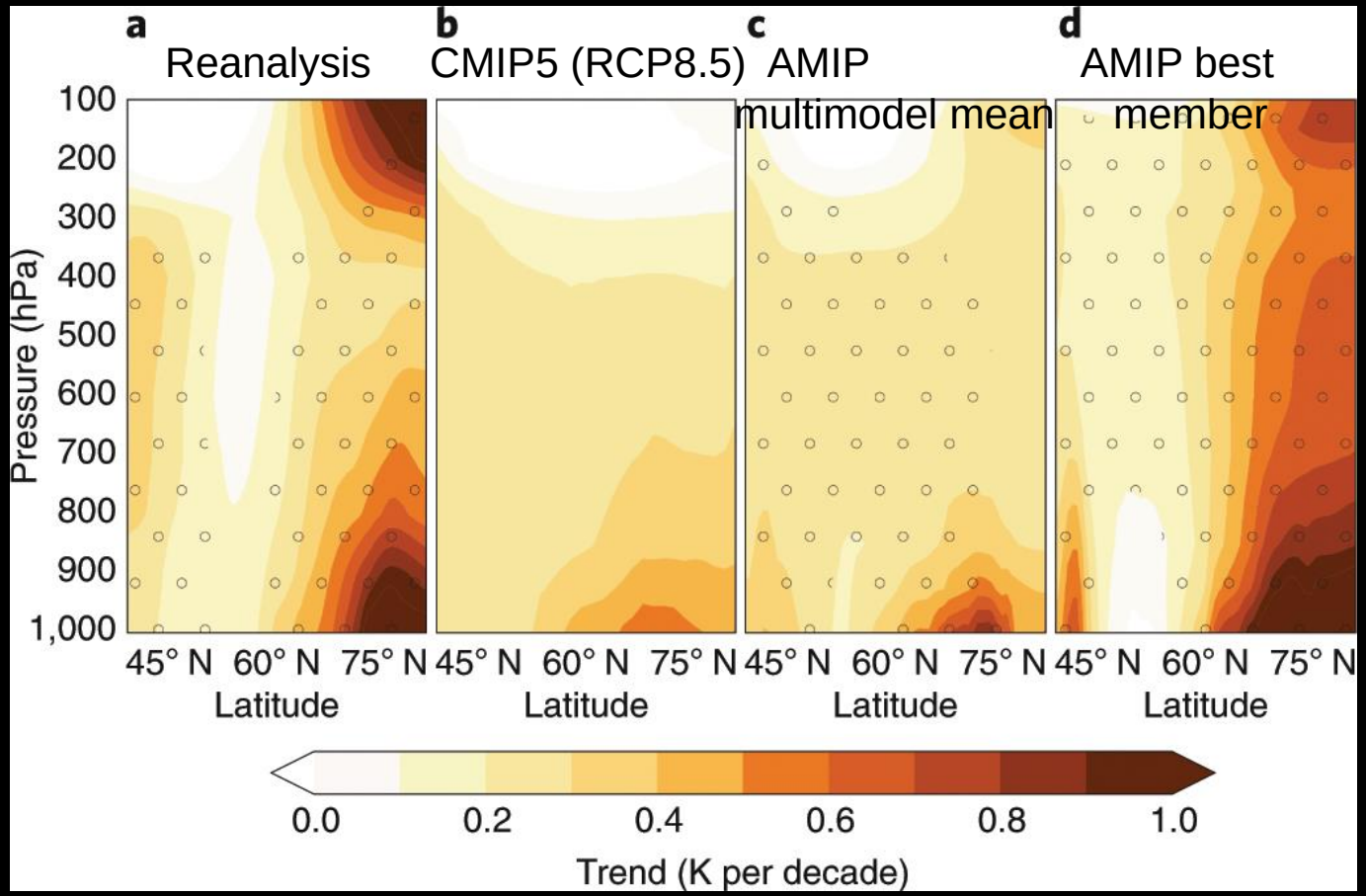


Graphic courtesy @ZLabe

(Data as of 2 June 2021)

University of Colorado Boulder

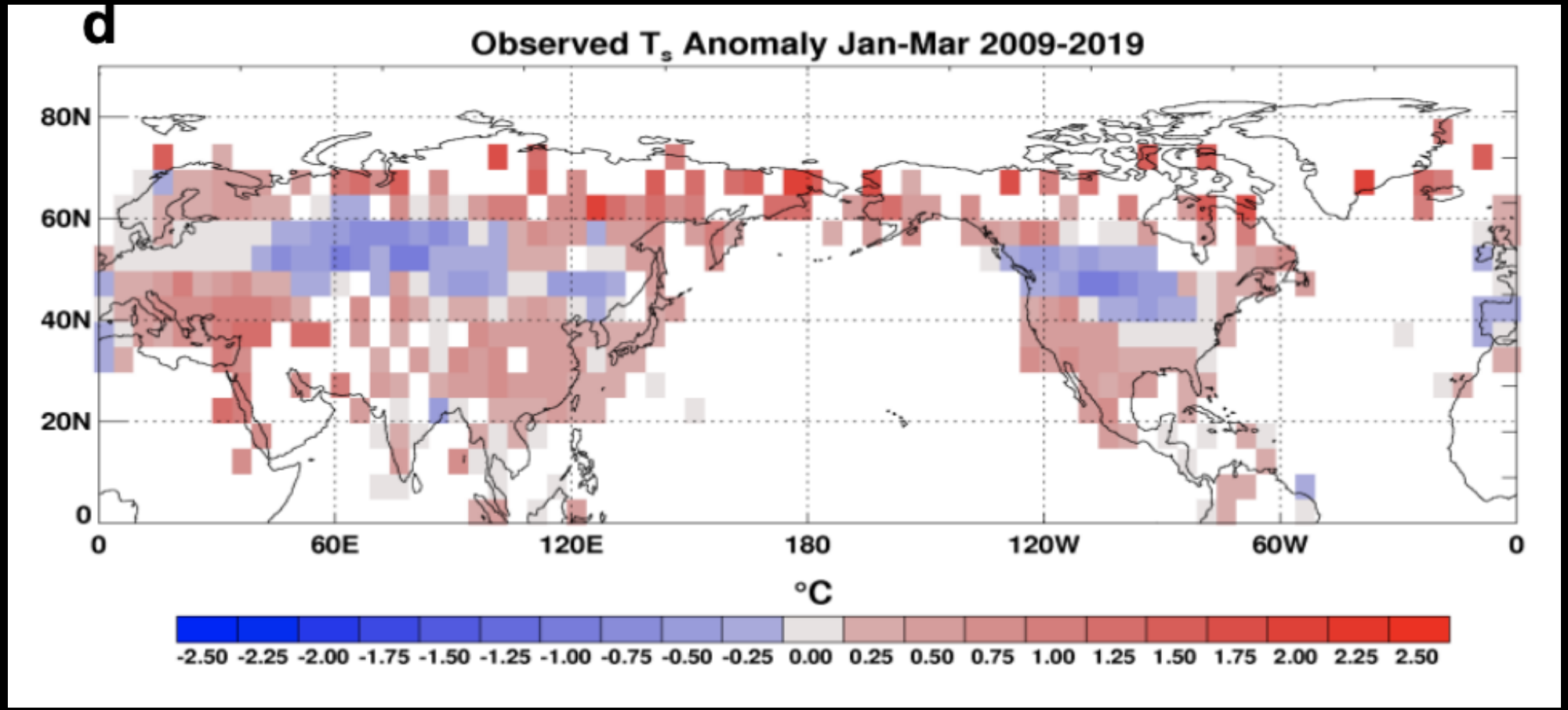
AA emerges in the zonal-mean winter air-temperature trends for the NH and Arctic between 1980–2019, from the surface to the upper atmosphere



Cohen, J. *et al.* Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10,** 20–29 (2020). https://doi.org/10.1038/s41558-019-0662-y

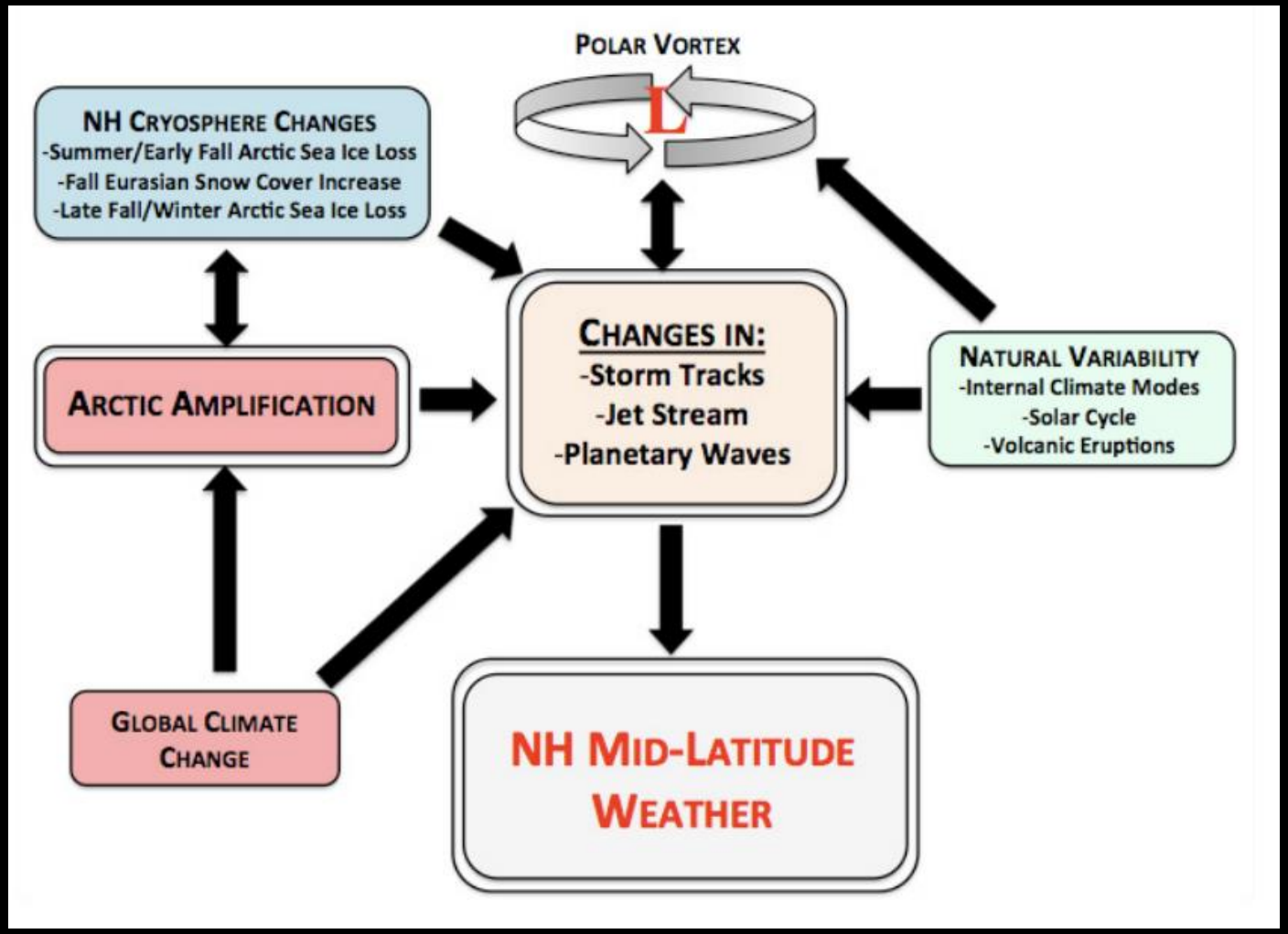
So Arctic amplification is unambiguous…the question is, how does it affect mid-latitudes?

The theory for mid-latitude cooling: Arctic warming influences midlatitude weather through a stratospheric pathway favoring cold temperatures in midlatitudes



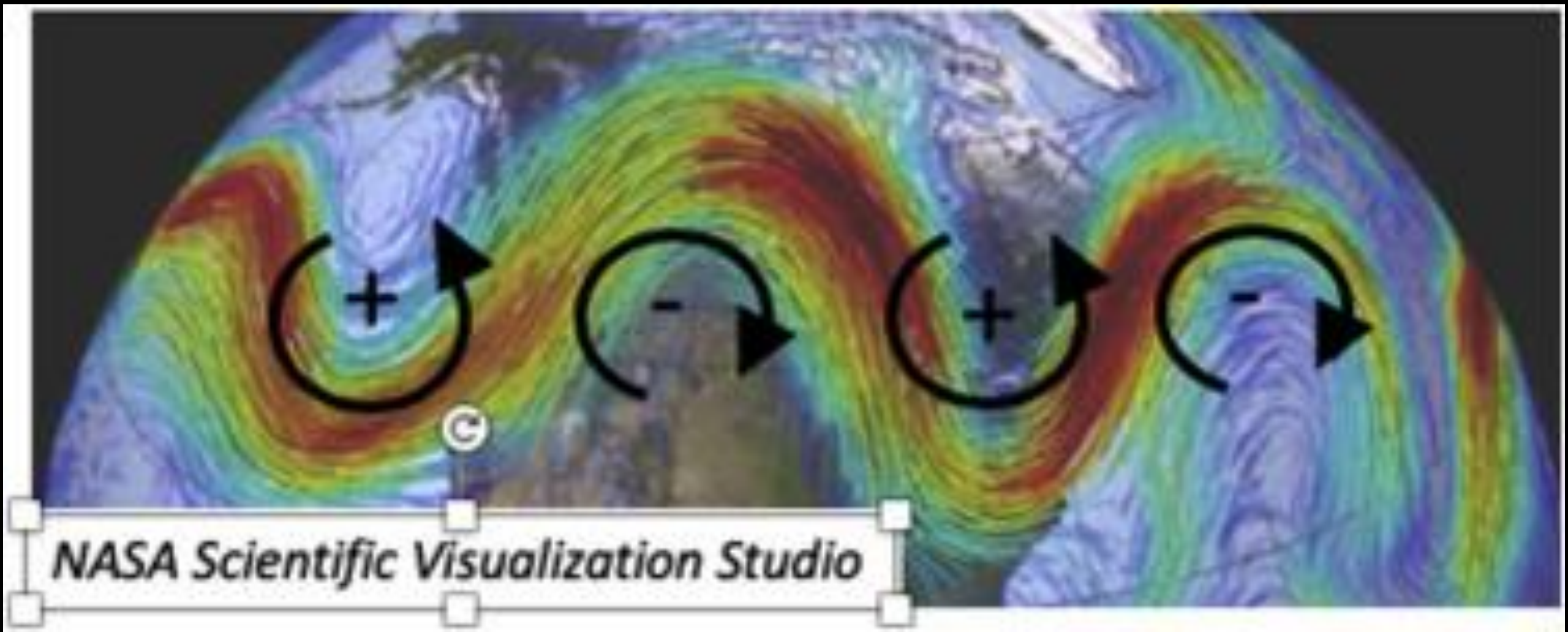
Cohen, J. *et al.* Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10,** 20–29 (2020). https://doi.org/10.1038/s41558-019-0662-y

Mid-latitude flow depends on multiple complex processes, which complicates detangling AA effects on the jet stream.



Cohen et al., 2014: Recent Arctic amplification and extreme mid-latitude weather. *Nat. Geosci*., 7, 627–637, doi:10.1038/ngeo2234.

Consider the jet stream and Rossby waves…



The tropospheric polar vortex structure is quasi-stable but can shift between pattern shapes

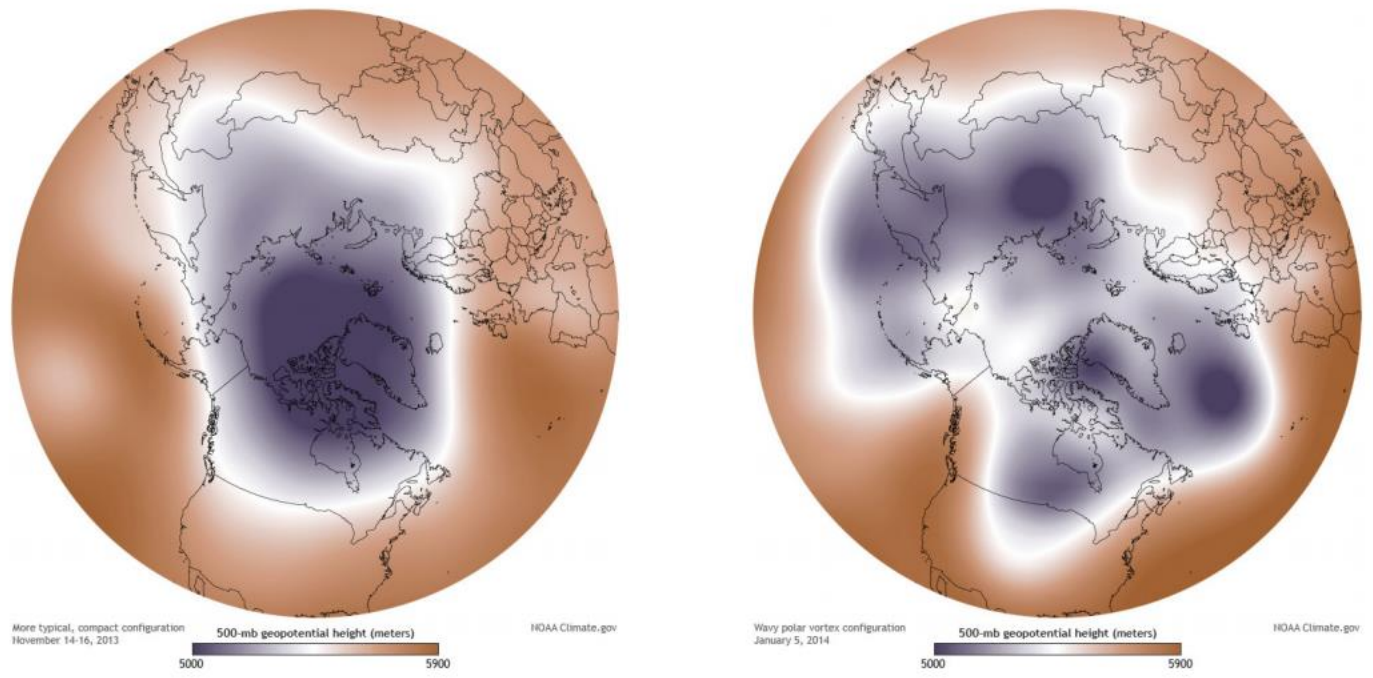
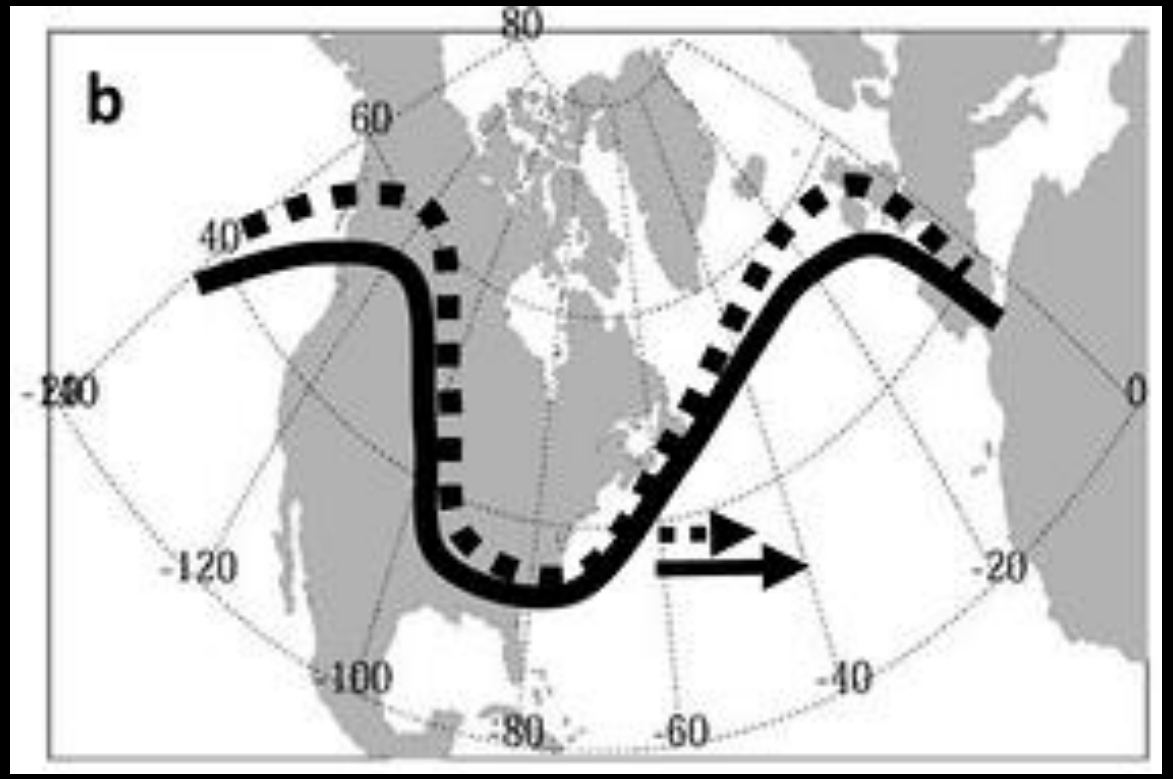


Figure 6. Sample geopotential height fields for 500 hPa with lower values in purple and the jet stream in white. (a) Contrasts a single, more zonal path encircling the tropospheric polar vortex versus a wavier configuration (b) with multiple low centers. (Figure from NOAA Climate.gov).

Climatological waves during winter usually consist of a ridge of higher geopotential heights over the northeastern Pacific and/or Greenland along with a trough of lower heights over central and eastern North America, although a great deal of interannual variability is common.

Cohen, J. et al. *Arctic Change and Possible Influence on Mid-latitude Climate and Weather*. US CLIVAR Report 2018-1, https://doi.org/10.5065/D6TH8KGW (2018).

The argument for Arctic Amplification effects on mid-latitudes has two components



1. Weaker poleward thickness gradients cause slower zonal winds

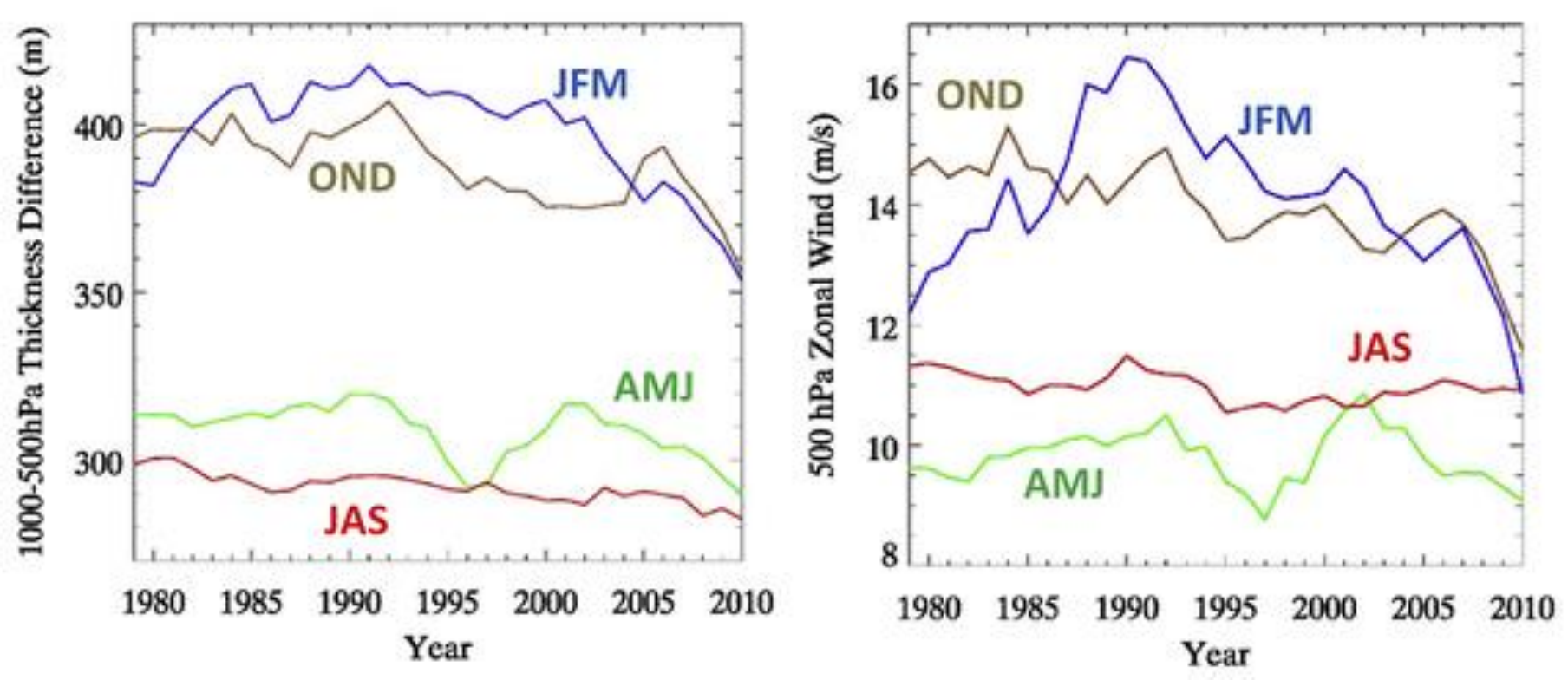
2. Enhanced high-latitude warming causes 500 hPa heights to rise more than in mid-latitudes, which elongates the peaks of ridges northward and increases wave amplitude

Both of these effects would slow eastward wave progression, leading to longer-lived events. Slower progression of upper-level waves causes more persistent weather conditions that can increase likelihood drought, prolonged precipitation, cold spells, heat waves, etc.

But is this really happening?

Francis & Vavrus, 2012, "Evidence linking Arctic amplification to extreme weather in mid-latitudes", *Geophysical Research Letters,* doi:10.1029/2012GL051000

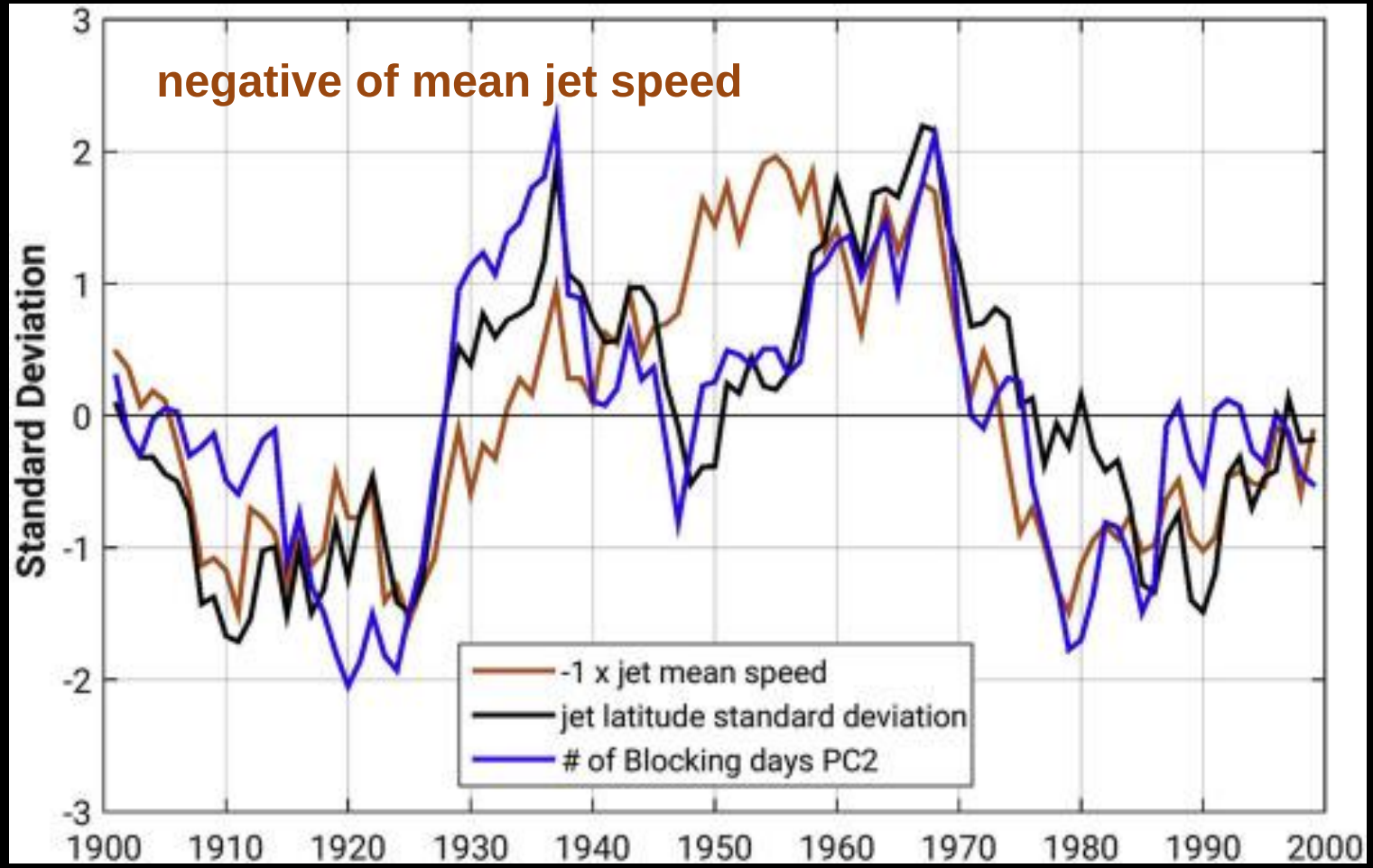
Preferential warming of the Arctic atmospheric column → increased geopotential height thickness → reduced meridional gradient → slowing of the polar jet stream.



Winds during fall have weakened by 14% since 1979; winter winds are more variable but also tend to decrease

Francis & Vavrus, 2012, "Evidence linking Arctic amplification to extreme weather in mid-latitudes", *Geophysical Research Letters,* doi:10.1029/2012GL051000

One analysis of 20CR suggests weaker jet streams → increased blocks and larger variance in latitude.



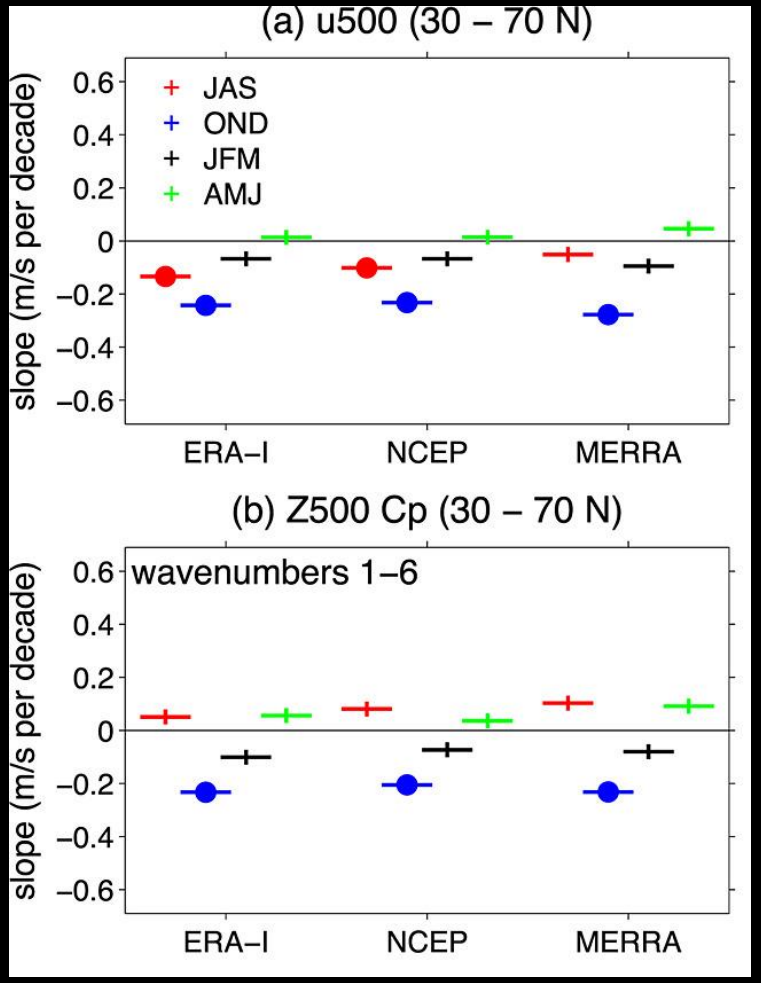
But these authors conclude that recent decades are **not unusual, suggesting that internal variability of the climate system is dominant**, not anthropogenic climate change.

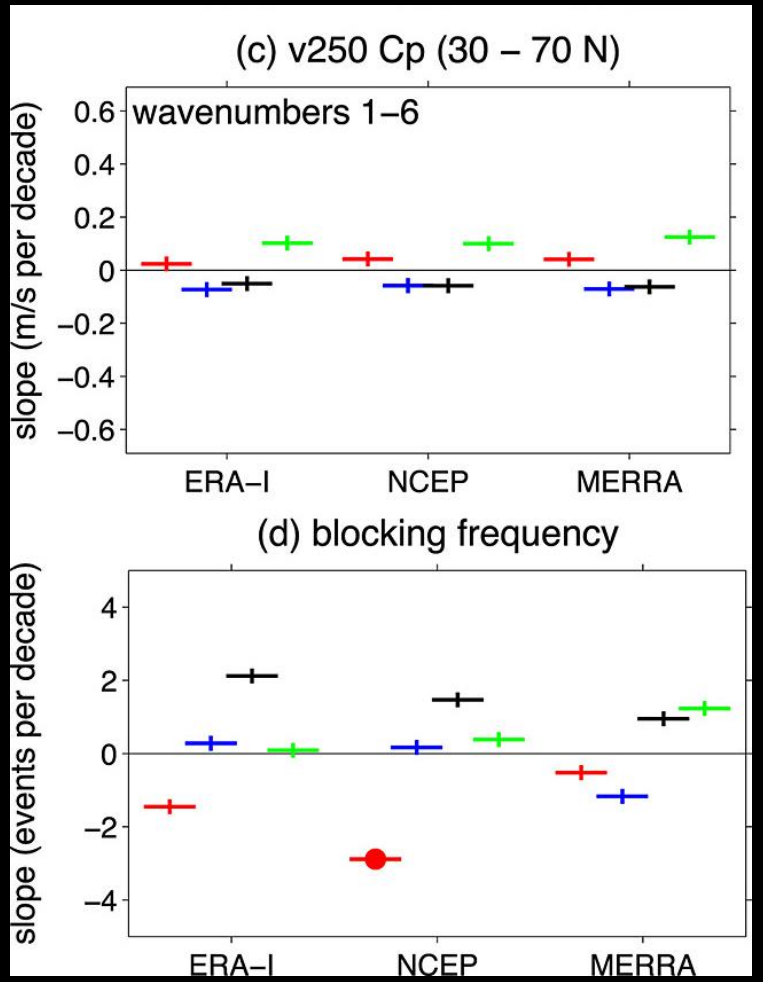
Woollings et al., 2018, "Daily to Decadal Modulation of Jet Variability," *Journal of Climate*, *31*(4), 1297-1314. https://journals.ametsoc.org/view/journals/clim/31/4/jcli-d-17-0286.1.xml

Other analysis of reported Arctic–mid-latitude linkages finds **no evidence** that Arctic amplification contributes to increased blocking or extreme weather.

Clear decreases in 500mb zonal winds in most seasons

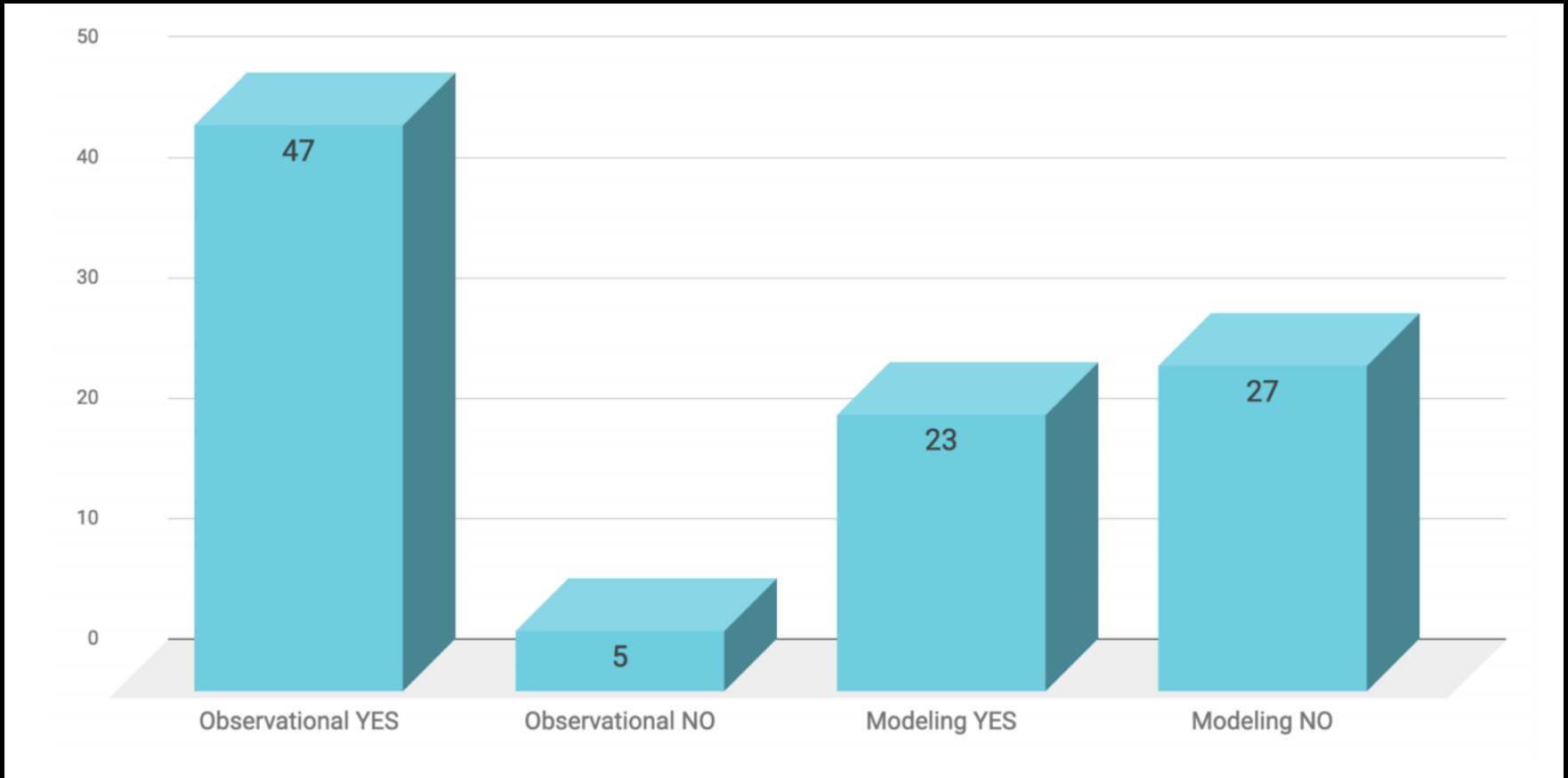
Fall (OND) shows robust decreases in speeds, but summer (JAS) shows increase: the link between wave phase speed and u500 is complex





Barnes, 2013, "Revisiting the evidence linking Arctic amplification to extreme weather in midlatitudes", *Geophysical Research Letters,* https://doi.org/10.1002/grl.50880

Survey of publications finds no community consensus on the link between AA and severe mid-latitude weather



"The challenge of demonstrating a linkage between AA and severe winter weather is daunting …. Simple causality statements for a general audience are not yet defendable. And despite a flurry of research and advances in the mechanisms linking AA to midlatitude weather, **the topic remains contentious**."

Cohen, J. *et al.* Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10,** 20–29 (2020). https://doi.org/10.1038/s41558-019-0662-y

Many of the observed trends through 2010 are not as robust with the addition of 10 more years of data, suggesting earlier results may be a result of internal variability.

Sea Ice Extent

Arctic Amplification

Arctic Oscillation index

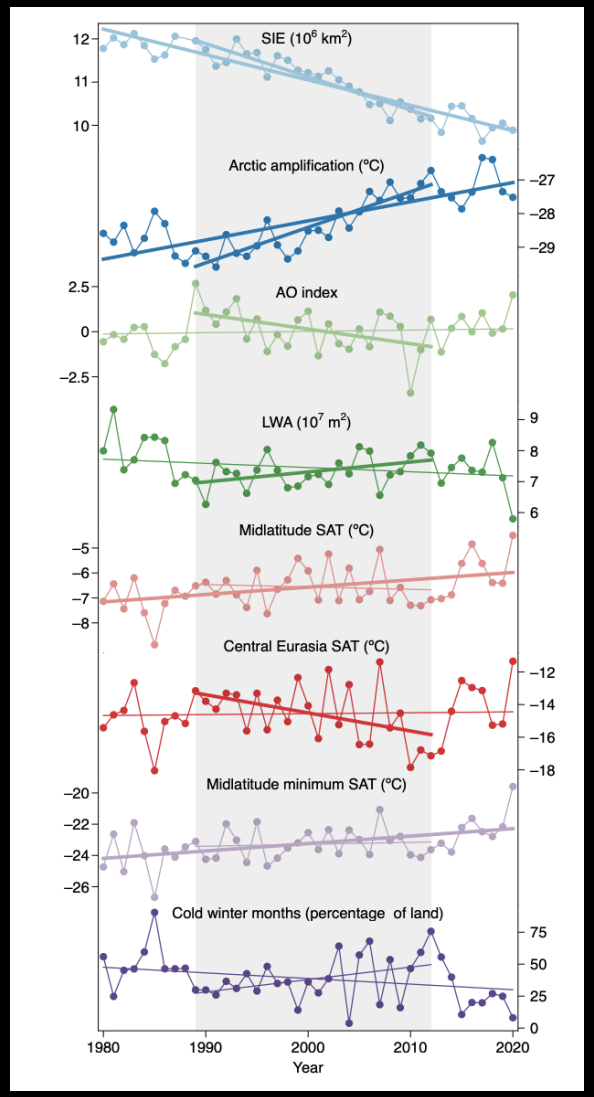
atmospheric waviness

Mid-latitude surface air temp (SAT)

Central Eurasian SAT

Mid-latitude land minimum daily SAT

% Mid-latitutde land experiencing at least one cold winter month



"updated observational and reanalysis records tell much the same story as models: that **the Arctic influence on mid-latitudes is small compared to other aspects of climate variability**, and that observed periods of strong correlation (such as 1988/89 to 2011/12) are an artefact of internal variability"

Blackport & Screen, "Weakened evidence for mid-latitude impacts of Arctic warming. *Nature Climate Change* 10, 1065–1066 (2020). https://doi.org/10.1038/s41558-020-00954-y

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Thanks for your attention

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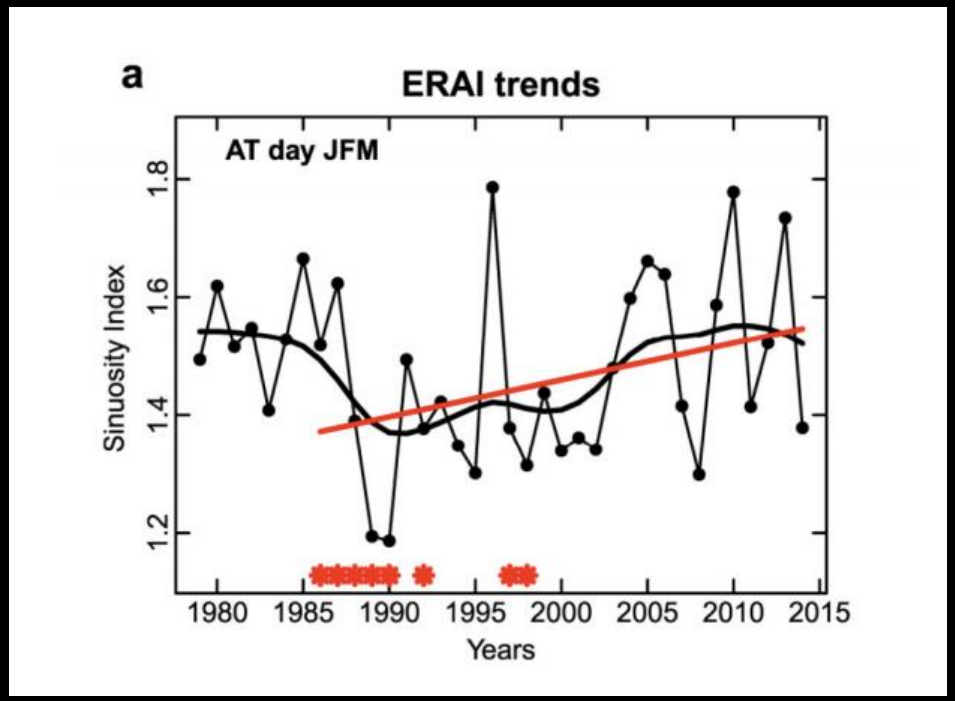
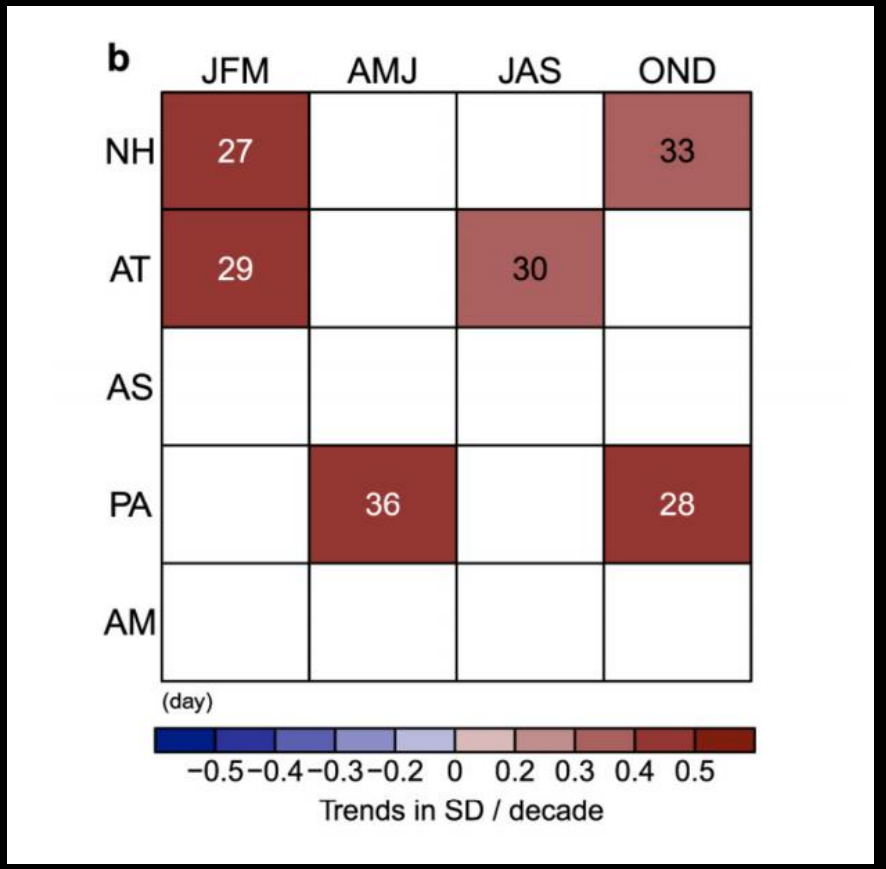
http://atoc.colorado.edu/~jlundqui

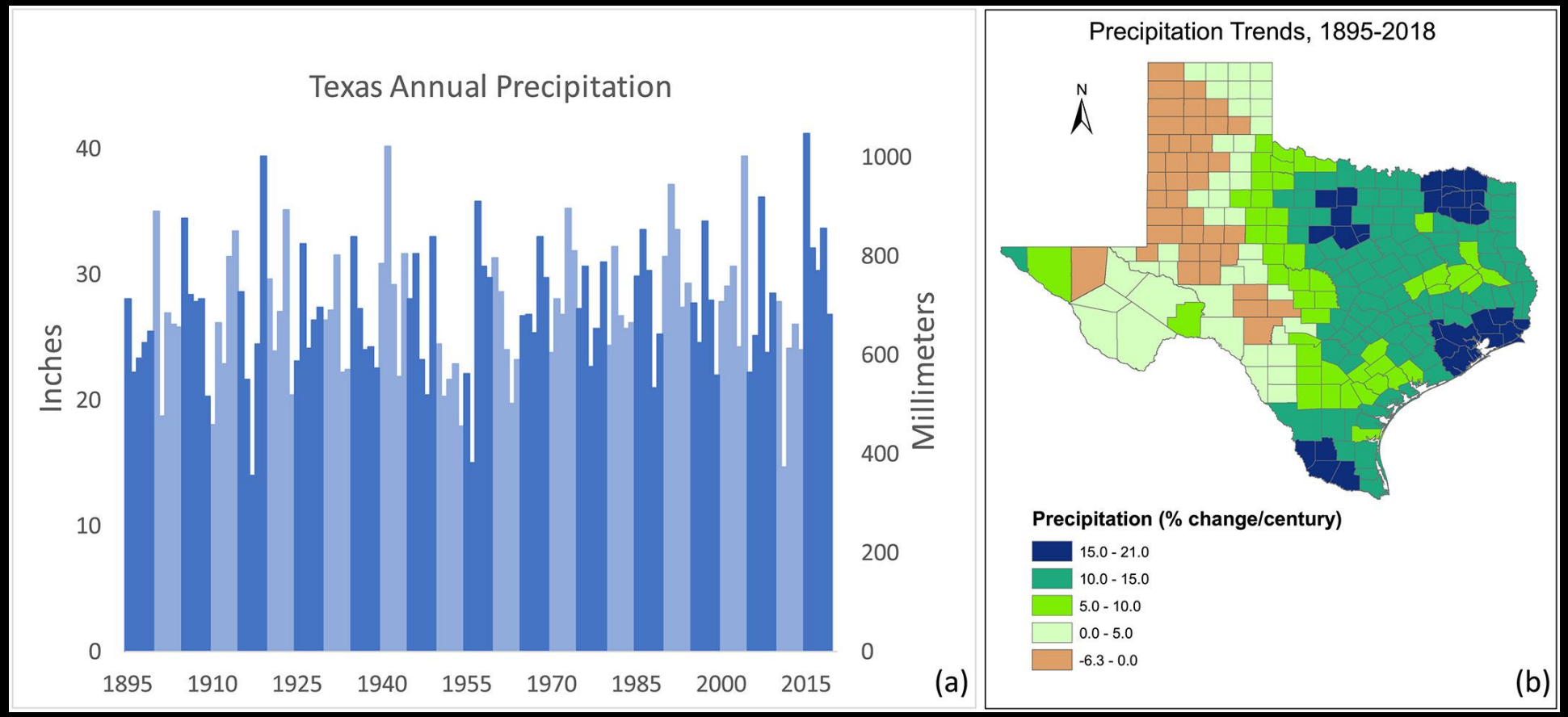
Backup slides

At this point, there is no scientific consensus on which waviness metric or even category of methods is preferable.





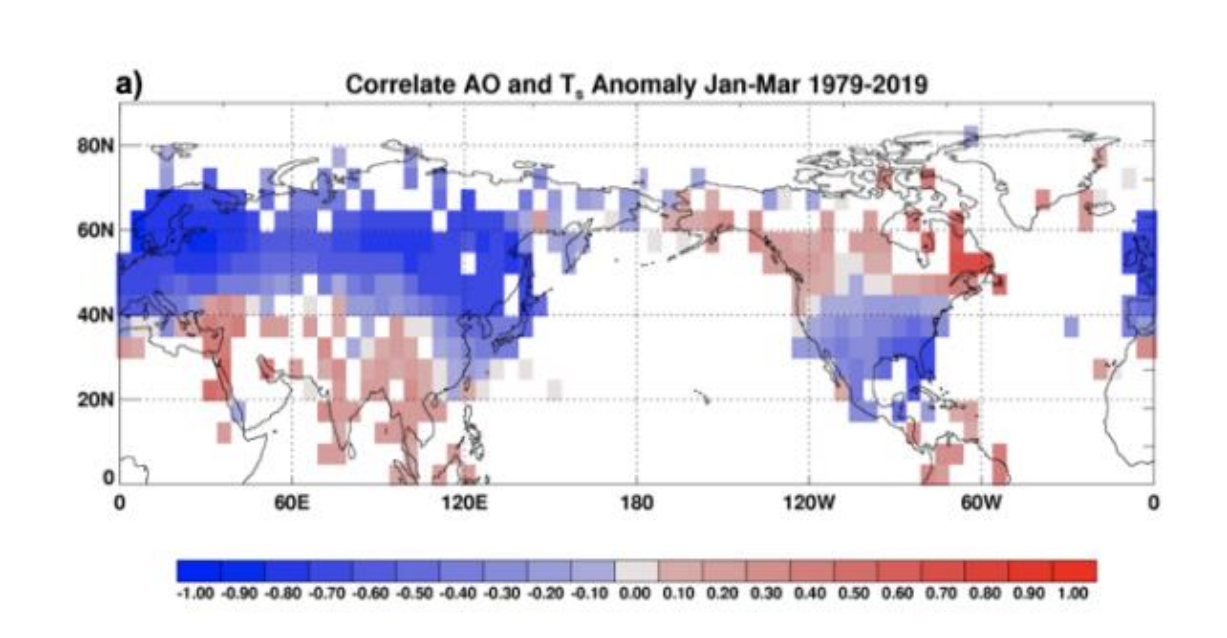
Natural variability commonly produces statewide variations of precipitation of 20% or more on a decadal scale.

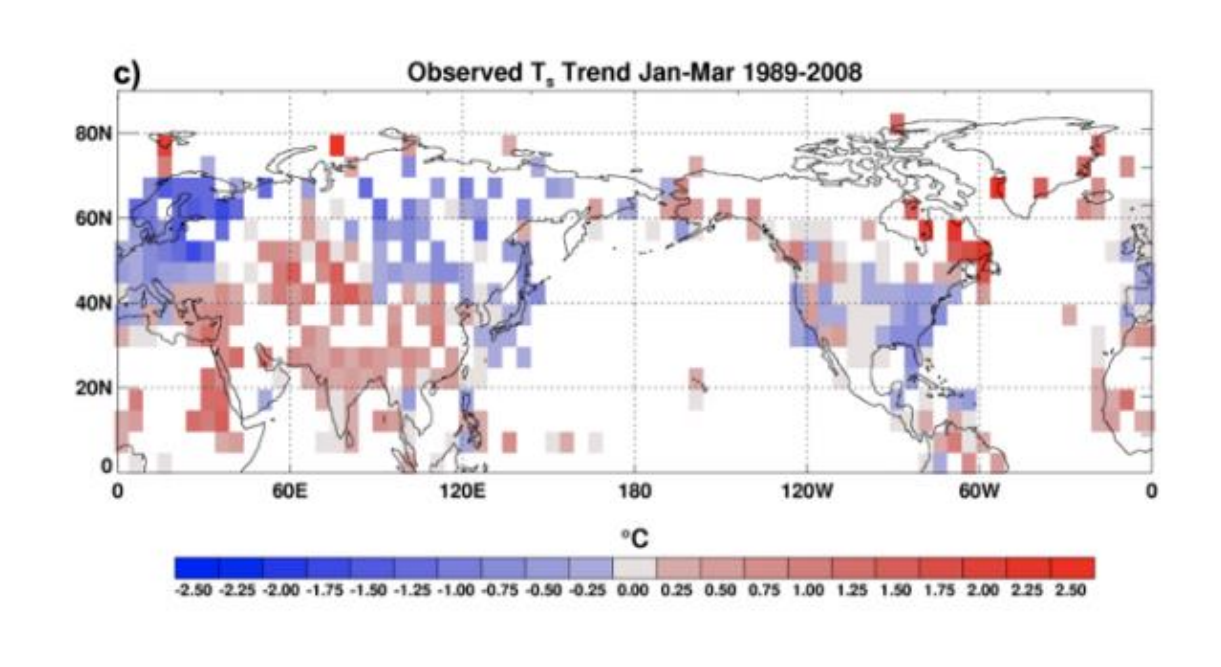


There has also been an upward trend in extreme precipitation at a variety of timescales (USGCRP, 2017).

Nielsen-Gammon et al. 2020 *Earth's Future,* https://doi.org/10.1029/2020EF001552

The Northern Hemisphere (NH) winter temperature anomaly pattern during the era of Arctic amplification (AA) resembles the that of the negative phase of the Arctic Oscillation (AO)





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