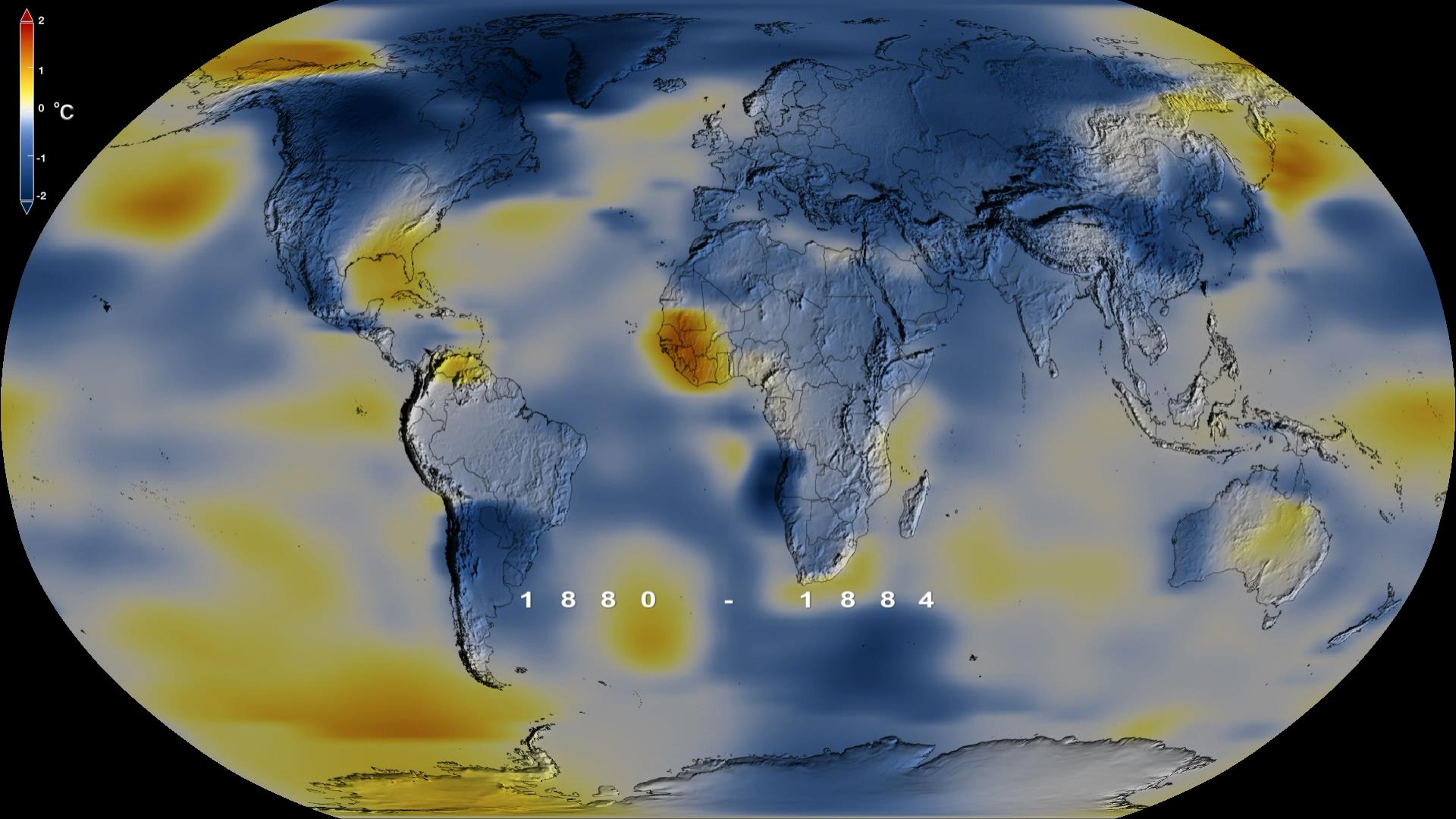




The Great Unfreezing: A brief history of the rapidly changing Arctic

Patrick Taylor
Research Scientist
June 23, 2025

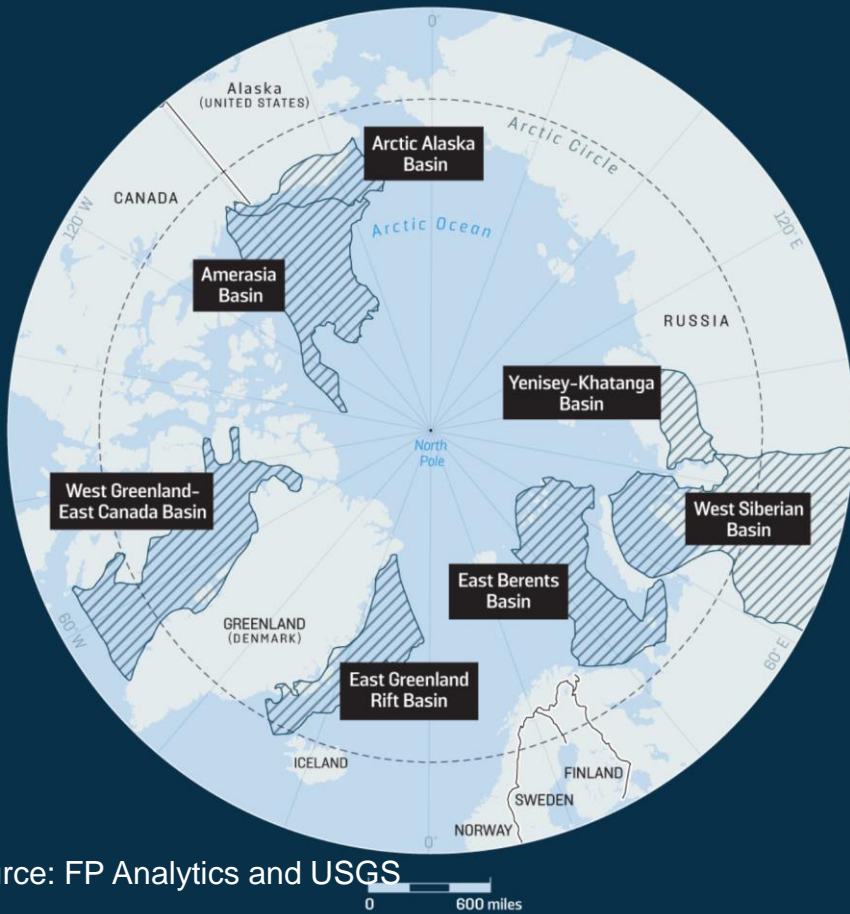
Kavli Institute of Theoretical Physics



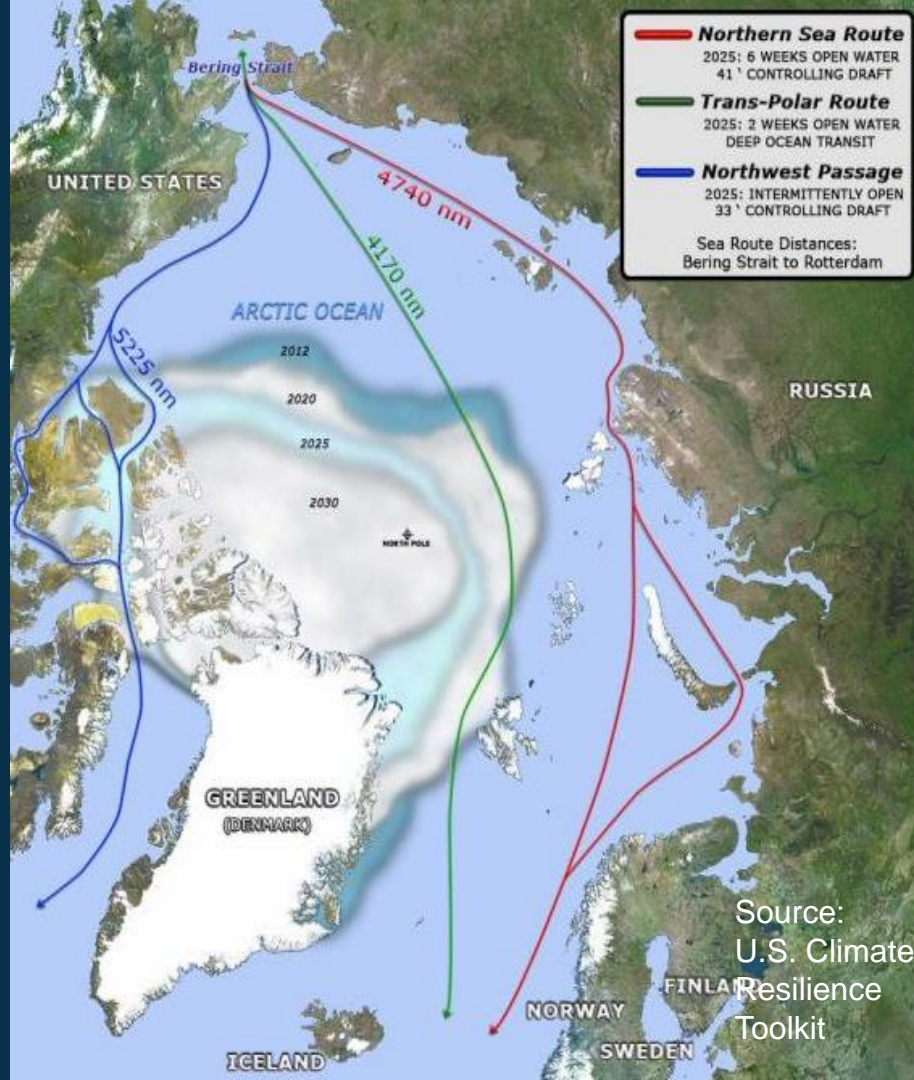
1 8 8 0 - 1 8 8 4

OIL AND GAS BASINS IN THE ARCTIC

The major discovered and accessible oil and gas basins in the Arctic are mapped below.

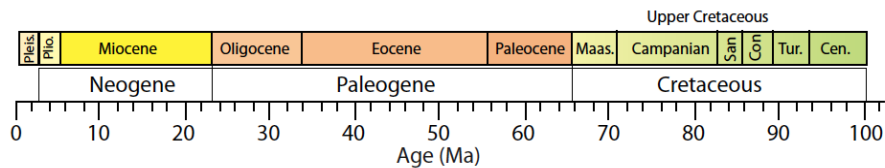
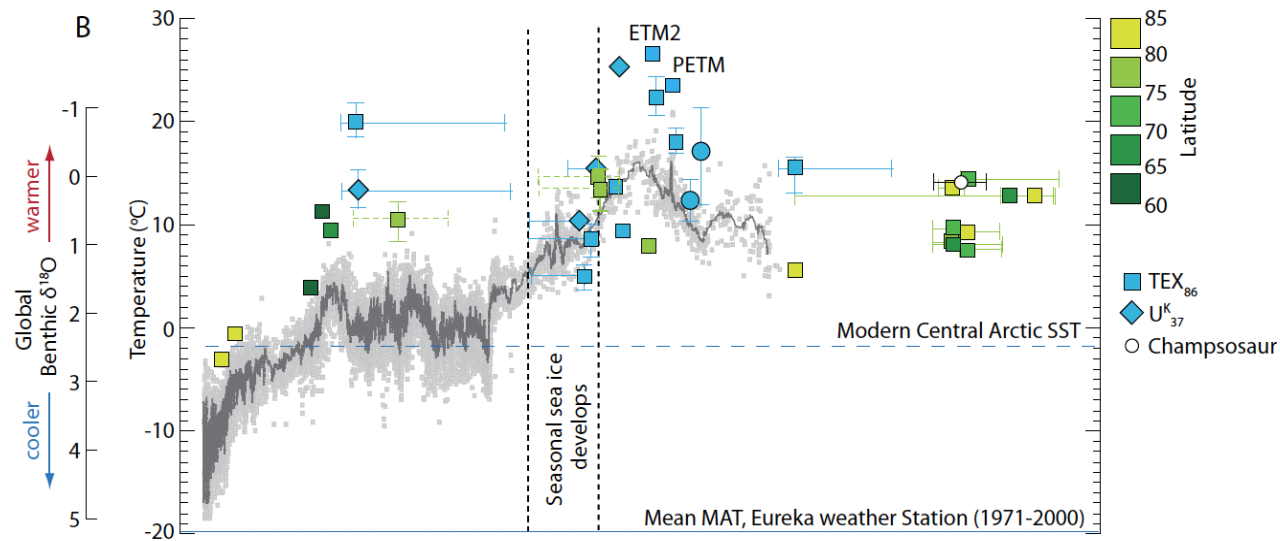


Source: FP Analytics and USGS

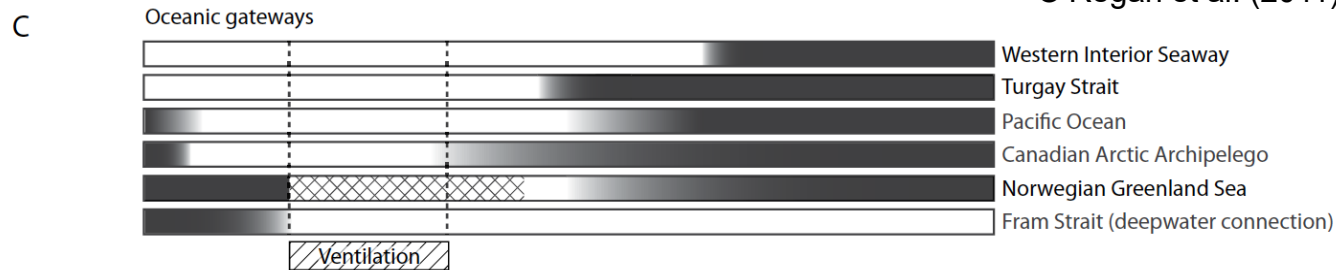


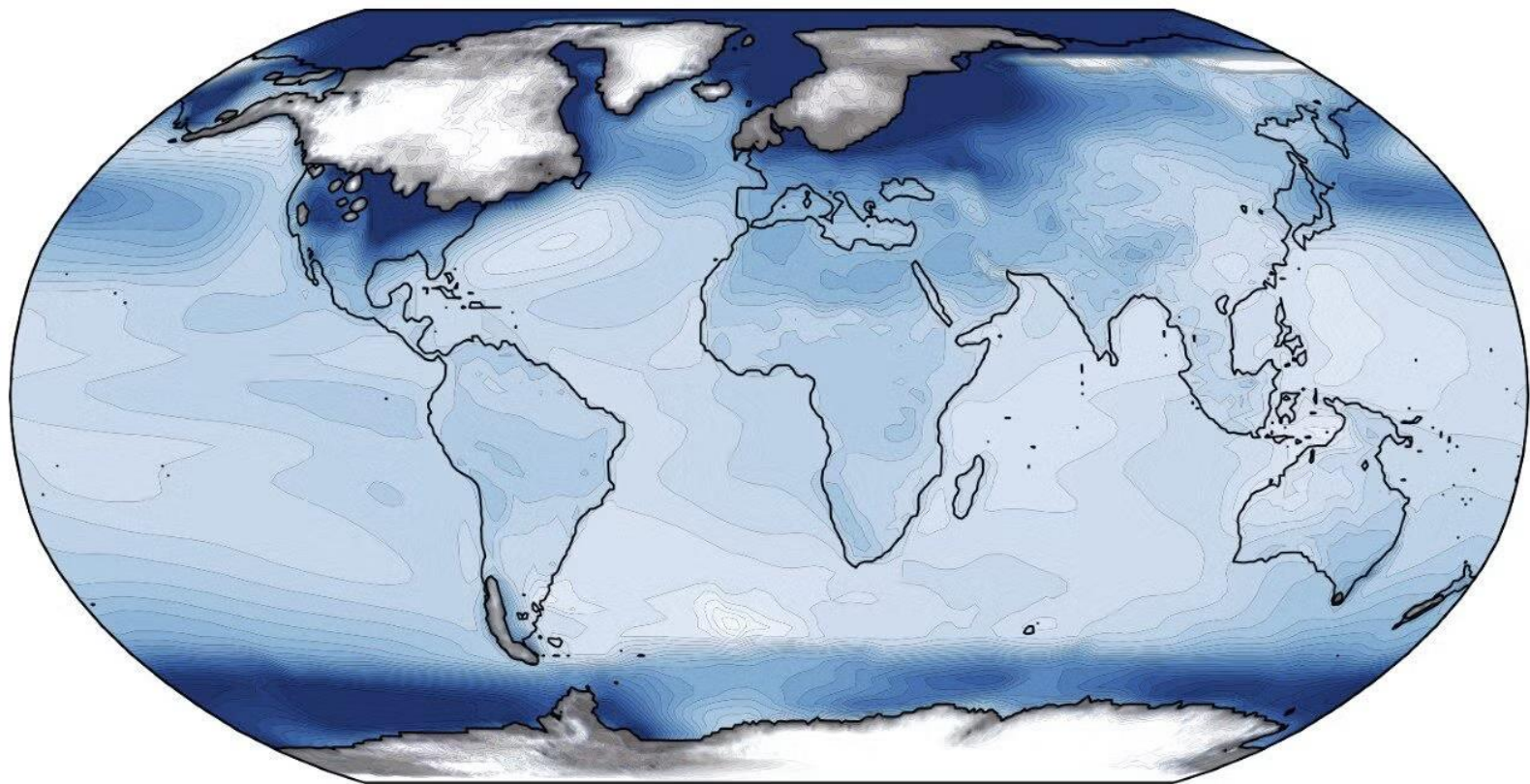
Source:
U.S. Climate
Resilience
Toolkit

100 million years of Arctic temperatures



O'Regan et al. (2011)





Last Glacial Maximum Surface Air Temperature

Difference from Preindustrial (°C)



-14 -12 -10 -8 -6 -4 -2 0

The Arctic Amplification (AA) Concept: Arrhenius (1896)

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

- Arrhenius (1896) provided one of the earliest descriptions of Arctic Amplification.
- Origins of AA came within the context of explaining glacial/inter-glacial periods of the Quaternary.
- **Key Mechanism:** Surface albedo changes due to the north-south progression of the snow-ice line.

KEY ADVANCES IN OUR SCIENTIFIC UNDERSTANDING OF ARCTIC AMPLIFICATION

1960's: EBM studies quantify magnitude of surface albedo feedback (Budyko 1966; Rakipova 1966)

Inclusion of horizontal heat transport in EBMs (Sellers 1969)

First use of a GCM with mixed layer ocean to study AA (Manabe and Stouffer 1980)

Emergence of multi-model intercomparisons (Cess 1989; 1990)

Emergence of surface-based AA in observation (Serreze et al. 2009)

Surface albedo proposed as driver of AA (Arrhenius 1896)

Inclusion of vertical heat transport in EBMs (Wetherald and Manabe 1967)

First use of a GCM to study AA (Manabe and Wetherald 1975)

Exploration of the role of ocean heat transport in AA (Washington and Meehl 1984; 1986; 1989)

2000s: AA emerged as a unique research topic, use of multi-decadal observations used, AA can occur without the surface albedo feedback (Alexeev 2003)



(C1) Positive local feedbacks (sea ice, clouds, and water vapor) amplify initial forcing more strongly in the Arctic than elsewhere.

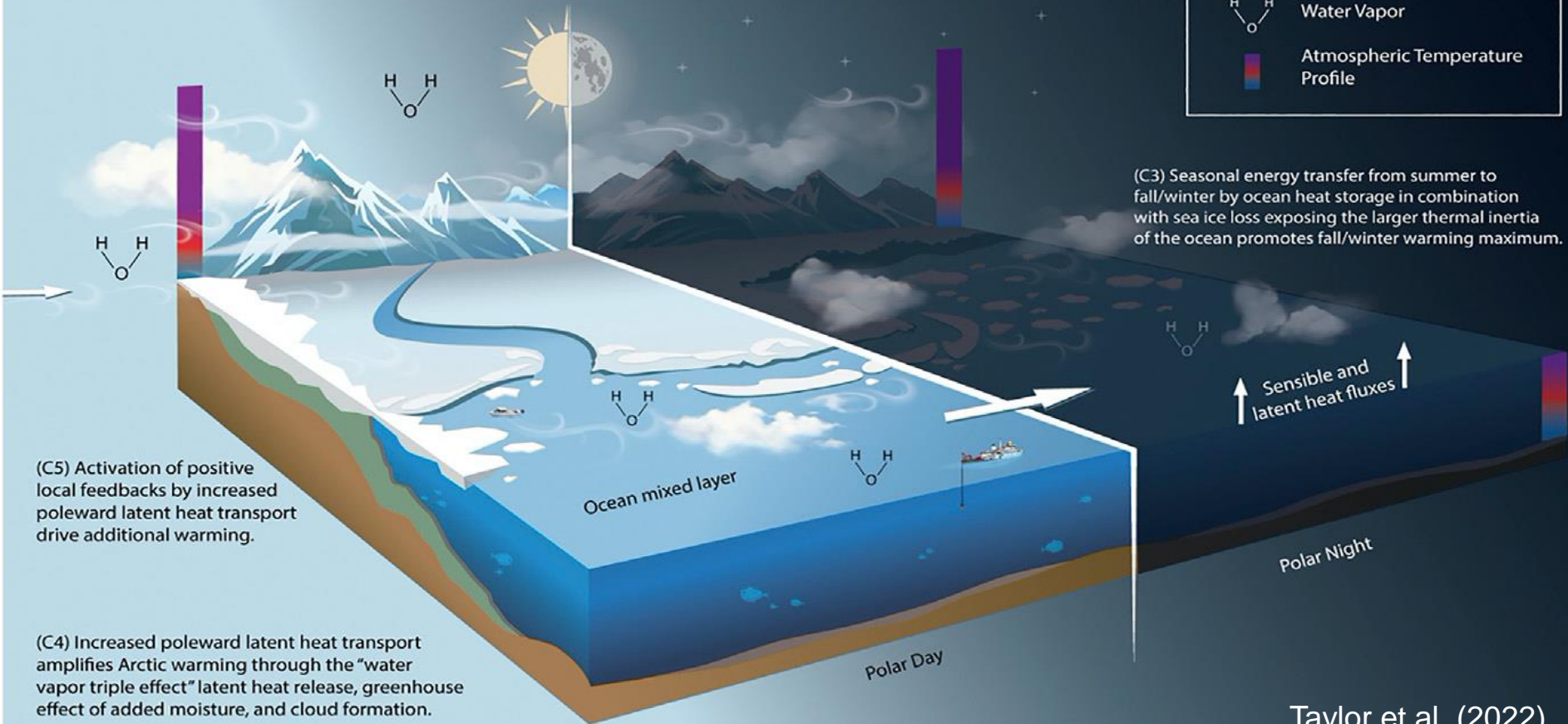
(C2) Strong stable atmospheric stratification restricts convective exchange with the free troposphere and focuses warming near the surface.

Legend	
	Atmospheric Circulation
	Water Vapor
	Atmospheric Temperature Profile

(C3) Seasonal energy transfer from summer to fall/winter by ocean heat storage in combination with sea ice loss exposing the larger thermal inertia of the ocean promotes fall/winter warming maximum.

(C5) Activation of positive local feedbacks by increased poleward latent heat transport drive additional warming.

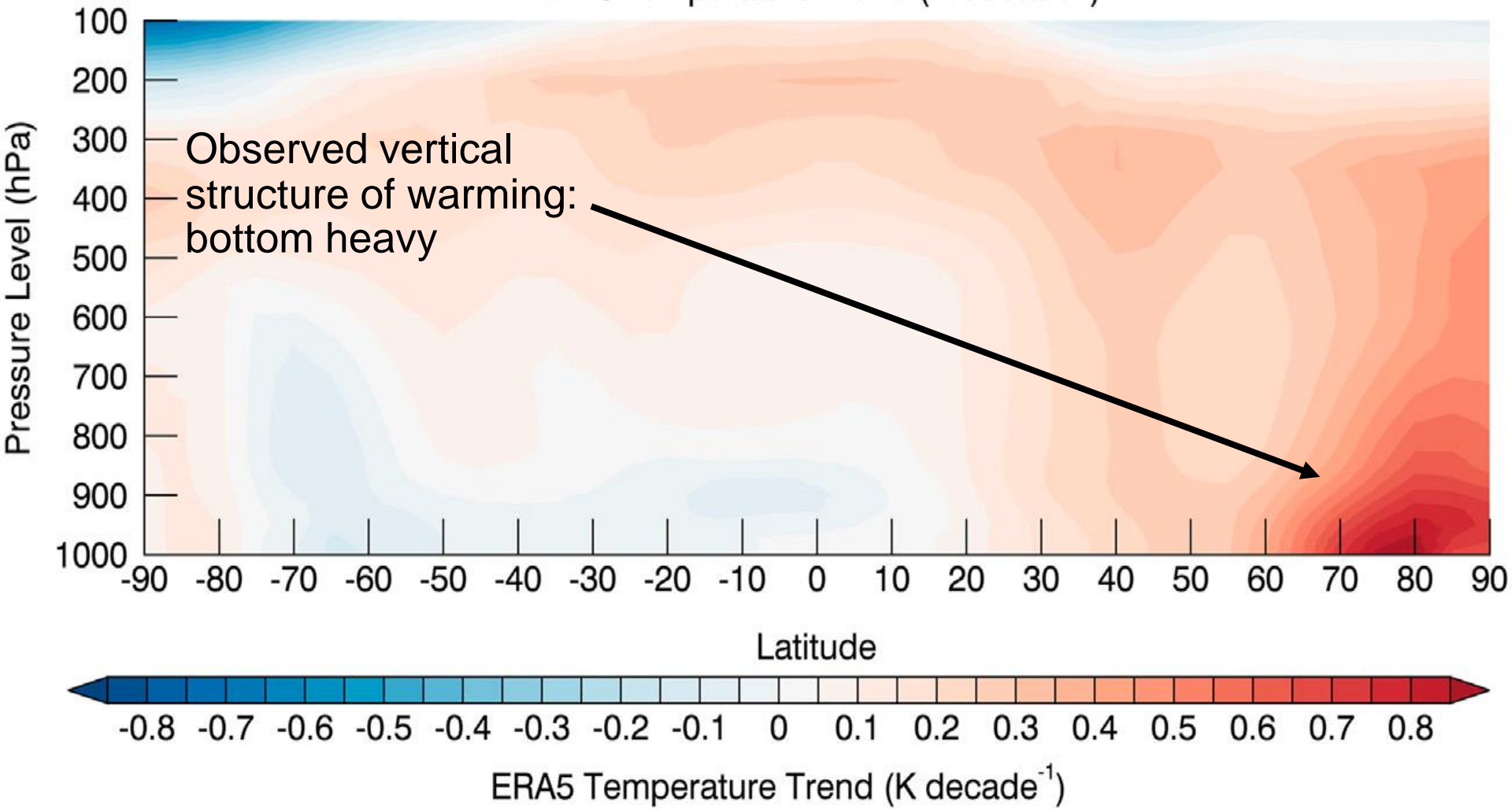
(C4) Increased poleward latent heat transport amplifies Arctic warming through the "water vapor triple effect" latent heat release, greenhouse effect of added moisture, and cloud formation.

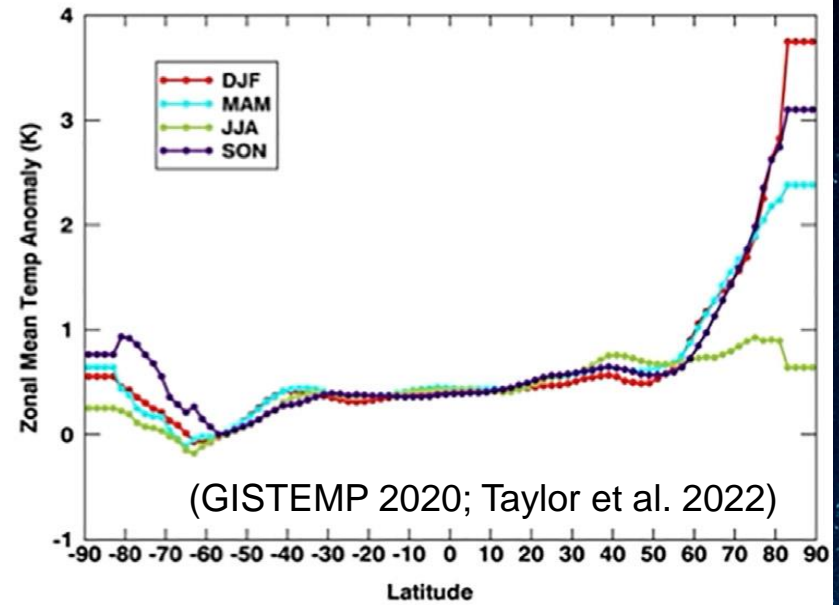
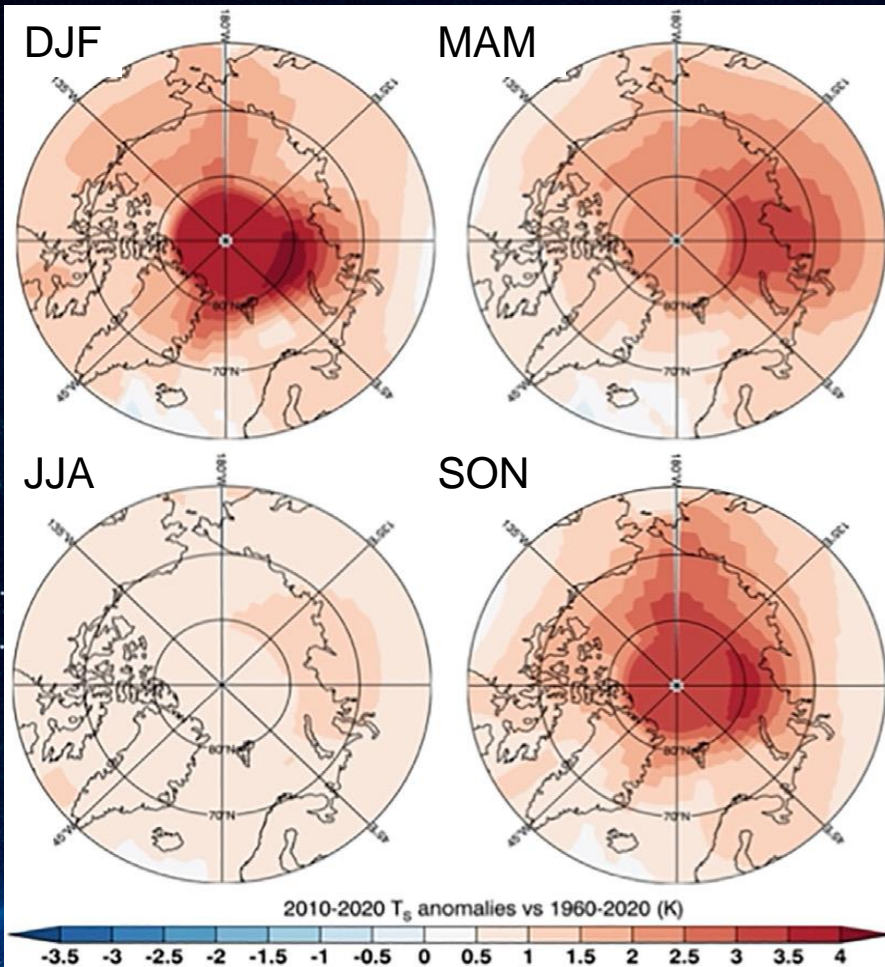


A view of Earth from space, showing the Americas and the Atlantic Ocean. The Earth's surface is illuminated by sunlight, creating a bright horizon line. The background is a dark, star-filled sky. The text "What changes have we observed?" is overlaid in white, sans-serif font in the upper center of the image.

What changes have we observed?

ERA5 Temperature Trend (K decade⁻¹)

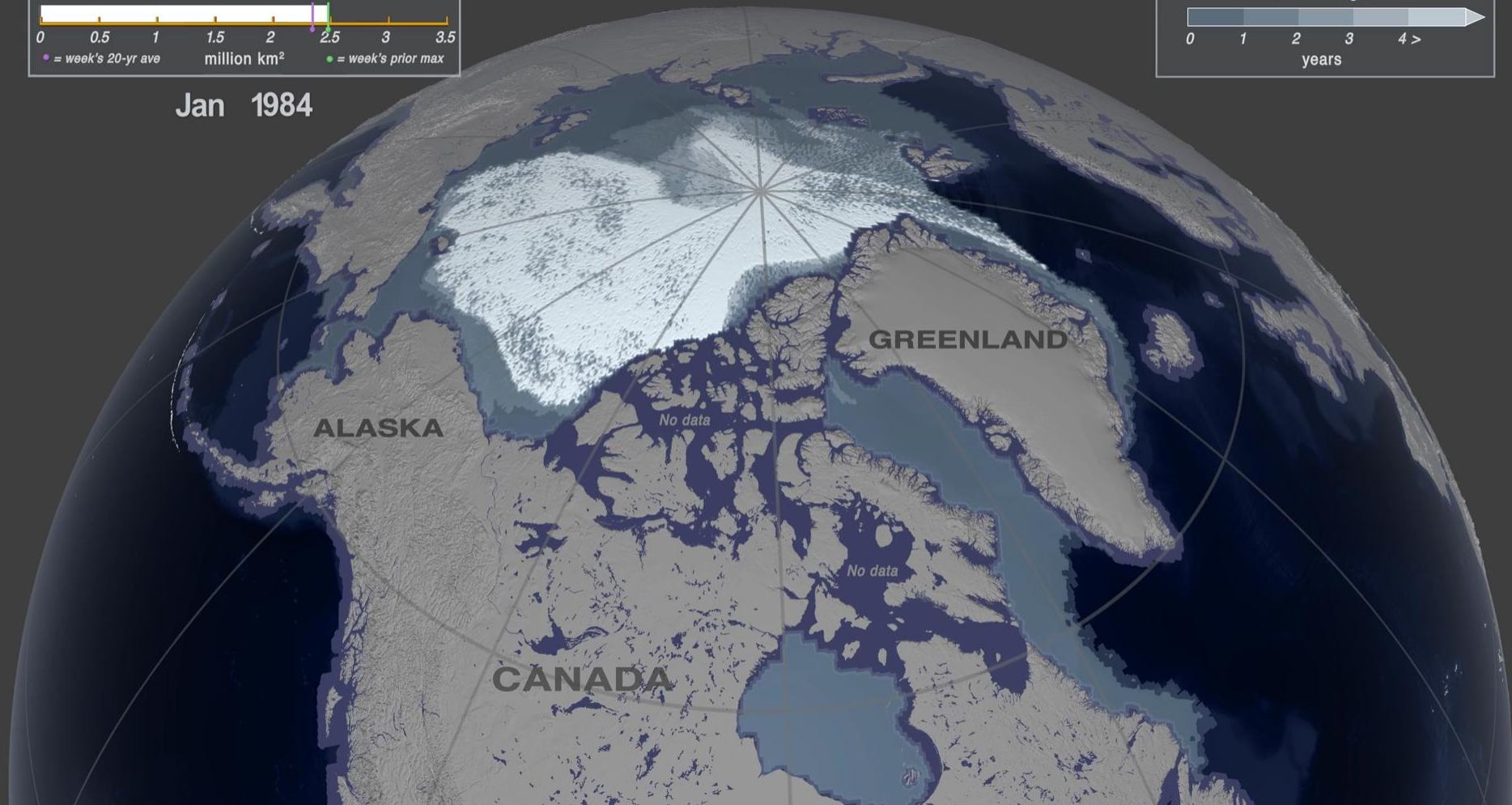




Observed seasonal and spatial structure of Arctic Amplification

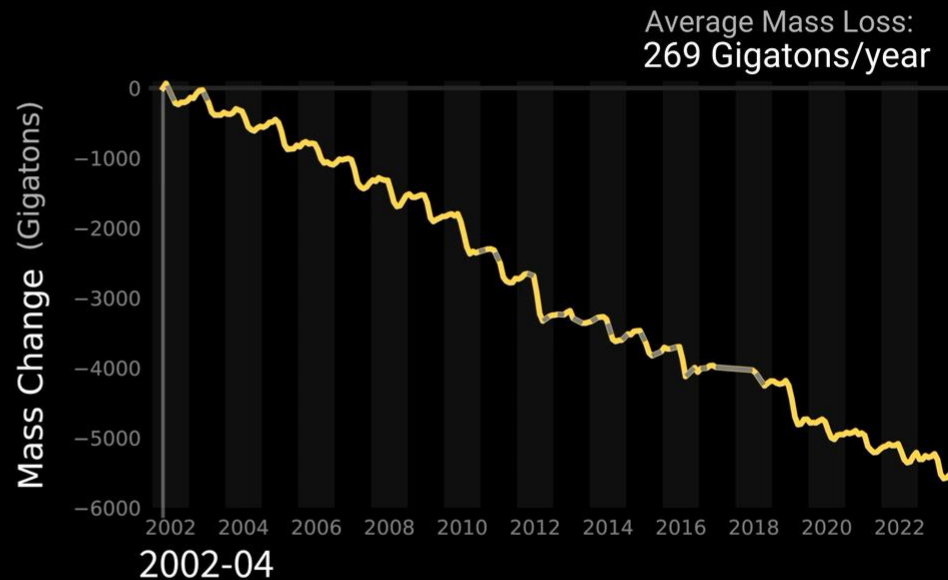


Jan 1984



2002-04

GRACE AND GRACE-FO Observations of Greenland Land Ice Mass Changes



The Arctic future

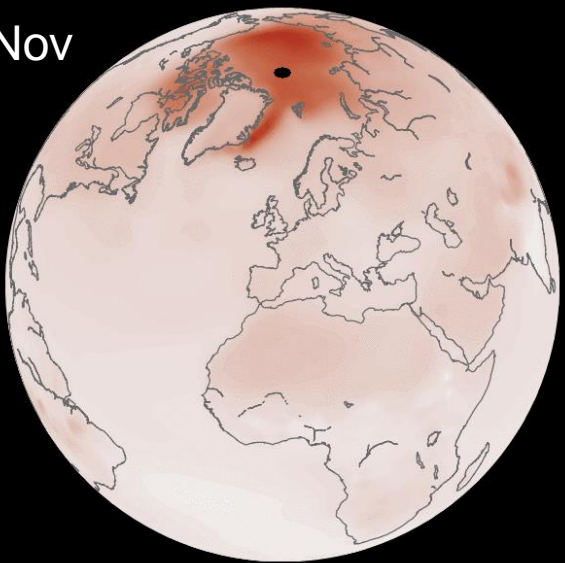


Temperature and sea ice concentration projections from CESM LENS

TEMPERATURE

Oct-Nov

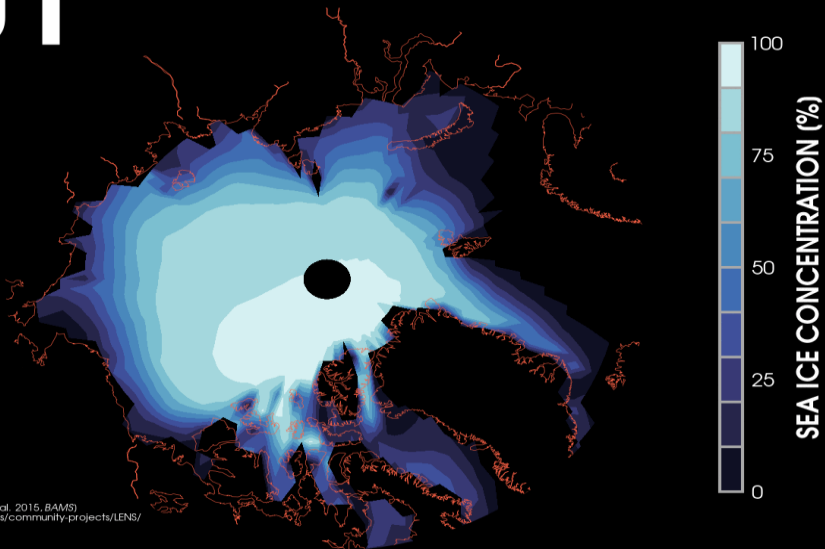
2001



GRAPHIC: Zachary Labe (@ZLabe)

DATA: CESM2 (CAM6) Large Ensemble Community Project (Rodgers et al., 2021, ESD)
ANIMATION: October-November, 2-m Air Temperature Anomalies (SSP3-7.0; Baseline: 1951-1980)
INFORMATION: <https://www.cesm.ucar.edu/projects/community-projects/LENS2/>

2001

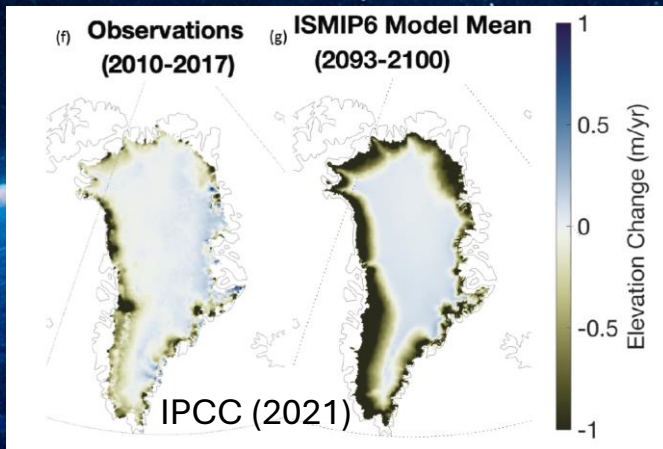
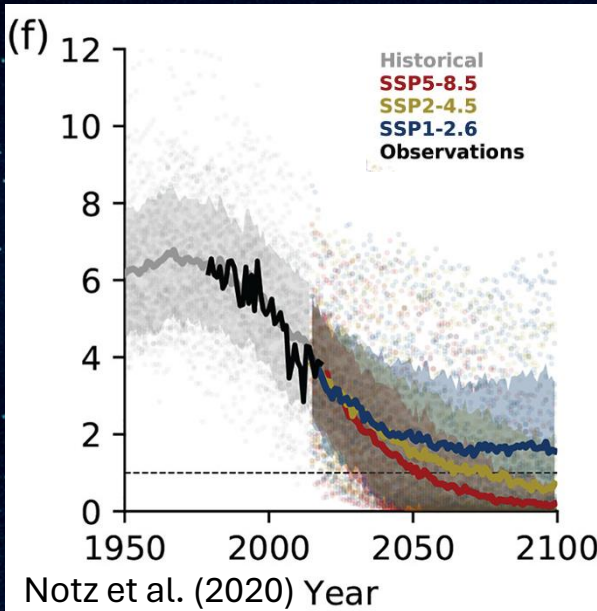
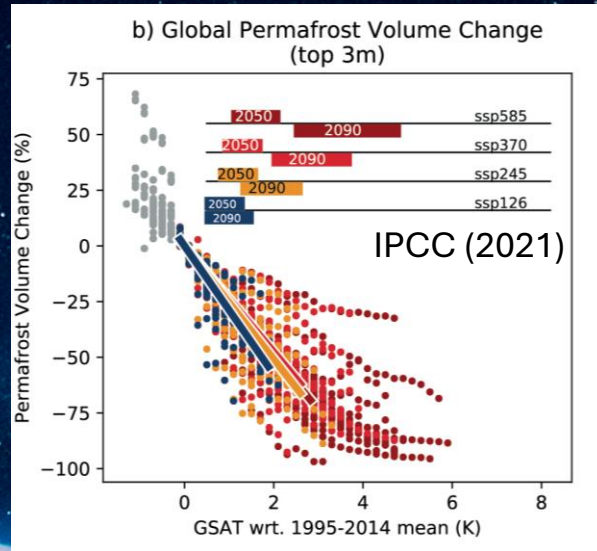
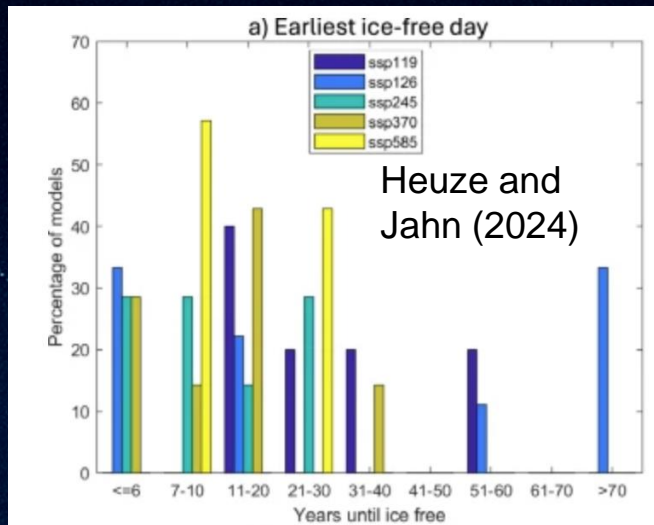


SEA ICE CONCENTRATION (%)

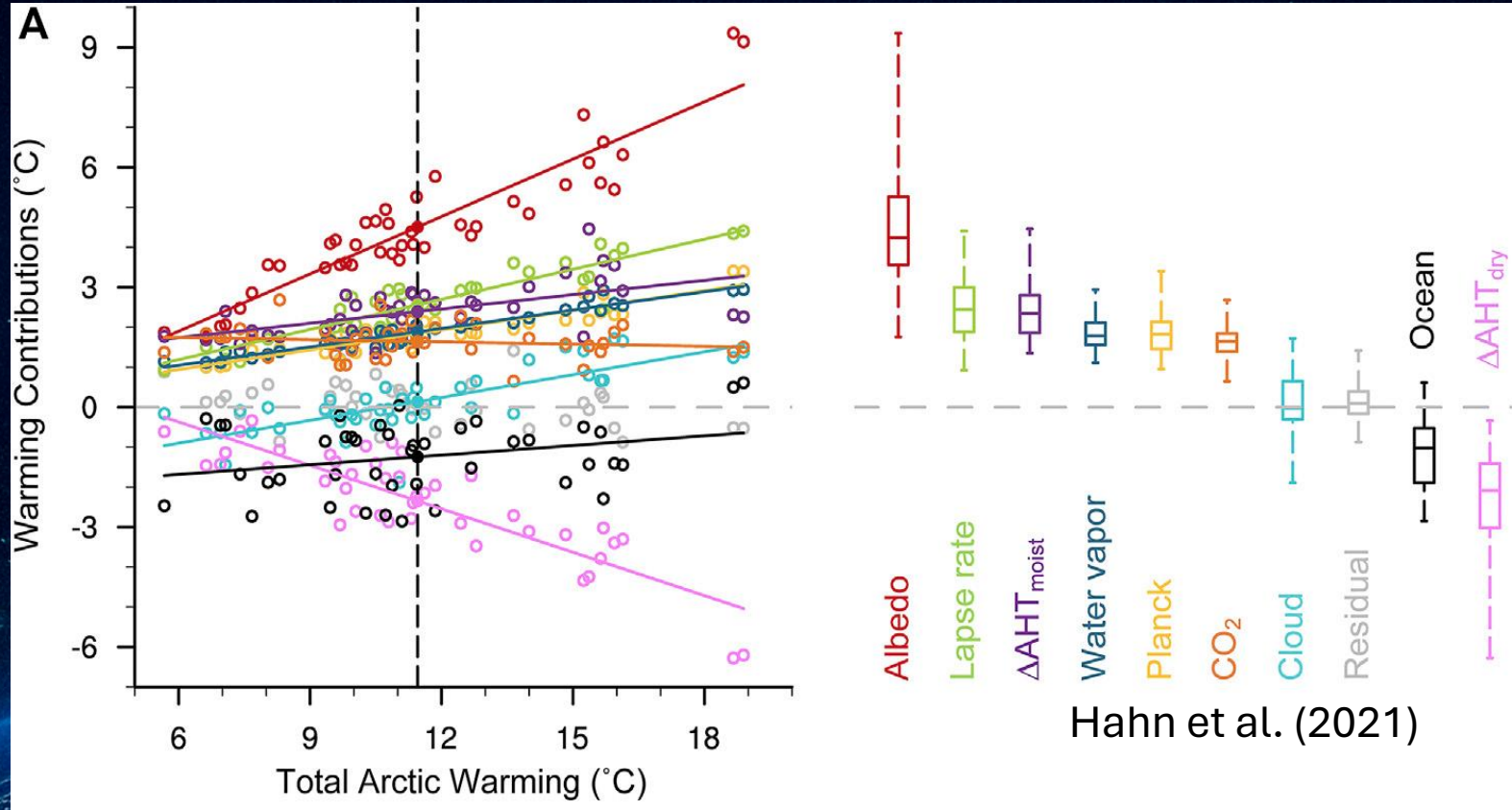
DATA: CESM Large Ensemble Project (Kay et al. 2016, BAMS)
SOURCE: <http://www.cesm.ucar.edu/projects/community-projects/LENS/>
GRAPHIC: Zachary Labe (@ZLabe)

(Z. Labe; Climate Viz; <https://zacklabe.com/climate-model-projections/>)

Other changes of importance...



Uncertainty in AA projections: The feedbacks

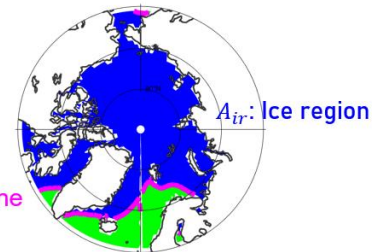




Ideas and Current Work

Linking processes and radiative
feedback

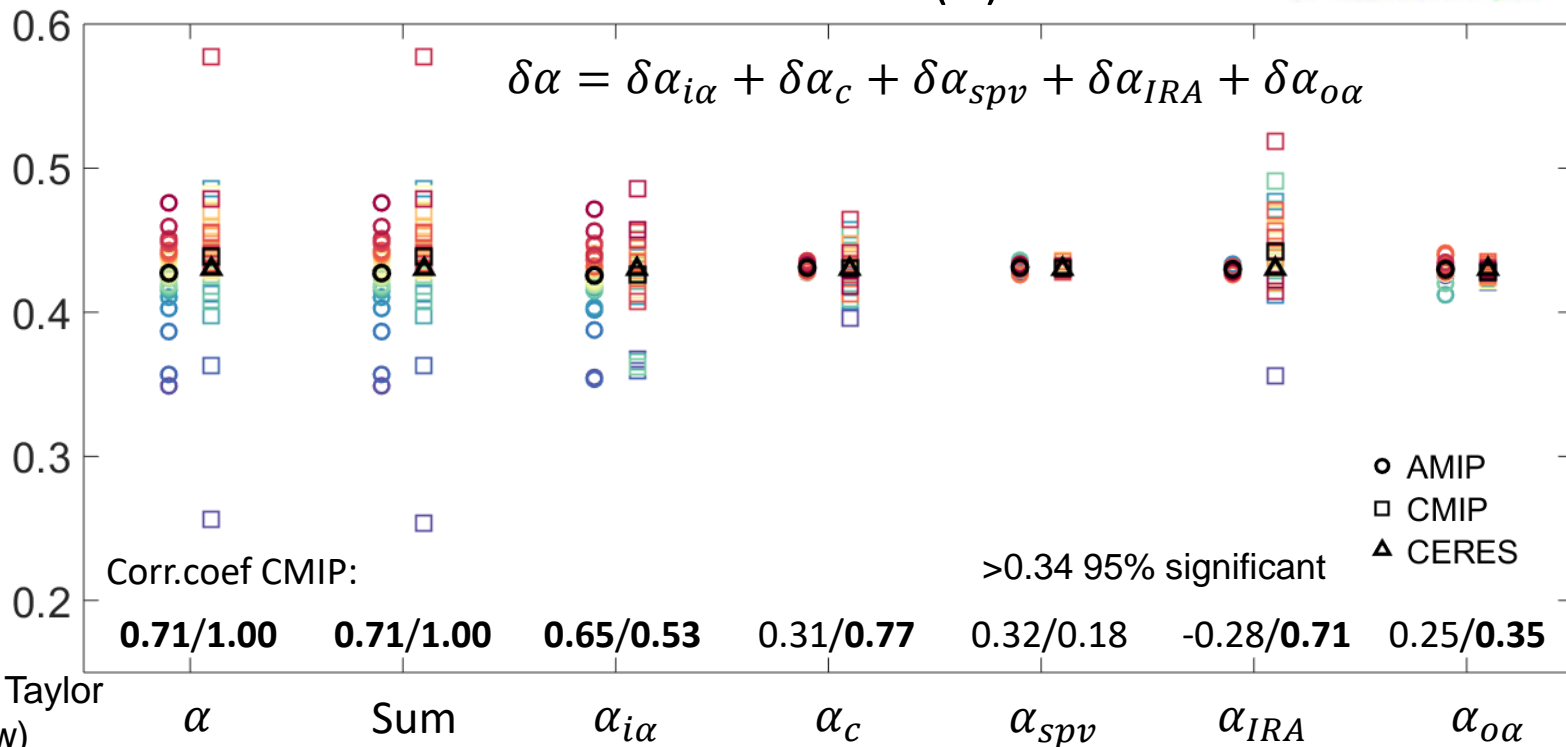
Sea ice albedo is a key component of the in modeling spread in surface albedo



15% Ice line

$(1 - A_{ir})$: Ocean region

surface albedo (α)



Ice extent change dominates contributions to the surface albedo feedback

$$\delta\alpha = \delta\alpha_i + \delta\alpha_c + \delta\alpha_e$$

$\delta\alpha$ => total albedo change

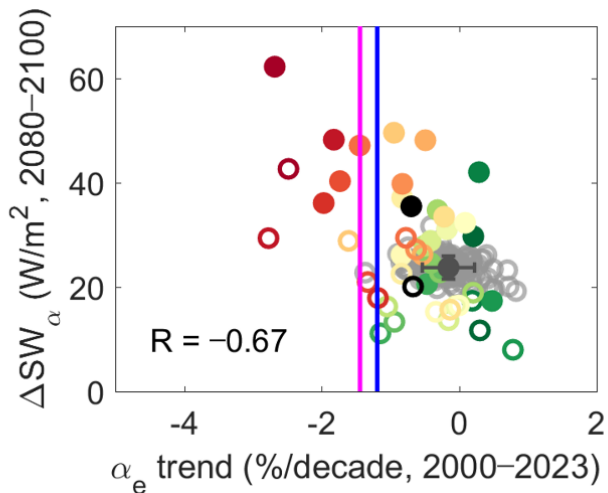
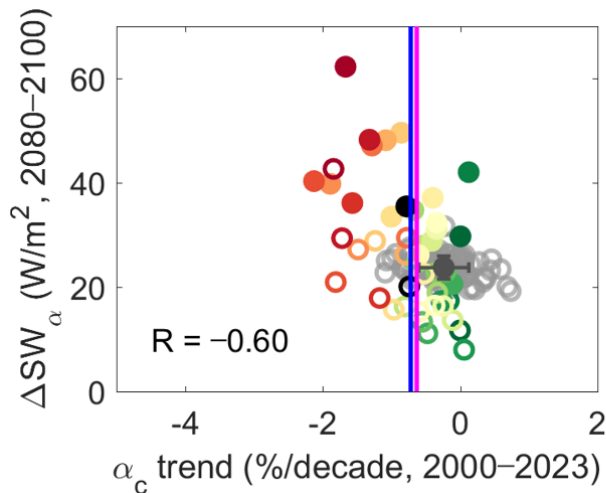
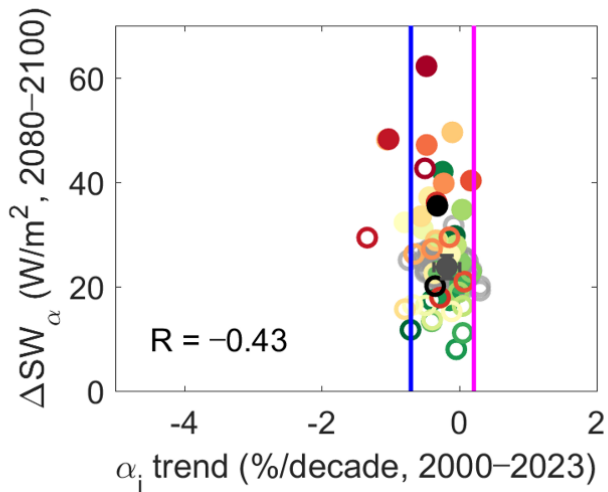
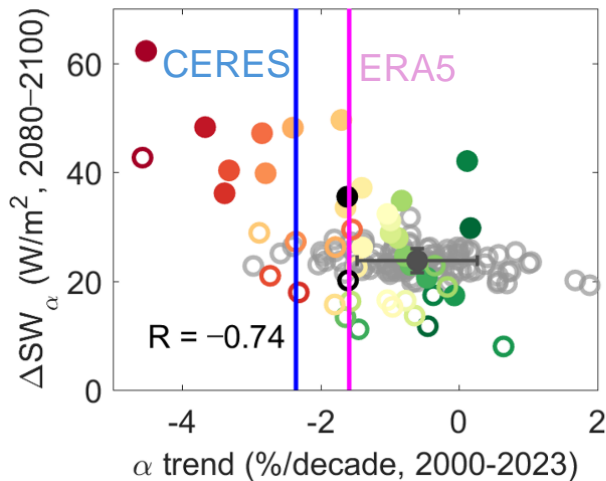
$\delta\alpha_i$ => ice albedo

$\delta\alpha_c$ => ice concentration

$\delta\alpha_e$ => ice extent

ΔSW_α => shortwave radiation perturbation

Kim and Taylor
(in prep.)



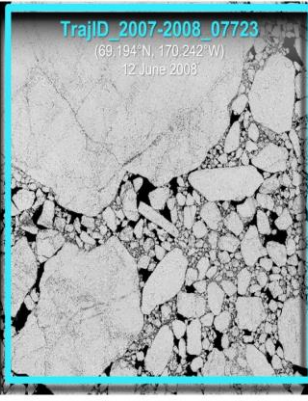
Sea ice parcel survivability

$$\text{Survivability} = \frac{N_{\text{surv}}}{N_{\text{total}}}$$

Sea Ice Characteristics:
 Ice Type (Buoys/SSM/I): First Year
 Concentration (NSIDC/CDR): 90%
 Snow Depth (SnowModel/LG): 0.06 m
 Sea Ice Thickness (PIOMAS): 2.10 m
 Surface Albedo (CERES): 0.50
 Ice Surface Temperature:

Lifecycle:
 Formation: 22 Nov. 2007
 Duration: 211 days
 End: 20 June 2008
 Origin & End Region: Chukchi Sea
 Survived: No

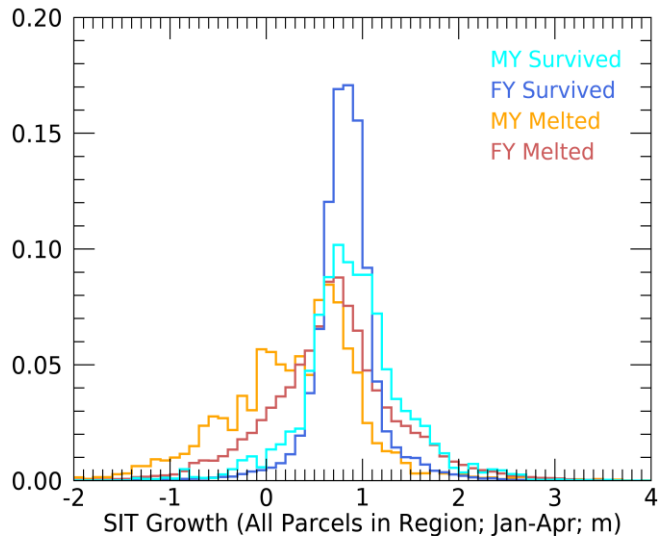
Flags:
 Cyclone (Melbourne U. Tracker): n/a
 Cyclone properties (ERA5): n/a



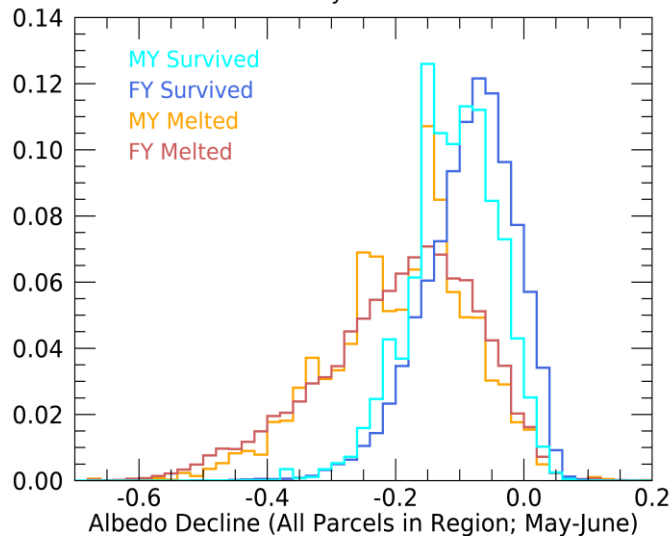
Atmospheric State:
 Air Press. (ERA5/MERRA2): 1018 hPa
 Cloud Cover (CERES): 15%
 Precipitable Water (ERA5/MERRA2): 19 kg m⁻²
 Liq. Water Path (CERES): 112 g m⁻²
 Ice Water Path (CERES): 96 g m⁻²
 Air T. (ERA5/MERRA2): 0.95°C
 Wind Speed & Direction (ERA5/MERRA2): 8.4 m·s⁻¹ & 30°
 Spec. Humidity (ERA5/MERRA2): ~0%
 Snowfall (ERA5/MERRA2): n/a
 Total Precipitation (ERA5/MERRA2): n/a

Surface Energy Budget:
 Upwelling SW (CERES): 134 W m⁻²
 Downwelling SW (CERES): 267 W m⁻²
 Upwelling LW (CERES): 312 W m⁻²
 Downwelling LW (CERES): 284 W m⁻²
 Sensible Heat (AIRS): -30 W m⁻²
 Latent Heat (AIRS): -0 W m⁻²

Arctic Sea Ice Thickness Growth



Arctic May - June Albedo

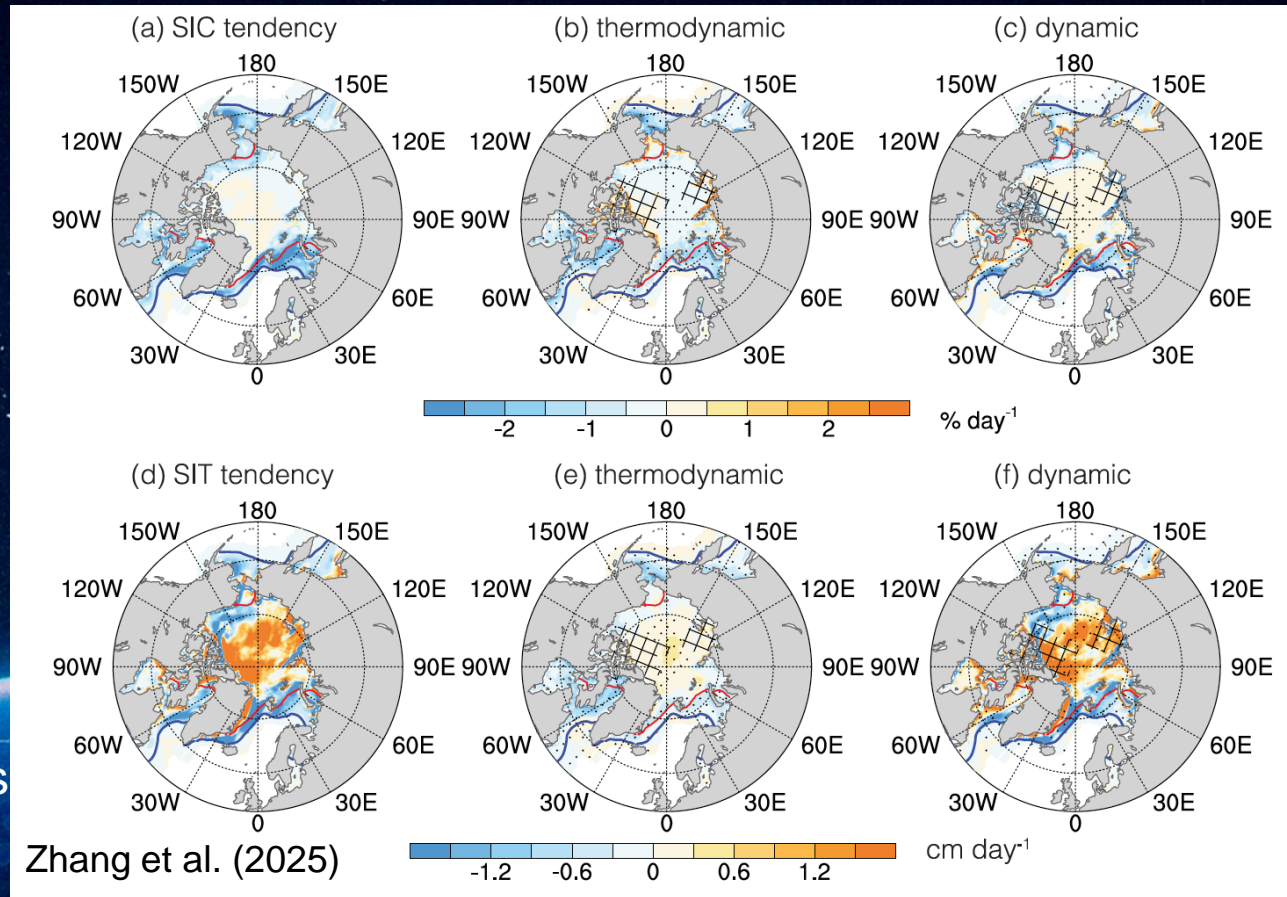


Survivability influencing factors:

- Winter SIT growth
- Parcel SIC
- Greater snow depth (threshold behavior)
- Early summer sea ice albedo change (June-May)

Influence of ARs on sea ice evolution

- Winds push ice floes from the marginal seas to the central Arctic leading to dynamical thickening.
- Thermodynamic factors: reduced congelation growth (54%–56%), enhanced basal melting (17%–26%), and inhibited snow-ice formation (11%–21%) play major roles in the sea ice loss in the marginal seas



In closing...We live on an interconnected planet!



Thank you!

A blue-tinted view of Earth from space, showing the curvature of the planet and the dark blue oceans. The text "Thank you!" is overlaid in white. The background is a dark blue space filled with numerous small white stars.

Thank you!