# Isolating the Contribution of Observed Winds to Recent Arctic Warming and Sea Ice Loss

Ash Gilbert[1,2], Jen Kay[1,2], Edward Blanchard-Wrigglesworth[3], David Schneider[2]

[1]Department of Atmospheric and Oceanic Sciences, University of Colorado at Boulder, [2]Cooperative Institute for Research in Environmental Sciences, [3]Department of Atmospheric and Climate Science, University of Washington at Seattle

## MOTIVATION

- **Arctic surface temperature** has **warmed** at over **4x** the **global rate** and **September sea ice area** has **declined 0.8 million km²/decade**
- The largest sources of **uncertainty** in **Arctic warming** and **sea ice loss** predications are **internal variability** and model **sea ice climatology**
- **Nudging** model winds to **observed winds** in historical climate models **replicates** observed **warming, sea ice loss,** and **internal variability**
- **Previous work** has assessed the **combined effects** of **anthropogenic forcing** and observed **winds** on **Arctic climate**, but the contribution of the **winds alone** is **unknown**
- Additionally, the **wind contribution** is **dependent** on mean state **sea ice thickness**, so we **quantify** the role of the winds alone as a **function of sea ice thickness**

## QUESTIONS

- What is the influence of observed winds alone on recent Arctic warming and sea ice loss?
- How do those results change for an increase in mean state sea ice thickness?

## RESULTS

**Winds alone cannot reproduce observed Arctic warming but can explain 21% of the interannual variability**

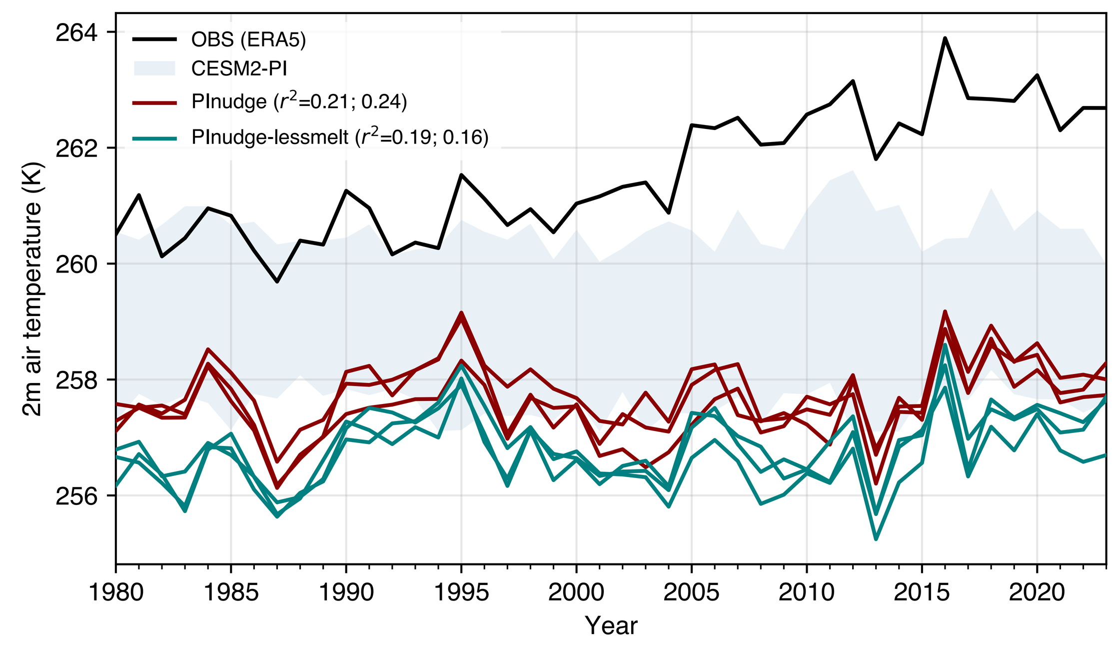


**Figure 2.** Timeseries (1980-2023) of Arctic (70-90°N) annual mean 2m air temperature. Coefficients of determination (absolute temperature; detrended anomalies) are between the wind-nudged experiment (PInudge, PInudge-lessmelt) ensemble mean and ERA5 for 1980-2023.

**Winds alone cannot reproduce monthly observed Arctic warming but still drive the seasonal pattern of temperature trends**

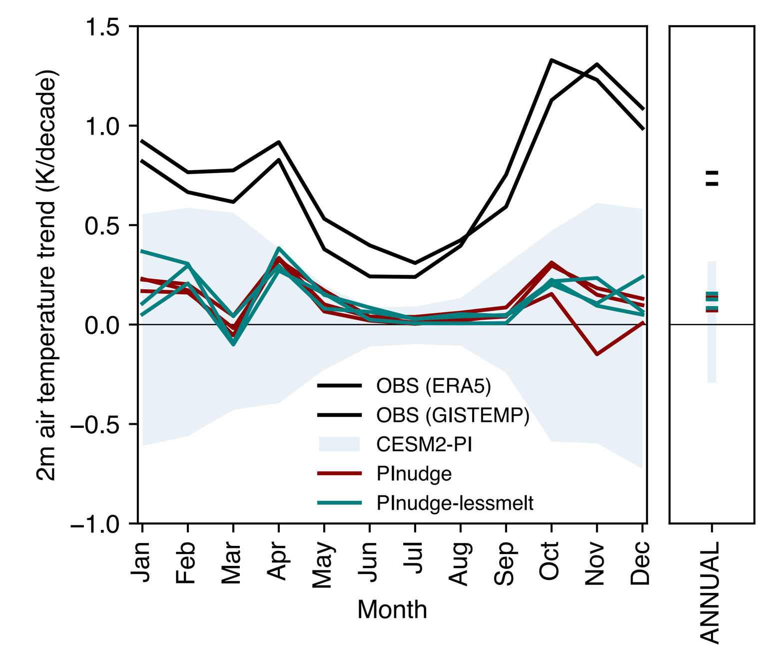


**Figure 3.** Monthly (left) and annual (right) trends in Arctic (70-90°N) 2m air temperature over 1980-2023.

**Winds alone cannot reproduce the magnitude of local warming, but still drive regional patterns of temperature trends**

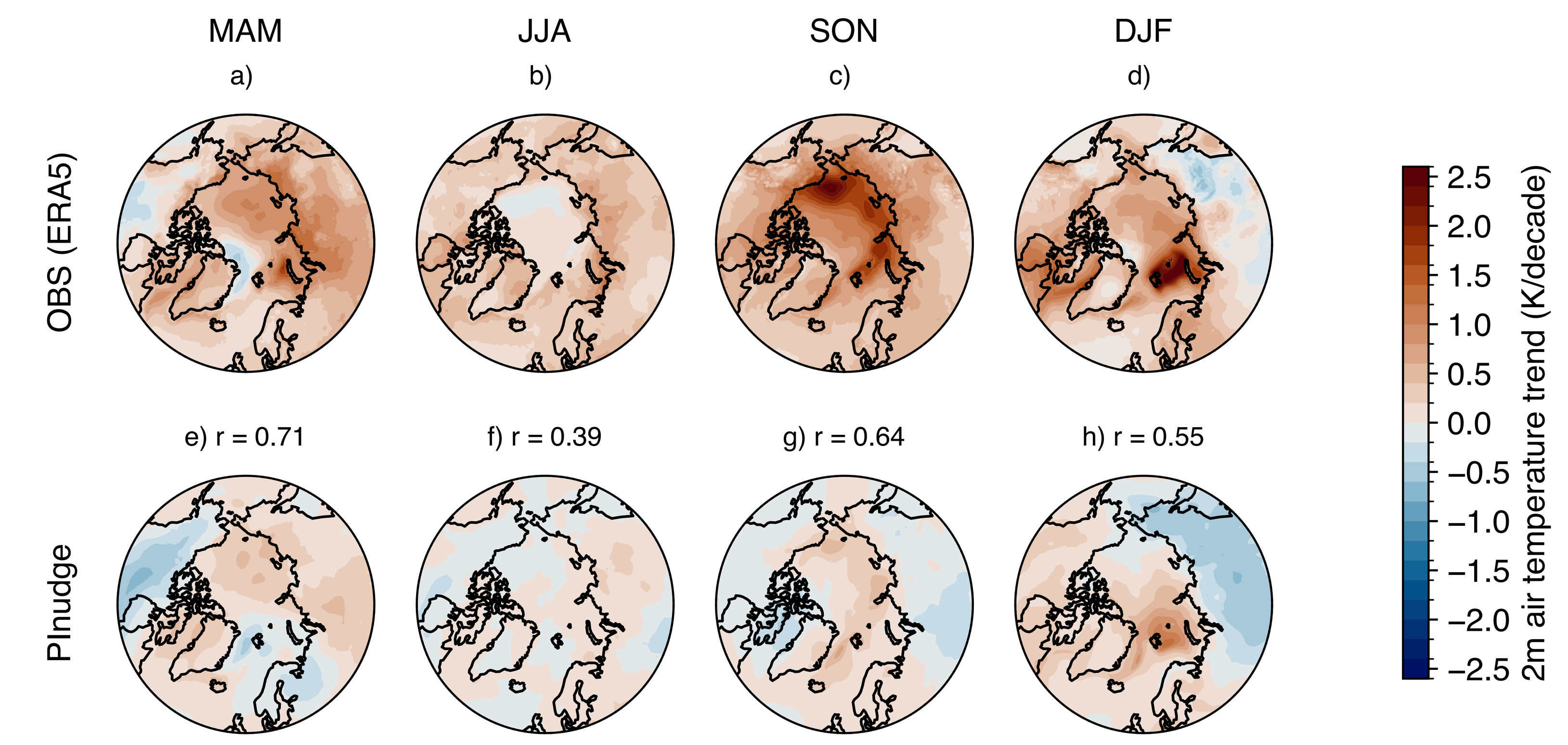


**Figure 4.** Spatial pattern of 2m air temperature trends: a) Observed (ERA5) MAM, b) Observed JJA, c) Observed SON, d) Observed DJF, e-h) as in a-d) but for PInudge. Pattern correlations between observations and PInudge are provided. Stippling on e-h) indicates PInudge differs from the 1850 pre-industrial control run (CESM2-PI) at the 95% confidence level.

**Winds alone cannot reproduce observed September sea ice loss but can explain 12% of the interannual variability**

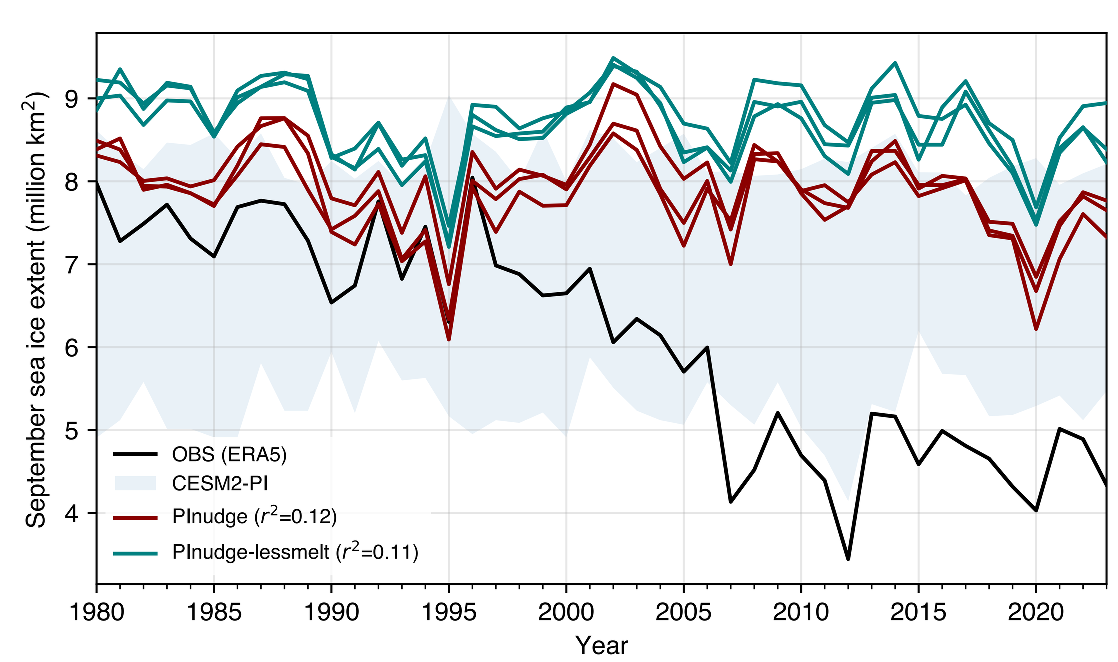


**Figure 5.** Timeseries (1980-2023) of Arctic September sea ice extent. Coefficients of determination are between the wind-nudged experiment (PInudge, PInudge-lessmelt) ensemble mean and ERA5 for 1980-2023.

**Winds alone cannot reproduce monthly observed sea ice loss but still have some influence on the seasonal pattern of sea ice trends**

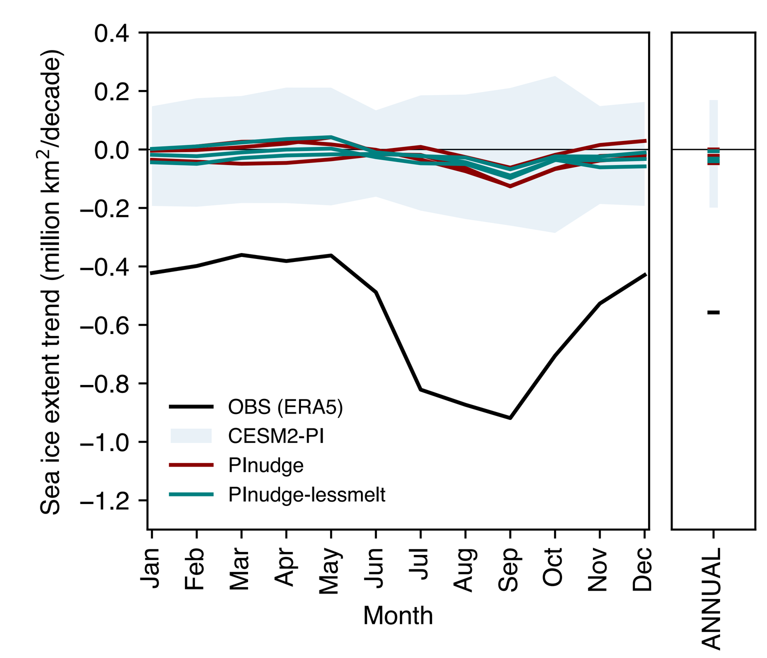


**Figure 6.** Monthly (left) and annual (right) trends in Arctic sea ice extent over 1980-2023.

**Winds alone cannot reproduce the magnitude of local sea ice loss, but still have some influence on regional patterns of sea ice trends**

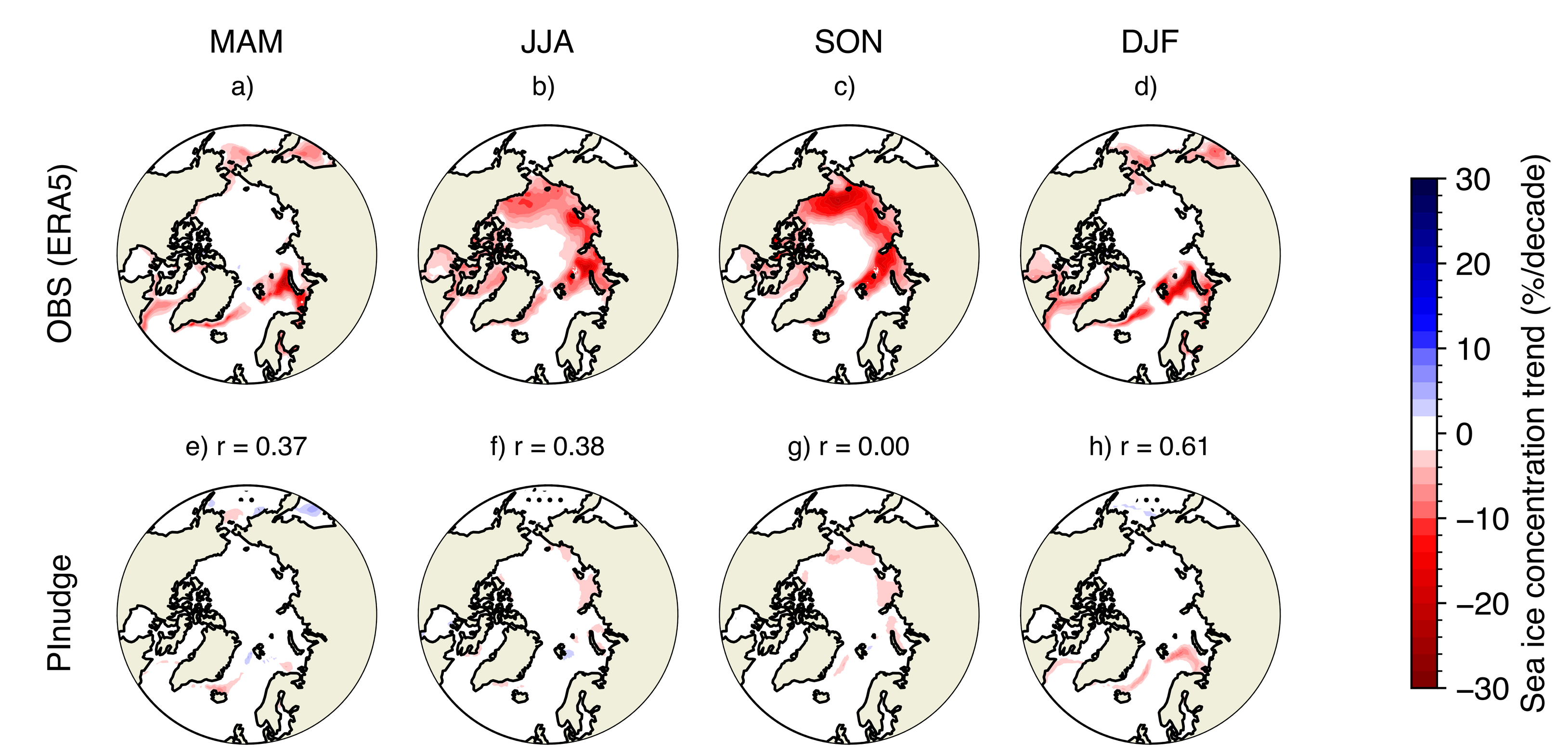


**Figure 7.** Spatial pattern of sea ice concentration trends: a) Observed (ERA5) MAM, b) Observed JJA, c) Observed SON, d) Observed DJF, e-h) as in a-d) but for PInudge. Pattern correlations between observations and PInudge are provided. Stippling on e-h) indicates PInudge differs from the 1850 pre-industrial control run (CESM2-PI) at the 95% confidence level.

## METHODS

| Dataset name | Type (members) | Description |
|---|---|---|
| PInudge | wind-nudged pre-industrial ensemble (3) | nudged with ERA5 winds 60-90°N above 850 mb for 1950-2023; initialized from spin-up |
| PInudge-lessmelt | wind-nudged pre-industrial ensemble (3) | nudged with ERA5 winds 60-90°N above 850 mb for 1950-2023; modified for thicker sea ice; initialized from spin-up |
| CESM2-PI | pre-industrial control ensemble (51) | 51 random 74-year segments of CESM2 pre-industrial control |
| OBS | observations | ERA5 for temperature & sea ice; GISTEMP for temperature only |

- Wind nudging induced model drift, so we cycled the wind nudging twice to remove the drift
- A third cycle confirmed removal of the drift

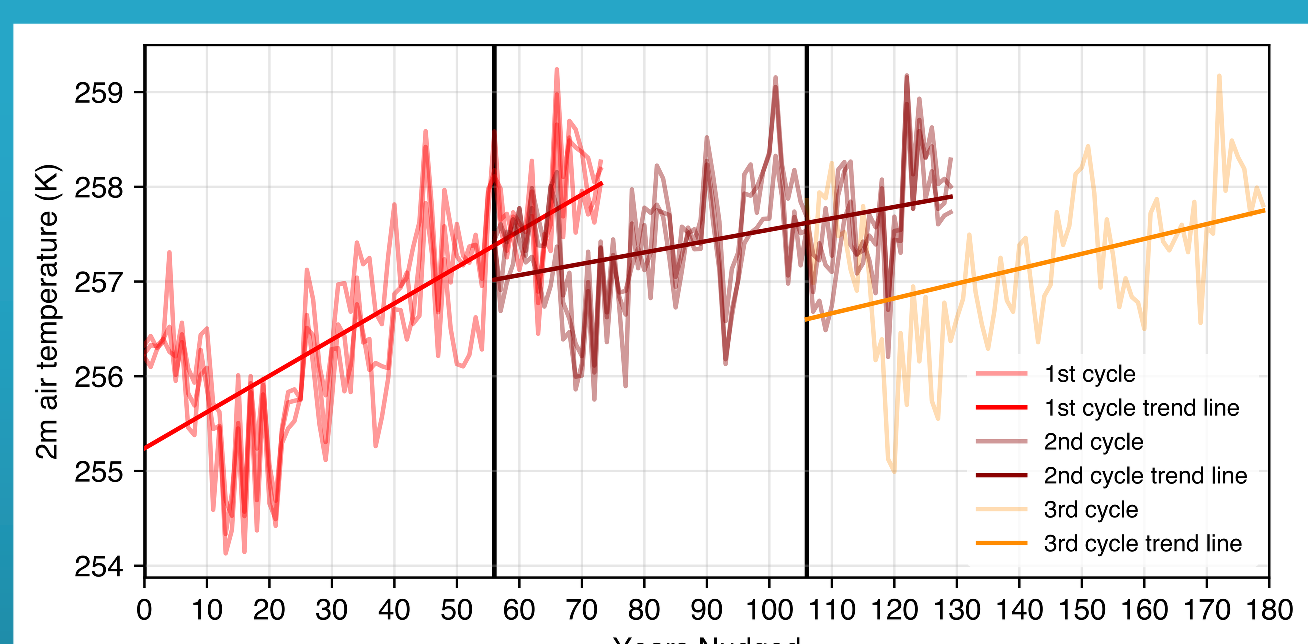


**Figure 1.** Timeseries of annual Arctic (70-90°N) 2m air temperature. Values are plotted as a function of how many years the model climate has been nudged. The first cycle ensemble (red) was initialized from the CESM2-PI. The second cycle (experiment PInudge) ensemble (dark red) was initialized from year 2006 of the first cycle. The third cycle (orange) was initialized from year 2000 of the second cycle. Vertical black lines indicate when a new model run was initialized. All model experiments have the trend line for the ensemble mean plotted.

## CONCLUSIONS

- Observed winds fail to reproduce the magnitude of recent (1980-2023) observed Arctic warming and sea ice loss
- Observed winds partially reproduce the interannual, seasonal, and spatial variability of observed Arctic temperature and sea ice
- In summary, observed winds drive Arctic variability but not long term trends
- Our results are independent of mean state sea ice thickness
- Future work with similar historical wind nudging experiments will precisely attribute the anthropogenic forcing contribution to Arctic warming and sea ice loss

## ACKNOWLEDGEMENTS

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Ash Gilbert
ash.gilbert@colorado.edu
gilbertcloud.github.io
ashgilbertcuboulder