Quantifying the Impacts of Atmospheric Rivers on the Surface Energy Budget of the Arctic Based on Reanalysis Data

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Motivations & Hypothesis

- Recent work has shown atmospheric rivers (AR) to be one of the factors that influence Arctic warming and sea ice decline through impacts on the surface energy budget
- We hypothesize that short-term perturbations in the surface energy budget of the Arctic, as caused by ARs, may be of climatological significance depending on their magnitude and frequency
  - ➢ These perturbations influence surface warming, surface melt, and can even contribute to sea ice melting and alter sea ice extent

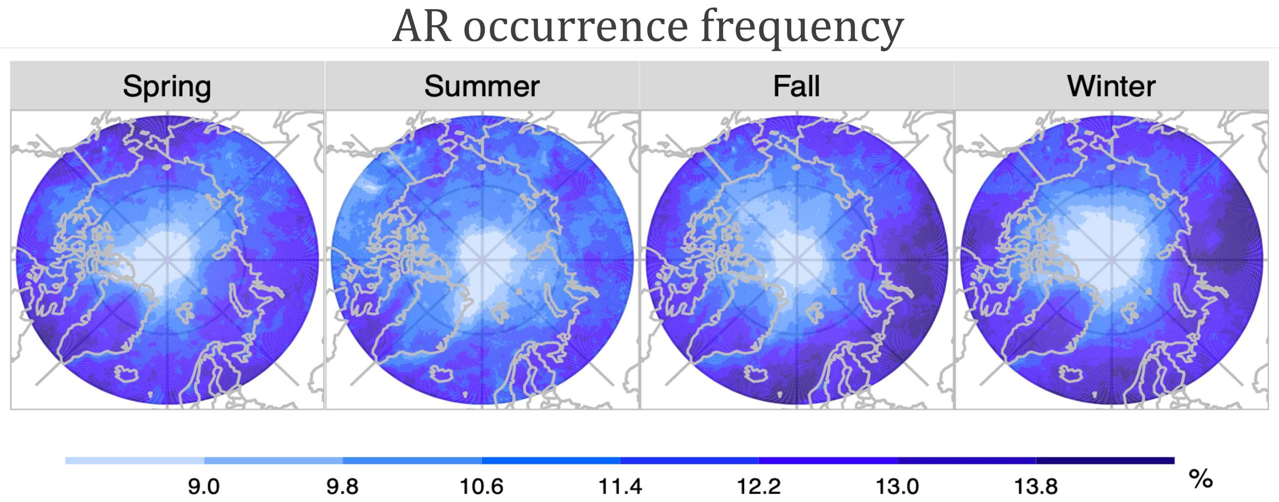
Scientific Questions

- Accurately and comprehensively quantify AR-related surface energy budget terms over the Arctic cross the entire annual cycle
  1. What are the spatiotemporal distributions of ARs and their associated anomalies in surface energy budget?
  2. What is the total climatological contributions of ARs to the surface radiative and turbulent heat fluxes as well as the net surface energy budget of the Arctic?

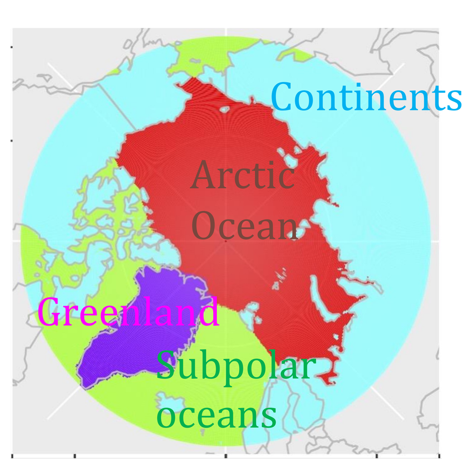
Data & AR detection algorithm

- ERA5
  - ➢ 0.25° latitude x 0.25° longitude
  - ➢ January 1980 to December 2019, sampled at 3 hourly intervals
- 85th_IVT-based AR detection algorithm[1] (most commonly adopted AR index)
  - ➢ IVT applied with 85th percentile of monthly climate thresholds, geometry (1500 km length & length/width>=2), and event duration (18 h) criteria

AR occurrence frequency



- Arctic Ocean: lowest (10.4% summer-10.8% spring)
- Subpolar: lower in summer (11.1-11.8%) and greater (> 12%) in fall, winter, and spring



Division of regions for calculating area averages

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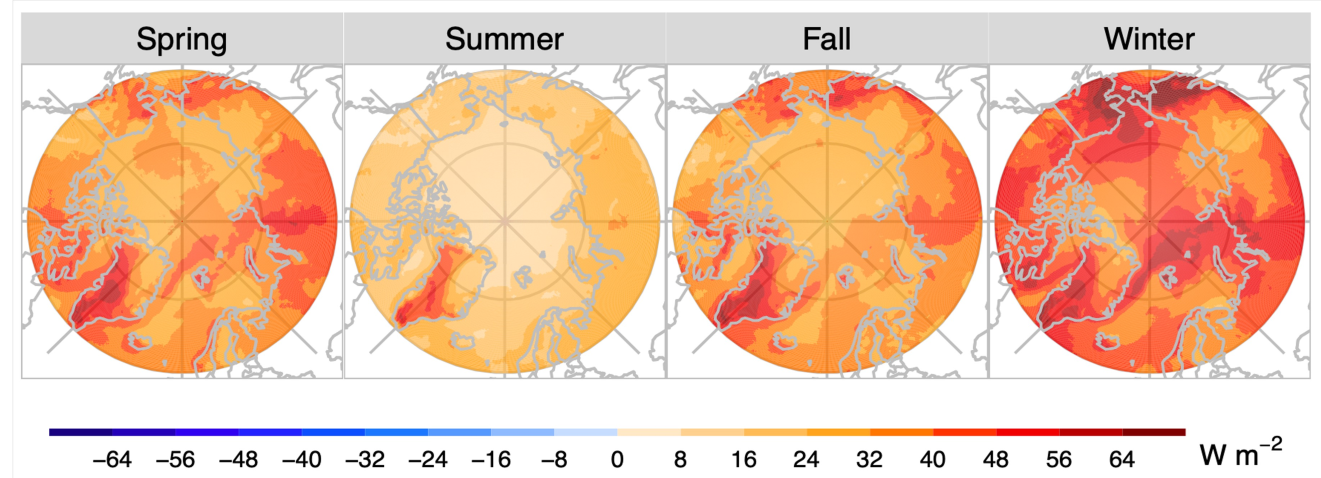
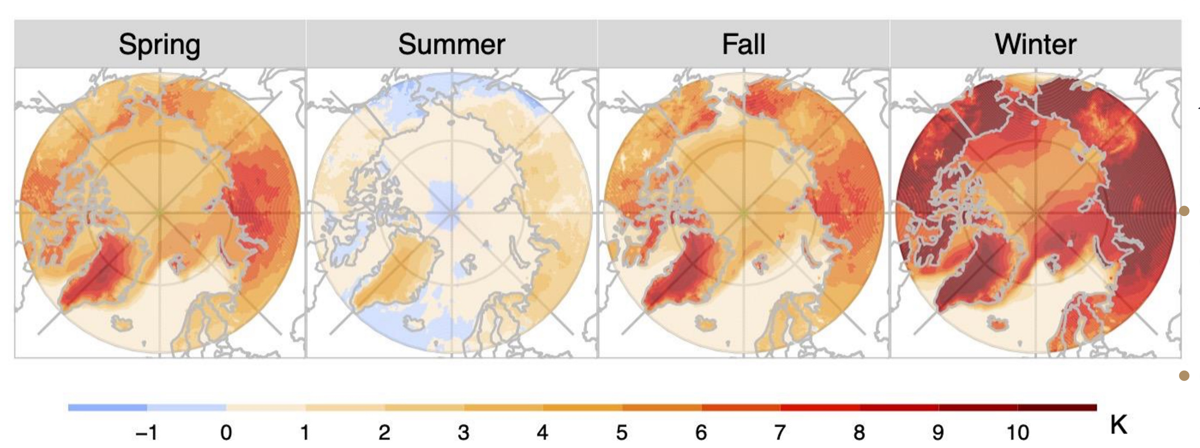
LWD anomalies during AR events



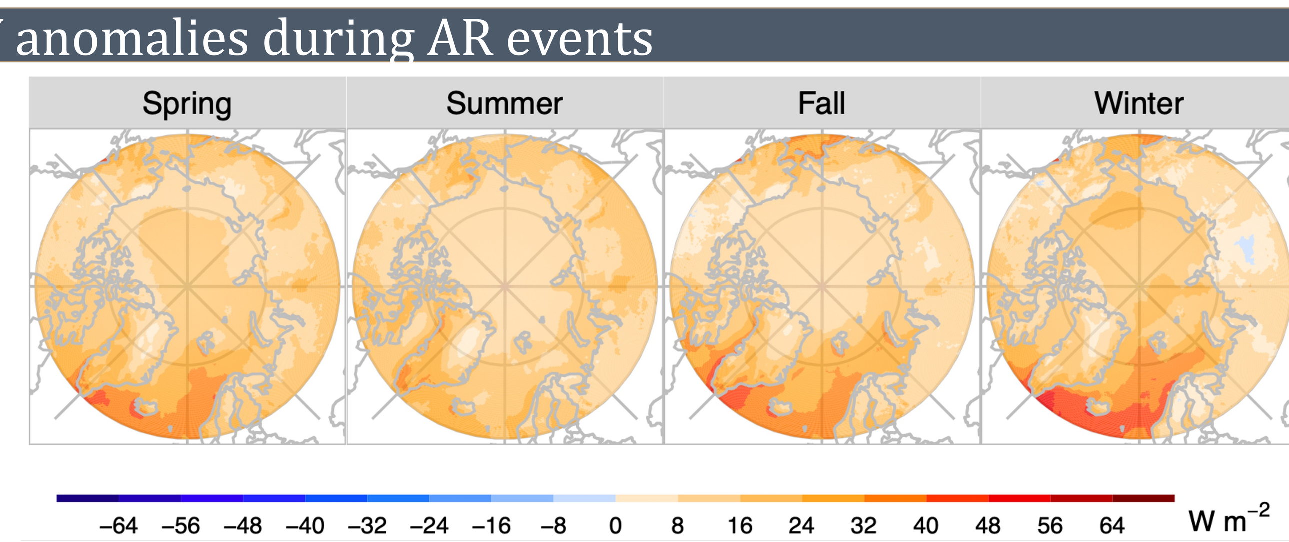
- Largest impacts in winter (>=44 W m^{-2} for all 4 regions)
  - ➢ Large impact near sea ice edge in cold seasons
- Smallest in summer (from 15 W m^{-2} Arctic ocean to 34 W m^{-2} over Greenland)
  - ➢ Consistent large impact over Greenland, triggering melt events over ice sheet

AR impacts on surface temperature



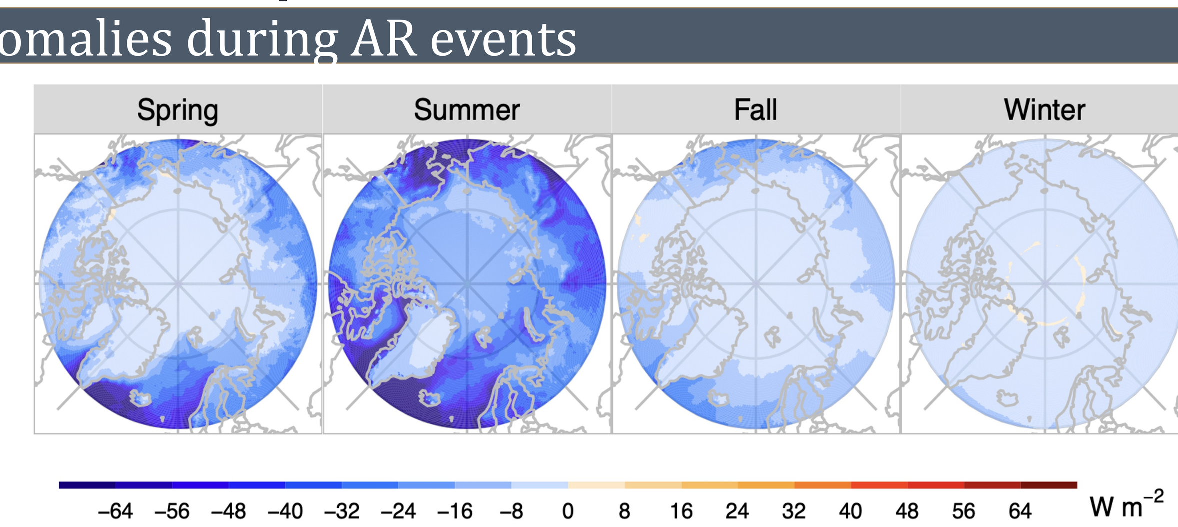
- Largest impacts in winter over land (>9 K) with the next largest impact over Arctic Ocean (6 K), especially near ice edge
- Smallest impacts in summer over Arctic Ocean (0.1 K) and subpolar oceans (0 K)
- Consistent amplified warming impacts over Greenland ice sheet across the year (3-9 K)
- Consistent minimal impacts over subpolar oceans across the year (0-3 K)

Net LW anomalies during AR events



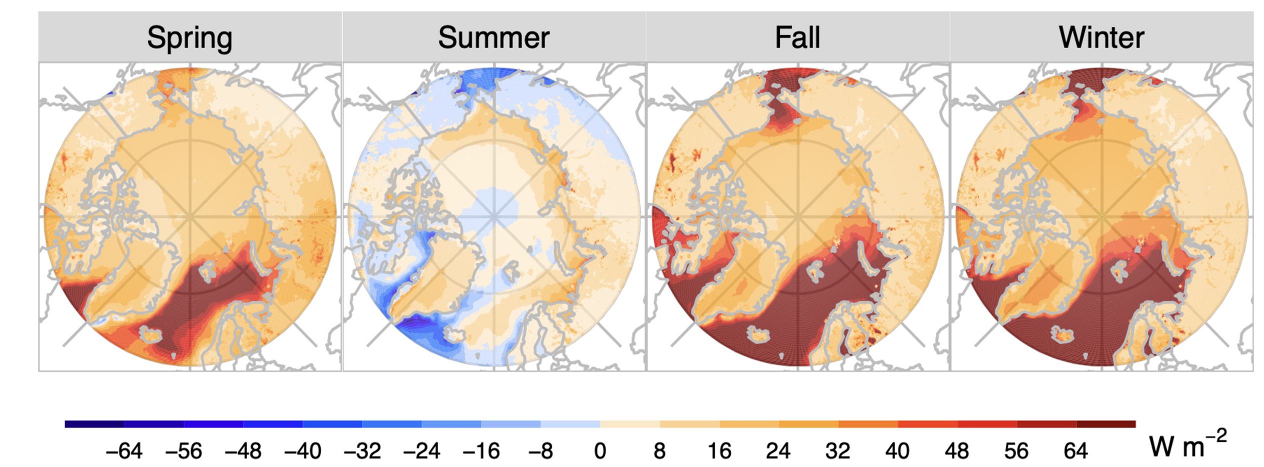
- Largest impacts over subpolar oceans in winter (31 W m^{-2}), smallest over continents in winter (12 W m^{-2})
  - ○ Larger impact over subpolar oceans in cold seasons: smaller response of SSTs to ARs
  - ➢ Next largest in winter over Arctic Ocean (22 W m^{-2}): large LWD AR anomalies offset by moderate surface temperature increases and increase in LWU

Net SW anomalies during AR events



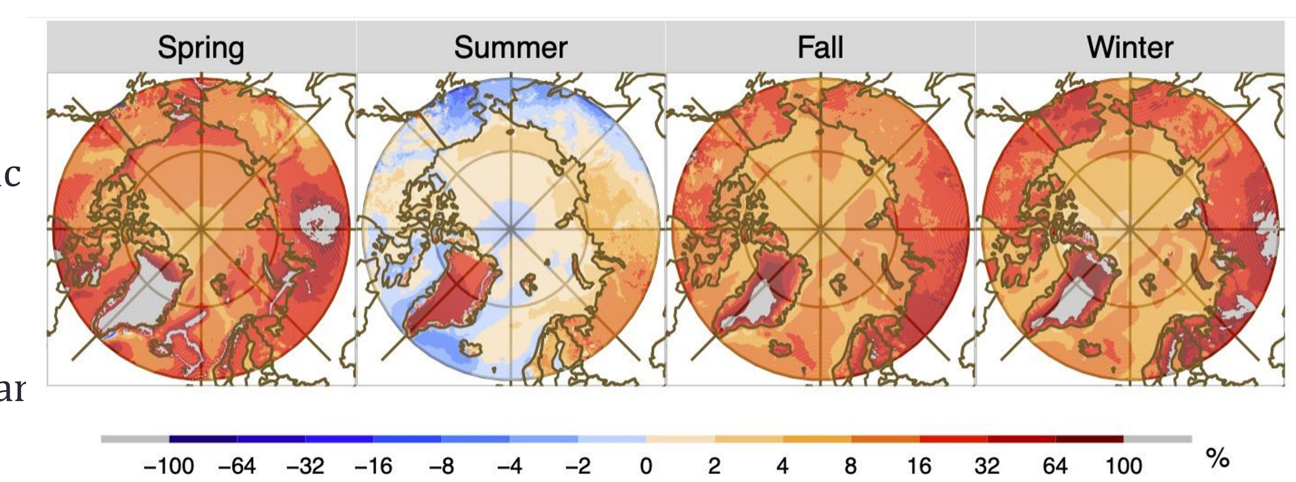
- AR net SW anomalies have a cooling effect due to reduced SWD from AR cloud cover
- Most pronounced cooling effects in summer (and to a lesser extent in spring)
- Larger anomalies in lower albedo subpolar regions (-35 ~-52 W m^{-2})
- Lower anomalies in high albedo central Arctic Ocean (-22 W m^{-2}) and Greenland (-17 W m^{-2})

Net SEB anomalies during AR events



- Continents
  - ➢ Small magnitude of AR impacts (3-16 W m^{-2})
- Greenland Ice Sheet
  - ➢ Positive net SEB anomalies (10-28 W m^{-2}) and amplified surface warming (3-9 K) year-round with importance for melt events in summer
- Arctic Ocean
  - ➢ Large absolute AR impacts on SEB (26 -40 W m^{-2}) and surface temperature (3-6 K) in fall, winter, and spring, dominated by LWD
- Subpolar oceans
  - ➢ Large positive anomalies (40-91 W m^{-2}) in fall, winter, and spring, driven by turbulent fluxes
  - ➢ Negative anomalies (-8 W m^{-2}) in summer driven by shortwave radiation

The contribution of net SEB anomalies to mean SEB



- Continents
  - ➢ Largest contribution in cold seasons (spring: 90%, winter: 50%, fall: 24%), far exceeding corresponding AR frequency
  - ➢ Lower contribution in summer (3%)
- Greenland Ice Sheet
  - ➢ Consistent year-round large contribution, suggesting to trigger the Greenland Ice Sheet melt
- Arctic Ocean
  - ➢ Smaller relative contribution that are less than AR occurrence frequency in all seasons (7-8% in fall and winter, 1% in summer), except for spring (32%)
  - ➢ Local maximum contributions over sea ice margins in spring
- Subpolar oceans
  - ➢ Small relative contribution, ranging from 65 % in spring to 8-9% in fall and winter
  - ➢ Cooling effects in summer (-8%)

Conclusions

- Arctic Ocean
  - ➢ Large absolute AR impacts on SEB (26 -40 W m^{-2}) and surface temperature in fall, winter, and spring, dominated by LWD
  - ➢ Most significant relative contribution to the mean SEB in spring (32%), exceeding AR frequency (10.8%), but eligible contribution in other seasons
- Subpolar oceans
  - ➢ Large positive anomalies (40-91 W m^{-2}) in fall, winter, and spring, driven by turbulent fluxes; the overall contribution to the mean SEB is most significant in spring (65.3%)
  - ➢ Negative anomalies (-8 W m^{-2}) in summer driven by shortwave radiation and weak contribution (-1%)
- Continents
  - ➢ Smaller absolute anomalies in net SEB, but substantial relative contribution to the mean SEB, particularly in cold seasons (24-90%), far exceeding the AR frequency
- Greenland Ice Sheet
  - ➢ Large AR impact year-round with importance for melt events in summer

(manuscript in prep.)

References

[1] Zhang, C., Tung, W., & Cleveland, W. S. (2023). Climatology and decadal changes of Arctic atmospheric rivers based on ERA5 and MERRA-2. Environmental Research: Climate. https://doi.org/10.1088/2752-5295/acdf0f