Influence of Atmospheric Rivers on Alaskan River Ice

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Key Points:

- Atmospheric Rivers (ARs) correlate to a one week increase in daily minimum temperature
- Robust ARs occuring during the coldest period of the year appear to prolong the annual breakup date of river ice
- ARs account for about one third (36%) of total precipitation and explain almost half (48%) of interannual variability of precipitation

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Abstract

Atmospheric rivers (ARs) transport vast amounts of moisture from low latitudes, mainly the Tropics, to high latitude regions. One region particularly impacted by ARs is Alaska USA. We analyze the role of ARs in raising local temperatures, their effect on precipitation variability, and their influence on the annual river ice breakup date for 25 locations. Precipitation and temperature records were provided by Daymet, with ARs determined from the Guan and Waliser tracking algorithm. We found ARs increase local temperatures for as long as one week post landfall, account for 36% of total precipitation and explain 48% of precipitation variability. Calculating the heat transport between ARs and river ice, fused with a temporal bias, we conclude that heavy precipitation events (HPEs) during the coldest period of the year prolong river ice breakup dates, while HPEs occurring close to the breakup date have little impact on breakup timing.

Plain language summary

We strategically selected 25 locations with annual river ice breakup dates recorded throughout Interior Alaska. Across all locations, we determined that daily temperature increases by up to one week post an atmospheric river (AR). We also found that ARs account for 36% of total annual precipitation from 1980 to 2023 and explain 48% of the variability of precipitation. We then calculated the total heat transfer between precipitation and river ice while taking into account a bias function for time. Surprisingly, we found that heavy precipitation events (HPEs), both local precipitation and ARs, that occur relatively close to river ice breakup dates, have little correlation to the breakup date. However, HPEs that occur during the coldest period of the year (typically late December to mid-January) are strongly inversely correlated with river ice breakup timing, and therefore prolong the breakup date.

1 Introduction

Atmospheric rivers (ARs) are narrow corridors of intense water vapor transport that significantly influence hydrologic events and transport most of the water vapor outside of the Tropics (USDOC, 2023). It is estimated that ARs are responsible for as much as 90% of poleward water vapor transport at midlatitudes (Zhu & Newell, 1998). ARs contribute to extreme precipitation events across various regions worldwide, including western North America (Dettinger et al., 2004; Guan et al., 2010; Paul J. et al., 2011; Ralph et al., 2006; F. Martin et al., 2019; Dettinger et al., 2011) Europe (Lavers et al., 2013; Harald & Andreas, 2013), and western South America (Viale et al., 2018). In recent years, the impacts of ARs on the cryosphere have been more extensively anlayzed. It was found that between 1981 and 2020 atmospheric moisture content anticorrelates significantly with sea ice concentration over almost the entire Arctic Ocean (Li et al., 2022). For those same years, another analysis found that 100% of extreme temperature events in the Arctic (above 0 $°C$) coincided with ARs (Ma et al., 2023). Many analyses have noted a relationship between heavy AR activity and sea ice loss, as a result of increased rainfall from lower latitudues (Zhang et al., 2023; Maclennan et al., 2022). However Arctic systems are complicated, as the intense moisture transport within ARs can also result in heavy snowfall events, thus contributing to the accumulation of snowpack, especially in mountainous regions (Saavedra et al., 2020; Guan et al., 2010). Under the right conditions, this relationship has been found to increase the mass balance of glaciers (Little et al., 2019). Understanding the role of ARs in the cryosphere is essential for assessing their broader impact on regional water resources and glacier dynamics in a changing climate. While a number of works have explored the relationship between ARs and sea ice, to our knowledge there haven't been any analyses that look at the relationship between ARs and Arctic river ice. Many works have used physics based processes and allometrics to model the annual breakup timing and conditions of Arctic river ice (Paily et al.,

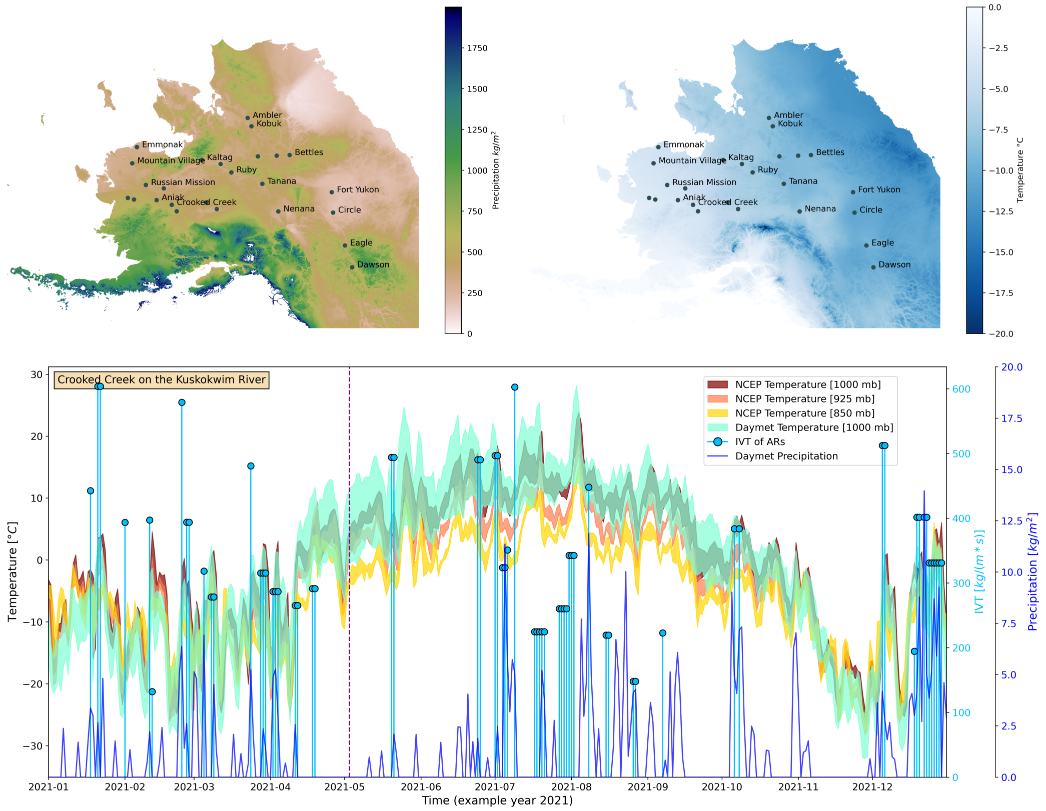

Figure 1. Top: (left) map showing summated precipitation for the year 2021; (right) map of average temperature for 2021. Bottom: One of the 25 locations (Crooked Creek on the Kuskokwim River) for the year 2021. Yellow, orange, red represents the temperature profiles (fill plot of tmin - tmax) from NCEP temperature data at 850, 925 and 1000mb respectively. Light green represents Daymet temperature profile. Dark blue shows modeled precipitation from Daymet while the light blue stem plots depict AR events. The purple dashed line shows the breakup date for the Kuskokwim River in 2021 for Crooked Creek.

1974; Ashton, 1986; Prowse et al., 2007; Jasek, 1998; Shen, 2010). While it is recognized that an increase streamflow alters the dynamics surrounding river ice breakup timing (Ashton, 1986), the relationship precipitation and to that end AR timing has on Arctic river ice has yet to be examined. This analysis sets out to answer the following questions: 1.) Is there a change in air temperature for each location, corresponding to the timing of ARs? 2.) How do ARs contribute to precipitation throughout interior Alaska? 3.) Do ARs impact the timing of river ice breakup?

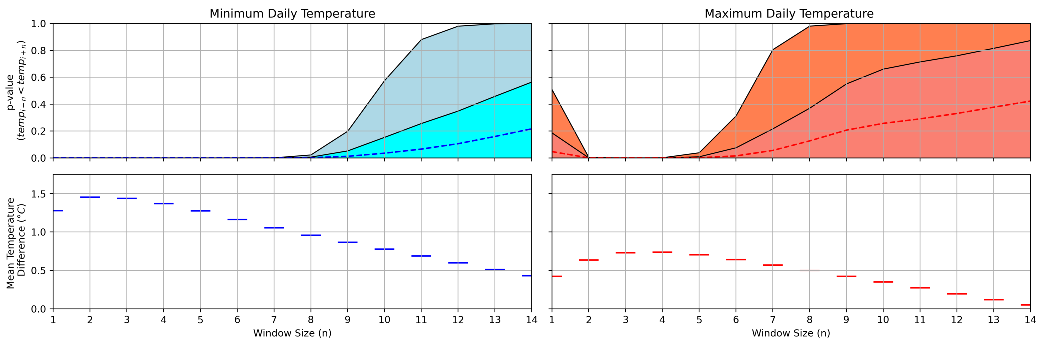

Figure 2. Top: the p-value of the paired t-test given the window size surrounding the AR event date. Dashed lines represent the mean p-value over the study area while the color transition depicts the IQR of p-values Bottom: the average increase in temperature from the lookback window to the forecast window.

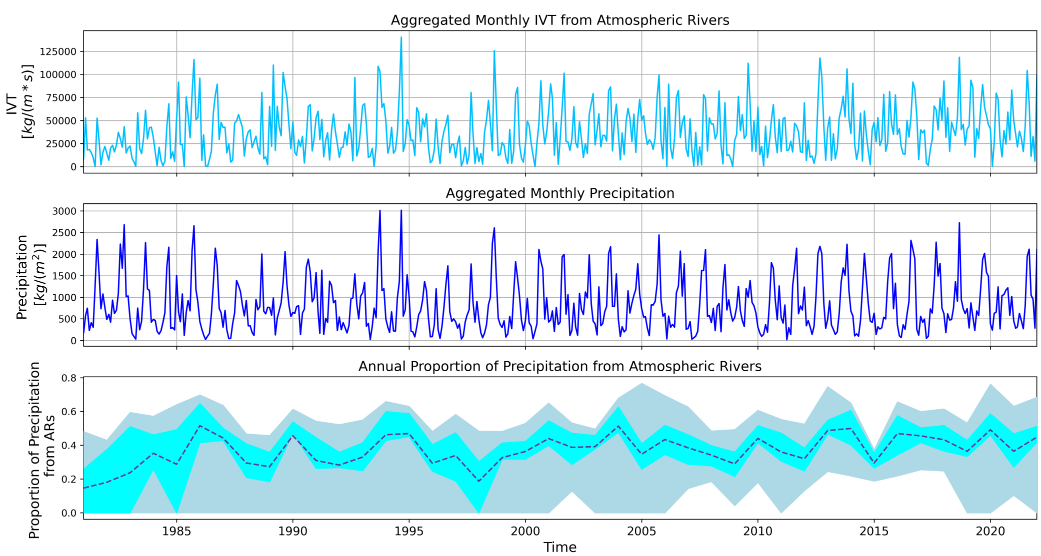

Figure 3. Top: time series of IVT aggregated over all locations. Middle: time series of precipitation aggregated monthly over all locations. Bottom: proportion of precipitation accounted for by ARs, fill colors depict IQR while dashed line depicts the mean, aggregated over all locations annually.

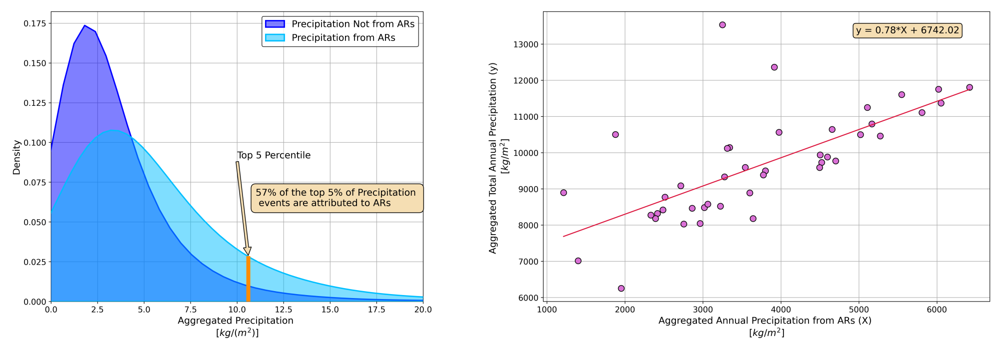

Figure 4. Left: kernel density plots showing the distribution of local precipitation (dark blue) and precipitation from ARs (light blue). Right: orindary least squares regression plot using annual, summated precipitation from ARs, to predict annual summated precipitation.

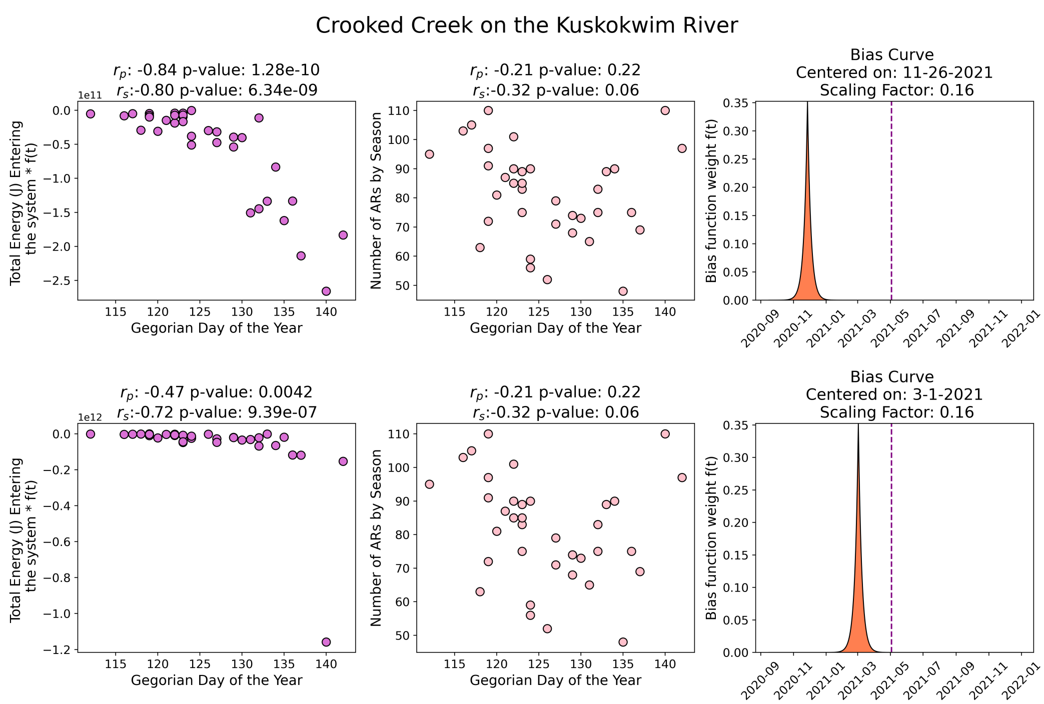

Figure 5. Top: (left) scatter plot between thermal energy transfer and DOY; (middle) scatter plot of the number of ARs that occured in the 6 months prior to the breakup date and DOY (right) temporal bias curve for the year 2021 with the breakup date represented by the vertical dashed ilne. Bottom: same as the top except depicting when the bias curve is not optimally placed (close to the breakup date).

2 Data

3 Methods

4 Results

5 Conclusion

Open research section

This section MUST contain a statement that describes where the data supporting the conclusions can be obtained. Data cannot be listed as "Available from authors" or stored solely in supporting information. Citations to archived data should be included in your reference list. Wiley will publish it as a separate section on the paper's page. Examples and complete information are here: https://www.agu.org/Publish with AGU/Publish/Author Resources/Data for Authors

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Enter acknowledgments here. This section is to acknowledge funding, thank colleagues, enter any secondary affiliations, and so on.

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Appendix A.