Quantifying the association between Antarctic atmospheric river characteristics and their impacts using extreme-value statistics

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Motivation

Atmospheric rivers (ARs) have extreme impacts on the Antarctic ice sheet (AIS)

- > 10% of AIS yearly snowfall budget *(Wille et al. 2021)*
- Extreme temperatures/anomalies *(Wille et al. 2022, 2024)*

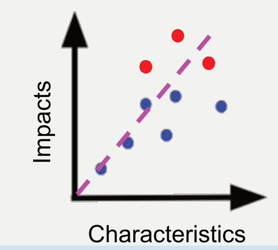
Impacts are highly variable across storms… ***any associations between storm characteristics (pressure, wind, moisture, etc.) with extreme landfalling impacts?***

Project Goals

Open catalog of AR events with variable info *(inc. tutorials, software tools, docs)*

	Var. 1	Var. 2
AR 1	…	…
AR 2	…	…

Statistical associations with extreme impacts



Building a Catalog of AR Events

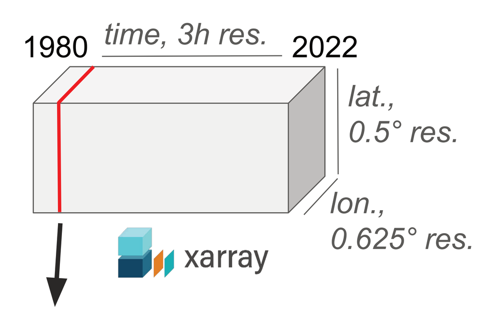
Poleward Integrated Vapor Transport (vIVT) Threshold Catalog (Wille et al., 2021)
vIVT from MERRA-2 (Gelaro et al., 2017)

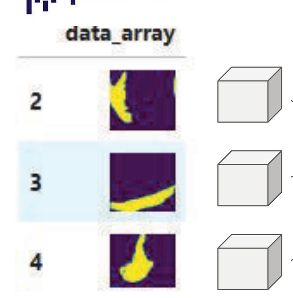
→ **Clustering in space + time** *(Modified DBSCAN)*

→ **Our Catalog of AR Events**

→ **Mask into MERRA-2** (downloaded or streamed)

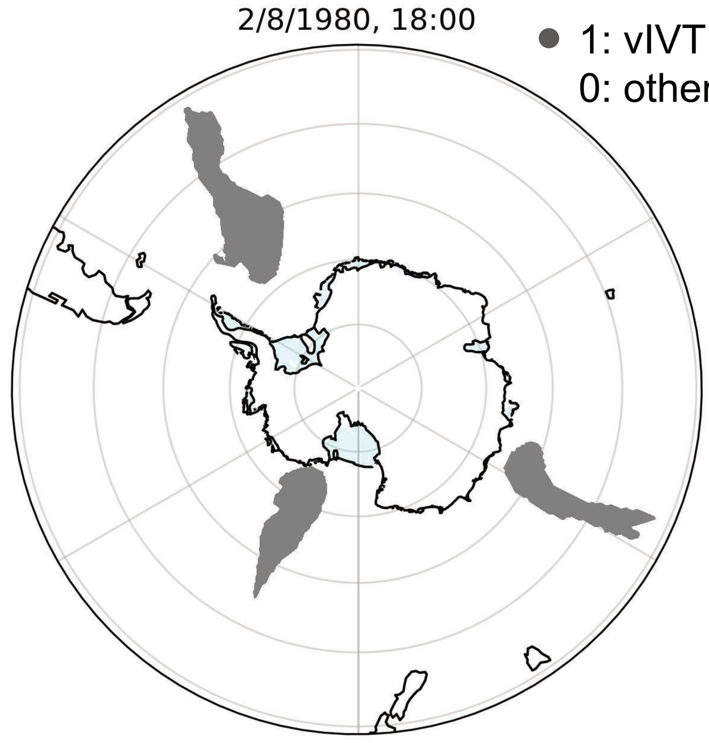
→ **Tabular dataset of landfalling storms with custom characteristics and impacts**



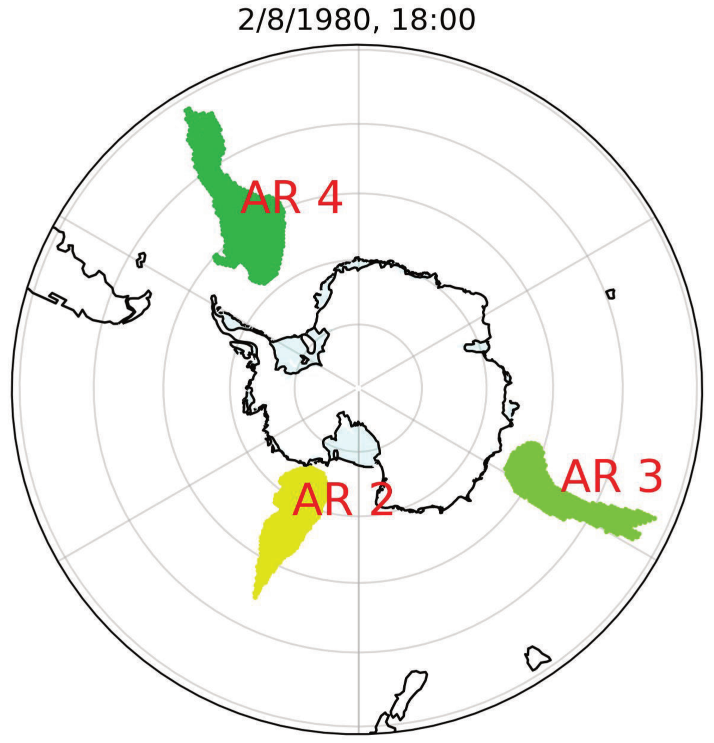


pandas

Pointwise Threshold Catalog
2/8/1980, 18:00



Our Event-based Catalog
2/8/1980, 18:00



Dataset

# of landfalling storms 2929

Characteristics
Cumulative Landfalling Area, Max IWV over AIS, Max 10m Poleward Wind over AIS, Min Landfalling Sea-level Pressure over Ocean, Max Southward Extent

Impacts
Cumulative Snowfall over AIS, Max 2m Temp. Anomaly over AIS

Method

***Linear quantile regression** models quantiles of an outcome variable as a linear combination of predictors*

Model

$$Q_{Y|X}(\tau) = X'\beta(\tau)$$

τth quantile of impact **Y** among ARs with characteristics **X**; Vector of characteristics; Vector of regression coefficients for τth quantile

***Signs** of coefficients convey direction of association between characteristics and quantiles of impact variable*

Inference

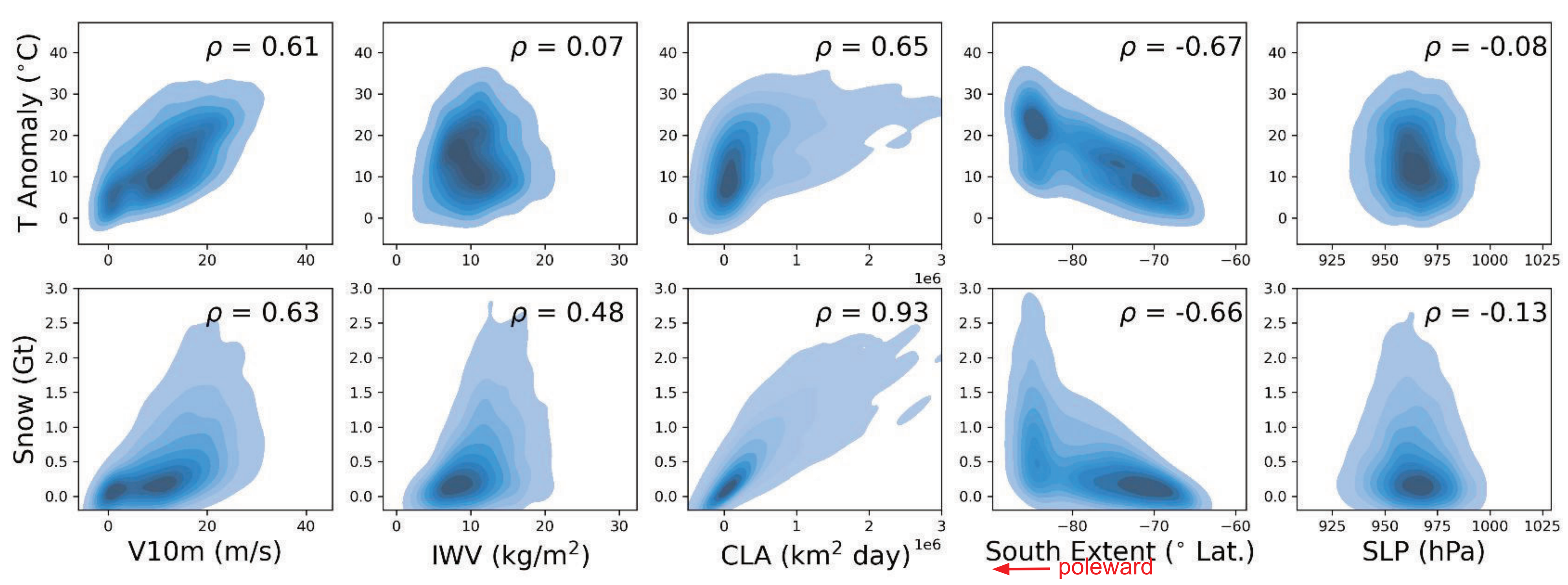
Dimension-adjusted order

$$(1-\tau)n/d$$

# of ARs; *# of characteristics*

$(1-\tau)n/d \geq 30$	$(1-\tau)n/d < 30$
Central	*Extremal*
$\hat{\beta}(\tau) \rightsquigarrow \mathcal{N}(\beta, \Sigma)$	$\hat{\beta}(\tau) \rightsquigarrow Z_\infty$
Koenker (2005)	Chernozhukov (2011)

Exploratory Data Analysis



Contour plots of bivariate kernel density estimates comparing pairs of characteristics (columns) with relevant impacts (rows); correlation computed using Spearman's rho

Takeaways

↑ **2m Temp. Anomaly**

↑	10m Poleward Wind	Cumulative Landfalling Area
↓	Southernmost Latitude	
?	IWV	Min. Landfalling SLP

↑ **Cumulative Snow**

↑	10m Poleward Wind	Cumulative Landfalling Area	IWV
↓	Southernmost Latitude		
?	Min. Landfalling SLP		

Preliminary Results

Coef. 95% Confidence Intervals, Temp. Anomaly

	τ = 0.5	τ = 0.9	τ = 0.99
V10m	[0.36, 0.45]	[0.16, 0.29]	[-0.43, 1.28]
IWV	[-0.23, -0.17]	[-0.22, -0.09]	[-0.36, 1.47]
CLA	[0.20,0.29]	[0.20, 0.43]	[-0.56, 1.34]
South	[-0.40, -0.30]	[-0.58, -0.42]	[-0.39, 1.41]
SLP	[0.04, 0.11]	[0.03, 0.12]	[-0.36, 1.45]

Coef. 95% Confidence Intervals, Snowfall

	τ = 0.5	τ = 0.9	τ = 0.99
V10m	[0.07, 0.11]	[0.11, 0.17]	[0.06, 1.18]
IWV	[0.08, 0.11]	[0.16, 0.22]	[-0.02, 0.95]
CLA	[0.85, 0.92]	[1.07, 1.21]	[-0.04, 0.96]
South	[-0.02, 0.02]	[-0.01, 0.04]	[0.04, 1.20]
SLP	[-0.04, -0.02]	[-0.04, -0.01]	[0.36, 1.57]

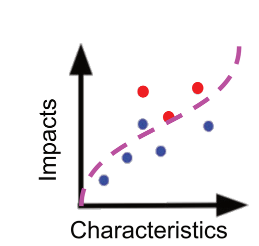
95% CIs for coefficients in quantile regression fits for different impact variables and different quantiles. Central inference used for τ = 0.5. 0.9, extremal inference used for τ = 0.99.
All variables standardized; no multiplicity adjustments performed

Conclusions and Next Steps

No significant associations between variables and extreme 2m temperature anomalies

Positive associations between 10m poleward wind, southernmost latitude, min. Landfalling SLP, and extreme snowfall

Future Work



More flexible modelling approaches

More extensive catalog ground-truthing

More variables (850 hPa wind, pressure of cyclone, etc.)

Explore regional variations

Make code, catalog, routines public and documented

In the meantime… check out this walkthrough detailing the current version of the catalog!

jupyter

References

Wille, J. D., Favier, V., Gorodetskaya, I. V., Agosta, C., Kittel, C., Beeman, J. C., et al. (2021). Antarctic atmospheric river climatology and precipitation impacts. *Journal of Geophysical Research: Atmospheres*, 126, e2020JD033788.
Wille, J.D., Favier, V., Jourdain, N.C. et al. (2022). Intense atmospheric rivers can weaken ice shelf stability at the Antarctic Peninsula. *Commun Earth Environ* 3, 90 (2022).
Wille, J. D., et al. (2024). The Extraordinary March 2022 East Antarctica "Heat" Wave. Part I: Observations and Meteorological Drivers. *J. Climate*, **37**, 757–778.
Gelaro, R., and Coauthors, 2017: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). *J. Climate*, **30**, 5419–5454,
Koenker, R. (2005). *Quantile Regression*. Cambridge University Press.
Victor Chernozhukov and Iván Fernández-Val (2011). Inference for Extremal Conditional Quantile Models, with an Application to Market and Birthweight Risks, *The Review of Economic Studies*, Volume 78, Issue 2, Pages 559–589.

Funding

JB was funded by a combination of NSF Award Number 1745640 and the Two Sigma PhD Fellowship