The role of extratropical cyclones in flooding in Quebec, Canada, from 1991 to 2020

Clarence Gagnon[A,1], Daniel F. Nadeau[1], Alejandro Di Luca[2], François Anctil[1], Benoit Brault[1], Romane Hamon[1], Nicolas Roy[1], Marc-André Bourgault[3]

[A]Presenting author, Master student in Water engineering
[1]Department of Civil and Water Engineering, Laval University, Québec, Canada
[2]Department of Earth and Atmospheric Sciences, UQAM, Montréal, Canada
[3]Department of Geography, Laval University, Québec, Canada

1 Introduction

RESEARCH OBJECTIVE

Evaluate the contribution of extratropical cyclones (ETCs) and atmospheric rivers (ARs) to flooding in Quebec between 1991 and 2020 through three steps

1- Identify floods
2- Quantify the contribution of ETCs and ARs to floods
3- Characterize ETCs in terms of contribution and origin

UNIQUE ASPECTS

- First study of its kind in Quebec
- Systematic study of all known floods between 1991 and 2020

Public Safety
Better anticipation of future floods

Property Damage
Hurricane Debby (summer 2024) - most expensive climate event in the history of Quebec (1)

Climate Change
- Increase of rainfall extremes associated with ETCs (2)
- Heavy rainfall from spring flood of 2017 3x more likely (3)

2 Data & Methods

SOURCES OF DATA

- Quebec flooding events database (4)
- ERA5 Reanalysis Precipitation data (7)
- Hydroclimatic Atlas of Southern Quebec (5)
- Global Atmospheric River (AR) Scale database (8)
- HydroBASINS Nested sub-basins (6)
- North America Extratropical Cyclone (NAEC) Catalogue (9)

KEY STEPS

Define flooding events
- Financial aid claims are grouped by location and time of occurrence

Id flood-contributing ETCs
- Physical and temporal boundaries for data search are set
- ERA5 precipitation is associated with ETCs and ARs

Classify & compare ETCs
- ETCs are classified by genesis location and involvement in flooding
- Flood-contributing ETCs are compared to non-flood-contributing ETCs

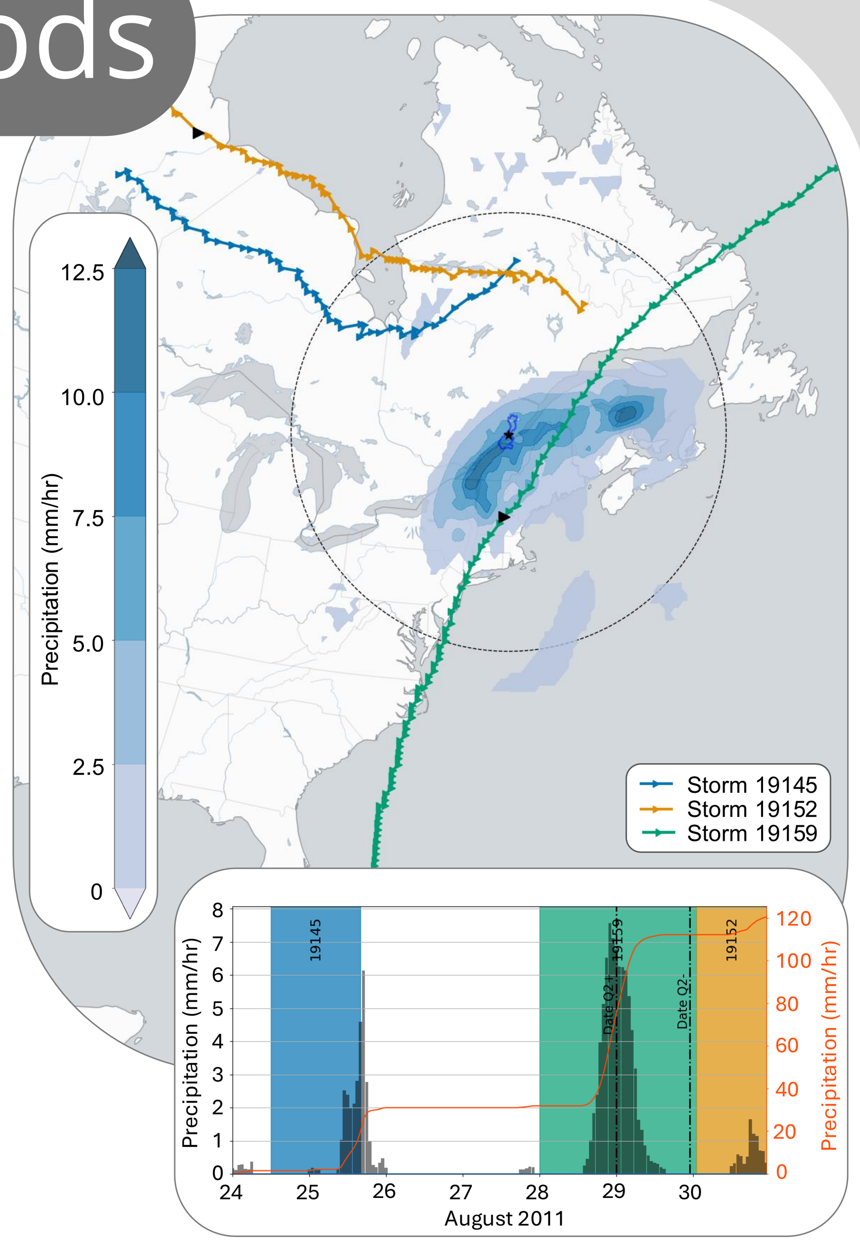

Figure 1: (Top): Storms around Center-of-Quebec watershed (outlined in blue) present in the boundary, during flooding of August 2011. (Bottom) Associated rainfall and important dates.

Date Q2- and Q2+ refer to times the rising and falling limbs of the hydrograph cross the 2-year average river discharge

3 Results

A 75% of floods occur in spring

- 479 flood events were identified at the watershed scale
- 11.5% of floods occur in fall, 9.8% in summer, and 4.2% in winter
- The 479 floods can be grouped into 82 meteorological events

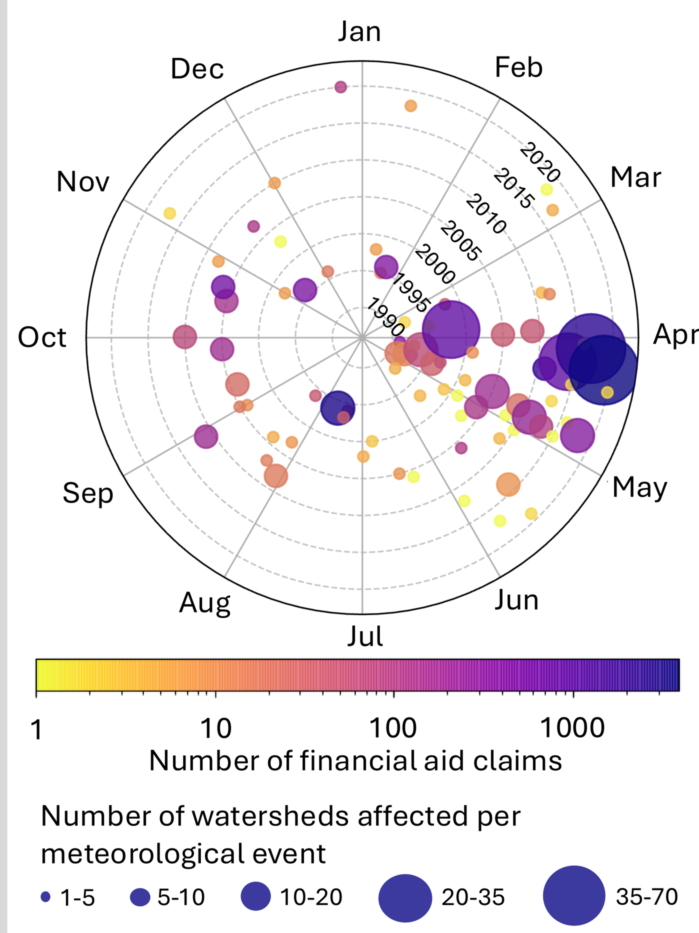

Figure 2: Meteorological flood events between 1991 and 2020 with their associated number of watersheds affected and financial aid claims

B ETCs are highly responsible for floods

High or very high contribution
- In 72% of floods for ETCs
- In 41% of floods for ARs

At least a mild contribution
- In 100% of floods for ETCs
- In 70% of floods for ARs

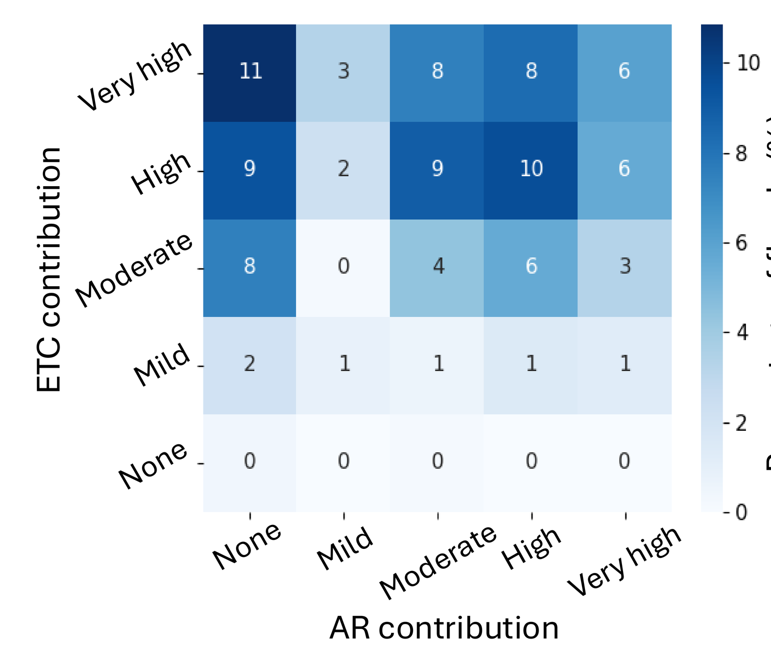

Figure 3: ETC vs AR contribution in flooding, for all 479 flood events analyzed, indicated in percentages, where None refers to no contribution

Table 1: Cumulated rainfall association necessary for the different contribution levels given to ETCs and ARs during flooding

Percentage range	[0, 25]	(25, 50]	(50, 75]	(75, 100]
Contribution	mild	moderate	high	very high

C Cyclogenesis of flood-contributing ETCs restricted to two main regions

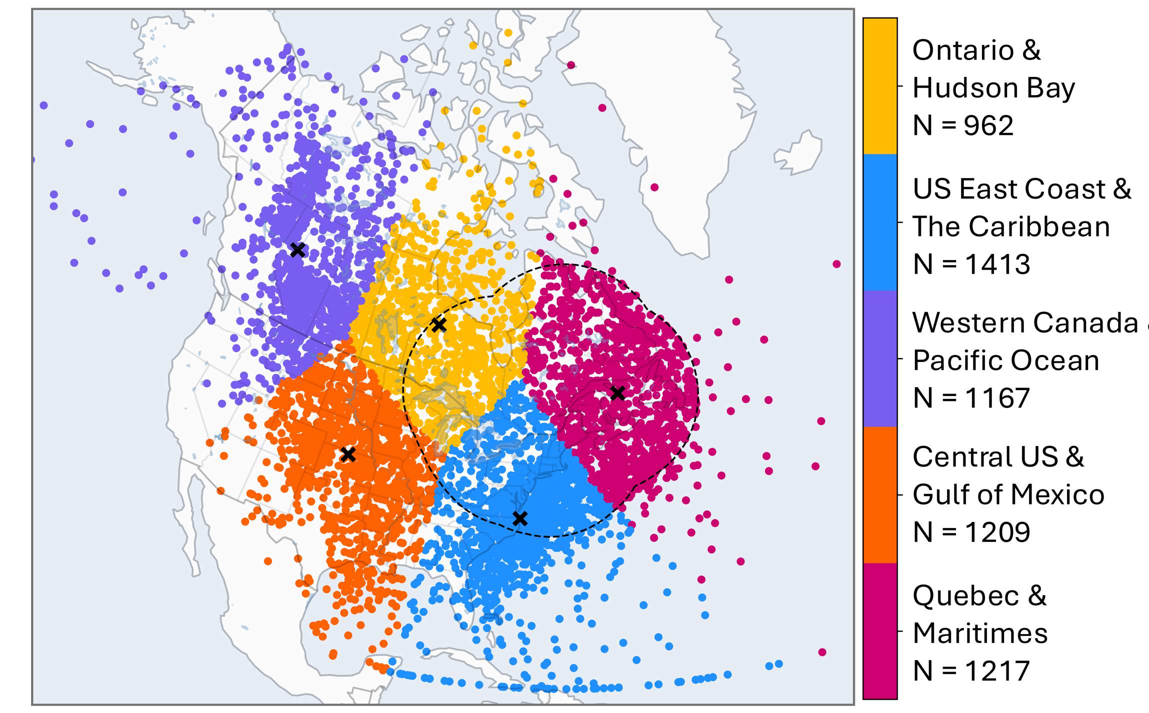

Figure 4: Five clusters obtained from clustering on genesis locations of the 5968 ETCs spending at least 1h in the dashed black domain between 1991 and 2020

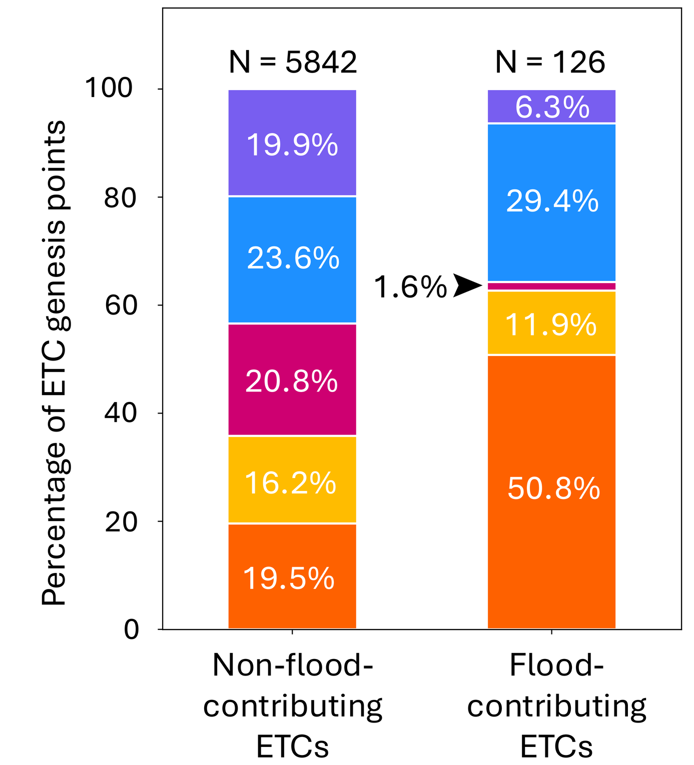

Figure 5: Comparison of genesis location distribution for flood-contributing and non-flood-contributing ETCs

- Five regions of cyclogenesis identified through clustering of 5968 ETCs found
- Region of cyclogenesis evenly distributed for non-flood-contributing ETCs
- Cyclogenesis in *Center US & the Gulf of Mexico* and *US East Coast & the Caribbean* are favored for flood-contributing ETCs

D 54% of financial aid claims can be linked to just four storms

- The number of financial aid claims associated with flood-contributing ETC varied greatly
- 90% of all financial aid claims were associated with 23 out of 126 storms

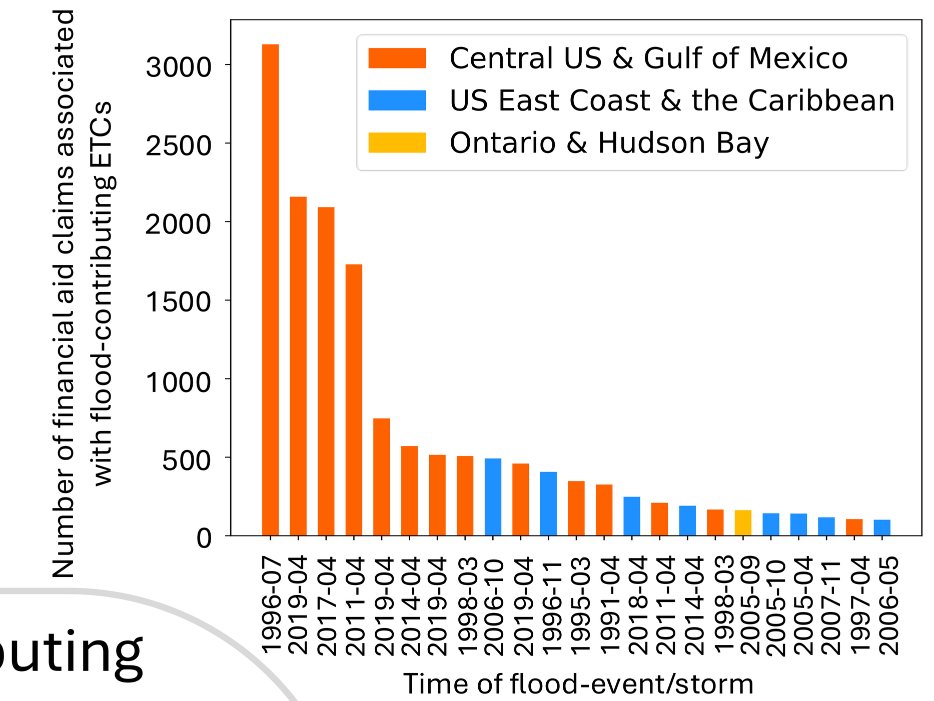

Figure 6: Financial aid claims associated with flood-contributing storms and their provenance

E Flood-contributing ETCs spend more time in the domain

- Flood-contributing ETCs spend on average 19.4 hours more in the domain

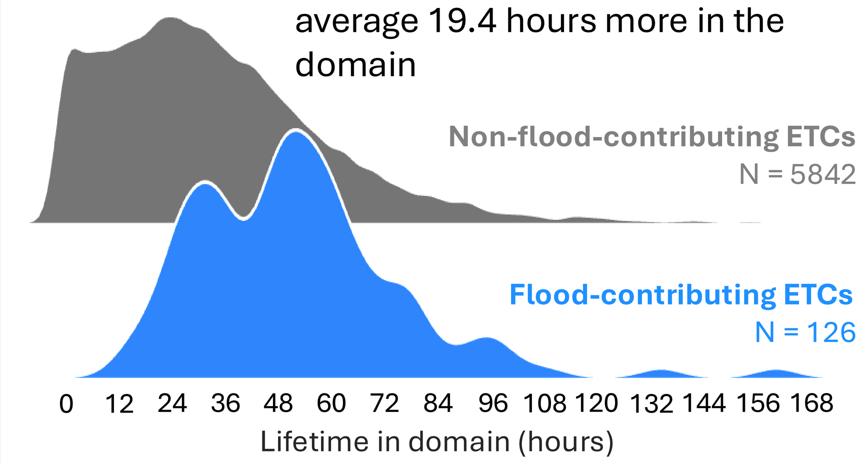

Figure 7: Distribution of lifetime in domain, by type of storms (flood-contributing or not)

- Average time spent in the domain is naturally lower for clusters *Western Canada & Pacific Ocean* and *Quebec & Maritimes*

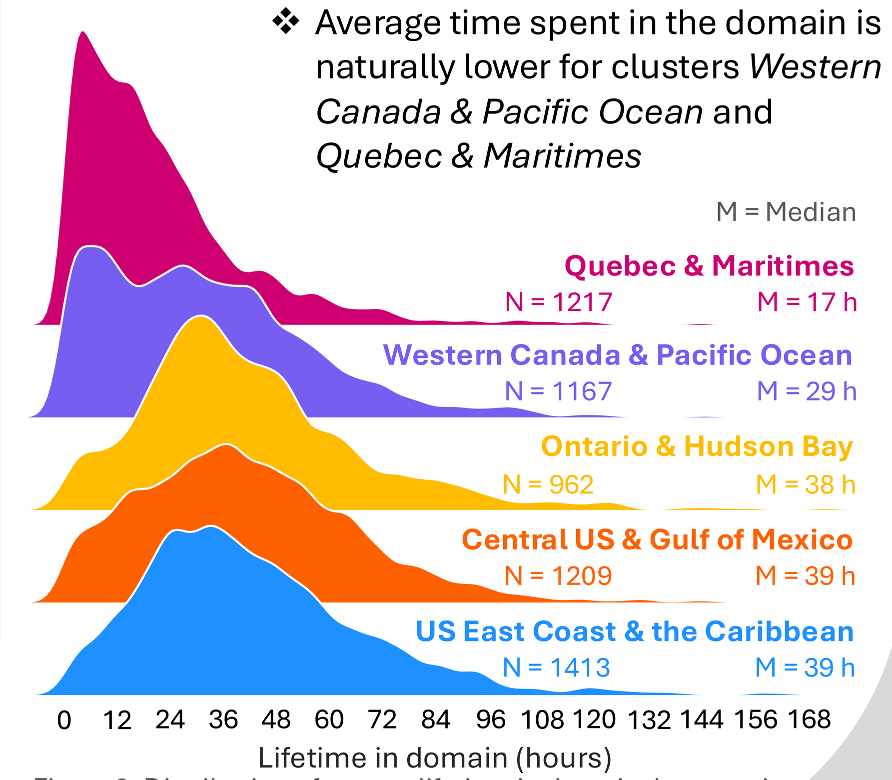

Figure 8: Distribution of storms lifetime in domain, by genesis location

4 Discussion & Conclusions

DISCUSSION

- Financial aid claims data skewed towards higher population density
- Added vulnerability to flooding in the spring due to snowmelt
- Heavy contribution of Colorado lows and Hatteras low in flooding/extreme events in Eastern North America agrees with other studies in Eastern watersheds (2, 10, 11)
- Longer lifetime in the domain is expected for ETCs forming outside the domain

MAIN FINDINGS

Between 1991 to 2020 in Québec, Canada:
- Most flooding happened in the spring
- ETCs were heavily involved in flooding, and favored cyclogenesis in *Center US & the Gulf of Mexico* and *US East Coast & the Caribbean*
- Flood-contributing ETCs spent more time in the domain
- Atmospheric rivers were involved in flooding most of the time

This presentation participates in OSPP

Sharing is encouraged

Outstanding Student & PhD candidate Presentation contest

CONTACT & LINK TO ABSTRACT
clarence.gagnon.1@ulaval.ca
linkedin.com/in/clarence-gagnon-03618717a
Find me on LinkedIn!

REFERENCES

1. Bureau d'assurance du Canada. (2024, September 13th). Événement météorologique le plus couteux de l'histoire du Québec: les inondations d'août causent près de 2,5 milliards de dollars de dommages assurés. *Bureau d'assurance du Canada (BAC)*. https://fr.ibc.ca/news-insights/news/the-costliest-severe-weather-event-in-quebec-s-history-august-flooding-caused-nearly-2-5-billion-in-insured-damage
2. Kunkel, K. E., et al. (2013). Monitoring and understanding changes in extreme storms: State of knowledge. Bull. Amer. Meteor. Soc., 94, 499–514, doi:10.1175/BAMS-D-11-00262.1.
3. Teufel, B., Sushama, L., Huziy, O., Diro, G. T., Jeong, D. I., Winger, K., Garnaud, C., De Elia, R., Zwiers, F. W., Matthews, H. D., & Nguyen, V.-T.-V. (2019). Investigation of the mechanisms leading to the 2017 Montreal flood. *Climate Dynamics*, *52*(7–8), 4193–4206. https://doi.org/10.1007/s00382-018-4375-0
4. Roy, N., Hamon, R., & Anctil, F. (2024). *Base de données d'évènements d'inondation survenus au Québec entre 1990 et 2023 (EVE)*. [Projet REX-PHY, Université Laval].
5. Lachance-Cloutier, S., Turcotte, R., & Cyr, J.-F. (2017). Combining streamflow observations and hydrologic simulations for the retrospective estimation of daily streamflow for ungauged rivers in southern Quebec (Canada). *Journal of Hydrology*, *550*, 294-306. https://doi.org/10.1016/j.jhydrol.2017.05.011
6. Lehner, B. & Grill, G. (2013). Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrological Processes, 27(15): 2171–2186. https://doi.org/10.1002/hyp.9740
7. Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., & Thépaut, J-N. (2023): ERA5 hourly data from 1991 to 2020. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), DOI: 10.24381/cds.adbb2d47
8. Guan, B. (2023). "[Data] Global Atmospheric River Scale Database", https://doi.org/10.25346/S6/MQRHJE, UCLA Dataverse, V1
9. Chen, T-C., Di Luca, A., & Winger, K. (2022). "North America Extratropical Cyclone (NAEC) Catalogue", https://doi.org/10.5683/SP3/LH8OBV, Borealis, V3
10. Bentley, A. M., Bosart, L. F., & Keyser, D. (2019). A Climatology of Extratropical Cyclones Leading to Extreme Weather Events over Central and Eastern North America. *Monthly Weather Review*, *147*(5), 1471–1490. https://doi.org/10.1175/MWR-D-18-0453.1
11. Smith, J. A., Baeck, M. L., Villarini, G., & Krajewski, W. F. (2010). The Hydrology and Hydrometeorology of Flooding in the Delaware River Basin. *Journal of Hydrometeorology*, *11*(4), 841–859. https://doi.org/10.1175/2010JHM1236.1