INCREASED OCEAN MOISTURE SUPPLIES HEAVY RAINFALL EVENTS IN THE MIDWEST UNITED STATES

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INTRODUCTION

Midwest (MW) United States (US)
- Summertime (June–July–August; JJA) precipitation is highly important for US agriculture and economy
- Great MW Flood of 1993 killed 48 people and cost over $12 billion in damages (Lott 1993)

Great Plains Low-Level Jet (GPLLJ)
- Southerly diurnal jet along the base of the Rocky Mountains (Bonner 1968; Weaver & Nigam 2011)
- Transports moisture from the Gulf of Mexico to the MW preceding pluvial events (Harding and Snyder 2015; Malloy and Kirtman 2020; Muñoz *et al*. 2023)
- Strength is measured using a GPLLJ index calculated via area averaged 850 hPa meridional wind velocity

North Atlantic Subtropical High (NASH)
- Semi-permanent high-pressure system over the North Atlantic Ocean (Davis *et al*. 1997)
- NASH Ridge is where the NASH western flank hugs 86°W
- Studies have found that the NASH Ridge couples with the GPLLJ to regulate moisture to the MW region on interannual time scales (Rodwell & Hoskins 2001; Carr & Ummenhofer 2024)

NASH Western Ridge (WR)
- Intersection of 0 m s^{-1} zonal wind and NASH Ridge
- Northwest extension (southeast recession) of the NASH WR increases (decreases) moisture input into MW US on interannual time scales (Li *et al*. 2012)

Research Question:
What drives MW US precipitation on intraseasonal time scales?

DATA & METHODS

Data:
- Climate Prediction Center (CPC) gauge-based monthly precipitation dataset (Higgens *et al*. 2000) on 0.25º by 0.25º grid
- European Centre for Medium Range Forecasting 5th Generation Reanalysis (ERA5; Hersbach *et al*. 2020) on 0.25º by 0.25º grid

Methods:
- Bayesian Statistical Model
  - Based upon the framework developed by Li and Li (2013)
  - Local climate parameters determine light, moderate, and heavy precipitation intensity categories using the CPC daily accumulated precipitation dataset
- WAM2Layers
  - Eulerian moisture tracking model that estimates moisture sources for a given region (Van der Ent *et al*. 2023)
  - Each day from June to August of 1970 to 2019 is backtracked 12 days to determine moisture sources for the MW US using hourly ERA5 humidity and wind velocity data
- Atmospheric Circulation Analysis
  - Uses ERA5 6-hourly datasets

- ERA5 slightly captures spatial and interannual variations well
- ERA5 is suitable for WAM2Layers

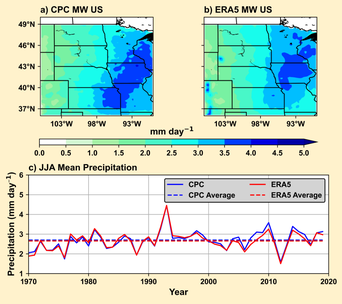


Figure 1. JJA 1970–2019 MW US precipitation climatologies (mm day^{-1}) for CPC (**a**) and ERA5 (**b**) datasets. Yearly JJA mean precipitation amounts (mm day^{-1}) for CPC (blue) and ERA5 (red) datasets.

RESULTS 1: HEAVY PRECIPITATION IS A DOMINATE CONTRIBUTOR TO SEASONAL MEAN PRECIPITATION

- Light: 1.62 mm day^{-1} climatology and 46.93% frequency of occurrence
- Moderate: 3.06 mm day^{-1} climatology and 38.45% frequency of occurrence
- Heavy: 5.12 mm day^{-1} climatology and 14.61% frequency of occurrence
- Precipitation maximum moves towards the northeast of the MW with increasing precipitation intensity

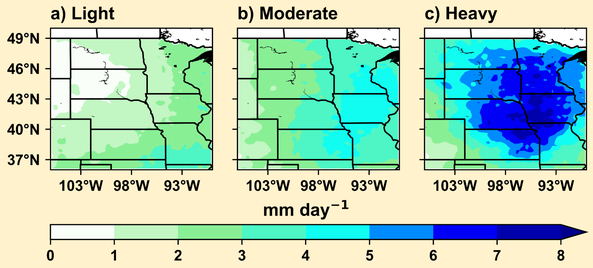


Figure 2. JJA 1970–2019 climatologies of light (**a**), moderate (**b**), and heavy (**c**) precipitation (mm day^{-1}).

- Light events decreased –2 days $decade^{-1}$
- Moderate events increased 1 day $decade^{-1}$
- Heavy events increased 1 day $decade^{-1}$

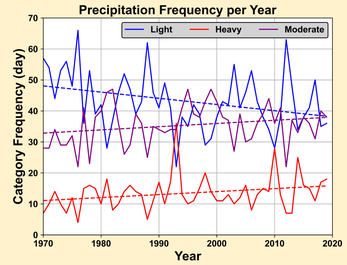


Figure 3. Frequency of precipitation category events per JJA for light (blue), moderate (purple), and heavy (red) precipitation events.

- Despite featuring the lowest frequency of occurrence, heavy precipitation contributes the most to the seasonal mean precipitation

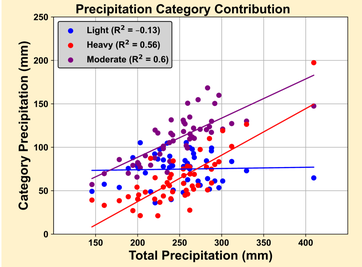


Figure 4. JJA 1970–2019 precipitation contributions (mm JJA^{-1}) for each precipitation category to the mean JJA precipitation (mm JJA^{-1}).

RESULTS 2: INCREASED OCEAN MOISTURE FLUXES YIELDS HEAVIER PRECIPITATION

- Moisture source contributors to MW US:
  - Land: 81.2%
    - Land outside (inside) MW US: 44.5% (36.7%)
  - Ocean: 18.8%
    - Atlantic (Pacific) Ocean: 13.75% (5.05%)

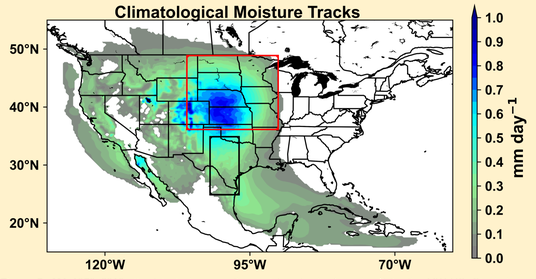


Figure 5. JJA 1970–2019 climatological evaporation moisture tracks (mm day^{-1}) for the MW US. Shaded area indicates the top 90% of moisture contributing grid cells. The red box indicates the precipitation region where the Bayesian statistical model and backwards tracking were applied, and the black box indicates the GPLLJ index boundaries.

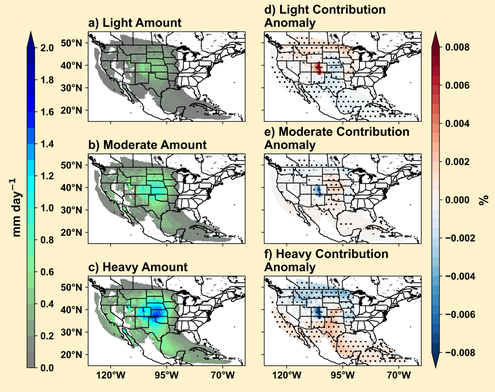


Figure 6. JJA 1970–2019 climatological moisture contribution amounts (mm day^{-1}) for light (**a**), moderate (**b**), and heavy (**c**) precipitation events, and moisture contribution anomalies (%) for light (**d**), moderate (**e**), and heavy (**f**) precipitation events with respect to the climatology. Black stippling indicates anomalies are significant at the 95% level (student t-test).

- As precipitation intensity increases, southern moisture source influence increases
  - Land is more important for light precipitation events
  - Ocean is more important for heavy precipitation events

- Increased moisture is transported to the MW via an intensified GPLLJ

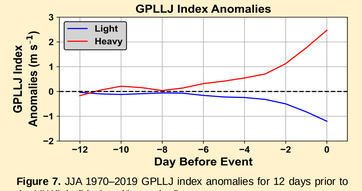


Figure 7. JJA 1970–2019 GPLLJ index anomalies for 12 days prior to the MW light (blue) and heavy (red) events.

CONCLUSIONS

- Heavy precipitation events are increasing, which could cause large ecological and economical damage given that they contribute the most to the seasonal mean total precipitation
- Atlantic Ocean moisture flux amount is determined by NASH WR positioning on intraseasonal time scales
  - Increased Atlantic Ocean moisture flux into the MW US results in heavy precipitation events
- Pacific Ocean moisture contributes to heavy events and modulates NASH WR positioning through Rossby wave trains of anomalous pressure systems
  - Anomalous low-pressure over eastern US results in southeast recession of NASH WR and light precipitation events
  - Anomalous high-pressure over eastern US results in northwest extension of NASH WR and heavy precipitation events

RESULTS 3: PACIFIC OCEAN MODULATES NASH WR POSITIONING THROUGH ROSSBY WAVE TRAINS

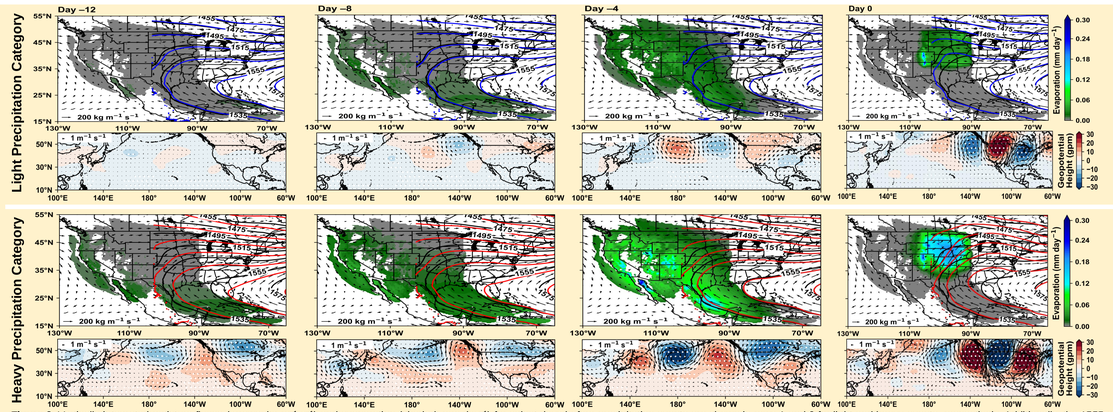


Figure 8. Vertically integrated moisture fluxes (arrows; kg m^{-1} s^{-1}) and evaporation (shaded; mm day^{-1}) for select days before precipitation events are shown in rows 1 and 3 for light and heavy events, respectively. Additionally, the 1555 gpm 850 hPa geopotential height is shown for climatology (black), light (blue), and heavy (red) and is indicative of the NASH WR. Rows 2 and 4 show anomalous 500 hPa wind (arrows; m s^{-1}) and anomalous 500 hPa geopotential height (shaded; gpm). Stippling indicates statistical significance at the 95% level (student t-test).

- Rossby wave trains of anomalous pressure systems ends with anomalous high-pressure system over MW US
- Coincides with southeast recession of NASH WR
  - Redirects Atlantic Ocean moisture fluxes along NASH WR away from the MW US
  - Results in light precipitation events

- Rossby wave train of anomalous pressure systems ends with anomalous low-pressure system over MW US
- Coincides with northwest expansion of NASH WR
  - Allows increased Atlantic Ocean moisture fluxes to be directed along NASH WR into the GPLLJ
  - Stronger GPLLJ increases moisture transport to MW US
  - Results in heavy precipitation events

REFERENCES

ACKNOWLEDGEMENTS

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