NORTH CENTRAL
Climate Adaptation
Science Center

James Watkins/flickr

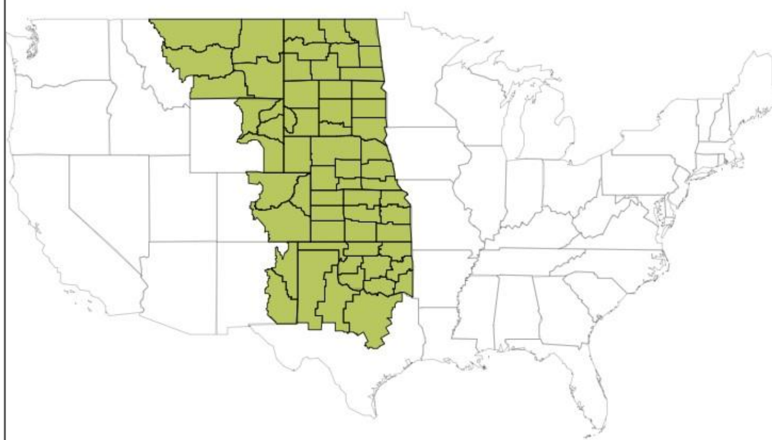
Examination of large-scale drivers of water availability in the Northern Great Plains

US Great Plains Region

The US Great Plains, stretching over 1,300 miles from the US-Canada border to Texas, constitutes a **crucial** and **ecologically diverse** region in the heart of North America. Known for its agricultural productivity and vital ecosystems, this vast expanse plays a **significant role** in supporting human livelihoods, wildlife, and natural resources.

Water availability, largely modulated by seasonal precipitation, plays **one of the most critical roles** for ecosystems and agriculture.

US Great Plains Region



source: NOAA

Sathish J/flickr

Motivation

The Great Plains region experiences **high variability** in precipitation which strongly affects water availability. However, existing research and applications are **limited** in their ability to robustly predict precipitation on seasonal and longer timescales in this region.

In the face of **increasing water demands**, growing environmental challenges, and the uncertainties associated with **future climate change,** advancement in our understanding of **large scale atmospheric-ocean processes** and **teleconnections** that drive **regional moisture transport** is therefore critical to informing preparedness and adaptation in different sectors in this region.

Review of Current Knowledge

- Pluvial (high precipitation) years in the Great Plains (GP) are driven by **synoptic-scale (1000s km) processes**, with **distinct** patterns for the **southern and northern** regions. Pluvials in the southern Great Plains (SGP) are associated with negative height anomalies over the southwestern US, while those in the northern Great Plains (NGP) with negative height anomalies in the northwestern US.
- GP **precipitation anomalies** are influenced by the **phase alignment** of the Pacific decadal oscillation (**PDO**) and El Niño–Southern Oscillation (**ENSO**). **Wet periods** are enhanced when PDO and ENSO are **both** in their **warm phases**, and vice versa for their cold phases while having **less connection** when in **out-of-phase**. These connections **vary seasonally** with spring being the strongest, autumn being the weakest, and summer and winter falling in-between.
- **The Pacific jet stream** serves as an important **conduit** for the extratropical cyclones impacting the GP precipitation; however in **summer**, moisture convergence facilitated by the Great Plains Low Level Jet (**GPLLJ**) transports moisture into the central United States, and serves as a key driver for precipitation.
- GPLLJ frequency and intensity over the summer are shown to be influenced by ENSO and the Pacific–North American teleconnection pattern, Pacific and Atlantic SST anomalies, the North Atlantic Oscillation, and the circumglobal teleconnections.
- ENSO significantly influences the path of the Pacific jet stream during the winter. During La Niña, the Pacific jet stream tends to meander high into North Pacific whereas during El Niño it tends to meander low towards southern-tier of US.

Data

Monthly precipitation (1951-2019) - NOAA Monthly U.S. Climate Gridded Dataset (NClimGrid)

Monthly Sea Surface Temperature (SST) (1951-2019) - Kaplan Extended SST V2

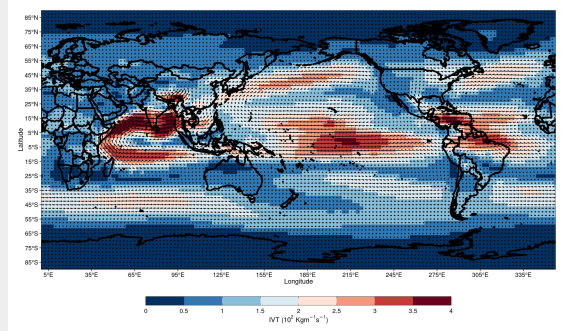
For the computation of Integrated Vapor Transport (IVT) (1951-2019): Monthly data of Specific humidity, horizontal winds (zonal and meridional) - NCEP-NCAR Reanalysis

Tools to Examine Large-Scale Drivers of Precipitation Variability

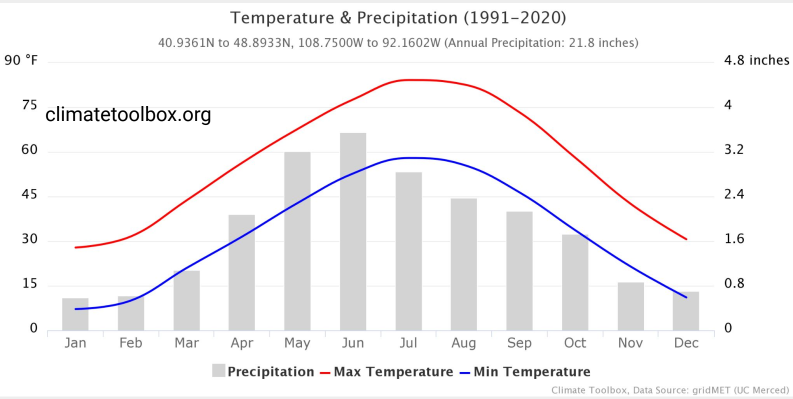
We have developed R-Shiny applications to provide a user-friendly platform for analyzing precipitation and moisture transport patterns, with a focus on spatially-contiguous precipitation clusters and their relationship with large-scale drivers such as moisture transport, and SST.

1. Clustering CONUS Gridded Precipitation App - Clustering of precipitation and teleconnections
2. IVT World App - Global moisture transport

These applications can be used to study precipitation and **teleconnections**, moisture transport patterns in any region of the contiguous US and for any period of the historical record by adjusting the geographic boundaries and time period of analysis, offering flexibility for a **wide-range of climate analyses.**

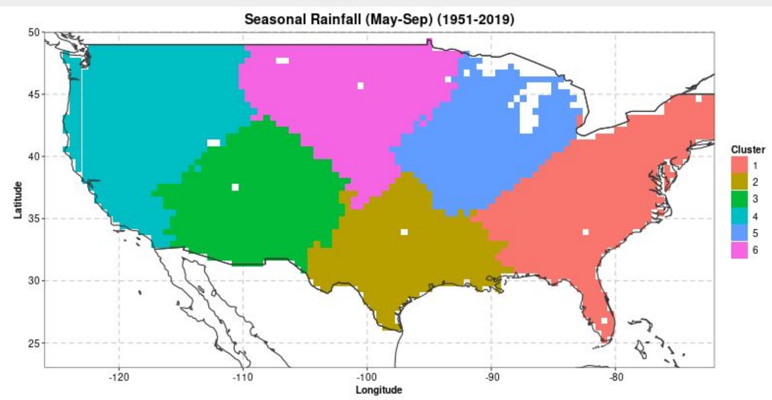


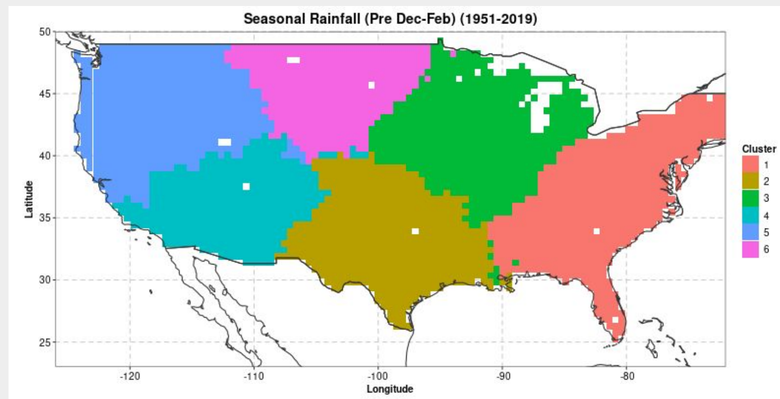
Methodology - Clustering



Precipitation regime in the Northern Great Plains (**NGP**), showing summer months (June to August) tending to be the wettest period. Conversely, winter months (December to February) in the region are typically drier.

- In our study, we identify May-Sep as the warm season and Dec-Feb as the cold season.





- Modified Partitioning around medoids (PAM) clustering technique, developed by - Bracken et al. 2015, and applied on seasonal precipitation over CONUS for cold and warm seasons.
- Identified six spatially coherent and homogeneous regions which are similar for both seasons.
- **Great Plains were captured in two clusters i.e., NGP, SGP for both seasons as shown in figures above.**

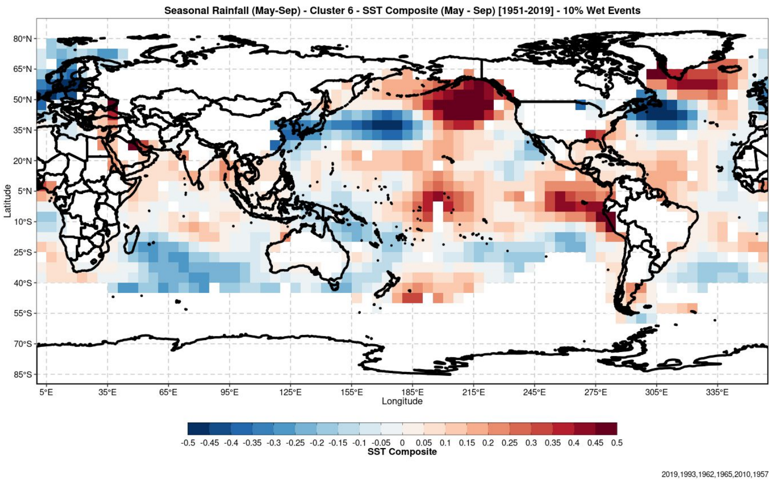
Analysis

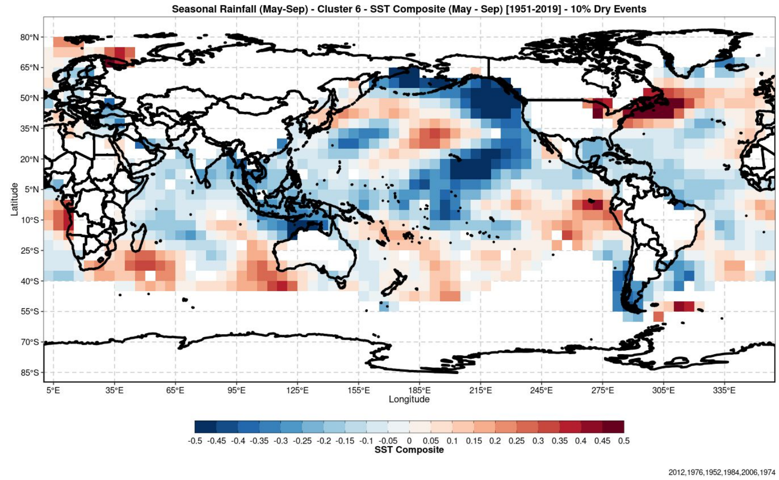
IVT is computed as proposed by Newell et al. (1992), where it has meridional and zonal components and are shown as vector fields that show the moisture transport direction.

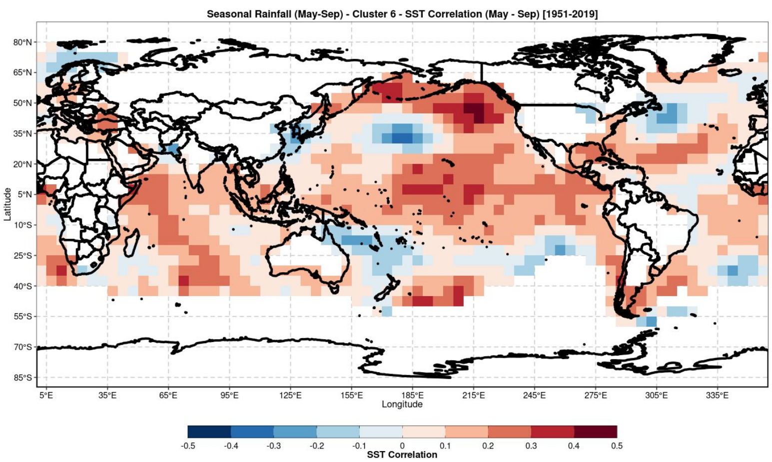
The extreme wet and dry years are obtained as the years as the top and bottom 10% of years from the cluster average precipitation time series, respectively.

Composite maps of SST and IVT for wet and dry years are obtained by averaging the anomaly detrended SST and IVT at each grid point over the extracted set of years in the wet and dry categories, separately for warm and cold seasons. Similarly, **correlation maps** of detrended SST with respective cluster average precipitation are generated.

NGP Case Study: Drivers Influencing Warm Season (May - Sep) Precipitation

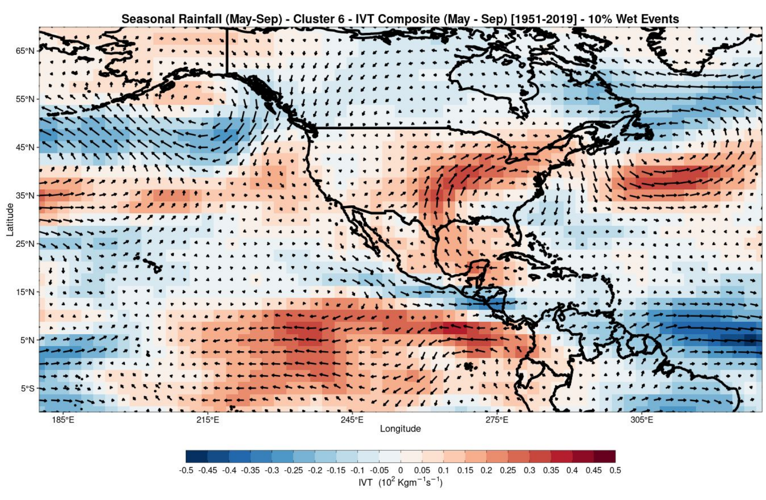


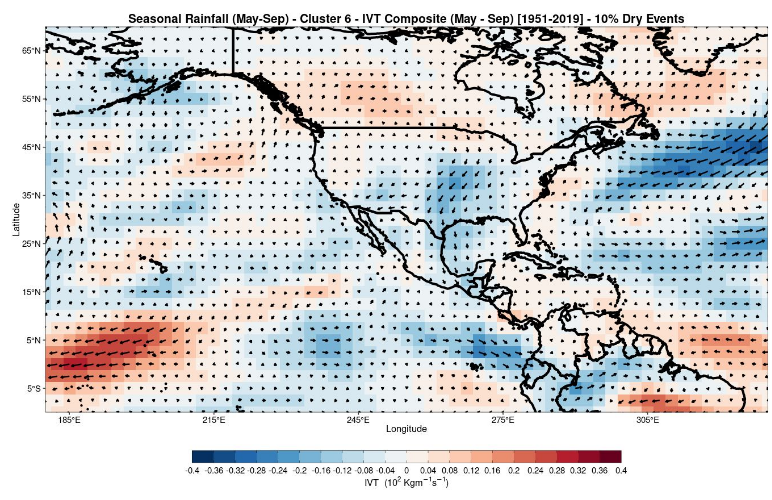




Above plots show anomalies (changes) in warm season detrended SST composites (°C) for top 10% wet (top left) and dry (top right) years in NGP. The plot on the left shows the correlation of detrended SSTs with the average warm season precipitation in the NGP cluster.

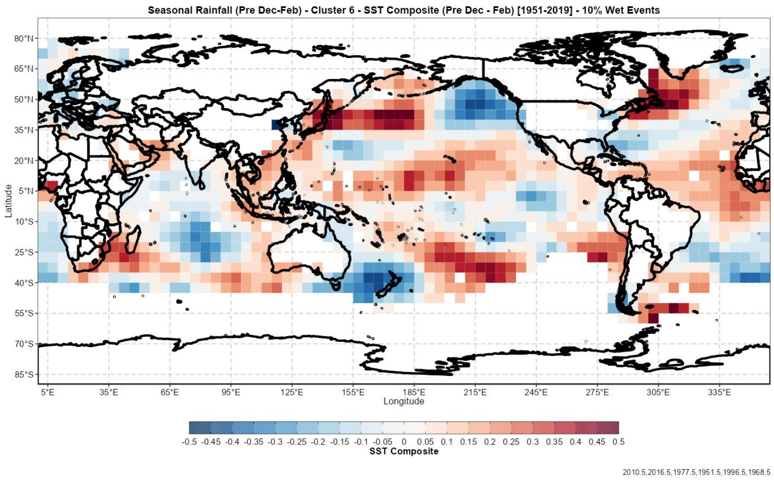
The NGP cluster shows **strong correlation** with SSTs in the tropical Pacific (ENSO) and mid-latitude Pacific region (PDO). The composites show that for wet years, warm ENSO (El Niño) and warm PDO conditions are present, whereas for the dry years, cold ENSO (La Niña) and cold PDO conditions can be seen, suggesting a **potential for predictability** of warm season precipitation based on these teleconnections.

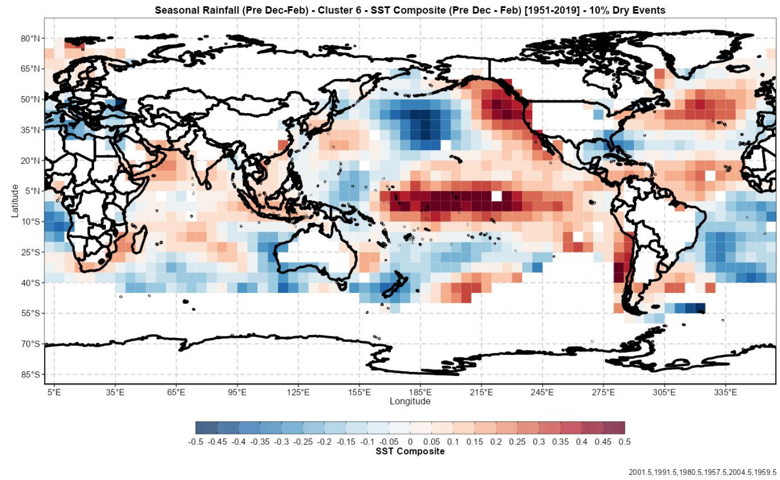


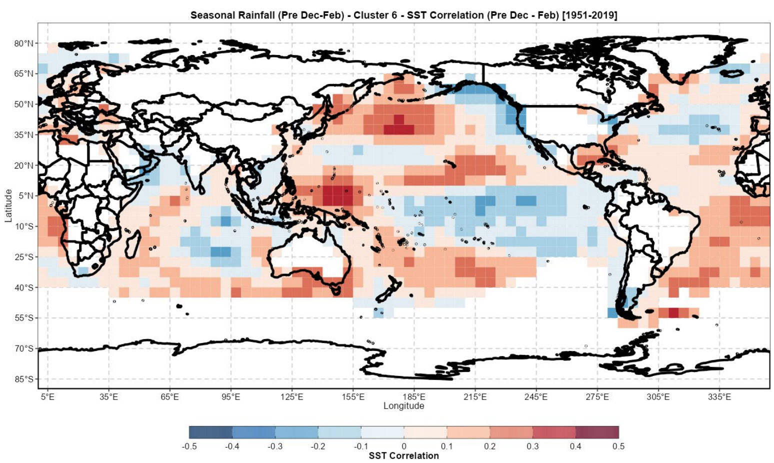


Above plots show anomalies (changes) in warm season IVT transport (10^2 Kg m^{-1} s^{-1}) for top 10% wet (bottom left) and dry (bottom right) years. Regions in **red** indicate above-average moisture while those in **blue** indicate below-average moisture. For wet years, there is increased moisture transport from Gulf expectedly facilitated by the Great Plains Low Level Jet (GPLLJ). This GPLLJ, which has often been associated with severe weather events, is well documented in observational studies. For dry years, the anomalous moisture transport is largely opposite of the wet year composite; the anomalous transport is from the land mass to Gulf. From the composite maps of anomalous IVT we can infer that **strong convergence of moisture from GPLLJ is crucial for warm season wet years.** Weaker or lack of convergence results in dry years.

NGP Case Study: Drivers Influencing Cold Season (Dec - Feb) Precipitation

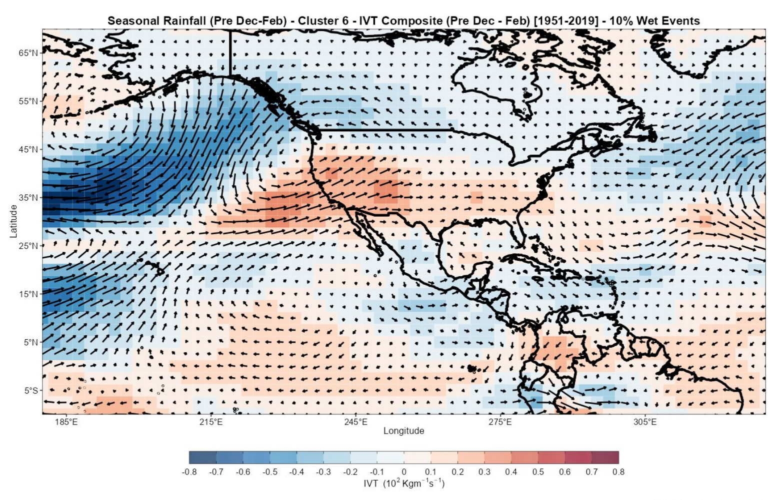


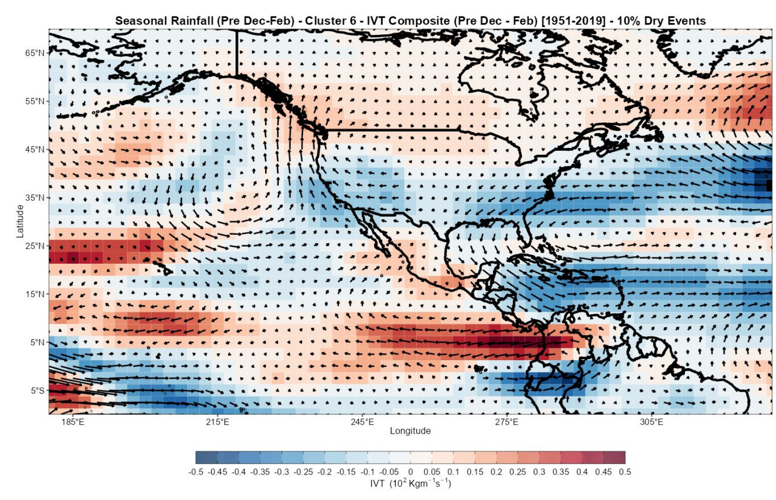




Above plots show anomalies (changes) in cold season detrended SST composites (ºC) for top 10% wet (top left) and dry (top right) years in NGP. The plot on the side shows the correlation of detrended SSTs with the average warm season precipitation in the NGP cluster.

Unlike in the warm season, the NGP cluster does not show a strong correlation with ENSO in the cold season. However, there is **some signal** in the central mid-latitude Pacific region. The composites show that, for dry years, we observe warmer tropical Pacific compared to the wet years. In the mid-latitudes, we see a contrast in patterns between wet and dry years, where eastern-warmer and western-colder pattern is seen in the dry years and vice versa in the wet years.





Above plots show anomalies (changes) in cold season IVT transport (10^2 Kg m^{-1} s^{-1}) for top 10% wet (bottom left) and dry (bottom right) years. Regions in red indicate above-average moisture while those in blue indicate below-average moisture. For wet years, the moisture transport is greater from the Pacific Ocean driven by the Pacific winter jet stream. For dry years, the anomalous moisture transport is largely opposite of the wet year composite; the anomalous transport is from the land mass to Pacific. From the composite maps of anomalous IVT we can infer that **strong convergence of moisture from winter jet stream is crucial for above average cold season precipitation.** Weaker or lack of convergence results in dry years.

Next Steps

- **Improved Mechanistic Understanding of Processes:** Examine space-time variability of hydroclimate in the region and their connections to regional and global ocean conditions and atmospheric circulation patterns. Analyze the sequence of climate events to understand how they manifest and propagate.

- **Develop a Predictive Modeling Framework:** Develop a robust modeling framework that captures important relationships between the large scale climate drivers and regional scale moisture transport to improve predictions of seasonal (and/or even multi-year) precipitation in the GP region.

- **Explore Extremes of Water Availability:** Examine extreme events, like droughts and floods, to understand their relationship with large-scale drivers.

- **Assess Climate Change Impacts:** Evaluate current CMIP models' ability to simulate observed climatic patterns and diagnose the causes (i.e., nature of large scale drivers) for projected wetter or drier future.

- **Scenarios for the Future:** Develop more robust scenarios of future water availability to inform adaptation strategies and policy decisions.

Contacts:

Samba Siva Sai Prasad Thota, PhD Student, CU Boulder, NC CASC Graduate Research Assistant, samba.thota@colorado.edu

Dr. Imtiaz Rangwala, Research Scientist, CU Boulder & NC CASC, imtiaz.rangwala@colorado.edu

Prof. Balaji Rajagopalan, Professor & Associate Chair, CEAE Department, CU Boulder, balajir@colorado.edu

Thota S.S.S.P., Rangwala I., Rajagopalan B. (2024). Rapid Climate Assessment: Examination of large-scale drivers of water availability in the Northern Great Plains. North Central Climate Adaptation Science Center, University of Colorado Boulder, Boulder, CO.

For more information about the NC CASC's Rapid Climate Assessment Program (RCAP), visit https://nccasc.colorado.edu/rcap-projects or use the QR code to the right.

Selected Resources

Flanagan, P. X., Basara, J. B., Furtado, J. C., & Xiao, X. (2018). Primary Atmospheric Drivers of Pluvial Years in the United States Great Plains. Journal of Hydrometeorology, 19(4), 643–658. 1

Hu, Z.-Z., & Huang, B. (2009). Interferential Impact of ENSO and PDO on Dry and Wet Conditions in the U.S. Great Plains. Journal of Climate, 22(22), 6047–6065.

Mo, K. C., Paegle, J. N., & Higgins, R. W. (1997). Atmospheric Processes Associated with Summer Floods and Droughts in the Central United States. Journal of Climate, 10(12), 3028–3046.

Agrawal, S., Ferguson, C. R., Bosart, L., & Burrows, D. A. (2021). Teleconnections Governing the Interannual Variability of Great Plains Low-Level Jets in May. Journal of Climate, 34(12), 4785–4802.

Harding, K. J., & Snyder, P. K. (2015). The Relationship between the Pacific–North American Teleconnection Pattern, the Great Plains Low-Level Jet, and North Central U.S. Heavy Rainfall Events. Journal of Climate, 28(17), 6729–6742.

Higgins, R. W., Yao, Y., Yarosh, E. S., Janowiak, J. E., & Mo, K. C. (1997). Influence of the Great Plains Low-Level Jet on Summertime Precipitation and Moisture Transport over the Central United States. Journal of Climate, 10(3), 481–507.

Bracken, C., Rajagopalan, B., Alexander, M., & Gangopadhyay, S. (2015). Spatial variability of seasonal extreme precipitation in the western United States. Journal of Geophysical Research: Atmospheres, 120(10), 4522–4533.