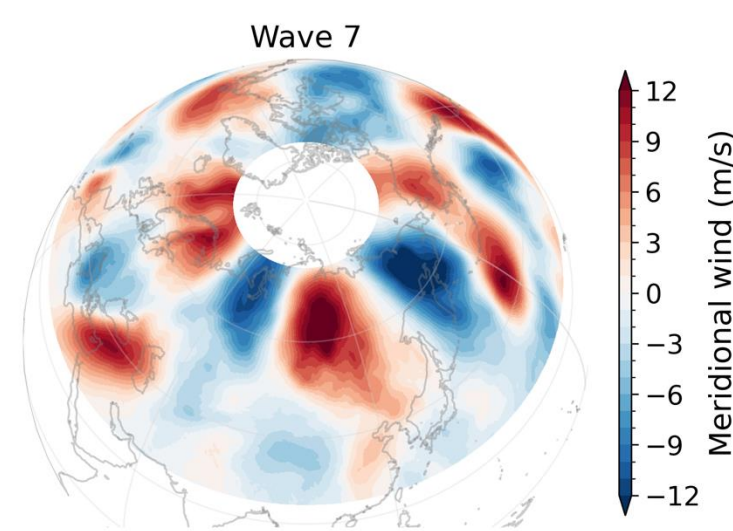


1. Quasi-resonant planetary wave amplification (QRA)

- The jet stream has played a significant role in recent devastating summer weather events. The jet stream, a narrow band of strong wind, runs from the west to east around the Northern Hemisphere and controls the daily weather. The band's behavior has been studied and various researchers have noted that during extreme weather events, the jet stream can take on big bends. These bends slow down or stay in place and the larger these bends, the more extreme weather we experience. These conditions permit heavy rain or high temperatures for a long period of time. **Under the right conditions, as the waves become stagnant, the amplitude of the waves can grow, creating a quasi-resonant amplification, or QRA. QRAs are more common in the summer and since climate change can impact the shape of the jet stream, it also impacts QRA events and the frequency of extreme weather.** The hemispheric-scale feature of the QRA, tends to synchronize extreme weather events in different regions across the Northern Hemisphere¹.
- Summer 2022 QRA event: June 27 – August 1, 2022 (lasted 36 days).
- Summer 2018 QRA events:
 - June 14 – June 19 (lasted 6 days)
 - June 19 – June 23 (lasted 5 days)
 - June 26 – July 11 (lasted 16 days)
 - July 27 – August 4 (lasted 9 days)



2. Extreme Weather Events in Pakistan and China

- China:
- The average summer temperature is 18-28 °C (65-82 °F).
 - The average summer rainfall (total) is 305 mm (12 in)².
 - In August 2022, China experienced the **longest lasting heatwave** since 1961. Record-breaking temperatures hit southern China and these extreme conditions lasted over **2 months**³.
- Pakistan:
- Summer 2022 saw record-breaking rainfall (**nation-wide daily average precipitation was 3.95 mm (0.16 in)**), exceeding the previous 42-year average of 1.03 mm per day (0.041 in)⁴.
 - Rainfall during the 2022 monsoon season (from June 30 to the third week of September) was +175% above average, across the whole country⁵.

3. Research Questions

- Why have floods in Pakistan been so abnormal in recent years, especially in 2022?
- Was there a correlation between the simultaneous occurrence of the heatwave in China and the flooding in Pakistan in the summer of 2022?

4. Broader Impacts and Future Research Inquiries

Understanding the relationship between floods and planetary wave resonance can help us prepare better for extreme weather events and build resilient communities.

Pakistan:

- Economic impacts of Pakistan 2022 floods: \$14.9 billion in damages and \$15.2 billion in economic losses.
- Estimates for rehabilitation and resilient reconstruction are at least \$16.3 billion.
- Humanitarian impacts of Pakistan 2022 floods:
 - 33 million people were affected.
 - 9 million people were at risk of falling into poverty (in addition to the 33 million people).
 - Food insecurity experienced by 10.5 million people from April to October 2023
 - About 8 million people were displaced⁶.

China:

- 360 million people experienced extreme temperatures above 40° C.
- Up to 51.2 billion yuan (approximately \$7.1 billion USD) in economic losses due to the unprecedented heatwave.
- Around 1.5 million km² experienced moderate or severe drought³.

5. Methods and Data Collection

- Downloaded the daily temperature and precipitation data from Pakistan and China from June 1 to August 31 for the years of 2018 and 2022.
- Selected the summers of 2018 and 2022 because:
 - Pakistan experienced record-breaking and devastating floods.
 - China experienced heatwaves simultaneously as Pakistan's floods and extreme precipitation.
- Strategy for selecting cities in each country:
 - Selected cities in the south of Pakistan with sufficient weather data since there was abnormal flooding in the south and capital city (since it often has more information).
 - It usually rains a lot in the North but in 2022, it rained a lot in the south and caused devastating flooding.
 - Selected cities to represent the West, East and South of China
- Used Python to conduct a statistical analysis (mean, maximum, minimum, standard deviation) of the daily precipitation and temperature during June, July, and compared with historical averages.
 - Used these figures to create graphs of each city.
- Determined whether the maximum daily precipitation of each city occurred during QRA events.

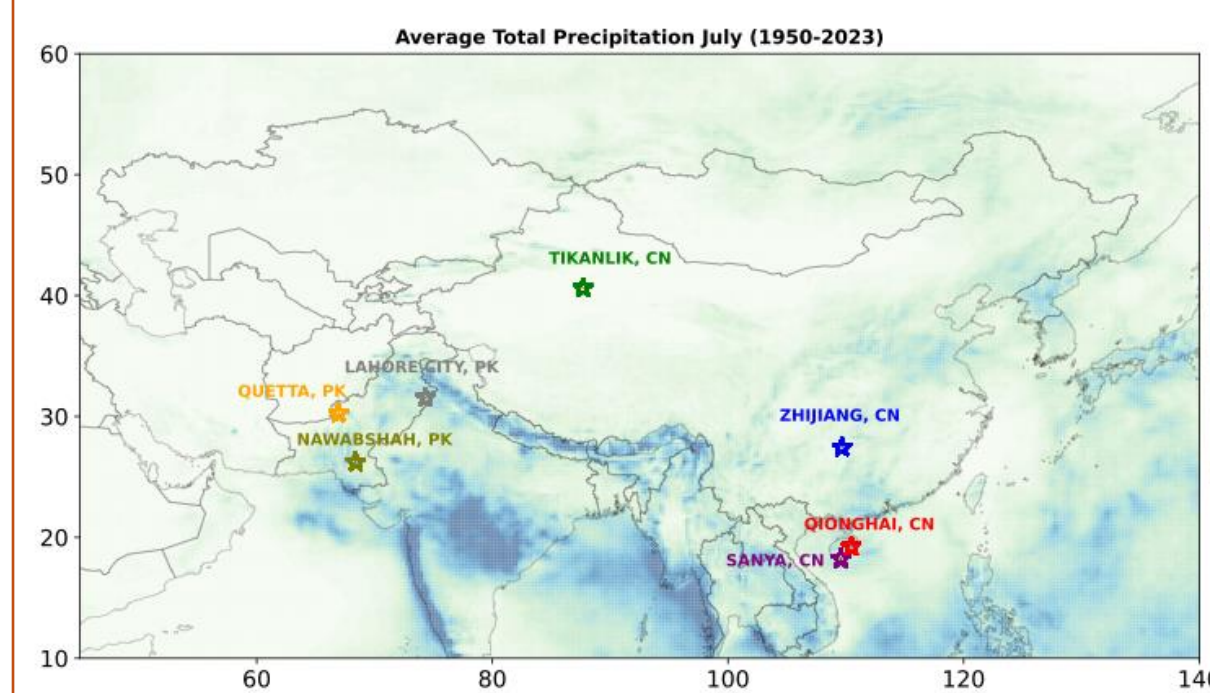


Figure 1. Calculated the mean precipitation over all years

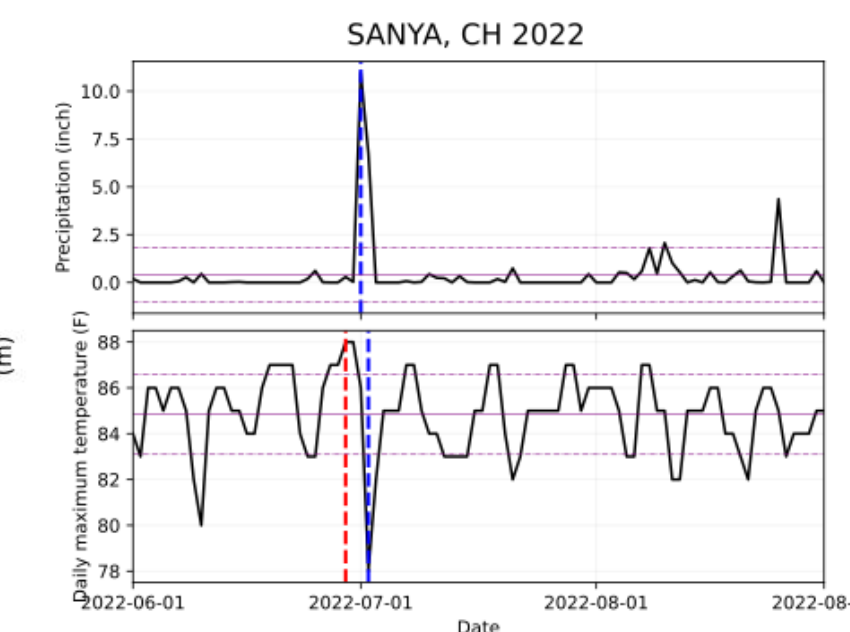


Figure 2. Example of a graph: red line indicates maximum temperature, blue line indicates minimum temperature and maximum precipitation.

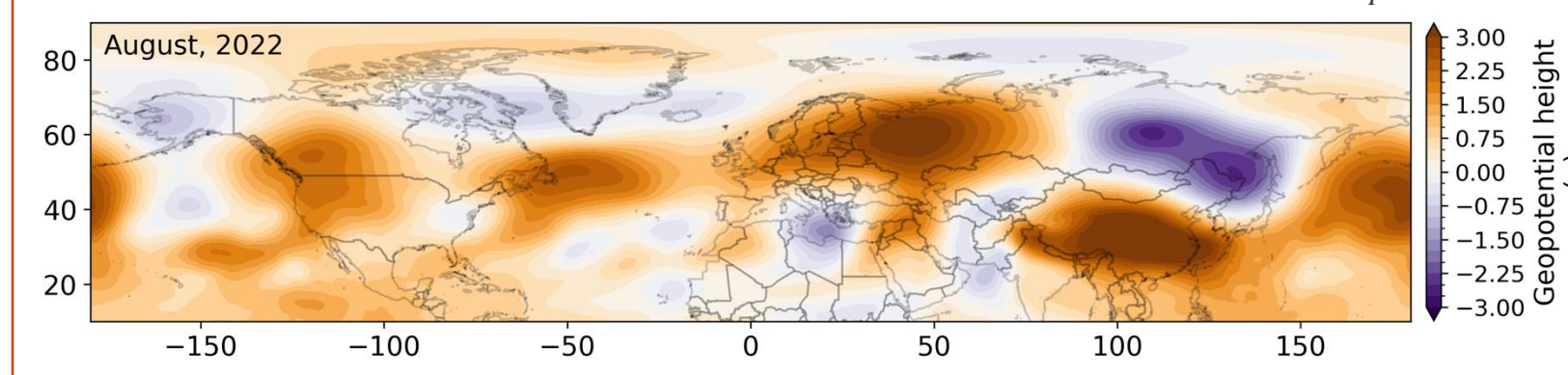
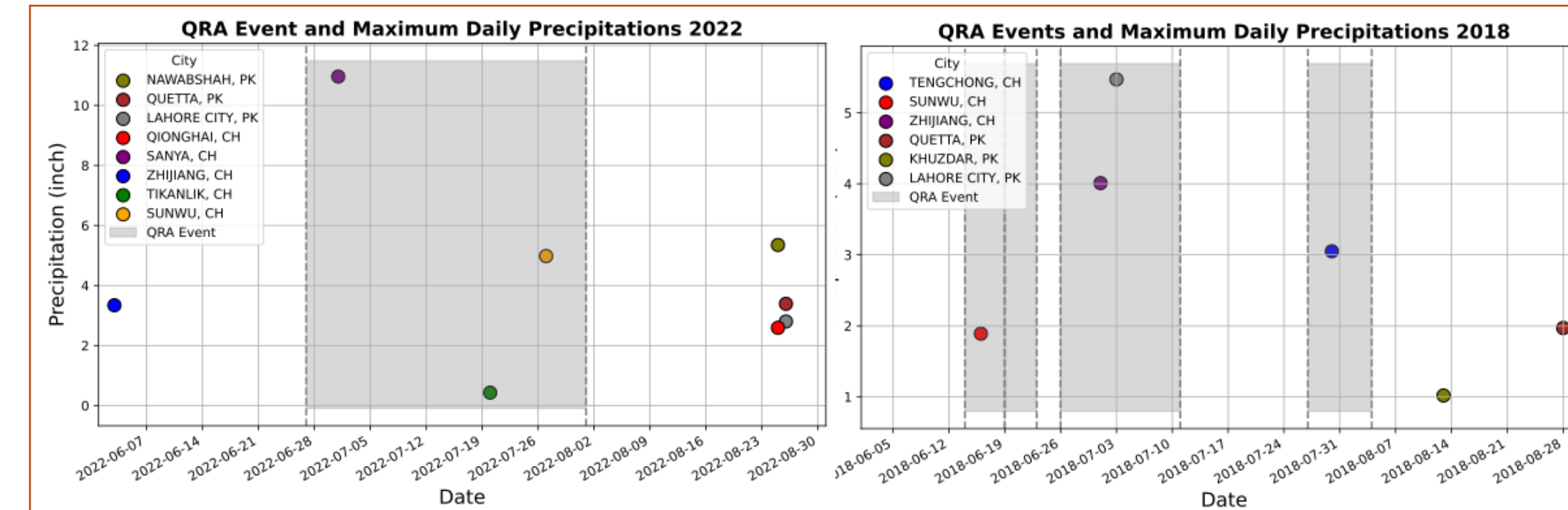


Figure 3. Geopotential height during August 2022.

6. Results & Conclusion



Pakistan Summer 2022:

- 0/3 max. precipitation days & 1/3 max. temperature days overlapped with QRA events
 - 1 recorded on August 25 while 2 were recorded on August 26 (however)

China Summer 2022:

- 3/5 max. precipitation days & 3/5 1/3 max. temperature days overlapped with QRA events

Pakistan Summer 2018:

- 1/3 max. precipitation days & 0/3 1/3 max. temperature days overlapped with QRA events
 - However, Khuzdar and Quetta recorded their daily maximum temperature on the same day and all 3 preceded a QRA event (for about 10 days)

China Summer 2018:

- 3/3 maximum precipitation days overlapped with QRA events (insufficient daily temperature data)

The role of QRA events in heavy rainfall, resulting in flooding, hasn't been proven. **The goal was to delve deeper into the subject because it remains relatively understudied.** While this project conducted statistical analysis of daily rainfall in Pakistan during the summers of 2022 and 2018, **further research is required to accurately explain the abnormal floods in Pakistan in recent years.** The data collected in this project is insufficient to explain the unprecedented floods and their possible linkage to QRA events. **Only one of the cities analyzed in Pakistan experienced its heaviest daily rainfall during a QRA event, in 2018,** however, this doesn't disprove the theory.

Out of the cities analyzed, none of the daily maximum temperatures recorded in China coincided with a daily maximum precipitation in Pakistan to support the correlation between these to simultaneous extreme weather events. Nonetheless, this doesn't discredit the possibility of a correlation among these events and a linkage to the planetary wave resonance. **A positive geopotential height (high pressure system) can be seen over China, at the same time of the heatwave, while there is a negative geopotential height (low pressure system) over the south of Pakistan where most of the flooding occurred in 2022.** Additionally, all three Pakistani cities analyzed recorded their daily maximum precipitation in August of 2022. A QRA event did not occur in August of 2022, but it's important to note the position of the planetary waves in figure 3 to support the theory that China's 2022 heatwave and the 2022 floods in Pakistan are correlated.

The time frame of this project limited the number of cities included in this analysis. Thus, future research that analyzes more cities is important to reach a final conclusion and accurate answers to these research questions.

- Limitations of weather station data: some cities have a lot of missing data, proving it difficult to accurately compare data from different years.
 - E.g. in 2022, the missing data for **Lahore City, PK**, is 12.50% and in 2018 it is missing 1.09% of the data.
 - E.g. in 2018, the missing data for **Zhijiang, CH**, is 48.91% for precipitation and **Quetta, PK**, is missing 6.67% .

7. Acknowledgments and References

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- Scan QR code for citations:
- For more climate research: <https://web.sas.upenn.edu/mannresearchgroup/people/>

