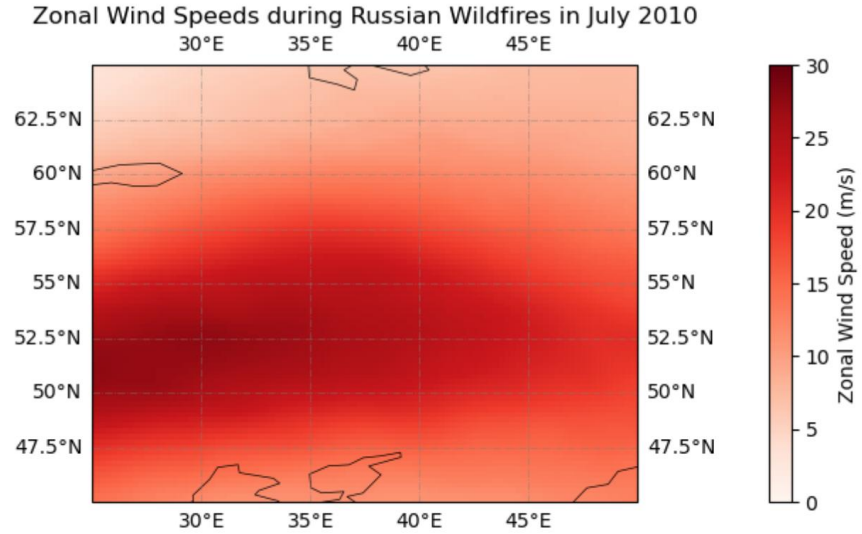
Summer Research

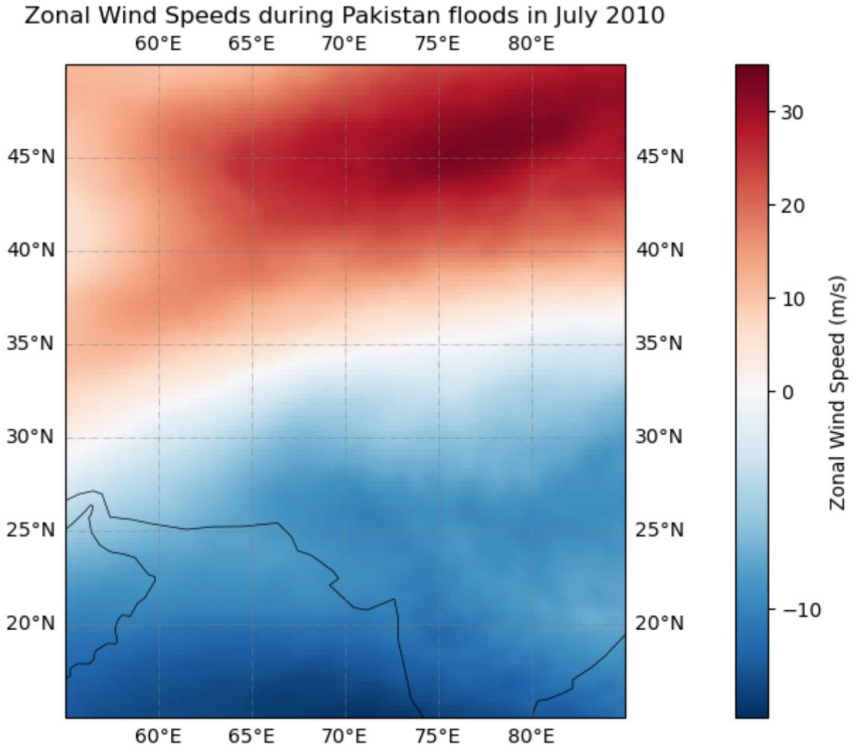
Refresher on Rossby Waves

- Rossby Waves
  - Large-scale and slow-moving
  - Balance the atmosphere
- Quasi-Stationary Wave (QSW) – same location for a prolonged period
- Quasi-Resonant Amplification (QRA) – phenomenon where Rossby waves are “trapped” and become amplified due to a resonance effect → increase in wave strength and persistence

Background research

- Zonal wind speeds during extreme events
  - 2010 Russian Wildfires
  - 2010 Pakistan Floods
- Global zonal wind speeds, 1940-2014 according to:
  - ERA5 reanalysis data
  - CMIP6 historical run
- Helped me get familiar with xarray, numpy, matplotlib, cartopy





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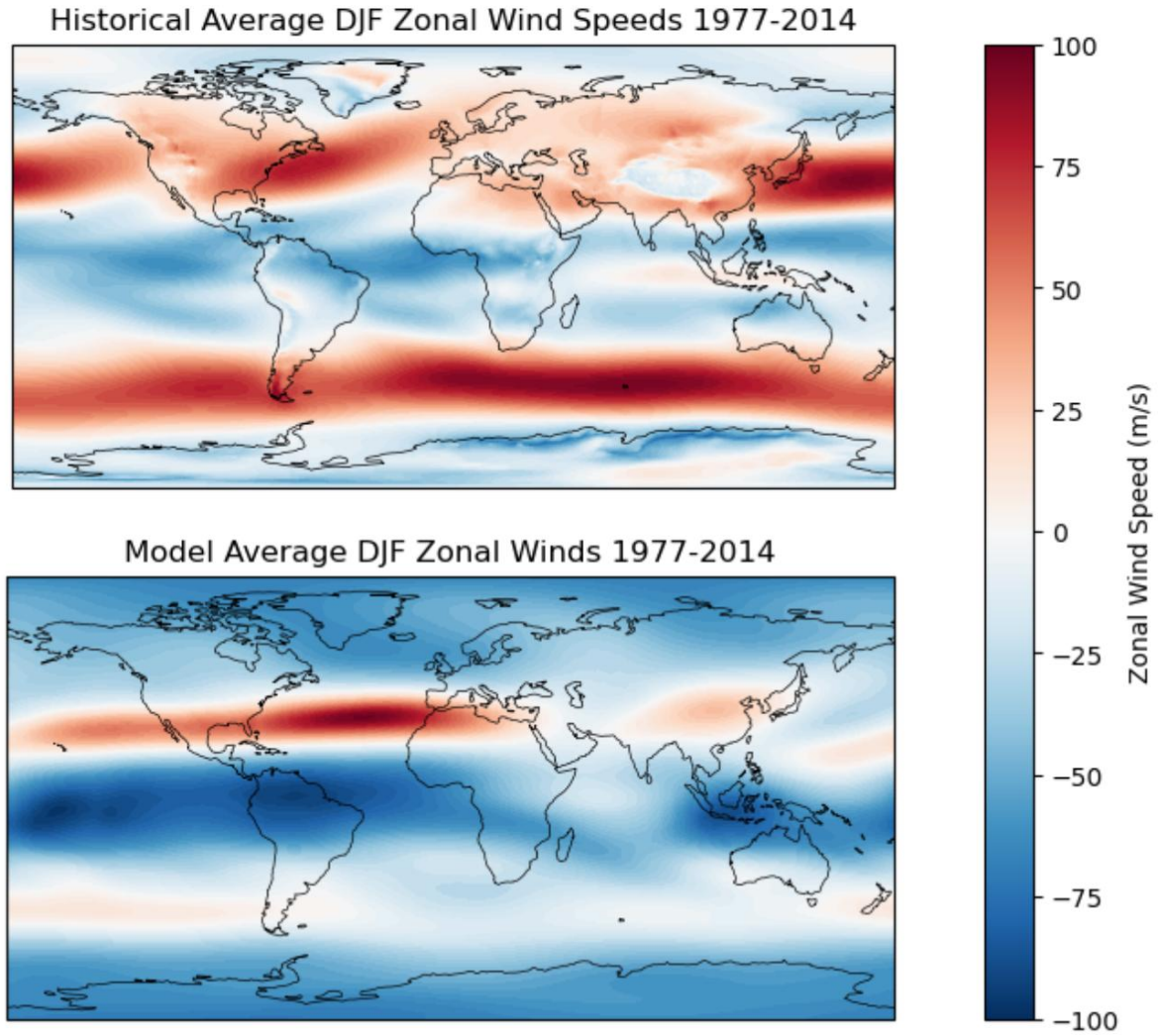
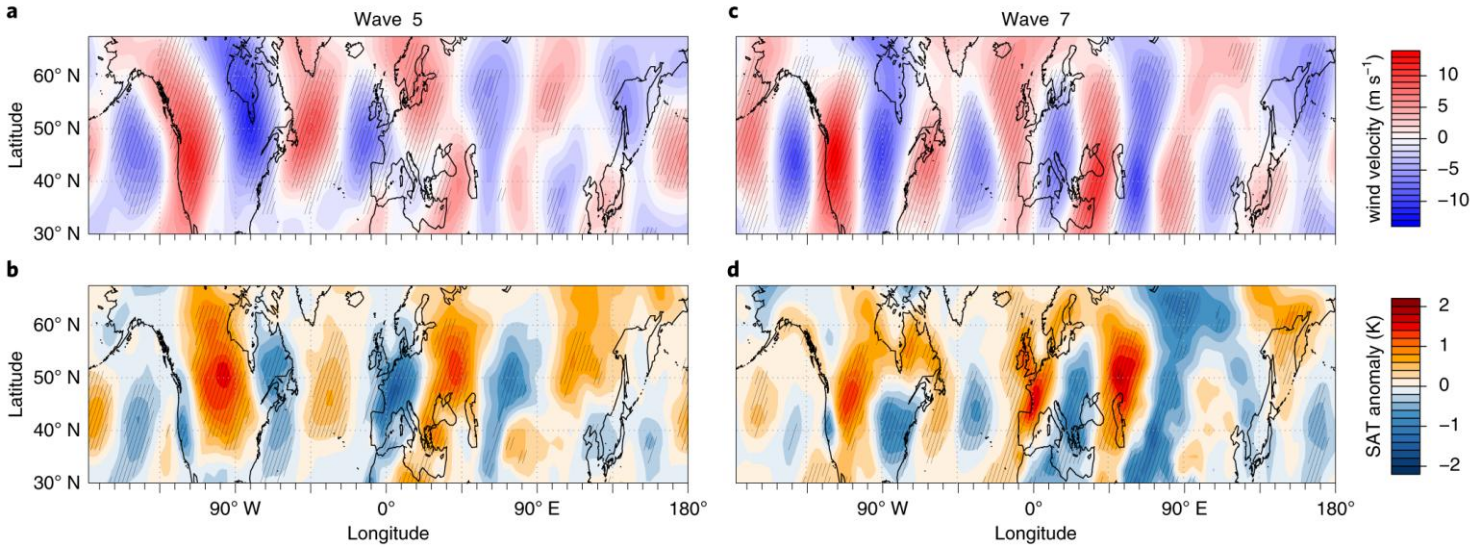


Previous research

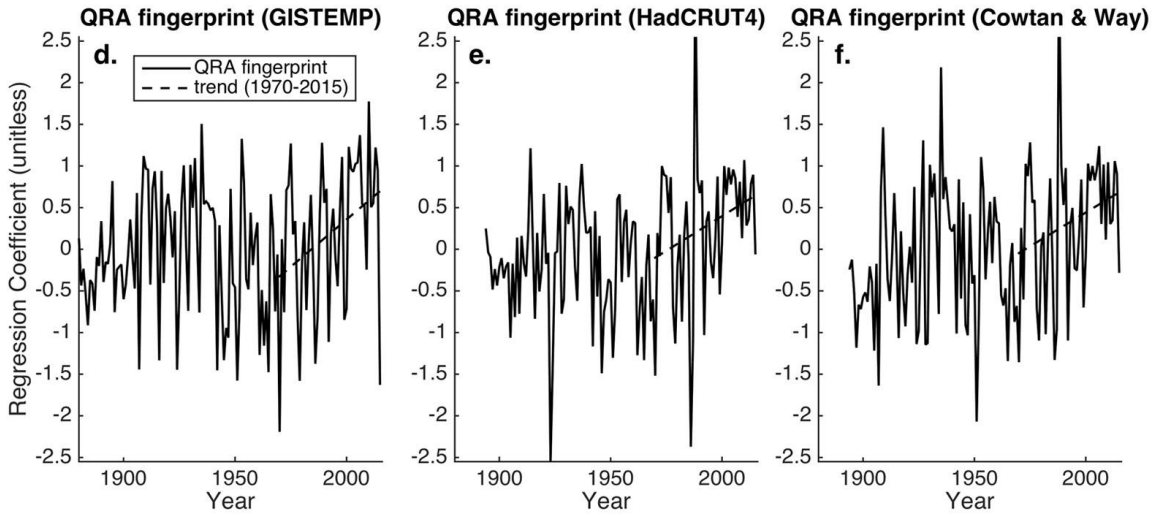
- Effect of amplified Rossby waves on concurrent heatwaves
  - Rossby waves with specific wavenumbers are associated with extreme heat events (i.e.: waves 5-8) *(1)*
  - These patterns seem to increase in frequency and persistence over time *(2)*
- Wave resonance causes quasi-stationary waves in summer (leading to atmospheric blocking and therefore extreme events) *(3)*
- Association between Northern Hemisphere midlatitude quasi-stationary meridional wind speed and high-amplitude wave patterns (#6-8) during extremes *(4)*



comparison of meridional wind speeds with the incidence of surface temperature anomalies (1)

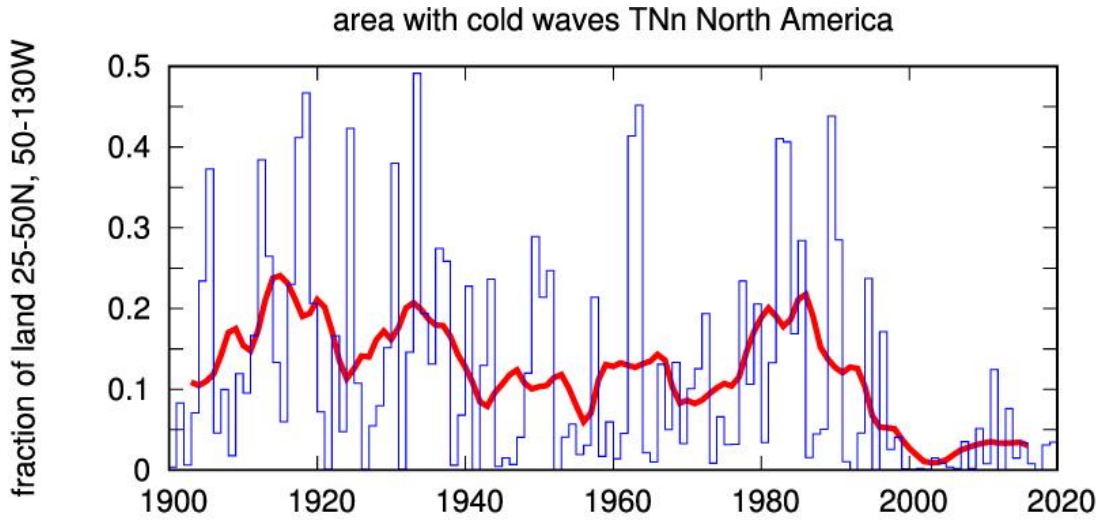
Previous research

- Quasi-resonant amplified wave events have been increasing in frequency and persistence over time *(5)*



Trend in the occurrence of the QRA fingerprint 1970-2015 (5)

- Cold waves getting milder and less frequent in the northern midlatitudes in the last few decades *(6)*



Fraction of area experiencing cold waves during daytime/nighttime (6)

Research Question:

Is the relationship between high-amplitude QSWs and extreme cold events on the Pacific Coast changing over time according to historical observations, 1979-2022?

Data used and Methodology

Data

- ERA5 DJF Quasi-Stationary Wave Amplitude data 1979-2022
- ERA5 DJF Daily Minimum Temperature Data 1979-2022
- ERA5 DJF Binary Masked Cold Wave Data 1979-2022; calculated by:
  - 15-day running window for temperatures lower than the 10^{th} percentile
  - 3-day threshold
  - 1 = cold wave, 0 = no cold wave

Methodology

- Composite analysis
- All trends were calculated using the Mann-Kendall function

Method Overview

Part 1: Annual Mann-Kendall Trends in North America:

1. QSW values
2. 90th percentile *high-amplitude* QSW values
3. 90th percentile *high-amplitude persistent* QSWs; frequency and length

Part 2: Daily Minimum Temperatures occurring at the same time as Pacific Coast 90th percentile high-amplitude QSWs

1. Anomaly in mean daily minimum temperatures in comparison to 1979-2022 climatology
2. Anomaly in annual trend of mean daily minimum temperatures in comparison to 1979-2022 trend

Part 3: Anomaly in mean number of cold wave days occurring at the same time as Pacific Coast 90th percentile high-amplitude QSWs

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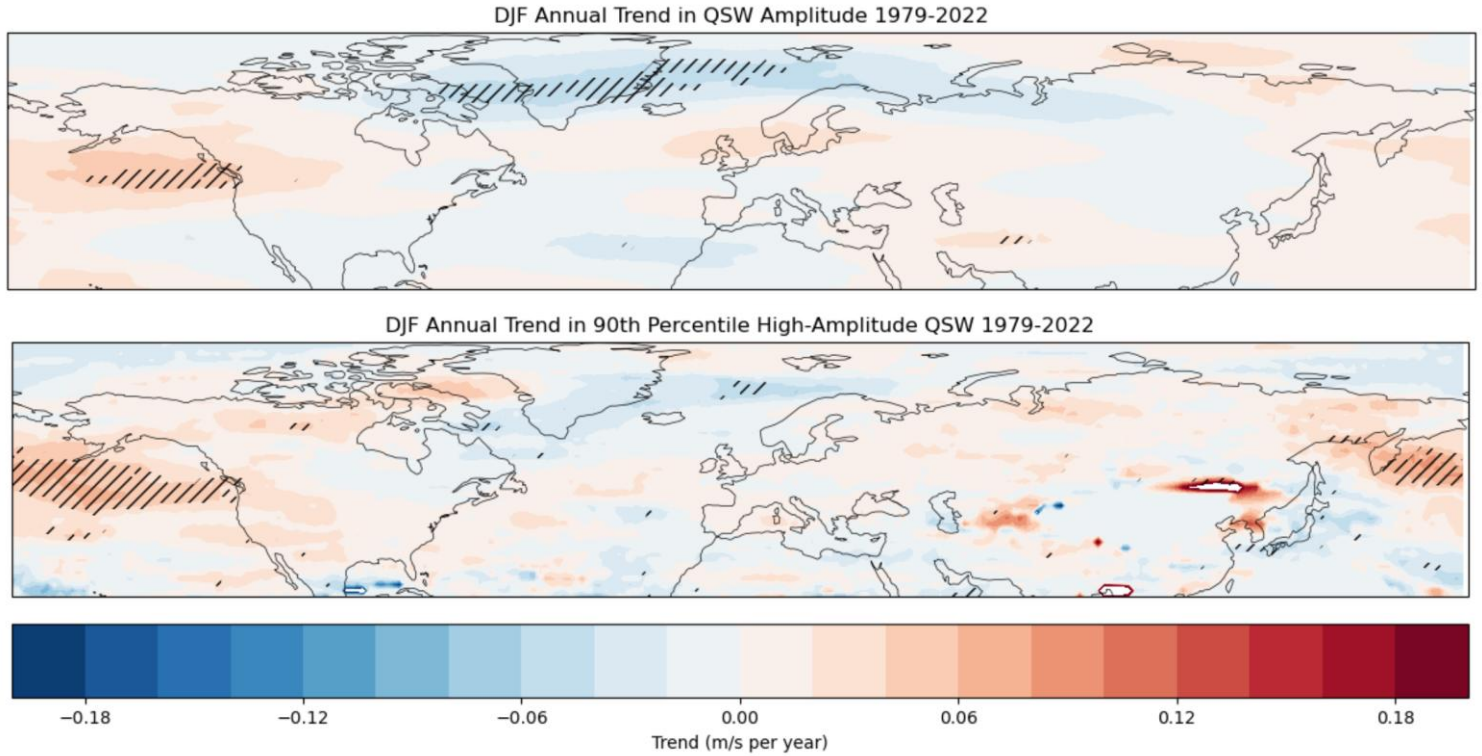
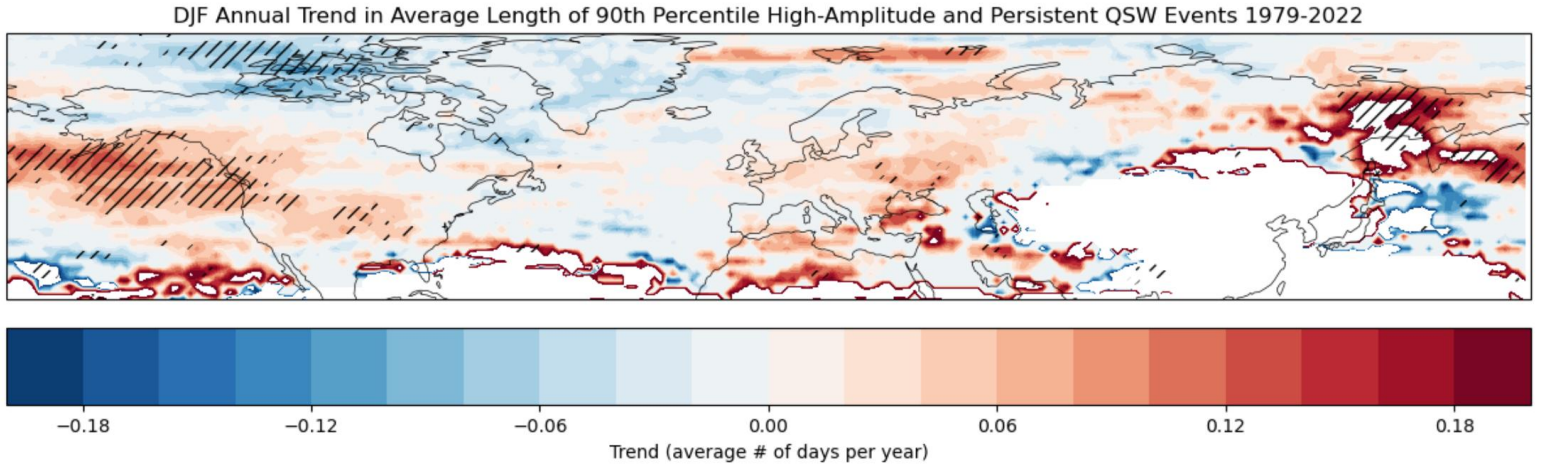
Annual Mann-Kendall Trends in QSWs

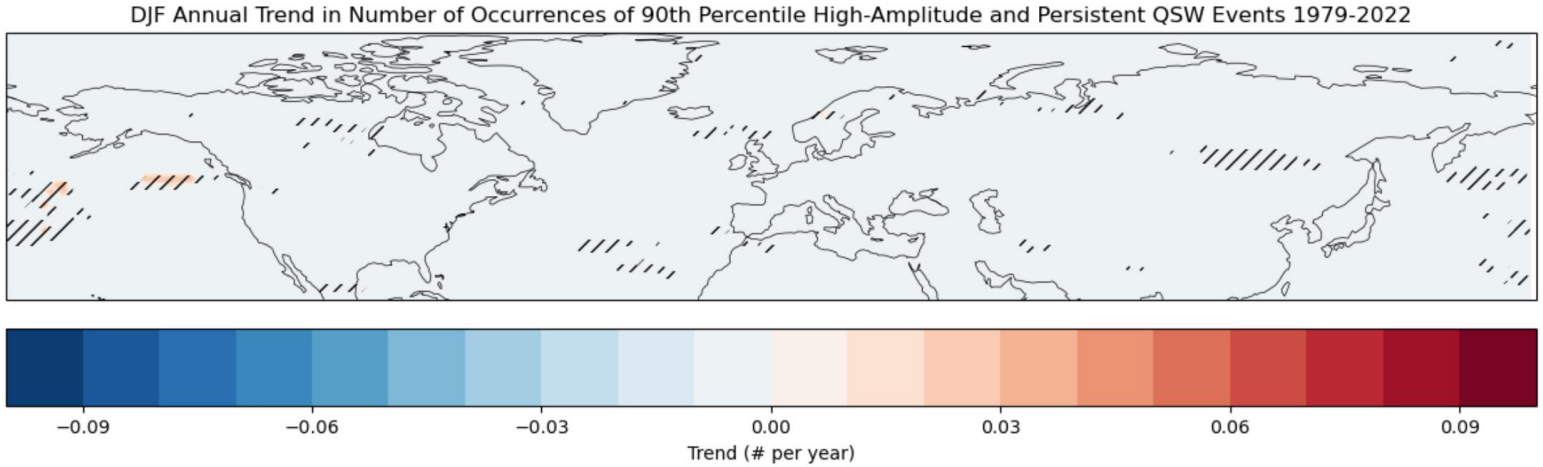


The annual trend in QSW Amplitudes and 90th percentile QSW Amplitudes are both significant in the Pacific Coast region, more so with 90th percentile waves

Trend in high-amplitude persistent QSWs

- The average length of strong QSW events appears to have a significant increase
- The number of occurrences of these events also has a significant increase, but to a much smaller extent





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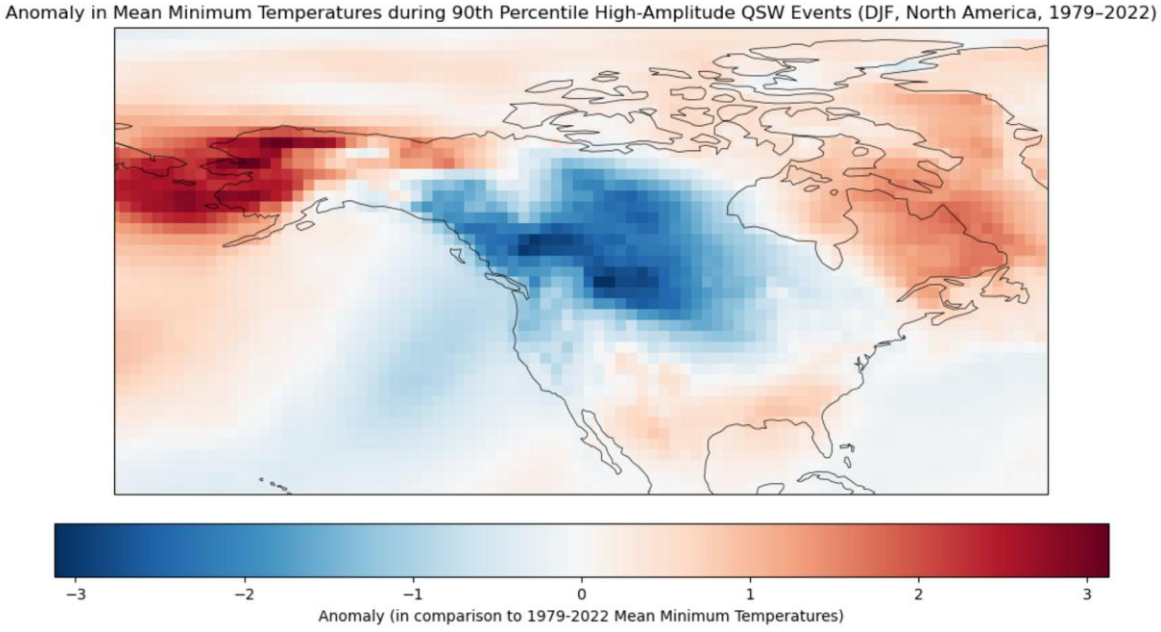
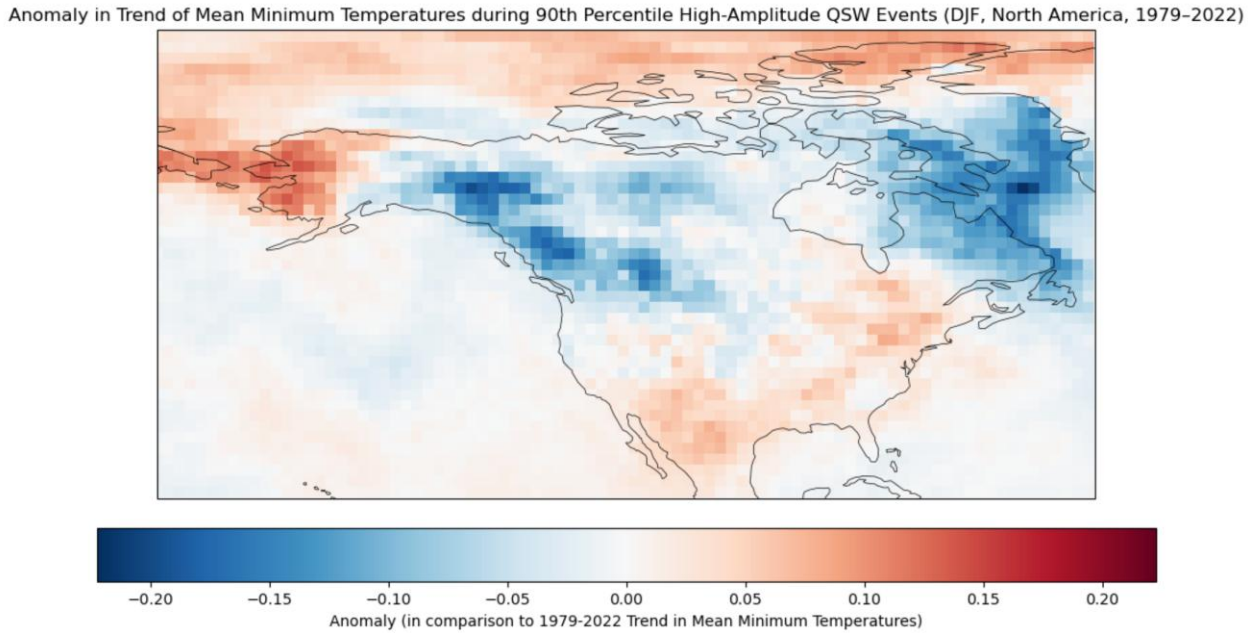
Mean Daily Minimum Temperatures during 90th percentile QSWs

- The minimum temperatures on average are considerably lower in the majority of North America
- The trend in mean minimum temperatures during 90th percentile QSWs is stronger compared to the regular trend of mean minimum temperatures





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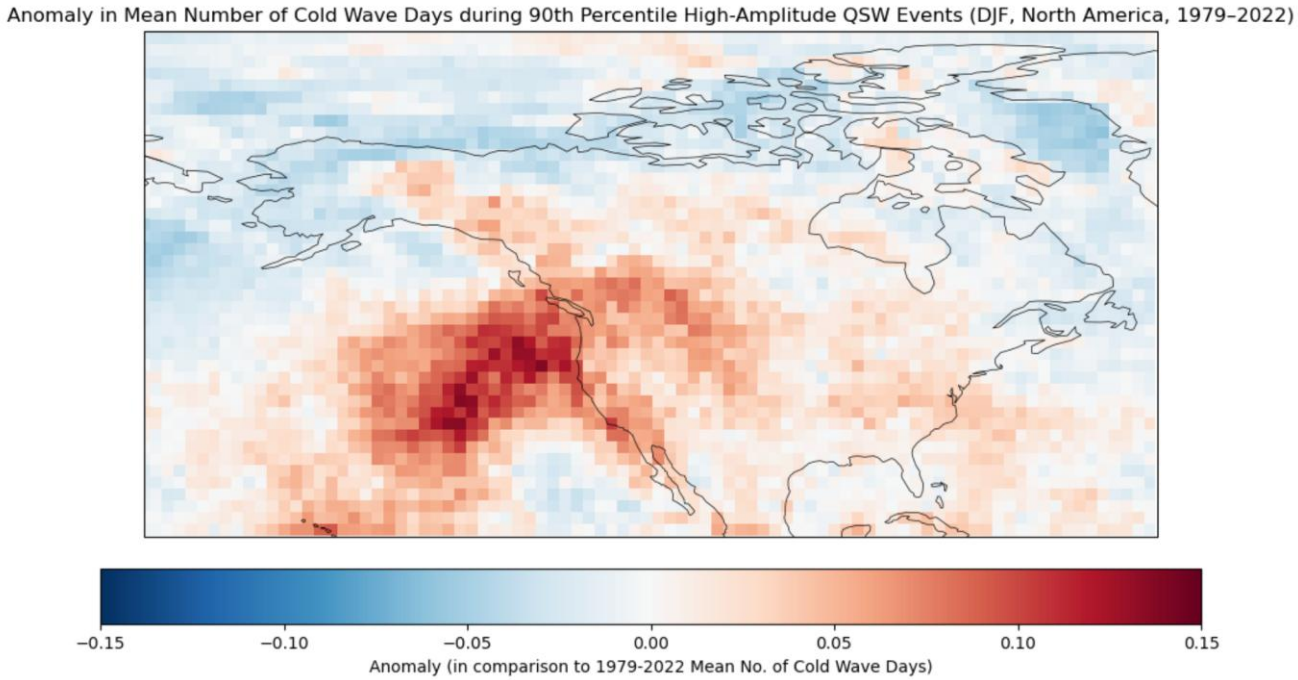
Cold waves during 90th percentile QSWs



- Mean number of cold wave days is much higher during a 90th percentile QSW event on the Pacific Coast, and generally higher in North America
- No trend in the mean number of cold wave days during 90th percentile QSW events

Conclusions

- Specific Rossby wave patterns seem to be becoming more intense over time in the Northern Hemisphere
- In the Pacific Coast area:
  - Annual trend in QSW amplitude increasing over time
  - 90^{th} percentile QSW amplitudes are becoming more extreme
  - Average length of 90^{th} percentile persistent events is increasing significantly
  - Frequency of above events is increasing to a lesser extent
- During Pacific Coast 90^{th} percentile QSW events:
  - Average minimum temperatures are becoming colder in most of North America
  - Strong negative trend in these temperatures
  - Average number of cold wave days is significantly higher in North America

Future Directions

- Test whether peak season for high-amplitude QSW events is becoming earlier/later + effect on timing of cold extremes
- Look into QSW activity during summer and effect on extreme cold/heat events

References

1. Kornhuber, K., Coumou, D., Vogel, E. *et al.* Amplified Rossby waves enhance risk of concurrent heatwaves in major breadbasket regions. *Nat. Clim. Chang.* **10**, 48–53 (2020). https://doi.org/10.1038/s41558-019-0637-z
2. Kornhuber, K., Osprey, S., Coumou, D., Petri, S., Petoukhov, V., Rahmstorf, S., & Gray, L. (2019). Extreme weather events in early summer 2018 connected by a recurrent hemispheric wave-7 pattern. Environmental Research Letters, 14(5), 054002. https://doi.org/10.1088/1748-9326/ab13bf
3. Kornhuber, K., Petoukhov, V., Petri, S., Rahmstorf, S., & Coumou, D. (2016). Evidence for wave resonance as a key mechanism for generating high-amplitude quasi-stationary waves in boreal summer. Climate Dynamics, 49(5–6), 1961–1979. https://doi.org/10.1007/s00382-016-3399-6
4. Petoukhov, V., Rahmstorf, S., Petri, S., & Schellnhuber, H. J. (2013). Quasiresonant amplification of planetary waves and recent Northern Hemisphere weather extremes. Proceedings of the National Academy of Sciences, 110(14), 5336–5341. https://doi.org/10.1073/pnas.1222000110
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6. Van Oldenborgh, G. J., Mitchell-Larson, E., Vecchi, G. A., De Vries, H., Vautard, R., & Otto, F. (2019). Cold waves are getting milder in the northern midlatitudes. Environmental Research Letters, 14(11), 114004. https://doi.org/10.1088/1748-9326/ab4867

Additional plots