Meteorological Drivers of the 2021 Pacific Northwest Heat Wave

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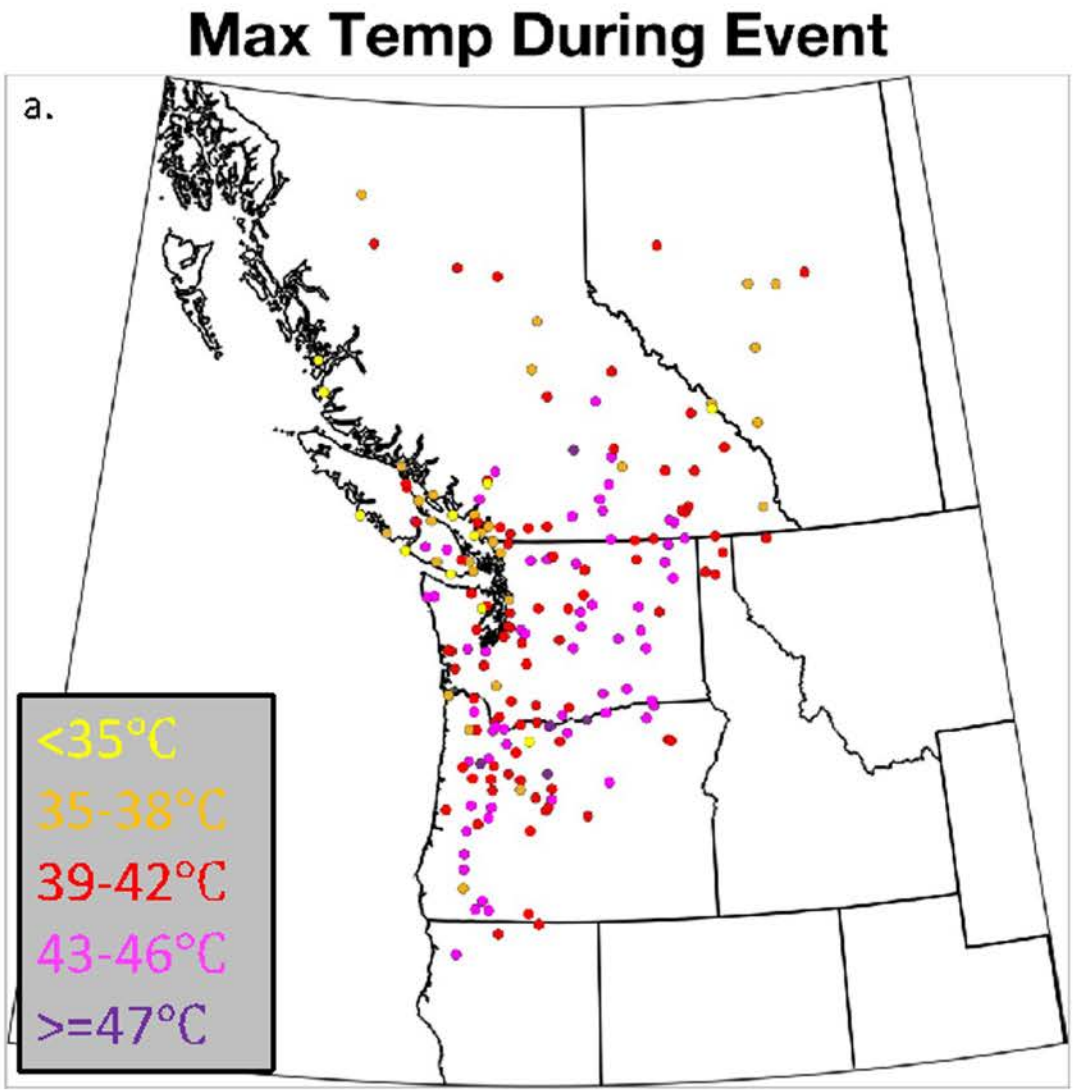
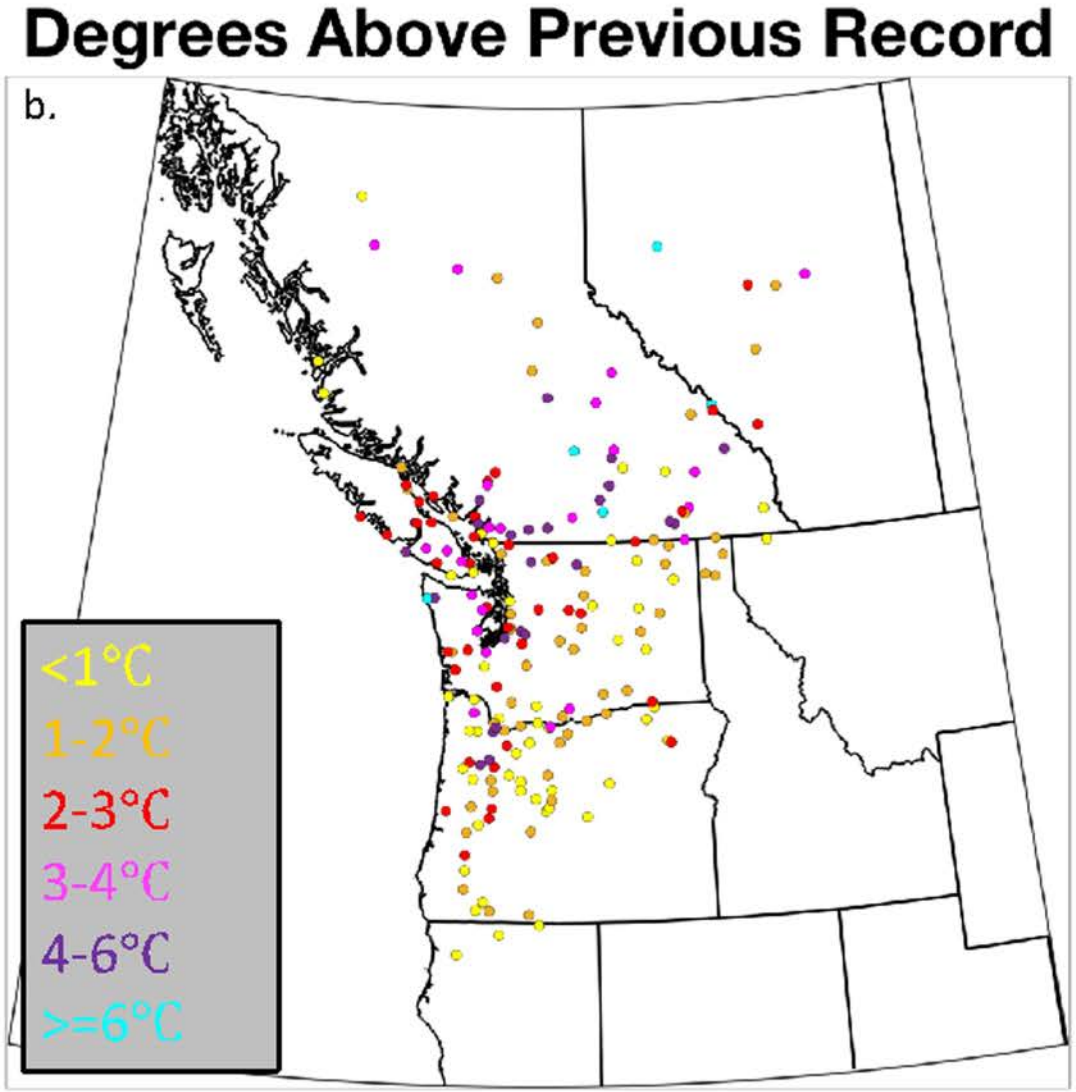
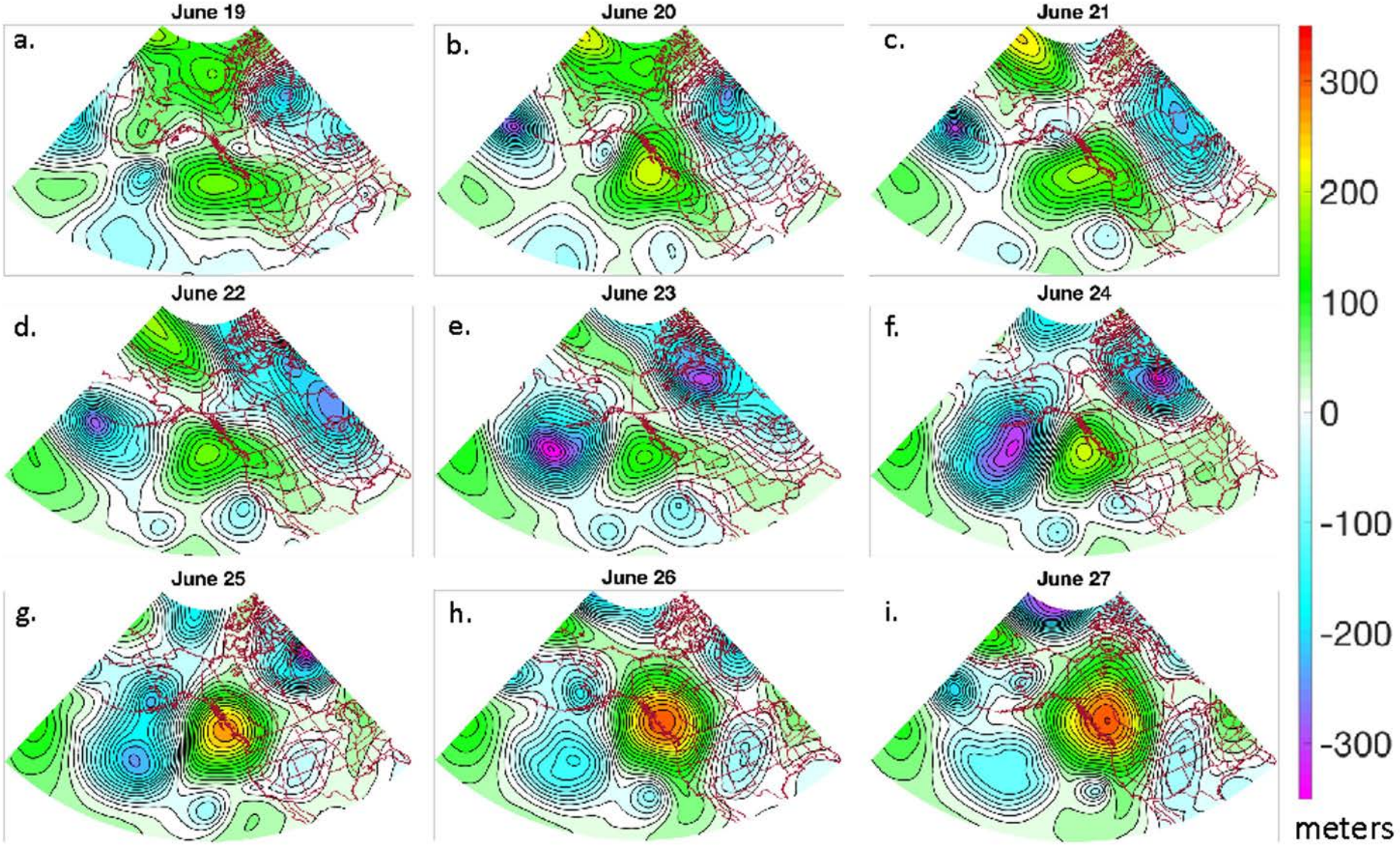
How Hot?





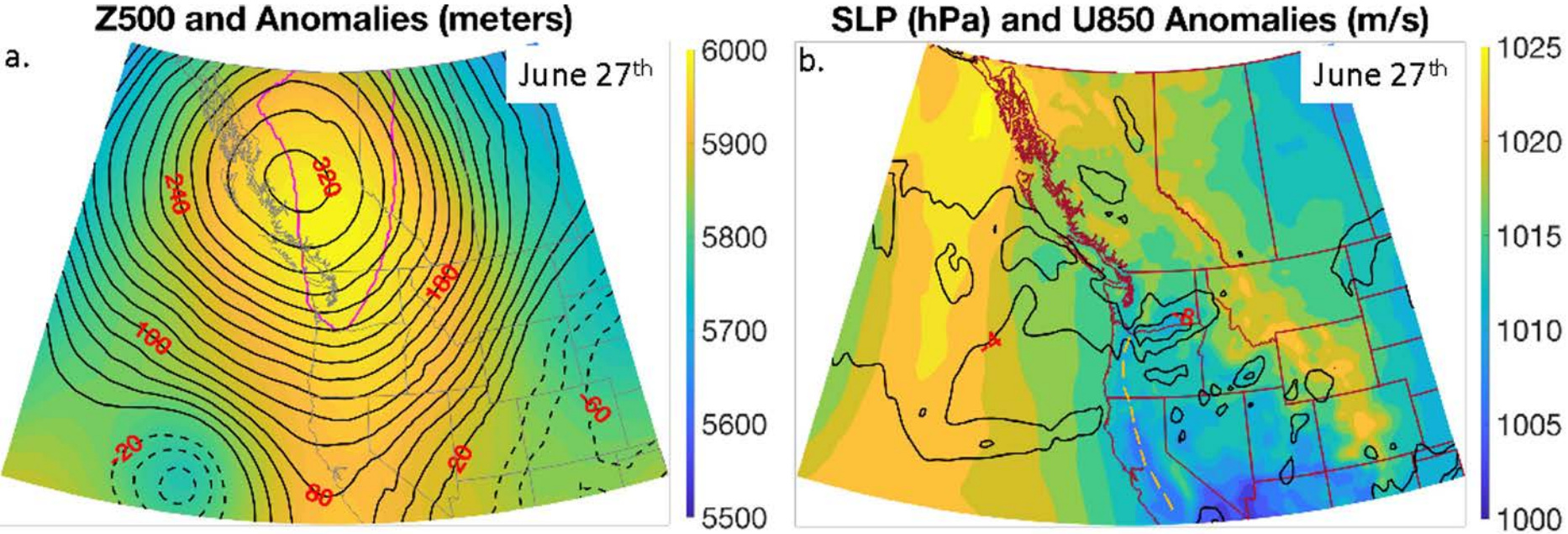
Some places broke their all-time record by more than 6°C

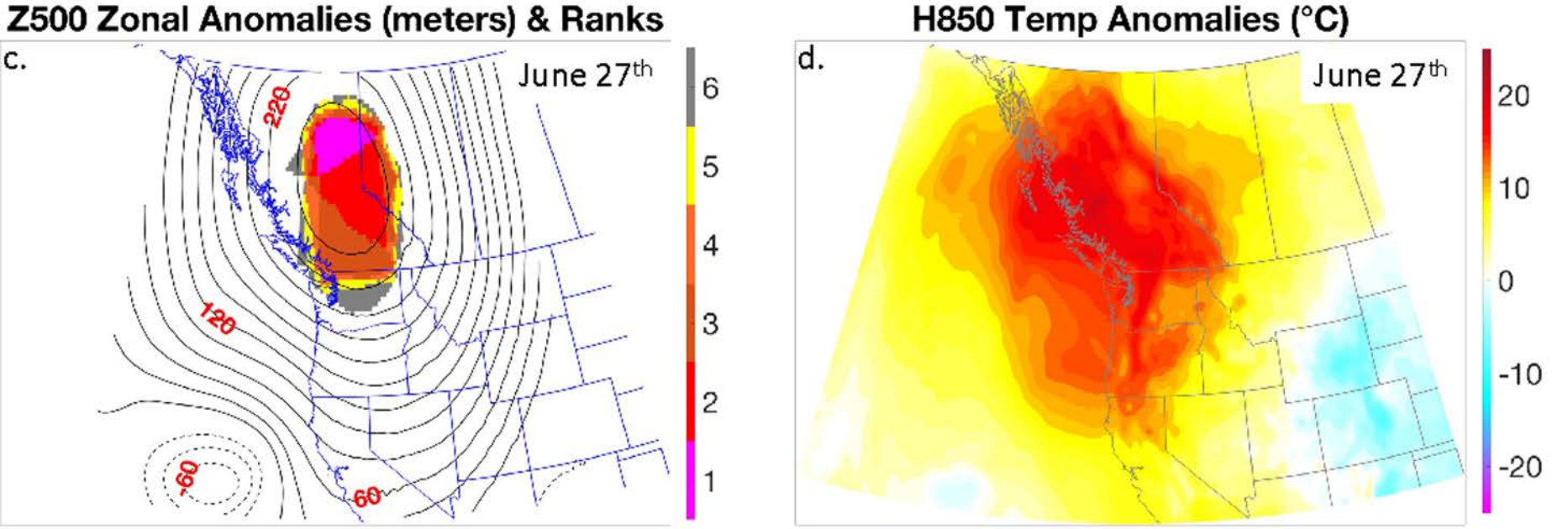
Evolution of the Record Breaking Ridge?



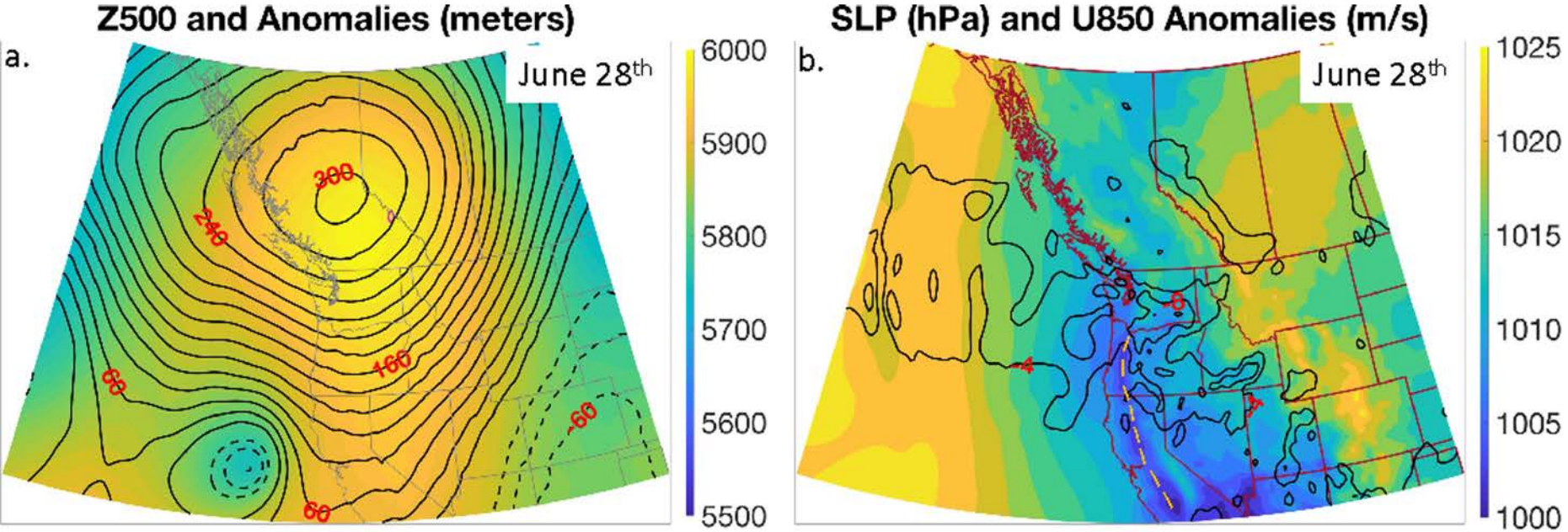
- Strong atmospheric river on upstream side of the ridge likely supplied heat to the ridge. (Mo et al. 2022, Neal et al. 2022)
- Ridge strength peaked over BC on June 26-27th, but heat was most severe on the 28th-29th.
- Small upper-level low to the west of NorCal was also key.

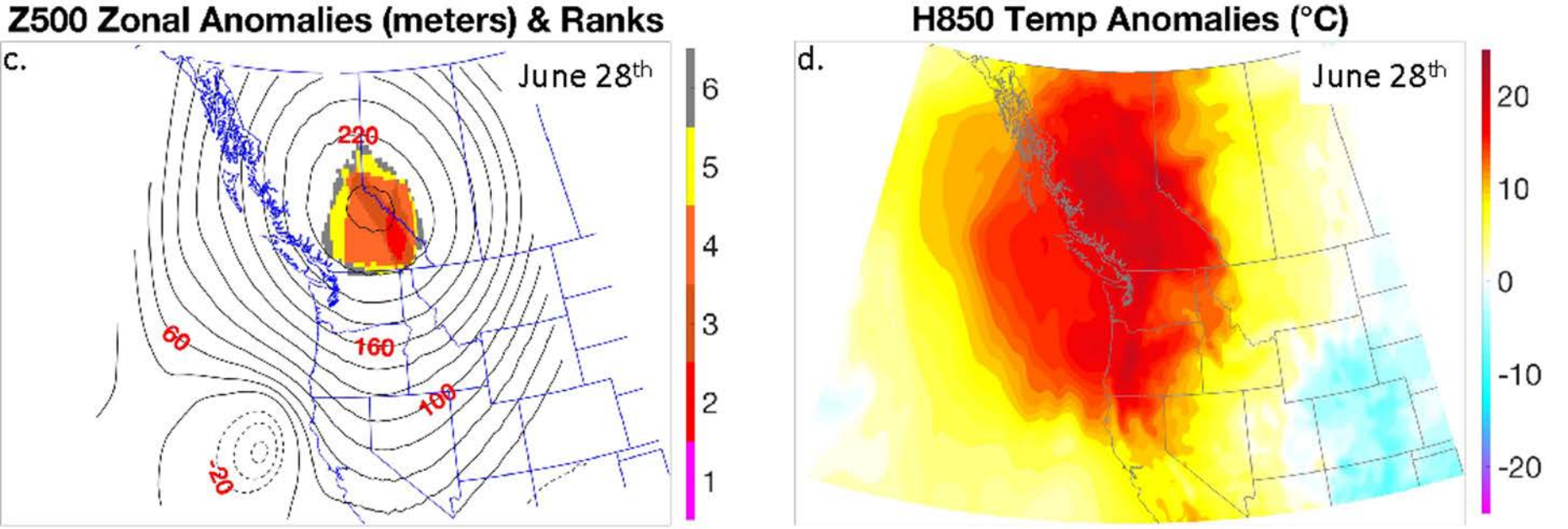
Meteorology of June 27th



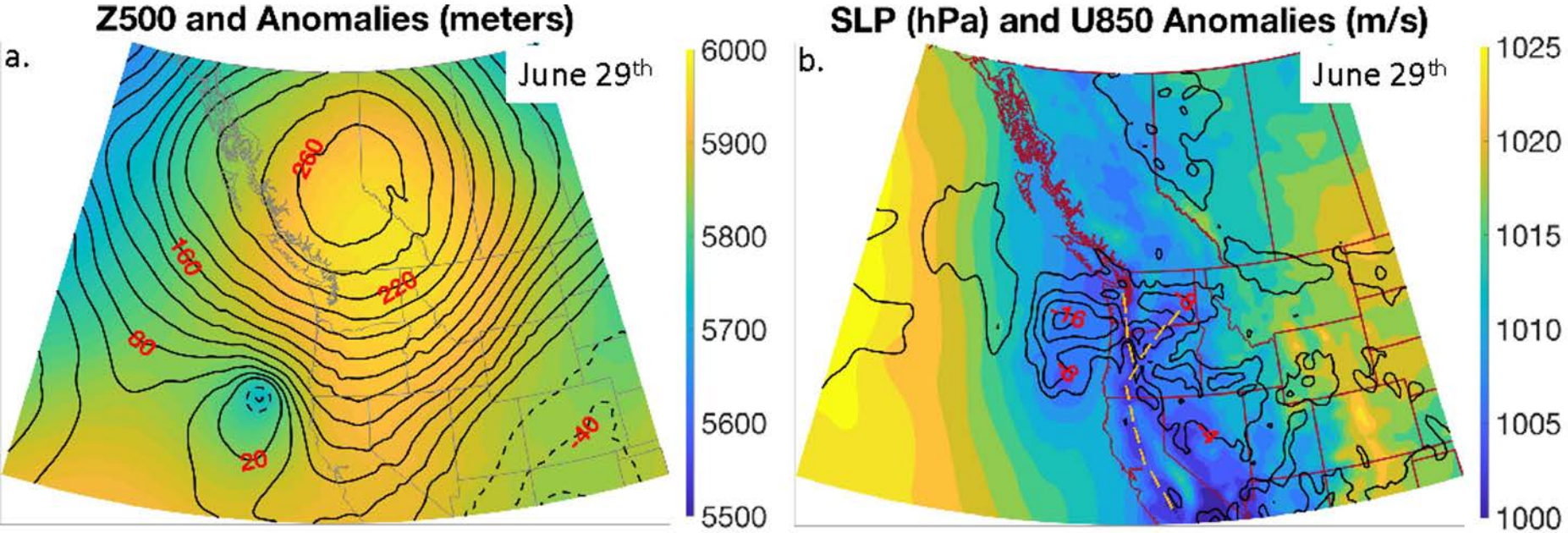


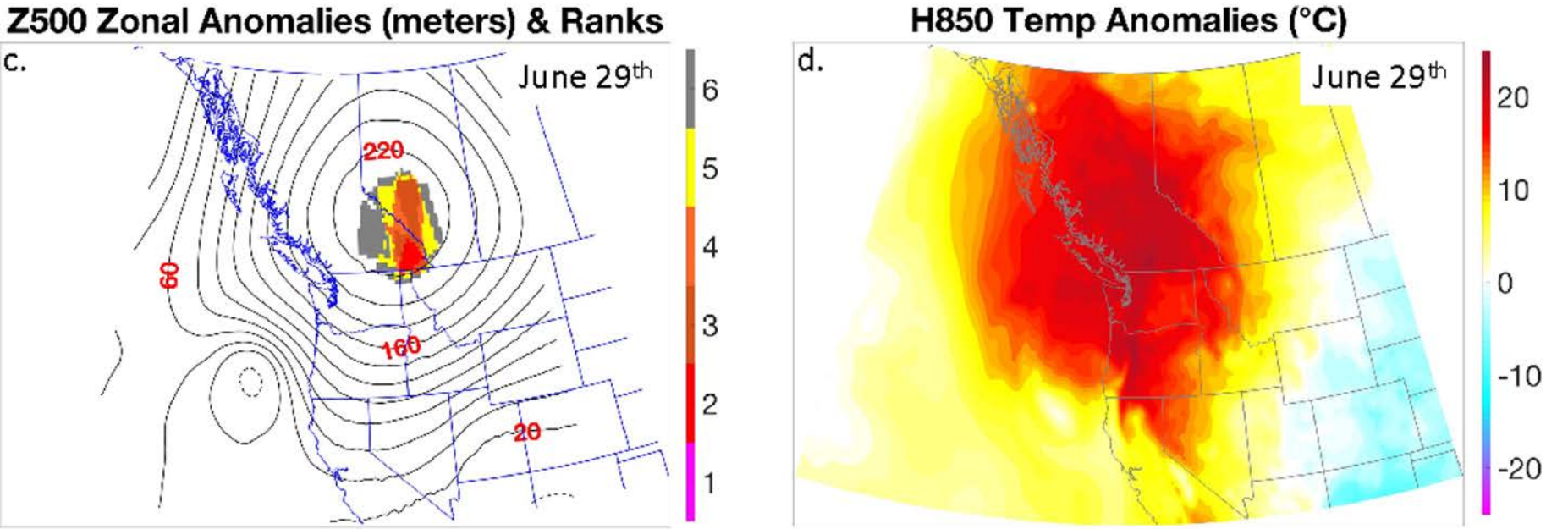
Meteorology of June 28th



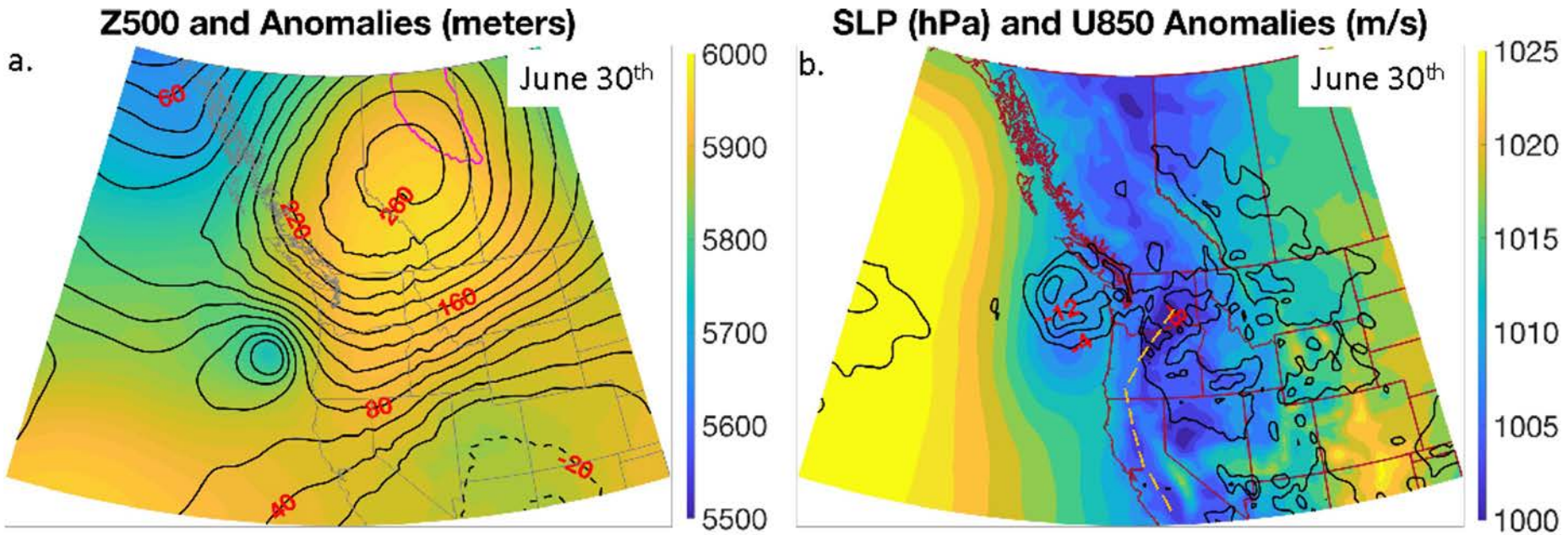


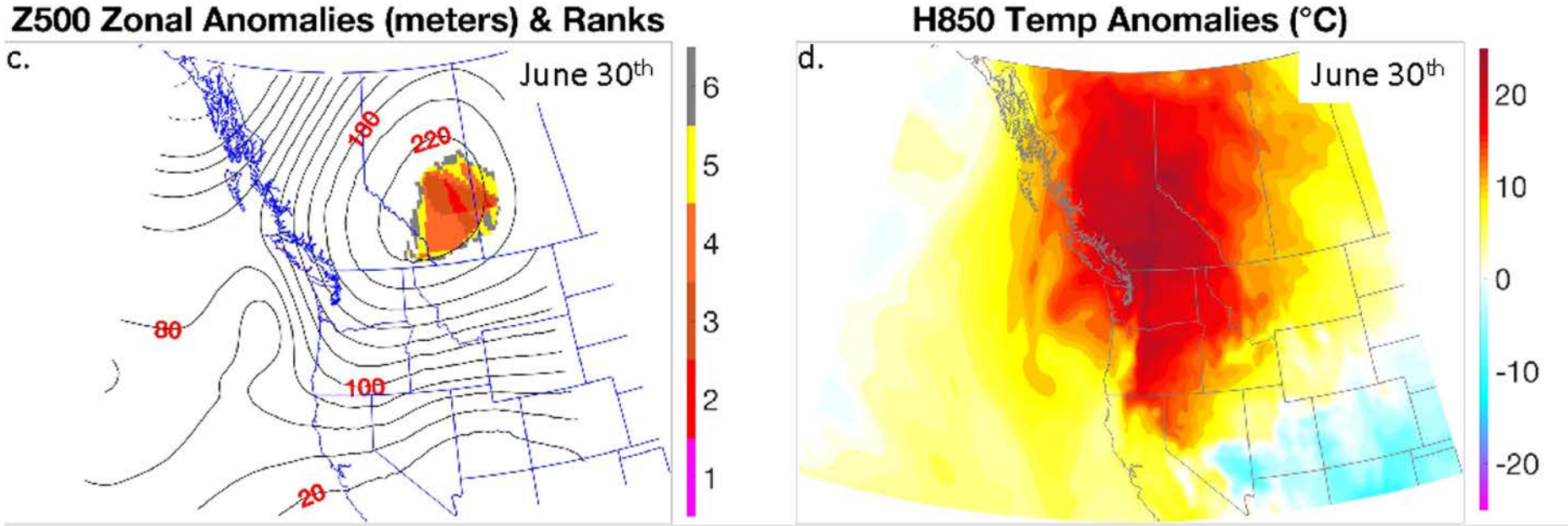
Meteorology of June 29th



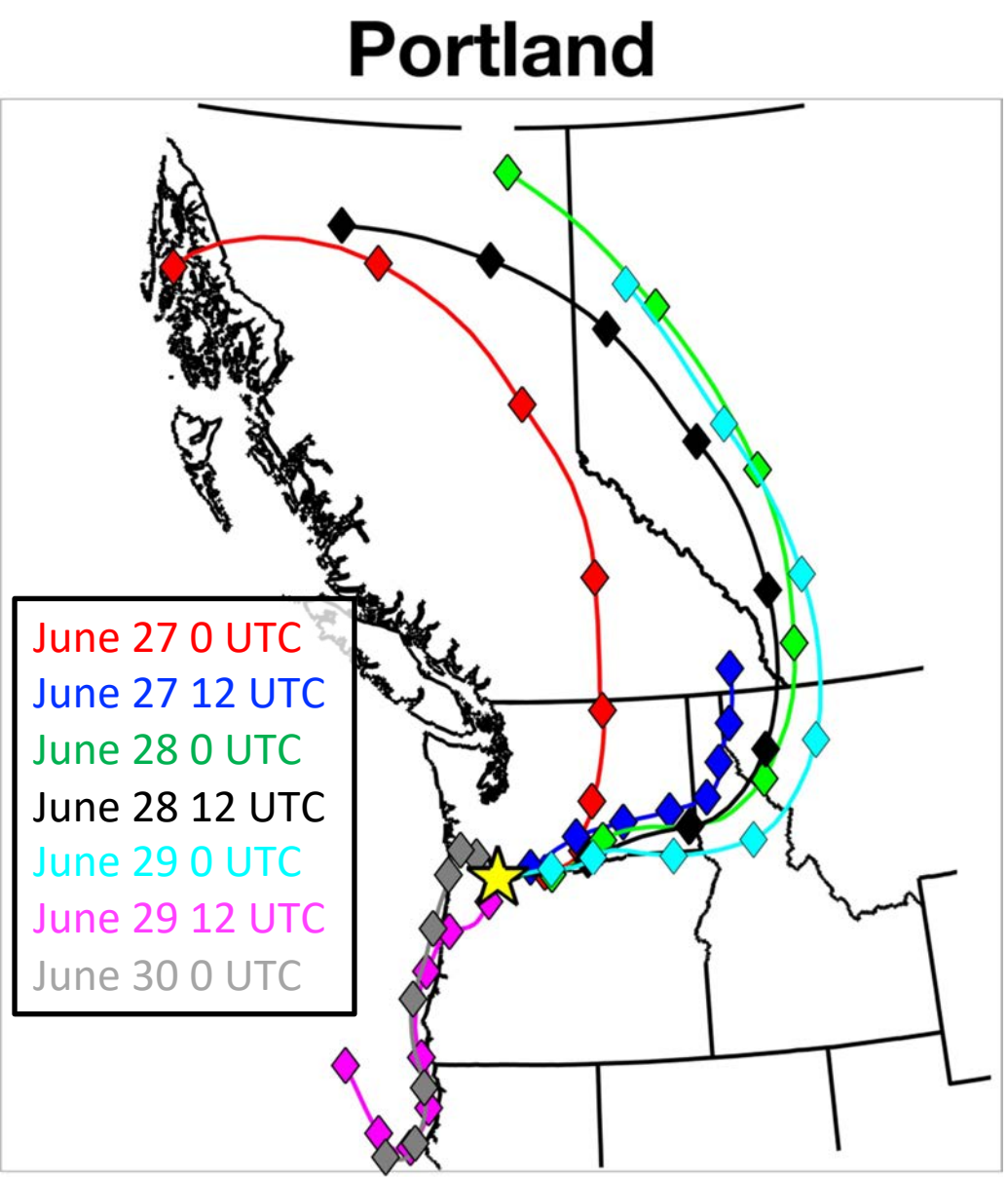


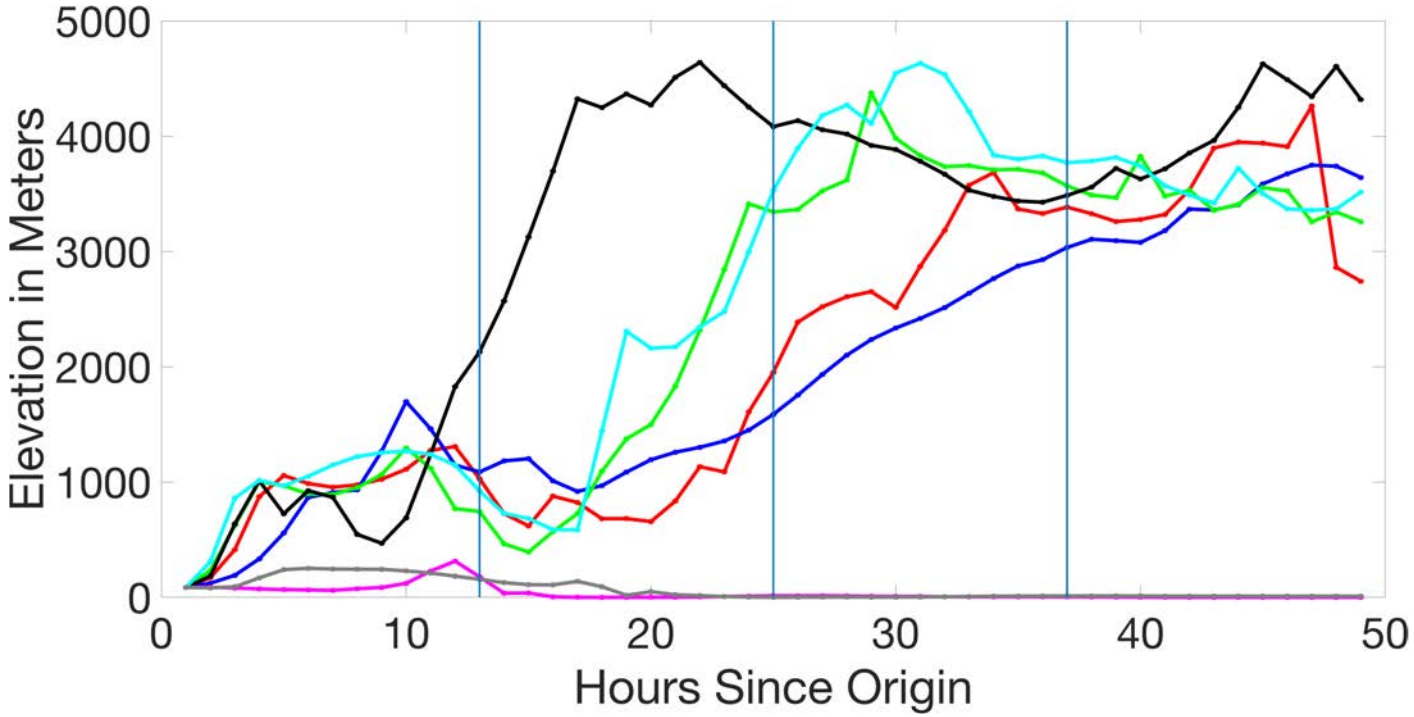
Meteorology of June 30th





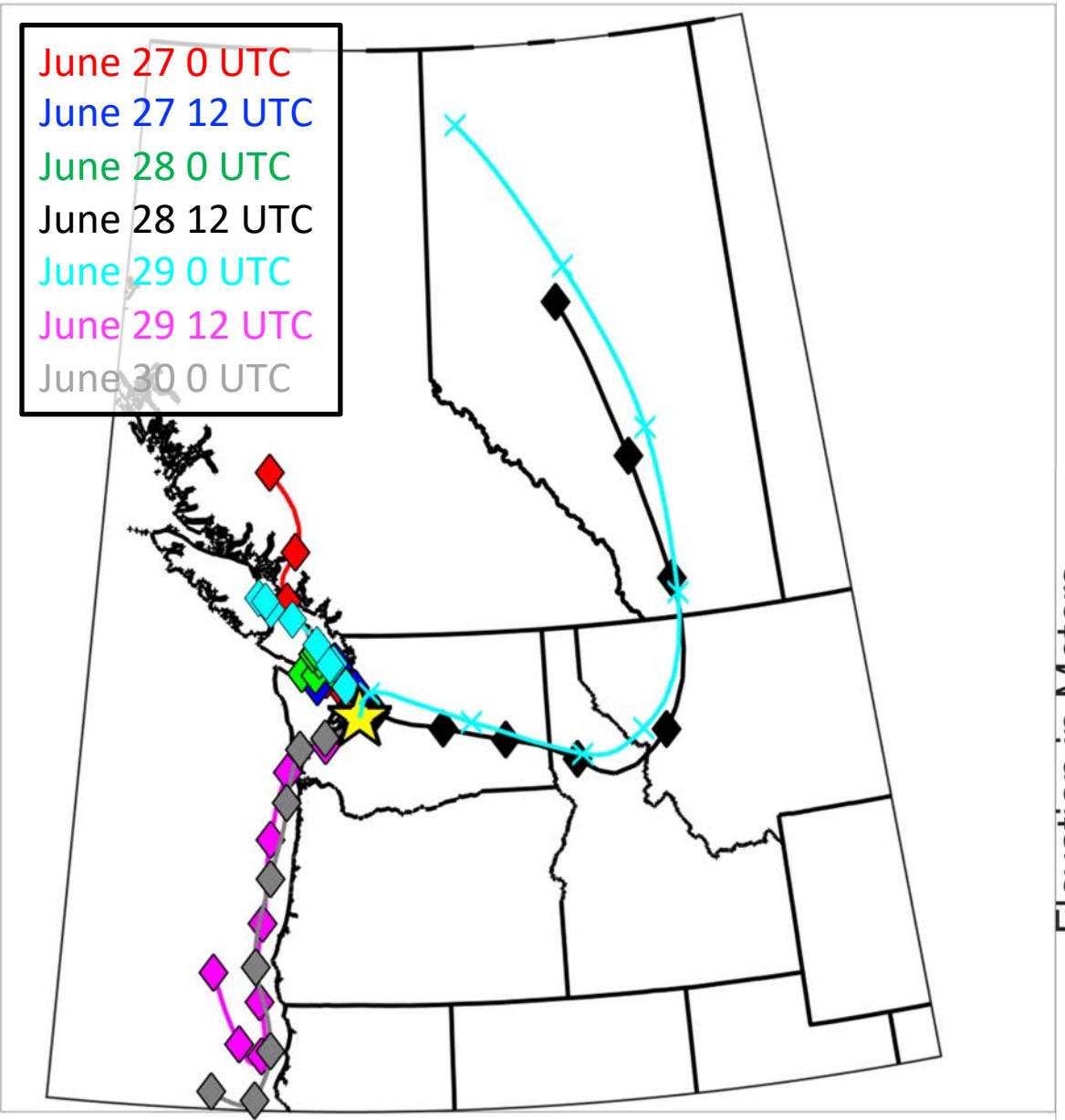
Air Parcel Trajectories for Portland



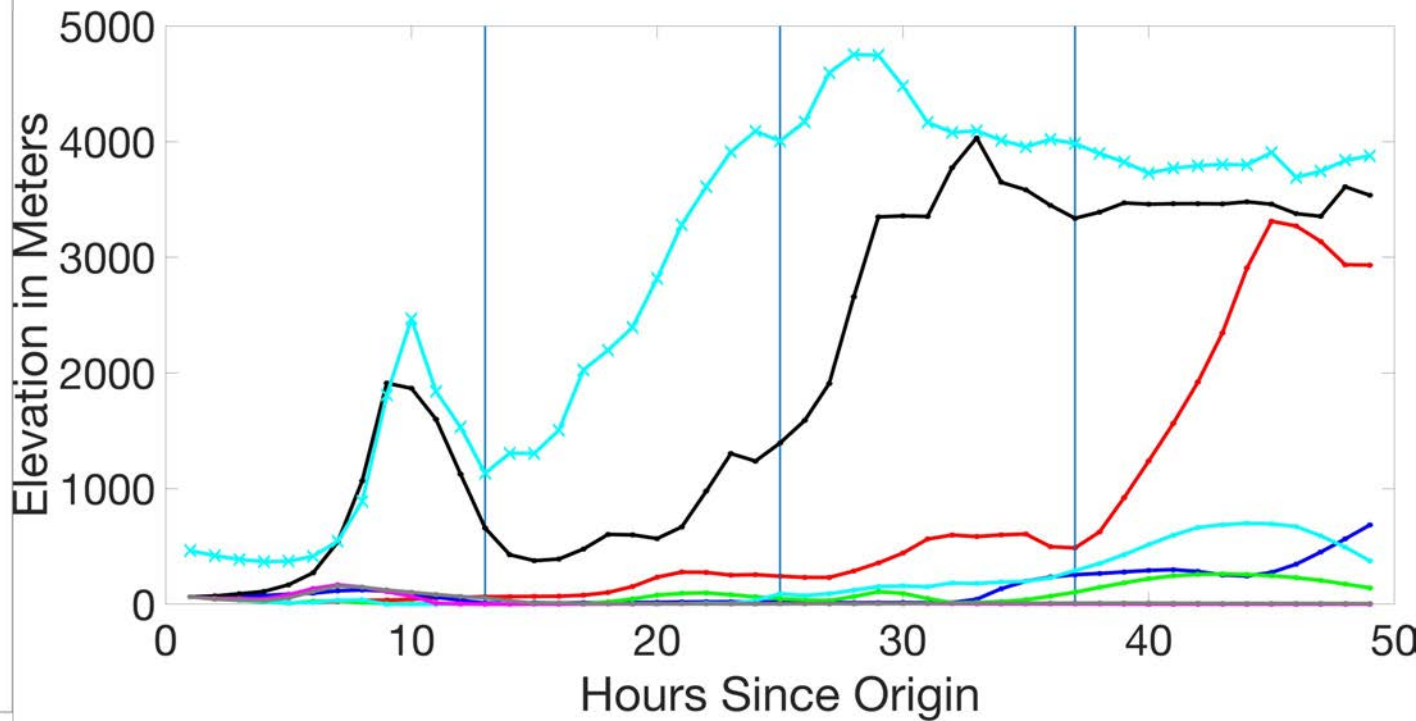


- Air parcels descended nearly 4500 meters over the 48 hours prior to arrival in Portland.
- Cool marine air at the end of the event originated from just above the ocean surface.

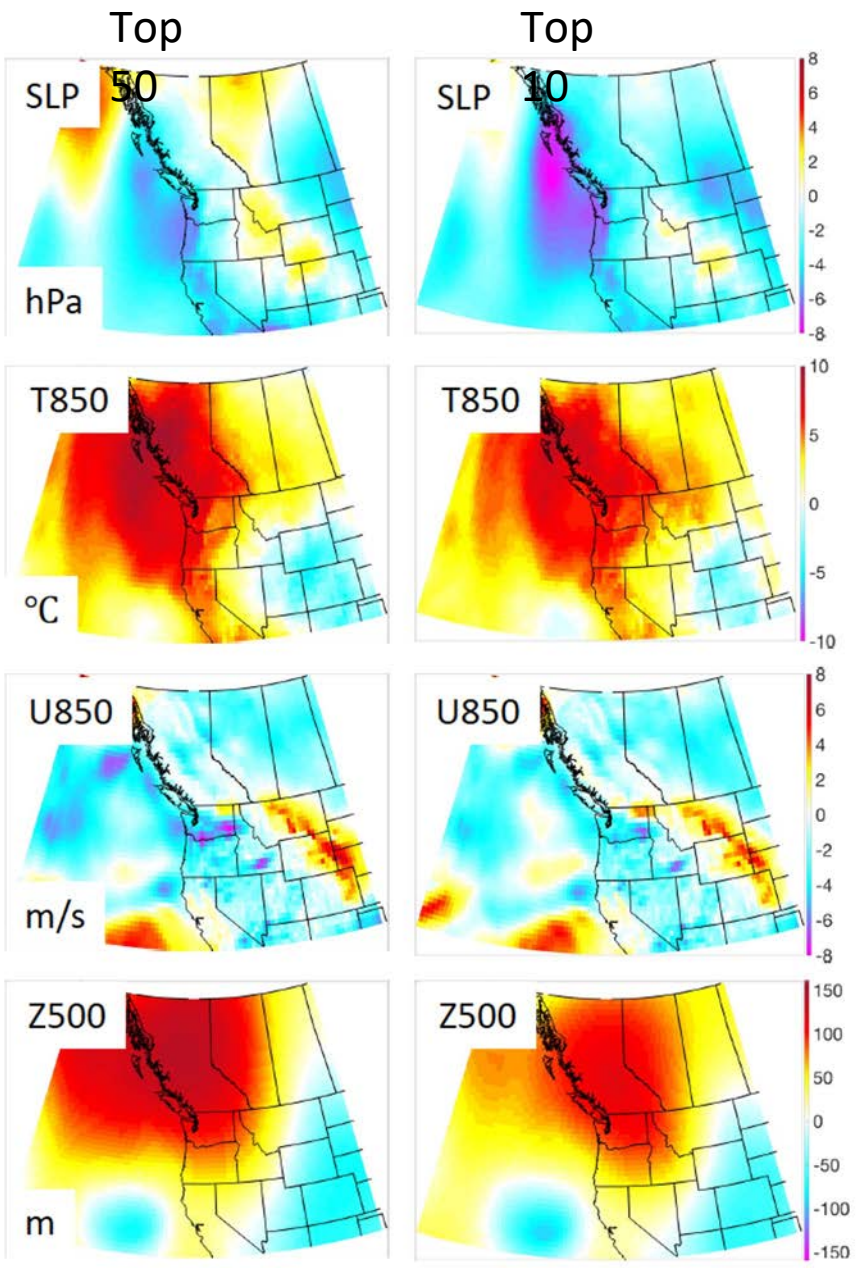
Air Parcel Trajectories for Seattle



- At start of heat wave, parcels traveled over Puget Sound before arriving in Seattle. How did that not cool them off?
  - Extreme sinking air suppressed the cool layer over the water, mixing of warmer air from just above the surface likely also contributed.
- Additional warming from air sinking down west slopes of the Cascades.
- Southerly wind reversal ended heat wave at Seattle too.



Why was this heat wave so much worse than others?



- Compared with other highly amplified summer ridges, the June 2021 event had more of everything that is important for heat.
- Stronger thermal trough.
- Much hotter lower tropospheric temperatures.
- Stronger offshore winds.
- Much stronger ridge.

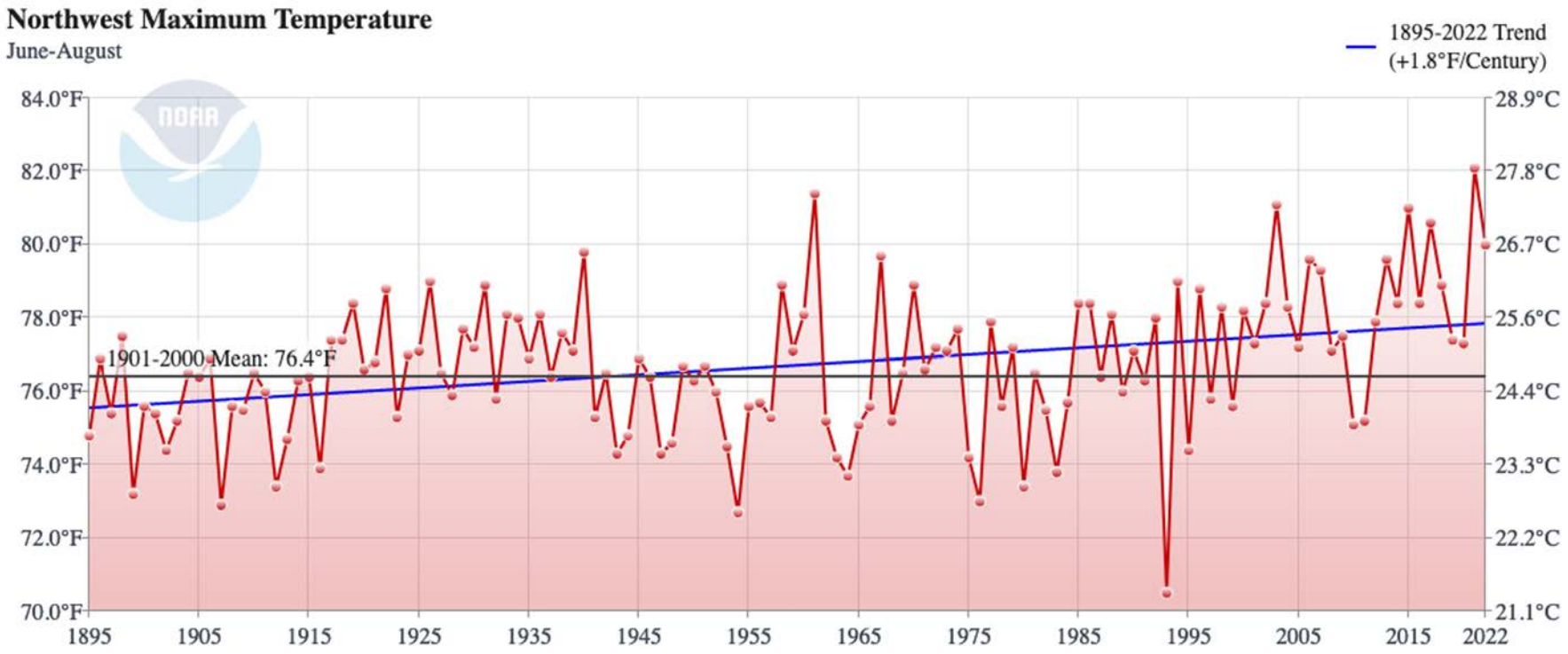
Role of Global Warming

Evidence points to global warming making the event hotter by ~1-3 degrees C compared to if it happened in the mid-20th century

Sample of findings:

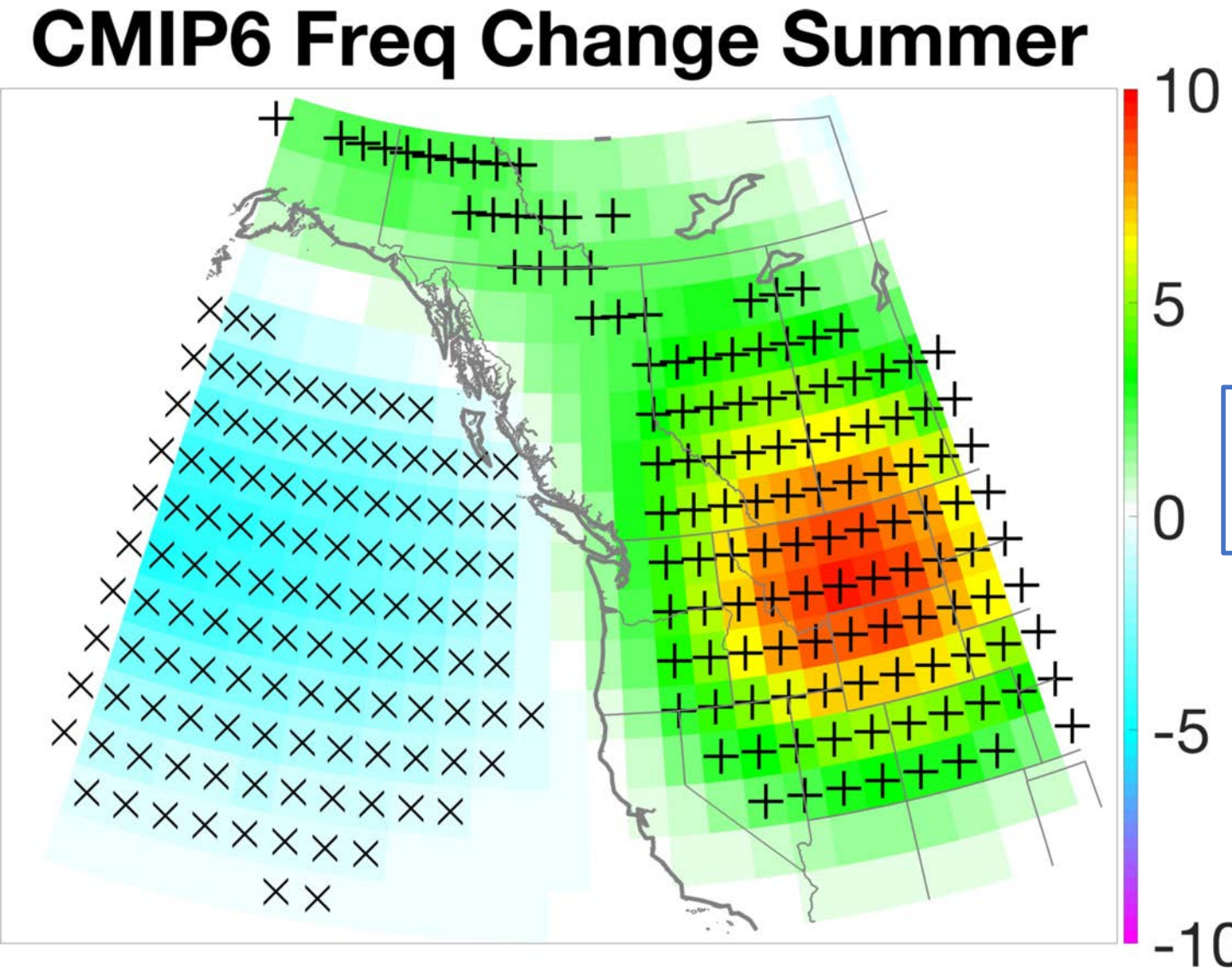
- Event of similar magnitude estimated at a 1 in 100,000 year frequency. Occurrence aided by positively skewed temperature distribution. Global warming made the event warmer by 1.5℃ compared with mid-century (McKinnon and Simpson 2022).
- Heat wave was about 2℃ hotter than if the heat wave occurred prior to 1900. (Philip et al. 2022)
- Global warming caused a .8-1℃ increase in temperature during the heatwave. Future warming could increase a similar heatwave by 5℃ by end of century under a high-end emissions scenario (Bercos-Hickey et al. 2022).
- Anomalously dry soil moisture increased magnitude of heat (Schumacher et al. 2022)
- Global warming has increased the likelihood of the temperatures observed from nearly impossible to 1 in 200 years. Heat of similar magnitude may increase to a 1 in 10 year occurrence under 2℃ global warming (Bartusek et al. 2022).
- The heatwave was mainly attributable to internal variability with global warming explaining 10% of the magnitude. Event magnitude scales nearly linearly with global warming with a factor of 2 (Terray 2023).

Role of Global Warming



- Summer daily maximum temperature has warmed about 2.5°F since 1895.
- Assuming all of this is global warming, and this was added to the heat wave, temps would have topped out around 113°F in Portland without global warming.
- Previous record at KPDX was 107°F

Future Projections of Summer Ridges



Projections from CMIP6 models do not suggest an increase in the frequency of summer ridges in the area affected by the heat wave.

From Loikith et al. 2022, *J. Climate*

Questions of Less Direct/Non-Linear Role of Global Warming

- Role of global warming in anomalously low soil moisture?
- Role of global warming in upstream heating in anomalous atmospheric river?
- Can climate models realistically capture processes that lead to ridge development and amplification?/Can they realistically simulate how all factors respond to warming?