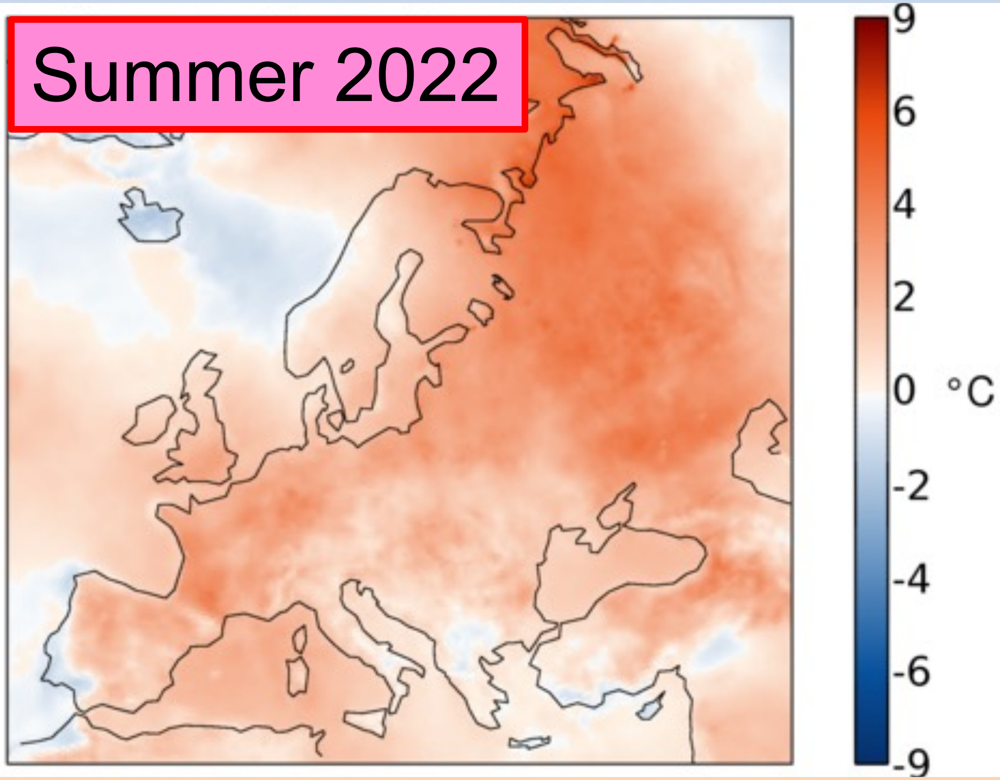
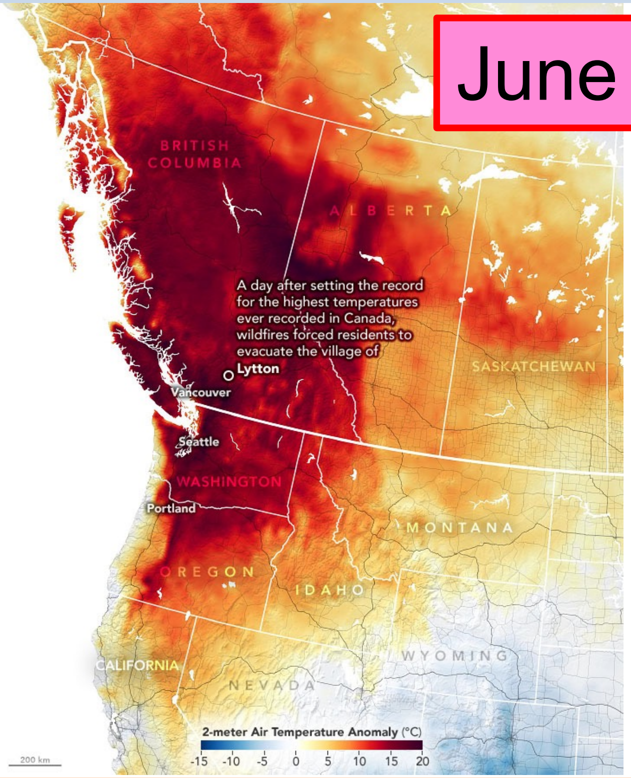
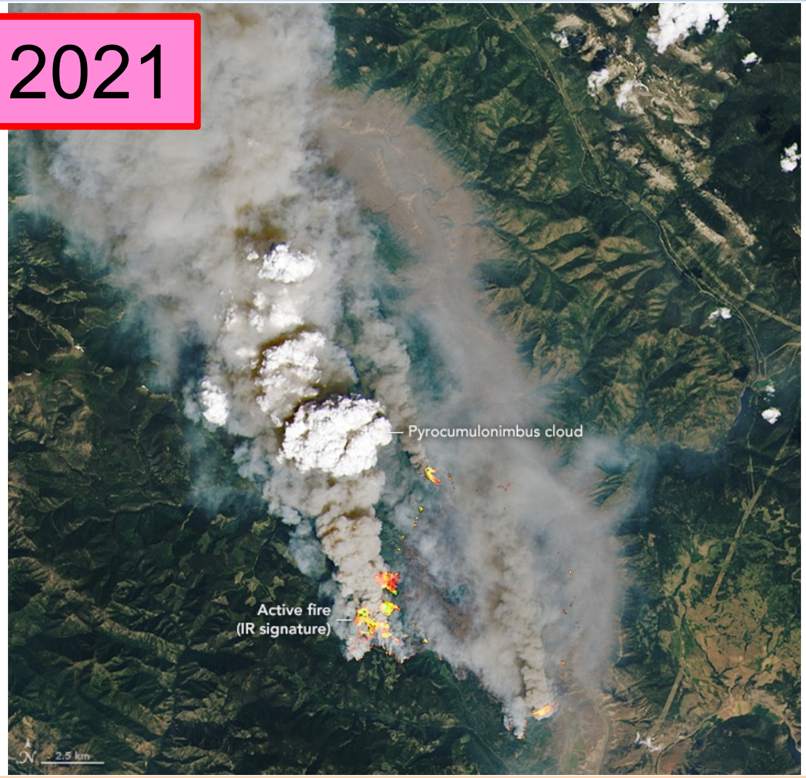
Attribution des événements extrêmes

Summer 2022



June 2021





Laurent Terray, CECI, Cerfacs/CNRS

Journées du GDR « Défis théoriques pour le climat », Paris, 5-7 juin 2023

Geert Jan Van Oldenborgh

Earth's Future

COMMENTARY

10.1029/2021EF002271

Key Points:

- The IPCC AR6 WG1 states the "frequency and intensity of hot extremes have increased"

Attributing and Projecting Heatwaves Is Hard: We Can Do Better

Geert Jan Van Oldenborgh[1], Michael F. Wehner[2], Robert Vautard[3], Friederike E. L. Otto[4], Sonia I. Seneviratne[5], Peter A. Stott[6], Gabriele C. Hegerl[7], Sjoukje Y. Philip[1], and Sarah F. Kew[1]

- The effect of increased greenhouse gas on high temperatures is amplified or moderated at local scales by other factors
- Confident quantitative attribution statements of the human influence on heatwaves are limited by our understanding of these local processes

Outline

1. Extreme event attribution

2. The case of very extreme events: the June 2021 Pacific Northwest heatwave

3. Summary

Extreme Event Attribution (EEA)

- **Question generally asked**: has climate change caused a specific extreme event (heatwave, drought, storm)?
- **Attribution science**: make robust and quantitative statements about the extent to which human influence (and other factors) have influenced the magnitude and/or probability of occurrence of extreme events
- Framing the attribution study of extreme event is key

Otto et al 2016, Nature Climate Change

Extreme attribution approaches

- The standard "probability-based" approach

Q: How was the likelihood/magnitude of the event affected by climate change?

→ Any extreme event is unique (will not happen again anytime soon !)

→ Need to assess risk for a **class** of events with *"similar or greater"* impacts

- The storyline or "singular/conditional" approach

Q: What were the relevant causal factors that led to the event?

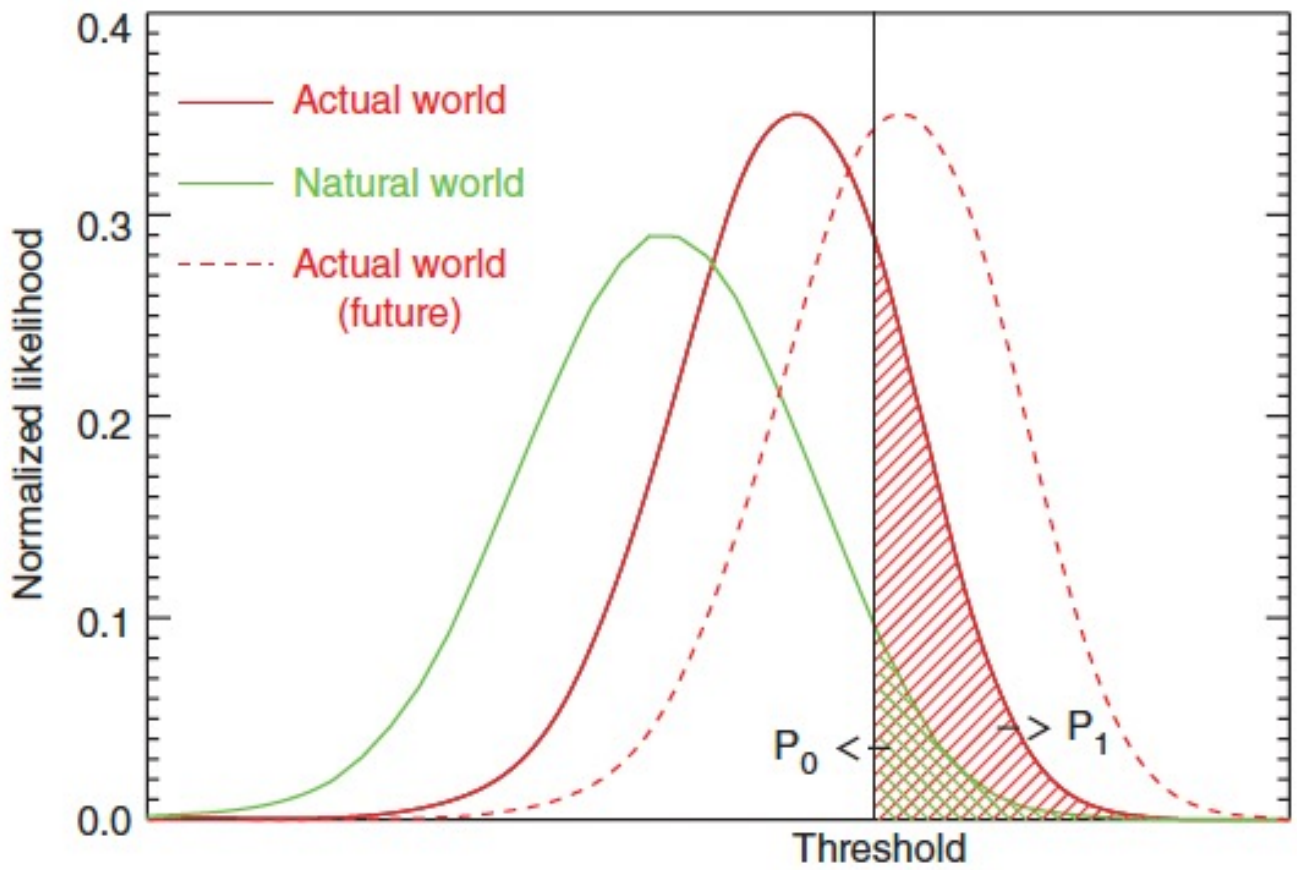
Q: How might climate change and/or internal variability have contributed to those causal factors?

Lloyd and Shepherd 2020, Ann. N.Y. Acad. Sci.

The probability-based approach

- Compare the frequency p_1 of a class of events in a factual world (the one we live in) with that of a counterfactual world p_0 (without anthropogenic forcing)

- **PR** = p_1 / p_0.   **FAR** = $1 – p_0 / p_1$



Class of events

Naveau et al., Annu. Rev. Stat. Appl. 2020. 7:89–110; Stott et al., WIRE, 2016

The probability-based approach in practice

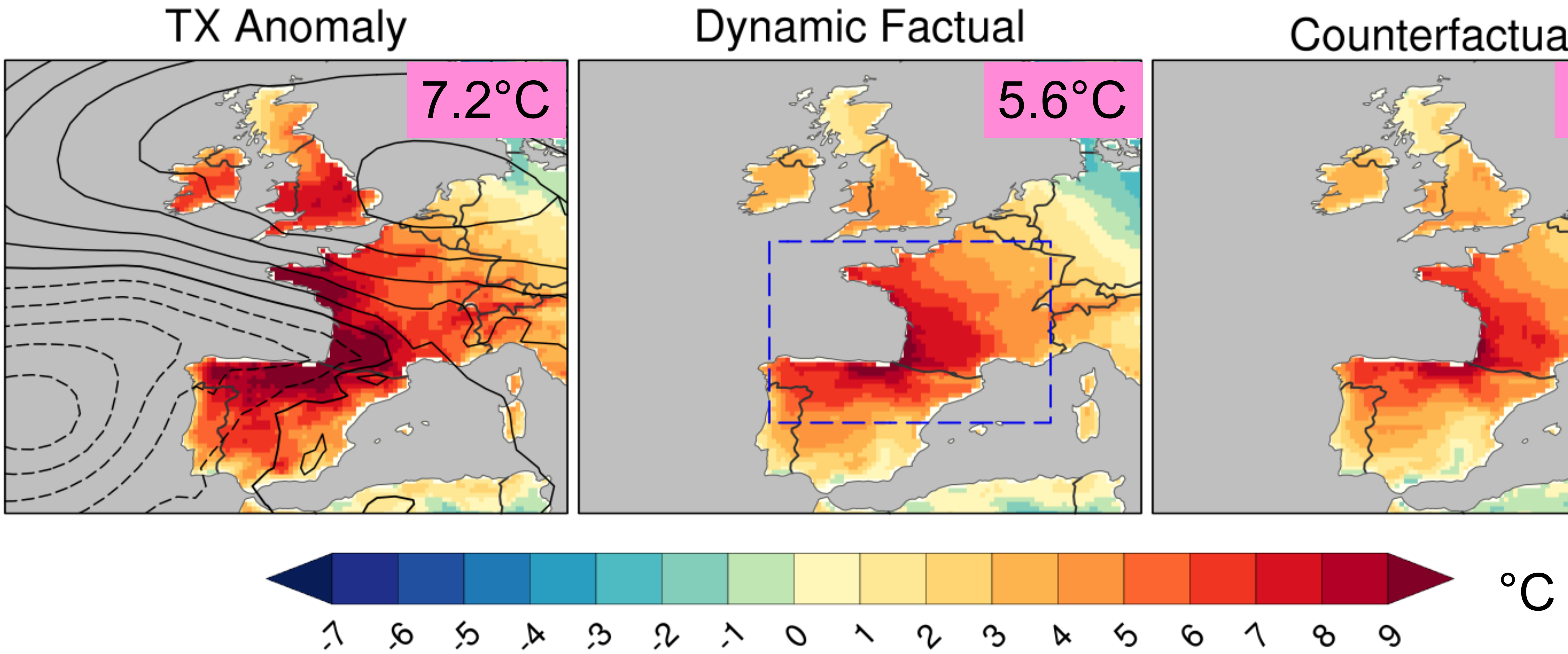
Probability – based approach

- **Without models**
  - **Empirical approach**
    Statistical fit to Obs. ★
  - **Analogue approach**
    Observations/reanalysis
- **With models**
  - **Coupled model approach**
    1. *Unconditional*
    2. *Conditional: external forcings* ★ *modes (AMV, PDV), atmospheric circulation*
  - **Atmospheric model approach**
    1. *Conditional to SST/SIC* ★
    2. *Atmospheric circulation, soil moisture*

Philip et al. 2020, ASCMO

The storyline/conditional approach

- Heatwave 15–18 July 2022
- Conditional to the atmospheric circulation (dynamical adjustment)



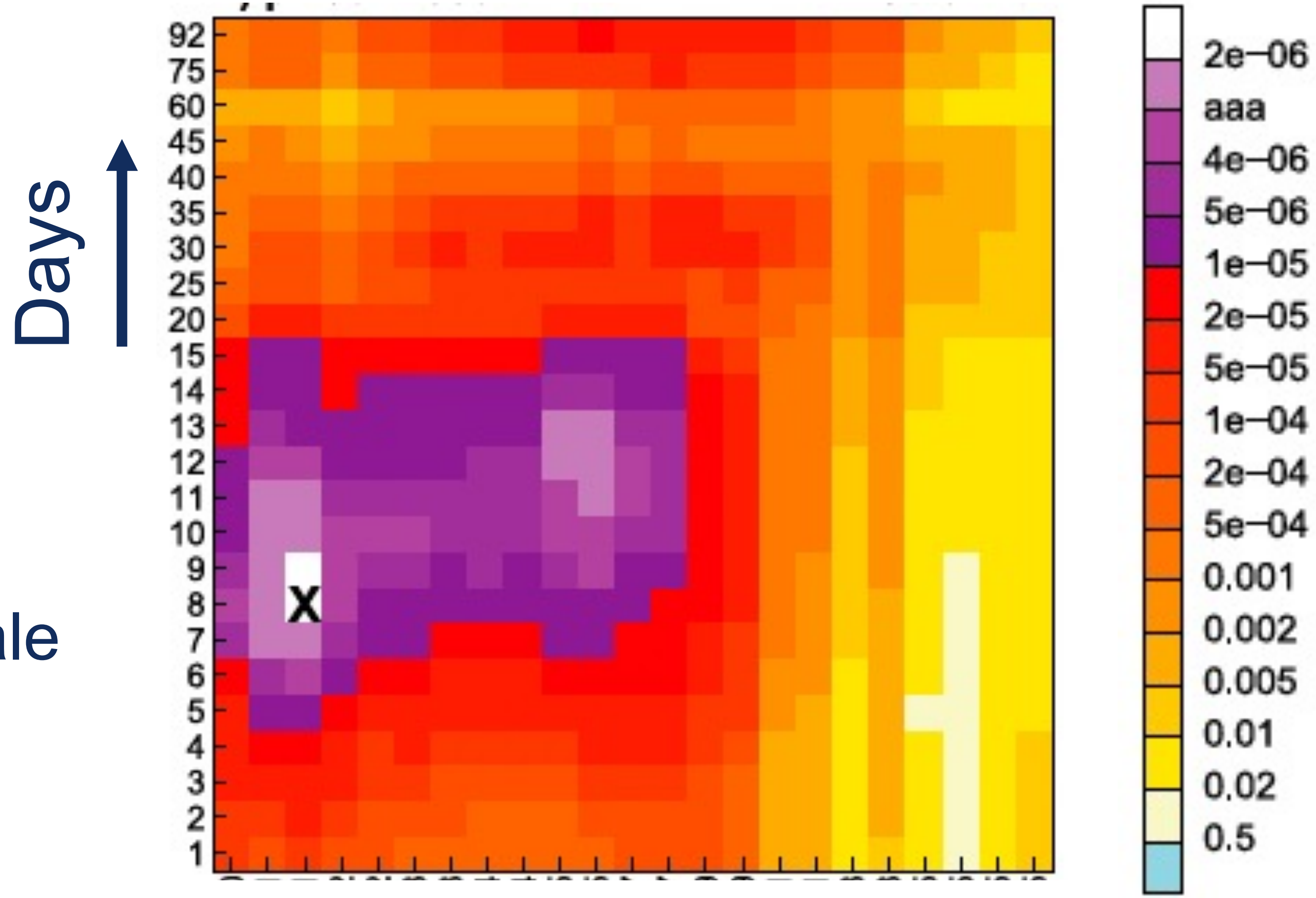
The WWA protocol

- Analysis trigger
- Event definition: spatial and time scale
- Observed analysis (GEV Fit and trend)
- Model evaluation and selection: statistical description and physical causes of extremes
- Multi-method – multi-model attribution
- Synthesis and communication

Philip et al. 2020, ASCMO; Van Oldenborgh et al., 2021, Climatic Change

Define the class of events: spatial and time scales ?

- Maximizing the rarity of the extreme event (minimize p_1)
- 2003 heatwave
- Temp. June 1, Paris
- 1950 – 2015
- Gaussian fit



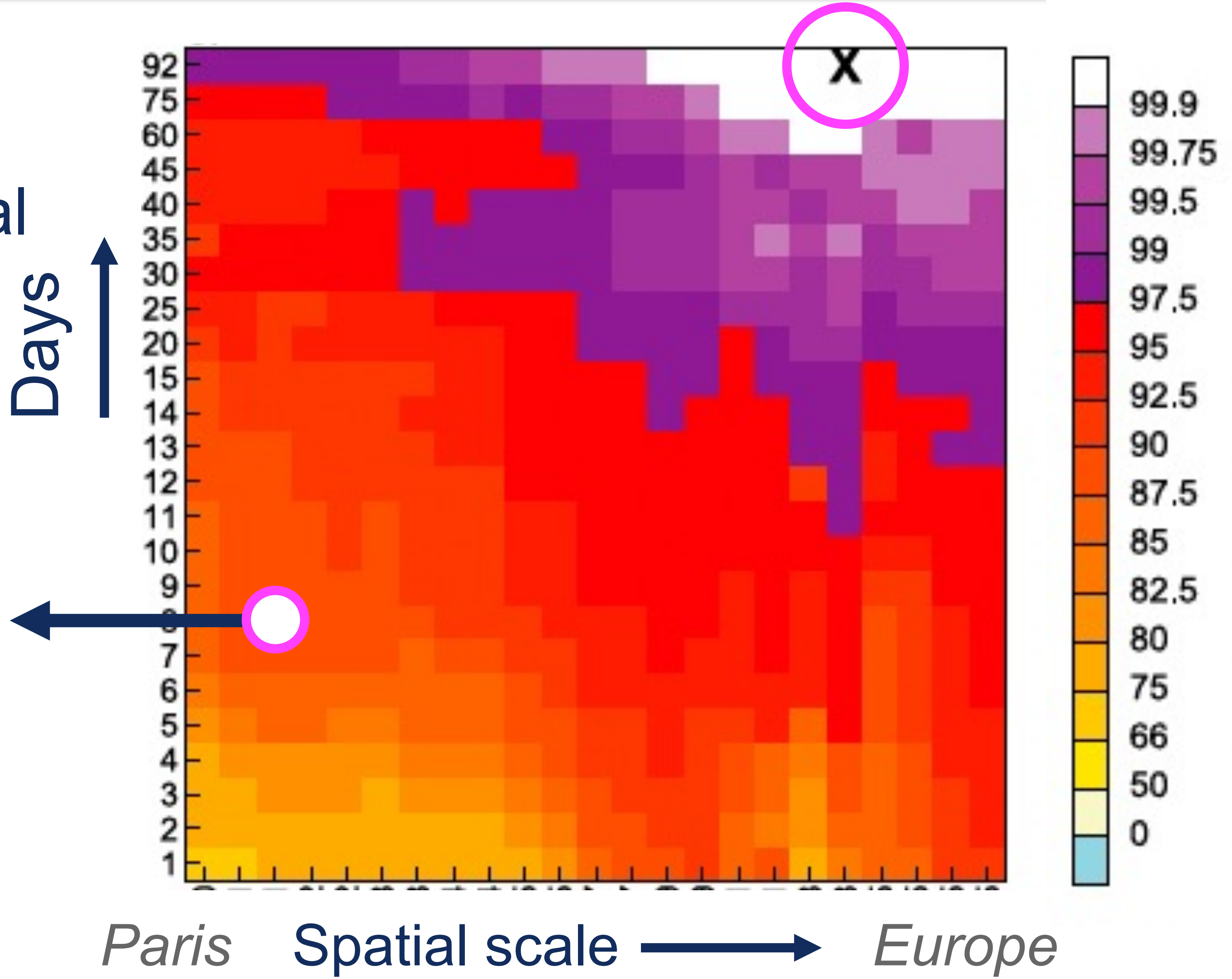
Minimize (P_1):

→ 8 days and small scale

Cattiaux et Ribes, BAMS, 2018

Maximizing the rarity does not bias attributable risk

- FAR : max. at large spatial and temporal scales



Cattiaux et Ribes, BAMS, 2018

Observations: GEV fit and trend

- Generalized extreme value distribution: block maxima

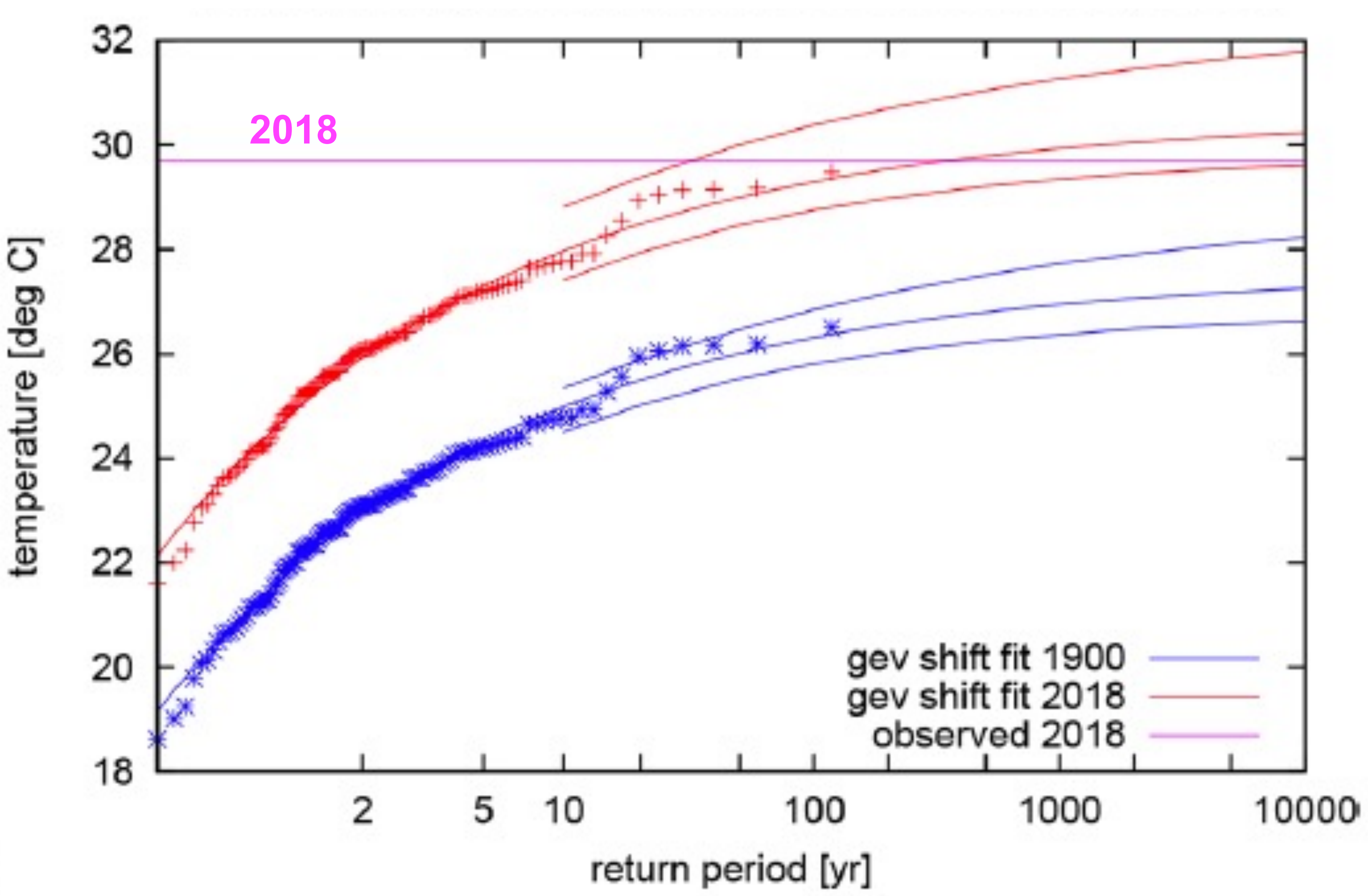
$$P(x) = \exp\left[-\left(1+\xi\frac{x-\mu}{\sigma}\right)^{-1/\xi}\right]$$

- Assume trend scales with GMST : $\mu \sim \mu_0 + \beta \, . \, \mathrm{GMST}$

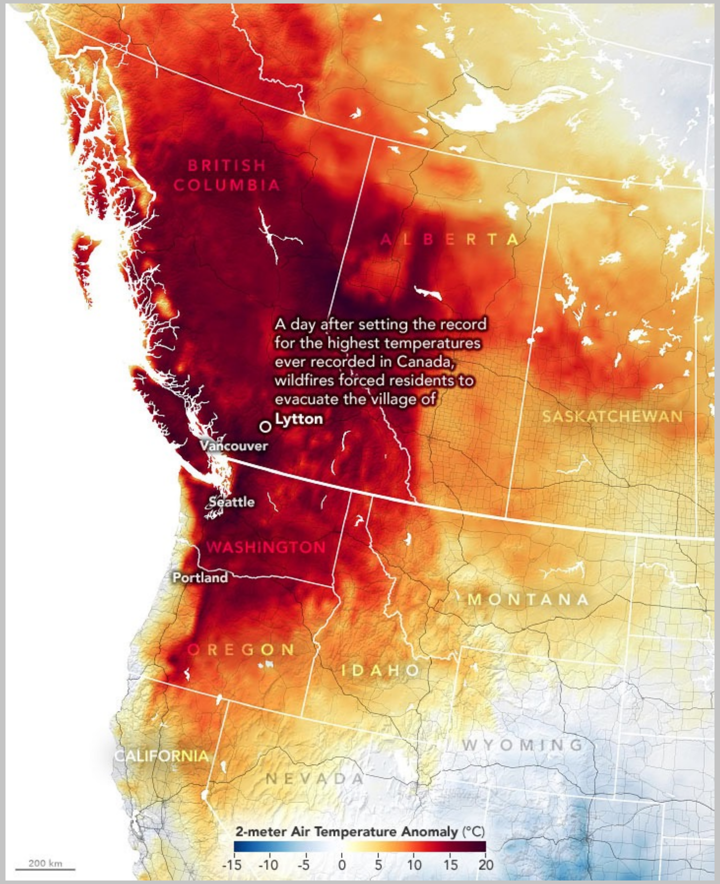
- Fit: estimation of β in addition to the GEV parameters

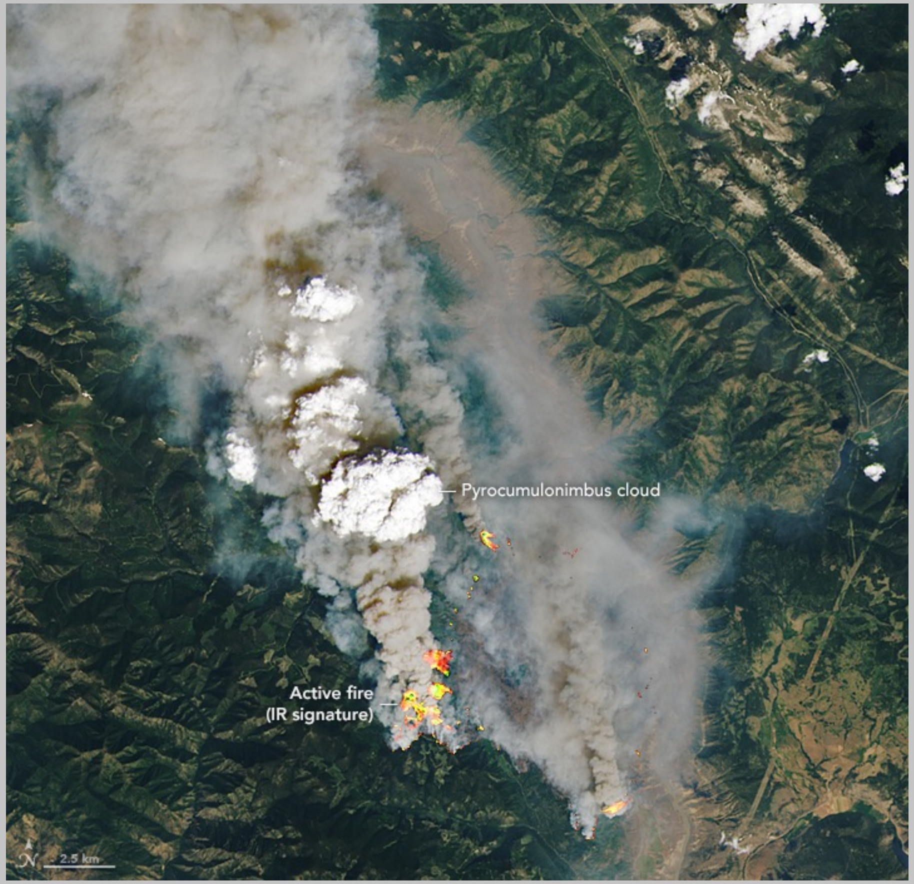
Observations: GEV fit and trend

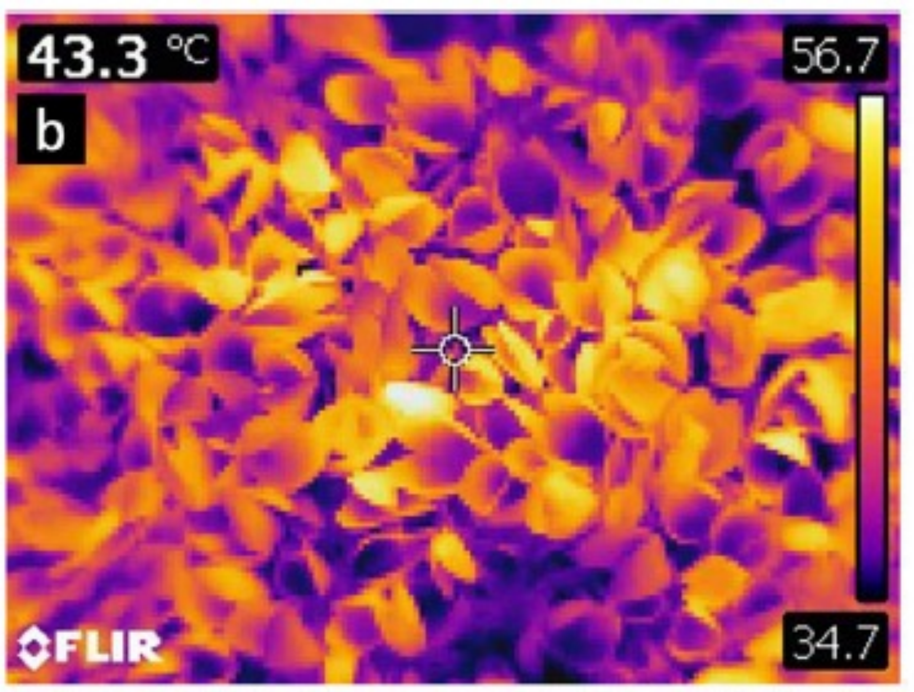
- Annual Max. TX in De Bilt (1900–1917)



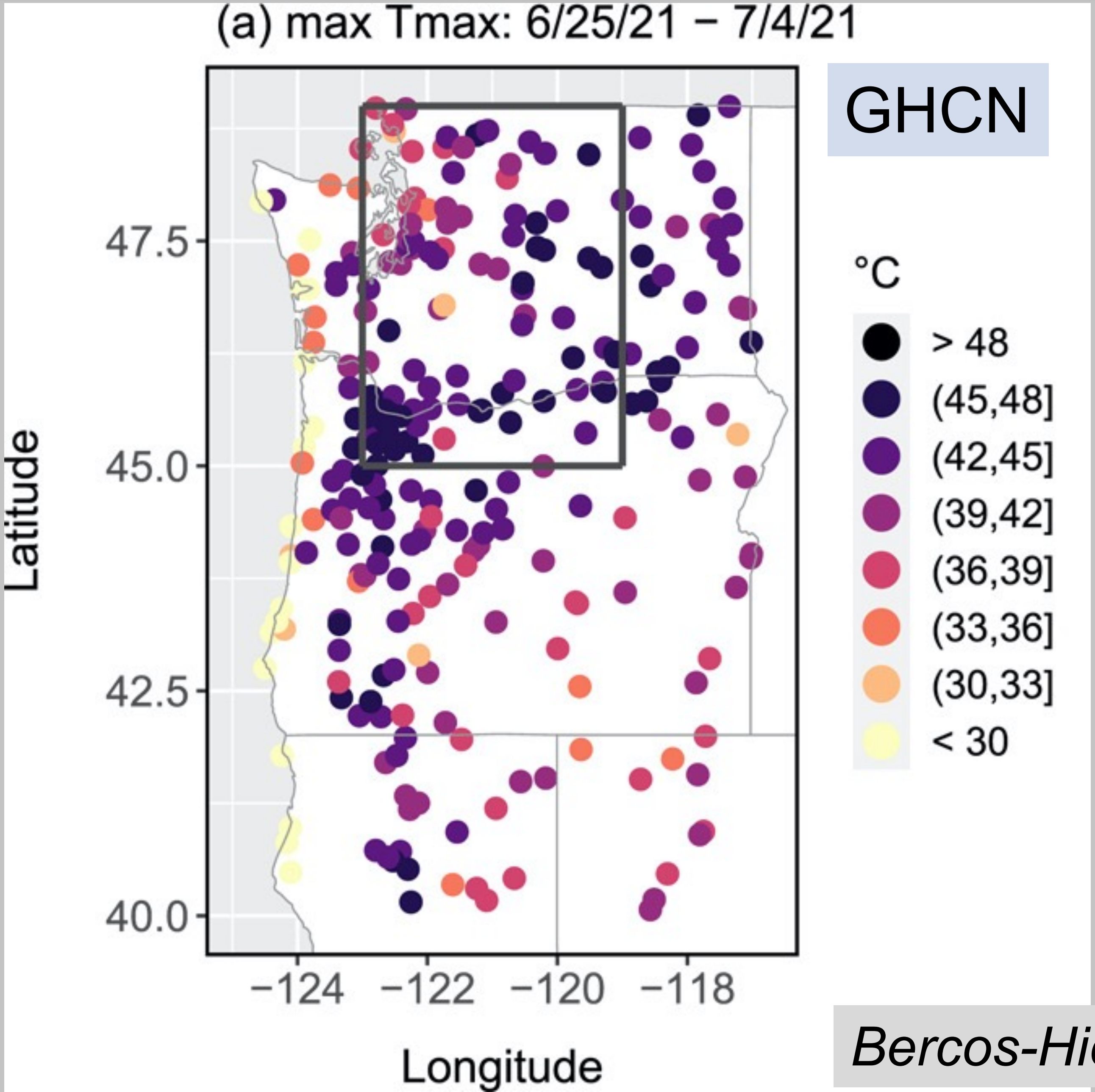
The June 2021 Pacific Northwest heatwave

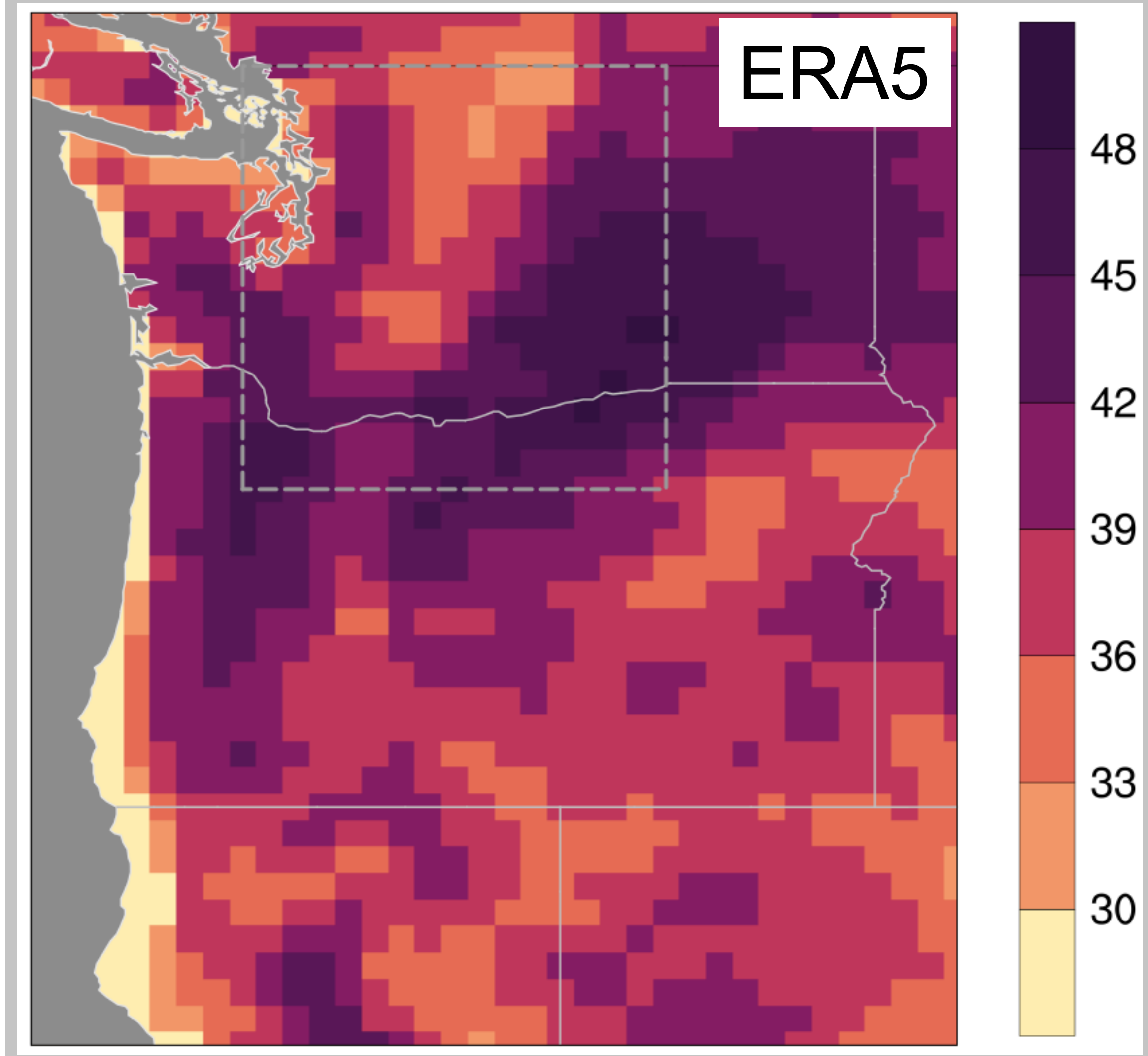






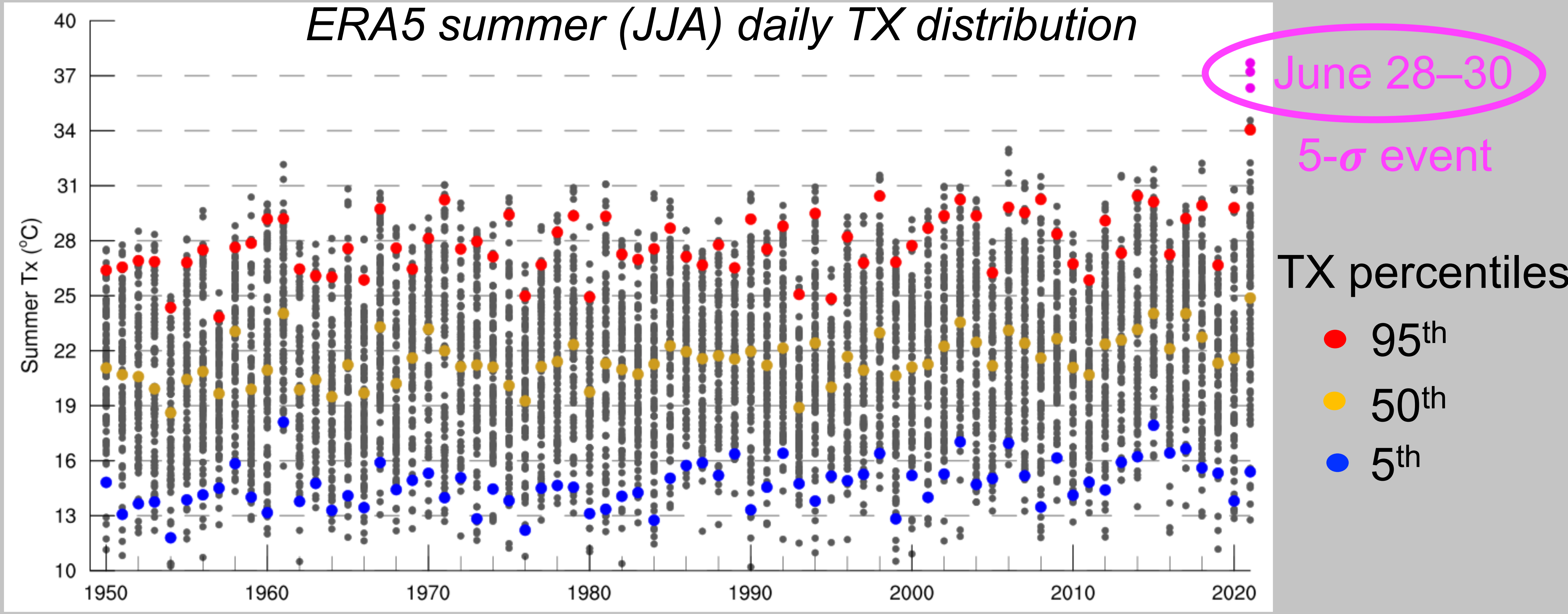
ERA5 and Observations for late June 2021





Bercos-Hickey et al.,2022, GRL

The extreme character of the June 2021 heatwave



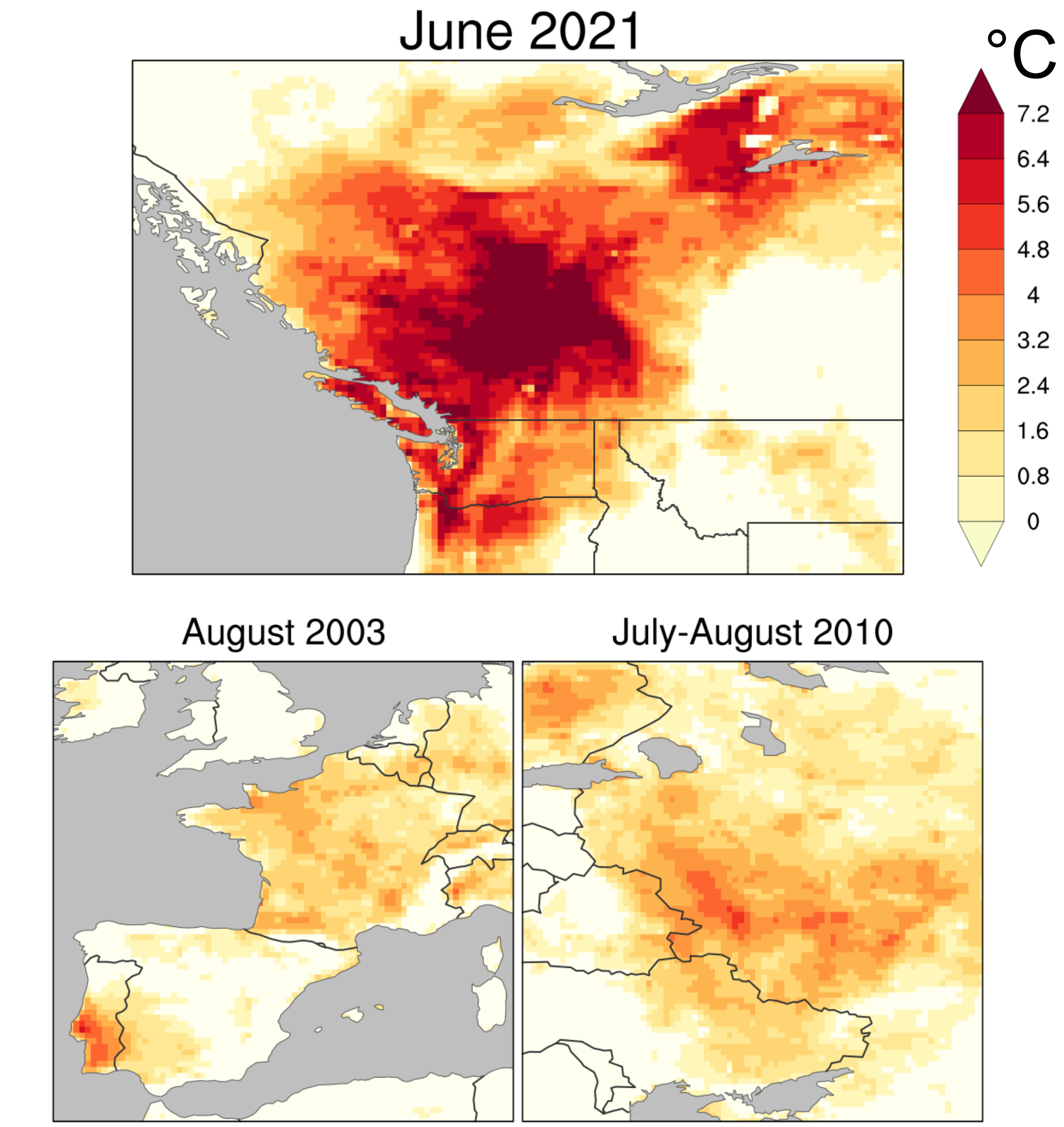
Terray, 2023, GRL

Heatwave period: 28–30 June

The extreme character of the June 2021 heatwave

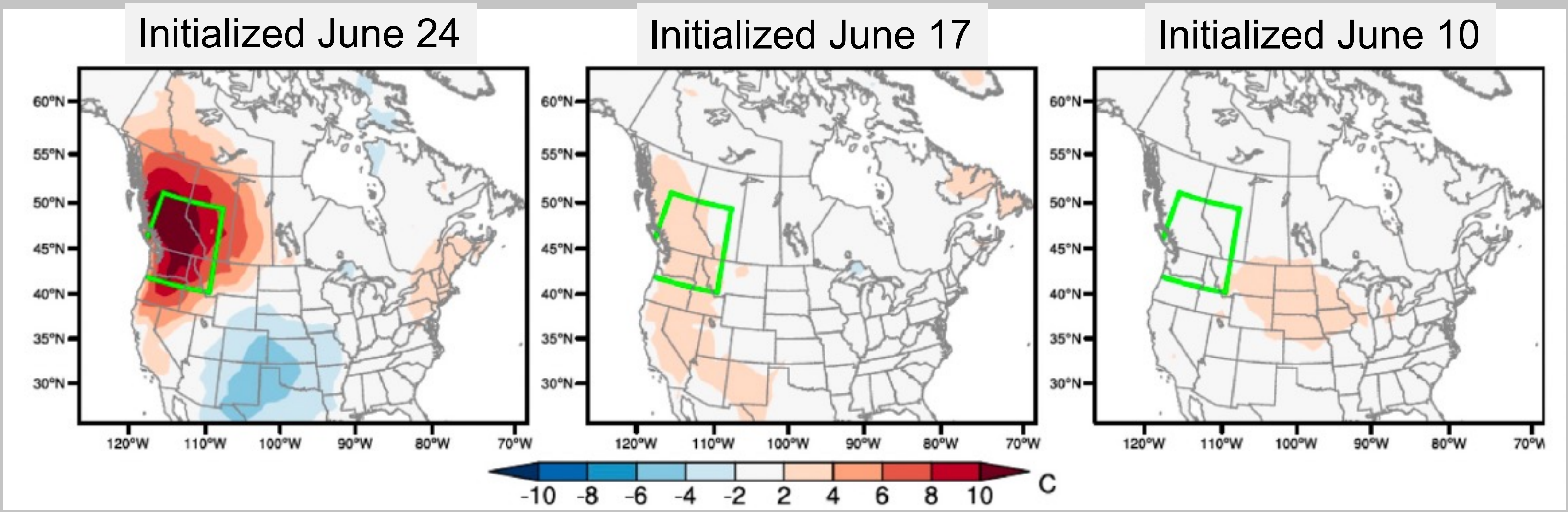
Increase in new TX records for 3 heatwaves:

- June 2021 (Canada)
- August 2003 (Europe)
- July-August 2010 (Russia)



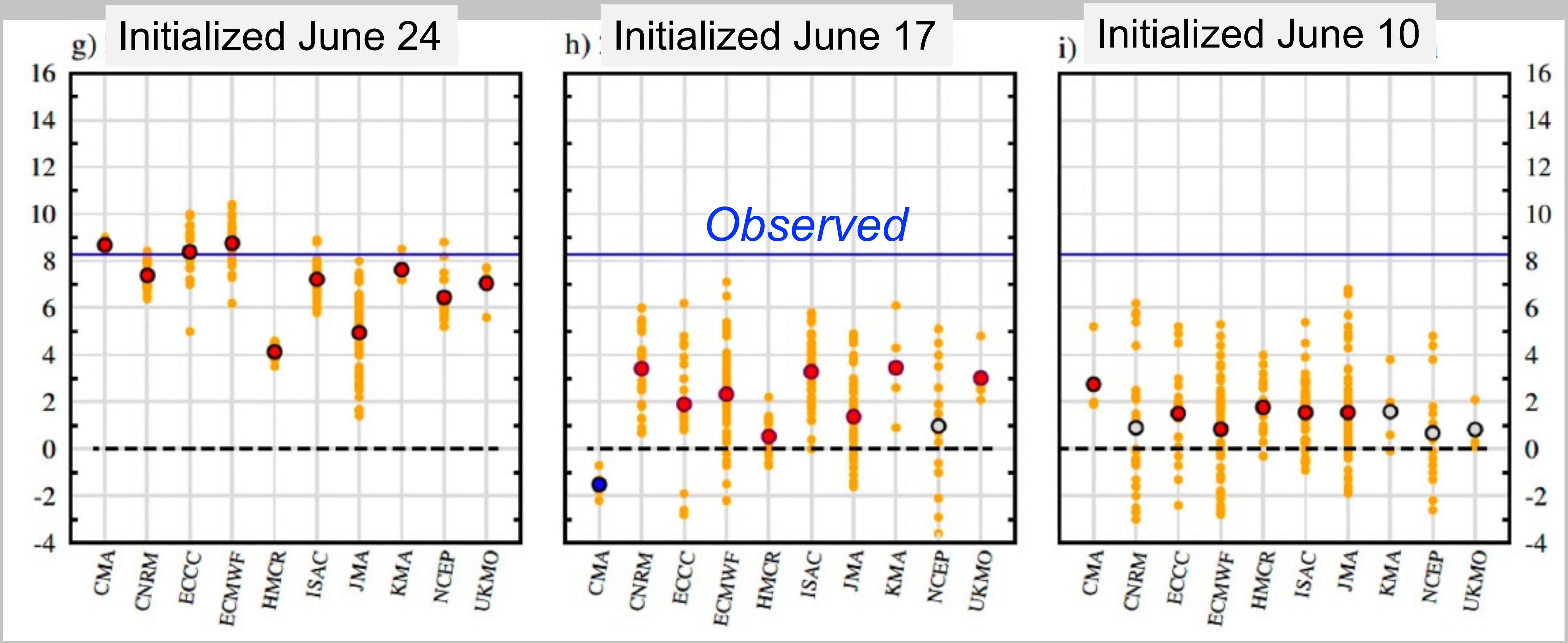
Was the June 2021 heatwave predicted ?

- Initialized S2S ECMWF forecast system



Was the June 2021 heatwave predicted ?

- S2S Multi-Model forecast system
- Prediction of box-averaged temperature

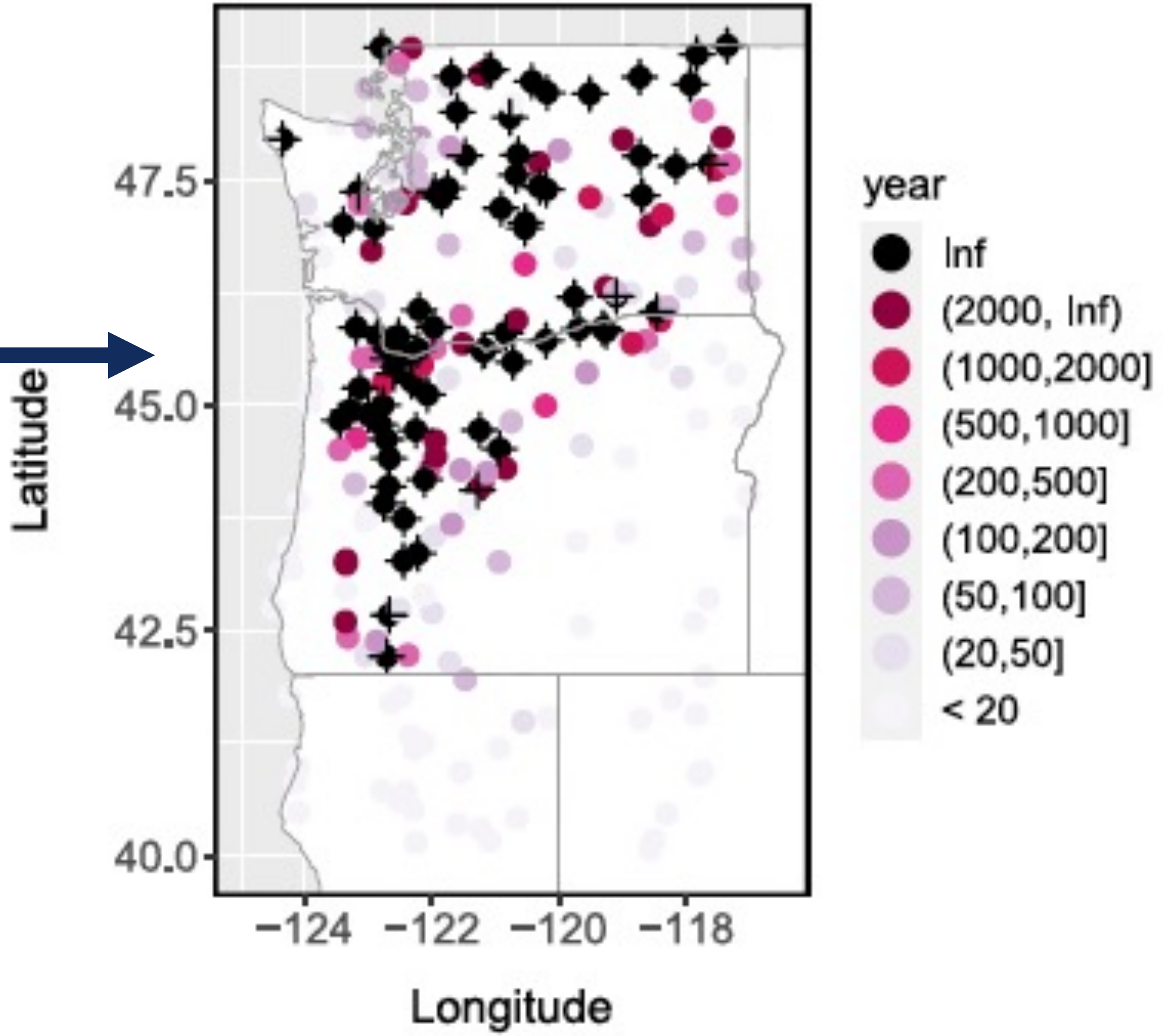


The probability-based approach fails ....

Out of sample: non-stationary GEV fit

Infinite return periods !

In sample (including 2021): poor fit to the past data !



Bercos-Hickey et al., 2022, GRL

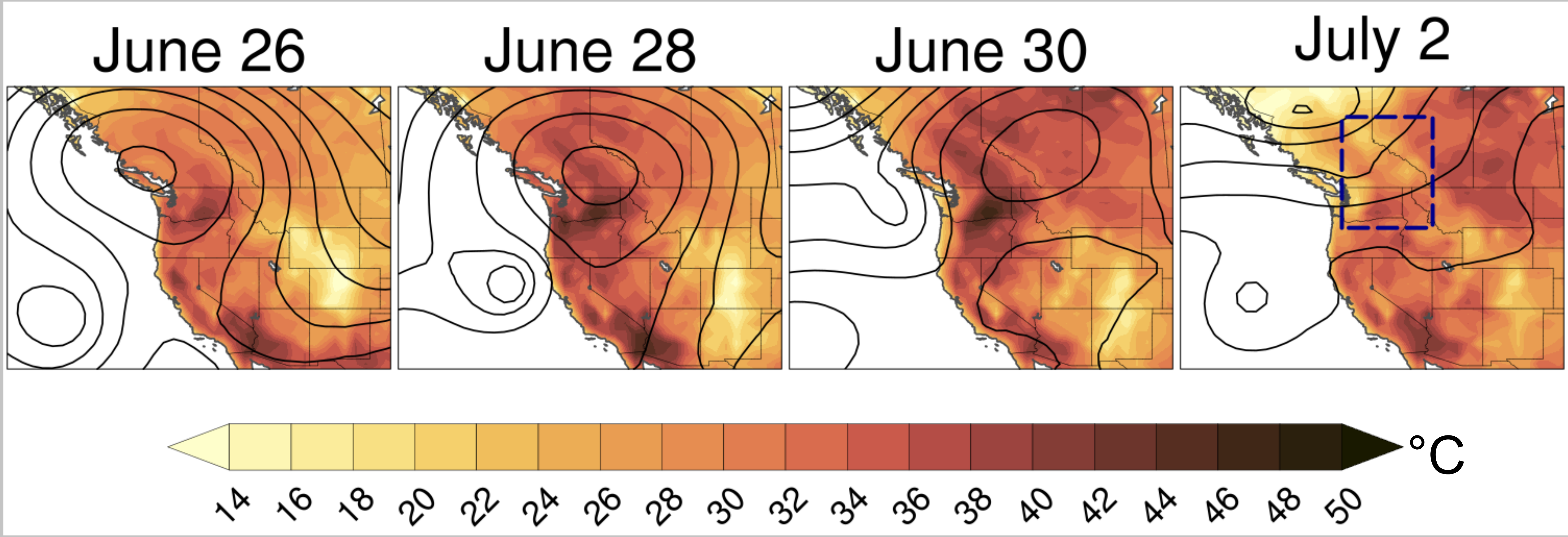
Storyline approach: drivers of the June 2021 heatwave

Four main potential ingredients:

- The atmospheric circulation pattern
- *A soil moisture deficit*
- *A late June atmospheric river*
- *Possible ocean influence (PDO) ?*

The atmospheric precursor

- ERA5 : maximum temperature (TX), 500-hPa geopotential height (Z500)



Dynamic contribution to the heatwave ?

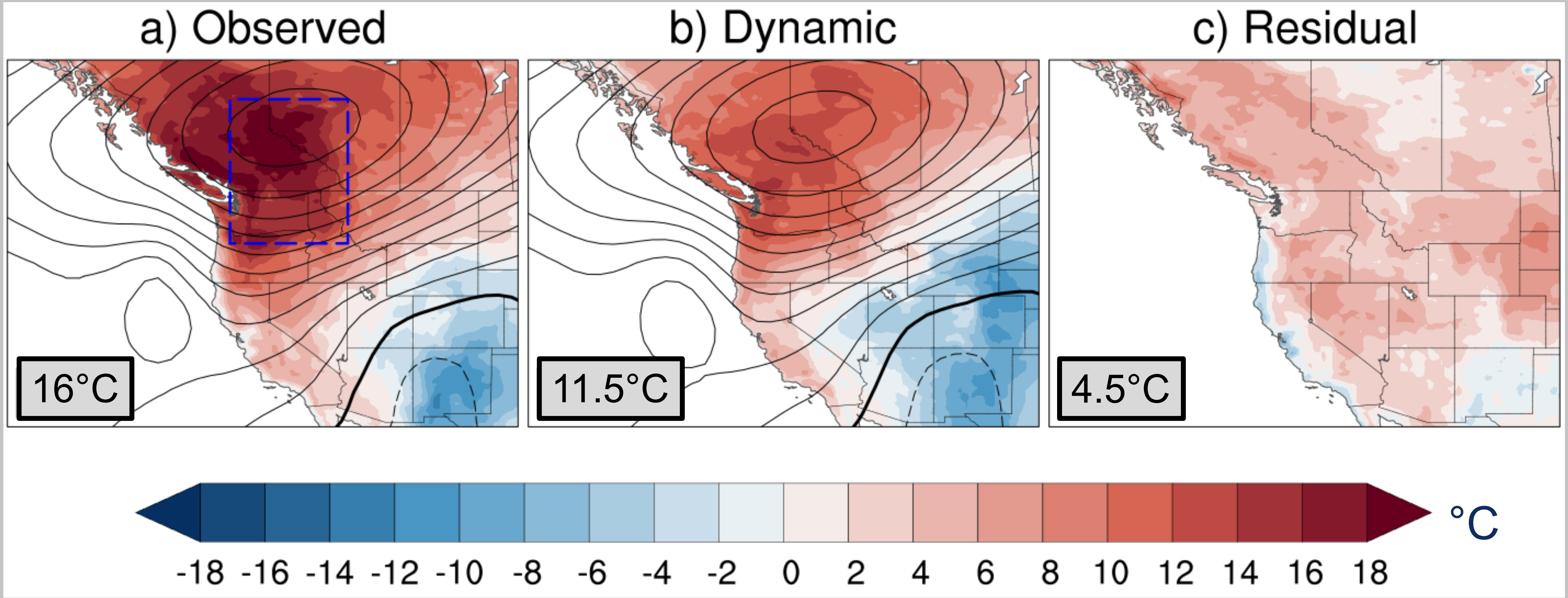
Dynamical Adjustment

- Separate the variability due to atmospheric circulation (*the dynamic component*) from a residual (« *thermodynamic* » *component*)

- Method based on constructed daily analogues (here Z500, 500 hPa geopotential height) to derive the TX (maximum temperature) dynamical component

- TX dynamic component is estimated in both factual and counterfactual worlds (removing a smooth non linear trend from TX data)

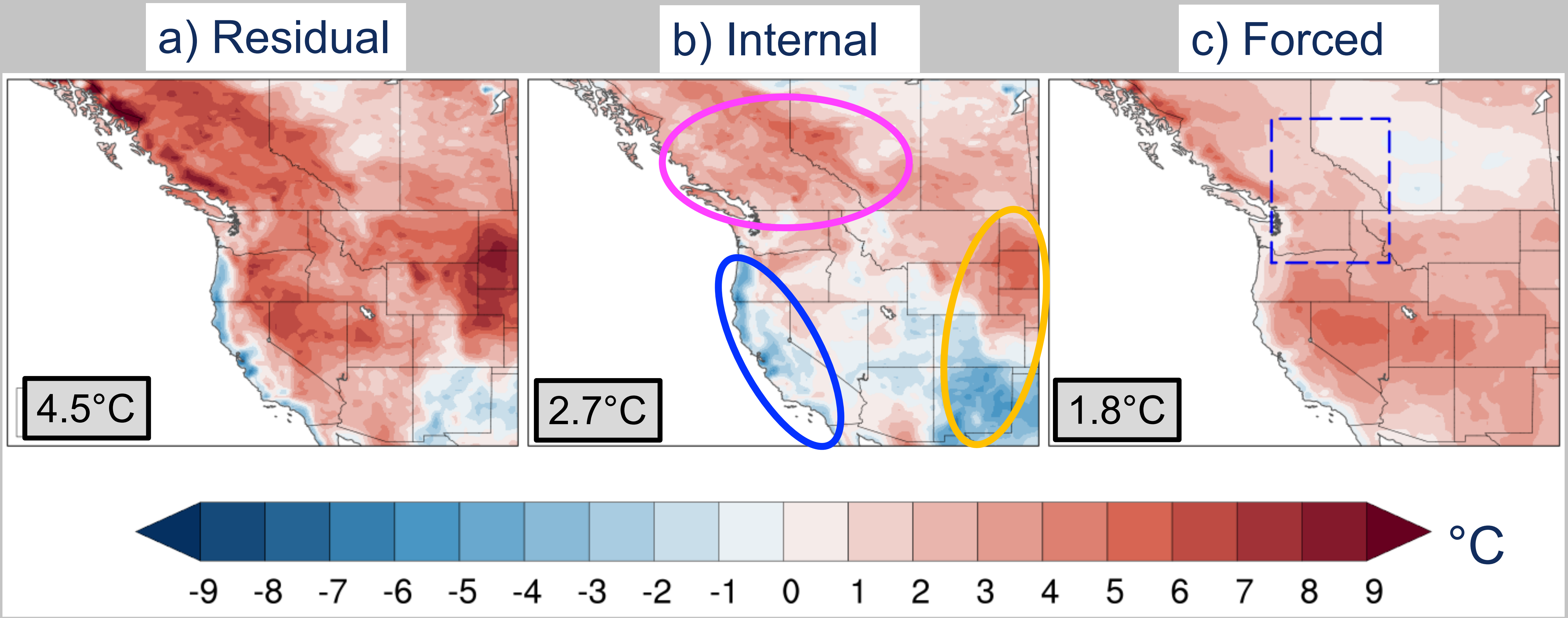
Heatwave Dynamic Component



TX anomalies relative to the 1991-2020 climatology

Terray, 2023, GRL

Residual: Internal and Forced Contributions



Note: different color scale !

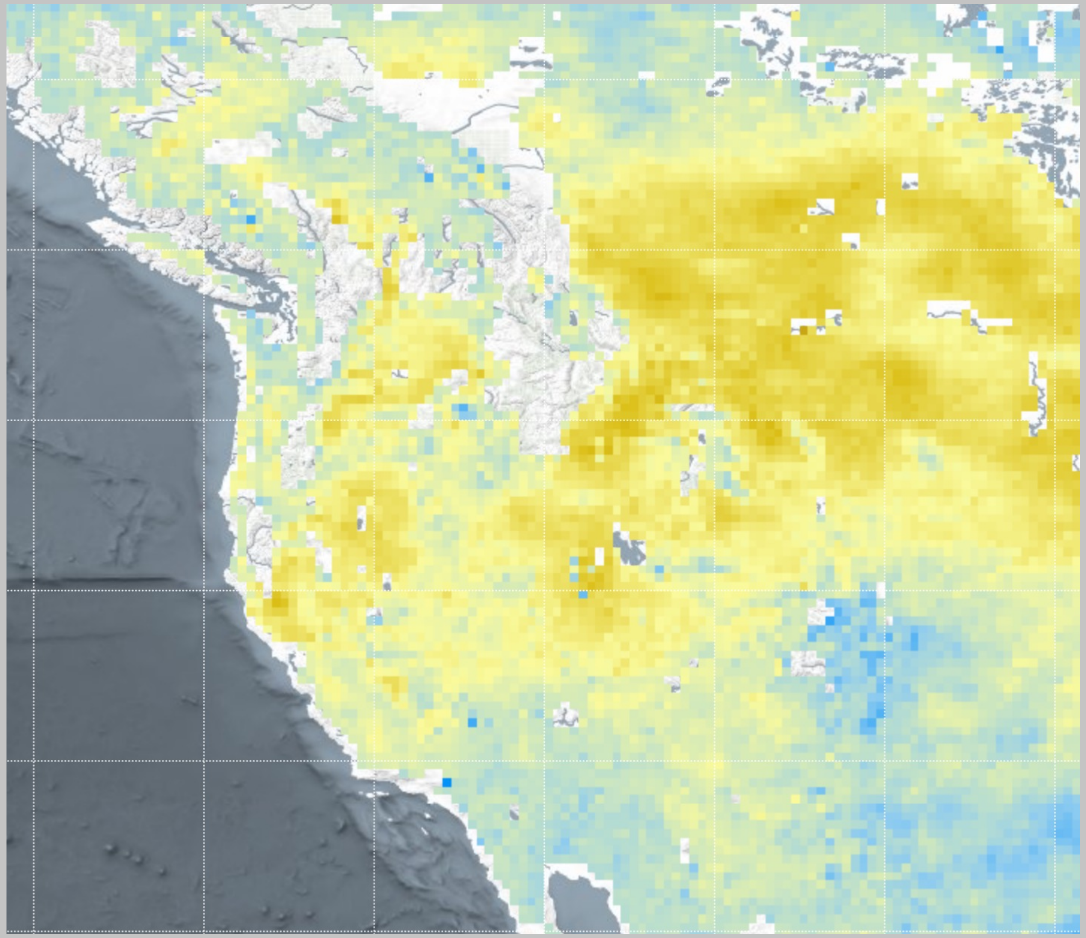
Drivers of the June 2021 heatwave

Four main potential ingredients:

- *The atmospheric circulation pattern*
- A soil moisture deficit
- *A late June atmospheric river*
- *Possible ocean influence (PDO) ?*

Soil moisture deficit in June 2021

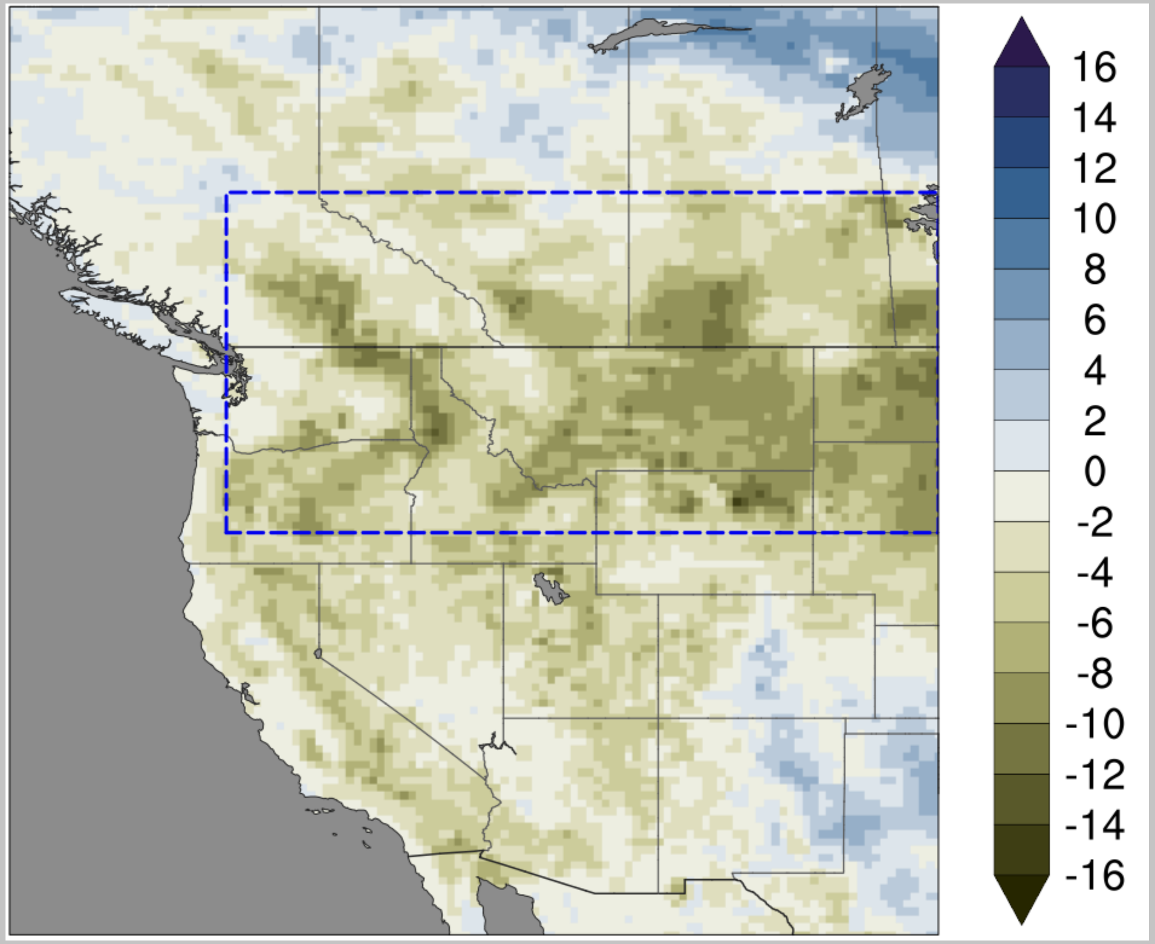
ESA CCI product (%)



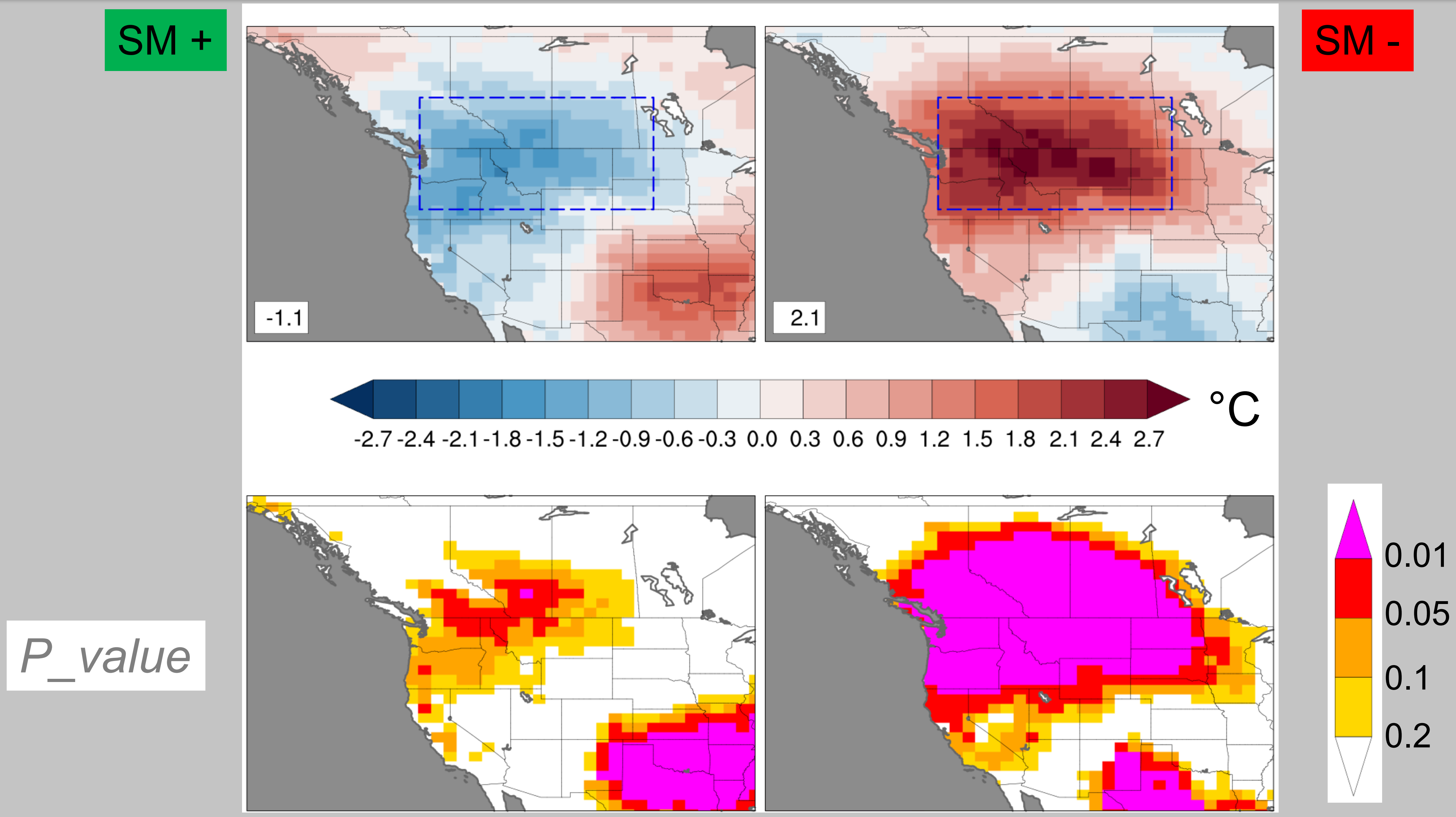
-16

+16

ERA5 (%)



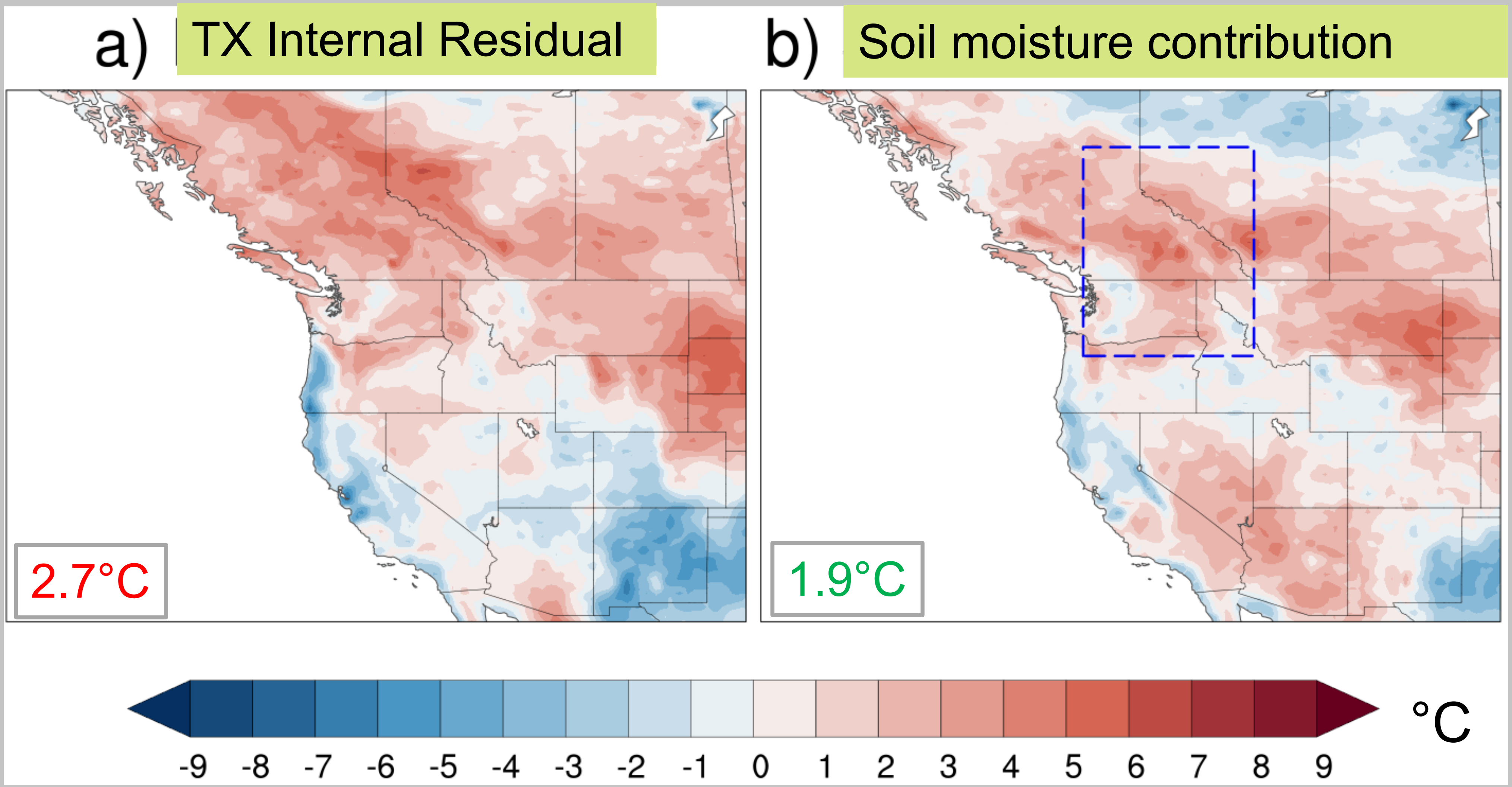
Summer TX composite ERA5



Estimate soil moisture contribution to the event ?

- Cannot be inferred directly from the composite analysis
- Select June-July ERA5 days with the region-averaged soil moisture anomaly > 1 sigma and < -1 sigma
- Perform dynamical adjustment separately on the two daily datasets
- Look at impact of a -2 sigma soil moisture anomaly.

Soil moisture contribution



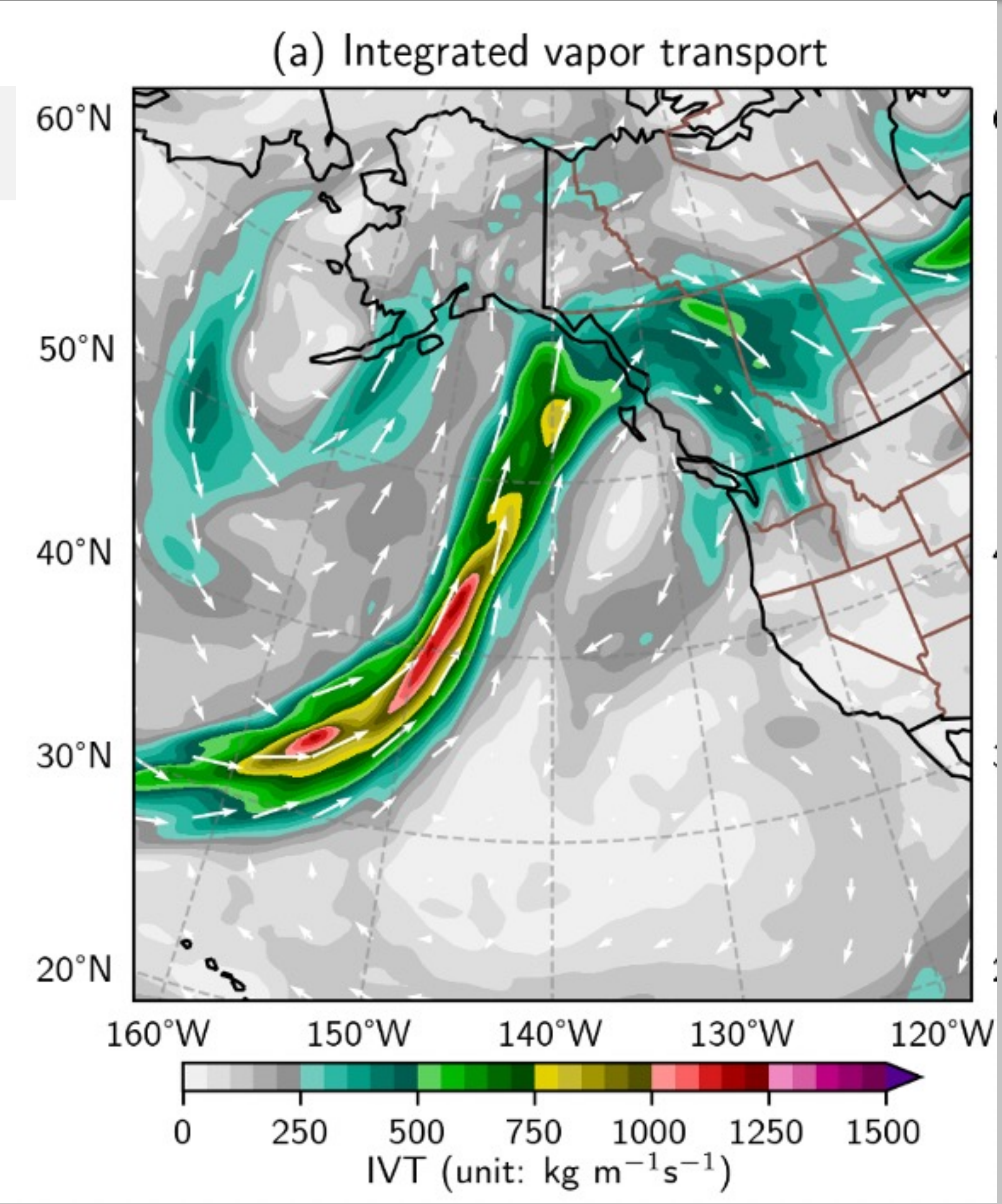
Drivers of the June 2021 heatwave

Four main potential ingredients:

- *The atmospheric circulation pattern*
- *A soil moisture deficit*
- A late June atmospheric river
- *Possible ocean influence (PDO) ?*

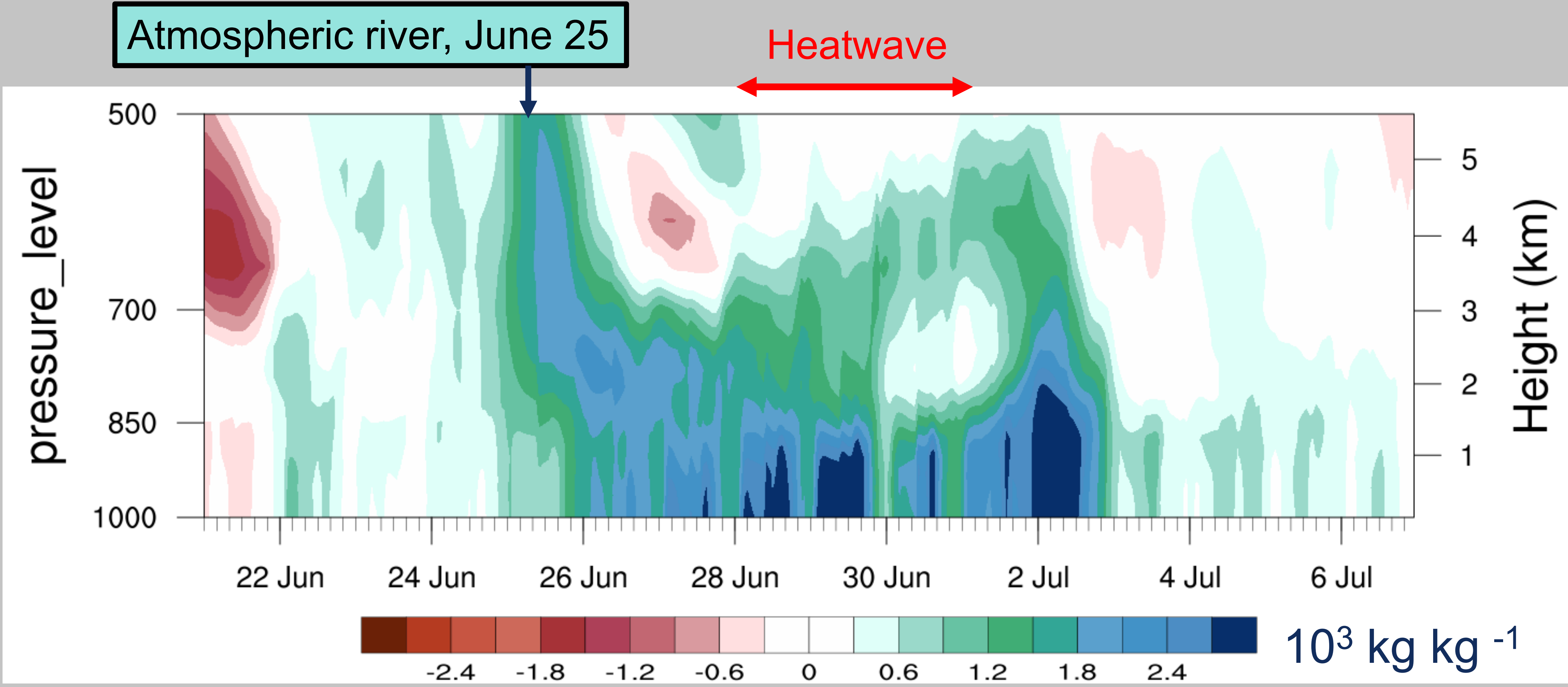
Late June 2021 atmospheric river

June 25, 12H00 UTC



Lin et al. 2022, GRL

The importance of moisture



Terray 2023, GRL

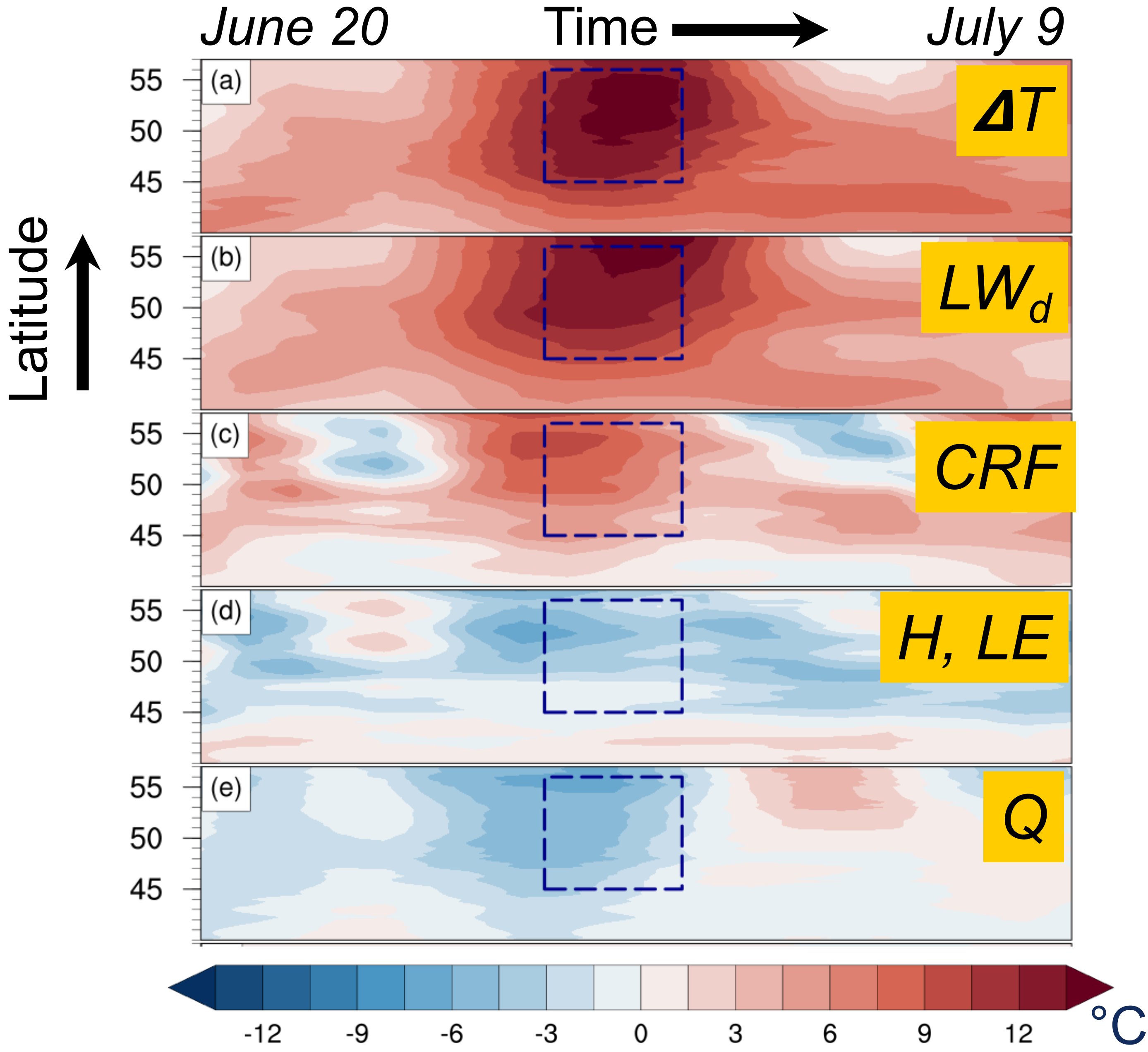
Surface heat budget for the heatwave region

$$Q = (1-\alpha)S^{\downarrow} + F^{\downarrow} + F^{\uparrow} - H - \mathrm{LE}$$

With $F \cong 4\,\sigma\,T_s^4$

Perturbed state: summer 2021

Reference : climatology



Summary

- Probability-based approach for the June 2021 heatwave fails to assess FAR and PR
- Storyline approach: circulation 72% ± 9%, soil moisture (12%), forced contribution (11%)
- Model-based approach (Schumacher et al. 2022, nudged experiments): circulation 81%, soil moisture 12% and forced TX response 7%
- Late June 2021 heatwave would have been an extraordinary event even without climate change (14.2°C instead of 16°C)
- Assuming a 7-day weather sequence and 30 d.o.f globally, one has ~156000 events over 100 years
- Non-zero probability to have some very extreme ones by chance