The Abdus Salam International Centre for Theoretical Physics

Attributing Extreme Events: Methods and Applications Using RCM Data

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Detection and attribution analysis

- Developed in the 1990s, detection and attribution analysis seeks to determine whether climate is changing significantly, and if so, what has caused such changes [1].
  - To identify the impacts of anthropogenic climate change that are already occurring.
  - Focused on long-term evolution/trend of climate variables and the statistics for the extremes averaged over a large area (usually global or continental scale).
  - Popular methods include optimal fingerprinting, spatial correlation, Granger causality.
- Attribution of a specific extreme event was considered impossible.

[1] Stott, P. A., Gillett, N. P., Hegerl, G. C., Karoly, D. J., Stone, D. A., Zhang, X., & Zwiers, F. (2010). Detection and attribution of climate change: a regional perspective. Wiley interdisciplinary reviews: climate change, 1(2), 192-211.

Extreme event attribution

Commentary | Published: 27 February 2003

Liability for climate change

Myles Allen

Nature **421**, 891–892 (2003) | Cite this article

9955 Accesses | **395** Citations | **314** Altmetric | Metrics

Will it ever be possible to sue anyone for damaging the climate?

As I write this article in January 2003, the flood waters of the River Thames are about 30 centimetres from my kitchen door and slowly rising. On the radio, a representative of the UK Met Office has just explained that although this is the kind of phenomenon that global warming might make more frequent, it is impossible to attribute this particular event (floods in southern England) to past emissions of greenhouse gases. What is less clear is whether the attribution of specific weather events to external drivers of climate change will always be impossible in principle, or whether it is simply impossible at present, given our current state of understanding of the climate system. The issue is important as it touches on a question that is far closer to many of our hearts than global sustainability or planetary survival — who to sue when the house price falls?

What fraction of a given loss was due to human influence on climate, and what fraction might have happened anyway, or happened for other reasons?

Extreme event attribution

- The main idea is to compare observed historical changes to a counterfactual climate in which the absence of all or some components of anthropogenic forcing is assumed [1].
- The necessity of extreme event attribution [1]:
  - Media and public communication
  - Climate litigation
  - Adaptation and resilience planning
  - Loss and damage

[1] Otto, F. E. (2023). Attribution of extreme events to climate change. Annual Review of Environment and Resources, 48(1), 813-828.

Framework

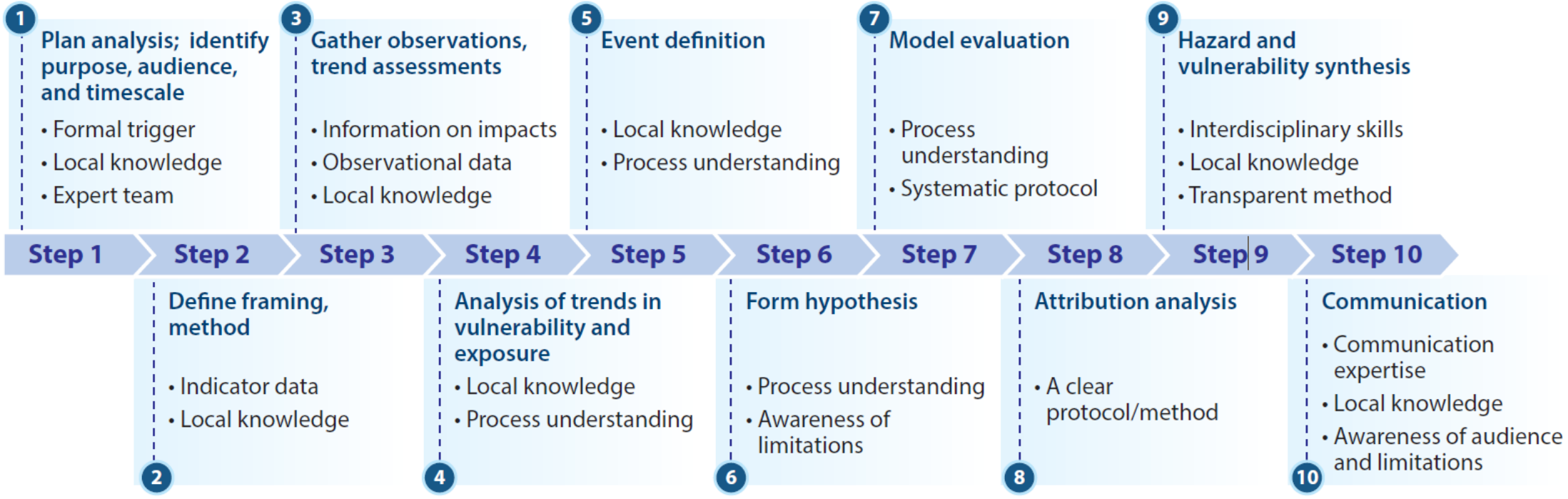


Figure: Otto, F. E. (2023). Attribution of extreme events to climate change. Annual Review of Environment and Resources, 48(1), 813-828.

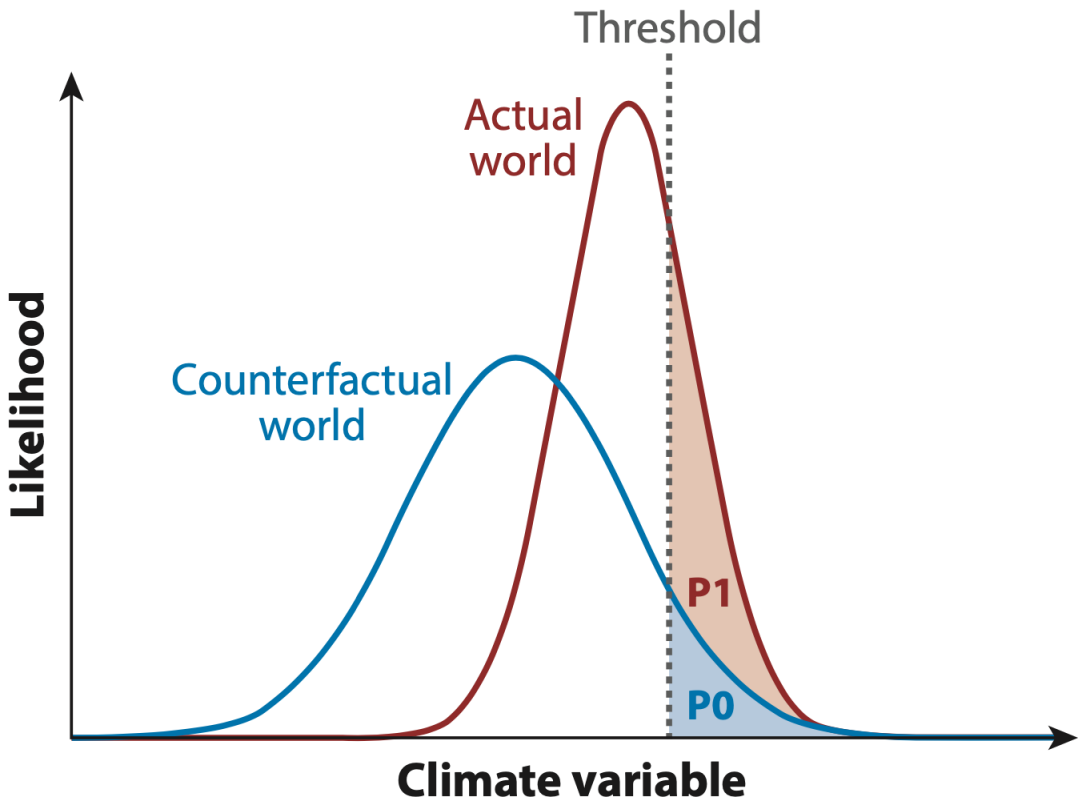
Counterfactual climate

- Observation-based
  - Less biased.
  - Short record, thus requires assumptions on the distribution of rare event.
- Model-based
  - Has model bias.
  - Has large ensemble, thus allow for the assessment of rare event statistics without assumptions on distribution.

Methods

- Probabilistic approach
- Storyline approach
- Analogues method

Probabilistic approach

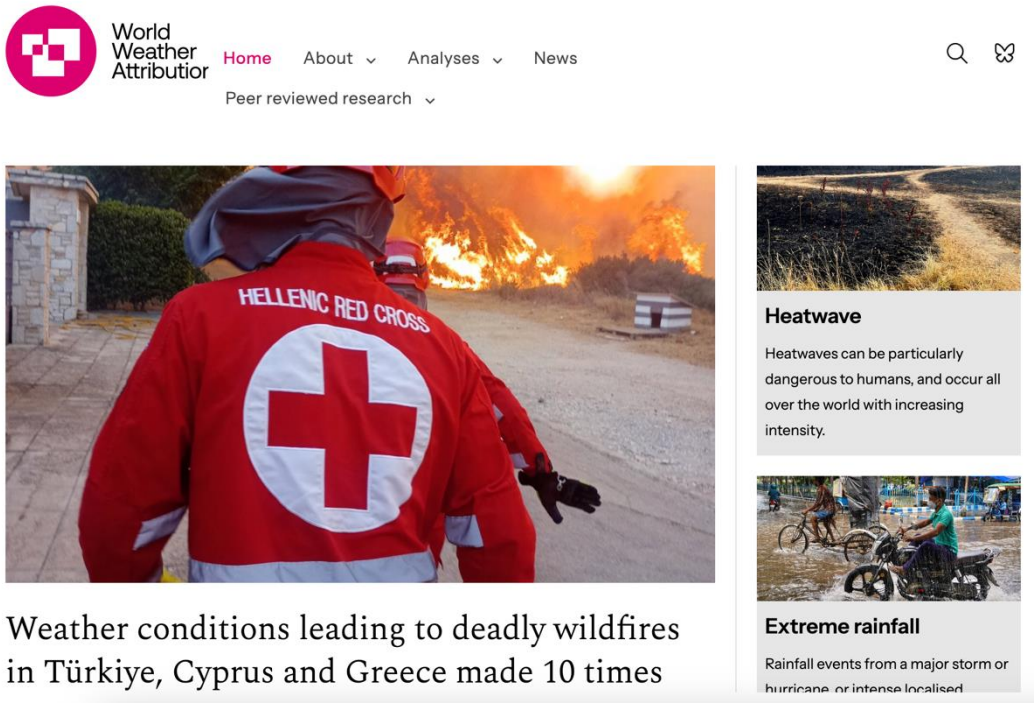


- To determine whether the frequency and/or intensity of a class of extremes is changing due to anthropogenic climate change [1].
- Probability of extreme event in
  - Counterfactual world: P_0
  - Factual world: P_1
- Probability ratio = P_1/P_0.

Figure: Otto, F. E. (2017). Attribution of weather and climate events. Annual Review of Environment and Resources, 42, 627-646.

[1] Philip, S., Kew, S., van Oldenborgh, G. J., Otto, F., Vautard, R., van Der Wiel, K., King, A., Lott, F., Arrighi, J., Singh, R. & van Aalst, M. (2020). A protocol for probabilistic extreme event attribution analyses. Advances in Statistical Climatology, Meteorology and Oceanography, 6(2), 177-203.

World Weather Attribution



DSR3x:

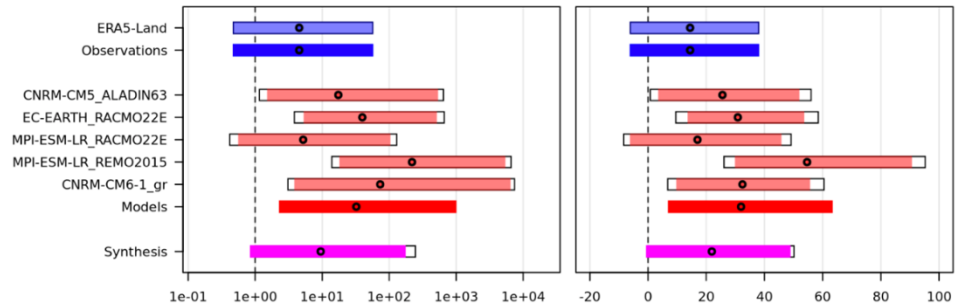


***Figure 7.1**: Synthesis of (left) probability ratio and (right) relative intensity change when comparing DSR3x over the study region with a 1.3℃ cooler climate.*

VPD7x:

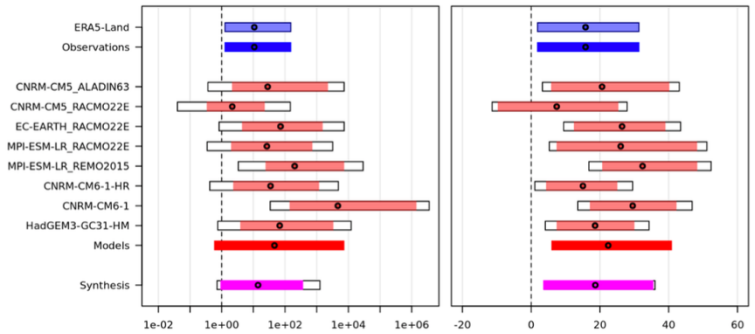


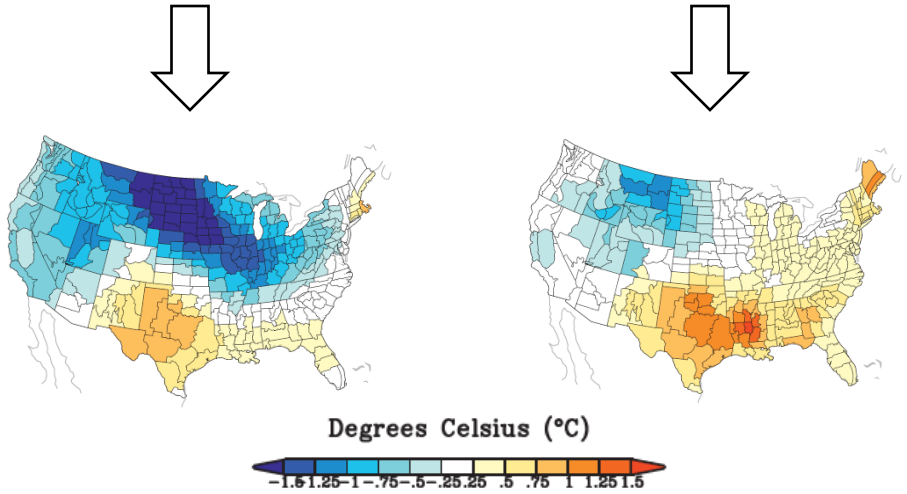
***Figure 7.2**: Synthesis of (left) probability ratio and (right) relative intensity change when comparing VPD7x over the study region with a 1.3℃ cooler climate.*

Figure: https://www.worldweatherattribution.org/

Storyline approach

External forcing fixed at pre-industrial level

Observed forcing

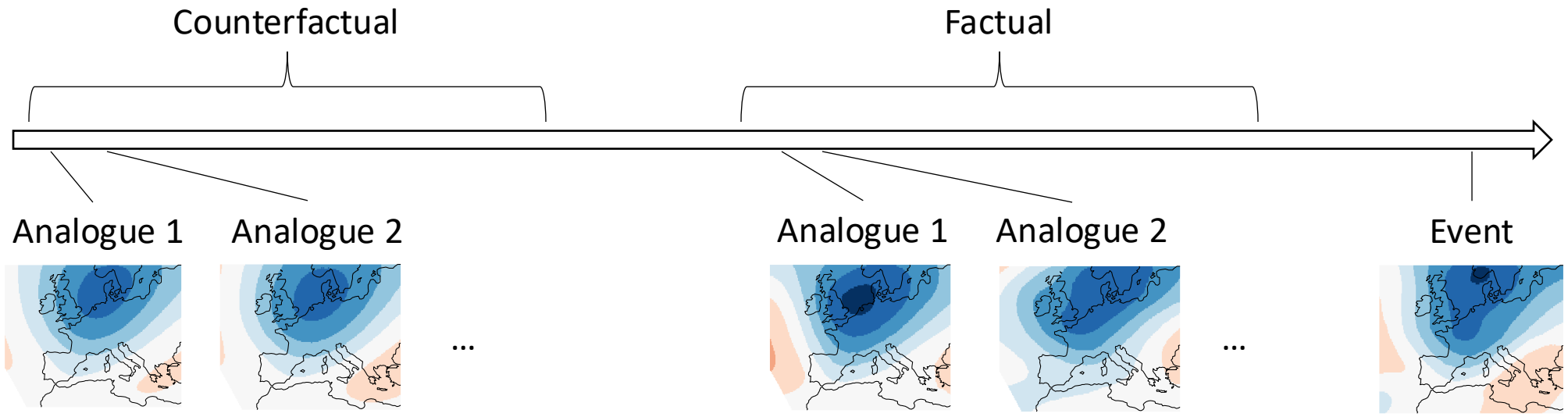


- Focused on examining the causal chain describing the extreme event [1].
- It looks at how the event was modified by the thermodynamic aspects of climate change, given the dynamical circulation [2,3].
- Common methods include Spectral nudging, pseudo-global warming, forecast-based attribution.

[1] Baldissera Pacchetti, M., Coulter, L., Dessai, S., Shepherd, T. G., Sillmann, J., & Van Den Hurk, B. (2024). Varieties of approaches to constructing physical climate storylines: A review. Wiley Interdisciplinary Reviews: Climate Change, 15(2), e869.
[2] Shepherd, T. G. (2016). A common framework for approaches to extreme event attribution. Current Climate Change Reports, 2(1), 28-38.
[3] van Garderen, L., Feser, F., and Shepherd, T. G.: A methodology for attributing the role of climate change in extreme events: a global spectrally nudged storyline, Nat. Hazards Earth Syst. Sci., 21, 171–186, https://doi.org/10.5194/nhess-21-171-2021, 2021.
Figure: Hoerling, M., Kumar, A., Dole, R., Nielsen-Gammon, J. W., Eischeid, J., Perlwitz, J., ... & Chen, M. (2013). Anatomy of an extreme event. Journal of Climate, 26(9), 2811-2832.

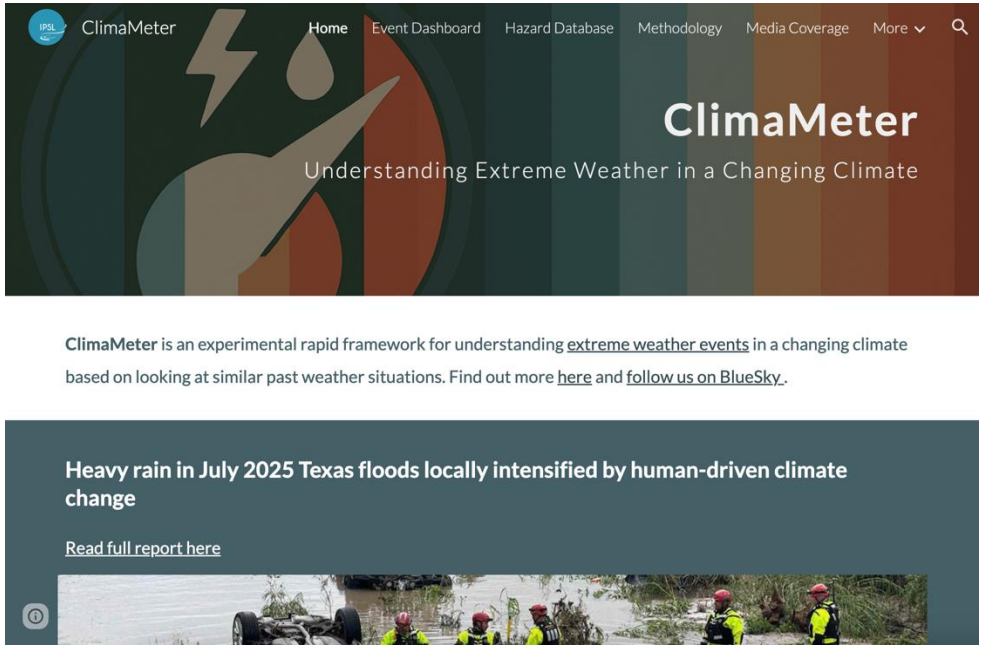
Analogues method

- The analogues method looks at large-scale circulation patterns similar to the one associated with the extreme event.
- By comparing the change in the circulation pattern and the associated impact/hazard in the counterfactual and factual period, conclusions can be drawn on whether and how much event of this type is made more intense by anthropogenic climate change.



[1] Faranda, D., Messori, G., Coppola, E., Alberti, T., Vrac, M., Pons, F., ... & Vautard, R. (2024). ClimaMeter: contextualizing extreme weather in a changing climate. Weather and Climate Dynamics, 5(3), 959-983.

ClimaMeter



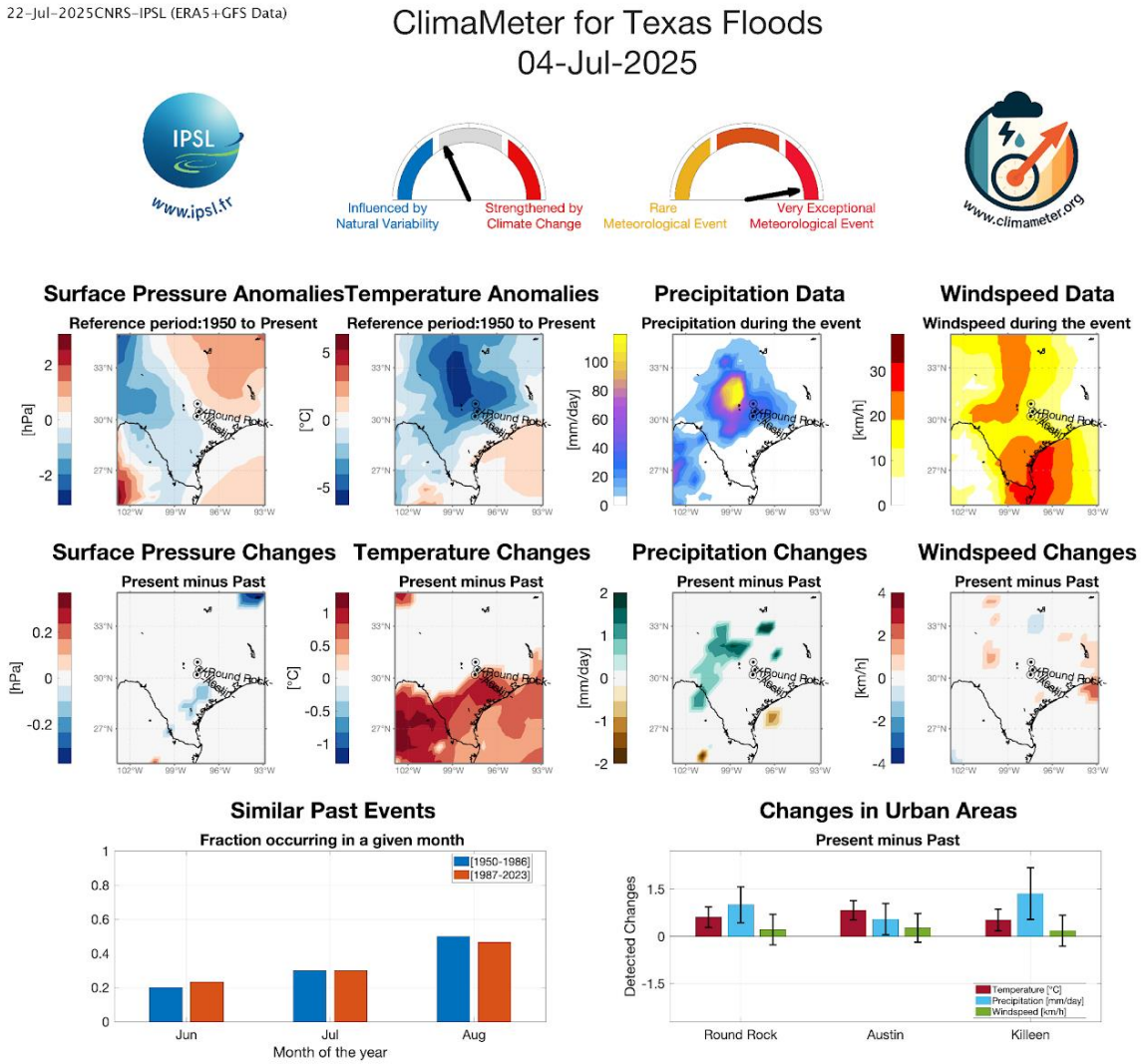


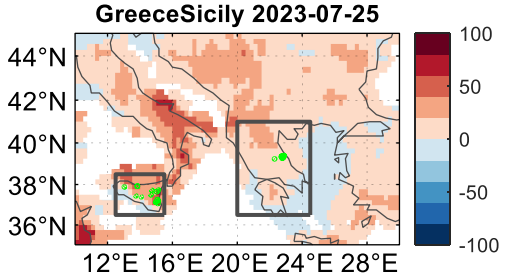
Figure: https://www.climameter.org/home

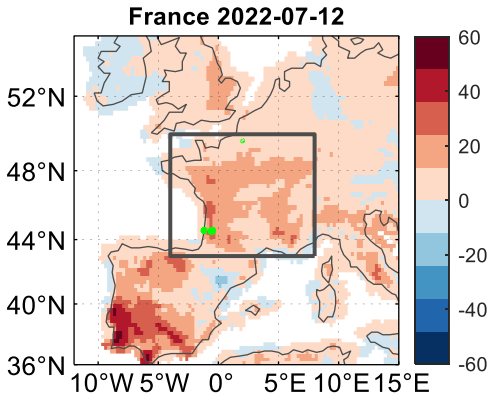
Example of extreme event attribution using RCM data:

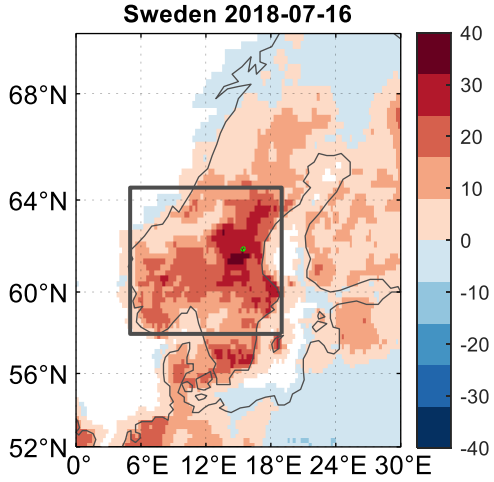
Assessing the Impact of Climate Change on Wildfire Development

Objectives

- To explore whether the analogues method used in ClimaMeter can be applied in attributing hazards such as wildfires,
- To employ high-resolution CORDEX ensemble to verify the observed change and to project future changes, and
- To extend the ClimaMeter protocol to include model results.







The EURO-CORDEX ensemble

- 34 simulations from the CORDEX European domain at a resolution of 0.11°.
- Historical and RCP8.5 scenarios.
- Counterfactual (CF) and factual (F) periods:
  - ERA5: CF: 1950-1979, F: 1995-2024
  - Model validation: CF: 1980-2009, F: 2022-2051.
  - Projection: CF: 1980-2009, F: 2069-2098.
- Bias correction of z500 using the Cumulative Distribution Function-transform (CDF-t) method [1,2].

[1] Michelangeli, P.-A., M. Vrac, and H. Loukos (2009), Probabilistic downscaling approaches: Application to wind cumulative distribution functions, Geophys. Res. Lett., 36, L11708, doi:10.1029/2009GL038401.
[2] Vrac M and Michelangeli P A 2021 CDFt: Downscaling and Bias Correction via Non-Parametric CDF-Transform r package version 1.2 URL https://CRAN.R-project.org/package=CDFt

Analogues analysis on models

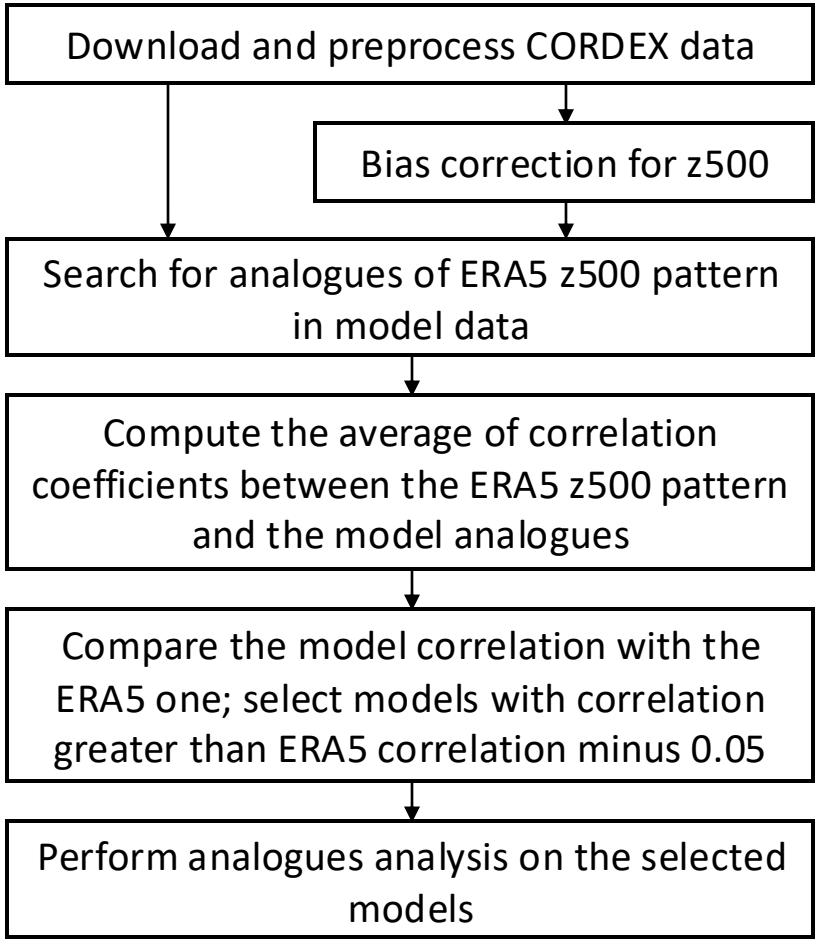
Download and preprocess CORDEX data

↓

Bias correction for z500

Number	GCM	Ensemble	RCM
1	CNRM-CERFACS-CNRM-CM5	r1	GERICS-REMO2015
2	CNRM-CERFACS-CNRM-CM5	r1	SMHI-RCA4
3	ICHEC-EC-EARTH	r12	CLMcom-ETH-COSMO-crCLIM-v1-1
4	ICHEC-EC-EARTH	r12	DMI-HIRHAM5
5	ICHEC-EC-EARTH	r12	KNMI-RACMO22E
6	ICHEC-EC-EARTH	r12	MOHC-HadREM3-GA7-05
7	ICHEC-EC-EARTH	r12	SMHI-RCA4
8	ICHEC-EC-EARTH	r1	DMI-HIRHAM5
9	ICHEC-EC-EARTH	r1	KNMI-RACMO22E
10	ICHEC-EC-EARTH	r1	SMHI-RCA4
11	ICHEC-EC-EARTH	r3	KNMI-RACMO22E
12	IPSL-IPSL-CM5A-MR	r1	GERICS-REMO2015
13	IPSL-IPSL-CM5A-MR	r1	KNMI-RACMO22E
14	MOHC-HadGEM2-ES	r1	CNRM-ALADIN63
15	MOHC-HadGEM2-ES	r1	ICTP-RegCM4-6
16	MOHC-HadGEM2-ES	r1	KNMI-RACMO22E
17	MOHC-HadGEM2-ES	r1	MOHC-HadREM3-GA7-05
18	MPI-M-MPI-ESM-LR	r1	CLMcom-ETH-COSMO-crCLIM-v1-1
19	MPI-M-MPI-ESM-LR	r1	CNRM-ALADIN63
20	MPI-M-MPI-ESM-LR	r1	DMI-HIRHAM5
21	MPI-M-MPI-ESM-LR	r1	ICTP-RegCM4-6
22	MPI-M-MPI-ESM-LR	r1	KNMI-RACMO22E
23	MPI-M-MPI-ESM-LR	r1	SMHI-RCA4
24	MPI-M-MPI-ESM-LR	r2	CLMcom-ETH-COSMO-crCLIM-v1-1
25	MPI-M-MPI-ESM-LR	r2	SMHI-RCA4
26	MPI-M-MPI-ESM-LR	r3	GERICS-REMO2015
27	MPI-M-MPI-ESM-LR	r3	SMHI-RCA4
28	NCC-NorESM1-M	r1	CLMcom-ETH-COSMO-crCLIM-v1-1
29	NCC-NorESM1-M	r1	GERICS-REMO2015
30	NCC-NorESM1-M	r1	KNMI-RACMO22E
31	NCC-NorESM1-M	r1	SMHI-RCA4

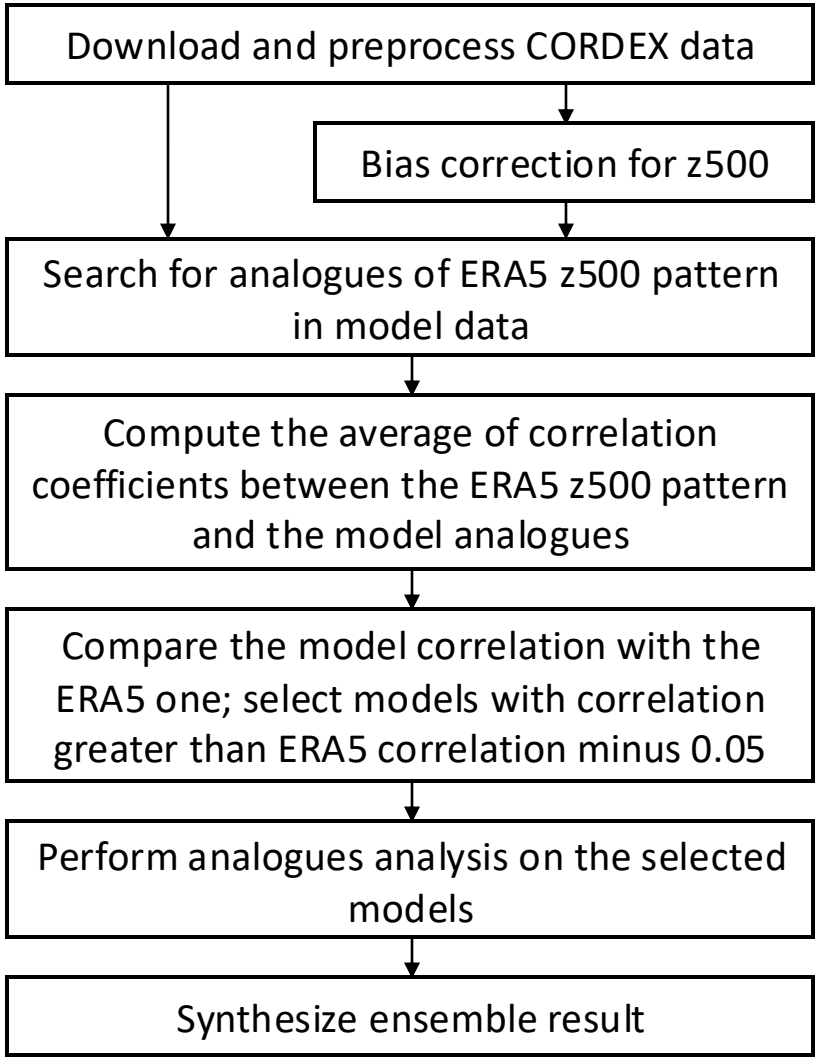
Analogues analysis on models



- Model evaluation and selection:
  - The days in RCM do not have a one-to-one correspondence with the actual calendar days.
  - The event-day pattern is not defined in the models.
  - Use the identified analogues as a proxy.

$$\text{threshold} = \text{ERA5 correlation} - 0.05$$

Analogues analysis on models



- Result synthesis:
  - Ensemble mean of changes.
  - Statistical significance: two-sided *t*-test ($\alpha = 0.05$).
  - False discovery rate control: Benjamini & Hochberg procedure ($\alpha_{FDR} = 0.05$) [1].
  - Model consistency: over 80% of the ensemble members agree on the sign of change.

[1] Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal statistical society: series B (Methodological)*, *57*(1), 289-300.

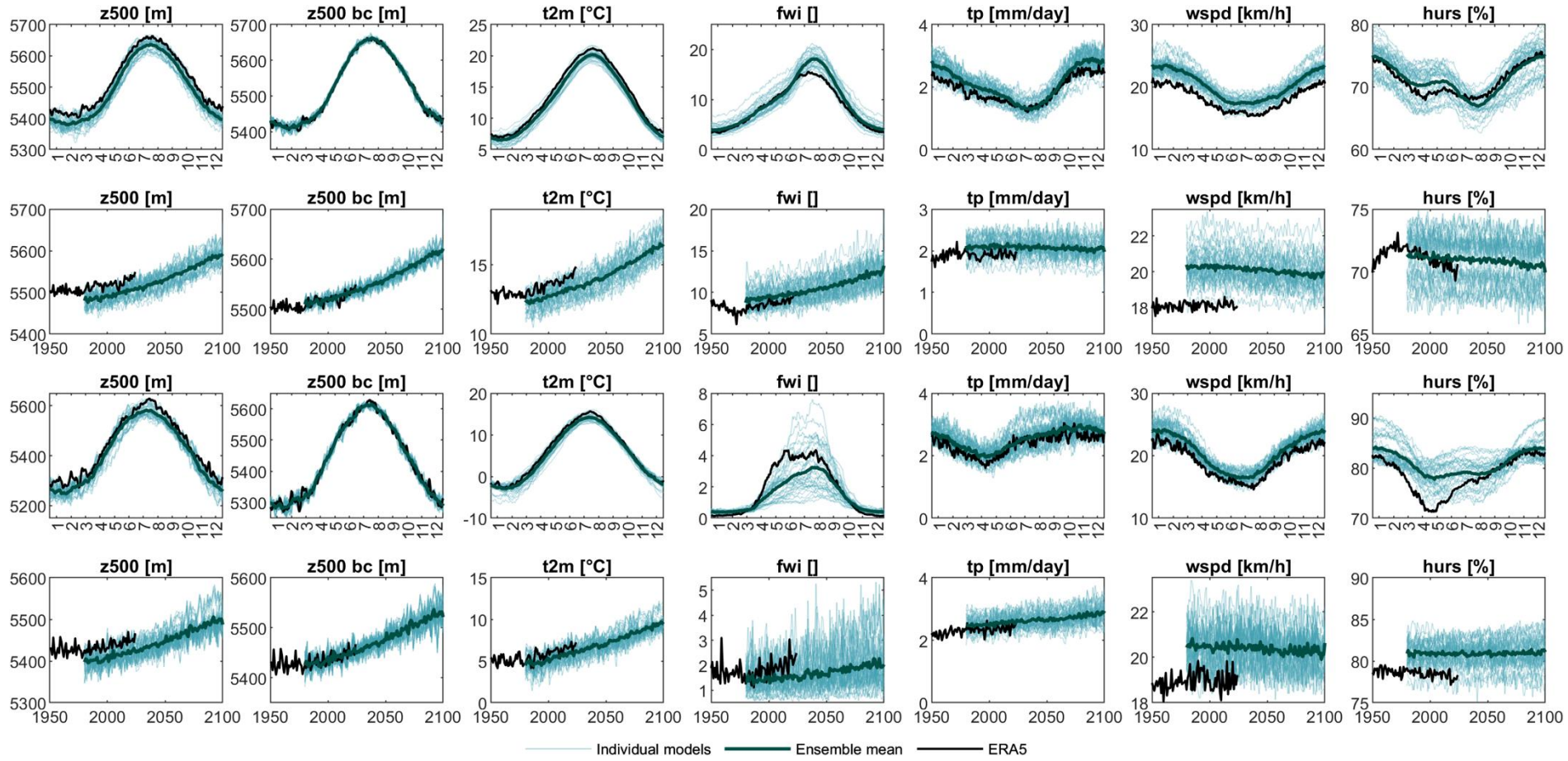
Model validation

Domain 1
Annual cycle

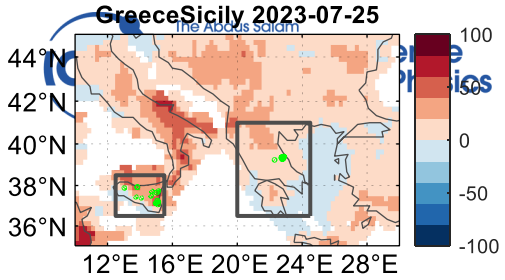
Domain 1
Yearly series

Domain 2
Annual cycle

Domain 2
Yearly series

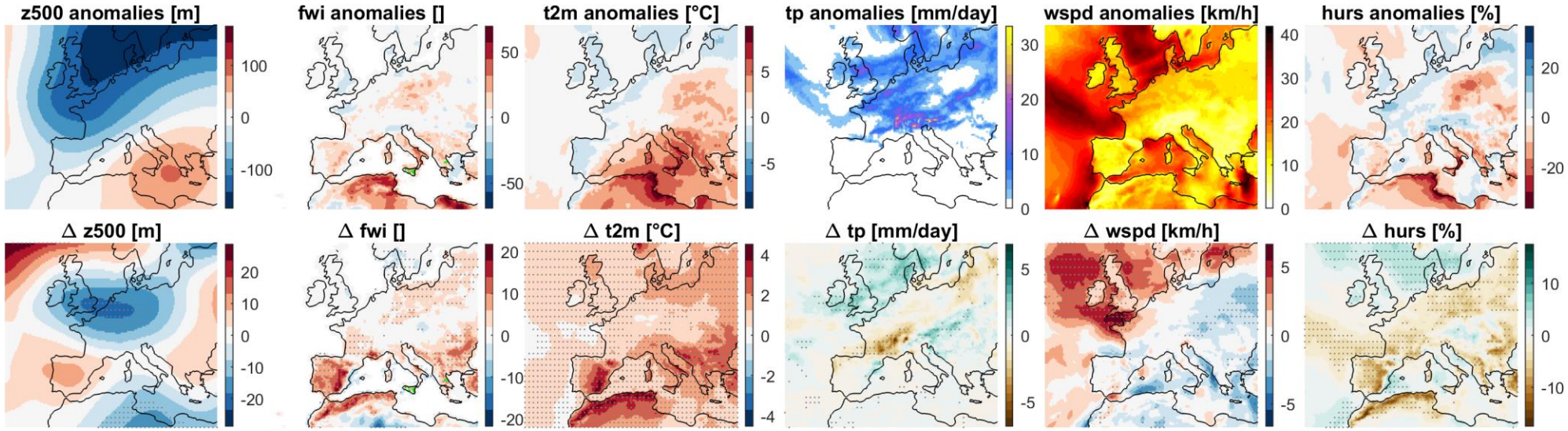


2023/07/25 Sicily-Greece wildfires



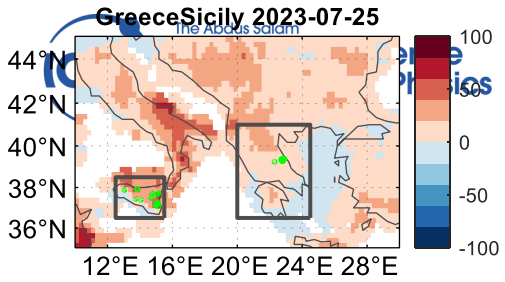
Anomalies

Change



Gray dots: significant change

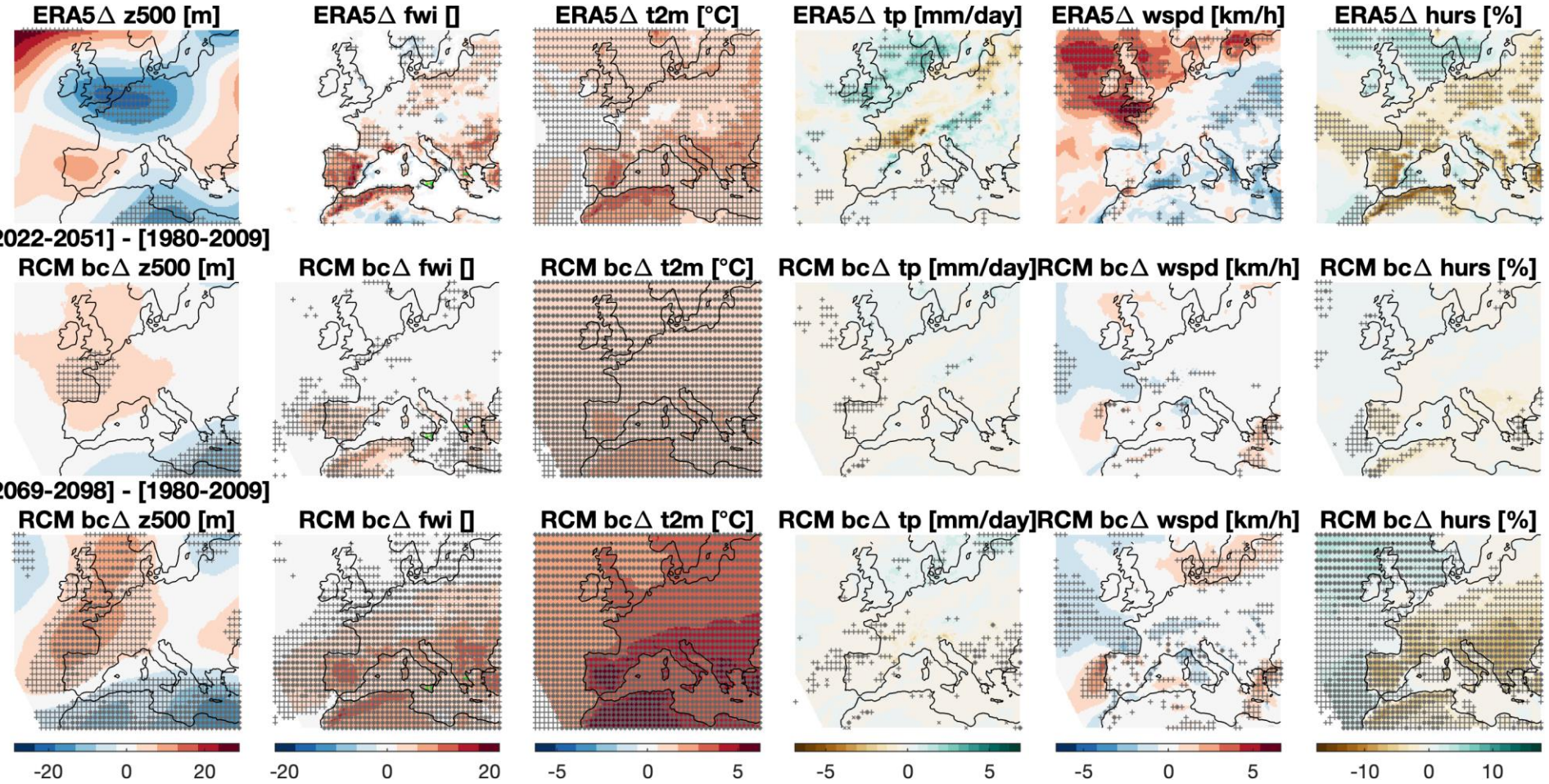
2023/07/25 Sicily-Greece wildfires



ERA5

Validation

Projection



Gray “+”: significant change

Gray “×”: consistent change

Further remarks

- The current practices is focused on hazard, and highlight the role of anthropogenic climate change to a degree that leads to an ignorance of the huge role vulnerability and exposure are playing in turning extreme weather into disasters [1].

[1] and Figure: Otto, F. E. (2023). Attribution of extreme events to climate change. Annual Review of Environment and Resources, 48(1), 813-828.