Defining single extreme weather events in a climate perspective

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Context

The analysis of single extreme weather events relates to:

– climate monitoring;
– physical understanding;
– estimation of return periods;
– attribution to climate change.

For the latter, one compares the probability of the event occurring:

– in the factual world (p_1);
– in a counter-factual world, e.g. non-anthropized (p_0).

One defines the Risk Ratio and the Fraction of Attributable Risk as:

$$RR = \frac{p_1}{p_0} \qquad \text{and} \qquad FAR = \frac{p_1 - p_0}{p_1} = 1 - \frac{1}{RR}$$

The four steps of event definition

1. Select the variable (X).

Usually straightforward — not crucial here.

2. Define the class of events.

Here, traditional "risk-based" approach, i.e. events *equally or more intense than* the observed one: $\Pr\{X \geq x_0\}$ with x_0 the event value.

N.B. Alternative "storyline" approach: events *of about the same intensity* — not appropriate for probabilistic framework since: $\Pr\{x_0 - \varepsilon \leq X \leq x_0 + \varepsilon\} \xrightarrow{\varepsilon \to 0} 0$.

3. Define the level of conditioning.

$\Pr\{X \geq x_0 \mid Y \in \Omega\}$ with Y a concurrent climate variable (e.g. SST, atmospheric circulation, ENSO) or the time of the year (e.g. winter heat wave)?

Here only the calendar conditioning is explored (relevant for climate monitoring).

4. Define the spatio-temporal scale.

The main topic of this talk.

Why spatio-temporal scale matters

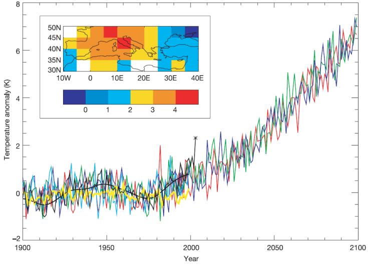
Example of the European heat-wave of summer 2003 (EHW03):

– Stott et al. (2004): EHW03 becomes a cold extreme after 2050.

– Beniston (2007): EHW03 remains a hot event in 2100.

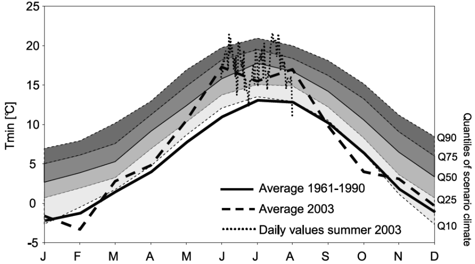
The difference? Seasonal/European vs. daily/local temperature anomalies.

a) JJA T Europe



Stott et al., Nature, 2004
(SRES A2 scenario).

b) Daily T Basel



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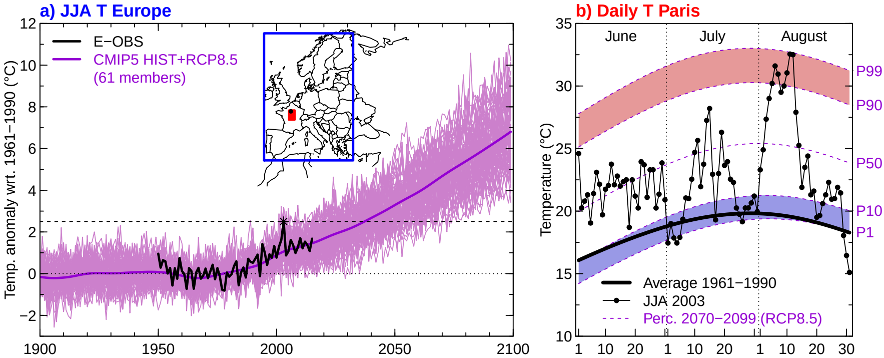


Cattiaux and Ribes, BAMS, 2018 (RCP8.5 scenario).

Choice of spatio-temporal scale

Most of the time: arbitrary.

Authors use predefined areas (e.g. a local station, a national territory) and periods (e.g., a day, a month, a season), and/or their own expertise.

Problem #1: this may not faithfully portray the event / be biased by our perception.

Problem #2: different definitions of the "same" event may lead to different attribution statements (see EHW03 example).

—

Our idea: select the scale at which the event has been the most extreme,

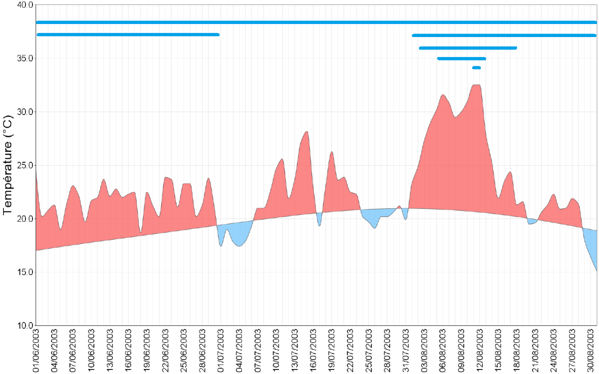
i.e. minimize the factual probability:

$$p_1 = \mathbf{Pr}\left\{X^{(t_1)} \geq x_{t_1}\right\},$$

with $X^{(t_1)}$ the random variable describing the temperature distribution at time $t_1 = 2003$,
and x_{t_1} the observed 2003 value.

Optimizing the time window

Example: Daily T at Paris-Montsouris station for Jun-Jul-Aug 2003.



Data: Météo-France.

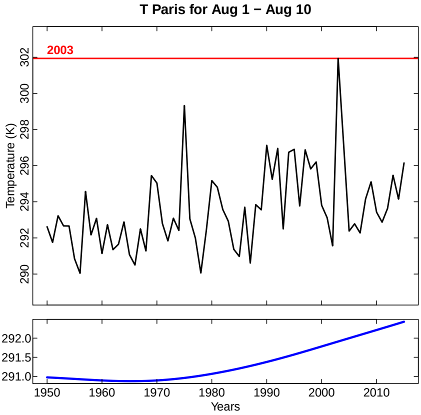
Question: Over which time window is the anomaly the most extreme?

1. Aug 11 (1 day);
2. Aug 5–12 (1 week);
3. Aug 2–17 (2 weeks);
4. August (1 month);
5. June (1 month);
6. Jun-Jul-Aug (1 season).

Optimizing the time window – Calendar method

For each time window $[\![d_1, d_2]\!]$:

– we consider the observed time series x_t & the climate change x_t^* at this location;



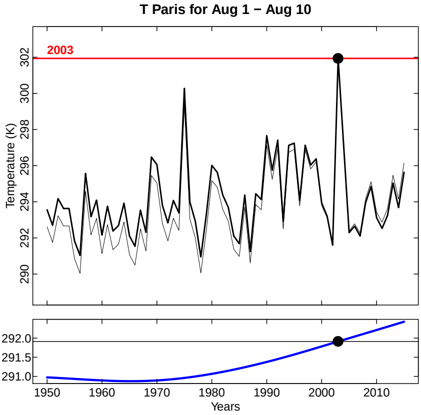
N.B. x_t^* = smoothed multi-model mean of CMIP5 JJA temperatures (common to all time windows but location-dependent).

Optimizing the time window – Calendar method

For each time window $[\![d_1, d_2]\!]$:

– we consider the observed time series x_t & the climate change x_t^* at this location;

– we correct for climate change before and after $t_1 = 2003$: $x_t^{(t_1)} = x_t - (x_t^* - x_{t_1}^*)$;



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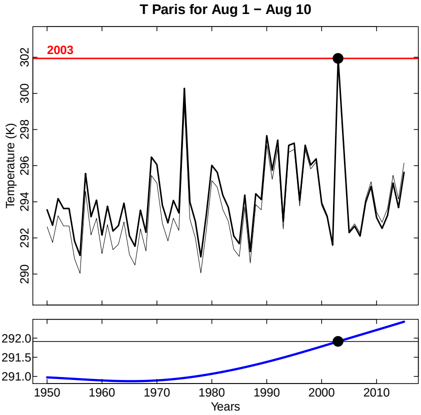
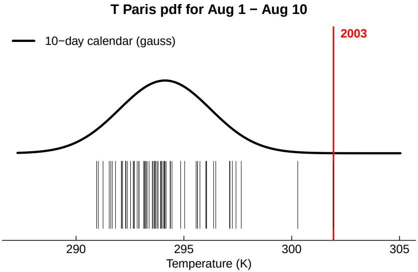
– we estimate p_1 from $x_t^{(t_1)}$, assuming $X^{(t_1)}$ follows a Gaussian distribution;





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Optimizing the time window – Calendar method

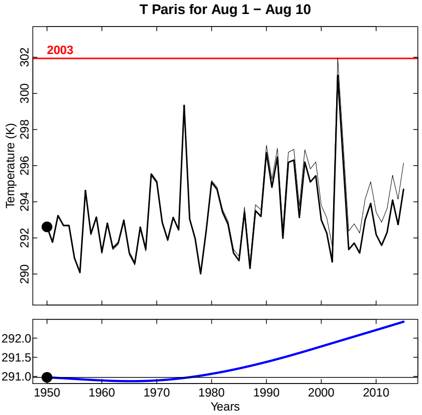
For each time window $[\![d_1, d_2]\!]$:

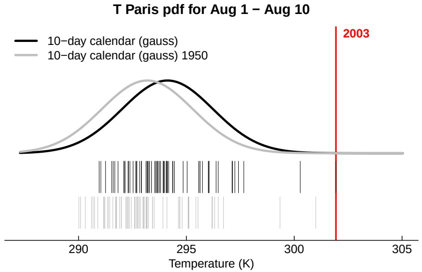
— we consider the observed time series x_t & the climate change x^*_t at this location;

— we correct for climate change before and after $t_1 = 2003$: $x^{(t_1)}_t = x_t - (x^*_t - x^*_{t_1})$;

— we estimate p_1 from $x^{(t_1)}_t$, assuming $X^{(t_1)}$ follows a Gaussian distribution;

— we also estimate p_0 by correcting wrt. $t_0 = 1950$ (our counter-factual world).

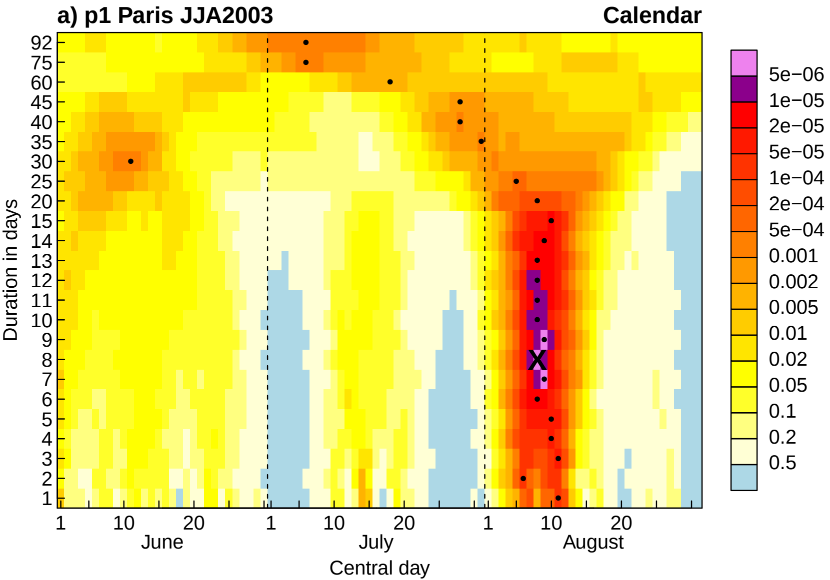




N.B. x^*_t = smoothed multi-model mean of CMIP5 JJA temperatures (common to all time windows but location-dependent).

Optimizing the time window – Result

The most extreme anomaly is found for Aug 5–12 ($p_1 = 4 \times 10^{-6}$, 250 000 y).



Calendar vs. annual maxima

The calendar approach is relevant for climate monitoring (seasonal context), but the obtained p_1 should not be interpreted as a formal return period.

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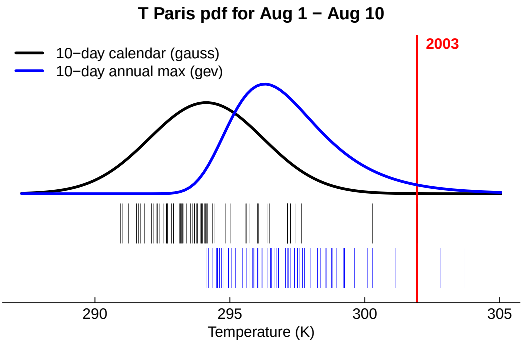
Alternative approach: consider $x_t^{(t_1)}$ as the time series of annual maxima, (now assuming that $X^{(t_1)}$ follows a Gumbel distribution).

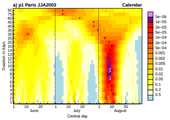


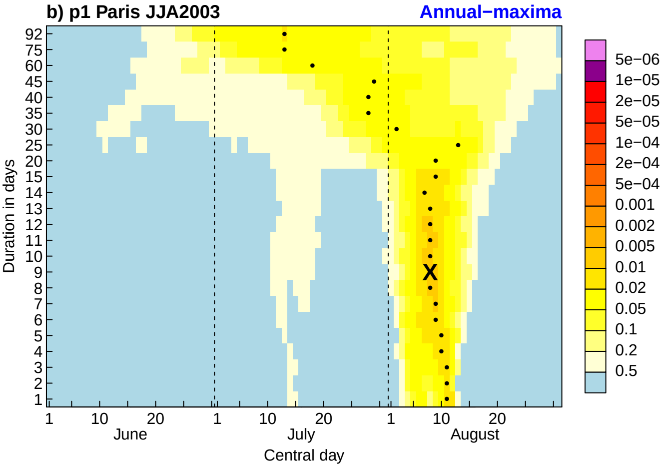
N.B. The question becomes: Over which time window is the ~~anomaly~~ **temperature** the most extreme?

Calendar vs. annual maxima – Result

The most extreme temperature is found for Aug 4–12 ($p_1 = 0.008$, 125 y).

Hot anomalies distant from the annual cycle peak disappear (e.g. June).

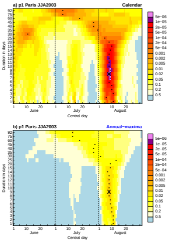


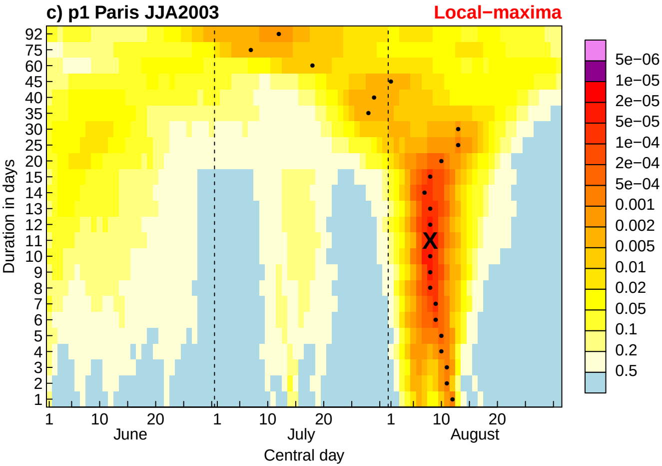


A compromise: local maxima

Idea : limit the search of annual maxima to a calendar neighborhood, i.e. consider $x_t^{(t_1)}$ as the time series of local maxima.

Here we use ± 7 days; similar to what is done for establishing record values.



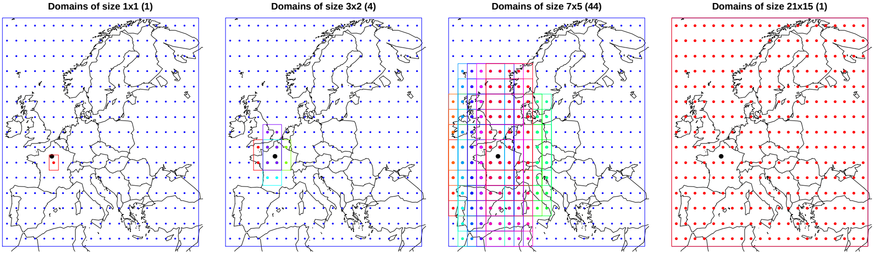


Optimizing the space window

Idea (simple): repeat the procedure for an ensemble of spatial domains...

Here: squared or near-squared domains including Paris / included in Europe.

Observations: E-OBS interpolated onto a $2.5 \times 2.5°$grid.

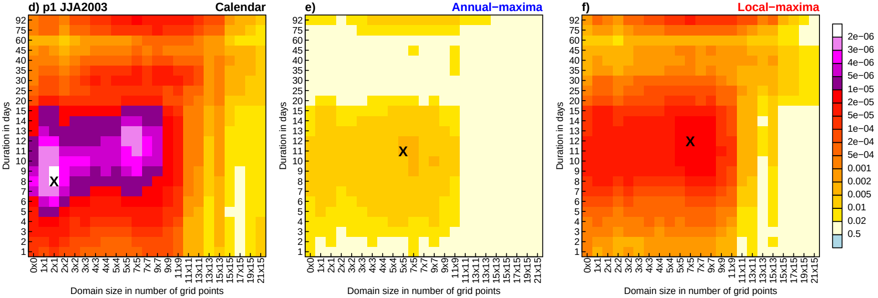


Alternative methods: successive grouping of countries or hierarchical collection of regions proposed by D.A. Stone (Climatic Change, submitted).

Optimizing the space window – Result

Annual-maxima / local-maxima: minimum p_1 (0.005, 200 y) is found for Aug 2–13 over France & Spain (12 days, 7×5 domain).

Calendar approach: other minimum at smaller scale (8 days, 2×1 domain).



x-axis: size of the space window from local (Paris) to the entire Europe.
y-axis: size of the time window from 1 day to the entire season (92 days).

Does it bias the FAR?

$p_1 = \Pr\left\{X^{(t_1)} \geq x_{t_1}\right\}$, $p_0 = \Pr\left\{X^{(t_0)} \geq x_{t_1}\right\}$ and $\text{FAR} = 1 - p_0/p_1$.

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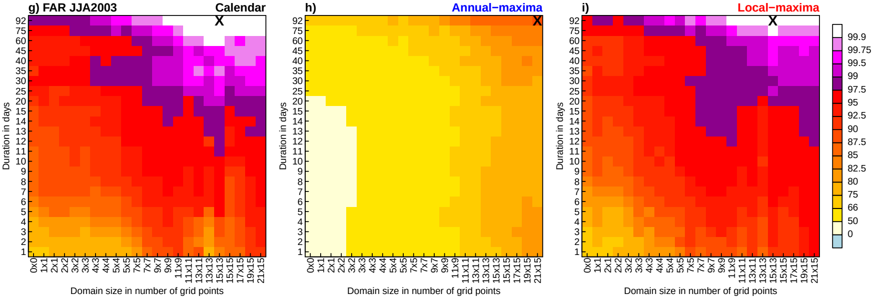
No. For this event, the FAR increases with spatio-temporal scale.
It is maximum for the scale chosen by Stott et al. (2004).



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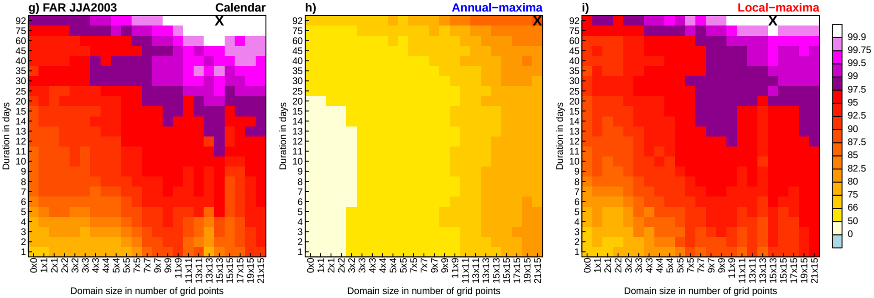


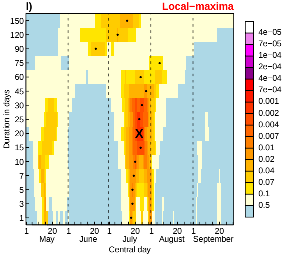
The FAR responds to the signal-to-noise ratio of the human-induced change.
For temperatures, the signal (warming) is rather uniform across scales, while the noise (variability) is stronger for small spatio-temporal scales.

Another temperature event

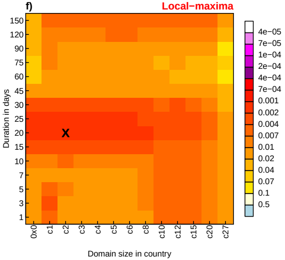
The European heat-wave of summer 2018.
Result: Sweden-Finland, Jul 14 - Aug 2, estimated return period 50 y.

- Higher p_1 than 2003: less extreme event.
- Higher FAR values: stronger signal-to-noise ratio in 2018 vs. 2003.
- Same behavior for the FAR: it increases with spatio-temporal scale.

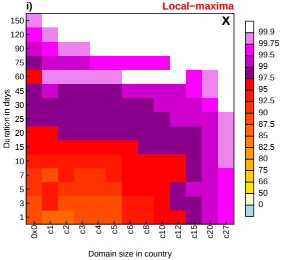
Local p_1 (Swe-Fin)



Minimum p_1



Associated FAR



Yiou et al., BAMS report on 2018 extremes, in prep.

A precipitation event

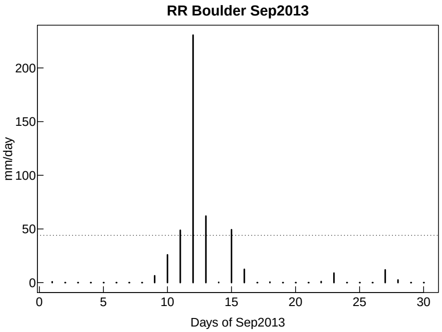
The intense rainfall in Boulder, Colorado, September 2013.

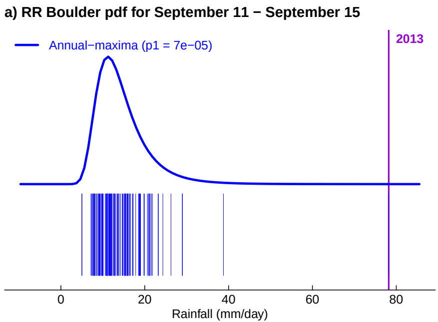
Method: annual maxima, with a different correction for climate change.

1. We estimate the local long-term T change x_t^* (in K, CMIP5).
2. We estimate the scaling of the annual n-day P maxima (in % par K, CMIP5).

$\longrightarrow$ *2.5 %/K for 1-day maxima, 0.7 %/K for 92-day maxima.*

3. We rescale the P annual max time series wrt. 2013 (p_1) or 1901 (p_0).
4. We use GEV distributions with shape parameter $\xi = 0.1$ across all time windows.





Data: GHCN daily data at Boulder station + regridded at $0.1 \times 0.1°$by M. Hoerling.

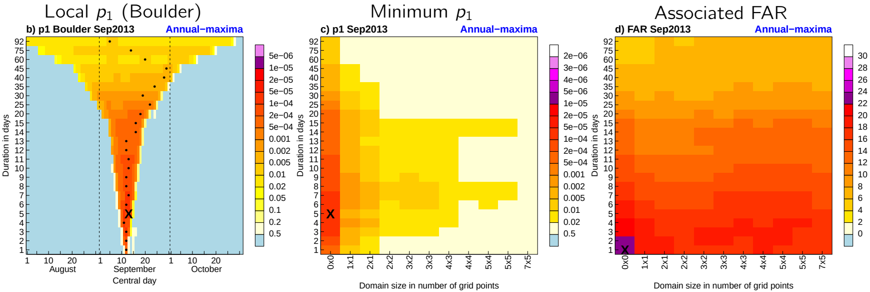
A precipitation event – Result

- p_1 is found to be minimum for Boulder local station, Sep 11–15.
- Large estimated return period: $p_1 = 7 \times 10{-}5$, i.e. 15 000 y.
- Rather small FAR values, typically between 10 and 25 %.

↪ Consistent with previous attribution studies (Hoerling et al., 2014; Eden et al. 2016).

For this event, the FAR decreases with spatio-temporal scale.

The signal-to-noise ratio is more complex for P than for T.



Summary

Select the space-time window that maximizes the event rarity (minimizes p_1) provides an *as-objective-as-possible* event definition.

Maximizing the rarity does not systematically maximize (or minimize) the attributable risk, contrarily to some arbitrary definitions.

Using p_1 allows to compare the rarity of different events and/or select the events that have been the most extreme within a year (e.g. for BAMS reports).

We have used very simple detrending + probability estimation procedures, future work may involve including more sophisticated techniques.

Cattiaux, J. and A. Ribes, Defining single extreme weather events in a climate perspective, *Bulletin of the American Meteorological Society*, 99, 1557–1568. doi:10.1175/BAMS-D-17-0281.1