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Non-Parametric Statistics Project

Quantification of the effects of climate change around the world

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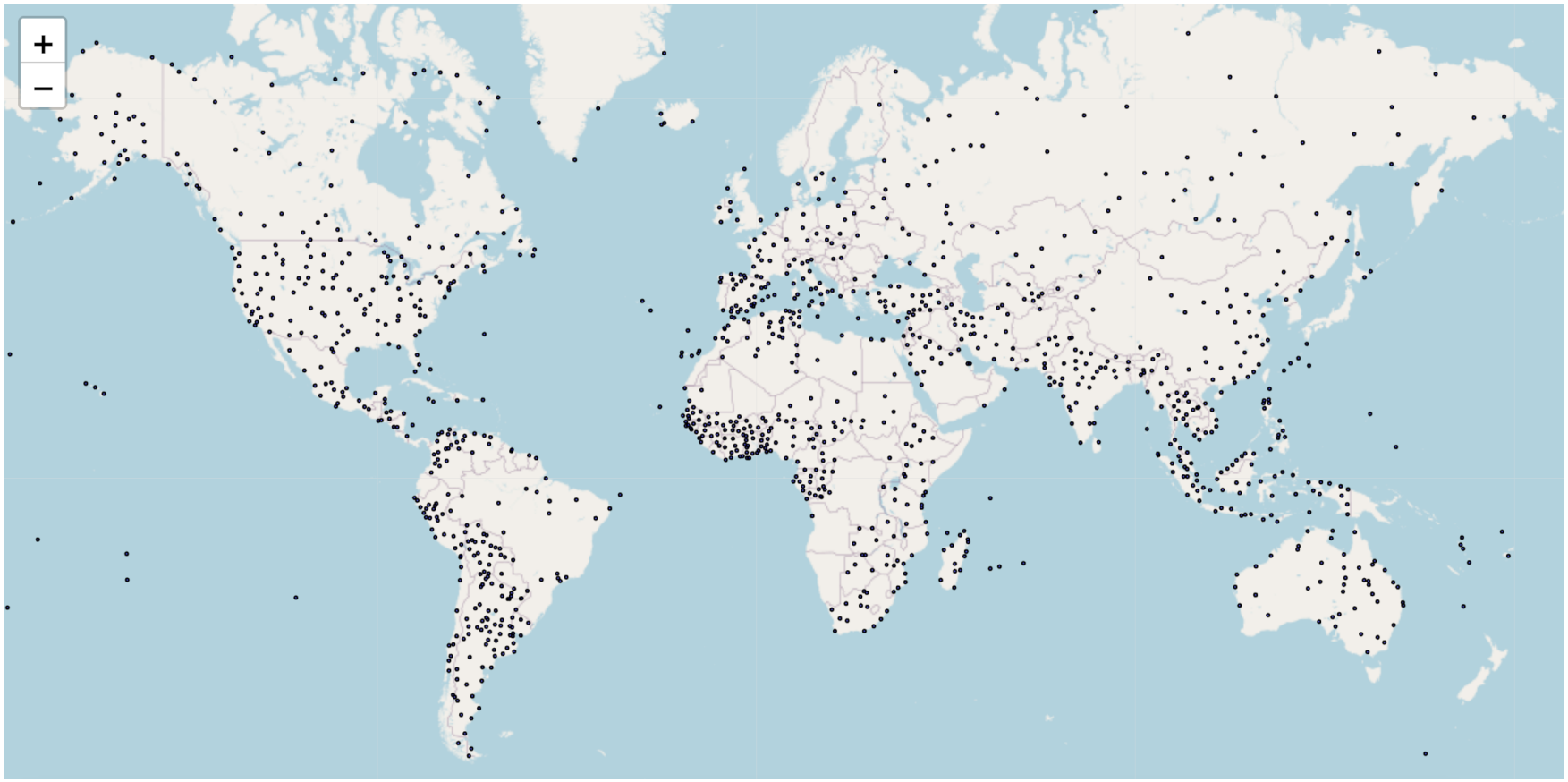
Who would need this study ?

- *Stakeholders :* NGO working for the climate.
- *Context :* they want to educate the population (even non-scientific) on the impacts of the climate change around the world

Research question : **What are the diverse impacts of climate change across various regions of the world?**

1315 weather stations around the world

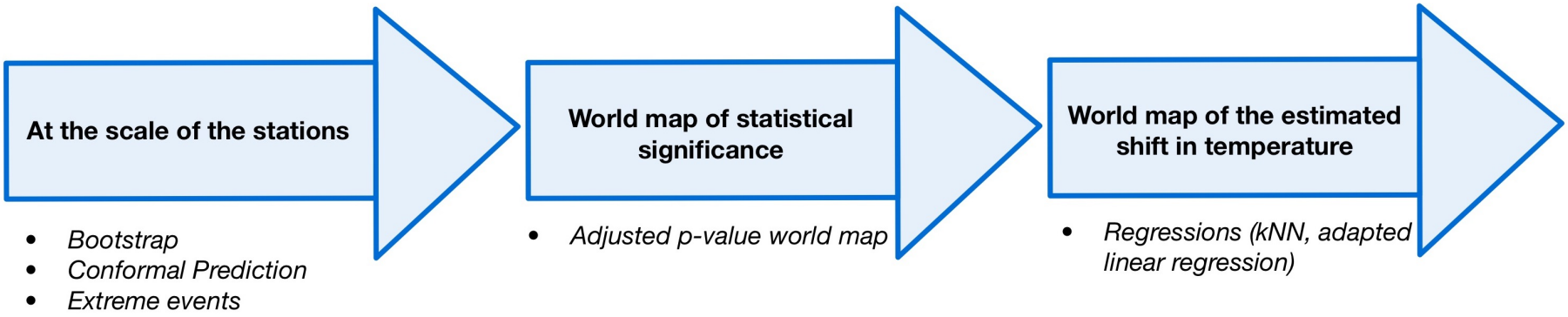


How do we use the data ?

time	tavg	tmin	tmax	prcp
1978-01-31	3,45	-0,49	8,23	2,28
1978-02-28	3,27	-0,30	7,25	2,99
1978-03-31	9,13	3,74	14,32	1,70
1978-04-30	10,76	6,39	15,37	2,70
1978-05-31	14,94	10,20	19,77	2,90
1978-06-30	20,02	13,70	25,83	2,53
1978-07-31	22,45	16,45	27,94	1,73
1978-08-31	21,79	16,20	27,23	1,85
1978-09-30	18,35	12,53	24,47	1,20
1978-10-31	12,71	7,75	18,48	3,03
1978-11-30	3,44	-1,48	9,50	1,07
1978-12-31	2,17	-0,26	4,90	2,27

Figure: 1978, Verona

To discern, quantify and illustrate climate change



Bootstrap : shift in temperature from 1978 to 2022 ?

- Linear regression :
  - Relationship between Monthly Tavg and Year
  - Interested in the slope
- Bootstrap analysis :
  - Pointwise estimation of the slope
  - Uncertainty estimation (*Reverse Percentile Interval*)
  - Statistical significance (*Does the RPI contain zero ?*)
- Exporting results :
  - For each station
  - For each month
  - Show the results on a world map

Bootstrap : shift in temperature from 1978 to 2022 ?

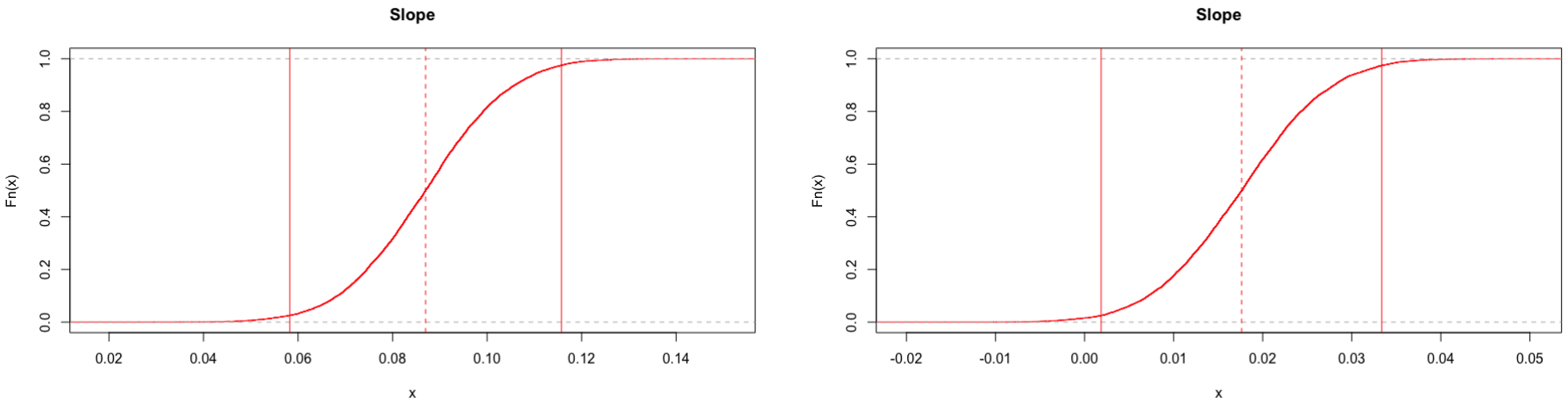


Figure: Pointwise estimation and Bootstrap Reverse Percentile Interval for the slope in the linear model of monthly-Tavg VS year, for June, in *Verona* (left), in *Cape Town* (right)

- *Verona* is very significant with a pointwise estimate of the slope of around $+0.08$ degree/year for June, *Cape Town* has a smaller slope

Bootstrap : shift in temperature from 1978 to 2022 ?

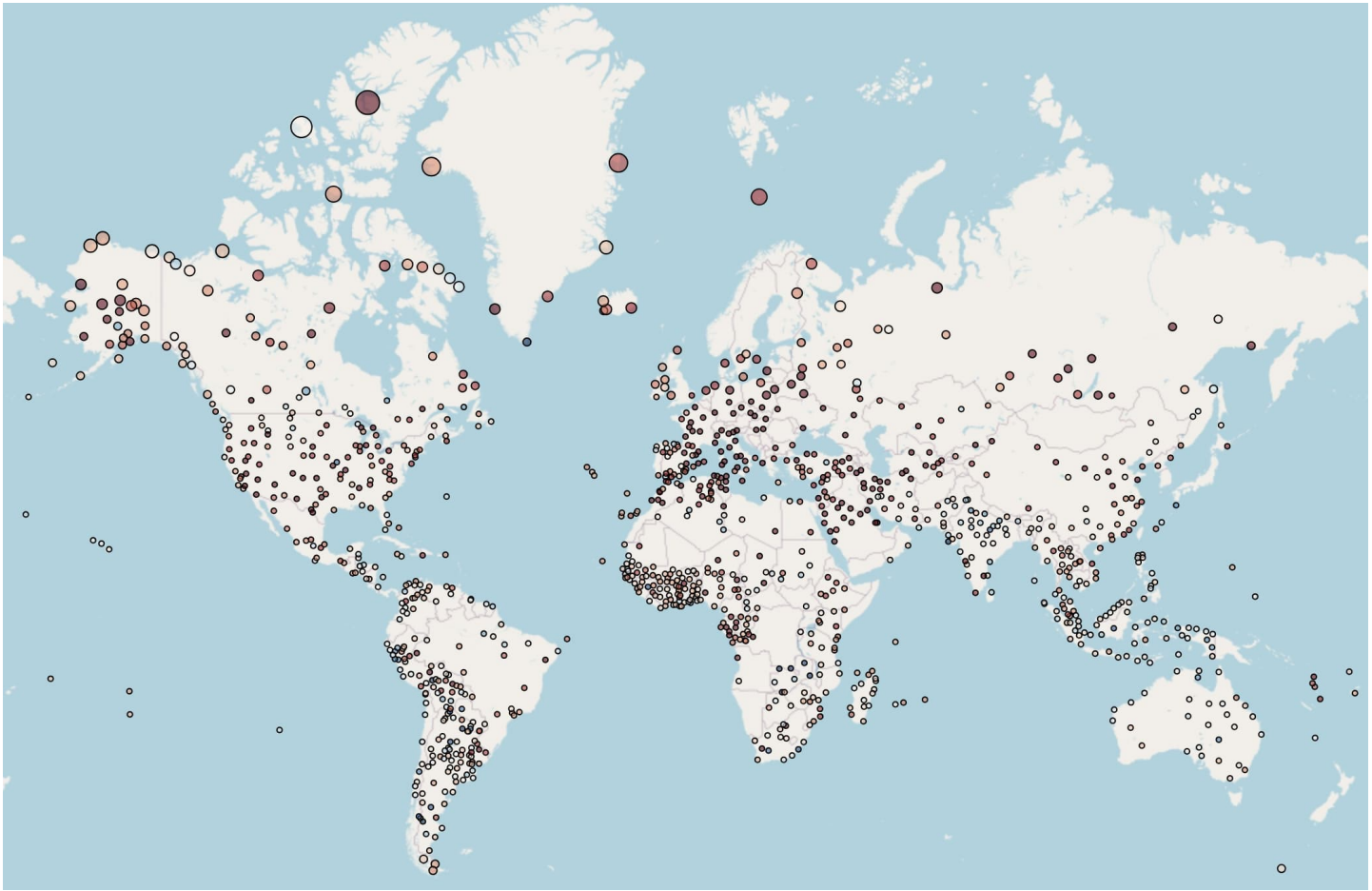


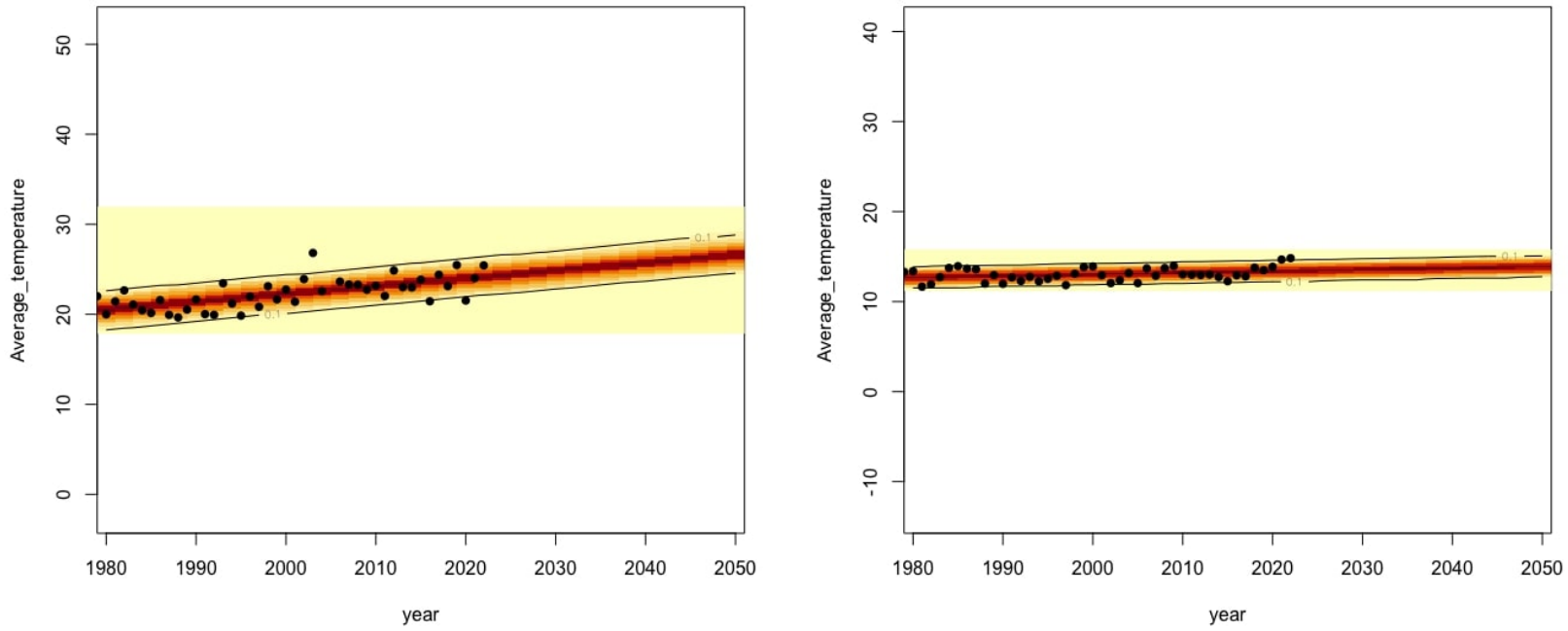
Figure: World map of the monthly-Tavg shift for June

Conformal Prediction : what about in the next years ?

- Conformal Prediction :
  - Prediction intervals for future monthly-Tavg
  - Full Conformal : limited 45 years of data
- Result examples for June :
  - Verona's 90% prediction intervals :
    - 2030 : [22.9, 26.9]
    - 2040 : [23.7, 27.9]
    - 2050 : [24.7, 28.7]
  - Cape Town's 90% prediction intervals :
    - 2030 : [12.5, 14.7]
    - 2040 : [12.7, 14.9]
    - 2050 : [12.9, 14.9]

Conformal Prediction : what about in the next years ?

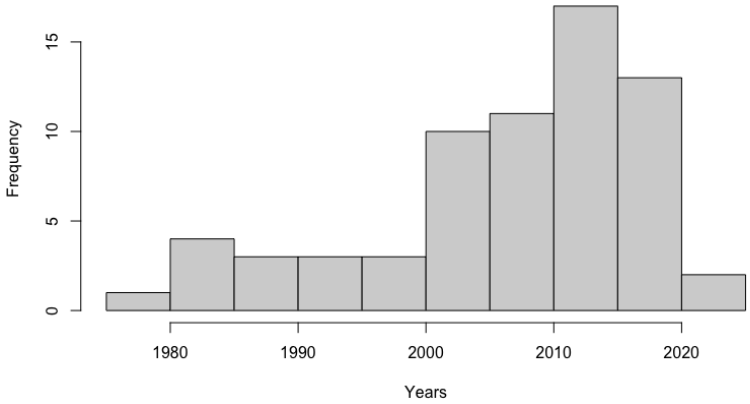
Conformal Prediction of the **Average-Monthly-Temperature** for **June**, in *Verona* (left) & *Cape Town* (right)



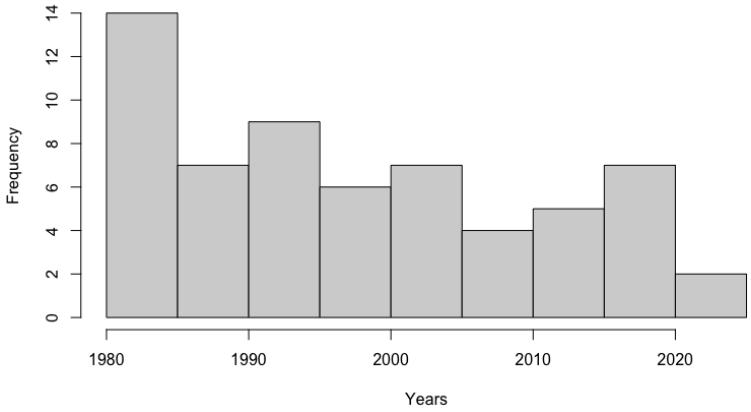
Cape Town exhibits more stable temperature patterns

What about the extreme meteorological events ?

- Aimed to detect extreme events (top 5%) at a daily scale.



Daily Tmax in *Verona* (left)



Daily Tmax in *Cape Town* (right)

- Observed alignment between extreme events and global warming patterns.
- Climate change manifests in various consequences, including extreme meteorological events.

The choice of the statistic T

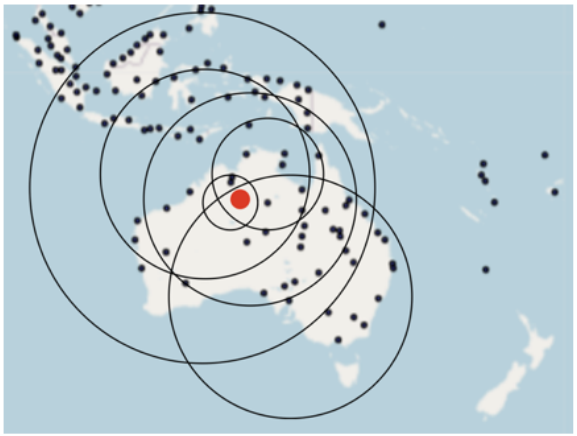
$$y(s,m,year) = a(s,m) + b(s,m)*year + \epsilon(s,m,year)$$

- Temperature :
  - H0 : $b(s,m) = 0$
  - H1 : $b(s,m) > 0$
  - $T \rightarrow max\left(0, \frac{\hat{b}}{SE(b)}\right)$
- Precipitation :
  - H0 : $b(s,m) = 0$
  - H1 : $b(s,m) \neq 0$
  - $T \rightarrow \hat{b}^2$

Permutation test with 500 random resampling.

Method to expand the results

- Definitions :
  - $T^I = \int_I T(x)dx$
  - $p^I = p_{H0}\left(T^I > T^I_{obs}\right)$
  - $\widetilde{p}(x) = \max_{I \in B : x \in I} p^I$
- Procedure :
  - Weights on the station to compute integrals
  - Compute the integral of T for I = B(x,r) $\rightarrow T^I$
  - Deduce p^I
  - From all the p^I, deduce $\widetilde{p}(x)$



Temperature results

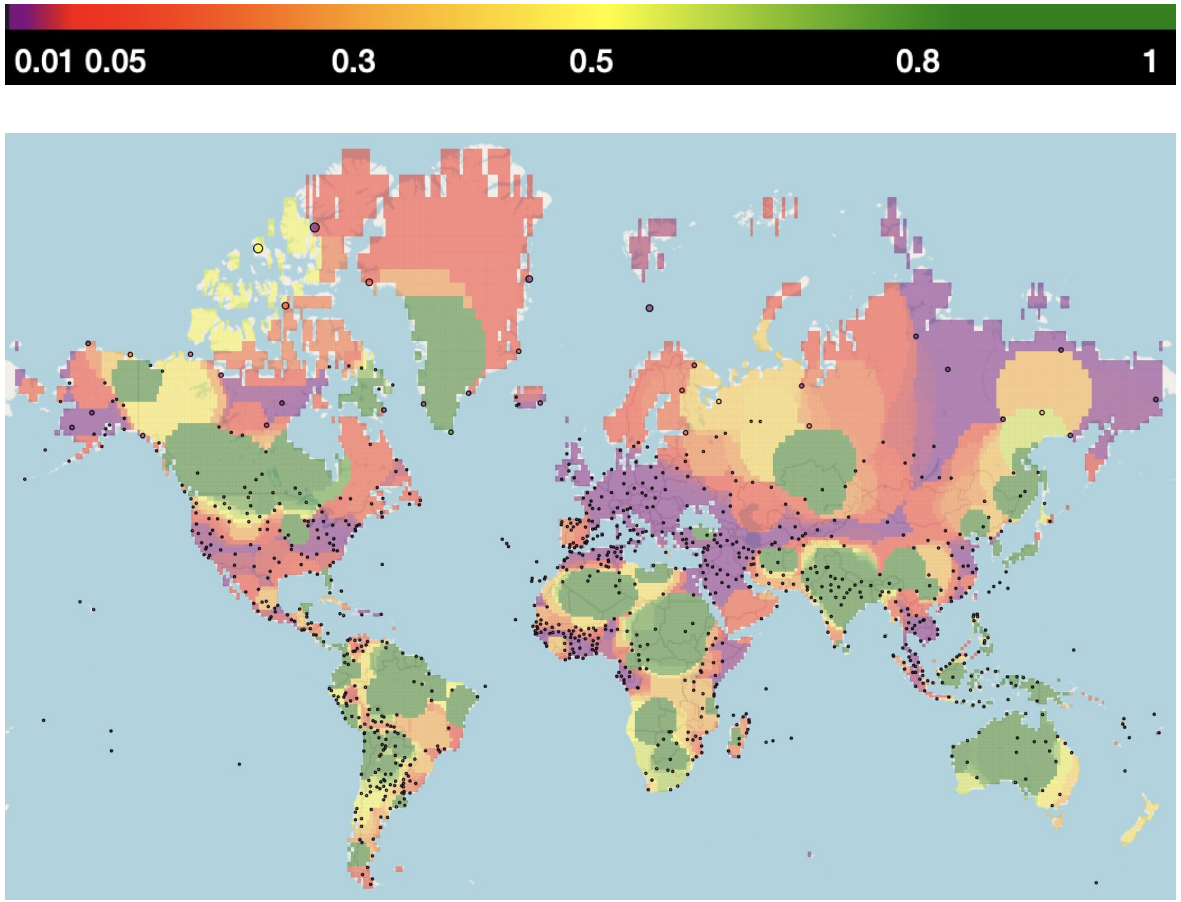


Figure: June adjusted p-value (temperature)

Precipitations results

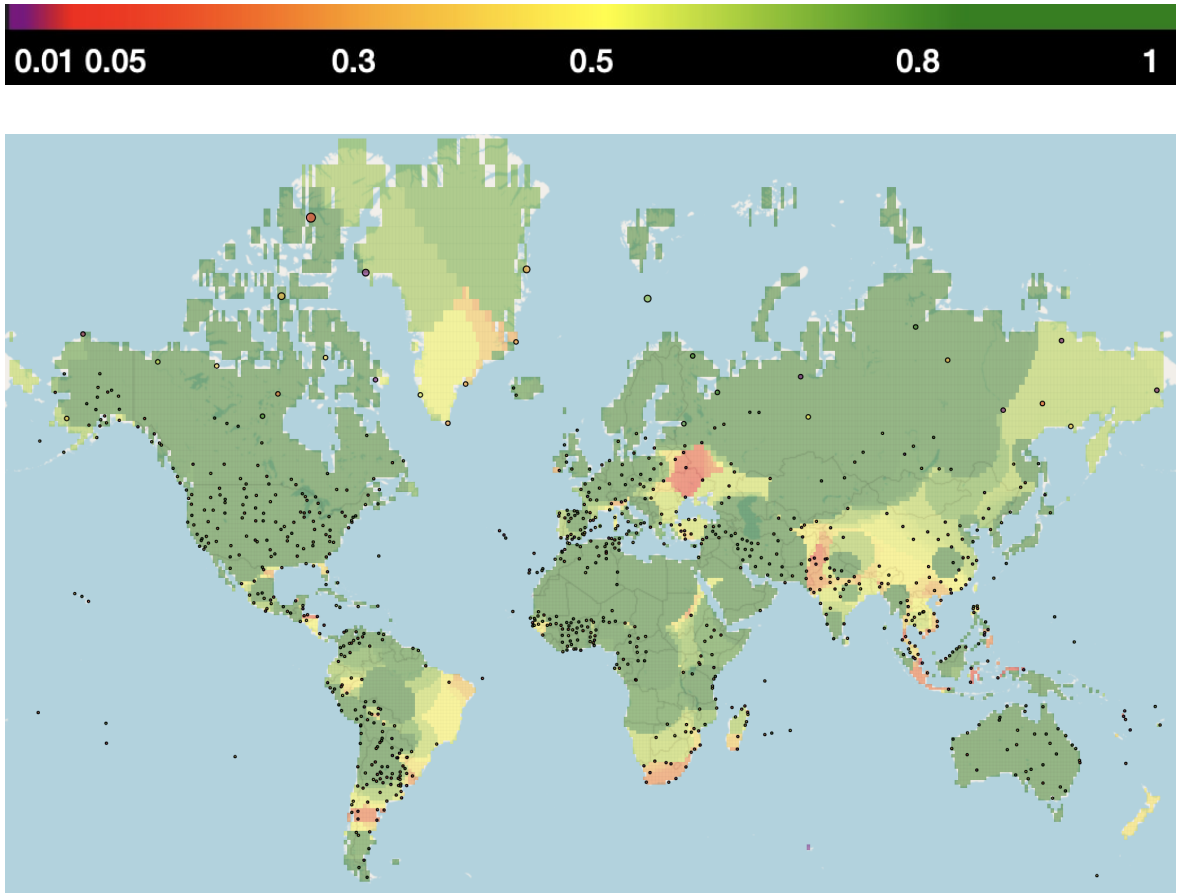


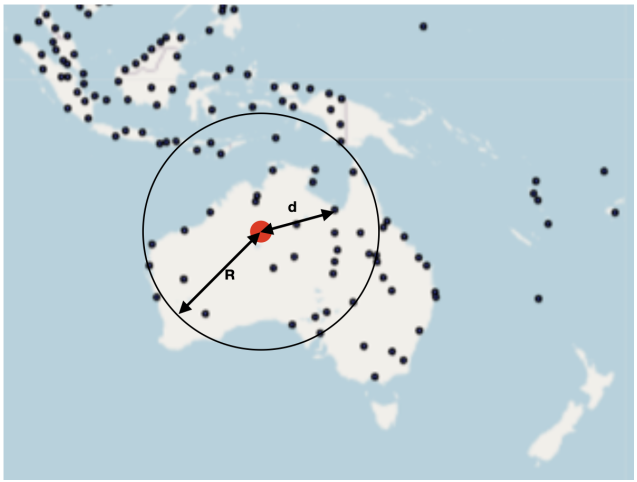
Figure: June adjusted p-value (precipitations)

Regression of the shift for the temperature

- K-nearest neighbors
- Linear like method : $f(x) = \frac{\sum_{s_i \in B(x,R)} f(s_i) \frac{w(s_i)}{d(x,s_i)}}{\sum_{s_i \in B(x,R)} \frac{w(s_i)}{d(x,s_i)}}$

  Inspired from the 1D linear regression :

  $f(x) = \frac{f(a)(b-x)+f(b)(x-a)}{b-a} = \frac{\frac{f(a)}{d(x,a)} + \frac{f(b)}{d(x,b)}}{\frac{1}{d(x,a)} + \frac{1}{d(x,b)}}$



KNN results

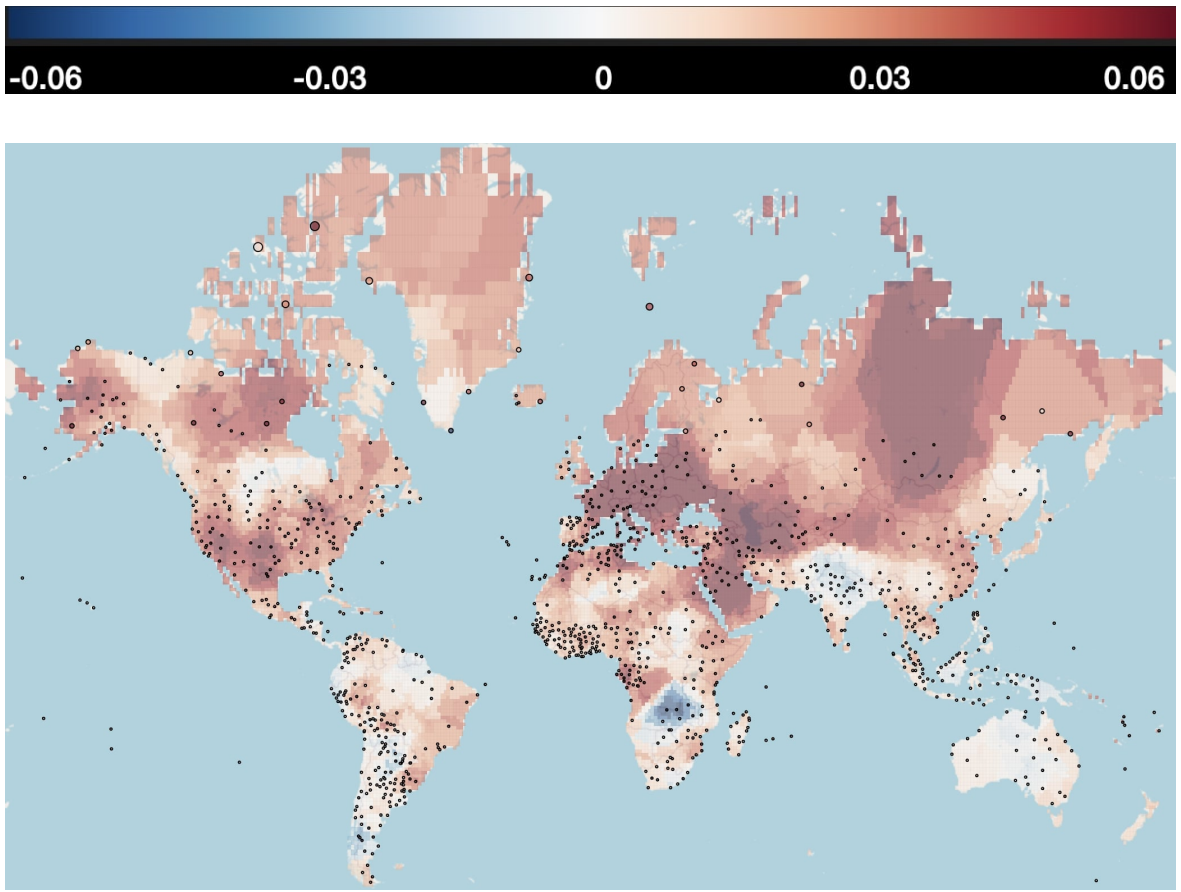


Figure: June estimated shift (degree per year)

Linear like method results

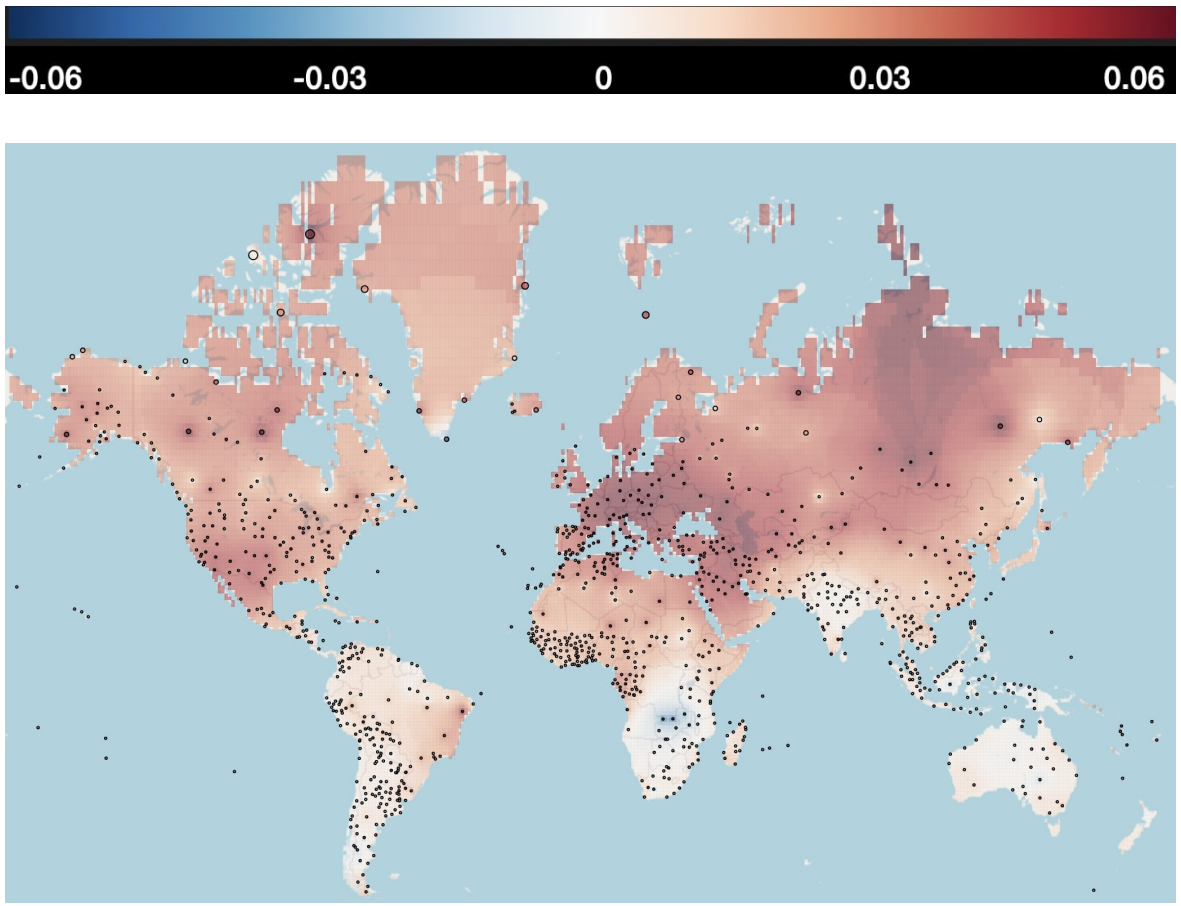


Figure: June estimated shift (degree per year)

In this study :

- Innovative method to compute p-values globally, inspired by the article of Niels Lundtorp Olsen and Alessia Pini and Simone Vantini (2023) *Local inference for functional data on manifold domains using permutation tests*
- There exists different paces in the climate change depending on the region in the world
- Different consequences of the climate change : global warming + higher frequency in extreme meteorological events
- Clear and accessible format so that results can be helpful even to non-scientific population (NGO)

Bibliography :

- Niels Lundtorp Olsen and Alessia Pini and Simone Vantini (2023) : `https://arxiv.org/pdf/2306.07738.pdf`

Data source :

- Deutscher Wetterdienst : `https://www.dwd.de/`
- US National Weather Service : `https://www.weather.gov/`
- European data : `https://data.europa.eu/`
- Canadian government : `https://open.canada.ca/`
- Meteorological Institute of Norway : `https://developer.yr.no/`