HYDROLOGY METEOROLOGY and COMPLEXITY

École des Ponts ParisTech

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Discrete Cascade Disaggregation of Climate Models for High Resolution Rainfall Estimation in urban environment

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Chaire Hydrologie pour une ville résiliente

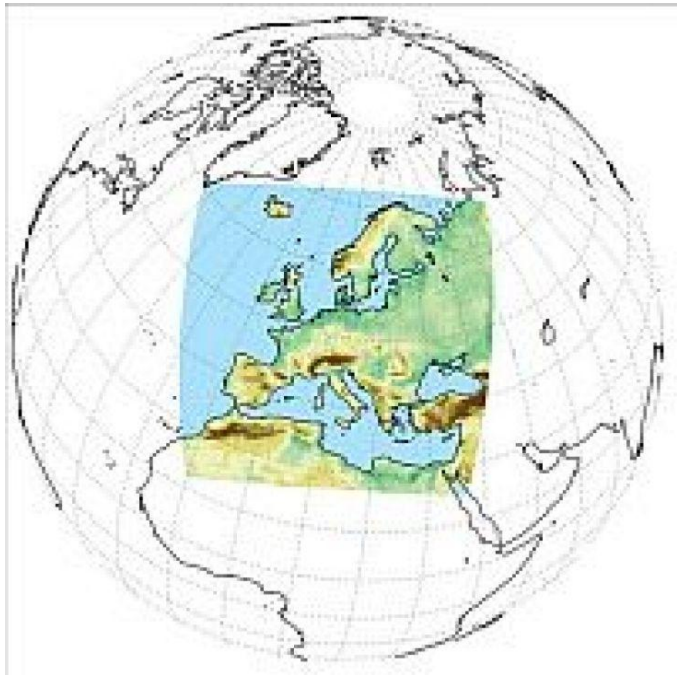
Analyzing climate models outputs using Multifractal formalism

Outputs downloaded from **Euro-Cordex** data
(https://www.euro-cordex.net/)

Models investigated :

-- 0.11°/12.5 km, hourly resolution --

GCM: CNRM-CERFACS-CM5 *(1)*
RCM: RCA4 *(2)*



We analyze precipitation outputs in a multifractal framework

Analyzing climate models outputs using **Multifractal formalism**

The **multifractal formalism** *(3)* is used to **statistically describe** and **simulate a field** by means of the **scale-invariant properties.**

l_0: **outer** scale ; $l =$ **observation** scale;

$$\boldsymbol{\lambda = \frac{l_0}{l}}$$: resolution ; $\boldsymbol{\varepsilon_\lambda}$: field considered at resolution λ

$$\Pr(\varepsilon_\lambda \geq \lambda^\gamma) \sim \lambda^{-c(\gamma)}$$

γ: **Singularity** of the field, $c(\gamma)$: **codimension function** of γ for this field

If D is the **dimension of space:** $\#\{\text{ points where } \varepsilon_\lambda \geq \lambda^\gamma\} \propto \lambda^{D-c(\gamma)}$

Analyzing climate models outputs using **Multifractal formalism**

$$\Pr(\varepsilon_\lambda \geq \lambda^\gamma) = \lambda^{-c(\gamma)}$$

Equivalent to :

$$\langle \varepsilon_\lambda^q \rangle \sim \lambda^{K(q)}$$

with $K(q) =$ Legendre transform of $[c(\gamma)]$

Generalized Central Limit Theorem:

$K(q)$ and $c(\gamma)$ governed by

3 parameters with physical meaning :

$$K(q) = \frac{C_1}{\alpha - 1}(q^\alpha - q) - Hq \;\; , \alpha \neq 1$$

$$K(q) = C_1 q \log(q) - Hq, \alpha = 1$$

α : *Multifractality index*

$\alpha \in [0,2]$

$$C_1 = \left.\frac{dK(q)}{dq}\right|_{q=1}$$

Mean intermittency of the field

H characterizes the non-conservativity of the field:

$H \neq 0$ if $\langle \varepsilon_\lambda \rangle \neq$ cst. (λ)

Analyzing climate models outputs using **Multifractal formalism**

<u>Evaluation of ***H***</u>:

β $:=$ spectral slope of energy density of the field

$\beta = 1 + 2H - K|_{H=0}(2)$ (see *(3)*)

If $\beta > 1$, one deals with the fluctuations field to extract parameters:

$$\phi_\lambda = \frac{|\delta\varepsilon_\lambda|}{\langle|\delta\varepsilon_\lambda|\rangle}$$

Where : $\delta\varepsilon = \varepsilon(i+1) - \varepsilon(i)$

So that all parameters are taken from conservative fields with approx. scale independent mean

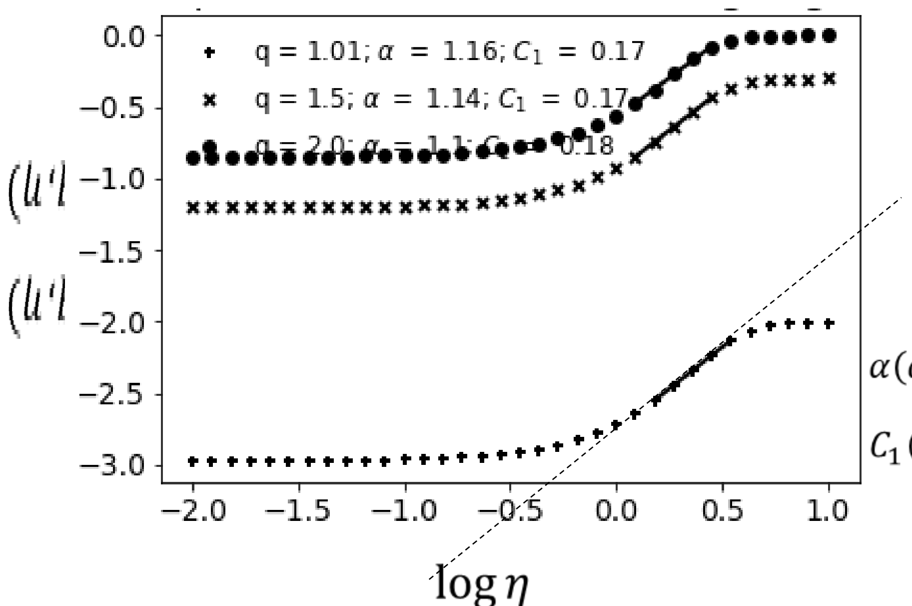
Analyzing climate models outputs using **Multifractal formalism**

$$K(q) = \frac{C_1}{\alpha - 1}(q^{\alpha} - q)\ ,\ \alpha \neq 1$$ most frequent case

$$K(q) = C_1 q \log(q),\ \alpha = 1$$

Evaluation of α and C_1 (*Double Trace Moment* method):

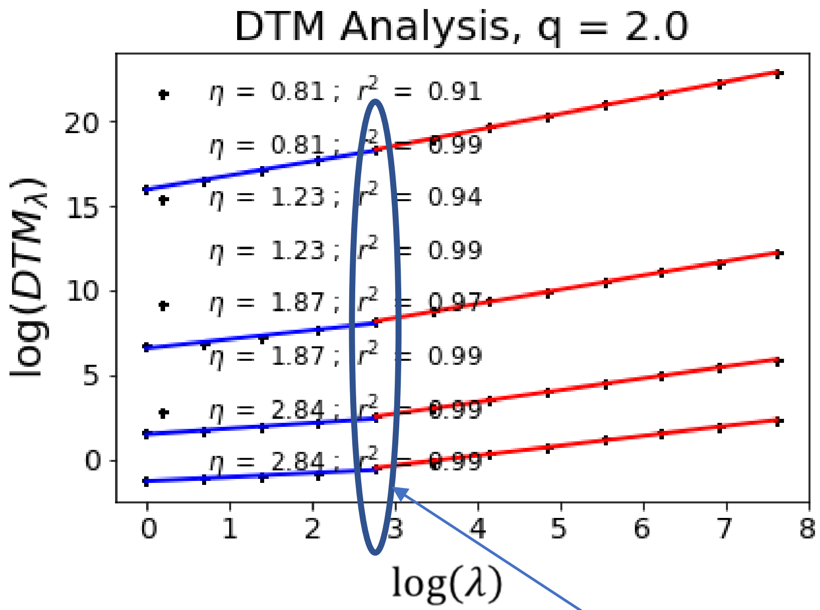
$$\left\langle \left(\varepsilon_\lambda^\eta\right)^q \right\rangle = \lambda^{K(q,\eta)} \quad K(q,\eta) = \eta^{\alpha} K(q)$$



$$\log K(q,\eta) = a \log \eta + b$$

$\alpha(q) \coloneqq$ a $\qquad \alpha = \langle \alpha(q) \rangle_q$

$$C_1(q) \coloneqq \frac{e^b(\alpha - 1)}{(q^{\alpha} - q)} \qquad C_1 = \langle C_1(q) \rangle_q$$



Scale break: each regime has its own parameters

Analyzing climate models outputs using **Multifractal formalism**

$$K(q) = \frac{C_1}{\alpha - 1}\,(q^{\alpha} - q)\ ,\ \alpha \neq 1$$

Finite-size sampling effects:

$$\boldsymbol{N_{\text{samples}}} = \boldsymbol{\lambda^{D_s}}$$

$\exists\, \gamma_s > 0$, largest observable singularity:

$$\gamma_s = \frac{\alpha}{\alpha - 1} C_1 \left(\frac{D + D_s}{C_1}\right)^{\frac{\alpha - 1}{\alpha}}$$

The larger γ_s, the stronger the extremes are in the observed field *(4)*

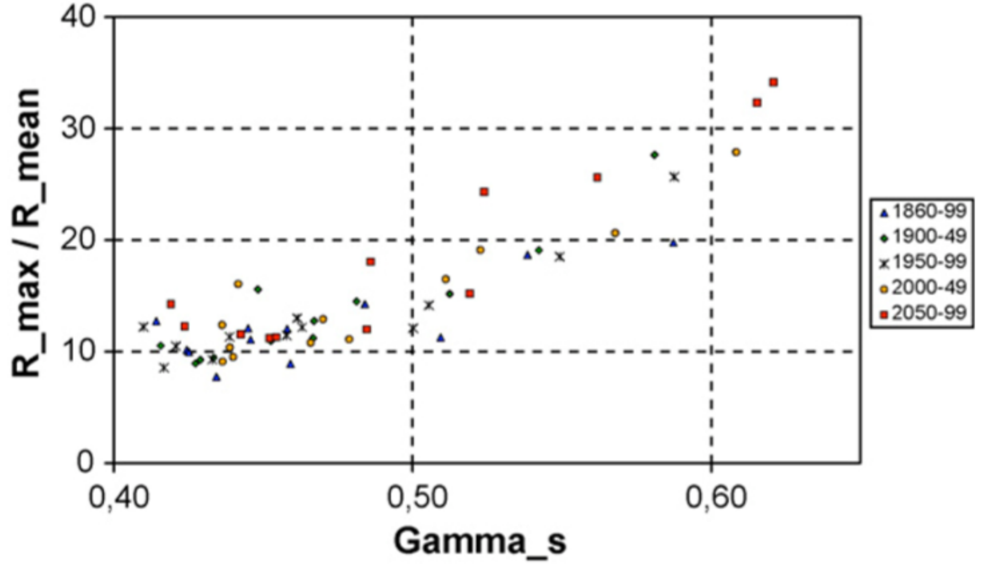


Fig. 8. Dispersion diagram showing the ratio of maximum to mean precipitation (R_{max}/R_{mean}) as a function of the maximal probable singularity γ_s for the different grid points and time intervals.

Figure taken from *(4)*

Analyzing climate models outputs using Multifractal formalism

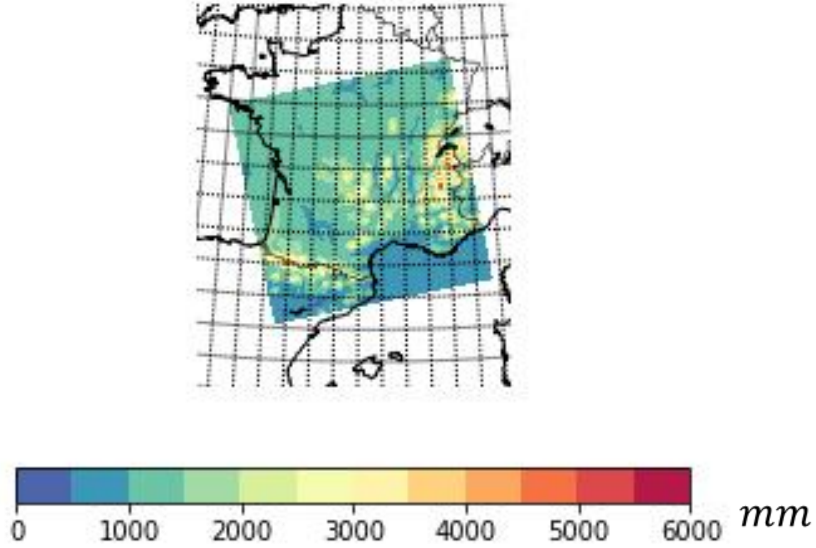
Analysis on 5-years periods

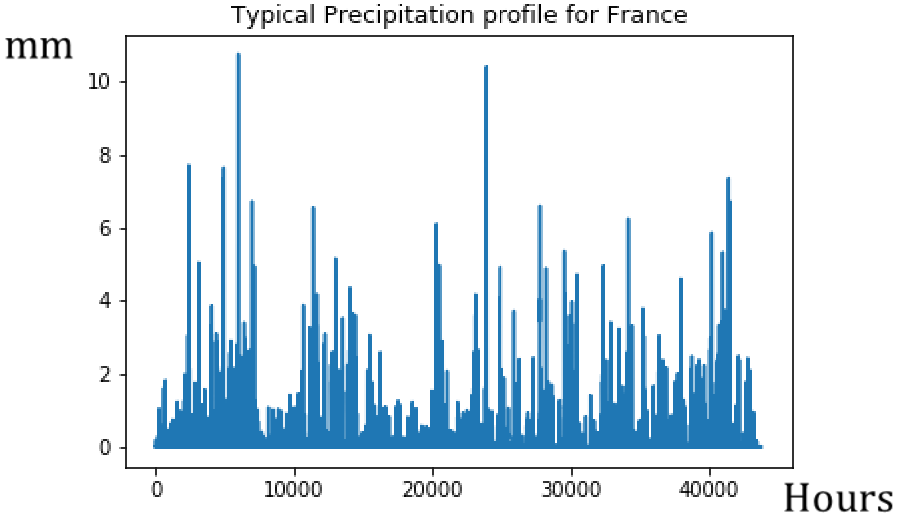
Hourly resolutions

1970-1974 | 2006-2010 | 2046-2050 | 2096-2100

Historical | **Scenario RCP 8.5**

Map of cumulative precipitations on the region of interest





Regions with 64×64 pixels with 12.5 km resolution are analyzed pixel-wise, as was done in *(5)*

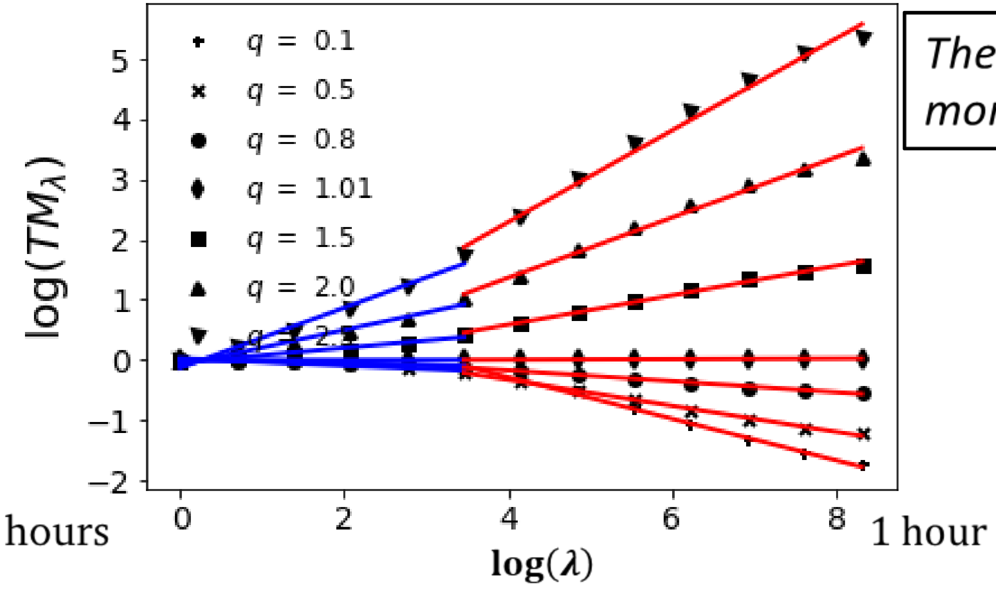
Analyzing climate models outputs using Multifractal formalism

Quality of scaling estimated using Trace Moment method : $\log \left\langle \varepsilon_\lambda^q \right\rangle = K(q) \log \lambda$

Graphs are fit using sample-averaged data from 8x8 pixels

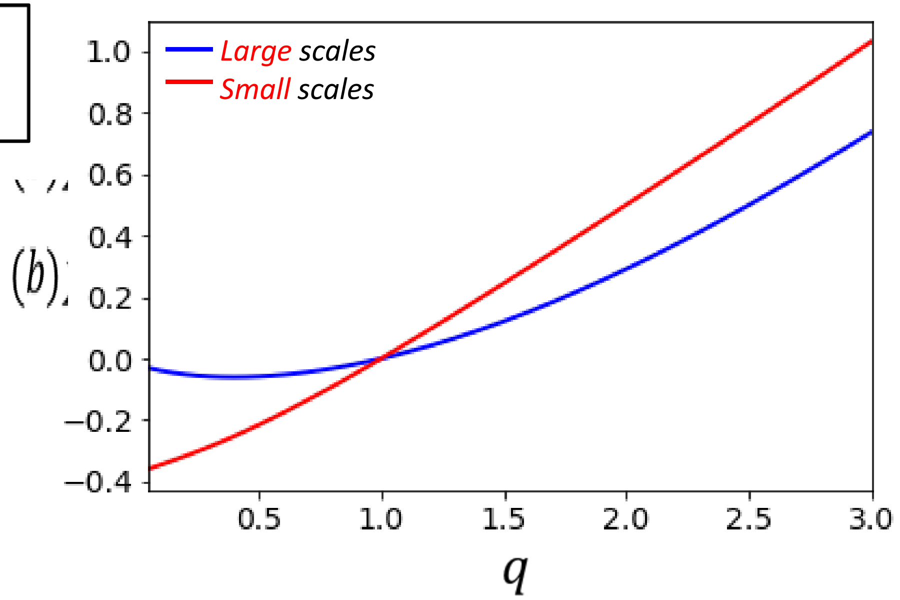
France, 1970-1974, Winter

TM Analysis



The slope on q^{th} moment is $K(q)$

$K(q)$ estimation from TM analysis



Scale break is at $128\ hrs \approx 5\ days$

Scaling is **poorer** for very **high resolution** (i.e smallest scales) & **high moments**, **consistently** with RCA4 underestimation of extremes events for timescales <12h *(6)*

Analyzing climate models outputs using Multifractal formalism

Seasonal analysis –

Year split into:

2048 hrs « **Summer** » (mid-June –September)

4096 hrs **« Winter »** (January –June)

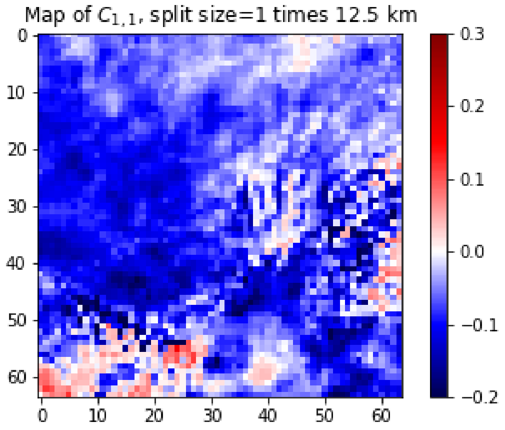
Separate MF analysis for each season, on each pixel

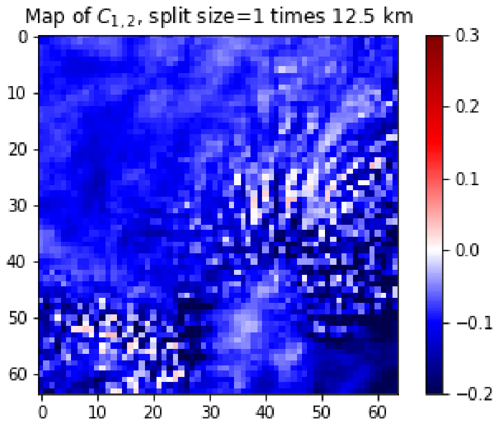
Powers of 2 used to numerically extract slopes

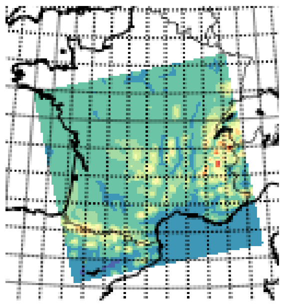
France, 1970-1974, ***Winter-Summer***

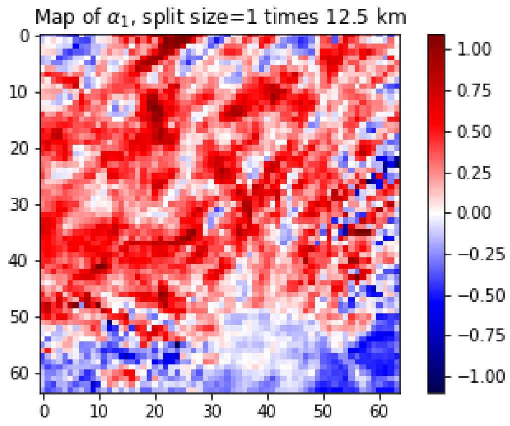
C_1(Winter)-C_1(Summer)

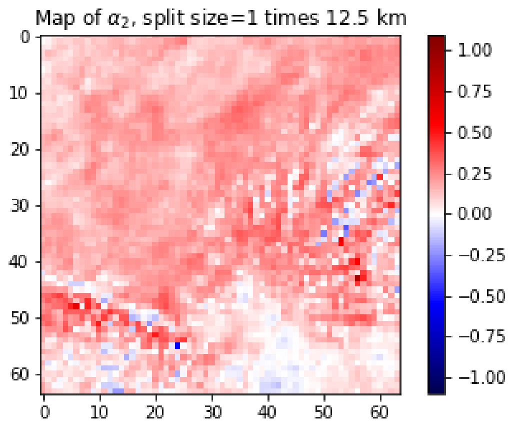
α(Winter) - α(Summer)











Large Scales VS Small Scales

Large Scales VS Small Scales

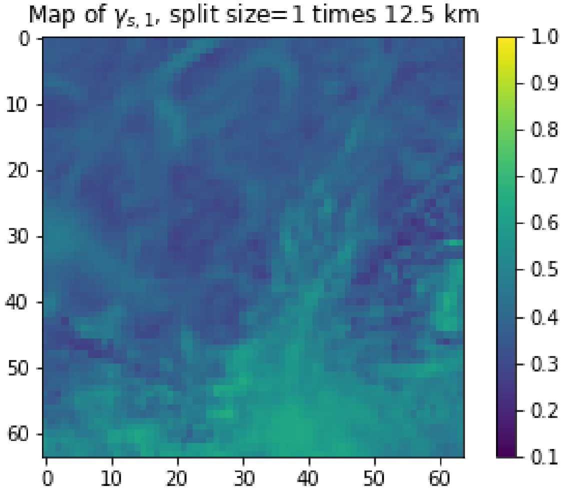
Effects of changing climate on the MF parameters: influence on extremes

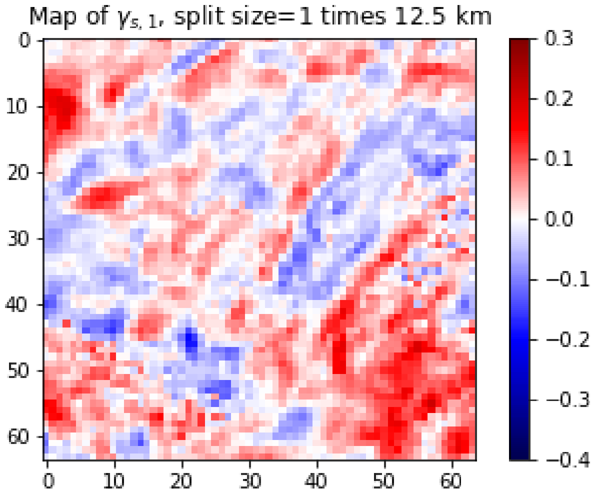
RCP 8.5 SCENARIO

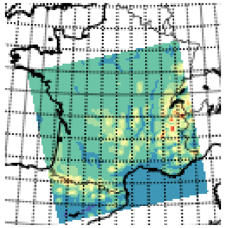
Winter 1970

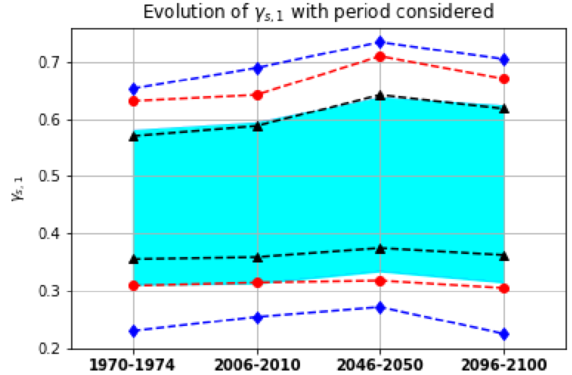
Winter δ(2100-1974)

Large Scales γ_s



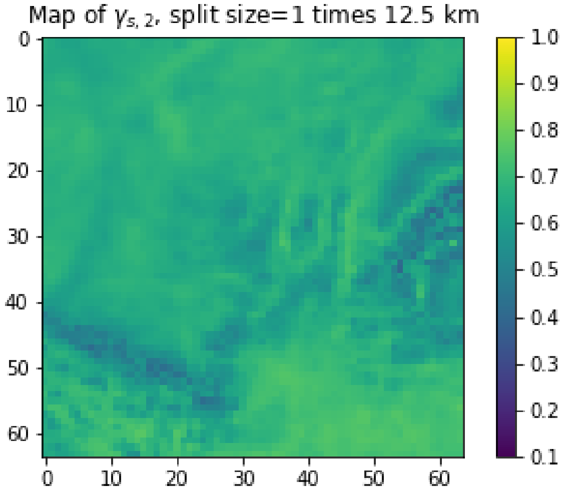


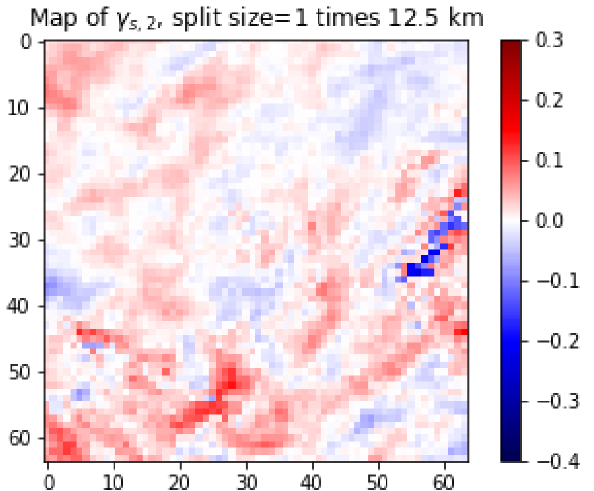


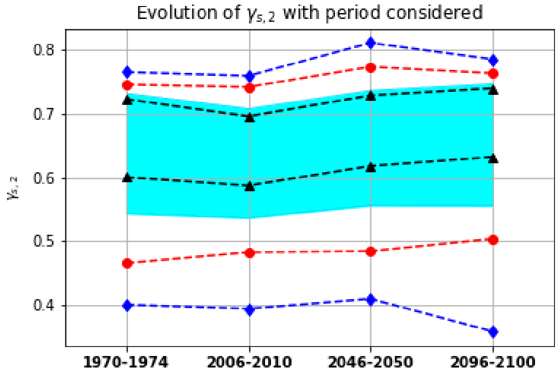


1x1 pixel (Min / Max)
4x4 pixels (Min /Max)
16x16 pixels (Min / Max)
5%-95% quantiles on 1x1 pixels

Small Scales γ_s







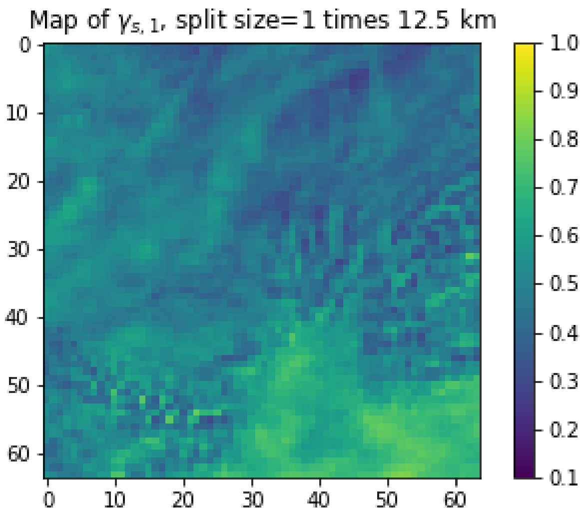
Effects of changing climate on the MF parameters: influence on extremes

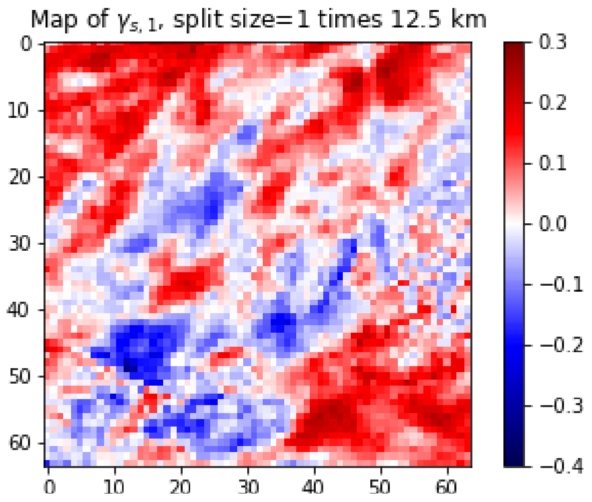
RCP 8.5 SCENARIO

Summer 1970

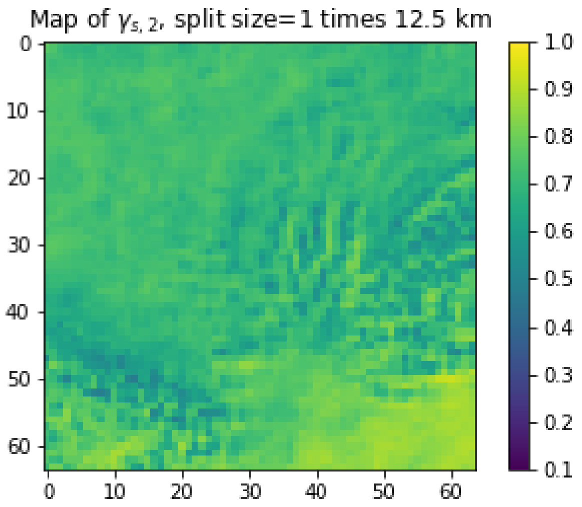
Summer δ(2100-1974)

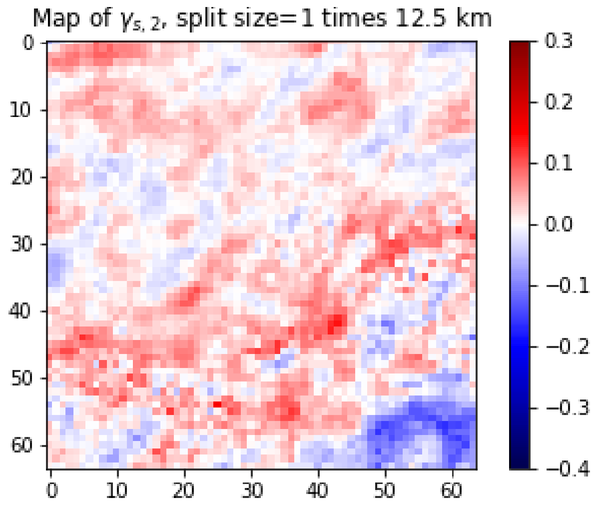
Large Scales γ_s

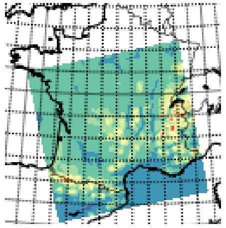


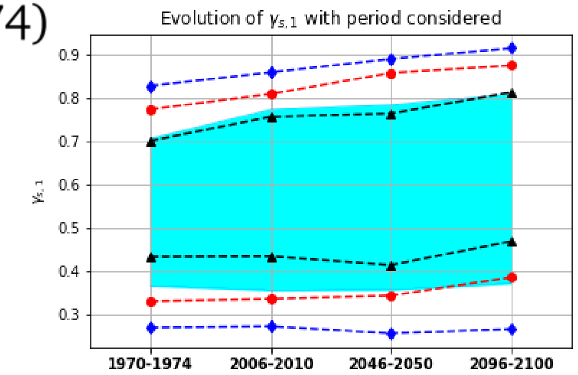


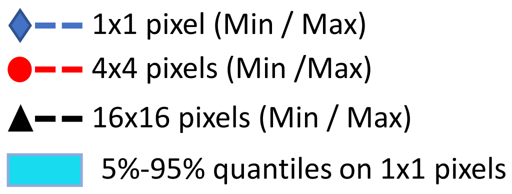
Small Scales γ_s

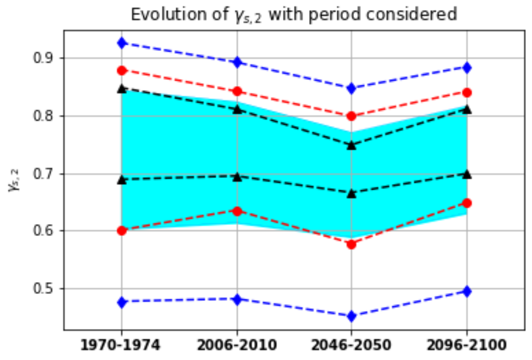












Conclusions and perspectives

- Significant seasonal variations for MF parameters:
  Robust wrt numerical choices ? To be confirmed with further analysis

- CNRM-CM5/RCA4 Model exhibits a scale break at small time scales (1h-8h) :
  Physical feature or model artifact related to precipitation parametrization ?

- Effect of climate change on extremes :

  - MF framework useful tool to extract **scale invariant quantification**
  - **Inhomogeneous** and Region-dependent (Mediterranea VS Continental)
  - Showing **contrasted evolution**, either augmenting or diminishing
  - **Stronger** in summer, but the trend is **weak on average**

- Further and refined investigations needed to confirm results
- Is it possible to design discrete **multiplicative cascade processes** including seasonal variations?

Bibliography

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