# A space-time simulator of daily temperature designed for mountain climatology

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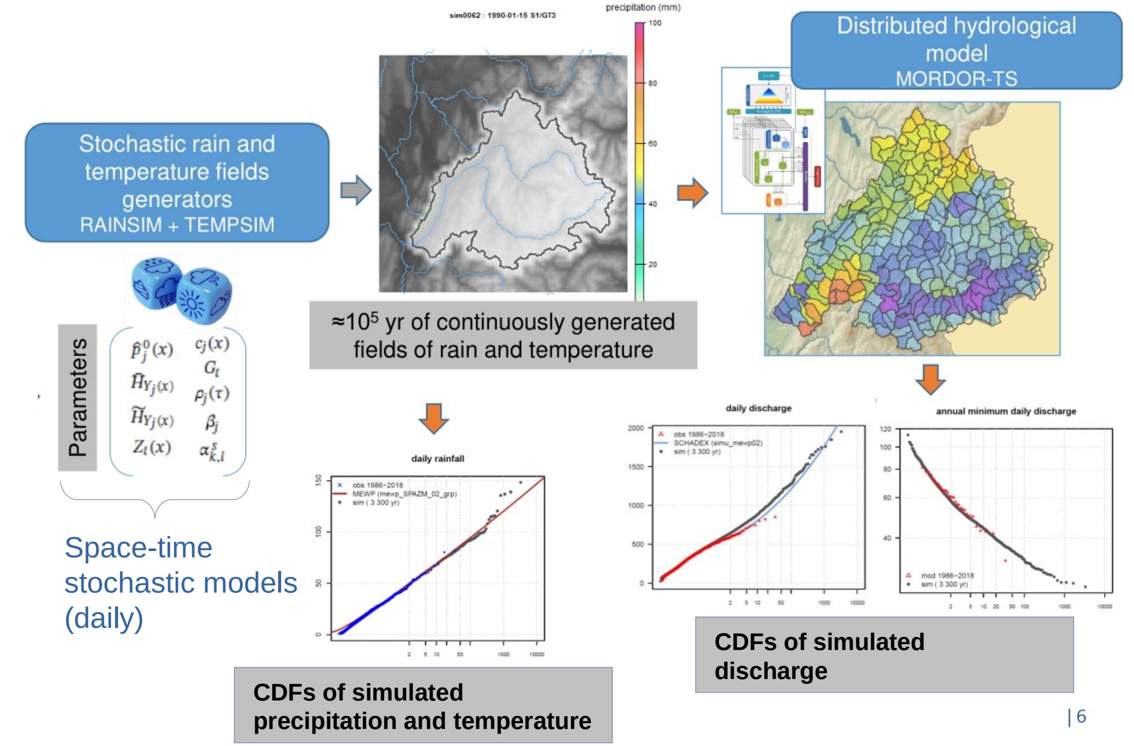
Avec la collaboration de Emmanuel Paquet, Guillaume Evin,
Mathieu Dode, Abubakar Haruna

*SWGEN conference*
*Grenoble, December 2-4 2025*

## GENERAL FRAMEWORK

Framework of **temperature & rainfall** stochastic generation to feed an hydrological model






@Emmanuel Paquet

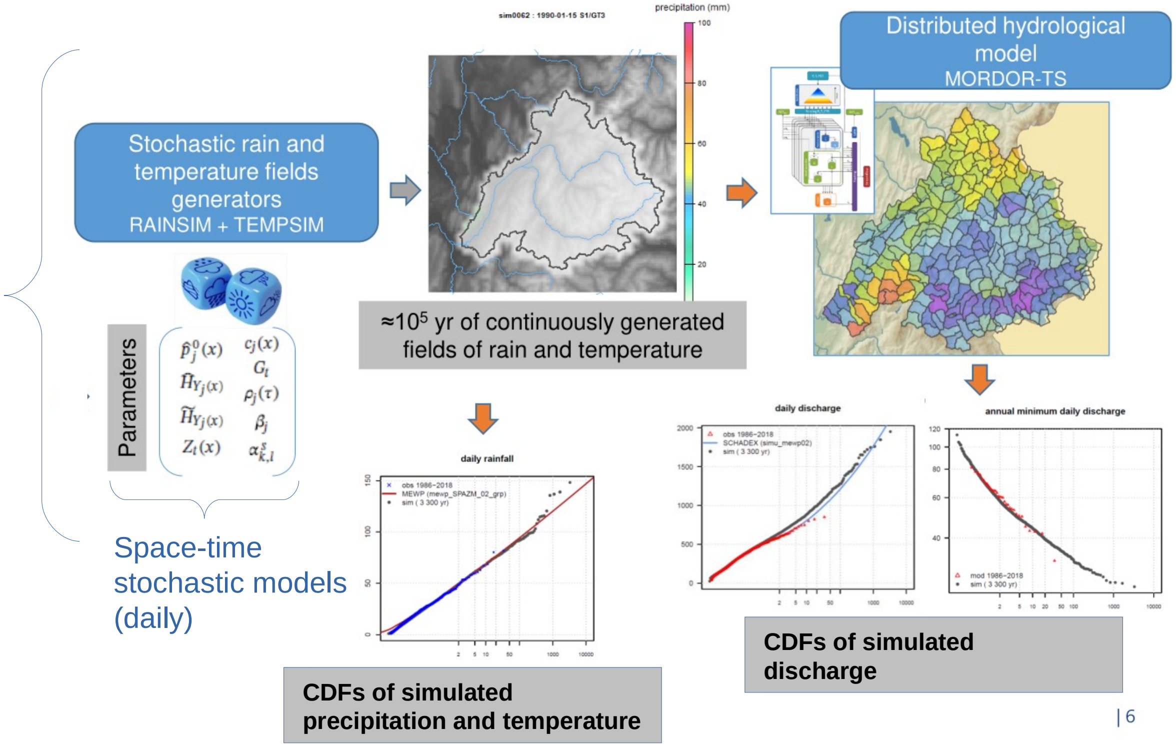
## ▪ GENERAL FRAMEWORK

Framework of **temperature & rainfall** stochastic generation to feed an hydrological model

**RAINSIM** : E.Paquet
(Wednesday afternoon)

Application of
**RAINSIM+TEMPSIM=hydro**
P. Guillemin
(Thursday morning)

This talk :
**TEMPSIM model**



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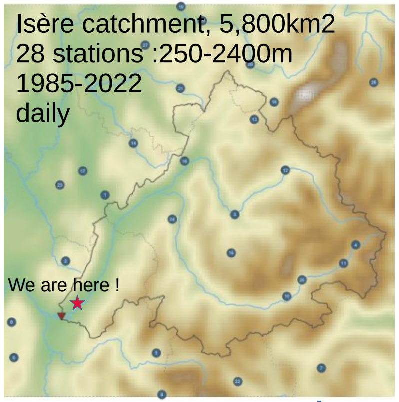
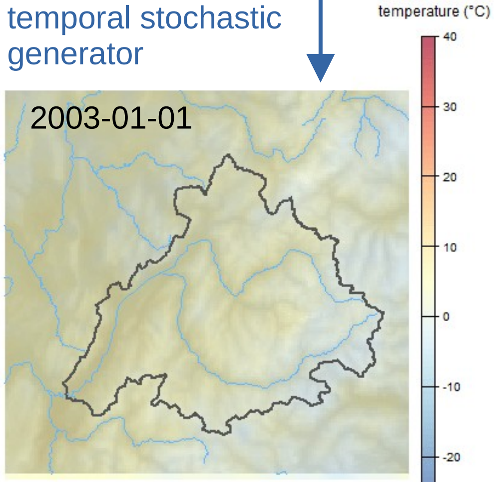
## PRINCIPLE




Learn a spatio-temporal stochastic generator



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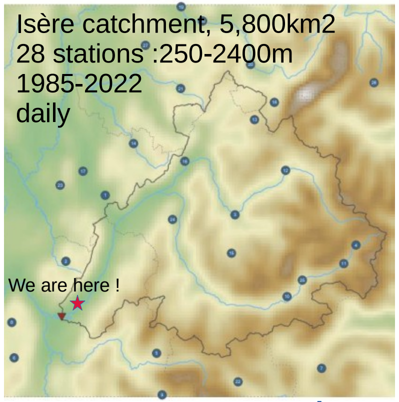


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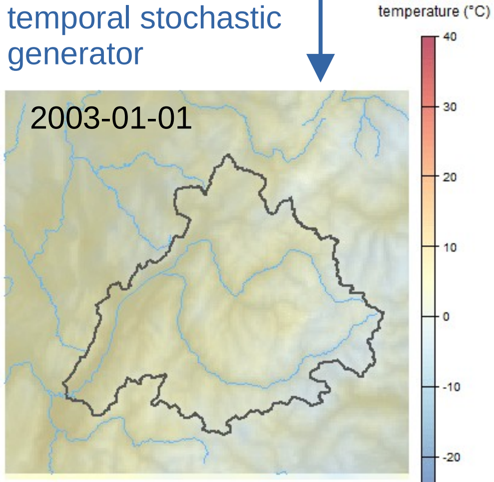
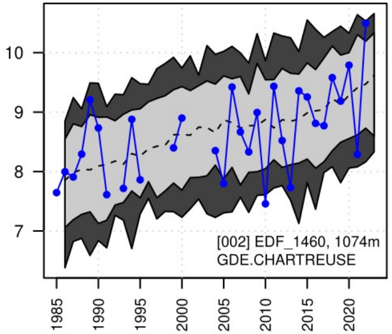
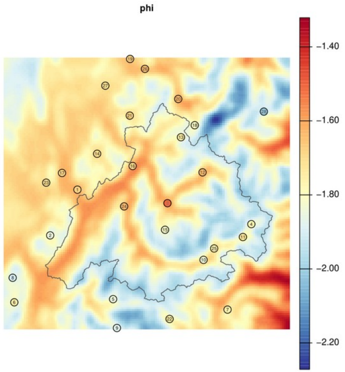


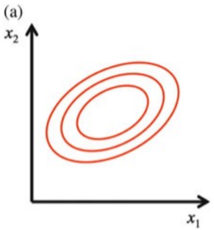

Marginal distributions (at-site)

Parameter spatialisation

Marginal distributions (everywhere)

Gaussian anamorphosis

Spatio-temporal correlation



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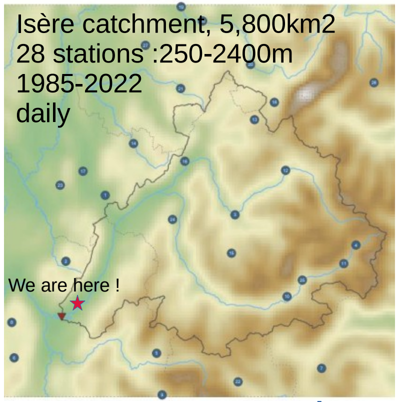


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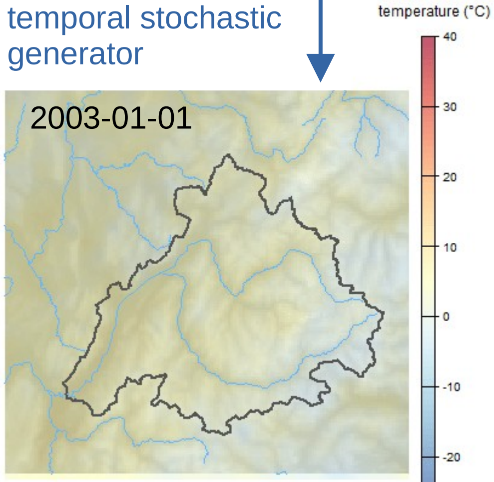


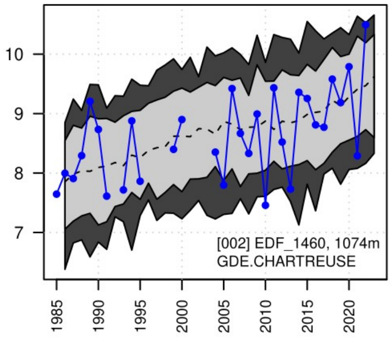


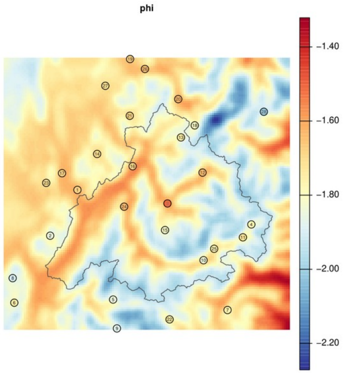


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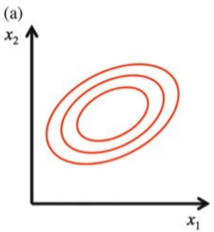


Spatio-temporal correlation

Simulation of autoregressive Gaussian fields

Inverse transformation

Series of daily temperature fields

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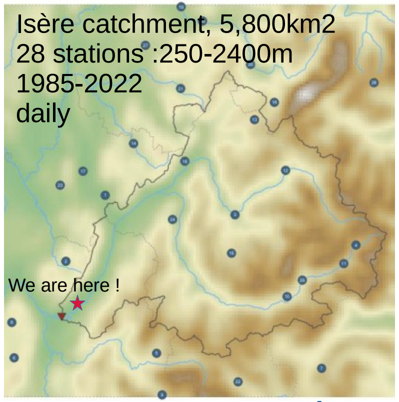


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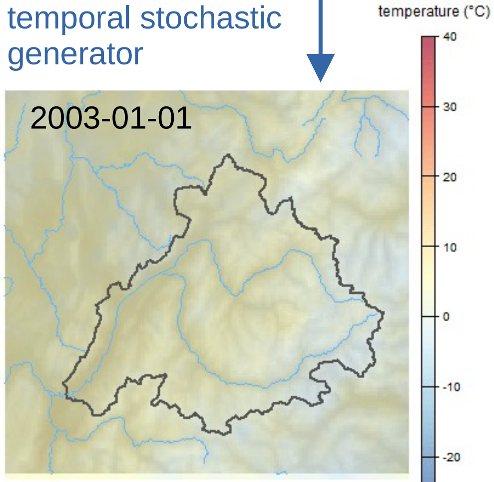


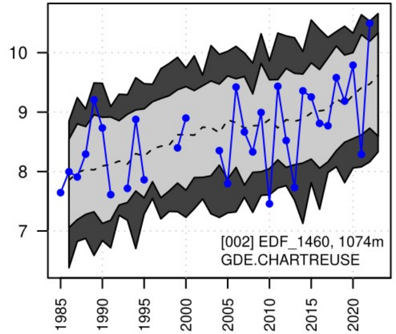


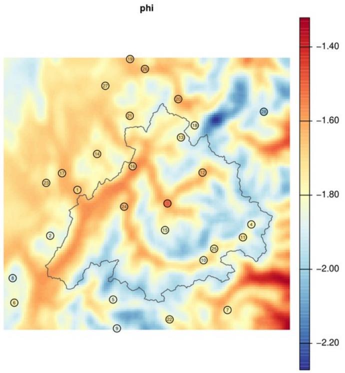


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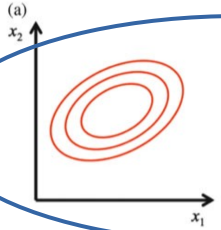
1-order temporal correlation & anisotropic covariance function

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## MARGINAL DISTRIBUTION

$$\text{daily temperature} = \underbrace{\text{climatic trend} + \text{seasonal cycle}}_{\textit{deterministic}} + \underbrace{\text{residuals}}_{\textit{stochastic}}$$

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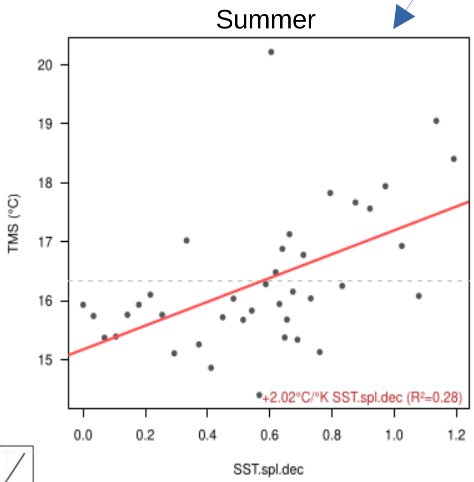
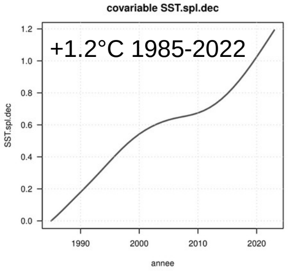


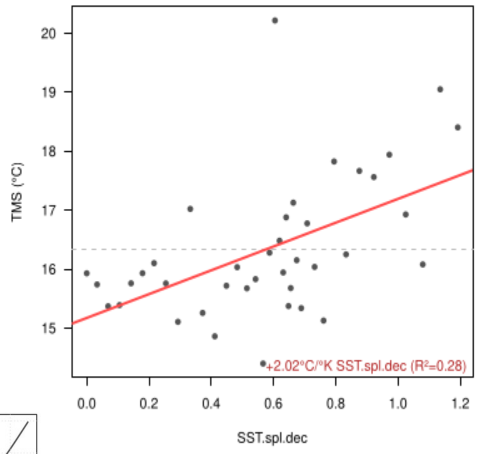




Climatic trend (1*4) : Sea surface temperature covariate

## MARGINAL DISTRIBUTION

$$\underbrace{\textit{daily temperature} = \textit{climatic trend} + \textit{seasonal cycle}}_{\textit{deterministic}} + \underbrace{\textit{residuals}}_{\textit{stochastic}}$$

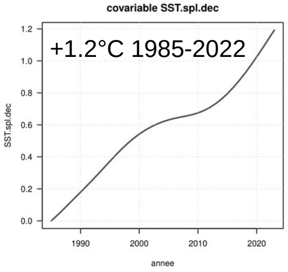
Summer




$$H_i(j) = \begin{cases} A_i + B_i \sin(\omega_i \times j + \phi_i) & \text{if } j < j_i \\ A_i + B_i \sin(\omega_i' \times j + \phi_i') & \text{if } j \geq j_i \end{cases}$$

$$\begin{aligned} \omega_i' &= \pi/(365 - j_i) \\ \phi_i' &= (\omega_i - \omega_i')j_i + \phi_i \\ j_i &= \pi/\omega_i \end{aligned}$$

Seasonal cycle (4) : gluing 2 sine functions

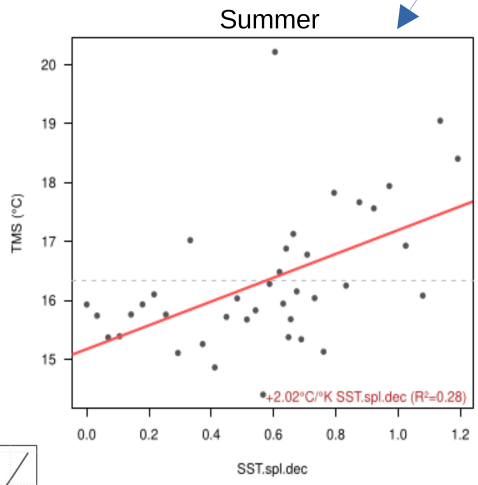


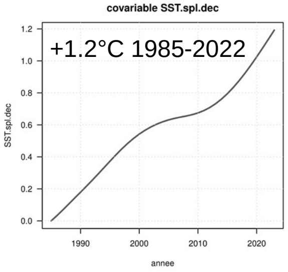

Climatic trend (1*4) : Sea surface temperature covariate

## MARGINAL DISTRIBUTION

*deterministic* *stochastic*

*daily temperature* = *climatic trend* + *seasonal cycle* + *residuals*

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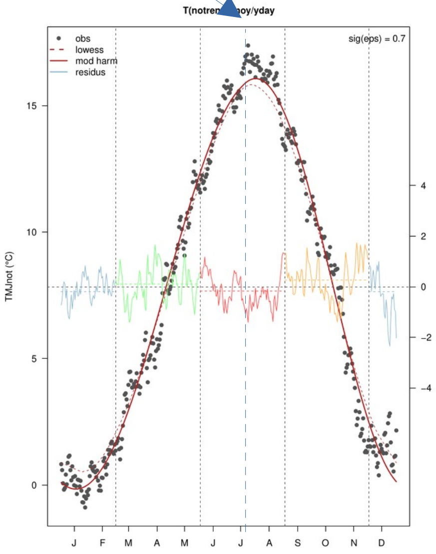


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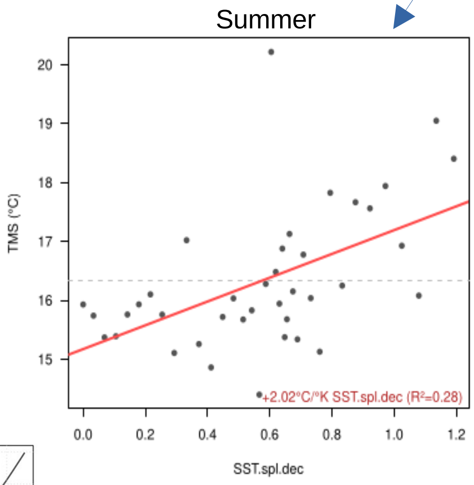


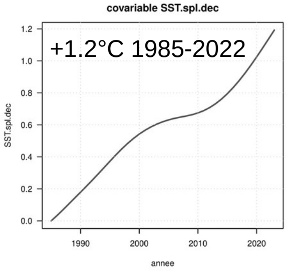


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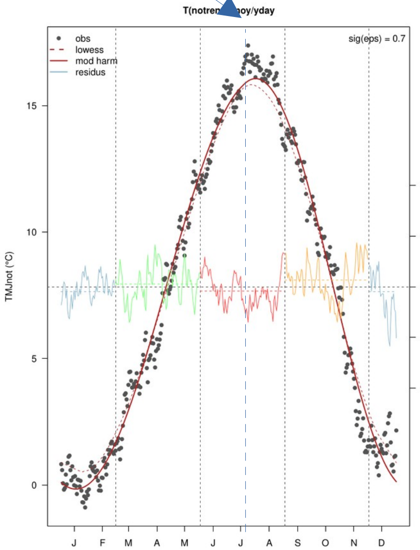


Seasonal cycle (4) : gluing 2 sine functions

Skewed Generalized Error Distribution

$$f_{SGED}(u) = \frac{2}{\xi + 1/\xi} g\left(\frac{u'}{\xi^{sign(u')}}\right),$$

$$\begin{aligned}
u' &= \mu' + \sigma' u \\
\mu' &= \gamma(\xi - 1/\xi) \\
\sigma' &= \sqrt{(1-\gamma^2)(\xi^2 + 1/\xi^2) + 2\gamma^2 - 1} \\
\gamma &= 2^{1/\nu}\lambda\Gamma(2/\nu)/\Gamma(1/\nu) \\
\lambda &= \sqrt{2^{-2/\nu}\Gamma(1/\nu)/\Gamma(3/\nu)},
\end{aligned}$$

Residuals (4*24=96) : SGED conditioned on seasons, weather types & precipitation occurrence at regional scale

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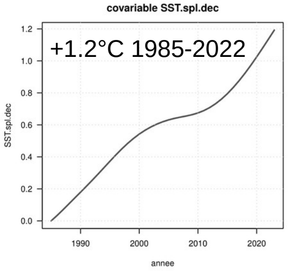
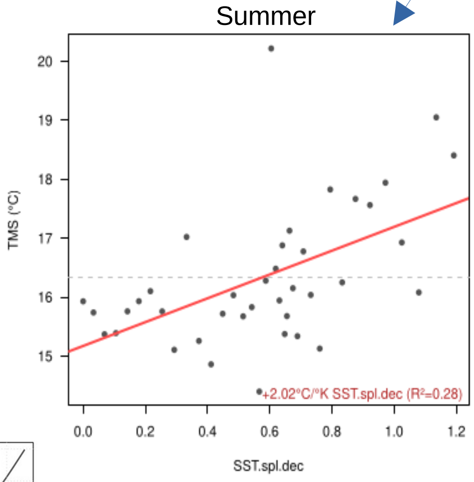
*daily temperature* = $\underbrace{\textit{climatic trend} + \textit{seasonal cycle}}_{\textit{deterministic}} + \underbrace{\textit{residuals}}_{\textit{stochastic}}$

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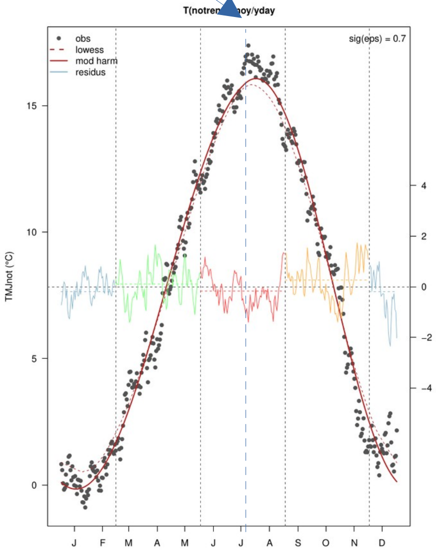


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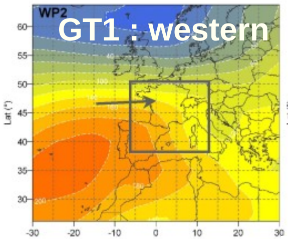
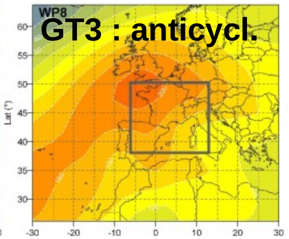
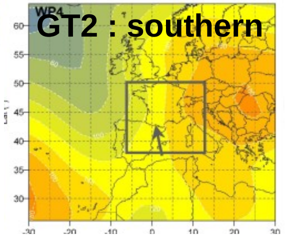
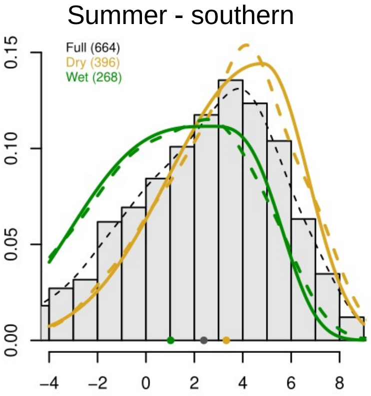


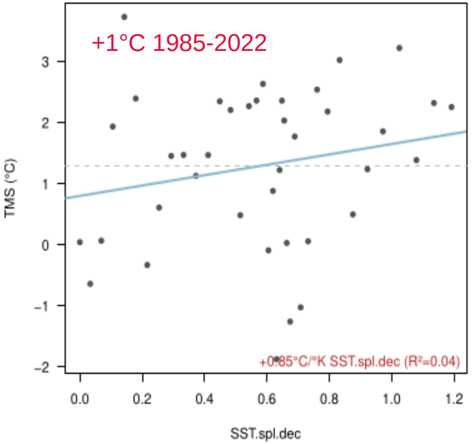



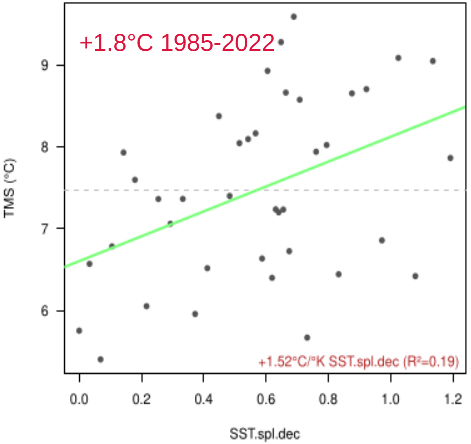

Residuals (4*24=96) : SGED conditioned on seasons, weather types & precipitation occurrence at regional scale

## CLIMATIC TREND - EXAMPLE

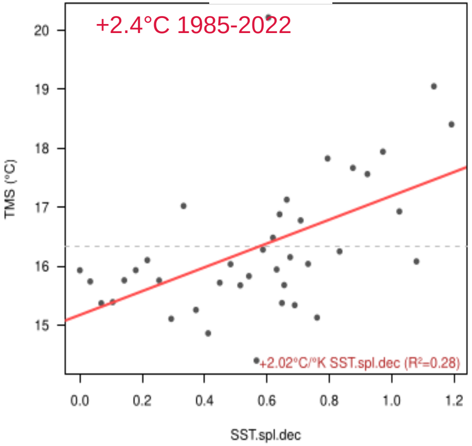

winter




spring




summer




autumn

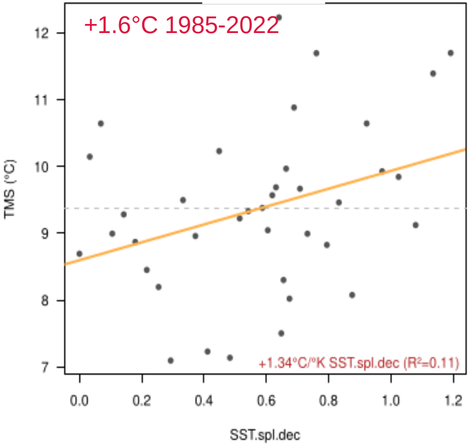



*Fig : Example at the Grande Chartreuse station (1074m)*

## SGED FOR THE RESIDUALS - EXAMPLE

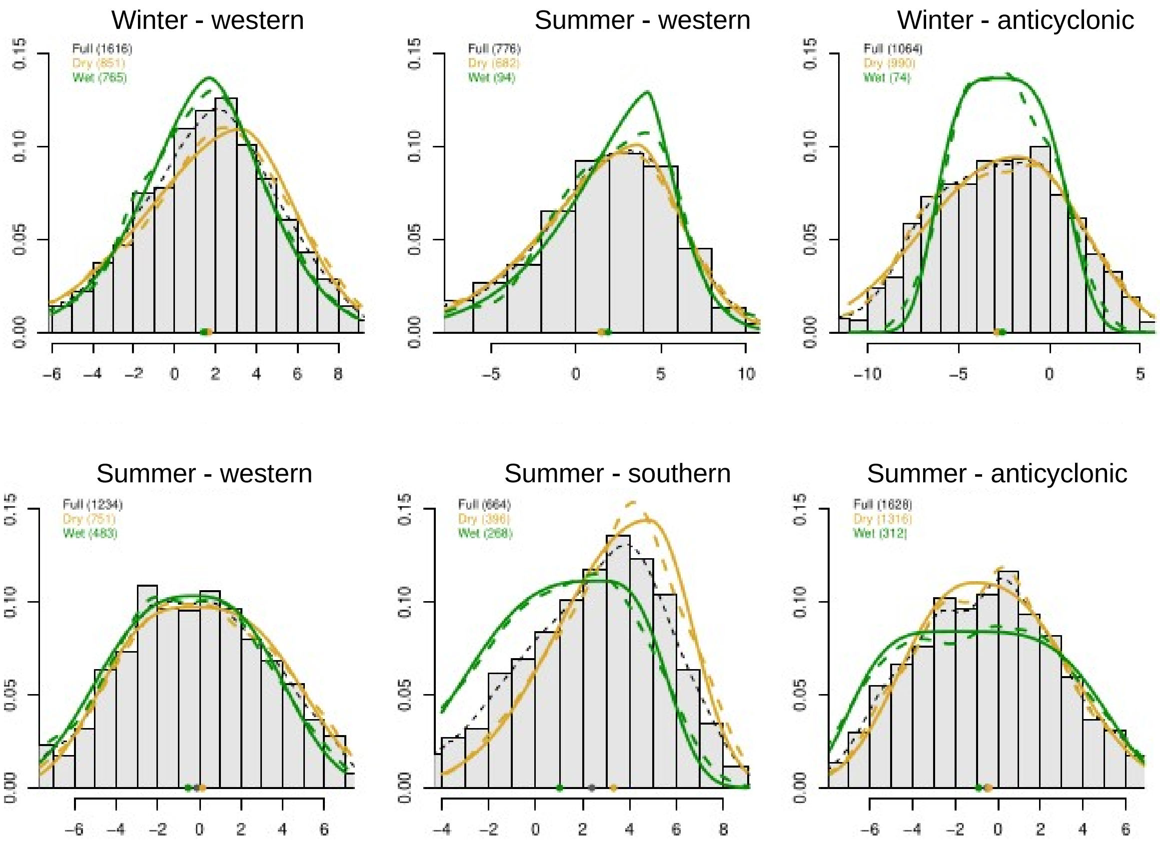
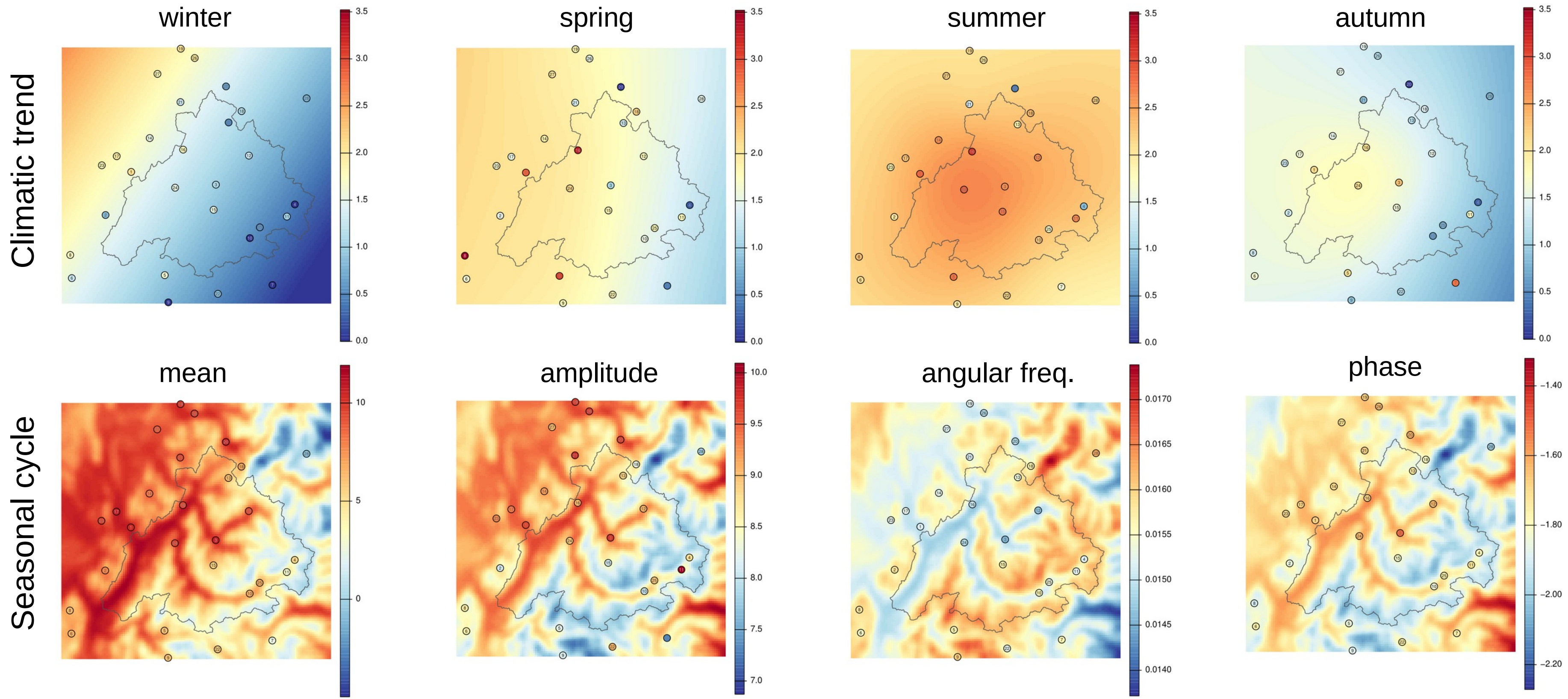



*Fig : Example at the Grande Chartreuse station (1074m)*

## MAPPING THE MARGINAL PARAMETERS

Thin plate spline to interpolate in space, separately for the 104 marginal parameters



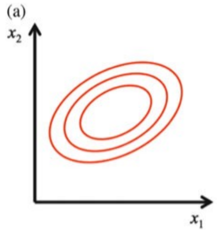
## SIMULATION SCHEME

Marginal distributions (at-site)

Parameter spatialisation

Marginal distributions (everywhere)

Gaussian anamorphosis




Spatio-temporal correlation

Simulation of autoregressive Gaussian fields

Inverse transformation

Series of daily temperature fields

Series of weather types ?
Series of precipitation occurrence ?

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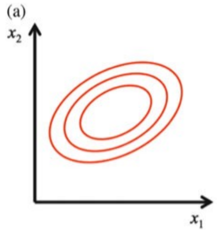


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(alternatives : WT=order-2 Markov chain
precipitation occurrence = RAINSIM)

Series of weather types ? The observed ones
Series of precipitation occurrence ? The observed ones
=> we only validate TEMPSIM

→ Repeat the simulation of 1985-2022 many times

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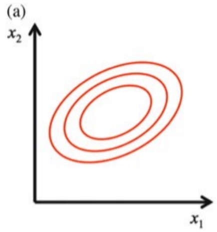


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**Which scores to validate a high dimensional problem ?**

## ▪ ANNUAL TEMPERATURE

With the **interpolated** marginal parameters

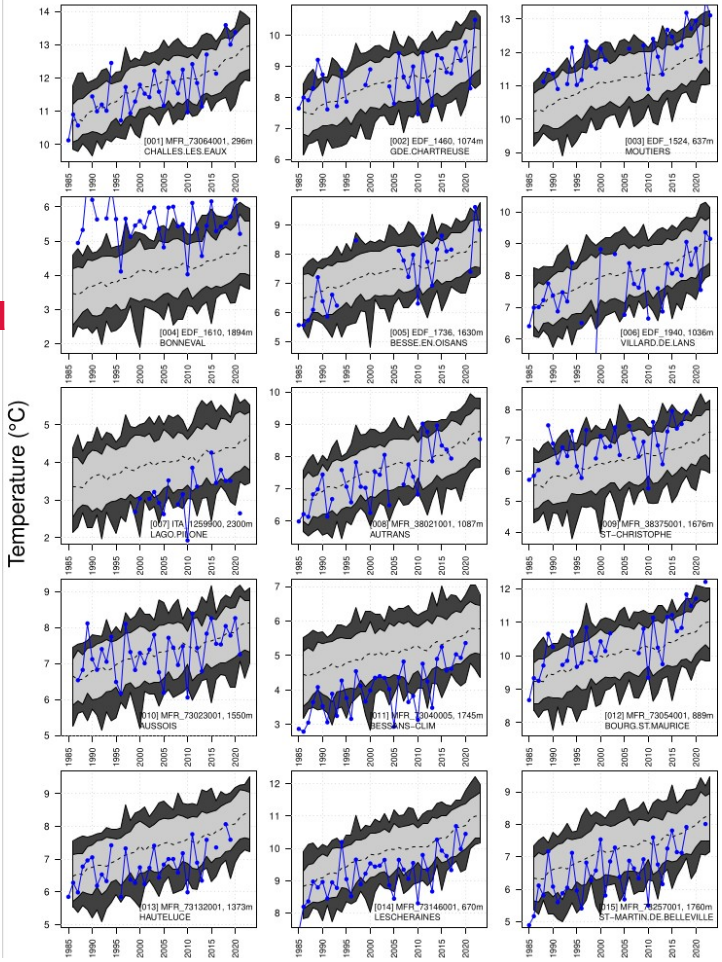
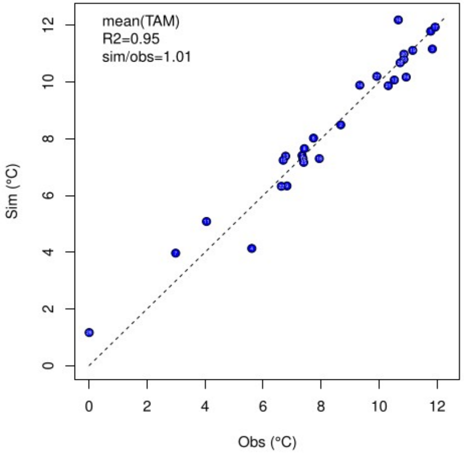
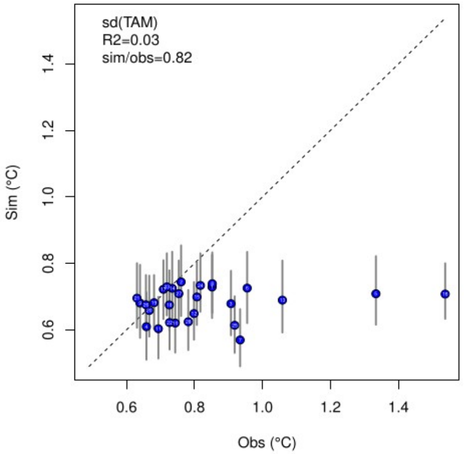



*Fig. : Annual mean temperature at 15 random stations*

## ANNUAL TEMPERATURE

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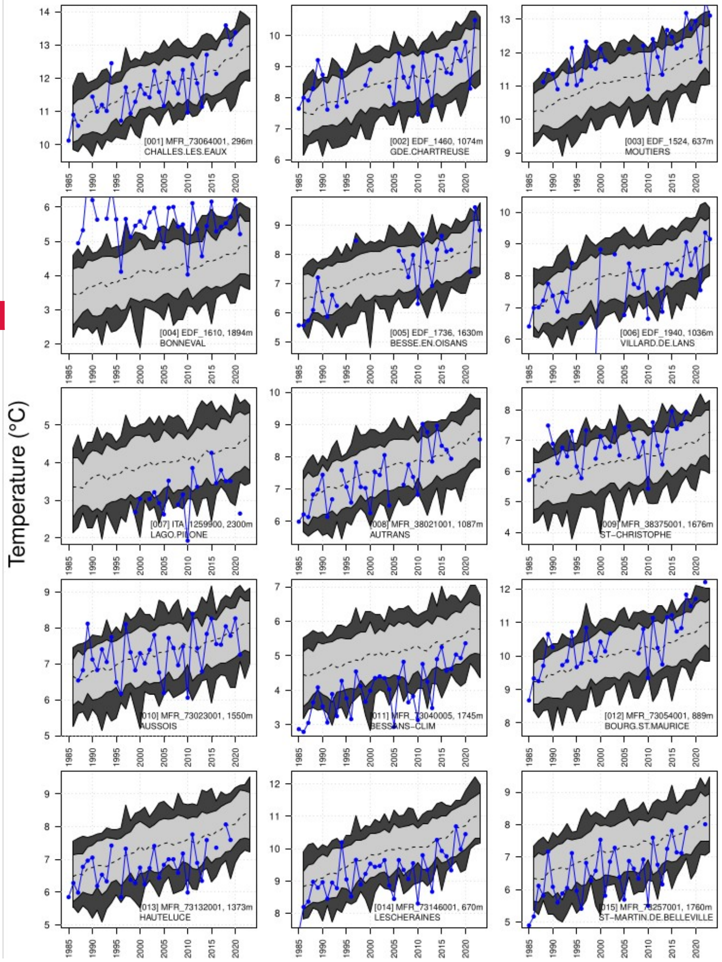


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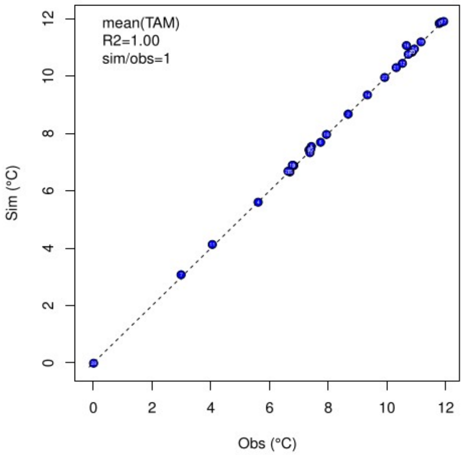
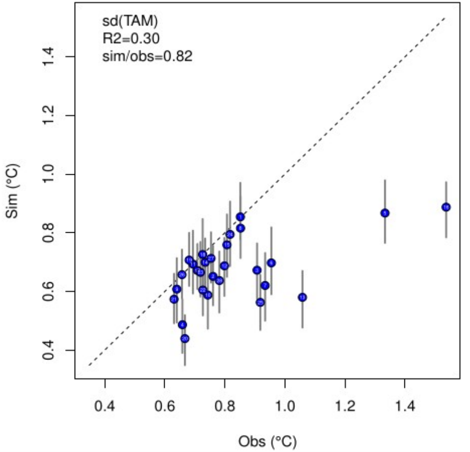
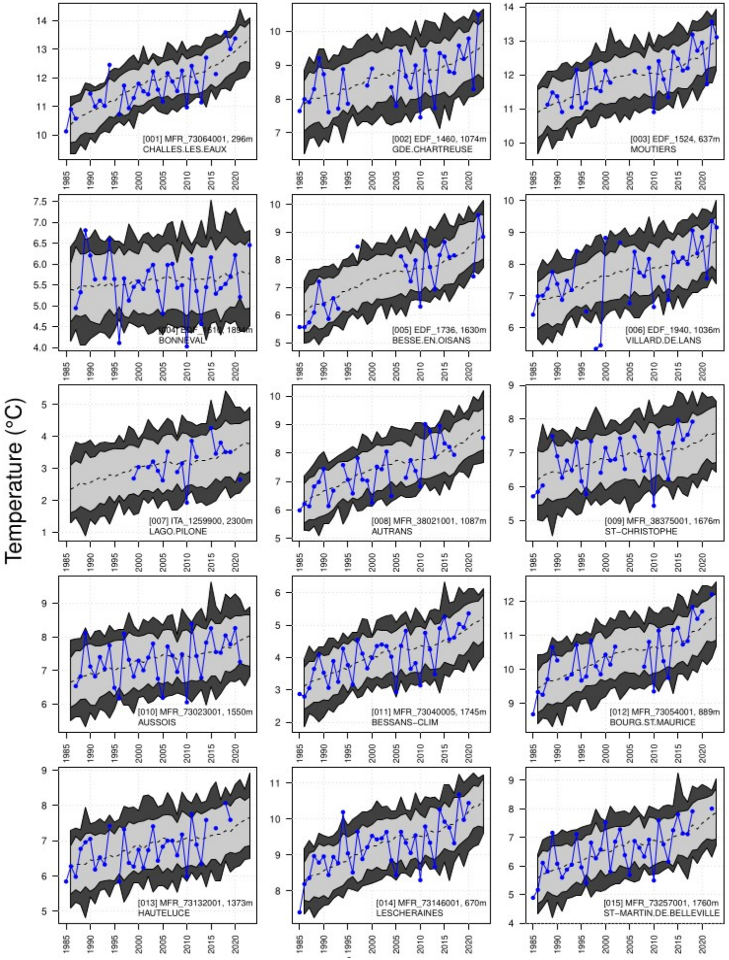



With the **at-site** marginal parameters

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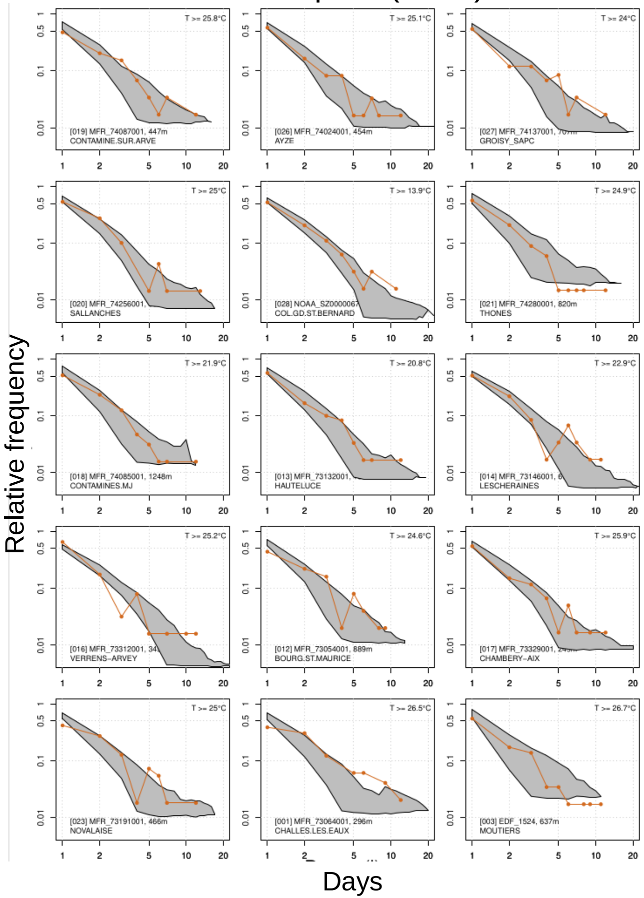
# ▪ LOCAL COLD AND HOTSPELLS

Cold spells (T<=0)




Hot spells (T>q99)

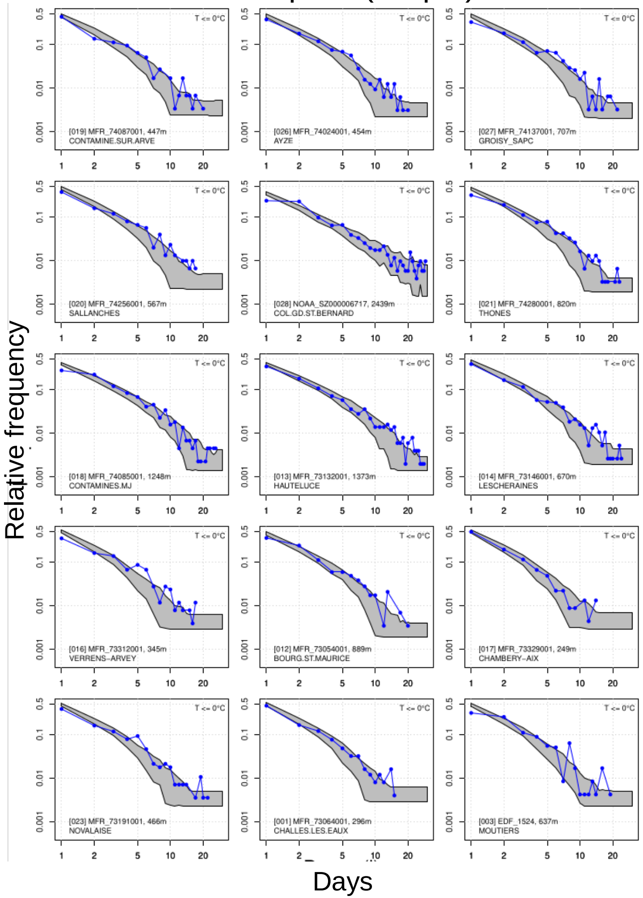



*Fig. : Frequency of cold and hot spells at 15 random stations*

With the **interpolated** marginal parameters

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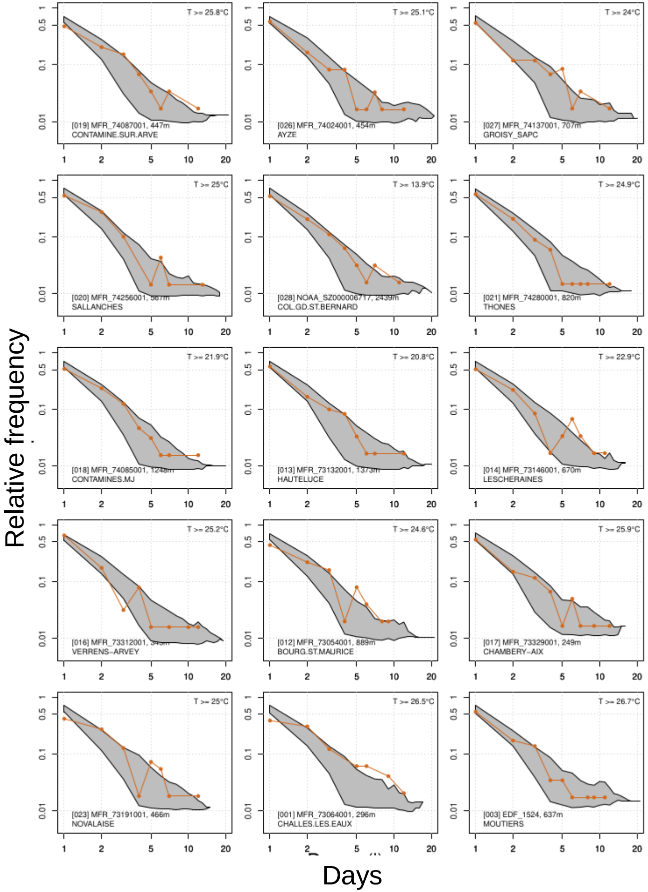



Hot spells (T>q99)

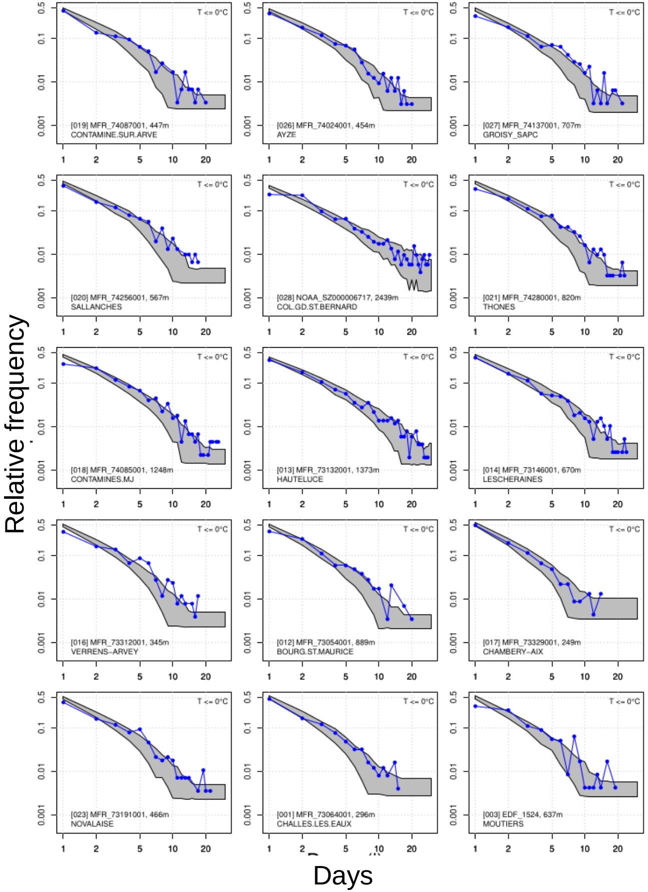



*Fig. : Frequency of cold and hot spells at 15 random stations*

With the **at-site** marginal parameters

## SPATIAL EXTENSION OF COLD AND HOT DAYS

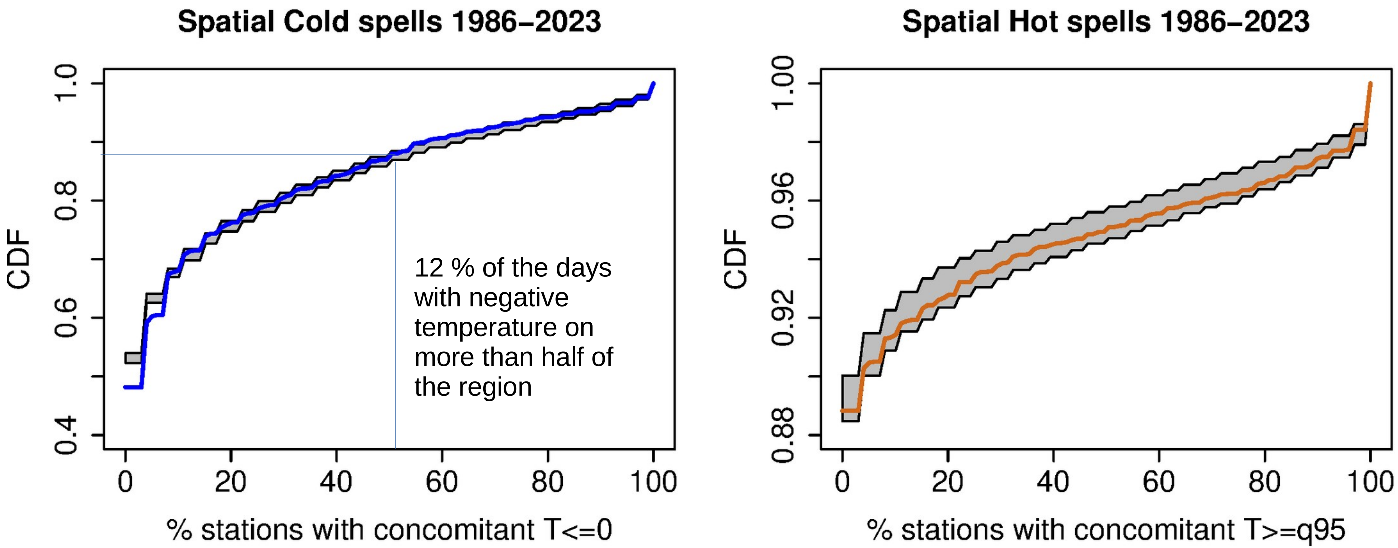
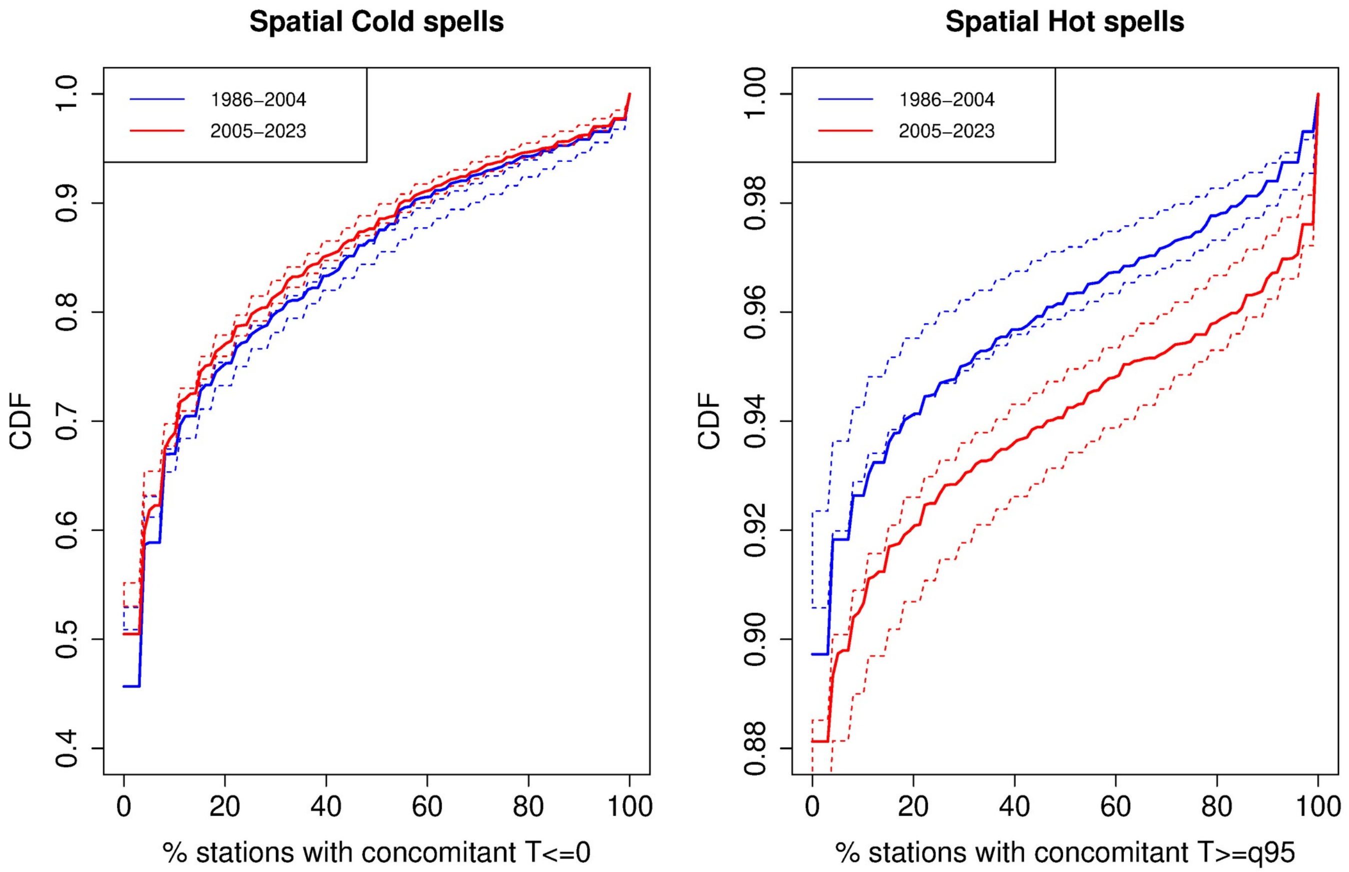
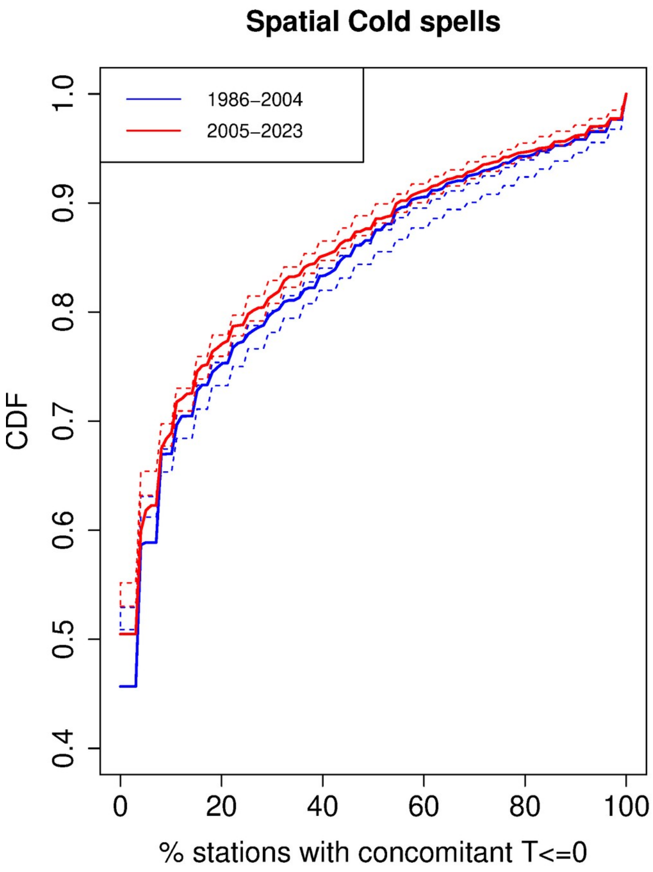


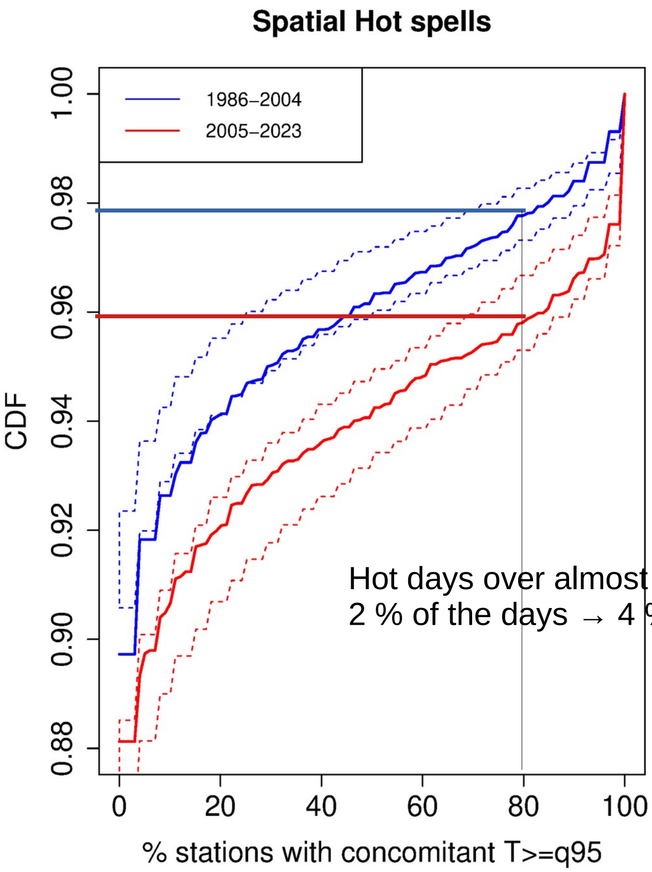

*Fig. : CDF of concomitant hot and cold days*

# ▪ CHANGE IN THE SPATIAL EXTENSION OF COLD AND HOT DAYS



## ▪ CHANGE IN THE SPATIAL EXTENSION OF COLD AND HOT DAYS

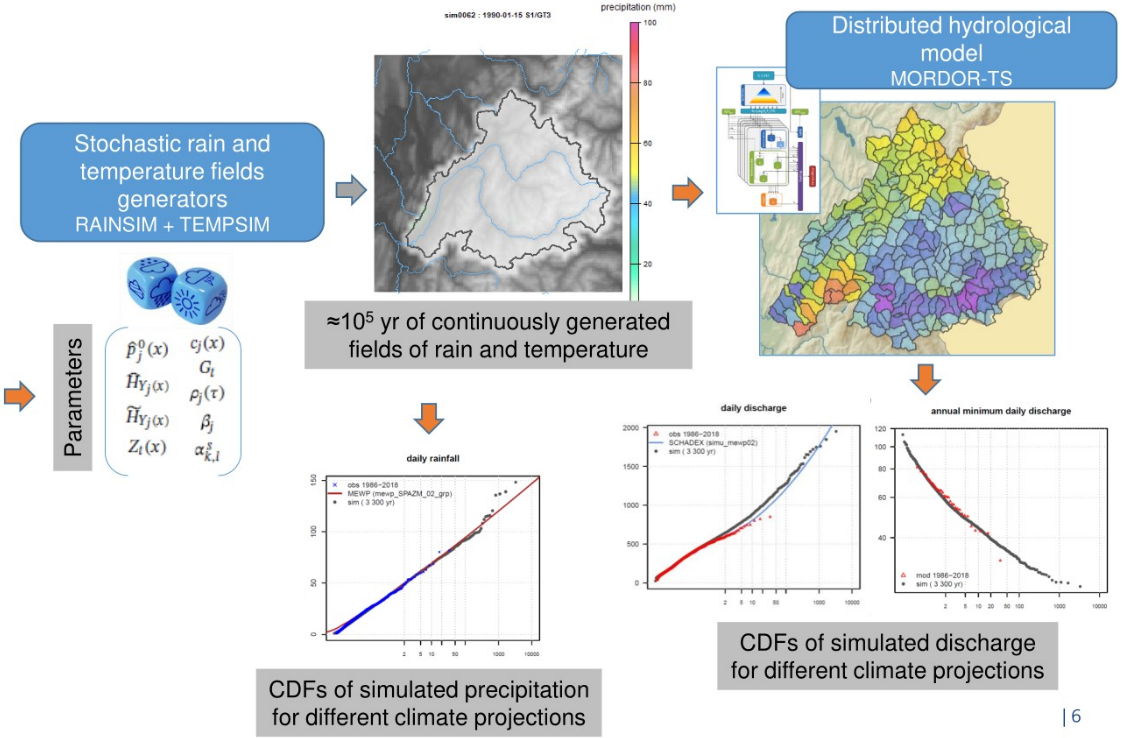



Hot days over almost all the region :
2 % of the days → 4 %

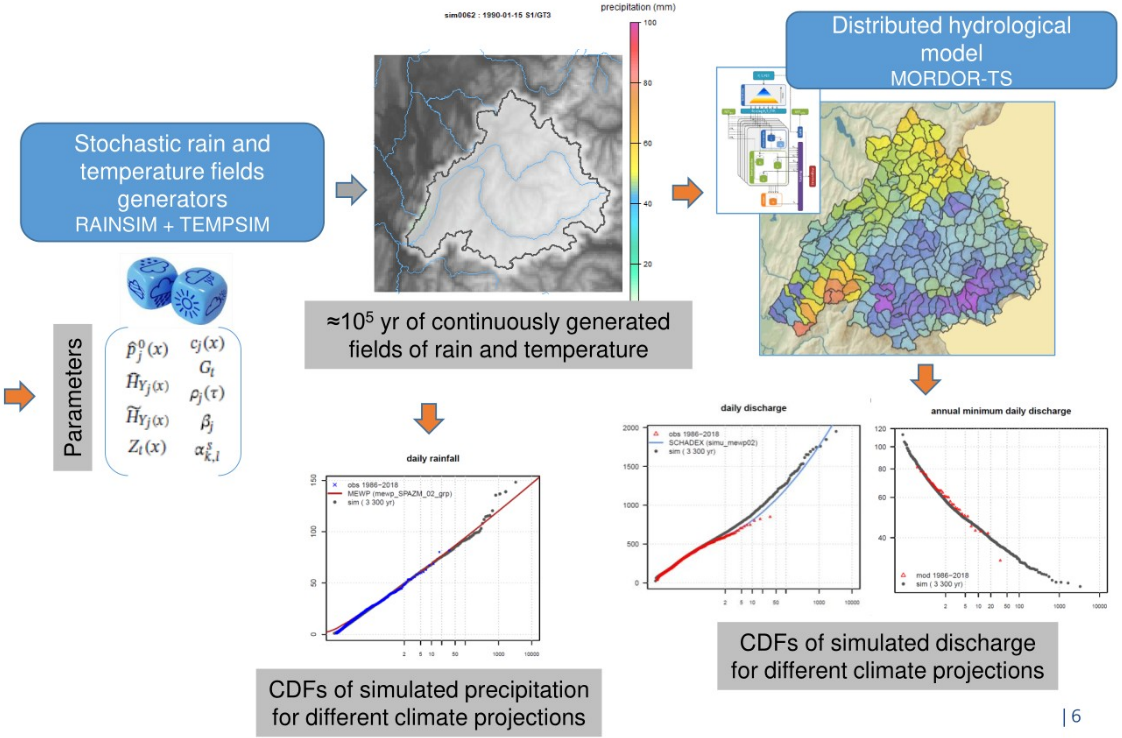
## HYDROLOGICAL VALIDATION

RAINSIM+TEMPIM=HYDROLOGY : See the talk by P. Guillemin (Thursday morning)



## HYDROLOGICAL VALIDATION

RAINSIM+TEMPIM=HYDROLOGY : See the talk by P. Guillemin (Thursday morning)
… but actually using the observed temperatures together with RAINSIM doesn't change much !



## ▪ HYDROLOGICAL VALIDATION

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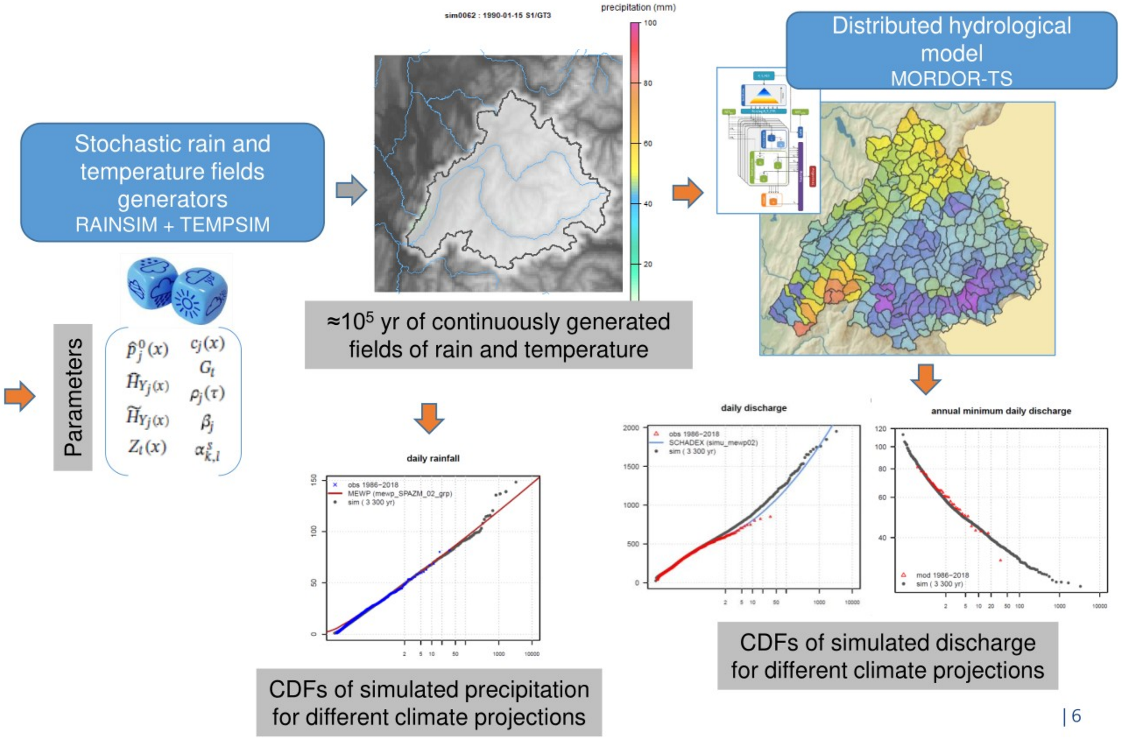
**True interest : for future climate**

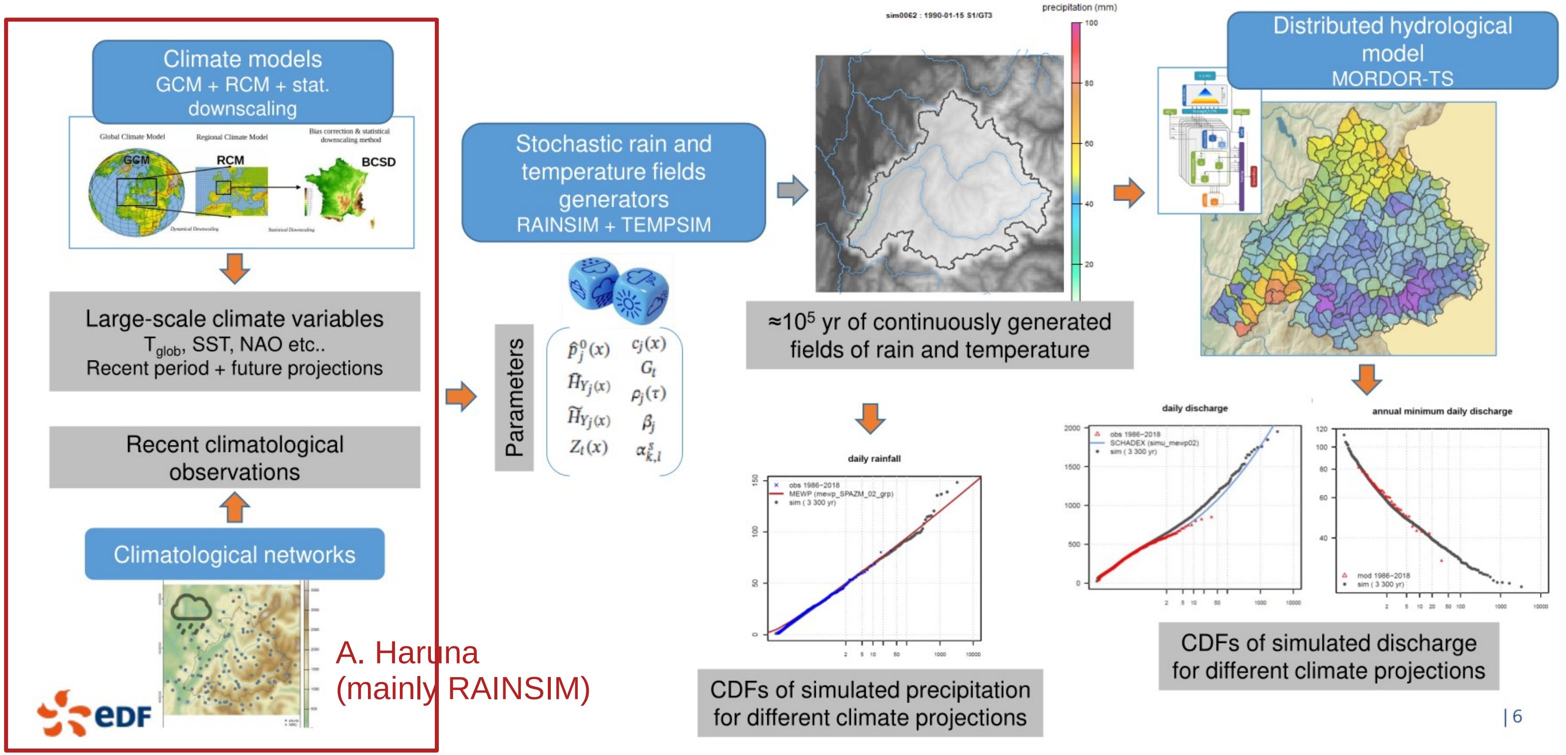


## ▪ IN PROGRESS : FOR FUTURE CLIMATE

RAINSIM+TEMPIM=HYDROLOGY : See the talk by P. Guillemin (Thursday morning)

… but actually using the observed temperatures together with RAINSIM doesn't change much !

**True interest : for future climate**



Thank you.