MSTWeatherGen: A Multivariate and Space-Time stochastic Weather Generator

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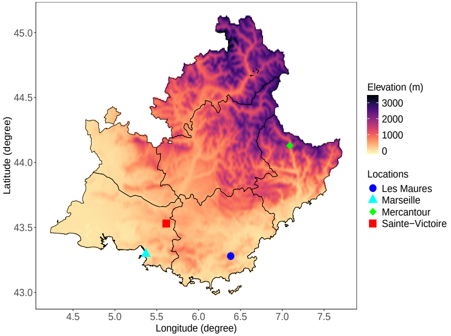
- **Region of Focus:** PACA, France
- **Period:** 2012-2021
- **Dataset:** Safran Daily Reanalysis
    - **Variables:** Humidity, Precipitation, Radiation, Min and max Temperature, Wind
    - **Resolution:** 8 km $\times$ 8 km



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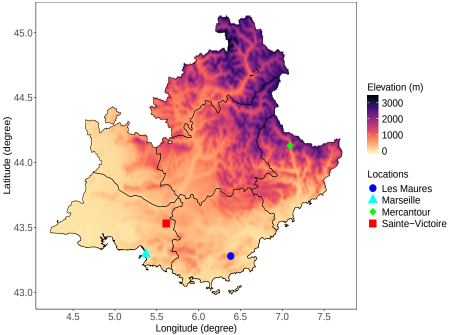
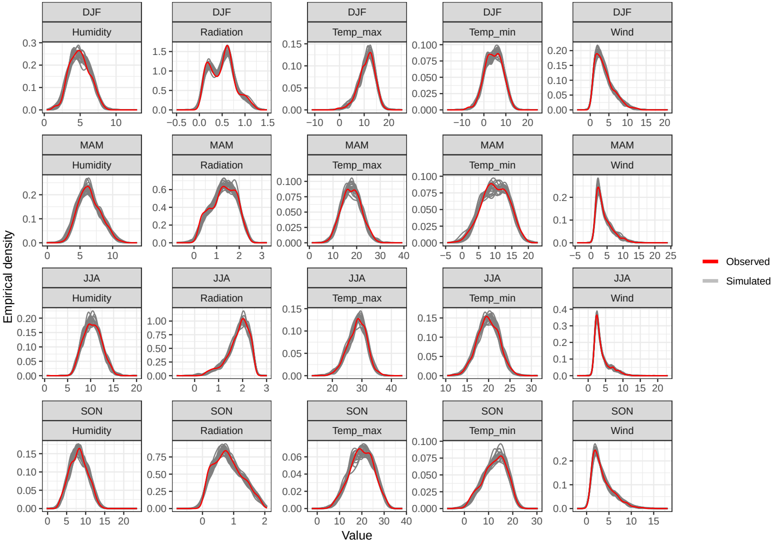
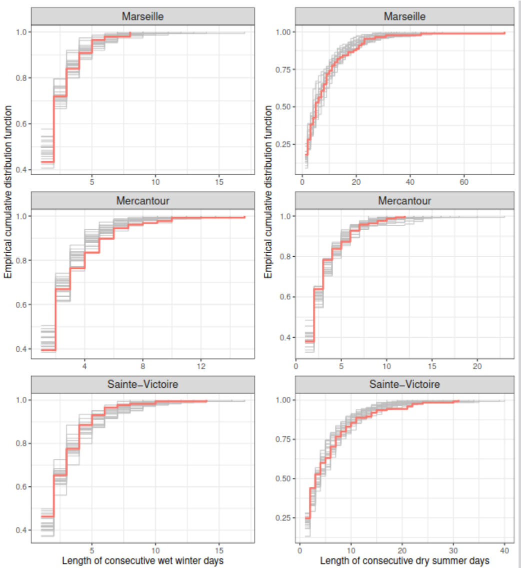
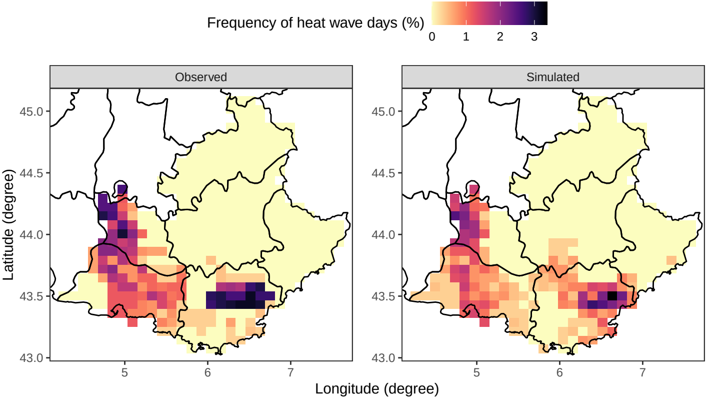


We run MSTWeatherGen and simulate the weather variables in this area for the period 2012-2021.


DJF
MAM
JJA
SON
Humidity
Radiation
Temp_max
Temp_min
Wind
Empirical density
Value
Observed
Simulated


Marseille
Mercantour
Sainte–Victoire
Empirical cumulative distribution function
Length of consecutive wet winter days
Length of consecutive dry summer days


Frequency of heat wave days (%)
0
1
2
3
Observed
Simulated
45.0
44.5
44.0
43.5
43.0
5
6
7
Latitude (degree)
Longitude (degree)

Fire Weather Index (FWI)

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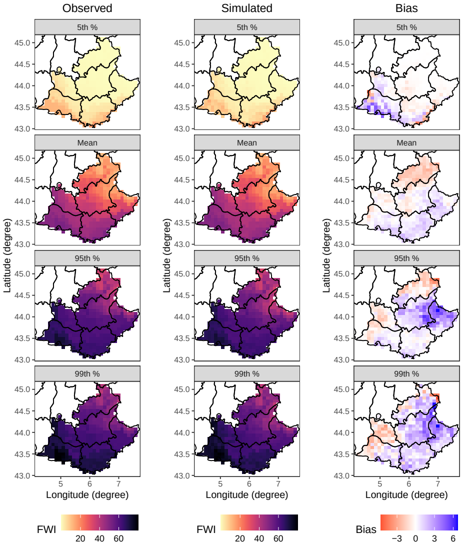
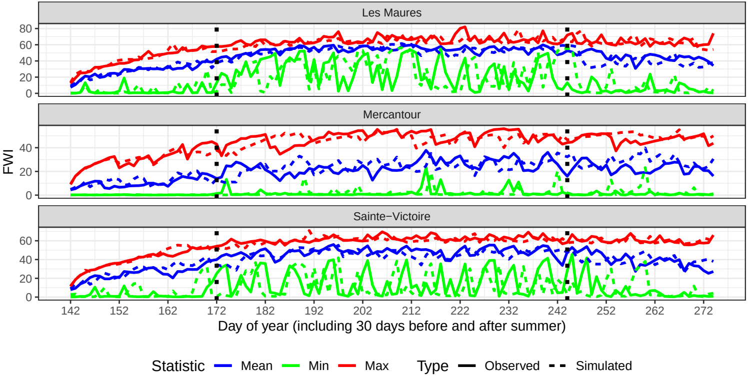
- Meteorologically-based metric used to assess fire hazards [Wagner, 1987]
- Uses precipitation, temperature, relative humidity, and wind speed
- Integrates the joint influence and dynamics among these variables
- FWI is used to evaluate MSTWeatherGen in PACA region

- Percentiles of summer FWI during the period 2012 to 2021
- MSTWeatherGen reproduces the overall spatial patterns of FWI





- MSTWeatherGen captures the temporal dynamics of FWI

Summary

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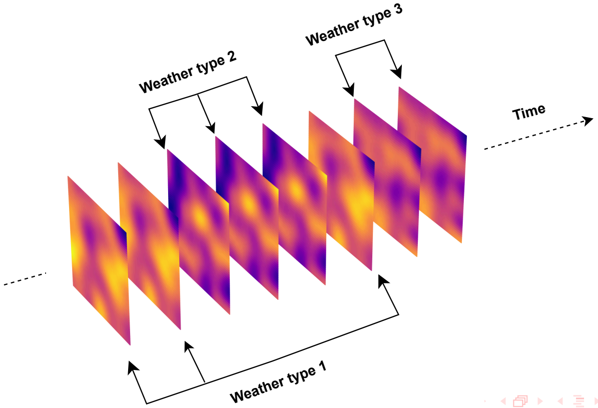
- This means that it models well the space-time dependencies and variable interactions
- How does MSTWeatherGen work?

MSTWeatherGen: Core components

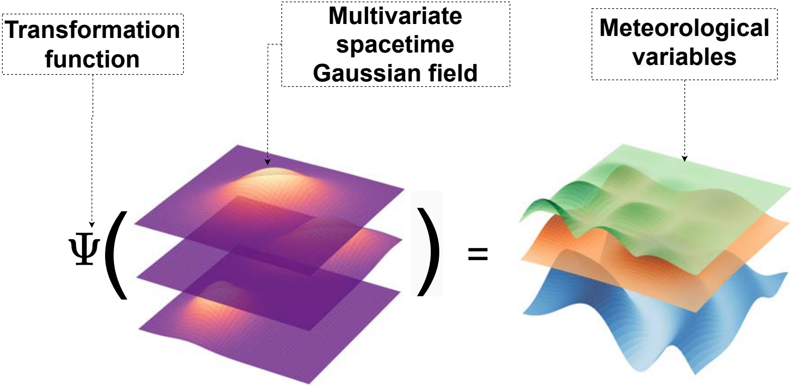
Weather types	**Transformation function**	**Latent Gaussian field**

Hypothesis

The atmosphere tends to exhibit certain recurring patterns or types of weather. These patterns are identifiable and can be statistically characterized.



At each weather types, meteorological variables are modeled as non-linear transformation of a latent Gaussian random field.

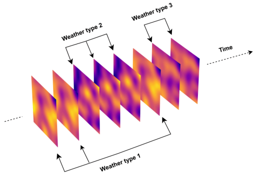


$$Y_i(\mathbf{s}, t) = \Psi_{k,i,\mathbf{s}}(Z_{k,i}(\mathbf{s}, t)), \quad \text{where } k = X(t)$$

- **Space-time domain:** $\mathcal{D} \times \mathcal{T} \subset \mathbb{R}^2 \times \mathbb{R}$
- **Meteorological variables:** $\mathbf{Y}(\mathbf{s}, t) = [Y_i(\mathbf{s}, t)]_{i=1}^{p}$
- **Weather types process:** $X(t) \in \mathcal{S} = \{1, \ldots, K\}$
- **Latent Gaussian fields:** $\mathbf{Z}_k(\mathbf{s}, t) = [Z_{k,i}(\mathbf{s}, t)]_{i=1}^{p}$

MSTWeatherGen: Core components

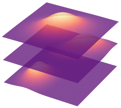
Weather types



Transformation function

$$\Psi$$

Latent Gaussian field



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- Then they are modeled as a non-homogeneous Markov chain
- Transition probabilities are estimated empirically

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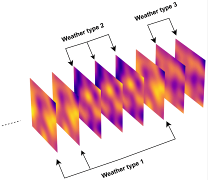
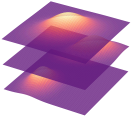
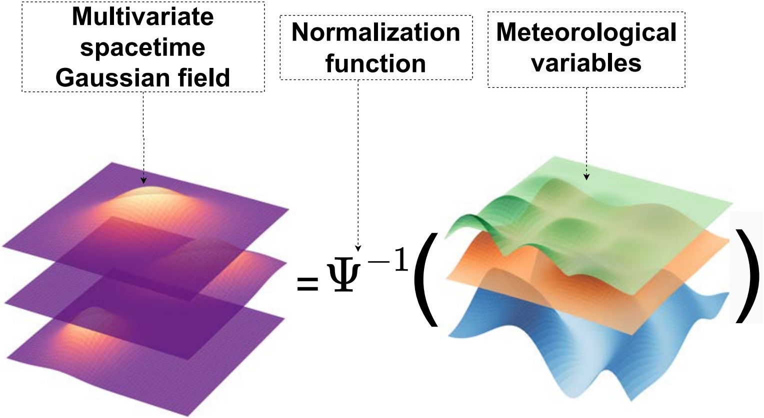


$$\Psi$$




Multivariate spacetime Gaussian field
Normalization function
Meteorological variables
$= \Psi^{-1}($ $)$

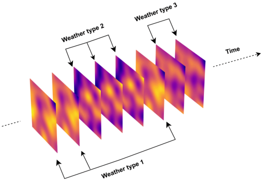
Non-linear Transformation

$$Y_i(\mathbf{s}, t) = \Psi_{k,i,\mathbf{s}}(Z_i(\mathbf{s}, t)) = \begin{cases} F^{-1}_{k,i,\mathbf{s}}\left(\Phi_{T_{k,i,\mathbf{s}}}\left(Z_{k,i}(\mathbf{s}, t)\right)\right) & \text{if} \quad Z_i(\mathbf{s}, t) > T_{k,i,\mathbf{s}} \\ 0 & \text{if} \quad Z_i(\mathbf{s}, t) \leq T_{k,i,\mathbf{s}}, \end{cases}$$

- Quantile-quantile transformation method called ordered quantile normalization (OQN)
- See [Peterson and Cavanaugh, 2019] for more details
- Adapted here for the zero-inflated distributions

MSTWeatherGen: Core components

Weather types



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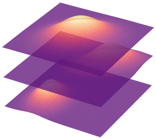

Gaussian field covariance function

$$\mathrm{Cov}(Z_{k,i}(\mathbf{s}, t), Z_{k,j}(\mathbf{s} + \mathbf{h}, t + u)) = C_{k,ij}(\mathbf{h}, u) = C^{(1)}_{k,ij}(u) + C^{(2)}_{k,ij}(\mathbf{h}, u)$$

- **Temporal Component:** $C^{(1)}_{k,ij}(u)$

$$C^{(1)}_{k,ij}(u) = \beta^{(1)}_{k,ij} \exp\left(-r^{(1)}_{k,ij}|u|\right)$$

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- **Space-Time Component:** $C^{(2)}_{k,ij}(\mathbf{h},u)$ [Allard et al., 2022]

$$C^{(2)}_{k,ij}(\mathbf{h},u) = \beta^{(2)}_{k,ij} \frac{\exp\left(-r^{(2)}_{k,ij}|u|\right)}{(\eta_{k,ij}(u)+1)^{d/2}} C_{\mathcal{M}}\left(\mathbf{h}; \sqrt{\frac{a^2_{k,ij}}{(\eta_{k,ij}(u)+1)}}, \nu_{k,ij}\right)$$

Conclusion

- MSTWeatherGen models well the multivariate spacetime dependencies
- Thanks to the covariance function [Allard et al., 2022]
- It reproduces well observed FWI values
- Can be used for risk assessment
- Improvements:
    - Including non-stationary covariance function
    - Focus on extremes

References I

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Fully nonseparable gneiting covariance functions for multivariate space–time data.
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