Green Rooftop Analysis

Performance Evaluation of Microclimatic and Ecological Impact

Presented by:

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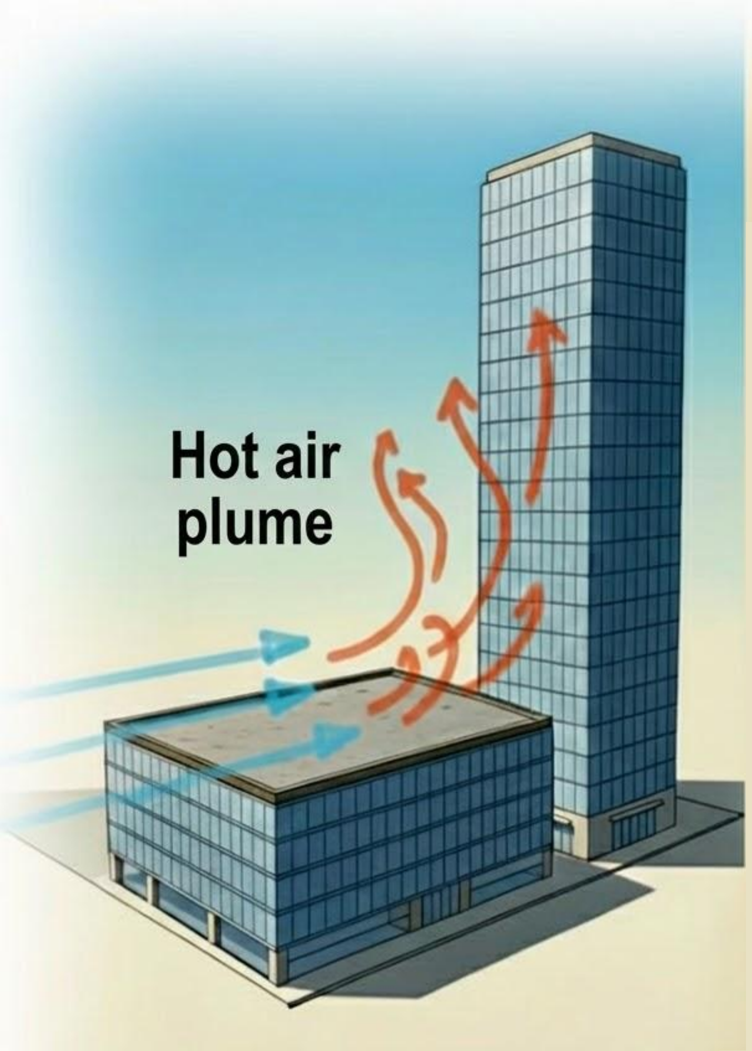
Alberto Messa

Course:

Simulation and Performance Evaluation

Addressing Urban Challenges



Baseline Scenario

Traditional Concrete Rooftops

Green Scenario

Eco-friendly Green Rooftops

Simulation Assumptions & Constraints

Spatial Assumptions:

- 2D cross section
- Unidirectional airflow, from the rooftop to the second building
- Uniform vertical air mixing over the rooftop

Physical simplification:

- Only convective heat transfer
- Linear approximations: eddy mixing, plume rise, ecological model

Project Workflow: The Three-Stage Pipeline

Input Modeling

Data source from open-meteo.com:

Historical weather and air quality data **(Rome, 5 years)**

Decomposition: trends and residuals

Residuals modeling:

- BIC scores
- GMM + AR(1)

System Modeling

Thermo-Aerodynamic Model:

- Roof temp
- Air temp above roof
- Mixing layer height
- Plume rise and temp decay

Ecological Model:

- Carbon Dioxide Sequestration
- Particulate and Gas Deposition

Simulation & Evaluation

Monte Carlo simulation (N=5000)

Evaluation on **Model Generated vs Real Historical data**

Evaluation on **Concrete vs Green scenario**

Synthetic Data Generation: trend and residuals

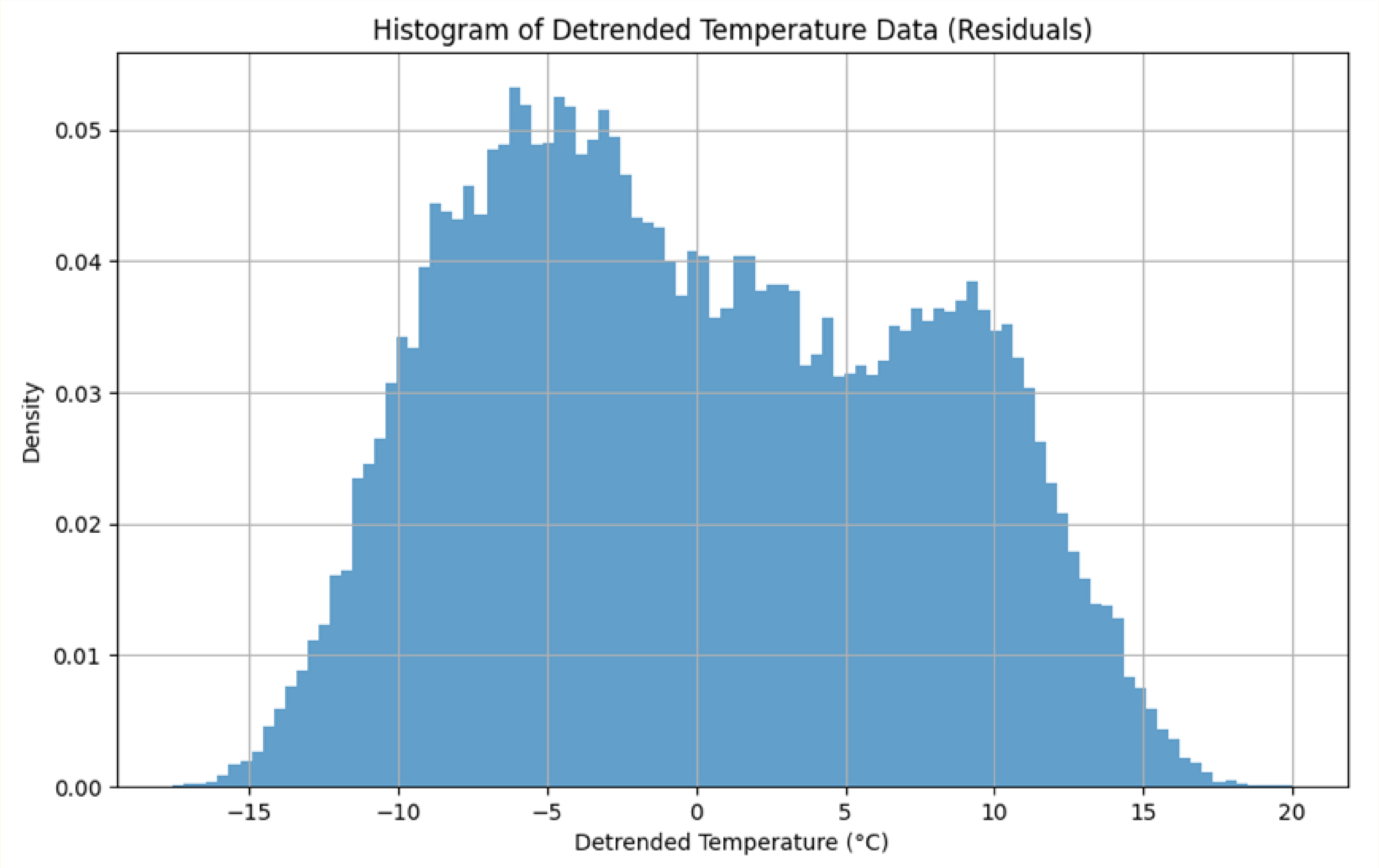
Deterministic Trend: Identifying predictable daily cycles by computing hourly mean

$$Trend_h = \frac{1}{N}\sum_{i=1}^{N} X_{i|hour=h}$$

Empirical Residuals: Obtained by subtracting the trend from historical samples X_t

These are used to calibrate the stochastic model

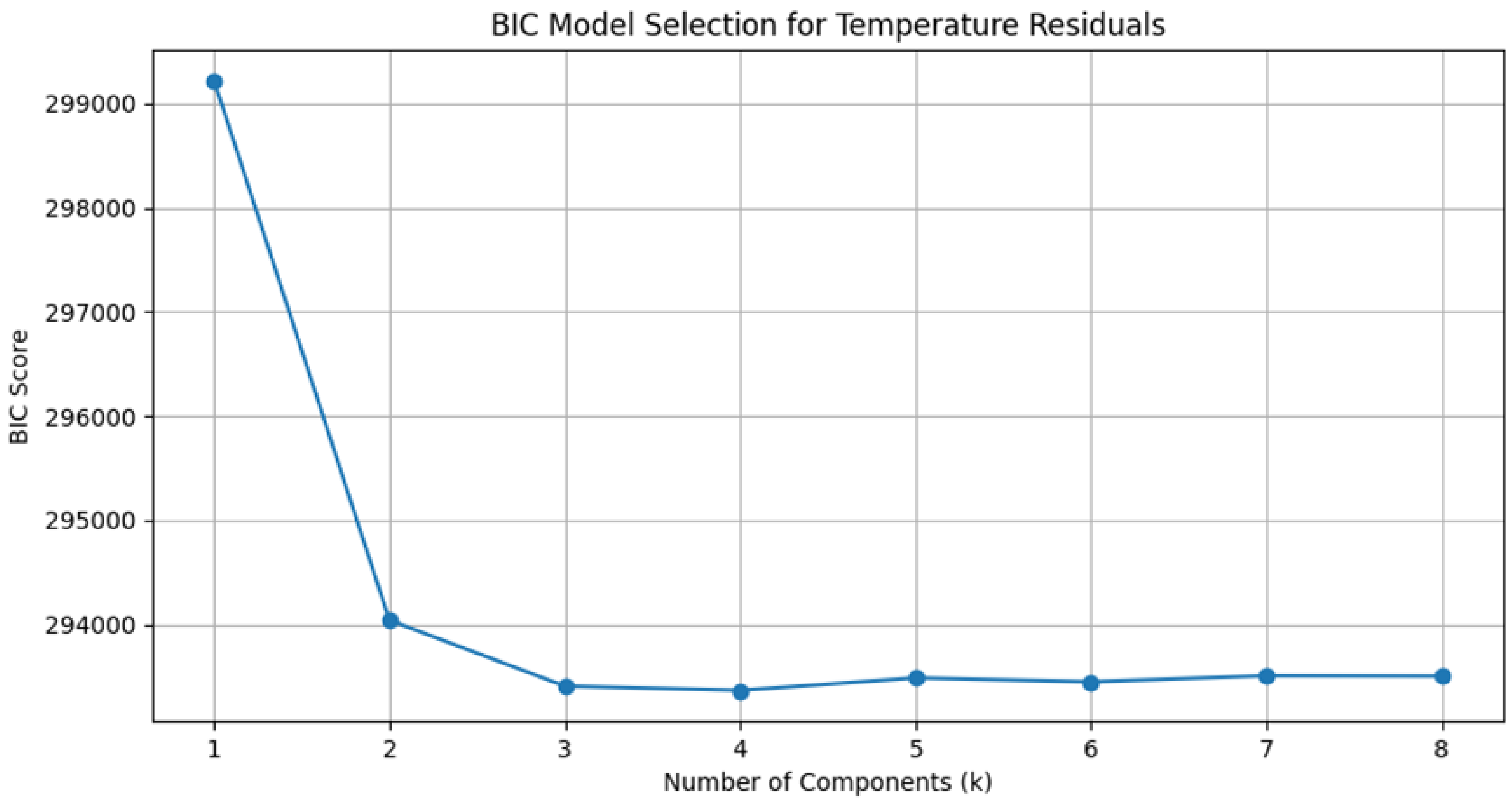
$$r_t = X_t - Trend_t$$

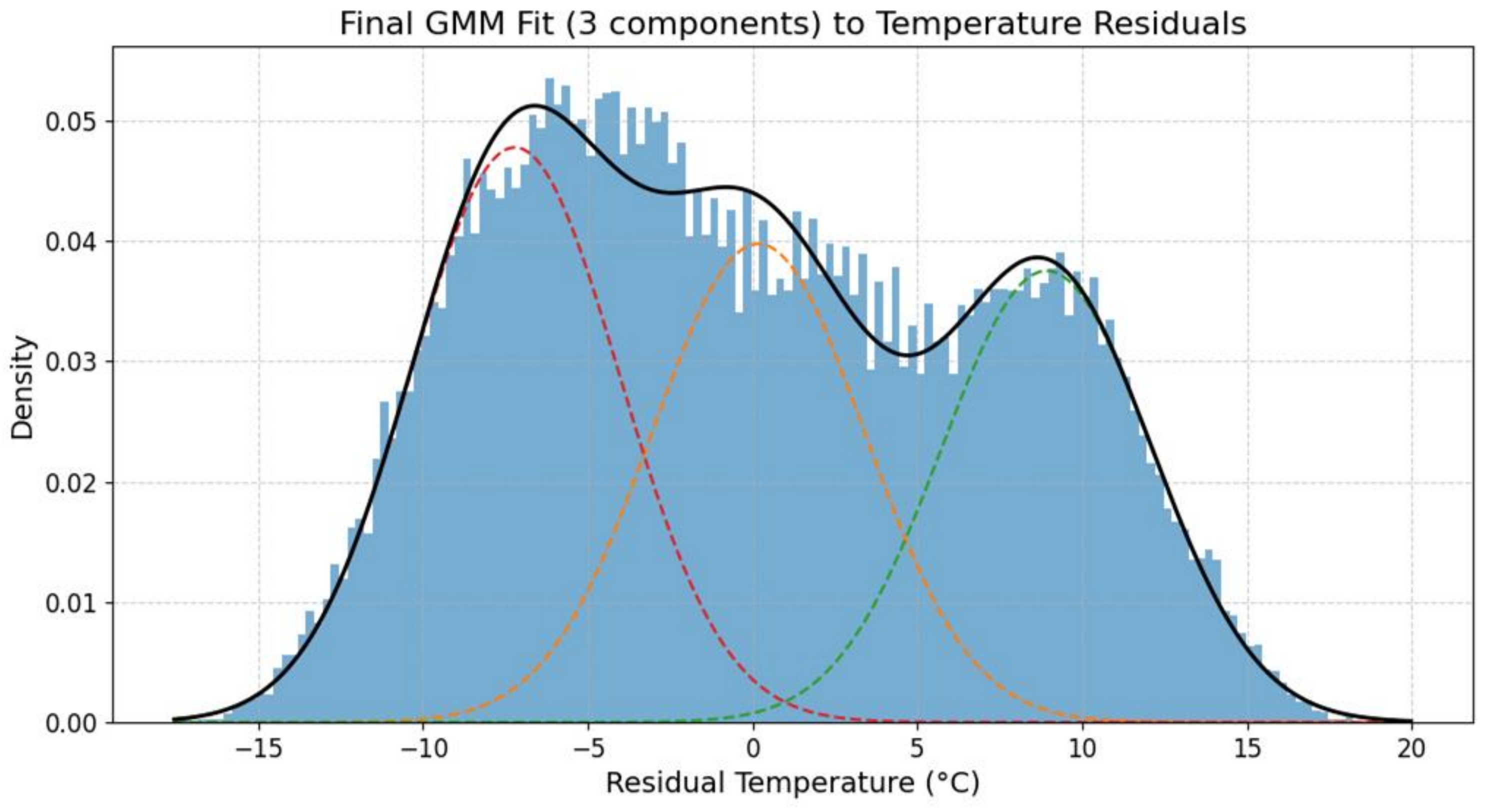


Synthetic Data Generation: BIC and GMM

Model selection (BIC)
Find the optimal number of Gaussian components K to avoid overfitting

Distribution Modeling (GMM)
The Gaussian Mixture Model provides the probability density function from which the innovation term (ε_t) is sampled





Synthetic Data Generation: AutoRegressive model - AR(1)

Parameters: Estimated on residuals

$$\phi = \frac{Cov(r_t, r_{t-1})}{\sqrt{Var(r_t)Var(r_{t-1})}}$$

$$\sigma = \sqrt{1-\phi^2}$$

Daily bias: captures inter-day variability (std dev of daily means)

Stochastic residual: ε is the new computed value from the GMM

$$r_t^{sim} = \Phi \cdot r_{t-1}^{sim} + \sigma \cdot \epsilon_t$$

Reconstruction: Add trend and daily bias to get final value

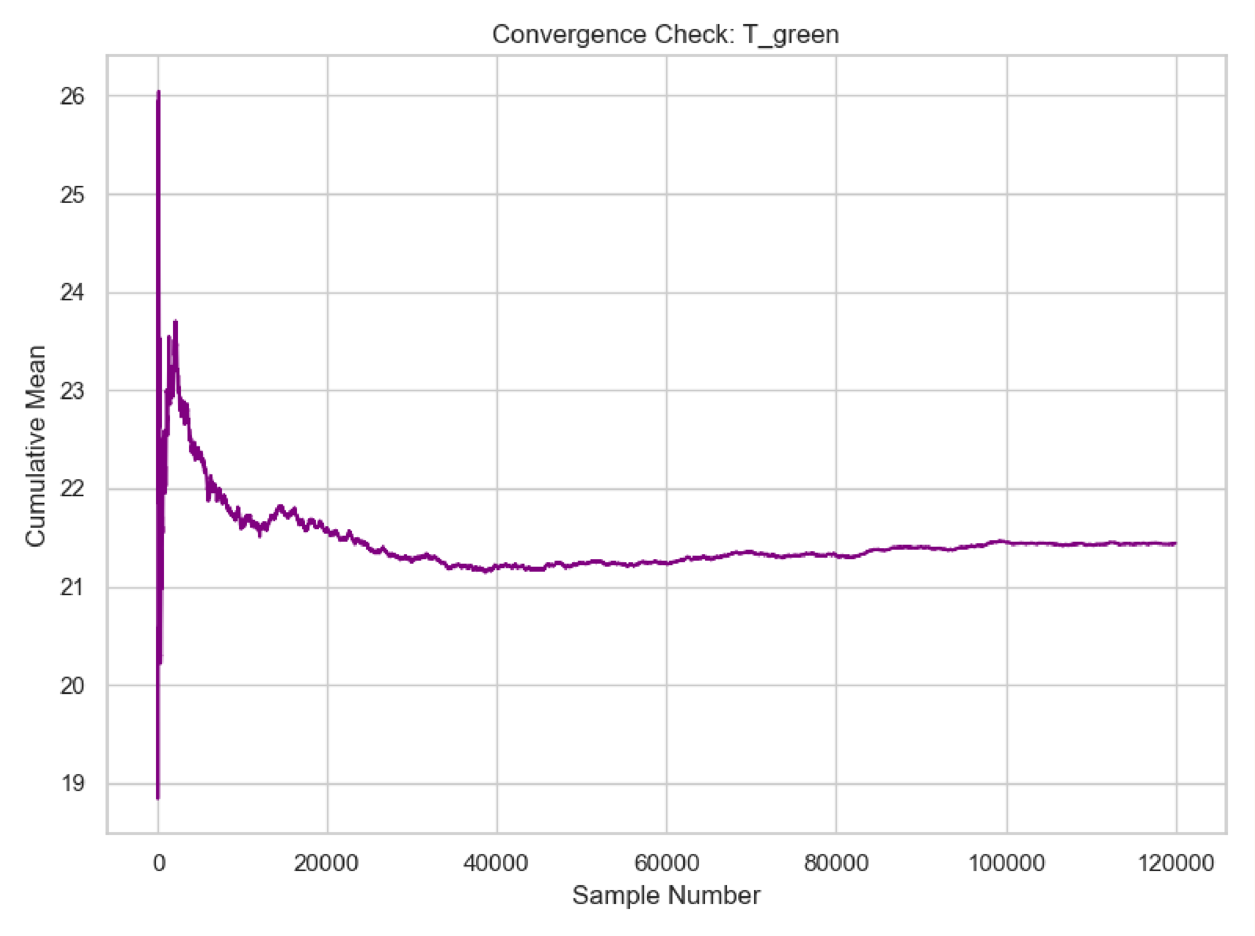
$$X_t^{final} = Trend_h + r_t^{sim} + N(0, bias)$$

Simulation Strategy: Monte Carlo Approach

Due to the stochastic nature of the system an analytical solution is not mathematically feasible. The goal is to obtain a probability distribution of results.

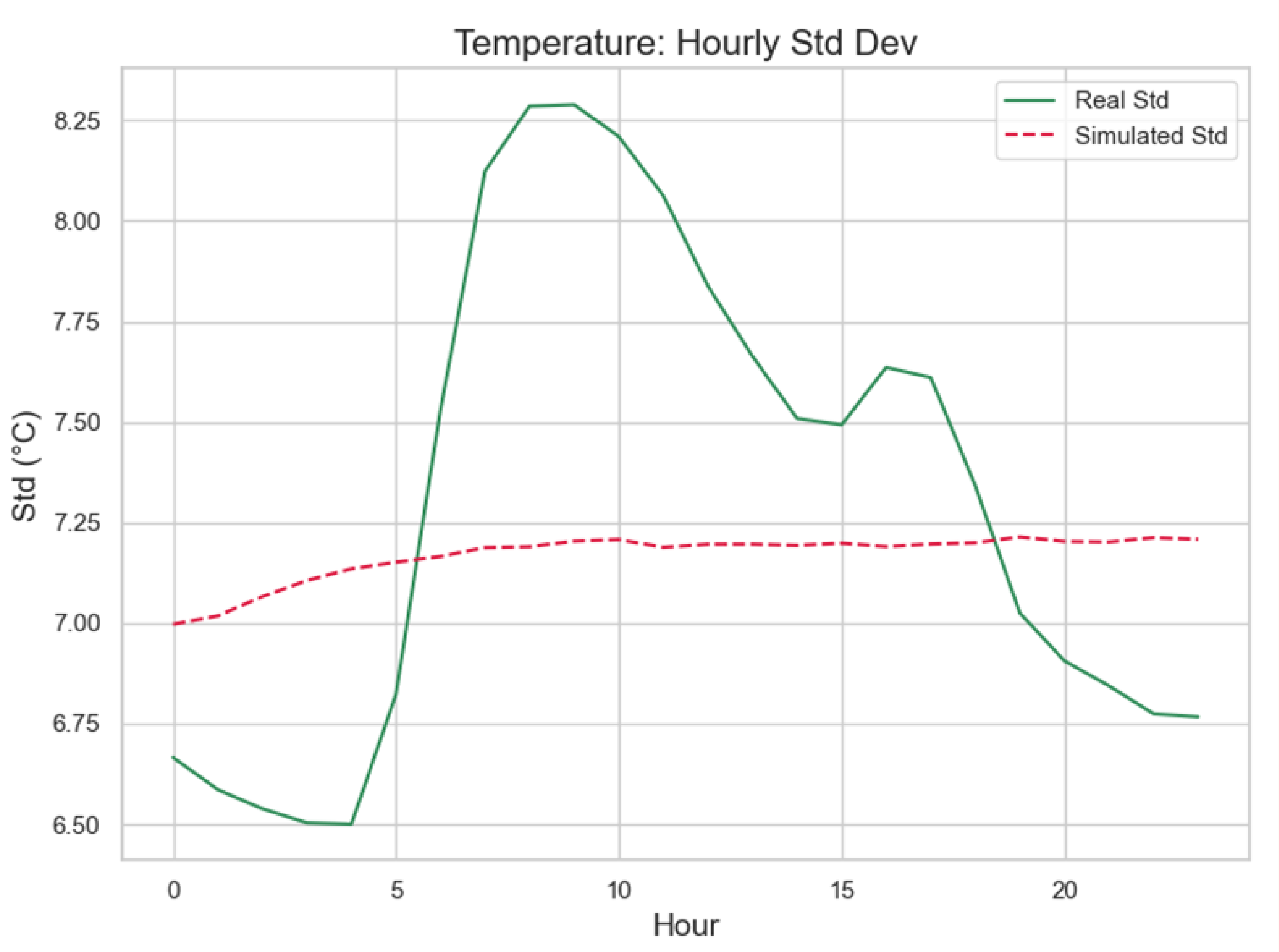
Setup: *N=5000* independent simulated days → 120000 simulated data point

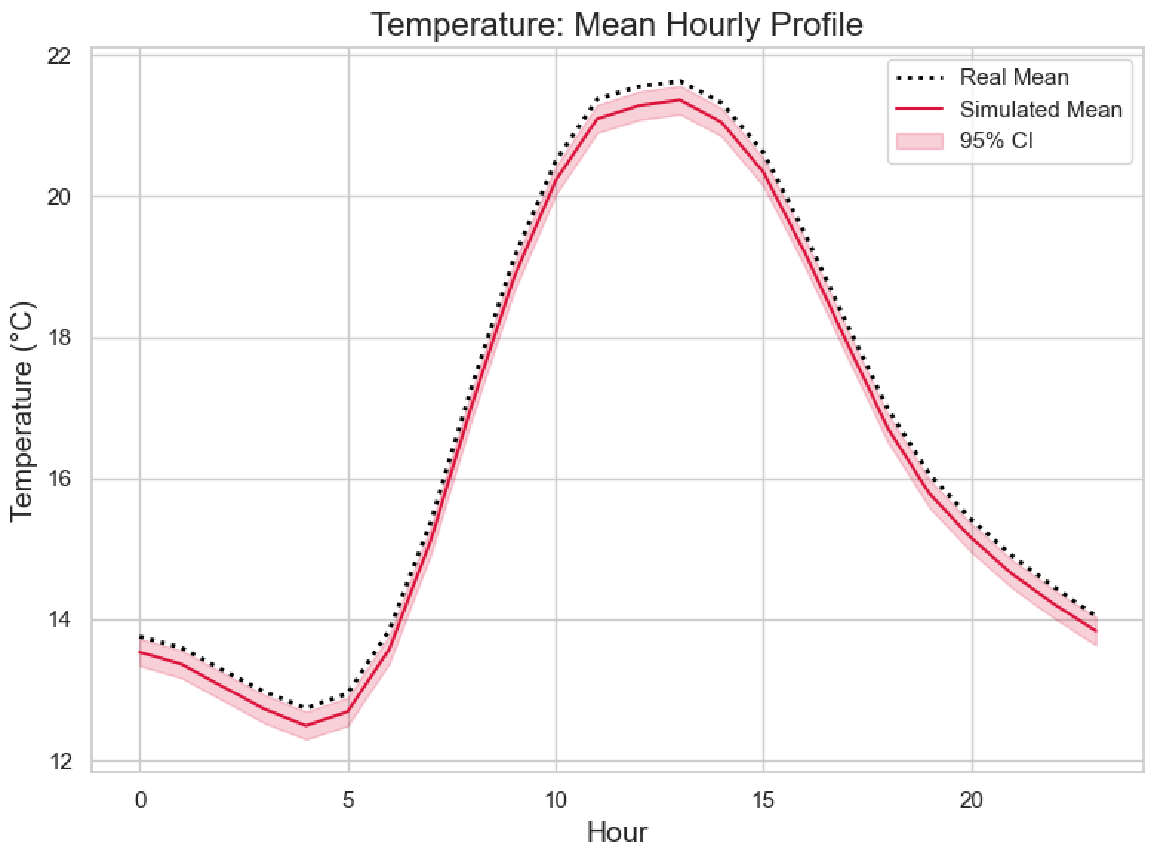
Convergence Analysis: Results are statistically valid when the estimator stabilizes. Convergence analysis on T_green achieved stability after approximately 40000 samples (≈ 1666 simulated days)

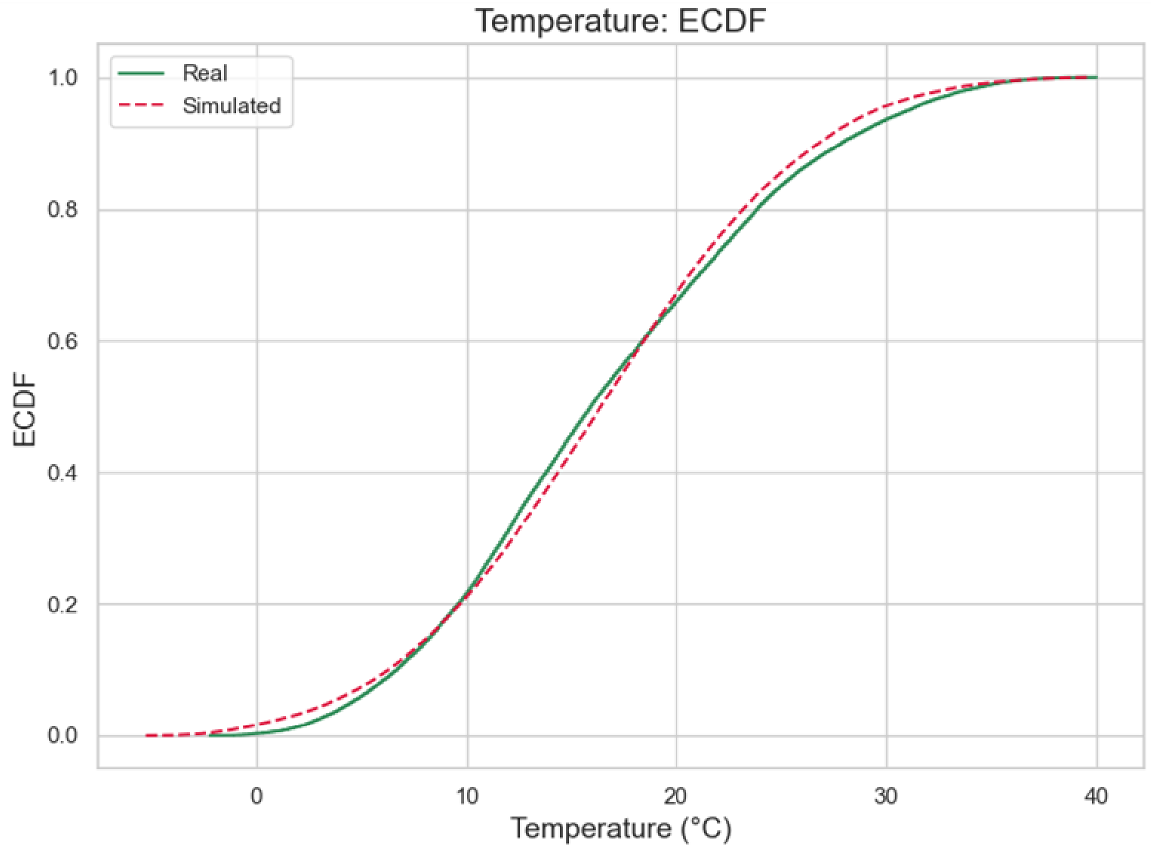


Input Validation: Temperature

Metrics: real mean vs CI, std, box, hist, ECDF and Q-Q Plots.

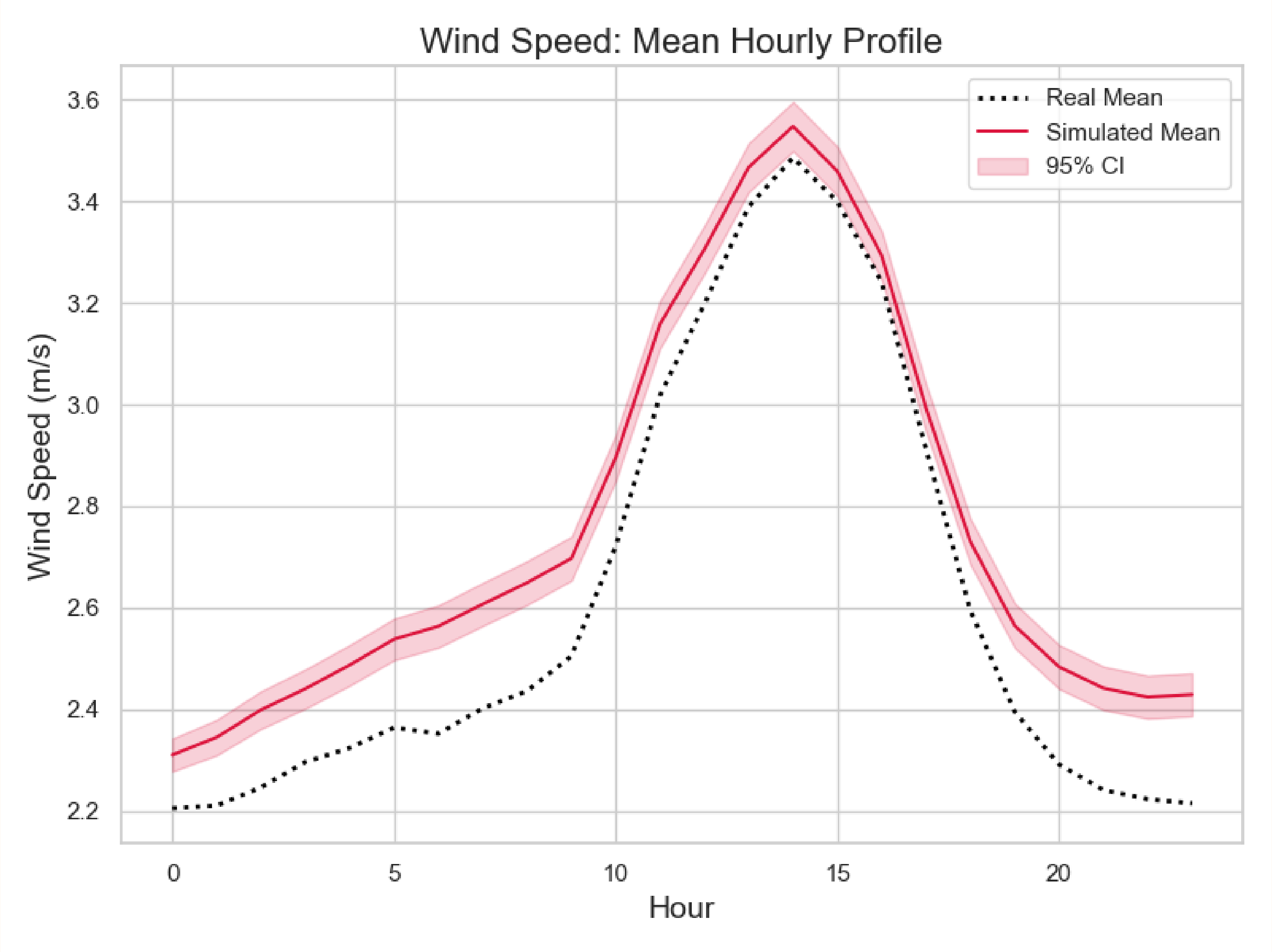


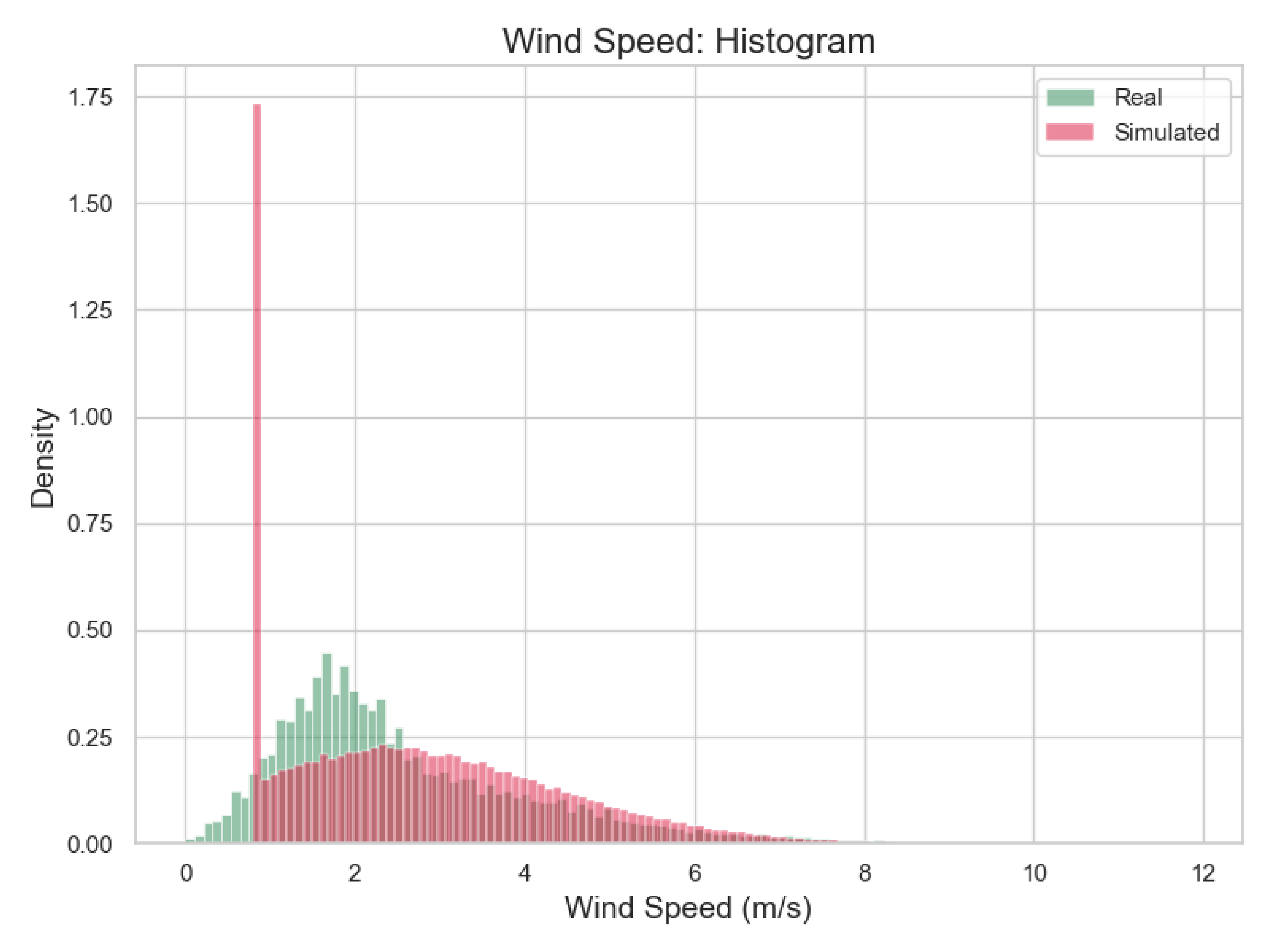




Input Validation: Wind

Metrics: real mean vs CI, std, box, hist, ECDF and Q-Q Plots.





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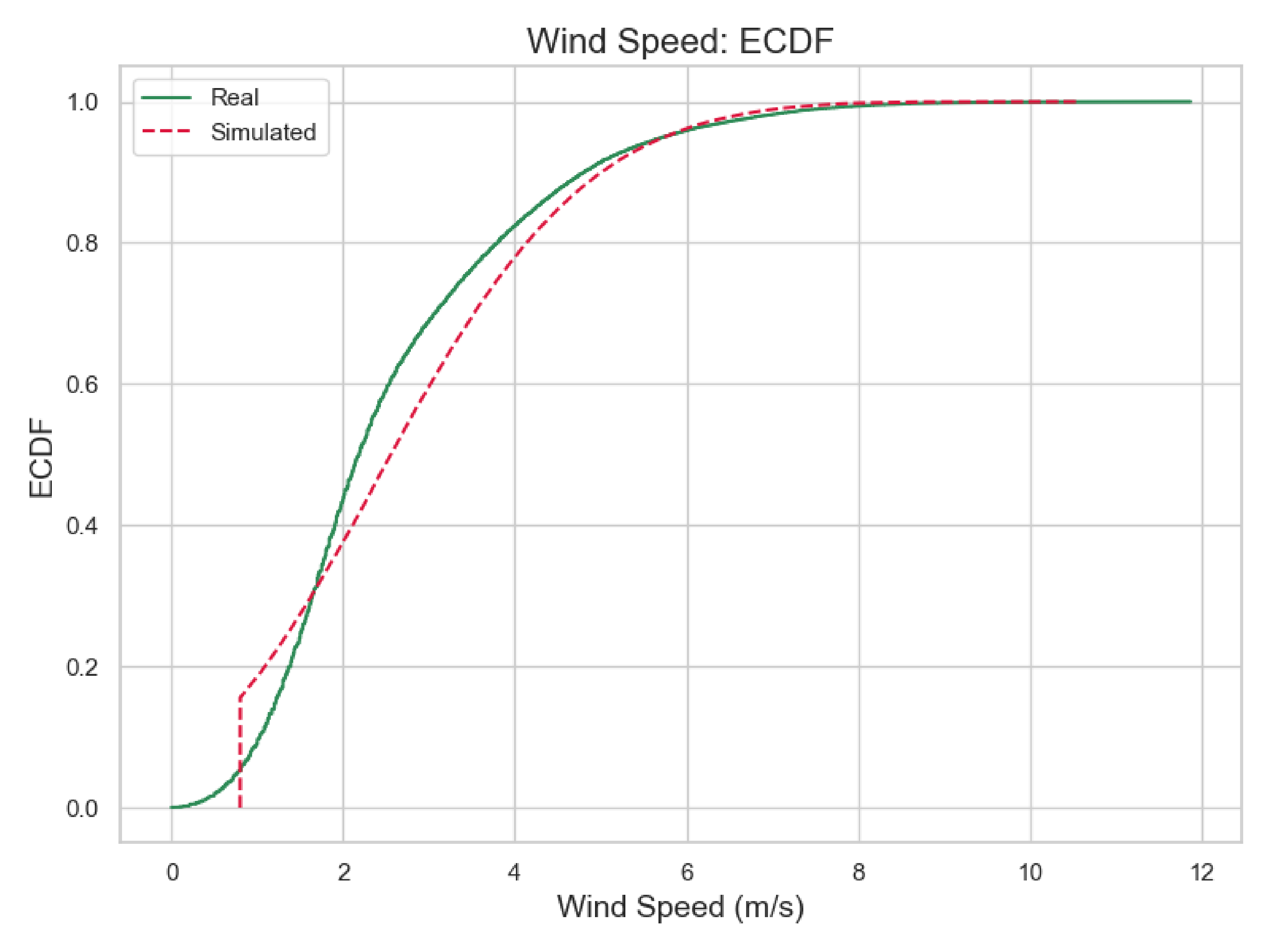
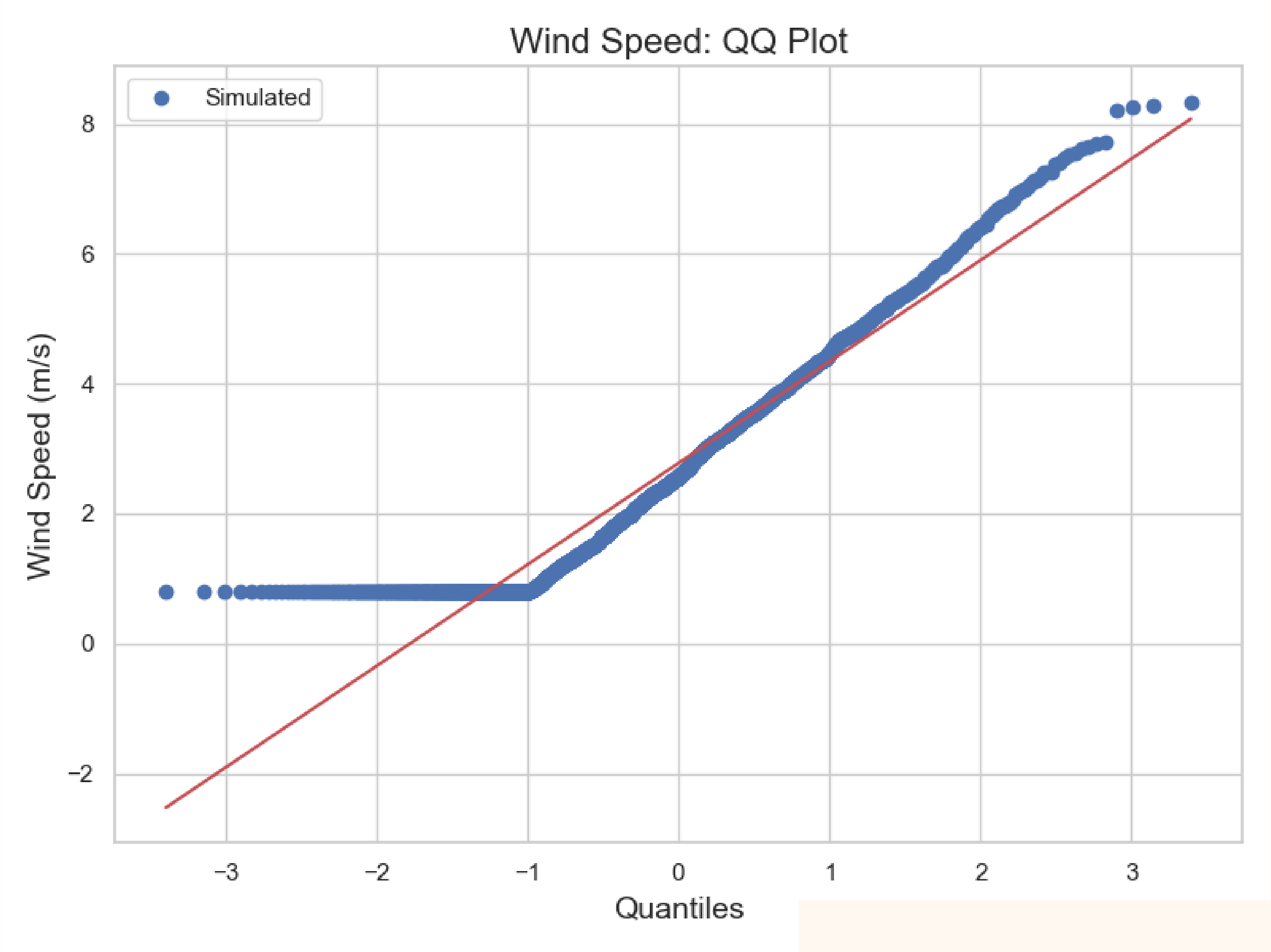




The Physical Model: Thermo-Aerodynamic Interactions

- Our physical model simulates a 2D urban scenario: a Source Building, an Urban Gap, and a Target Facade
- The core of this model is the energy balance on the rooftop

Concrete Roof

Absorbs solar heat, leading to convection and warming of the ambient air.

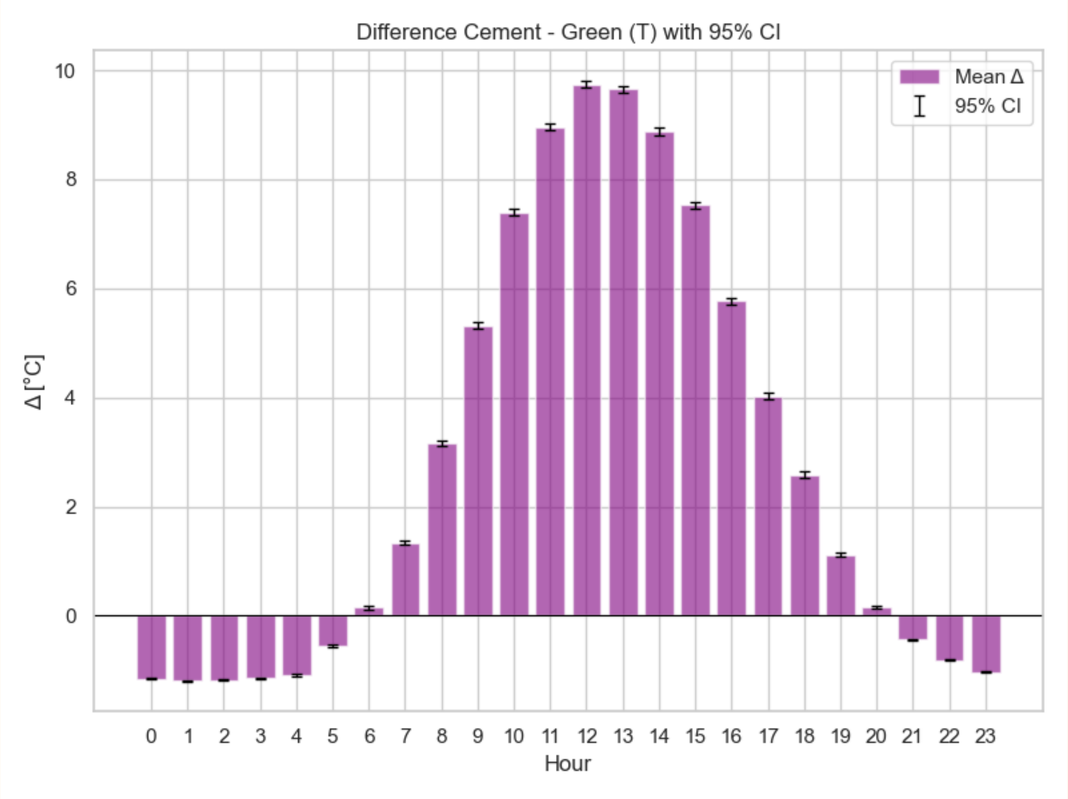
Green Roof

Evapotranspiration cools the surface, resulting in cooler ambient air above.

Results: Quantifying the "Green Delta"

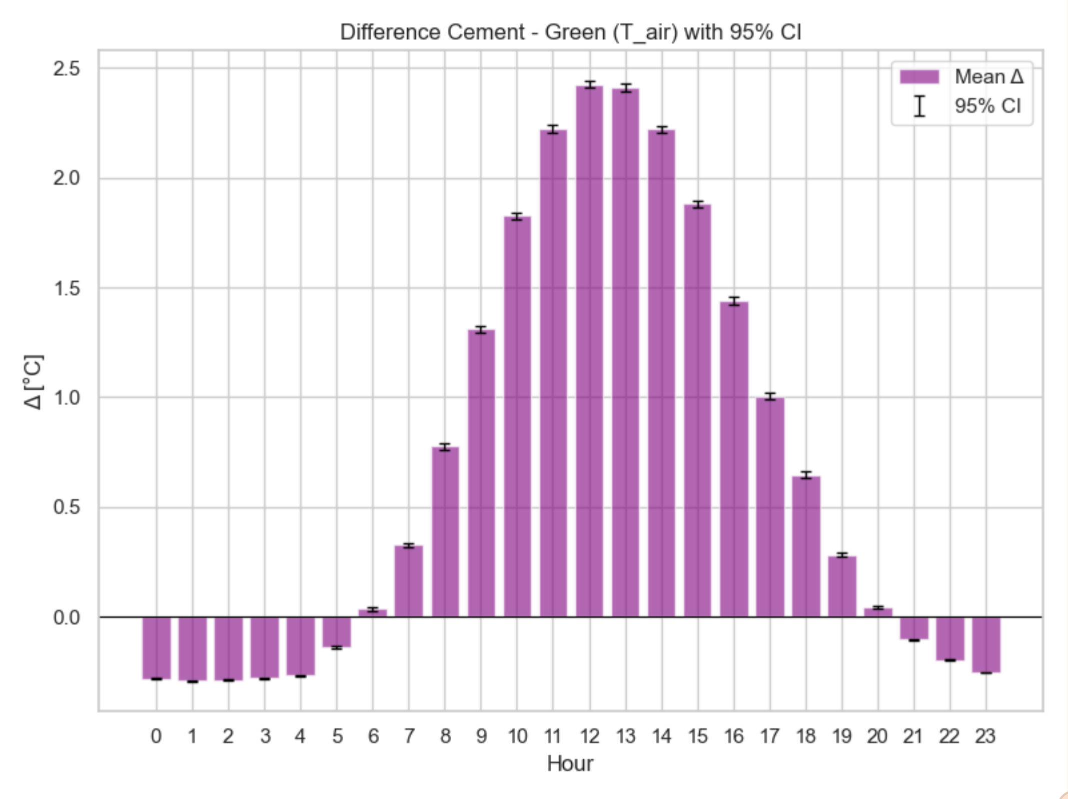
ΔT_surf: Massive Reduction

Surface temperature on green roofs is approximately 8-10°C lower.



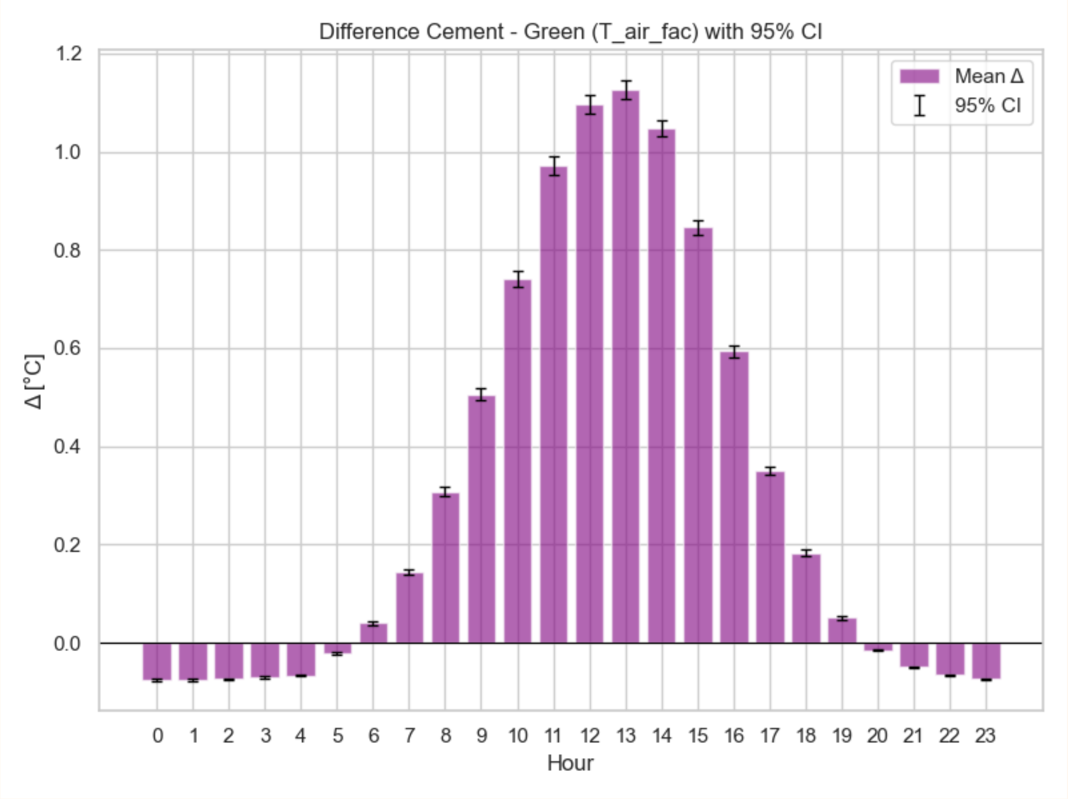
ΔT_air: Cooler Air

Air above the green roof is notably cooler by approximately 2.5°C.



ΔT_air_fac: Minor Cooling

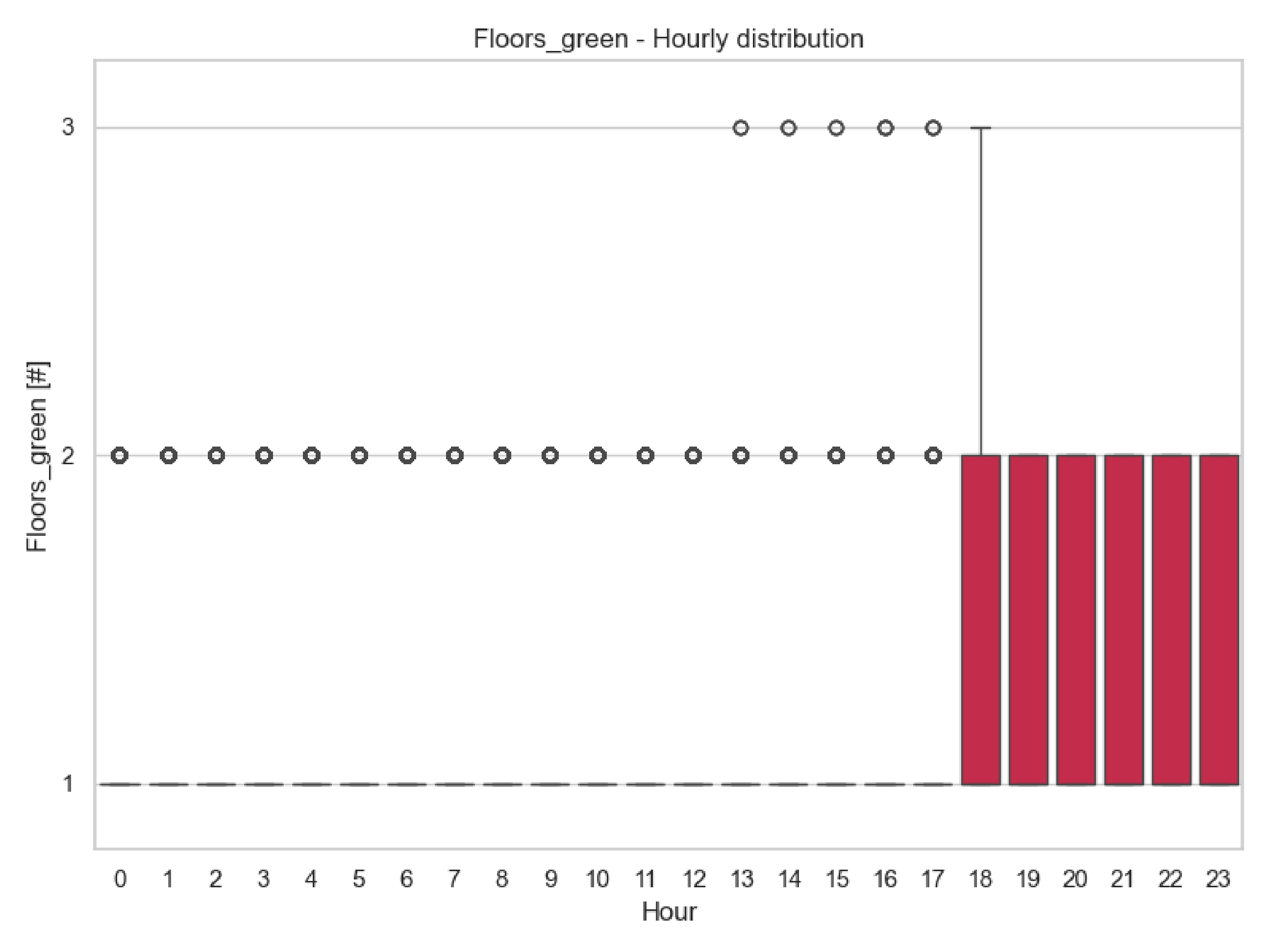
The cooling benefit decreases, delta approximately 1.1°C

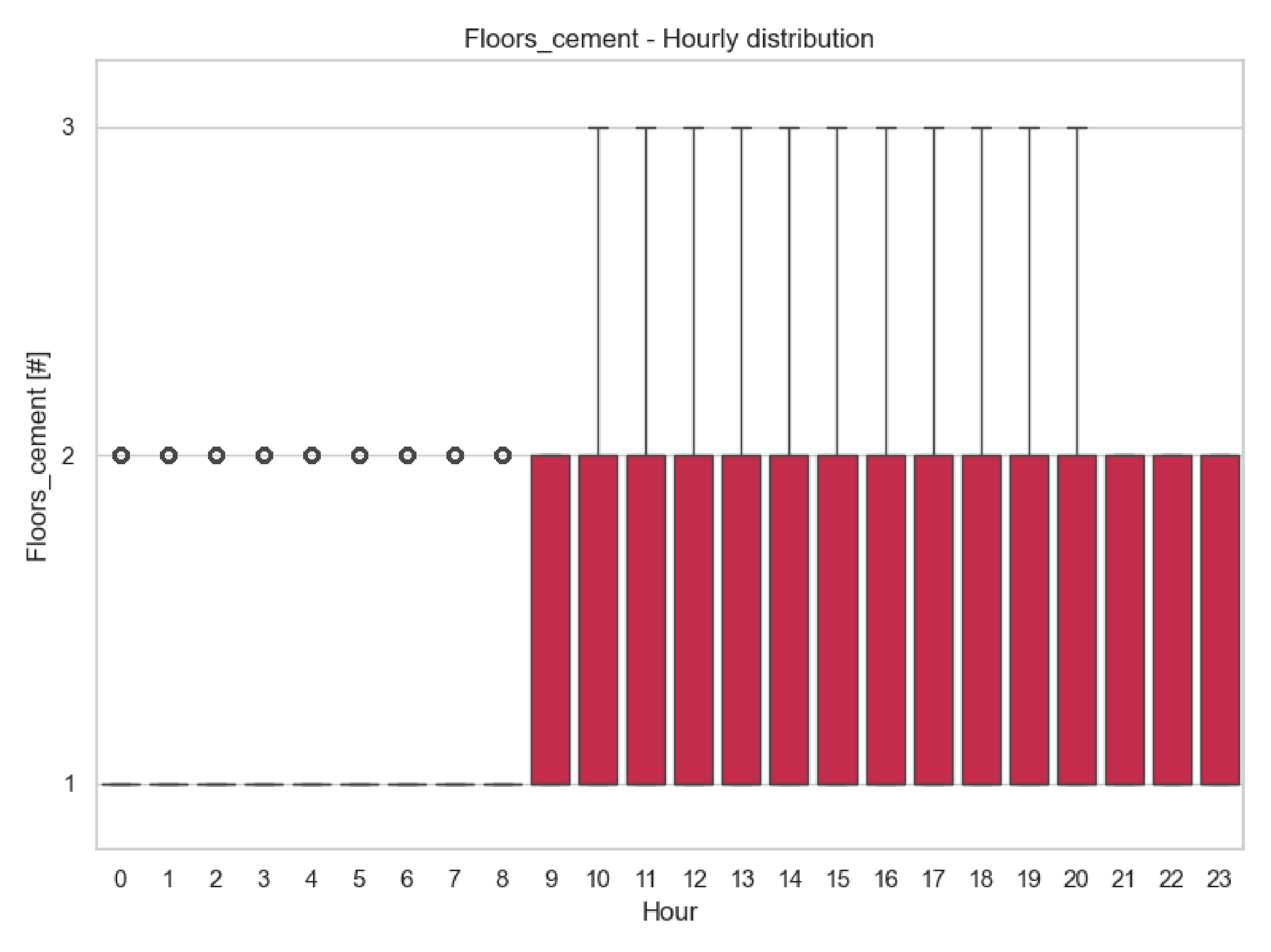


Results: Quantifying the "Green Delta"

Architectural Impact: Reduced Plume Rise

In the concrete scenario, heat impacts up to the 3rd floor. With green roofs, this effect is contained to the 2nd floor, enhancing comfort for adjacent buildings.





Conclusion: Green Roofs as Functional Infrastructure

The stochastic generator (`GMM+AR1`) has proven highly reliable for creating accurate test scenarios, reflecting real-world variability.

Our simulator has unequivocally demonstrated that green rooftops are functional infrastructures for urban environments:

- a significant reduction in thermal stress on neighbouring buildings
- active removal of harmful air pollutants.

THANKS FOR THE ATTENTION

By Luca Bissoli & Alberto Messa

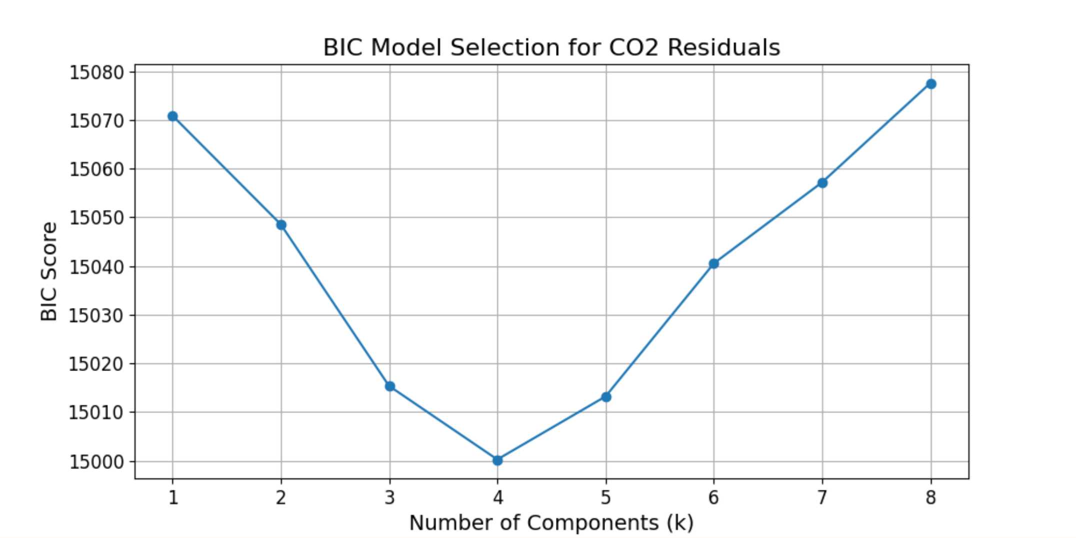
git repo: https://github.com/bissochan/GreenRooftopAnalisys

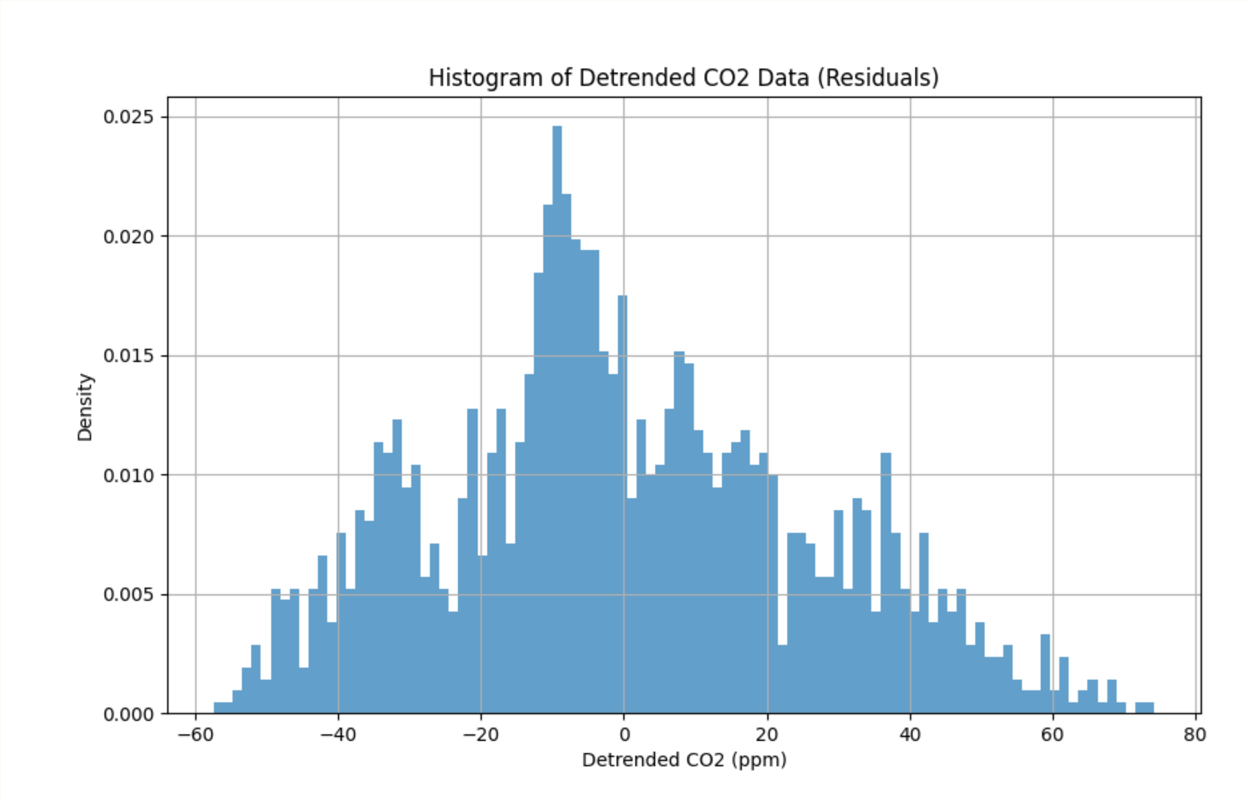
Why choosing GMM?

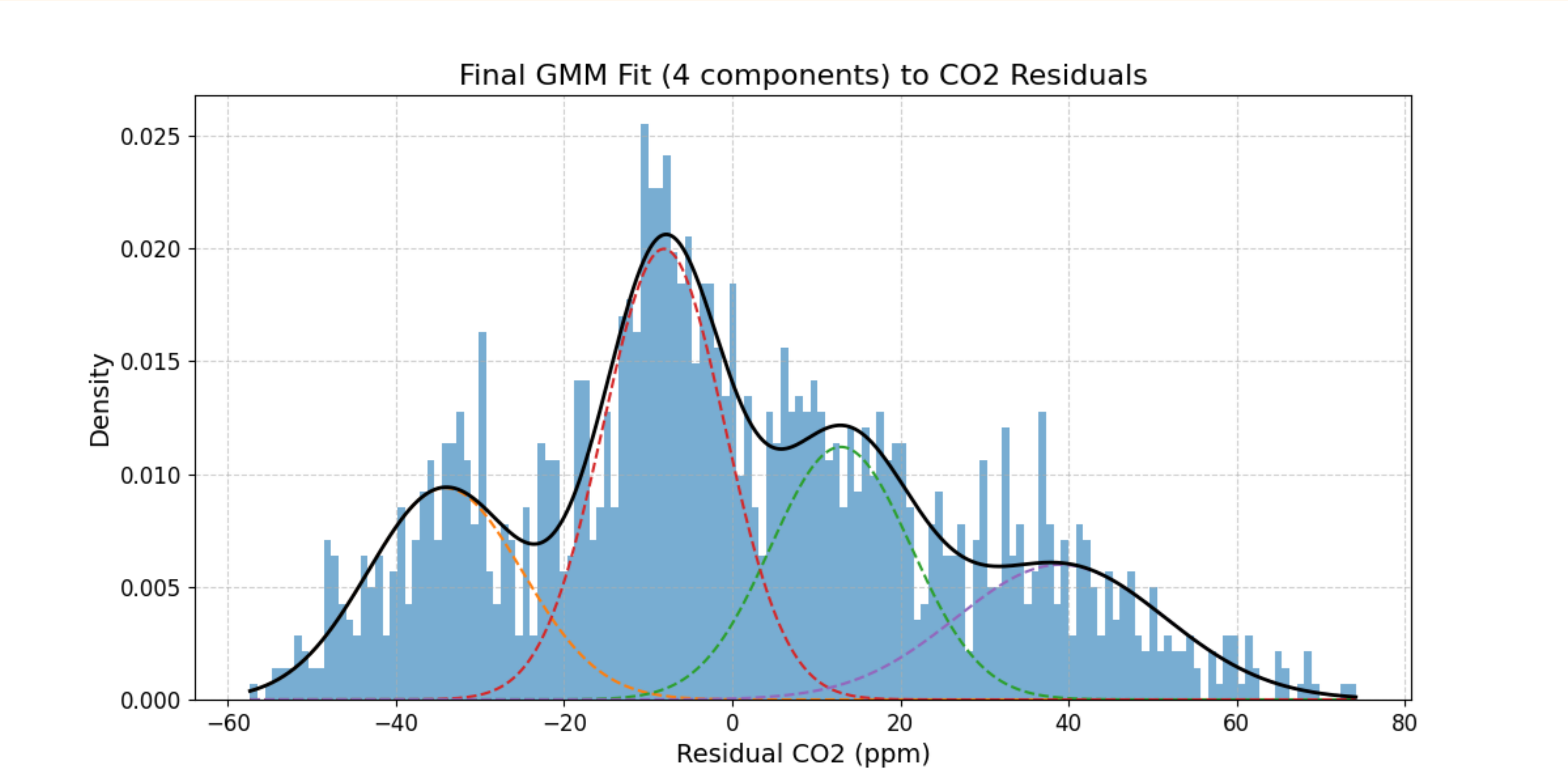
Advantages:
- can approximate nearly every CONTINUOUS distribution
- flexible
- useful for data simulation

Disadvantages
- needs i.i.d. data (and we need to have some temporal correlation)

Note: we needed to choose how many gaussian and we used BIC to choose







Limit of the ecology simulator

due to all the different information on the topic we thought to do a simpler version with simple multiplication for parameters, without taking into account factors like:

- reversing of photosynthesis during night
- limit of neat deposition for square meter

in the field there are many different opinions:
examples: pm10 reduction in summer = -50% https://www.reportpistoia.com/prato-centraline-diffuse-e-politiche-data-driven-per-la-lotta-allinquinamento/
for someone esle is only -10%
https://www.intersezioni.eu/it/articoli/31-verde-urbano/61-la-rimozione-di-inquinanti-atmosferici-da-parte-della-vegetazione-urbana

How to improve?

there are some simulators that could be helpful like i-Tree or UFORE
it could be possible to implement LAI (Leaf Area Index) and meteo to dramatically increase the similarity of the model, but that comes with a great increase in complexity

REF.

https://www.diva-portal.org/smash/get/diva2:794669/FULLTEXT01.pdf
https://www.itreetools.org/documents/53/UFORE%20Methods.pdf