A Soft Geostatistical Application in Urban Climate Research

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Abstract

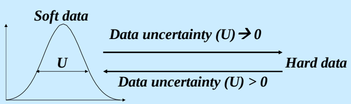
The pressing problem of Phoenix's urban heat island (UHI) has spawned numerous academic studies of the spatiotemporal nature of this physical process and its relationship to energy and water use, urban design features, and ecosystem processes. Critical to these studies is accurate representation of the UHI over space and time. This article is concerned chiefly with accurately representing the UHI by using the Bayesian Maximum Entropy (BME) method of modern geostatistics to account for data uncertainty of soft data. We successfully applied BME to the UHI in Phoenix by retrieving and mapping minimum temperature observations over time from historical weather station networks, then testing our mapping accuracy compared to traditional maps that do not account for data uncertainty. The results demonstrated that BME led to substantial increases of mapping accuracy (up to 35.28% over traditional linear kriging analysis) and provided high spatiotemporal resolution of estimated minimum temperatures. Resulting maps of the UHI can be integrated with other data about human and environmental processes in future studies of urban sustainability.

Objective

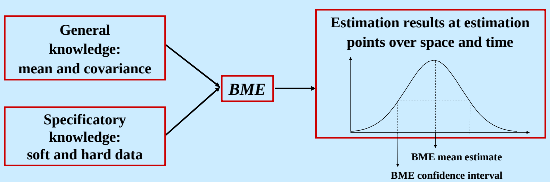
Our aim is to accurately represent the UHI (i.e., monthly mean minimum temperatures) over space and time by rigorously assimilating data uncertainty from incomplete sample size.

Background

- The UHI remains the most intensely studied climatic feature of cities.
- Monitored data are sparsely located over space and time.
- Hard data occur for stations where we have a complete set of daily records.
- Soft data come from stations where more than one daily observation is missing.



- BME goes beyond GIS and kriging due to
  1) *spatiotemporal* mapping ability
  2) incorporation of additional *soft data.*
- BME knowledge processing.



Data

- Daily minimum temperatures measured at 73 sites over Jan., 1990 to Dec., 2004

Methods

- Calculate monthly mean minimum temperatures, $\mu_1 = \frac{1}{n}\sum_{u=1}^{n} Z(s,u)$.

  where $Z(\boldsymbol{s},u)$: daily temperatures at location $\boldsymbol{s}$ and day u, and n: sample size in days within a month.
- If n is a number of full days (N) within a month: Hard data with no data uncertainty.
- If n is less than the full days: Soft data characterized by student's t-distribution, f_η:

$$\frac{1}{\sqrt{\left(\frac{s^2}{n}\right)\left(1-\frac{n}{N}\right)}} f_\eta\left(\frac{x-\mu_l}{\sqrt{\left(\frac{s^2}{n}\right)\left(1-\frac{n}{N}\right)}}\right)$$

  where s^2: unbiased estimate of population variance.
- Obtain general knowledge base.
- BME knowledge processing to produce spatiotemporal BME estimates of the UHI.
- Validate mapping accuracy of BME over two kriging methods:
  - define purely spatial kriging not accounting for soft data and time aspects
  - define spatiotemporal kriging not accounting for soft data
  - produce Mean Square Error (MSE) of each method as an indication of accuracy
  - The less MSE a mapping method has, the more accurate it is

Validation Results

	Method 1 purely spatial kriging	Method 2 Spatiotemporal kriging	Method 3 Spatiotemporal BME
MSE $({}^\circ C)^2$	4.1492	3.0675	2.6854

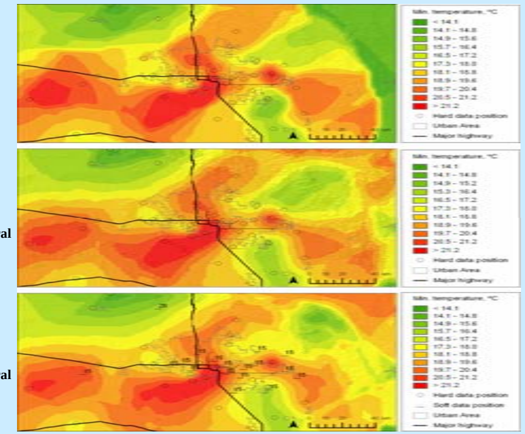
- Method 3 is 36.28% more accurate than Method 1.
- Method 3 is 12.46% more accurate than Method 2.

Mapping Results

Method 1 spatial kriging

Method 2 spatiotemporal kriging

Method 3 spatiotemporal BME



Conclusions

- The spatiotemporal BME led to more accurate UHI estimates than purely spatial kriging or spatiotemporal kriging due to its unique flexibility to integrate the data uncertainty source into mapping process.
- BME produced greater details on the urban fringe even though there were few monitoring stations.
- BME maps could produce even more accurate estimates with more stations and more information about the nature of data uncertainty.
- The resulting BME maps are crucial inputs into further studies related to
  - causes of the UHI
  - potential mitigation strategy
  - warmer temperature vs. water and energy demand, human comfort, and public health
  - social vulnerability

Acknowledgment

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