Natural and Anthropogenic Contributions to Urban Heat Island

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Outline

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- Background
- Objectives and Hypotheses
- Method
- Preliminary Results
- Future work

Background: urban parameterizations

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- Current urban parameterizations in three categories:
  - Empirical models
  - Vegetation models adapted to include an urban canopy
  - Single-layer and multi-layer models with a three-dimensional representation of the urban canopy

Background: urban parameterizations

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- Empirical models (e.g. LUMPS):
  - Statistical relationships determined from observed data
  - Limited to the range of conditions experienced during the observation campaign
  - Cannot be generalized to other urban areas

Background: urban parameterizations

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- Vegetation models with adaptations (e.g. Noah)
  - Modifying important surface parameters to better represent urban surfaces, e.g. albedo, roughness length, displacement length, heat capacity,…
  - Treat the city as an aggregated area (averaged effect)
  - Anthropogenic heat is usually omitted or simply considered as a constant

Background: urban parameterizations

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- Category 1 and 2:
  - May not have sufficient functionality to be suitable for inclusion in global climate models
  - More importantly, do not fully describe the fundamental processes that determine UHI
- Single-layer or multi-layer urban canopy models are likely needed to investigate the relative contributions of the factors to UHI

Background: urban parameterizations

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- Single-layer & multi-layer models (e.g. UCM, CLMU):
  - Treat roofs, walls, and roads individually
  - Require more surface information
  - Physical-based model

Background: UHI

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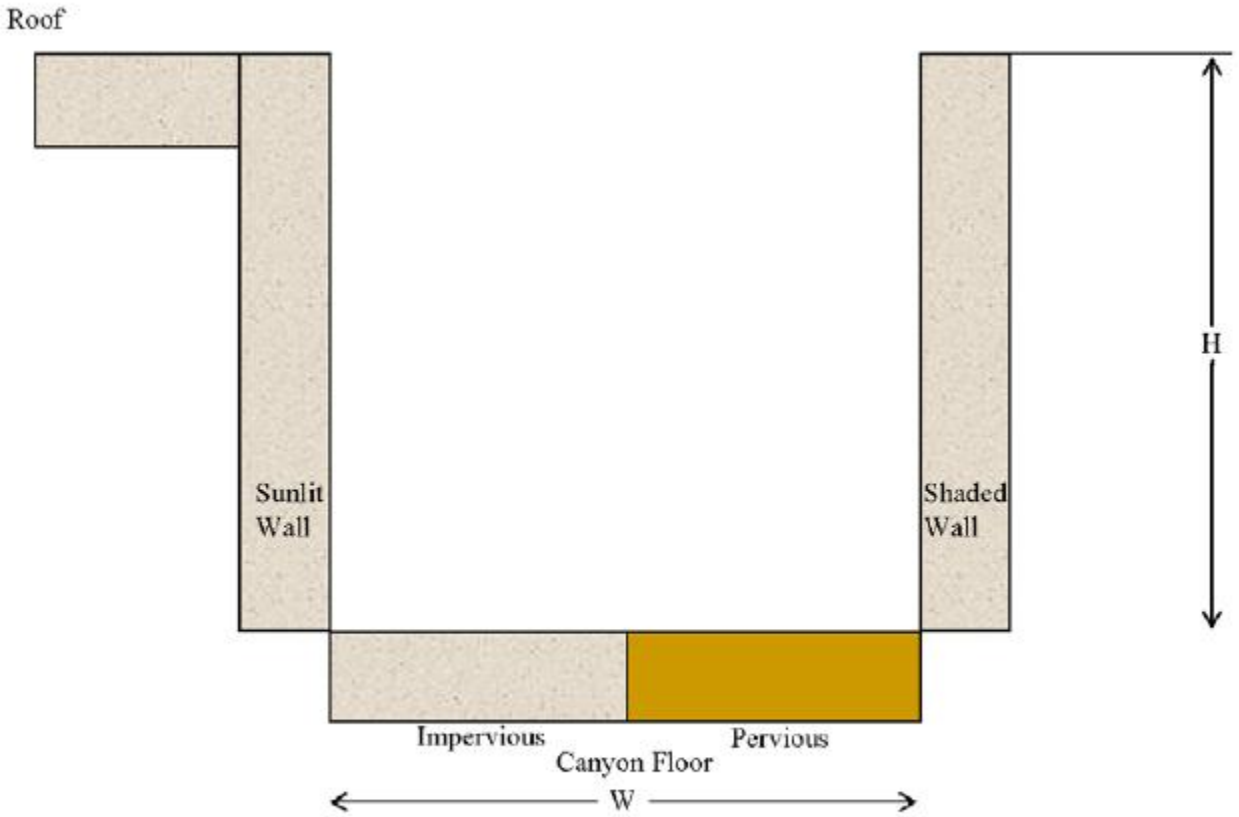
- Known candidate causes to UHI:
  - Reduction of evapotranspiration
  - Reduced transfer of heat
  - Increased storage of sensible heat within urban materials
  - Anthropogenic emission of heat
  - Increased downwelling longwave radiation from the atmosphere (pollution and aerosols effect)
  - Decreased longwave radiation loss and increased absorption of solar radiation and longwave radiation (canyon effect)



(Oleson et al 2010)

Background: questions

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- Research questions:
  - What else factors drive the UHI?
  - To what extent does each of these factors contribute to UHI?
  - Are the mechanisms of UHI the same during day and night?

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Objectives

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- Comprehensive analysis of the mechanisms generating UHI (causes of UHI)
- Separate the contributions of the factors to UHI (UHI sensitivity to the causes) using our own adapted urban land surface parameterization
- Understand how the natural and anthropogenic contributions relate to surface energy partition

Hypotheses

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- The background environment, other than urban surface properties, is a crucial factor to determine the UHI as well
- UHI is generated by separate contributors, each of which contributes a certain portion to UHI
- The physics to form UHI will show asymmetry between daytime and nighttime

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Method: UHI intensity

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- Correlation analysis
  - To find out what quantities drive the variation of UHI
  - *UHI intensity* = $T_{urban} - T_{rural}$
    where *T* is MODIS LST
  - Important step to investigate the undiscovered variables

Method: urban LSM

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- Urban Parameterization for Community Land Model (CLMU)
  - Simple enough to be compatible with structural, computational and data constraints of a LSM
  - Complex enough to enable exploration of physically-based processes of UHI
  - Further simplify the CLMU in terms of data requirements
  - Modify the CLMU by adding unknown physical processes

Method: simulation

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- To examine the contributions of each factor
  - perturb one of the variables yet leave others unchanged
  - Test one variable at one time
  - Simulate the total UHI by assuming all the causes of UHI function together

Method: simulation

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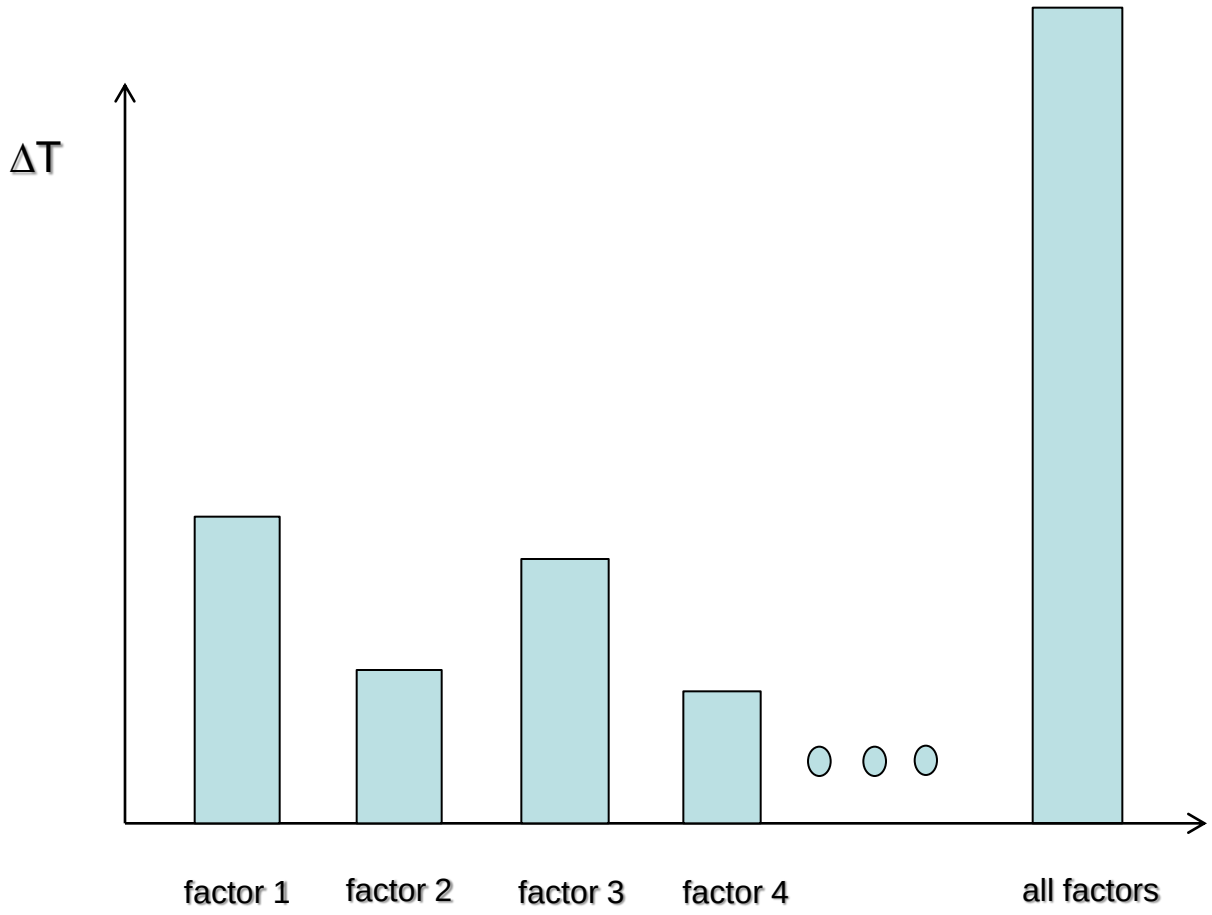
- Schematic of the strategy



Method: forcing data

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- The urban LSM will be run in the offline mode
- Forcing data to drive the model are needed

Method: forcing data

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- North America Regional Reanalysis (NARR)
  - Spatial resolution: 32km at the lowest latitude
  - Temporal resolution: 3-hourly
  - Provide both surface and atmospheric data
  - Routinely meteorological variables: wind speed, air temperature, specific humidity, precipitation, pressure, solar and longwave radiation at reference level

Method: forcing data

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- Ideally, model should be driven by observations
- Systematic errors existing in the reanalysis
- Validation with FLUXNET tower observations

Method: forcing data

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- Validation of NARR
  - Tower sites: selected from Flux Canada and Ameriflux
  - All the variables as the model input should be validated
  - Solar radiation is expected the most biased variable

Method: forcing data

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Site_ID	Yeas_included	R^2	Mean of Site Observation	Mean of NARR values
SK_OA	10	0.7135	136.3887	167.9017
SK_OBS	10	0.723	134.5896	165.3259
SK_OJP	10	0.4976	133.3343	165.0992
mmsf	9	0.3557	167.6258	209.6167
umbs	8	0.6952	150.7828	190.123
borden	14	0.5522	149.1808	194.1131
wb	10	0.7289	174.3128	214.9634
nwr	5	0.0365	187.9796	249.0567
donaldson	7	0.0747	182.1068	231.8715
mize	7	0.0117	184.2007	232.6262

Table 1 Summary of the r square and mean value of tower observation and NARR for each site

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Preliminary Results: UHI Intensity

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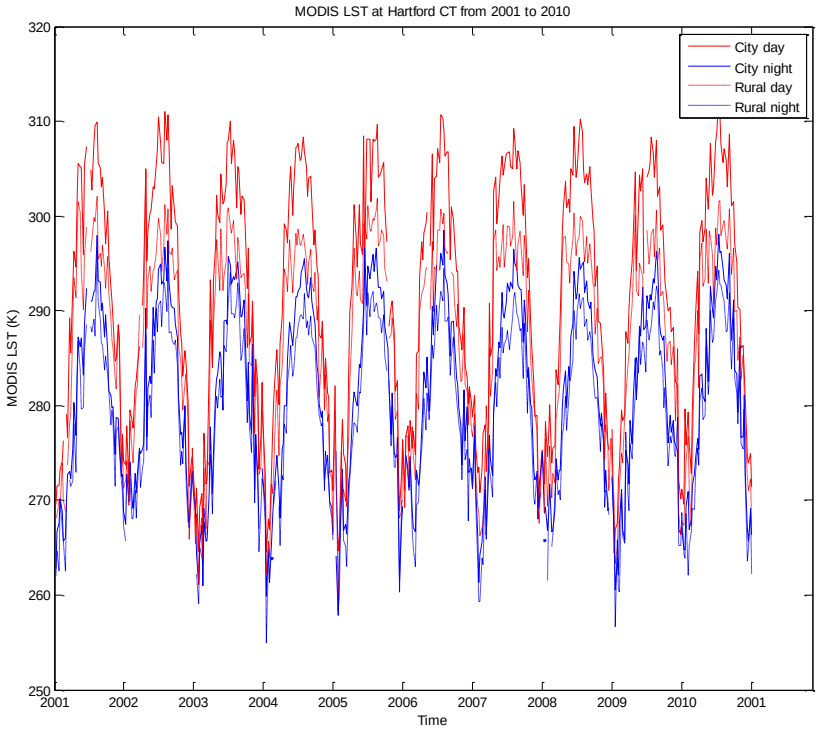

Preliminary Results: UHI Intensity

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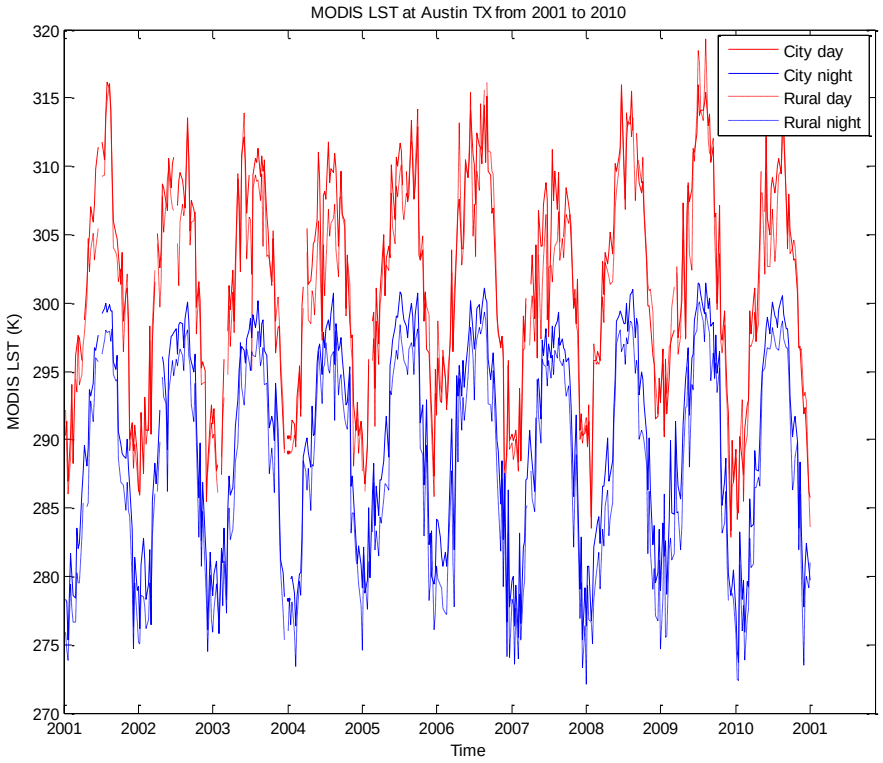

Preliminary Results: UHI Intensity

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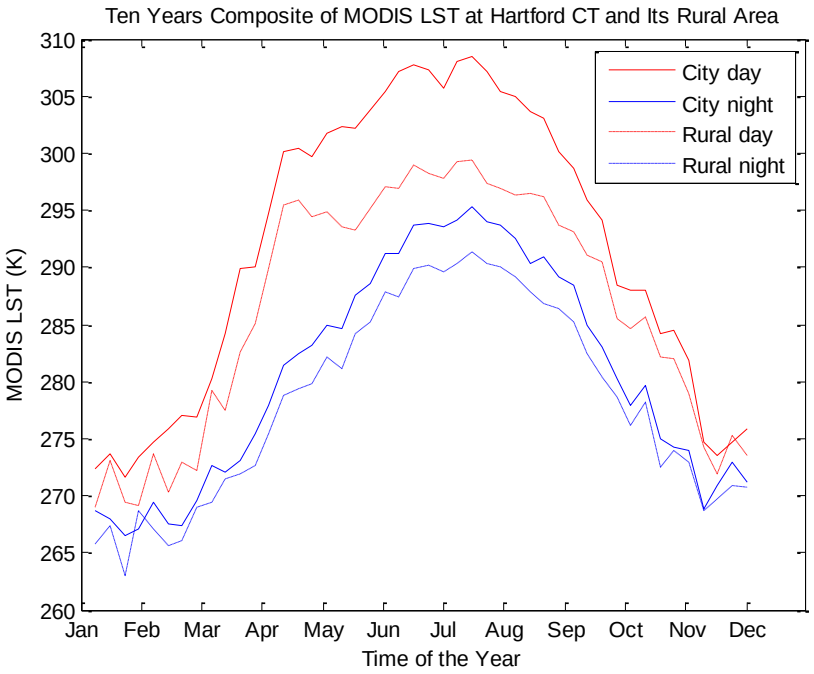

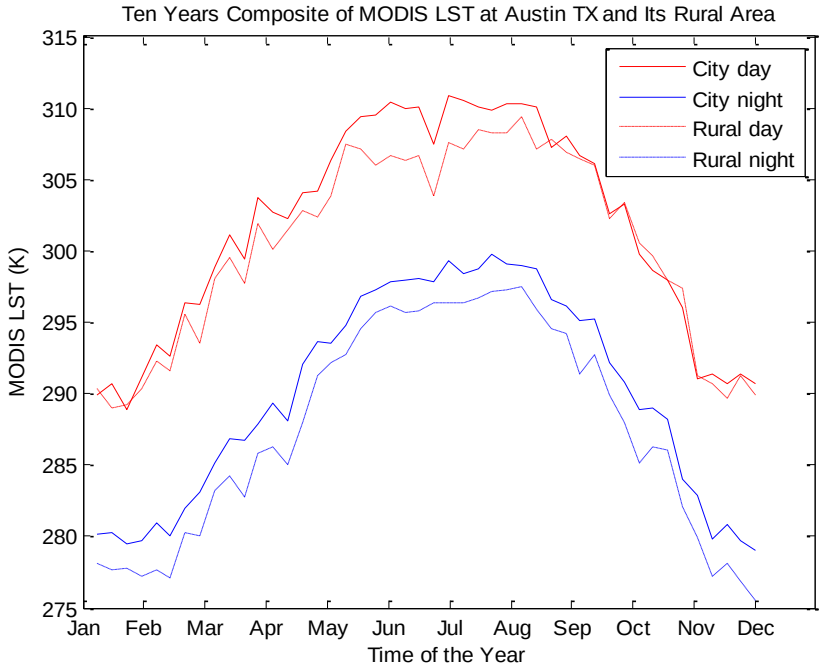

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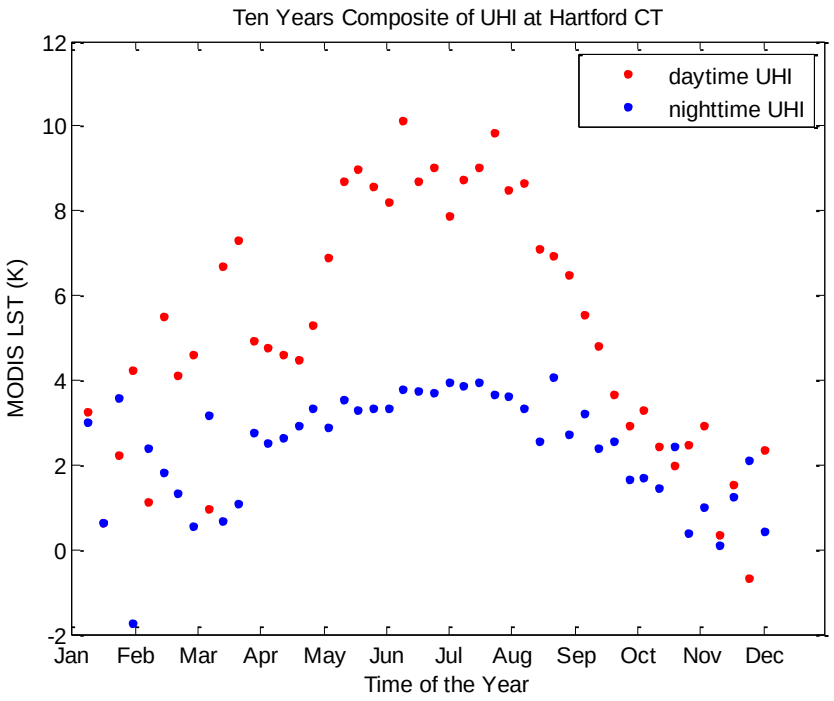

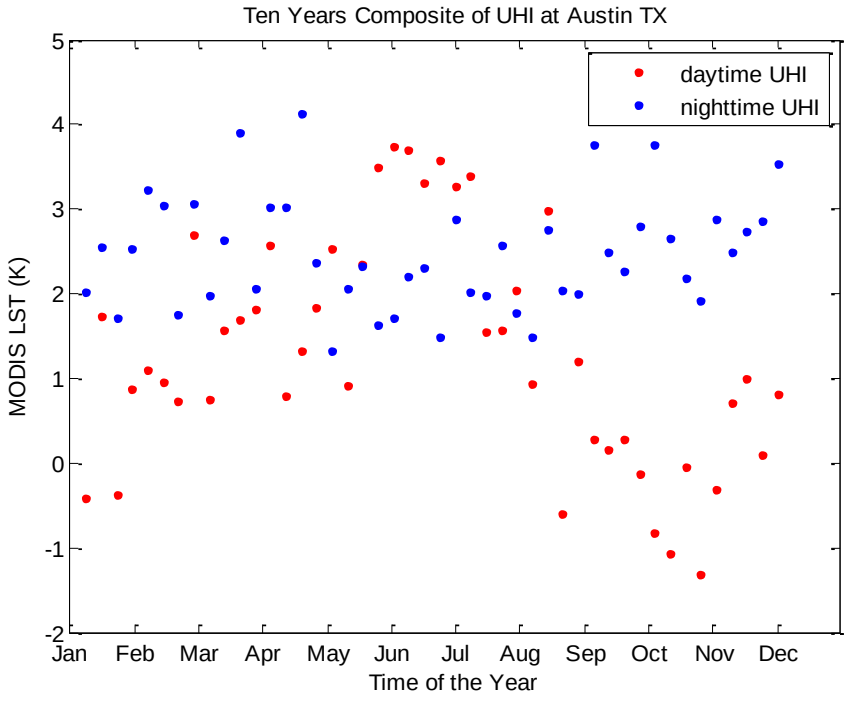

Preliminary Results: correlation analysis

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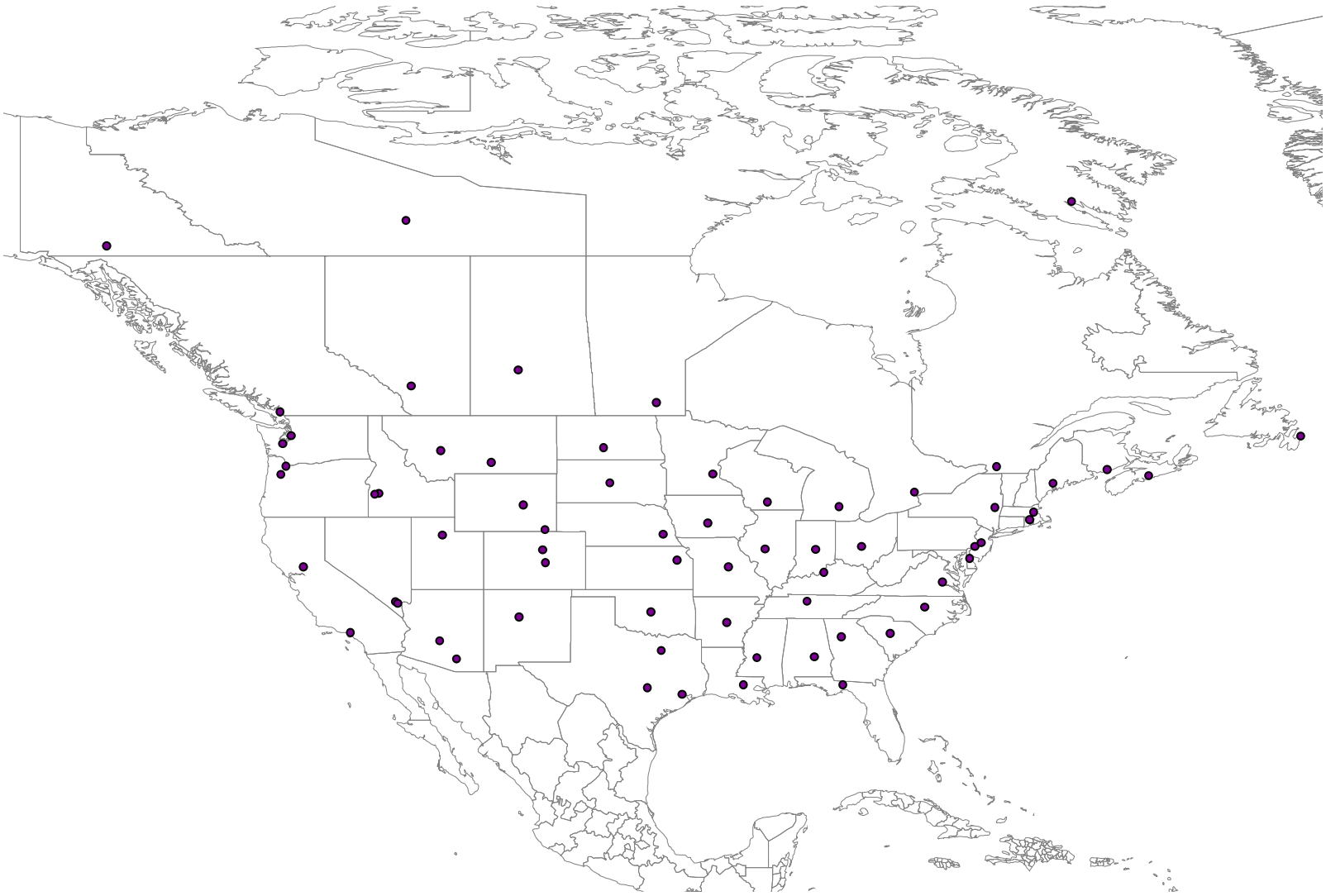

Preliminary Results: correlation analysis

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- Aridity Index may be a good indicator of background environment
- Correlation analyses of more variables are needed
- Nighttime UHI intensity is not driven by natural parameters
- Quantities driving the variation of nighttime UHI remain uncertain

Preliminary Results: modelling

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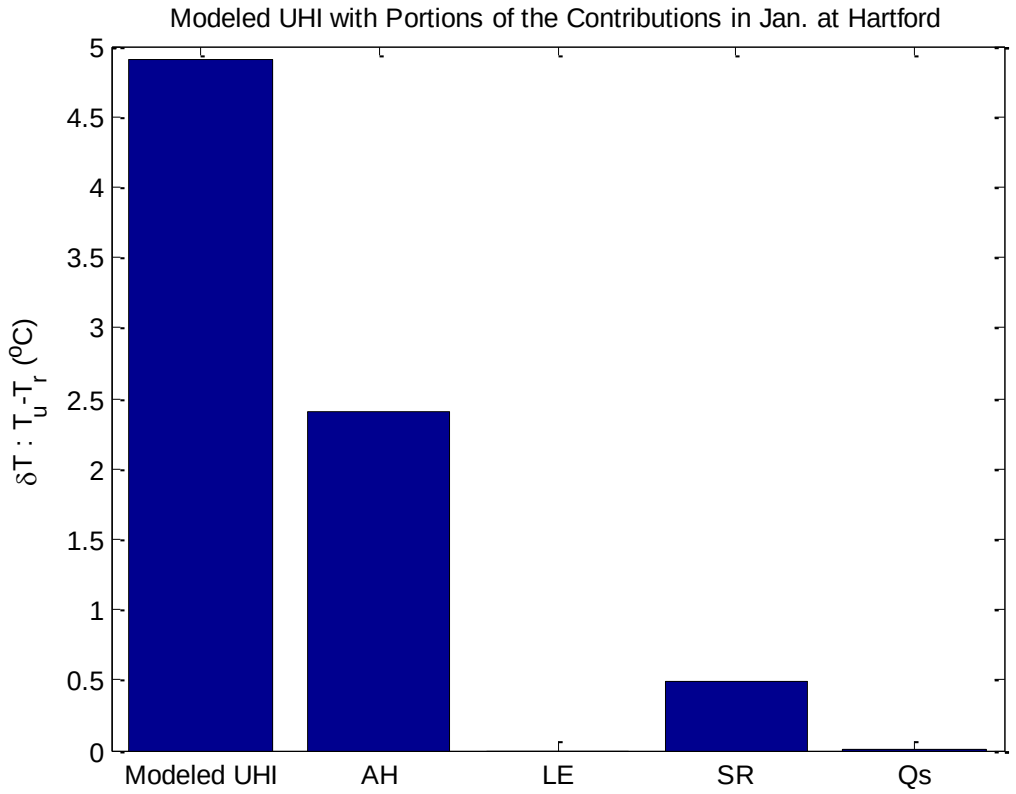
- Adapted Noah LSM



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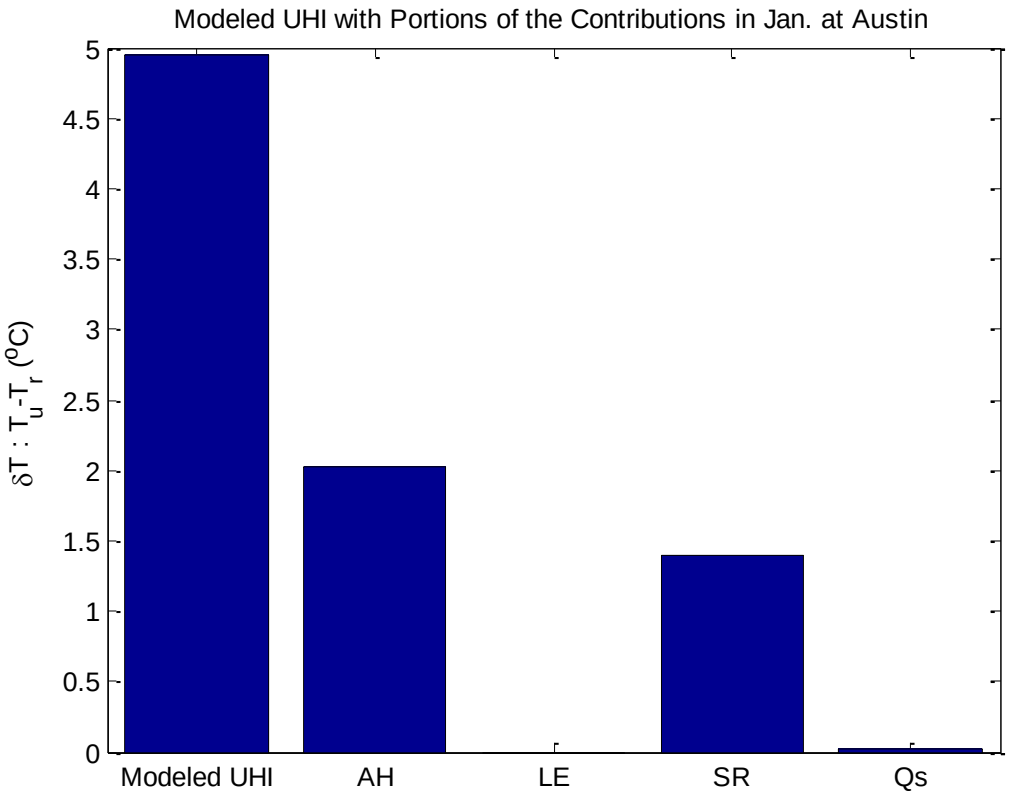

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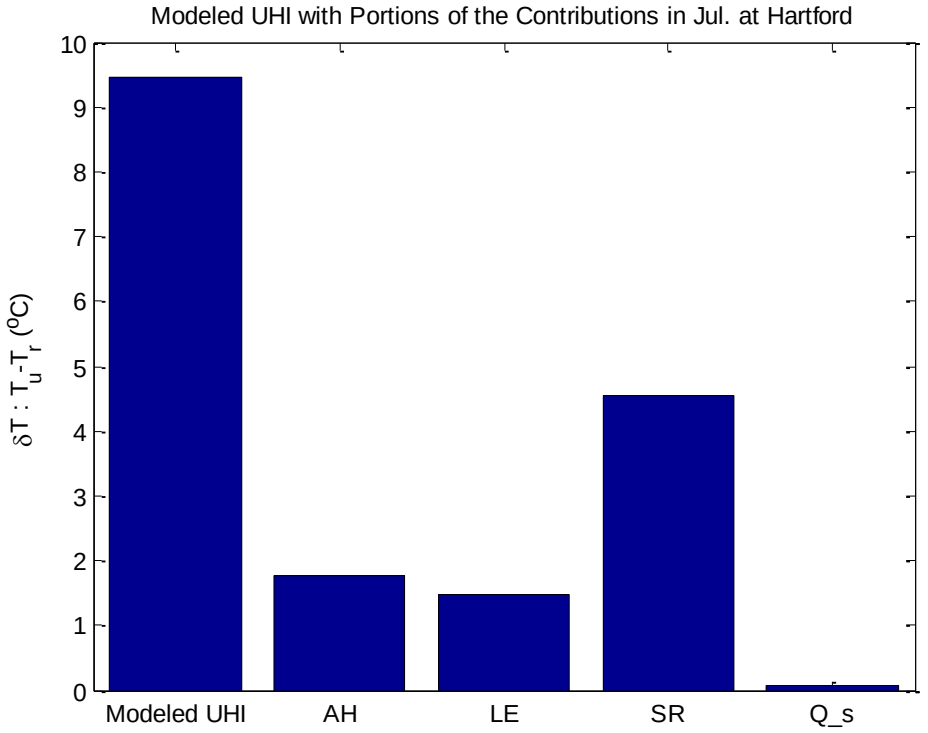

Preliminary Results: modelling

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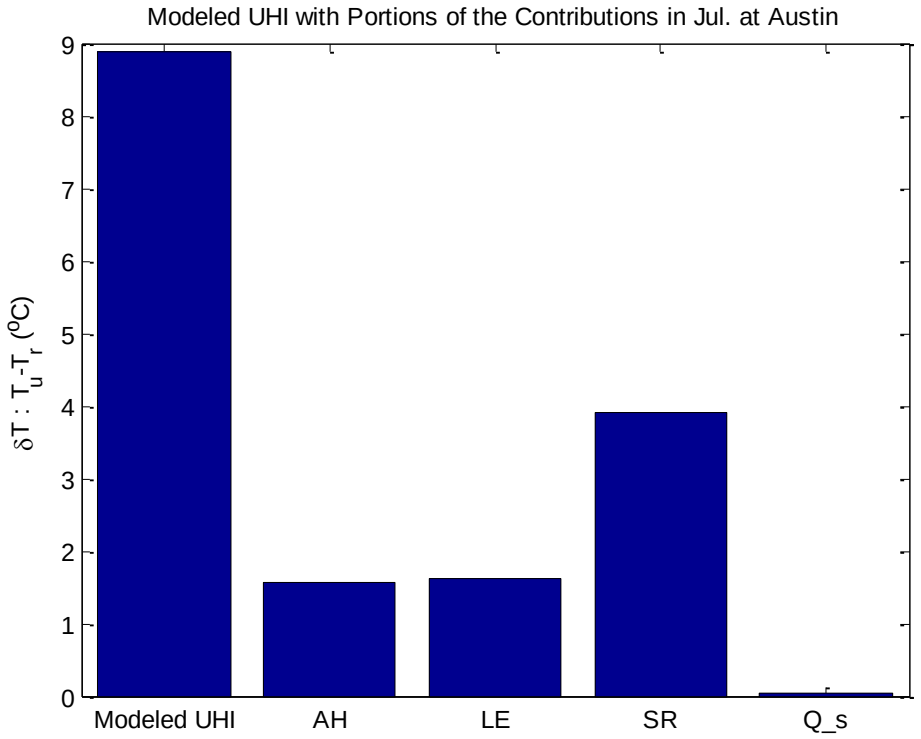

Preliminary Results: modelling

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- NARR overestimation could bias the surface temperature estimate
- Noah LSM does not force the energy balance (residue not reused)
- Nonlinearity:
  - Inherent nonlinearity
  - Model deficiency (such as Noah)

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Future Work

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- Find out the best variable to describe the effect of background environment on UHI
- Establish the parameterization of anthropogenic heat
- Simplify and modify CLMU
- Simulate the contribution of each factor
- Interpret the results and establish a good understanding of the physics of UHI

Thank you

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