Measurement and statistical modeling of the urban heat island of the city of Utrecht (the Netherlands)

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Outline

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- Study area and instrumentation
- Measurement
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Introduction

- In this study we performed mobile measurements with a bicycle instead of a car.
- More recently, the emphasis has moved toward modeling the spatial distribution of the UHI intensity using land use parameters and geometric characteristics of the build-up area as explaining variables.
- We attempt to further extend the statistical modeling approach.
- The spatial distribution of the nighttime UHI intensity of the city of Utrecht in the Netherlands is modeled using high-resolution multiday mobile observations for a single transect through the city.
- UHI： urban heat island

Study area

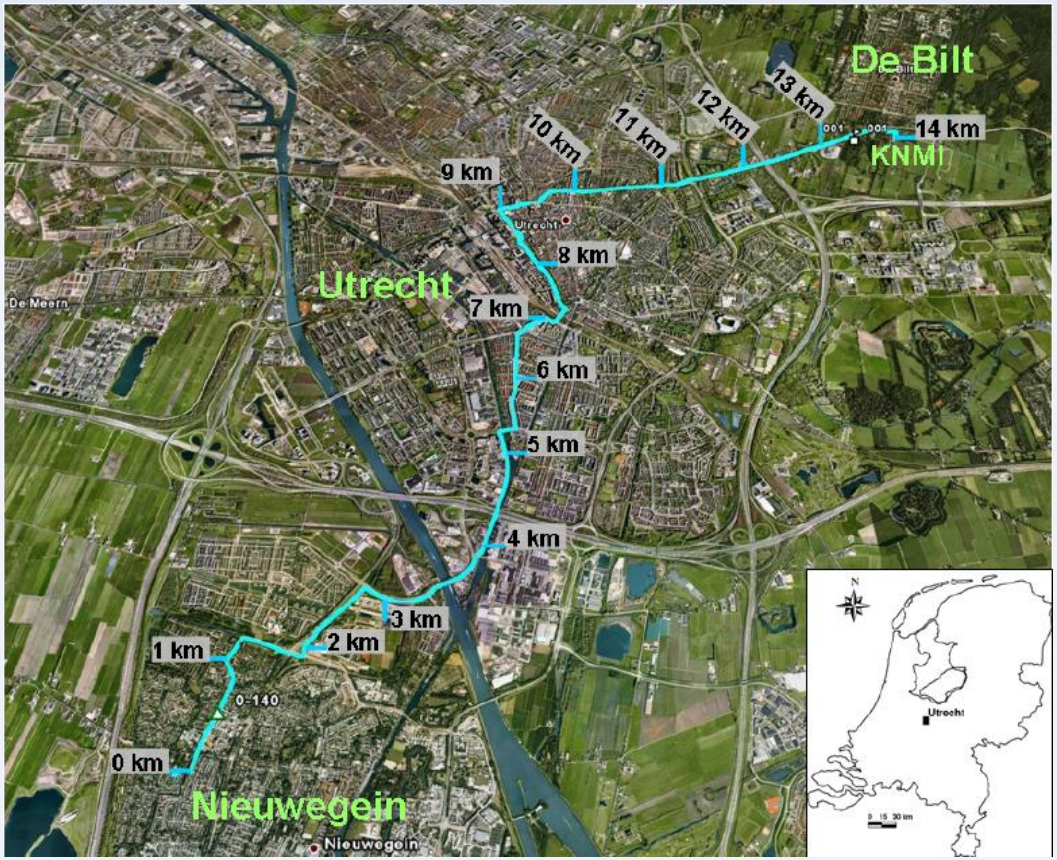

Figure 1 shows the 14 km long transect running from the western boundary of the town of Nieuwegein through the city of Utrecht to the KNMI building near the southern border of the town of De Bilt.

Instrumentation

Figure 2

The measurements were made with an Elpro datalogger with two external sensors: a combi-sensor for temperature/humidity, protected by a filter, and a NTC temperature drop probe with a diameter of 2.5 mm.

Measurements

- The measurements were taken in the period March 2006-January 2009 during commuter traffic and resulted in 106 nighttime profiles (before sunrise) and 77 daytime (afternoon) profiles.

- The average time needed for the early morning transects (Nieuwegein-Utrecht-De Bilt) was 37.3 min, and for the afternoon transects (De Bilt-Utrecht-Nieuwegein) was 41.3 min.

Results of the measurements

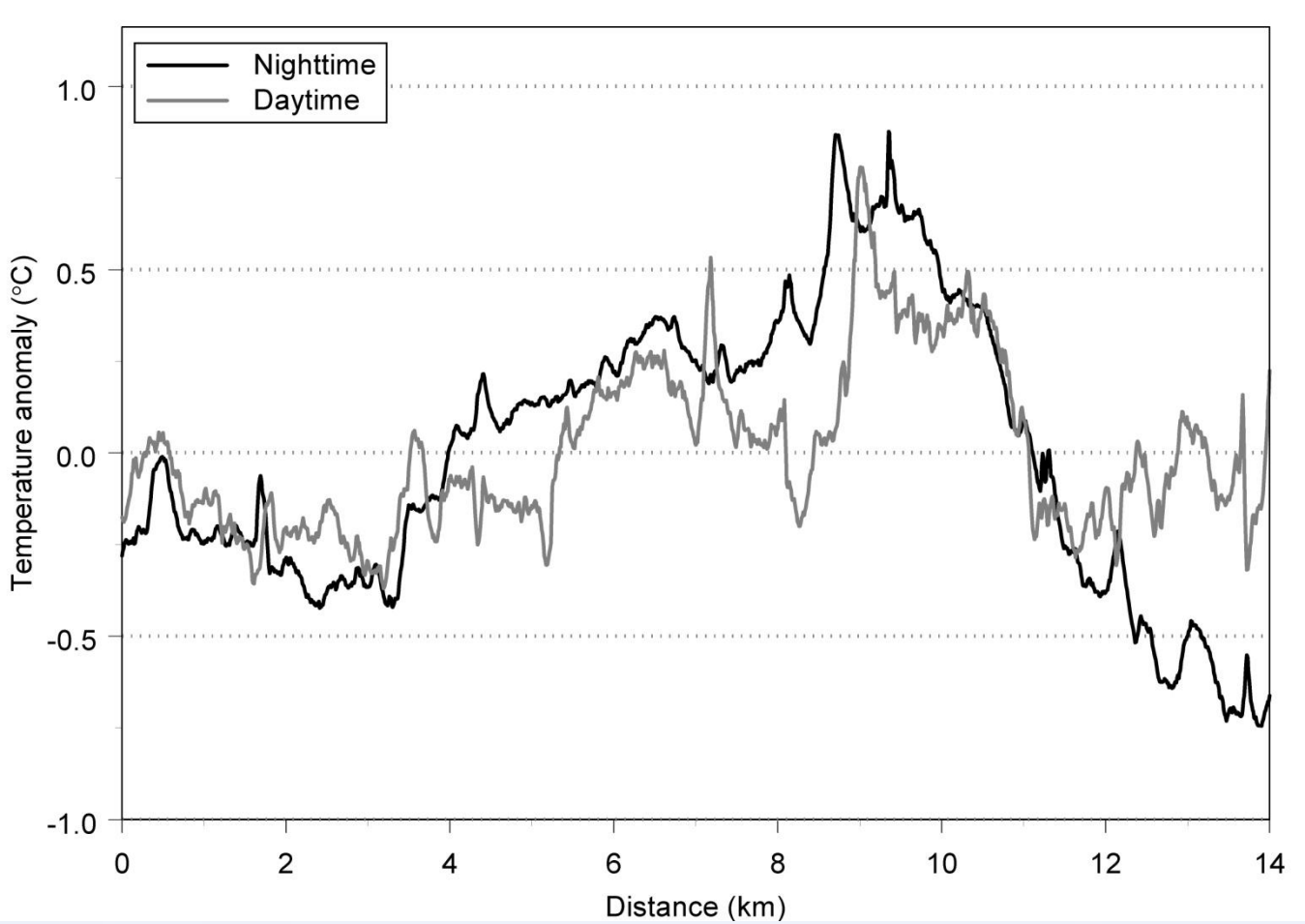

Figure 3: Average temperature anomaly profiles for nighttime(106 profiles) and daytime (77 profiles) conditions.

Results of the measurements

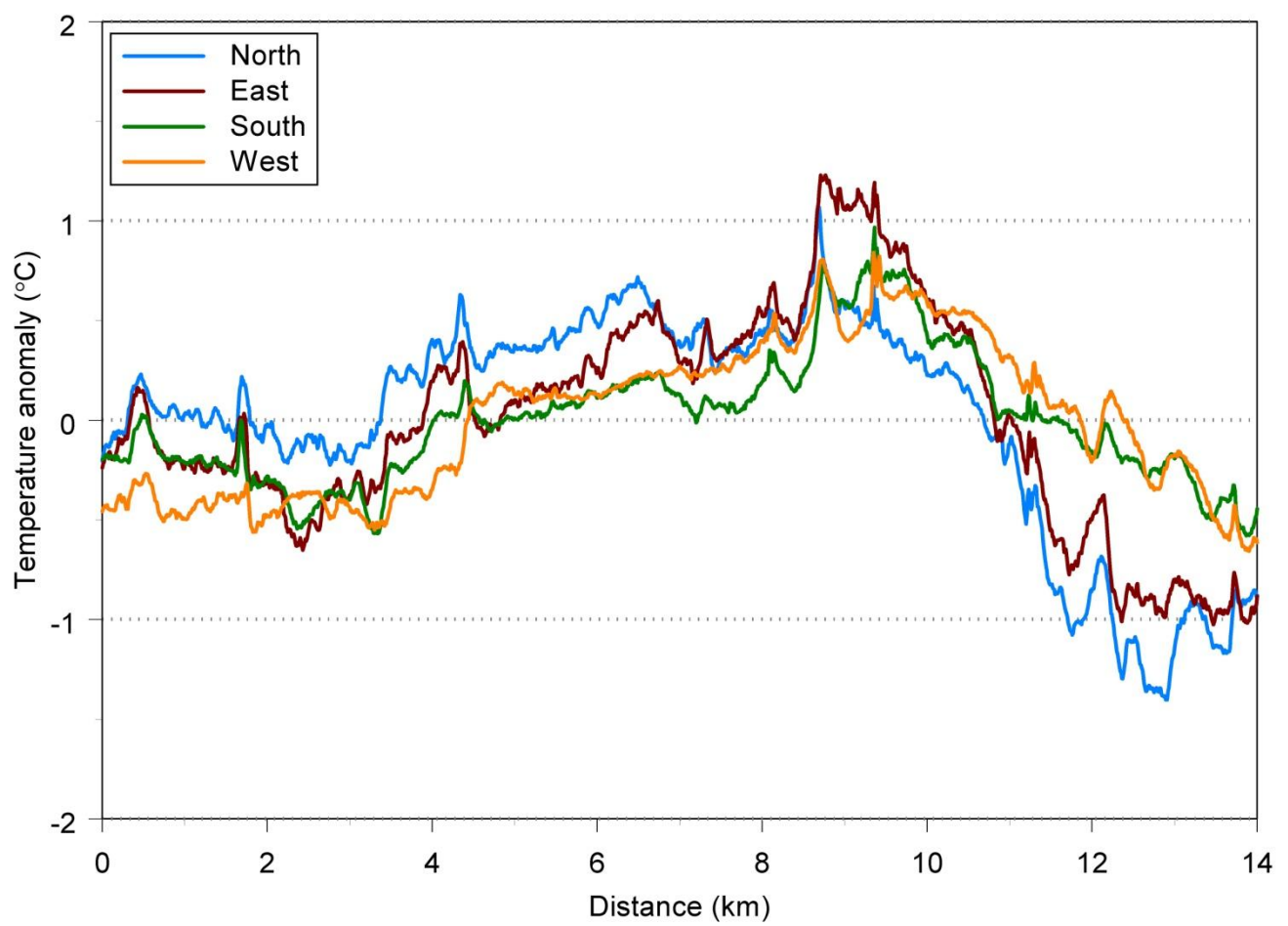

Figure 4: Average nighttime temperature anomaly profiles for 4 wind direction classes: north (23 profiles), east (18),south (35), west (30). Anomalies are with respect to profile means.

Results of the measurements

Here we define the maximum nighttime temperature difference (UHImax) for a certain nighttime temperature profile as the difference of the median of the twenty highest temperatures along the profile and the median of twenty lowest temperatures.

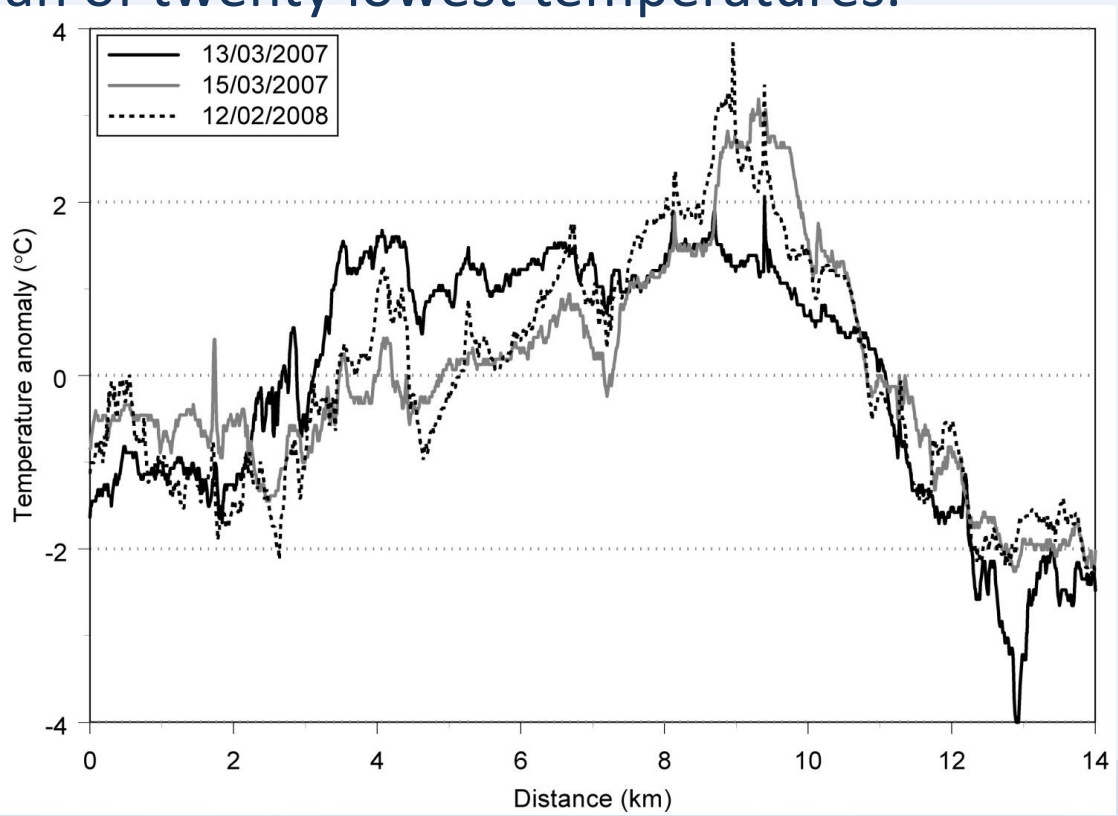

Figure 5: Temperature anomaly profiles for the 3 days with the largest UHImax.

Results of the measurements

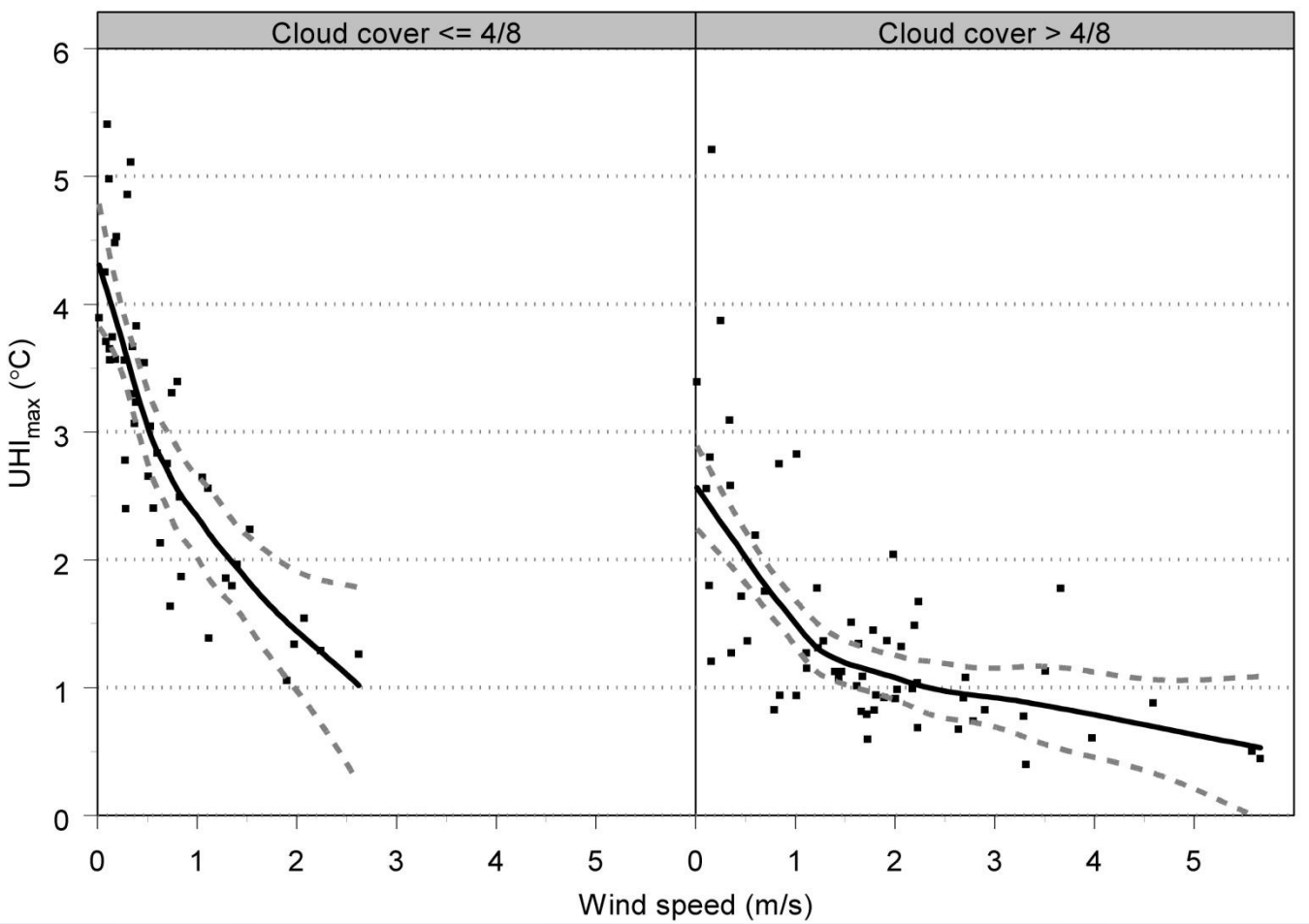

Figure 6

Model construction

- Our goal is to construct three models:
  - model for mean nighttime UHI intensity ;
  - model for maximum nighttime UHI intensity;
  - model for UHImax.

- The sky-view factor(SVF) and land use parameters are important explanatory variables of the UHI intensity.

- Land use was expressed as fractions summing up to 1.

  FB： fraction build-up

  FV： fraction vegetated **FB+FV+FW=1**

  FW： fraction open water

Model construction

The following model is proposed to describe the temperature profiles:

$$T' = \alpha_0 + \alpha_1 SVF_{r1} + \alpha_2 FB_{r1} + \alpha_3 FW_{r1} + \alpha_4 SVF_{r2} + \alpha_5 FB_{r2} + \alpha_6 FW_{r2} + \varepsilon \quad (1)$$

Because FB+FV+FW=1, one of them can be omitted from the equation. Here FV was omitted.

Model construction

$$UHI_{max} = g(W+N) + \varepsilon \qquad (2)$$

After some trial and error, the following parametric non-linear model was found acceptable:

$$UHI_{max} = \frac{\beta_1 + \beta_2 N}{(W + 0.5)^{\beta_3}} + \varepsilon \qquad (3)$$

Results of the UHI modeling

Table 1: Comparison of models with several combinations of r_1 and r_2 in Eq.1

	R^2	
(r_1, r_2) (in m)	weighted	non-weighted
(25,100)	0.632	0.646
(25,200)	0.758	0.774
(25,300)	0.800	0.814
(25,400)	0.810	0.816
(25,500)	0.812	0.809
(25,600)	0.811	0.807
(50,100)	0.643	0.647
(50,200)	0.760	0.775
(50,300)	0.798	0.812
(50,400)	0.809	0.817
(50,500)	0.814	0.814
(50,600)	0.815	0.815

We therefore choose the non-weighted alternative with r_1 = 50 and r_2 = 400 m.

Results of the UHI modeling

Table 2 Parameter estimates for the model in Equation 1 with r_1 = 50 m, r_2 = 400 m and R^2 = 0.817 for the mean nighttime UHI intensity.

	value	st.error	t-value
$\hat{\alpha}_0$	-	-	-
$\hat{\alpha}_1$	−0.463	0.051	−9.073
$\hat{\alpha}_2$	0.270	0.027	10.083
$\hat{\alpha}_3$	0.358	0.037	9.723
$\hat{\alpha}_4$	−1.012	0.055	−18.464
$\hat{\alpha}_5$	1.032	0.021	48.781
$\hat{\alpha}_6$	0.764	0.065	11.808

Use SVF_{50}、FB_{50}、FW_{50}、SVF_{400}、FB_{400}、FW_{400} and mean of 106 nigttime profiles to fit the parameters of the model.

$$T' = -0.463SVF_{50} + 0.270FB_{50} + 0.358FW_{50} - 1.012SVF_{400} + 1.032FB_{400} + 0.764FW_{400} \quad (4)$$

Results of the UHI modeling

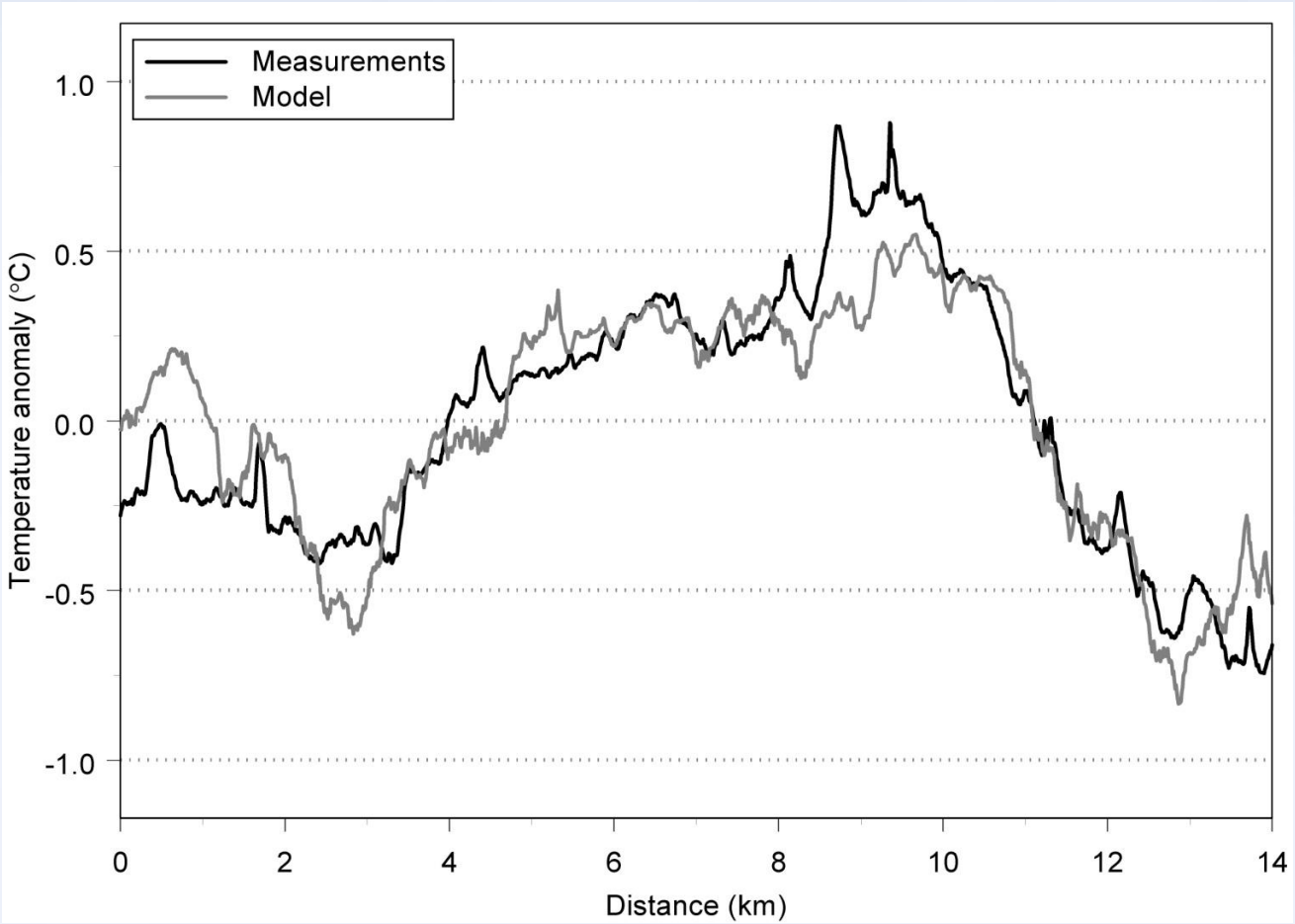

Figure 7: Comparison of the measured and modeled mean nighttime UHI intensity. Anomalies are with respect to profile means.

Results of the UHI modeling

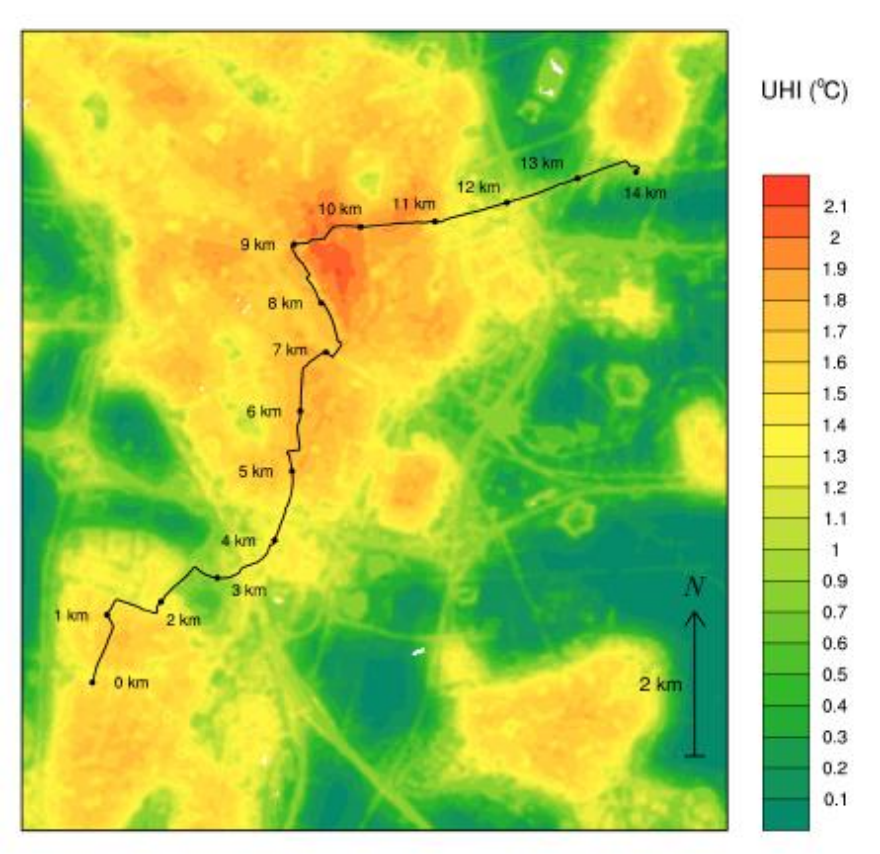

Figure 8: Spatial distribution of the mean nighttime UHI intensity for the city of Utrecht and its surroundings as calculated from the model in Equation 4 with respect to the rural background temperature.

Results of the UHI modeling

Table 3 Parameter estimates for the model in Equation 1 with r_1 = 50 m, r_2 = 400 m and R^2 = 0.759 for the mean nighttime UHI intensity.

	value	st.error	t-value
$\hat{\alpha}_0$	–0.823	0.269	–3.056
$\hat{\alpha}_1$	–2.008	0.195	–10.309
$\hat{\alpha}_2$	0.301	0.104	2.903
$\hat{\alpha}_3$	0.584	0.142	4.120
$\hat{\alpha}_4$	–1.523	0.330	–4.618
$\hat{\alpha}_5$	3.754	0.124	30.213
$\hat{\alpha}_6$	5.183	0.272	19.078

$$T' = -0.823 - 2.008SVF_{50} + 0.301FB_{50} + 0.584FW_{50} - 1.523SVF_{400} + 3.754FB_{400} + 5.183FW_{400} \quad (5)$$

Results of the UHI modeling

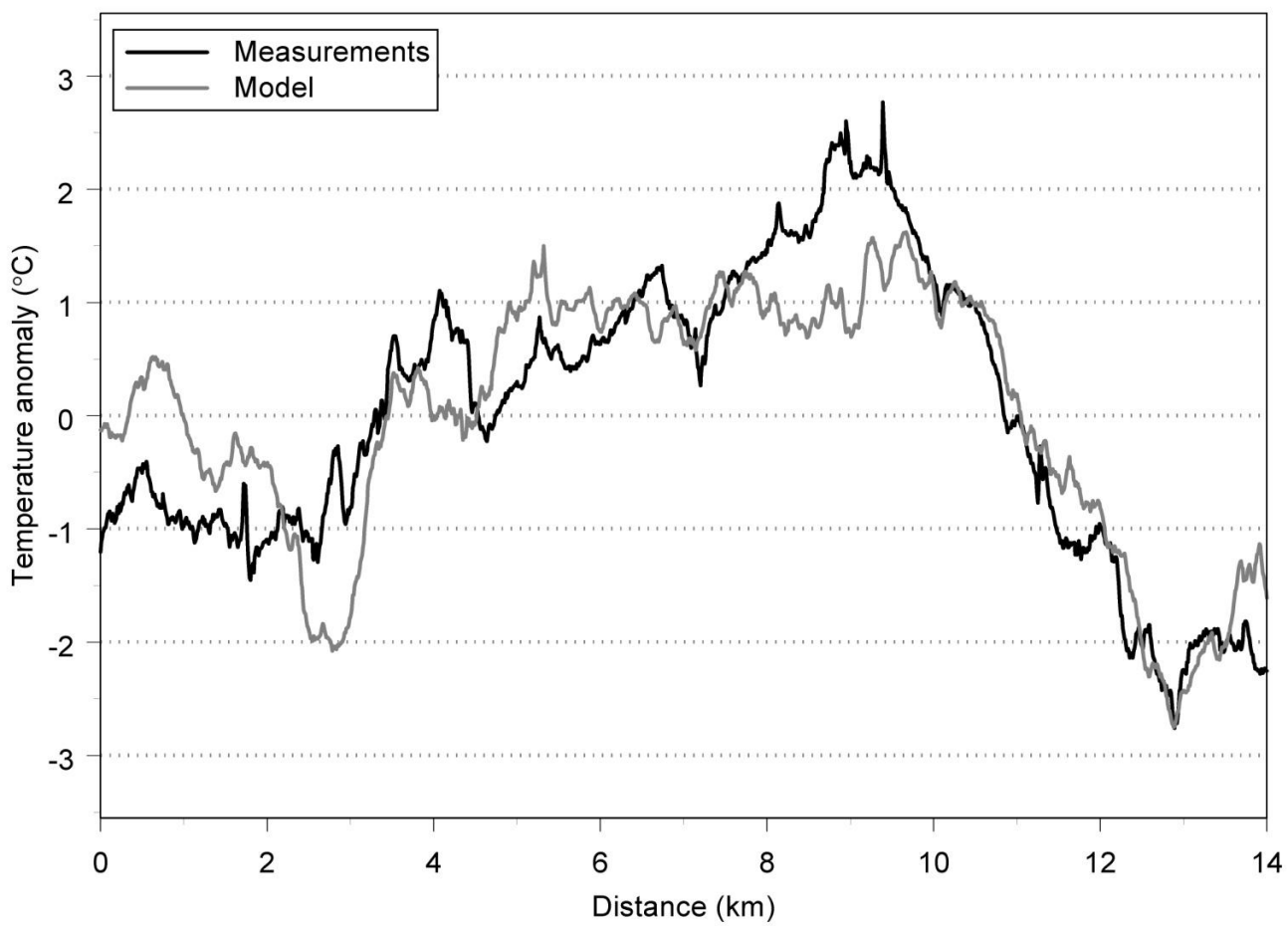

Figure 9: Comparison of the measured and modeled maximum nighttime UHI intensity. Anomalies are with respect to profile means.

Results of the UHI modeling

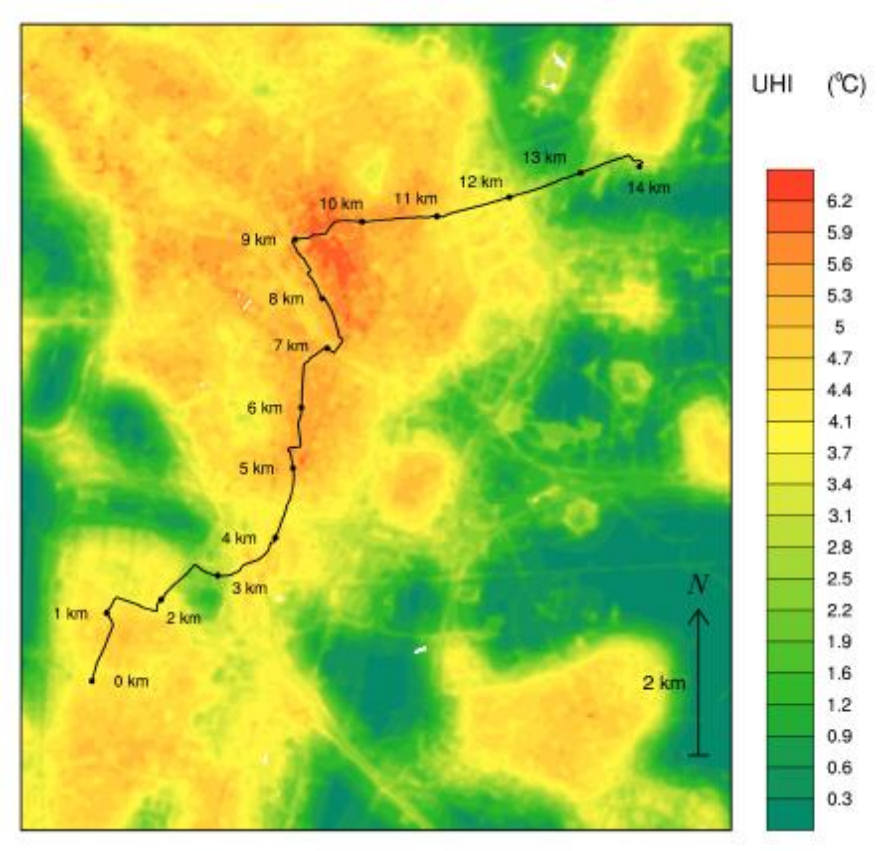

Figure 10: Spatial distribution of the maximum nighttime UHI intensity for the city of Utrecht and its surroundings as calculated from the model in Equation 5 with respect to the rural background temperature.

Results of the UHI modeling

Table 4: Parameter estimates for the model in Equation 3 for UHImax.

	value	st.error	t-value
$\hat{\beta}_1$	3.081	0.095	32.5
$\hat{\beta}_2$	−0.144	0.019	−7.4
$\hat{\beta}_3$	0.672	0.056	11.9

The resulting model for UHImax is:

$$\mathrm{UHI}_{\max} = \frac{(3.081 - 0.144N)}{(W + 0.5)^{0.672}} \qquad (6)$$

Discussion

- Two multiple-linear regression models have been proposed to describe the mean and maximum nighttime UHI intensity profiles of the city Utrecht.

- In addition to the two linear models, a non-linear model is constructed that relates the temperature difference between the warmest and coldest part along the profiles(UHImax) to wind speed and cloudiness.

- A difficult point in each UHI study is the choice of the rural reference. Because of climatological temperature differences, it is desirable to have a rural reference as close as possible to the urban area.

Conclusions

- The mean and maximum nighttime UHI intensity could be described by a statistical model using the SVF and the fractions of build-up area and water area as predictors.

- Together, the models present an easy tool to obtain first order estimates of the nighttime UHI intensity in Utrecht and probably also other cities in comparable climates.

Thank you