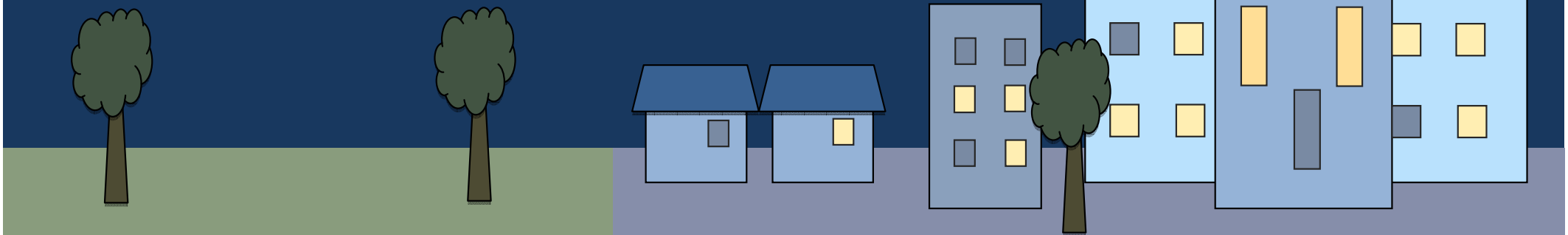
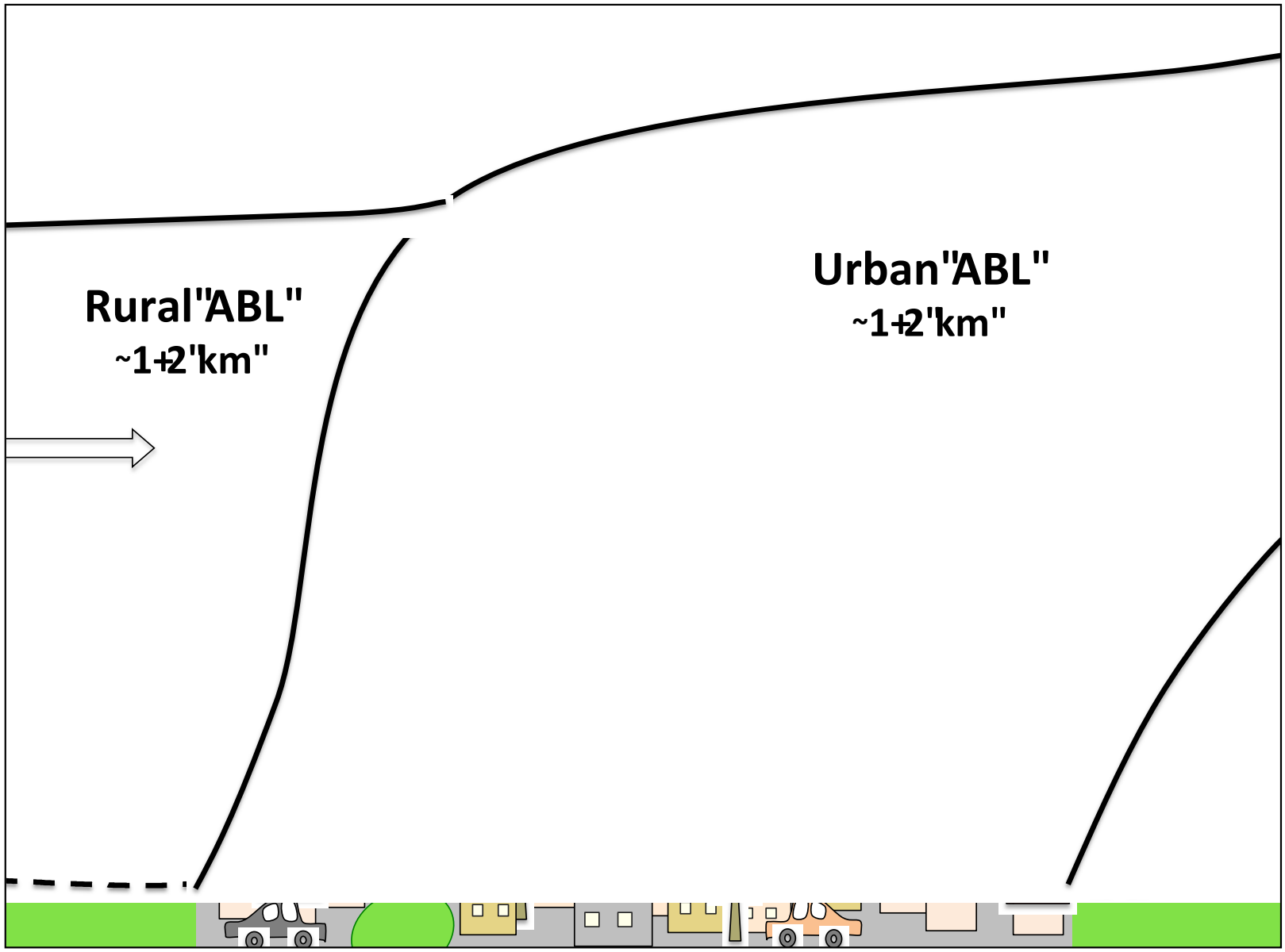
Urban boundary layers

and the influence on the urban heat island

Natalie Theeuwes, Gert-Jan Steeneveld,
Reinder Ronda, Mathias Rotach and Bert Holtslag



What are the differences between the urban and rural BL?



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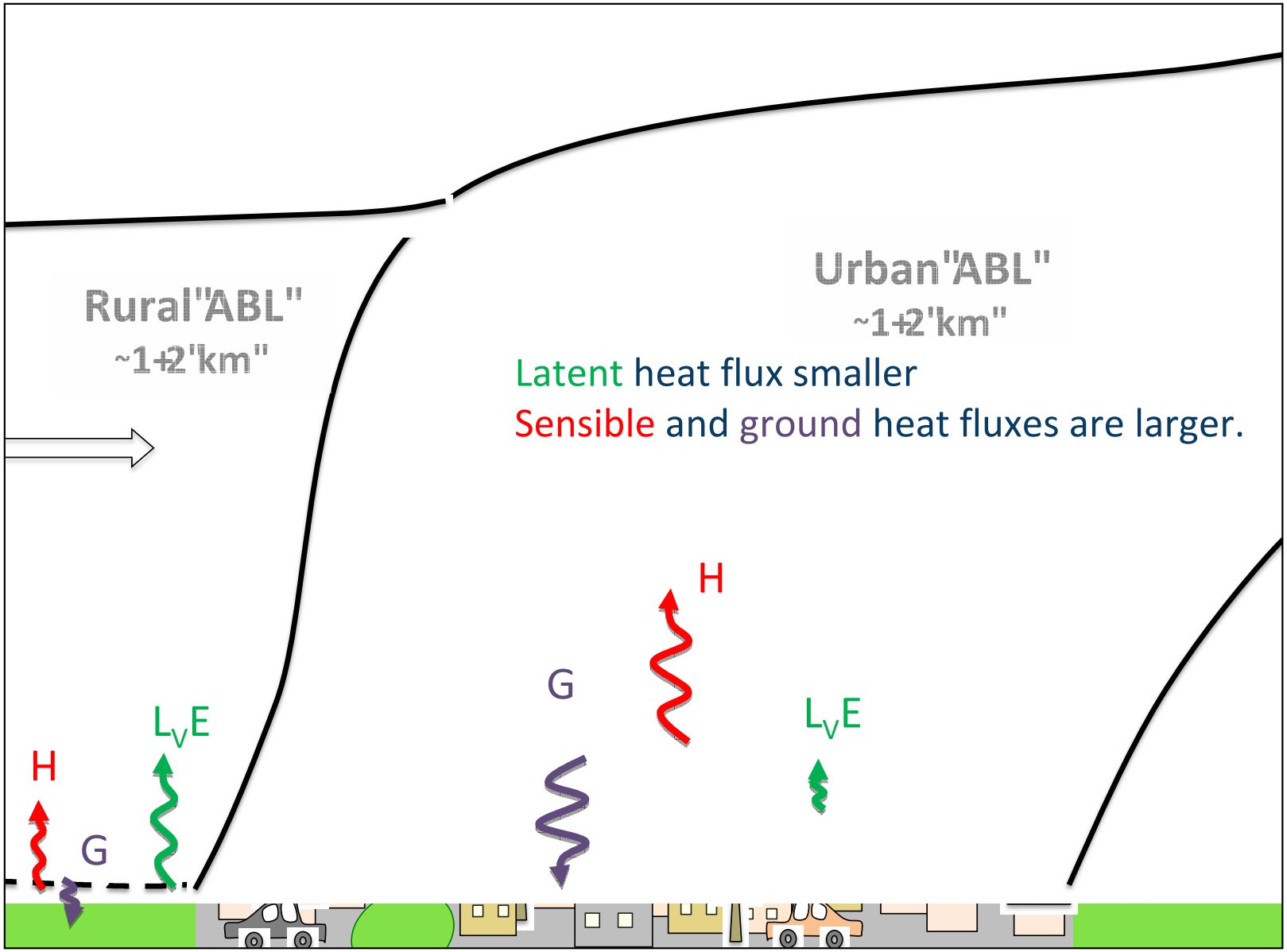
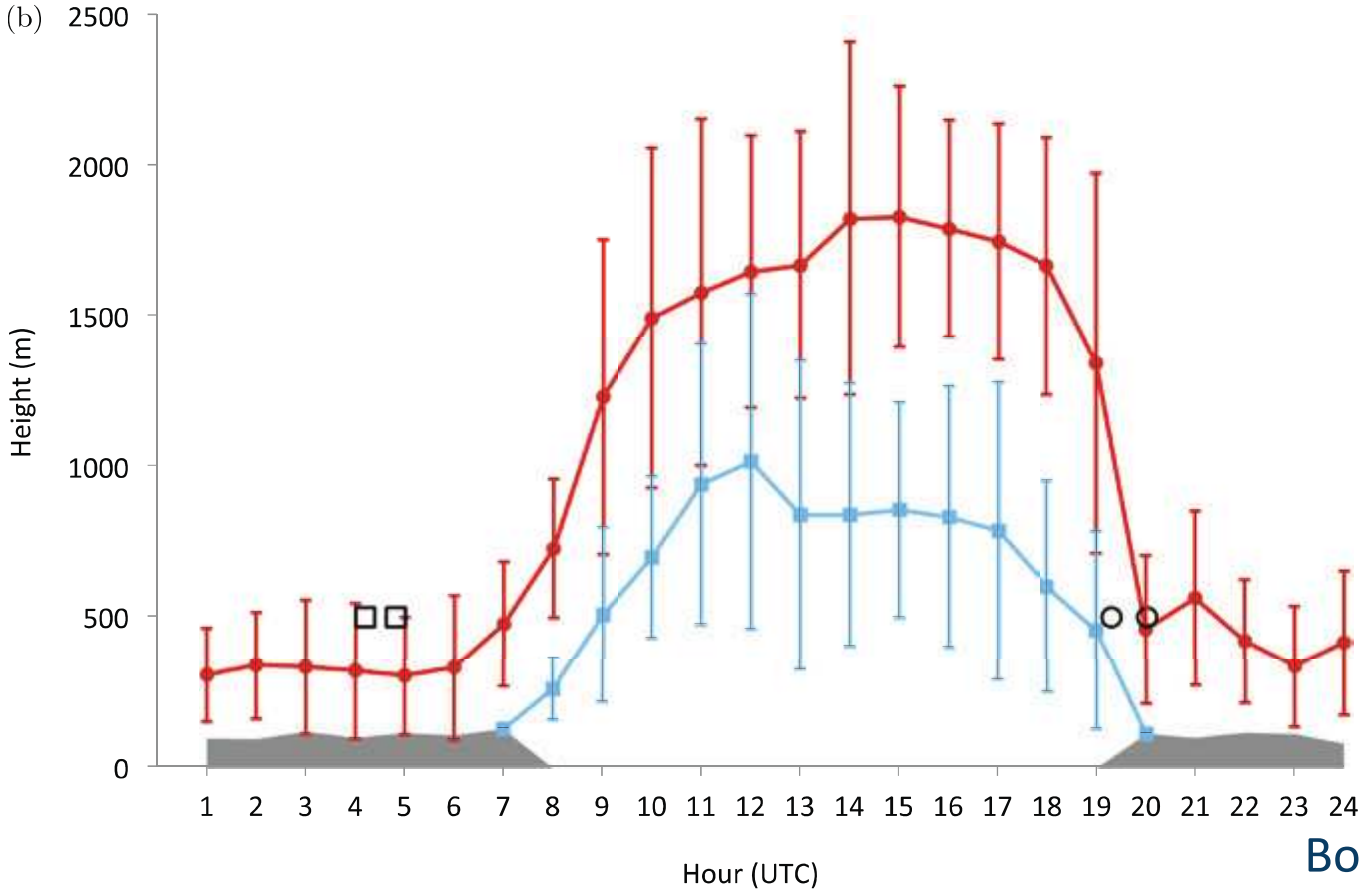


What are the differences between the urban and rural BL?

- Sensible and ground heat fluxes are higher.
- Generally deeper PBL over the city.



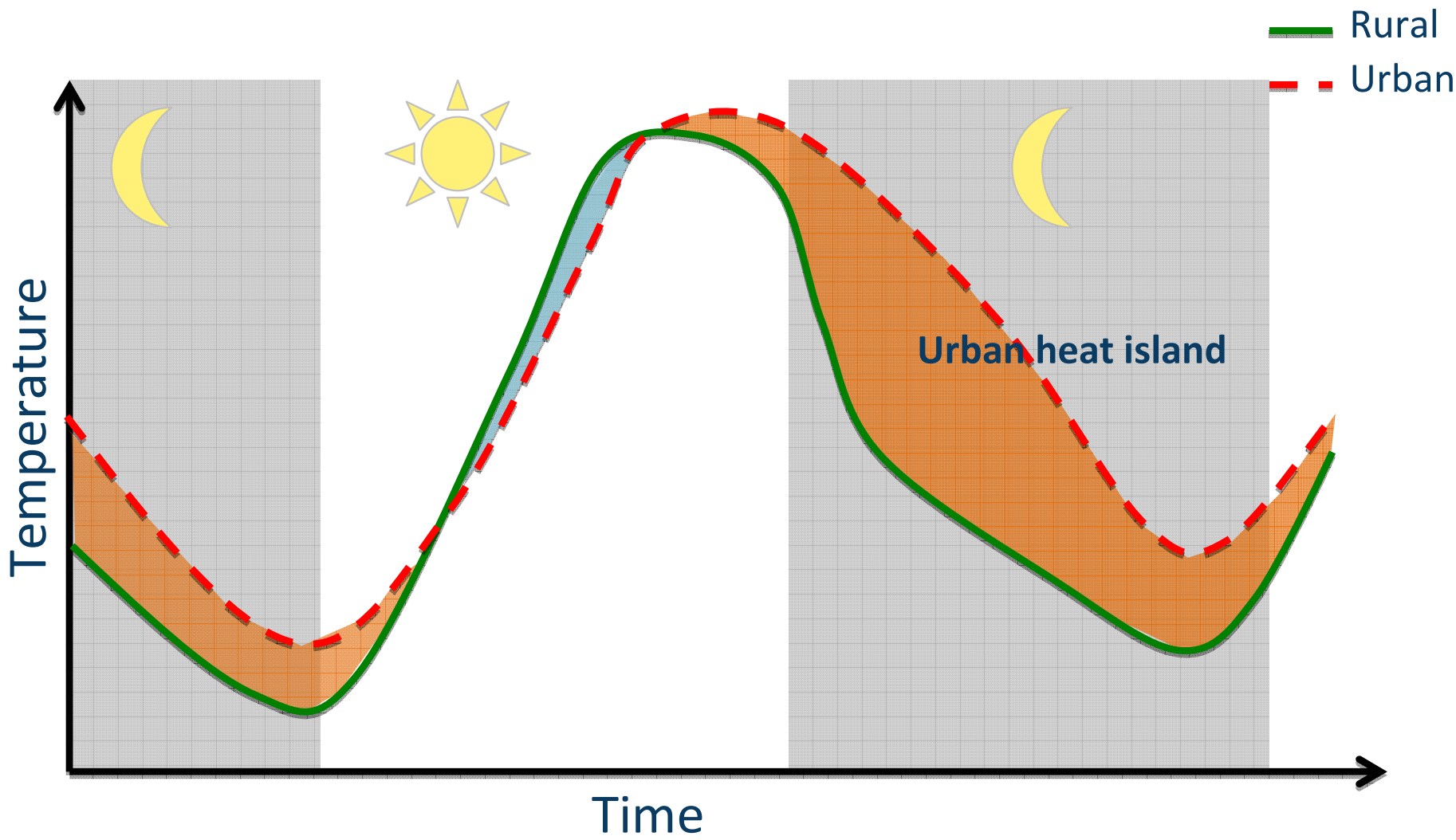
Mixed-layer depths over London and Chilbolton

Rural mixed layer depth

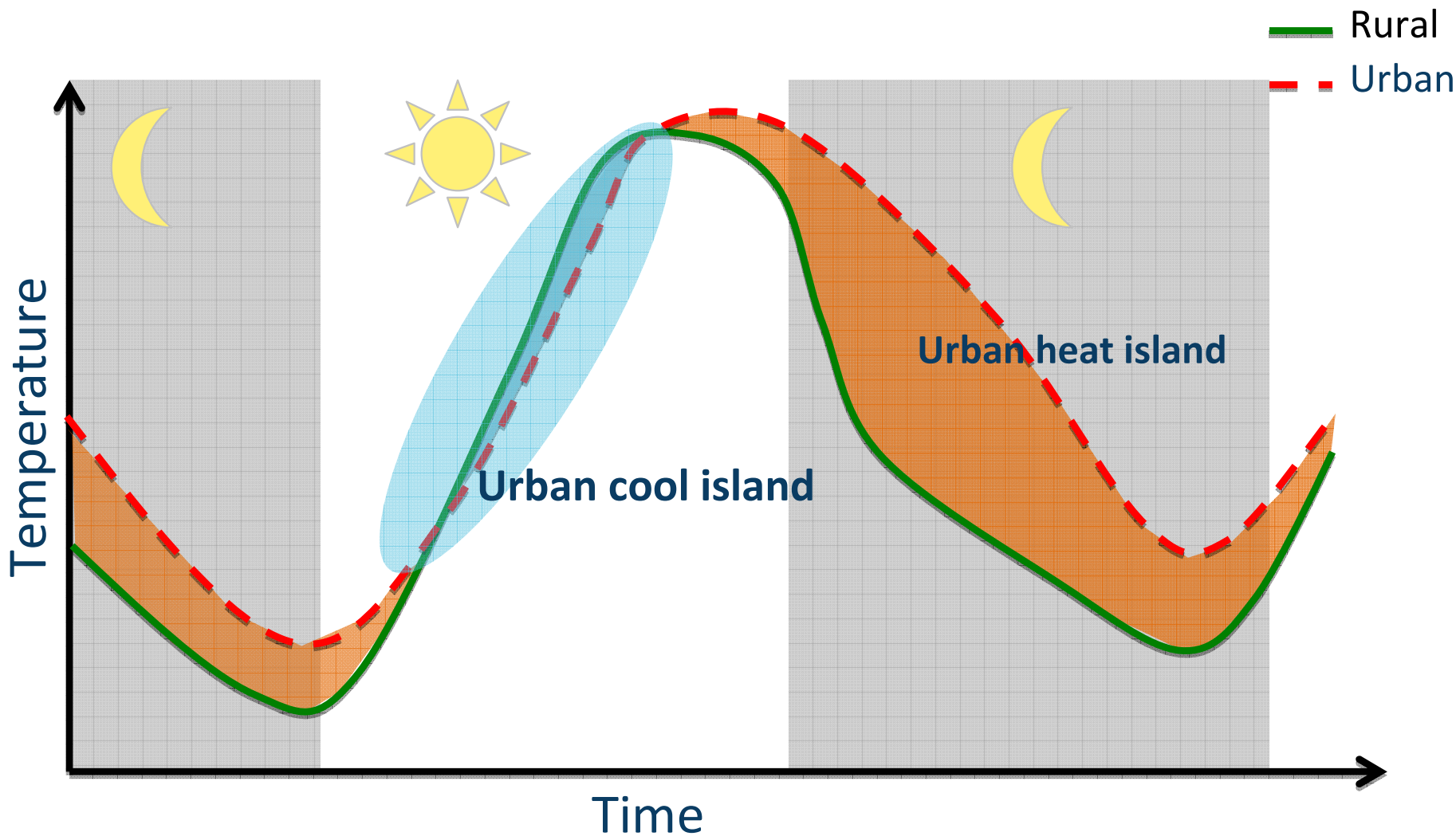
Urban mixed layer depth

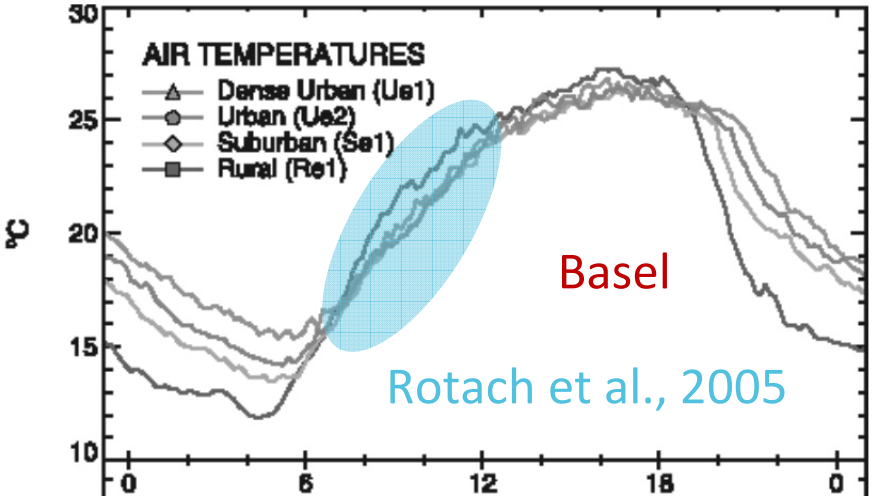
Bohnenstengel et al., 2015, BAMS

The urban heat island



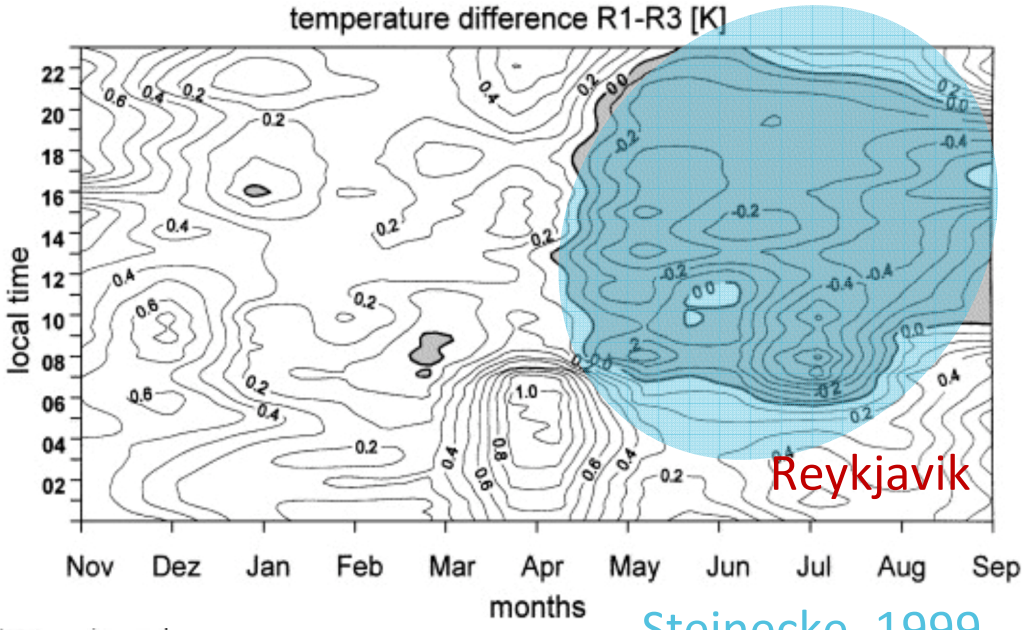
The urban cool island





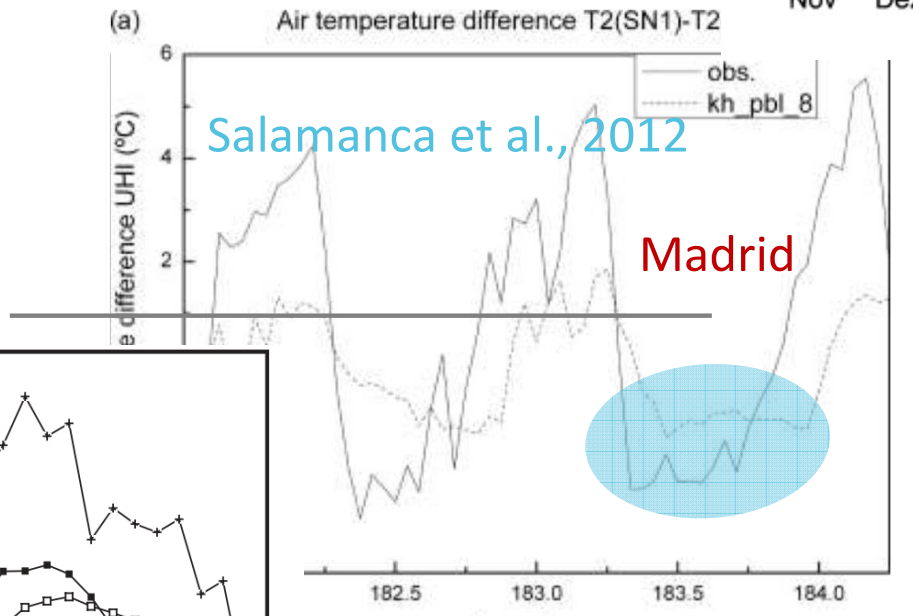
Basel

Rotach et al., 2005



Reykjavik

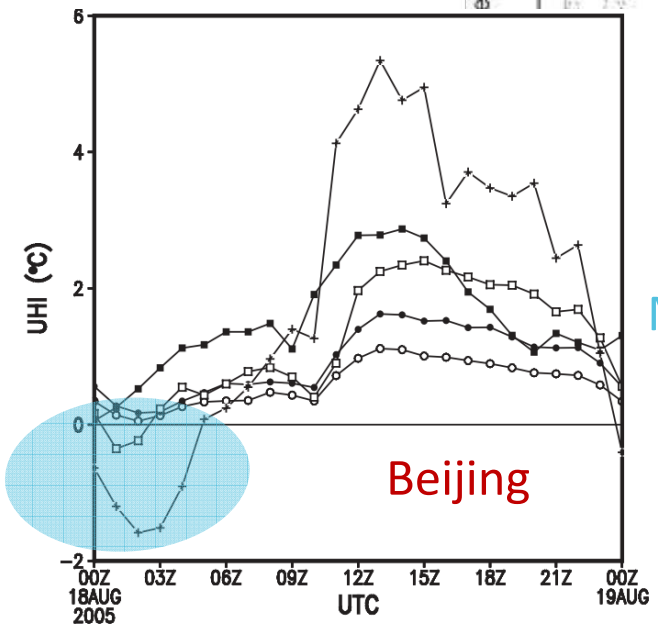
Steinecke, 1999



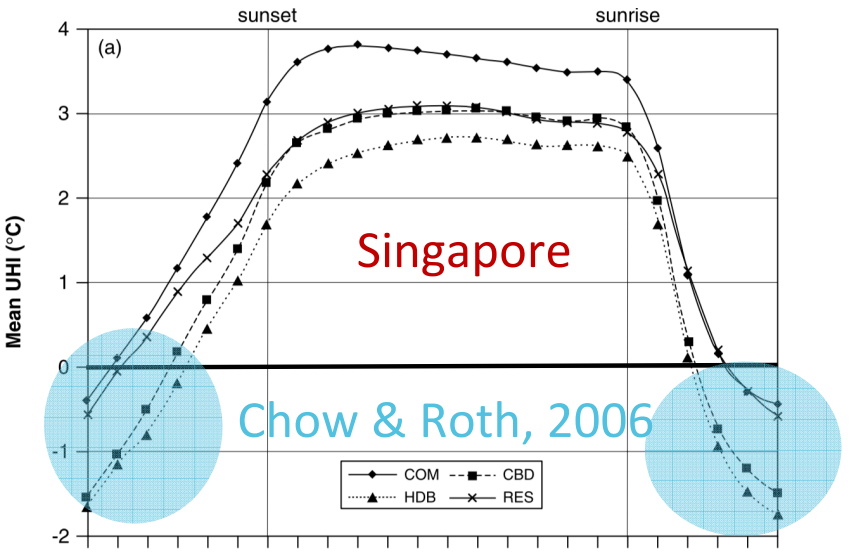
Salamanca et al., 2012

Madrid

Miao et al., 2006



Beijing



Singapore

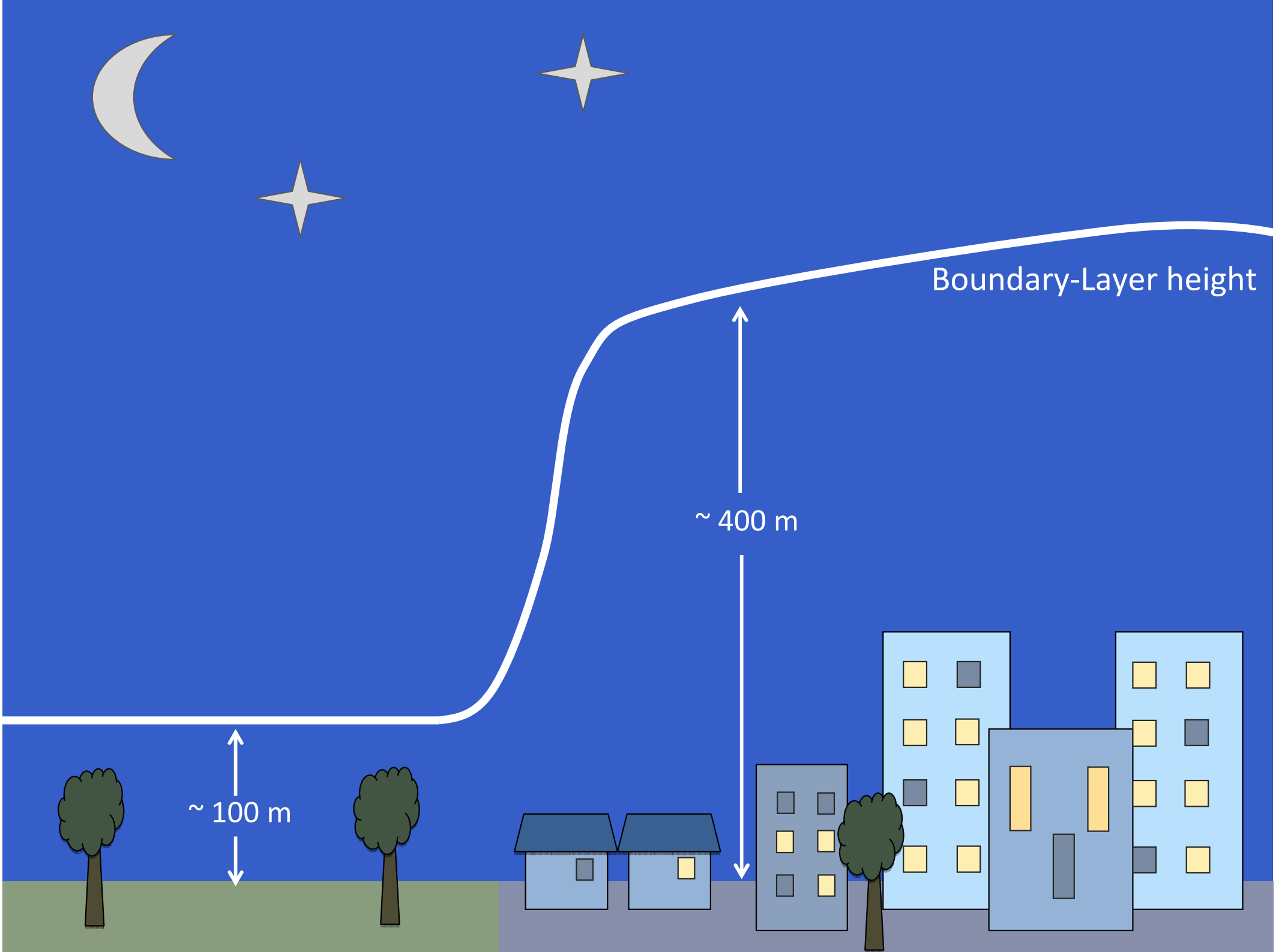
Chow & Roth, 2006

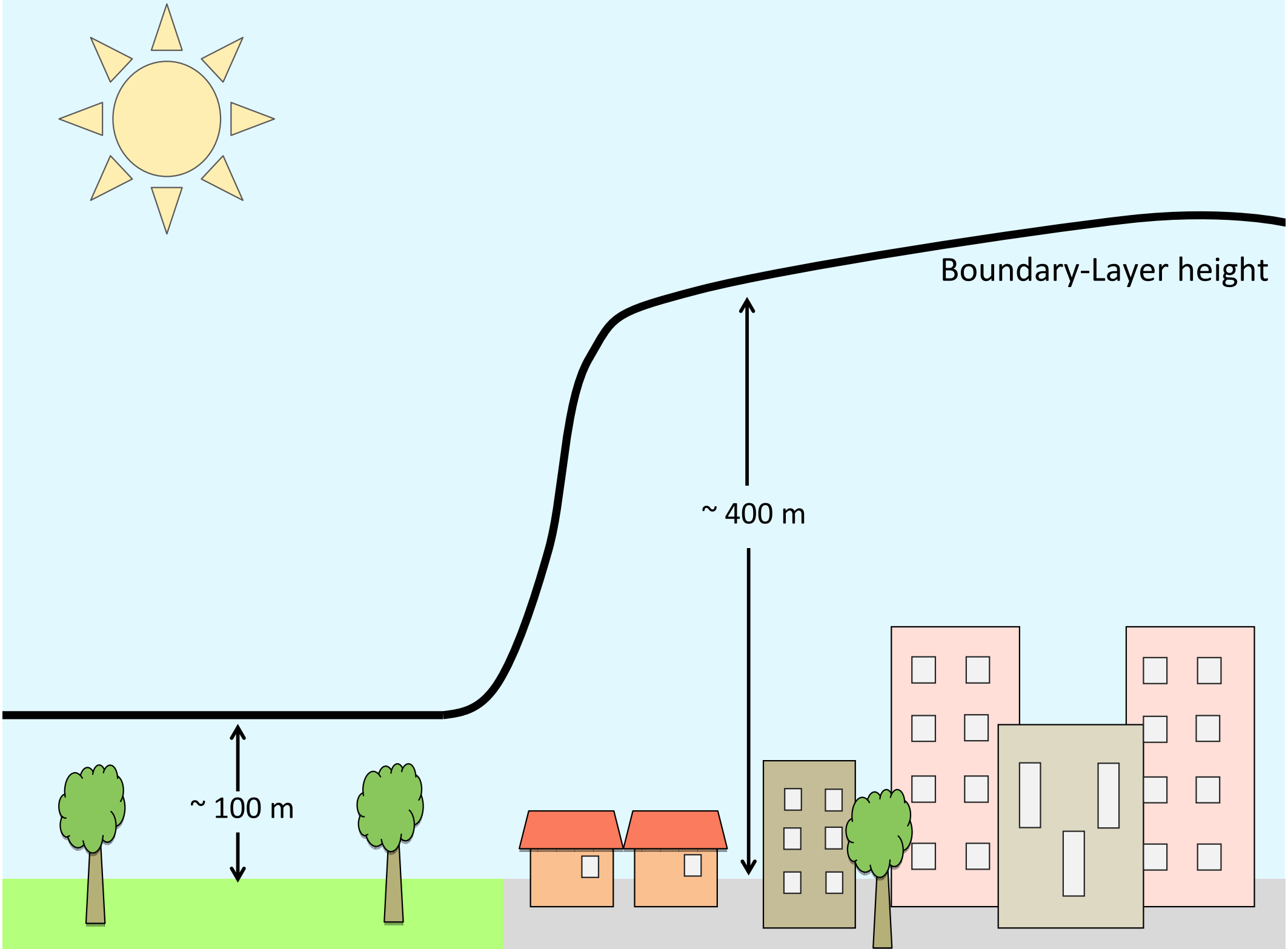
What do we know about the UCI?

- Mostly found in fair-weather, low wind speed conditions.
- Strongest in the morning, in some cases can last throughout entire day.
- In most cases UCI < 2 °C.

Our hypothesis:

The UCI is formed through atmospheric boundary-layer dynamics


Boundary-Layer height
~ 400 m
~ 100 m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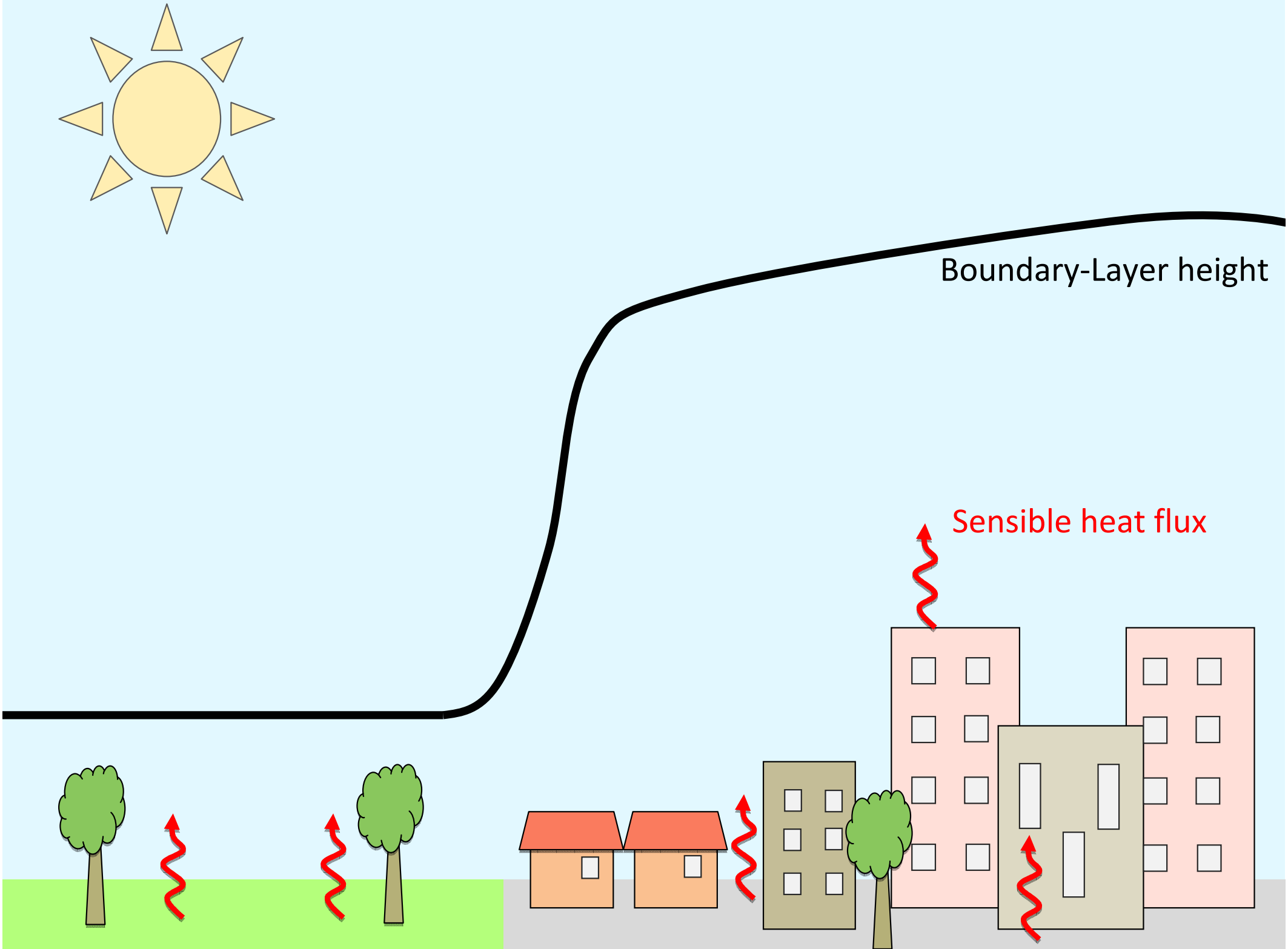
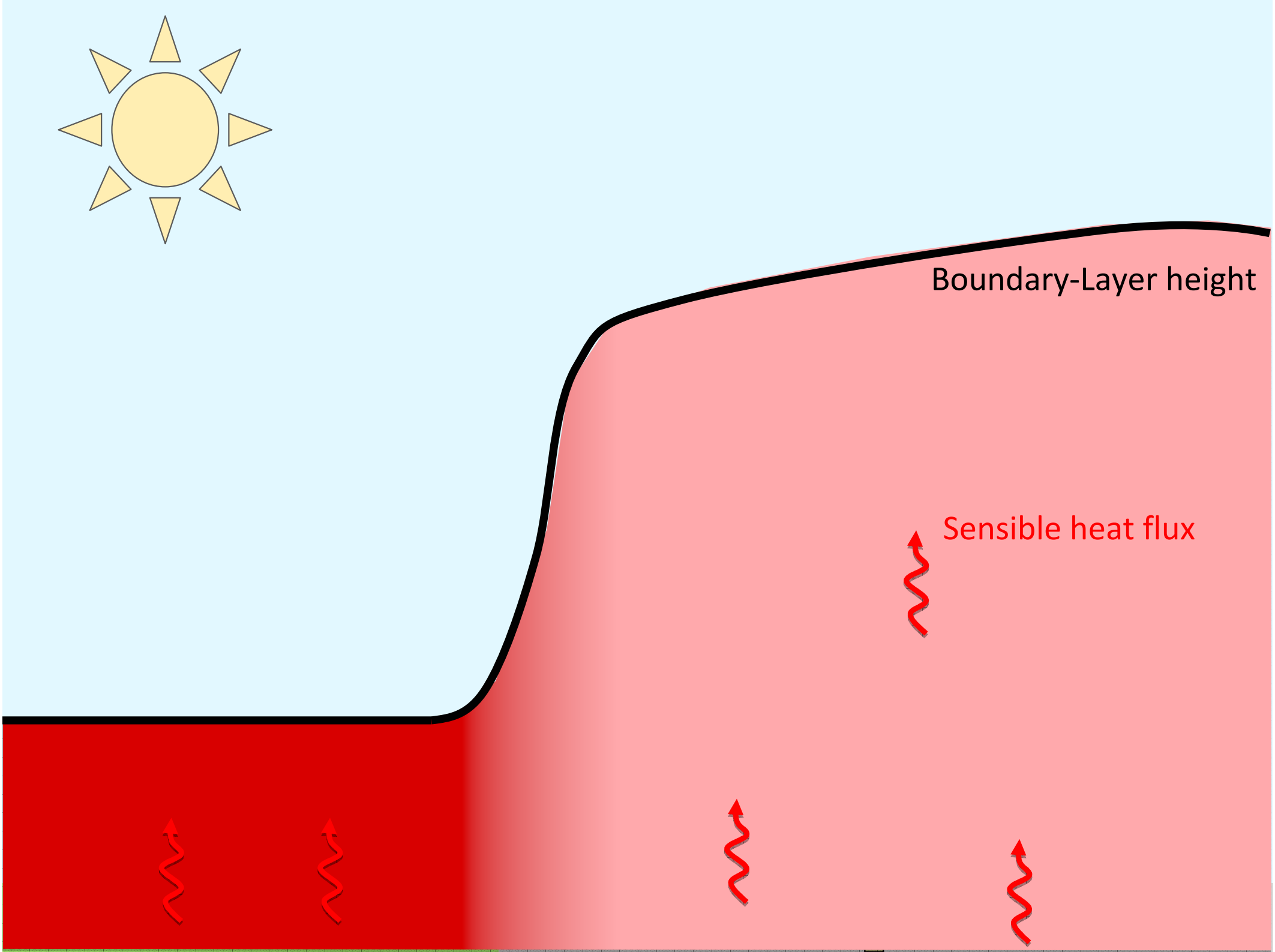

Boundary-Layer height
Sensible heat flux


Boundary-Layer height
Sensible heat flux

How do we test this hypothesis?

We use the following **tools**:

- Mixed layer equations, forced by land surface model

- Observations from the BUBBLE (Basel, Switzerland) campaign.

$$\frac{\partial < \theta_v >}{\partial t} = \frac{\overline{w'\theta'_v} - b \cdot \overline{w'\theta'_v}}{h}$$

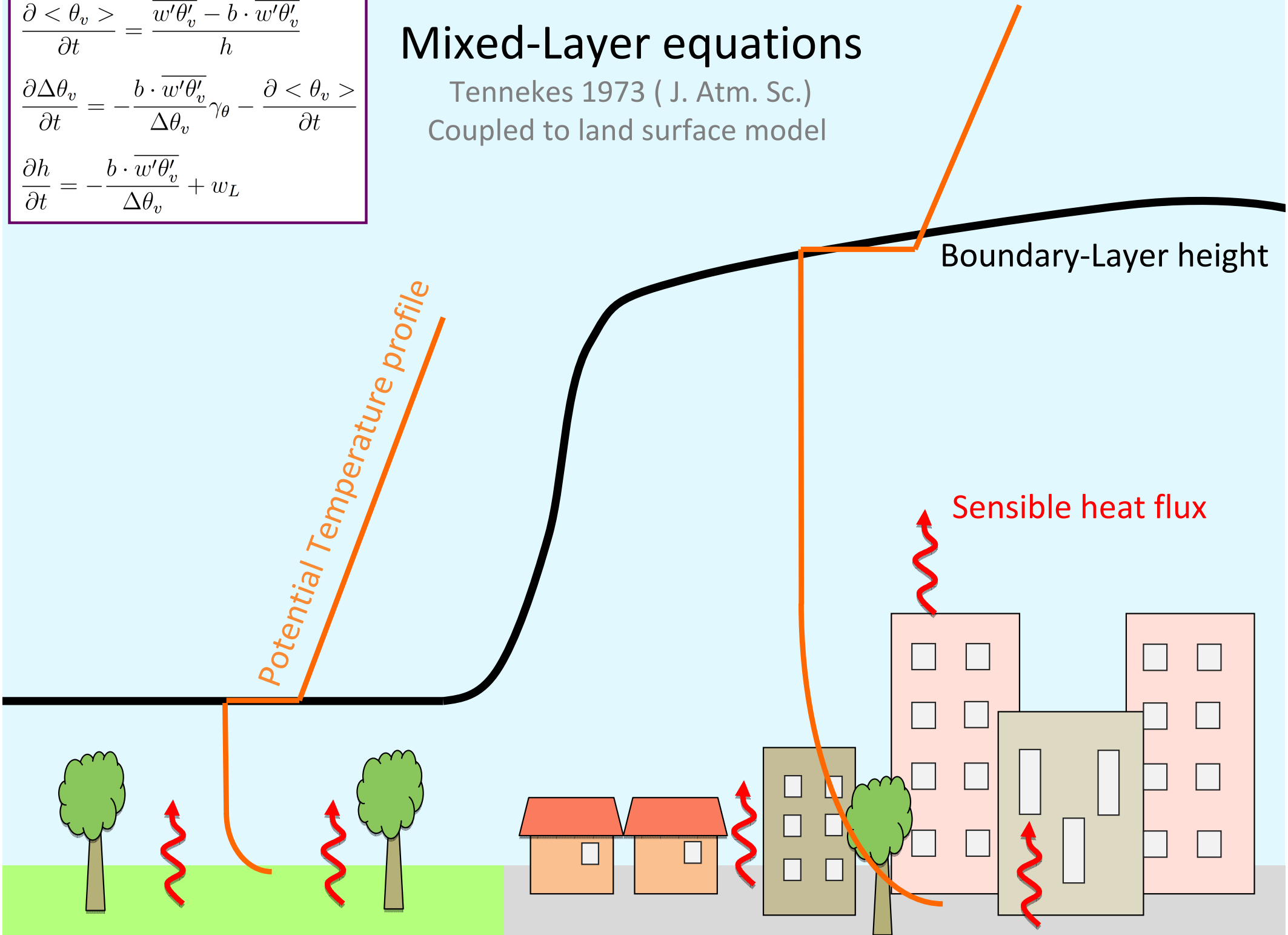
$$\frac{\partial \Delta\theta_v}{\partial t} = -\frac{b \cdot \overline{w'\theta'_v}}{\Delta\theta_v}\gamma_\theta - \frac{\partial < \theta_v >}{\partial t}$$

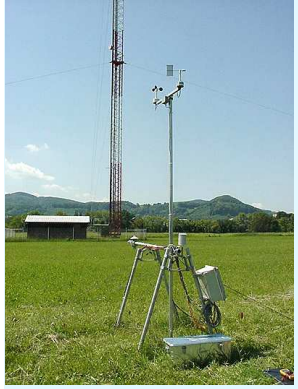
$$\frac{\partial h}{\partial t} = -\frac{b \cdot \overline{w'\theta'_v}}{\Delta\theta_v} + w_L$$

Mixed-Layer equations

Tennekes 1973 (J. Atm. Sc.)

Coupled to land surface model





BUBBLE observations

Rotach et al., 2005 (Th. Appl. Clim.)

Case based on 26 June 2002

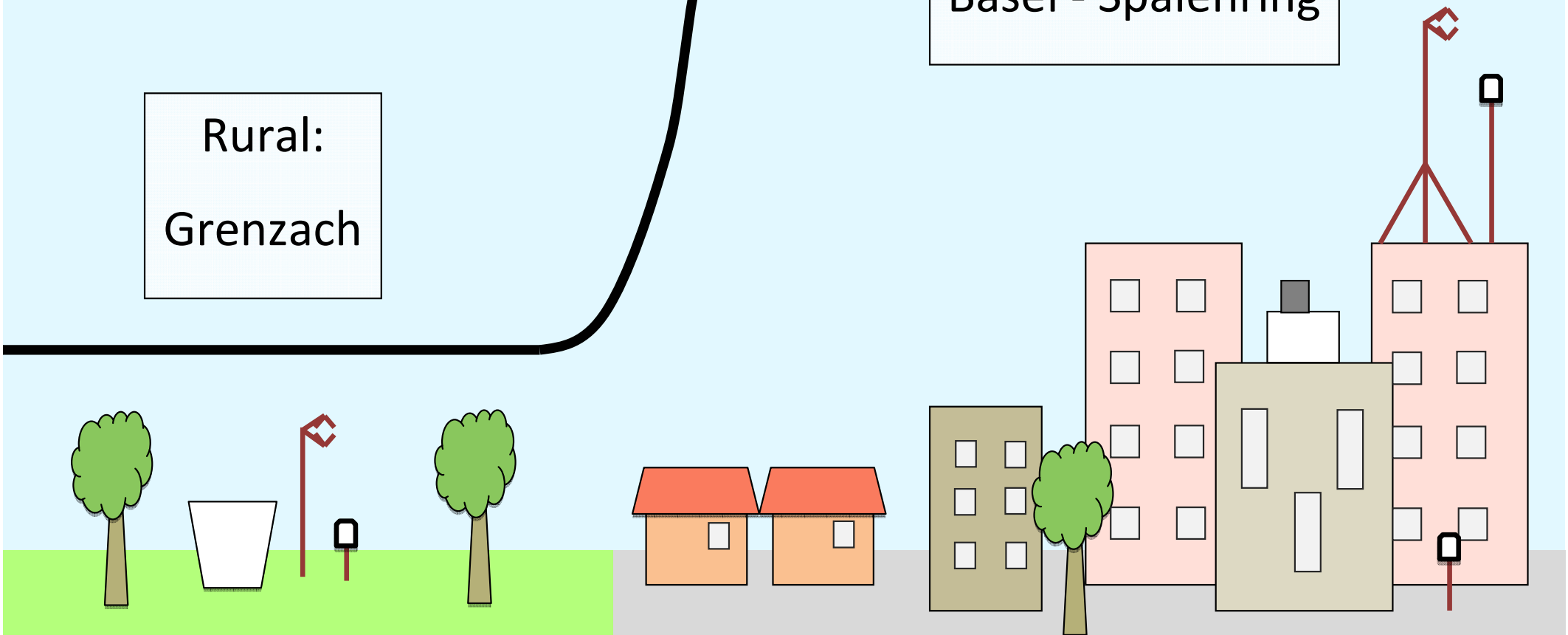
Boundary-Layer height

Urban:

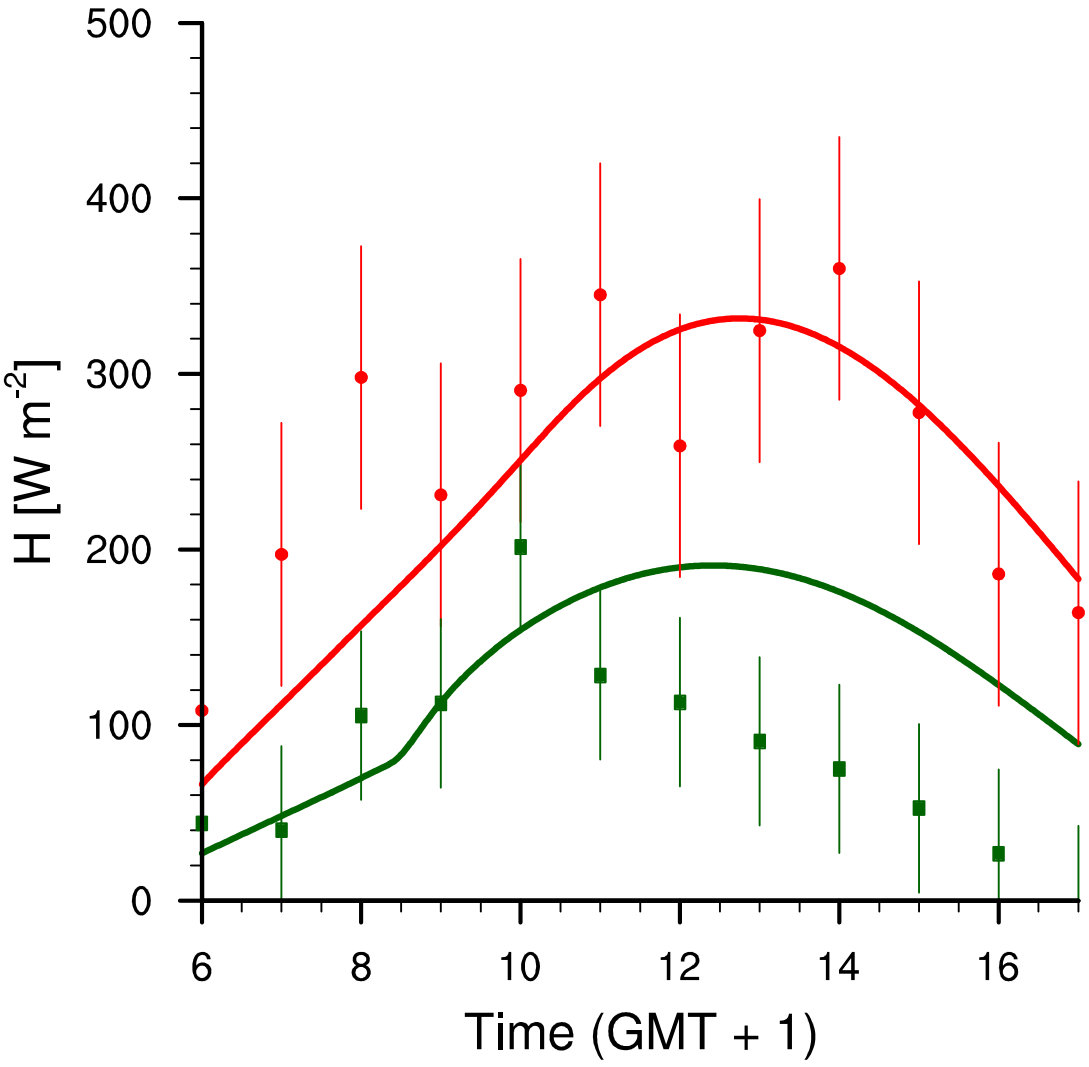
Basel - Spalenring

Rural:

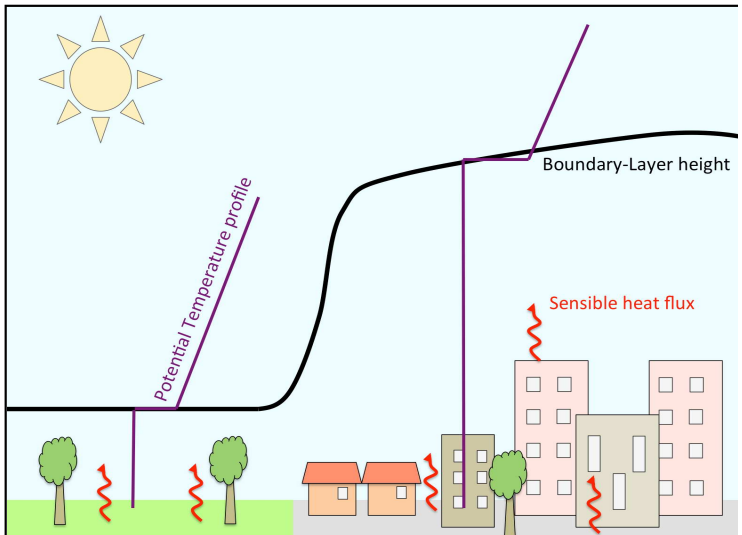
Grenzach



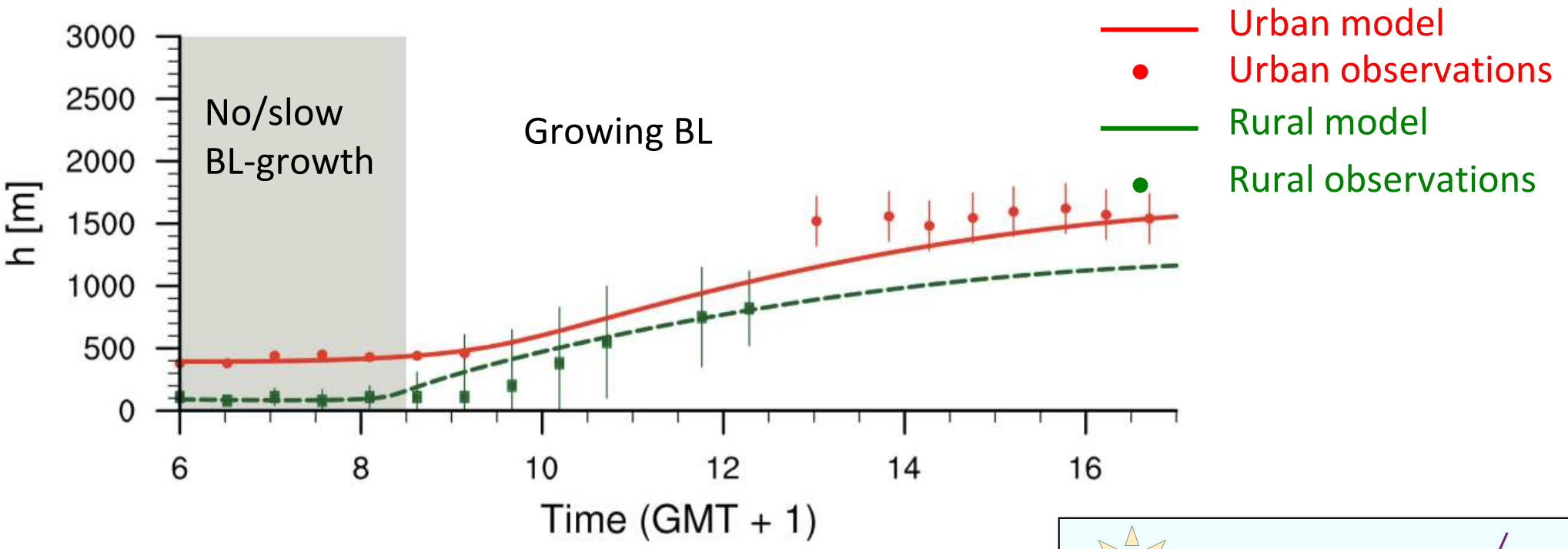
Results: sensible heat flux

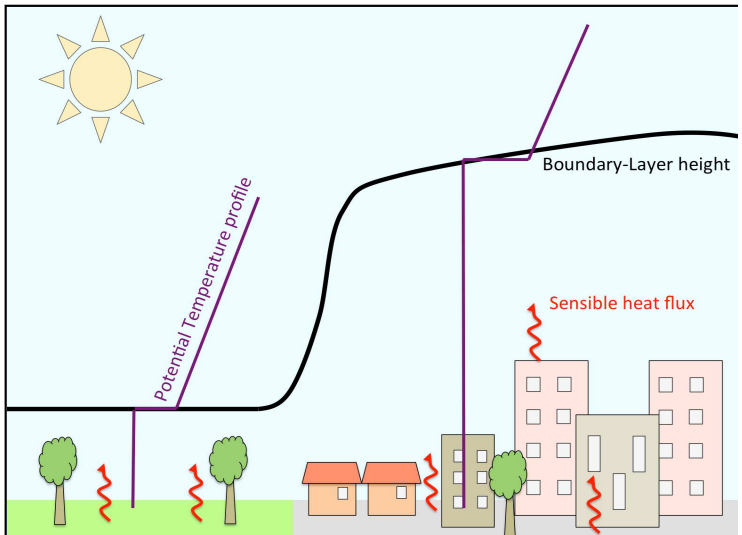


Urban model
Urban observations
Rural model
Rural observations

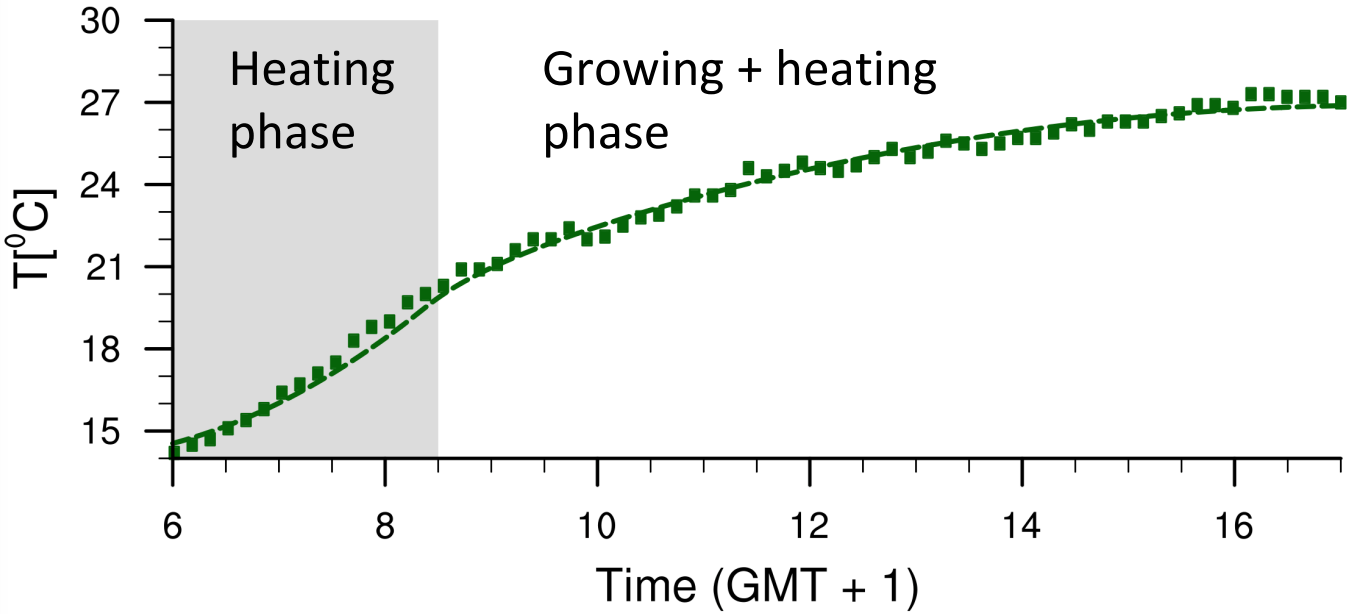


Results: boundary-layer growth

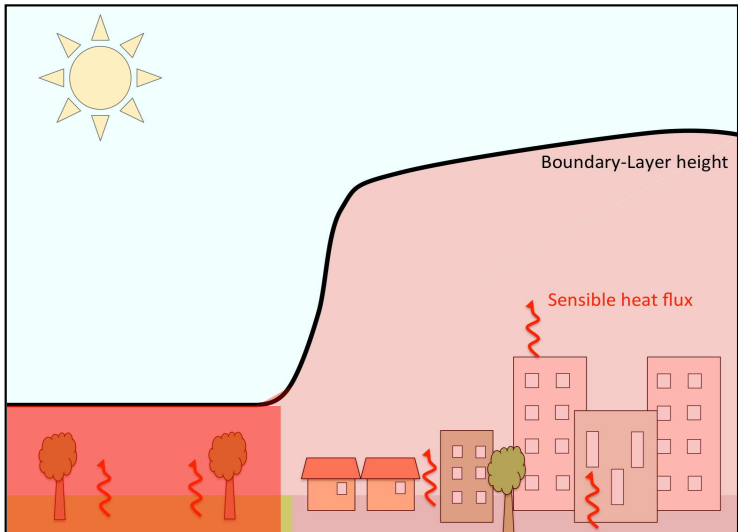




Results: temperature evolution



Urban model
Urban observations
Rural model
Rural observations



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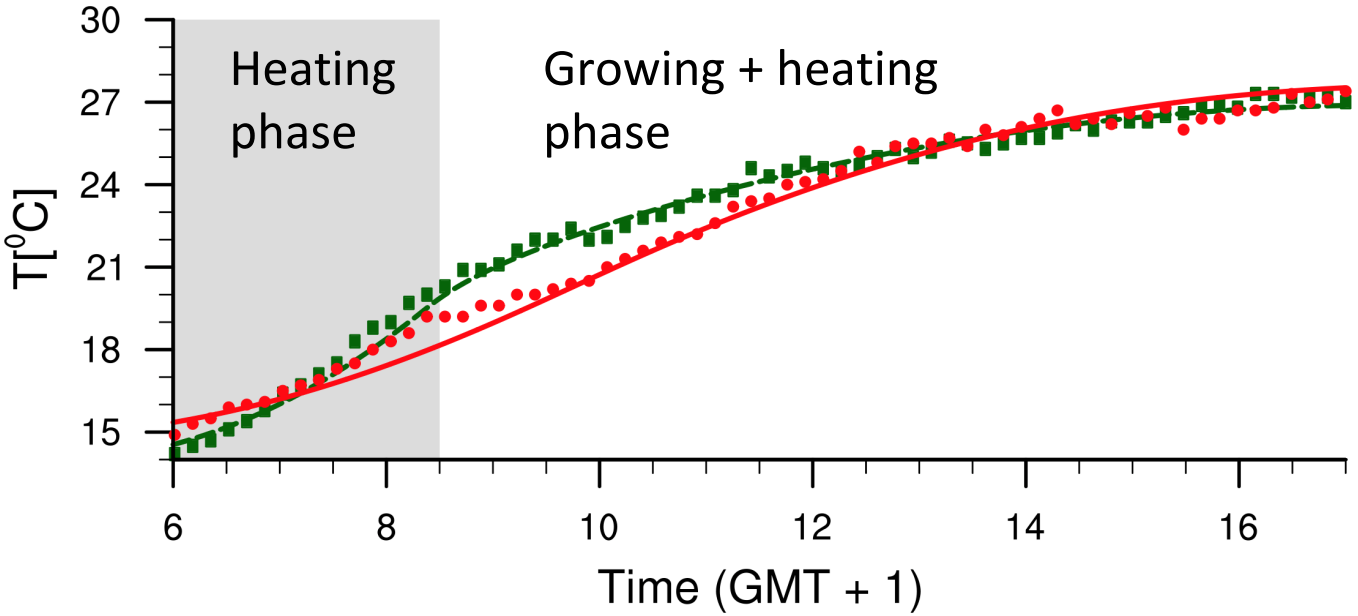

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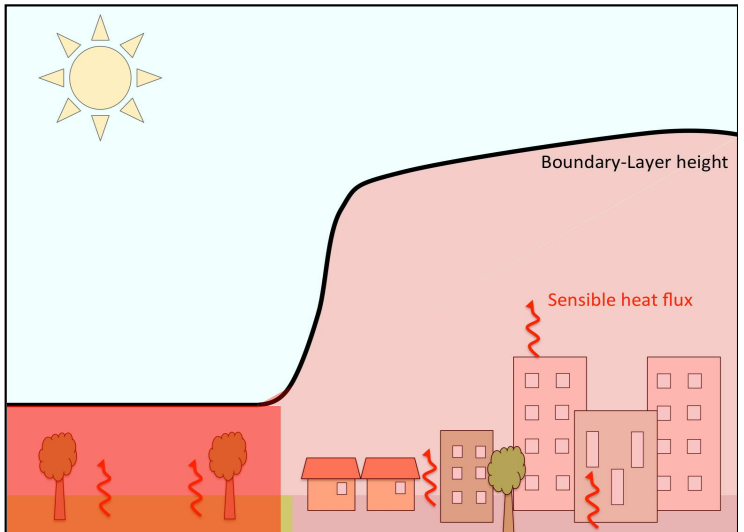

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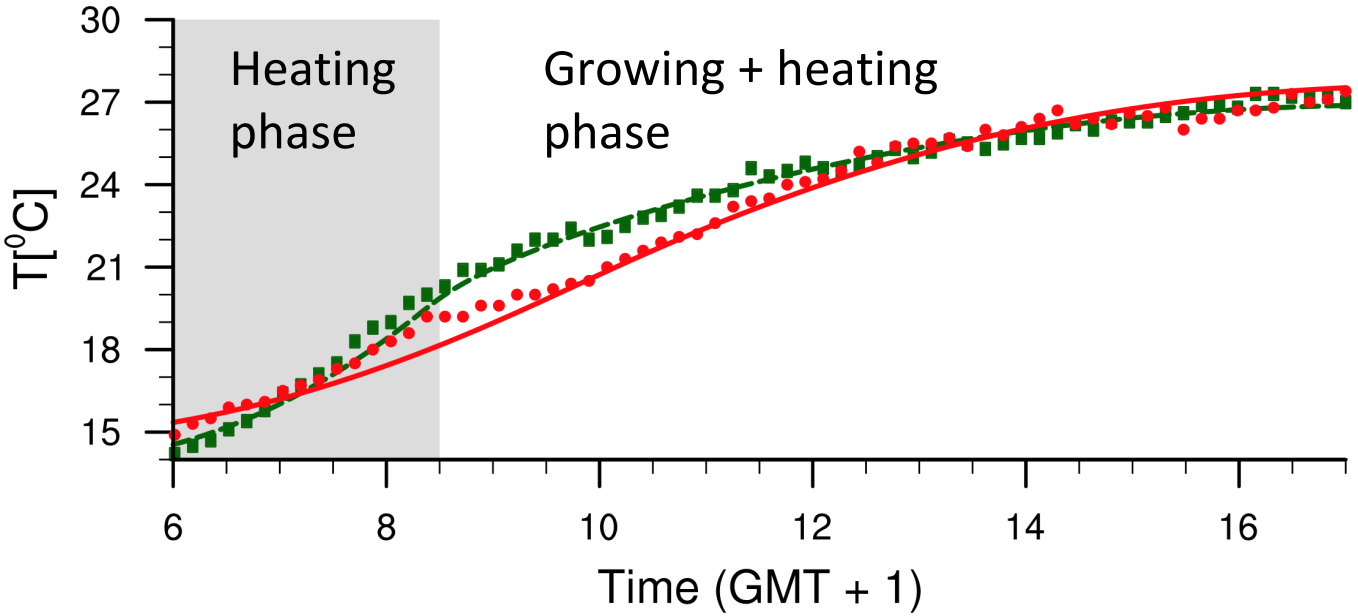

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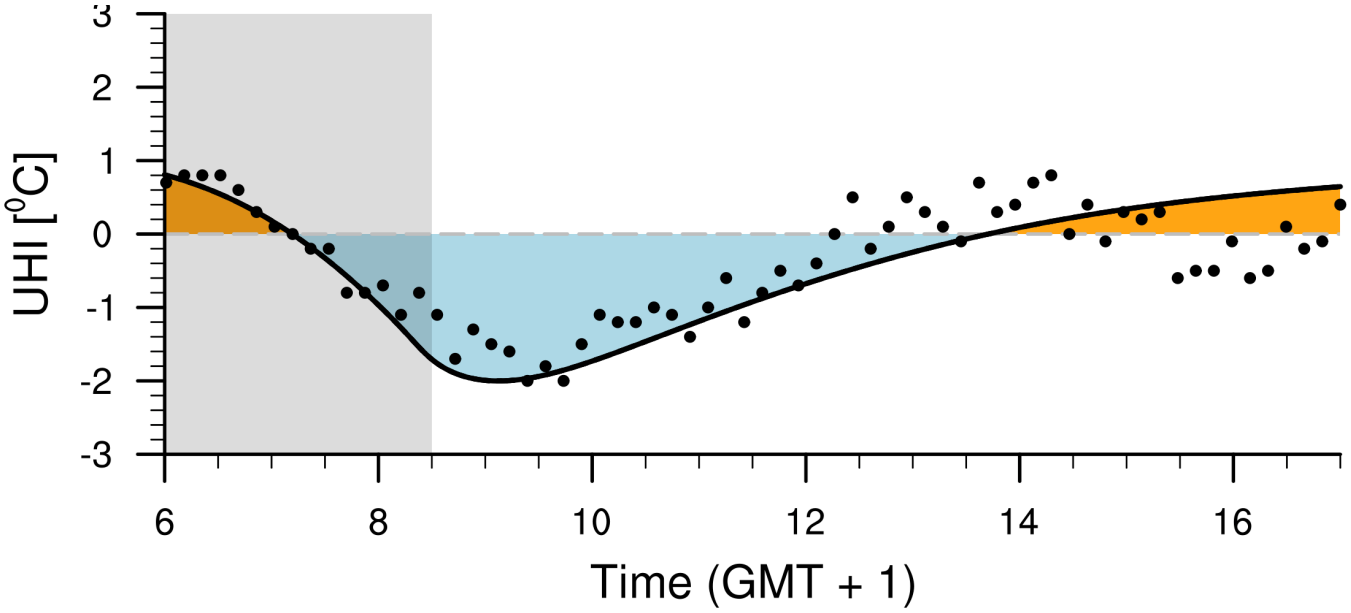

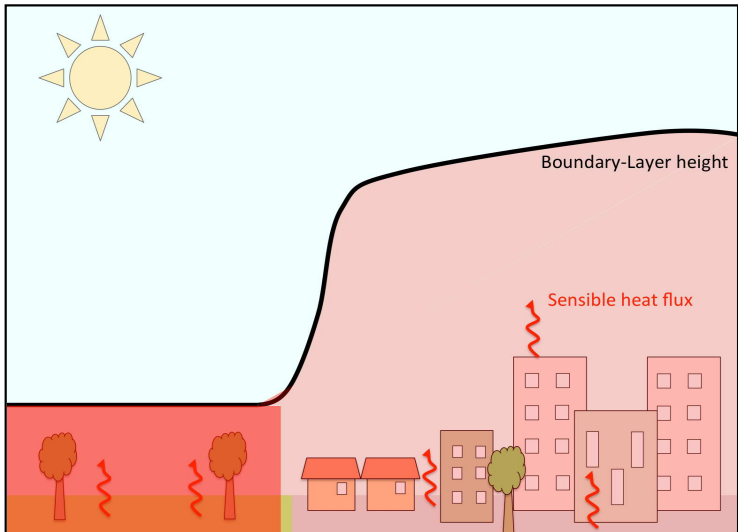

Sensitivity analysis

The urban cool island can be explained using different early-morning boundary-layer heights.

What is the UCI sensitivity to initial boundary-layer heights?

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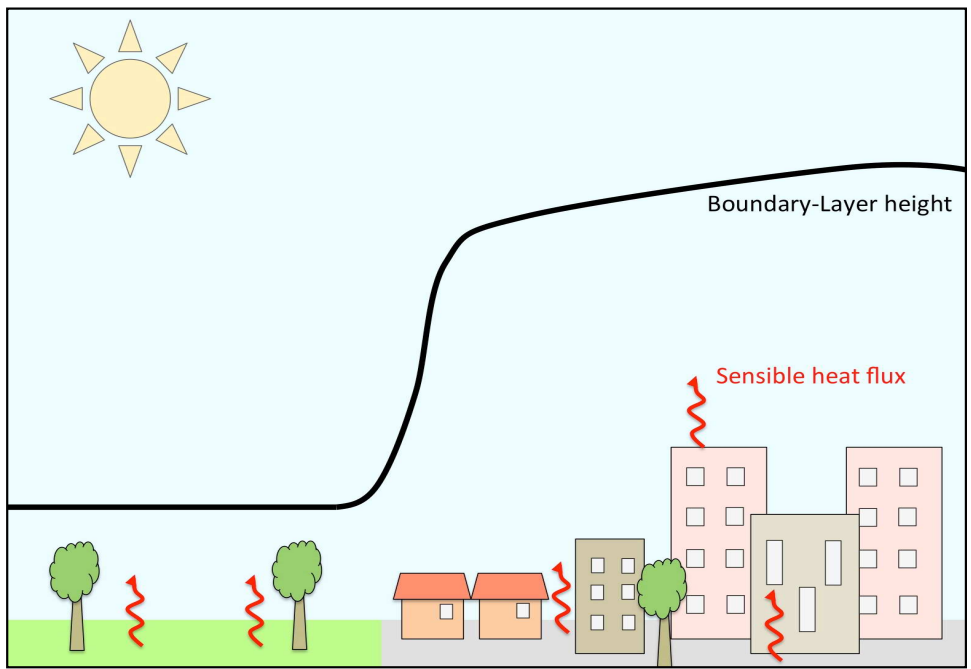
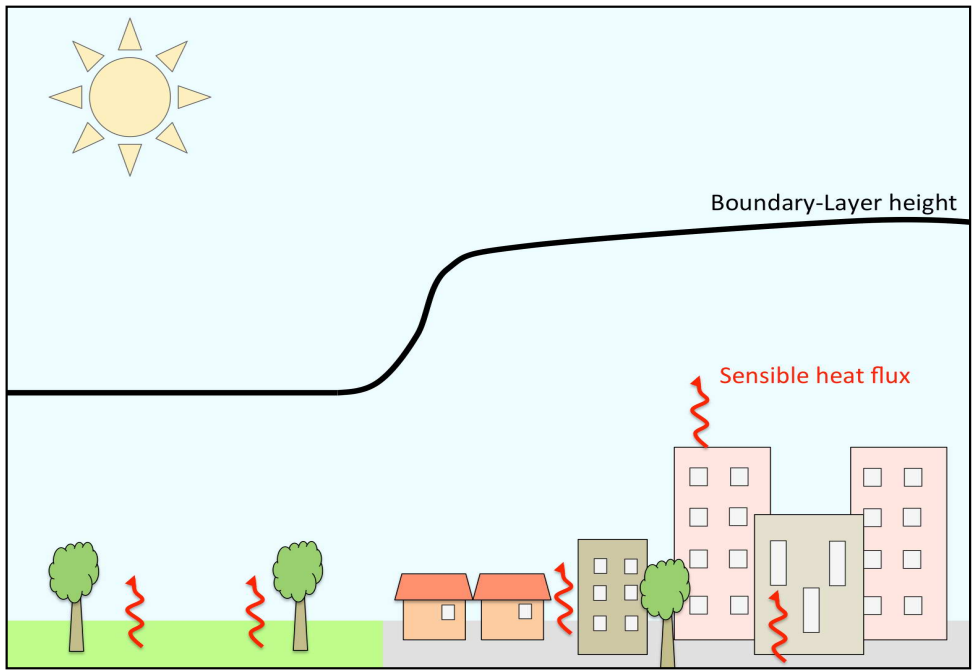
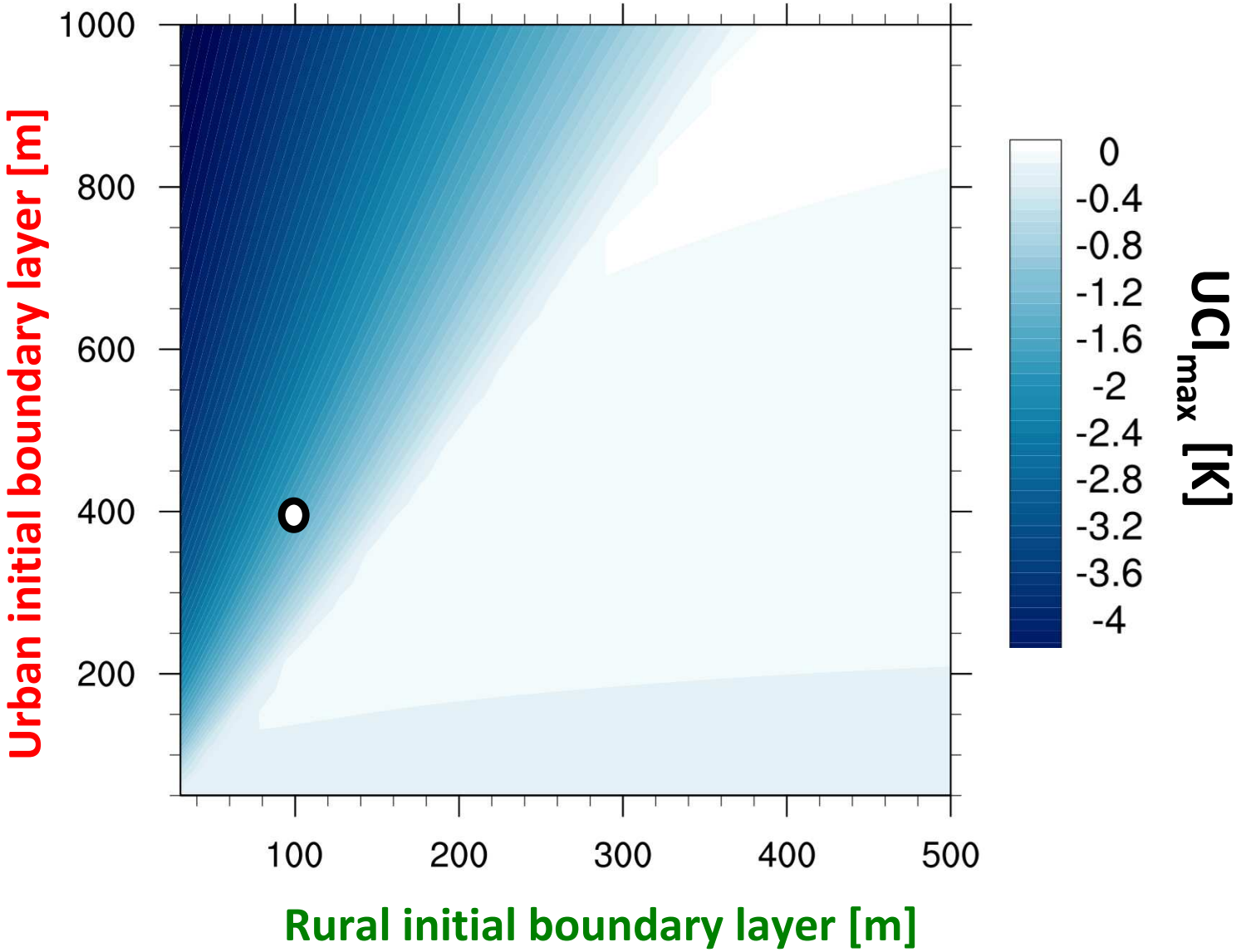




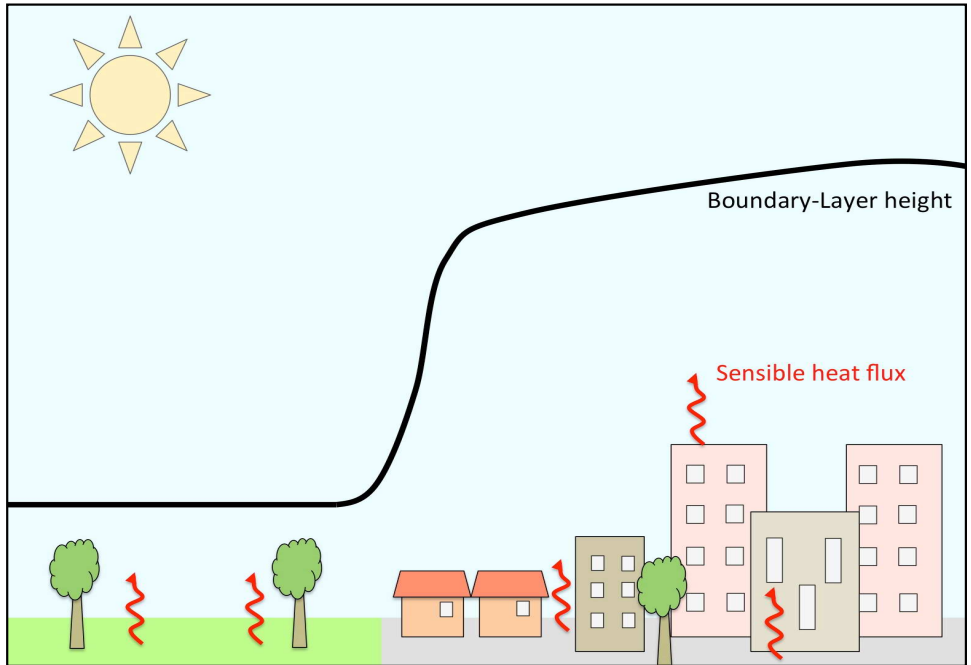
UCI and boundary layer height

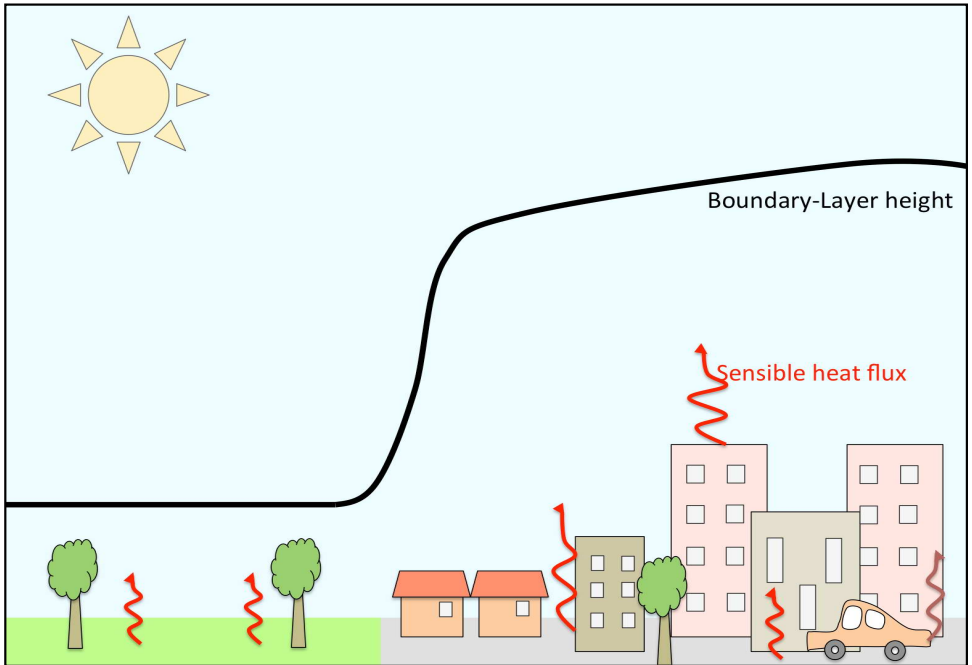


Sensitivity analysis

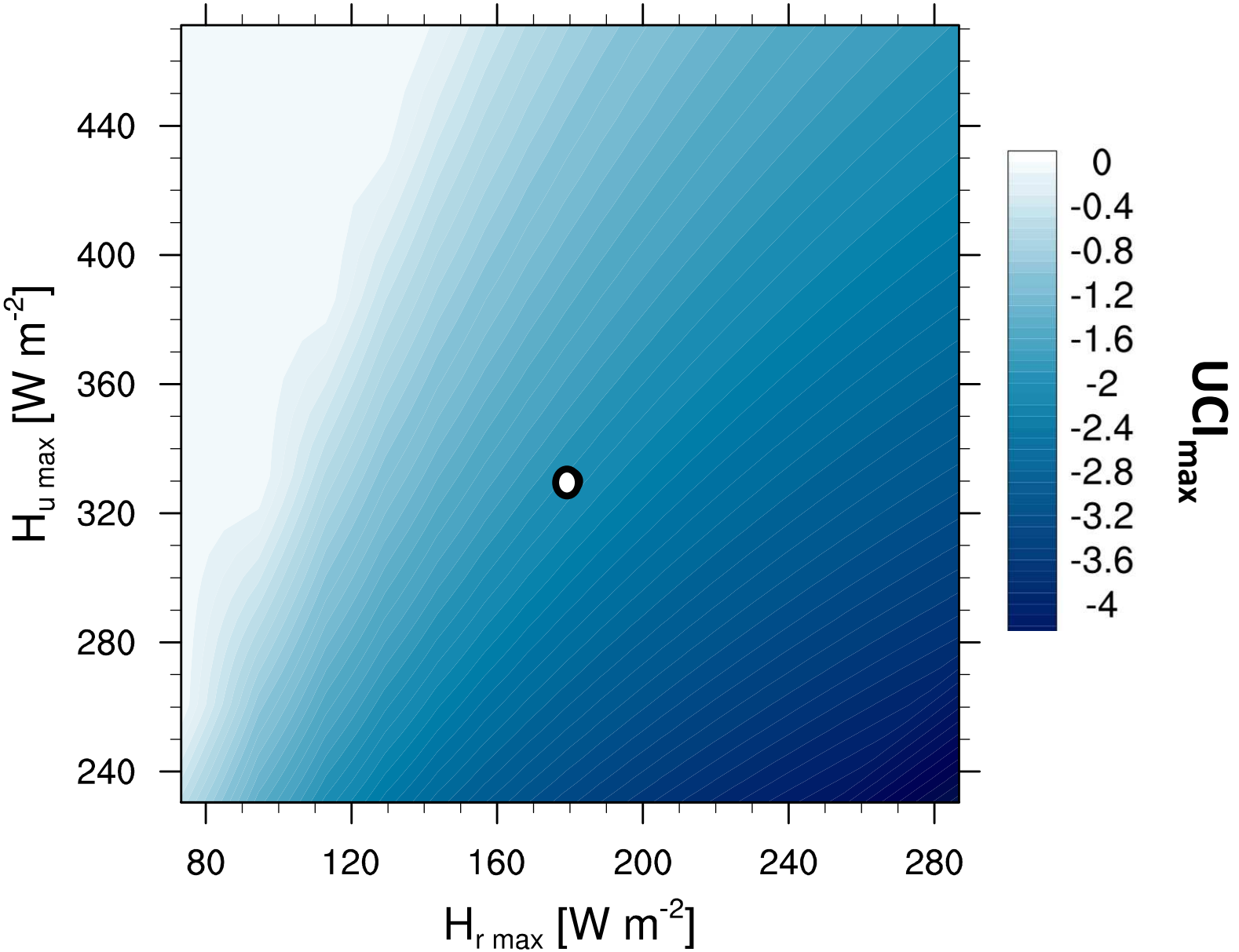
The urban cool island can be explained using different early-morning boundary-layer heights.

What is the UCI sensitivity to surface fluxes?





UCI and sensible heat flux



Conclusions

- Higher morning boundary layer over the city causes an urban cool island effect

- Important to take into account PBL in urban temperature studies

Theeuwes, N.E., G.J. Steeneveld, R.J. Ronda, M.W. Rotach, A.A.M. Holtslag 2015: Cool city mornings by urban heat, Environmental Research, 10 (11), 114022.