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General introduction to urban climate modelling

Leena Järvi

28 September 2022

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Lecture content

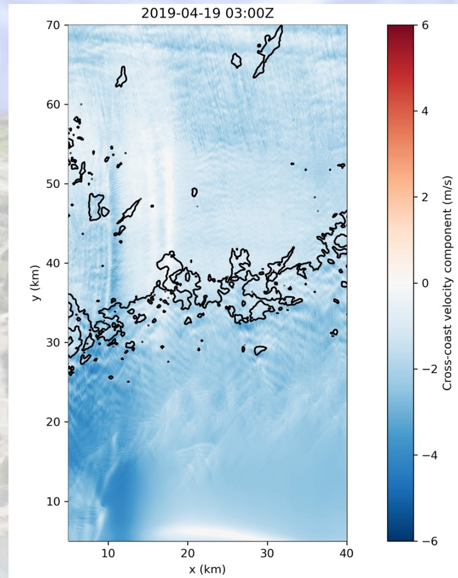
- Short introduction to me and urban meteorology group at the University of Helsinki
- Basics and scales of urban climate modelling
- Short introduction to land surface (LS) models
- Input data needed in urban climate modelling
  - Urban form
  - Urban function
  - Meteorological forcing data

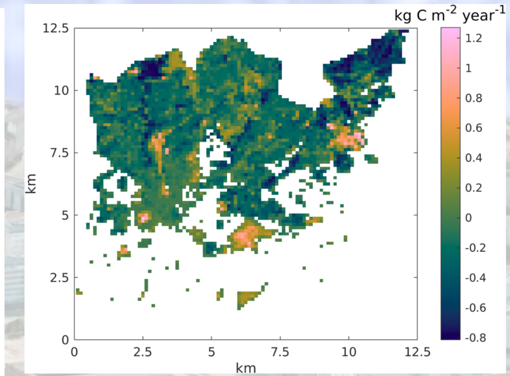
Short introduction to me and Urban meteorology research group at UHEL

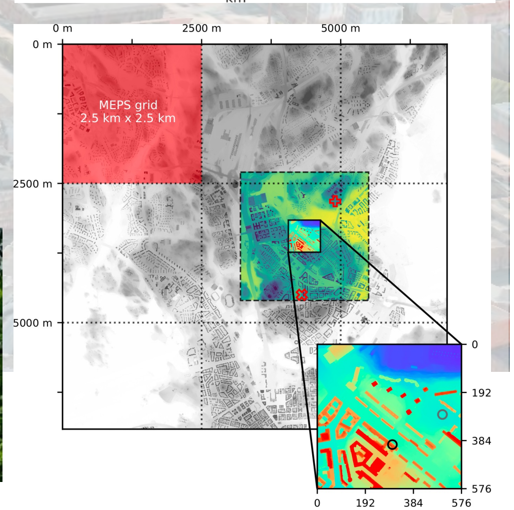
- Professor in urban meteorology
- Leader of urban meteorology research group
  - 3 postdocs, 6 doctoral researchers and 3 undergraduate students
- Research is applied with close collaboration with decision makers and city planners
- Projects multidisciplinary together with forest, social and computer scientists, landscape architects and traffic planners

Wide range of research topics

- How urban surface affects surface-atmosphere exchanges of momentum, heat, CO_2, aerosols, COS, VOC,…
- Coastal city boundary layer turbulence
- AI to reduce traffic related air pollutant and CO_2 emissions
- CO_2 sequestration of urban green areas (together with other socio-physical effects)







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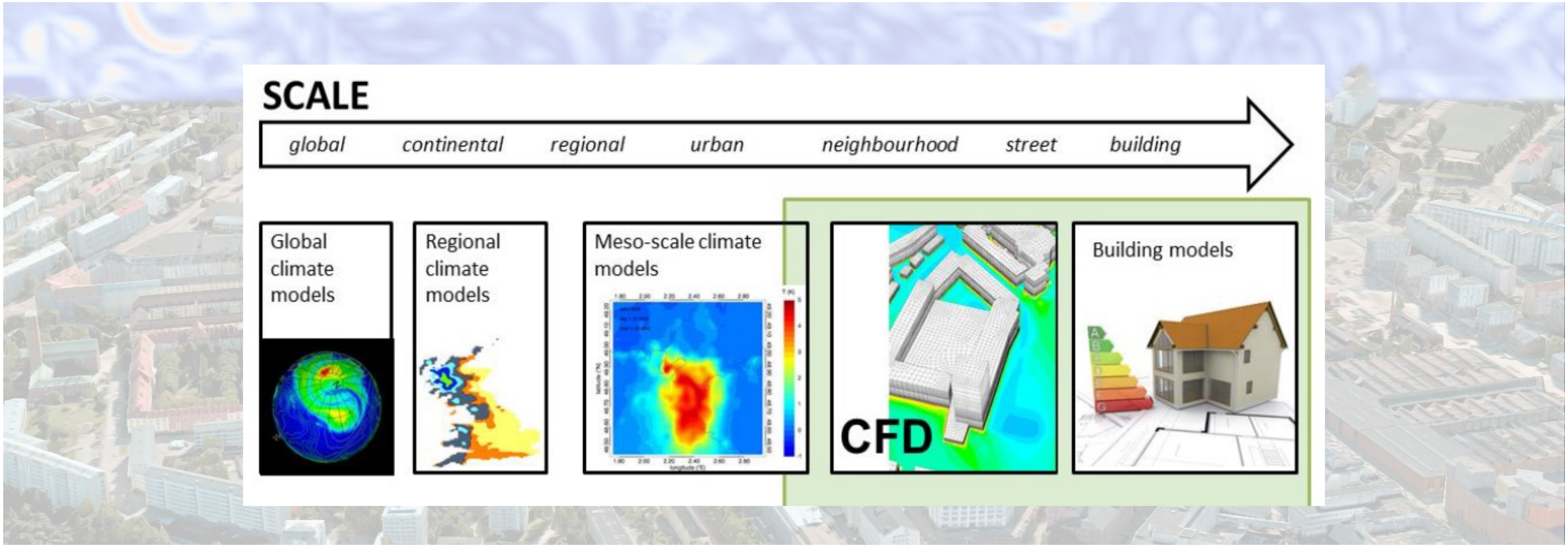
Modelling scales in the atmosphere



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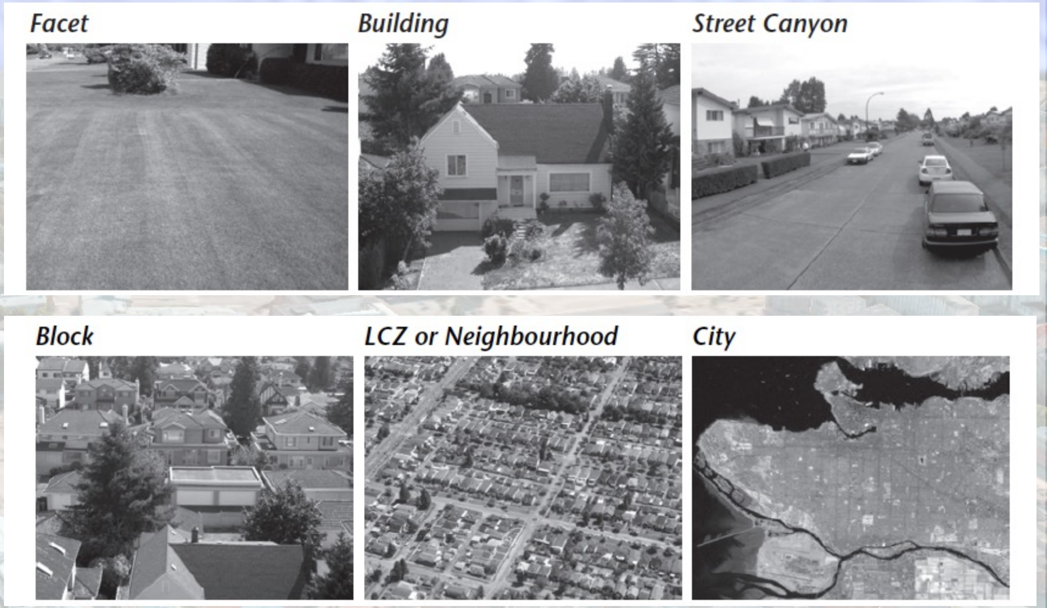
Modelling of urban climate

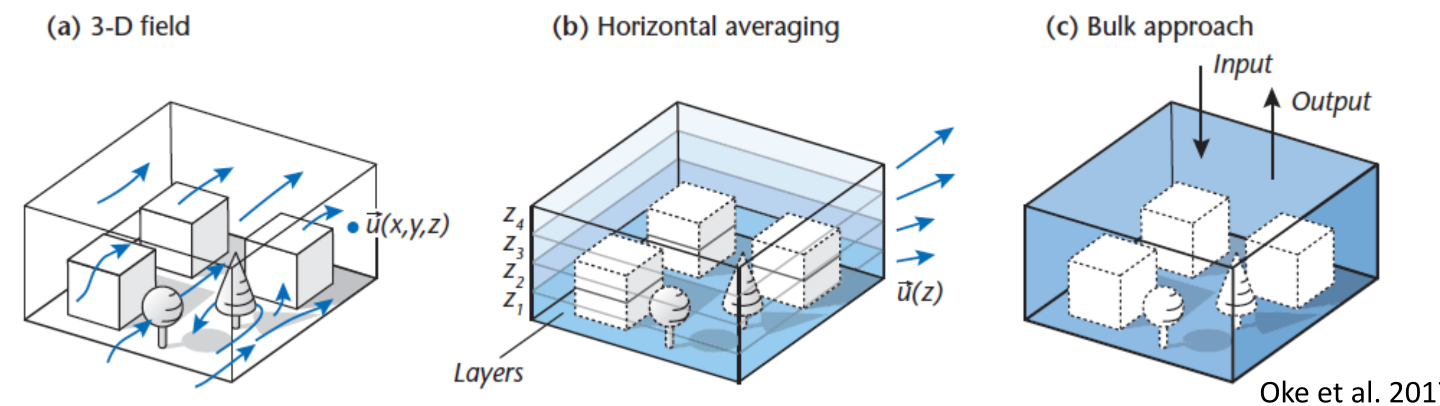
- Multi-scale nature of urban climate creates challenges
- Your scale of study needs to be fit for the phenomenon of interest
  - Interested on urban boundary layer? Not possible to use models (or observations) from UCL
  - Interested on flow around a single building? Cannot use larger scale (mesoscale) models



Oke et al. 2017

Modelling of urban climate

- Challenge 3D structure and dependency on location (several active layers!)
- Can and often needs to be simplified



Oke et al. 2017

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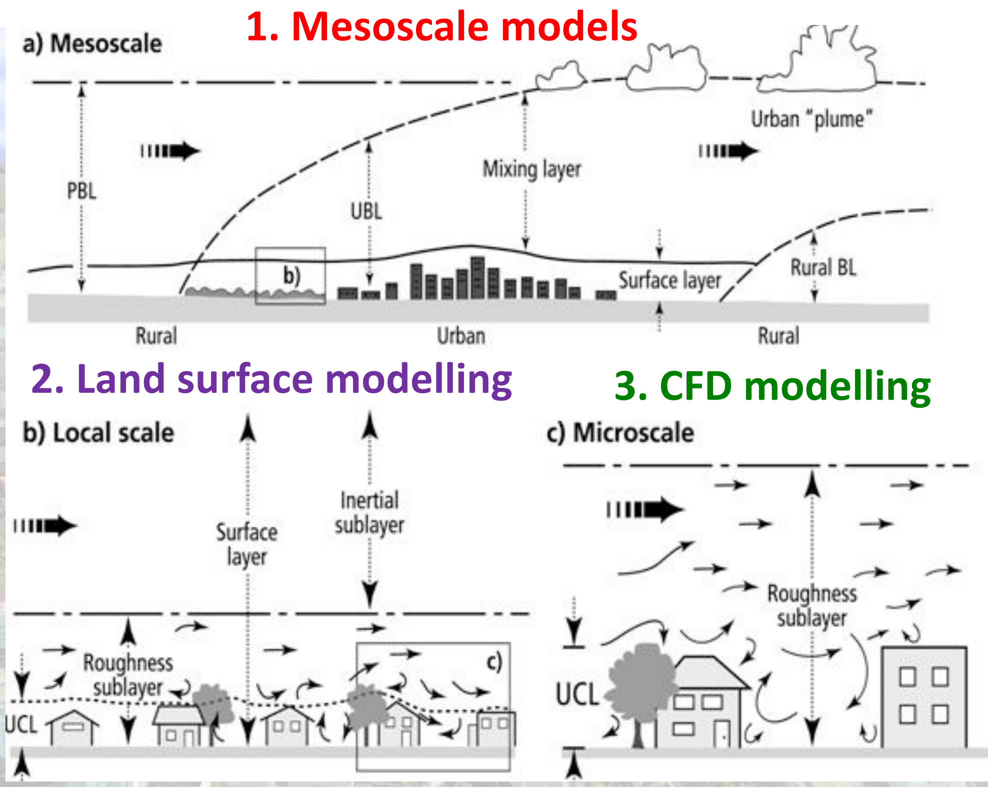
Overview of urban scales



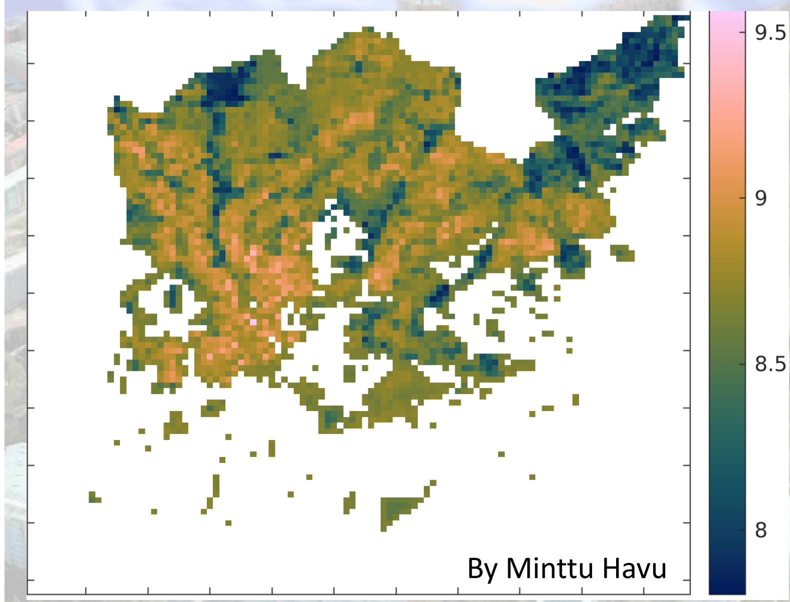
Oke, 2004

Different climate components:

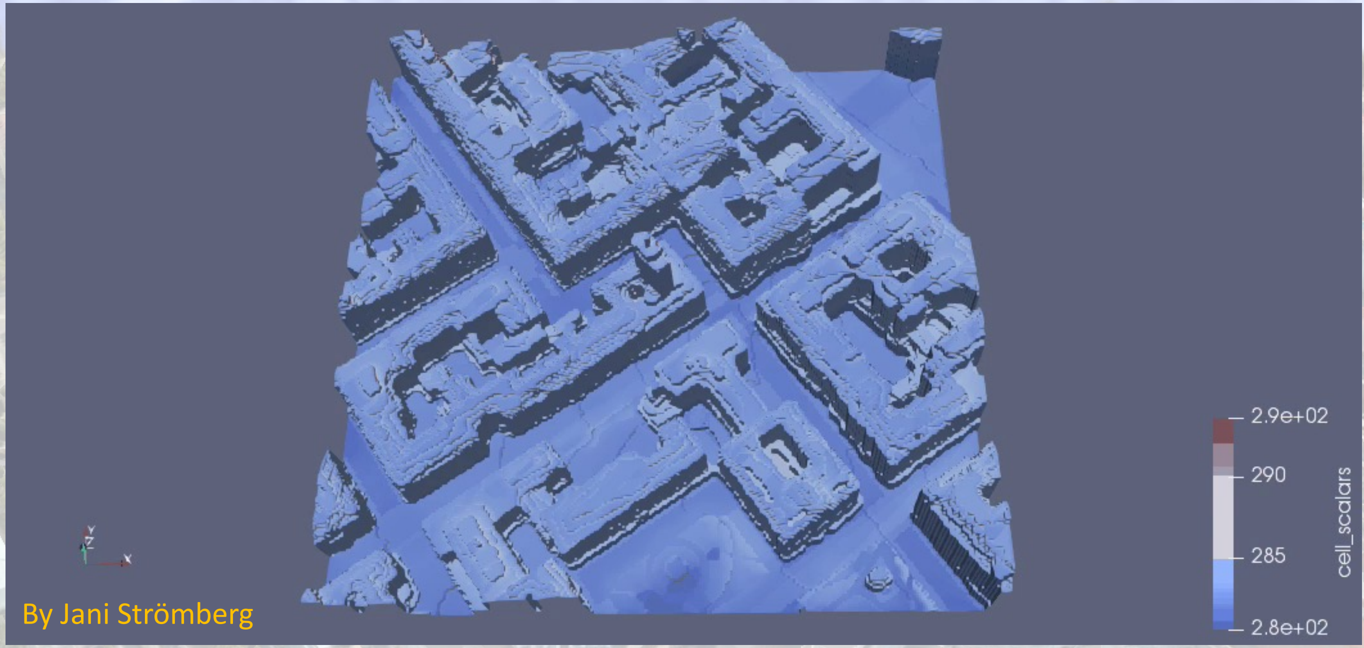
- Urban heat island
- Air quality
- Hydrological cycle
- Turbulence
- Radiation effects
- ….

Example on scale – temperature variability in Helsinki, Finland

Mean 2 m air temperature in Helsinki in2019

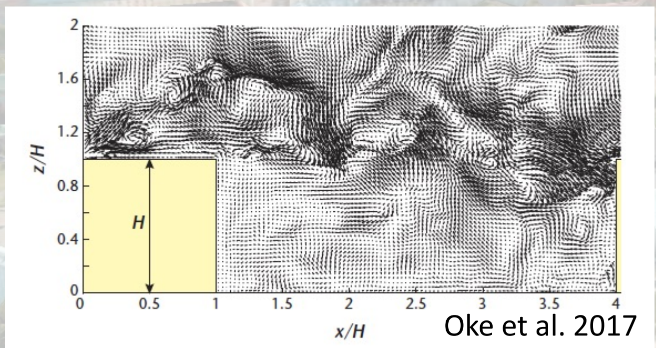


Surface temperature in Helsinki city centre at 8 – 10 am in 9 June 2017



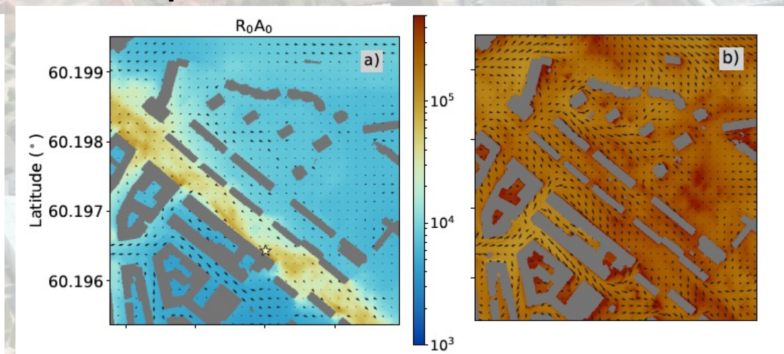
Urban modelling at the micro-scale

- Solving the impact of individual obstacles
  - Thermal comfort
  - Flow
  - Energy use
  - Air quality



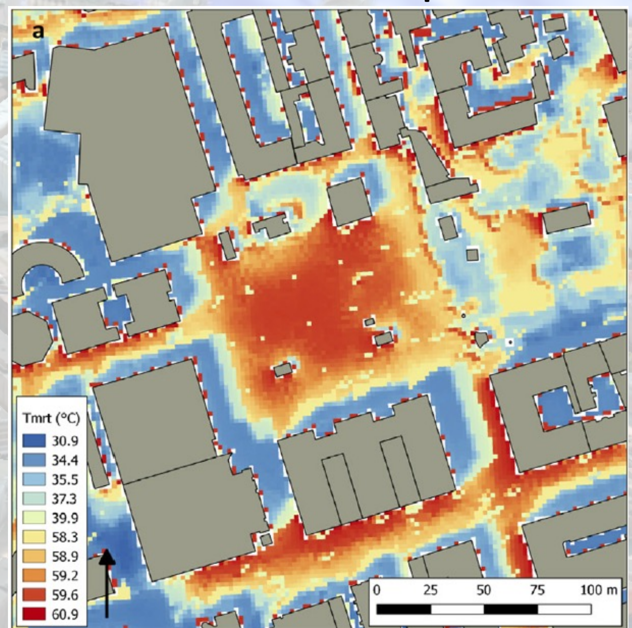
Oke et al. 2017

Aerosol particle number **2 m air temperature**



Strömberg et al. 2022

Mean radiant temperature



Lindberg et al. 2017

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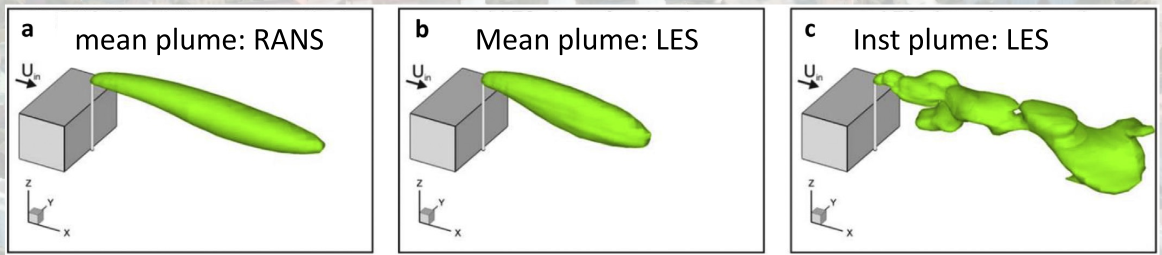
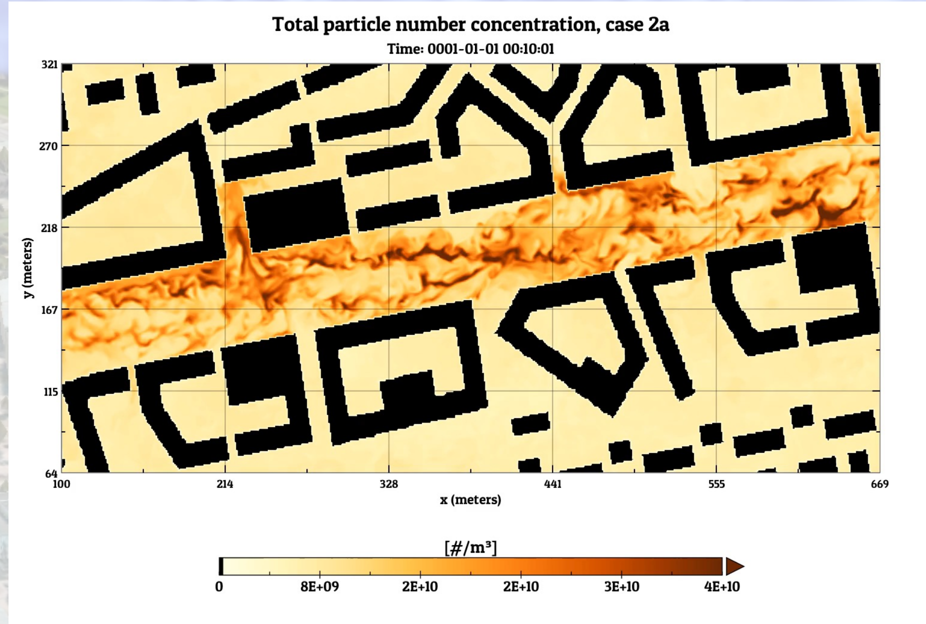
CFD = Computational fluid dynamics

- RANS (*Reynolds Averaged Navier-Stokes*) – mean flow solved in Navier-Stokes-equations
- LES – Solves also turbulence in the grid scale but parameterizes the sub-grid scale turbulence



Tominaga & Stathopoulos 2016



By Sasu Karttunen

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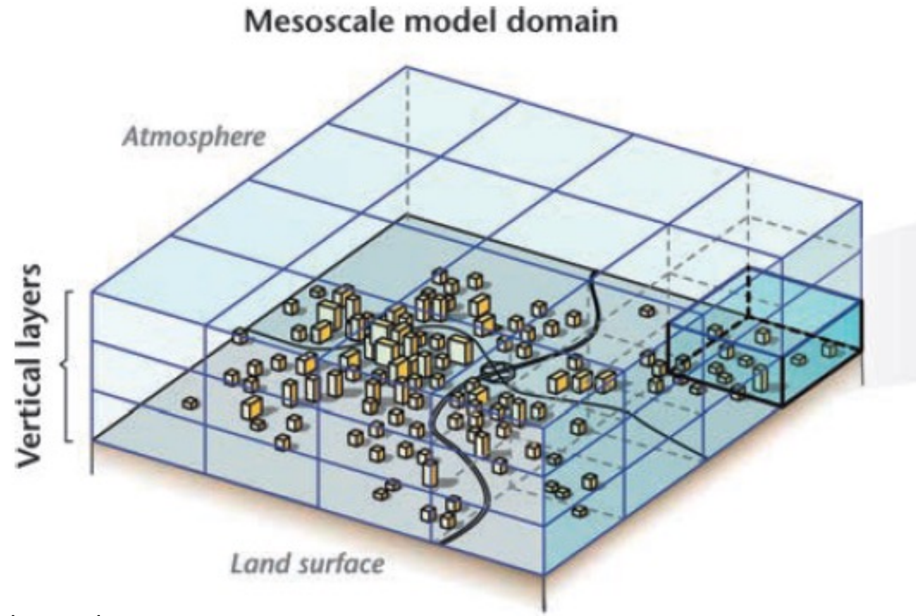
Mesoscale models – city-scale modelling



Oke et al. 2017

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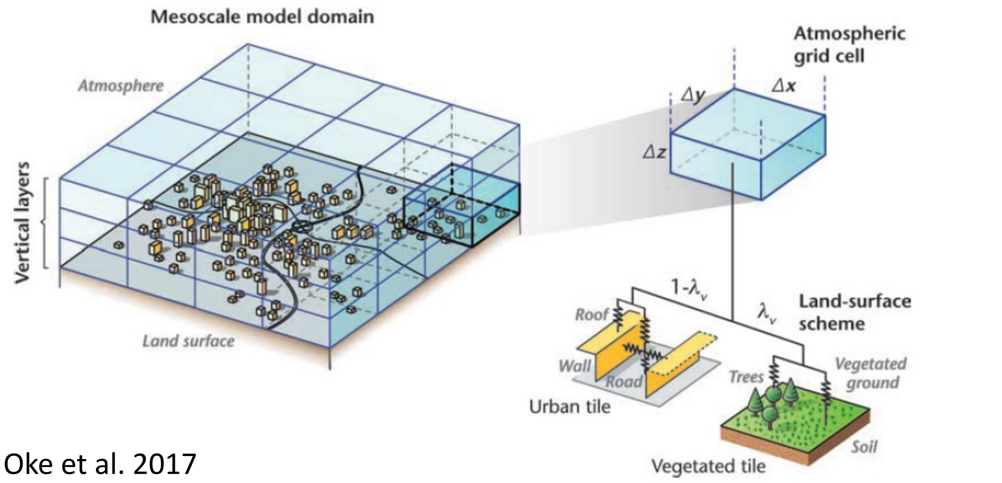
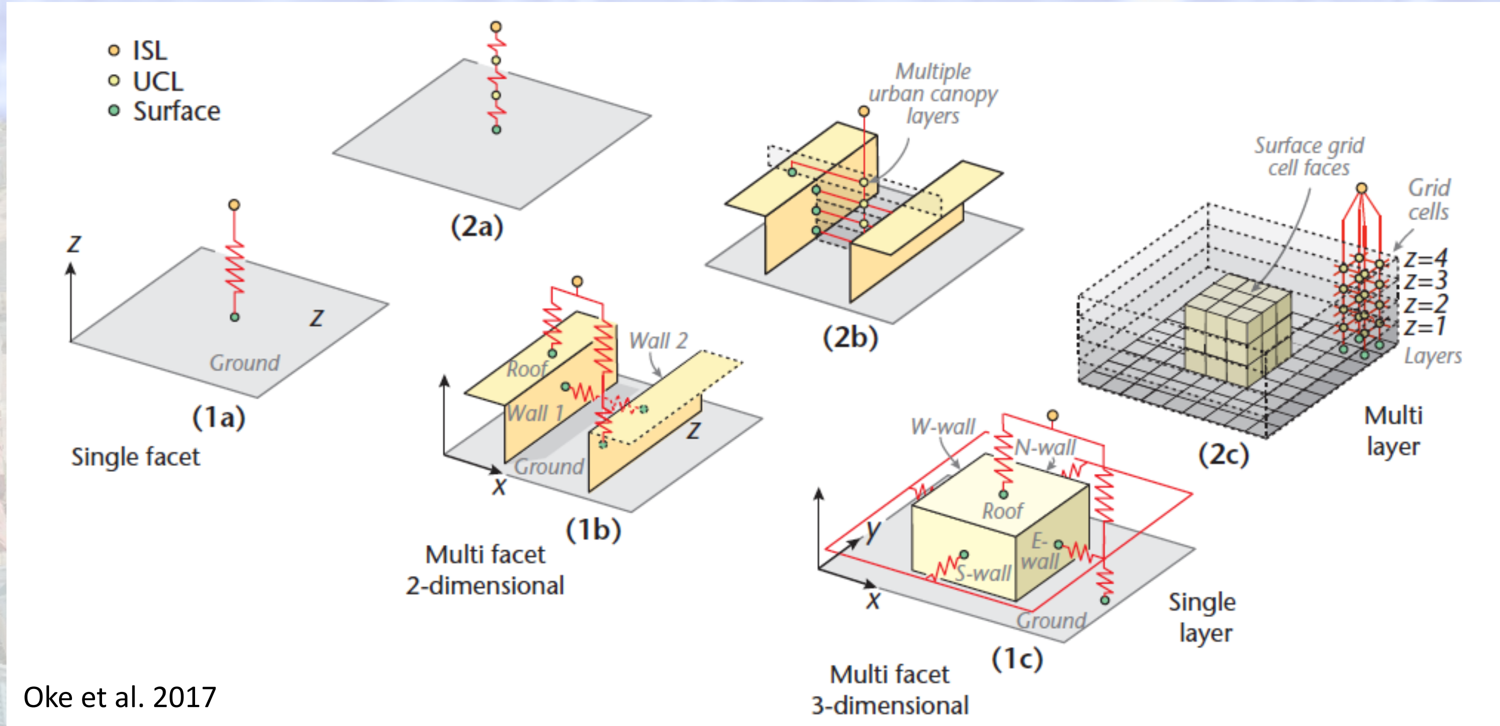
Land surface (LS) schemes give surface forcing to the atmosphere

- Fluxes of momentum, water and energy (and CO_2)
- Give lower boundary conditions for weather prediction, AQ and climate models
- Can be used independently as urban ecosystem or hydrological models

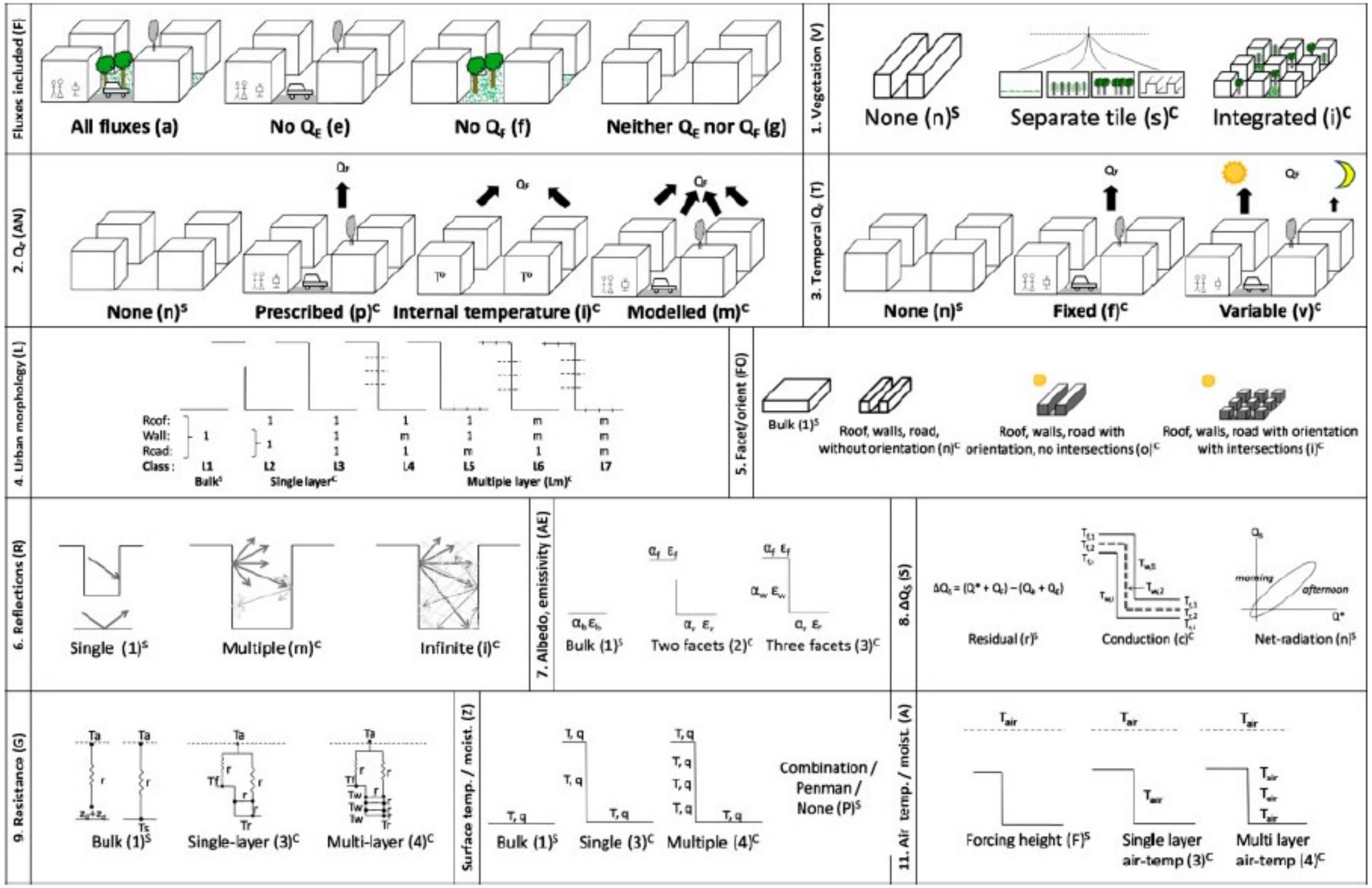


Oke et al. 2017

Complexity of local-scale LS schemes/surface energy balance models



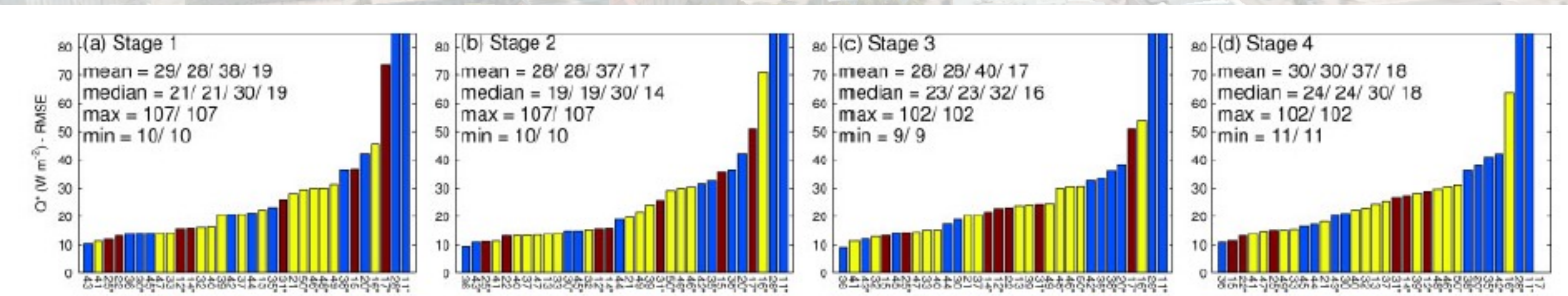
Oke et al. 2017



Grimmond et al. 2010

Model inter-comparison shows a wide range of model performances

- 32 LS schemes evaluated
- Offline-mode
- Increasing details of the site characteristics
- Large variety between the different models



Grimmond et al. 2011.

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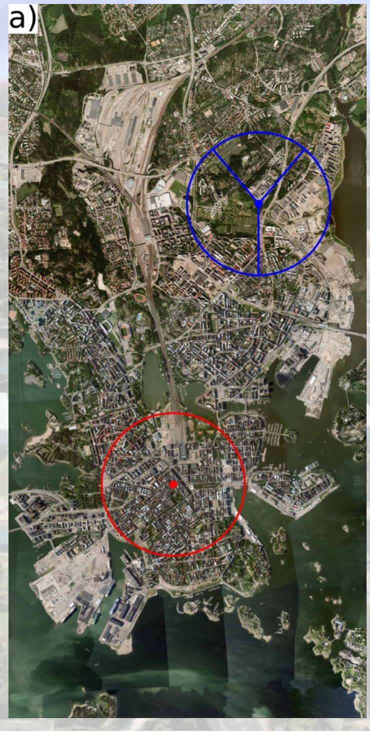
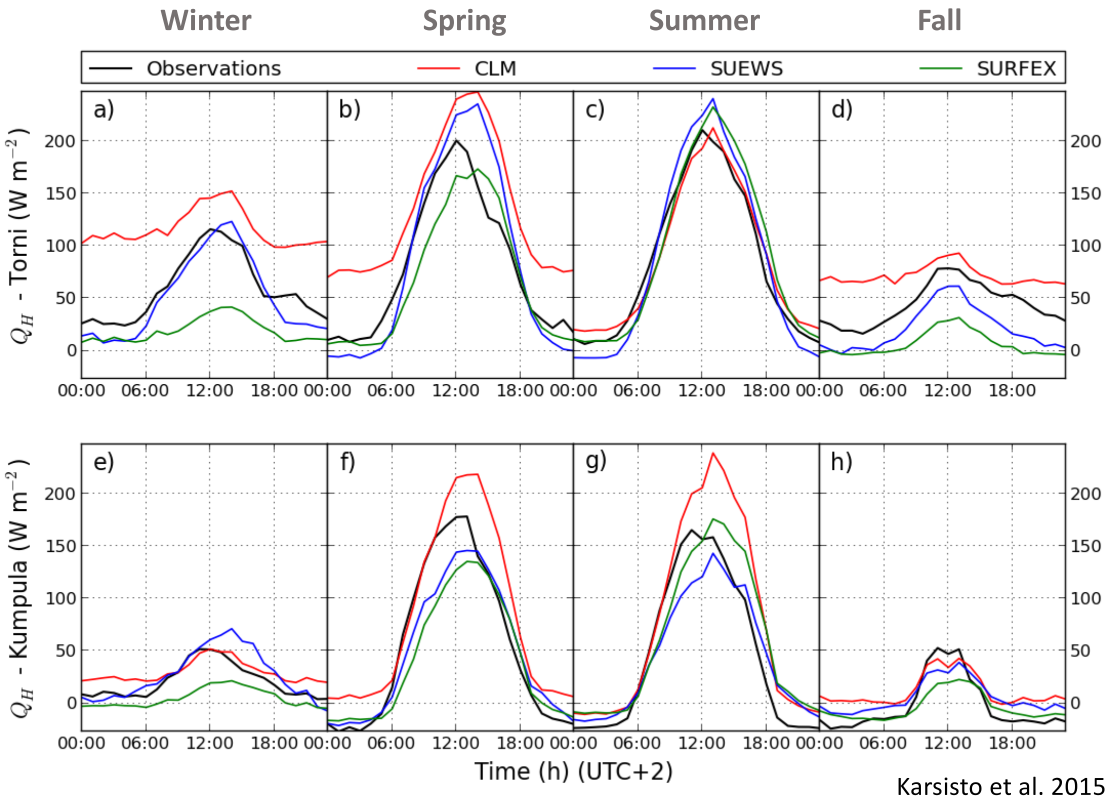
Example on modelling sensible heat flux in Helsinki

Simulation:

- July 2011 – Dec 2012
- 2012 used in evaluation
- 1 km radius circle
- Hourly time step
- Same forcing data
- Real surface cover fractions (2 m resolution)
- Q_H from eddy covariance observations





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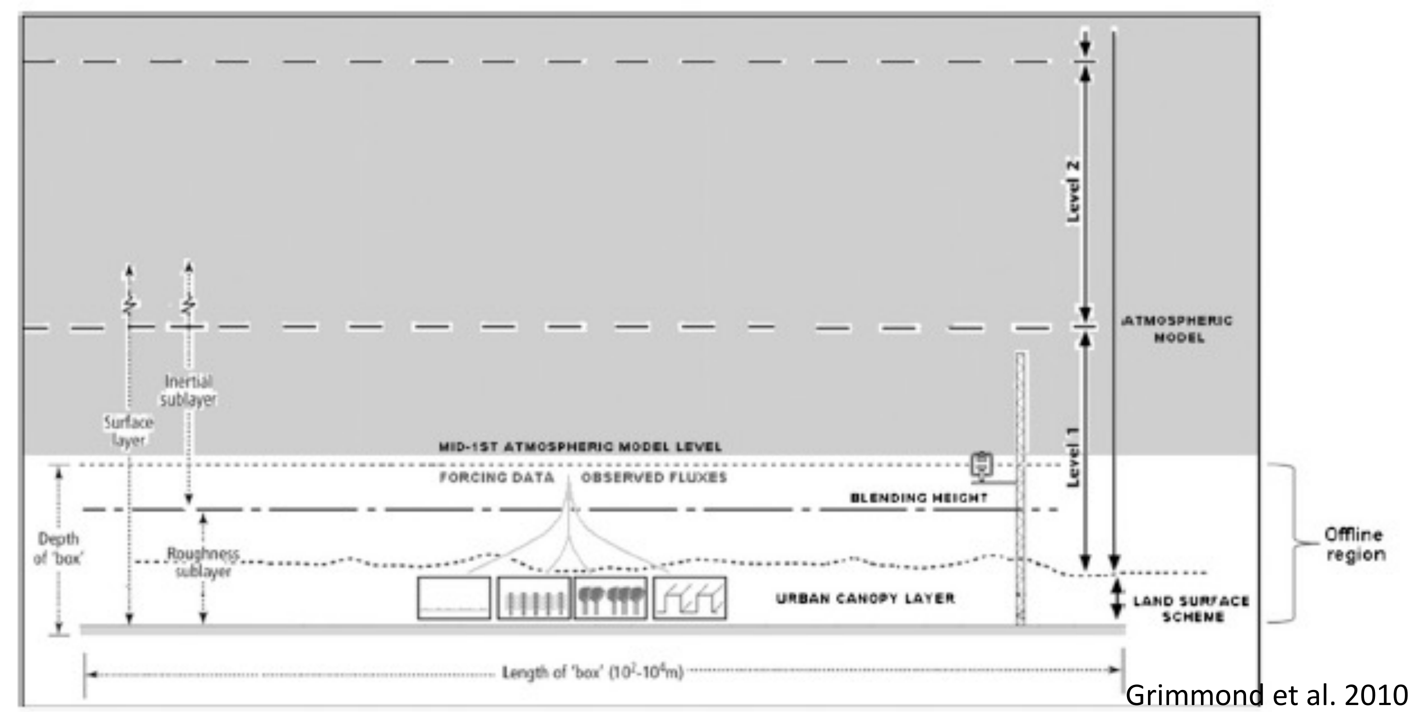
What do you think is causing the overestimation by CLM in winter?

LS models can be run coupled to mesoscale model or offline as standalone



Grimmond et al. 2010

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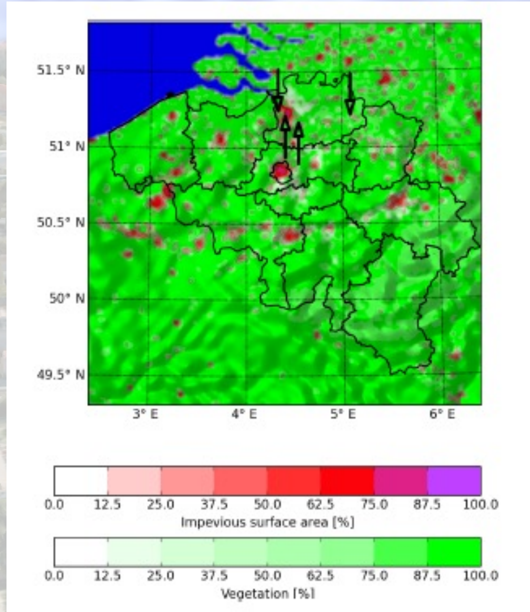
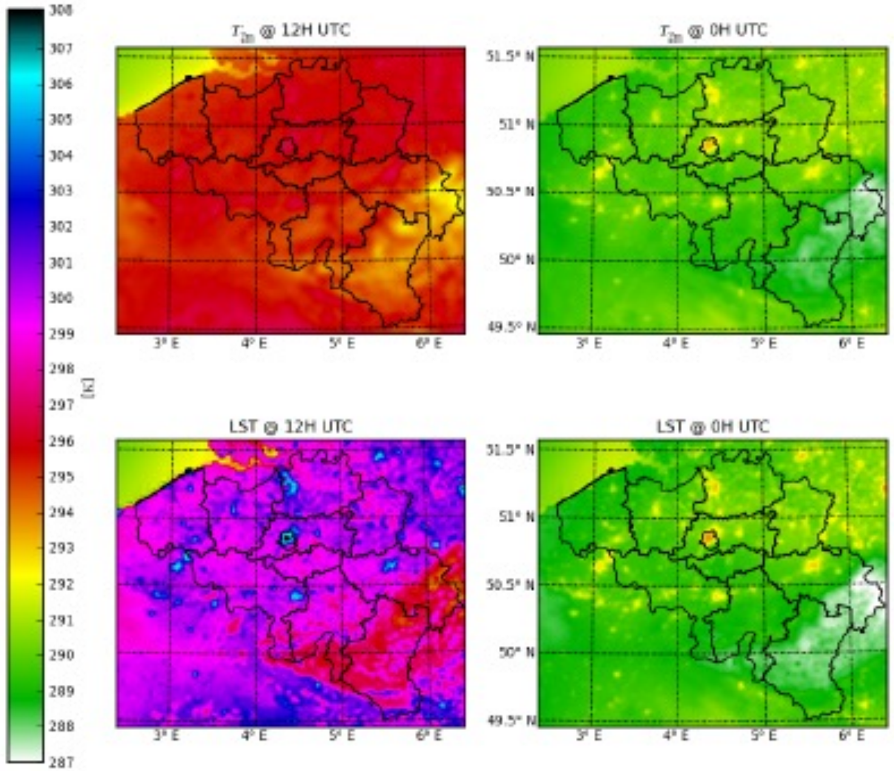
Example of modelling UHI using online coupled model COSMO - CLM

- 2.9 km resolution
- 175x175 grids
- 40 vertical layers
- Lateral boundaries from ECMWF
- LS scheme TERRA_URB + SURY





Wouters et al. (2016)

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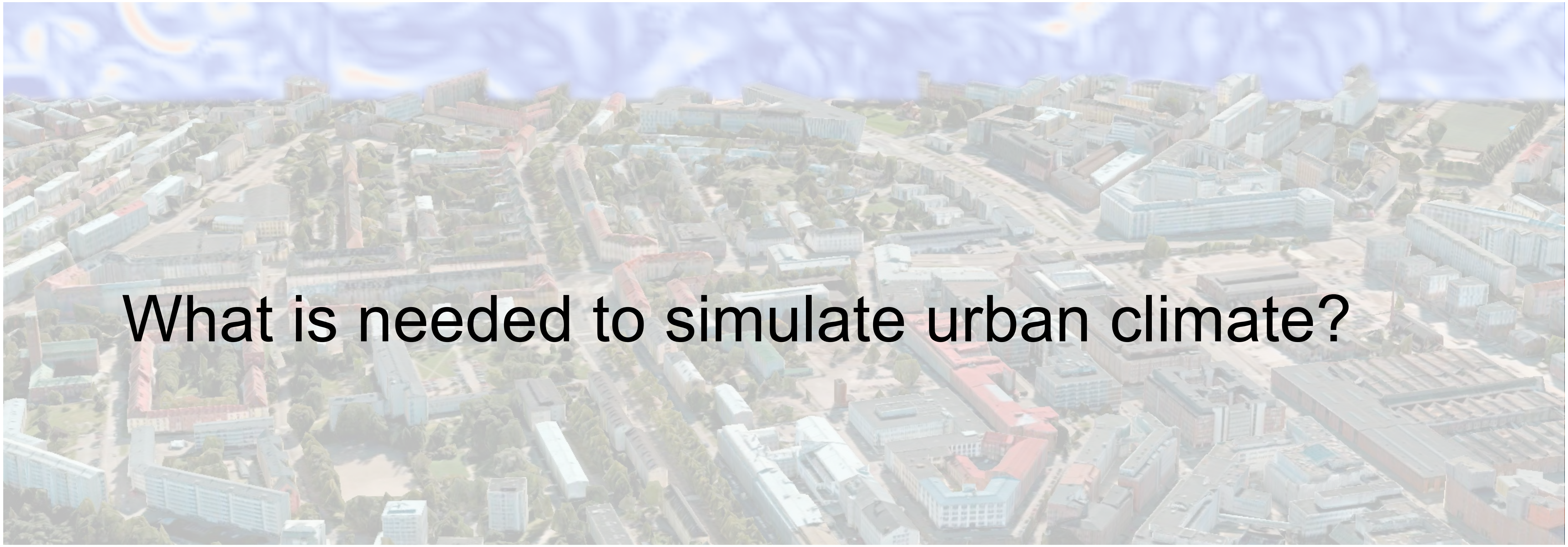

What is needed to simulate urban climate?

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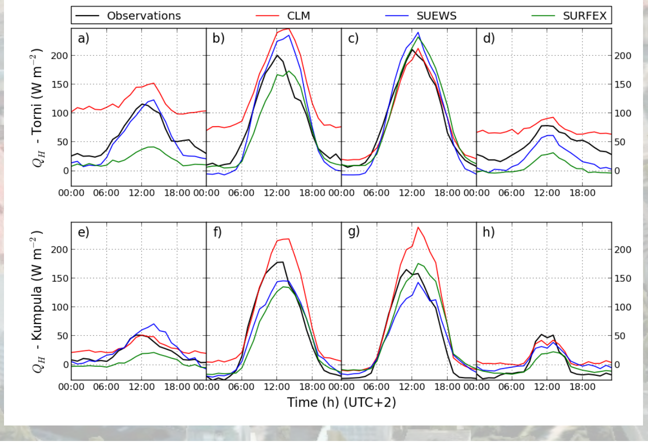
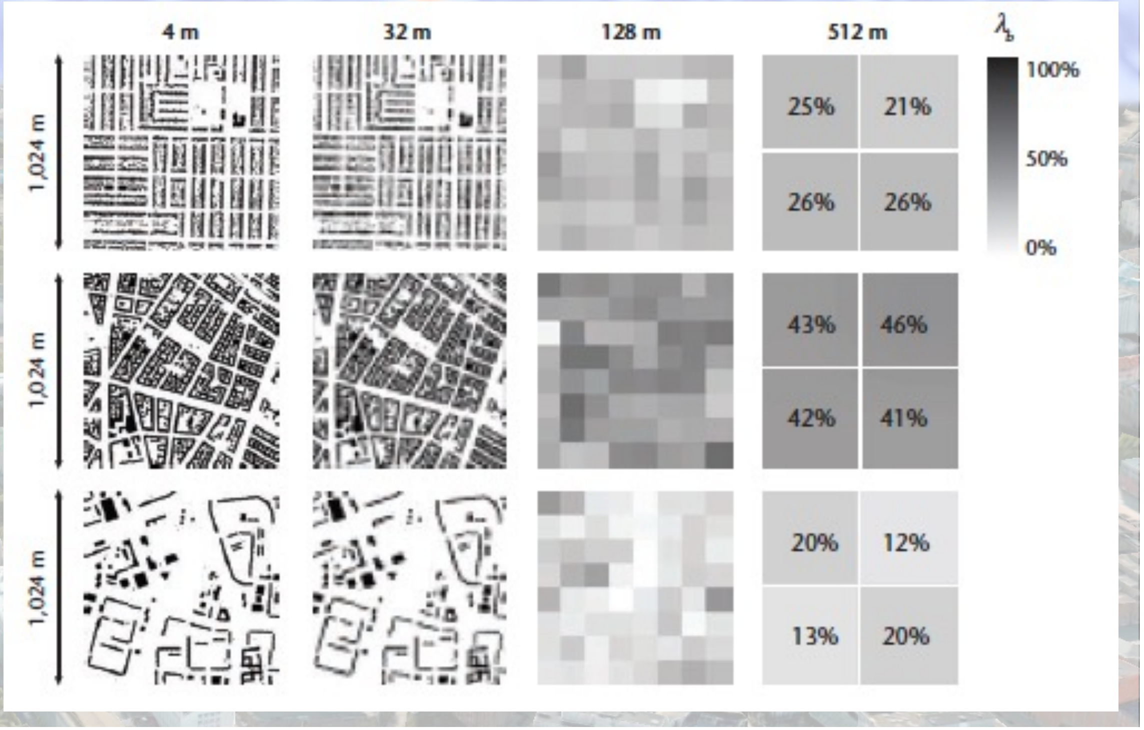
Correct description of surface (urban form) important for all urban modelling

- Surface information reason for some of the seen differences in Helsinki
- In addition resolution of surface data important





Oke et al. 2017

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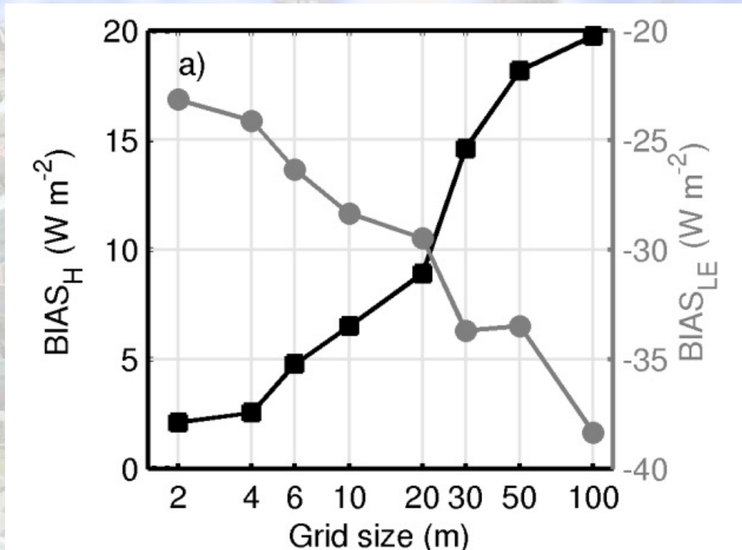
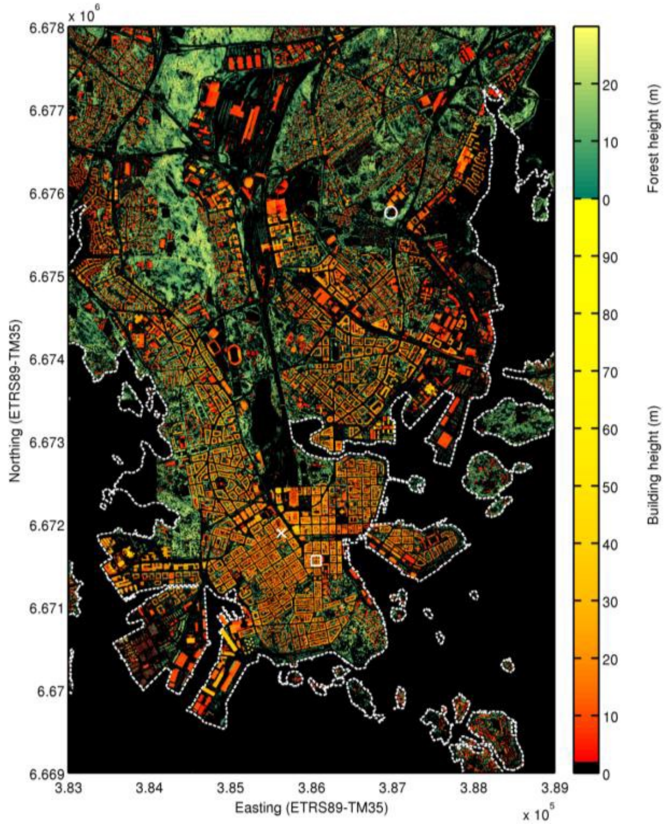
Impact of spatial resolution to LS modelling



- Airborne lidar
- 5 classes: buildings, roads, trees, low vegetation, water
- Model: SUEWS
- June-August 2012

Nordbo et al. 2012



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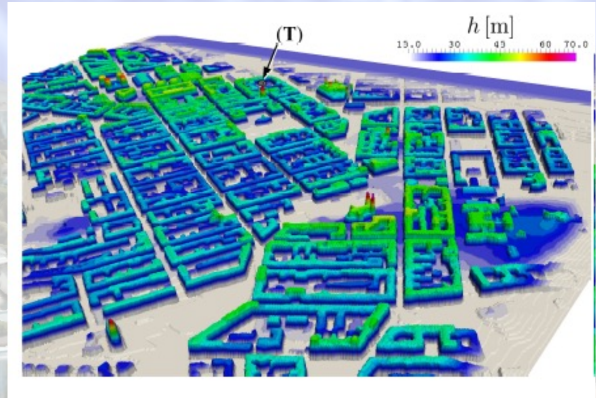
Possible surface data sources

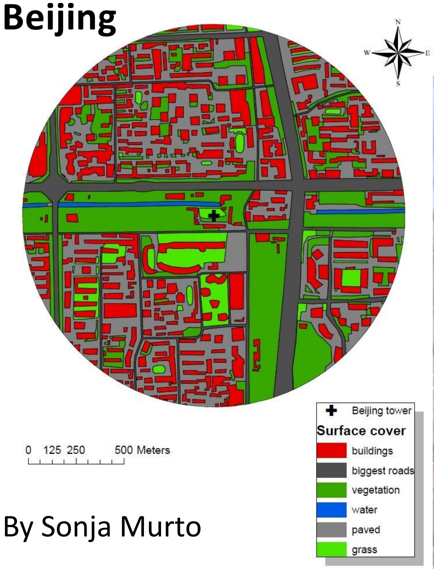
- ➢LCZ-
- ➢Land cover databases
  - ✓ e.g. CORINE, MODIS, ECOCLIMAP
- ➢Google, open street map
- ➢Laser scanning
  - ✓High resolution
  - ✓Information on both building and tree information
  - ✓Not available from everywhere

Helsinki

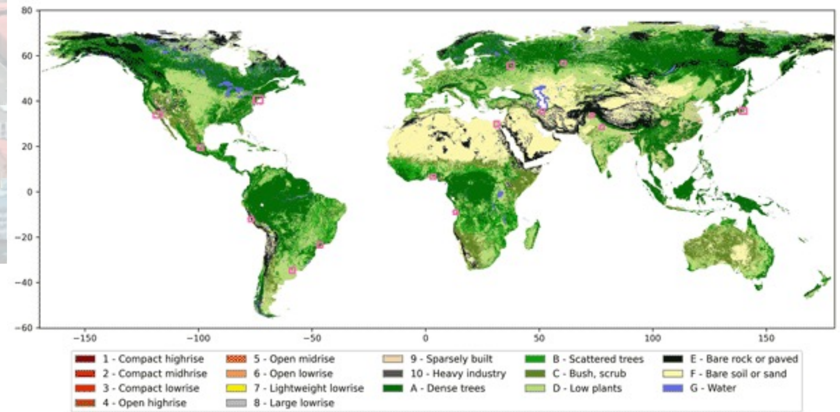


Auvinen et al. 2017

Beijing



By Sonja Murto



Demuzere et al. 2022

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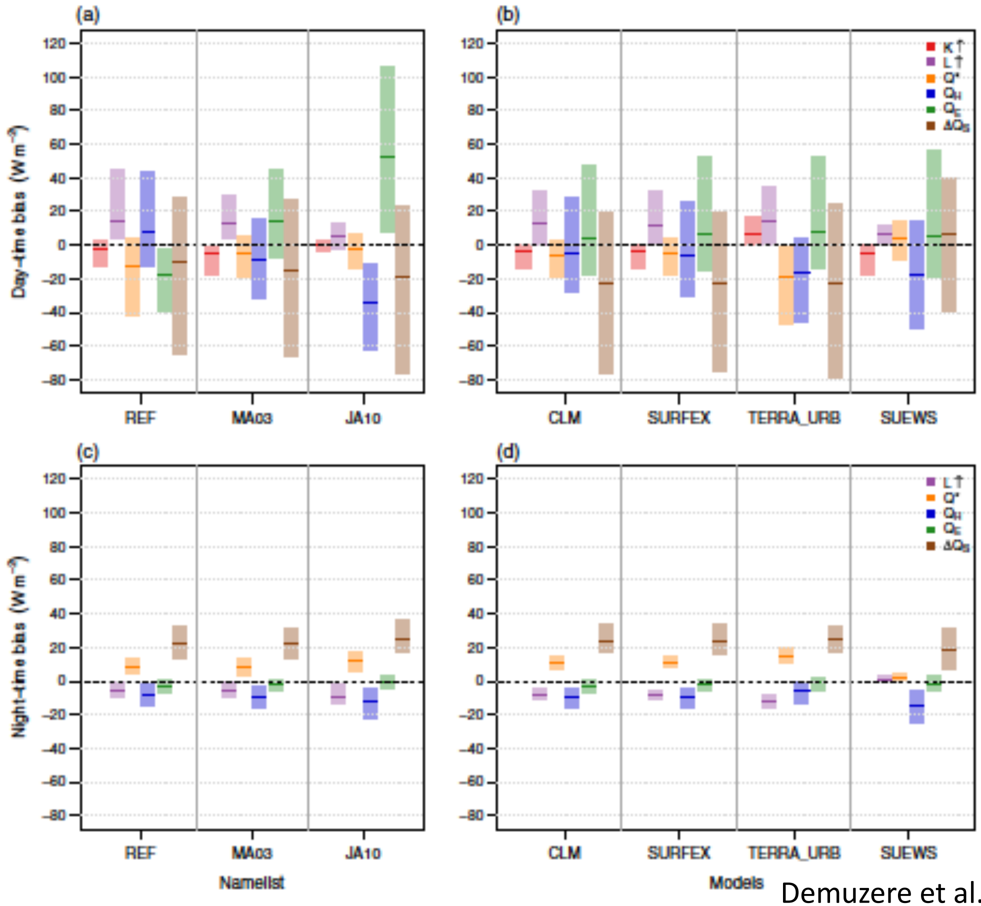
Surface data will directly affect your model simulations

➢ Surface information often obtained from global databases
➢ Surface cover fractions, building and vegetation information

REF – Actual surface characteristics
MA03 – ECOCLIMAP
Ja10 – Jackson et al. (2010) database



Demuzere et al. (2017)

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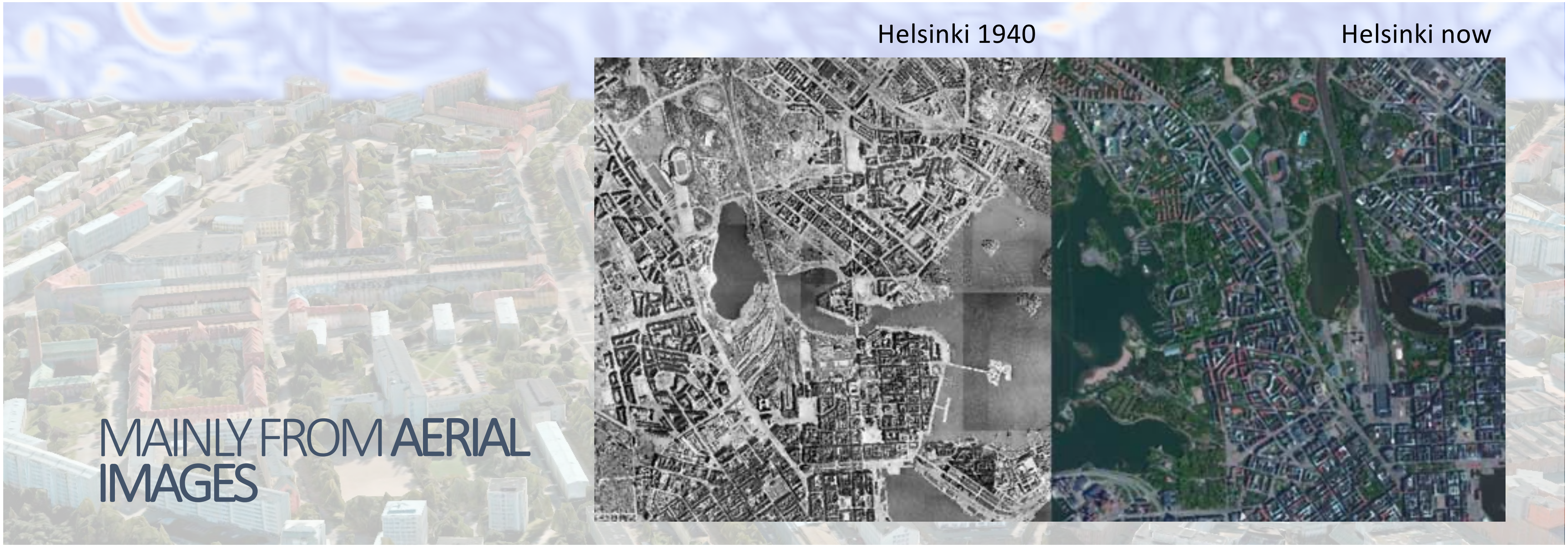
Surface information from the past?



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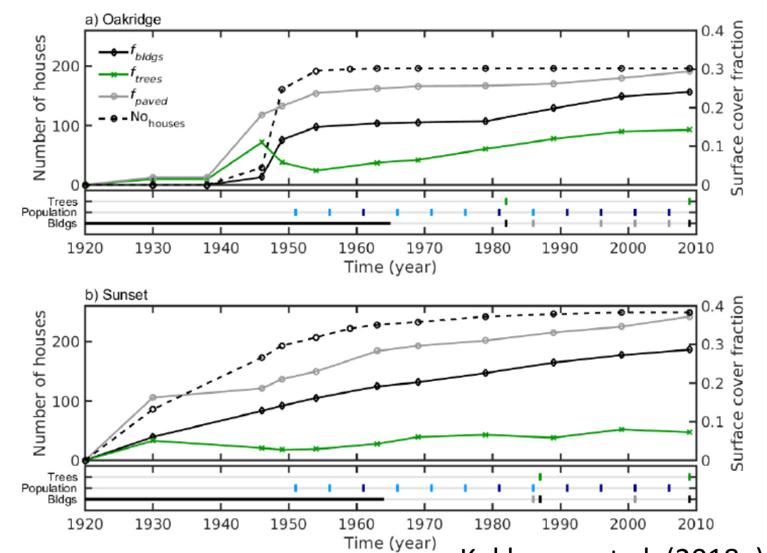
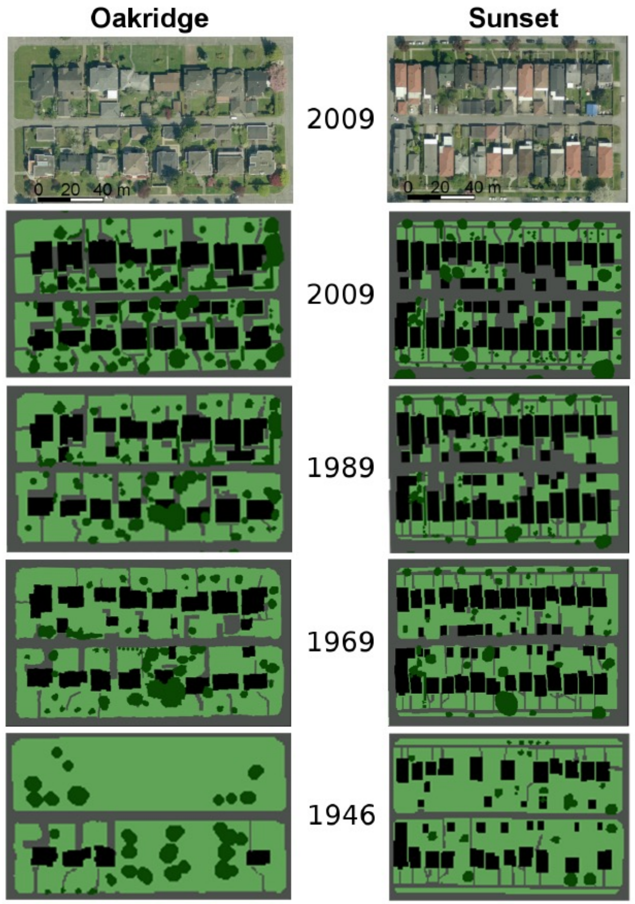
Example from Vancouver

- Aerial images for surface cover fractions
- CENSUS data for population and building information
- Tree information via interpolation from laser scanning and tree models



Kokkonen et al. (2018a)



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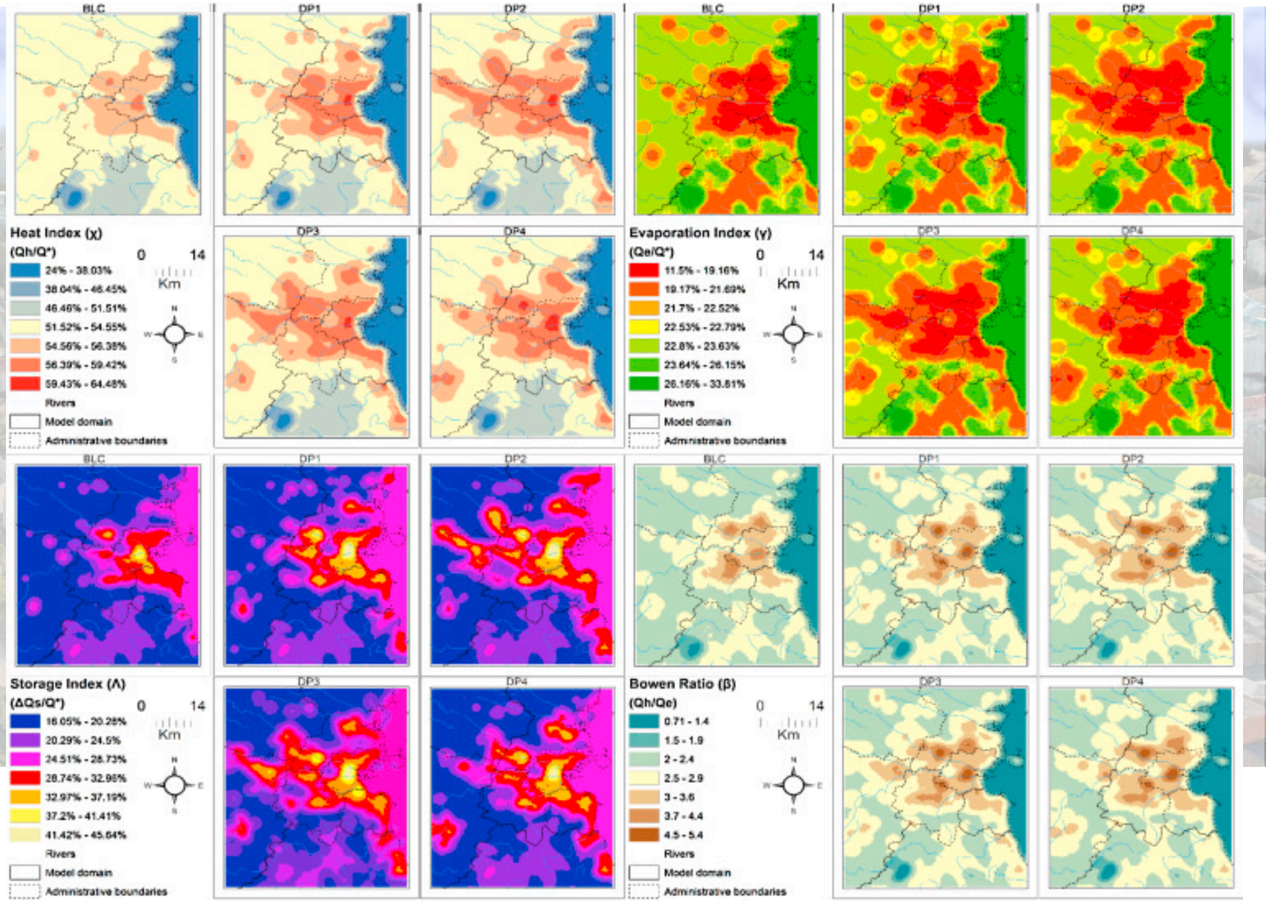
For future coarser resolution datasets commonly used

- Corine land cover classes

Alexander et al. 2016



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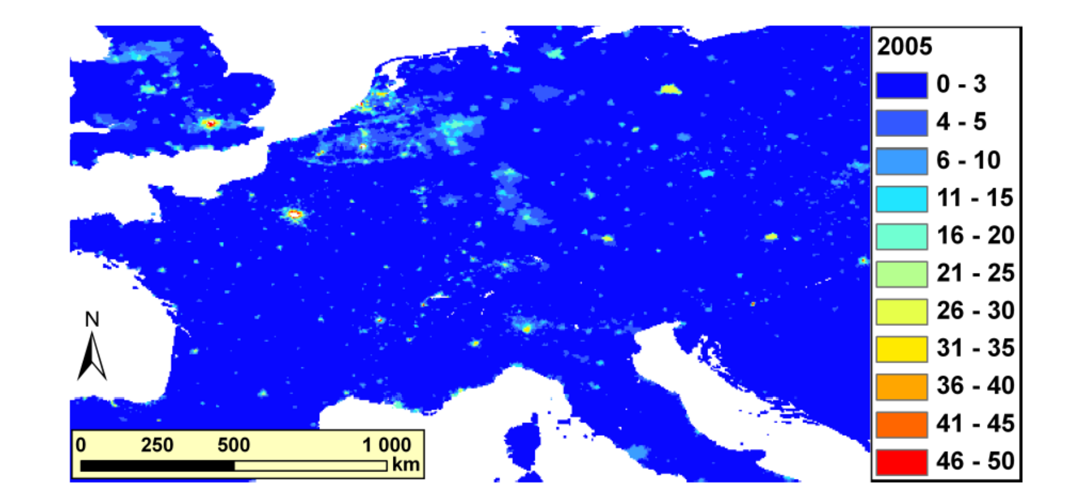
You also need information on urban function (anthropogenic heat flux, CO_2 emission)

- Some models consider Q_F as constant value (i.e. 10 W m^{-2} in Helsinki with SURFEX)
- Some calculate Q_F via emission inventory

  $Q_F = Q_{F,traffic} + Q_{F,metab} + Q_{F,buildings}$

- Some using cooling/heating degree day approach (originally SUEWS)

Mean Q_F in central Europe from LUCY



Allen et al. 2011

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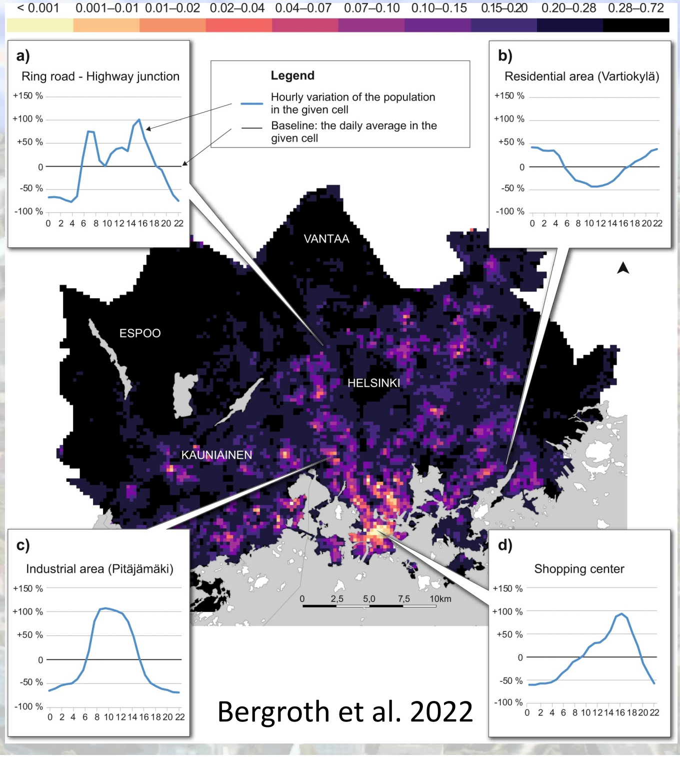
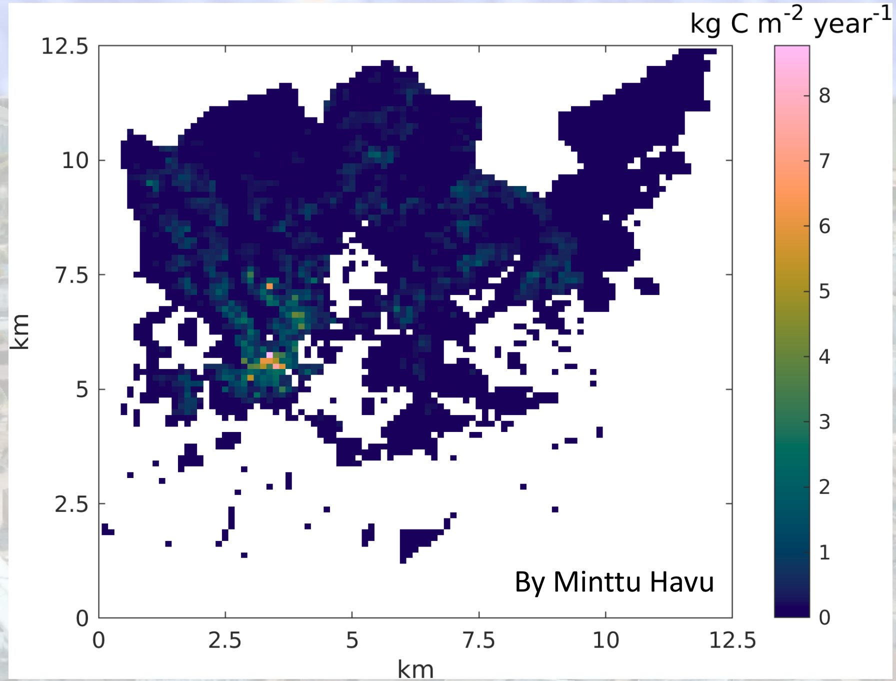
New emerging datasets improve our understanding on urban function



Bergroth et al. 2022



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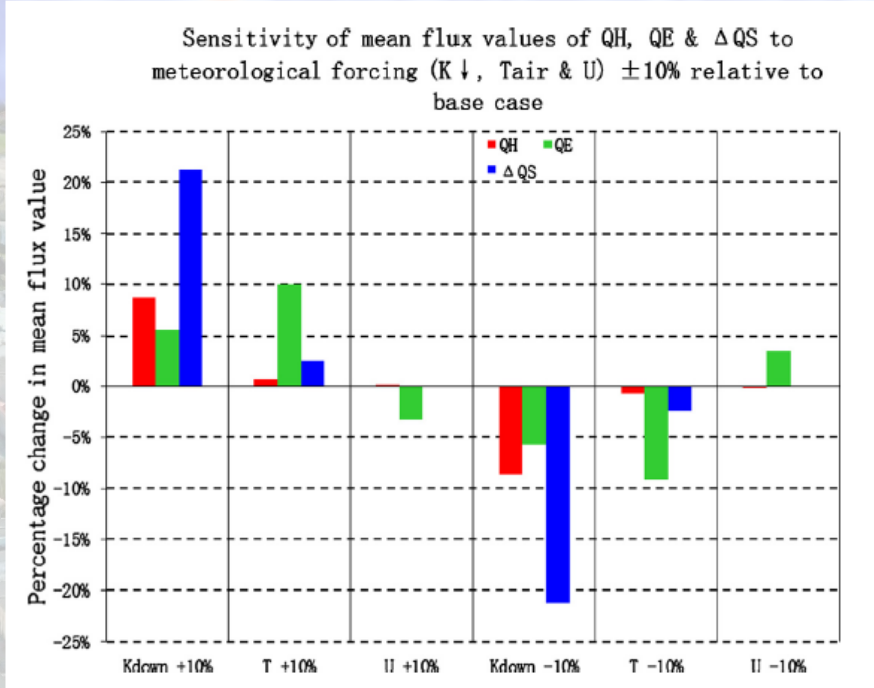
What about dynamic forcing for offline model runs?

- Model forcing data can come from
  - Observations
  - Mesoscale models
  - Re-analysis data
  - Scenarios runs (e.g. RCP)
- What is the sensitivity of the land surface models for the input data?



Alexander et al. 2015

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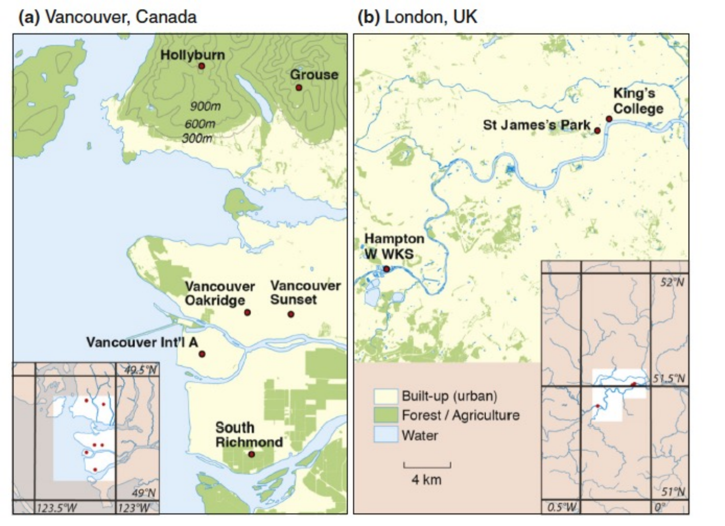
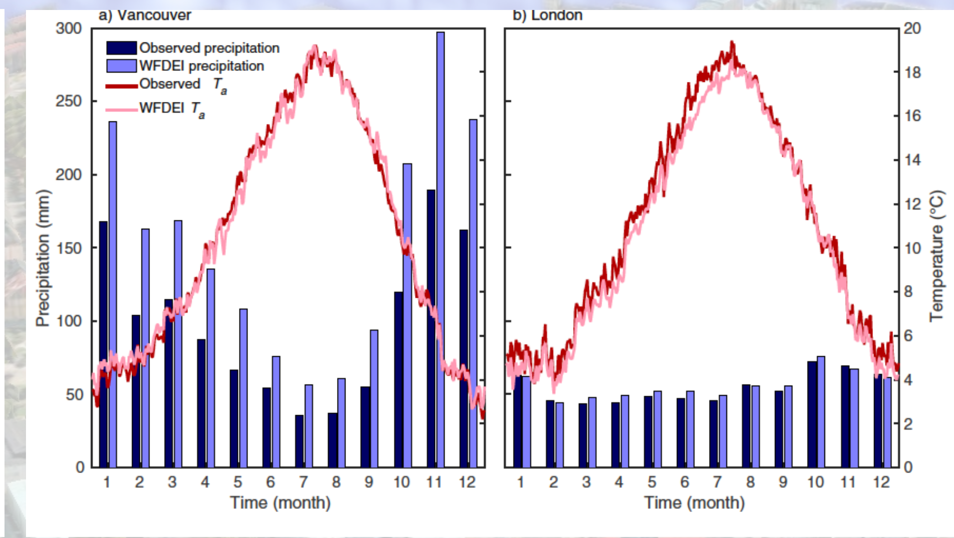
Using re-analysis data for meteorological forcing





Details

- WATCH FORCING Data ERA-Interim (WFDEI)
- Derived from ERA-Interim reanalysis product
- Designed particularly for hydrological modelling

Problems

- Grid size 0.5 x 0.5°
- Grid height (213 m in Vancouver, 87 m in London)
- 3-hour time resolution
- Bias correction needed

Kokkonen et al. (2018b).

Some parameters might be needed to be downscaled to the scale of interest

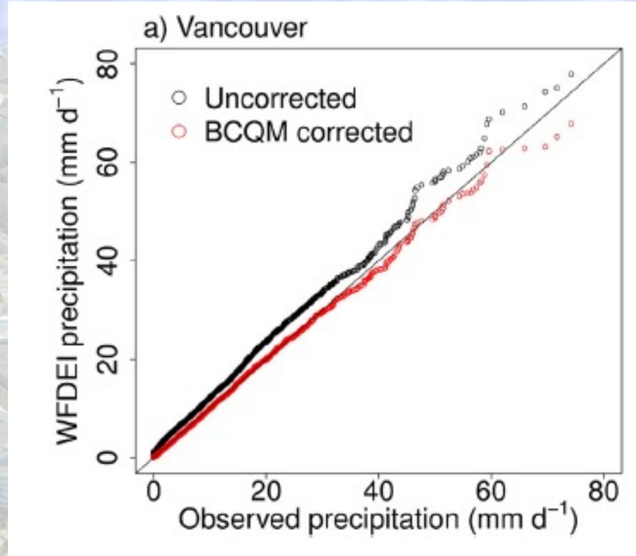
Daily observed precipitation for calibration period (1990-2008)

Daily re-analysis precipitation for calibration period (1990-2008)

Bias correction parameters to correct the re-analysis data

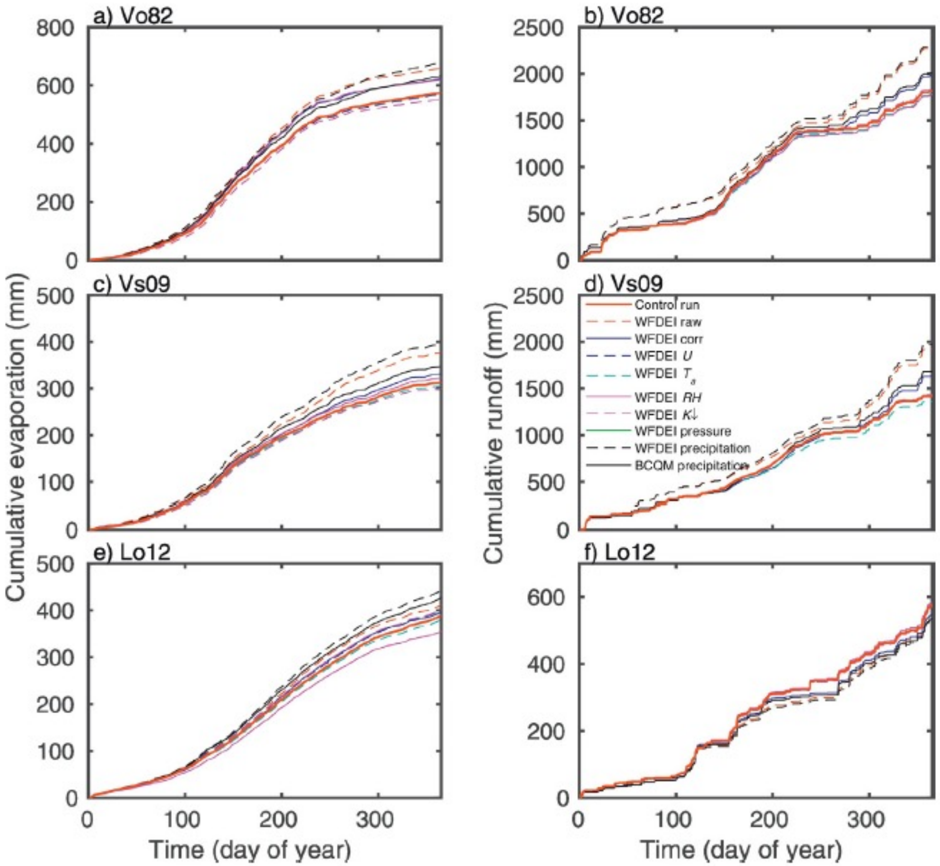
Choose the years of interest

Corrected precipitation



Kokkonen et al. (2018b)

Effect of the correction to evaporation and runoff



Kokkonen et al. (2018b)

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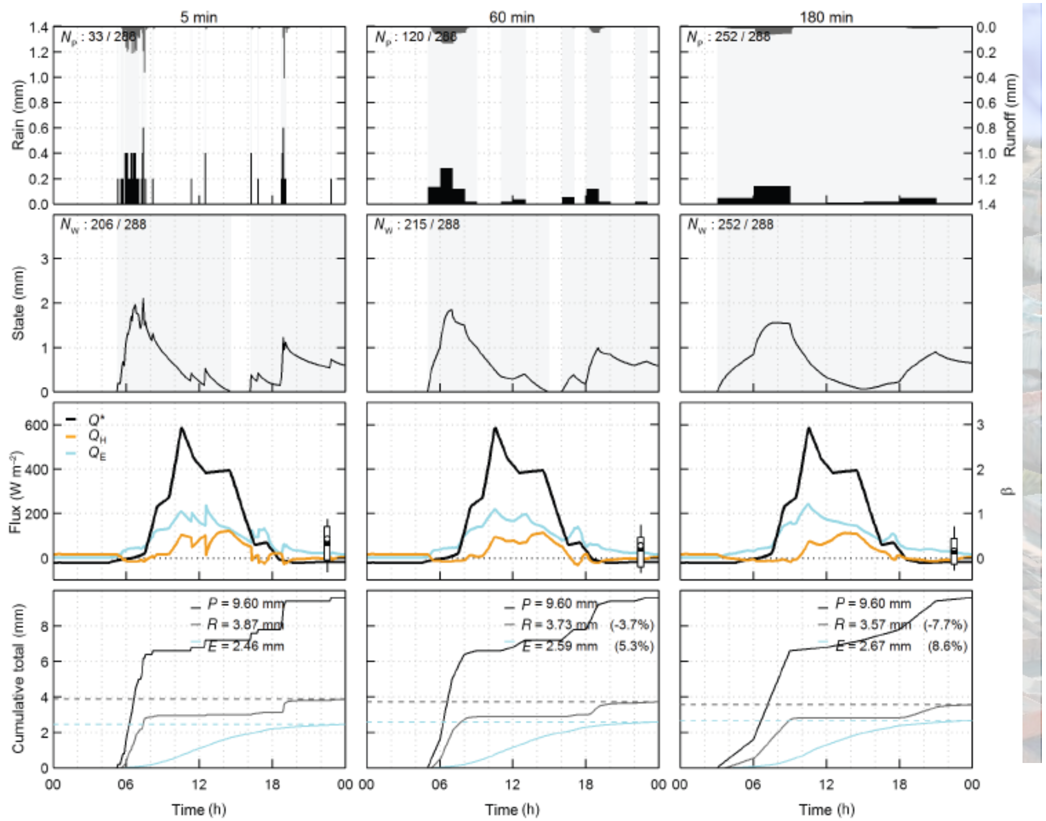
How temporal resolution of precipitation impacts surface energy balance and hydrological cycle

- Peak intensities can be lost which are vital for correct prediction of flood events

5 August 2012, Swindon, UK



Ward et al. 2018.

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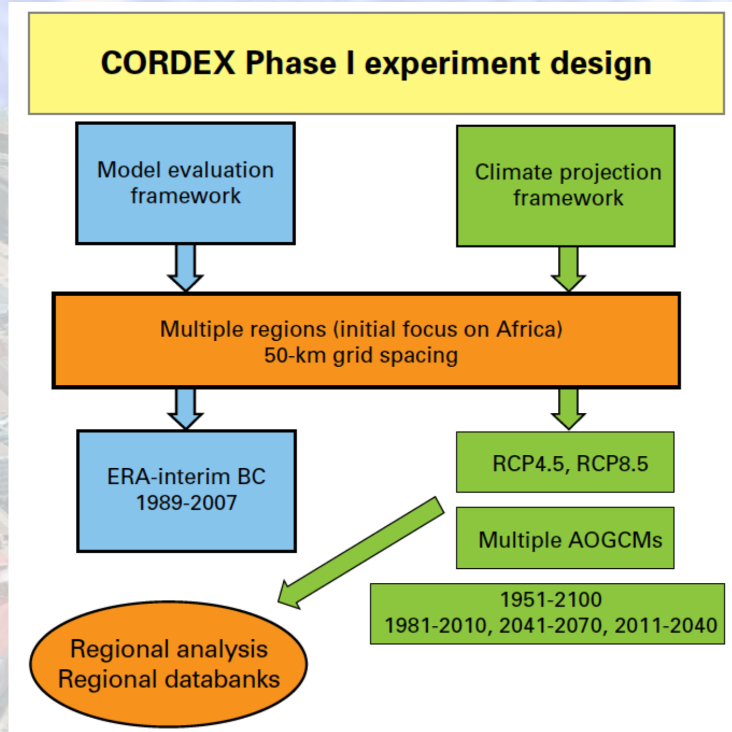
Downscaling necessary also for future scenarios

- Necessary for the global models from providing an accurate description of extreme events
- Dynamical and statistical scaling methods
- E.g. Coordinated Regional climate Downscaling Experiment (CORDEX)
- Furthermore, downscaling can be done to a local/catchment scale



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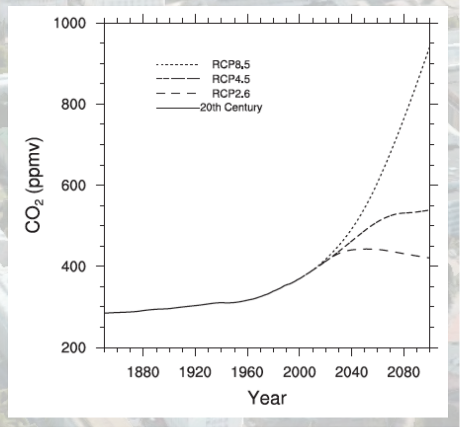
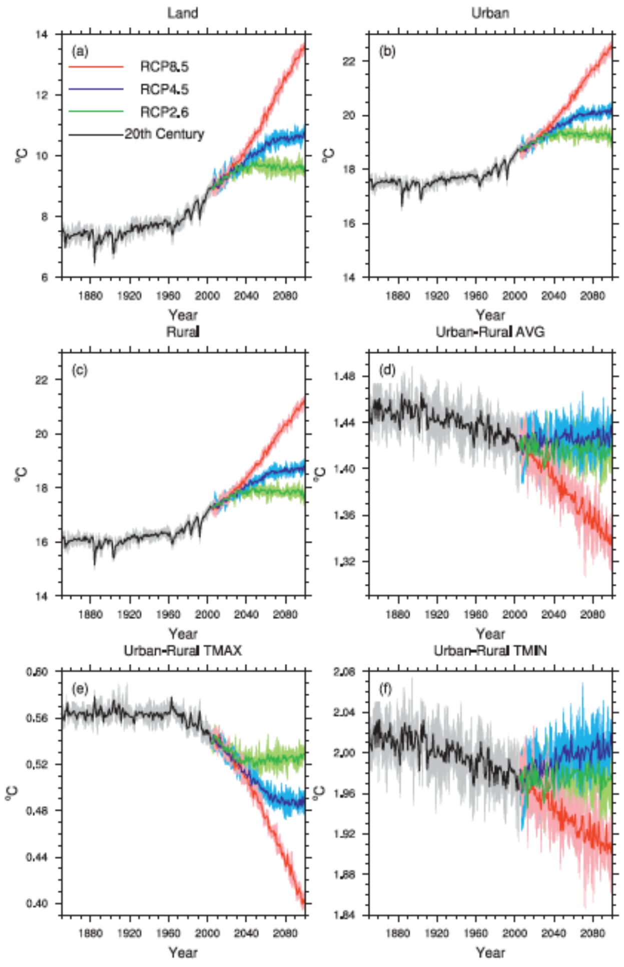
Example on UHI with future projections

- Community climate system model version 4
- Urban land surface model is CLMU
- Representative Concentration Pathways (RCP)
- No separate local scaling





Oleson 2015

Take home messages

- ➢Modelling urban climate can be done at different scales
- ➢Microscale models solve individual street canyons, buildings, a few blocks
- ➢Mesoscale models for whole cities
- ➢Land surface models describe the interaction between the surface and the atmosphere in neighbourhood scale in mesoscale models
- ➢Description of surface form and function plays a vital role both at present and future climate modelling
- ➢You get results out from any urban climate model, but this does not mean you are simulating correctly!

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