Monitoring and Managing Urban Heat Islands under Climate Change

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- University of Potsdam, Dept. of Geo- and Environmental Sciences
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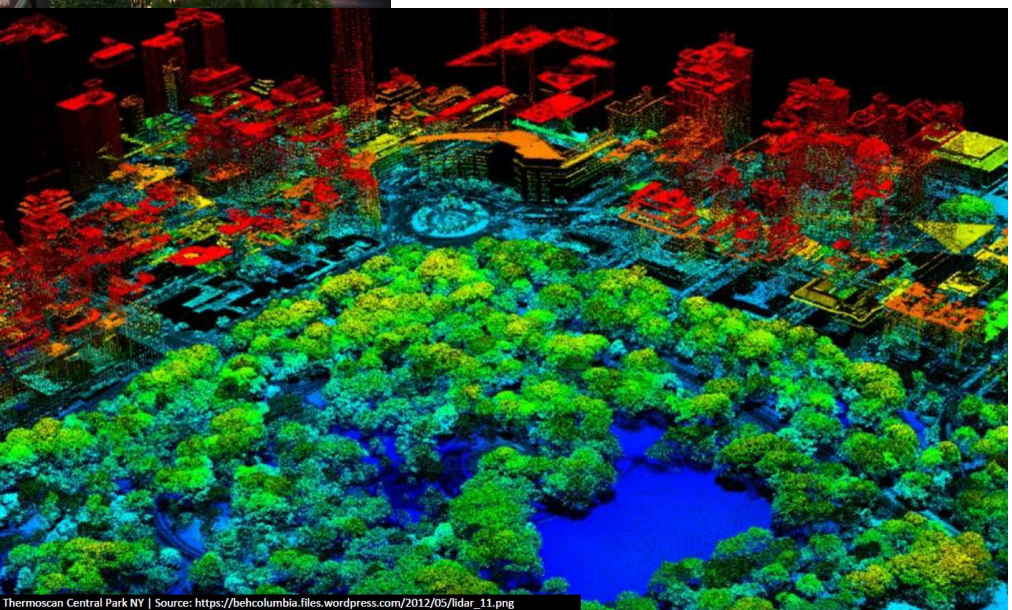

Thermoscan Central Park NY | Source: https://behcolumbia.files.wordpress.com/2012/05/lidar_11.png

Quarterly Journal of the Royal Meteorological Society

RMetS

Article

The energetic basis of the urban heat island

T. R. Oke

First published: January 1982 | https://doi.org/10.1002/qj.49710845502 | Citations: 1,262

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551.524:551.588.7

The energetic basis of the urban heat island

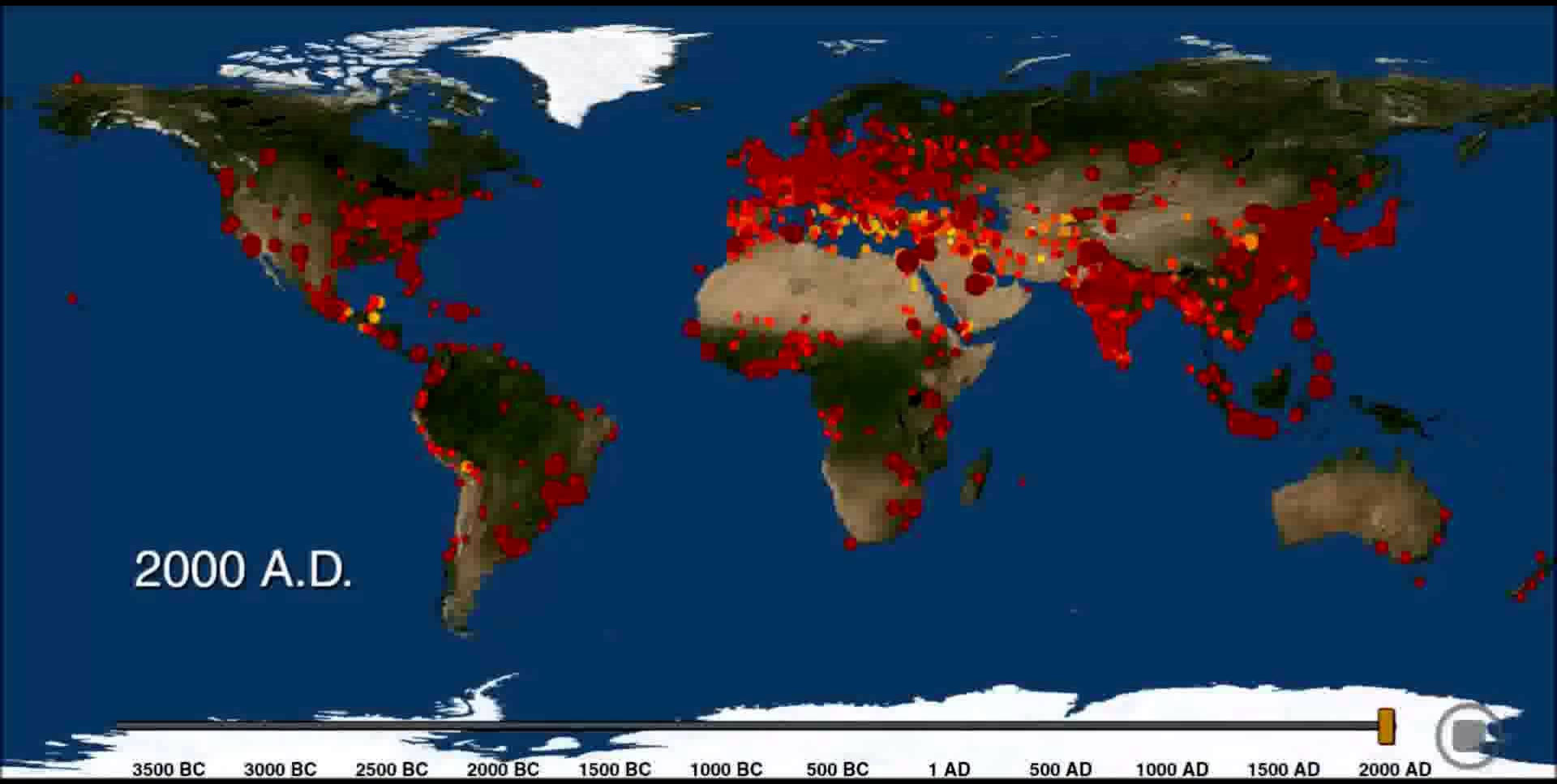
By T. R. OKE

Department of Geography, The University of British Columbia, Vancouver

(*Symons Memorial Lecture, delivered 20 May 1980*)

Table of Contents

The Rise and Fall of Great World Cities

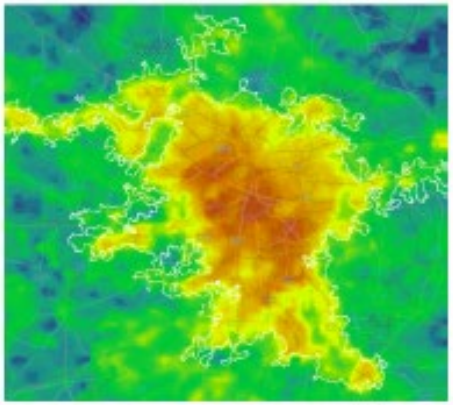


The History of Urbanization, 3700 BC - 2000 AD

Animation: Max Galka

Motivation

Urbanization → Urban Heat Island(UHI) ← Climate Change



Status quo:

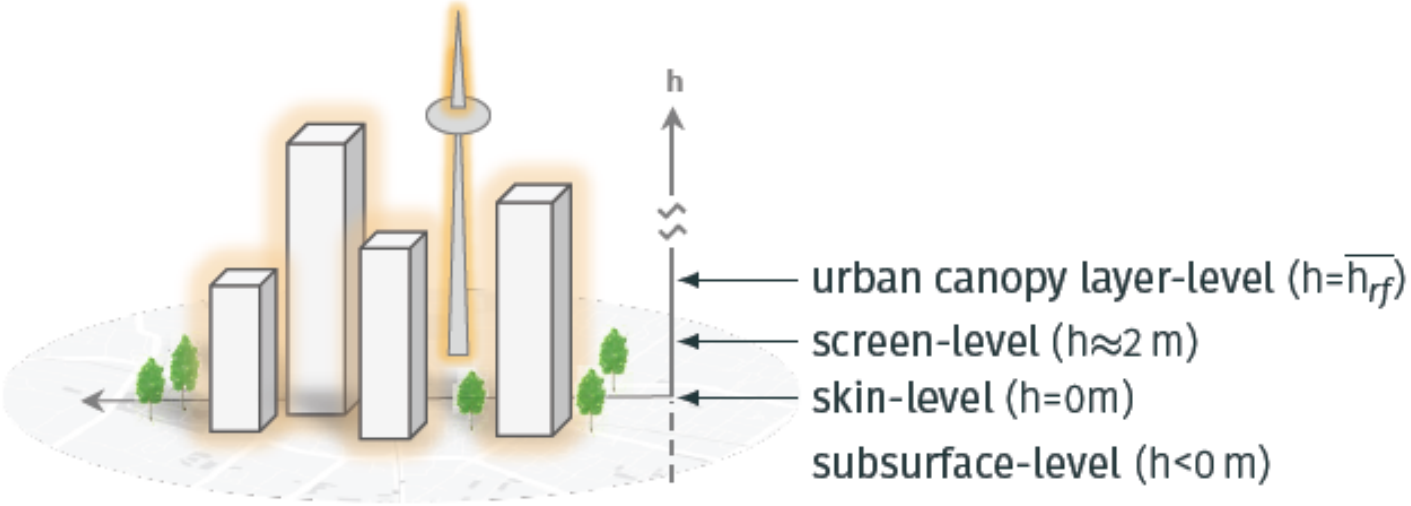
- Cities cover 2% of the global land but accommodate 54% of the world's population in 2016.
- The number of heat wave days is expected to increase by up to 10 fold by 2100 in the worst scenario (RCP 8.5) [Hooyberghs et al., 2015].
- Total economic costs of climate change for cities are estimated to reach 10.9 % of GDP by 2100 – 2.6 times larger than without considering the UHI [Estrada et al., 2017].

UHI_S vs. UHI_C

Horizontal dimension of UHI – *scale*

micro-scale ($1\text{-}10^4 m^2$) local-scale ($10^5\text{-}10^7 m^2$) meso-scale ($10^8\text{-}10^{10} m^2$)

Vertical dimension of UHI – *level*



Distinction between SUHI & CUHI

UHI_C:
Air temperatures within the urban canopy layer (UCL), the layer of air in the urban canopy beneath the mean height of the buildings and trees.

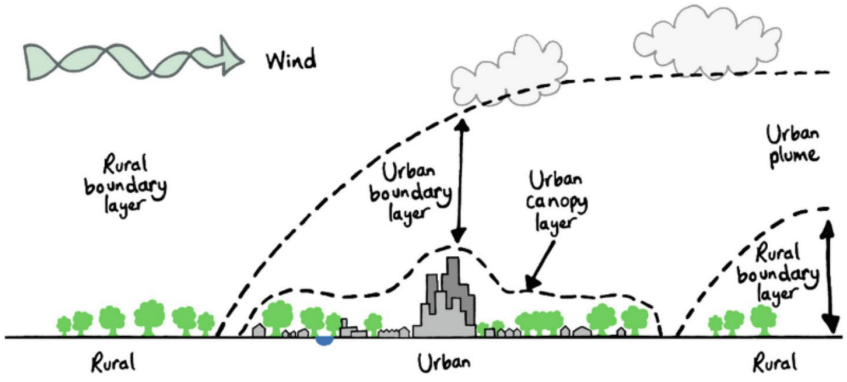
Influenced by:
- presence of buildings,
- street cover,
- Trees & parks
- vehicles,
- human activity.

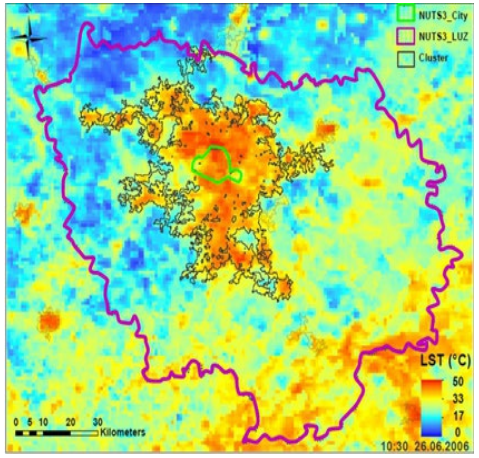
Question?

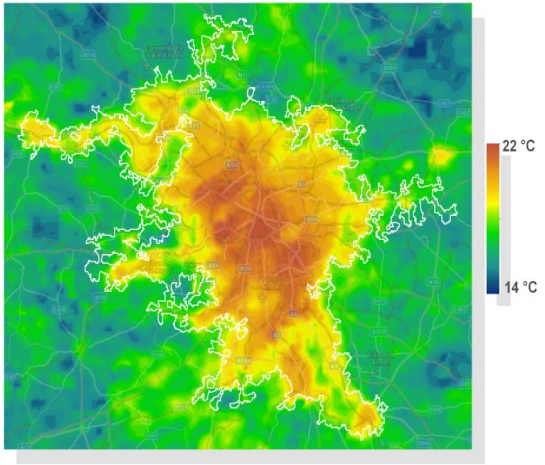
How do UHI_S/UHI_C interfere and forms the UHI

UHI_S:
Effect refers to the difference in Land Surface Temperature (LST) between an urban area and its surrounding non-urban area.

Measures:
- radiative skin temperature of the ground (refer: SB law: $E = \sigma\varepsilon T^4$) dependent on ground material (cf. albedo)
- Relevant: specific heat capacity (SHC)
- Large SHC (e.g. water, concrete) take longer to heat up and cool down!





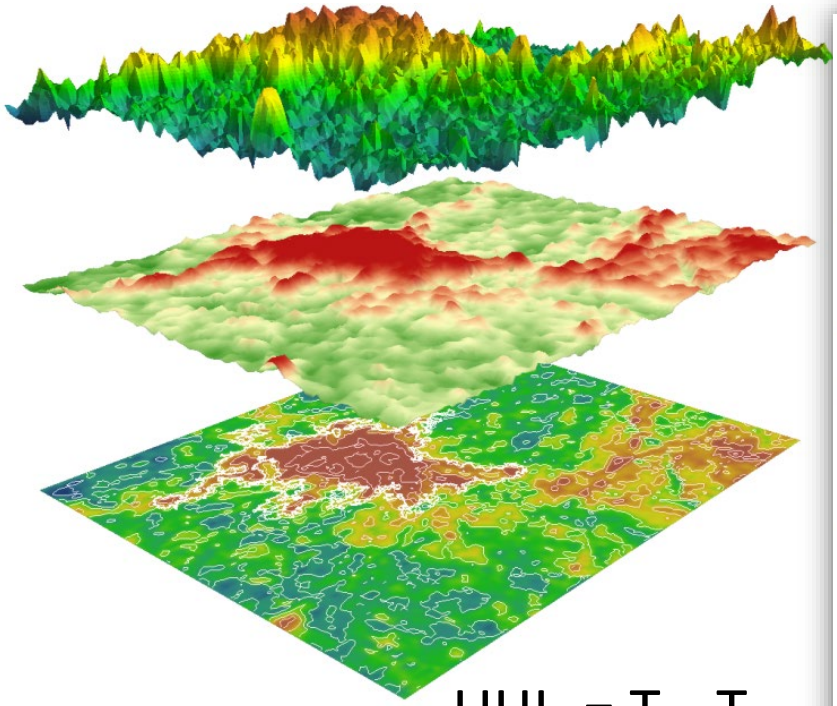


LST situation of greater Paris

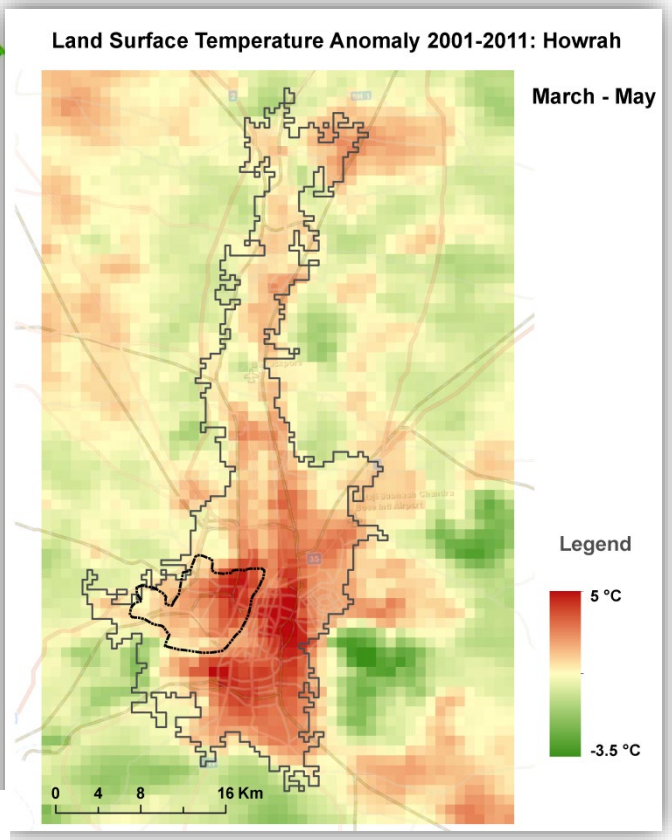
Modelling and Assessment of UHIs

Two approaches: SUHI & CUHI

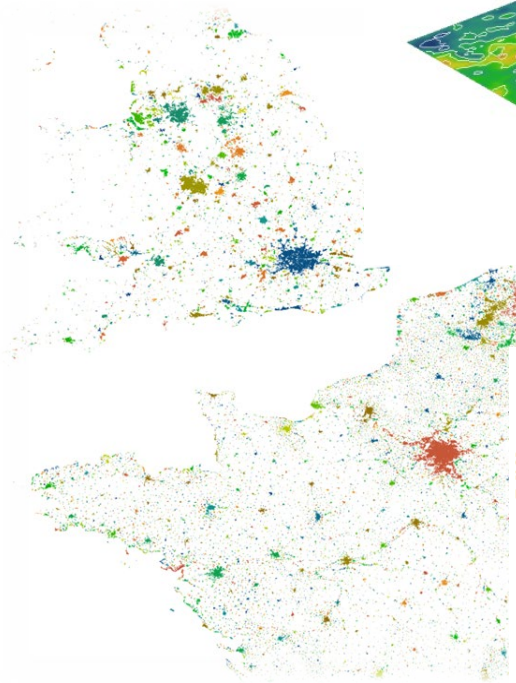
Statistical LST modelling for heat burden in cities (120,000 villages)

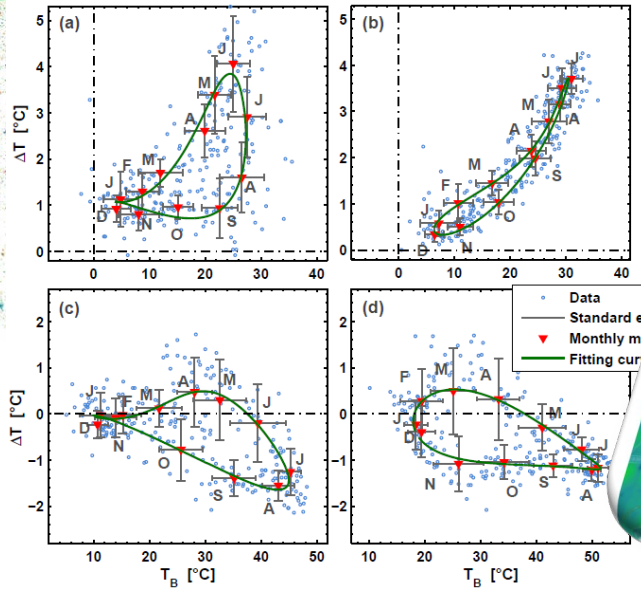


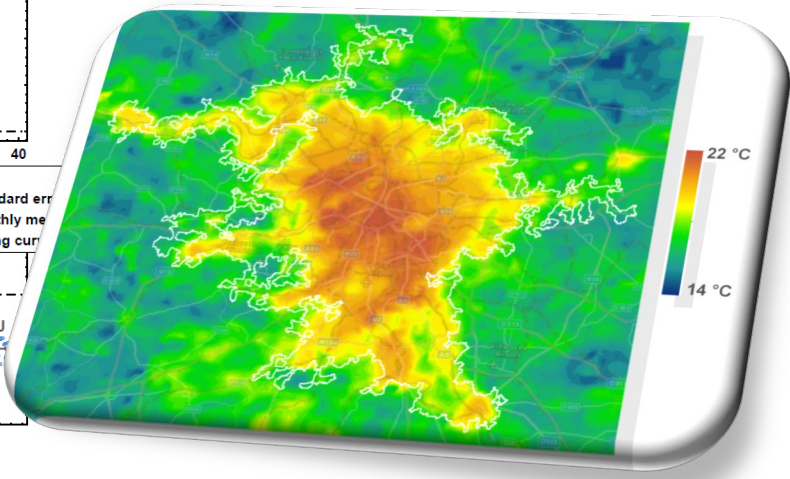
$UHI_S = T_C - T_B$



Zhou/Rybski/Kropp (2013): Geophys. Res. Lett.



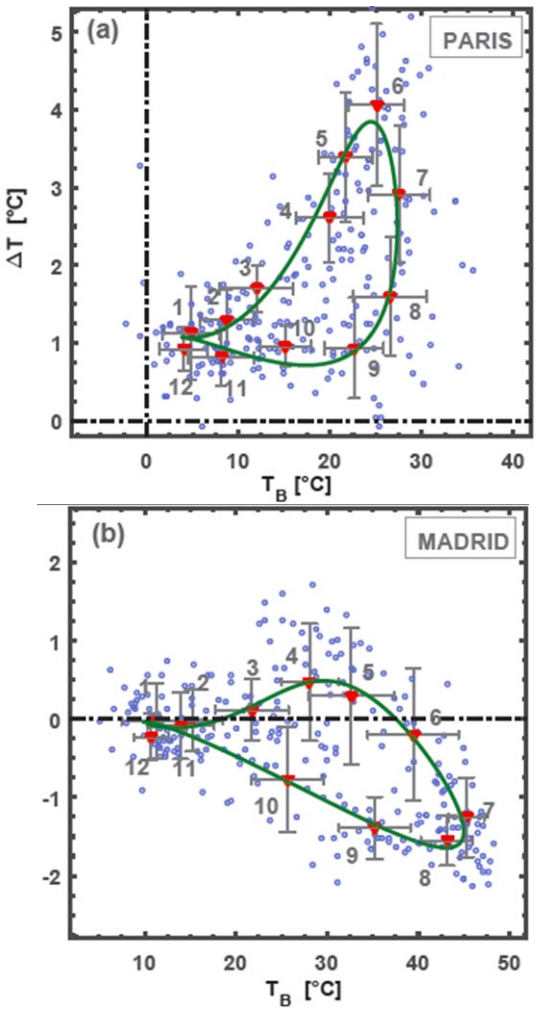


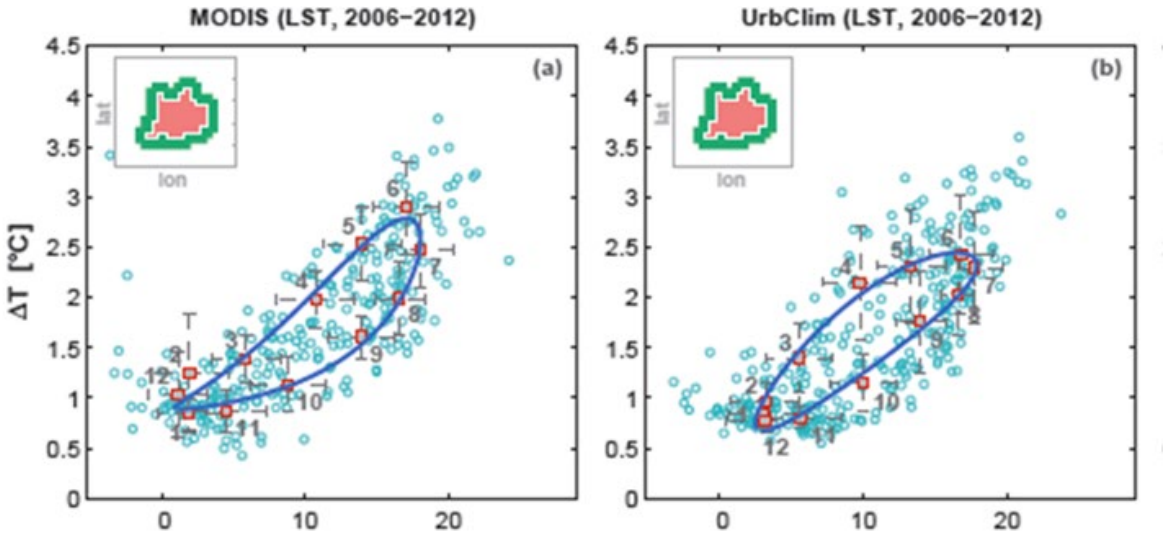


Types and thresholds

Paris, (b) Milan, (c) Madrid (d) Nicosia

Seasonality comparison of SUHI





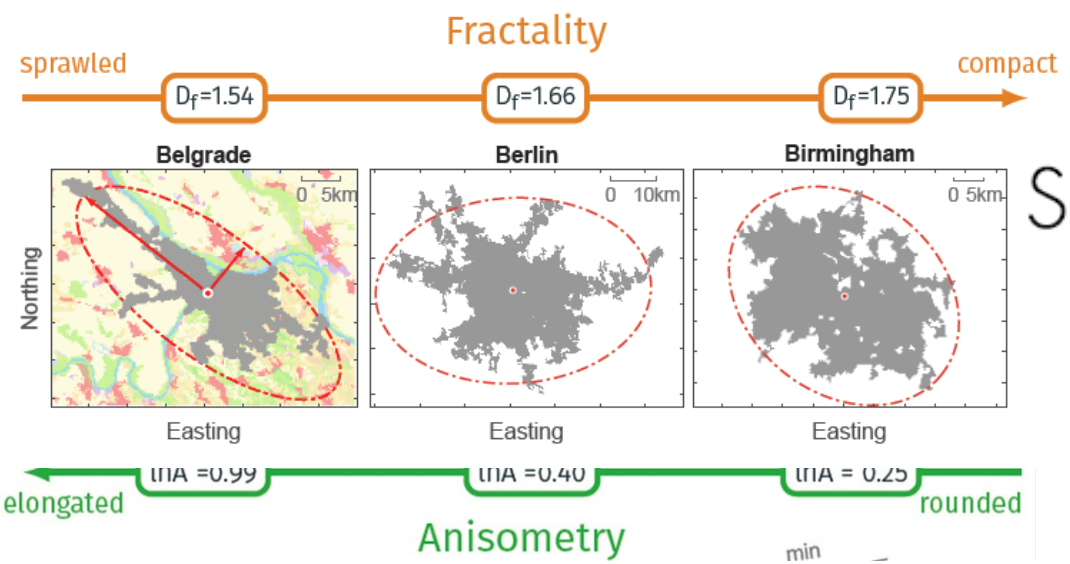
„Oasis Effect“ – evaporative cooling due to heat advection

Greater London: CCA (SUHI) & UrbClim (CUHI): Bulk parameterization of the urban surface energy balance, coupled to a 3-D atmospheric boundary layer scheme

7 different typologies

Zhou /Rybski/Kropp (2013): *Geophys. Res. Lett*, 40(20): 5486

Zhou/Lauwaet/Hooyberghs/De Ridder/Kropp/Rybski (2016) *J. Appl. Meteorol. Clim. 55(3) 493*



SCIENTIFIC REPORTS

OPEN

The role of city size and urban form in the surface urban heat island

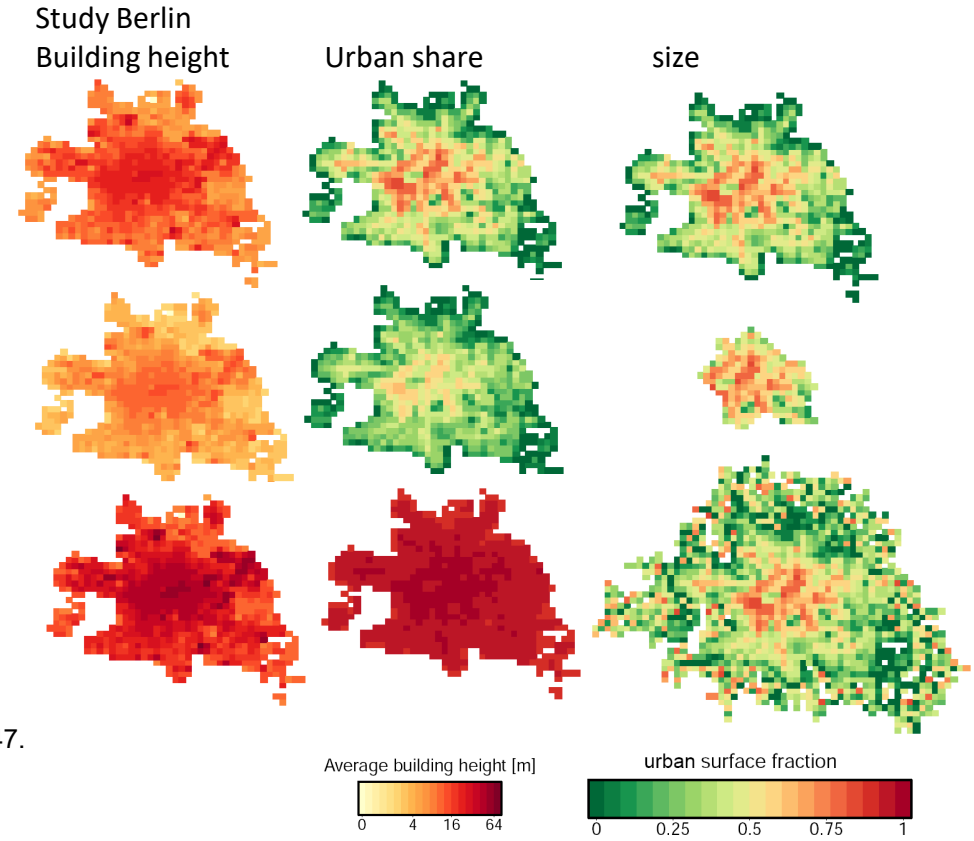
Bin Zhou[1], Diego Rybski[1] & Jürgen P. Kropp[1,2]

Urban forms and heat islands

Constant weather conditions: density, height, size and distance between urban clusters changed.

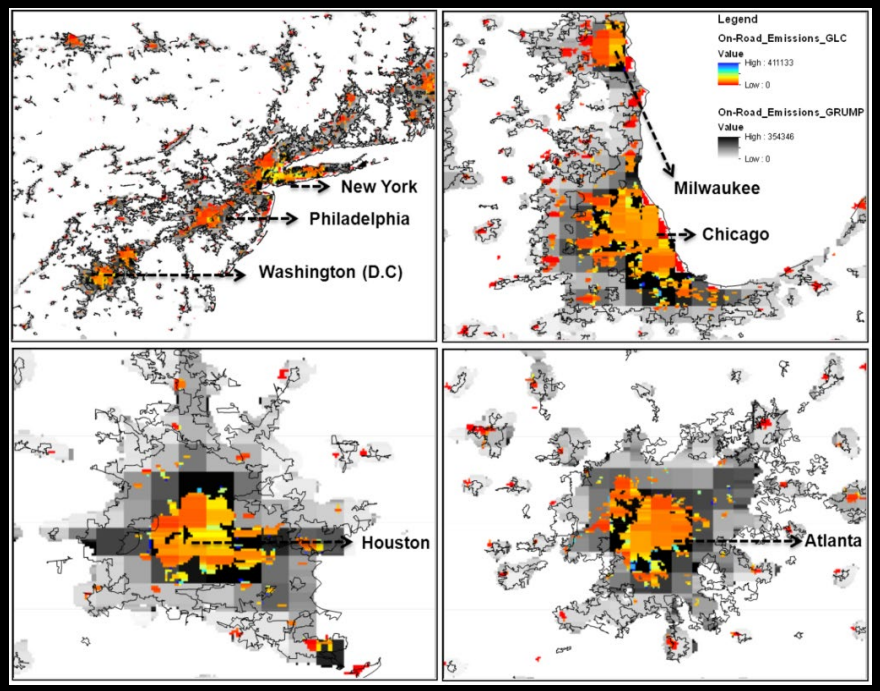
Polycentric systems are better at coping with heat stress!

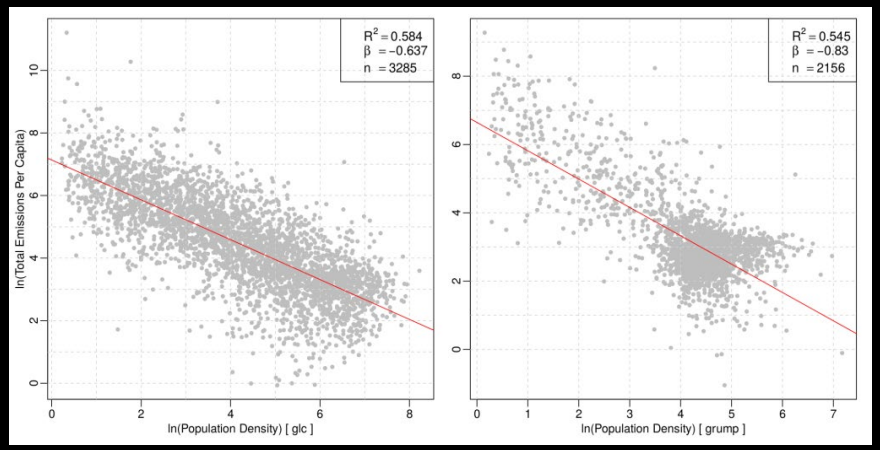
Size, building heights and structure!



Li Y, Schubert S, Rybski D, Kropp JP (2020): *Nature Communications*, 11: 2647.
Zhou/Rybski/Kropp (2017) : *Scientific Reports*, 7, 4791
Li Y, Rybski D, Kropp, J.P. (2021):. *Environment and Planning B,* 48(1):43-59

City density and CO_2 emissions





Standardized analytical approach applied to NA cities, i.e. combination of

1.) remote sensing/land use data
2.) population data
3.) gridded emission data
4.) city clustering algorithm

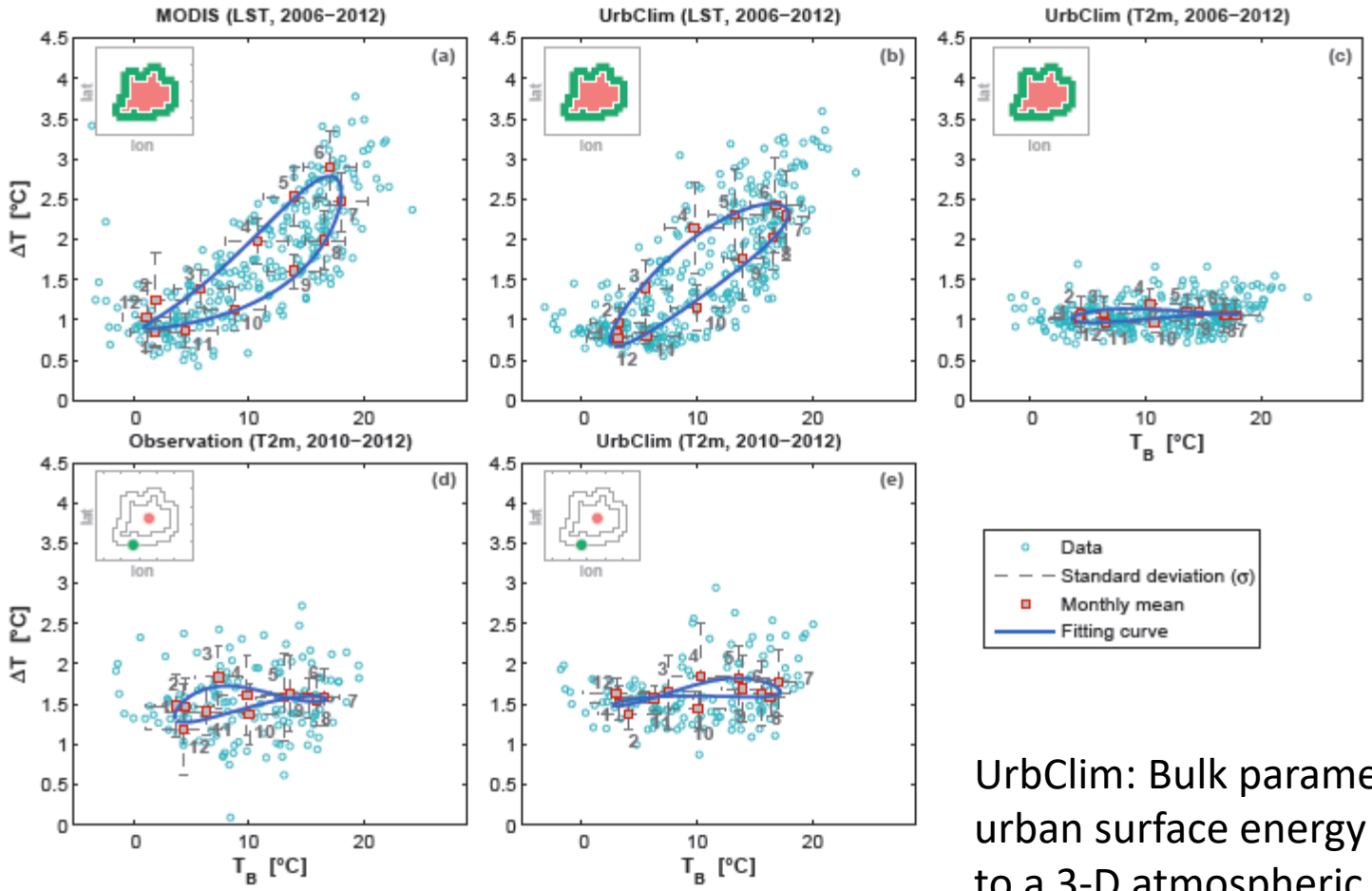
Emission profile differs for cities

- On-road emissions correlate with density
- Housing emissions correlates with density & climate

.....denser cities emit less (theoretically up to 40%)!

Gudipudi/Lüdeke/Rybski/Kropp (2016): *Energy Policy*, 91:352

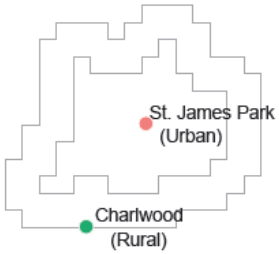
LST vs. UrbClim Modelling (LST/T_{2m})

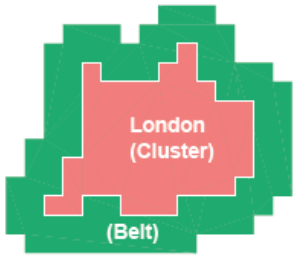


T_{2m} cannot represented by LST modelling

UrbClim: Bulk parameterization of the urban surface energy balance, coupled to a 3-D atmospheric boundary layer scheme (de Ridder et al. 2015)

London case study

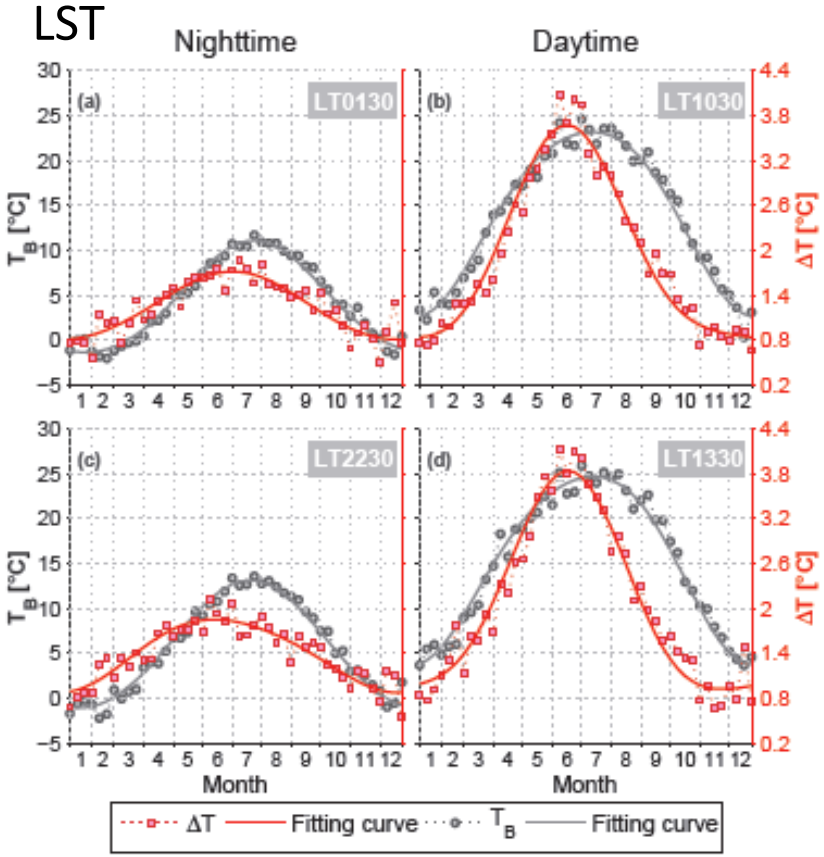




RAMSES
Science for cities in transition

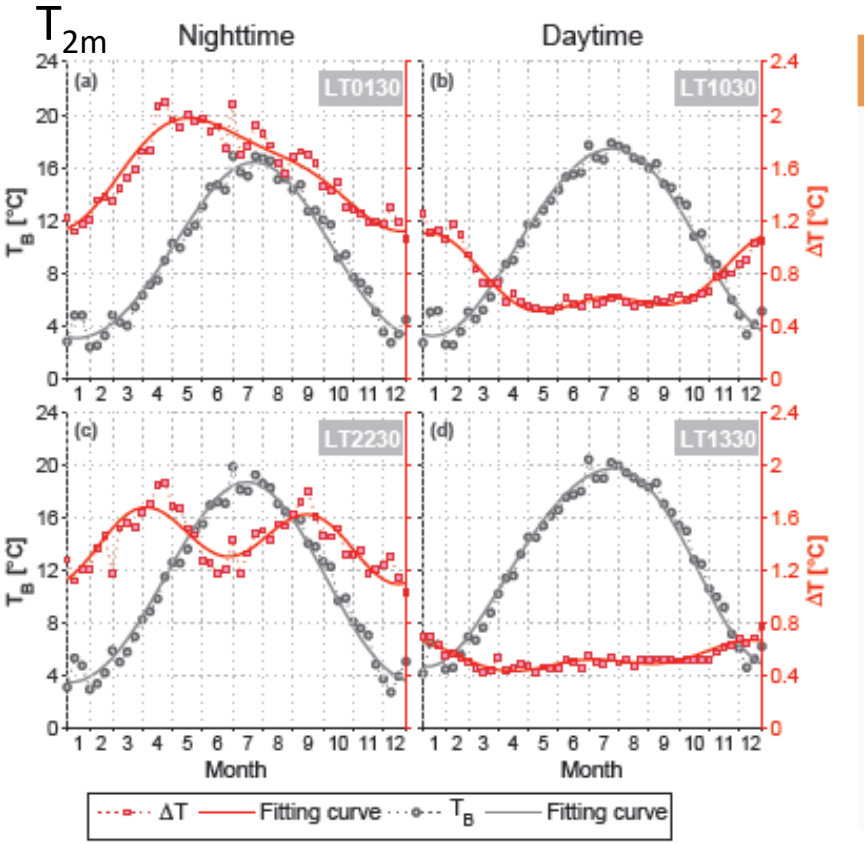
Comparison of seasonality (modeled: T_B, ΔT)

LST



- Daytime ΔT > Nighttime ΔT
- Maximum ΔT appears around the
- summer solstice.
- Phase shift between ΔT and TB.

T_{2m}



Diurnal cycle of ambient T not reflected in LST

•Daytime: solar insolation

Unstable urban boundary layer, convection / turbulent mixing

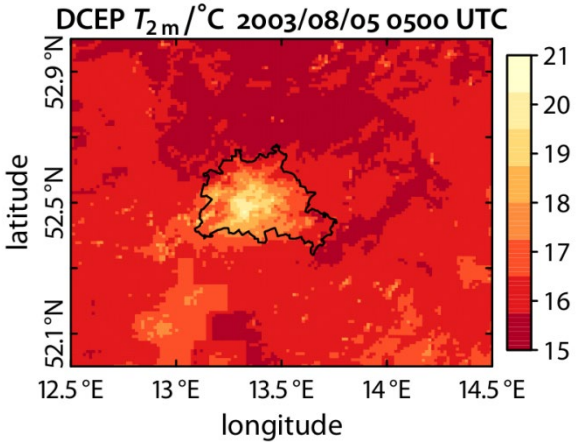
•Nighttime: Longwave radiation

Stable urban boundary layer, Bimodality at 22:30, late sunset in Jun/Jul.

Urban Regional Climate Modelling (UHI_S)

Simulation of urban effects on the atmosphere such as the urban heat island

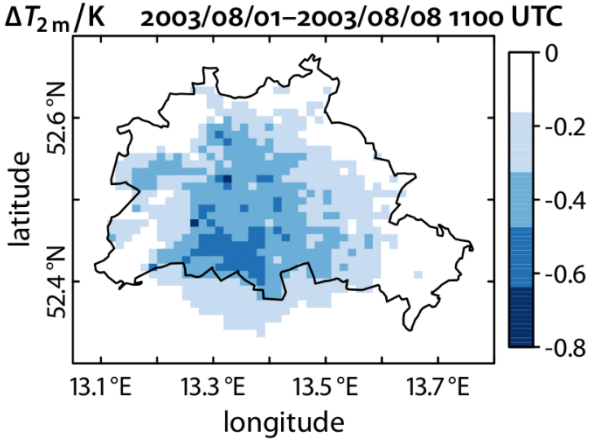
Improved urban canopy layer implemented in regional climate model COSMO-CLM (CCLM)



Typical night time T in Berlin

Assessment of urban heat island mitigation measures

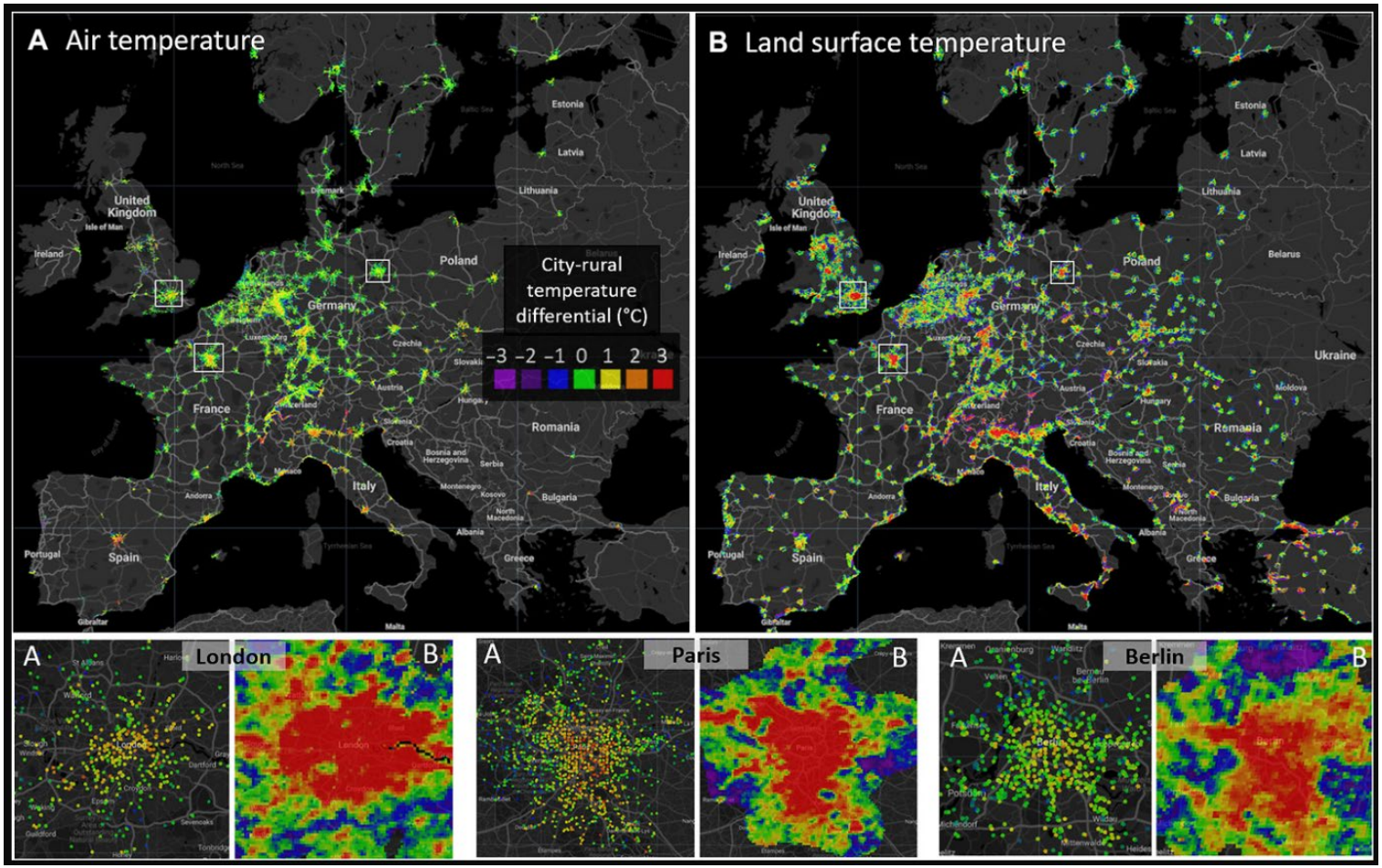
Application of city-wide high-albedo roof coatings in Berlin: up to 0.8K cooling midday during heat wave of 2003



Schubert, Grossman-Clarke & Martilli (2012) Boundary Layer Meteorology
Li Y, Schubert S, Rybski D, Kropp JP (2020): *Nature Communications*, 11: 2647

Crowdsourced temperature data reveal how satellites overestimate urban heat islands across Europe

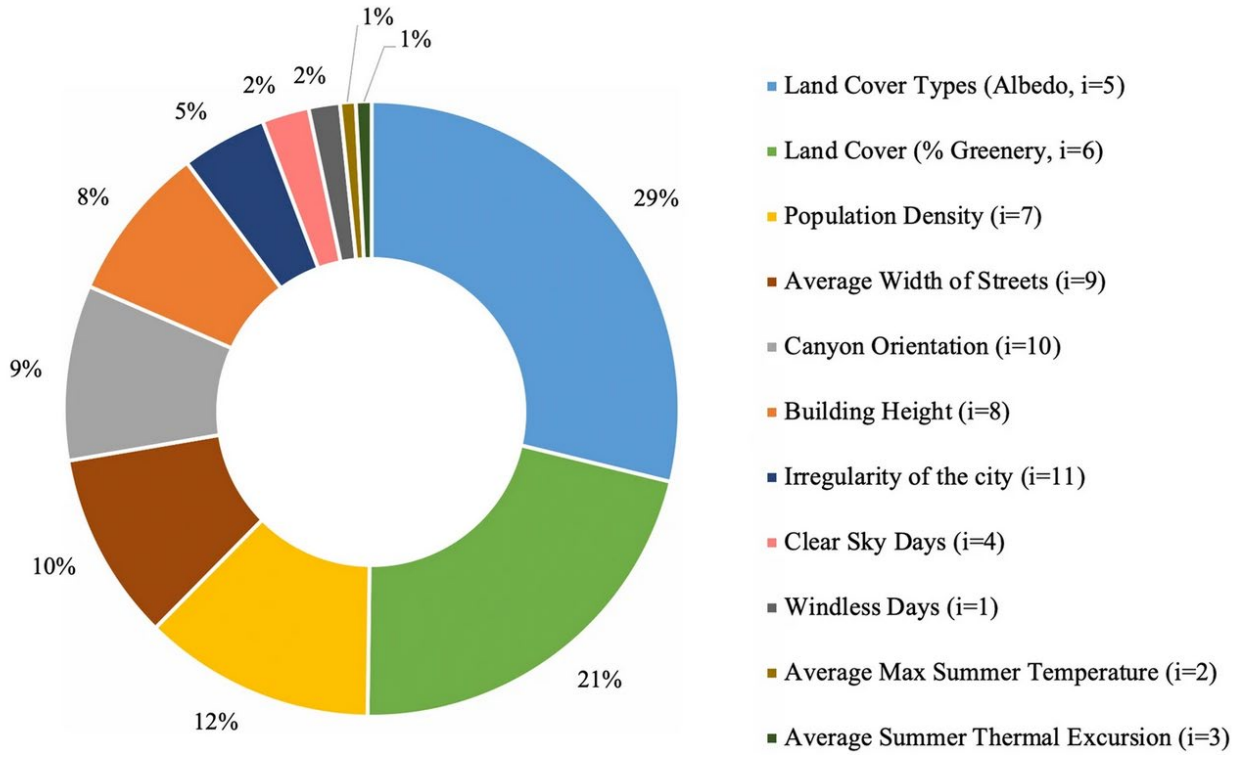
Approx.
1.4 °C



Data: NETATMO (https://netatmo.com/)

Zander S. Venter ZS, Chakraborty T, Lee X (2021): Science Advances, 7, 22,DOI: 10.1126/sciadv.abb9569

An index for UHI assessment!



Land cover (material) and urban greens explain 50% of UHI, another 24% is related to urban structure and form!

Sangiorgio V, Fiorito F & Santamouris M (2020) *Scientific Reports* **10**, 17913 (2020)

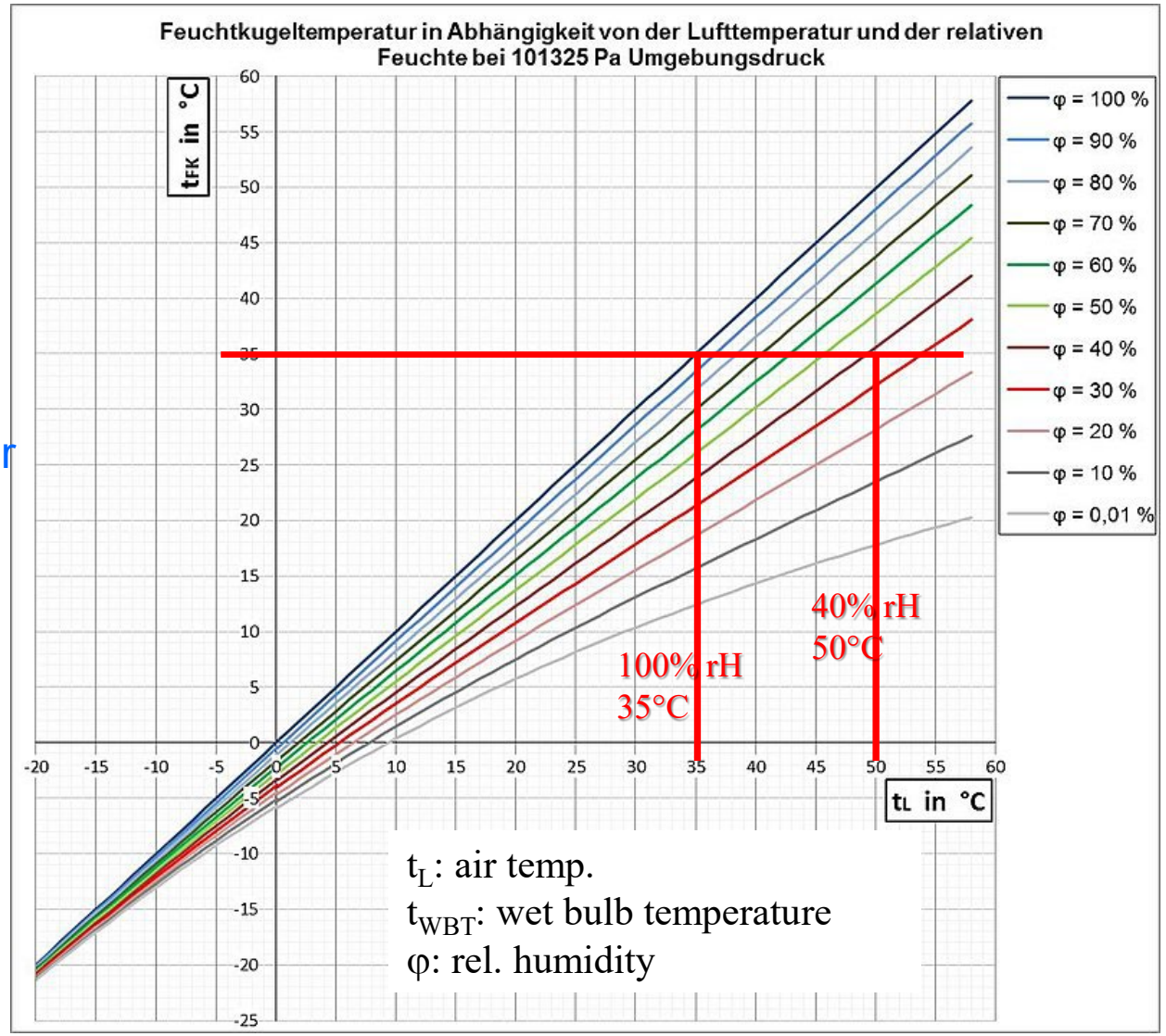
4% Background Weather

Impact on humans: T_{2m} plus humidity plus individual behaviour plus age!

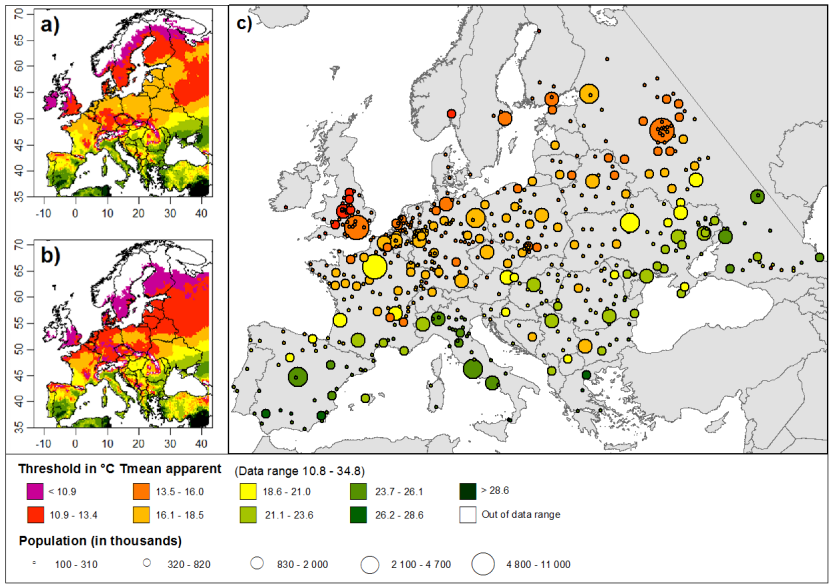
e.g. > 6 hrs 35 °C WBT potentially deadly

> 30° WBT is dangerous for elderly people!

Wet-bulb temperature better proxy

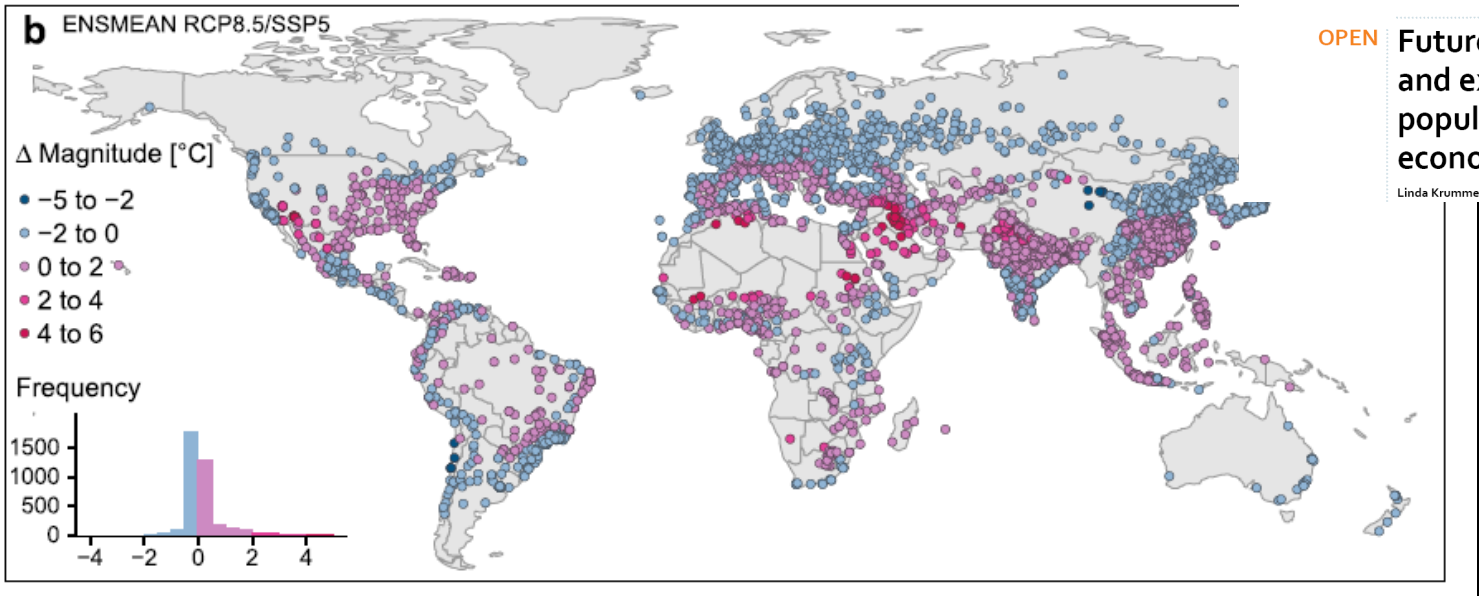


Impacts of Heat Burden in Cities



Modelling of changes in minimum mortality temperatures as a function of climate change and socio-economic progress for 3,820 cities

Hot spots: South Europe, Near and Far East, North/Central America! Cities in these regions are prone to increase mortality until 2100.



www.nature.com/scientificreports

scientific reports

Check for updates

OPEN

Future heat adaptation and exposure among urban populations and why a prospering economy alone won't save us

Linda Krummenauer[1,2✉], Luís Costa[1,3], Boris F. Prahl[1,3] & Jürgen P. Kropp[1,2]

Krummenauer L, Costa L, Prahl BF & Kropp JP (2021): *Scientific Reports* **11**, 20309.
Krummenauer L, Costa, L., Walther C, Prahl BF, Holsten A, Kropp JP *(2019): The Science of the Total Environment* **695**: 133560.

Monitoring data:

Corine Land Cover data (various, urban morphological zones)
https://land.copernicus.eu/en/products/corine-land-cover/clc2018
MODIS LST data (various):
https://modis.gsfc.nasa.gov/data/dataprod/mod11.php
Atmospheric Crowd Data:
https://weathermap.netatmo.com/
NASA Landcover data (various):
https://www.earthdata.nasa.gov/topics/land-surface/land-use-land-cover/data-access-tools
Gridded Population of the World (GWPv4):
https://www.earthdata.nasa.gov/data/projects/gpw

For local UHI assessments:

- Original data
- Subsets, e.g. urban greens, distance to the sea, elderly people
- Derived data, e.g. surface sealing

Summary

- For urban heat burden a log-logistic relationship between surface UHI intensity and city size was derived, which has been usually observed as log-linear.
- Urban form does influence the UHI intensity, but exhibits pronounced regional heterogeneity.
- The distinct seasonality at surface levels are ascribed to weak diurnal variation of T_{2m} complex regimes governing the temperature gradient of T_{2m}.
- Discernible regional patterns of UHI imply the role of climate zones in the development of UHI.
- UHI_S is a proxy for UHI, but the difference regimes between boundary and center (insolation vs. longwave radiation) needs further investigations

Solutions for Buildings

Kö-Bogen II, Ingenhoven Architects. Photo: www.ubm-development.com

Bsco verticale, Stefano Boeri. Photo: F. Ludwig

Tower Flower, Maison Edouard François

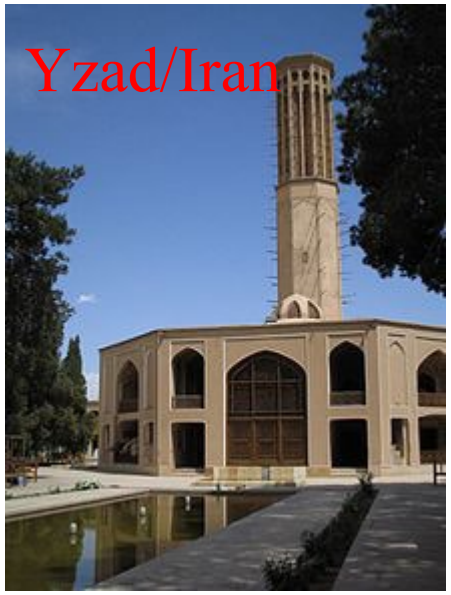
Tower of Biodiversity, Maison Edouard François

Skygarden Seoul, MVRDV. Photo: dezeen.com

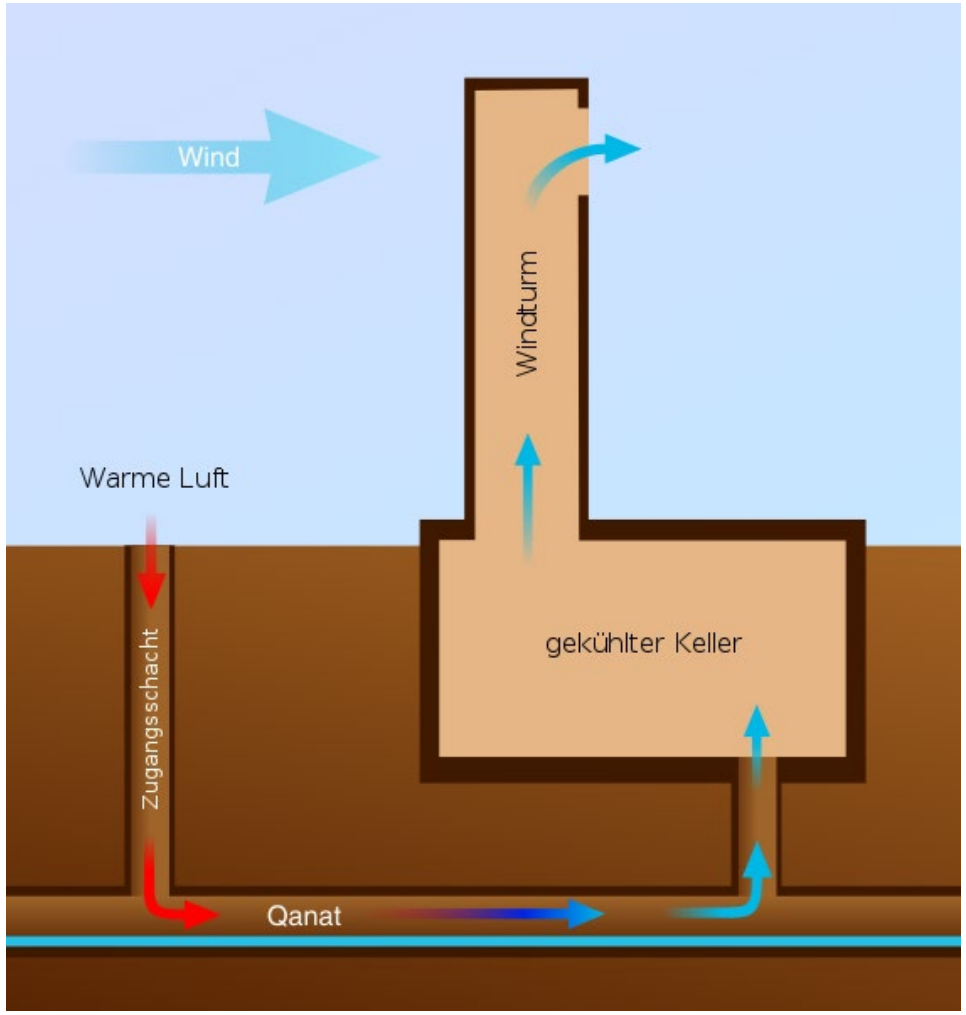
Evaporative Cooling: Trees & Parks!

Maschrabiyyas

Wind Towers



Adaptation: Refer to Experiences!



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Questions?