Urban Climate –
impact and interaction of air quality and Global Change

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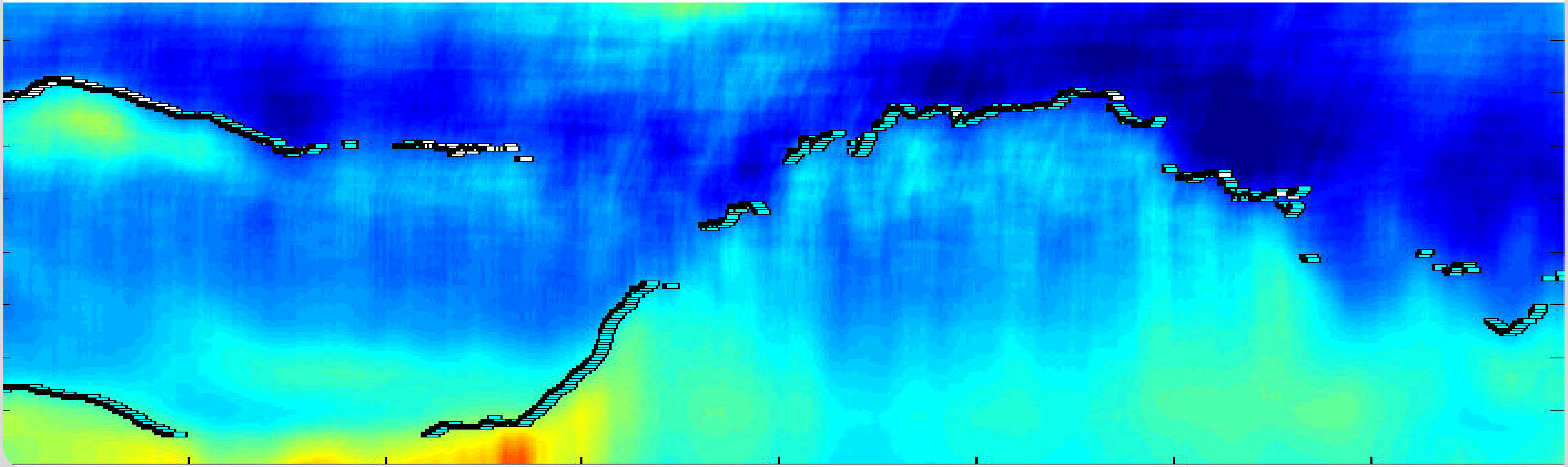

Some urban facts

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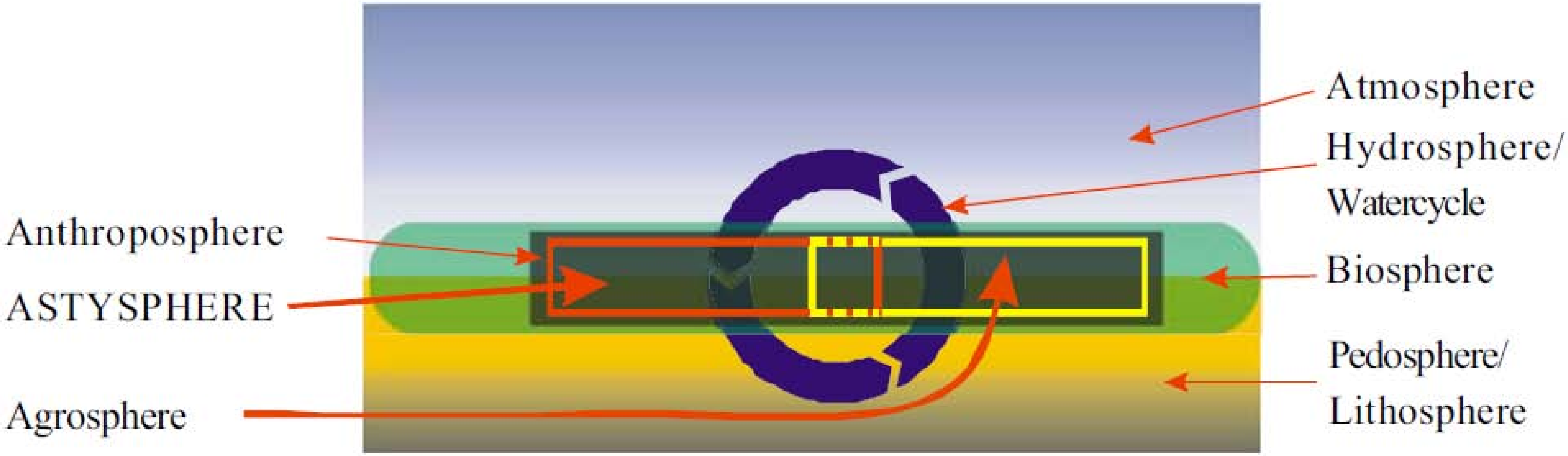
- Since **2007** more than **50 %** of the world's population live in urban agglomerations; it is estimated that **70 %** do so by **2050**
- Until 2030 there will be **59 cities** with more than 5 000 000 inhabitants and **23 megacities** with more than 10 000 000 people. (Brennan-Galvin 2000)
- Urban agglomerations in China increased from **20 % to 41 %** (between 1980-2005)
- Europe has an **urbanization rate of 72 %**
- **1.2 %** of the land surface is considered to be urban

Anthroposphere comprises cities and agricultural areas

Urbanisation has been the most drastic change in land use and land surface properties ever.

Stefan Norra therefore suggested the term **astysphere**.

The **astysphere** surrounds the globe like a spider net. The knots are the cities, and the silks represent the connecting transport network (Norra 2009).



from: Norra 2009

Peculiarities of the climate in the **astysphere**

buildings ➔ enhanced roughness ➔ reduced mean wind speed
➔ increased turbulence
➔ flow convergence at upwind edge ➔ mean upward motion
➔ clouds, precipitation
➔ short wave radiation is trapped (multiple scattering in street canyons, etc.)
➔ long wave radiation is retained (reduced sky view)
➔ heat is stored

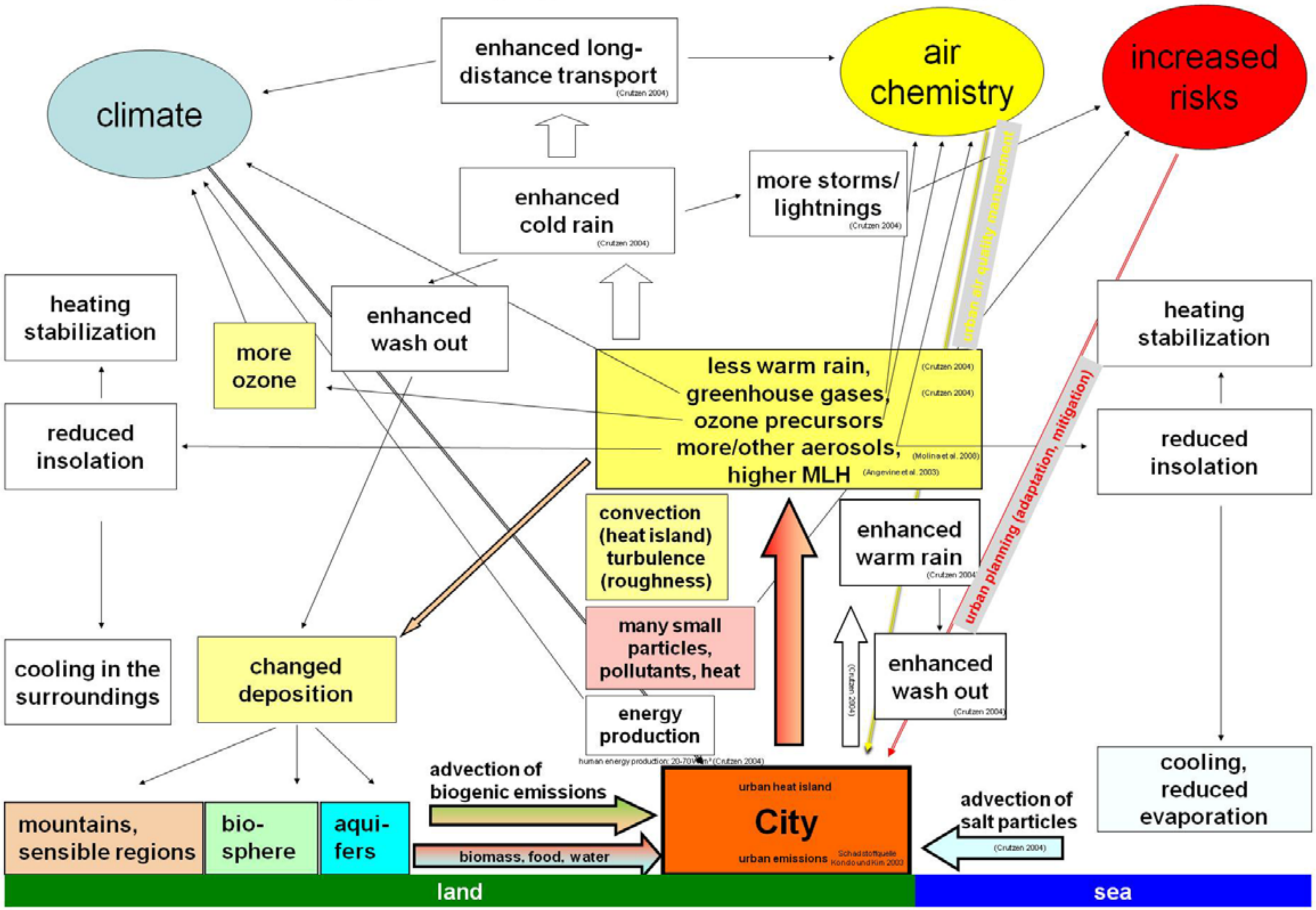
impervious surfaces ➔ stronger run off during precipitation events
➔ less humidity available for evaporation long after precipitation events

less vegetation ➔ less humidity available for evaporation

human beings ➔ anthropogenic heat production
➔ trace gas emission ➔ changed radiative properties of the air
➔ contribution to global warming
➔ aerosol production ➔ clouds, precipitation
➔ regional dimming

excess heat ➔ upward motion over cities ➔ compensating inflow from rural areas
(UHI) ➔ clouds, precipitation
➔ enhanced chemical transformations ➔ photo-oxidants ➔ health risks
➔ health risks

A city and its regional interrelations due to climate change, anthropogenic emissions and energy production



existing reviews

topic	reference
turbulence over cities	Roth (2000)
climatology of tropical cities	Jauregui (2000)
circulation and dispersion	Fernando et al. (2001)
urban climatology	Arnfield (2003)
precipitation	Shepherd (2005)
surface transfer coefficients	Hagishima et al. (2005)
scientific cooperation on urban climate	Oke (2006)
measurements and observations	Grimmond (2006)
surface models	Masson (2006)
physical models	Kanda (2006)
sustainable urban development	Mills (2006)
weather forecast	Best (2006)
CFD for street canyons	Li et al. (2006)
urban meteorology	Kanda (2007)
urban heat island	Hidalgo et al. (2008)
mitigation of UHI	Corburn (2009)
heat waves and health	Kovats und Ebi (2006)
UHI and air quality	???

The urban boundary layer

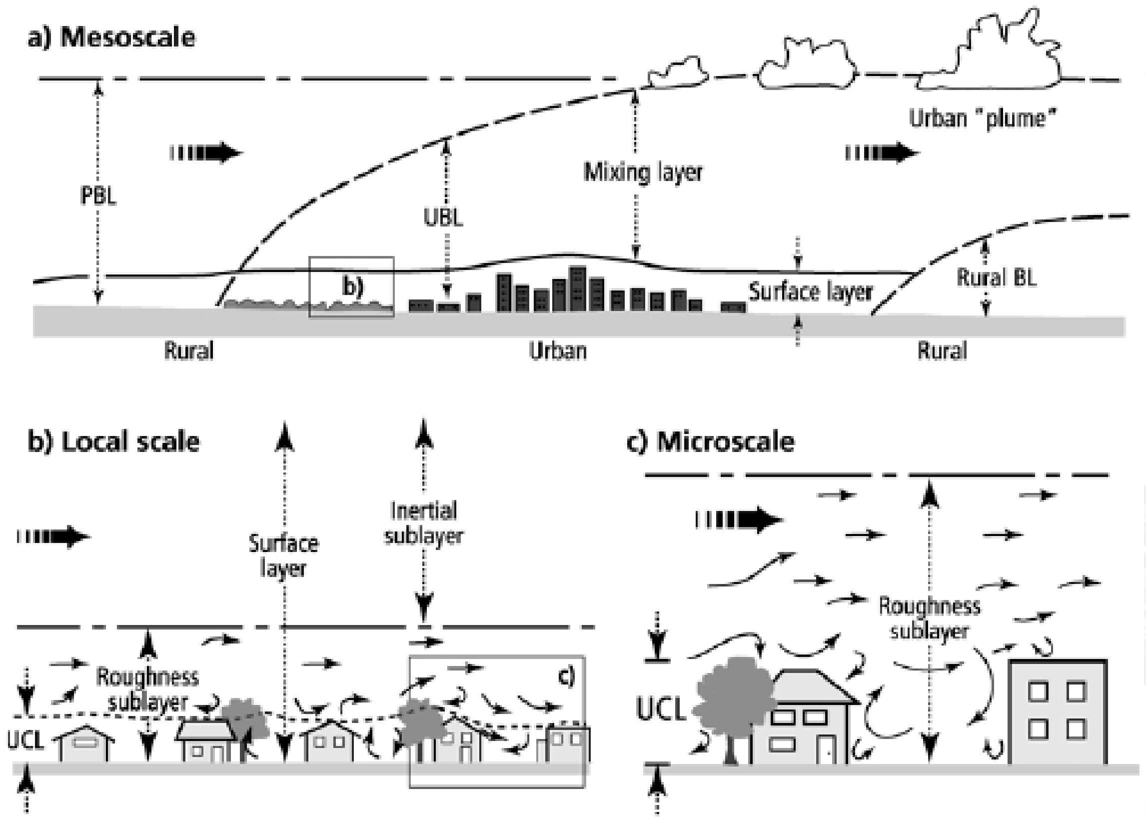
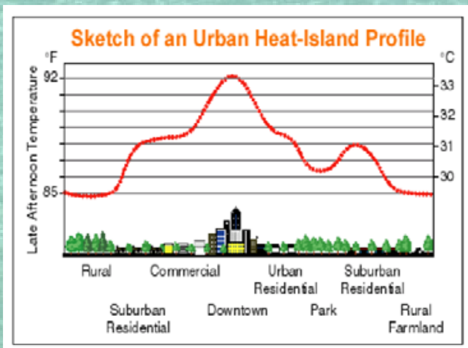


Figure 1. Schematic of the urban boundary layer including its vertical layers and scales. 'UBL' stands for Urban Boundary Layer, and 'UCL' for Urban Canopy Layer (revised by Oke and Rotach after a figure in Oke, 1997).

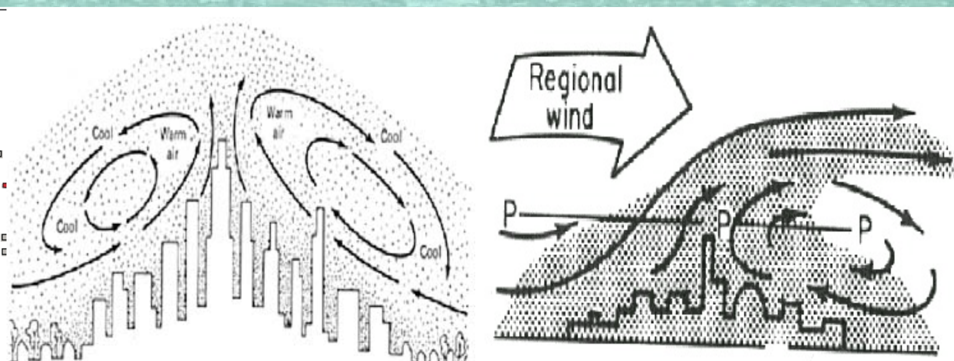
Piringer, M., C. S. B. Grimmond, S.M. Joffre, P.Mestayer, D. R. Middleton, M.W. Rotach,
A. Baklanov, K. de Ridder, J. Ferreira, E. Guilloteau, A. Karppinen, A. Martilli, V. Massoni,
B. M. Tombrou, 2002: Investigating the surface energy balance in urban areas –
C. recent advances and future needs. Water, Air, and Soil Pollution: Focus 2: 1–16.

Urban Heat Island: Definition

- "Urban Heat Island" (UHI) refers to the tendency for a city or town (urbanized areas) to remain **warmer than its surroundings**.
- The **annual mean temperature** of a large city may be **1°–2°C warmer** than the surrounding areas, and on individual calm, clear **nights** may be up to **12°C warmer (→ Heat Island Intensity)**.
- **Closed isotherms** indicating an area of the surface **(→ island)** that is relatively warm; most commonly associated areas of human disturbance such as towns and cities (urbanized areas).
- The warmth extends vertically to form an **urban heat dome** in near calm, and an **urban heat plume** in more windy conditions.



Source: Lawrence Berkeley National Lab.



Source: NASA Global Hydrology and Climate Center

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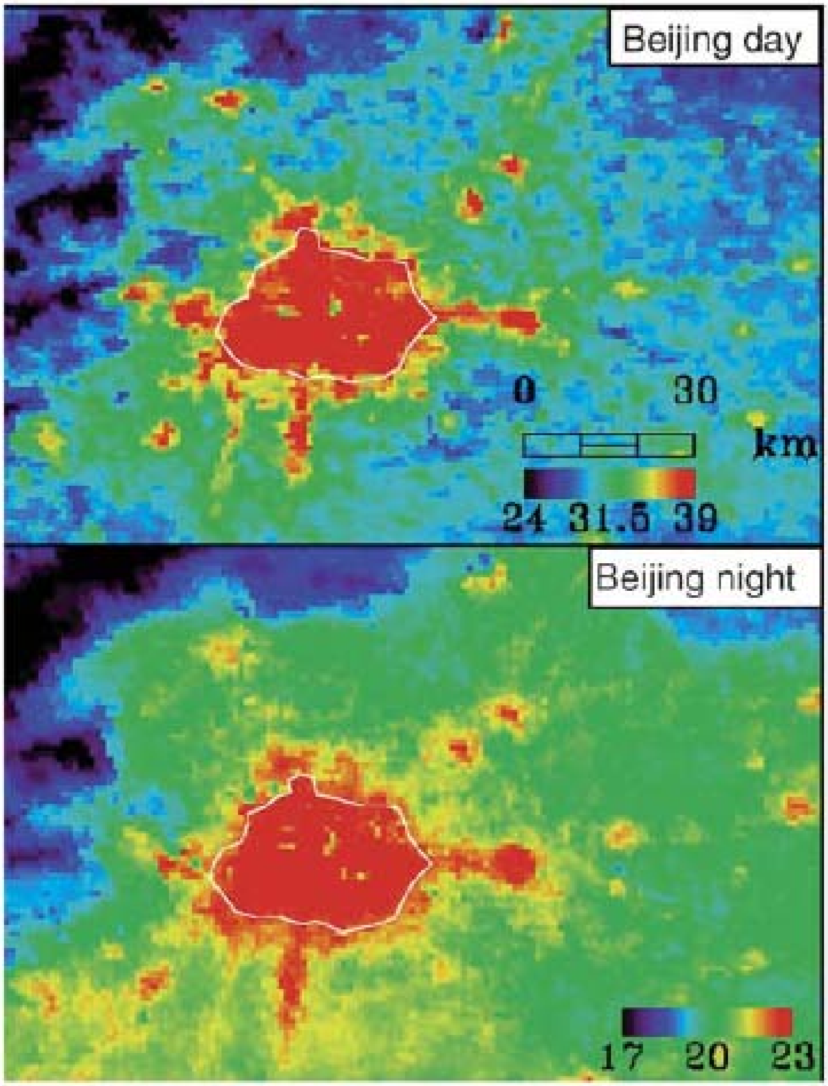
existing UHI studies

climate zone		examples	references
tropical	humid	Singapore, Kuala Lumpur	Tso (1996)
	dry-humid	Mumbai	Kumar et al. (2001)
	elevated terrain	Mexico	Jauregui (1997), Doran et al. (1998)
	deserts	Kuwait City, Phoenix	Nasrallah et al. (1990)
sub-tropical		Johannesburg	Goldreich (1992)
mediterranean		Athens	Philandras et al. (1999)
temperate	coastal	Tokio	Saitoh et al. (1996)
	continental	Moscow	Shahgedanova et al. (1997)
	complex terrain	Santiago de Chile	Romero et al. (1999)
higher latitudes		Göteborg	Eliassen und Holmer (1990)

Infrared images from MODIS (Hung et al. 2006)



spatial pattern of UHI

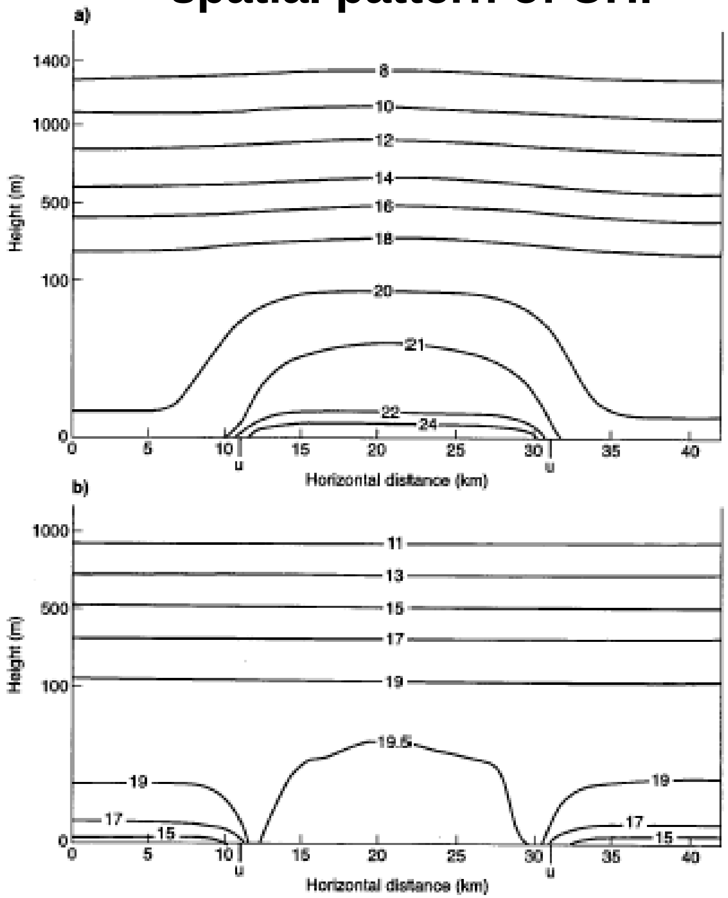
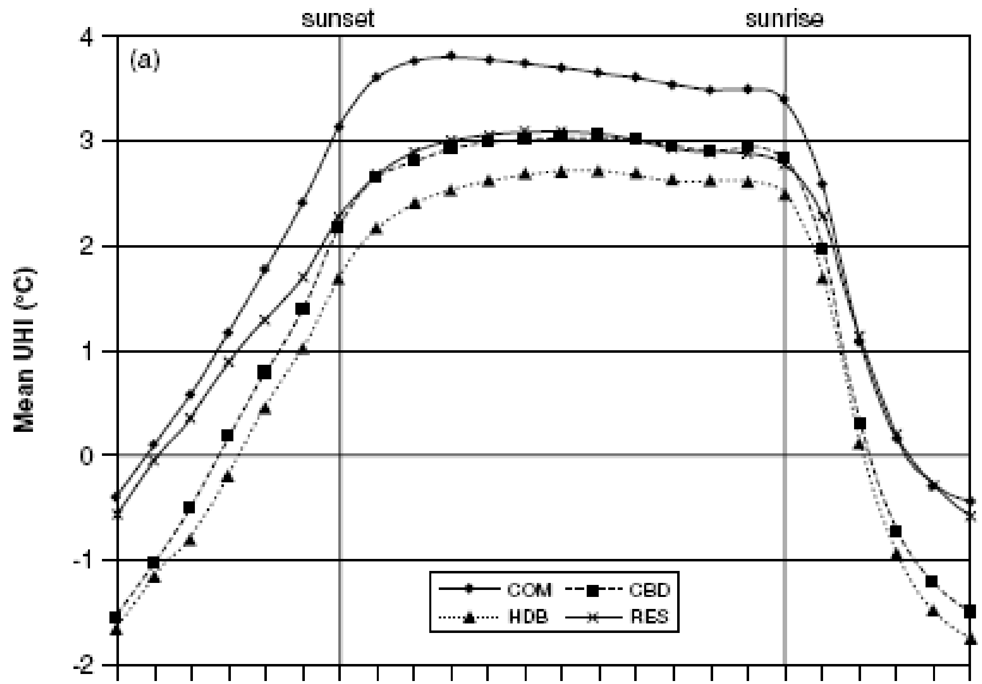


Figure 2. Cross section of simulated UHI at: (a) 1500 hr; (b) 0300 hr. U marks the limit of the urban area; temperature is in °C.

temporal pattern of UHI



Left: Fig. 2 from Atkinson (2003). Top: day-time, below: nighttime.
Right: Time series from Singapore (Fig. 6 top from Chow und Roth 2006)
COM: commercial site,
CBD: Central Business District,
HDB: high-rise residential site (Hochhaussiedlungen),
RES: low-rise residential site).

Atkinson, B.W., 2003: Numerical modelling of urban heat-island intensity. Bound.-Lay. Meteorol., 109, 285-310.

Chow, W.T.L., M. Roth, 2006: Temporal dynamics of the urban heat island of Singapore. Int. J. Climatol., 26, 2243-2260.

magnitude of UHI

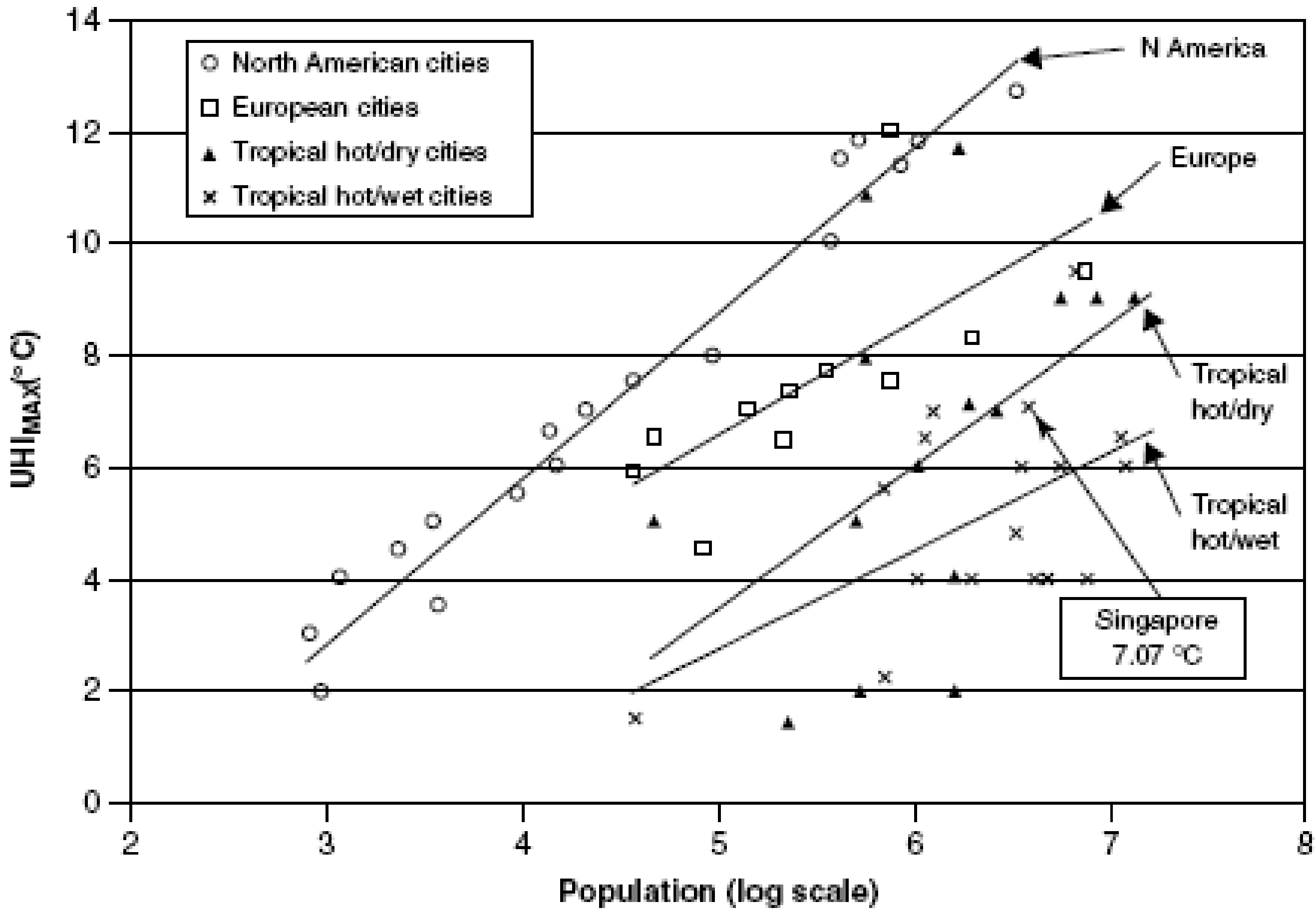
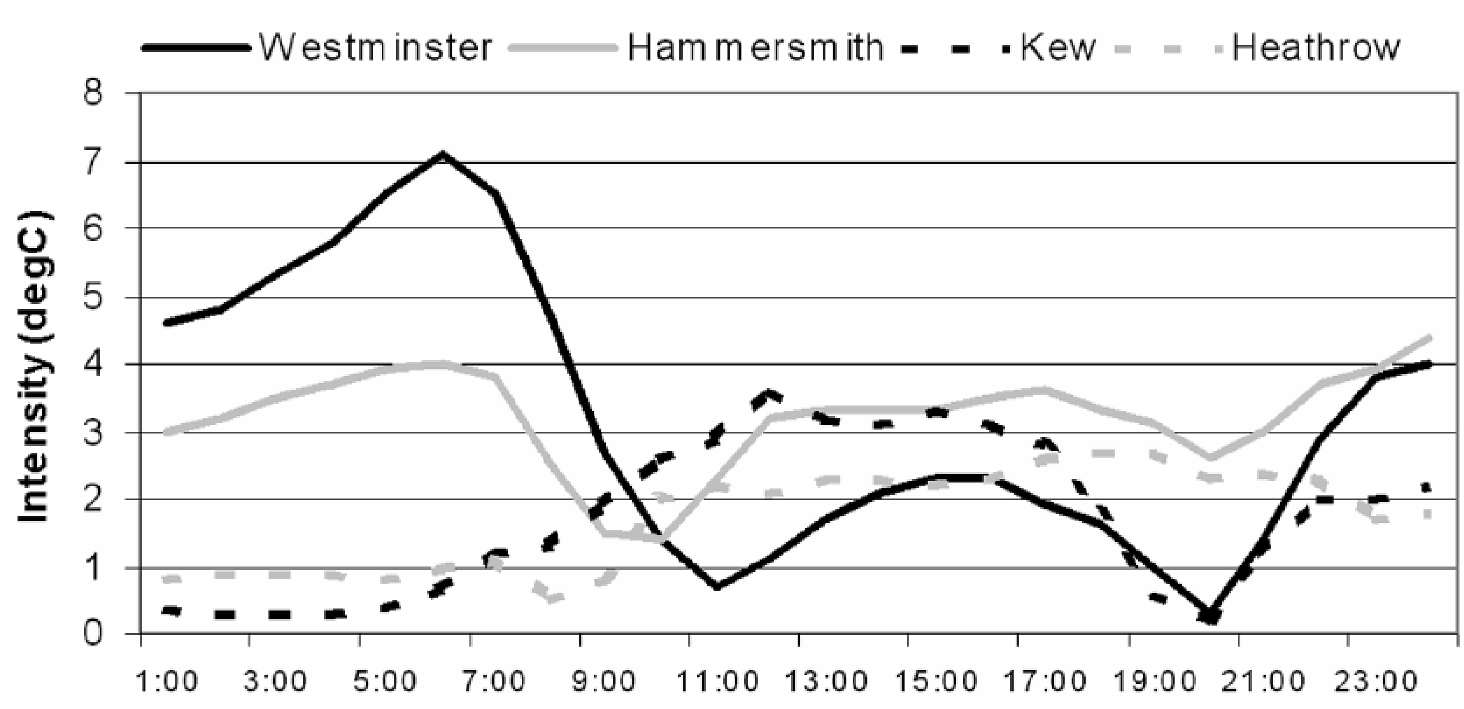


Fig. 10 from Chow, W.T.L., M. Roth, 2006: Temporal dynamics of the urban heat island of Singapore. Int. J. Climatol., 26, 2243-2260.

spatial variation of UHI



annual variation of UHI

Tokyo | **Bangkok**

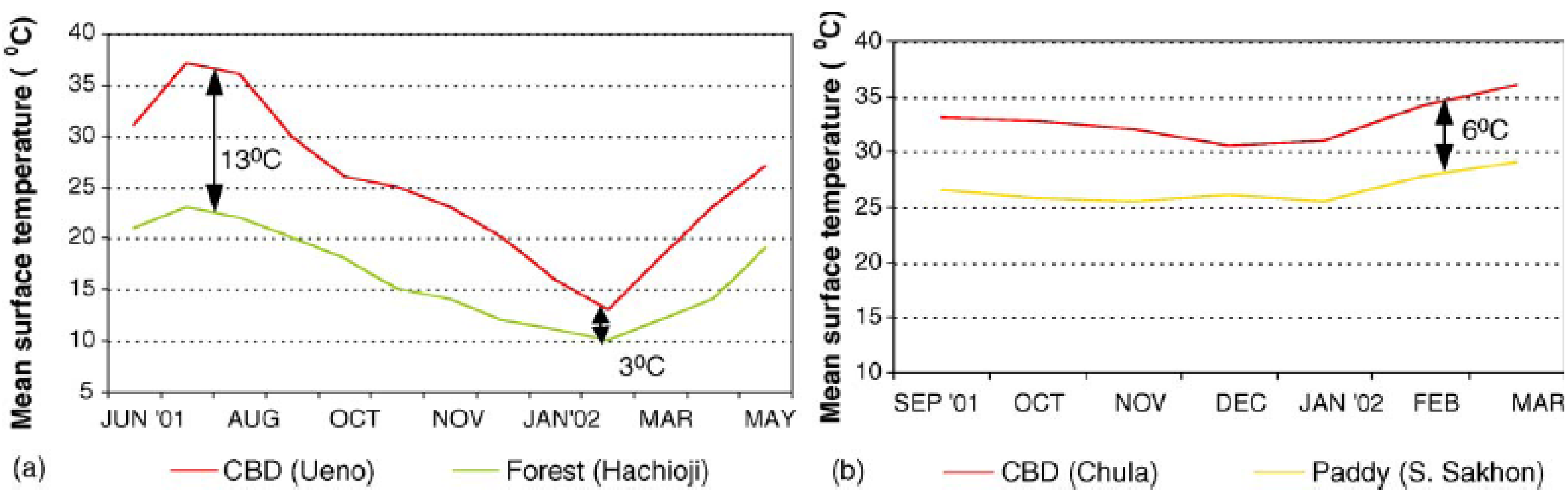
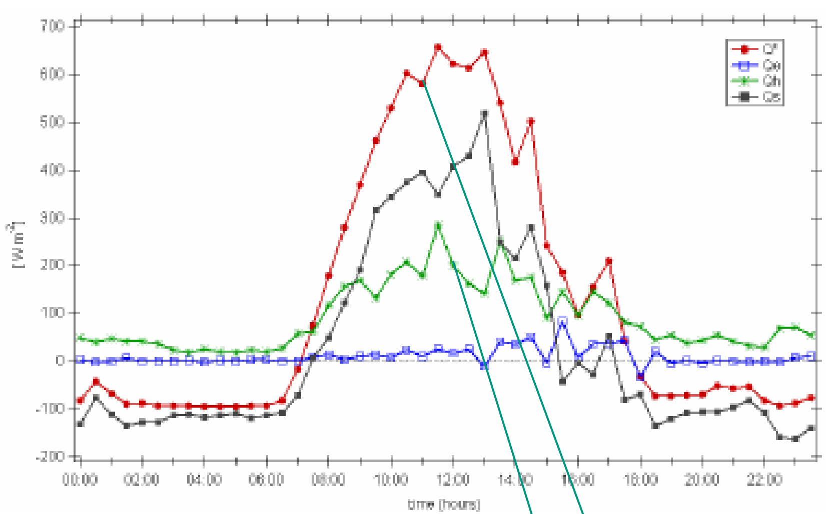


Fig. 2. Temporal variations of the day-time surface UHIs in: (a) Tokyo throughout the year and (b) Bangkok over the dry season.

from: Hung et al. 2006

energy balance of UHI



from: Velasco et al. 2007

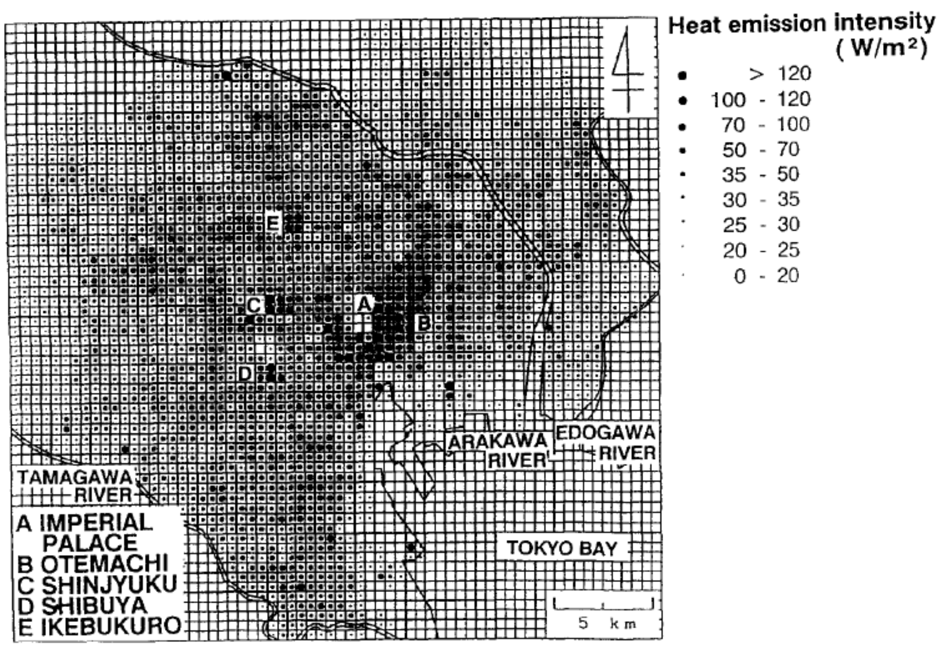


Fig. 6. Anthropogenic heat emission map in Tokyo (Summer, 1991).

from: Saitoh et al. 1996

net radiation

sensible heat flux

Cloud formation over urban heat islands (May 28, 2011)

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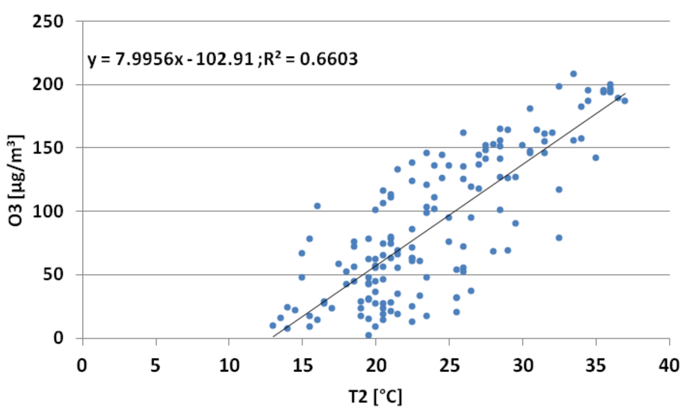
Interaction with air quality

cities ➔ trace gas emission ➔ changed radiative properties of the air
➔ contribution to global warming
➔ production of secondary trace gases (e.g., ozone)

➔ aerosol production ➔ clouds, precipitation
➔ regional dimming

➔ more heat ➔ faster chemical reactions (e.g., more ozone)
➔ shifted chemical equilibria
➔ secondary circulation ➔ brings rural biogenic and urban anthropogenic emissions together (e.g., ozone from BVOC and NO_x)
➔ enhanced the import of fresh air



Correlation between measured ozone and temperature at a urban centre

Interaction with Global Change

cities ➔ trace gas emission ➔ changed radiative properties of the air
➔ contribution to global warming

➔ aerosol production ➔ changed clouds and precipitation patterns
➔ regional dimming

➔ heat ➔ changed regional circulations

➔ growing urban population ➔ more emissions
➔ more heat
➔ more fresh water demand

....

Global Change ➔ warmer and partly dryer climate ➔ even warmer cities ➔ health
➔ less fresh water availability

➔ more people ➔ larger cities ➔ larger climate impacts
➔ problems in food supply

risks ➔ mitigation
➔ adaptation

Mitigation

solar radiation management (SRM) techniques

- increasing albedo, e.g., cool/white roofs
- less capturing of incoming short wave radiation in warm seasons
- more capturing of incoming short wave radiation in cold seasons
- less capturing of outgoing long wave radiation in warm seasons
- more capturing of outgoing long wave radiation in cold seasons

less heat storage

- reducing heat capacity of urban structures, e.g., better insulation of buildings

less anthropogenic heat production

- less cooling
- less air conditioning
- more effective (i.e. less) energy consumption

➔ nearly no negative consequences

white roofs …

white reflecting roof

darker absorbing walls

ideal combination for higher latitudes

Baufritz

… still quite unusual ?

but …

Corbis, spiegel.de

… take Santorin in Greece for example

desert towns …

good solution for sunny climates in low latitudes

Tindouf, Algeria

www.panoramio.com

Shibam, Hadramaut, Yemen

www.awesome-robot.com

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more insulation ➔ reduces heat capacity ➔ effective energy use

Baufritz

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Adaptation

more urban vegetation

- green roofs — irrigation, better insulation
- trees, parks — irrigation, BVOCs; parks cooler at night

more urban water

- lakes, creeks — breeding place for insects; supply humidity

passages for colder air

- open spaces, wide roads — windy conditions for pedestrians; open spaces cool at night

more cooling

- air conditioning — high energy consumption

more care

- health service — expensive

➔ many negative consequences

green roof in Chicago

www.explorechicago.org

green tram tracks in Zurich and Stuttgart

Murdoch University

www.bahnbilder.de

urban water in Vancouver

Murdoch University

how to decide which measure is suitable?
how to avoid to much negative side effects?

Tools - observation/monitoring
- complex numerical assessment models

Surface-based Remote Sensing Systems

at IMK-IFU

Karlsruhe Institute of Technology

SODAR (Large system), acoustic backscatter, Doppler shift analysis ➔ wind, turbulence

SODAR-RASS (Doppler-RASS), acoustic, electro-magnetic backscatter, determines speed of sound ➔ wind and temperature profiles

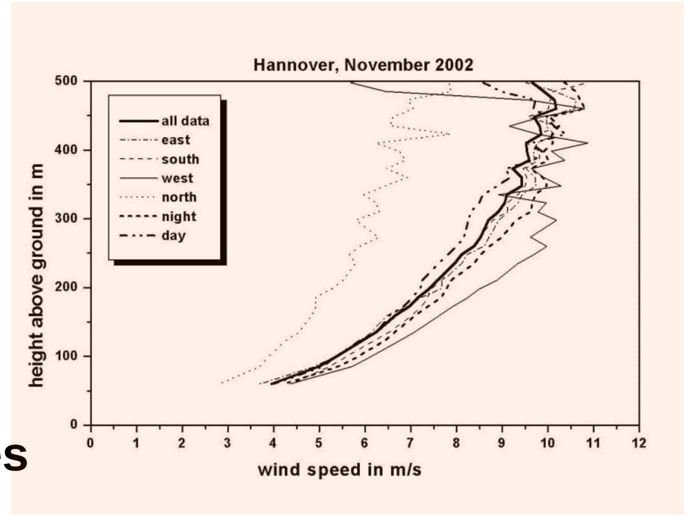
Ceilometer, backscatter, optical pulses, wave length ~ 0.9 µm ➔ aerosol profiles

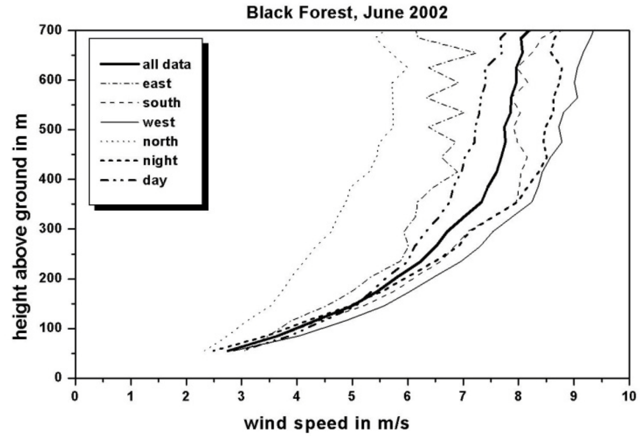
Wind-LIDAR, optical backscatter, Doppler shift analysis, wave length ~ 1.5 µm ➔ wind and aerosol profiles

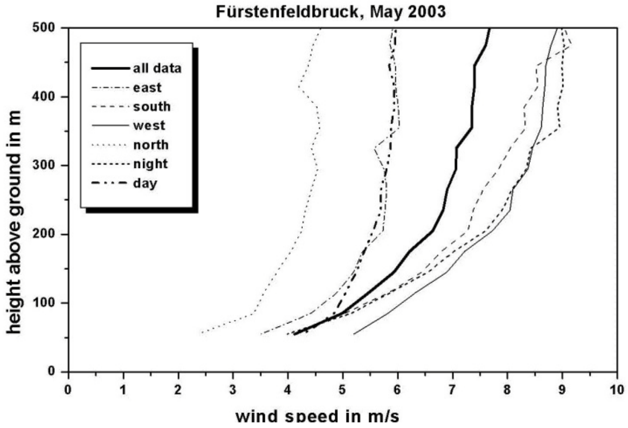
image: Halo Photonics

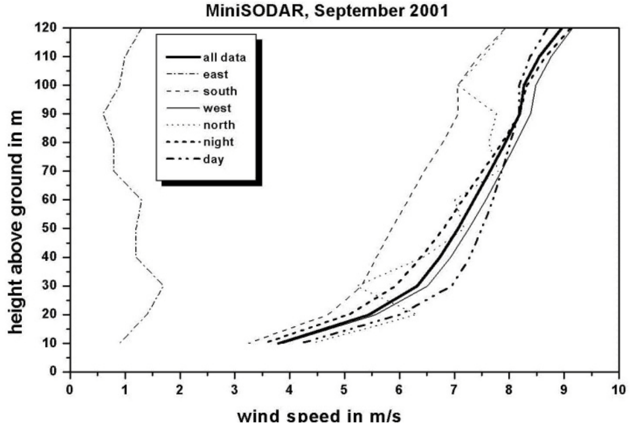
comparison of urban and rural wind profiles from sodar measurements

Monthly mean vertical profiles of wind speed



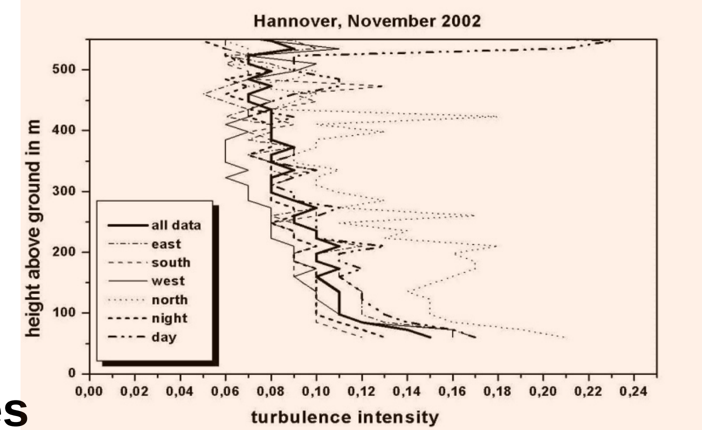


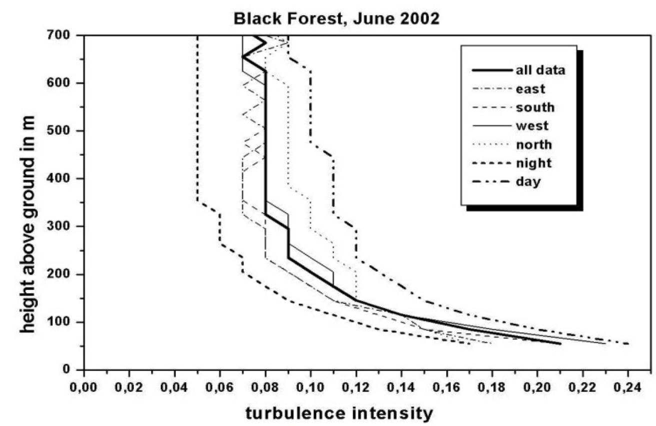


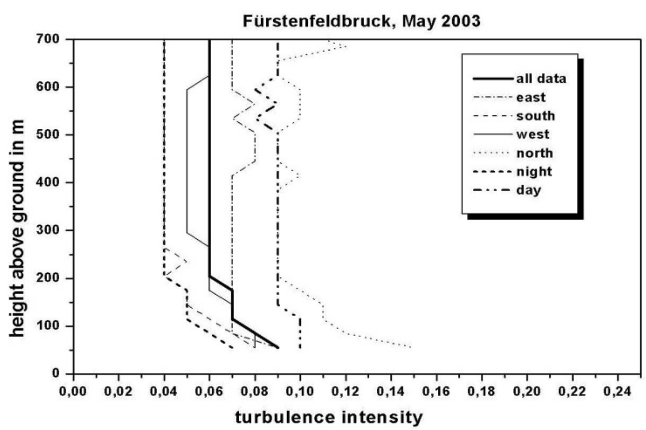


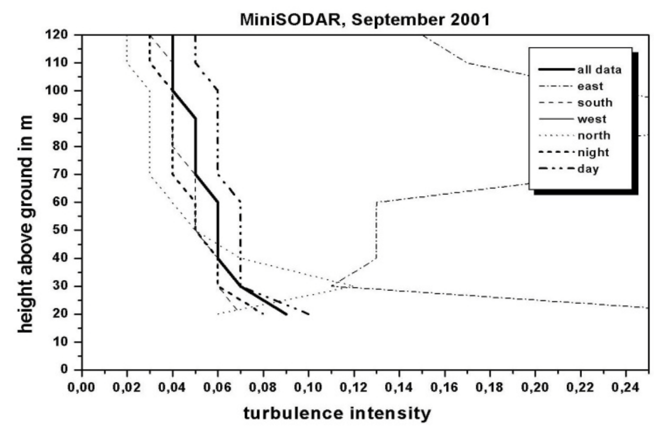
comparison of urban and rural turbulence profiles from sodar measurements

Monthly mean vertical profiles of turbulence intensity

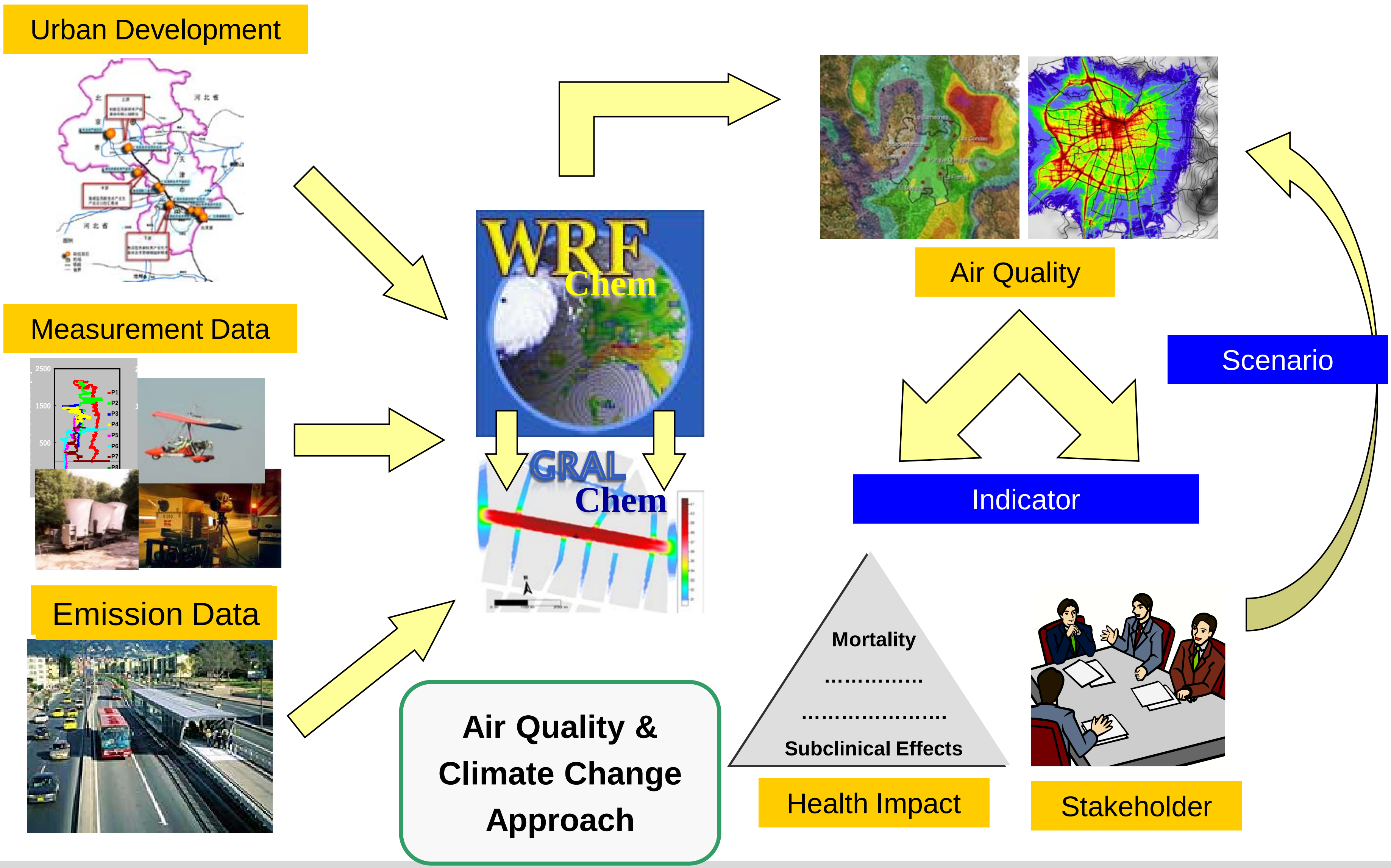








Integrated model approach



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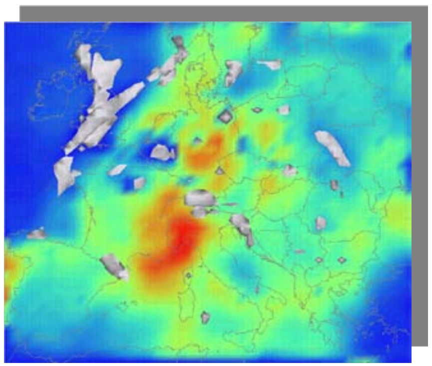
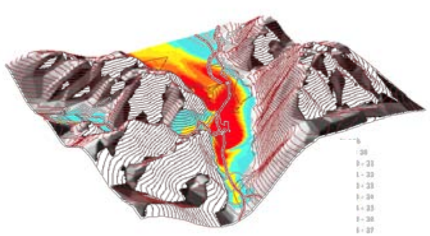
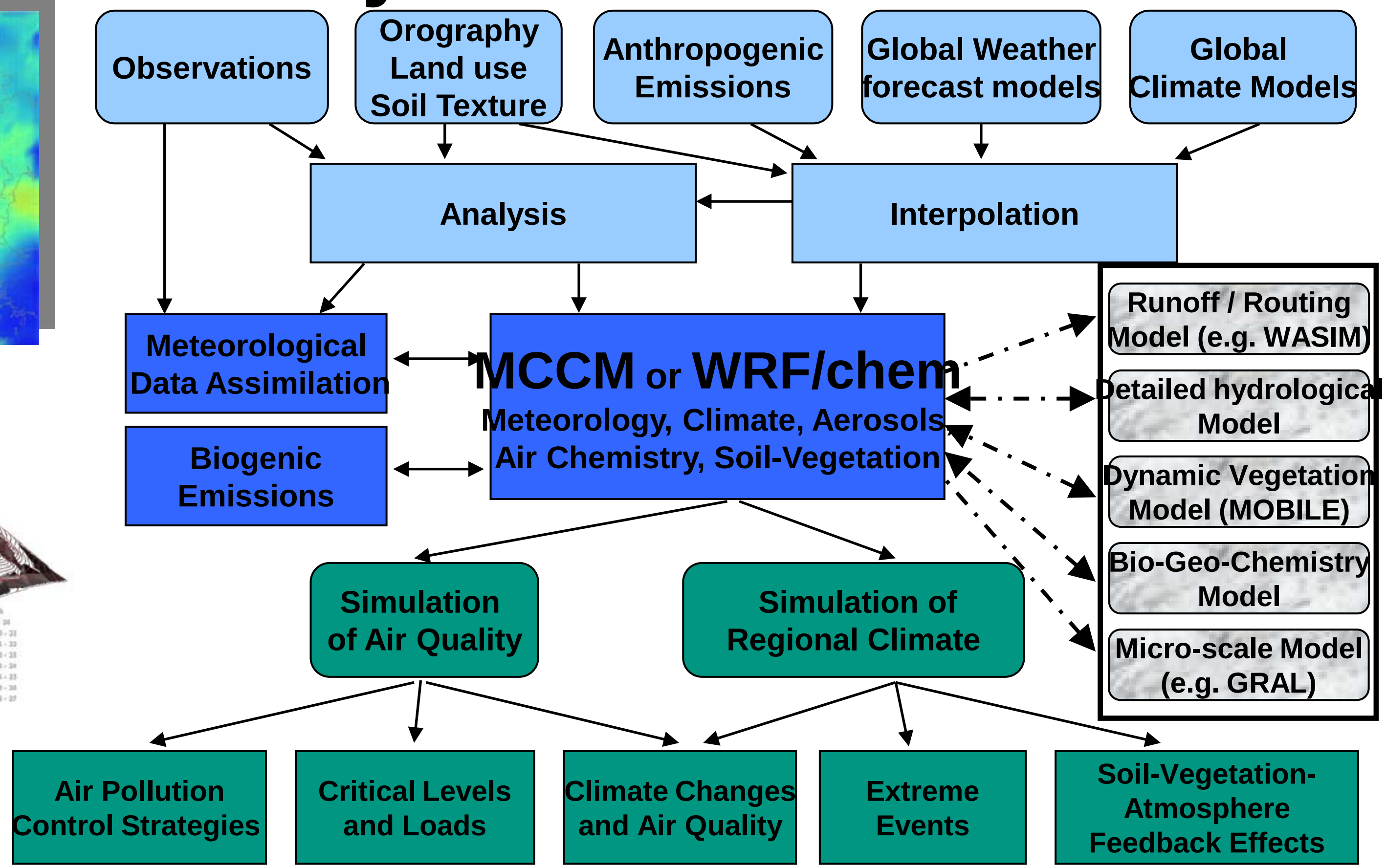
Coupling of models/Modelling System



regional

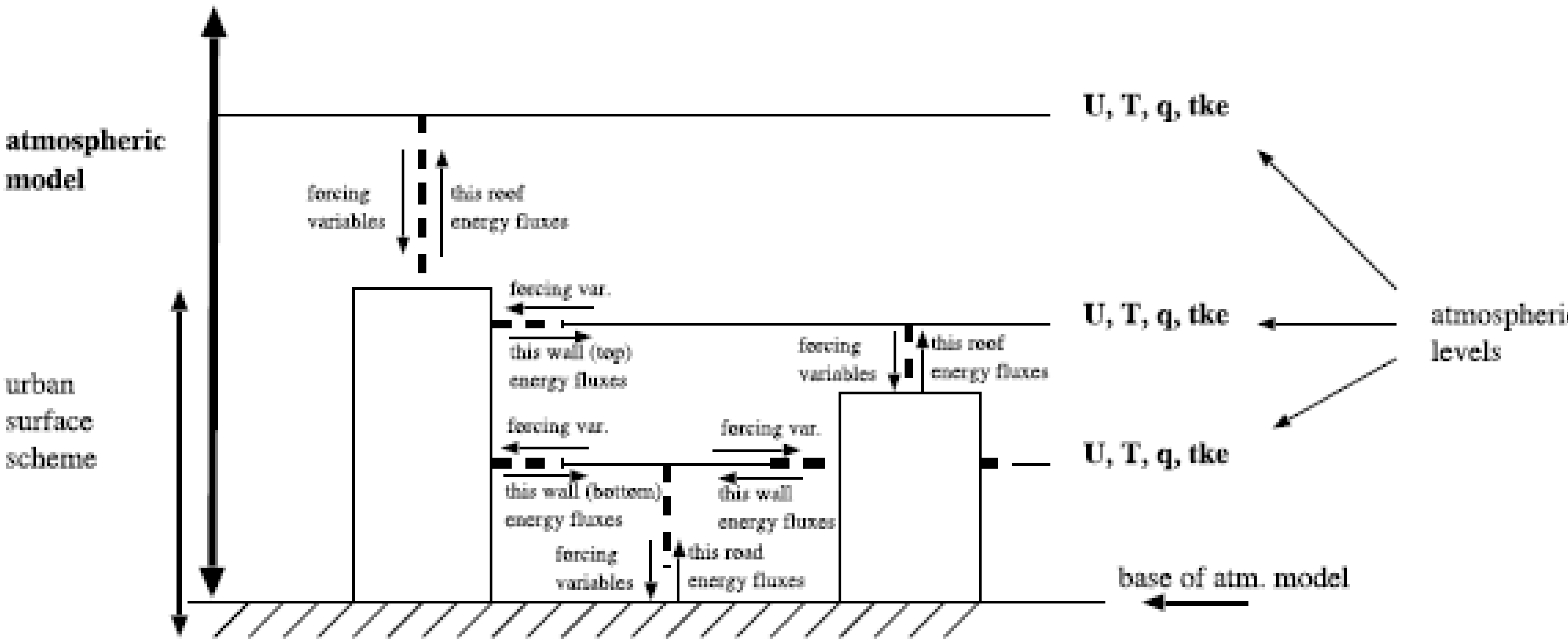


local



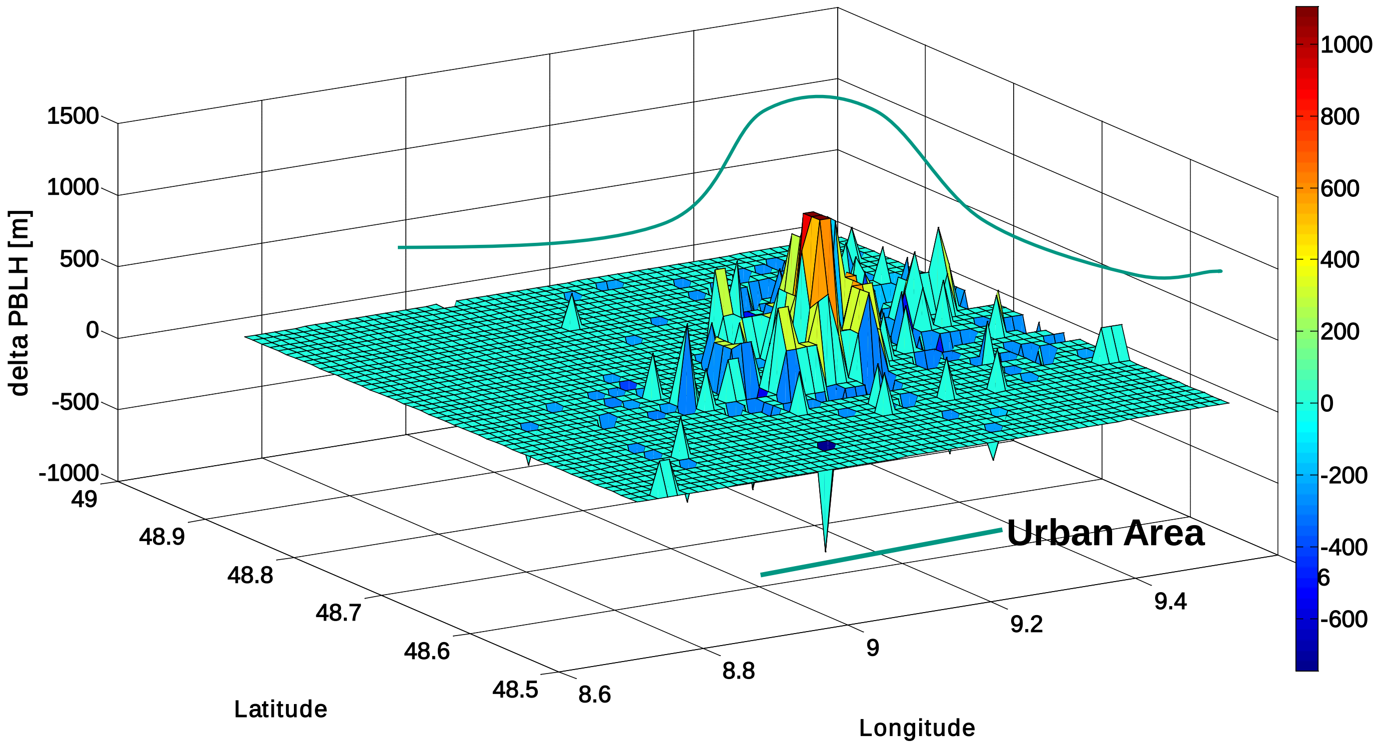
representation of a city in a numeircal model

multi-layer approach



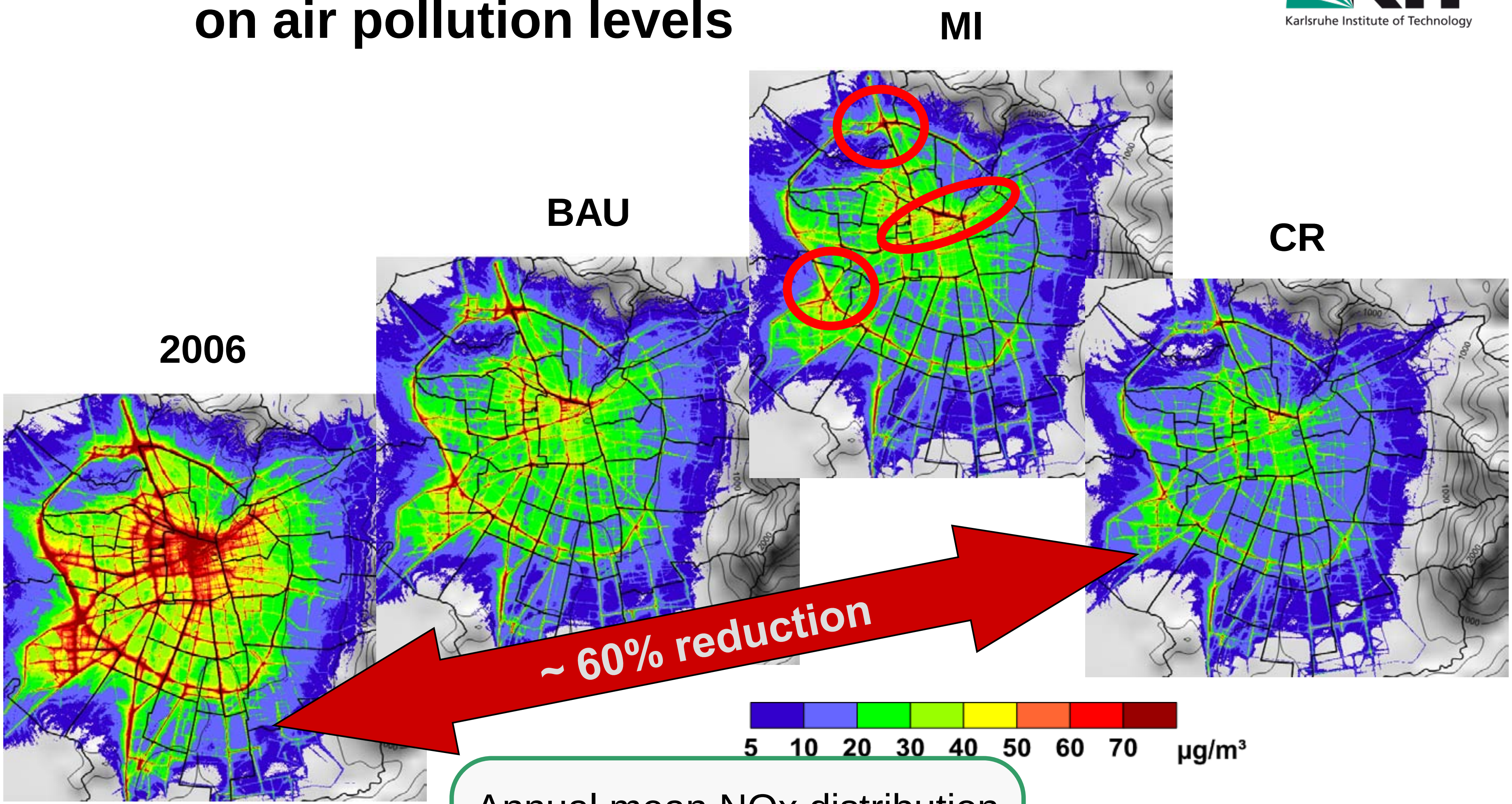
Masson 2006

modelled increase of PBL height over a city



Difference in PBLH for 3rd domain (48x60km); BEP; Aug 12th 2003 – 17:00 UTC

Impact of mitigation/adaptation on air pollution levels

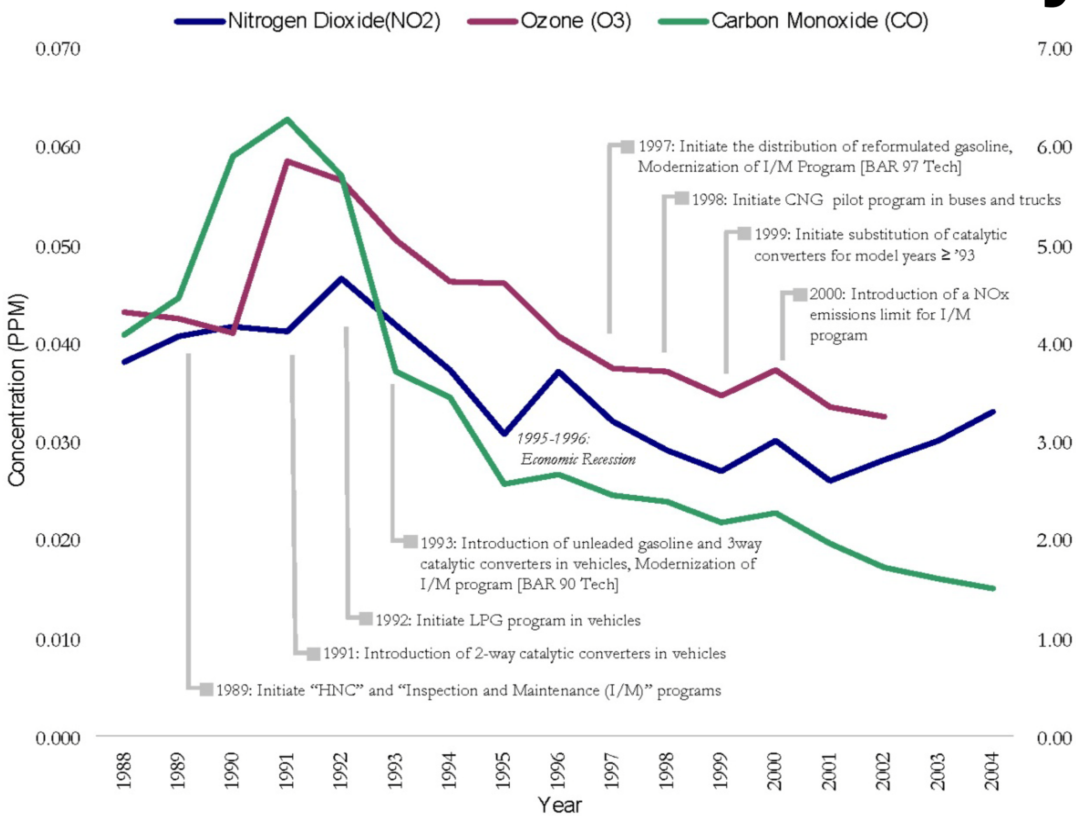


Annual mean NOx distribution for 2006 (only traffic emissions) in the Greater Region of Santiago de Chile

BAU - business as usual
MI - market individualism
CR - collective responsibility

Source: Johannes Werhahn, IMK-IFU

Governance & Sustainability



Air Quality management policies, emission control programs and pollutant trends in Mexico City

Source: APERC (2007): Urban Transport Energy Use in the APEC Regions

Conclusions and summary

urban climate needs attention	**- risks** **- growing urban population**
solution strategies	**- mitigation** **- adaptation**
good tools available	**- observation and monitoring devices** **- complex assessment models**
special urban climate features	**- urban heat island**

Conclusions and summary

The Urban Heat Island (UHI)

excess heat

- ➔ upward motion
  - ➔ clouds, precipitation
  - ➔ inflow from rural areas
    - ➔ brings biogenic and anthropogenic emissions together
      - ➔ chemical reactions
        - ➔ health risks

- ➔ enhanced chemical transformations
  - ➔ photo-oxidants
    - ➔ health risks

- ➔ enhanced energy demand for cooling/air conditioning
  - ➔ more anthropogenic heat and emissions

- ➔ direct health risks

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Thank you very much for your attention