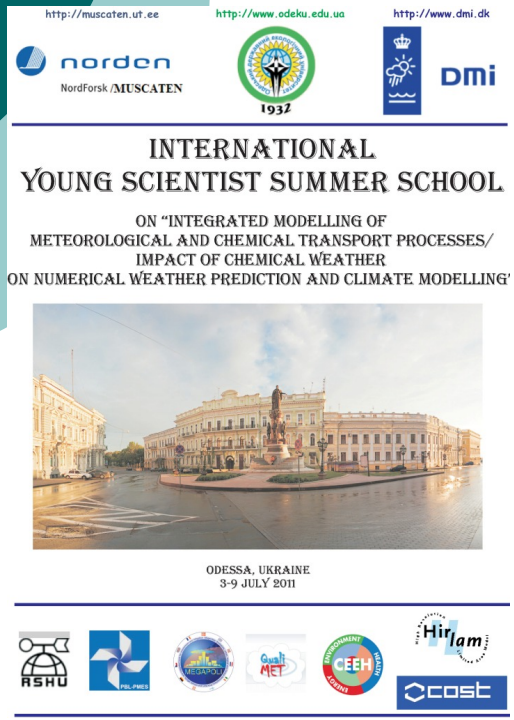
Treatment of Land-Use and Urbanization

LECTURE 6



Alexander Mahura

Danish Meteorological Institute, DMI,
Copenhagen, Denmark

MUSCATEN et al. Young Scientist Summer School
on Integrated Modelling …
3-9 July 2011, Odessa, Ukraine

Outline of the Lecture

- Land-cover and land-use: classification, datasets, etc.;

- Urban lands: some statistics;

- Urbanized areas: urban boundary layer, features, controls, characteristics, approaches for treatment, etc.

- Urbanization of Enviro-HIRLAM: modules, urban districts, anthropogenic heat flux, some results (on examples), applicability, etc.


LAND COVER and LAND USE

Land Cover and Land Use

Land cover -

defined as observed physical cover, as seen from the ground or through remote sensing, including natural or planted vegetation and human constructions (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces count as land cover.

Land Use –

defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one or several pieces of land, and several land uses may occur on the same piece of land.

Why There is a Need for Meteorological Modelling

Simulate exchanges between surface and atmosphere (momentum, heat, water, chemical species, etc.);

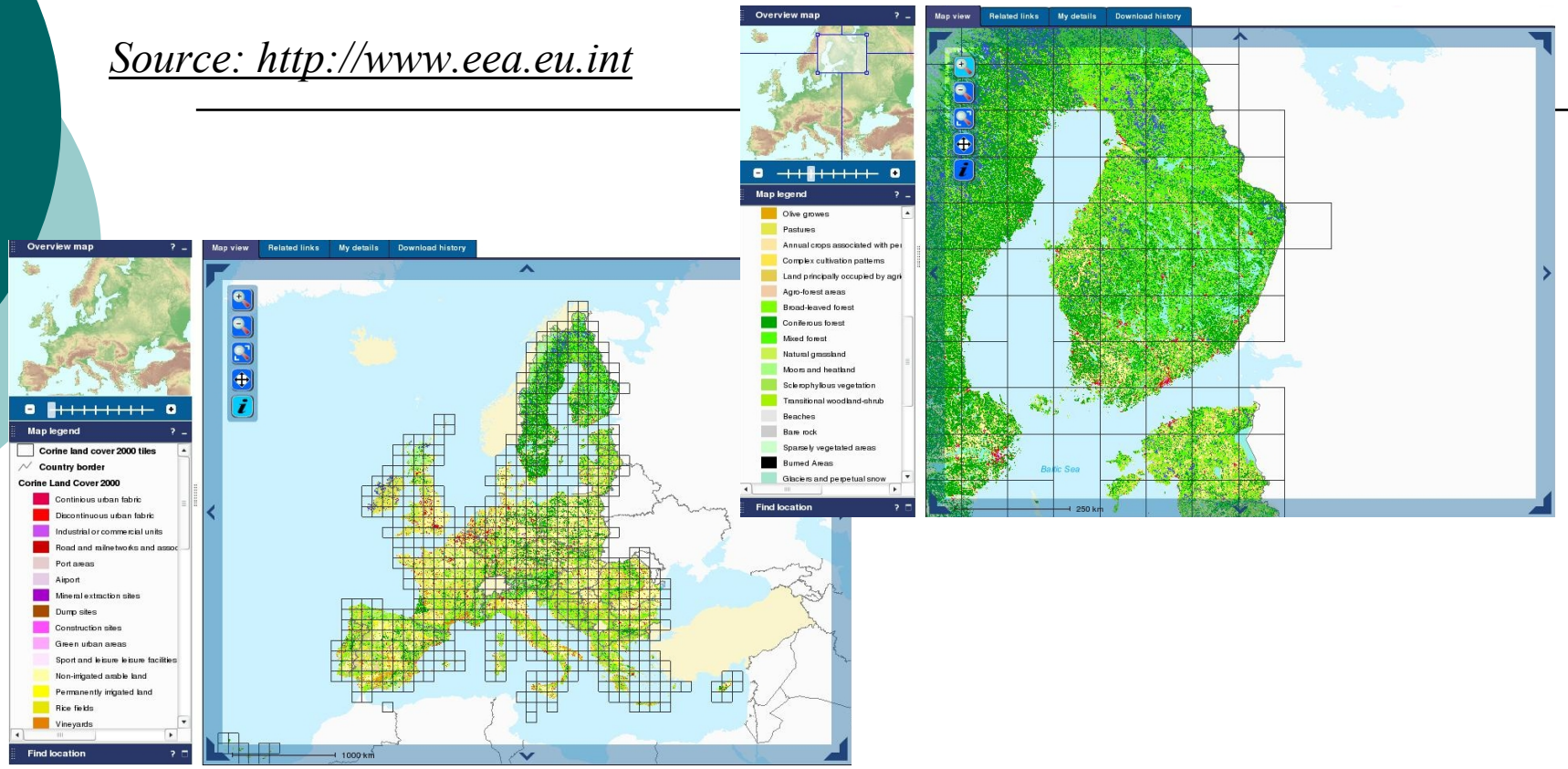
Take into account the climate variability from one region to another;

Separate the surface schemes from the atmospheric model - allows to use the same surface code for several atmospheric models (NWP models runs) - easy switch between surface schemes and options;

All surface fields necessary to land surface schemes

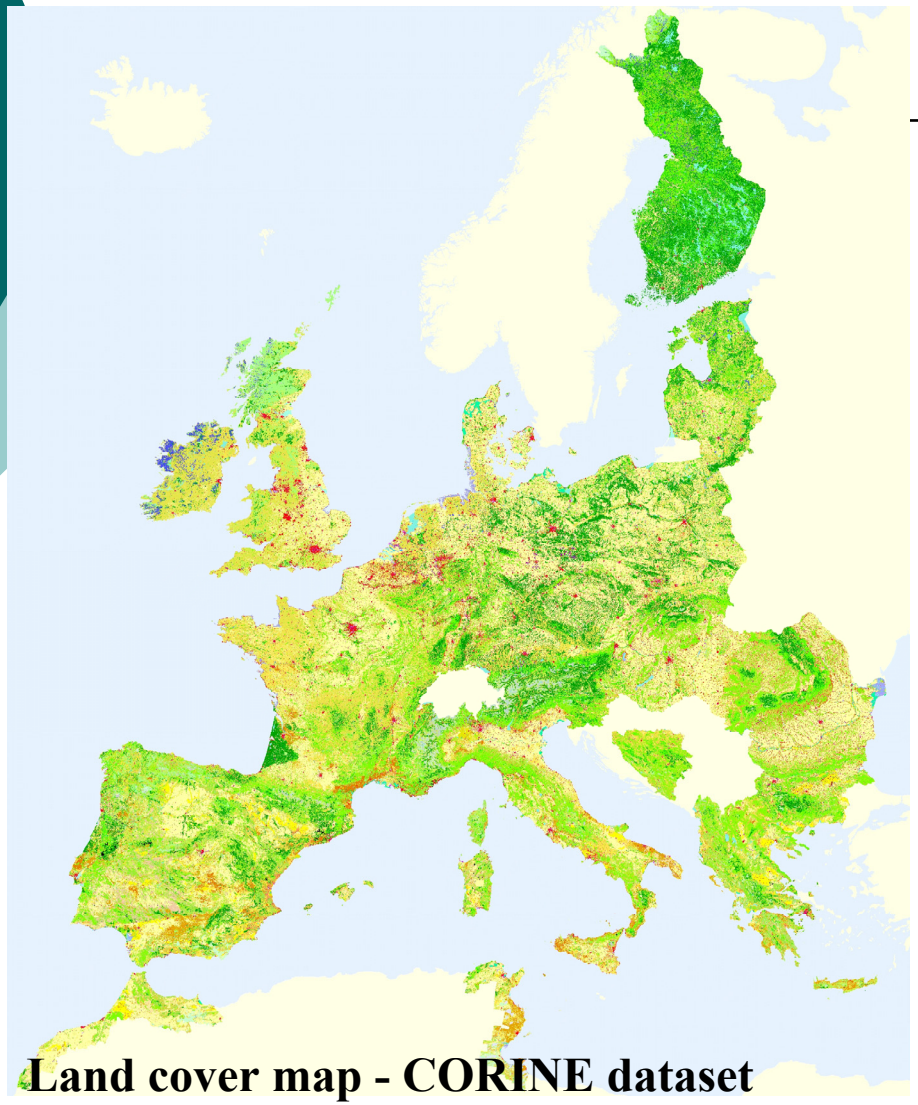
CORINE:
Coordination of Information on the Environment

Source: http://www.eea.eu.int



LCDB - based on interpretation of satellite images for 1989 and 1990,
land cover types in 44 standard classes,
GIS ARC/INFO format, at an original scale of 1:100,000 (consistent and comparable with similar land cover databases in other European countries.
Update - 2000

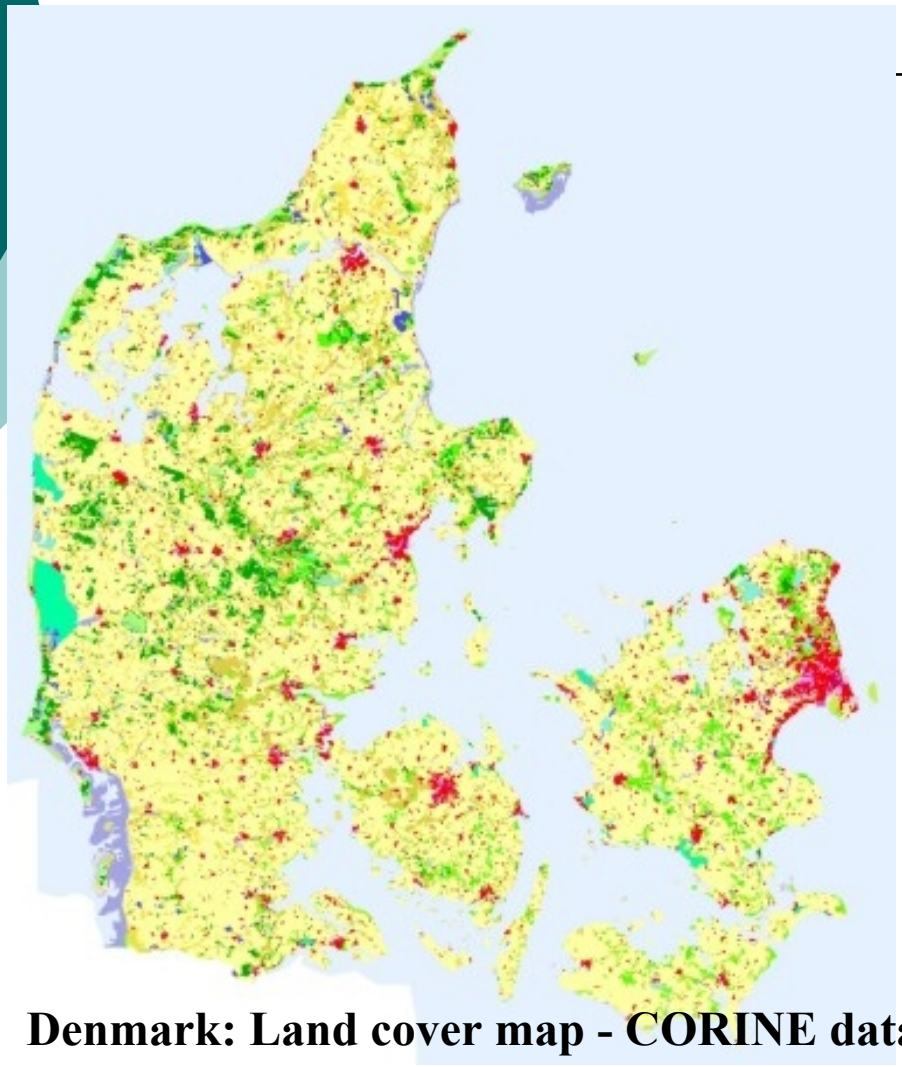
CORINE : EU Countries



Land cover map - CORINE dataset
250 m resolution, 44 classes

- Continuous urban fabric
- Discontinuous urban fabric
- Industrial or commercial units
- Road and rail networks and associated land
- Port areas
- Airports
- Mineral extraction sites
- Dump sites
- Construction sites
- Green urban areas
- Sport and leisure facilities
- Non-irrigated arable land
- Permanently irrigated land
- Rice fields
- Vineyards
- Fruit trees and berry plantations
- Olive groves
- Pastures
- Annual crops associated with permanent crops
- Complex cultivation patterns
- Land principally occupied by agriculture, with significant areas of natural vegetation
- Agro-forestry areas
- Broad-leaved forest
- Coniferous forest
- Mixed forest
- Natural grasslands
- Moors and heathland
- Sclerophyllous vegetation
- Transitional woodland-shrub
- Beaches, dunes, sands
- Bare rocks
- Sparsely vegetated areas
- Burnt areas
- Glaciers and perpetual snow
- Inland marshes
- Peat bogs
- Salt marshes
- Salines
- Intertidal flats
- Water courses
- Water bodies
- Coastal lagoons
- Estuaries
- Sea and ocean
- NODATA

CORINE : Denmark : Classification



Denmark: Land cover map - CORINE dataset (21 class, *Sattler, 1999*)

Description of land-class
Crops, Mixed Farming
Irrigated Crops
Bogs and Marshes
Evergreen Needle-leaf Trees
Deciduous Needle-leaf Tree
Deciduous Broad-leaf Trees
Evergreen Broad-leaf Trees
Evergreen Shrubs
Deciduous Shrubs
Interrupted Forest
Mixed Forest
Tundra
Short Grass
Tall Grass
Desert
Semi-desert
Ocean
Inland Water
Water and Land Mixtures
Ice Caps and Glaciers
Urban area

ECOCLIMAP, USGS, PELCOM, etc.

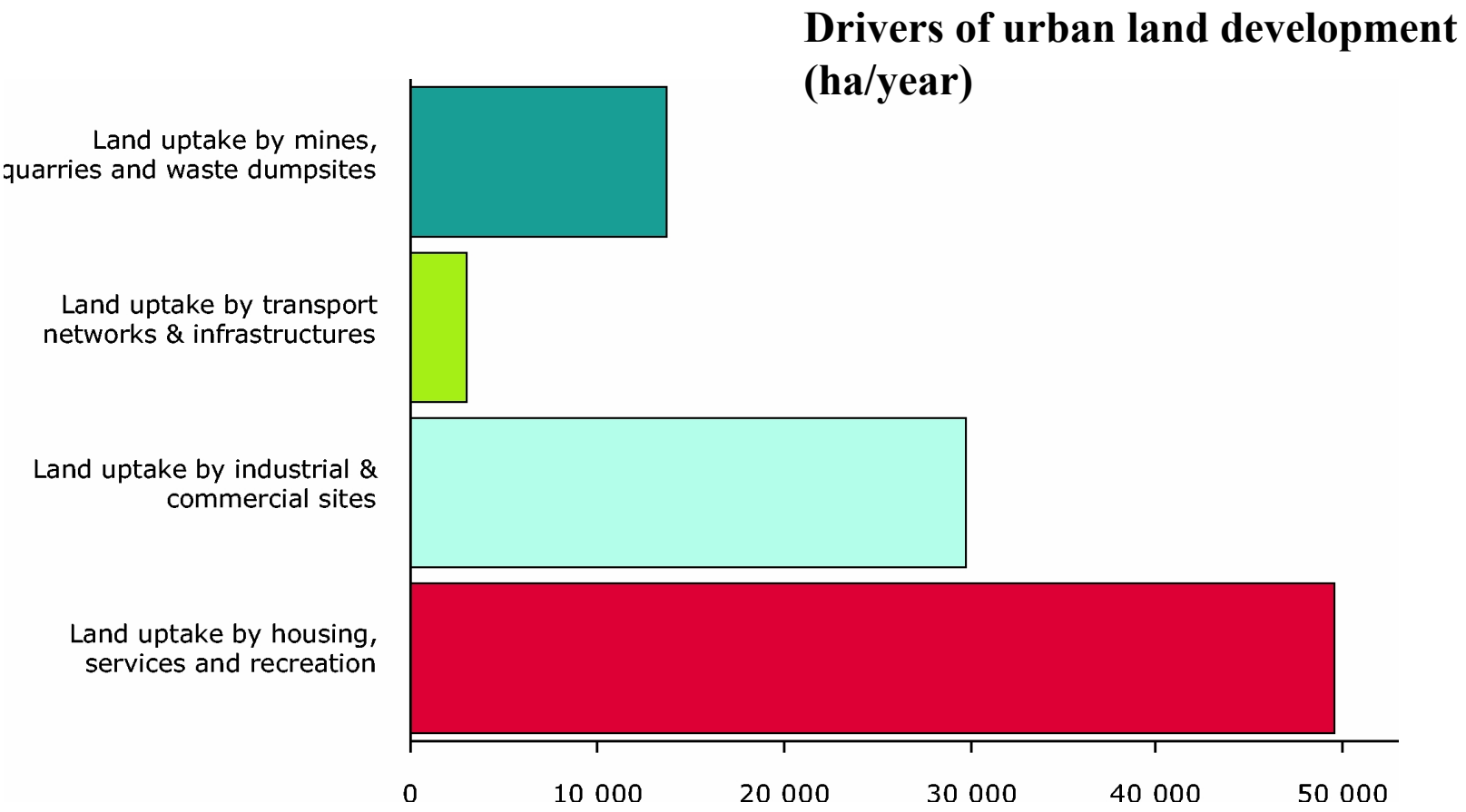
Land cover map - ECOCLIMAP dataset
1 km resolution

+ Other datasets, USGS, PELCOM, etc.

URBAN LANDS

EU: Urban Land Development

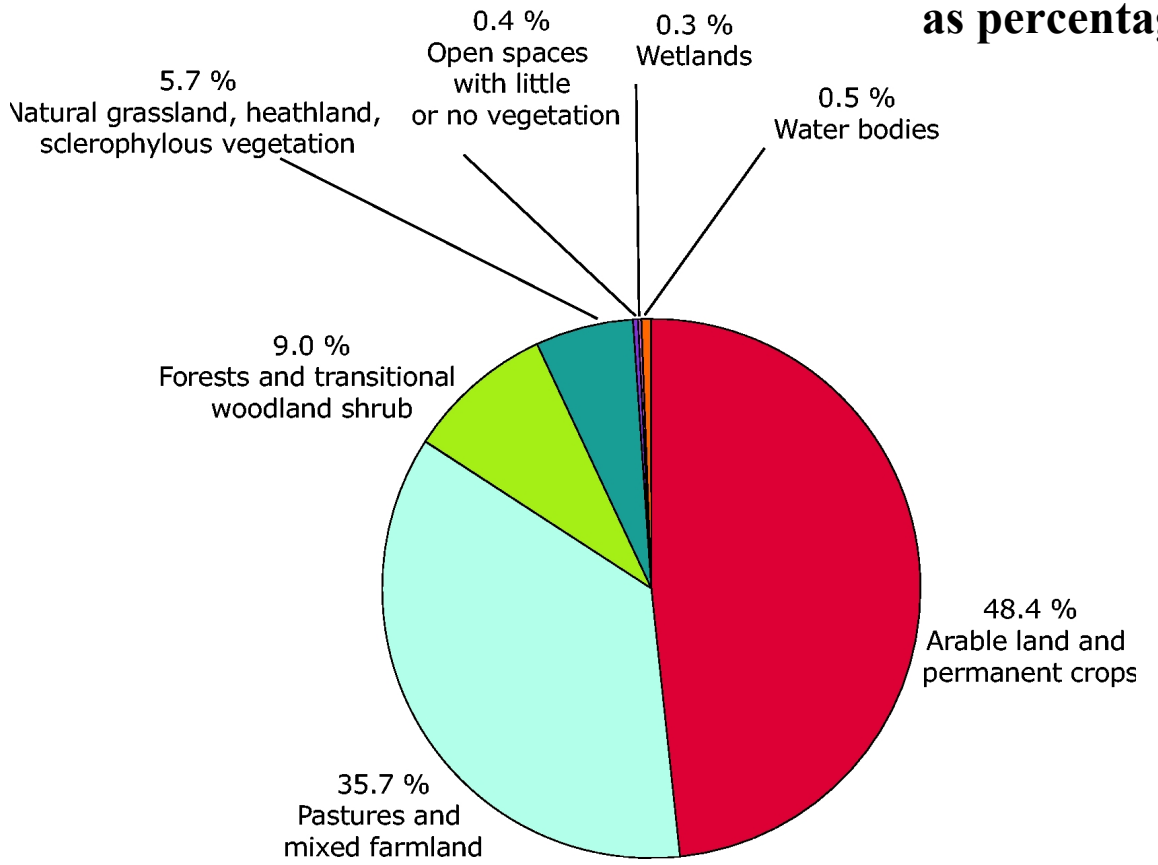
Some statistics



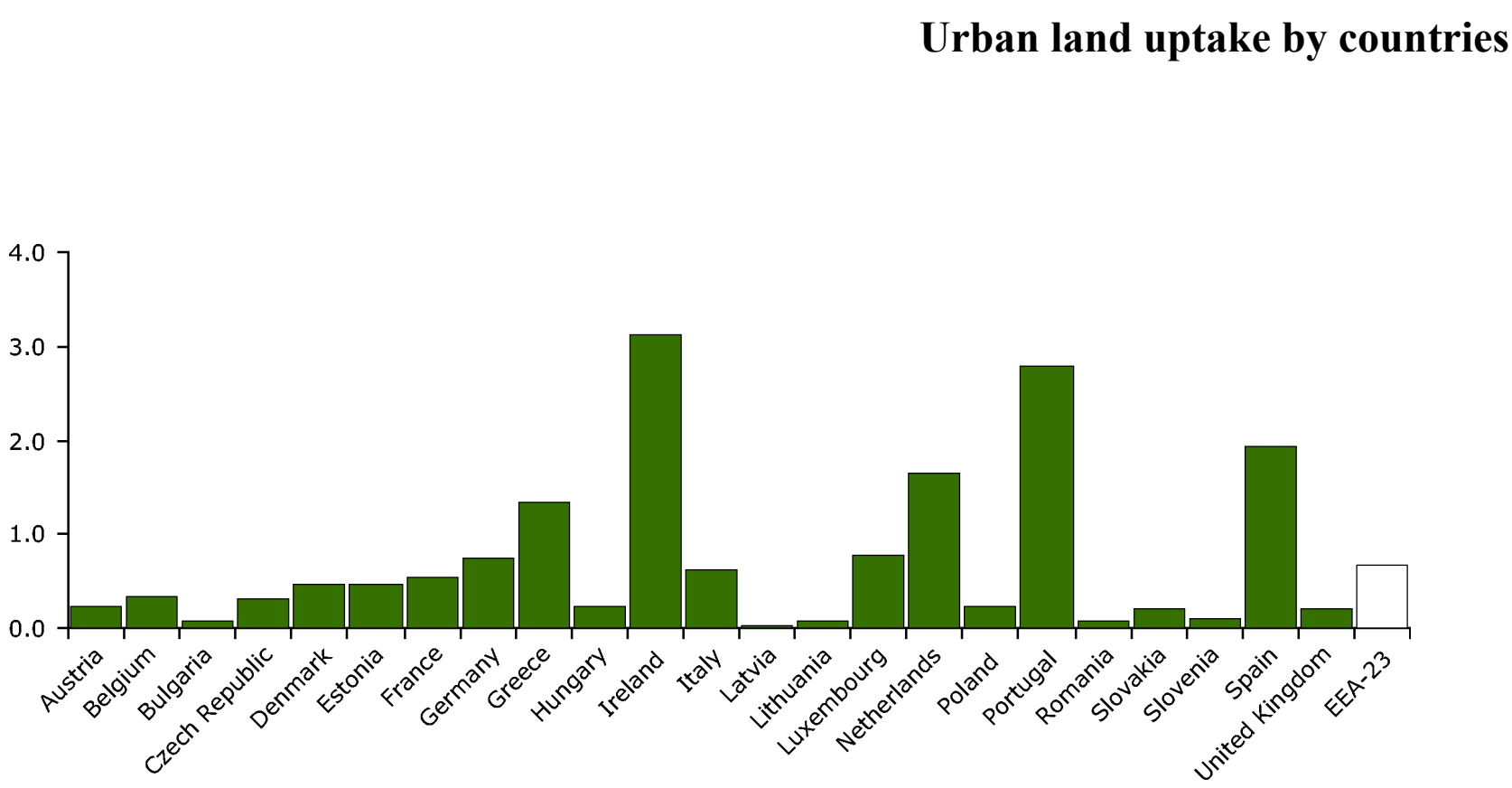
EU: Urban Land Uptake by Origin

From all areas converted to artificial land-use

Origin of urban land uptake as percentage of total uptake



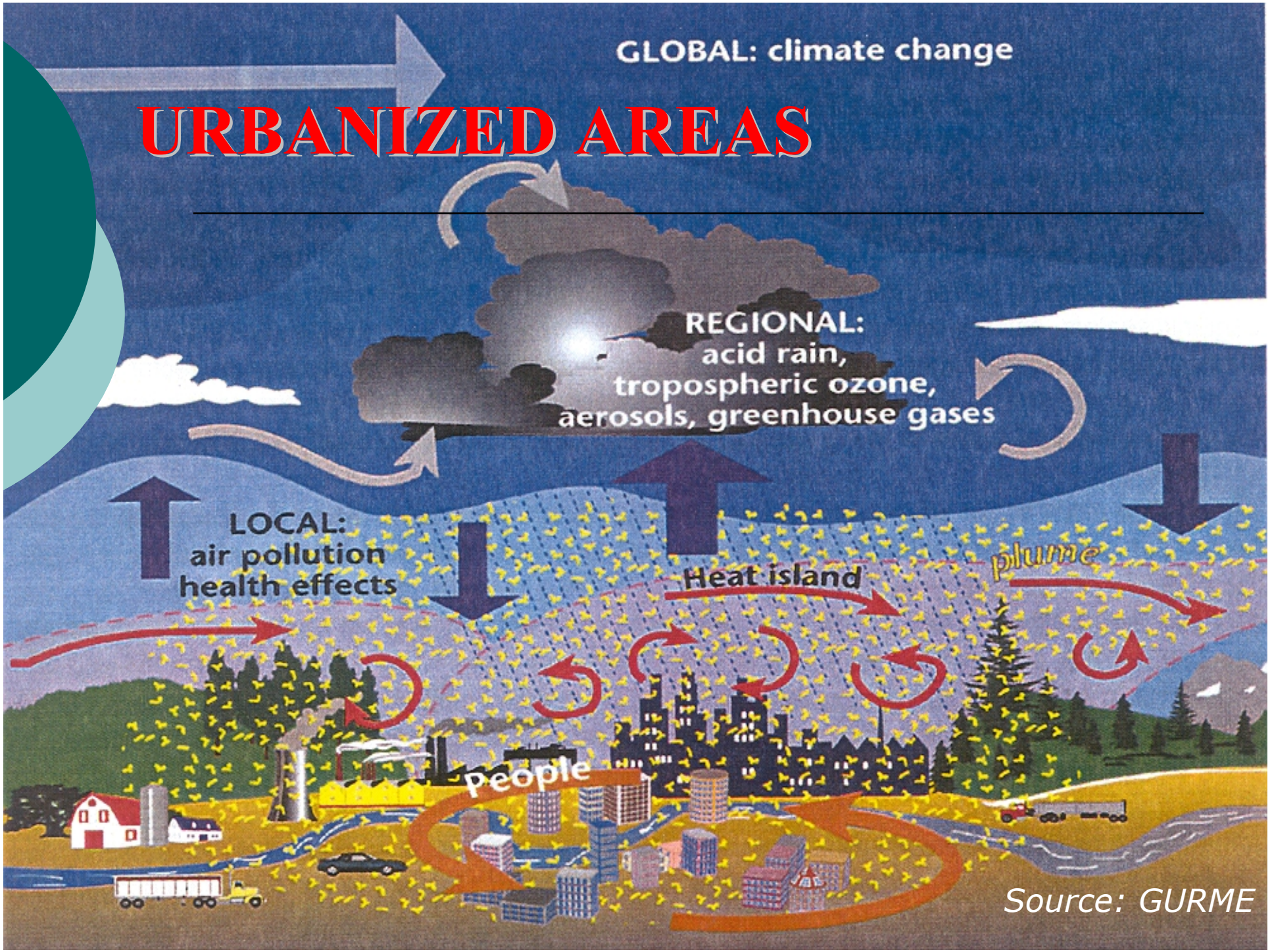
EU: Urban Land Uptake by Countries



EU: Urban Land Uptake by Metropolitan Areas

Urban land uptake by megacities

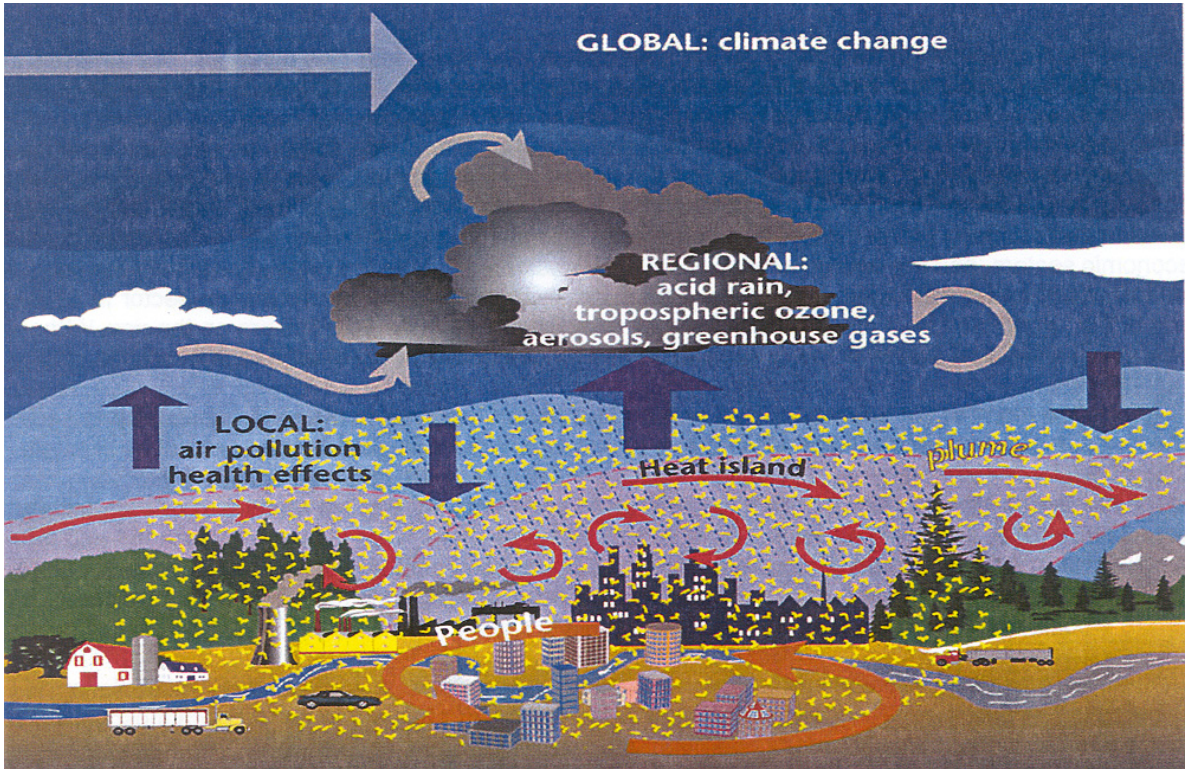
URBANIZED AREAS



Source: GURME

Urban Boundary Layer

Urban Boundary Layer, UBL vs. 'rural' homogeneous boundary layer is characterised by greatly enhanced mixing, resulting from both the large surface roughness and increased surface heating, and by horizontal inhomogeneity of meteorological fields due to variations in surface roughness and heating from rural, sub-urban, to central areas of cities.

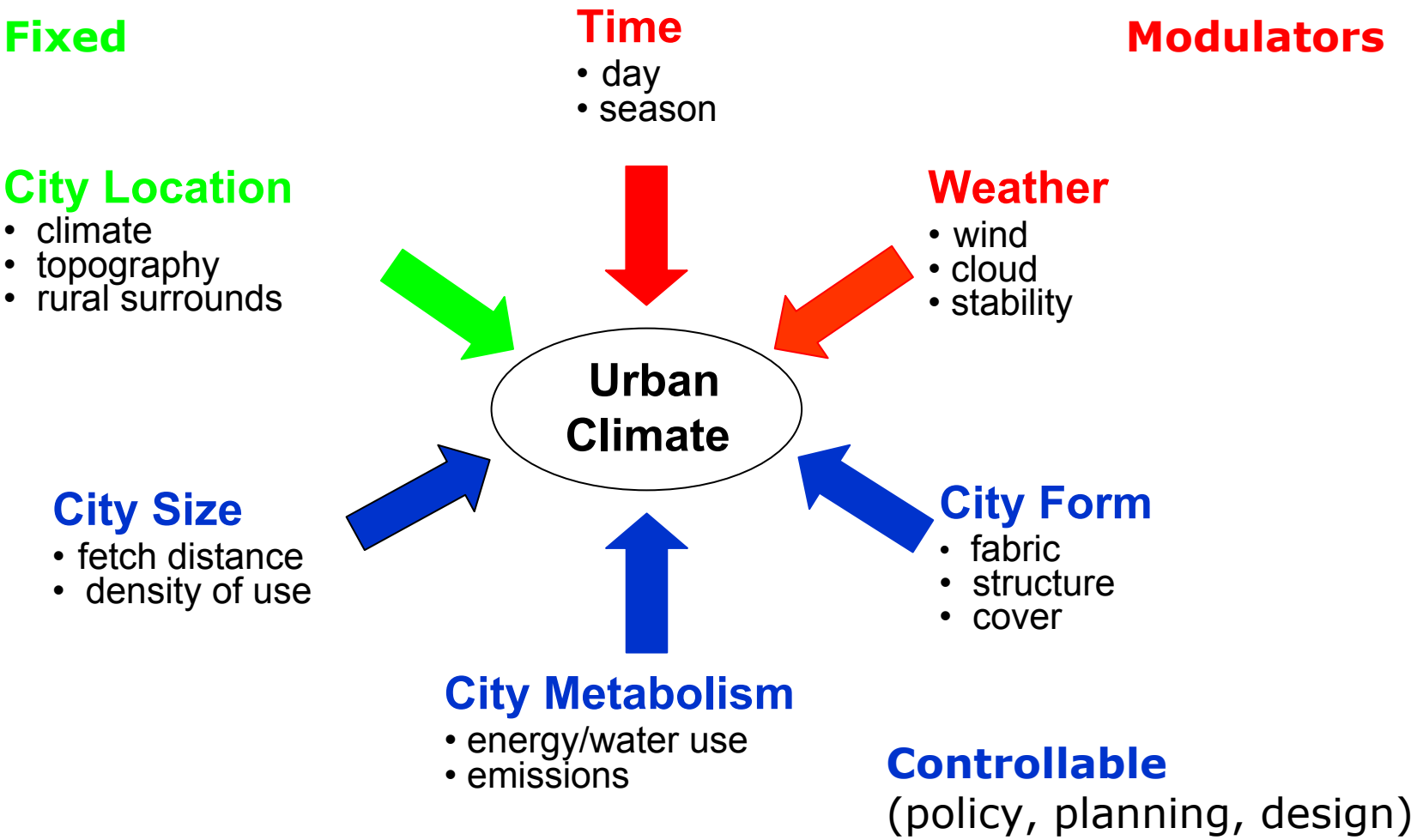


Features for Urban Areas

- **Local-scale inhomogeneties, sharp changes of roughness and heat fluxes;**
- **Wind velocity reduce effect due to buildings;**
- **Redistribution of eddies due to buildings, from large to small;**
- **Trapping of radiation in street canyons;**
- **Effect of urban soil structure, diffusivities heat and water vapour;**
- **Anthropogenic heat fluxes, urban heat island;**
- **Internal urban boundary layers, urban mixing height,**
- **Effects of pollutants (aerosols) on urban meteorology and climate;**
- **Urban effects on clouds, precipitation and thunderstorms.**

Controls on Urban Climate Effects (including Urban Heat Island)

(Oke et al., 1980)



Surface Energy Balance, Characteristics of Urban Surfaces

$$Q^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow = Q_H + Q_E + \Delta Q_S + Q \ [W/m^2]$$

Q^* - net all-wave radiation;
$K\downarrow$ and $K\uparrow$ - incoming and outgoing reflected shortwave radiation;
$L\downarrow$ and $L\uparrow$ - incoming and outgoing longwave radiation;
Q_H and Q_E - turbulent sensible and latent heat fluxes,
ΔQ_S - storage heat flux,
Q – other sources/sinks.

- **Altered albedo – can be higher or lower,**
- **Higher heat capacity,**
- **Lower moisture flux to atmosphere,**
- **Larger roughness elements,**
- **Increased surface area,**
- **Source of anthropogenic heat and emissions,**
- **Impermeable to water,**
- **Decreased net longwave radiation loss.**

Approaches for Treatment of Urban Boundary Layer Features

- **Urban roughness effects**
  (*Bornstein, 1975, 2001; Hunt et al., 2003*)

- **Urban surface energy balance**
  (*Oke et al., 1999; Piringer et al., 2002*)

- **Town Energy Balance scheme**
  (*Masson, 2000*)

- **Urban surface exchange sub-layer model**
  (*Martilli et al., 2002*)

- **Soil model for sub-meso scales urban version**
  (*Dupont et al., 2006ab*)

- **Prognostic equations for UBL height**
  (*Zilitinkevich et al., 2002+; Gryning and Bartchvarova, 2002*).

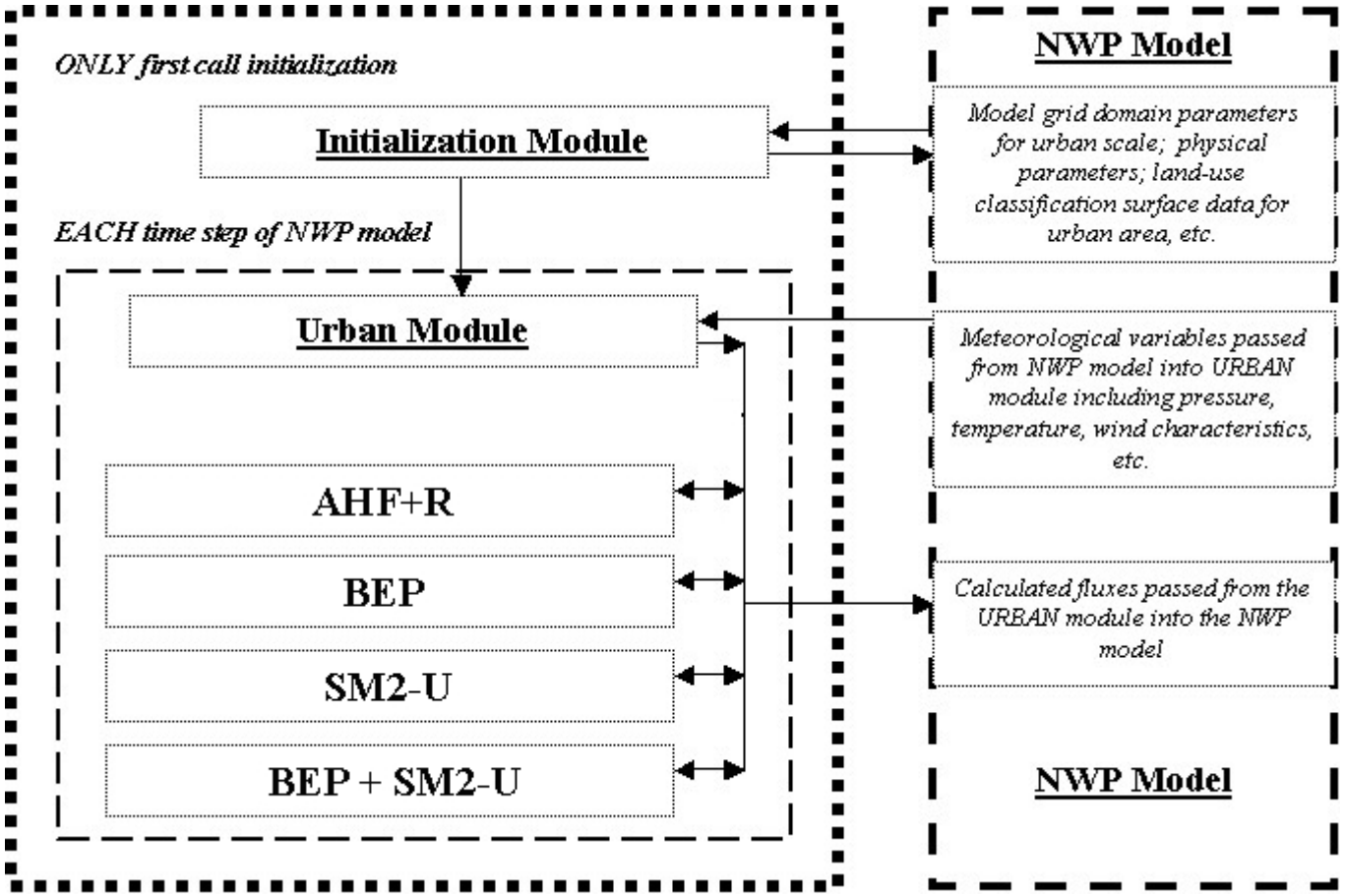
Methodologies for Urbanization of Meteorological Models

- Increased grid resolution and nesting of models
- Urban land-use classification & algorithms for roughness parameters
- Urban fluxes and sublayer parameterisation
- Approach based on improved urban roughness and fluxes
- Effect of urban canopy roughness
- Effective roughness over inhomogeneous terrain
- Surface energy budget in urban areas


URBANIZATION
for Enviro-HIRLAM

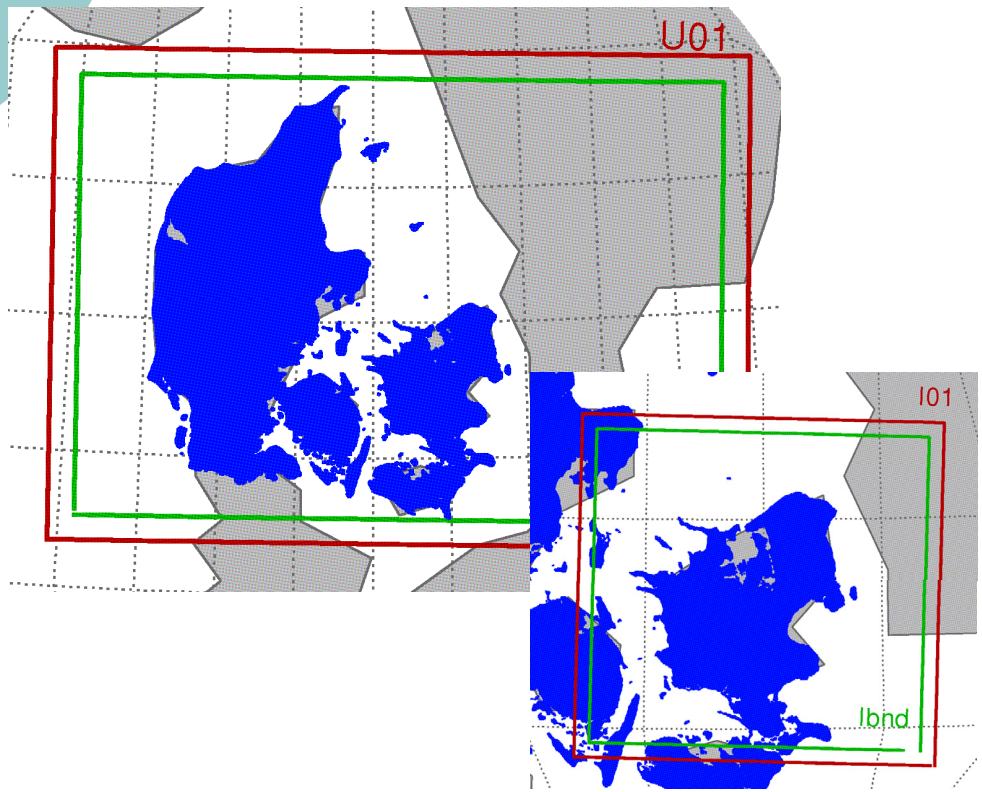
Enviro-HIRLAM: Urbanization Modules

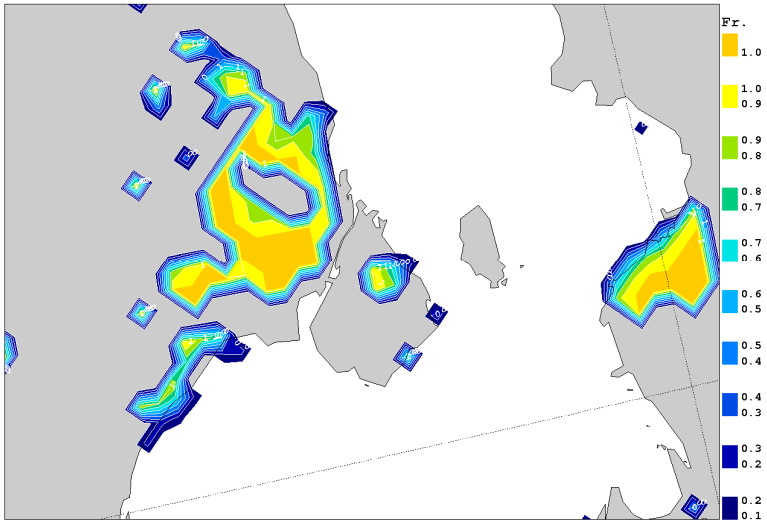
- anthropogenic heat flux and roughness (**AHF+R**)
- building effect parameterization (**BEP**)
- soil model for sub-meso scales urban version (**SM2-U**)



Enviro-HIRLAM : Urban : Land Surface Scheme, Tiles and Urban Areas, Modelling Domains, and Focus

- Land surface scheme: Interaction Soil-Biosphere-Atmosphere (ISBA)
- Tiles (low vegetation, forest, ice, snow, water, bare soil) + urban fraction
- High resolution domains: -U01/-I01 (horiz resol of 1.4 km)
- Climate Generation Files, + surface and meteorology related data
- Focus: Copenhagen metropolitan area (Island of Sjealland)





Urban Districts : Classification

Residential (RD)

City Center/High Buildings District (CC/HBD)

GIS

Industrial Commercial (ICD)

Extraction of districts related characteristics (statistics):

Morphology parameters **(avg. height, volume, perimeter, compactness, space between buildings),**

Cover modes **(surface density (SD) of buildings, of vegetation, hydrography, roads, N buildings),**

Aerodynamic parameters **(roughness length, displacement height, frontal and lateral SD),**

Anthropogenic Heat Flux in Urban Areas

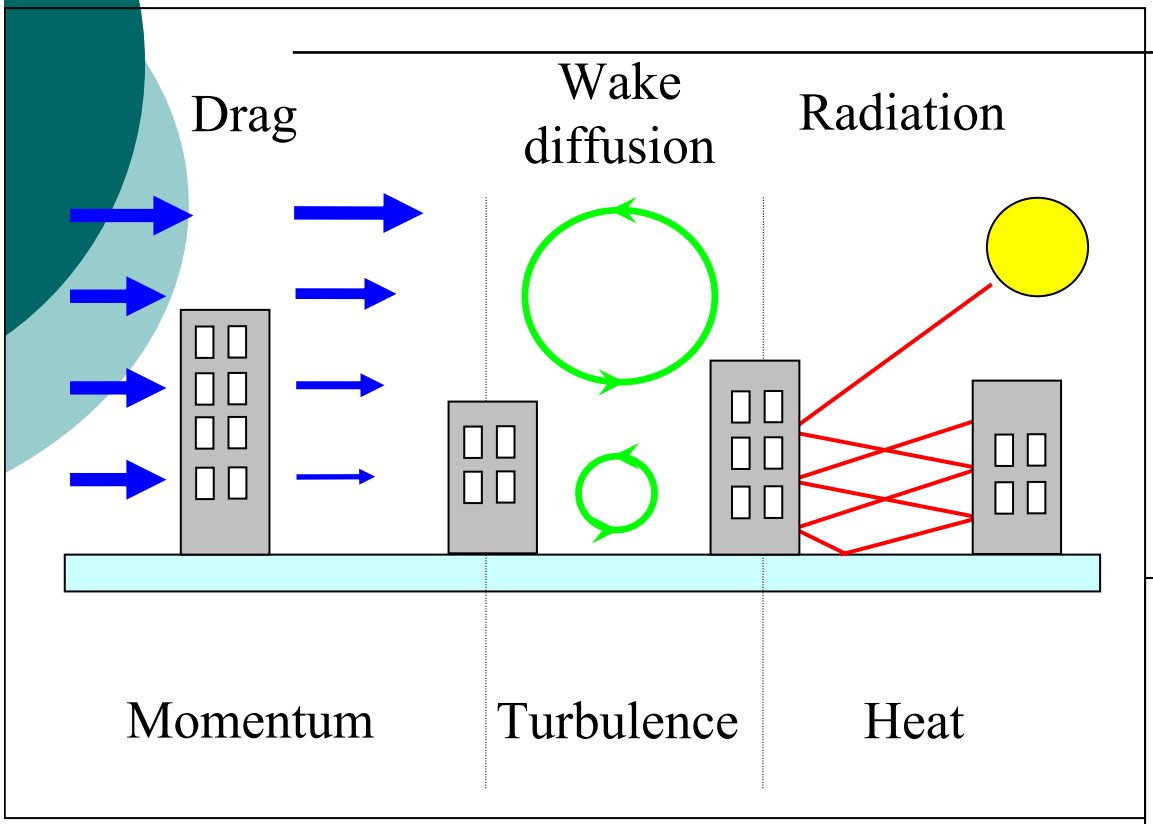
can be calculated based on assumption of dependency/ proportionality to other urban characteristics:

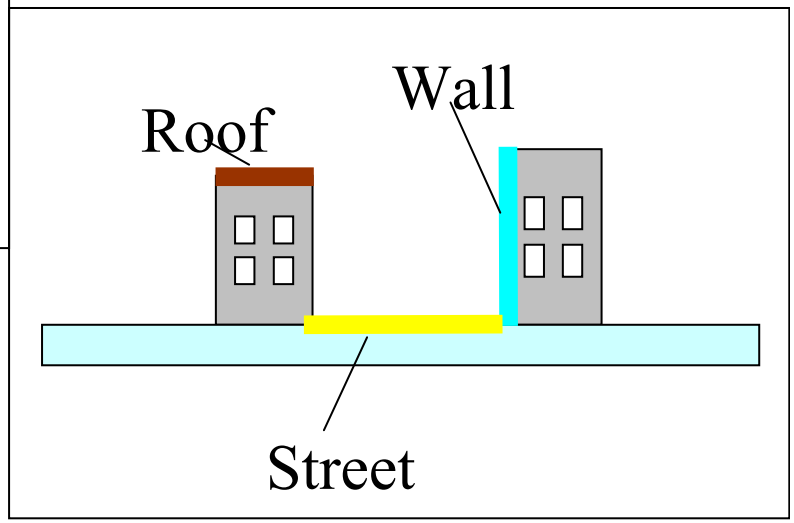
1. **Population density maps with a high resolution in urban areas;**
2. **Satellite images of the night lightness over urban areas (but difficulties to use for industrial and developing countries, should be corrected);**
3. **Land-use classification as a percentage of urban classes (central part, urban, sub-urban, industrial, etc.);**
4. **Emission inventory for specific pollutants typical for urban areas (e.g., due to traffic emission, etc.);**
5. **Monitoring or simulation of concentration fields for specific air pollutants typical for urban areas.**

Reference avg. value: up to 100 W/m^2

BEP : Building Effect Parameterization

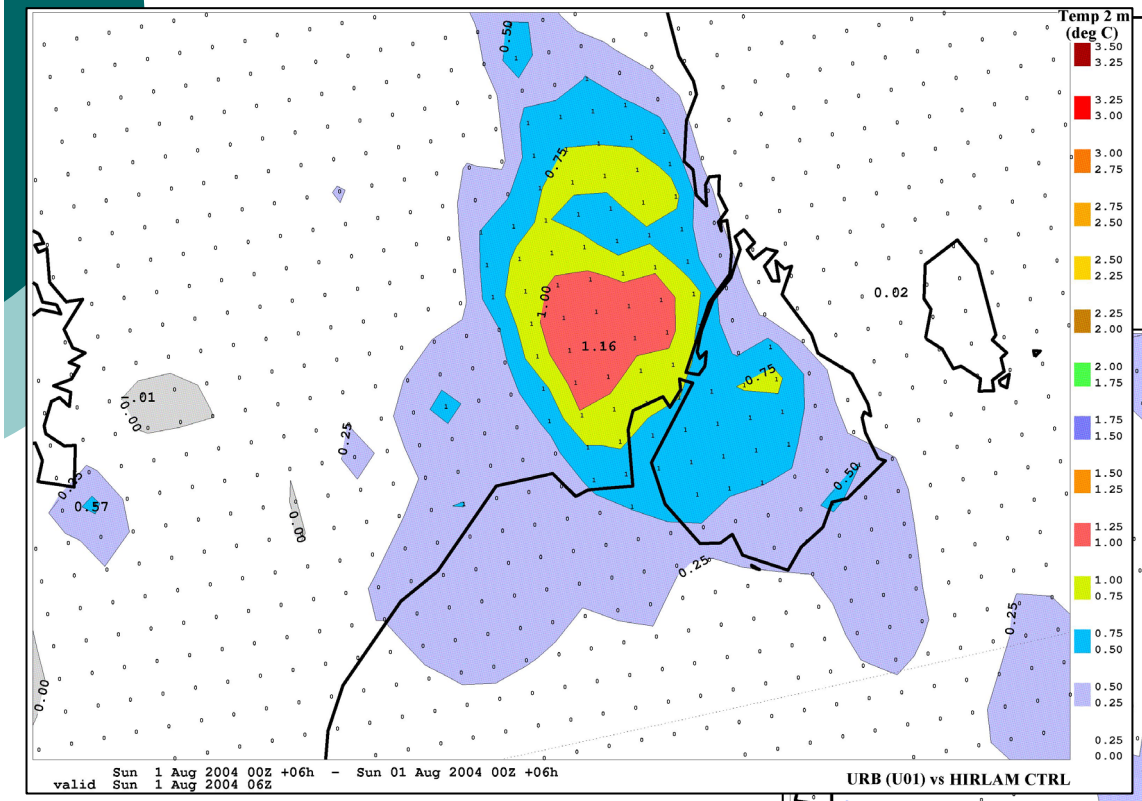
(Martilli et al., 2002)





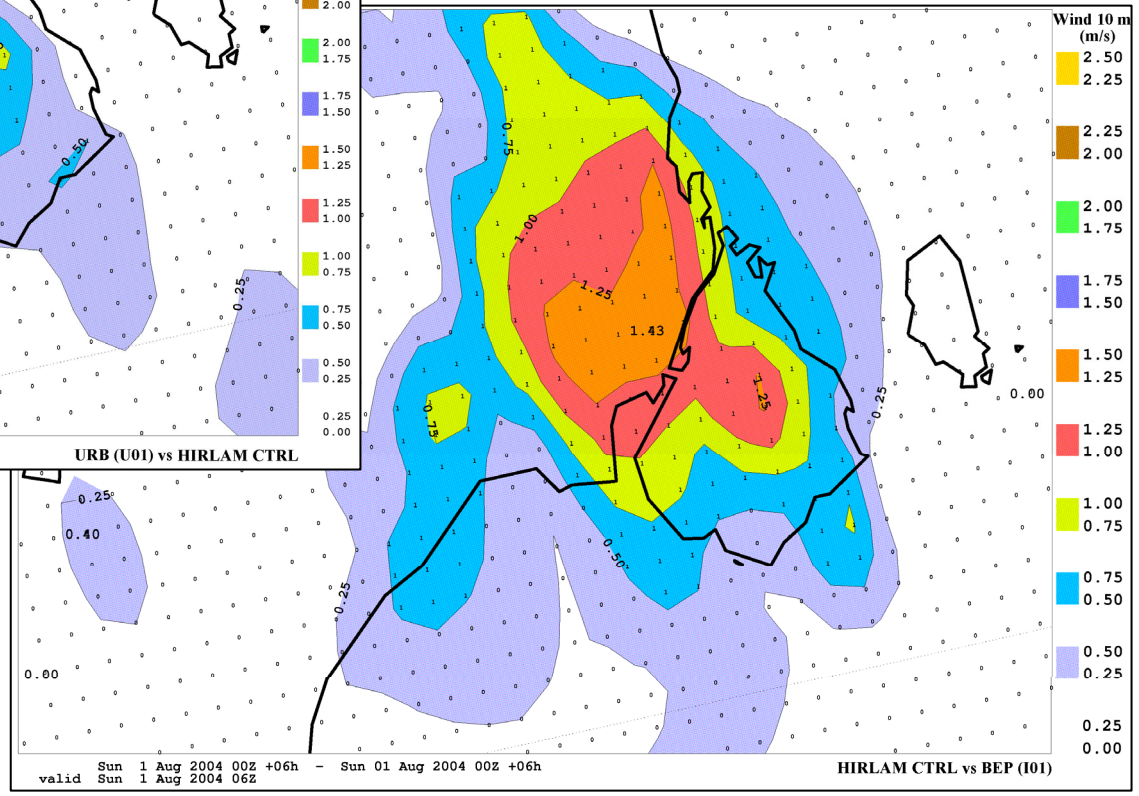
MeteoModelling: BEP Module

Difference between runs: 01 Aug 2004, 06 UTC



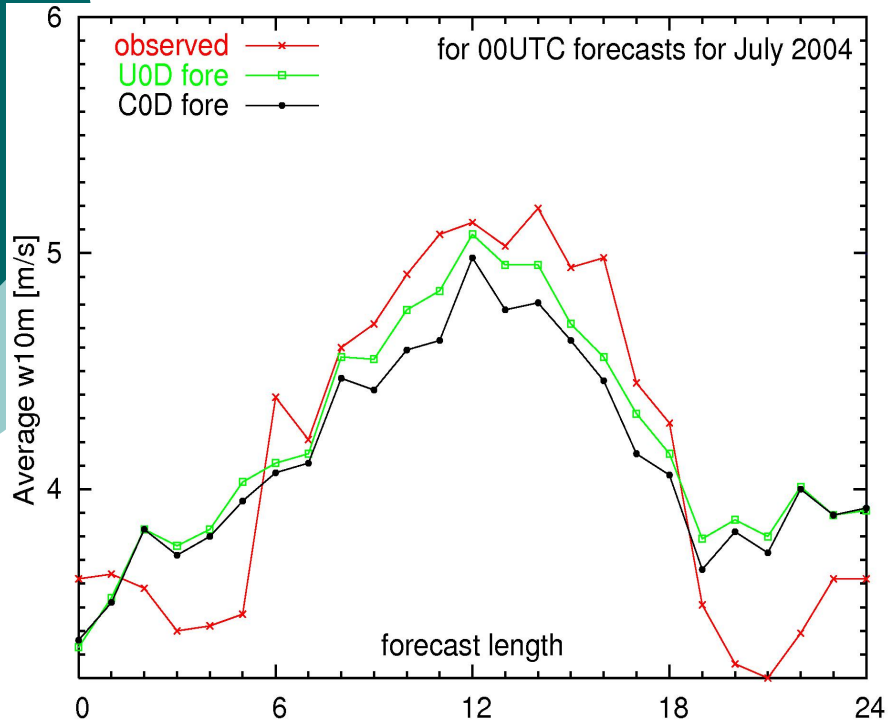
(control vs. urbanized run)
Difference field for temperature at 2 m

(control vs. urbanized run)
Difference field for wind at 10 m

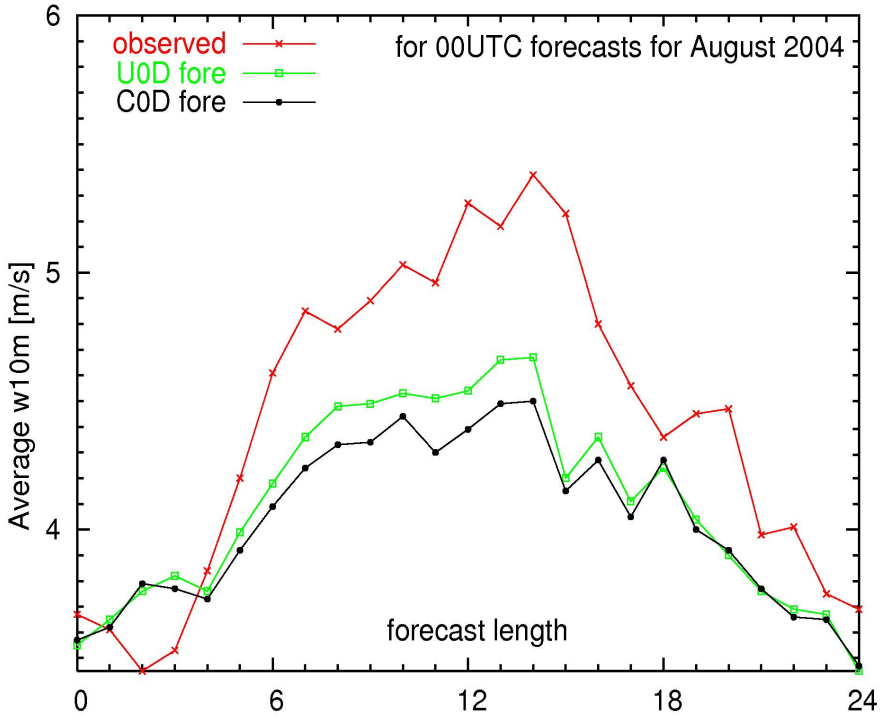


MeteoModelling: BEP Module

Urban station N-6180: Copenhagen area : Verification



July 2004

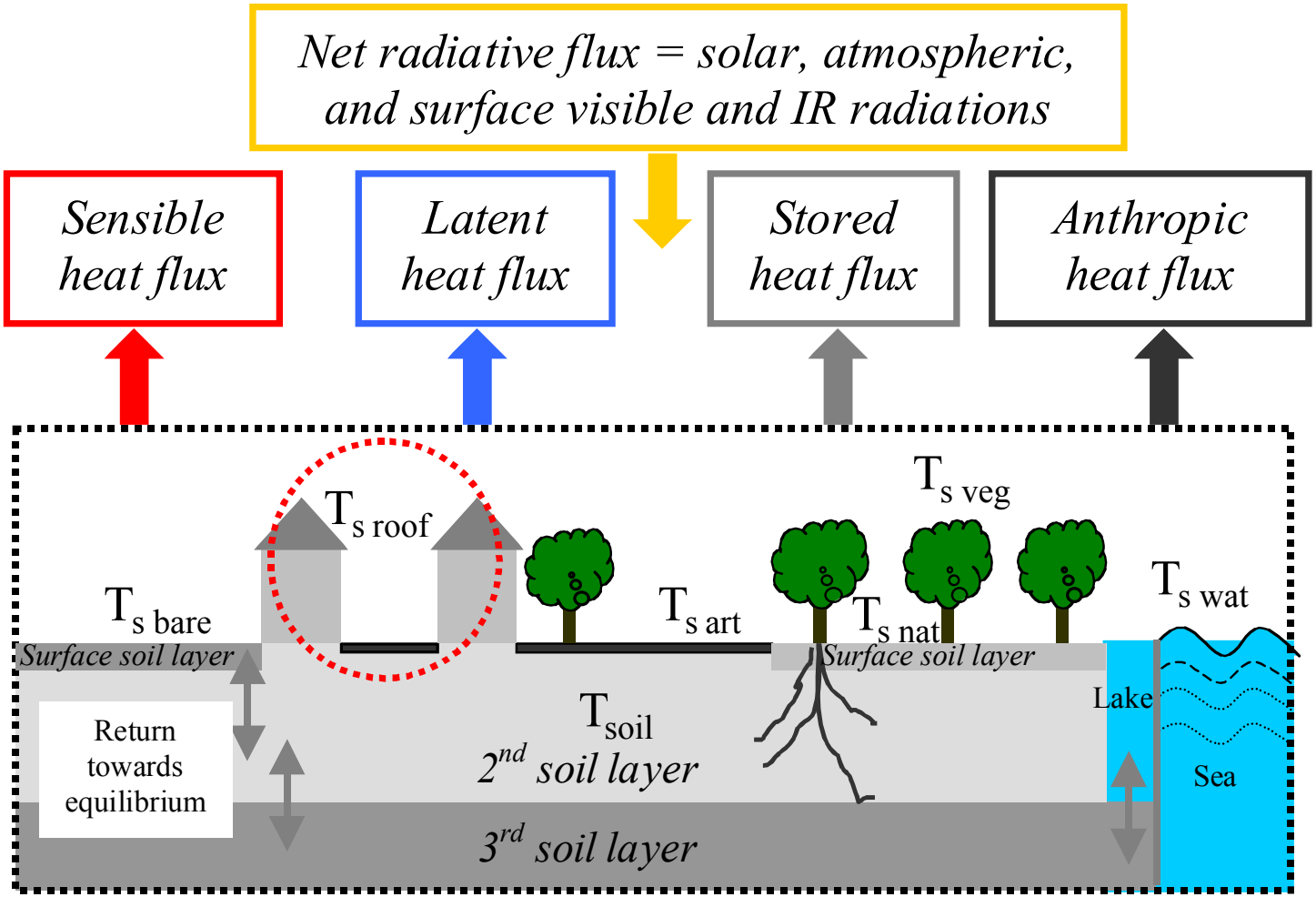


August 2004

Diurnal variability for 00 UTC forecasts for the average wind velocity at 10 m for the urban station N–6180 in the Copenhagen metropolitan area as function of the forecast length based on the DMI–HIRLAM–I01+BEP /U0D/ and –I01–CTRL /C0D/ model runs vs. observations

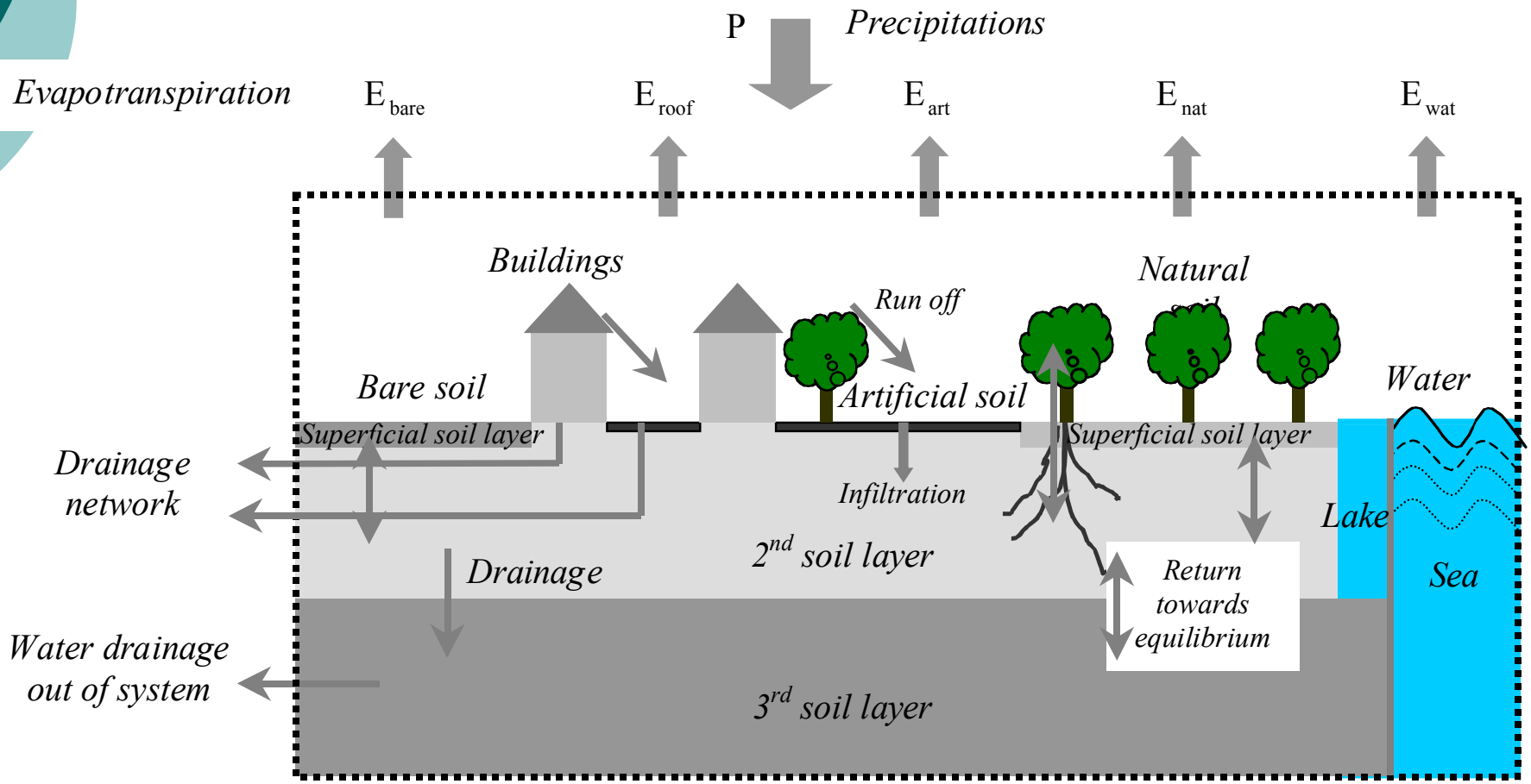
SM2-U : Soil Model for Sub-Meso scales
Urbanized version : Thermal budget

(Dupont et al., 2006ab)



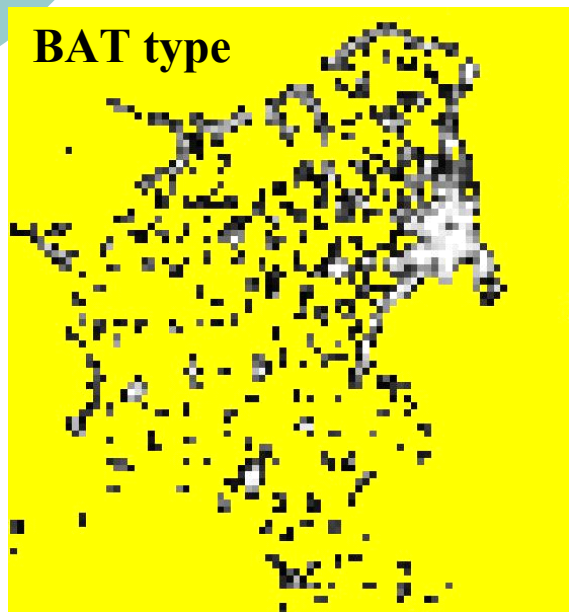
SM2-U : Soil Model for Sub-Meso scales
Urbanized version : Water budget

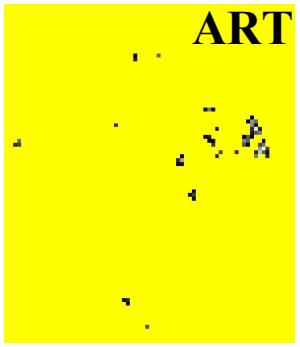
(Dupont et al., 2006ab)

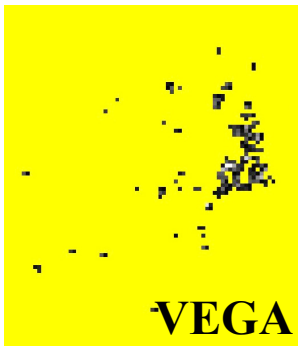


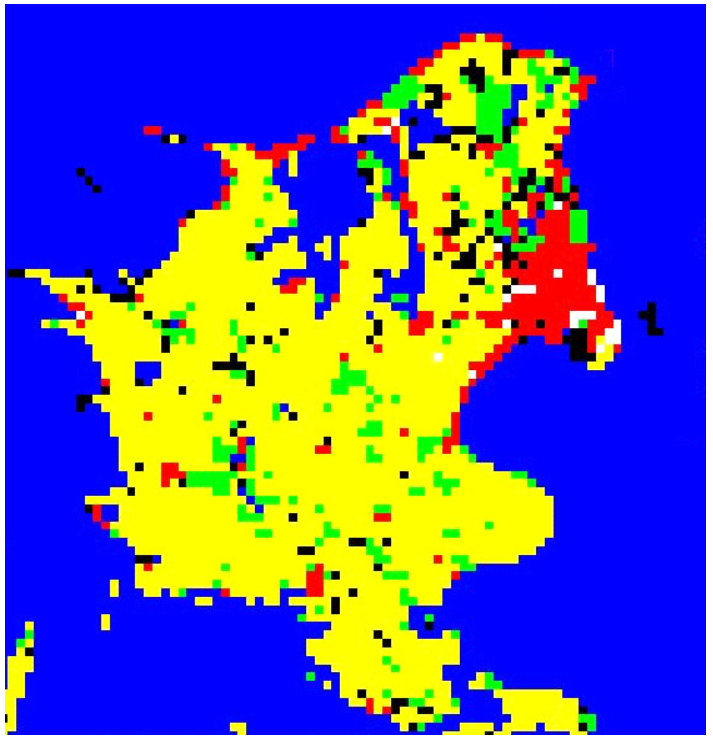
Revised Land Use Classification : SM2-U Module

BARE	Bare soil without vegetation
NAT	Bare soil located between sparse vegetation elements
VEGN	Vegetation over bare soil
VEGA	Vegetation over paved surfaces
ART	Paved surfaces located between the sparse vegetation elements
BAT	Building/roofs
EAU	Water surfaces



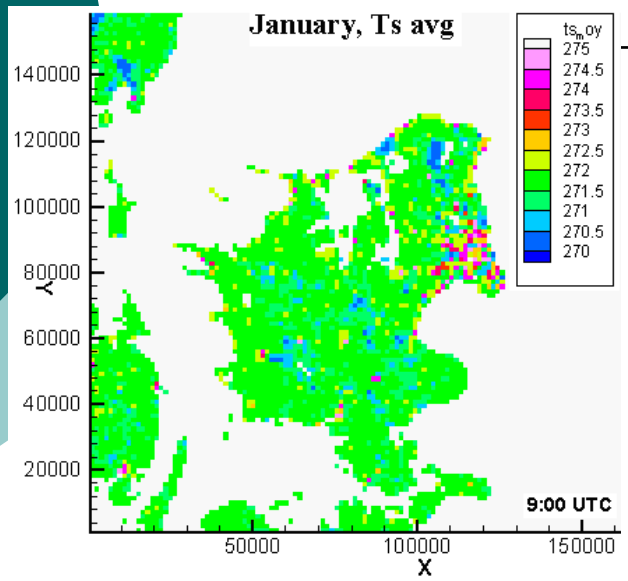


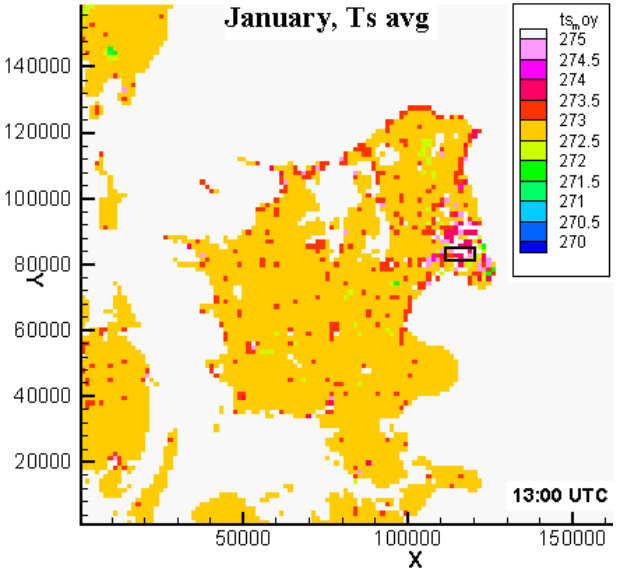


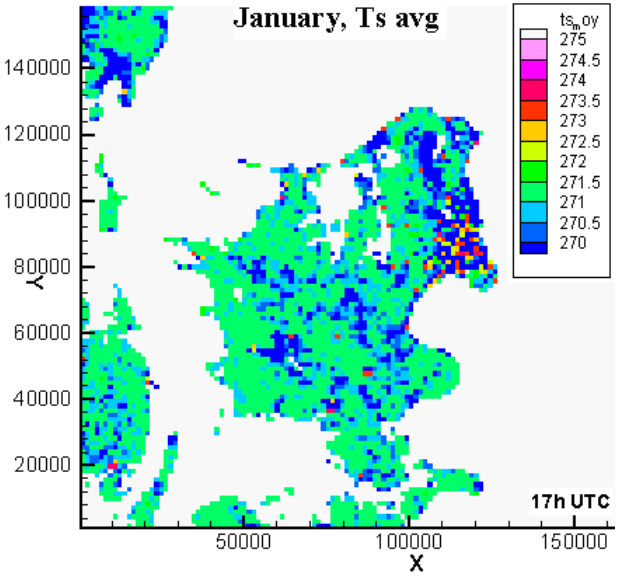

Dominated type

MeteoModelling: SM2-U Module

Metropolitan area : Copenhagen : Surface temperature

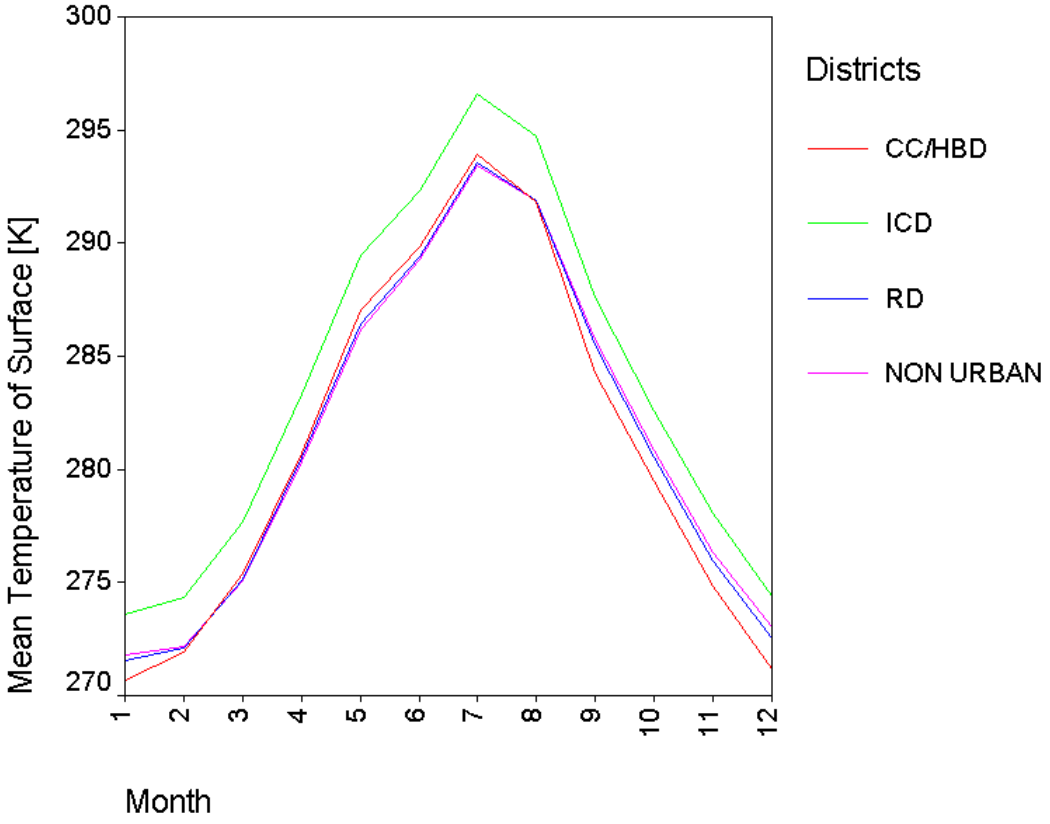


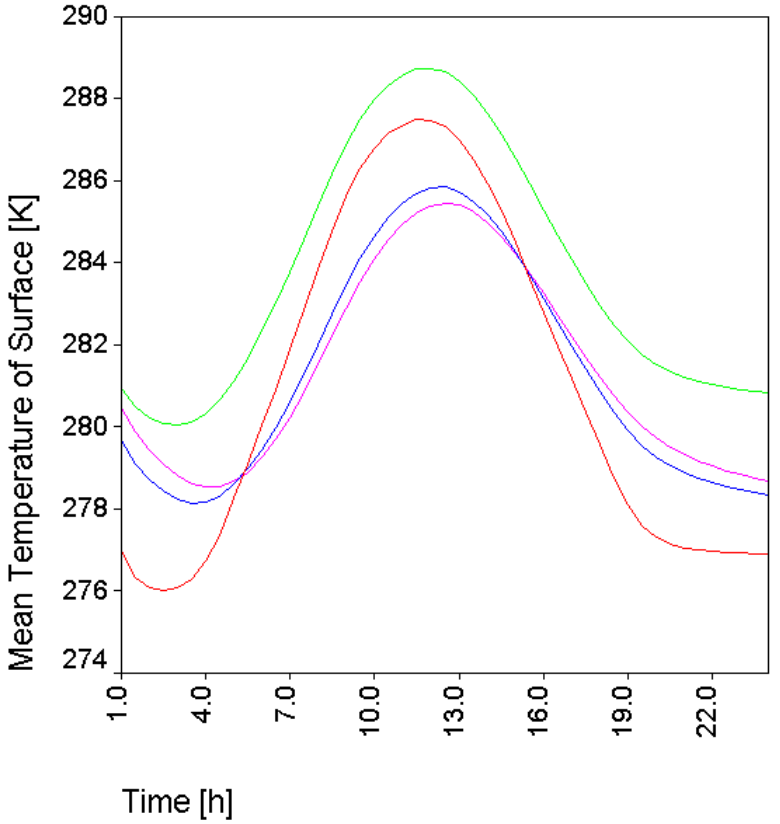




MeteoModelling: SM2-U Module

Metropolitan area : Copenhagen : Surface temperature : Urban districts

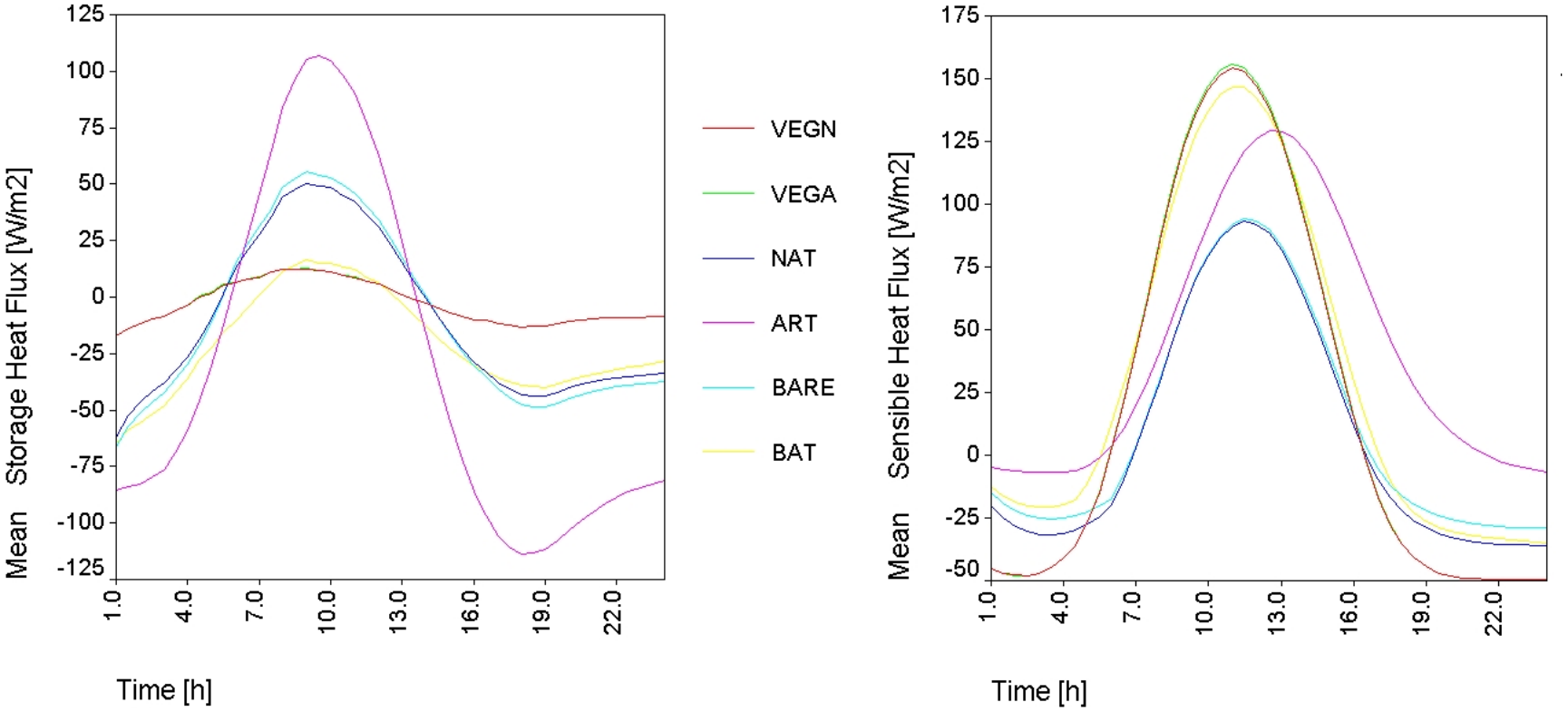




CC/HBD	City center / high buildings district
ICD	Industrial commercial district
RD	Residential district
Non-urban	Non-urban areas (no BAT type)

MeteoModelling: SM2-U Module

Metropolitan area : Copenhagen : Storage and sensible heat fluxes : Types of surfaces



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BAT	Building/roofs
EAU	Water surfaces

Evaluation of Results : Items

- Specific dates/ short- and long-term periods selected,
- Diurnal cycle,
- Month-to-month variability,
- Difference between the control vs. urban runs,
- Meteorological variables of key importance,
- Urban districts of different nature:
  - City Center,
  - High Buildings District,
  - Industrial Commercial District,
  - Residential District,
- Types of surfaces (including urban variants),
- Focus: impact of urban areas on simulated meteorological fields

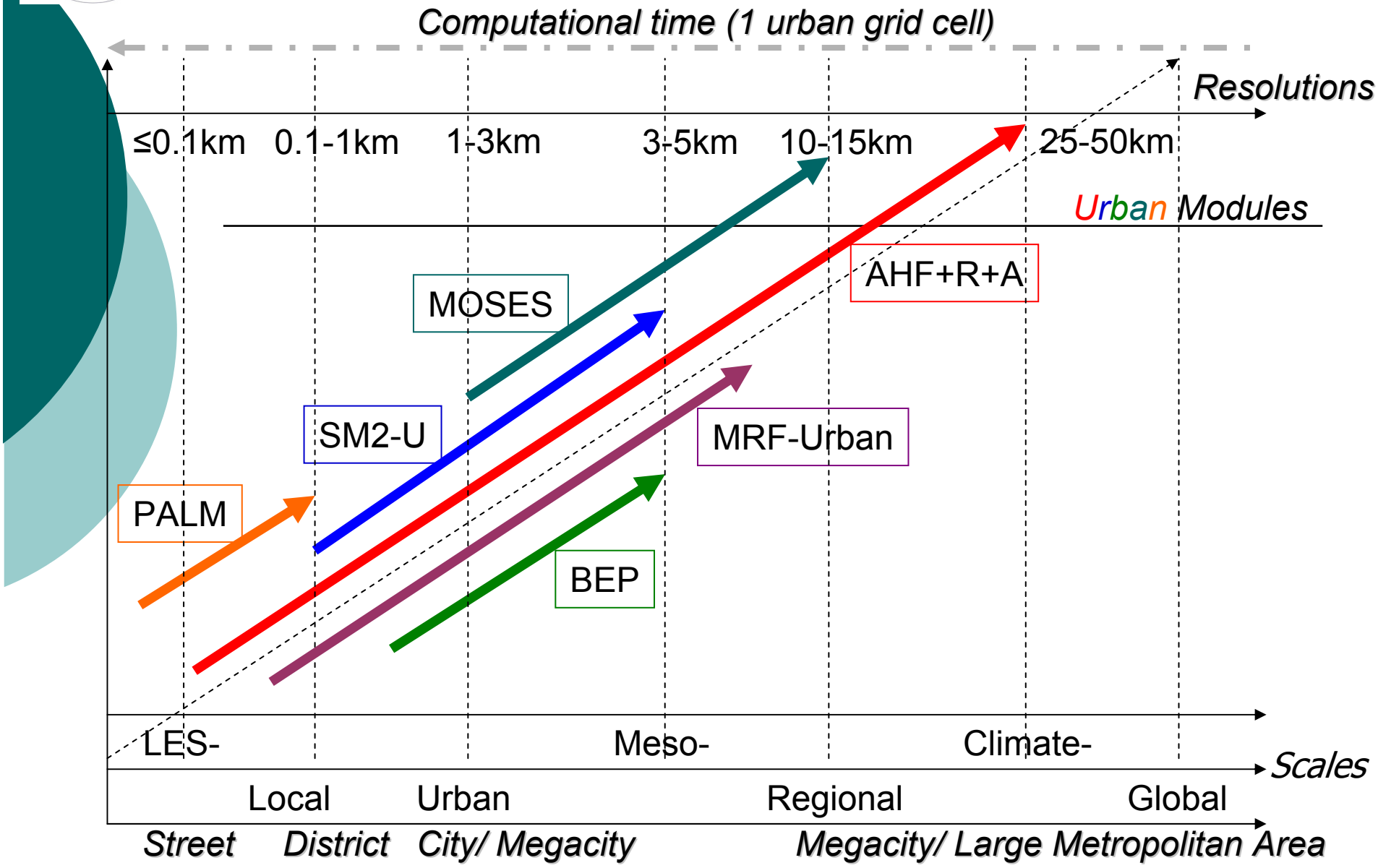
Urbanization: Applicability of Results

- Testing and verification of numerical weather prediction and climatological models performance over high resolution model domains, and especially, over the urbanized areas;
- Investigation of temporal and spatial variability of various meteorological and derived variables over urbanized areas;
- Improvements in land use classification and climate generation properties;
- Distinguishing and selection of types of urban districts and their properties;
- Urbanization of climate regional and global models.

Testing with Different Urbanizations
(example of FP7 EU MEGAPOLI project)

- **Simple modification of land surface schemes (AHF+R+A)**
- **Medium-Range Forecast Urban Scheme (MRF-Urban)**
- **Building Effect Parameterization (BEP)**
- **Soil Model for Sub-Meso scales Urbanised version (SM2-U)**
- **UM Surface Exchange Scheme (MOSES)**
- **Urbanized Large-Eddy Simulation Model (PALM)**

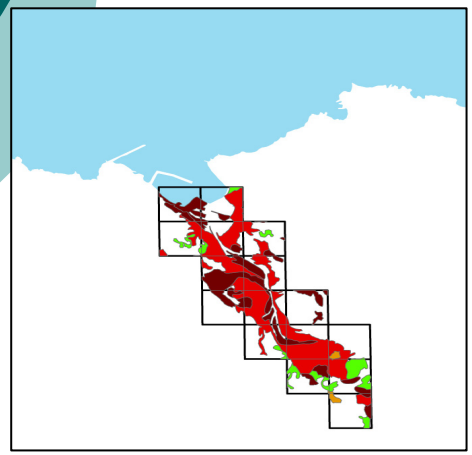
Hierarchy of Approaches

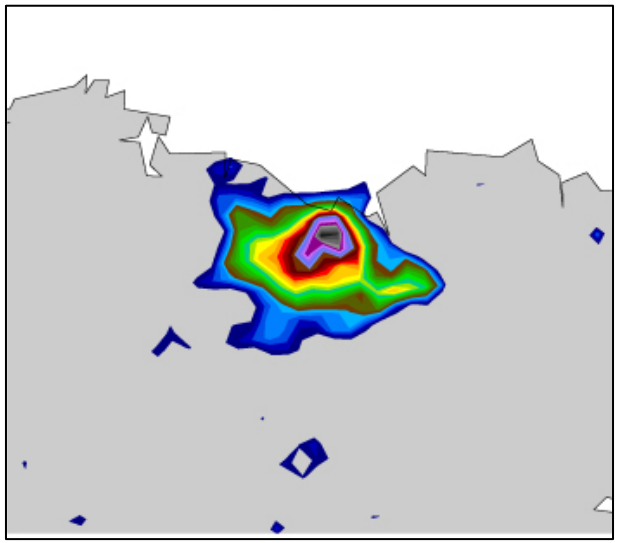


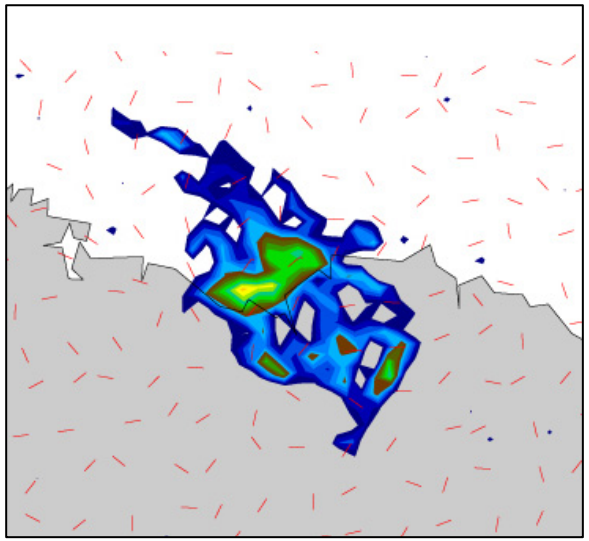
Bilbao metropolitan area, Spain

Gonzalez et al., (2010)
MEGAPOLI NewsLetter 9, Dec 2010

Bilbao metropolitan area:
urban fractions + districts



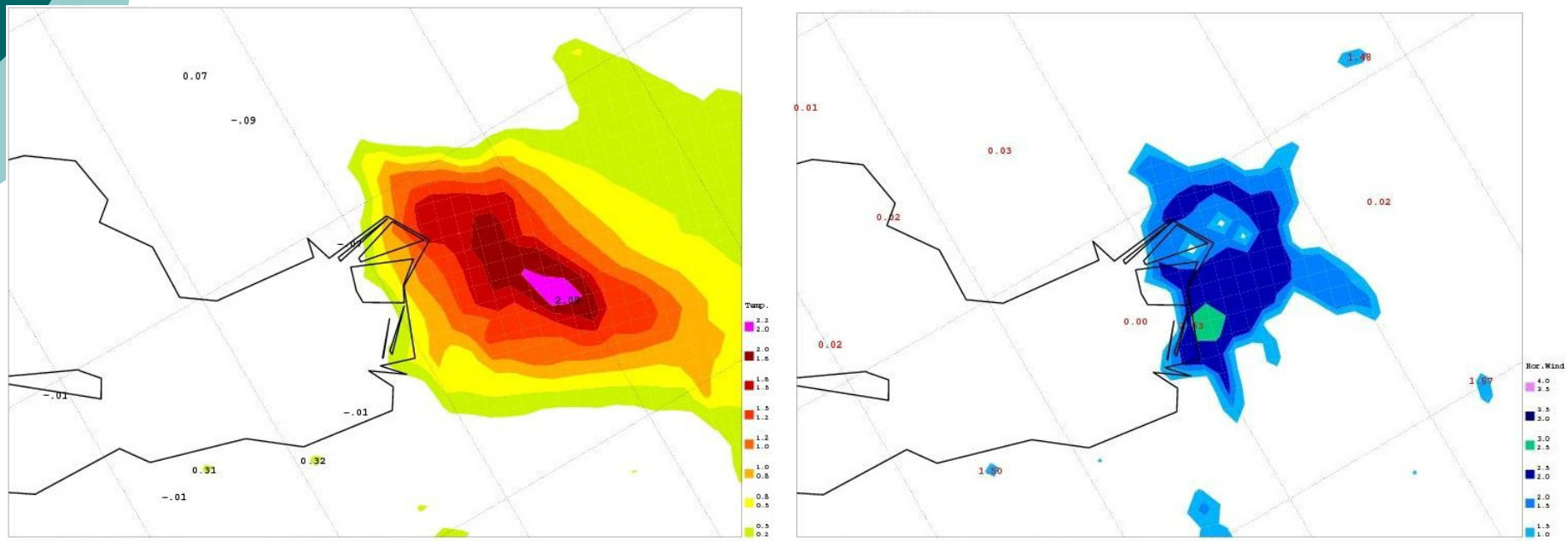




Difference plots between the Enviro-HIRLAM control vs. urban (BEP+AHF module) runs for the (left) air temperature at 2 m & (right) wind at 10 m at 06 UTC on 12 Aug 2009.

St. Petersburg, Russia – Winter Case Study, Low Wind Conditions

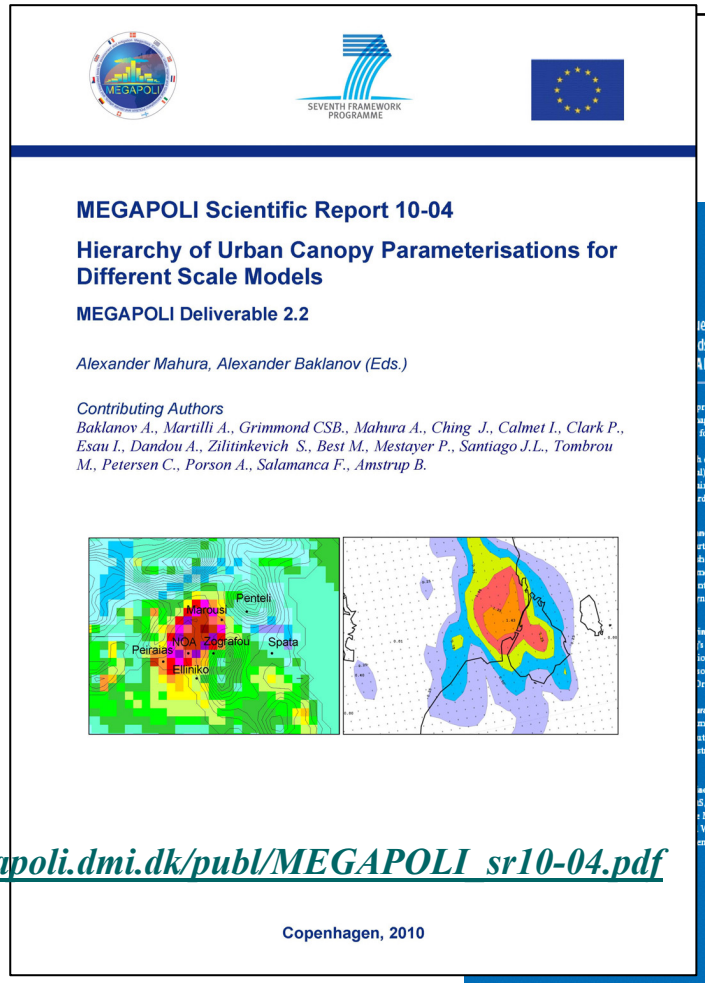
Gavrilova Yu., MSc thesis (2010)

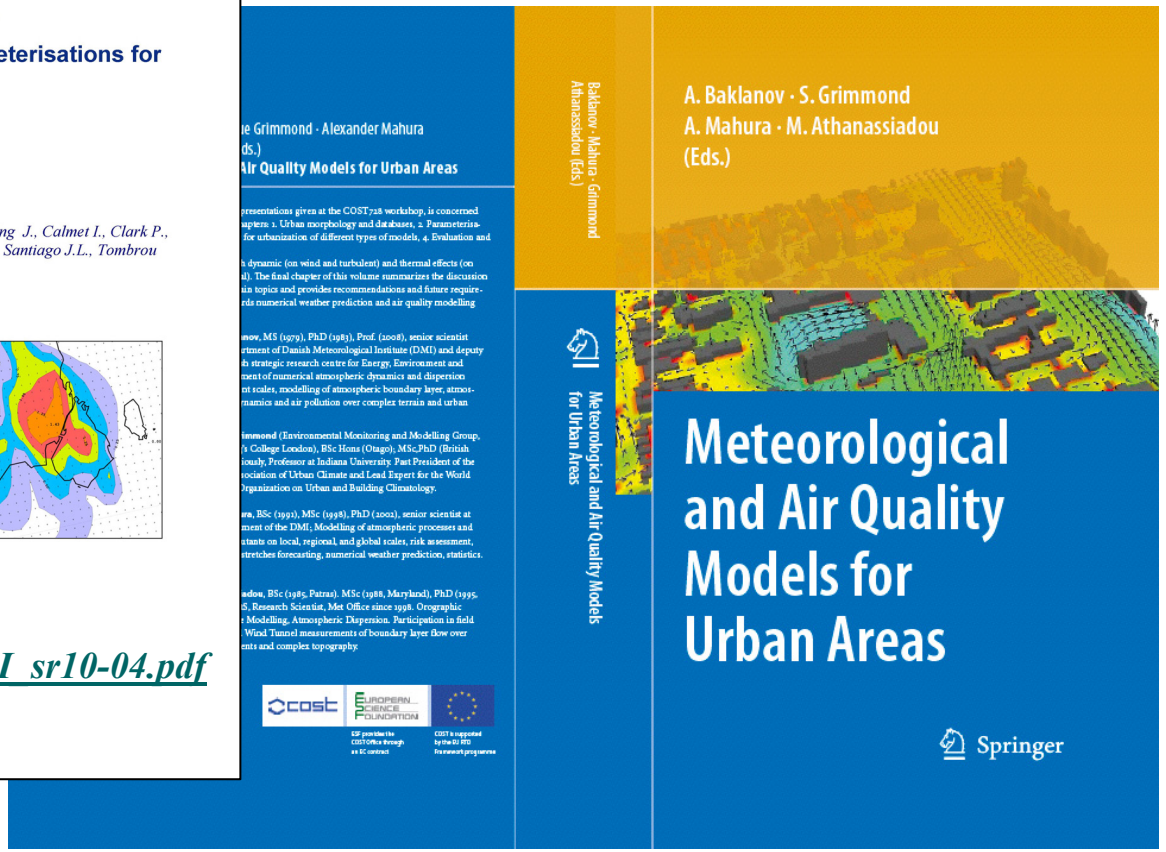


Difference plots between the HIRLAM control vs. urban runs (A+R+AHF) for the (a) air temperature at 2 m & (b) wind velocity at 10 m at 00 UTCs on 29 Jan 2009.

Urbanization: Approaches, Modules, Testing

See urban modules examples:





http://megapoli.dmi.dk/publ/MEGAPOLI_sr10-04.pdf

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