

Treatment of Land-Use and Urbanization

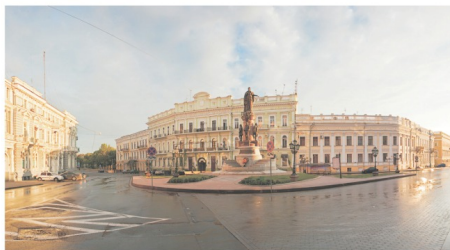


LECTURE 6

Alexander Mahura



INTERNATIONAL
YOUNG SCIENTIST SUMMER SCHOOL
ON "INTEGRATED MODELLING OF
METEOROLOGICAL AND CHEMICAL TRANSPORT PROCESSES/
IMPACT OF CHEMICAL WEATHER
ON NUMERICAL WEATHER PREDICTION AND CLIMATE MODELLING"



ODESSA, UKRAINE
3-9 JULY 2011



*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.

An aerial photograph of a rural landscape. A winding river flows through the center of the image. The surrounding area is a mix of green fields, yellow fields, and brown patches. In the background, a town or village is visible. The text "LAND COVER and LAND USE" is overlaid in red, serif font with a white outline. There are decorative teal and light blue circular shapes on the left side of the image.

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.);

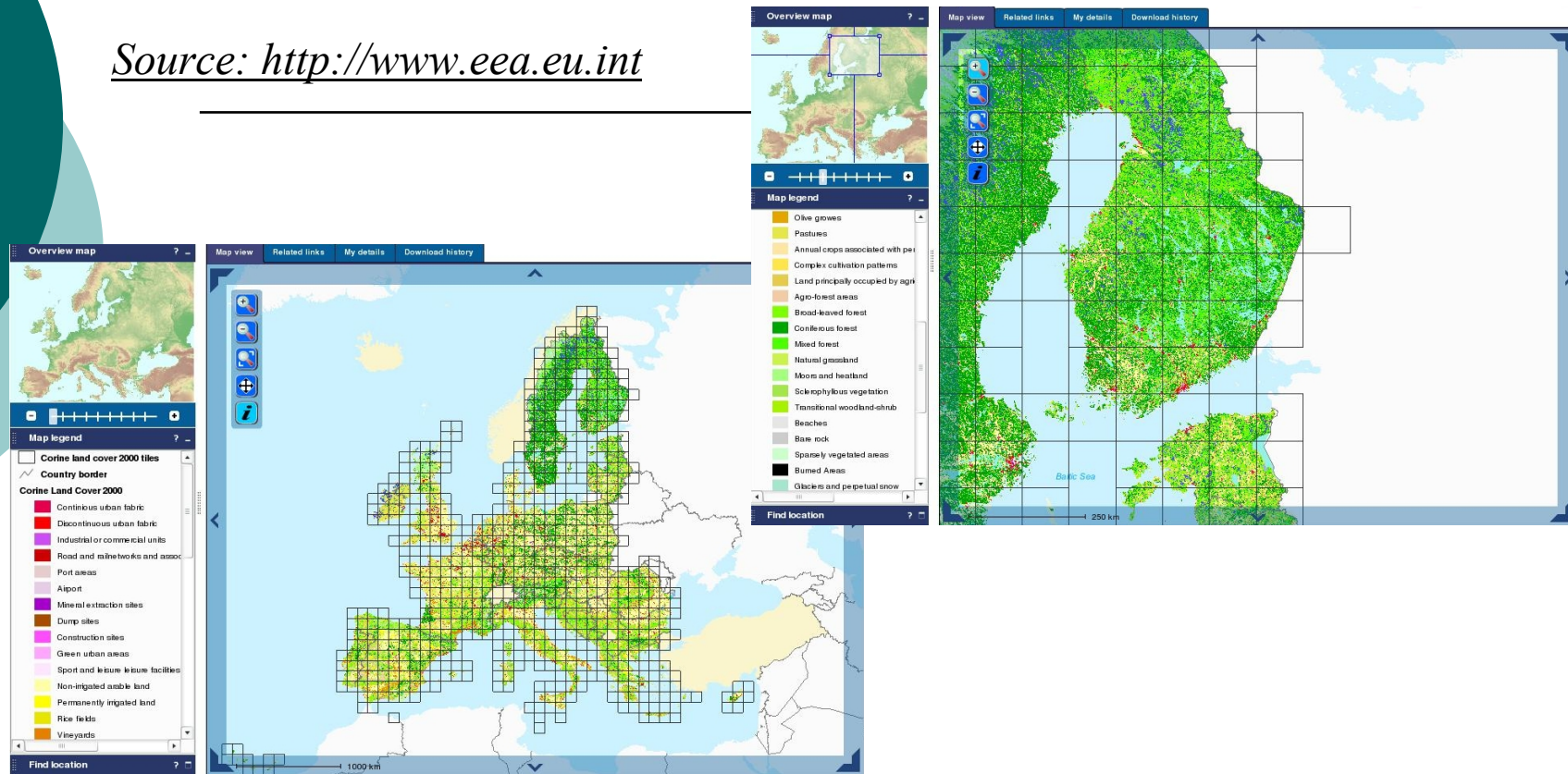
Take into account the climate variability from one region to another;

**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

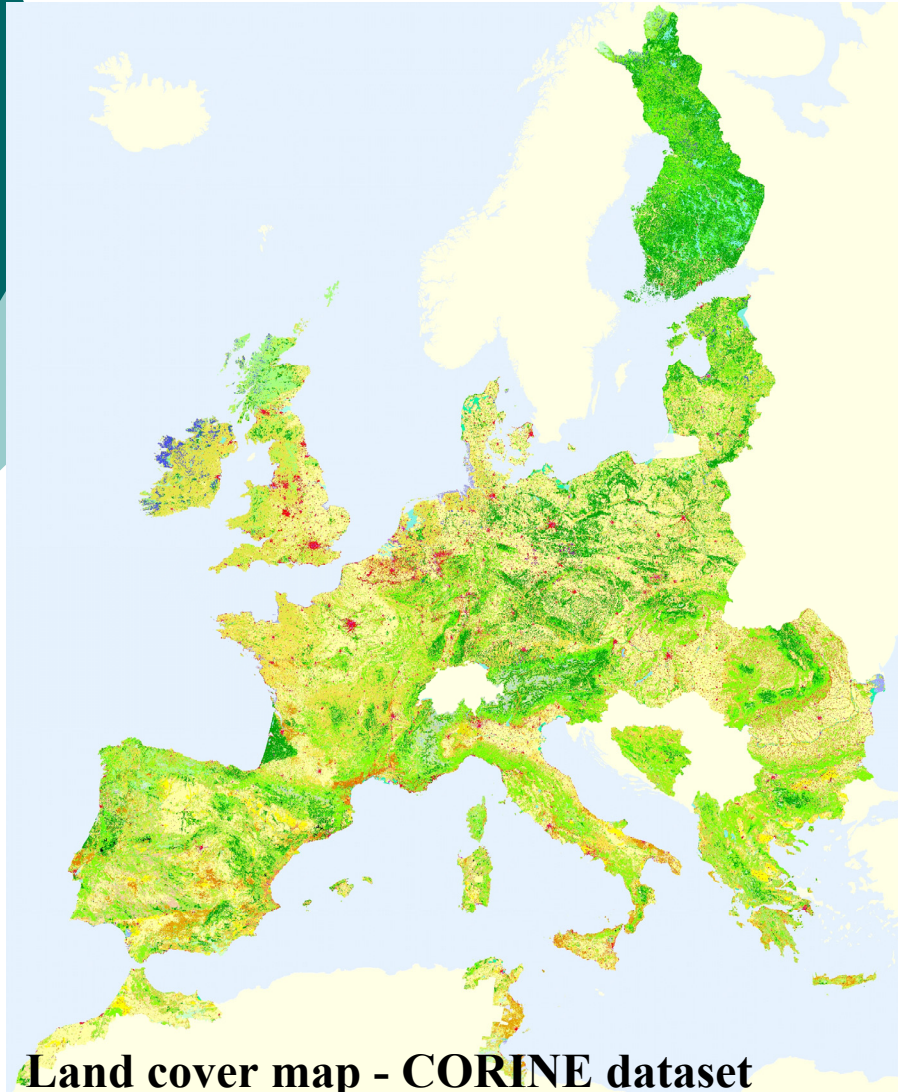
CORINE: Coordination of Information on the Environment

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

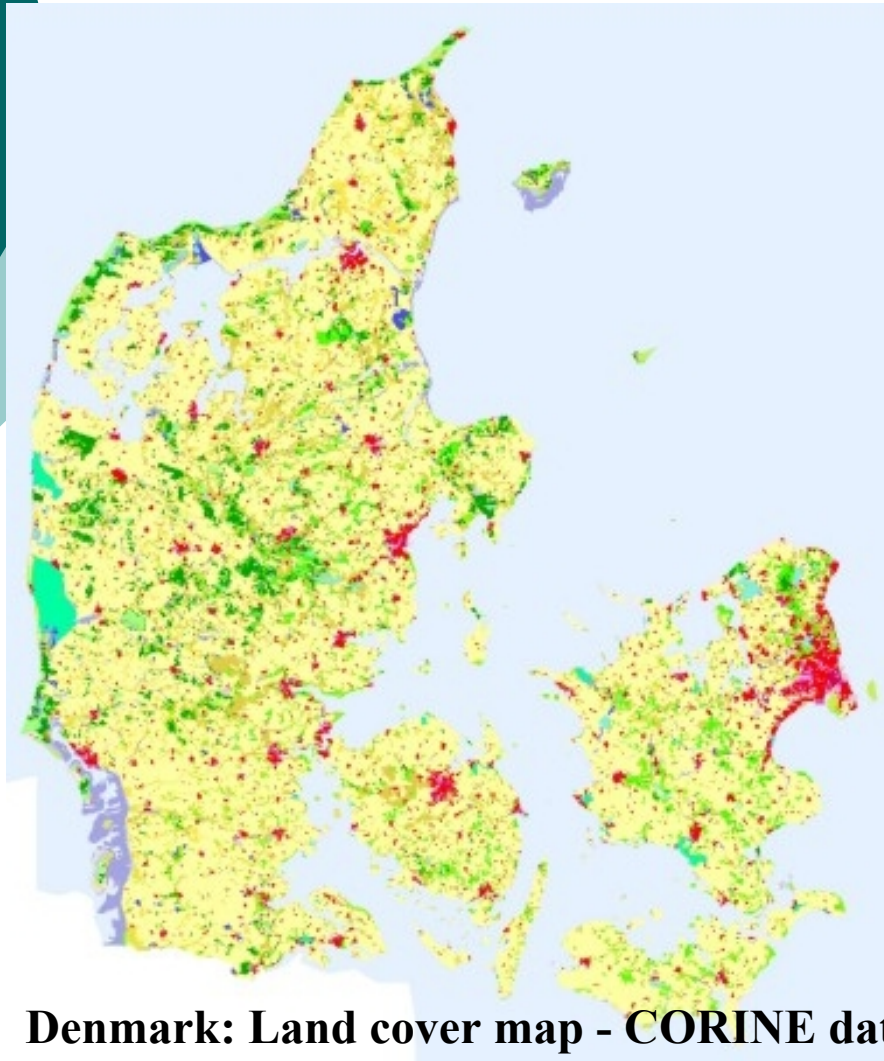


Land cover map - CORINE dataset

250 m resolution, 44 classes

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



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

**Land cover map - ECOCLIMAP dataset
1 km resolution**

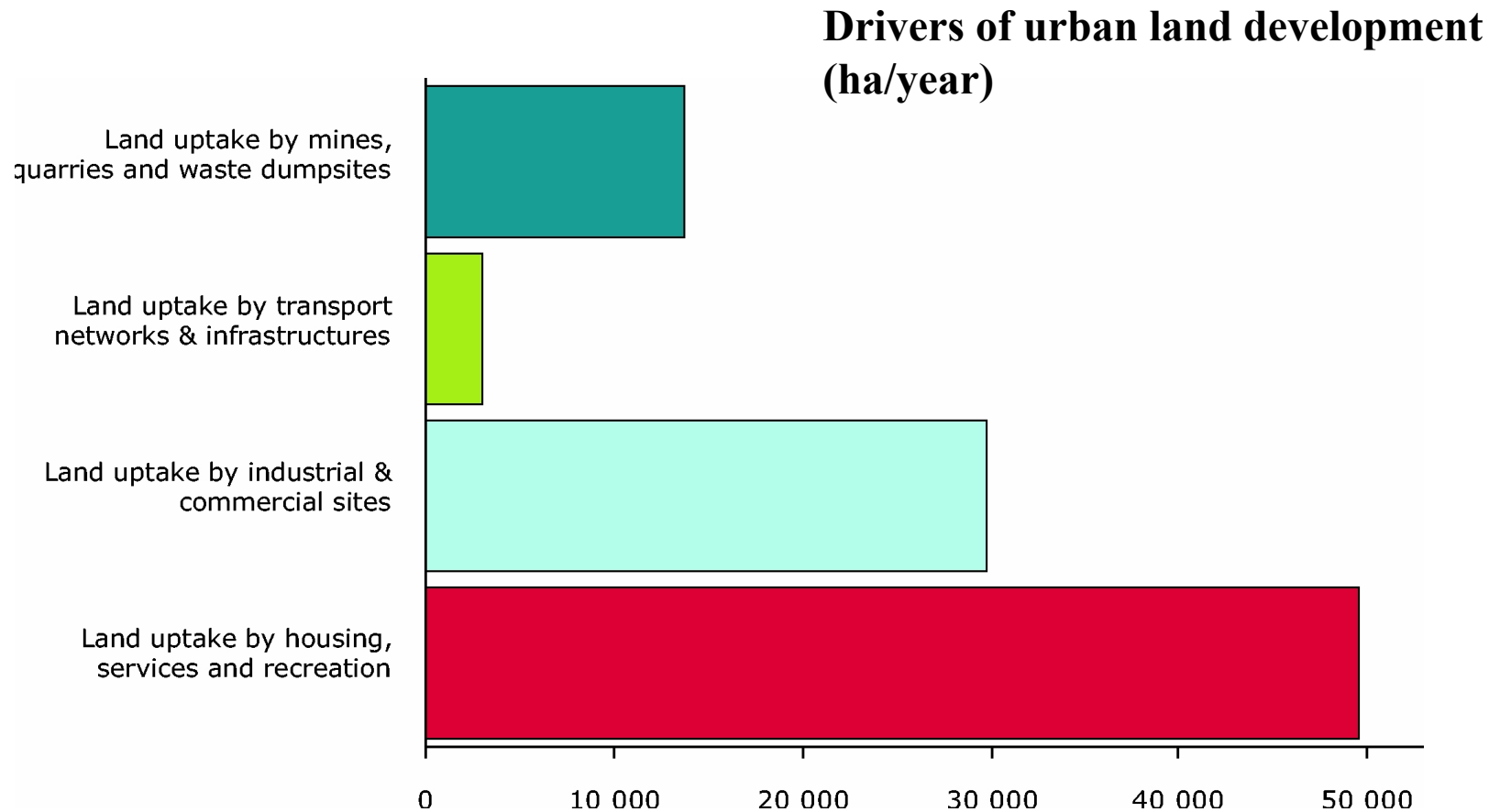
+ Other datasets, USGS, PELCOM, etc.

URBAN LANDS



EU: Urban Land Development

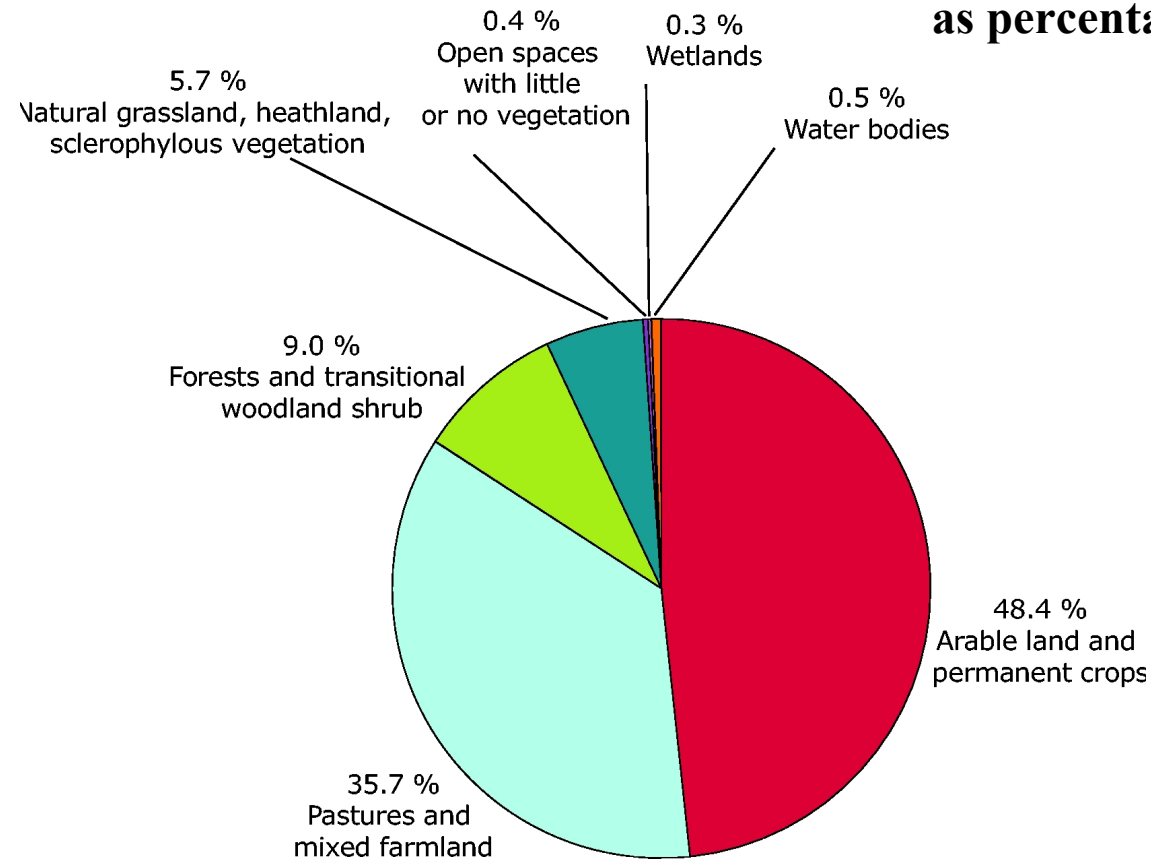
Some statistics



EU: Urban Land Uptake by Origin

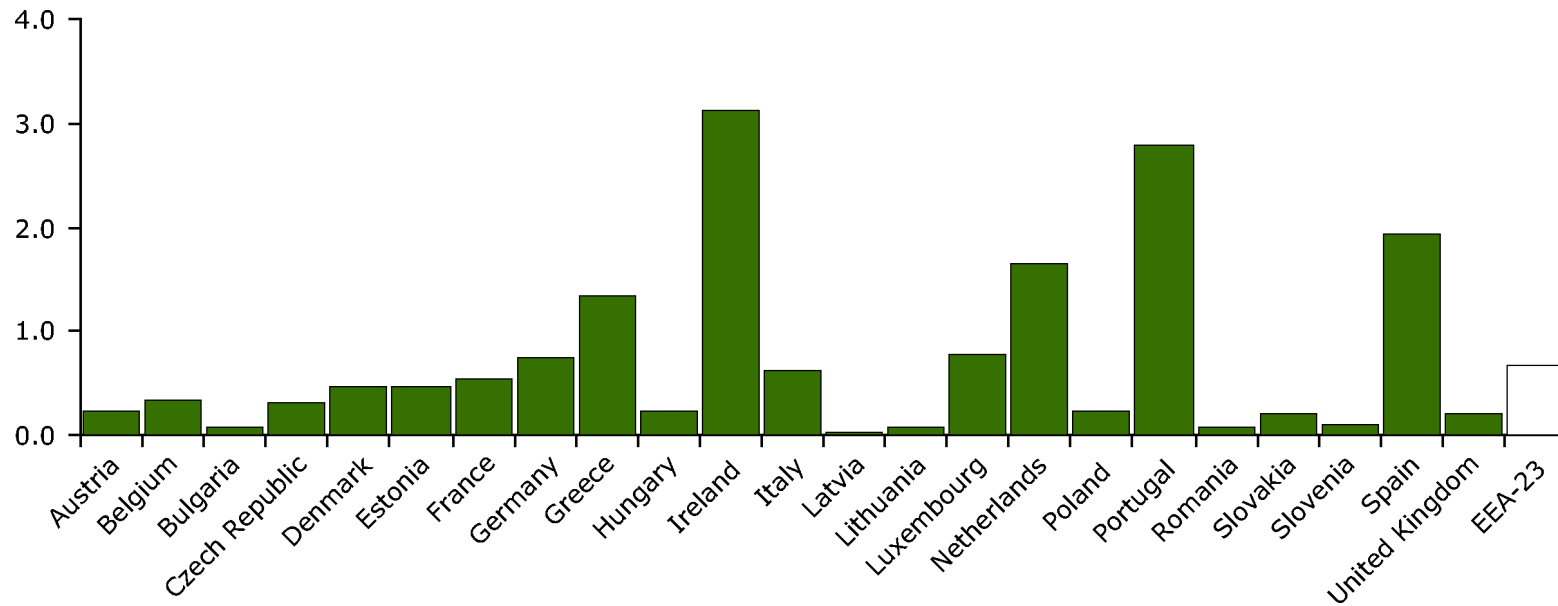
From all areas converted to artificial land-use

**Origin of urban land uptake
as percentage of total uptake**

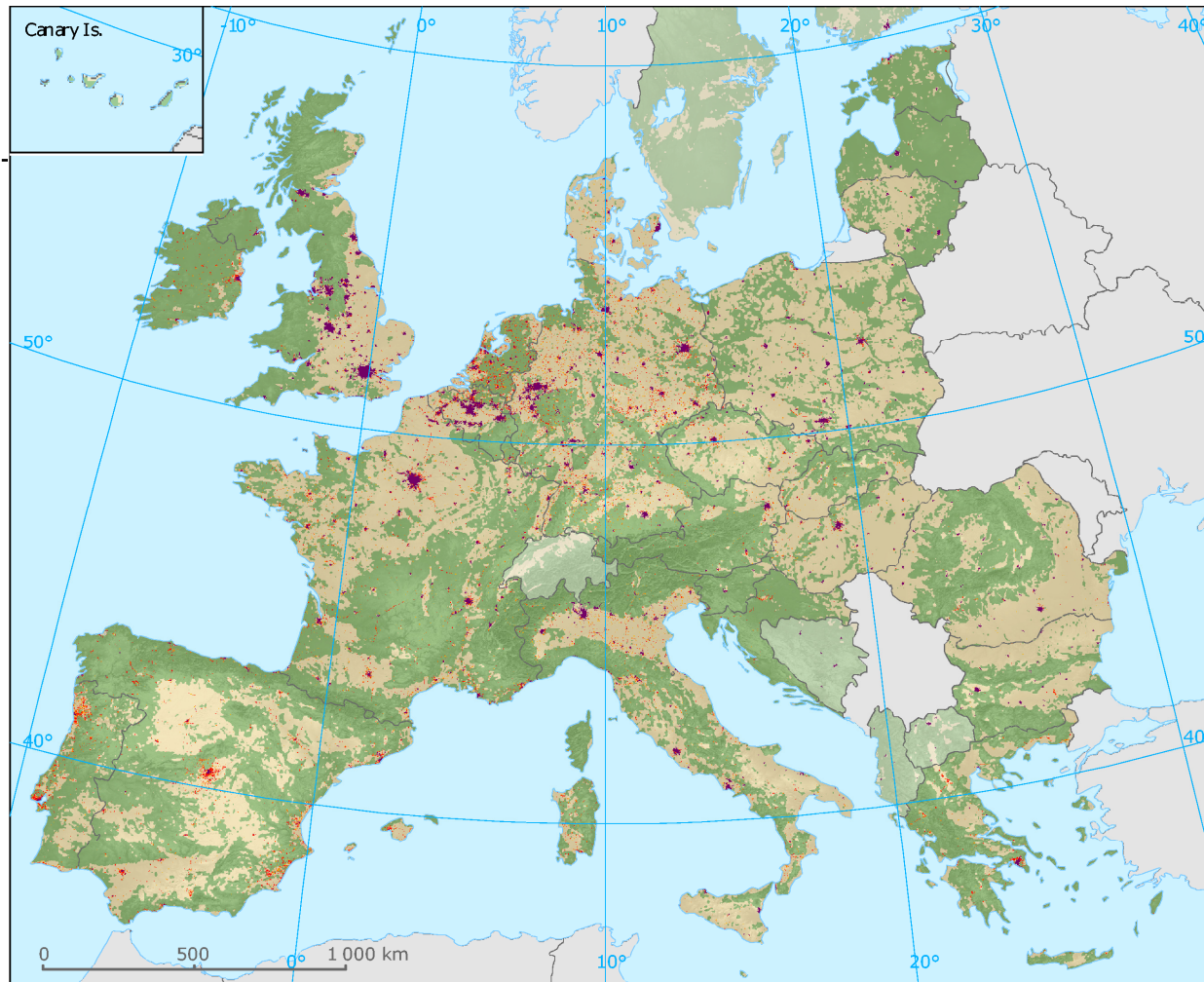


EU: Urban Land Uptake by Countries

Urban land uptake by countries



EU: Urban Land Uptake by Metropolitan Areas



Urban land uptake by megacities

Urban and infrastructure development

- 1 to 5 %
- 5 to 10 %
- More than 10 %

Urban zones 1990

- More than 50 000 people

Green background index

- 0 to 60 %
- 61 to 100 %

GLOBAL: climate change

URBANIZED AREAS

REGIONAL:
acid rain,
tropospheric ozone,
aerosols, greenhouse gases

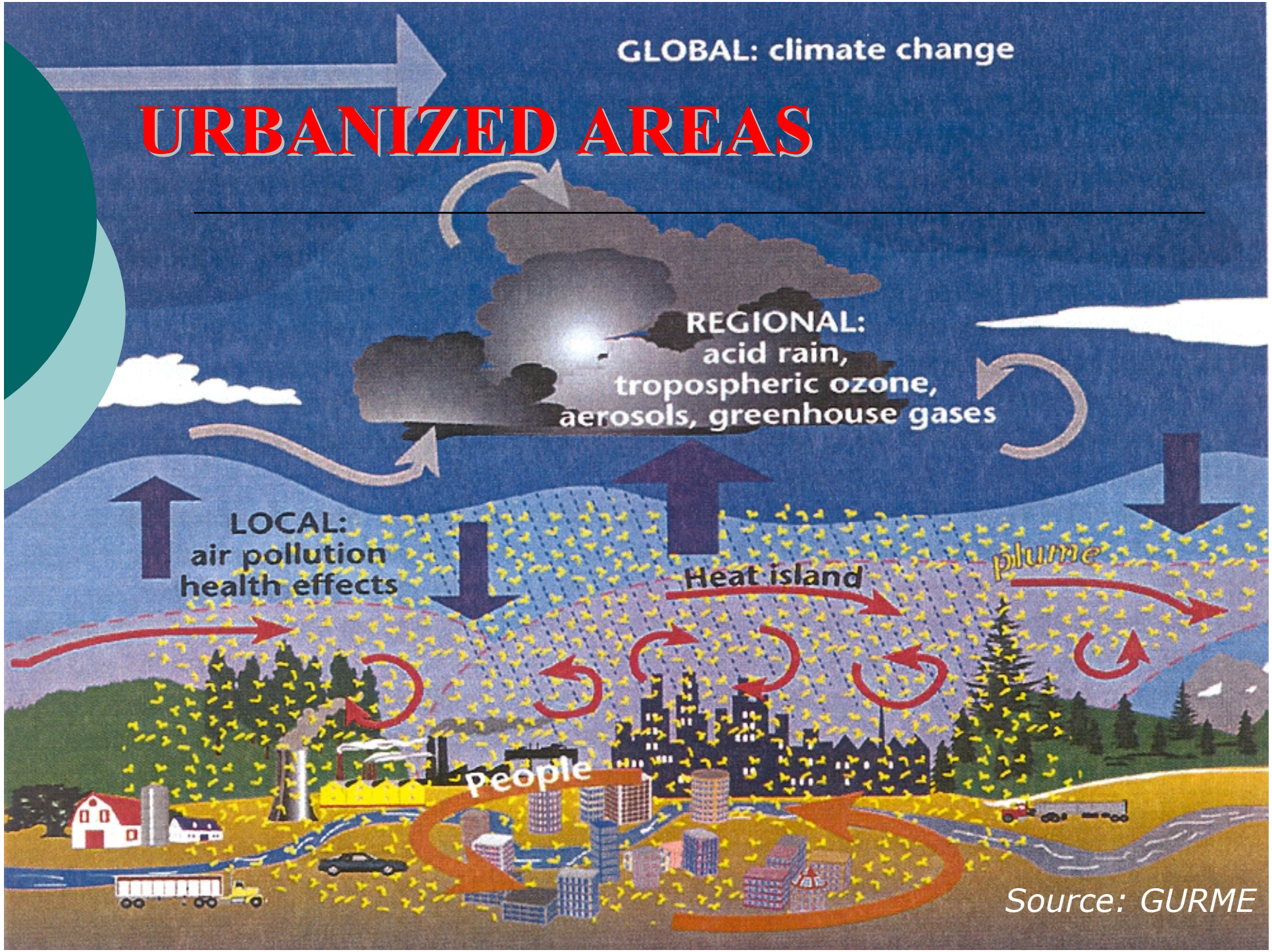
LOCAL:
air pollution
health effects

Heat island

plume

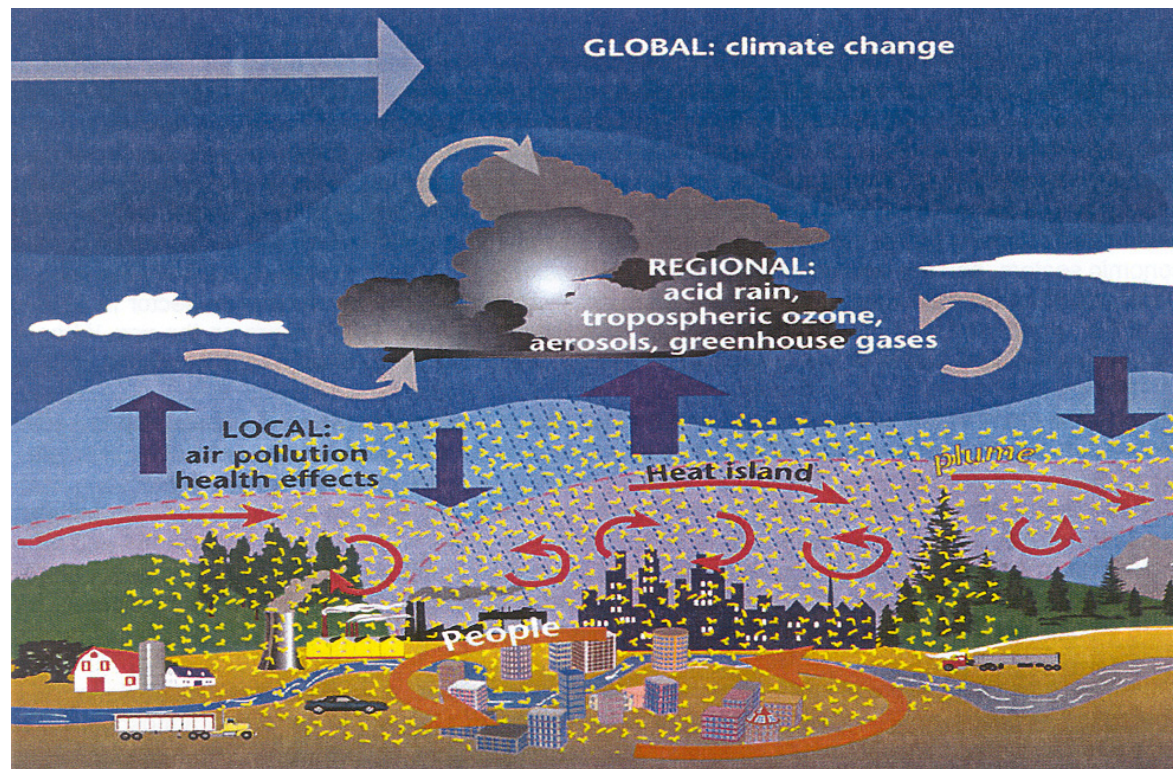
people

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)

Fixed

City Location

- climate
- topography
- rural surrounds

City Size

- fetch distance
- density of use

Time

- day
- season

Modulators

Weather

- wind
- cloud
- stability

City Form

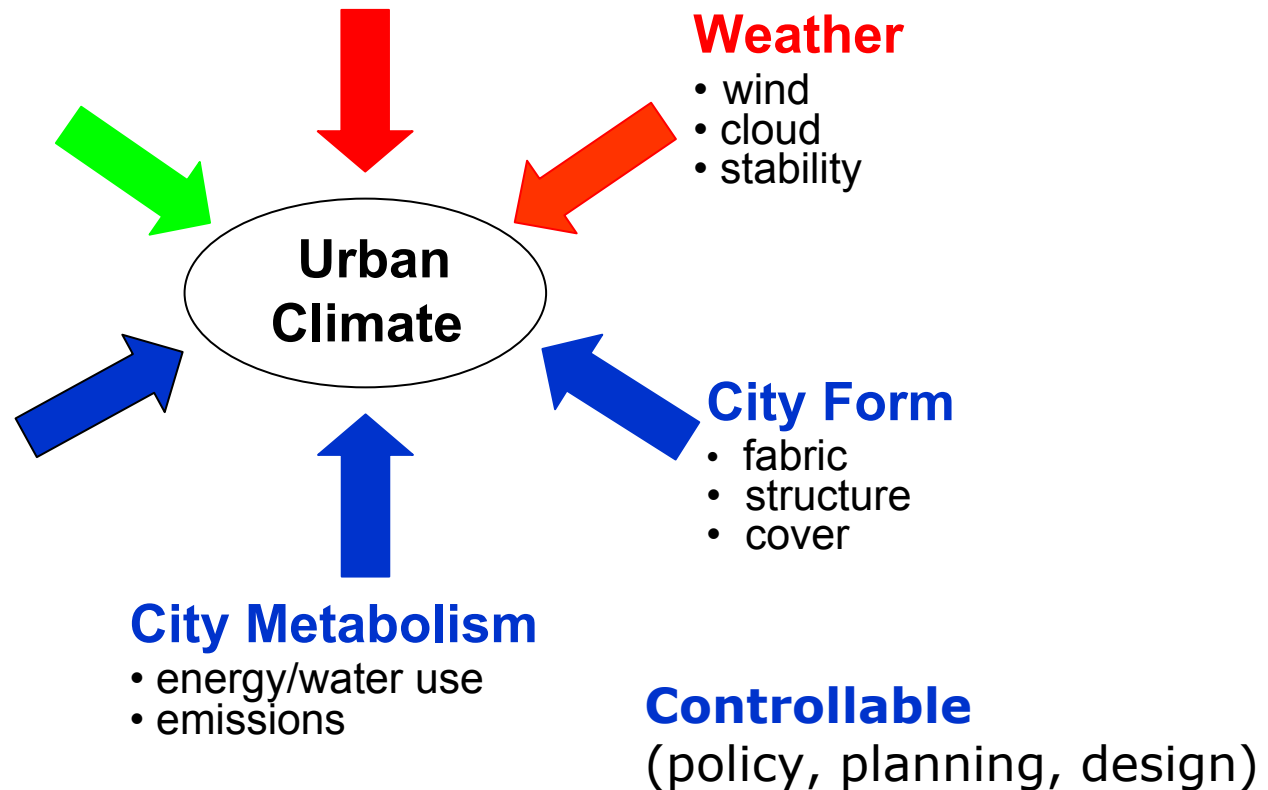
- fabric
- structure
- cover

City Metabolism

- energy/water use
- emissions

Controllable

(policy, planning, design)





Surface Energy Balance, Characteristics of Urban Surfaces

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

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

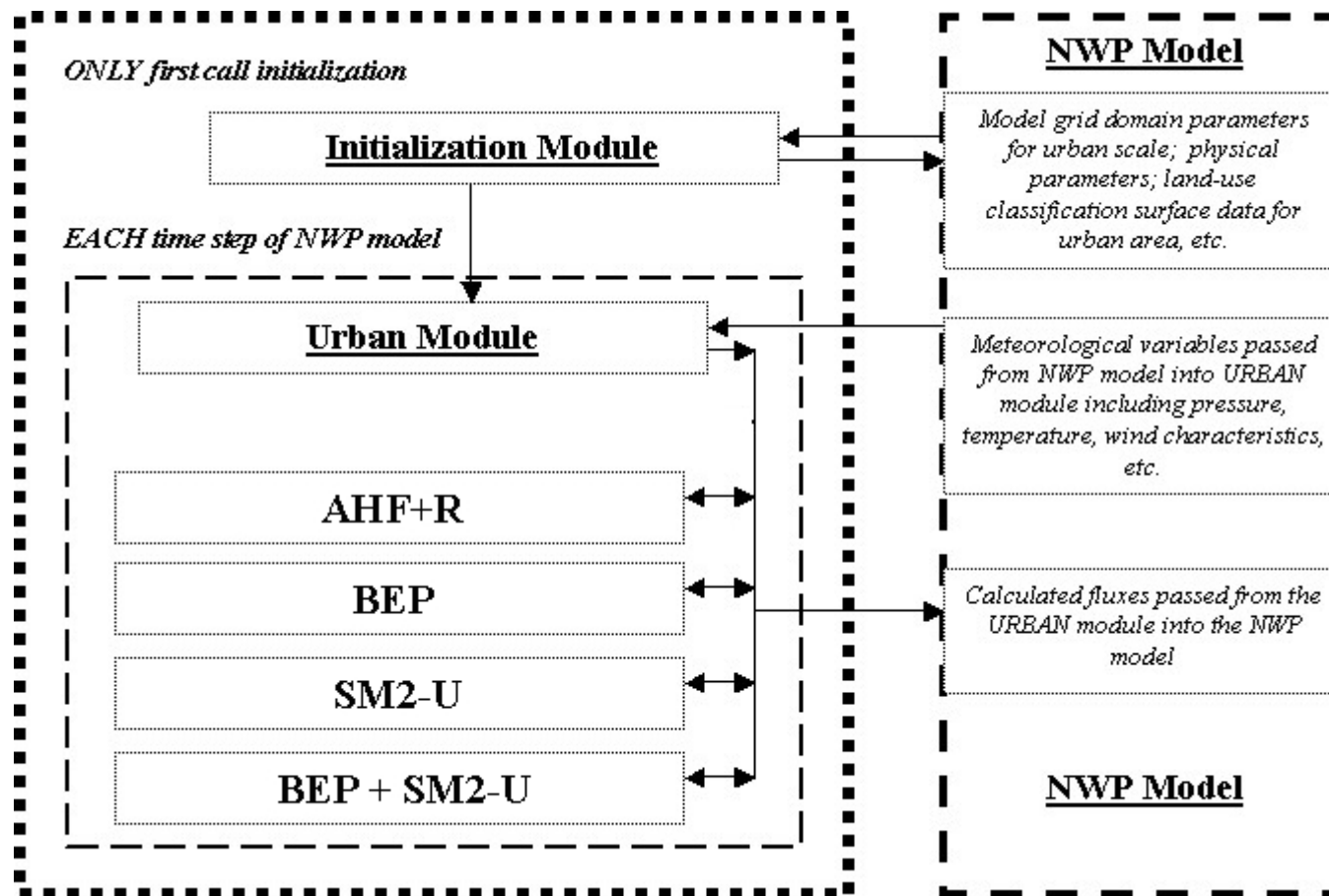
- **Increased grid resolution and nesting of models**
- **Urban land-use classification & algorithms for roughness parameters**
- **Urban fluxes and sublayer parameterisation**
- **Approach based on improved urban roughness and fluxes**
- **Effect of urban canopy roughness**
- **Effective roughness over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

An aerial photograph of a city grid, showing a dense network of streets and buildings. The image is overlaid with a teal circular graphic on the left side. The text "URBANIZATION for Enviro-HIRLAM" is written in white, serif font across the top left portion of the image.

URBANIZATION for Enviro-HIRLAM

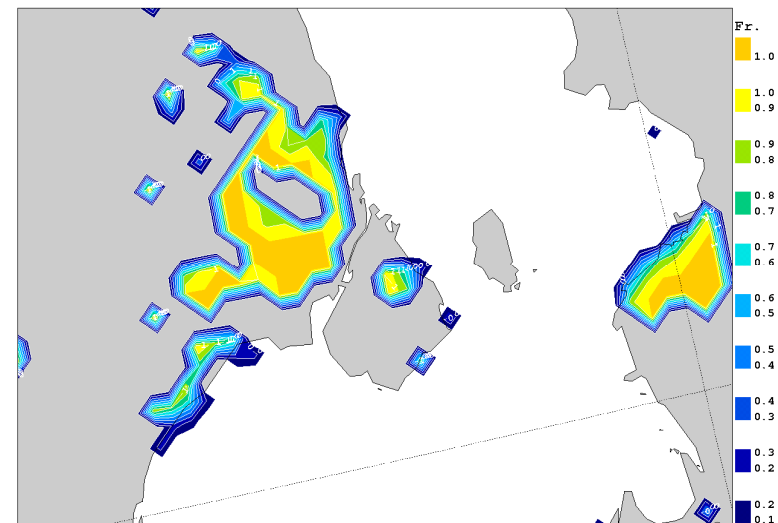
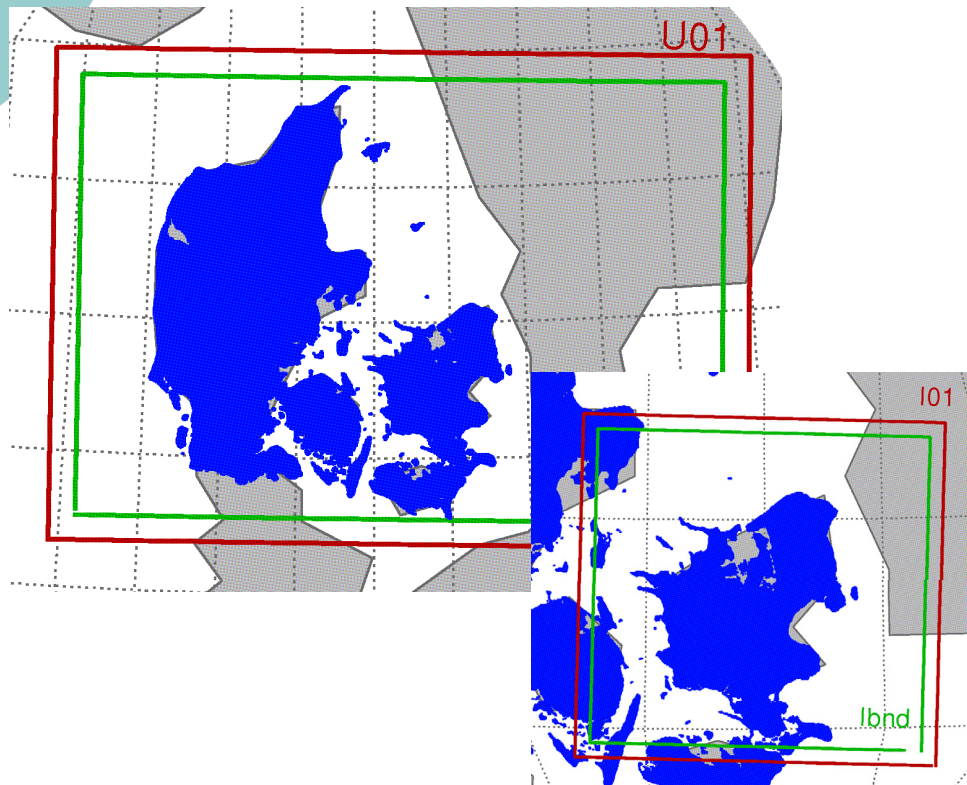
Enviro-HIRLAM: Urbanization Modules

- 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:

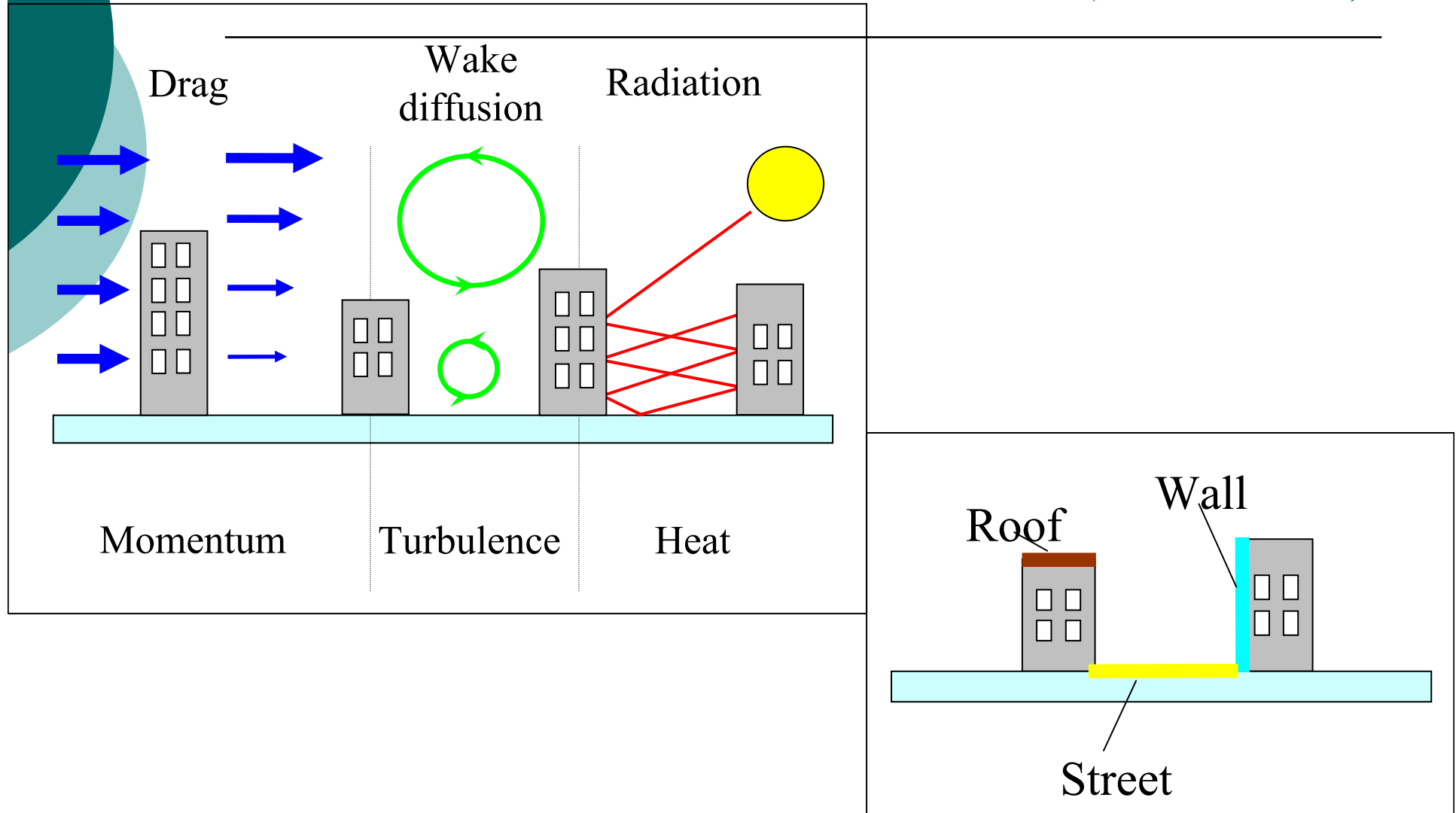
1. Population density maps with a high resolution in urban areas;
2. Satellite images of the night lightness over urban areas (but difficulties to use for industrial and developing countries, should be corrected);
3. Land-use classification as a percentage of urban classes (central part, urban, sub-urban, 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/m²

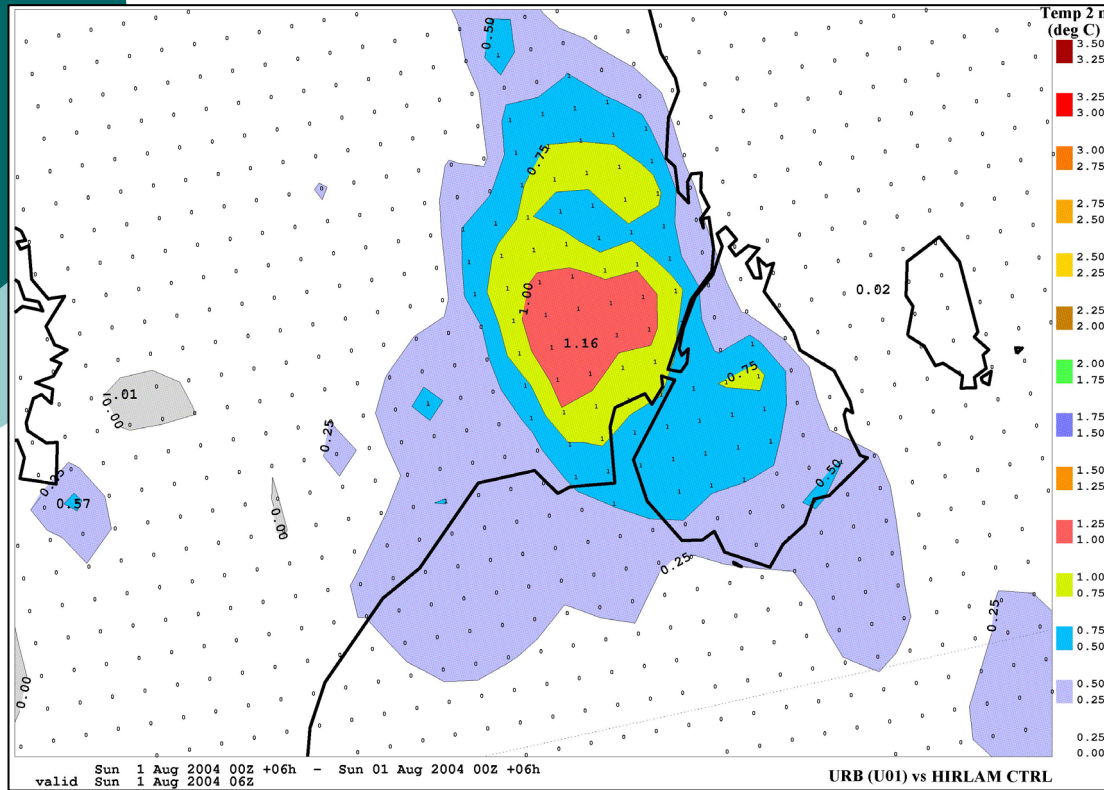
BEP : Building Effect Parameterization

(Martilli et al., 2002)



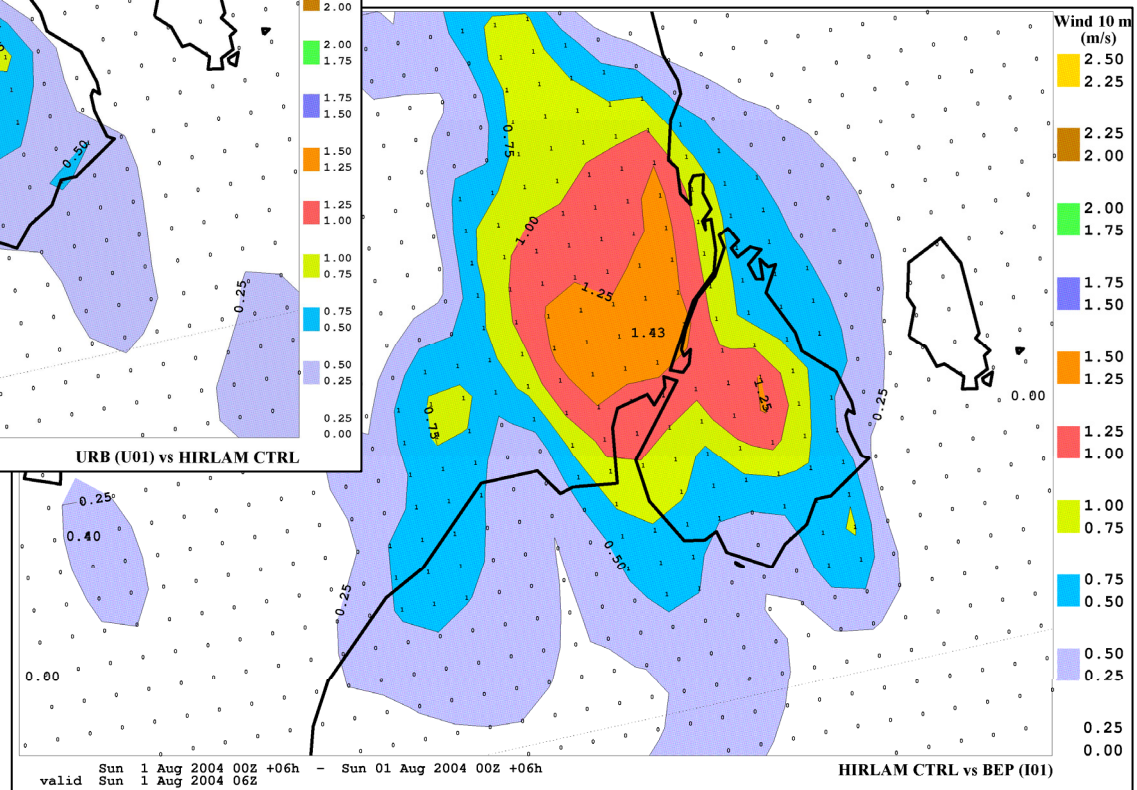
MeteoModelling: BEP Module

Difference between runs: 01 Aug 2004, 06 UTC



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

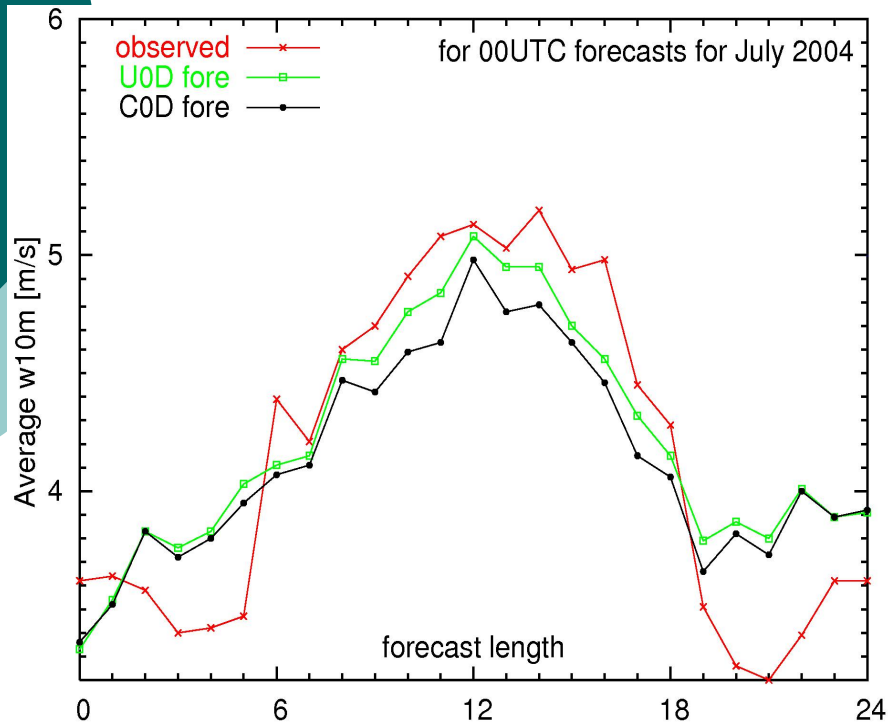
(control vs. urbanized run)
Difference field for wind at 10 m



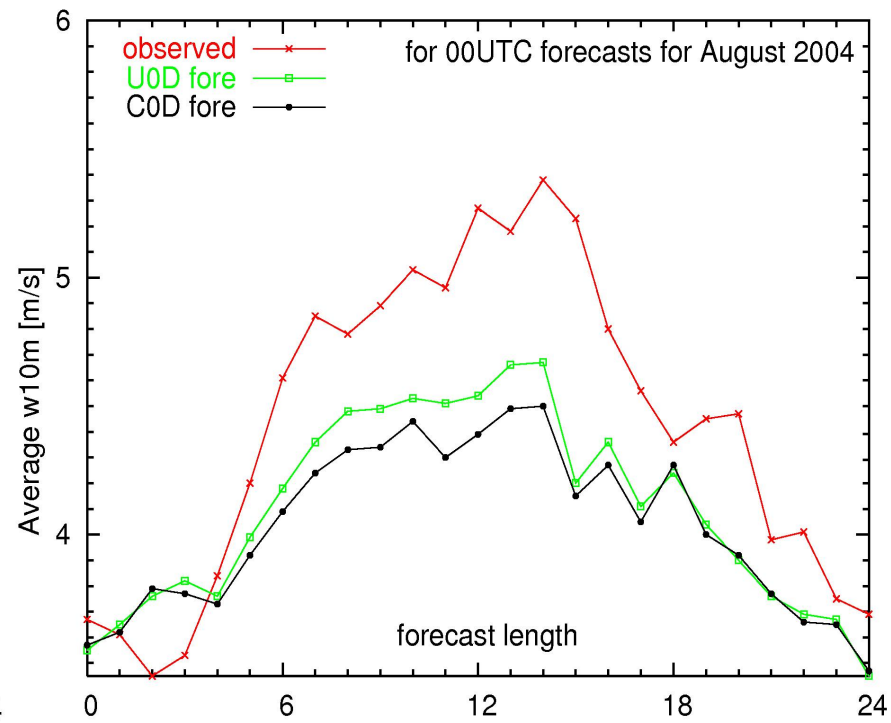
MeteoModelling: BEP Module



Urban station N-6180: Copenhagen area : Verification



July 2004



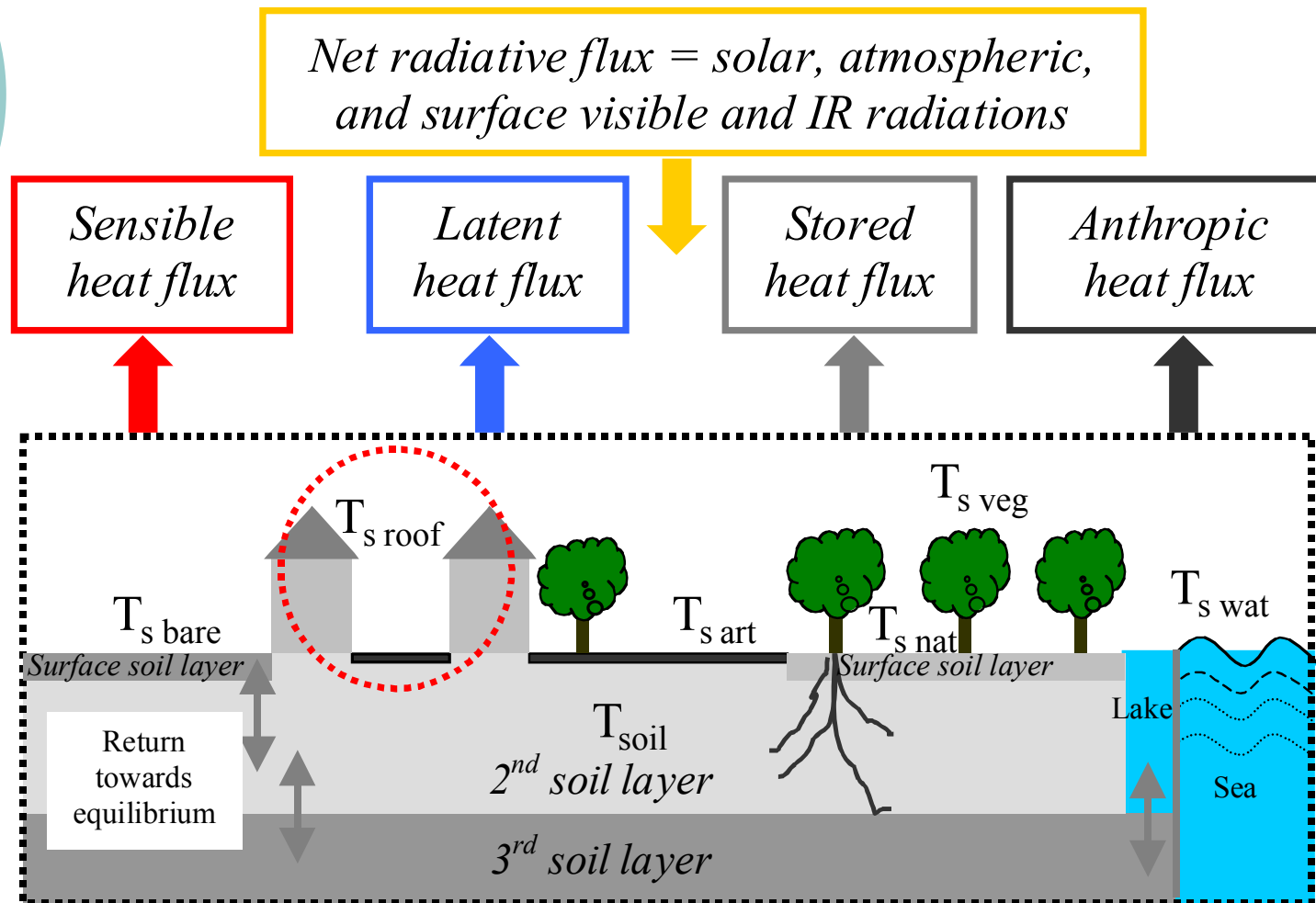
August 2004

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

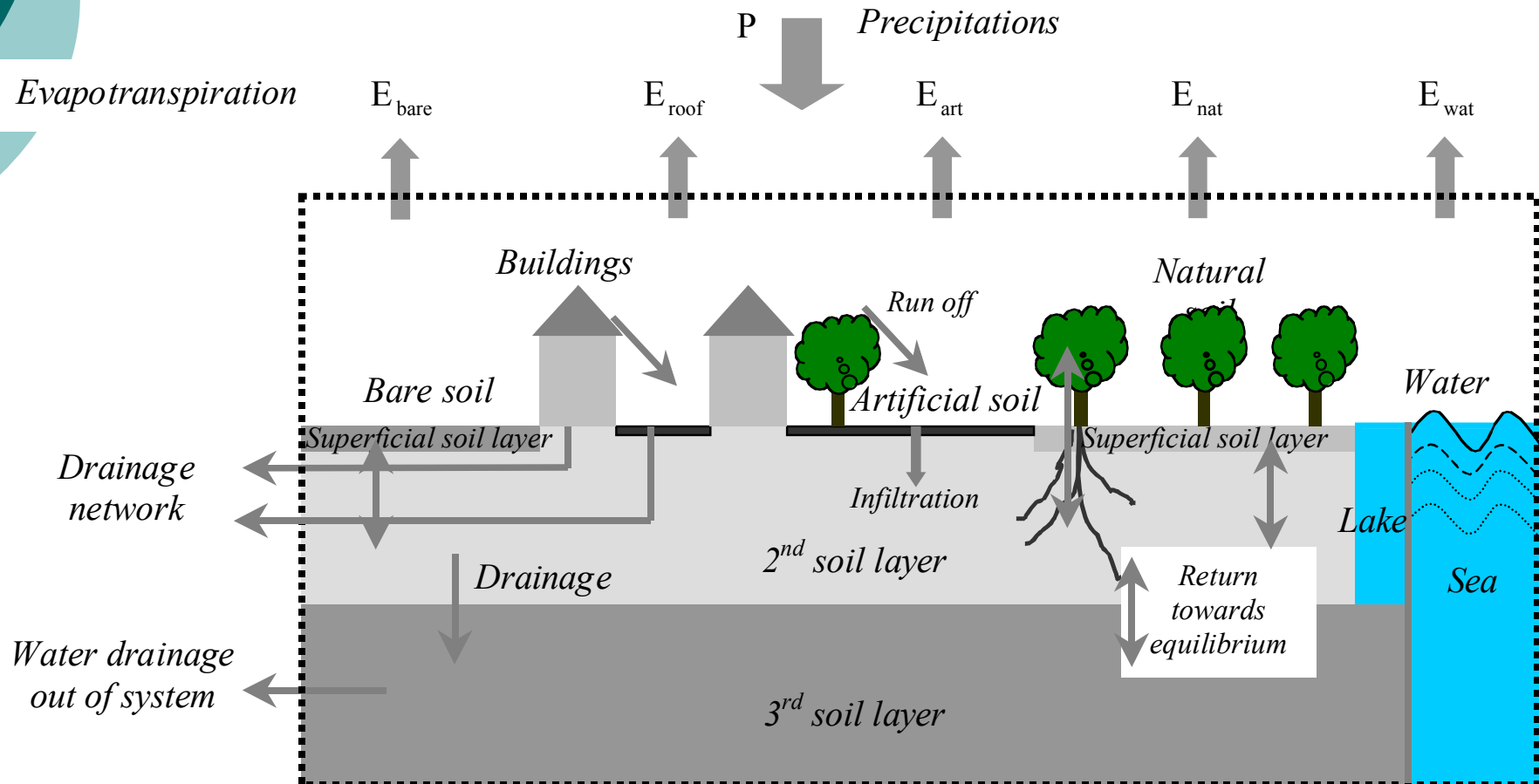
(Dupont et al., 2006ab)



SM2-U : Soil Model for Sub-Meso scales

Urbanized version : Water budget

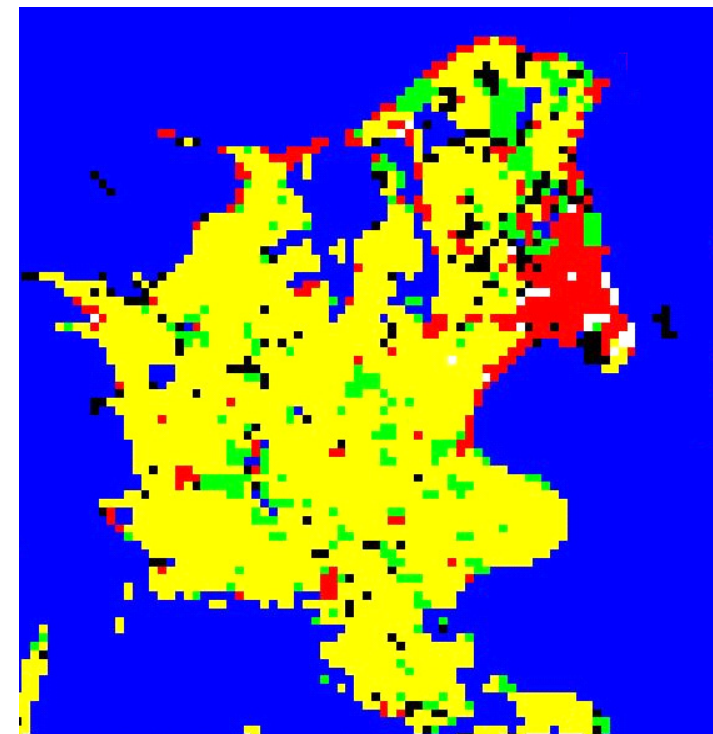
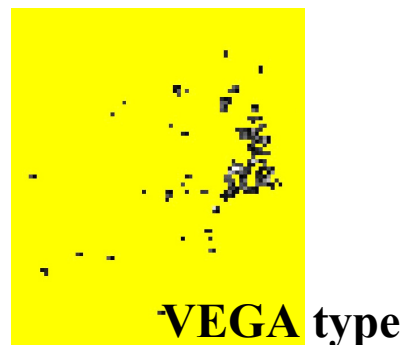
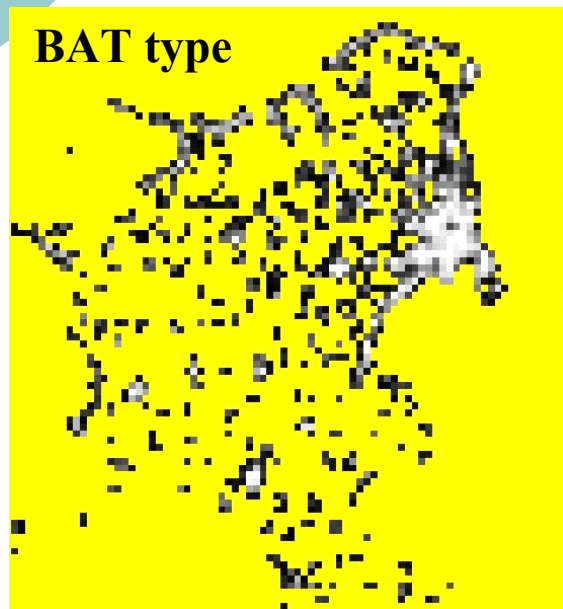
(Dupont et al., 2006ab)



Revised Land Use Classification : SM2-U Module



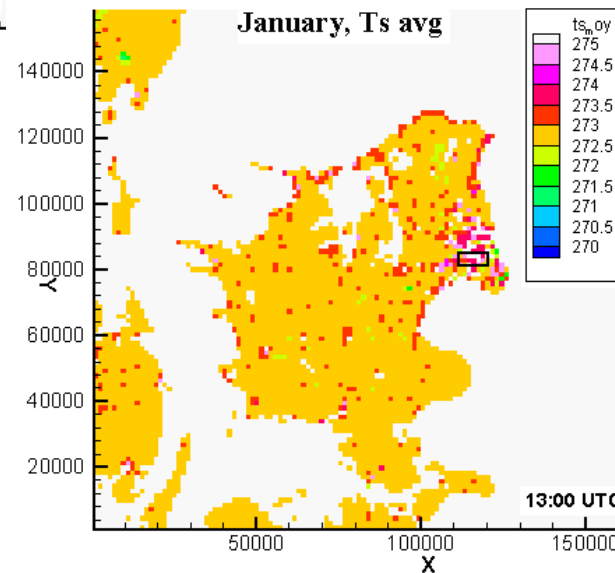
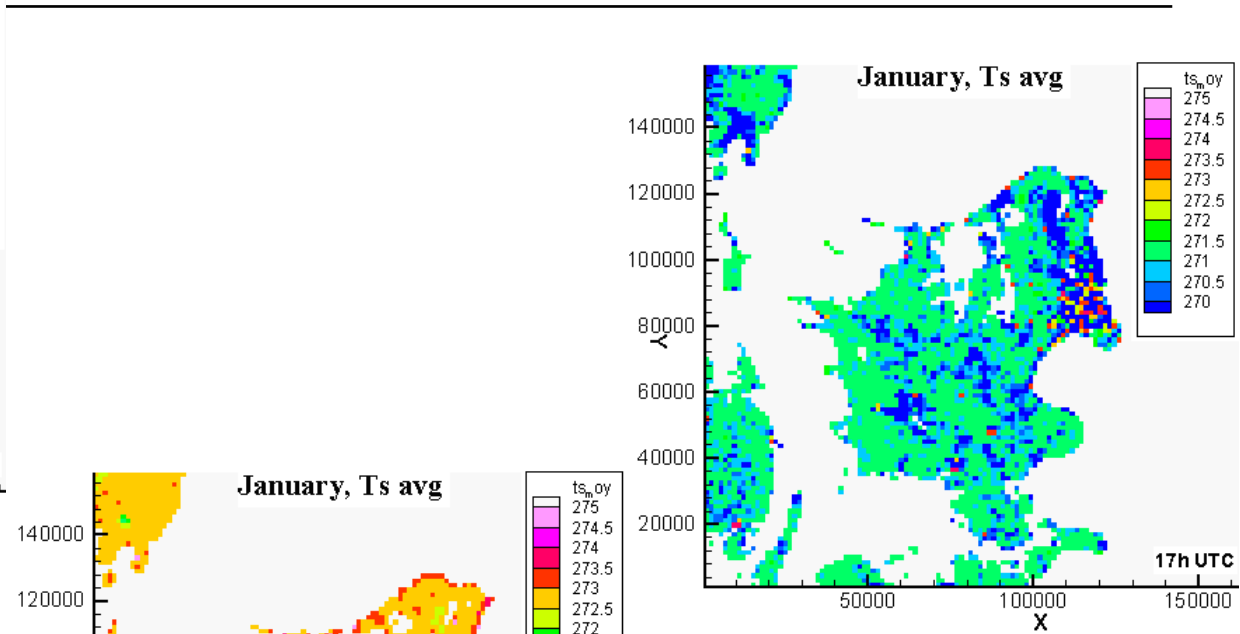
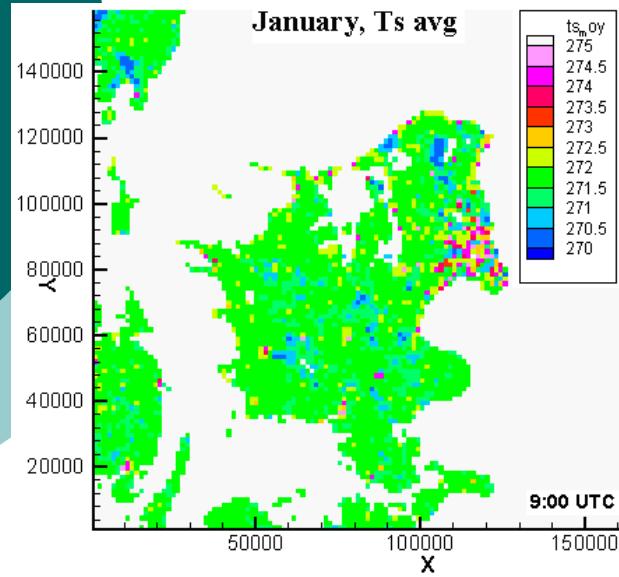
BARE	Bare soil without vegetation
NAT	Bare soil located between sparse vegetation elements
VEGN	Vegetation over bare soil
VEGA	Vegetation over paved surfaces
ART	Paved surfaces located between the sparse vegetation elements
BAT	Building/roofs
EAU	Water surfaces



Dominated type

MeteoModelling: SM2-U Module

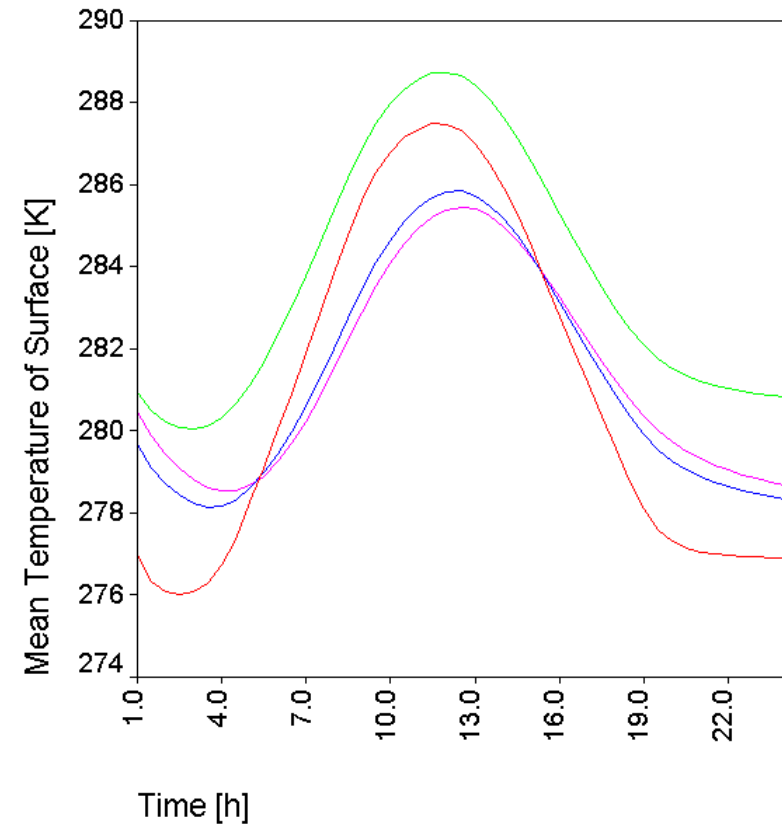
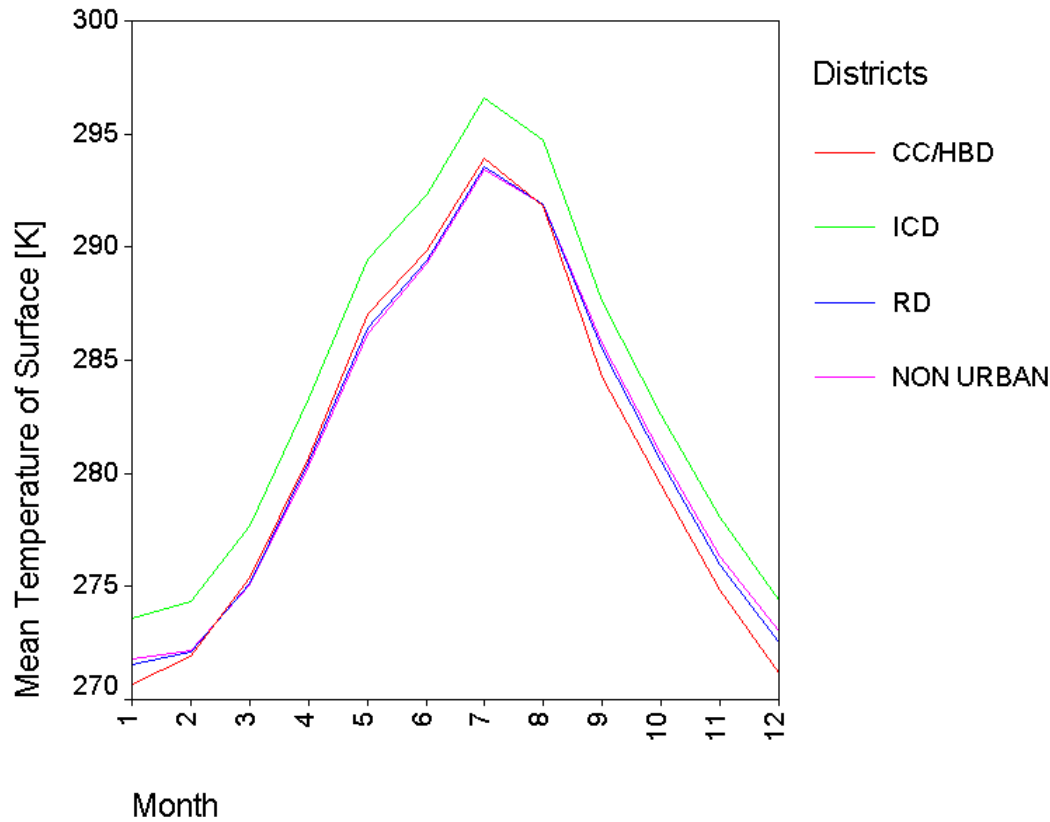
Metropolitan area : Copenhagen : Surface temperature



MeteoModelling: SM2-U Module



Metropolitan area : Copenhagen : Surface temperature : Urban districts

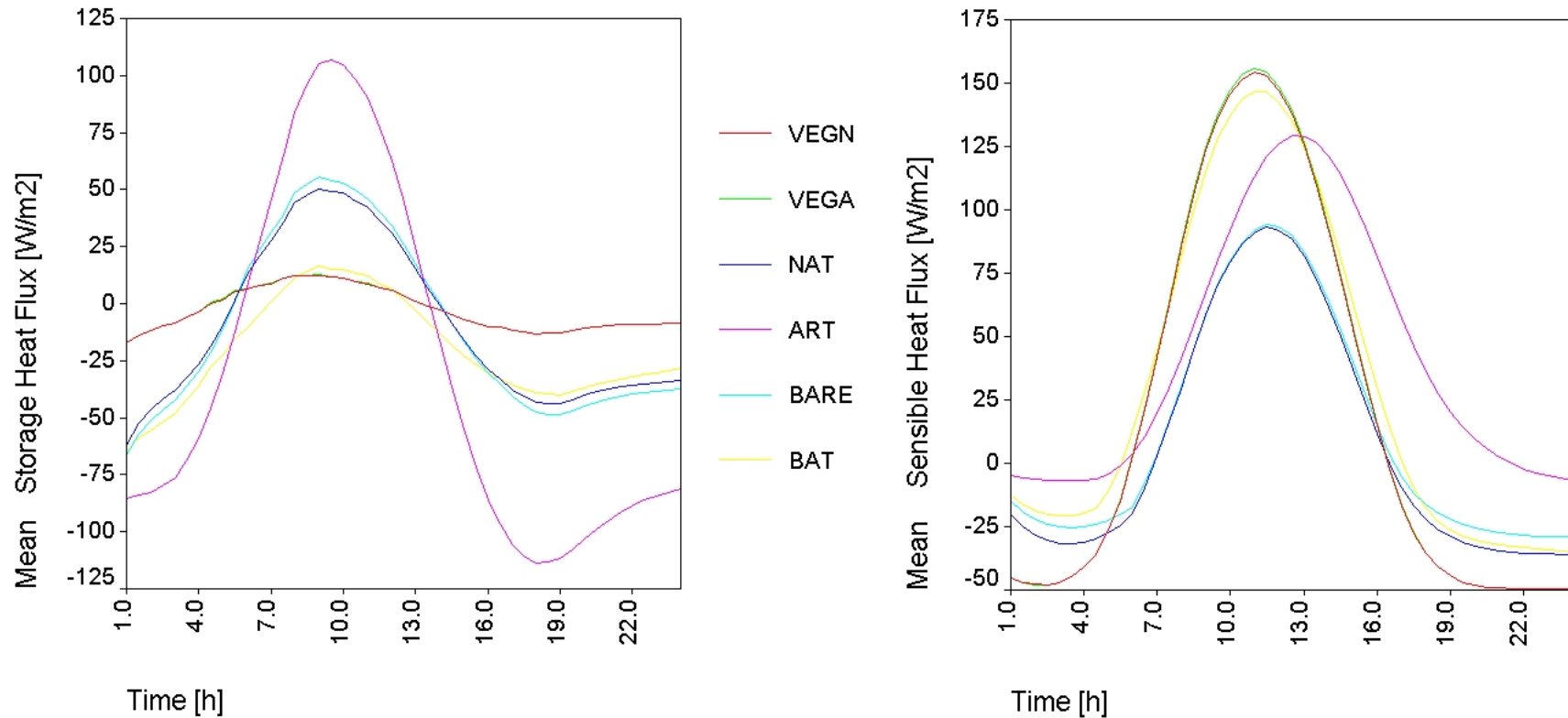


CC/HBD	City center / high buildings district
ICD	Industrial commercial district
RD	Residential district
Non-urban	Non-urban areas (no BAT type)

MeteoModelling: SM2-U Module



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



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



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

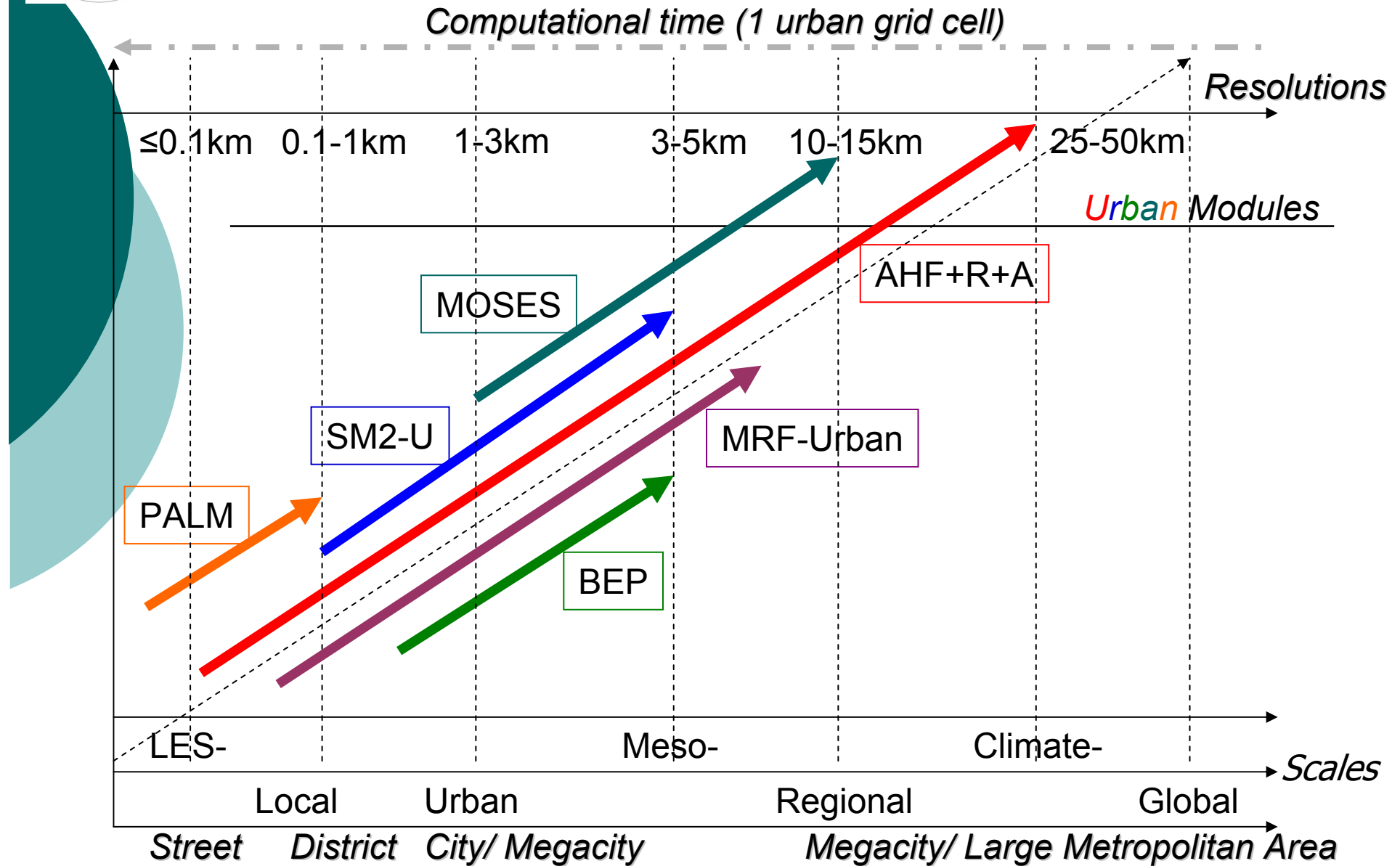
(example of FP7 EU MEGAPOLI project)



-
- **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

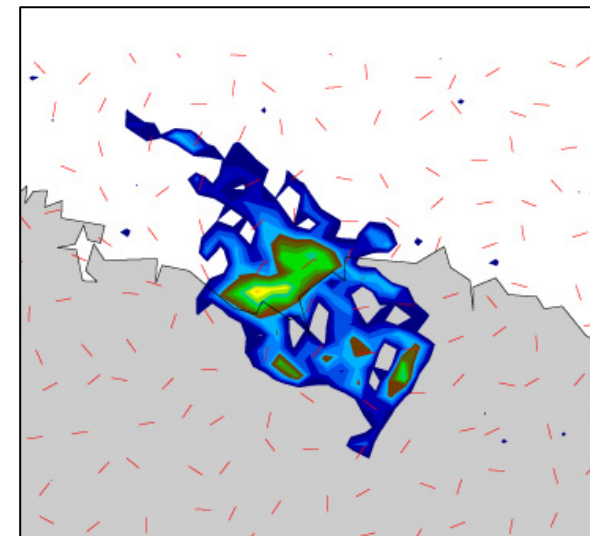
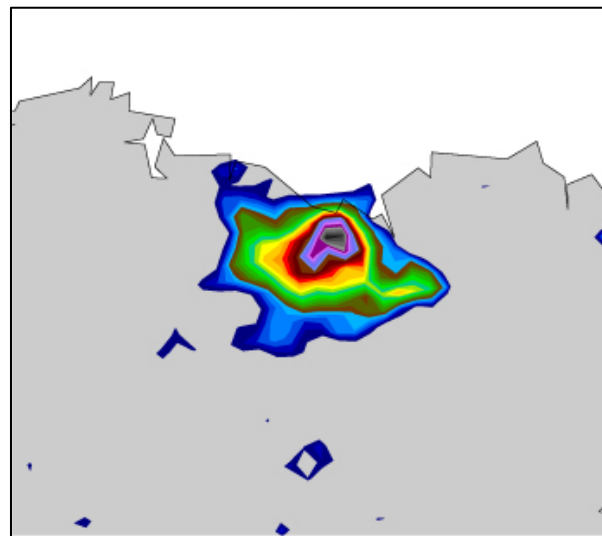
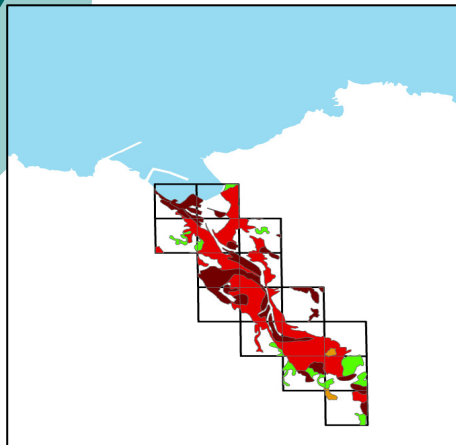


Bilbao metropolitan area, Spain



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

*Bilbao metropolitan area:
urban fractions + districts*

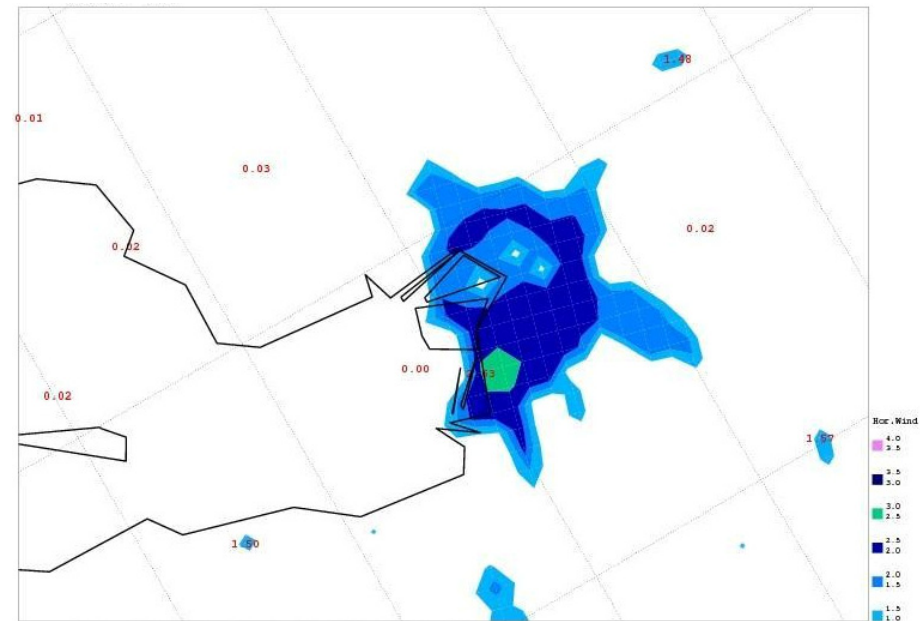
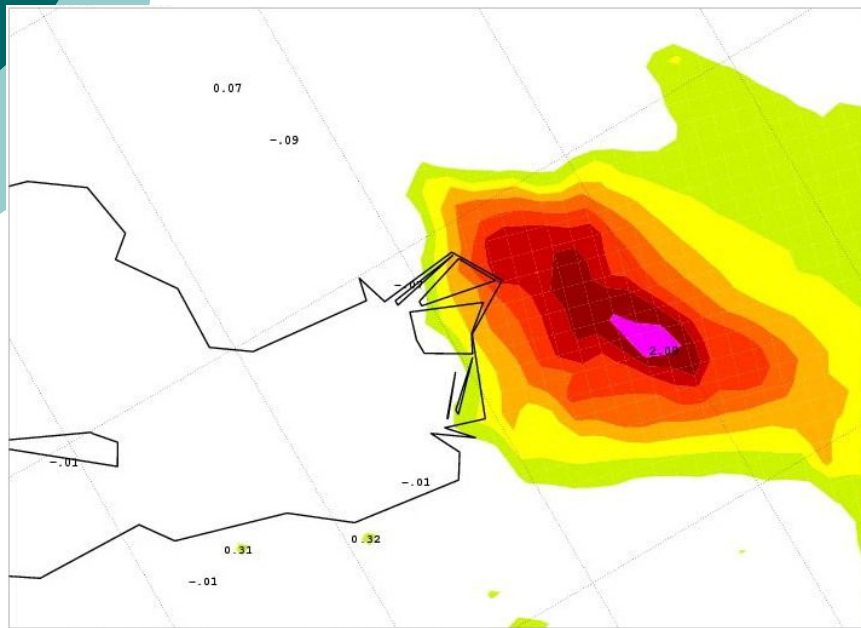


Difference plots between the Enviro-HIRLAM control vs. urban (BEP+AHF module) runs for the (left) air temperature at 2 m & (right) wind at 10 m at 06 UTC on 12 Aug 2009.

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:

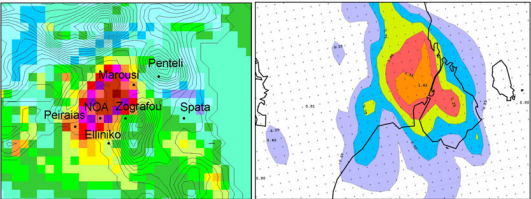
MEGAPOLI Scientific Report 10-04

Hierarchy of Urban Canopy Parameterisations for Different Scale Models

MEGAPOLI Deliverable 2.2

Alexander Mahura, Alexander Baklanov (Eds.)

Contributing Authors
Baklanov A., Martilli A., Grimmond CSB., Mahura A., Ching J., Calmet I., Clark P., Esau I., Dandou A., Zilitinkevich S., Best M., Mestayer P., Santiago J.L., Tombrou M., Petersen C., Porson A., Salamanca F., Amstrup B.



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

Copenhagen, 2010

... Grimmond - Alexander Mahura (Eds.)

Air Quality Models for Urban Areas

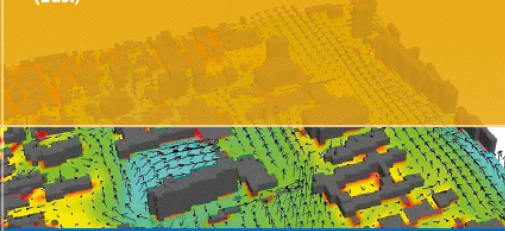
presentations given at the COST728 workshop, is concerned with: 1. Urban morphology and databases, 2. Parameterisation for urbanization of different types of models, 4. Evaluation and validation, 5. Dynamic (on wind and turbulent) and thermal effects (on air quality). The final chapter of this volume summarizes the discussion and provides recommendations and future requirements for numerical weather prediction and air quality modelling.

... Grimmond, MS (1979), PhD (1981), Prof. (2008), senior scientist at the Danish Meteorological Institute (DMI) and deputy director of the strategic research centre for Energy, Environment and Health (E3H) at the DMI. Research interests include: modelling of atmospheric boundary layer, atmospheric dynamics and dispersion at various scales, modelling of atmospheric boundary layer, atmospheric dynamics and air pollution over complex terrain and urban areas.

... Grimmond (Environmental Monitoring and Modelling Group, City College London), BSc Hons (Otago), MSc-PhD (British Columbia), Professor at Indiana University. Past President of the International Association of Urban Climate and Lead Expert for the World Meteorological Organization on Urban and Building Climatology.




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