Land-Use Changes and Approaches for Urbanization of Numerical Weather Prediction

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Part 1
Land Cover / Use in Urban Areas

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

• Urban lands:
some statistics;

• Urbanized areas:
urban features, controls on urban climate, characteristics, approaches for treatment of urban boundary layer features

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.);

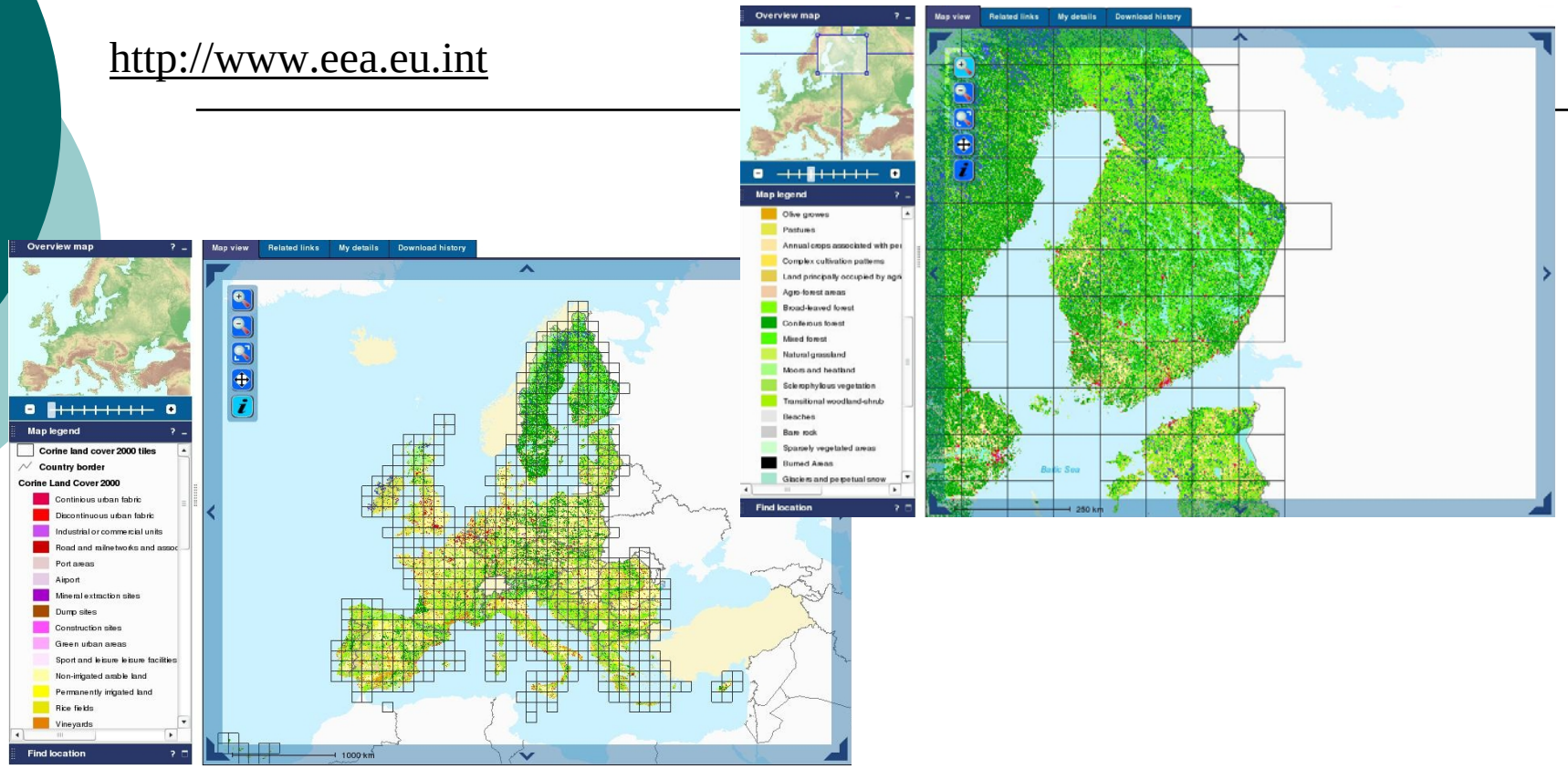
Take into account the climate variability from one region to another

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

http://www.eea.eu.int



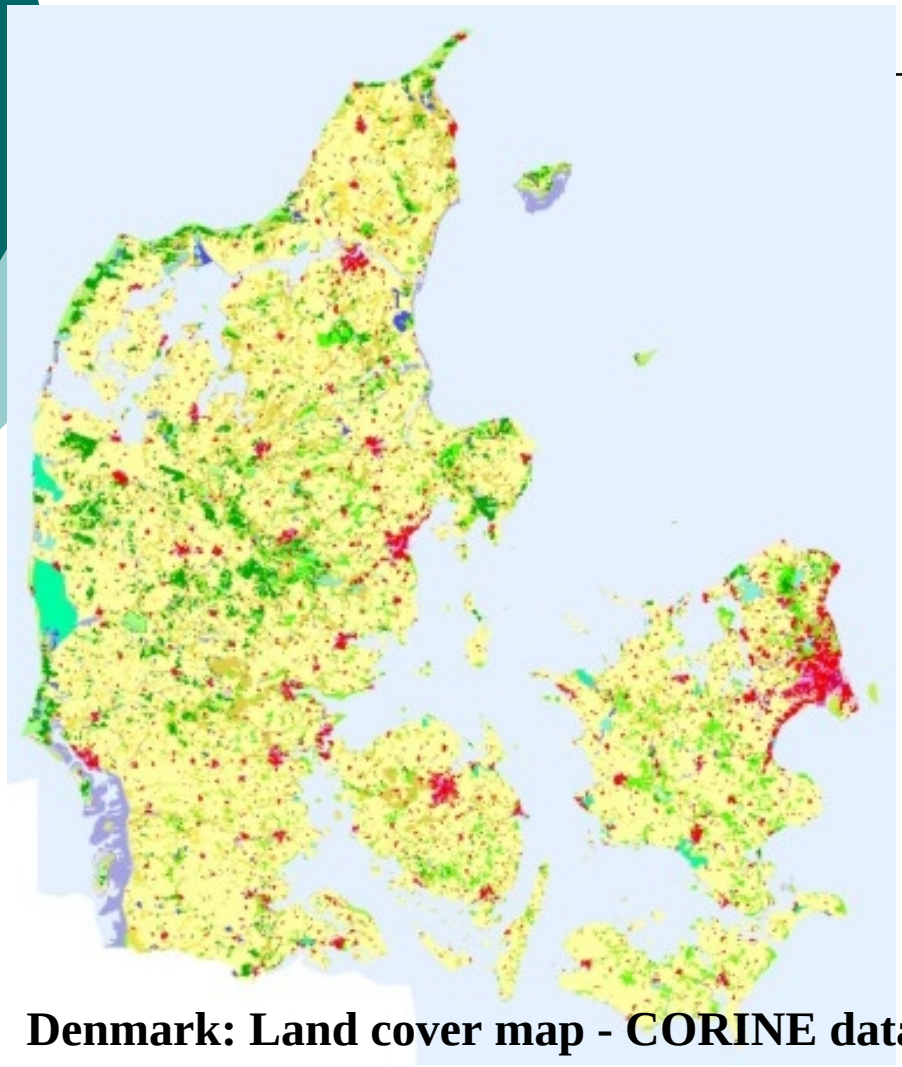
LCDB - based on interpretation of satellite images for 1989 and 1990,
land cover types in 44 standard classes,
GIS ARC/INFO format, at an original scale of 1:100,000 (consistent and comparable with similar land cover databases in other European countries.
Update - 2000

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)

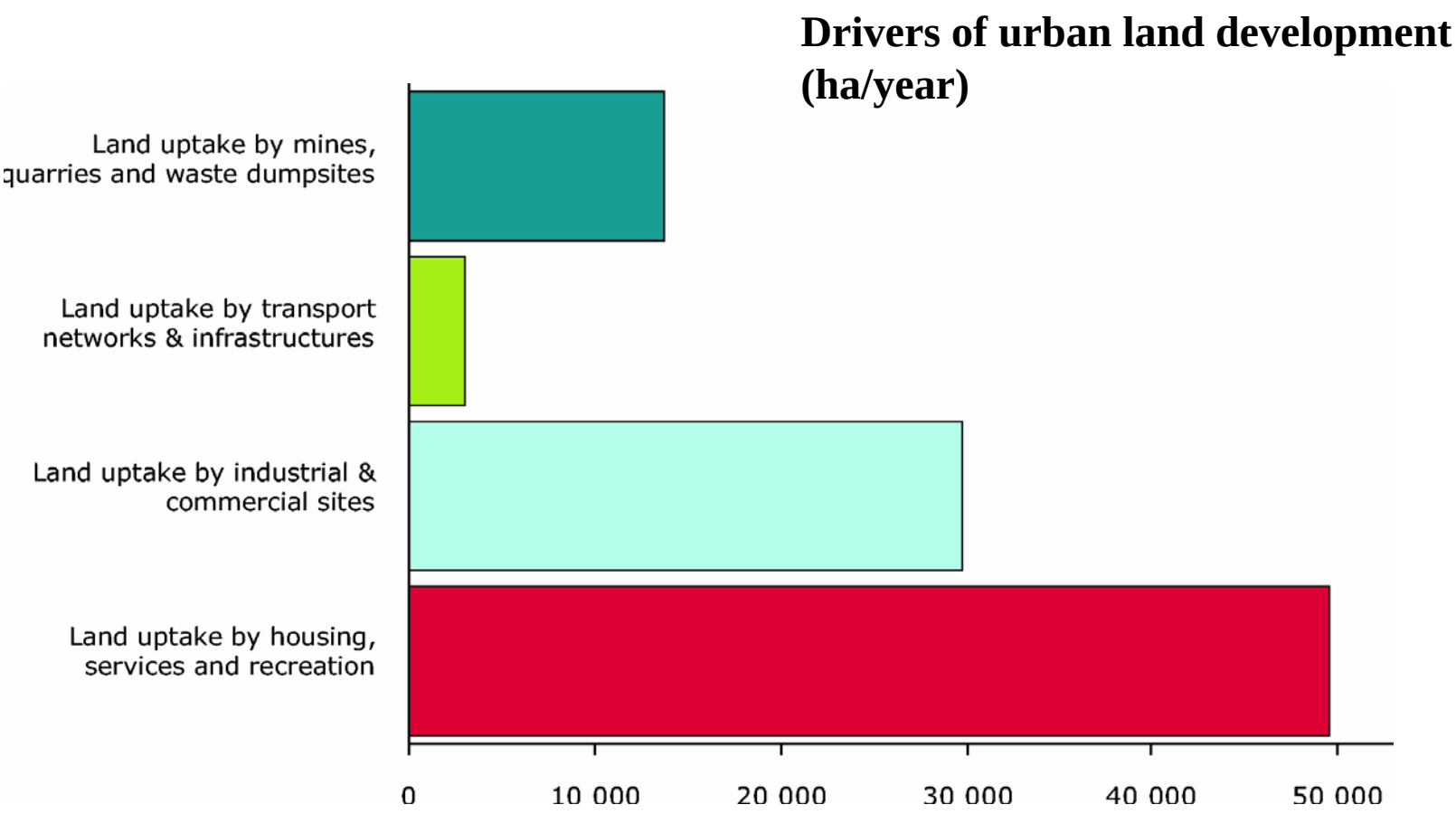
Description of land-class
Crops, Mixed Farming
Irrigated Crops
Bogs and Marshes
Evergreen Needle-leaf Trees
Deciduous Needle-leaf Tree
Deciduous Broad-leaf Trees
Evergreen Broad-leaf Trees
Evergreen Shrubs
Deciduous Shrubs
Interrupted Forest
Mixed Forest
Tundra
Short Grass
Tall Grass
Desert
Semi-desert
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.

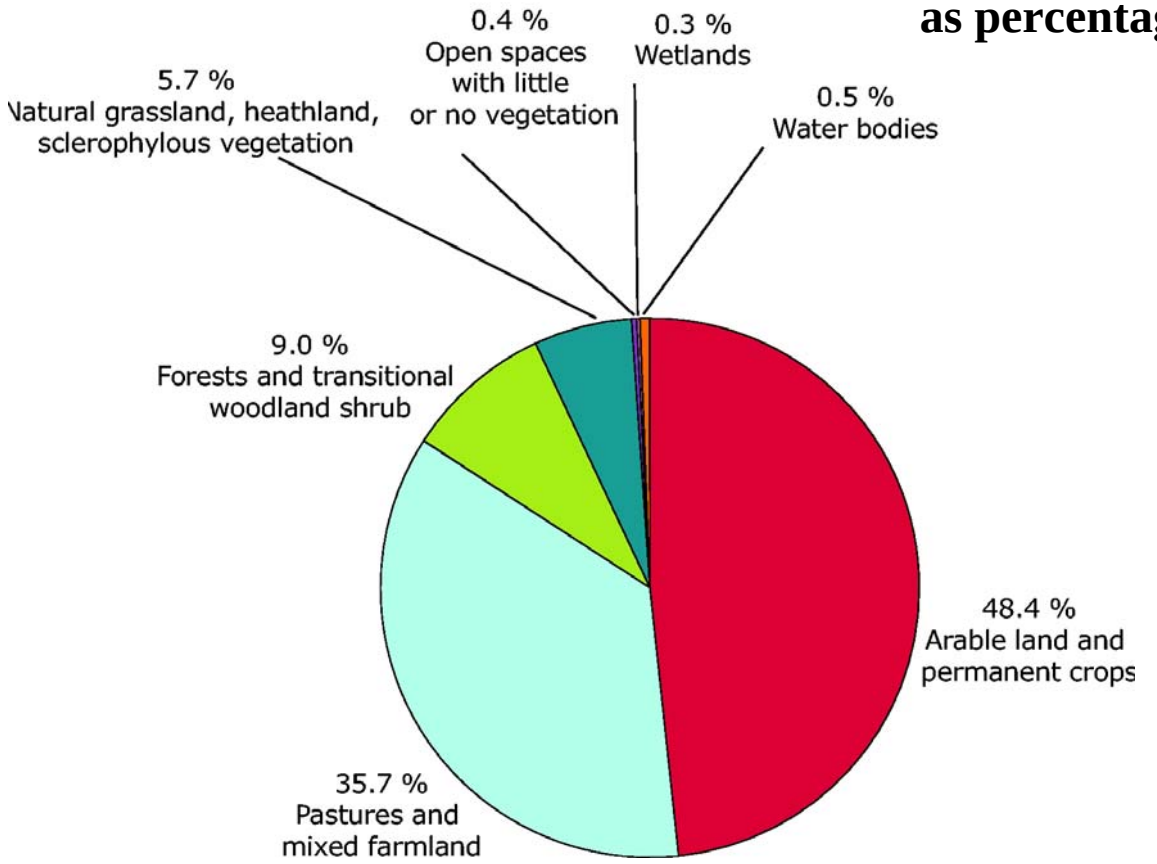
EU: Urban Land Development



EU: Urban Land Uptake by Origin

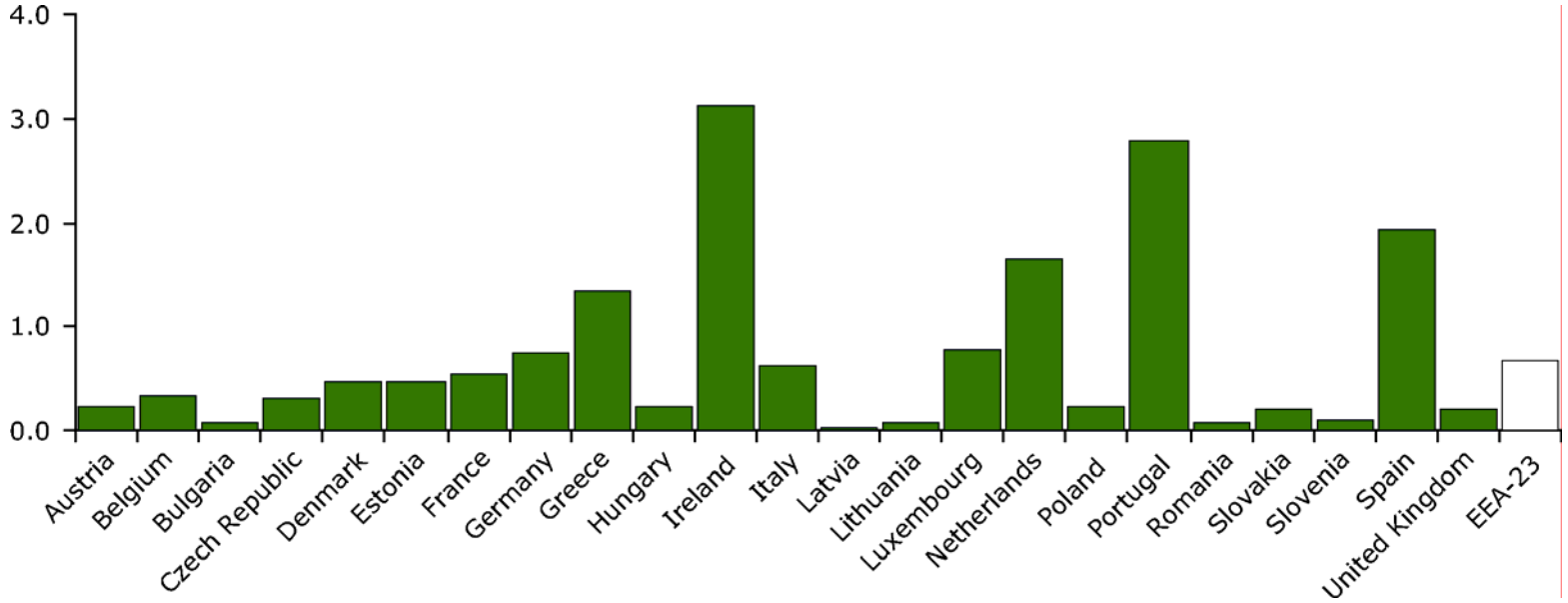
During 1990-2000 from all areas converted to artificial land-use

Origin of urban land uptake as percentage of total uptake

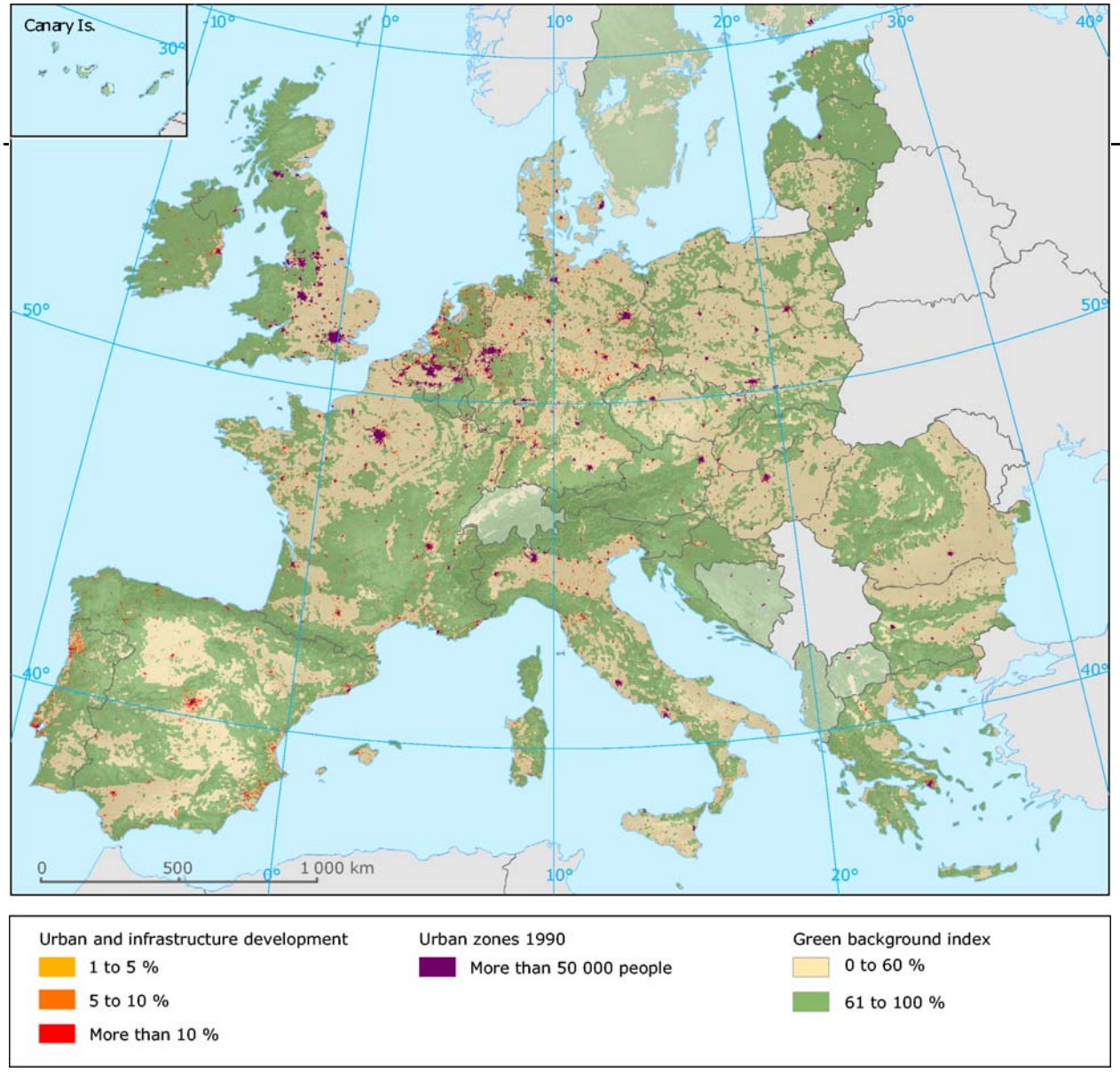


EU: Urban Land Uptake by Countries

Urban land uptake by countries



EU: Urban Land Uptake by Metropolitan Areas



Urban land uptake by megacities

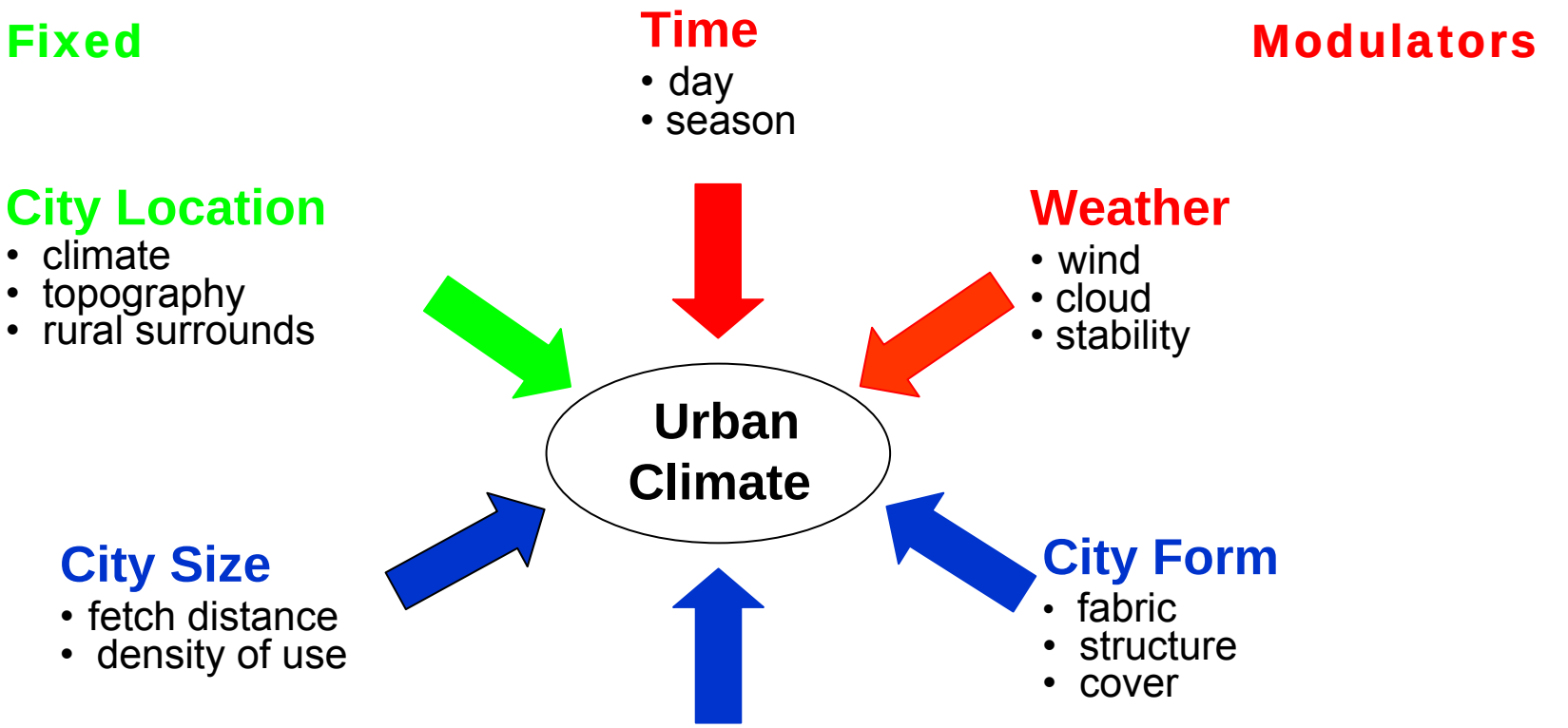
Features of Urban Areas

- **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 vapor;**
- **Anthropogenic heat fluxes, urban heat island;**
- **Internal urban boundary layers, urban mixing height,**
- **Effects of pollutants (aerosols) emissions, transformation and transport on urban meteorology and climate;**
- **Land use drastic changes due to urbanization;**
- **Urban effects on clouds, precipitation and thunderstorms.**

These urban features influence formation of airflow, its turbulence regime, microclimate, and accordingly modify transport, dispersion, and deposition of atmospheric pollutants in urban areas.

Controls on Urban Climate Effects (including Urban Heat Island)

(Oke et al., 1980)



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*)

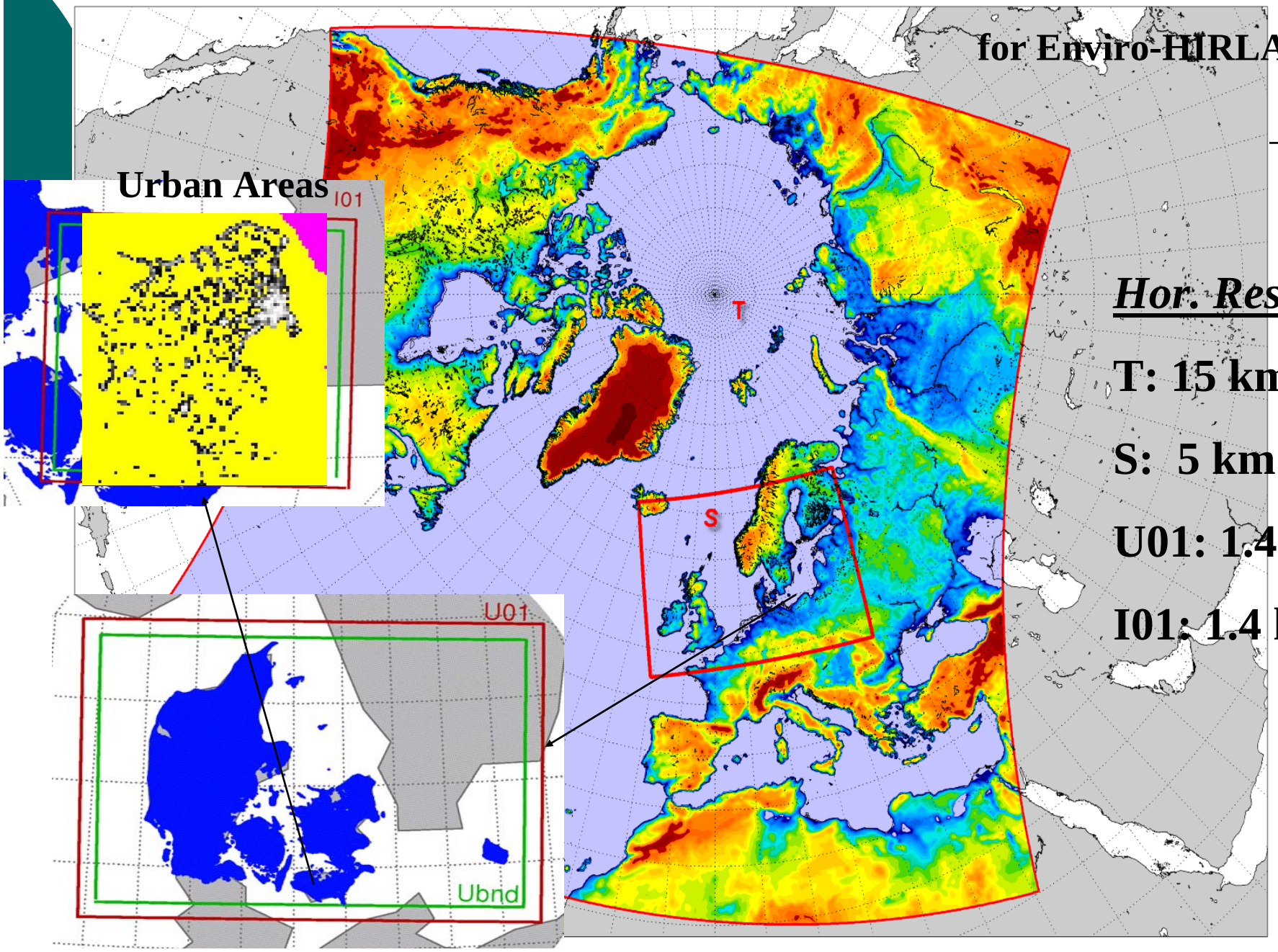
- **Soil model for sub-meso scales urban version**
  (*Dupont et al., 2006ab*)

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

Part 2
Enviro-HIRLAM - Urbanization

- HIRLAM modelling domains
- Urbanization modules schematics
- Main aim and objectives
- Land surface scheme, tiles and urban areas
- Anthropogenic heat flux in urban areas
- Urban districts – classification
- NWP models overall performance
- Meteorological Modelling: modules - AHF+R, BEP, SM2-U – results
- Other specific urban features to include into UAP Models
- Applicability of results

HIRLAM Modelling Domains



Hor. Resol.:

T: 15 km

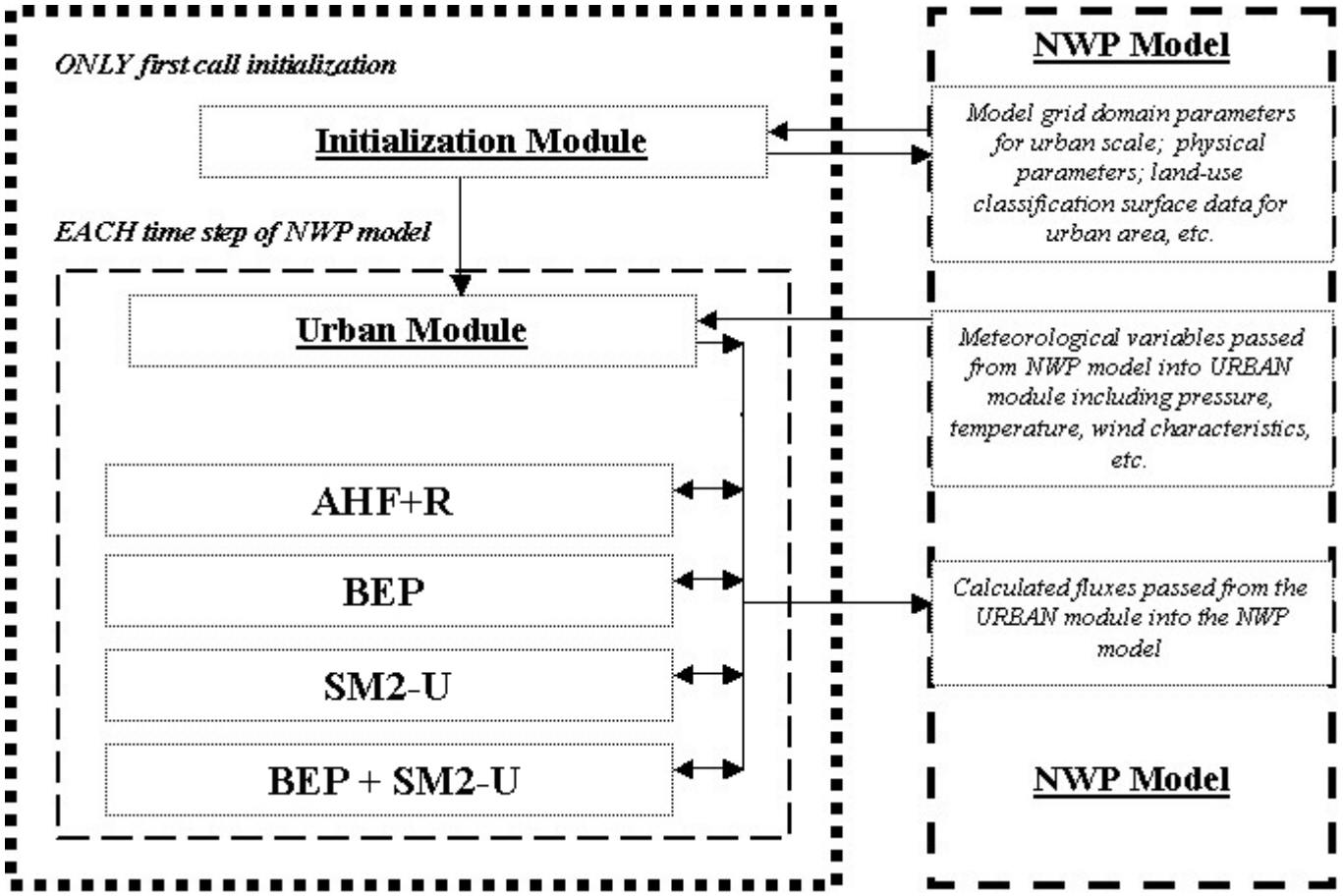
S: 5 km

U01: 1.4 km

I01: 1.4 km

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**)



Main Aim and Objectives

AIM:

Evaluate effects of urbanization of numerical weather prediction (NWP) model on simulated meteorological and pollution patterns over the urbanized areas and surroundings

(on example of **Copenhagen metropolitan area**, Denmark)

OBJECTIVES:

- Modify the existing NWP land surface scheme using:
  - 1) anthropogenic heat flux and roughness (**AHF+R**) module
  - 2) building effect parameterization (**BEP**) module
  - 3) soil model for submeso scales urban version (**SM2-U**) module

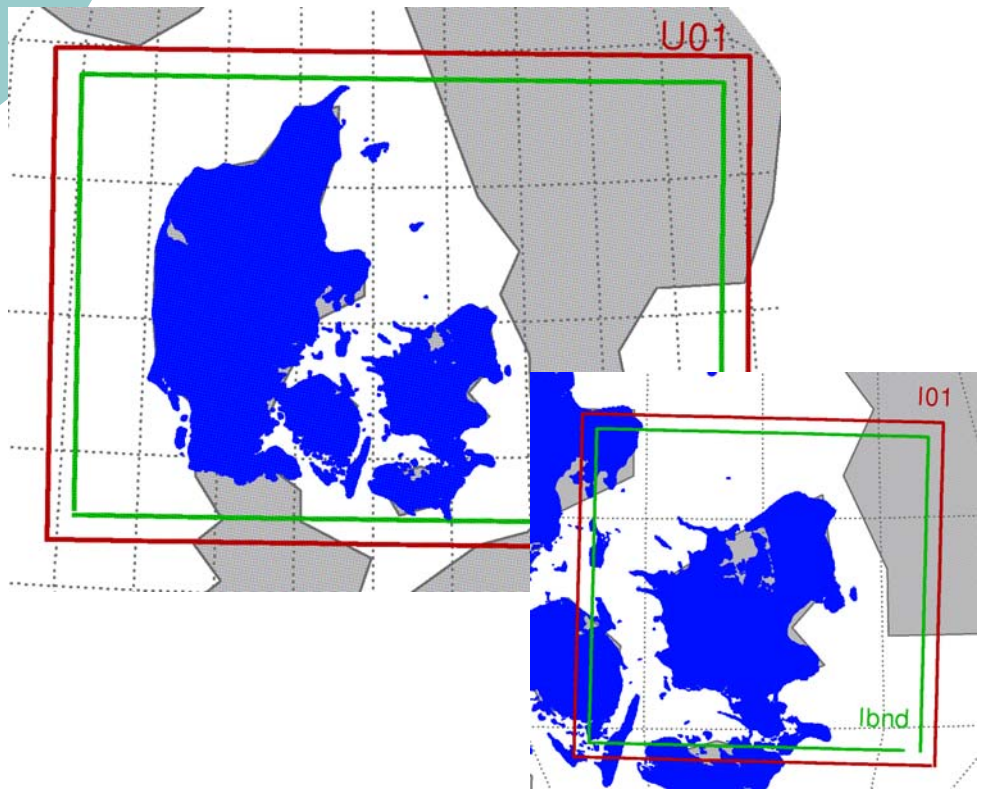
- Perform simulations of meteorological fields using DMI-HIRLAM model:
  - for two modes: 1) **Control** vs. 2) **Urban** runs,
  - for two types: 1) **Case Studies** and 2) **Long-Term Simulations**

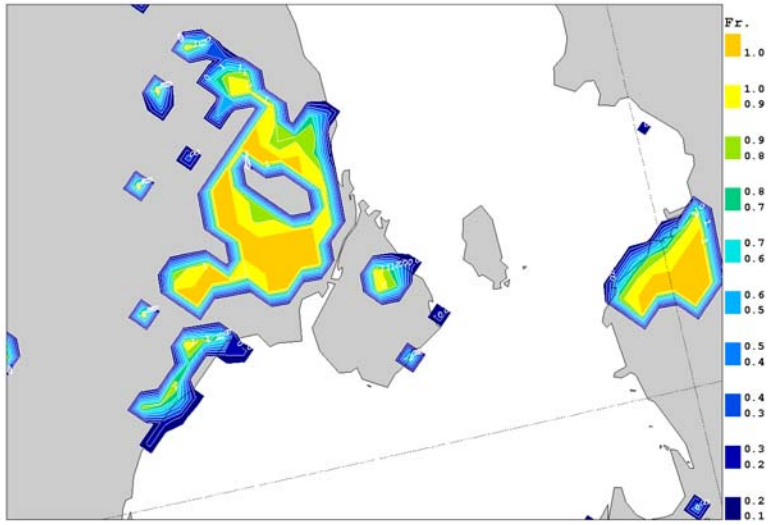
- *For Case Studies*: Simulate on a diurnal cycle pollution patterns (concentration and deposition fields) for selected specific dates reflecting different atmospheric conditions such as **low, typical, and high winds conditions**

- *For Both*: Evaluate effects of urbanization on temporal-spatial structure and variability of meteorological fields by estimation on a diurnal cycle the differences between control and urban runs for meteorological variables (**temperature, wind velocity, relative humidity**)

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)





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

Urban Districts : Classification

Residential (RD)

City Center/High Buildings District (CC/HBD)

GIS

Industrial Commercial (ICD)

Extraction of districts related characteristics (statistics):

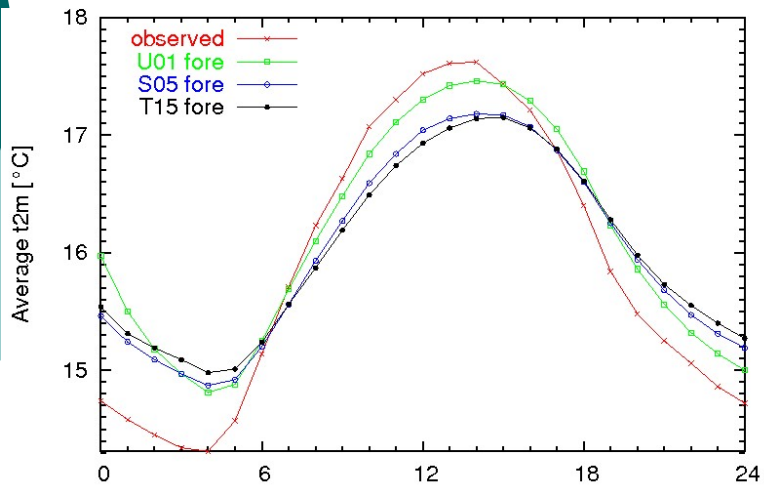
Morphology parameters **(avg. height, volume, perimeter, compactness, space between buildings),**

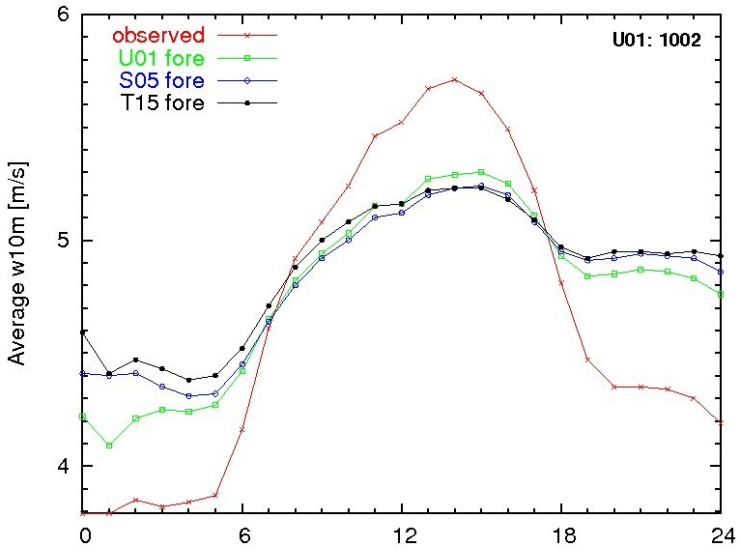
Cover modes **(surface density (SD) of buildings, of vegetation, hydrography, roads, N buildings),**

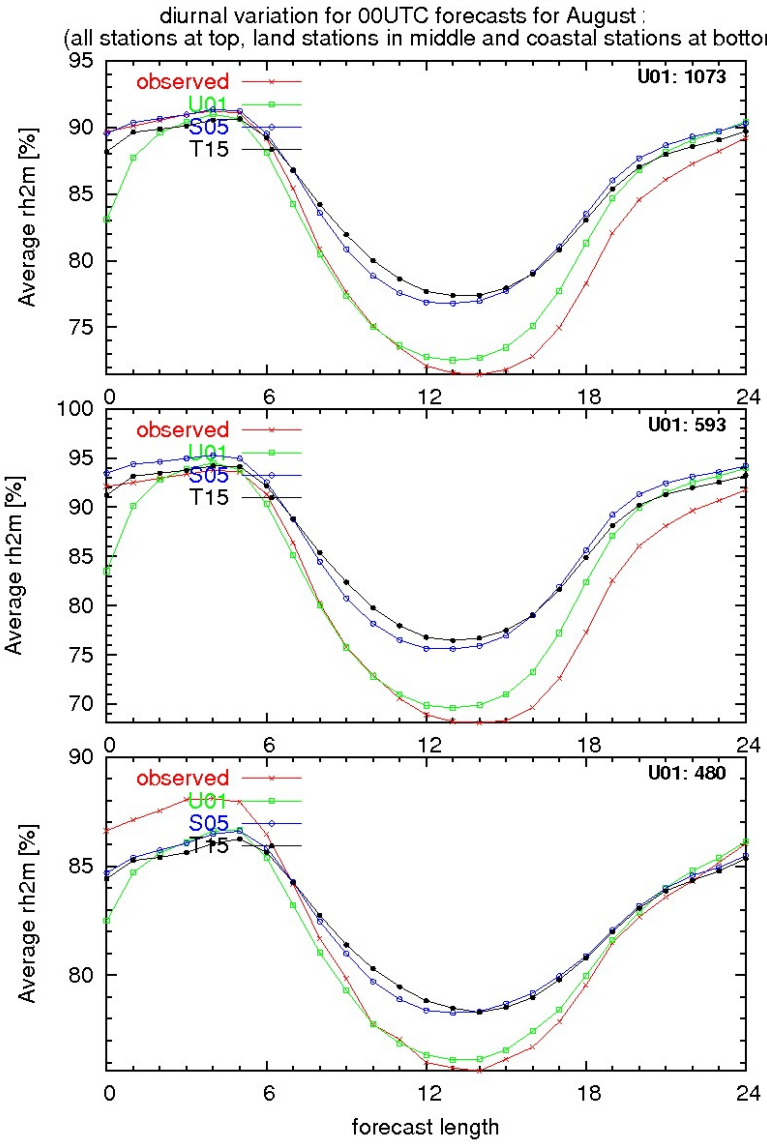
Aerodynamic parameters **(roughness length, displacement height, frontal and lateral SD),**

NWP Models Overall Performance

-------- all stations --------

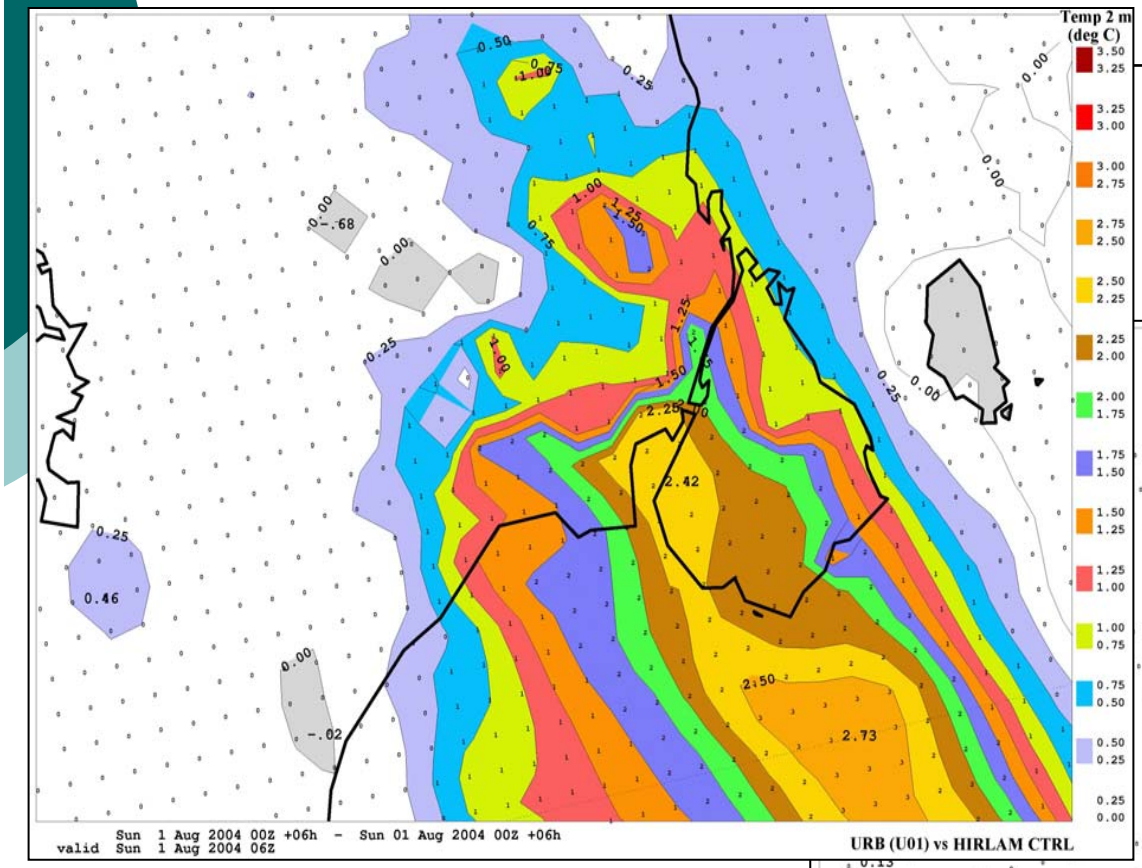






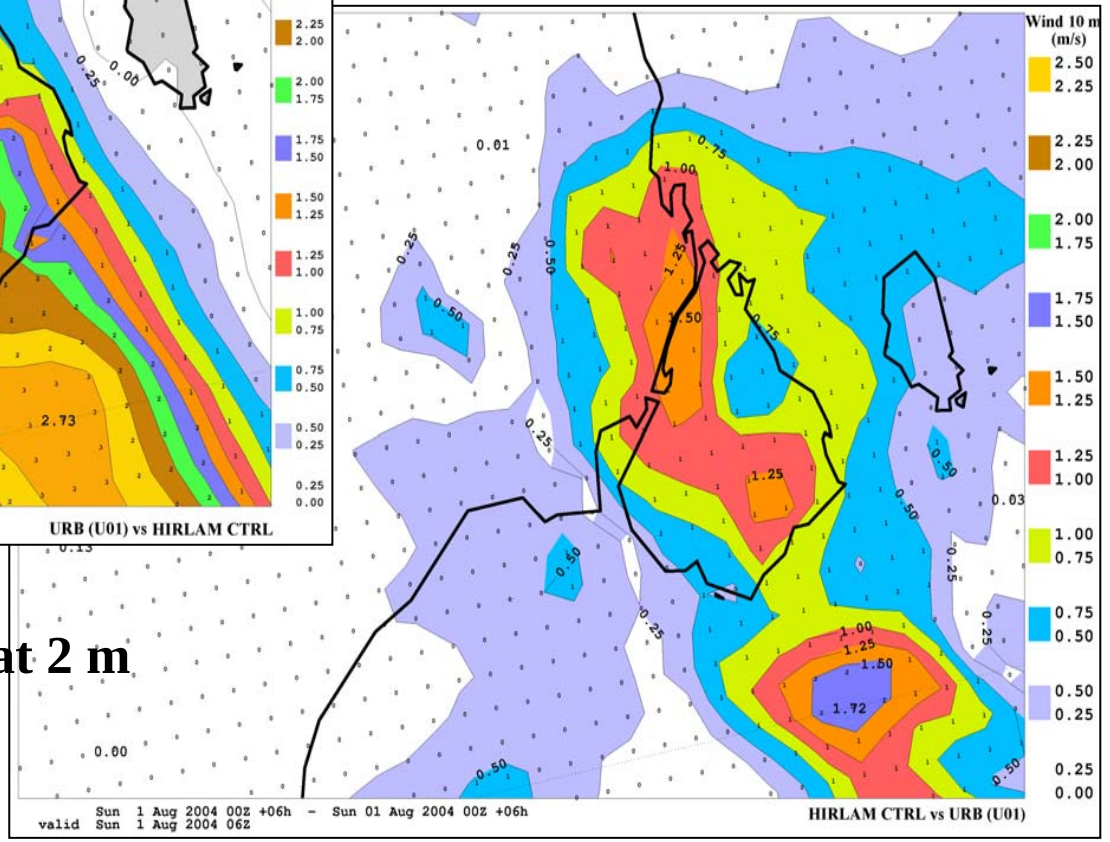
MeteoModelling: AHF+R Module

Difference between runs: 01 Aug 2004, 06 UTC



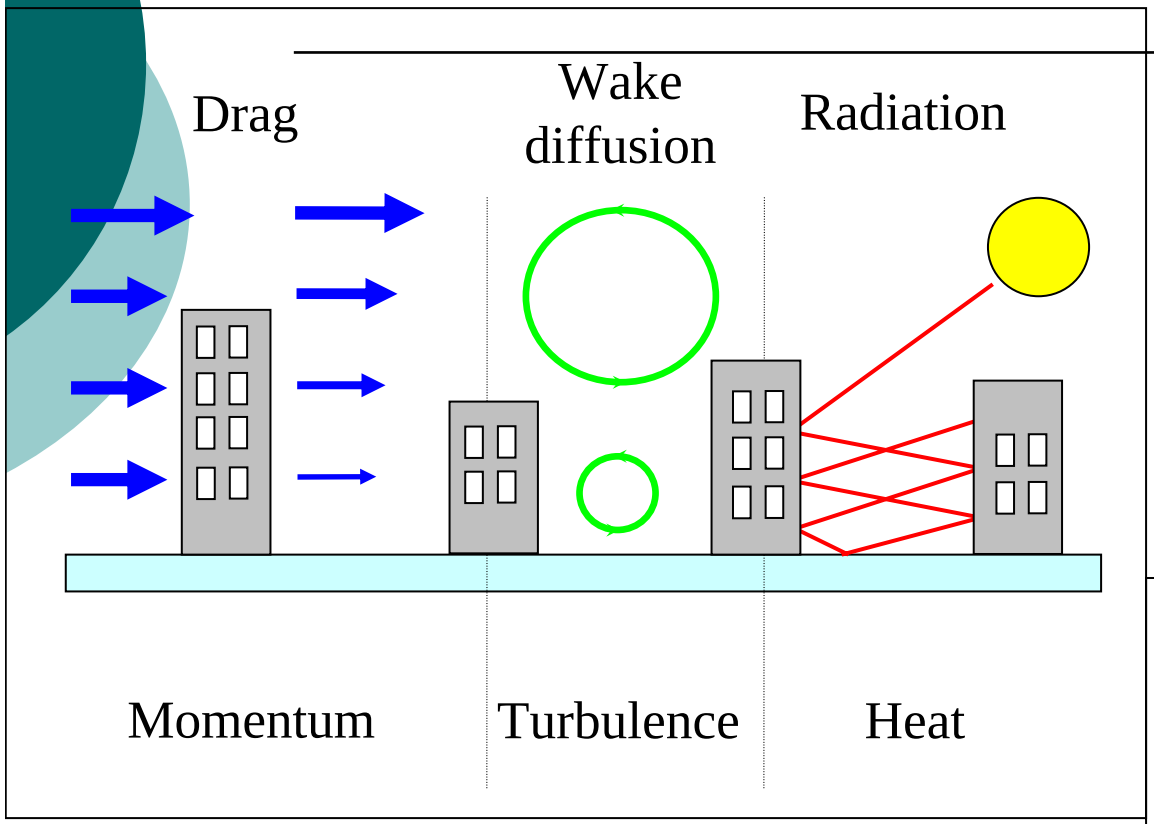
(control vs. urbanized run)
Difference field for temperature at 2 m

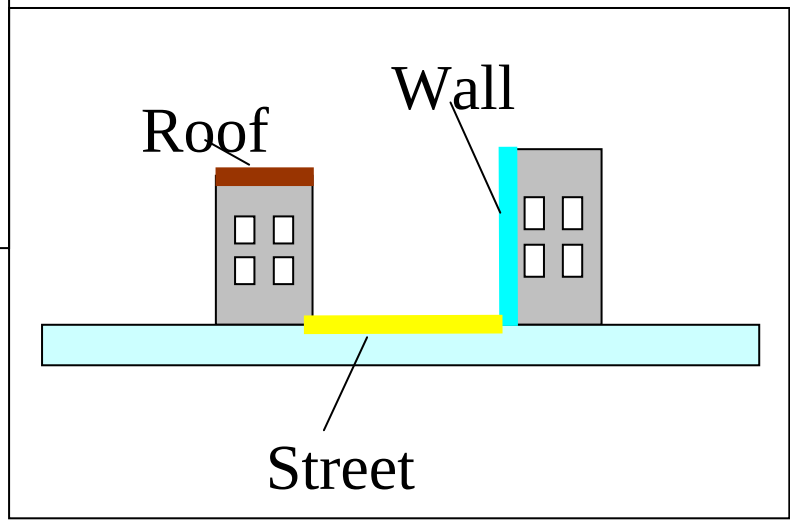
(control vs. urbanized run)
Difference field for wind at 10 m



BEP : Building Effect Parameterization

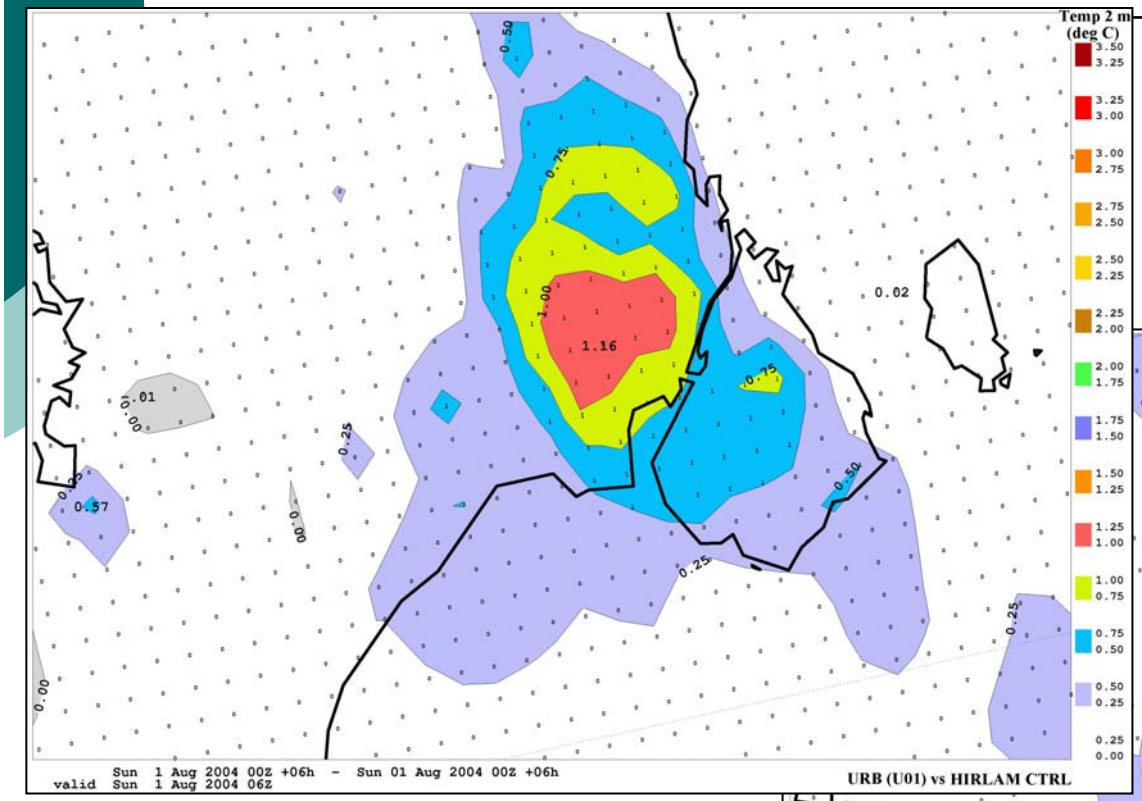
(Martilli et al., 2002)





MeteoModelling: BEP Module

Difference between runs: 01 Aug 2004, 06 UTC



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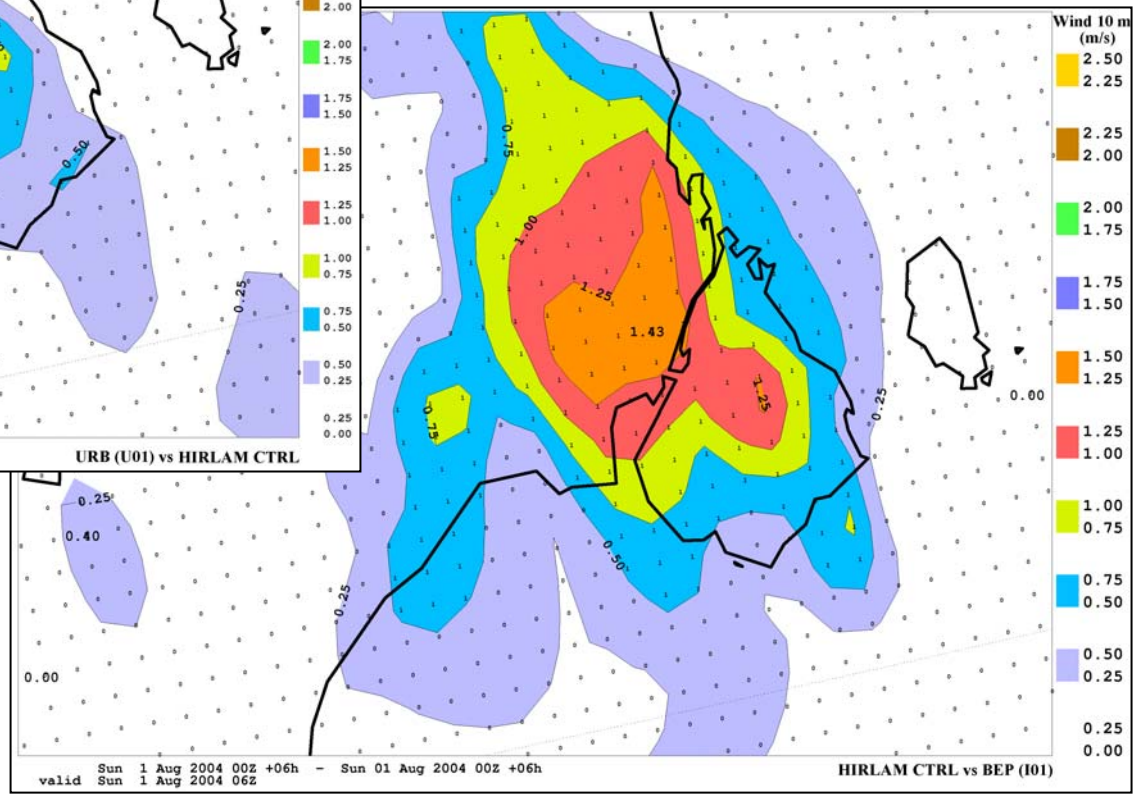
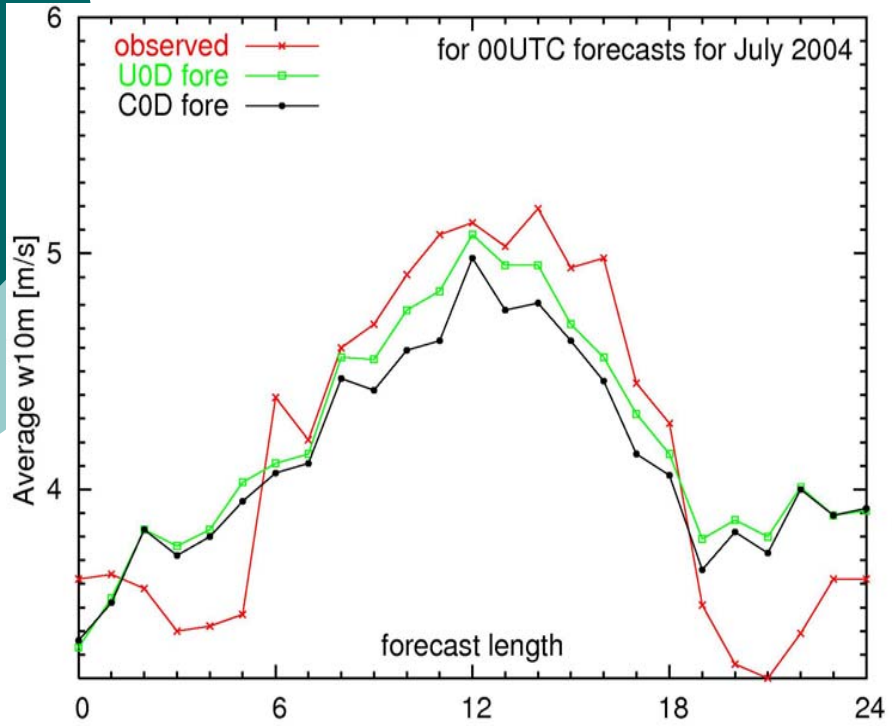
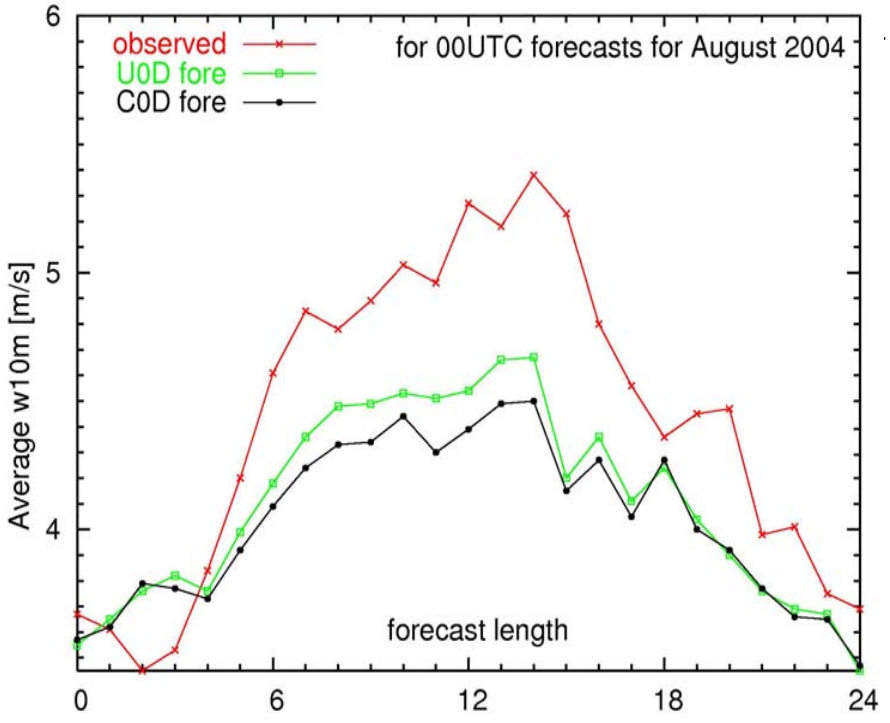


MeteoModelling: BEP Module

Urban station N-6180: Copenhagen area : Verification



July 2004

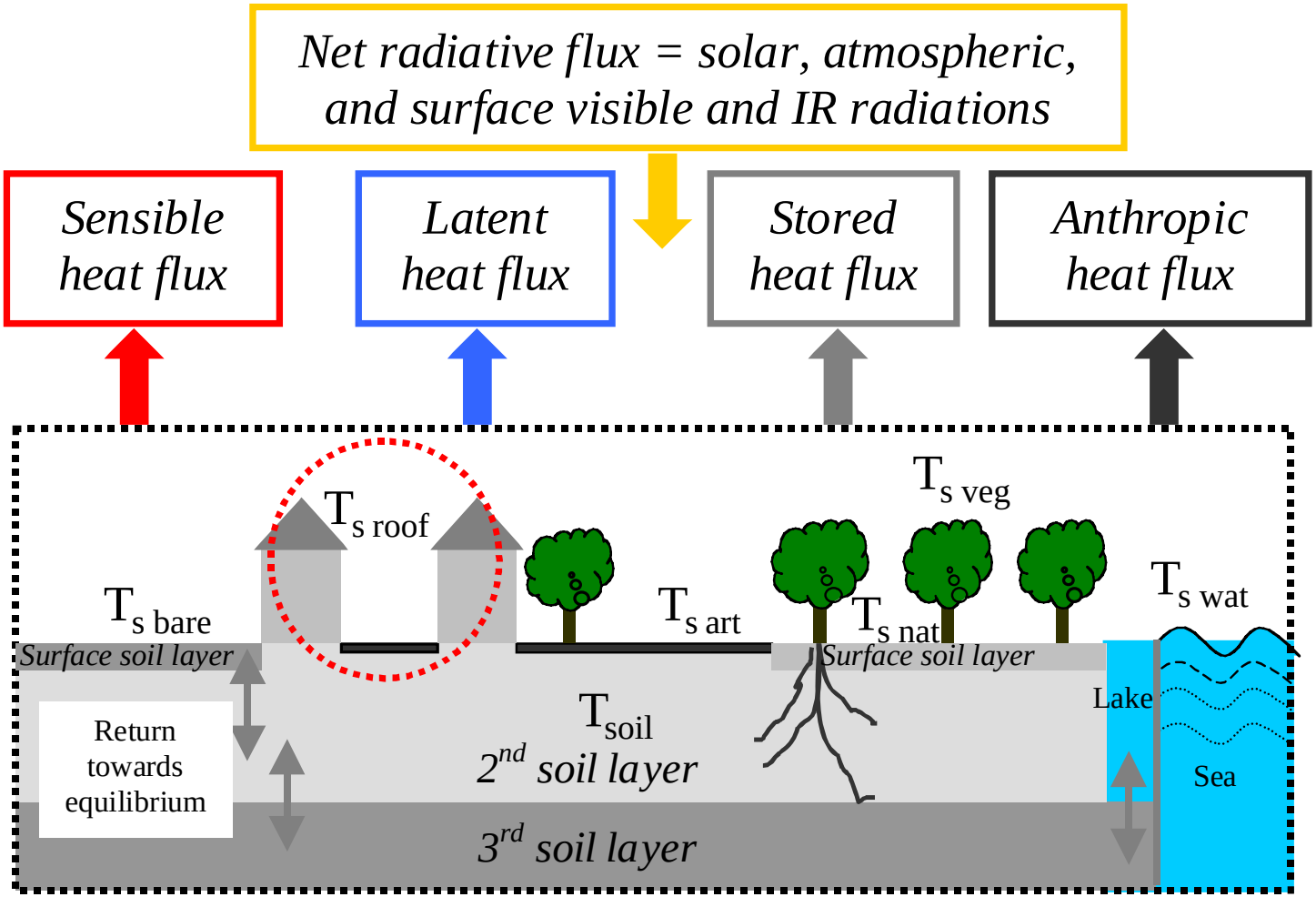


August 2004

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

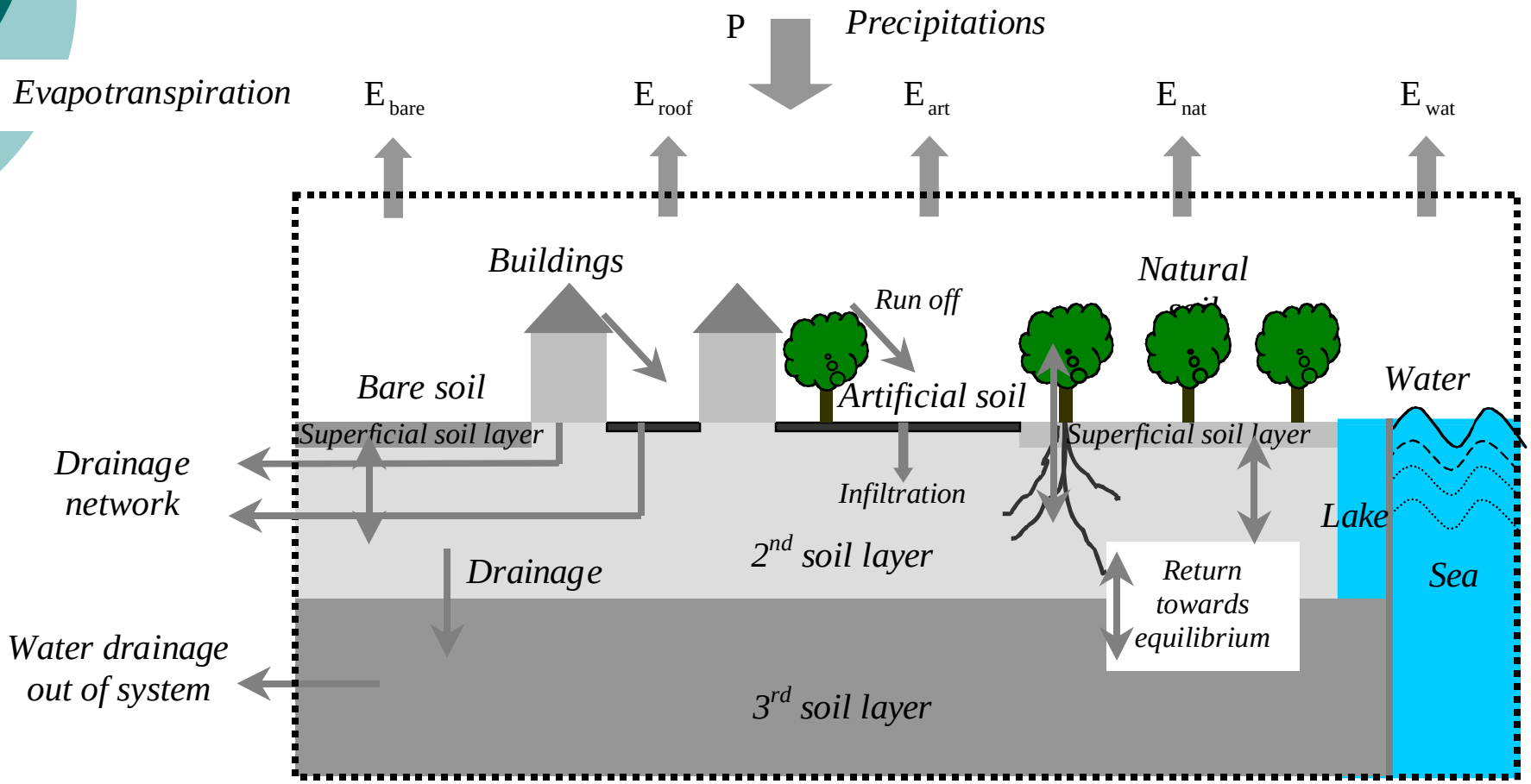
SM2-U : Soil Model for Sub-Meso scales
Urbanized version : Thermal budget

(Dupont et al., 2006ab)



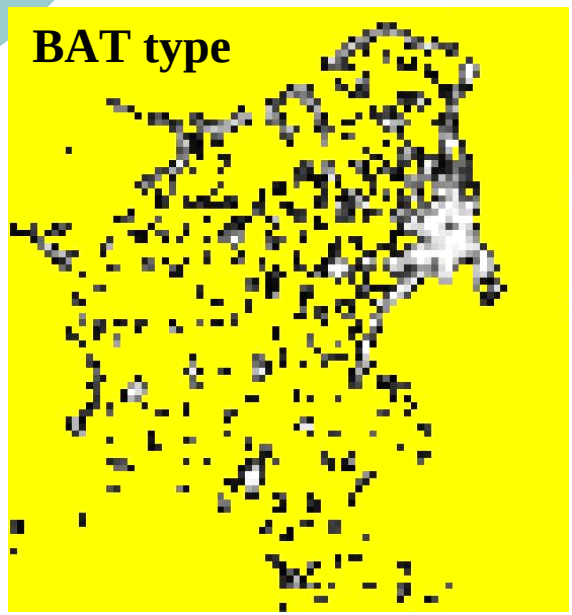
SM2-U : Soil Model for Sub-Meso scales
Urbanized version : Water budget

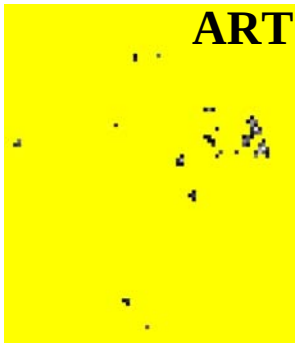
(Dupont et al., 2006ab)

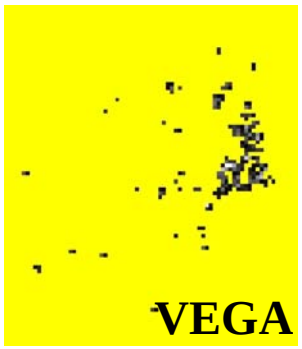


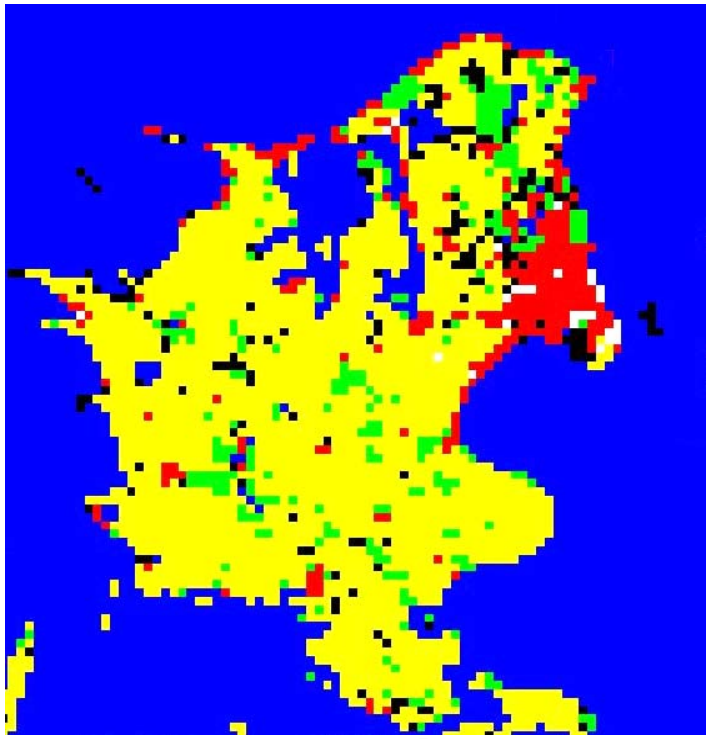
Revised Land Use Classification : SM2-U Module

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



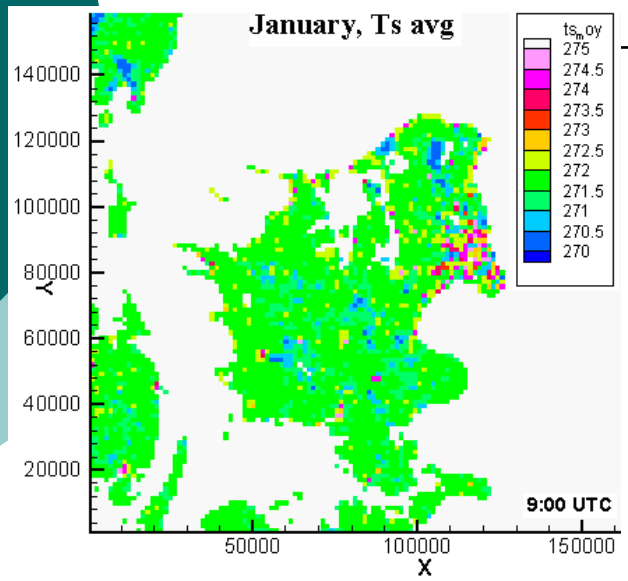


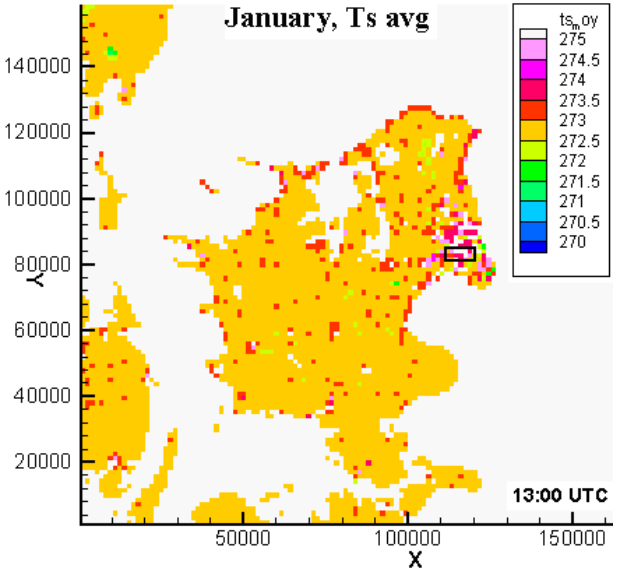


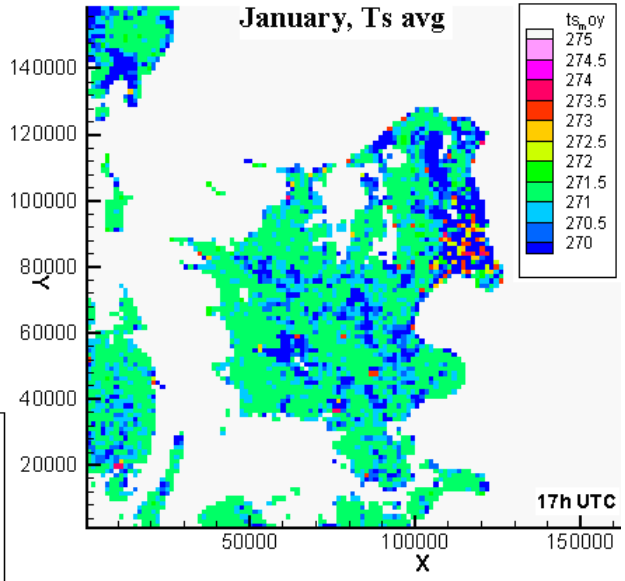

Dominated type

MeteoModelling: SM2-U Module

Metropolitan area : Copenhagen : Surface temperature

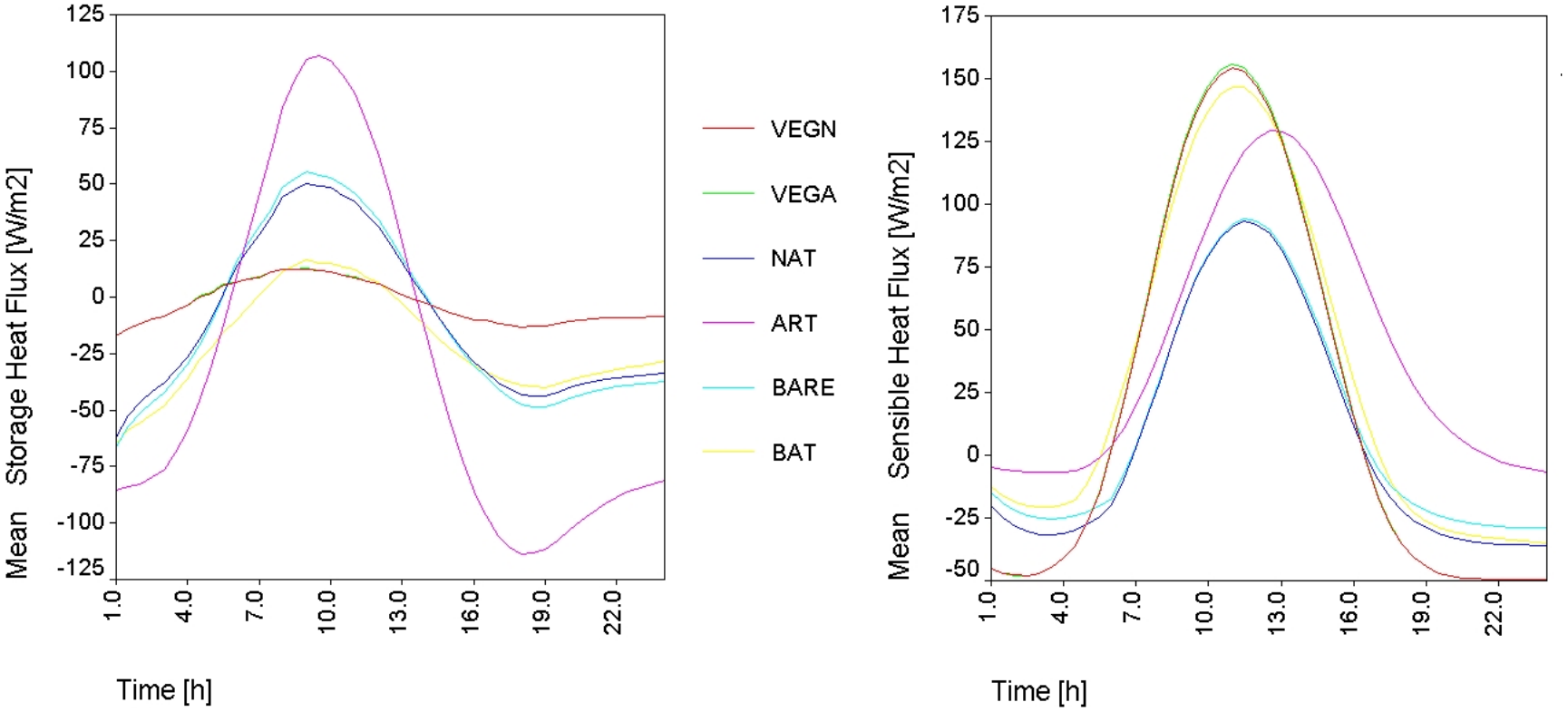






MeteoModelling: SM2-U Module

Metropolitan area : Copenhagen : 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

Other Specific Urban Features to Include into Urban Air Pollution Models

• Different pollutant deposition on urban surfaces, e.g. due to vertical walls, different building materials and structure, vegetation, etc.;

• Chemical transformation specifics (e.g. different photolysis rates due to street shadows) and specific aerosol dynamics in street canyons (e.g. re-suspension of aerosols);

• Very heterogeneous emissions of pollutants, especially due to traffic;

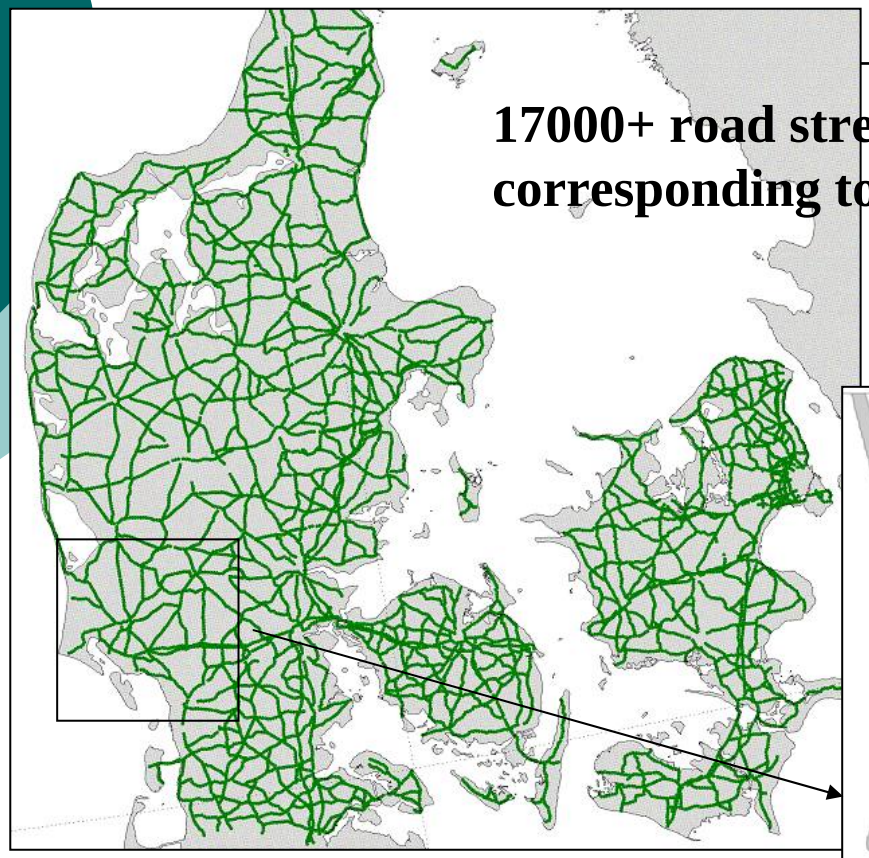
• Indoor-outdoor interactions;

• Important to integrate the UAP and population exposure modelling (for purposes of quantifying of air pollution health related effects) with including of high-resolution databases on urban morphology, population distribution, social, administrative, etc. activities.

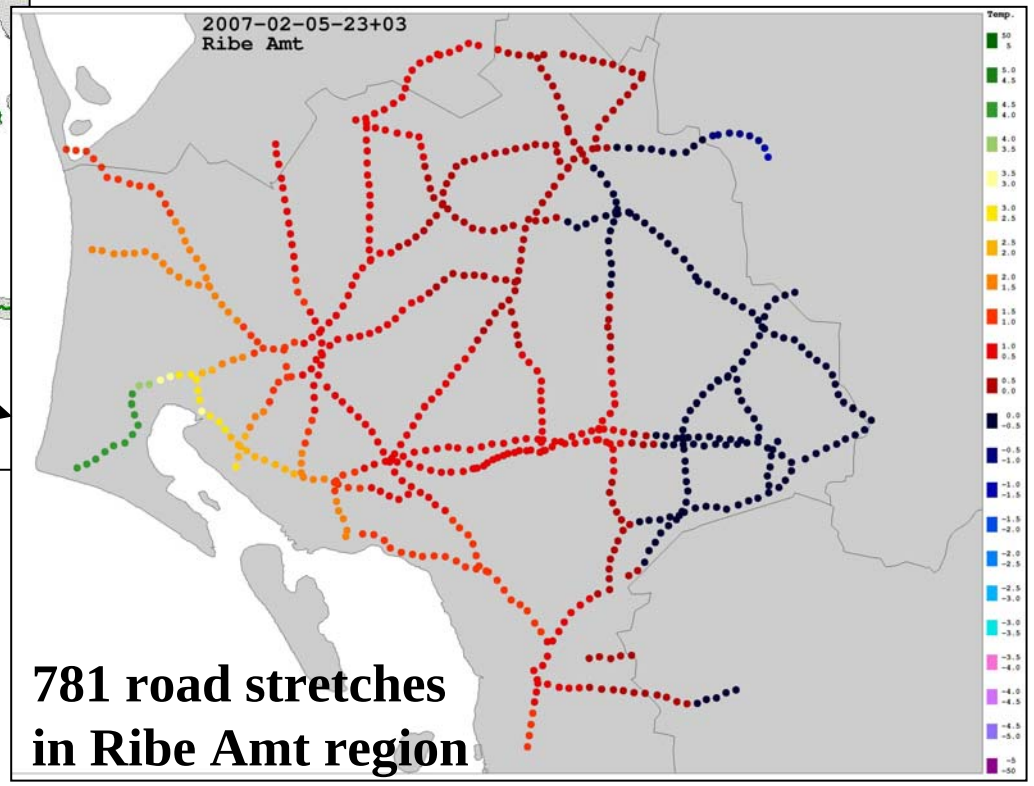
Urbanization: Applicability of Results

- 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.

Applicability: Road Stretches Forecasting



17000+ road stretches
corresponding to Danish road network

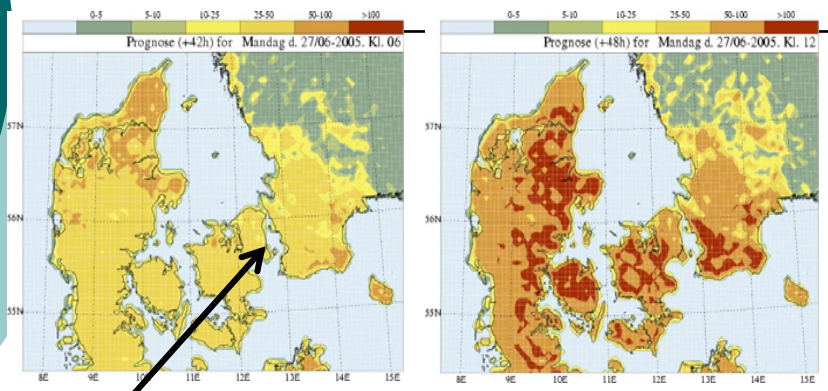


781 road stretches
in Ribe Amt region

Collaboration –
Danish Road Directorate

Applicability: Birch Pollen Forecasting

Phenological model output

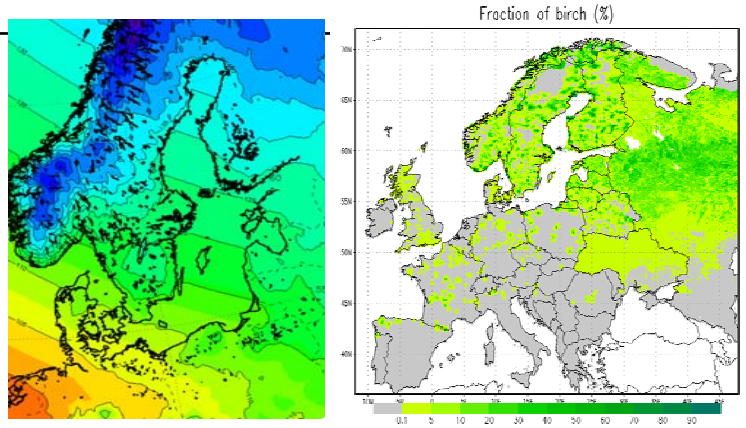


Normalized concentrations

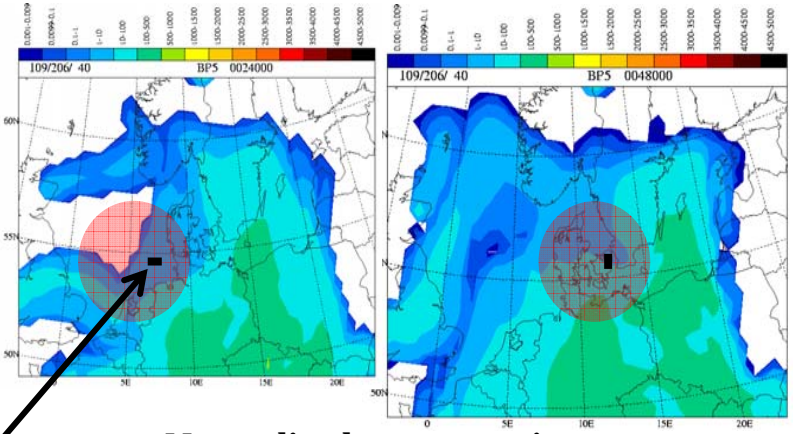
24 hours forecast **48 hours forecast**

Copenhagen, Denmark

Emission rate & fractions of birch trees



Enviro-HIRLAM model output



Normalized concentrations

24 hours forecast **48 hours forecast**

Copenhagen, Denmark

Collaboration –
Danish Asthma Allergy Association,
Finish Meteorological Institute

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- DMI FM HIRLAM/NWP and Environmental Meteorology Groups, the ECN (France) and EPFL (Switzerland) research teams,

- FUMAPEX: fumapex.dmi.dk
  COST-728: www.cost728.org
  MEGAPOLI: megapoli.dmi.dk
  HIRLAM: hirlam.org

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Part 3
Enviro-HIRLAM – Domains, Land-use, Climate data

- Selection of Modelling Domain Parameters

- Preparation of the Climate Generation Files, CGFs

(include land-use and climatic meteorological data);

- Preparation of the boundary conditions, BCs,

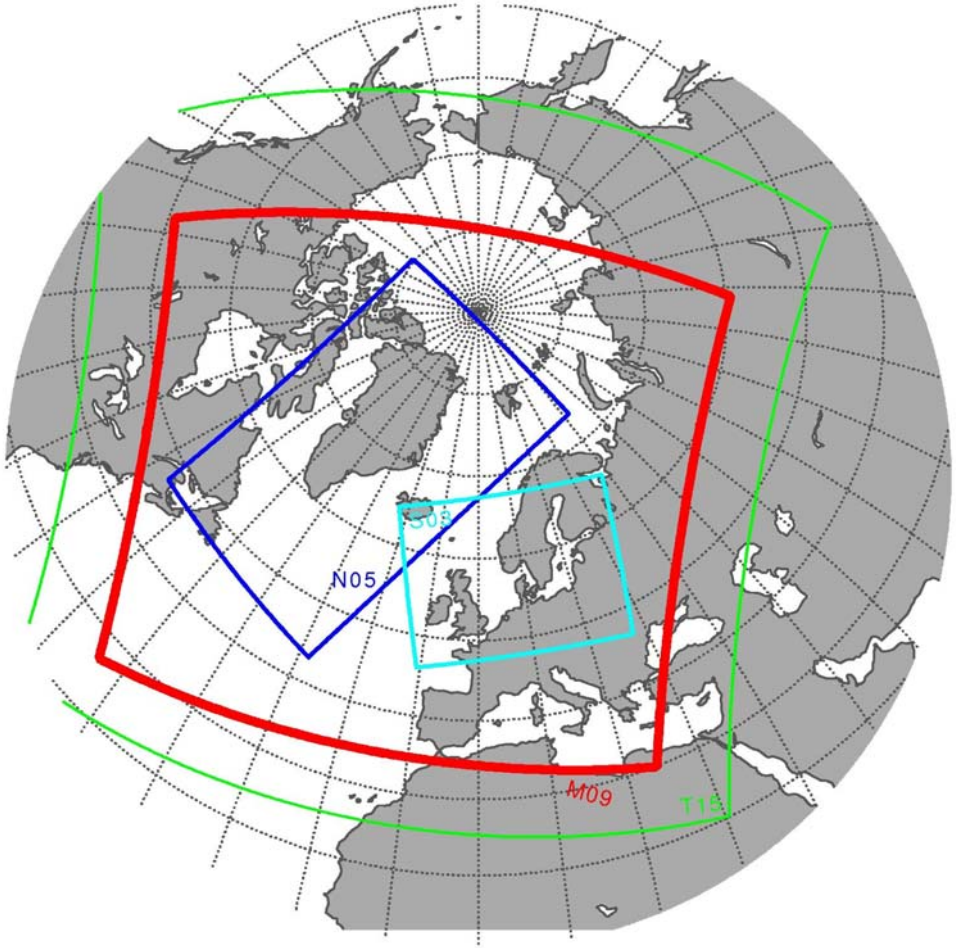
files for the selected meteorological situations or long-term runs.

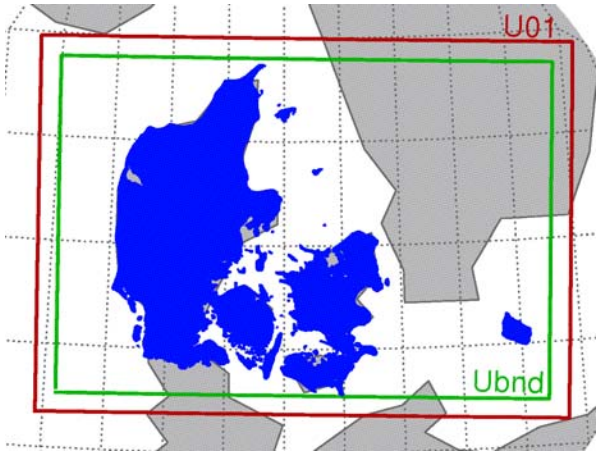
Define Boundaries of New Modelling Domain (0)

- Select the geographical area of interest/ research;
- Select the horizontal resolution for domain;
- Look/trade off between the number of the points along the latitude vs. longitude;
- Look/trade off for number of boundary points/ relaxation zone;
- Look for terrain variability/ water objects/ etc. on boundaries of new domain.

Define Boundaries of New Modelling Domain (1)

T15: 610x568; S03: 874x658; M09: 730x746; N05: 874x534





Define Boundaries of New Modelling Domain (2)

- Select resolution of new modelling domain (NMD) as ΔLON = ΔLAT (in degrees) = $0.0\overline{14}^{o}$
- Calculate total number of passive boundary points for NMD:

  if select NPBP = 4 (number of passive boundary points)

  NBNDRY = 2 · (NPBP + 1) = 2 · (4 + 1) = **10**
- Since selected number of grid points along longitude for DMI-HIRLAM NWP - $NLON_{NWP}$ -should satisfy a set of (n, m, p) conditions ($2^n \cdot 3^m \cdot 5^p$), check that - $NLON_{NWP}$ = 360 - this value exist/given in Table of ***Appendix 2*** and for this value conditions are true:

  $2^n \cdot 3^m \cdot 5^p = 2^3 \cdot 3^2 \cdot 5^1 = 8 \cdot 9 \cdot 5 =$ **360**
- Calculate total number of grid points in NMD along longitude:

  $NLON_{NMD} = NLON_{NWP} + NBNDRY = 360 + 10 =$ **370**
- Calculate number of grid points /minus one/ in NMD along longitude:

  $NLON_{NMD}$ -1 = 370 – 1 **= 369**

  (*note: NLON must be even number*)

Define Boundaries of New Modelling Domain (3)

- Select the values for the south-east corner of NMD in rotated system of coordinates:

  EAST = 3.343 and SOUTH = 4.379

  (*note: values must be given in millidegrees*)

- By try/error/iteration select values for the WEST-EAST boundaries of NMD in the rotated system of coordinates that it should cover geographical area of interest and also satisfy condition:

  $| \text{WEST} - \text{EAST} | / \Delta\text{LON} = | -1.823 - 3.343 | / 0.014 = 5.166 / 0.014 =$ **369**

  (*note: values must be given in millidegrees*)

- Calculate number of grid points /minus one/ in NMD along latitude:

  $\text{NLAT}_{NMD} - 1 = 260 - 1 =$ **259**

  (*note: NLAT must be even number*)

- By try/error/iteration select values for NORTH-SOUTH boundaries of NMD in the rotated system of coordinates that it should cover geographical area of interest and also satisfy condition:

  $| \text{NORTH} - \text{SOUTH} | / \Delta\text{LAT} = | 8.005 - 4.379 | / 0.014 = 3.626 / 0.014 =$ **259**

  (*note: values must be given in millidegrees*)

Define Boundaries of New Modelling Domain (4)

- NLON – number of grid points along longitude;
- NLAT – number of grid points along the latitude;
- DLAT vs. DLON – horizontal resolution along the latitude vs. longitude;
- LATS – “south” latitude in the rotated system of coordinates;
- LATN – “north” latitude in the rotated system of coordinates;
- LONW – “west” longitude in the rotated system of coordinates;
- LONE – “east” longitude in the rotated system of coordinates;
- PLON & PLAT – position of the pole in the rotated system of coordinates;

- ***EXAMPLE***

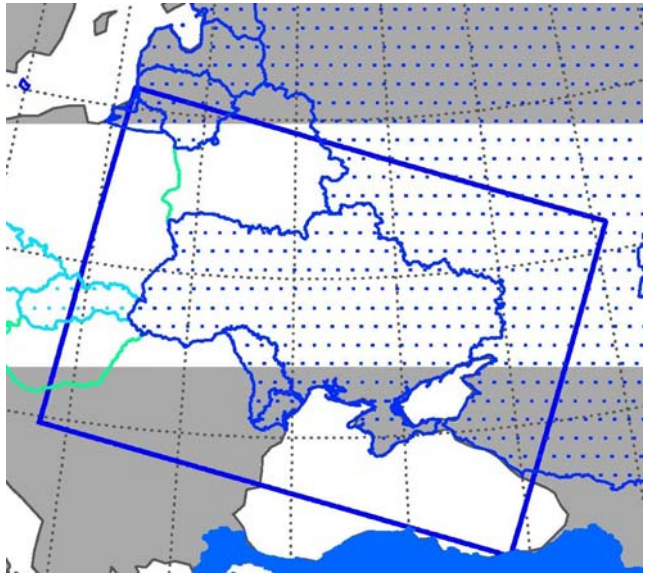
  NLON – 300; NLAT – 220;

  DLAT vs. DLON – 0.05 deg (or 5 km);

  LATS : – 4.825; LATN : 6.125;

  LONW : 6.225; LONE : 21.675;

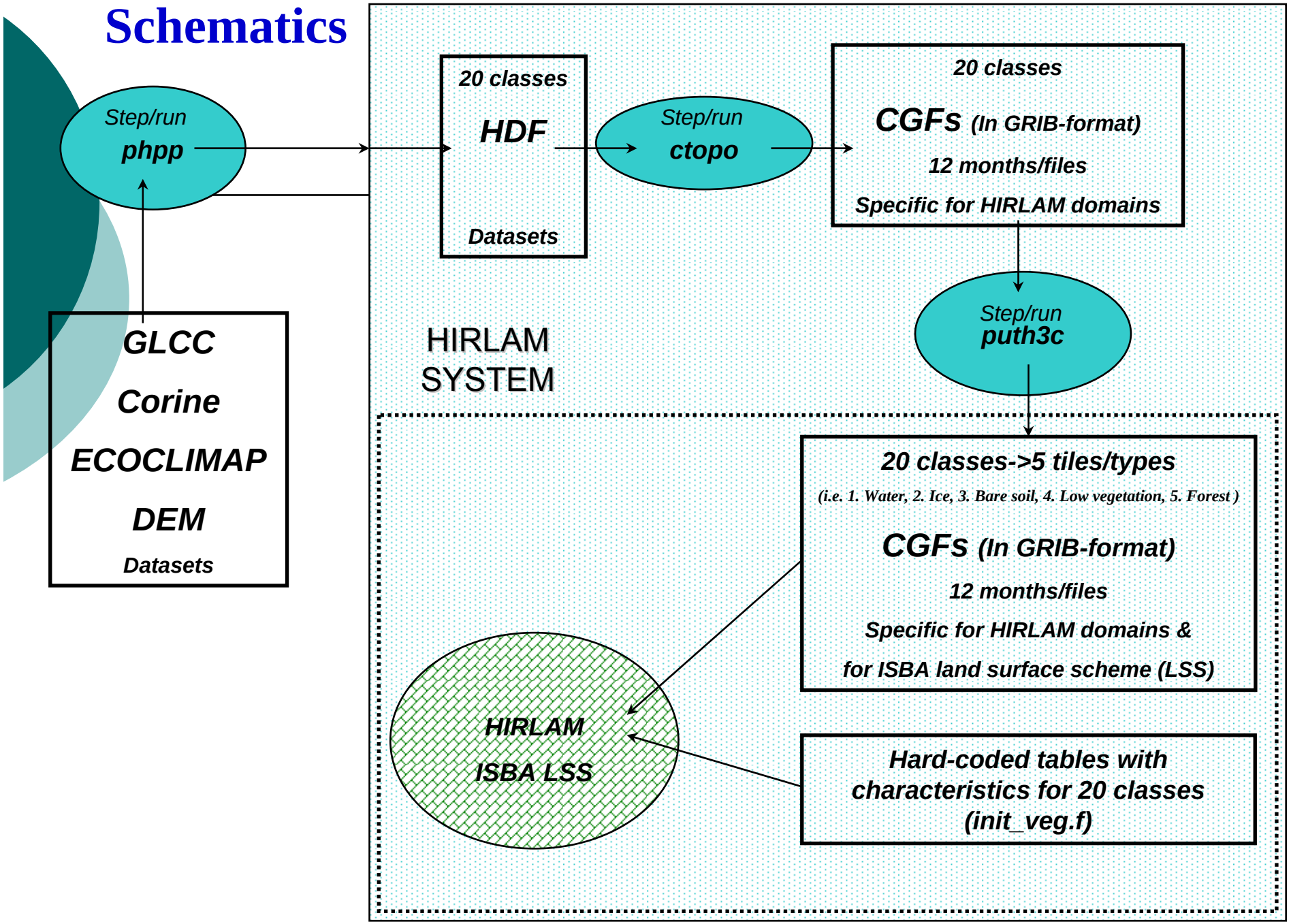
  PLON : 10.; PLAT : –40.



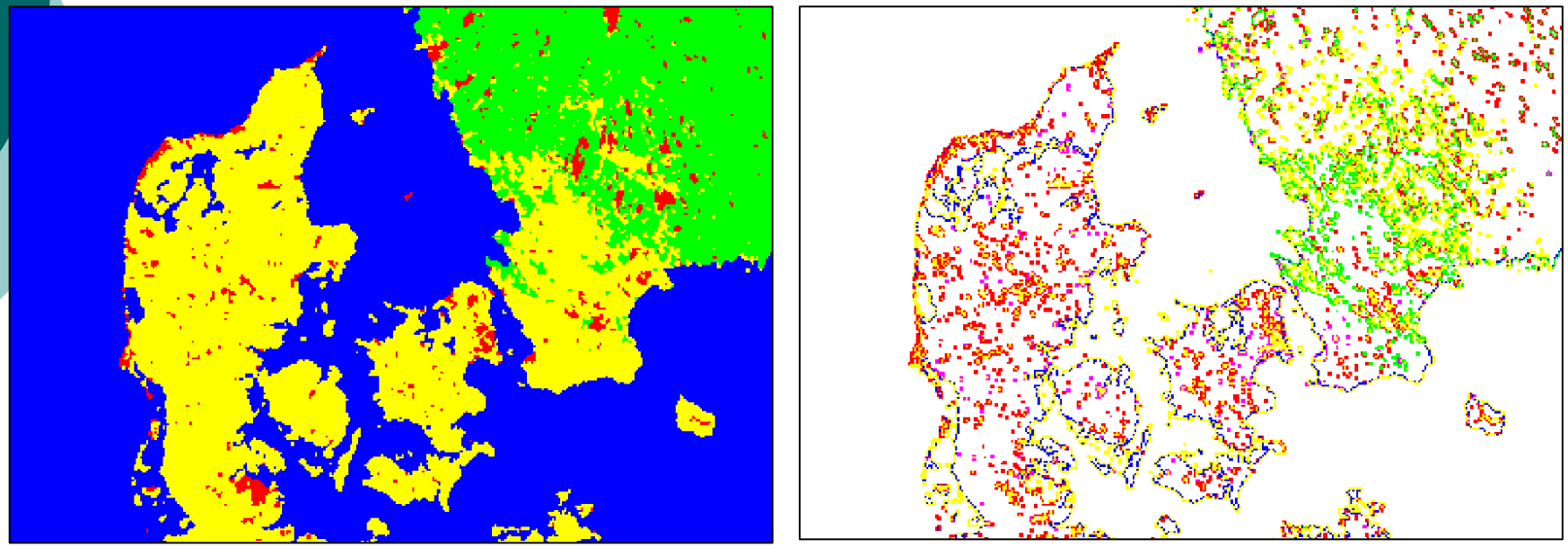
Climate Generation Files (CGFs)

- After selection of new modelling domain parameters
- Schematics
- Original datasets used
- Tiles & Classes (1st, 2nd) dominating
- Examples

Schematics


Step/run
phpp
20 classes
HDF
Datasets
Step/run
ctopo
20 classes
CGFs (In GRIB-format)
12 months/files
Specific for HIRLAM domains
Step/run
puth3c
GLCC
Corine
ECOCLIMAP
DEM
Datasets
HIRLAM
SYSTEM
20 classes->5 tiles/types
(i.e. 1. Water, 2. Ice, 3. Bare soil, 4. Low vegetation, 5. Forest)
CGFs (In GRIB-format)
12 months/files
Specific for HIRLAM domains &
for ISBA land surface scheme (LSS)
HIRLAM
ISBA LSS
Hard-coded tables with
characteristics for 20 classes
(init_veg.f)

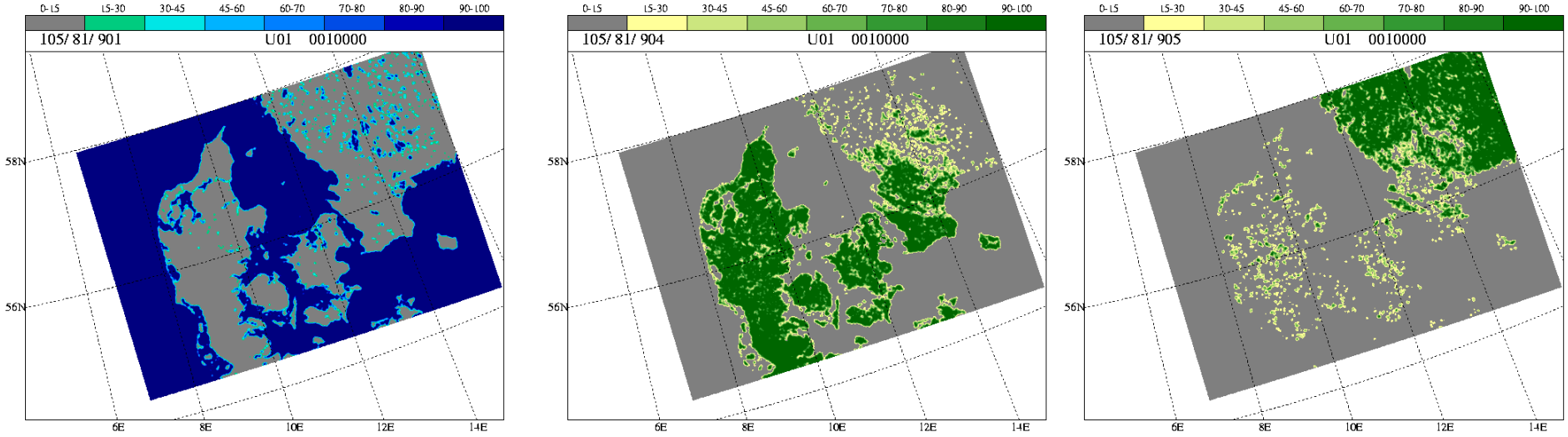
Land Use Classification for U01 Domain (1)



Distribution of the (left) first dominating class and (right) second dominating class within major tiles represented in the U01 domain and generated for the HIRLAM ISBA use.
Used colors: **blue** – water tile (class 15 - sea);

green – forest tile (class 3 – evergreen forest);
yellow – low vegetation tile (class 1 - cropland),
red – all other classes;
white – no second dominating class.

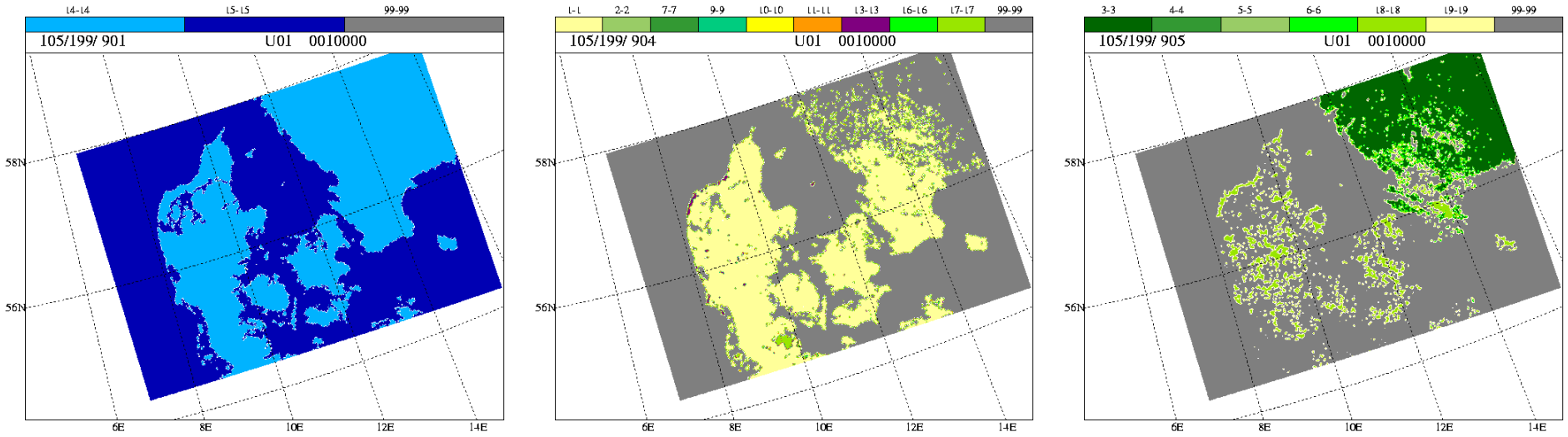
Land Use Classification for U01 Domain (2)



(a) (b) (c)

Fig. Example of output of climate generation file for January: fractions (in percentage) of three (from 5) major tiles – a) water, b) low vegetation and c) forest - represented in the U01 domain and generated for the HIRLAM ISBA LSS use.

Land Use Classification for U01 Domain (3)



(a) (b) (c)

Fig. Example of output of climate generation file for January: types of classes (from 20) for three (from 5) major tiles - a) water, b) low vegetation, and c) forest - represented in U01 domain and generated for the HIRLAM ISBA LSS use.