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Land-use Database Processing Approach for Meso-Scale Urban NWP Model Initialization

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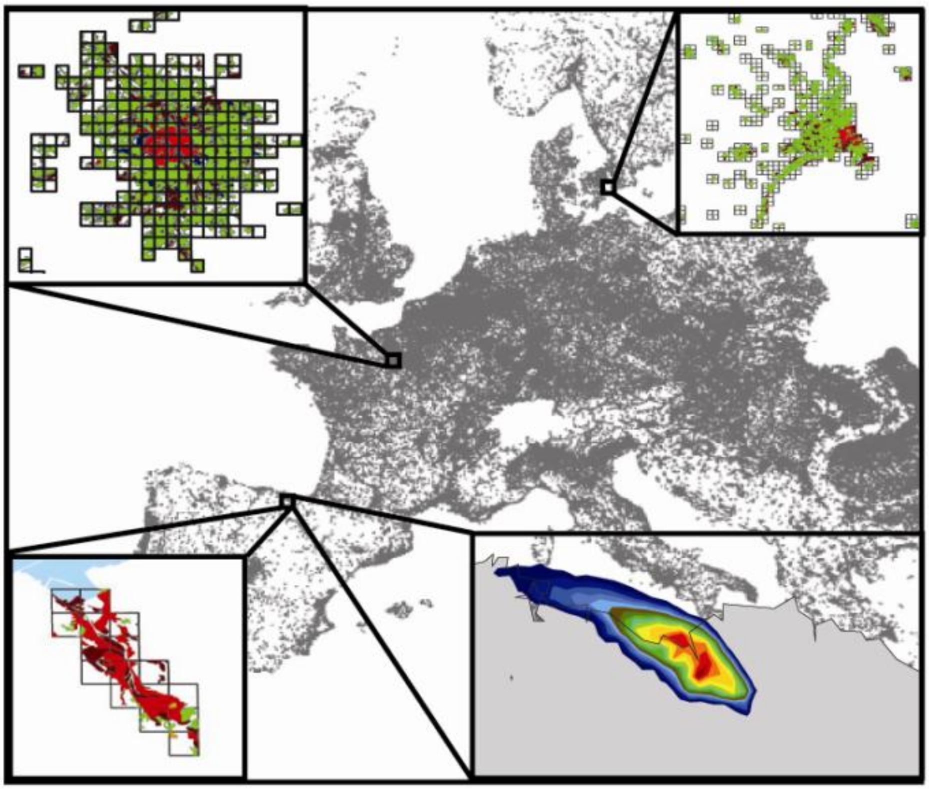

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Abstract

This study is devoted to elaboration of general methodology for adjustment of land-use database (CORINE Land Cover 2000; *CORINE, 2000*) for urban scale modelling in numerical weather prediction (NWP) and environmental applications. Three metropolitan areas – Paris (France), Copenhagen (Denmark), and Bilbao (Spain) – of different spatial sizes and population were considered. The CORINE and Basque Government land-use (*UDALPLAN, 2009*) databases of different characteristics and resolutions were selected. Several approaches were suggested for treatment of the databases multilayer content using Geographical Information System (GIS) tools, depending on the available data in each case. This approach is applied to an online coupled numerical weather prediction and atmospheric chemical transport modelling system Enviro-HIRLAM (Environment-HIgh Resolution Limited Area Model). The Interaction Soil-Biosphere-Atmosphere (ISBA) land surface scheme was modified to include urban effects using the Building Effect Parameterization (BEP, *Martilli et al., 2002*) module and Anthropogenic Heat Fluxes (AHF) extracted from LUCY model which considers energy fluxes from traffic, metabolism and energy consumptions (*Allen et al., 2010)*.

High resolution (2.4 x 2.4 km) short-term runs for specific dates (summer 2009 and winter 2010) with variable wind conditions were performed for the Bilbao metropolitan area, based on different urban scenarios generated by means of this approach. Three scenarios were generated with AHF=40 W/m^2 and with modified size of the city: firstly, the area considered in CORINE 2000 (16 urban grid points); then the double size city expansion (31 urban grid points) and the triple size city expansion (48 urban grid points). Other scenario considers an increase of AHF in double (80 W/m^2) with the original size of the city (16 urban grid points). The last scenario combined the triple size city expansion (48 urban grid points) and the doubled AHF (80 W/m^2).

The goal was to evaluate the urbanized (with BEP module and AHF) Enviro-HIRLAM and to estimate the influence of the city on formation of the air temperature at 2 m and wind velocity at 10 m. For example, for the temperature at 2 m, the averaging for selected winter 2010 days (for time interval between 03-09 UTCs) showed that, on average, the difference found was 0.7 ºC. In summer, averaging (for time interval between 03-06 UTCs when effects are more intense), the difference could be 1ºC. For the wind speed at 10m, during selected winter days for the same selected intervals as above, on average the difference was 1.3 m/s, but during summer days this difference was smaller (1 m/s). However, for the urban scenario (combining triple size city expansion and double increase in AHF) on a selected winter date, for the air temperature at 2 m the difference on average can be doubled up to 1.5ºC (with a maximum of 2.7ºC at 06 UTC); and for the wind speed at 10 m can be increased up to 1.4 m/s (with a maximum of 2 m/s at 06 UTC).

1 Introduction

Climate research and the interaction with atmospheric chemistry in urbanized areas play an important role for the scientific community at the present time. The impact of the pollution on the air quality; the urban microclimate-to-local and regional scale effects; and the human health alterations are factors of interest due to the consequences of the rapid growth and development of our societies. Urban metropolitan areas are called the most sensitive "hot spots" due to this changeable situation: expansion of the cities, the movement of population to urban cores, etc. However, present and future planning, new constructions and its quantification are under the control of the zoning and planning guidelines of each community, region, country and even continent by means of the land-use-cover databases.

At the same time, numerical weather prediction (NWP) systems are improving to focus on high resolution modelling in urban areas by means of urban parameterization modules, for example - the Building Effect Parameterization (BEP, *Martilli et al., 2002*) module; Anthropogenic Heat Fluxes (AHF) in urban areas from Large scale Urban Consumption of energY (LUCY) model (*Allen et al, 2010*); the Town Energy Balance (TEB; *Masson, 2000*), etc. Urban parameterizations utilize existing urban land-use databases of different scales and resolutions.

For example, the Global Land Cover Characterization (GLCC, 1993; http://edc2.usgs.gov/glcc/glcc.php) database has public access and it is given by different layers for each continent. This database is provided by the U.S Geographical Service (USGS; (http://www.usgs.gov/).

The other database – ECOCLIMAP (http://www.cnrm.meteo.fr/gmme/PROJETS/ECOCLIMAP/page_ecoclimap.htm) - is also an open-source global database of land surface parameters at 1 km resolution. This database is provided by the Centre Nationale de Recherches Météorologiques (CNRM), Météo-France, France.

The COoRdinate INformation on the Environment (CORINE 2000; http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database) is a public access European database based on 40 different types of surfaces over Europe with the resolution of 250 m. This database is provided by the European Environmental Agency, EEA (http://dataservice.eea.eu.int/dataservice). In addition, other regional and local urban land-use databases with precise information are available in many countries and communities.

The main goal of this study is to present a methodological approach for adjustment of the original land-use databases integrated into any NWP models running at the urban scale in the metropolitan areas. In addition, the effects of several urban scenarios (i.e. city expansion) on formation of key meteorological fields in a medium size city were analysed. Therefore, the results of this study can be used for urban scale modelling and environmental applications.

The Section 2 of this report commences on description of the methodological approach suggested: the land-use databases utilised, the metropolitan areas considered, the pre-processing of land-use data in urban areas; the description and setup of the model used. The Section 3 contains analysis of results obtained and discussions with respect to three different metropolitan areas – Bilbao (Basque Country, Spain), Copenhagen (Denmark), and Paris (France) – as well as analysis of urban area impact on meteorological fields (due to several urban scenarios). The report is summarized with conclusions obtained from this study.

2 Methodology

The suggested approach can be used to adjust local/regional/European/global land-use databases at any resolution employing the GIS tools for any size metropolitan area. However, the higher is the resolution of databases, the more precise and accurate will be the urban area classification. This approach can be applied to pre-process urban relevant data for using in urban scale modelling with NWP–ACT models running at high resolution.

2.1 Land-use databases

2.1.1 CORINE

The first land-use database used in this study was: CORINE for year of 2000 (*CORINE 2000*) and an up-to-dated version of CORINE for year of 2006. These both are publicly available European database based on 40 different types of surfaces over Europe with the resolution of 250 m. The direct link to the CORINE database is http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database). This database is provided by the European Environmental Agency (http://dataservice.eea.eu.int/dataservice/). The database is focused on different layers with information on air pollution, biodiversity, climate change, coasts and seas, energy, industry, land-use, natural resources, policy instruments, population and economy, soil, specific regions, urban environment, waste and material resources and water. As stated it gives consistent information on land-cover changes across 32 European countries during the decade of 1990s. It should be noted that the up-to-date CORINE 2006 database gives a better representation, especially, for orography and identification of urban surface features.

2.1.2 UDALPLAN

The second database used was the TownHall Planning database for the Basque Country (*UDALPLAN, 2009*). It is a regional database which contains a general structure and an identification of the land-use over the autonomous region of the Basque Territory. Public access for this database is provided by the Environmental and Zoning Department of the Basque Government (http://www1.euskadi.net/udalplan/visor/viewer.htm). The resolution of the database is 1:10.000 (cm) that is, at a resolution of 100m. Database contains classification of land-use by historical territories, autonomous regions, functional areas and municipalities. The urban surface classification follows the following zoning guidelines: residential (high and low density areas), economical activities, general systems and non-urbanized areas.

2.2 Metropolitan areas

Three metropolitan areas in Europe were considered and the developed methodological approach was applied for testing.

The first city is the Bilbao (Spain, Basque Country) metropolitan area. It is located in a coastal area (Cantabric Sea), north of the Iberian Peninsula and surrounded by complex terrain. It is considered as a medium size city (0.875 million inhabitants). Within the boundaries of this metropolitan area there are 17 municipalities (Arrigorriaga, Barakaldo, Basauri, Bilbao, Etxebarri, Erandio, Getxo, Larrabetzu, Leioa, Lemoa, Lezama, Derio, Loiu, Portugalete, Santurtzi, Sestao and Sondika) based on analysis of the Basque Statistical Institute (*EUSTAT, 2008*).

The second city is Copenhagen (Denmark) metropolitan area located in north-east territories of the Island of Zealand over a flat terrain. According to the Danmarks Statistik (Danish governmental organization under the Ministry of Economic and Business Affairs) it is considered as a medium size city with a population around 1.181 million inhabitants. Within the boundaries of this metropolitan area there are 18 districts/ municipalities (Copenhagen, Frederiksberg, Albertslund, Ballerup, Brøndby, Gentofte, Gladsaxe, Glostrup, Greve Strand, Herlev, Hvidovre, Ishøj, Lyngby-Taarbæk, Rødovre, Søllerød (present Rudersdal), Tårnby, Vallensbæk, Værløse (present Furesø).

The third city is the Paris (France) located inland of the country (Ile-de-France Region) over a semi-flat terrain. It is considered as a megacity (with population of 11.836 million inhabitants according to census 2007; *Paris, 2007*); and moreover, it is one of the target megacities in the FP7 EU MEGAPOLI project (http://megapoli.info) together with the largest metropolitan areas in Europe – London (UK), Rein-Ruhr (Germany) region, and Po Valley (Italy). In total, there are 20 municipalities/ arrondissements in the Paris area.

The three metropolitan areas represent the typical cities in Europe with different: sizes and extensions of urban areas, cities located in flat and complex terrains, in a close proximity to the sea (coastal city) and inland, population densities and urban surface characteristics, etc.

Figure 1 represents the modelling domains created for the NWP model runs with the three metropolitan areas located in the centre of the domains. The summary on characteristics (horizontal resolution, total number of grid points as well as number of urban grids in the domains, number of grid points associated with the metropolitan areas, and total area covered by metropolitan grids) for each modelling domain is shown in Table 1. The Figure 2 shows extracted urban grids over 3 modelling domains for the three urban areas.

Metropolitan area	**Domain**	**Horizontal Resolution (km)**	**Total # grid points in domain**	**# Urban grid points in domain**	**# Metropolitan Grids in domain**	**Area covered by metropolitan grids (km^2)**
Bilbao	B02	2.4x2.4	14834	68	16	92.16
Copenhagen	U01	1.4x1.4	65022	3080	500	980
Paris	P01	2.5x2.5	10148	580	220	1375

Table 1: *Summary of characteristics of the modelling domains – B02, U01 and P01 – for the Bilbao, Copenhagen and Paris metropolitan areas, respectively*

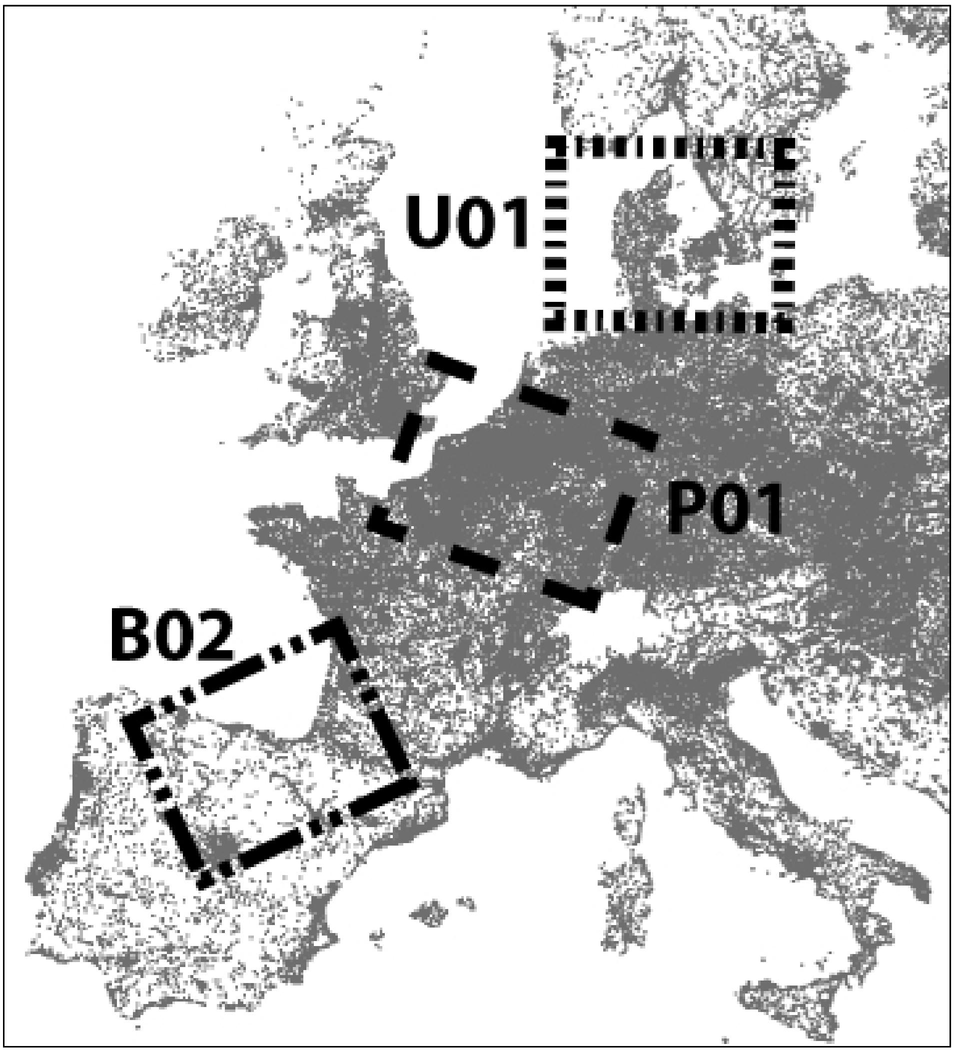
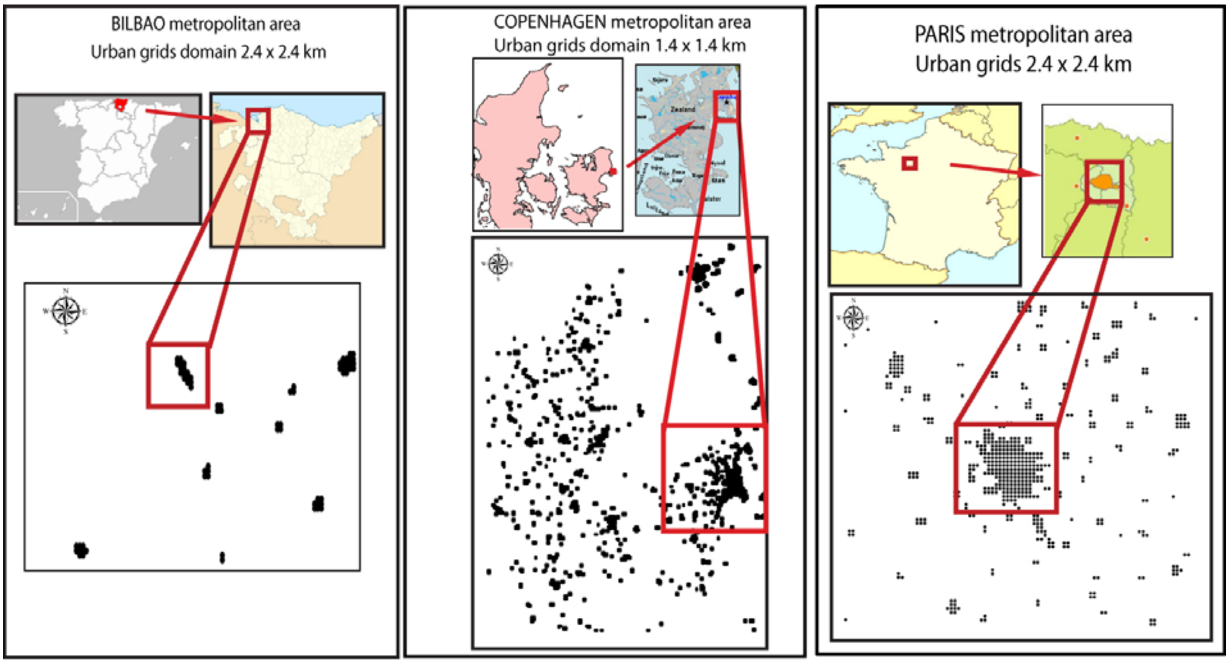


Figure 1: *Geographical boundaries of the modelling domains: B02 - for Bilbao; U01 –for Copenhagen and P01 – for Paris metropolitan areas located in the centres of domains*

2.3 Pre-processing of land-use databases for urban modeling

A general scheme of the methodological approach suggested in this study is shown in Figure 3. It summarizes the description of the procedure through several stages: (I) the extraction of the land-use-cover database, (II) the integration of urban grid cells into GIS environment, and (III) the urban area re-classification into urban districts.



(a) *(b)* *(c)*

Figure 2: *Downscaling of extracted urban grid cells in the modelling domains based on the CORINE 2000 land-use database for the (a) Bilbao, (b) Copenhagen and (c) Paris metropolitan areas*

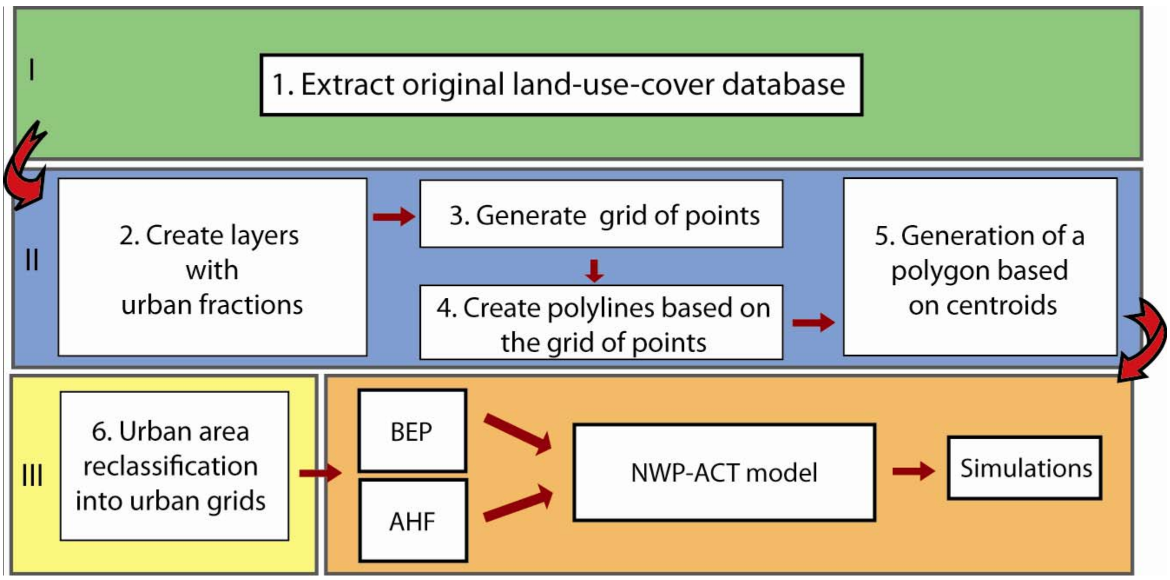


Figure 3: *General scheme for the approach to adjust the urban data from the land-use database*

2.3.1 Extraction of land-use-cover database

The original CORINE database was re-processed and the climate files were built for the three selected modelling domains to be used in the numerical weather prediction model (Sattler K., 1999). All selected domains were constructed in a rotated lat-lon coordinate system (see Table in Figure 7). For integration and analysis in the Geographical Information System (GIS; *ArcGIS software; http://www.gis.com/*) these should be converted into geographical coordinates (lat - lon). For urban areas the information contains the following: latitude and longitude of the urban grid cell with a fraction of urban class in the cell. The World Geographical System 1984 (*WGS84*) is preferable for the GIS analysis in order to overlap with land-use databases. One of the key elements of the proposed approach is the sorting of the grid points (which is equal to number of grid cells + 1 in latitudinal and longitudinal directions). Note that the order of the columns and the rows (along the longitude and latitude, respectively) plays an important role when converting any features to points, lines or polygons in the GIS environment (Step 1; see Appendix B).

2.3.2 Integration of the urban grids into GIS environment

- **Create a new layer of points with urban fractions:**

The "*ArcMap*" component of the geospatial processing program *ArcGIS* allow viewing, editing and analyzing geospatial data. Thereafter, this *ArcMap* tool is employed to perform the following steps.
At first, the system of coordinates must be defined for the GIS environment. For that, from working space select the WGS84 geographical system of coordinates and create a new layer containing only urban points (Step 2; see Appendix B).

- **Create a polygon from irregular grid**:

This procedure is carried out employing the *Hawth* package-tools (more details can be found at http://www.spatialecology.com/htools/tooldesc.php).
If the modelling domain was a regular grid of points then there would be a direct way to create a polygon. The *Sampling* option in *Hawth* allows generating either a line or a polygon (when the distance between points is known and equal).
If the modelling domain was a non-regular (i.e. rotated) grid of points then there would be a need to follow another way because the resulted grid will be shifted and irregular. Hence, the procedure to create polygons is based on the type of sorting: at first, creating points and lines, and finally, transforming features into polygons (Steps 3-4; Apendix B; see details in Figure 4).

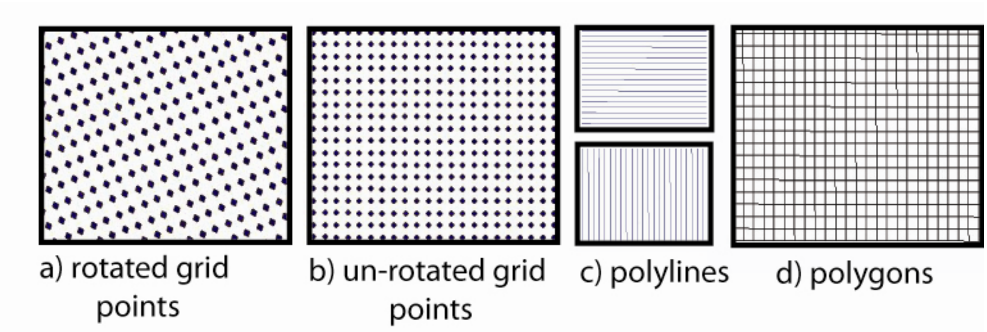


Figure 4: *Procedure to create a polygon from irregular grid points: a) irregular grid points in rotated system of coordinates; b) grid points in the un-rotated system of coordinates; c) horizontal and vertical lines (polylines) generated from the sorted points; and d) final polygons formed by the polylines*

- **Generation of a polygon based on centroids:**

If the urban fraction value is given in the corners of each polygon in domain shown in Figure 4d, then there is a direct way to calculate the mean urban fraction per polygon. If the urban fraction value is located in a centroid of the grid, then it is necessary to re-allocate value to a new polygon having different total area. This can be done using the *Xtoolspro* package tools (http://www.xtoolspro.com) and it is based on the centroids of the previous polygons (Steps 4-5; see Appendix B and Figure 5).

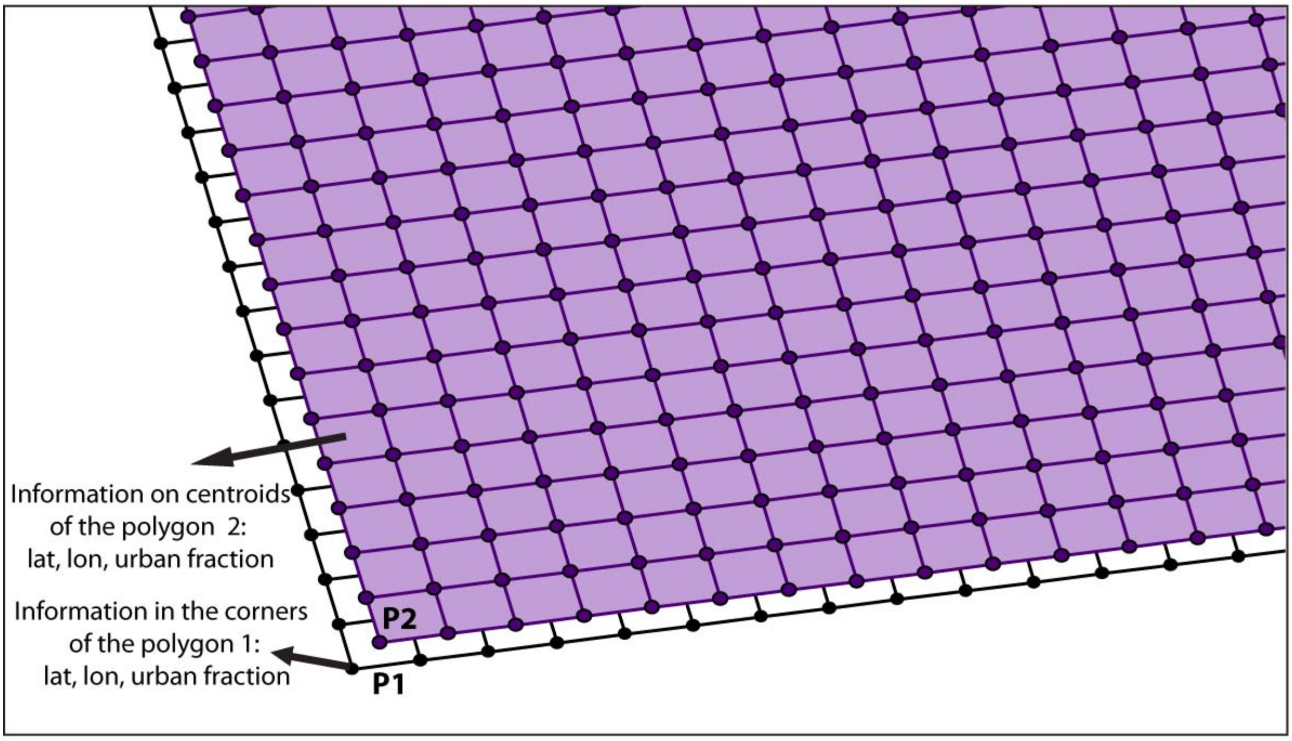


***Figure 5**: Re-allocation of the polygons (P2) based on the centroids of previous polygons (P1) /each polygon contains information on latitude, longitude and urban fraction/*

2.3.3 Re-classification of urban area into urban districts

The last part is re-classification of the land-use database (from the local, regional, European or Global databases) classes into different types of urban districts which are characteristic for the specific metropolitan area. To carry out this step, at first, import available database into the *ArcMap*, then select available classes corresponding with urban districts (see Tables 2-3) and create new layers having information on newly created urban districts.
There is a probability that within each polygon might exist several types of districts, and hence, information on districts will be classified into a new table of attributes through an overlay intersection within the polygon. The areas or percentage of different urban districts inside the polygon can be calculated using the *Geometry* tool (Step 6; see Appendix B).

2.4 Enviro-HIRLAM: Environment – HIgh Resolution Limited Area Model

2.4.1 Model description

The Enviro-HIRLAM (Environment – High Resolution Limited Area Model) is an online coupled numerical weather prediction (NWP) and atmospheric chemical transport modelling system for research and forecasting of both meteorological and chemical weather (*Korsholm et al 2008; Baklanov et al., 2009; Baklanov et al., 2008, Chevenez el at., 2004*). The meteorological and chemistry model solve the governing equations describing by six processes: emission, advection, horizontal diffusion, vertical diffusion and dry deposition, convection and wet deposition, chemistry and aerosols (*Korsholm et al., 2008*). The system realisation includes the nesting of domains for higher resolutions, different levels of urbanization; improvement of advection schemes, implementation of chemical mechanisms and aerosol dynamics, realisation of feedback mechanisms and assimilation of meteorological monitoring data (*Baklanov et al., 2008*).

Urban scale modelling with Enviro-HIRLAM is carried out using the Building Effect Parameterization (BEP, *Martilli et al., 2002*) module. The metropolitan area is represented by a combination of several urban districts. Each district is represented as a combination of multiple streets and buildings of constant widths but with different heights. Each district is characterized by an array of buildings of the same width located at the same distance from each other and with the similar thermo-dynamical characteristics. The parameterization includes computation of contributions from every type of urban surface (street canyon floor, roofs and walls of buildings) for the momentum, heat and turbulent kinetic energy equation separately as contributions of the vertical surfaces (building walls) as well as horizontal surfaces (floors and roofs).

The Large scale Urban Consumption of energY model (LUCY) simulates the Anthropogenic Heat Fluxes (AHF, $Q_{F;}$ in W/m^2) from the global to each city scale at 0.25 x 0.25 arc-minute resolution (*Allen et al., 2010*). This database is an open-source, that is, accuracy of the model can be improved if data from national communities will became available. It includes information on different working patterns, public holidays, and vehicle use and energy consumption in each country. The model is based on a simple partition of the AHF (*Grimmond, 1992; Sailor and Lu, 2004*):

$$Q_F = Q_V + Q_B + Q_M ,$$

where:

Q_V is heat from vehicle emissions,
Q_B is heat released from buildings,
Q_M is human metabolic heat.

2.4.2 Setup for case studies

The Interaction Soil-Biosphere-Atmosphere (ISBA) land surface scheme originally developed by *Noilhan and Planton (1989)* and further up-dated in the HIRLAM model was modified by *Mahura et al. (2005b)* to include the urban effects using the BEP module of *Martilli et al. (2002)* and simple AHF addition to the surface scheme. In this study, in addition, the AHF was extracted from output of the LUCY model considering energy fluxes from traffic, metabolism and energy consumption (*Allen et al., 2010*). It calculates AHFs only for summer and winter period during year of 2005. Figure 6 shows a spatial distribution with typical values of fluxes extracted from the LUCY for the Bilbao, Copenhagen and Paris metropolitan areas for winter 2005.
As estimated, for the Bilbao metropolitan area, on average, for summer AHF was 23 W/m^2 (with the highest value 38 W/m^2) and for winter 30 W/m^2 (with the highest value 50 W/m^2).
For Copenhagen metropolitan area, on average, for summer AHF was 23 W/m^2 (with the highest value 57 W/m^2) and for winter 30 W/m^2 (with the highest value 68 W/m^2).
For the Paris metropolitan area, on average, for summer AHF was 57 W/m^2 (with the highest value 211 W/m^2) and for winter 95 W/ m^2 (with the highest value 261 W/m^2).
In addition, the urban areas were divided into different types of districts with specific morphological and thermo-dynamical characteristics such as height of buildings, street width, wall building temperature, specific heat, etc, following approach of *Mahura et al. (2010).* The

parameters used as input for the BEP module calculations are summarized in Appendix A (on example of the Bilbao metropolitan area). These were classified by means of the information available from regional, European, or global databases, and other sources. For Bilbao, the characteristics for selected districts were calculated based on the *EPA report* (*2009)* and *CTE (2010).* For example, Figure 8 shows the Bilbao metropolitan area classification into four different types of districts (see details in Section 3.1).

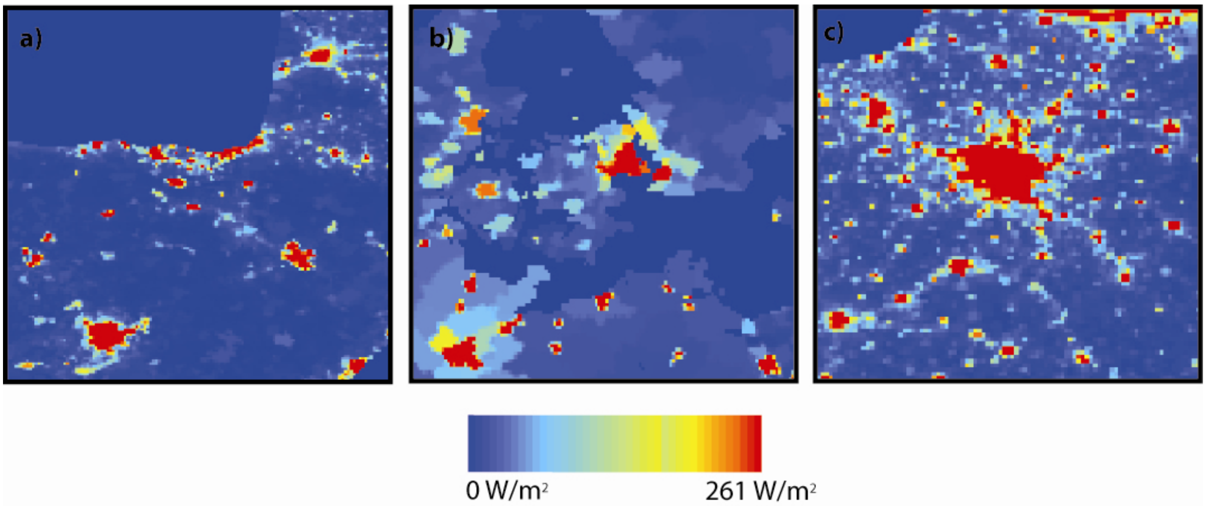
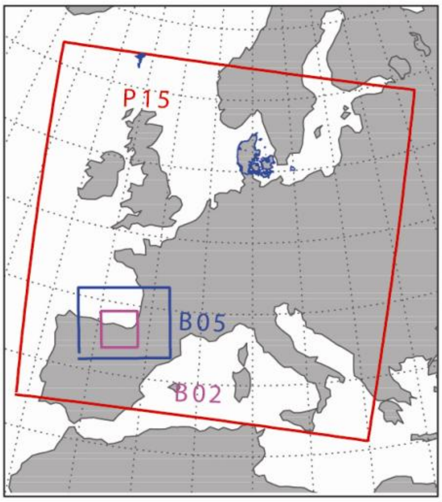


Figure 6: *Anthropogenic heat fluxes (in W/m^2 for winter 2005) extracted from the LUCY model output for the: a) Bilbao; b) Copenhagen and c) Paris metropolitan areas*

2.4.3 Meteorological input

The meteorological data used as boundary conditions of the outer domain originate from the European Centre for Medium Range Weather Forecast (ECMWF). The resolution is 15 km and 40 levels were available in the vertical direction. These data were used as boundary conditions with input frequency of 3 hours: three nested domains were selected with spatial grid resolution of 15, 5 and 2.4 km which contain 154 x 148, 130 x 100, and 130 x 116 cells, respectively (Figure 7).



Resolution	**15 km**	**5 km**	**2.4 km**
Domain	**P15**	**B05**	**B02**
Size			
NLON	154	130	130
NLAT	148	100	116
NLEV	40	40	40
PLON	0	10	10
PLAT	-40	-40	-40
Boundaries			
SOUTH	-12	-8,041	-7,279
WEST	-15	-12,263	-10,932
NORTH	10,05	-3,091	-4,749
EAST	7,95	-5,813	-8,094
Grids	22792	13000	15080

Figure 7: *Boundaries and setup parameters (see Table) of the selected modelling domains – P15, -B05 and B02 – of Enviro-HIRLAM setup for the simulations*

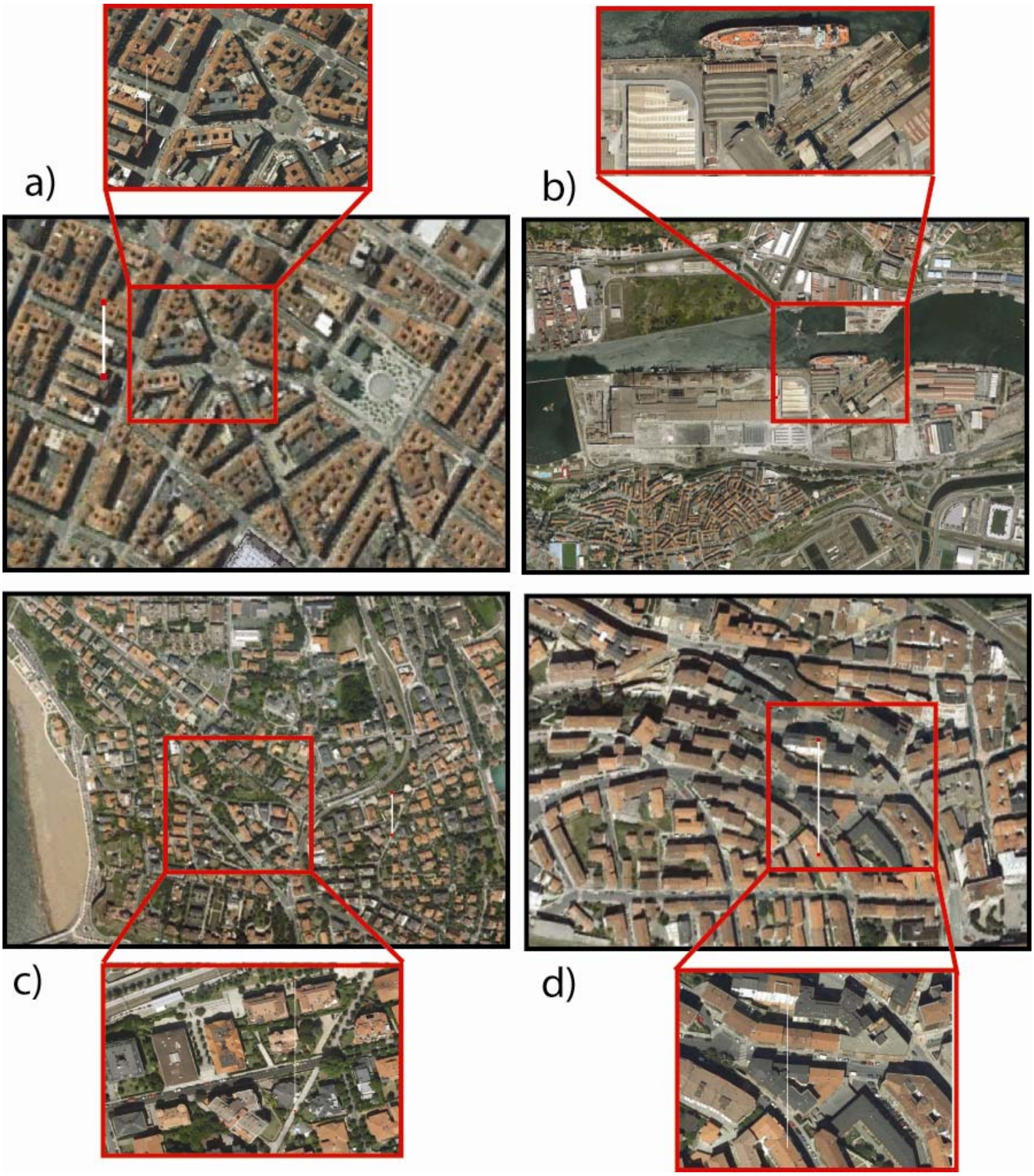


Figure 8*: The urban districts in the Bilbao metropolitan area: a) High building district; b) Industrial commercial district; c) Residential Low density district; and d) Residential High Density district (Illustrations had been extracted from the Google-Earth)*

3 Results and Discussions

3.1 Revised urban classification

3.1.1 Types of districts in metropolitan areas

Industry, services, parks and vegetation, landscape and population density are some of the factors which are used to make classifications of metropolitan areas. The urban districts to classify such areas are characterized by a group of buildings of the same width located at the same distance from each other, but having different heights. Each city has own classification and, commonly, data are collected in urban land-use databases available for each community or country. For example, the open-source European CORINE 2000 land-use database (http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-2) is grouped into different classes:

- Artificial surfaces: (1) urban fabric, (2) industrial, commercial and transport units, (3) mine, dumps and construction sites, and (4) artificial non-agricultural vegetated areas;
- Agricultural areas;
- Forest and semi-natural areas;
- Wetlands;
- Water bodies.

The urban land-use is a class of urban fabric layer and it is divided into two different sub-classes:

- **Continuous urban fabric**: where most of the land is covered by structures and the transport network; buildings, roads and artificial surface areas cover more than 80% of the total area of the surface.
- **Discontinuous urban fabric**: where most of the land is covered by structures; building, roads and artificial surfaces areas are associated with vegetated areas and bare soil, which occupy discontinuous, but significant areas of the surface.

For this study, the urban re-classification from the land-use classes into the urban districts is based on the CORINE 2000 database for the Paris and Copenhagen metropolitan areas; and in addition, the regional UDALPLAN 2009 (http://www1.euskadi.net/udalplan/visor/viewer.htm) database is used for the Bilbao metropolitan area. The UDALPLAN is regional database containing four types of urban related classes:

- Residential: (1) urban; (2) urbanizable (under construction) and (3) non-urbanizable (parks, gardens, etc.);
- Economical activities: (1) urban and (2) urbanizable;
- General systems: (1) equipments; (2) free spaces; (3) ports and airports; (4) rail networks, and (5) basic infrastructures;
- Non-urbanizable areas: (1) protected areas; (2) environmental improvement; (3) forestry and agriculture, and (4) rural cores.

Table 2 summarizes the re-classification used for the Paris and Copenhagen metropolitan areas and Table 3 is devoted to the re-classification for the Bilbao metropolitan area.

Code	CORINE 2000 classes	Urban district
111	Continuous urban fabric	HBD and CC
112	Discontinuous urban fabric	
141	Green urban areas	
142	Sport and leisure facilities	ReD
121	Industrial and commercial districts	
122	Road and rail networks and associated land	
123	Port areas	
124	Airports	
131	Mineral and extraction sites	
132	Dump sites	
133	Construction sites	ICD

Table 2: *Summary on re-classification of the urban land-use data from the CORINE 2000 database into urban districts for the Paris and Copenhagen metropolitan areas*

UDALPLAN classes	Urban districts
Urban residential (High and low density)	RHB/RHB
Urbanizable residential	
Non urbanizable residential	RLD
Urban economical activities	
Urbanizable economical activities	ICD
Equipments	
Free spaces	RLD
Ports	
Airports	
Rail networks	ICD
Basic infrastructures	
Protected areas	No classified
Environmental improvement	No classified
Forestry	No classified
Agriculture	No classified
Rural cores	No classified

Table 3: *Summary on re-classification of the urban land-use data from the UDALPLAN 2009 database into urban districts for the Bilbao metropolitan area*

3.1.2 Bilbao metropolitan area

The Bilbao metropolitan area was divided into four districts according to the characteristics of its urban environment: (1) city centre (CC); (2) industrial commercial district (ICD); (3) residential low density district (RLD), which is characterized by 2-3 floor private houses grouped in neighbourhoods of 50-100 houses; and (4) residential high density district (RHD), which is represented by neighbourhoods of buildings of 10-15 floors, commonly located in the suburbs of the city. Note this classification is typical for Spanish cities. Figure 9 shows the urban reclassification for the Bilbao city (16 urban grid cells) based on the UDALPLAN 2009.
In addition to this, because UDALPLAN 2009 presents information at high resolution (100 m), then each urban grid cell can have several types of districts for which the calculation of percentage of the districts inside each urban grid can be done (see Table 4).

GRID	ICD		RLD		RHD		HBD		Non-Urban	Dominant district
	Total Area (km2)	percen(%)	Total Area (km2)	percen(%)	Total Area (km2)	percen(%)	Total Area (km2)	percen(%)	percen (%)	
1	3	44,98	1	1,12	0,1	2,26	0	0	51,64	ICD
2	3	4,66	2	24,2	0	0	0	0	71,14	RLD
3	4	5,93	1	2,43	1	12,58	0	0	79,06	RHD
4	3	4,25	1	24,92	1	23,34	0	0	47,49	RLD
5	1	12,02	1	21,68	0	0	0	0	66,3	RLD
6	2	38,87	0,5	3,87	1	11,92	0	0	45,34	ICD
7	1	19,75	1	1,49	2	32,14	0	0	46,62	RHD
8	1	13,31	0,5	5,17	2	3,24	0	0	78,28	ICD
9	2	24,13	0,5	2,9	3	43,01	0	0	29,96	RHD
10	1	22,94	0	0	0,5	5,3	0	0	71,76	ICD
11	0,5	7,42	0,5	4,31	1	14,46	0	0	73,81	RHD
12	0	0	0,2	3,08	1	9,51	2	31,29	56,12	HBD
13	0	0	0	0	1	18,33	2	2,54	79,13	RHD
14	0,1	2,27	0,3	4,48	1	9,39	2	30,97	52,89	HBD
15	1	16,14	0,5	6,24	3	43,15	1	2,54	31,93	RHD
16	0,1	1,81	0,2	3,58	0,5	8,32	0	0	86,29	RHD

Table 4: *Results of reclassification of the Bilbao metropolitan area into different types of urban districts with corresponding areas and percentage*

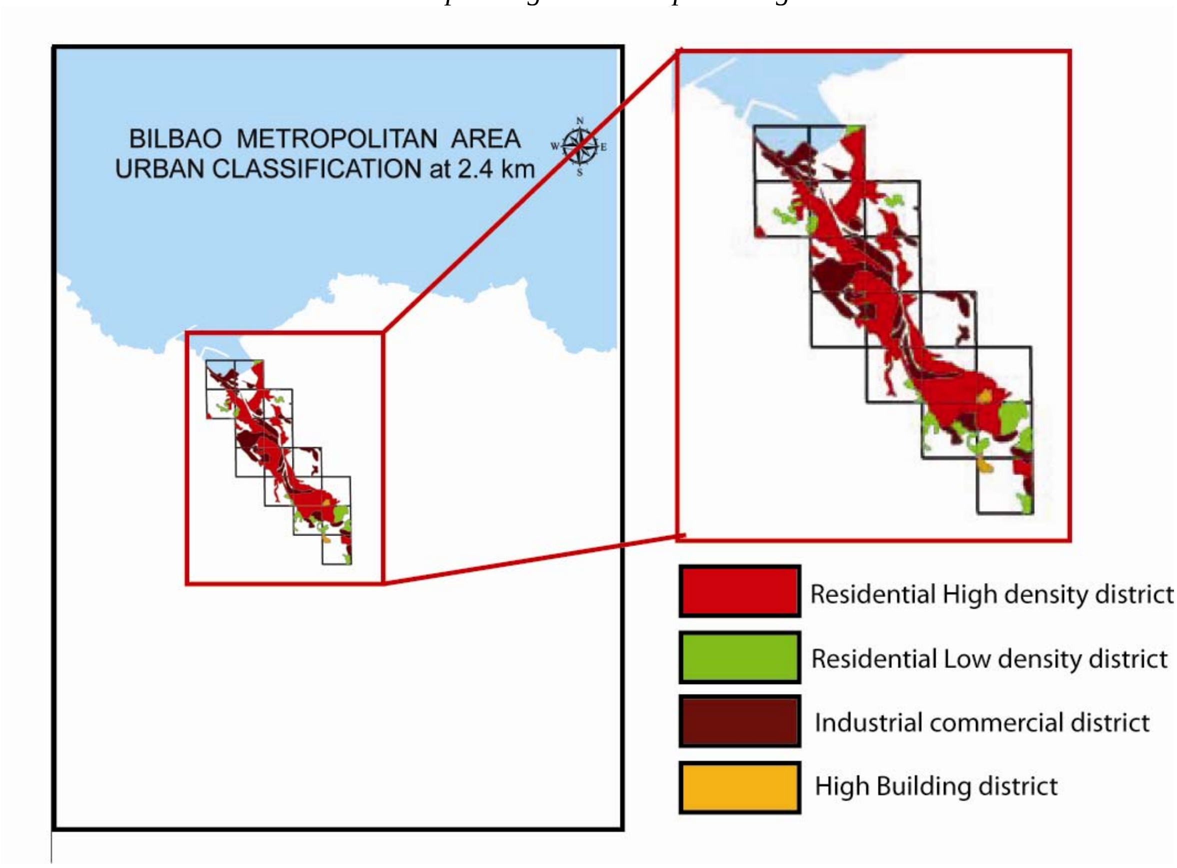


Figure 9*: Urban reclassification into different districts based on the UDALPLAN 2009 for the Bilbao metropolitan area*

3.1.3 Copenhagen metropolitan area

From the urban related classes of the CORINE 2000, the Copenhagen metropolitan area was reclassified into three urban districts (*Mahura et al., 2005a*): (1) city centre and high building district (CC/HBD); (2) industrial commercial district (ICD); and (3) residential district (ReD).
For this study, as shown in Figure 10, the improved urban reclassification based on the CORINE 2000 was performed. The U01 modelling domain contained 65022 grids in total, where 3080 points were assigned as the urban grids. The Copenhagen metropolitan area was represented by 500 urban grid points and each urban grid was represented by the dominating urban district. In particular, HBD was attributed to 20 urban grids (4%), ICD 70 urban grids (14%) and ReD 410 urban grids (82%).

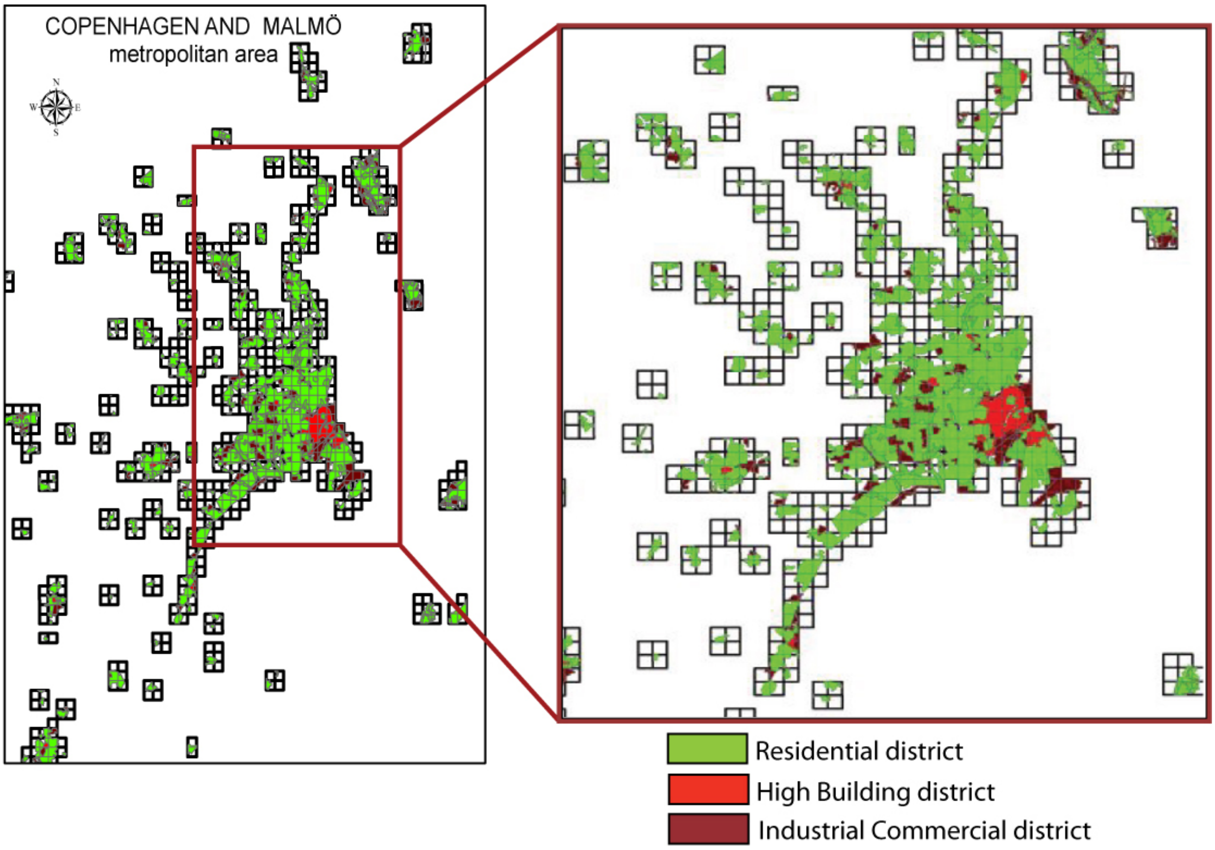


***Figure 10**: Urban reclassification into different districts based on the CORINE 2000 for the Copenhagen metropolitan area*

3.1.4 Paris metropolitan area

For the Paris metropolitan area four urban districts were identified (*Mahura et al., 2010*): (1) city centre (CC) which included 13th, 15th and 19th arrondissement of the Paris Ile-de-France region; (2) high building district (HBD); (3) industrial commercial district (ICD) and (4) residential district (ReD). Figure 11 shows the urban reclassification of this city based on the CORINE 2000. The P01 modelling domain contained 65022 grids in total, where 3080 points are urban grids. The Paris metropolitan area was represented by 220 urban grid points and each urban grid was represented by the dominant urban district: HBD was attributed to 21 urban grids (9%); CC - 4 urban grids (2%); ICD - 30 urban grids (14%) and ReD - 165 urban grids (75%).

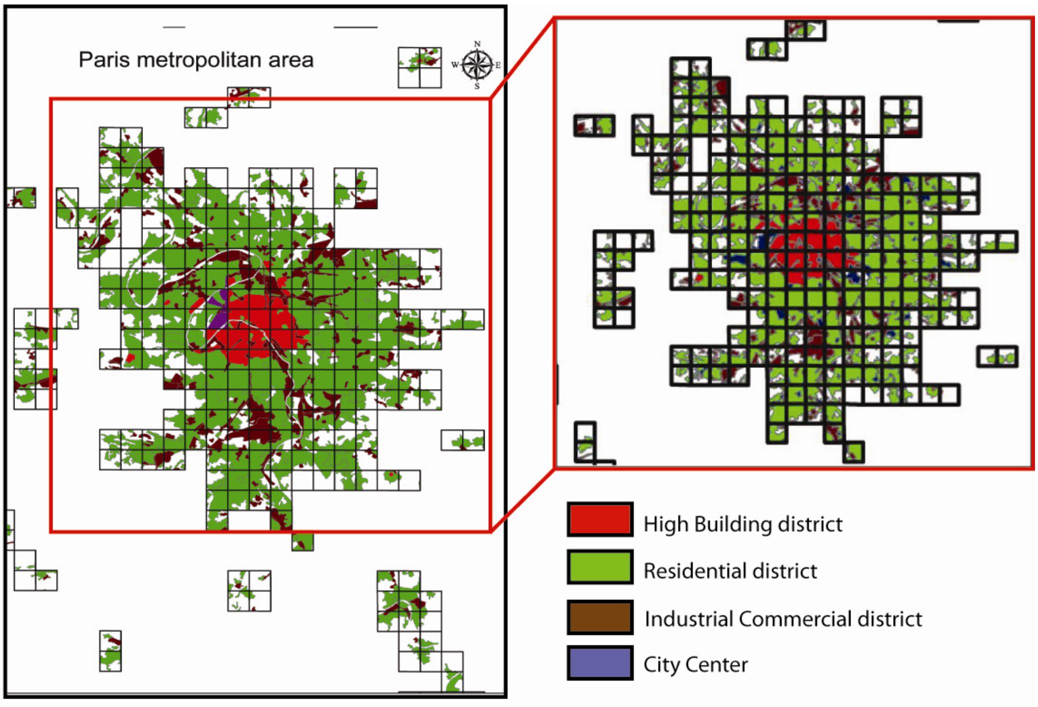
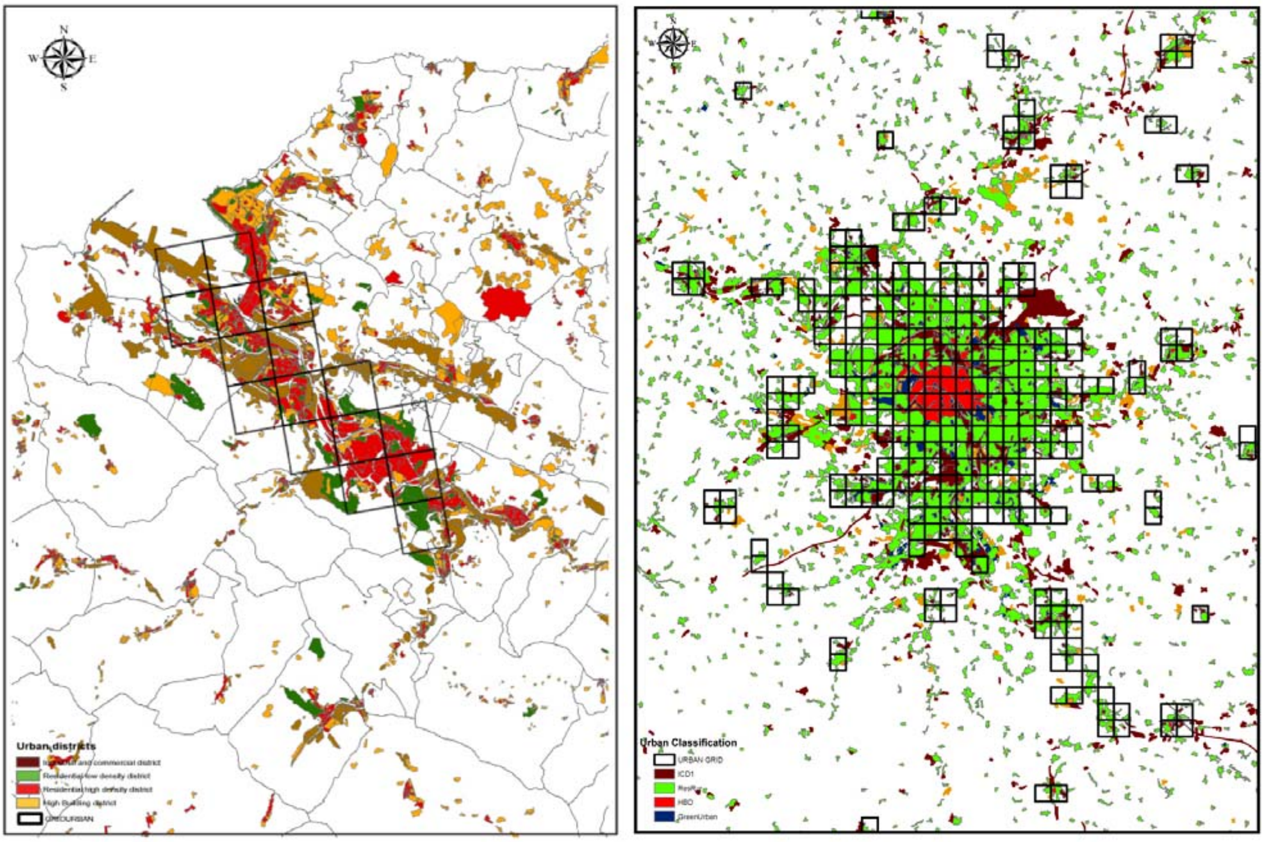


Figure 11*: Urban reclassification into districts based on CORINE 2000 for the Paris metropolitan area*

3.1.5 Land–use adjustment related to urban districts and scenarios for development

The rapid economical growth, development and expansion of urban areas are represented by land-use databases in the zoning and planning of each community. However, the land-use databases used in numerical weather prediction models are not usually up-to-date to such rapidly changeable situations, and sometimes, the information defined is not so precise for all the metropolitan areas. For instance, there are 16 urban grid cells (at 2.4 km resolution) in the CORINE 2000 database for the Bilbao metropolitan area. However, the regional database of the Basque Country (UDALPLAN 2009) considers, at least, additional 30% more of urbanized area which is not shown in the CORINE 2000 database. Figure 12a shows the 16 urban grids from the CORINE 2000 and the overlay urbanized area represented by the UDALPLAN 2009. In the Paris metropolitan area the suburbs are not covered completely (Figure 12b) by the CORINE 2000 database for the Enviro-HIRLAM simulations. Hence, for improvement of NWP simulations the adjustment of originally used database will be needed, i.e. more information on land-use classes is required to be used further for re-classification into districts.

In this study, it has been tested on examples of the urban scenarios developed for the Bilbao metropolitan area in order to show importance of urban relevant input for the Enviro-HIRLAM simulations. Three scenarios were generated with the Anthropogenic Heat Fluxes (AHF) = 40 W/m^2 and modified sizes of the city (Figure 13): 1) the area considered in CORINE 2000 (16 urban grids); 2) the double size city expansion (31 urban grids); and 3) the triple size city expansion (48 urban grids). The 4th scenario considers an increase of AHF in double (80 W/m^2) with the original size of the city (16 urban grids). The 5th last scenario combines the triple size city expansion (48 urban grids) with the increased AHF in double (80 W/m^2).



(a) (b)

Figure 12*: (a) Differences between 2000 vs. 2009 based on urban zoning data from the UDALPLAN 2009 and CORINE 2000 for the Bilbao metropolitan area; (b) Differences between the urban zoning situations and urban grids in the Paris metropolitan area*

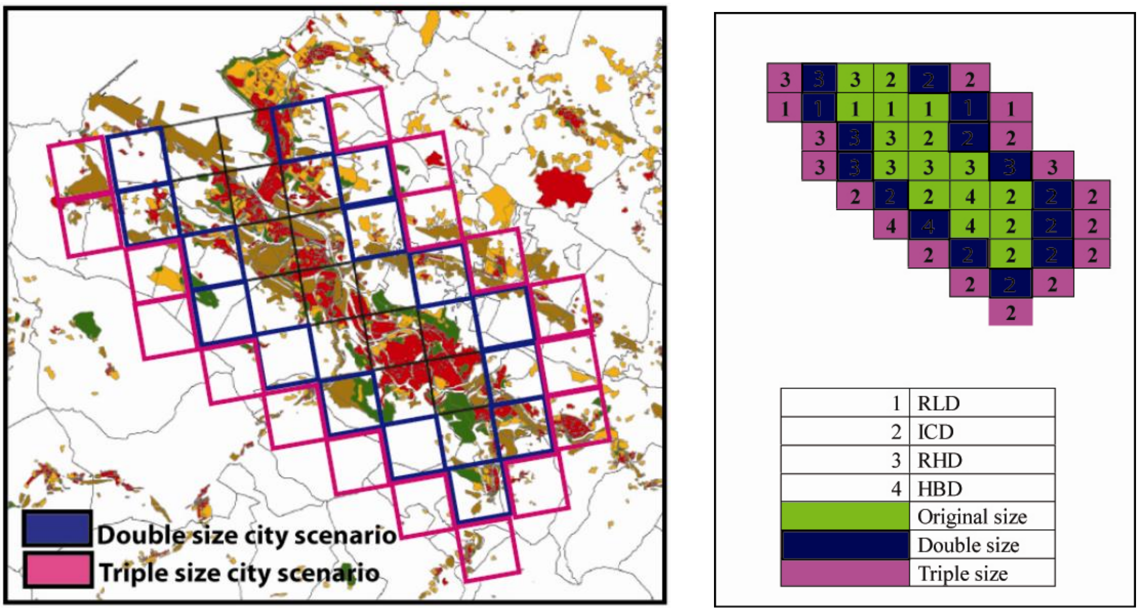


Figure 13*: Urban scenarios generated for the Bilbao metropolitan area: 1) considered in CORINE 2000 (16 grid cells); 2) double size city (31 grid cells), and 3) triple size city (48 grid cells)*

3.2 Impact on meteorological fields due to urban scenarios

3.2.1 Specific case studies with Enviro-HIRLAM

High resolution (2.4 x 2.4 km) short-term runs for specific dates (during summer 2009 and winter 2010) with variable wind conditions were performed for the Bilbao metropolitan area. These runs took into account the urban scenarios generated by means of the proposed approach. The goals were to evaluate the performance of the urbanized (with BEP module and AHF) vs. non-urbanized Enviro-HIRLAM model and to estimate the influence of the city on formation of the meteorological fields for the air temperature at 2 m and wind velocity at 10 m.
For that the simulations were performed in two modes for each urban scenario: 1) control run (without any modifications) and 2) urban run which included BEP+AHF. The impact of the city on the meteorological variables was studied by evaluating the difference between outputs of the urbanized vs. control runs for selected scenarios.
For the periods considered the selection of days was based on the criteria of calm conditions during the day. Calm days were chosen to minimize synoptic scale effects. Moreover, since the effect of the city on meteorological fields is more visible during the Low Wind Conditions (LWC) (*Mahura et al., 2005b*), these cases were considered in more details in this study. The criteria for calm days are: clear sky, low humidity, low wind speed and changeable direction (and considering the mean of wind speed during the day is less than 3 m/s), high atmospheric pressure, and horizontally almost homogeneous air temperature field (*Velazquez-Lozada et al., 2005*). The LWC days analysed were 5th and 12th of August 2009, 18th January and 15th of February 2010. Simulations were also performed for one day with Typical Wind Condition (TWC) in summer (3rd August 2009) and one day in winter (16th February 2010).
Detailed verification of simulations versus observations and analysis of the Urban Heat Island (UHI) development were carried out in *González-Aparicio et al.,* (2011).

3.2.2 Influence of metropolitan area on formation of air temperature fields

Original size city

At first, the simulations for the Bilbao metropolitan area were performed based on a representation of the city by 16 urban grids (from CORINE 2000 database) and AHF = 40 W/m^2.
Simulations showed that for the modelled days, the urbanized version of the Enviro-HIRLAM modifies the structure of the air temperature field over the metropolitan area and surroundings. In fact, the differences between the two modes were more pronounced for the winter days during night – early morning hours (in particular, during 03-09 UTCs). For example, during 18th January 2010, on average, on a diurnal cycle for air temperature at 2 m the difference between the urban and control runs was 0.5ºC. But the effect on temperature was larger when the 03-09 UTC interval was considered. On average, the difference was 0.7ºC (with a maximum of 1ºC at 06 UTC). Figure 14 shows the difference plots for the air temperature at 2 m on the diurnal cycle.
Averaging for 3 winter days (for selected short interval between 03-09 UTCs) showed that the difference for air temperature at 2 m was around 0.7 ºC (as shown in Table 5). Note that in summer 2009 (see also Table 5), averaging for 3 summer days (for selected short interval between 03-06 UTC when effects are more intense), on average, for air temperature at 2 m the difference was 1ºC. The maximum difference was observed at 06 UTC.
It should be noted that during other time intervals – for winter (between 10-18 UTCs) and for summer (06-18 UTCs) - the difference is almost negligible.

Period	Date	Wind Conditions	t2m av. diff. (ºC)	t2m max. diff(ºC)
Winter	18/01/2010	LWC	0.65 for 3-9 UTC	1.00 at 6 UTC
	16/02/2010	LWC	0.8 for 3-9 UTC	1.2 at 6 UTC
	15/02/2010	TWC	0.6 for 3-9 UTC	0.8 at 3 UTC
Summer	03/08/2009	TWC	0.55 for 3-6 UTC	0.95 at 6 UTC
	05/08/2009	LWC	1.25 for 3-6 UTC	2.10 at 6 UTC
	12/08/2009	LWC	1.25 for 3-6 UTC	2.1 at 6 UTC

Table 5: *Summary of the differences on air temperature at 2 m for the days selected during summer 2009 and winter 2010*

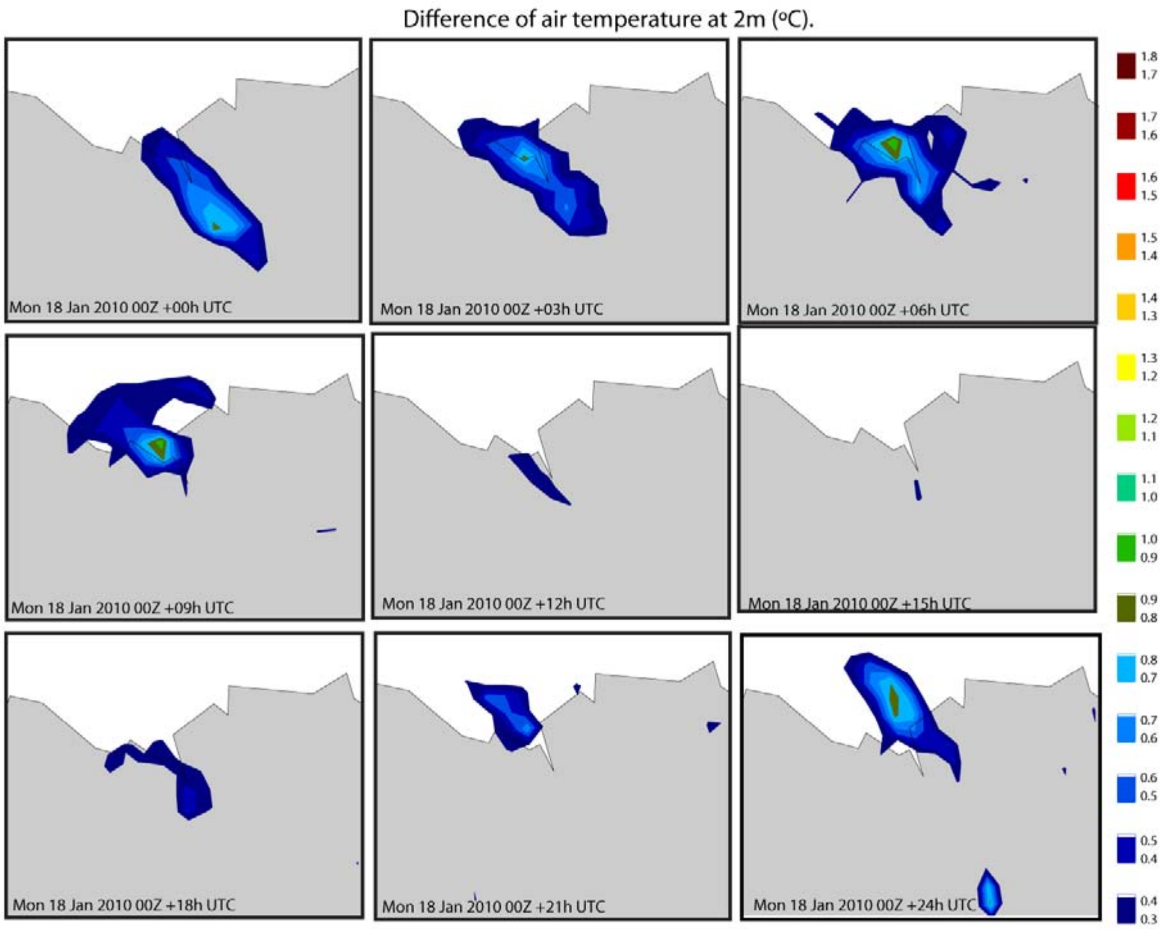


Figure 14*: Difference plots for the air temperature at 2 m between outputs of the urbanized (BEP + AHF) vs. control runs of the Enviro-HIRLAM model during 18th January 2010*

Urban scenarios

Considering 18 Jan 2010, it was also found that each urban scenario can modify the structure of the air temperature field over the metropolitan area and surroundings, and especially, during 03-09 UTCs. The analysis of scenarios for this date is given below. If the city is expanded from its original size (16 urban grid cells) then for the air temperature at 2 m the difference will also enlarge. For example, if the city is almost doubled in size (i.e. from 16 to 31 urban grids) and AHF remained the same (i.e., 40 W/m^2), on average, the temperature difference will be 0.75ºC (with a maximum of 1.15ºC at 06 UTC; Figure 15a). For the tripled size city scenario (48 urban grids and the same AHF=40 W/m^2), on average, the difference is 0.85ºC (with a maximum of 1.35ºC at 06 UTC; Figure 15b). For the urban scenario with AHF increased in double (80 W/m^2) but with the original size of the city (16 urban grids), on average, the temperature difference will be 0.85ºC (with a maximum of 1.35ºC at 06 UTC; Figure 15c). Finally, for the urban scenario combining triple size city (48 urban grids) and double increased AHF (i.e. 80 W/m^2), on average, for the air temperature at 2 m the difference was 1.5ºC (with a maximum of 2.65ºC at 06 UTC; Figure 15d).

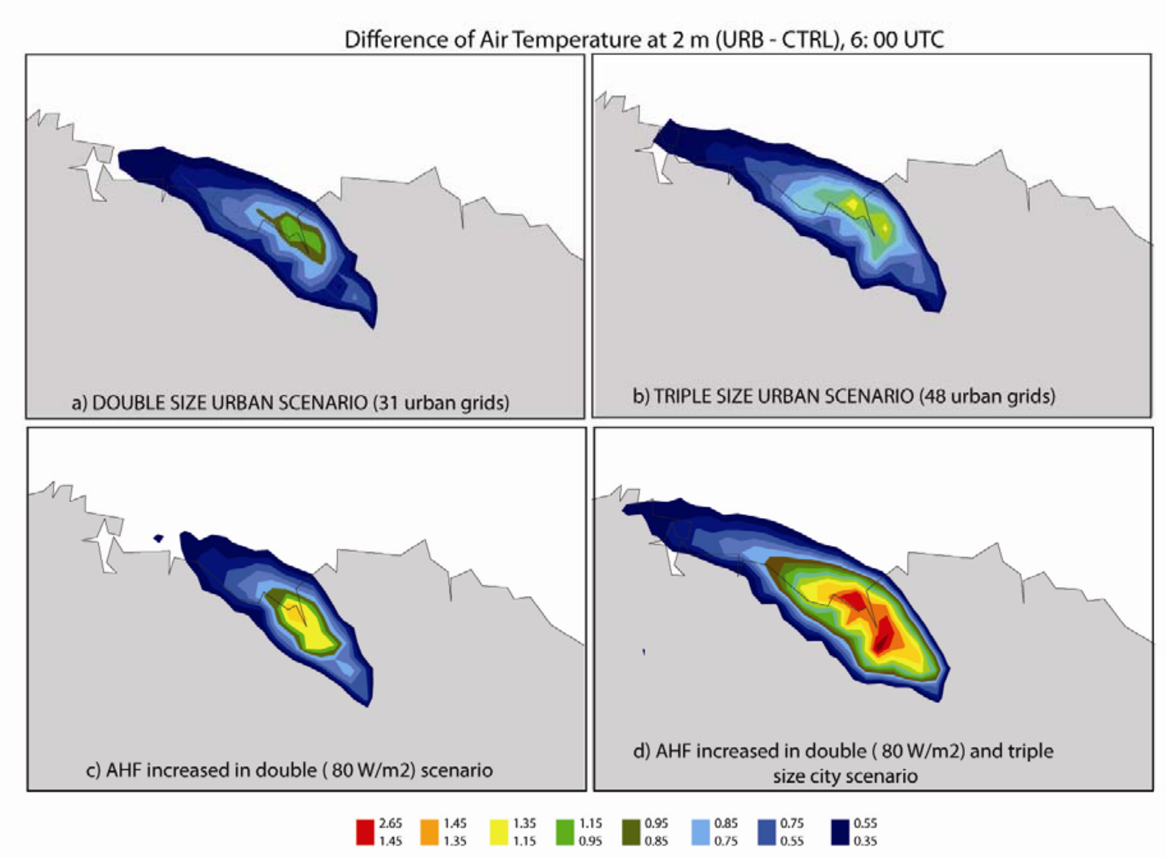


***Figure 15**: Difference plots for the air temperature at 2m [ºC] (on 18th January 2010, at 06 UTC) between outputs of the urbanized (BEP + AHF) and non-urbanized Enviro-HIRLAM model runs for the following scenarios: (a) double size city; (b) triple size city; (c) standard size city with AHF doubled; and (d) triple size city with AHF doubled.*

3.2.3 Influence of metropolitan area on formation of wind patterns

Original size city

In the Bilbao metropolitan area, during selected summer 2009 days (all these days were LWC situations; see Table 6), the wind direction at 10 m was originated from NW to SE, i.e. from the Cantabric Sea to inland of the Iberian Peninsula. However, in winter 2010 the wind direction was opposite, from SE to NW. It was found that under LWC the Bilbao metropolitan area (even with 16 urban grids; with AHF=40 W/m^2) can already modify the structure of the wind patterns. During 18th January 2010, on average, on a diurnal cycle for wind speed at 10 m the difference between the urban and control runs was 0.35 m/s. But the effect on the wind field was also larger when the 03-09 UTC intervals was considered. For this date, for this interval, on average, for the wind speed at 10 m the difference was 1 m/s (with a maximum of 1.1 m/s at 06 UTC; Figure 16). In general (see

Table 6), during selected winter 2010 days for the selected interval, for the wind speed at 10 m the difference was 1.3 m/s. But during summer 2009 days (for 03-06; see also Table 6) this difference was 1 m/s.

Period	Date	Wind Conditions	wind 10 m av. diff (m/s)	wind 10 m max diff (m/s)
Winter	18/01/2010	LWC	0.85 for 3-9 UTC	1.10 at 6 UTC
	16/02/2010	LWC	1.35 for 3-9 UTC	1.30 at 6 UTC
	15/02/2010	TWC	1.75 for 3-6 UTC	2.00 at 3 UTC
Summer	03/08/2009	TWC	1.00 for 3-6 UTC	1 .30 at 3UTC
	05/08/2009	LWC	1.00 for 3-6 UTC	1.25 at 6 UTC
	12/08/2009	LWC	1.00 for 3-6 UTC	1.50 at 6 UTC

Table 6: *Summary of the differences on wind velocity at 10 m for the days selected during summer 2009 and winter 2010*

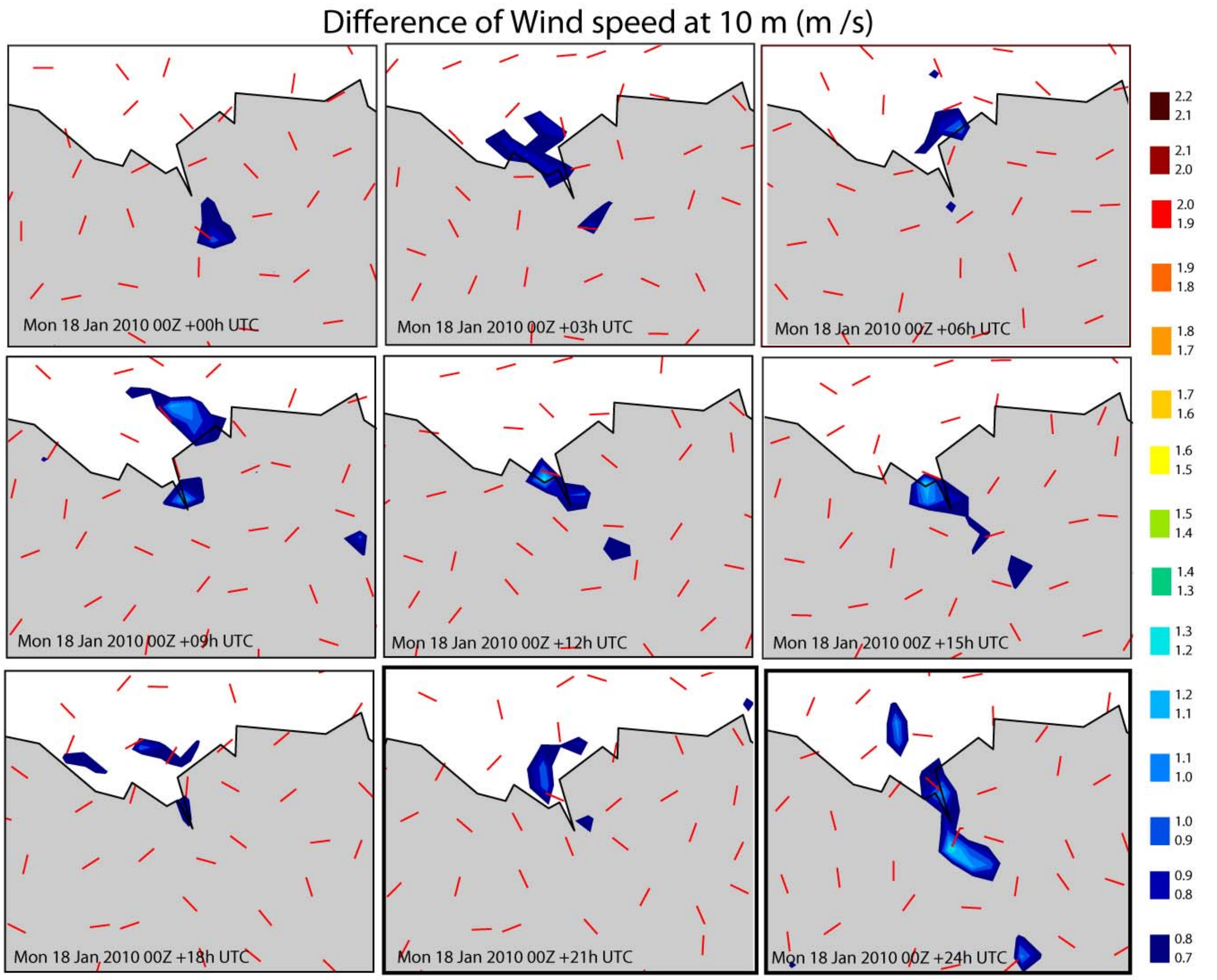


Figure 16*: Difference plots for the wind velocity (m/s) at 10 m between outputs of the urbanized (BEP + AHF) vs. control runs of the Enviro-HIRLAM model during 18th January 2010*

Urban scenarios

Considering 18 Jan 2010, it was also found that each urban scenario can modify the structure of the wind field over the metropolitan area, and especially, during 03-09 UTCs. The analysis of scenarios for this date is given below. For example, if the city is almost doubled in size (i.e. from 16 to 31 urban grids) and AHF remained the same (i.e. 40 W/m^2), on average, for the wind speed at 10 m the difference between the urban vs. non-urban run was almost 1 m/s between 03-09 UTCs (with a maximum of 1.5 m/s at 06 UTC; Figure 17a). For the triple size city scenario (48 urban grids and AHF=40 W/m^2), on average, the difference was 1.13 m/s (with a maximum of 1.65 m/s at 06 UTC; Figure 17b). For the urban scenario of original size of the city (16 urban grids) with AHF increased in double (80 W/m^2), on average, the difference was 1.3 m/s (with a maximum of 2 m/s at 06 UTC; Figure 17c). And finally, for the urban scenario combining triple size city (48 urban grids) and double increased AHF (80 W/m^2), on average, the difference for the wind speed at 10 m was 1.4 m/s (with a maximum of 2 m/s at 06 UTC; Figure 17d).

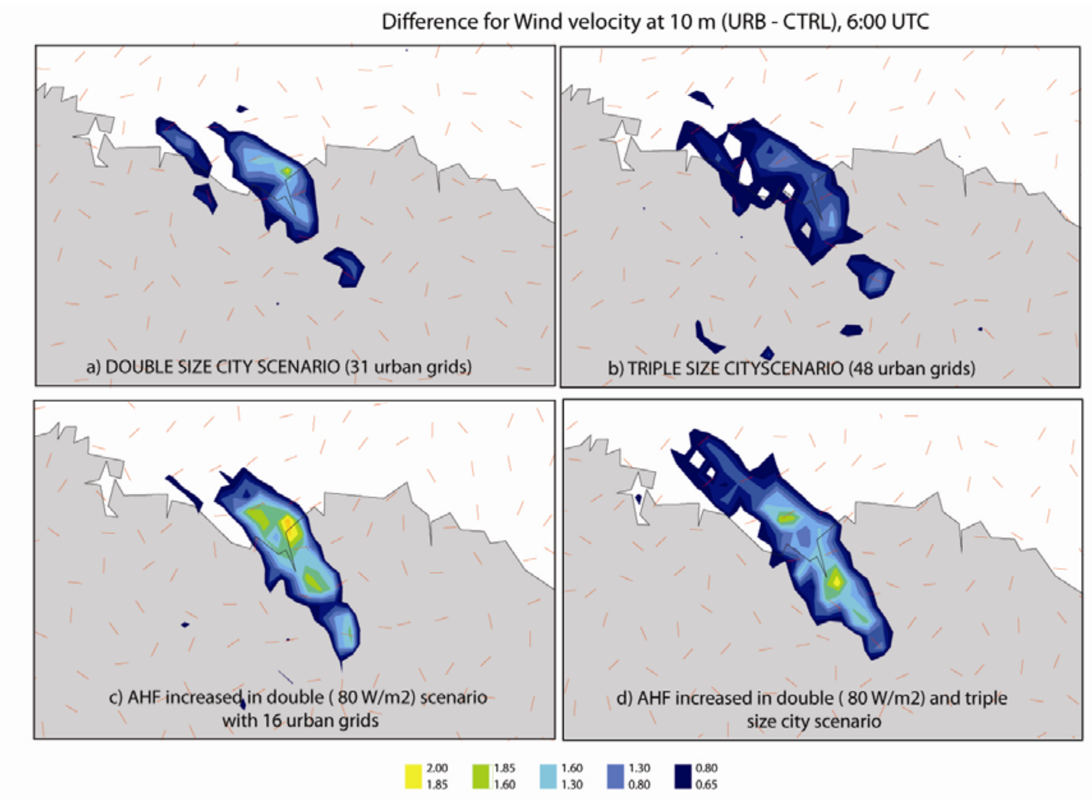


***Figure 17**: Difference plots for the wind velocity [m/s] at 10 m (on 18th January 2010, at 06 UTC) between outputs of the urbanized (BEP + AHF) and non-urbanized Enviro-HIRLAM model runs for the following scenarios: (a) double size city; (b) triple size city; (c) standard size city with AHF doubled; and (d) triple size city with AHF doubled*

Conclusions

This study is devoted to elaboration of general methodological approach for adjustment of original land-use databases (such as CORINE Land Cover 2000; *CORINE, 2000*) for urban scale modelling in numerical weather prediction and environmental applications. Three metropolitan areas – Paris (France), Copenhagen (Denmark) and Bilbao (Basque Country, Spain) - of different spatial sizes and population were considered. Several approaches were suggested for treatment of selected databases multilayer content using GIS tools. Approaches were tested on examples of the European database CORINE 2000 for the Paris and Copenhagen metropolitan areas, and on example of the regional database UDALPLAN 2009 for the Bilbao metropolitan area. For testing the urban scenarios were generated for the Bilbao metropolitan area and used for the Enviro-HIRLAM model evaluation to study impact on formation of the air temperature at 2 m and wind velocity at 10 m field.

High horizontal resolution (2.4 km) short-term runs for selected dates with low and typical wind conditions (during summer 2009 and winter 2010) were performed for the Bilbao metropolitan area employing the Enviro-HIRLAM model. Different urban scenarios were considered. These accounted the city size expansion and modifications of anthropogenic heat flux (AHF). At first, scenario with a standard original size city (16 urban grids) and AHF=40 W/m^2 was selected. At second, the city has been expanded double in size (31 urban grids), and then it has been tripled in size (48 urban grids). Other scenario considered an increased AHF in double (80 W/m^2) with the original size of the city (16 urban grids). The last scenario combines the triple size city expansion (48 urban grids) and increased AHF in double (80 W/m^2).

The evaluation was performed for the urbanized (with BEP module and AHF added) vs. non-urbanized Enviro-HIRLAM model runs. The influence of the city on formation of the air temperature at 2 m and wind velocity at 10 m was evaluated.

Analysis of the surface layer air temperature and wind patterns for the original size of the city (with AHF=40 W/m^2) through difference fields between runs showed the following.

For the air temperature at 2 m, the averaging for selected winter days (for time interval between 03-09 UTCs) showed that, the difference could be 0.7 ºC. In summer, averaging (for time interval between 03-06 UTCs when effects are more intense), the difference could be 1ºC. During other time intervals – for winter (between 10-18 UTCs) and for summer (06-18 UTCs) - the difference is almost negligible. For the wind speed at 10m, during selected winter days for the same selected intervals as above, on average, the difference was 1.3 m/s, but during summer days this difference is smaller (1 m/s).

However, for the urban scenario (combining triple size city expansion and double increase in AHF) on a selected winter date, for the air temperature at 2 m the difference, on average, can be doubled up to 1.5ºC (with a maximum of 2.65ºC at 06 UTC); and for the wind speed at 10 m can be increased up to 1.4 m/s (with a maximum of 2 m/s at 06 UTC).

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APPENDIX A Morphological and thermo-dynamical parameters for districts of the Bilbao metropolitan area

Parameters	Units	RLD	ICD	RHD	HBD
Ground thermal diffusivity	m^2 s^-1	3,33E-007	3,33E-007	3,33E-007	3,33E-007
Wall thermal diffusivity	m^2 s^-1	4,81E-007	4,27E-006	2,26E-006	1,61E-006
Roof thermal diffusivity	m^2 s^-1	1,00E-006	1,00E-006	1,00E-006	1,00E-006
Specific heat of the ground material	J m^3 K^-1	2100000	2100000	2100000	2100000
Specific heat of the wall material	J m^3 K^-1	946000	2602500	2323500	2305500
Specific heat of the roof material	J m^3 K^-1	2400000	2400000	2400000	2400000
Temperature inside the buildings behind the wall	K	291	298	295	293
Temperature inside the buildings behind the roof	K	293	300	297	295
Albedo of the ground		0,2	0,1	0,15	0,2
Albedo of the wall		0,2	0,25	0,18	0,2
Albedo of the roof		0,2	0,18	0,5	0,2
Emissivity of ground		0,95	0,95	0,95	0,95
Emissivity of wall		0,72	0,9	0,9	0,91
Emissivity of roof		0,9	0,78	0,92	0,91
The ground's roughness length		0.67/1.01	0.61/0.74	0.72/0.98	0.86/1.05
The roof's roughness length		0.67/1.01	0.61/0.74	0.72/0.98	0.86/1.05
Number of street direction for each urban class		2	2	2	2
Street length (fix to greater value to the horizontal length of the cells) 1	m	100000	100000	100000	100000
Street length (fix to greater value to the horizontal length of the cells) 2	m	100000	100000	100000	100000
Street direction SD1	radian	45.*pi/180.=0.785	45.*pi/180.=0.785	45.*pi/180.=0.785	45.*pi/180.=0.785
Street direction SD2	radian	135.*pi/180.=2.335	135.*pi/180.=2.335	135.*pi/180.=2.335	135.*pi/180.=2.335
Street width SD1	m	13	10	15	13
Street width SD2	m	13	10	15	13
Building width SD1	m	20	100	30	20
Building width SD2	m	20	100	30	20
Number of height leves for each urban class		2	2	2	2
Bulding's heights, level HL1	m	5,7	6,09	75	21
Bulding's heights, level HL2	m	5,7	6,09	50	21
The probability that a building has an height h_b, level 1		100	75	50	60
The probability that a building has an height h_b, level 2		0	25	50	40

APPENDIX B Example of the methodological approach based on GIS.

Steps	File generation	GIS	Remarks
1	domain.dbf	XYdata	Create array: latitude (y), longitude (x) and urban fraction. Sorted in selected order. Add one column with the sorted sequence numbers of the latitude (from 1 to nlat) and for the longitude (from 1 to nlon)
2	urbanfraction.dbf	Selection by attributes	Select urban values non-equal zero from domain.dbf
3	rows.shp columns.shp	Animal movement tool (Convert location to paths)	Define domain.dbf as the location layer and use the rows and columns data to make the sorting
4	Polygon1	Data management tools (arctoolbox)	Generate polygon 1. Join the information based on the spatial location creating a new layer
5	Centroidcolumns Centroidrows Polygon2	Conversion from shapes to centroids	Generate a new grid of points based on (1) rows and (2) columns. Join the information based on spatial location. Repeat step 2,3,4 to obtain polygon 2
6	Joinurban	Selection by location	Use the urbanfraction.dbf file to create the Newpolygon only with urban grids.

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