Urban Scale Modelling for a Megacity and a Medium size city: Evaluating Urban Heat Island and Sulphate Aerosol Effects

Iratxe González-Aparicio[1,2], Julia Hidalgo[3], Alexander Baklanov[2], Roman Nuterman[2], Alexander Mahura[2], Ulrik Korsholm[2]

[1] TECNALIA Research and Innovation, Bilbao, Spain
[2] Danish Meteorological Institute (DMI), Copenhagen, Denmark
[3] Centre National de Recherches Météorologiques CNRM-Météo-France, Toulouse, France

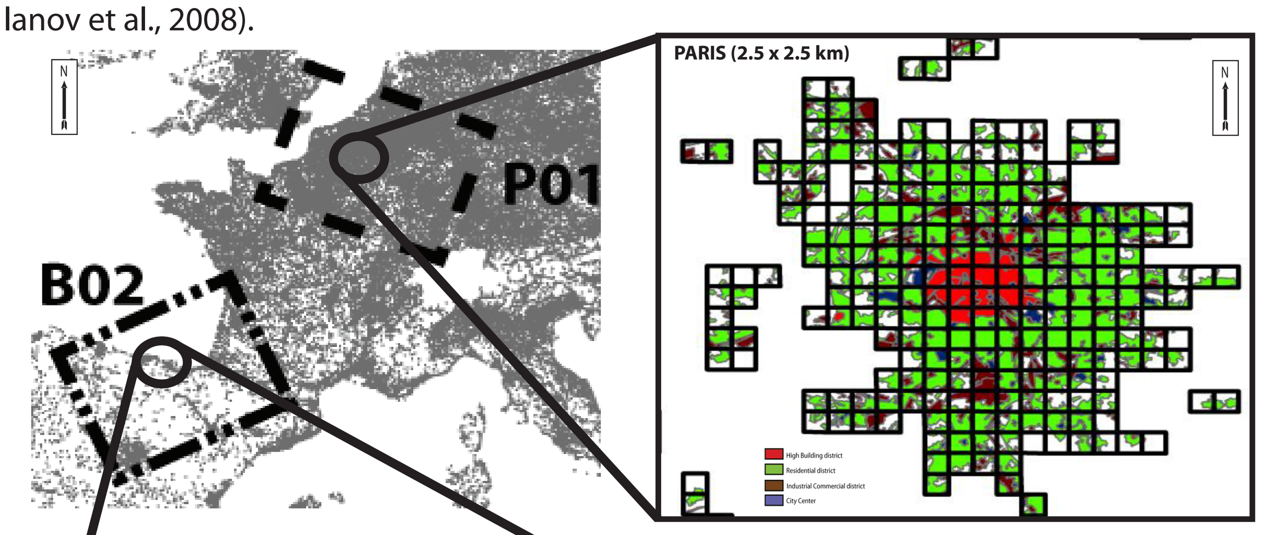
(Contact: E-mail: iratxe.gonzalez@tecnalia.com; Phone: +34 667 17 89 95)

Main goal

This research is devoted to the surface layer analysis in urban areas. The performance was carried out by means of long-term simulations using the Enviro-HIRLAM model for the Paris metropolitan area, considered as a Megacity and for the Bilbao metropolitan area, considered as a medium size city. The variability of the PM10 concentration was also analyzed to obtain a parametric equation for the generation of future scenarios of climate change effects.

Methodology and Model Setup

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



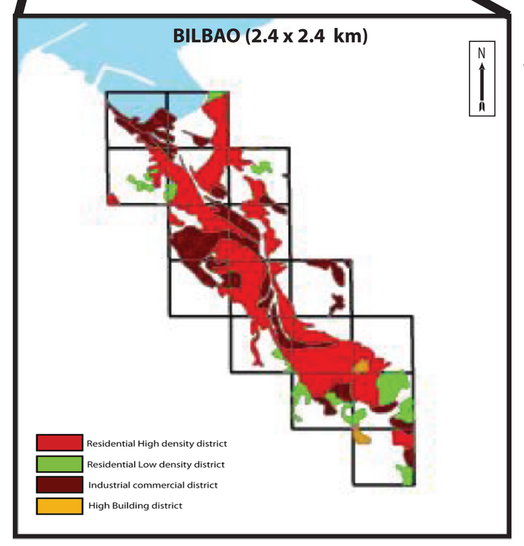


Figure 1: Urban classification into different districts based on the UDALPLAN 2009 (for Bilbao) and the CORINE 2000 (for Paris) databases. (Gonzalez-Aparicio et al., 2010).

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 mentioned urban districts. Each district is represented as a combination of multiple streets and buildings of constant widths but with different heights. The parameterization includes computation of contributions from every type of urban surface (street canyon floor, roofs and walls of buildings) as well as vertical surface.

Bilbao is placed in a coastal area, north of the Iberian Peninsula and surrounded by a complex terrain. It is considered as a medium size city (0.875 million inhabitants). Paris (France) is 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). High resolution (2.4 x 2.4 km for Bilbao and 2.5 x 2.5 km for Paris) long-term runs for two specific months (during July 2009 and January-February 2010) with different wind conditions were performed. The main objectives were to evaluate the performance of the urbanized (with BEP module and Anthropogenic Heat Fluxes, calculated based on LUCY model, Allen et al, 2010) vs. non-urbanized and to estimate the influence of the city on formation of the meteorological fields for the air temperature, relative humidity at 2 m and wind speed at 10 m.

For the Paris city, additionally, the scheme of sulphate aerosol dynamics was implemented to assess its indirect effects on meteorology. The simulations were performed in different modes for each selected city:

1) Control run; i.e. without any modifications
2) Urban run which included BEP and Anthropogenic Heat Fluxes (AHF, 40 W/m2)
3) Feedbacks of the sulphate aerosols.
4) BEP+AHF and feedbacks of the sulphate aerosols

The impact of the cities on the meteorological variables was studied by evaluating the difference between outputs of the urbanized vs. control runs (Figure 2: the 5th of July for Bilbao and the 28th July for Paris). The impact of the feedbacks on meteorological variables was studied by assessing the difference between the outputs of the urbanized+feedbacks vs. urbanized runs for the Paris metropolitan area (Figure 2, left-side).

Urban Canopy analysis

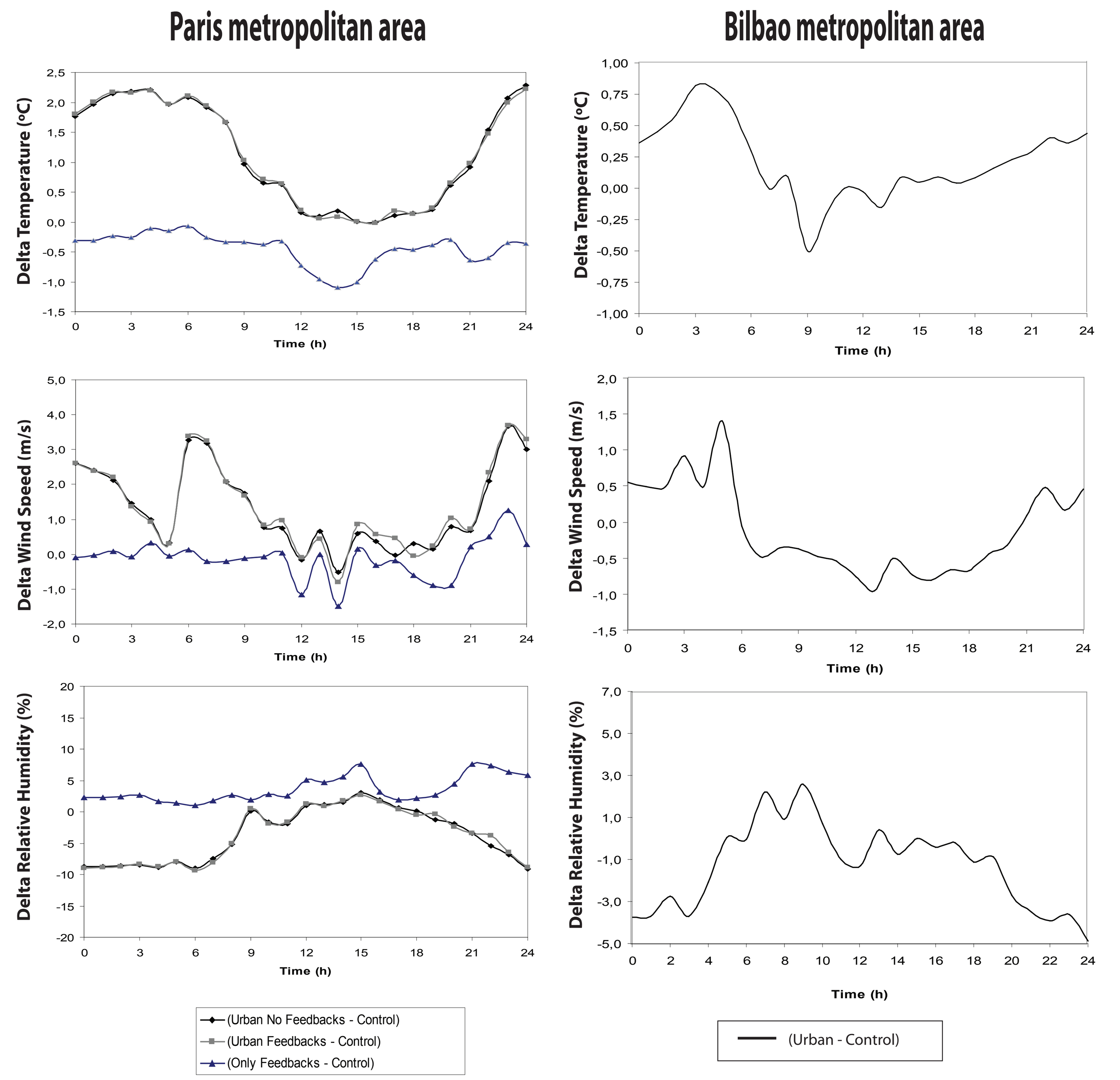


Figure 2: Difference plot s for modified vs. control runs for (a) the 2 m temperature, (b) the 10 m wind, (c) the 2 m relative humidity on 5th of July 2009 (Bilbao) and 28th July 2009 (Paris).

Temperature and Wind anomalies for UHI maximum

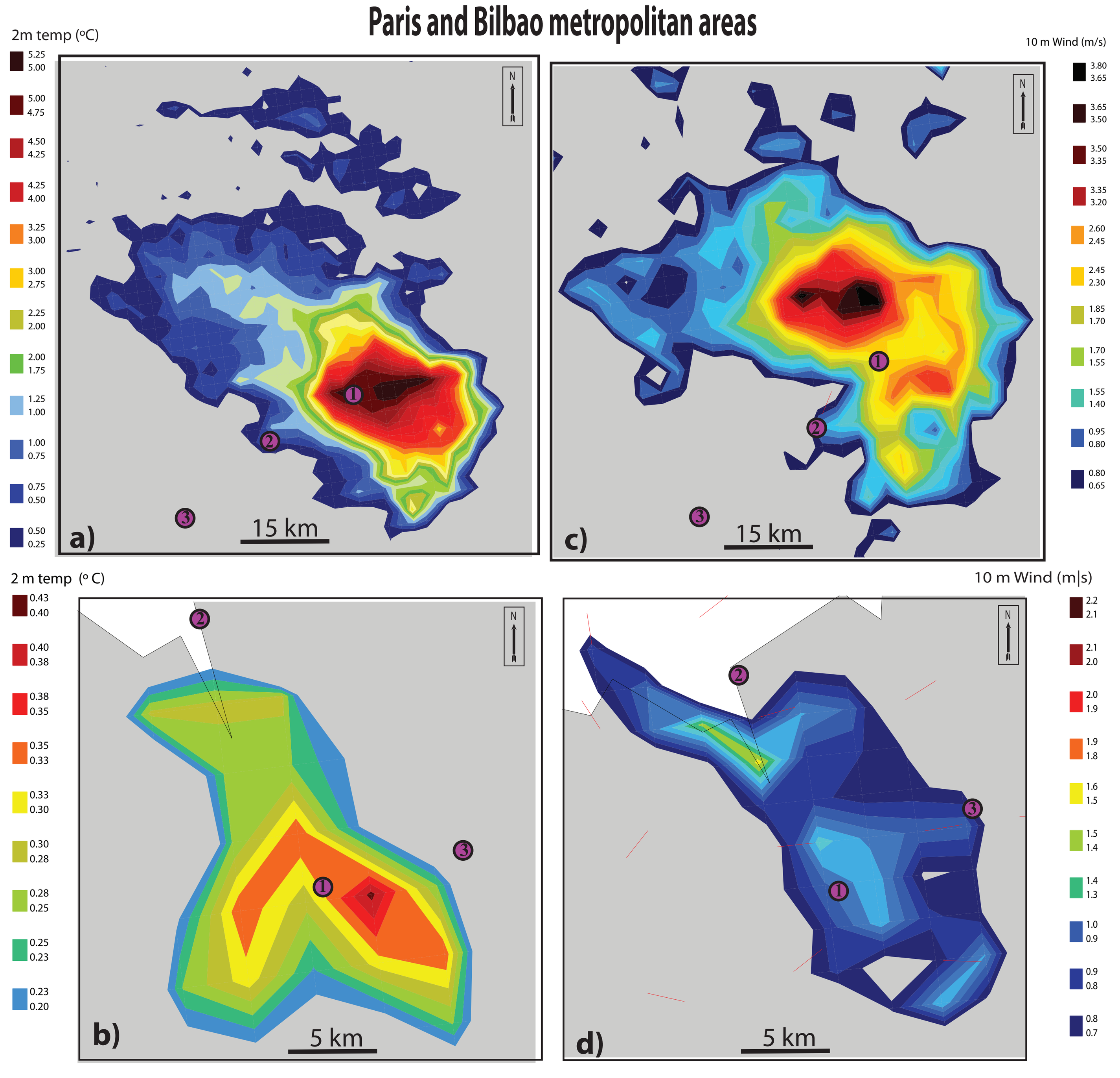


Figure 3: Difference plots for the (a,b) 2 m temperature (ºC) and (c,d) wind velocity (m/s) at 10 m for Bilbao and Paris metropolitan areas, respectively between outputs of the urbanized (BEP + AHF) vs. control runs of the Enviro-HIRLAM model on the 5th July 2009 at 6 UTC for the Bilbao metropolitan area and on the 21st July 2009 at 6 UTC for the Paris metropolitan area.

In the Paris metropolitan area, the wind flowed from South-East, transporting the plume of the UHI to the North-West. At the urban station (1-LHVP), on average, the 2 m temperature anomaly was 2.5 ºC (with a maximum of 2.75 ºC at 6 UTC) and the 10 m wind anomaly was 2.0 m/s (with a maximum of 3.5 m/s at 6 UTC). However, at the sub-urban station (2-SIRTA), the maximum anomaly 2 m temperature was 0.2 ºC and the 10 m wind was 0.5 m/s. At the rural station (3-CHARTRES) the anomalies were negligible. For the Bilbao metropolitan area, the pattern of the UHI is elongated following the shape of the river which stretches from the North to the South along the city. The wind flowed from the North-West transporting the plume of the UHI to the South-East. The UHI intensity is higher in the densest urban canopy. At the urban station (1-DEUSTO), on average, the 2 m temperature anomaly was 0.21 ºC (with a maximum of 0.55 ºC at 6 UTC) and the 10 m wind anomaly was 0.5 m/s (with a maximum of 1.1 m/s at 6 UTC). At the rural stations (3-DERIO and 2-GALEA) the anomalies were negligible.

Predicting PM10 to generate future scenarios, the case of Bilbao

Multiple Linear Regression (MLR) Method and Principal Component Analysis were applied to find predictive equations for PM10 concentrations with the input variables (Table 1) as predictors. The MLR method attempts to model a relationship between the input variables and a response variable (PM10) by fitting a linear equation to observations. The observed data were extracted from an urban station (Mazarredo) in Bilbao, the frequency was hourly data for 2005 to 2010 in summer (June, July and August) and winter (December, January and February). The main objective is to force the predicting equation to generate PM10 future projections for the Bilbao metropolitan area.

a) **INPUT VARIABLES**

- SO2 (g) (µg|m3)
- NO2 (g) (µg|m3)
- Temperature (ºC)
- Wind Speed (m/s)
- Wind Direction (º)
- Relative Humidity (%)
- Precipitation (mm)
- Irradiance (W/m2)
- Pressure (Hpa)
- Day (5-19 UTC) Night (20-4 UTC)
- Working Day or Weekend
- Hour of the day (1,2,…,24)
- Day of the month (1,2,…,31)
- Season (winter or summer)
- Year (2005-2010)

b)

	b_i	Std. Error
(Constant)	17,27	0,85
1-SO2		0,01
2-NO2	0,36	0,01
3-Irradiance	0,01	0,01
4-Temperature	0,39	0,01
5-RelativeHumidity	0,14	0,01
6-Type of day	3,67	0,24
7-Precipitation	3,64	0,61
8-Winddirection	-0,01	0,01
9-Windspeed	0,14	0,05

c)

PM10 = C + b1[SO2]+b2[NO2]+b3[Irradiance]+b4[Temp]+b5[RH]+b6[day]+b7[Precip]+b8[Winddir]+ b9[Windsp]

Table 1: a) Input variables; b) unstandardized coefficients; c) linear predicting equation

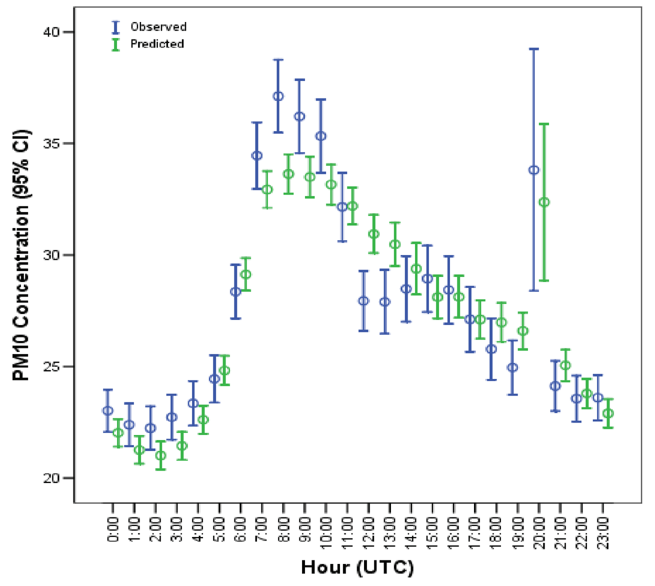


Figure 4: Plot for the 6-year (2005 to 2010) PM10 concentration means on a diurnal cycle for the observations and for the predictions.

The equation calculated predicts the 40.1% (R^2) of the PM10 variability for the selected period. Before forcing it to generate the future scenarios, the equation must be improved by adding new input variables, to increase the R^2 and to overlap the intervals in the error bars at 7,8, 11 and 12 UTC (Figure 4).

REFERENCES

- Korsholm U.S., 2009: Integrated modeling of aerosol indirect effects. Development and application of an o nline couled chemical weather model. PhD thesis.
- Korsholm U.S., Baklanov A., Gross A. and Sorensen J.H. , 2008: On the importance of the meteorological coupling interval in dispersion modelling during ETEX-1, Atmos. Environ., doi: 1016/ j.atmosenv.2008.11.017.
- Baklanov A., Grimmond S., Mahura A., Athanassiadou M., (Eds) 2009: Meteorological and air Quality Models for Urban Areas. Springerdoi 10.1007/978-3-642-00298-4.
- Baklanov A., Korsholm U., Mahura A., Petersen C., Gross A., 2008: Enviro-HIRLAM online couplied modelling of urban meteorology and air pollution, Adv.Sci. Res., 2, 41-46.
- Gonzalez-Aparicio I., Nuterman R., Korsholm U., Mahura A. , Hidalgo J. , Baklanov A., 2010: Land-use database Processing approach for meso-scale urban NWP Model Initialization. Sci. Report: ISBN: 978-87-7478-593-4.
- Martilli A., Clappier A., Rotach M.W., 2002: An Urban Surface Ex-change Parameterisation for Mesoscale Models, Boundary-Layer Meteorol. 104, 261-304.

ACKNOWLEDGEMENTS

Thank you to Oscar Santa Coloma and the Urban Climate Team (TECNALIA Reseach and Innovation Bilnao, Spain) for supporting research and financial activities of this study within the framework of the PhD Programme. Thank you to Enviro-Hirlam modelling research team (DMI) for the constructive discussions. Thanks for the funding from the European Union's Seventh Framework Programme FP/2007-2011 within the project MEGAPOLI (grant agreement n°212520) and from the Iñaki Goenaga foundation (Bilbao, Basque Country, Spain).