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INFLUENCE OF HORIZONTAL GRID RESOLUTION ON AIR QUALITY MODELLING IN BARCELONA METROPOLITAN AREA (SPAIN)

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6-9 May 2013, Madrid (Spain)

Introduction

- EC4MAC: Scale dependency exercise
  (56, 28, 14, 7 km)
- APPRAISAL:


ScaleDep

Performance of European chemistry-transport models as function of horizontal spatial resolution

19MAR2013

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- Plans de Millora de la Qualitat de l'Aire
  - **Pla d'actuació per a la millora de la qualitat de l'aire horitzó 2015**

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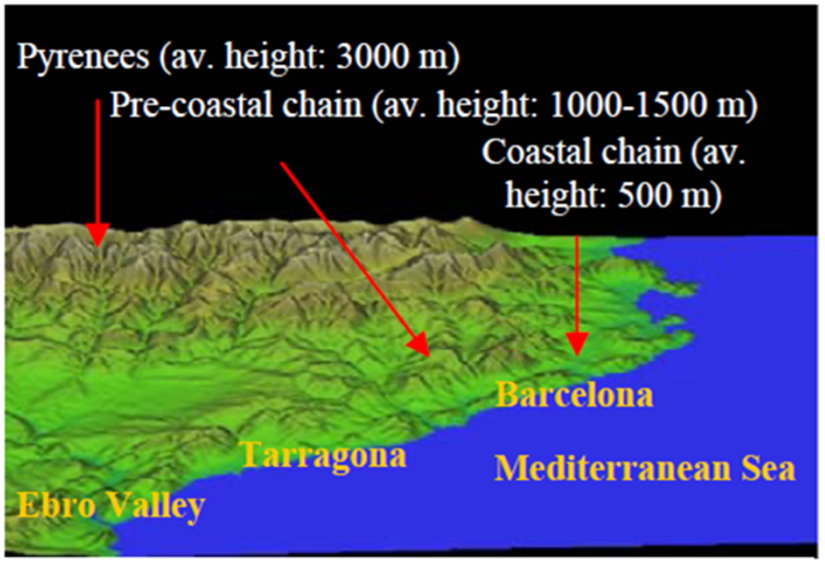
These initiatives lead us to focus on the effect the increase of grid resolution in the Barcelona Metropolitan area

*Air pollution in the **Barcelona** city (Spain). Source: El País.*

Objective

- **To assess the grid horizontal resolution effect on model performance over the Barcelona Metropolitan Area (BMA) (complex topography).**
- Two high horizontal resolution domains:
  - Spain at **4 km x 4 km** (**IP4**).
  - Barcelona Metropolitan area at **1 km x 1 km** (**BCN1**).
- Pollutants: O_3, NO_2, SO_2, and PM10.
- Study period: from 1 September 2011 to 1 September 2012
  - Focus on a air pollution episode 3 – 13 October 2011

Northeaster Spain shows a complex topography, emission pattern, high population → complex air quality dynamic



The CALIOPE AQFSystem (http://www.bsc.es/caliope/)

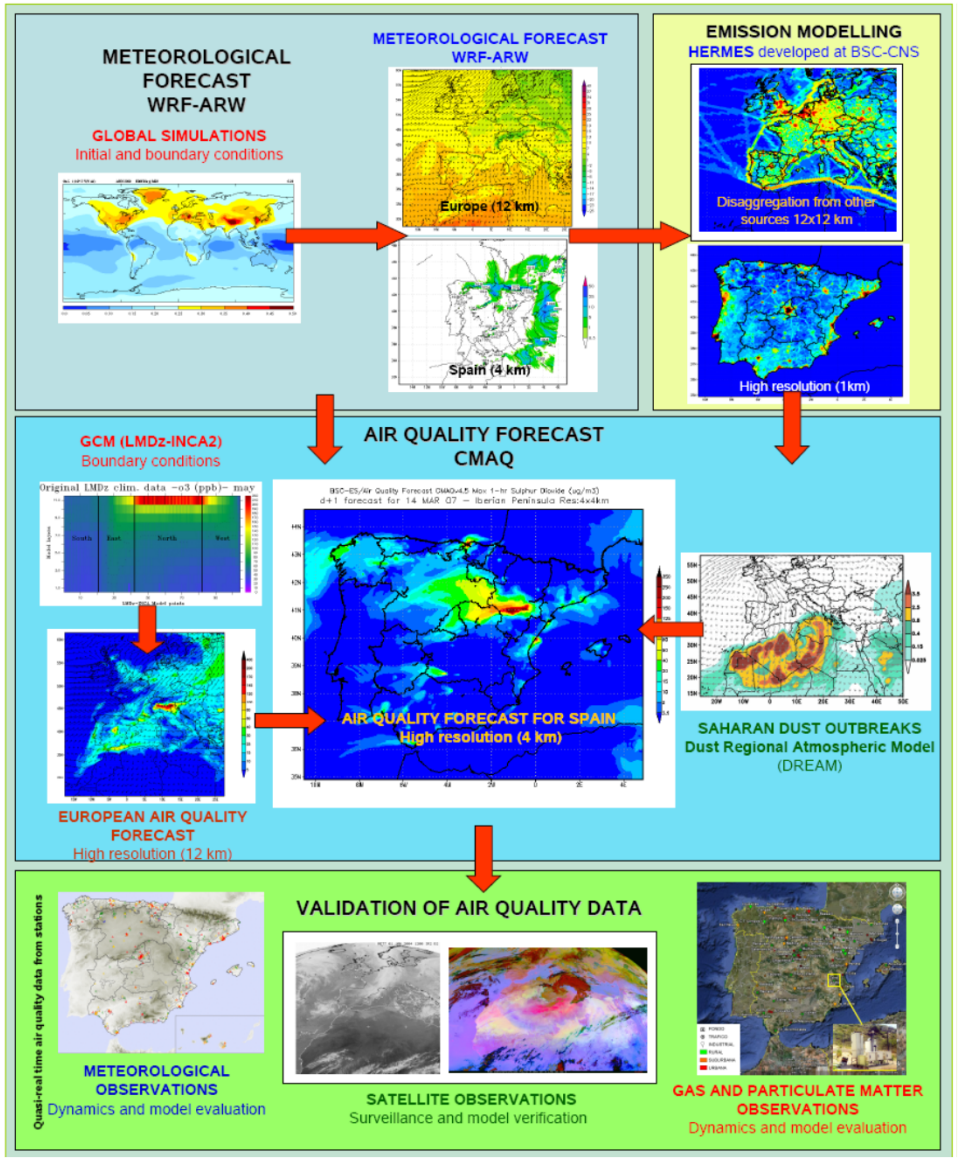
The Air Quality Forecasting System

Domains:

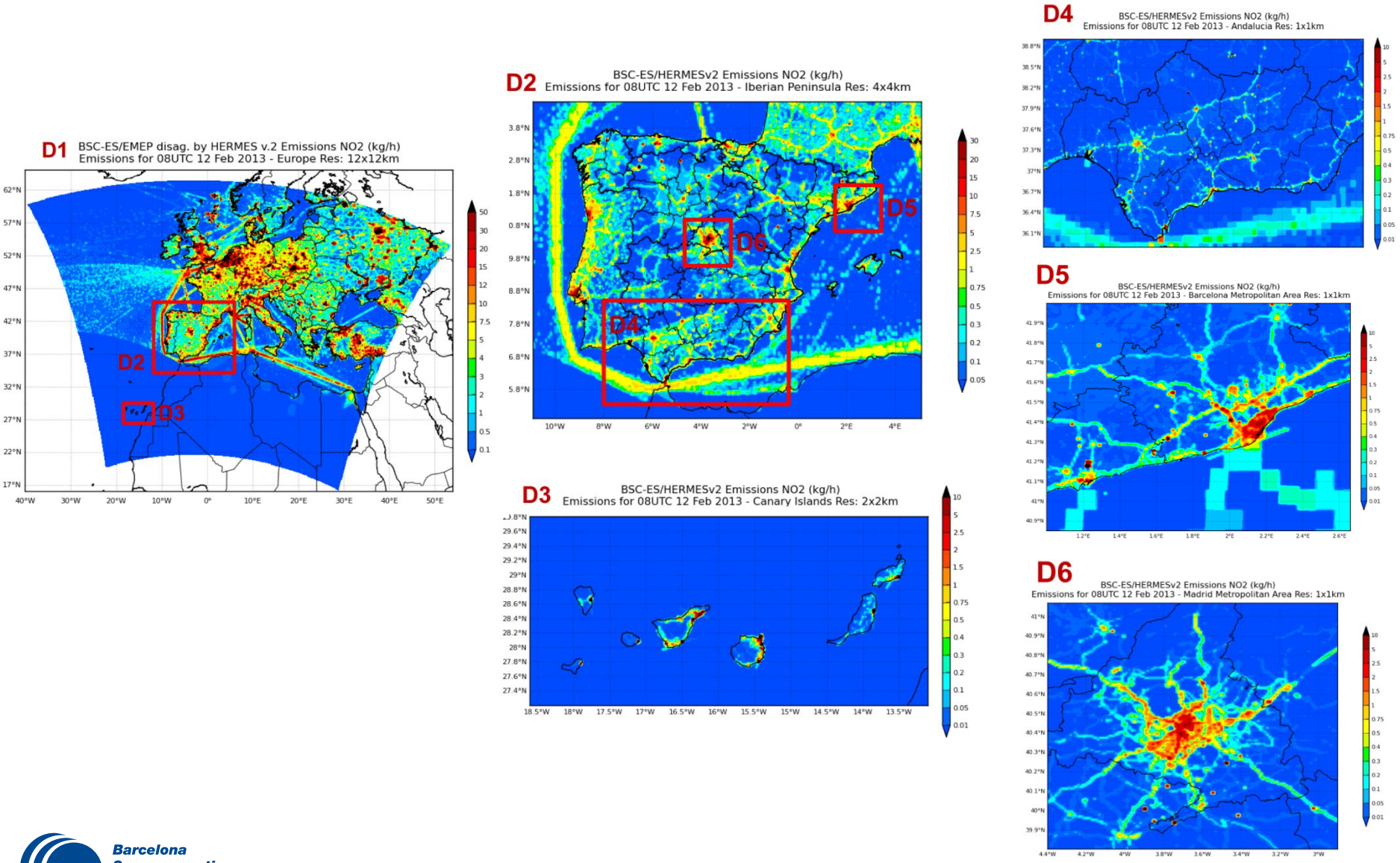
- EU = 12 km x 12 km (480 x 400 grid cells)
- IP = 4 km x 4 km (399 x 399 grid cells)

Modules

- **Meteorology*: WRF-ARW v3.0.1.1*,**
  - EU = IC & BC: GFS/FNL (NCEP)
  - IP = one-way nesting
  - 38 sigma levels (50 hPa)
- **Emissions*: HERMES2004***
  - EU = Disaggregation from EMEP inventory.
  - IP = HERMES model bottom-up.
- **Chemical Transport Model*: CMAQv4.5***
  - EU = BC: LMDz-INCA2
  - IP = one-ways nesting
  - 15 sigma levels (50 hPa)
  - CBIV, Cloud chem., AERO4
- **Mineral dust from Africa*: BSC-DREAM8b***
- **Model evaluation:**
  - **Near-real time**
  - **Kalman filter post-processing**



CALIOPE domains and resolution



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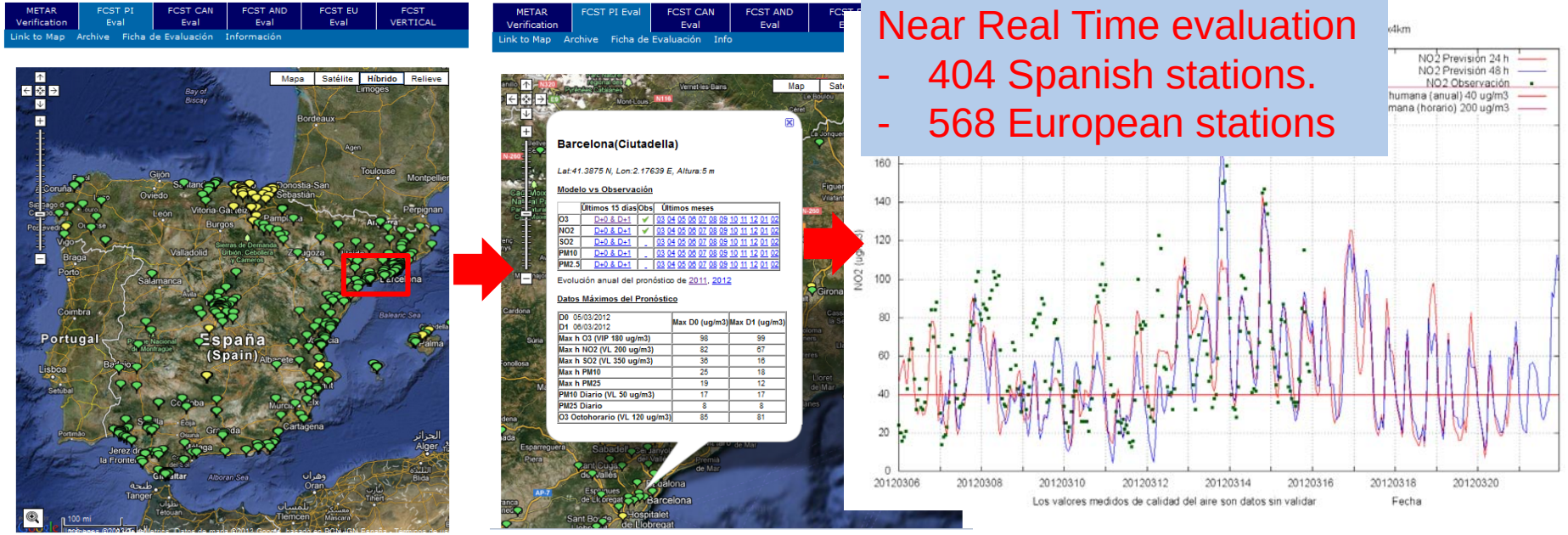
Adapted from: Guevara et al., 2013

Confidence on the CALIOPE system

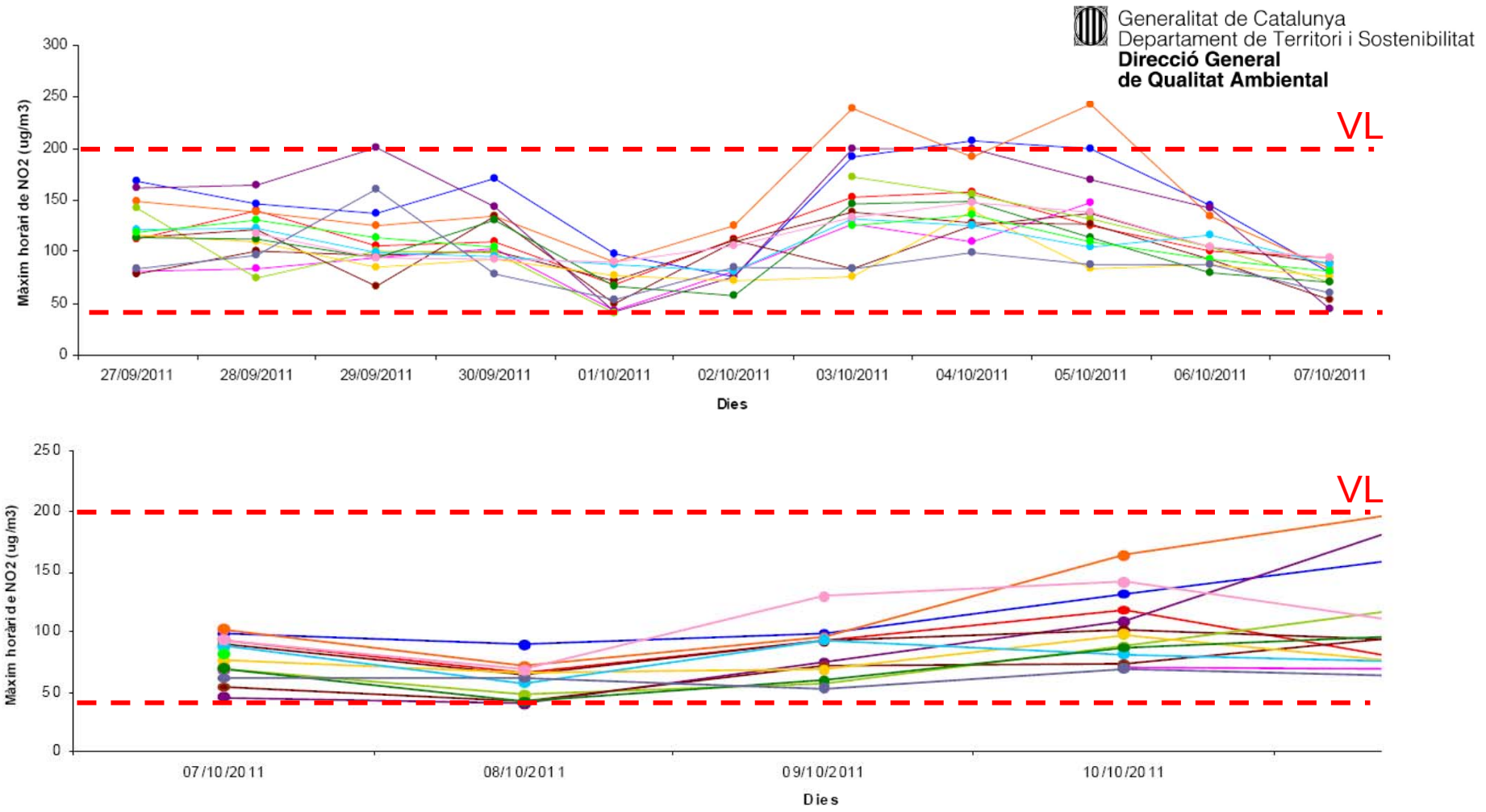
1. Several published studies:

Domain	Reference
Europe	Pay *et al* (2010, 2012a)
	Basart *et al* (2012)
Spain	Baldasano *et al* (2011)
	Pay *et al* (2011, 2012b)
	Borrego *et al* (2011) Sicardi *et al* (2012)
Barcelona & Madrid	Gonçalves *et al* (2009)
Cataluña (NE Spain)	Jiménez *et al* (2008) Aguilera *et al* (2013)

2. Near-Real Time (NRT) evaluation:

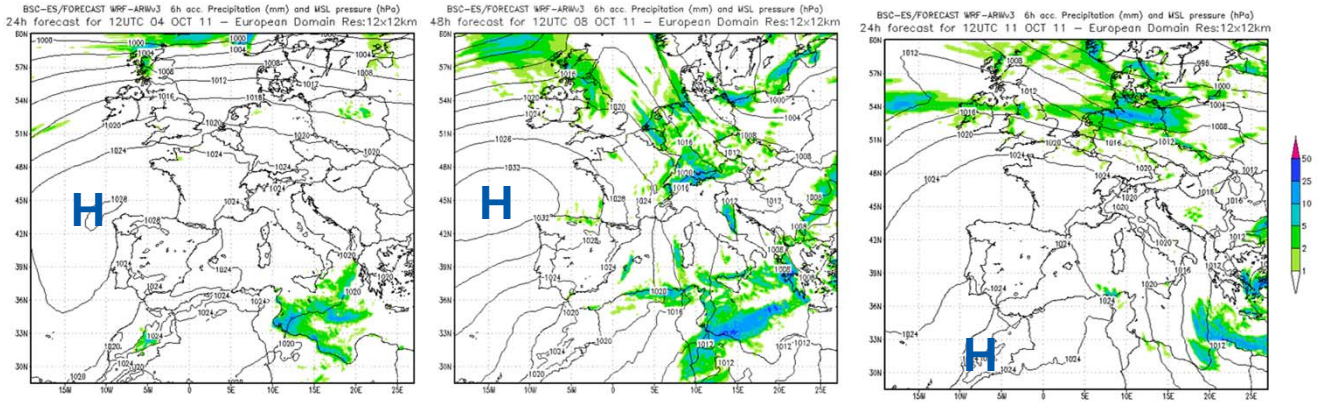


NO_2 pollution episode, from 3rd to 13rd October 2011



Meteorological situation, from 3rd to 13rd October 2011

12UTC 03 OCT **12UTC 08 OCT** **12UTC 11 OCT**



Simulated 6-hr accumulated precipitation (mm) and sea level pressure (haPa) for the European domain

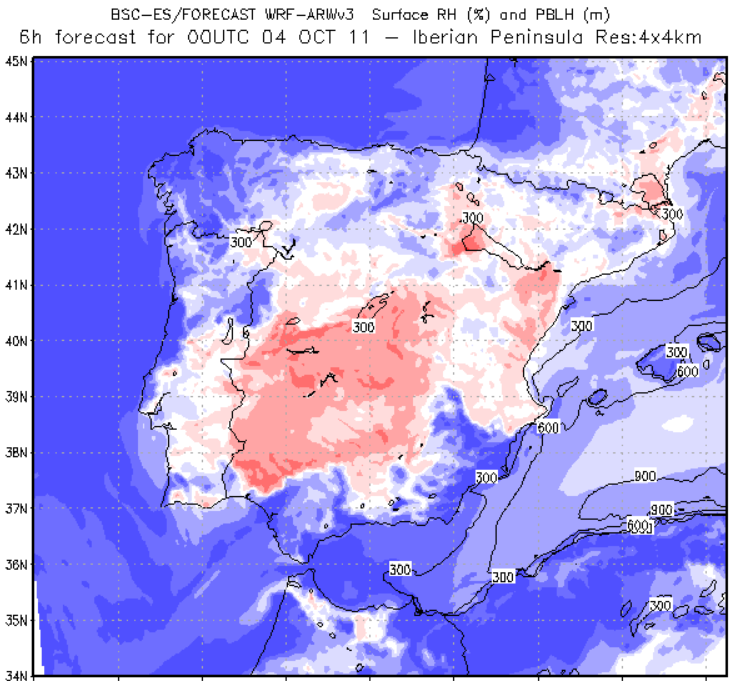
Synoptic pattern (from 3rd to 13rd October)	
3 – 6	anticyclonic situation, low pressure gradient in the wester Mediterranean Basin and which developed high-pressure condition over IP with high isolation and development of thermally-driven wind flows, with a poor development of the boundary layer (max 600 m at 12z).
7 – 9	frontal system that inhibits the mesoscale circulation and leads precipitations events in northern, center, and northeastern Spain. Tramontana in Barcelona (high northern winds)
10 – 13	anticyclonic situation with a dominant northern winds.

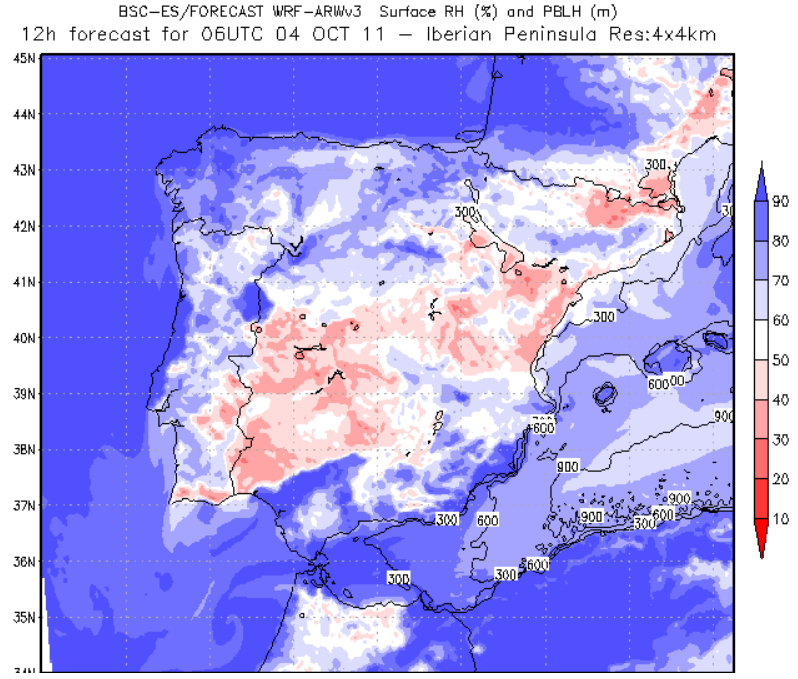
The weak synoptic forcing allow that mesoscale phenomena dominates the superficial wind flows

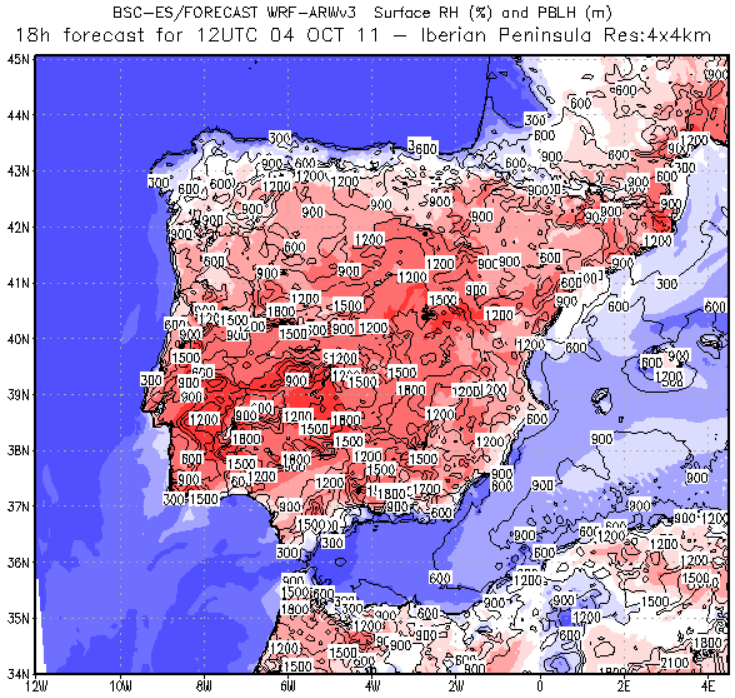
- inland, convective circulations (developed by the surface heating) and the formation of compensatory subsiding flows in coastal areas.
- **Iberian Thermal Low** (ITL) development.
- the atmospheric circulation in the eastern coast is dominated by well developed **land-sea breezes**.

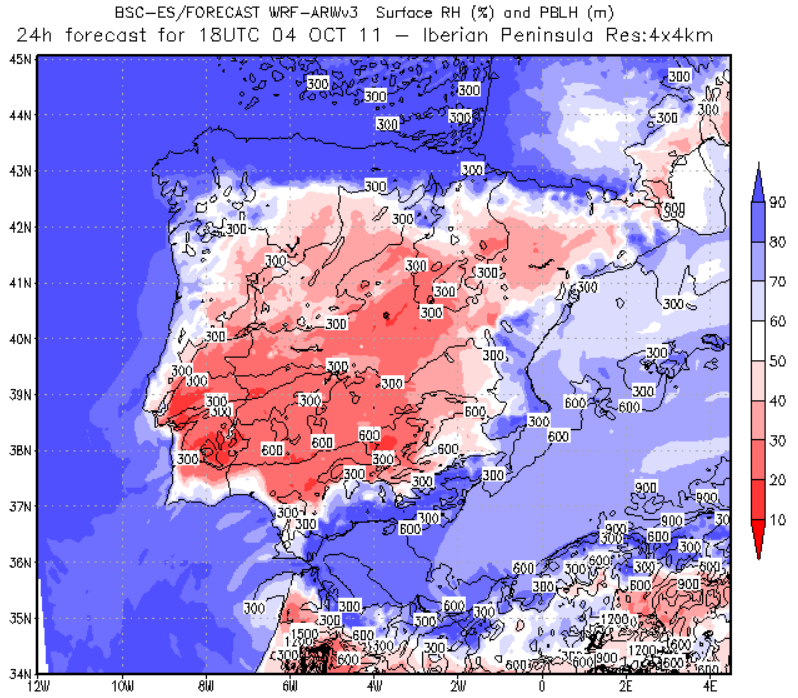
Daily cycle PBL

4/10/2011









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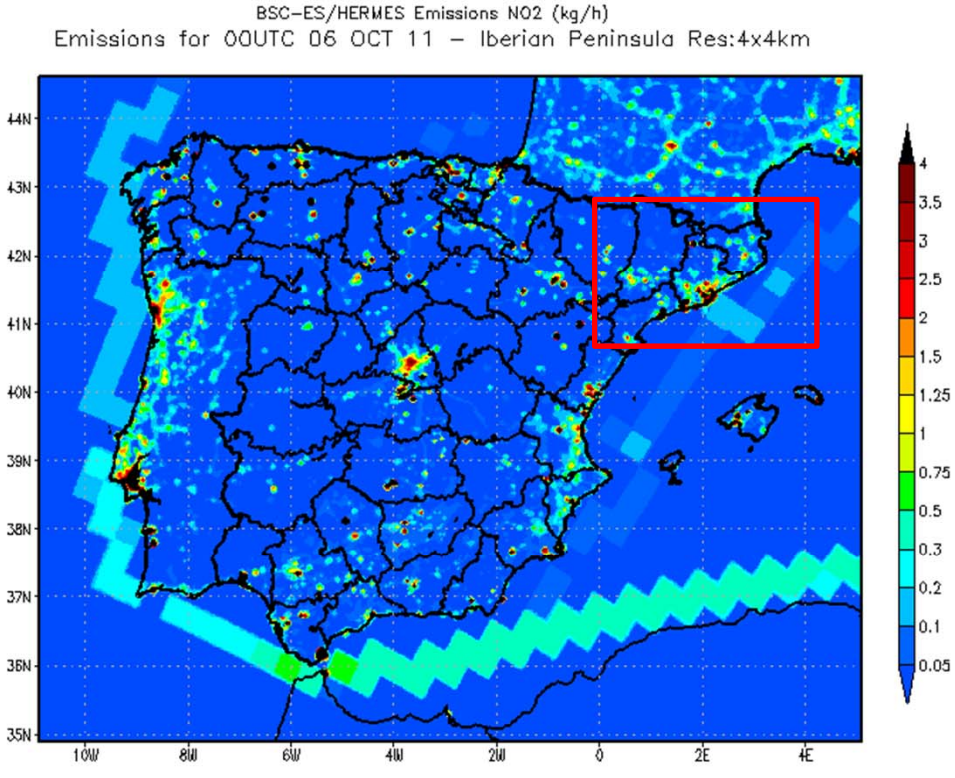
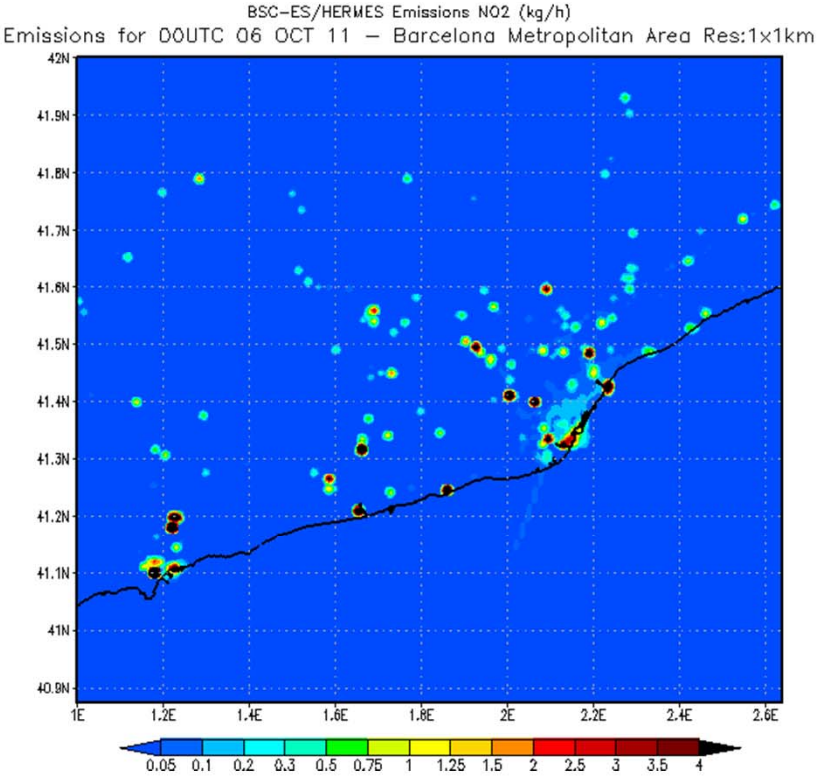
Emissions IP and BCN domains, 6th October 2011





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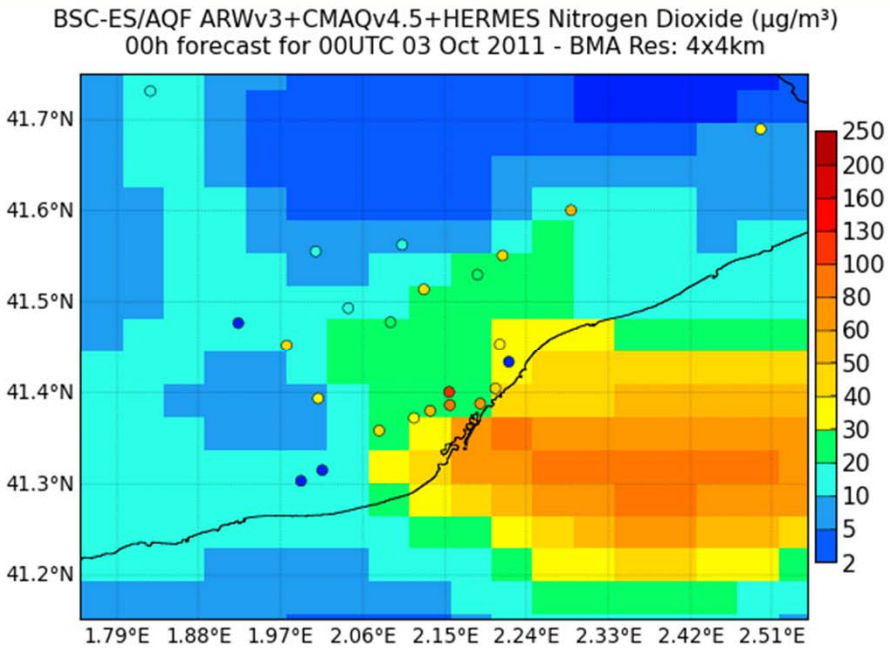

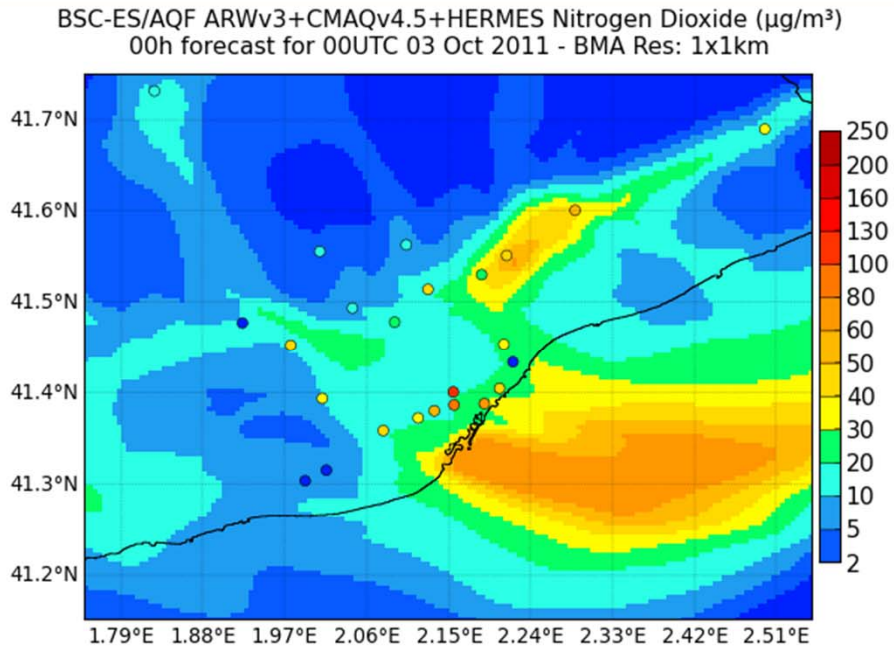

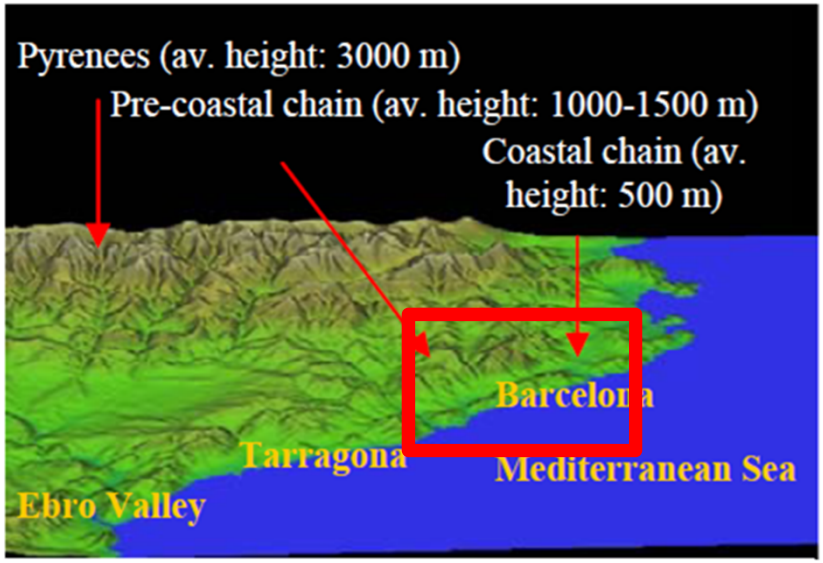

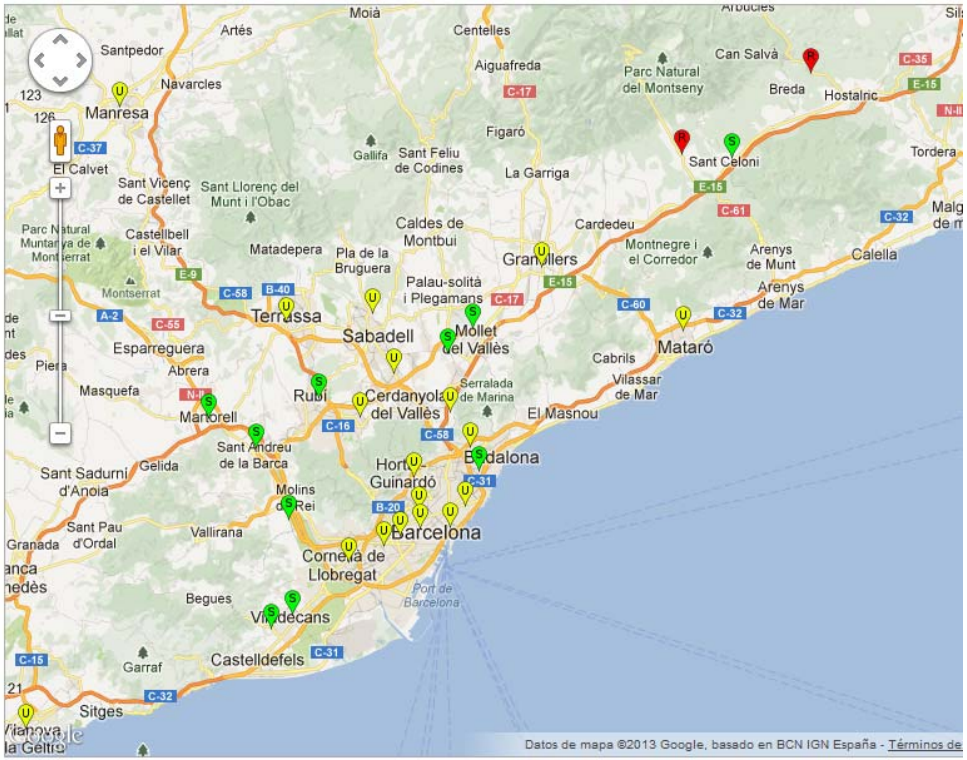

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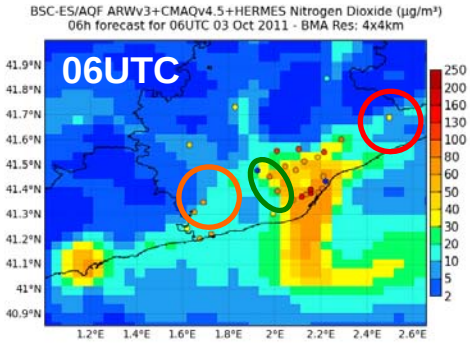
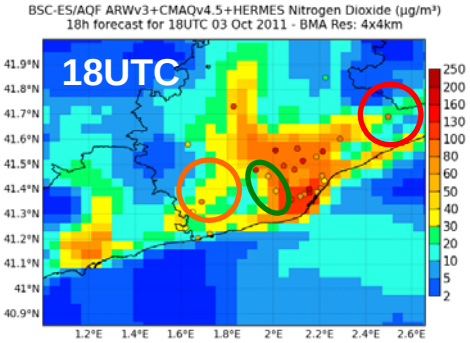
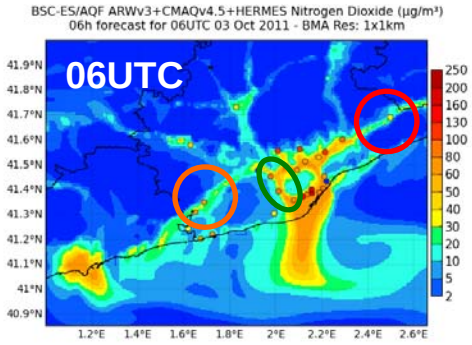
Model performance in suburban stations: NO_2, 3 Oct 2011

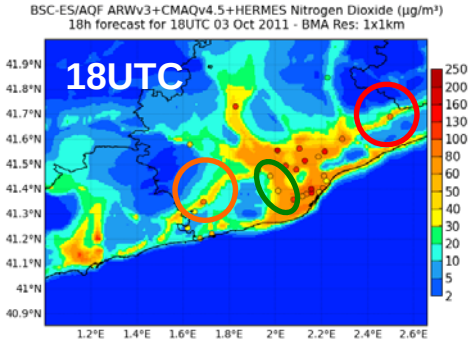
IP4

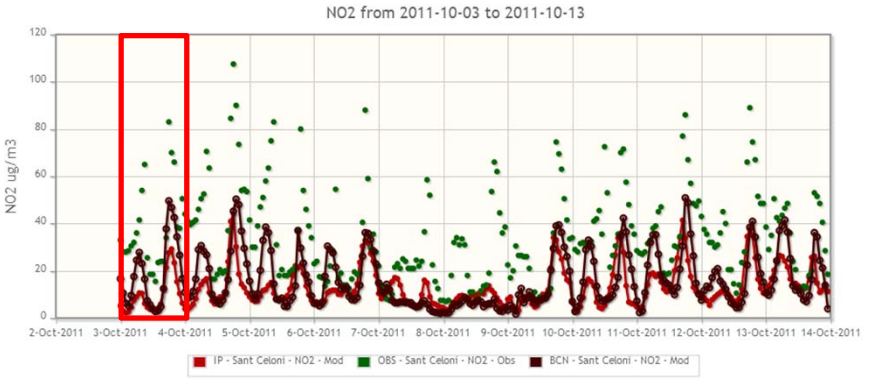


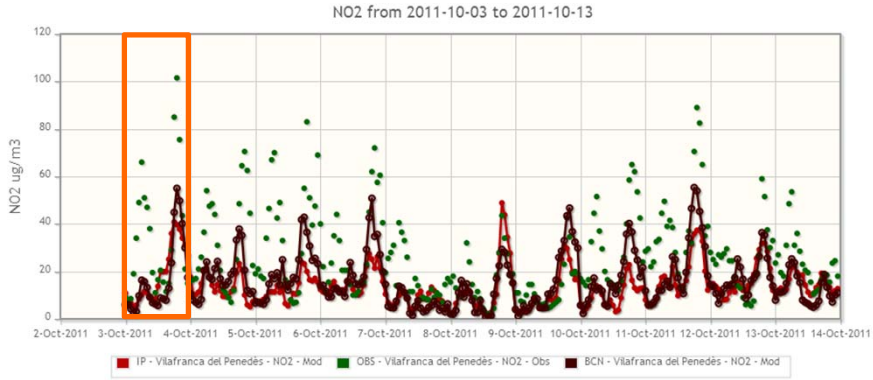


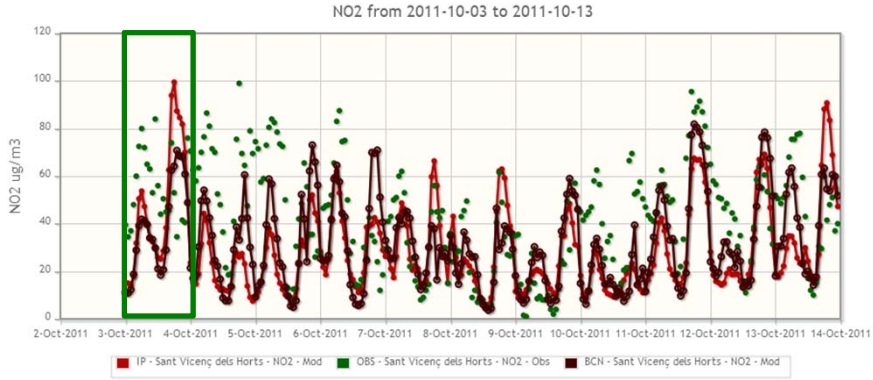
BNC1











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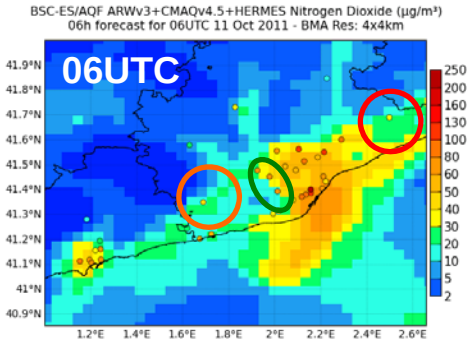
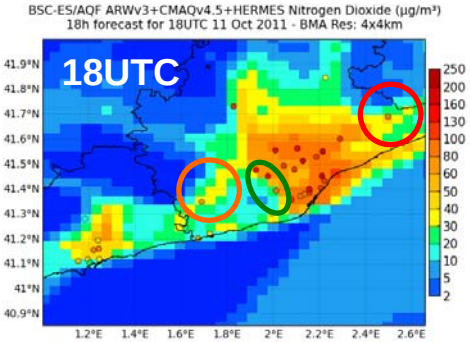
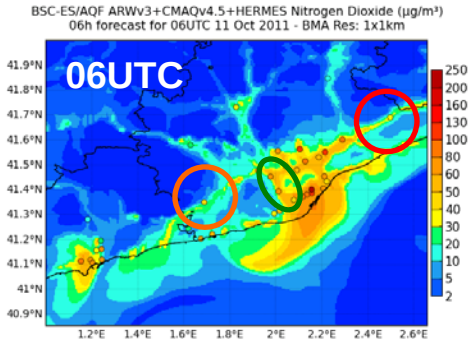
Model performance in suburban stations: NO_2, 11 Oct 2011

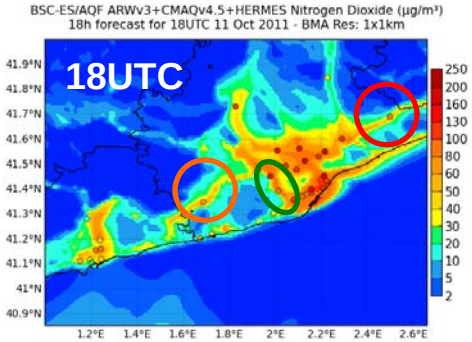
IP4

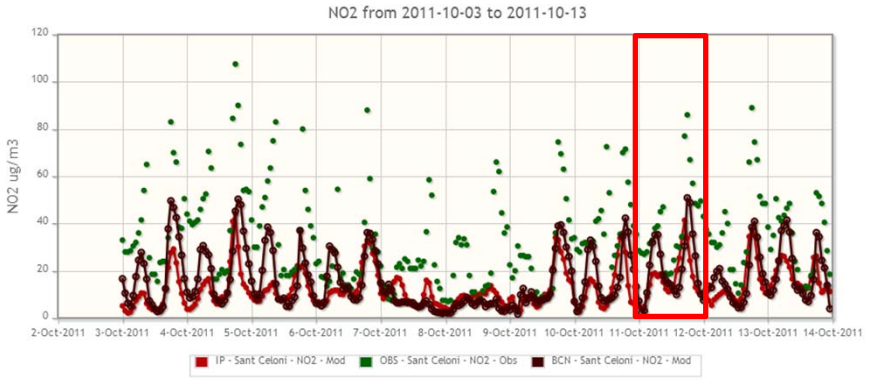


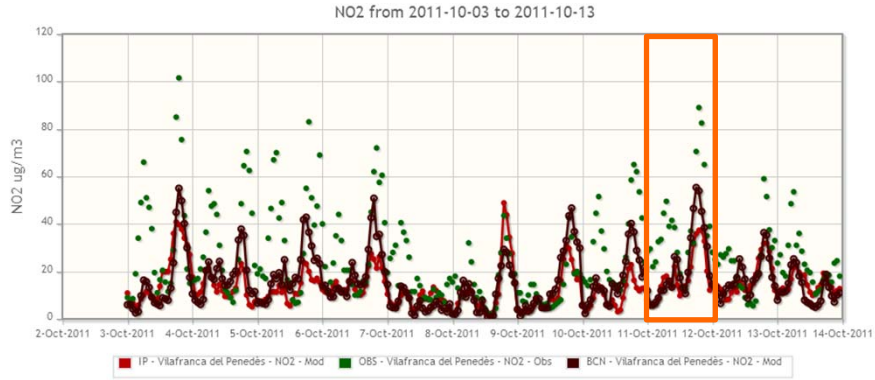


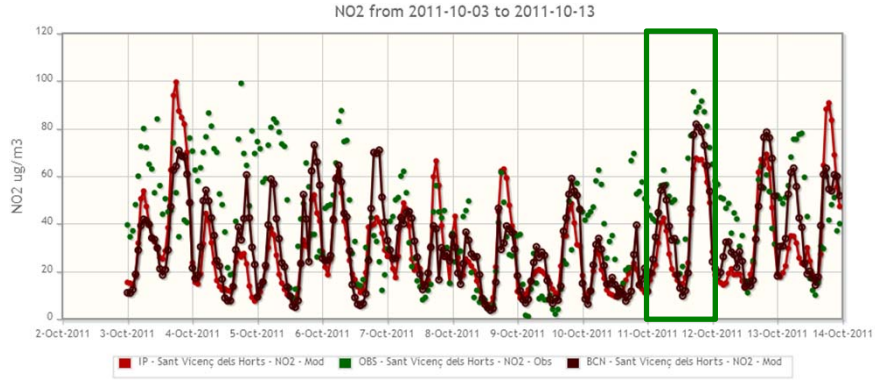
BNC1





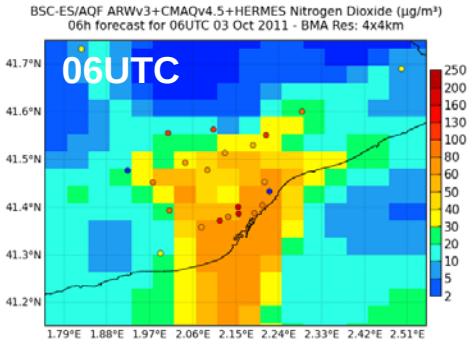


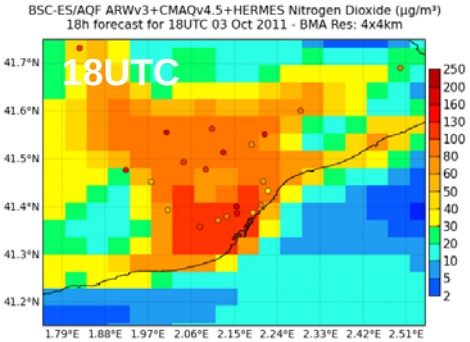




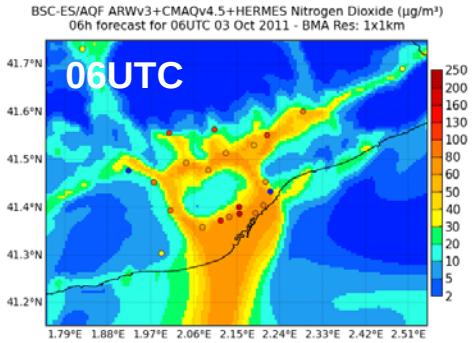
Model performance in urban stations: NO_2, 3 Oct 2011

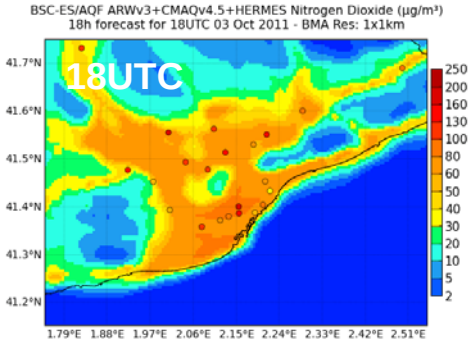
IP4

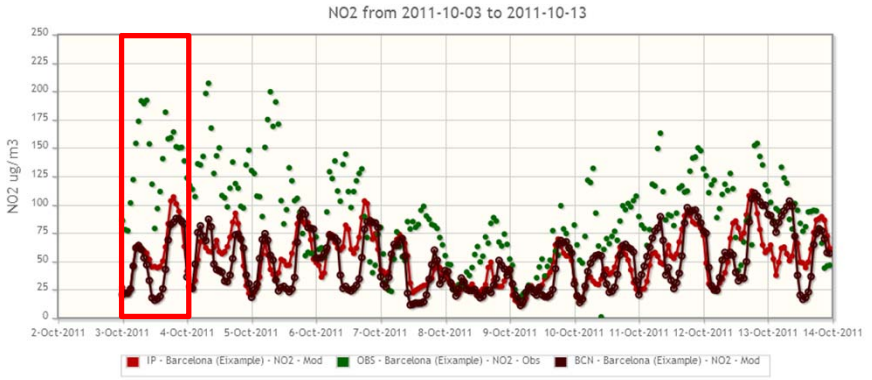


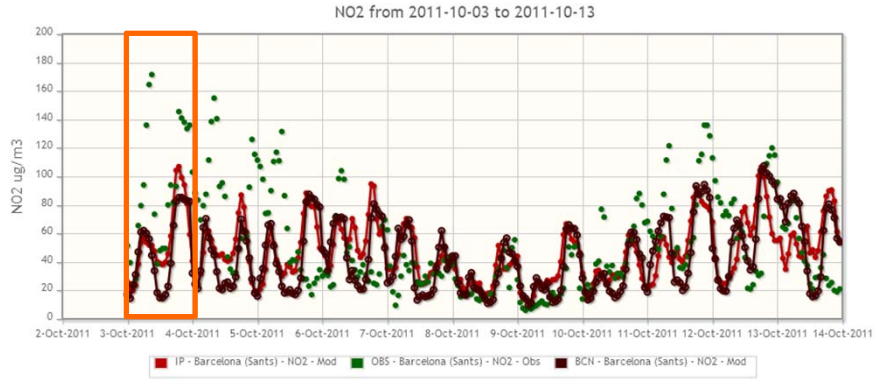


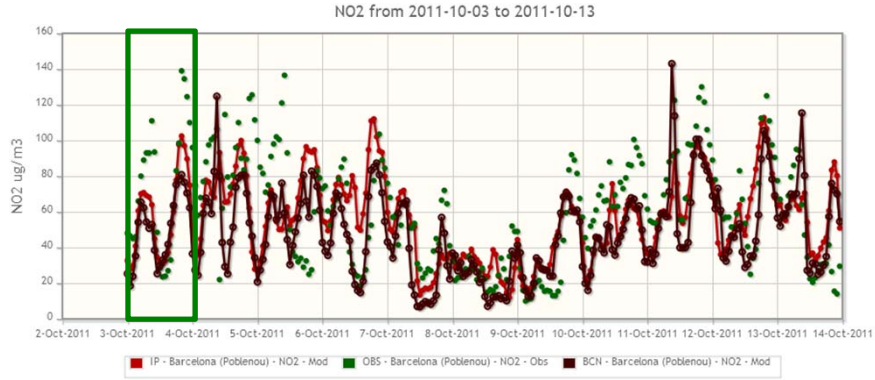
BNC1











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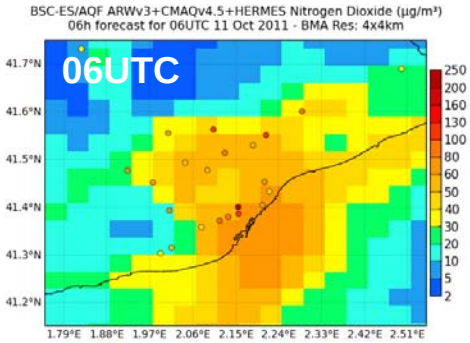
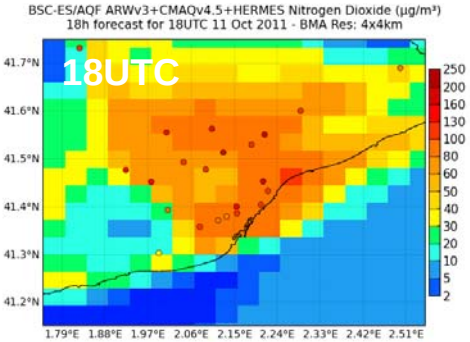
Model performance in urban stations: NO_2, 11 Oct 2011

IP4





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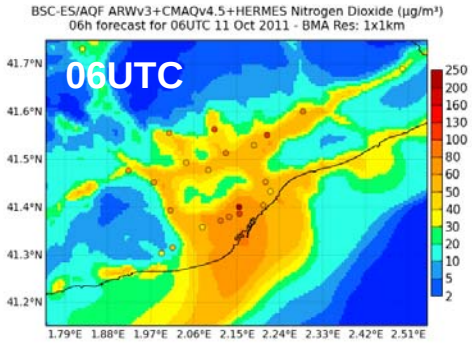

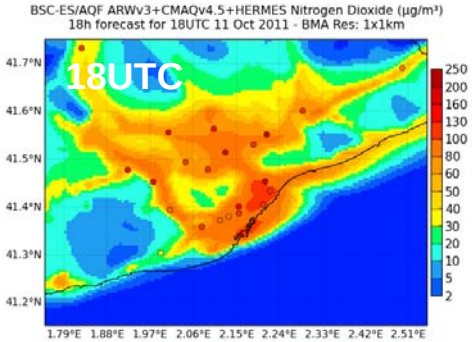

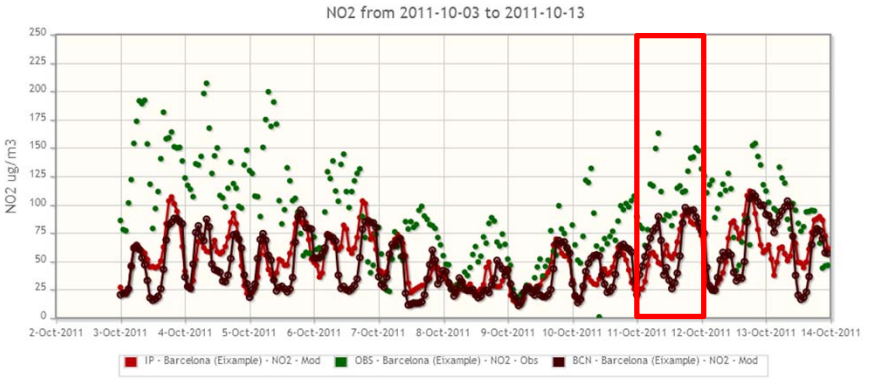

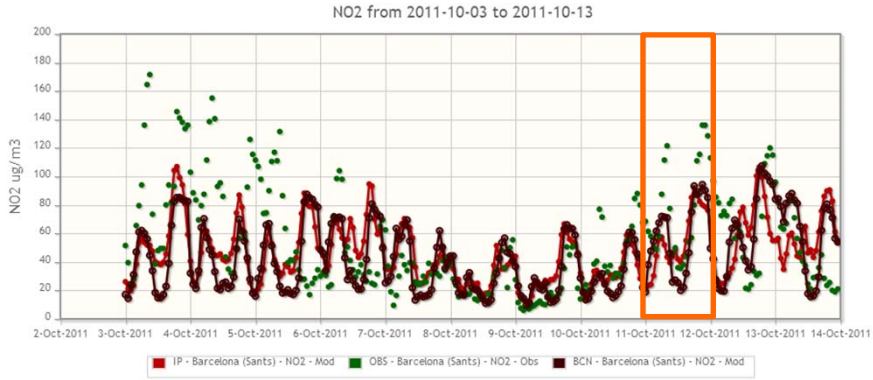

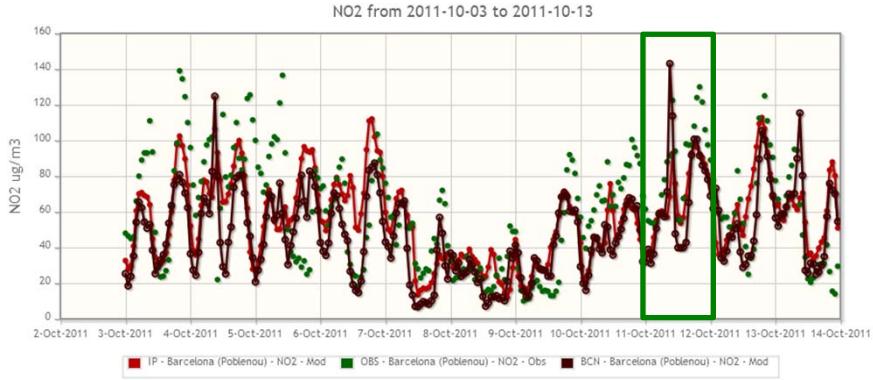

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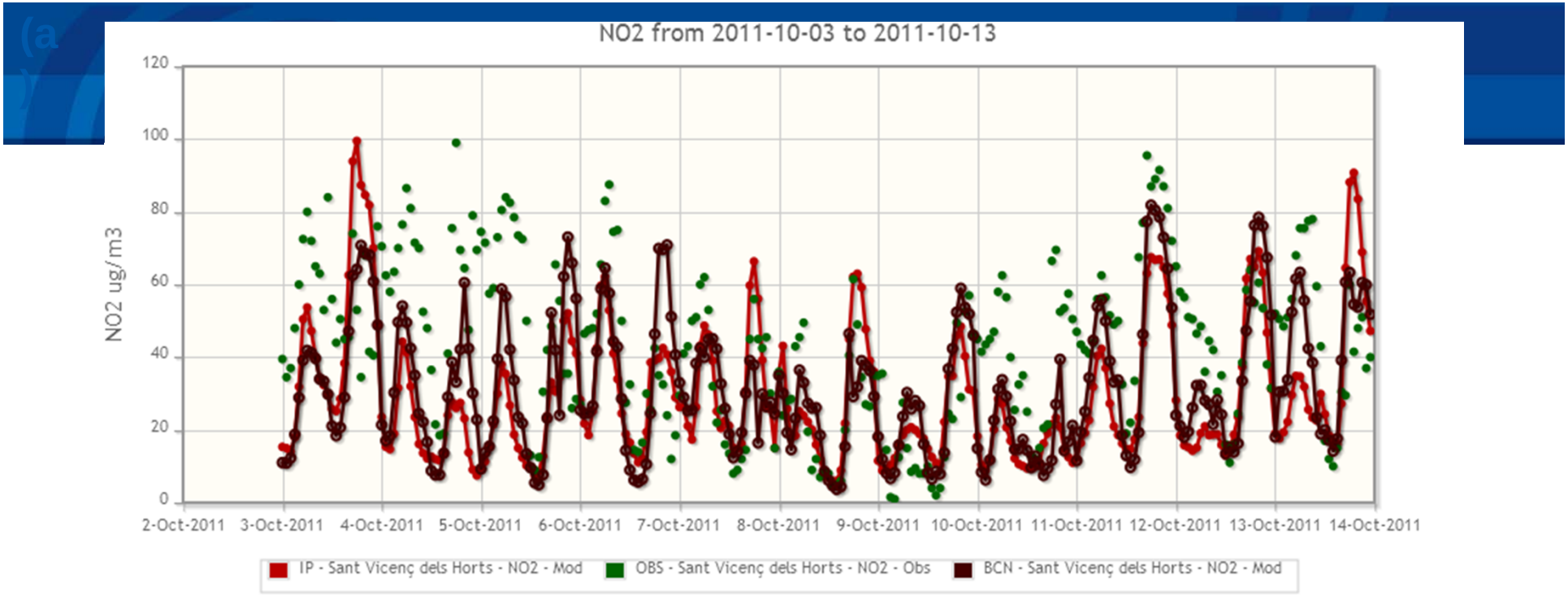
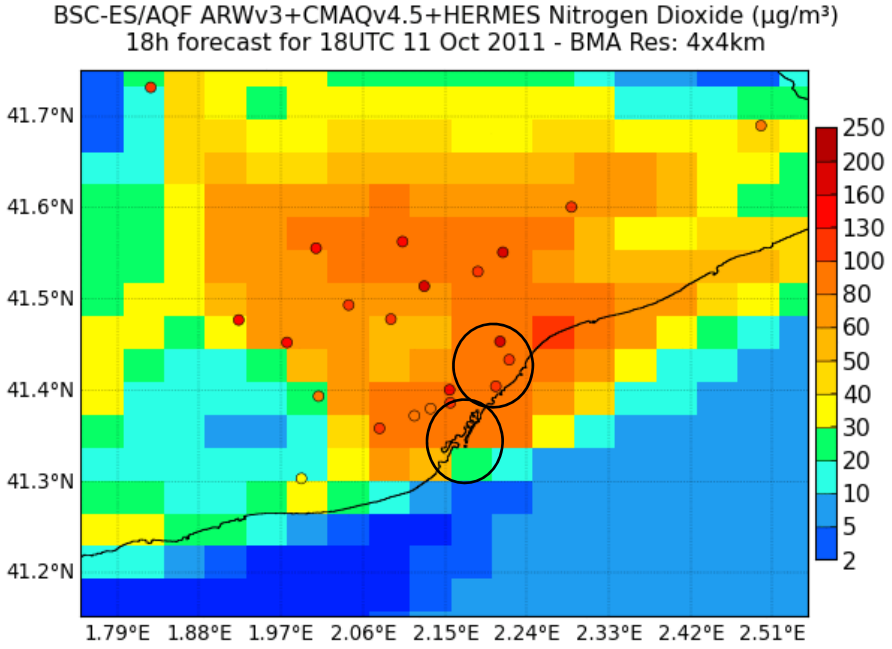
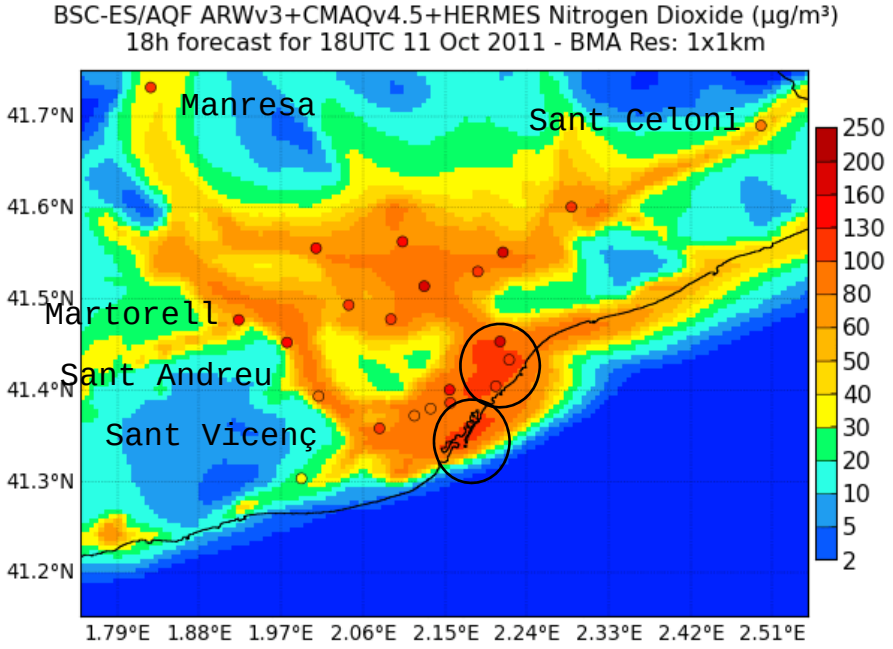

NO2 from 2011-10-03 to 2011-10-13
NO2 ug/m3
120
100
80
60
40
20
0
2-Oct-2011
3-Oct-2011
4-Oct-2011
5-Oct-2011
6-Oct-2011
7-Oct-2011
8-Oct-2011
9-Oct-2011
10-Oct-2011
11-Oct-2011
12-Oct-2011
13-Oct-2011
14-Oct-2011
IP - Sant Vicenç dels Horts - NO2 - Mod
OBS - Sant Vicenç dels Horts - NO2 - Obs
BCN - Sant Vicenç dels Horts - NO2 - Mod


BSC-ES/AQF ARWv3+CMAQv4.5+HERMES Nitrogen Dioxide (µg/m³)
18h forecast for 18UTC 11 Oct 2011 - BMA Res: 4x4km
41.7°N
41.6°N
41.5°N
41.4°N
41.3°N
41.2°N
1.79°E
1.88°E
1.97°E
2.06°E
2.15°E
2.24°E
2.33°E
2.42°E
2.51°E
250
200
160
130
100
80
60
50
40
30
20
10
5
2

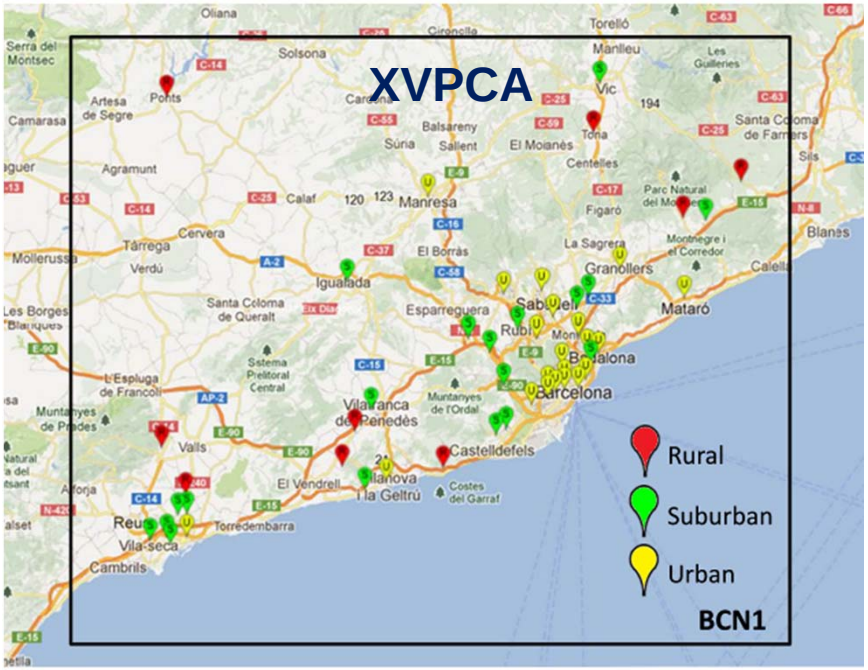

BSC-ES/AQF ARWv3+CMAQv4.5+HERMES Nitrogen Dioxide (µg/m³)
18h forecast for 18UTC 11 Oct 2011 - BMA Res: 1x1km
Manresa
Sant Celoni
Martorell
Sant Andreu
Sant Vicenç
41.7°N
41.6°N
41.5°N
41.4°N
41.3°N
41.2°N
1.79°E
1.88°E
1.97°E
2.06°E
2.15°E
2.24°E
2.33°E
2.42°E
2.51°E
250
200
160
130
100
80
60
50
40
30
20
10
5
2

Evaluation method

- Modelled concentrations are compared against observations from the **Xarxa de Vigilància i Previsió de la Contaminació Atmosfèrica (XVPCA)** providing Near Real Time (NRT) measurements on an hourly basis over the BCN1 domain.
- The evaluation is based on the annual analysis of classical statistics such as correlation coefficient (**r**), Mean Bias (**MB**), and Root Mean Square Error (**RMSE**) performed on an hourly basis.

	# stations	%U	%S	%R
O_3	27	12	11	4
NO_2	40	16	18	6
SO_2	28	8	16	4
PM10	14	4	9	1

rural stations (R), suburban stations (S), urban stations (U)
Note that the evaluation is done in NRT, and observations are not validated



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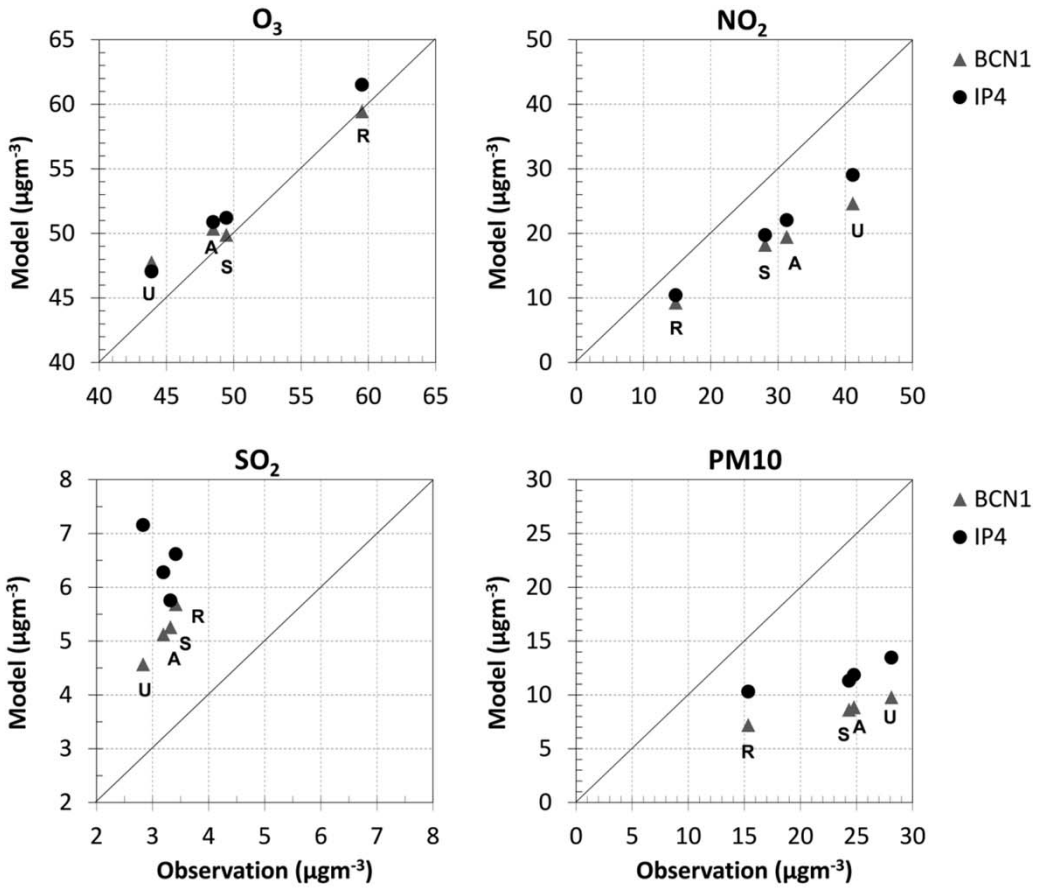
Annual evaluation (2011/09/01 – 2012/09/01)



This figure shows the annual mean concentration of **O_3, NO_2, SO_2** and **PM10** by station type (R = rural, U = urban, S = Suburban and A = all stations)

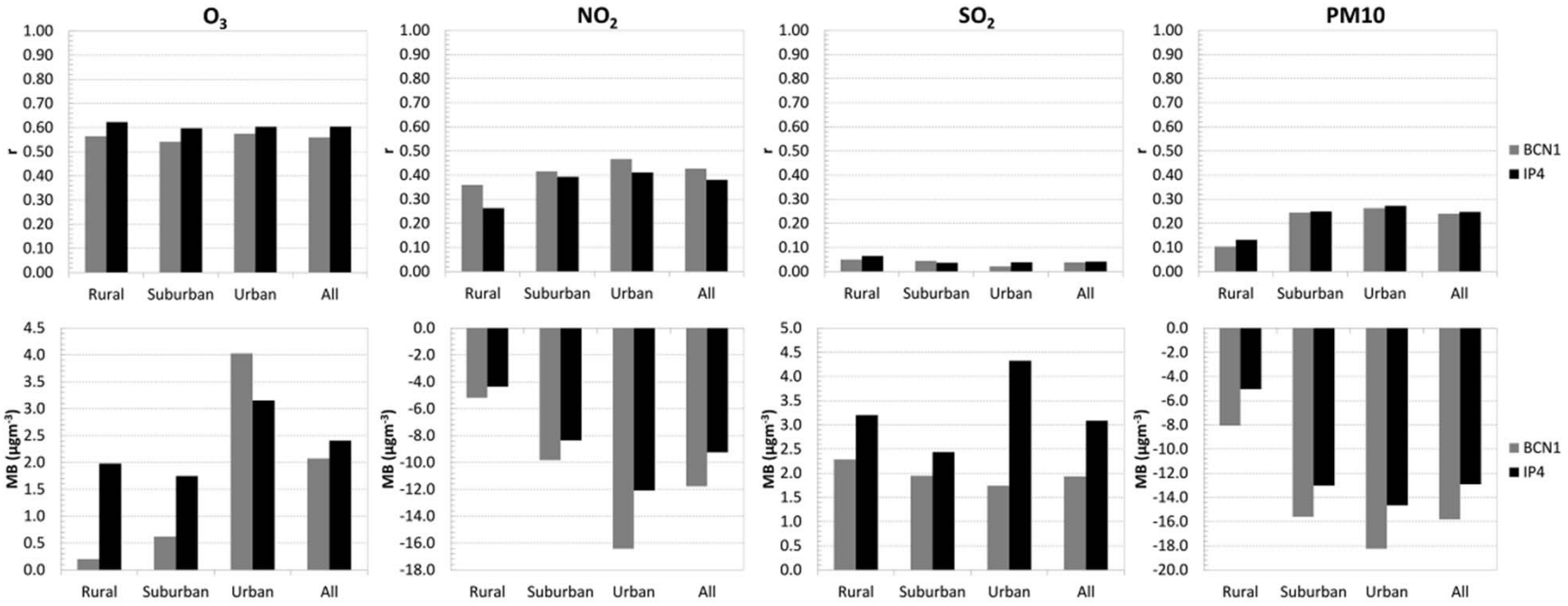
O_3 is the pollutant which presents the lowest impact with resolution increase. The rural group (3/27 stations) shows the highest sensitivity. However, this result in deviated by the Alcover rural station, located downwind the industrial emissions from Tarragona area, where the resolution increase improve the annual bias.

NO_2 annual mean concentrations (underestimated in both resolutions) show high increments for urban stations.

The resolution increase has the highest impact in **SO_2** concentrations, mainly for urban stations where concentration increase ~3µgm^{-3}.

The resolution increase has also a significant impact in **PM10** annual concentration, decreasing concentrations (~3µgm^{-3}) in the same order of magnitude for all the station types.

Annual statistics (2011/09/01 – 2012/09/01)



When resolution increase (4 km -> 1 km):	
O_3	- r decreases (< 0.1). - MB decreases (exception U stations). MB shows low variation < 2 µg m^{-3}.
NO_2	- r increases (0.05-0.1). - |MB| increases (~3 µg m^{-3}).
SO_2	- r shows low variability for low correlation (>0.01). - MB decreases (~1 µg m^{-3}).
PM10	- r shows low variations (< 0.1). - |MB| increases (~3 µg m^{-3}).

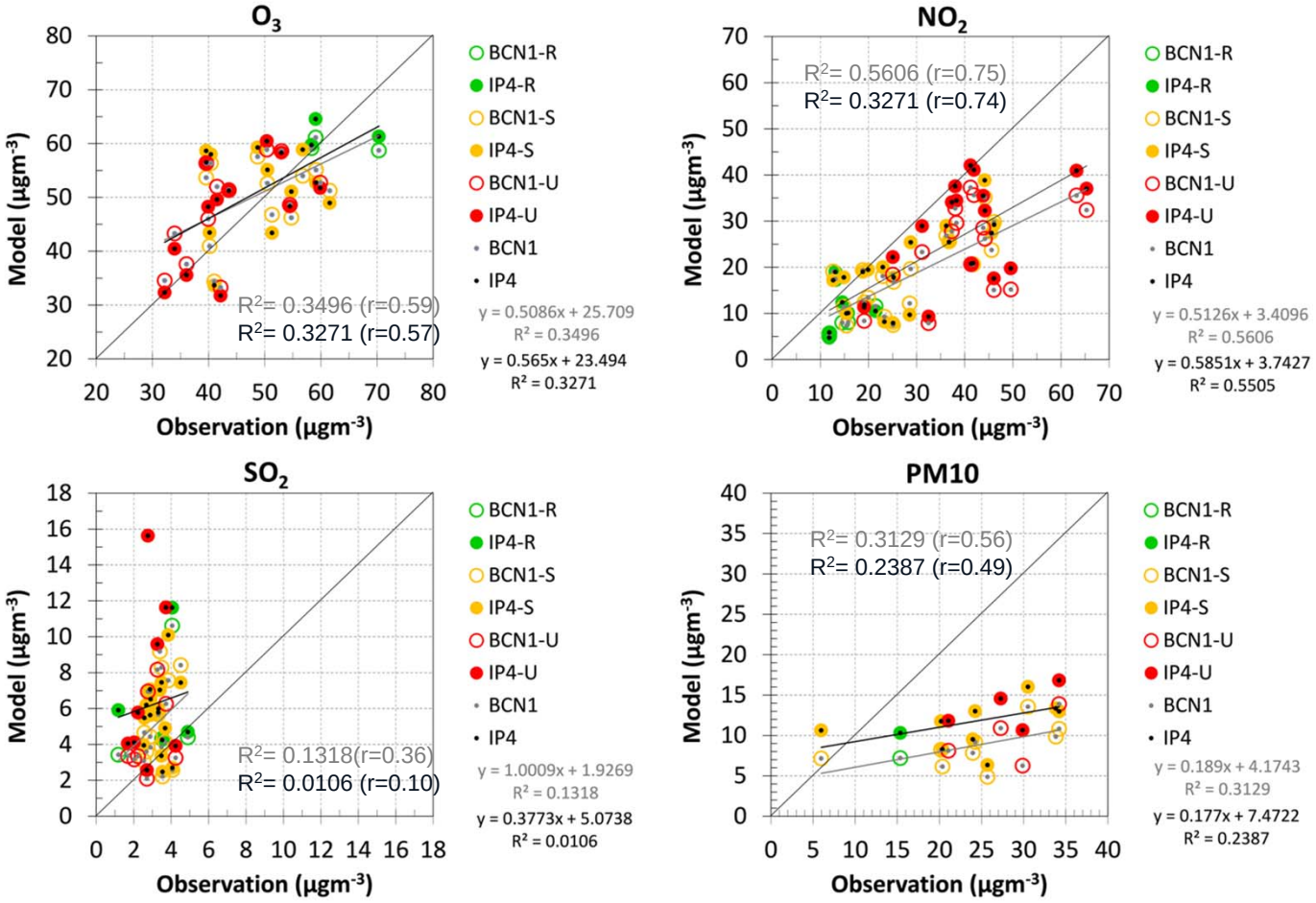
Annual statistics (2011/09/01 – 2012/09/01)

Station type		O_3				NO_2				SO_2				PM10			
		N	IP4	BCN1	%	N	IP4	BCN1	%	N	IP4	BCN1	%	N	IP4	BCN1	%
Rural	r	4	0.62	0.56	-9	6	0.26	0.36	37	4	0.06	0.05	-23	1	0.13	0.10	-22
Suburban		11	0.60	0.54	-9	18	0.39	0.42	6	16	0.04	0.04	22	9	0.25	0.24	-2
Urban		12	0.60	0.57	-5	16	0.41	0.47	13	8	0.04	0.02	-46	4	0.27	0.26	-4
All		**27**	**0.60**	**0.56**	**-7**	**40**	**0.38**	**0.43**	**12**	**28**	**0.04**	**0.04**	**-6**	**14**	**0.25**	**0.24**	**-3**
Rural	MB	4	2.0	0.2	-90	6	-4.4	-5.2	19	4	3.2	2.3	-29	1	-5.0	-8.1	60
Suburban		11	1.7	0.6	-64	18	-8.4	-9.8	18	16	2.4	1.9	-20	9	-13.0	-15.6	20
Urban		12	3.2	4.0	28	16	-12.1	-16.4	36	8	4.3	1.7	-60	4	-14.6	-18.2	25
All		**27**	**2.4**	**2.1**	**-14**	**40**	**-9.2**	**-11.8**	**27**	**28**	**3.1**	**1.9**	**-37**	**14**	**-12.9**	**-15.8**	**22**
Rural	RMSE	4	27.9	29.3	5	6	15.1	14.6	-3	4	16.7	17.4	4	1	16.4	17.0	4
Suburban		11	29.3	30.1	3	18	22.2	22.2	0	16	13.8	14.0	1	9	21.1	22.4	6
Urban		12	25.3	26.1	3	16	27.9	28.8	3	8	12.1	10.5	-14	4	22.4	24.8	10
All		**27**	**27.3**	**28.2**	**3**	**40**	**23.4**	**23.7**	**1**	**28**	**13.7**	**13.5**	**-2**	**14**	**21.2**	**22.7**	**7**

N = number of stations, % = percentage of variability between 1 km (BCN1) and 4 km (IP4).
Red = the statistic gets worse from 4 km (IP4) to 1 km (BCN1).
Green = the statistic improves from 4 km (IP4) to 1km (BCN1).

When resolution increase (4 km -> 1 km):	
O_3	- r decreases from 0.62 to 0.56 (28%). - MB shows low variation from 2.4 to 2.1 µg m^{-3} (12%, < 1 µg m^{-3}). Exception U stations, especially the traffic stations.
NO_2	- r increases from 0.38 to 0.43 (13%). - |MB| increases from 9.2 to 11.8 µg m^{-3} (22%, ~3 µg m^{-3}).
SO_2	- r shows low variability for low correlation, maximum from 0.06 to 0.05 in rural stations. - MB decreases from 3.1 to 1.9 µg m^{-3} (39%, ~1 µg m^{-3}).
PM10	- r shows low variations (< 5%) from 0.25 to 0.24 for all the stations. - |MB| increases from 12.9 to 15.8 µg m^{-3} (22%, ~3 µg m^{-3}).

The annual spatial variation



The explained spatial variability improves as function of resolution for all the pollutants support by the increase of the annual correlation coefficient

Slopes of the fist shows slow variability (<15%) for O_3, NO_2 and PM10. In the case of SO_2 the slopes significantly improves with resolution increase (> 100%) from 0.10 (4 km) to 0.36 (1 km), dominated by the improvement of model behaviour in urban stations, indicating that CALIOPE-AQFS explain better the magnitude of the variability between urban regions at 1 km.

Conclusions

The present work shows the effect on increasing the horizontal resolution from 4 km to 1 km by means of a one-way nesting over the BMA in terms of air quality concentrations using the CALIOPE-AQFS.

- The horizontal grid influence highly depends on the environment (from urban to rural) and the studied pollutant.
- The increase of the resolution, from 4 km to 1 km, improves the CALIOPE performance at stations near large emission sources.
- Differences between both resolution in terms of annual statistical is relatively low (MB and RMSE less than 3 µg m^{-3}, and r less than 0.1) :
  - The NO_2 shows an improvement based on annual correlation coefficient from 0.38 (4 km) to 0.43 (1 km). However, the mean bias slightly increases by 27% (~3 µg m^{-3}).
  - Concerning SO_2, the resolution increase contributes to reduce annual MB by 37% for all stations and by 60% in urban areas.
  - The increase of grid resolution is not favourable for O_3 and PM10 especially at rural stations. For O_3, spatial r decreases from 0.60 (4 km) to 0.56 (1 km) since O_3 is secondary formed downwind from VOC and NO_x sources.
  - The grid effect is less pronounced for PM10 than for O_3, because there is a part of the urban PM10 mass consists of secondary aerosols and this part is less affected by a decreasing grid size in contrast to the locally emitted primary components.
- The analysis of the NO_2 concentration maps during a pollution episode revels that NO_2 concentrations are better allocate at 1 km than at 4 km, increasing the concentration (~20 µg m^{-} in Barcelona urban conglomeration and the harbour with high agreement with observations.

Thank you for your attention

Webs:

- **Air Quality Forecasts Europe / Spain**: http://www.bsc.es/caliope
- **BSC-DREAM8b mineral dust model forecasts North Africa/Europe/East-Asia**: http://www.bsc.es/projects/earthscience/DREAM/
- **NMMB/BSC-Dust mineral dust model forecasts Global and Sahara desert area**:
- http://www.bsc.es/earth-sciences/mineral-dust/nmmbbsc-dust-forecast

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