

# **AIR QUALITY MANAGEMENT STRATEGIES IN URBAN AREAS: EFFECTS OF INTRODUCING HYBRID CARS IN MADRID AND BARCELONA METROPOLITAN AREAS (SPAIN)**

**María Gonçalves Ageitos, Pedro Jiménez Guerrero and José María Baldasano.**

**Presented at: HARMO12-Conference**

***12th International Conference on Harmonisation within Atmospheric  
Dispersion Modelling for Regulatory Purposes***

**6-9, October, 2008. Cavtat, Croatia.**

# Introduction



**Urban air quality improvement**

**Deaths from urban air pollution**  
**Strategies addressed to reduce on road traffic contribution to emissions**



Reduction of number of vehicles

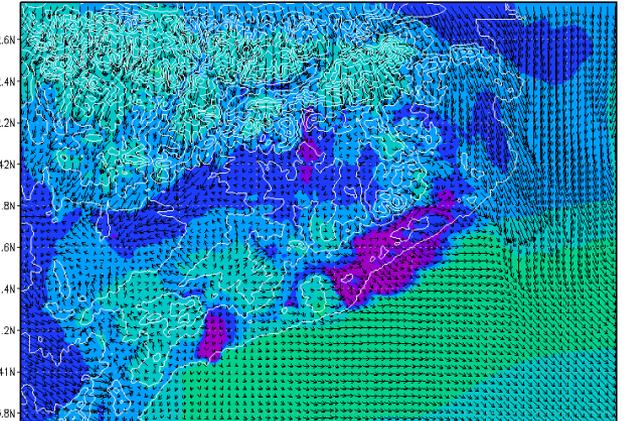
Reduction of unitary emissions per vehicle

- ✓ Circulating
- ✓ Public transport improvement
- ✓ Urban tolls

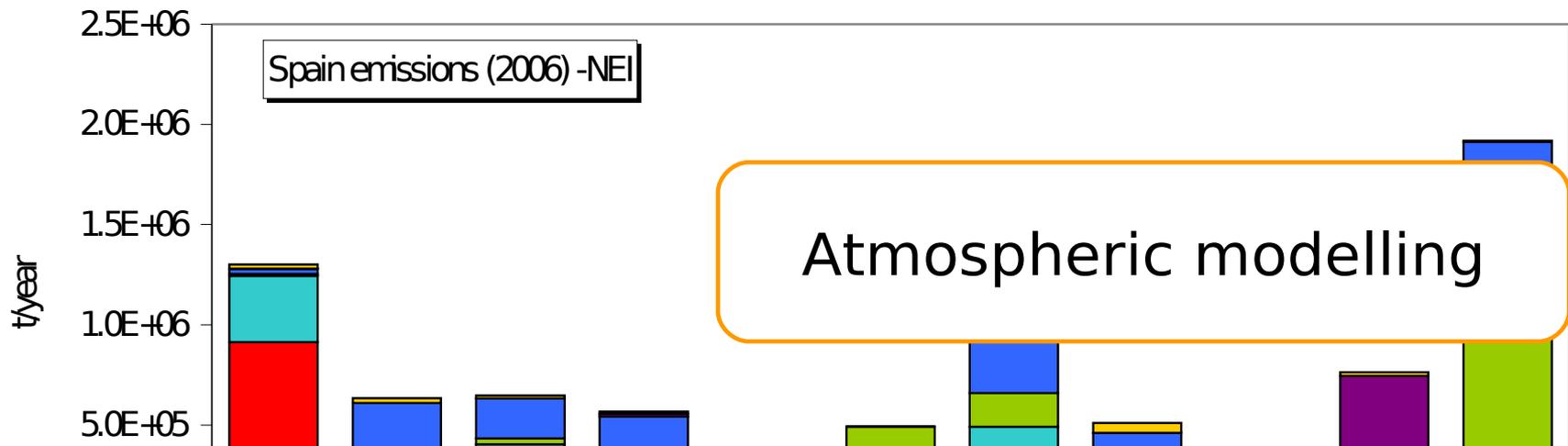
- ✓ Changes in circulation speed
- ✓ Alternative fuels (NG, biofuel)
- ✓ New technology vehicles
- Hybrid electric vehicle
- Electric vehicles



BSC-CT Ozono superficial (ug/m3)  
 0h 17/06/2004 Escenario EB - Catalunya 1x1km



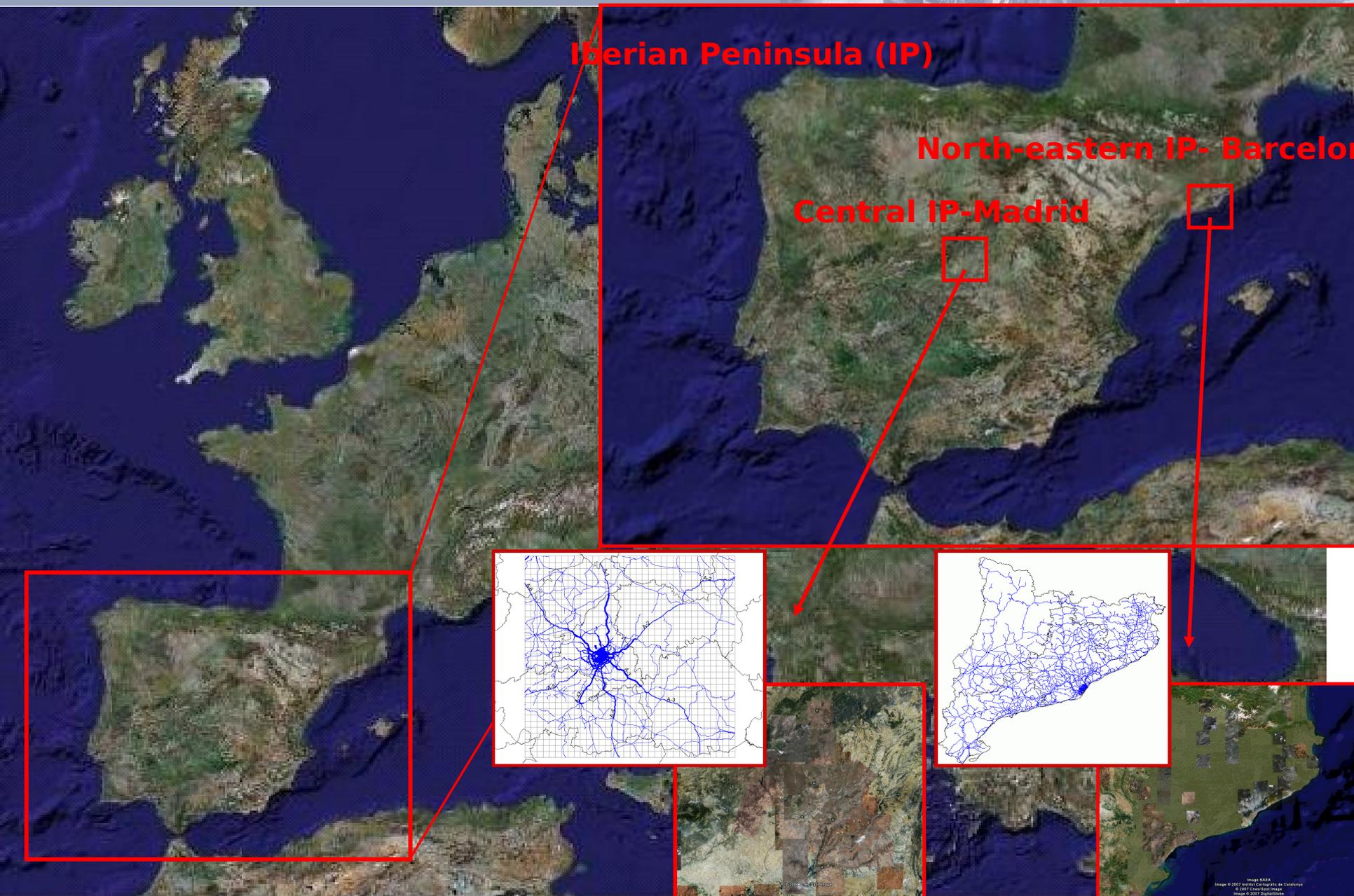
Spain emissions (2006) -NEI



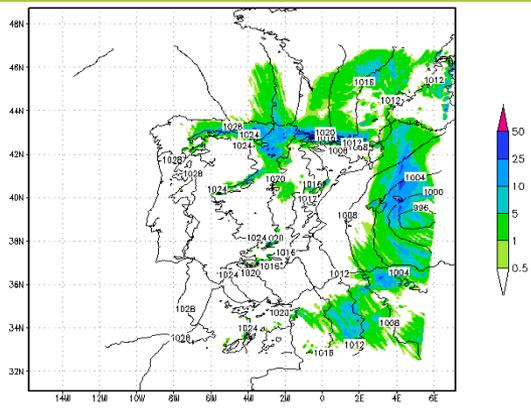
Atmospheric modelling

October

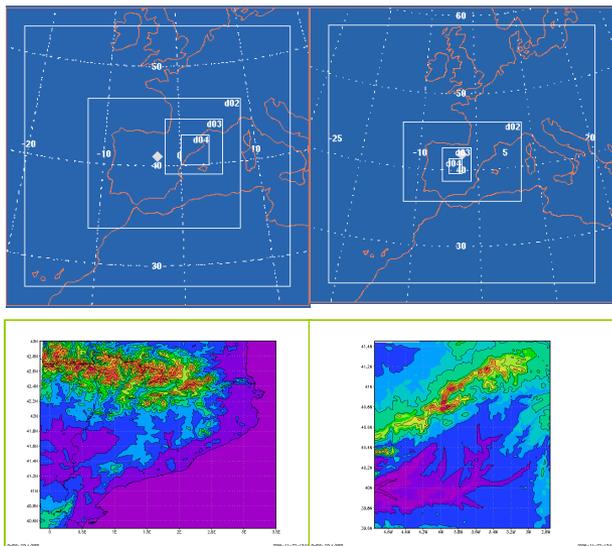
# Study areas: Barcelona and Madrid location



# Methodology - Air quality modelling system: WRF-ARW/HERMES/CMAQ



Meteorological model  
**WRF-ARW**



**4 one-way nested domains**

D1 Europe: 55x55 cells of 54km

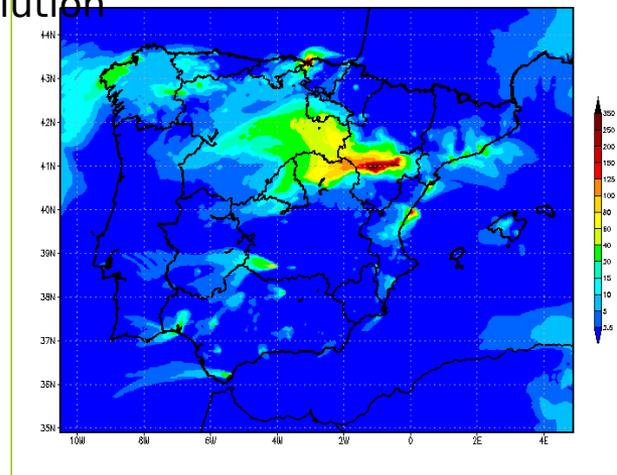
D2 Iberian Peninsula: 94x82 cells of 18 km

D3 Iberian Peninsula Area: 104x103 cells of 6 km

D4 NEIP area: 322x259 km<sup>2</sup> - 1 km resolution

D4 CIP area: 181x214 km<sup>2</sup> - 1 km resolution

BSC-ES/Air Quality Forecast CMAQv4.5 Max 1-hr Sulphur Dioxide (ug/m3)  
#1 forecast for 14 MAR 07 - Iberian Peninsula Res:4x4km



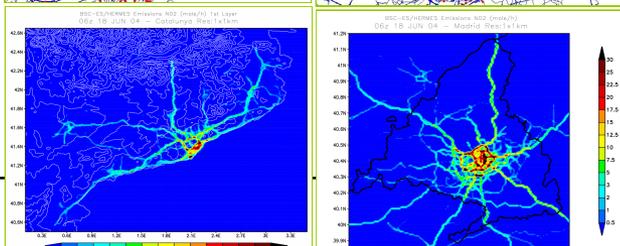
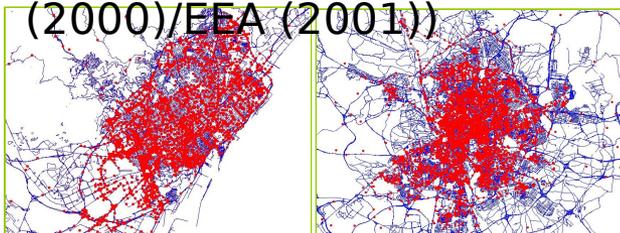
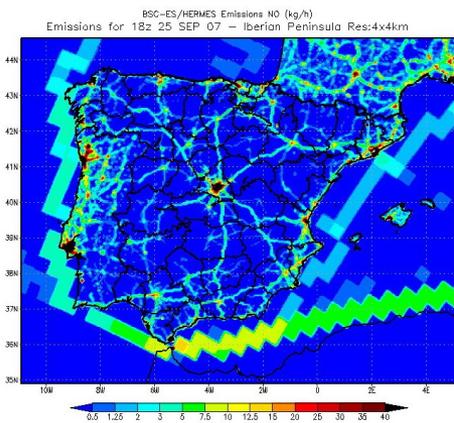
Chemistry transport model  
**CMAQ**

**Initial and boundary conditions**

Nested domain in the Iberian Peninsula using EMEP data

Emissions model  
**HERMES (2004)**

Traffic module  
(Ntziachristos and Samaras (2000)/EEA (2001))



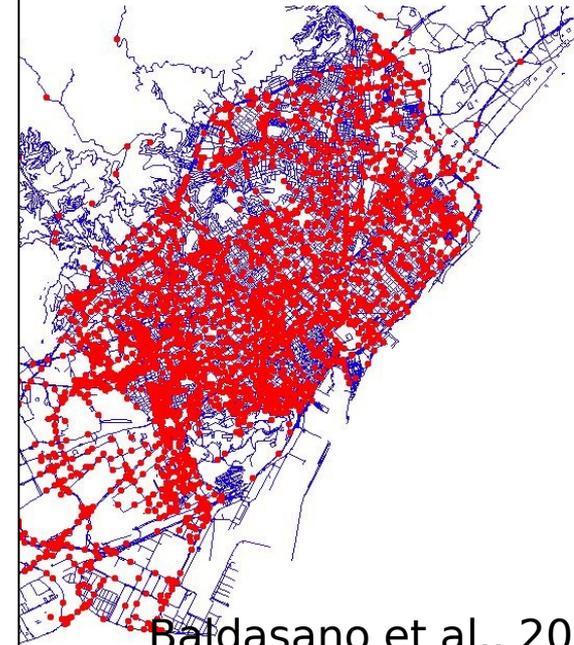
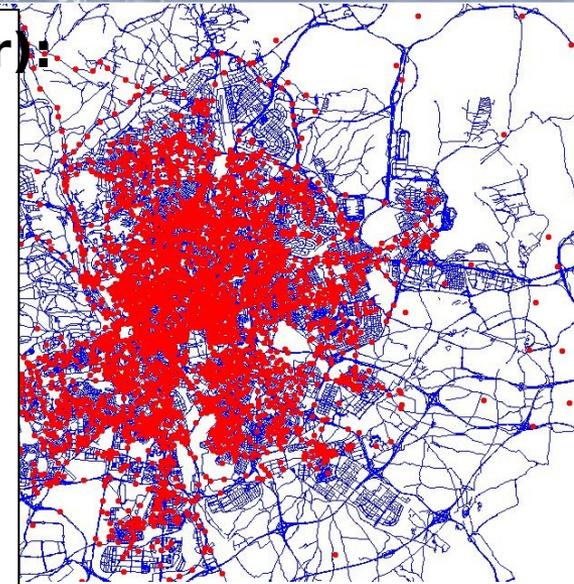
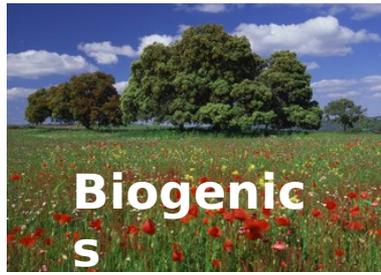
# HERMES-2004: On-road traffic for Madrid and Barcelona

The implemented information covers **67% of the intercity roads length** for the whole national territory, **80-85% of total traffic volume**.

The urban road network of Barcelona and Madrid greater areas is fully covered by the model, which involves the **50% of the national urban traffic volume**

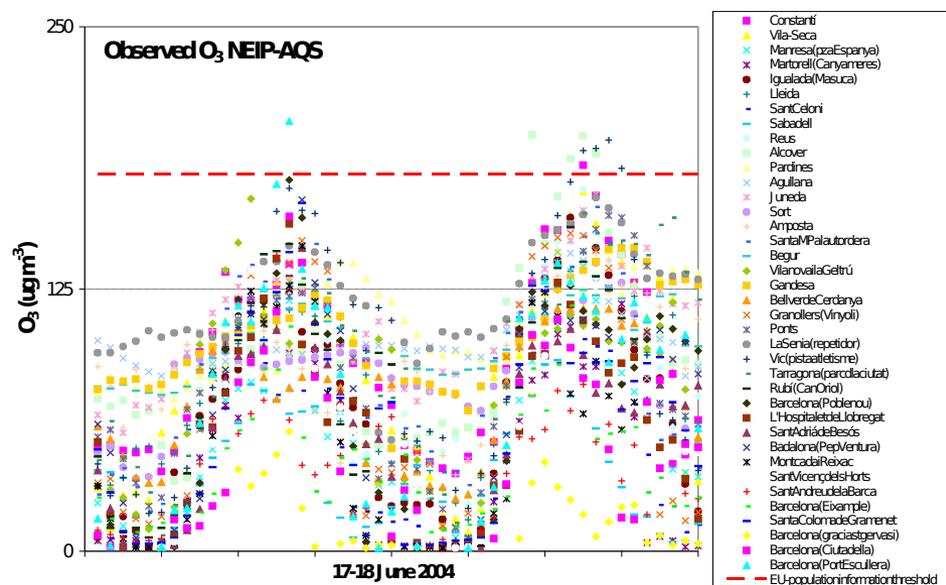
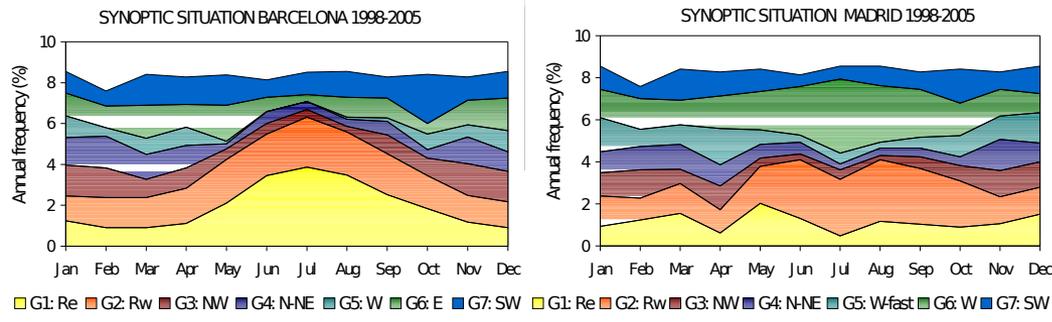
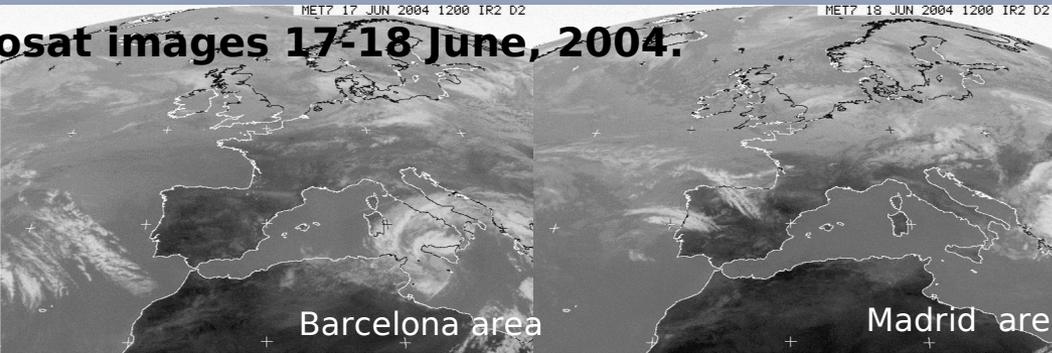
miss

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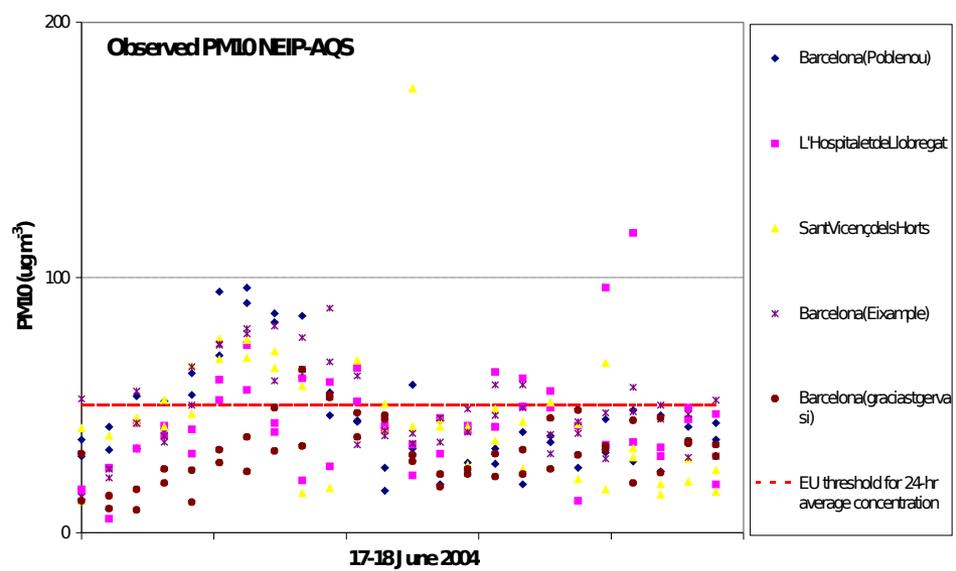


# Episode selection.

## Air quality and atmospheric circulation



- Episode representative of **poor air quality conditions** over the study areas
- Western recirculation in the synoptic scale:
  - 45% of the annual and 78% of the summertime transport patterns over north-eastern IP (Jorba et al, 2004)
  - 36% of the annual and 45% of the summertime transport patterns over central IP
- Weak synoptic forcing: the superficial wind flows are dominated by mesoscale



# Scenarios design. Implementation in HERMES emissions model

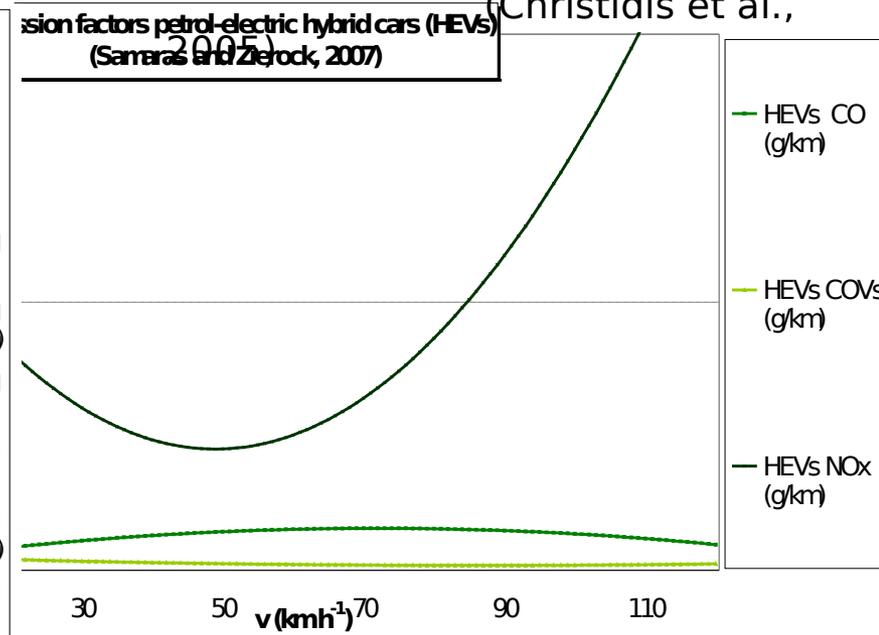
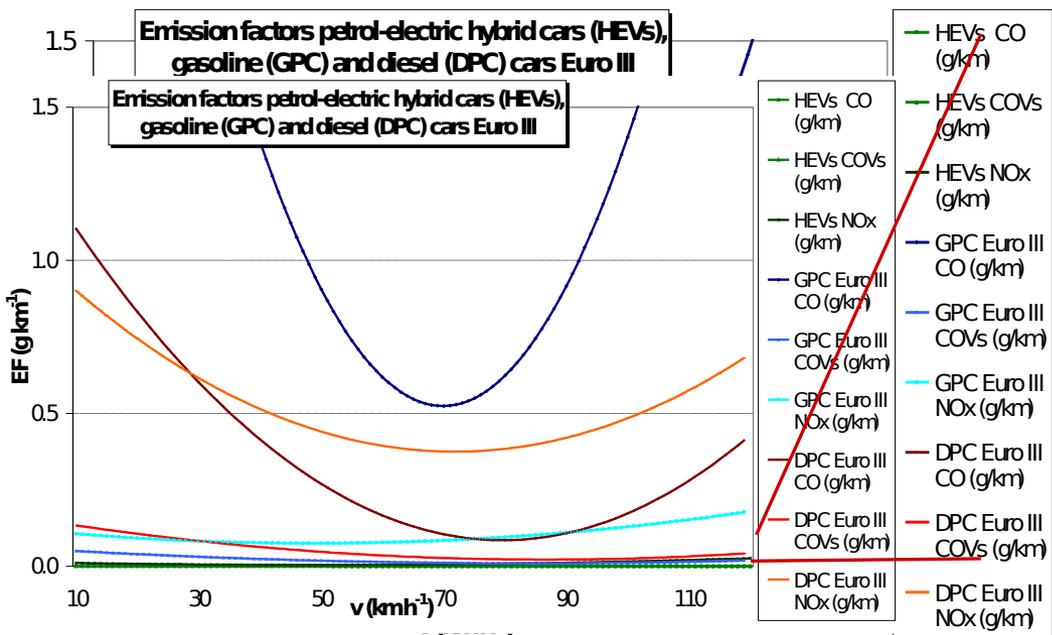
- URBAN FLEET CHANGES:
  - H1-** Scenario of introduction of 10% of gasoline - electric hybrid cars instead of the oldest petrol and diesel cars in the Barcelona and Madrid urban areas.
  - H2-** Scenario of introduction of 30% of gasoline - electric hybrid cars instead of the oldest cars (including taxis) in Barcelona and

	Barcelona	Madrid
Number of vehicles (2004, DGT)	<b>925839</b>	<b>1678942</b>
New vehicles (2004, DGT)	269,386	455,955
N HEVs <b>H1</b>	59742	136819
N HEVs <b>H2</b>	182337	415151
% HEVs/NewVeh <b>H1</b>	22%	30%
% HEVs/NewVeh <b>H2</b>	68%	91%
Considering a 5 years period for the introduction		
% HEVs/NewVeh <b>H1</b> - 5 years	4%	6%
% HEVs/NewVeh <b>H2</b> - 5 years	14%	18%

Estimated market share for hybrid vehicles:

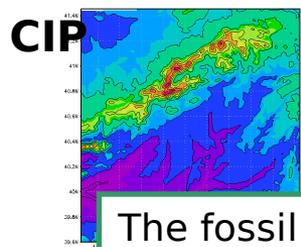
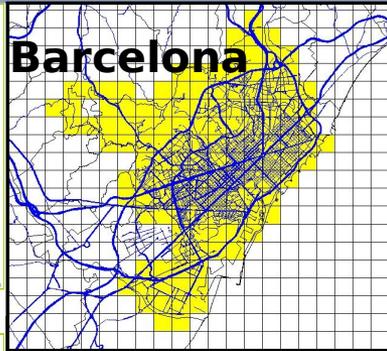
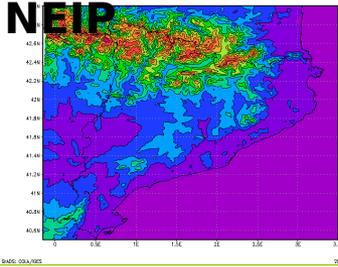
6% of market share in 2010 **H1**  
 slightly above 12% by 2020 **H2**

(Christidis et al., 2007)

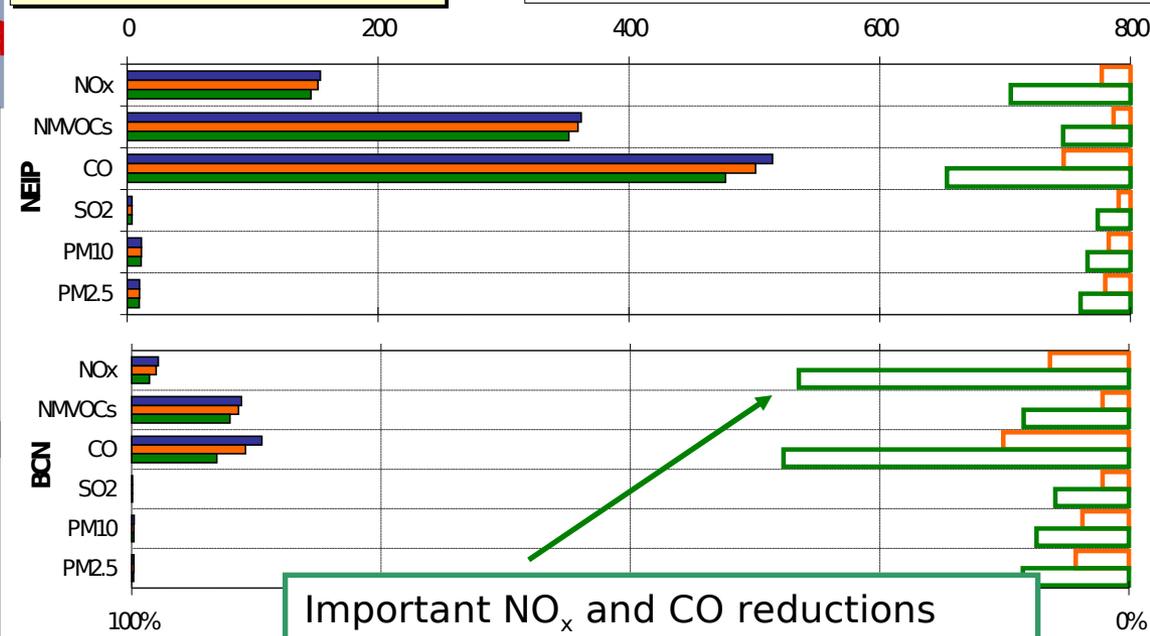




# Traffic emissions cha



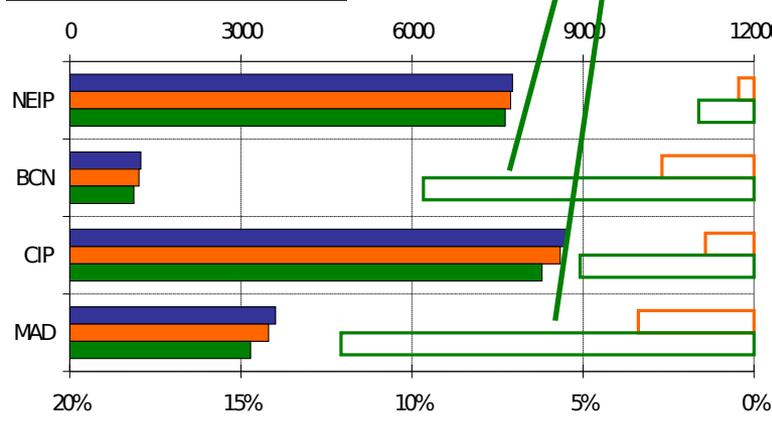
On-road traffic emissions (t d<sup>-1</sup>) 17/06/2004



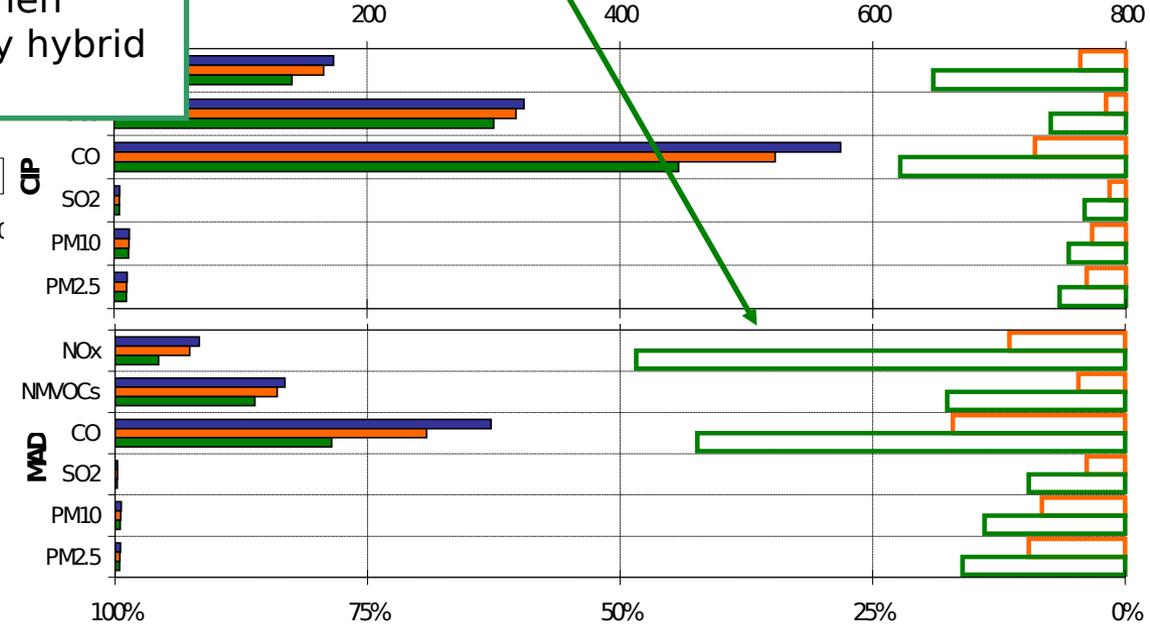
Important NO<sub>x</sub> and CO reductions specially in Madrid area with H2

The fossil fuel consumption in the urban areas is reduced 9.7% to 12.1% when changing 30% of the oldest cars by hybrid cars

Fossil fuel consumption (t d<sup>-1</sup>) 17/06/2004



On-road traffic emissions (t d<sup>-1</sup>) 17/06/2004



# 8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Barcelona and Madrid areas.



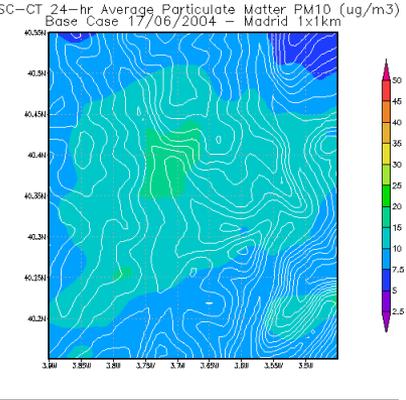
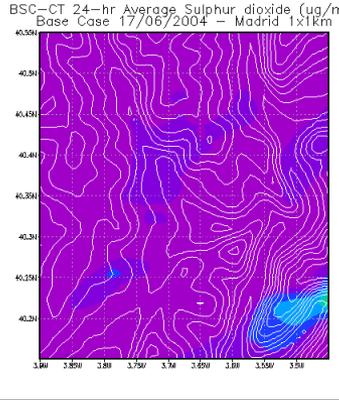
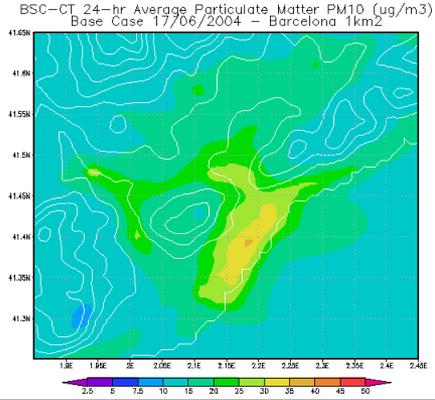
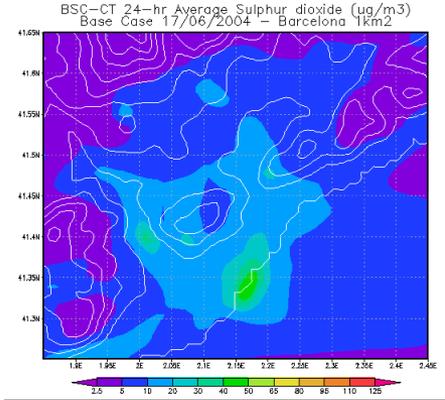
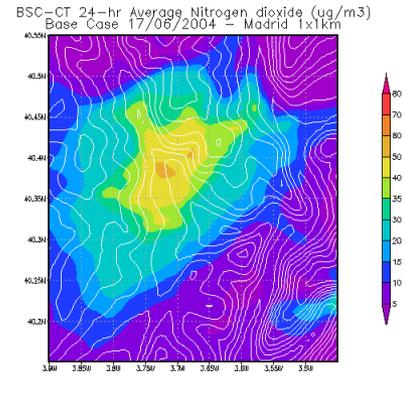
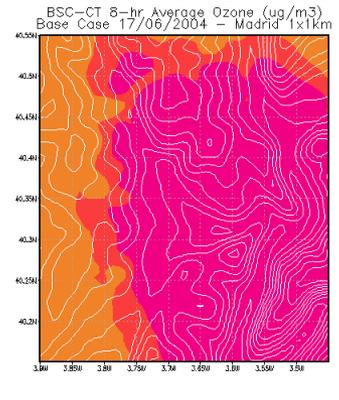
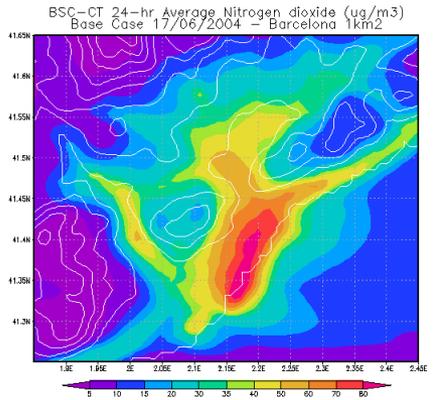
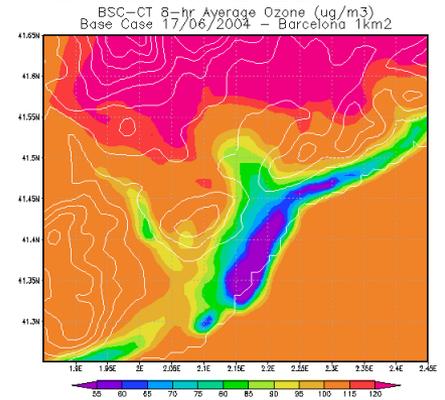
Model evaluation	Number of stations	Ndata	MNBE(%)	MNGE(%)	UPA(%)
O <sub>3</sub>	46	1222	-10%	25%	-16%
NO <sub>2</sub>	30	1258	-31%	55%	-26%
SO <sub>2</sub>	23	481	-43%	55%	-35%
PM10	12	512	-49%	56%	-48%

BASE CASE

BASE CASE

8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Barcelona area

8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Madrid area



# Differences in average concentration when introducing petrol electric hybrid cars. H1 scenario. Barcelona and Madrid urban areas. 17/06/2004.



**Barcelona**



**Madrid**

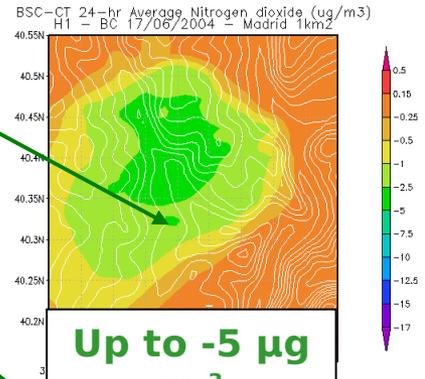
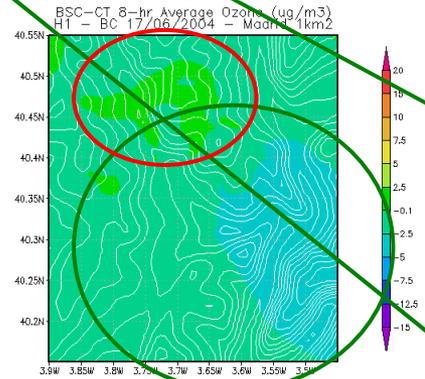
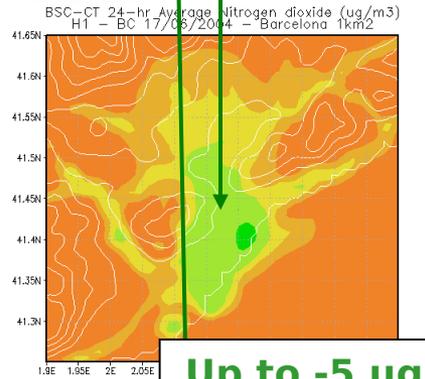
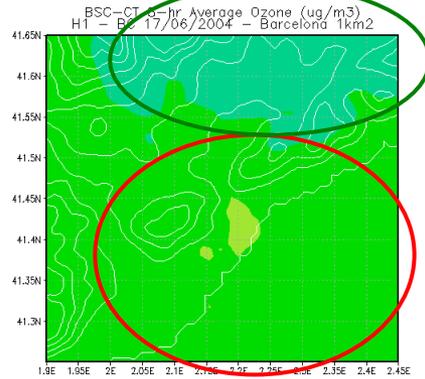
Reductions on NO<sub>2</sub> and PM10 levels, especially in the downtown

**H1-BC**

8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Barcelona area

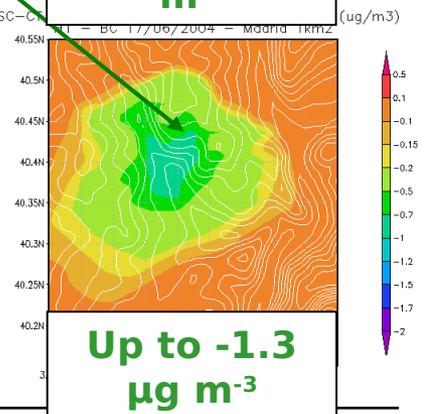
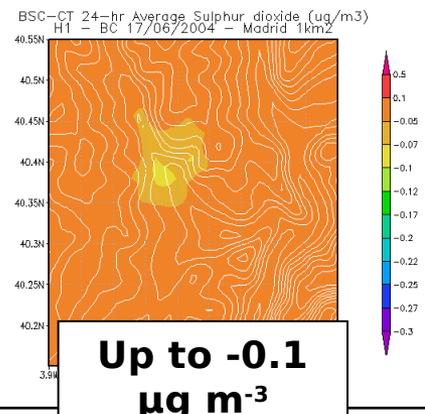
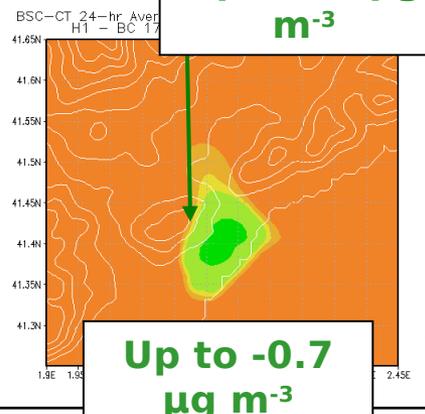
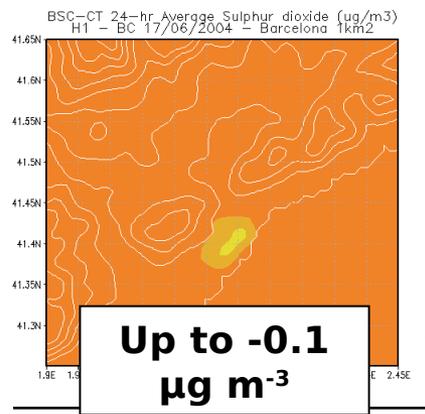
**H1-BC**

8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Madrid area



Up to -5 μg m<sup>-3</sup>

Up to -5 μg m<sup>-3</sup>



Up to -0.1 μg m<sup>-3</sup>

Up to -0.7 μg m<sup>-3</sup>

Up to -0.1 μg m<sup>-3</sup>

Up to -1.3 μg m<sup>-3</sup>

# Differences in average concentration when introducing petrol electric hybrid cars. H2 scenario. Barcelona and Madrid urban areas. 17/06/2004.



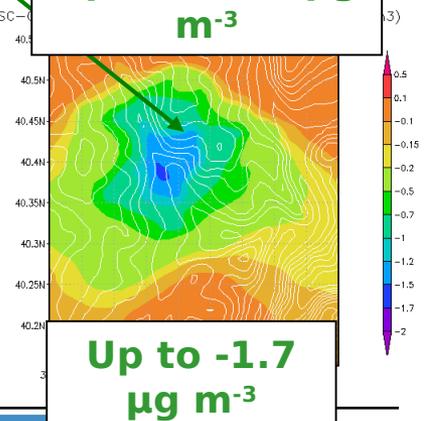
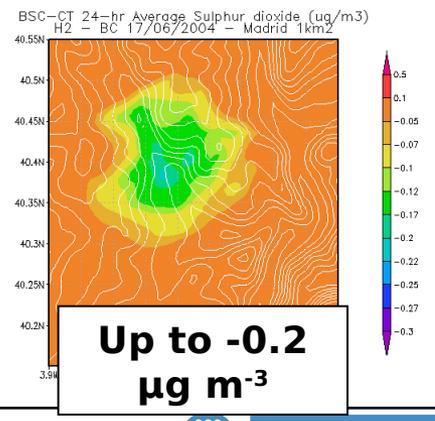
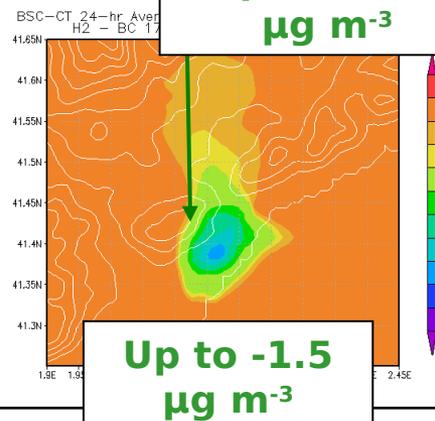
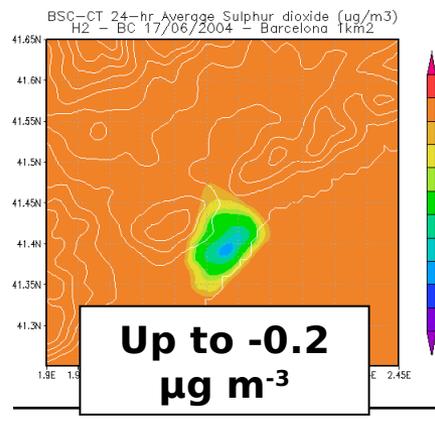
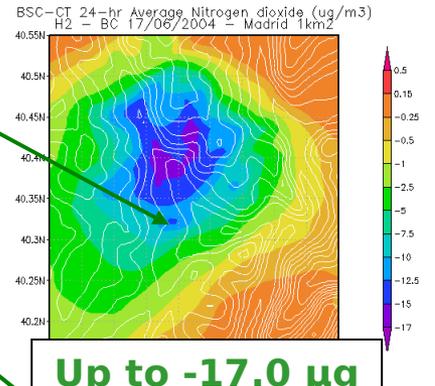
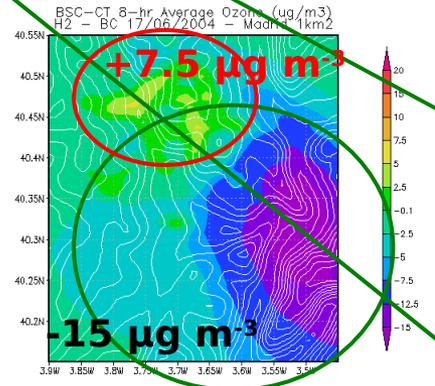
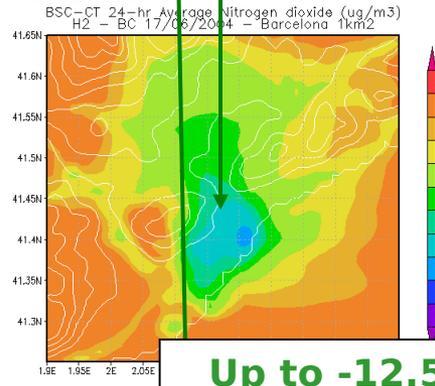
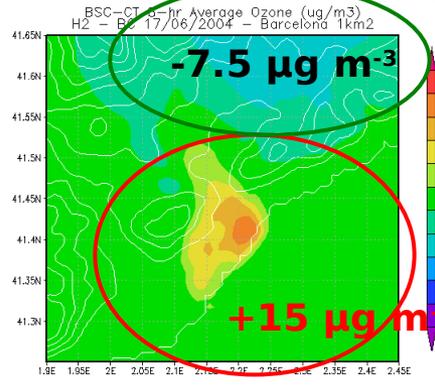
Reductions on NO<sub>2</sub> and PM10 levels, especially in the downtown

**H2-BC**

**H2-BC**

8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Barcelona area

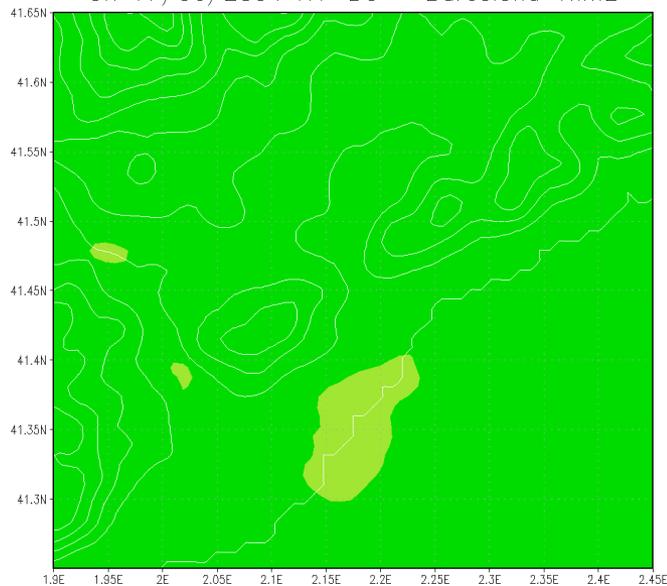
8-hr average O<sub>3</sub>, 24-hr average NO<sub>2</sub>, SO<sub>2</sub> and PM10 concentrations for 17 June, 2004 over the Madrid area



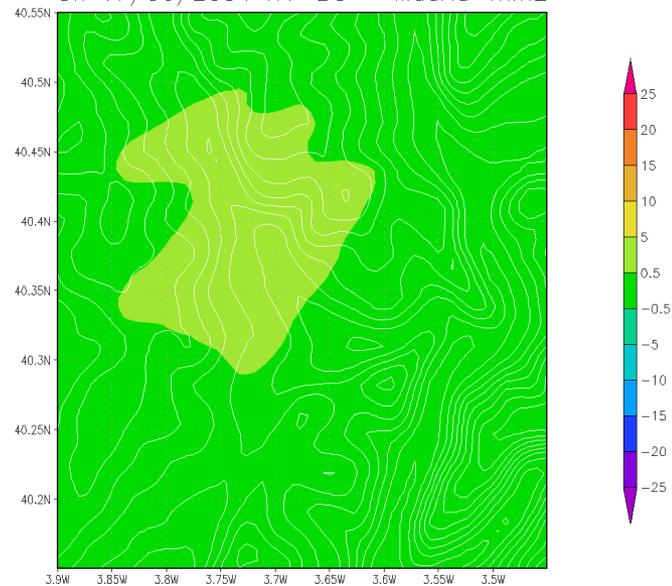
# Barcelona

# Madrid

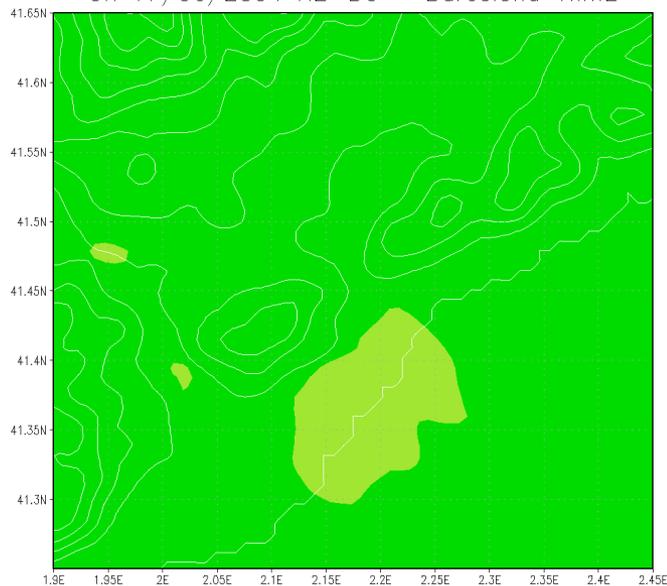
BSC-CT Ozone ( $\mu\text{g}/\text{m}^3$ )  
0h 17/06/2004 H1-BC - Barcelona 1km2



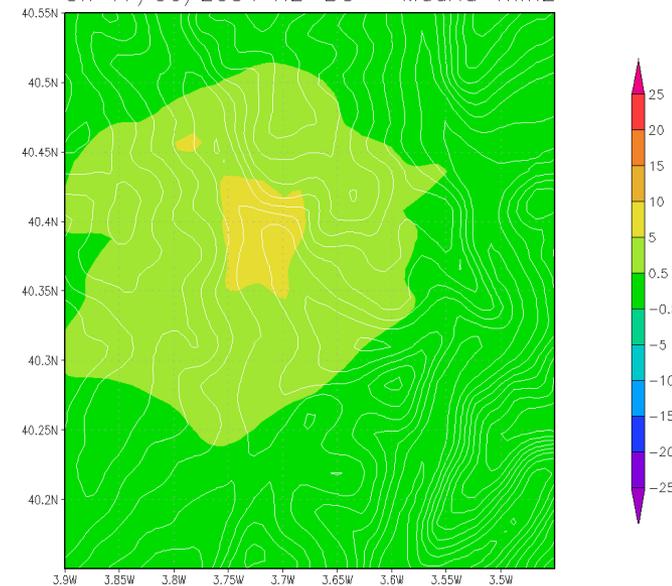
BSC-CT Ozone ( $\mu\text{g}/\text{m}^3$ )  
0h 17/06/2004 H1-BC - Madrid 1km2



BSC-CT Ozone ( $\mu\text{g}/\text{m}^3$ )  
0h 17/06/2004 H2-BC - Barcelona 1km2



BSC-CT Ozone ( $\mu\text{g}/\text{m}^3$ )  
0h 17/06/2004 H2-BC - Madrid 1km2



**Ozone  
behaviour  
in the  
urban  
areas  
when  
introduci  
ng the  
hybrid  
vehicles  
scenarios**

**(H1 - BC)  
up**

**(H2 - BC)  
down**

# Air quality changes in selected domains



The NO<sub>x</sub> emissions reductions involves ...



... The SO<sub>2</sub> levels decrease in the Madrid area, but changes in Barcelona concentrations are almost negligible

... Increase in average O<sub>3</sub> levels in the urban areas, specially in Barcelona



17 June, 2004	24hr ave NO2		24hr ave SO2		8hr ave O3		24hr ave PM10		24hr ave PM2.5		24hr ave NO2		24hr ave SO2		8hr ave O3		24hr ave PM10		24hr ave PM2.5	
Conc (ug m <sup>-3</sup> )	BGA	B-D	BGA	B-D	BGA	B-D	BGA	B-D	BGA	B-D	MGA	MD	MGA	MD	MGA	MD	MGA	MD	MGA	MD
Base Case	23.0	75.1	8.7	20.0	104.4	52.4	15.0	29.8	11.5	26.3	15.9	36.4	2.2	2.4	132.8	124.8	10.1	13.1	6.5	13.1
H1	22.6	73.0	8.7	19.9	104.6	54.7	15.0	29.3	11.4	25.8	15.1	33.7	2.2	2.3	131.4	124.5	9.9	12.6	6.4	12.6
H2	21.8	66.9	8.7	19.8	104.9	60.3	15.0	29.9	11.4	25.4	12.2	23.6	2.2	2.2	127.1	124.9	9.8	12.2	6.3	12.2
Diff conc (ug m <sup>-3</sup> )	BGA	B-D	BGA	B-D	BGA	B-D	BGA	B-D	BGA	B-D	MGA	MD	MGA	MD	MGA	MD	MGA	MD	MGA	MD
BC-H1	0.4	2.0	0.005	0.1	-0.3	-2.4	0.04	0.5	0.04	0.5	0.0	0.0	0.0	0.0	0.1	0.5	0.1	0.5	0.1	0.5
BC-H2	1.2	8.2	0.01	0.2	-0.5	-8.0	0.1	0.9	0.1	0.9	0.3	0.3	0.0	0.0	0.3	1.0	0.3	1.0	0.3	1.0
% Diff.	BGA	B-D	BGA	B-D	BGA	B-D	BGA	B-D	BGA	B-D	MGA	MD	MGA	MD	MGA	MD	MGA	MD	MGA	MD
BC-H1	1.7%	2.7%	0.1%	0.3%	-0.3%	-4.5%	0.3%	1.8%	0.4%	2.0%	5.1%	8.2%	0.0%	0.0%	1.5%	4.1%	2.3%	4.1%	2.3%	4.1%
BC-H2	5.1%	10.9%	0.2%	1.0%	-0.5%	-15.2%	0.4%	3.2%	0.6%	3.6%	23.3%	9.1%	2.6%	7.3%	4.0%	7.3%	4.0%	7.3%	4.0%	7.3%

The reductions on PM are specially important in Madrid area, the finest fraction is the most affected

# Conclusions



- The **hybrid electric cars** are a short term option to **reduce fossil fuel consumption** in urban areas.
- The substitution of 10% of the oldest diesel and petrol cars by gasoline hybrid electric cars (**H1**) **reduces NO<sub>x</sub> and CO** emissions. The substitution of a 30% of those cars by hybrids (**H2**) has also noticeable effects on **PM emissions**.
- The impact of the scenarios is larger in Madrid than in Barcelona because of the vehicle fleet composition, mainly constituted by cars in Madrid.
- The reduction on NO<sub>x</sub> emissions **reduces NO<sub>2</sub> concentration** in the **conurbations** and slightly **decreases O<sub>3</sub> levels downwind**. The effect in local O<sub>3</sub> concentration depends on the photochemical regime. O<sub>3</sub> levels decrease in Madrid during the central hours of the day. Meanwhile in Barcelona higher levels are found when introducing the hybrids scenarios.
- The effects of **H2** are noticeable in the **PM<sub>2.5</sub> fraction** in the **Madrid** area.
- The **SO<sub>2</sub> levels are low in the urban areas**, the hybrids introduction does not affect the concentration of this pollutant in the Barcelona area, because of its mainly industrial origin. Larger reductions are observed for Madrid areas.
- The **high resolution** used and the **detailed emission inventory** permit to use the **WRF-ARW/HERMES/CMAQ** as a **management tool**.
- The **results** obtained **depend on the study area** and **should be analyzed specifically for each case**. Extrapolations are not recommendable.

# Thanks for your attention



  **Barcelona Supercomputing Center**  
Centro Nacional de Supercomputación

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6-9, October, 2008. Cavtat, Croatia.

**Peak Performance of 94,21 Teraflops**  
**10240 IBM Power PC 970MP processors at 2.3 GHz (2560 JS21 blades)**  
**20 TB of main memory**  
**280 + 90 TB of disk storage**  
**Interconnection networks: Myrinet and Gigabit Ethernet**  
**Linux: SuSe Distribution**



## **MareNostrum Supercomputer**

Located in the Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS, Barcelona, Spain)

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Earth Sciences Department developments:

Daily Operational Air Quality Forecasts Europe/Iberian Peninsula:

<http://www.bsc.es/projects/earthscience/aqforecast-en/>

Daily DREAM mineral dust model forecasts North Africa/Europe/East Africa

<http://www.bsc.es/projects/earthscience/DREAM/>

**Acknowledgements:** O. Jorba provided the necessary meteorological inputs and E. López the emissions estimates necessary to perform the air quality simulations. Location maps were obtained from Google Earth software.