DIPARTIMENTO DI INGEGNERIA
CIVILE EDILE E AMBIENTALE

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AN INVERSE MODELING METHOD TO IDENTIFY VEHICULAR EMISSIONS IN URBAN COMPLEX AREAS

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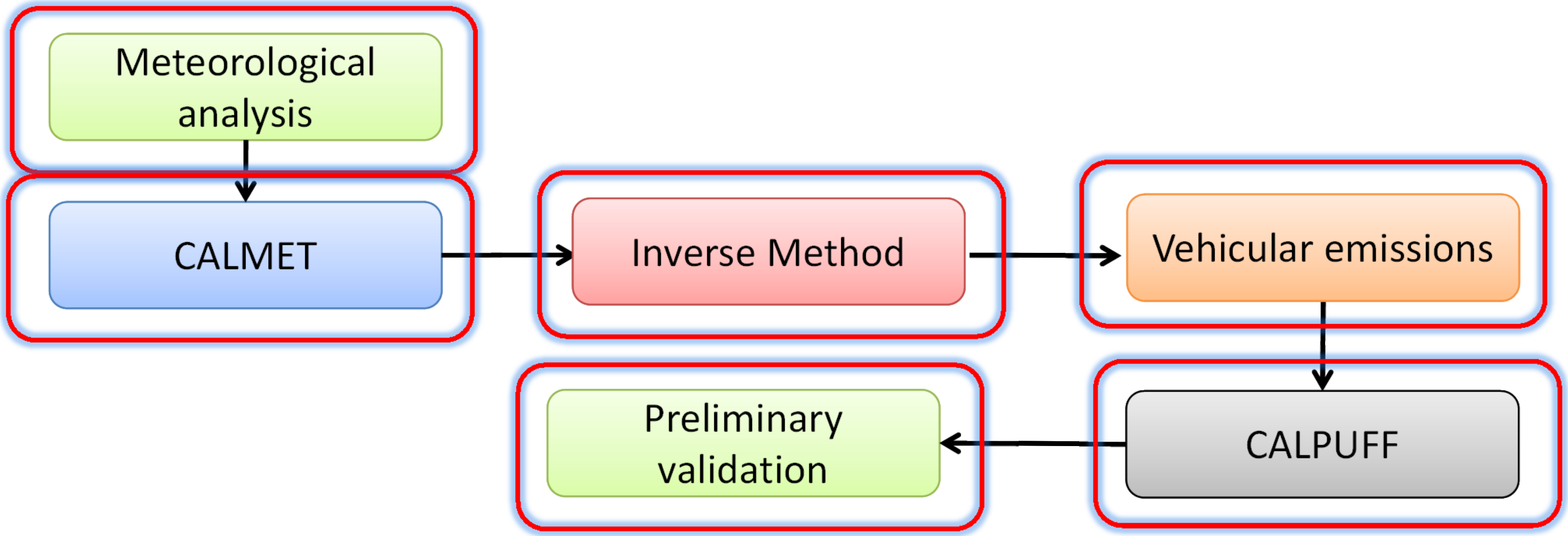
Background

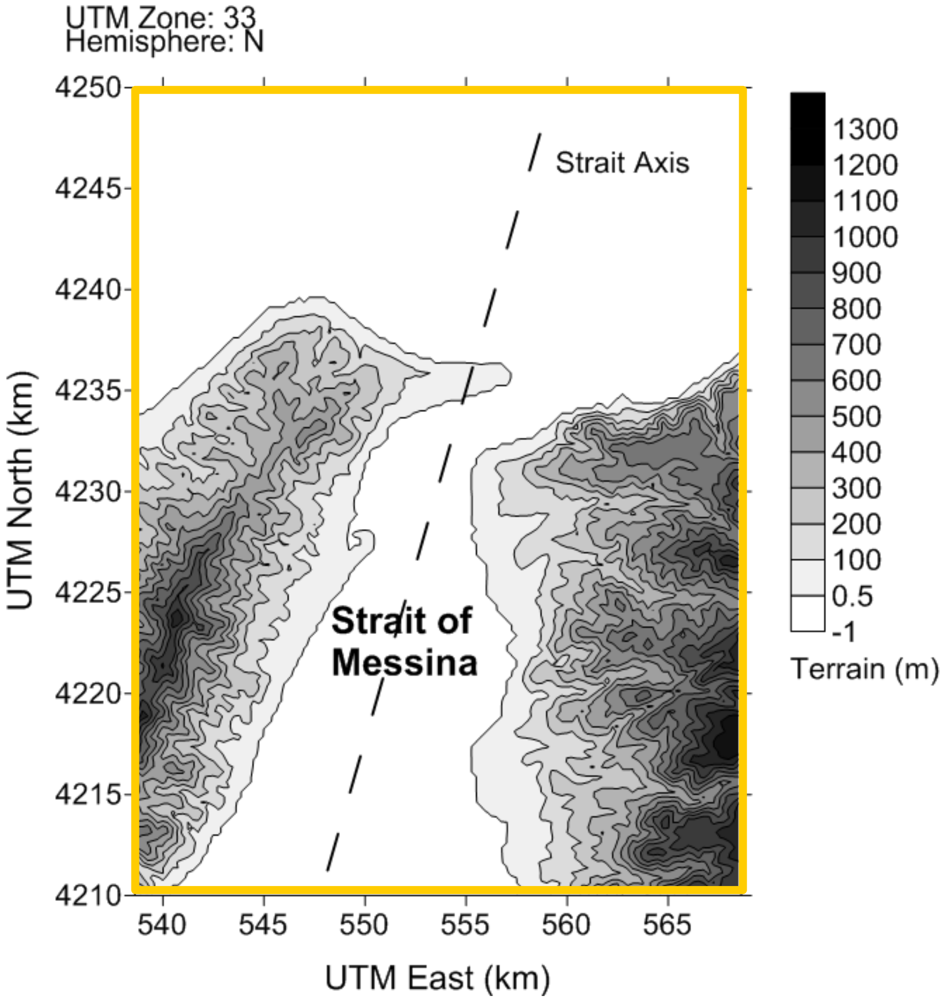
- ✓ The evaluation of urban air quality represents one of the most important environmental task. This also due to the increment of vehicular traffic in urban road networks
- ✓ Most local municipalities have developed networks of air quality monitoring
- ✓ Often no information is available about vehicular traffic, possible solutions are:
  - ✓ An origin-destination model
  - ✓ Inverse method
- ✓ Inverse method based on the Gaussian solution has been applied by several authors (Jeong, H.-J. et al, 2005; Hogan, W.R. et al., 2005; Lushi, E. and J.M. Stockie, 2010; Stockie, J.M., 2011)

Aim

- ✓To identify vehicular emissions in urban complex areas
  - ✓ Development of an inverse approach based on the model CALPUFF
  - ✓Model application on a complex area, which includes urban complexes, coastal areas and mountains
- ✓Preliminary validation of the method



Study Domain



The domain includes all pollutants sources that can potentially affect the area of interest, due to:

Two urban areas, several harbors, an incinerator and an airport.

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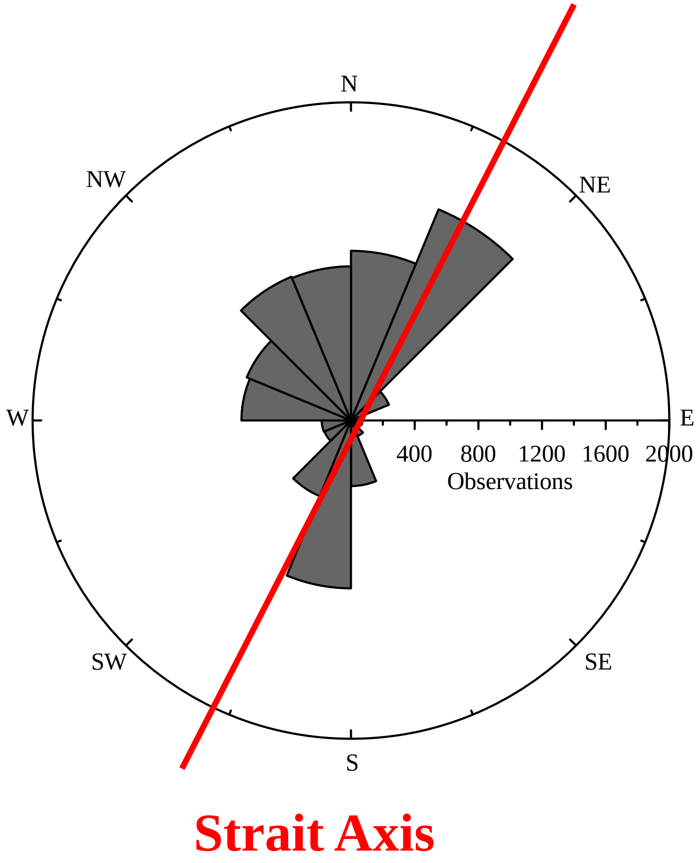
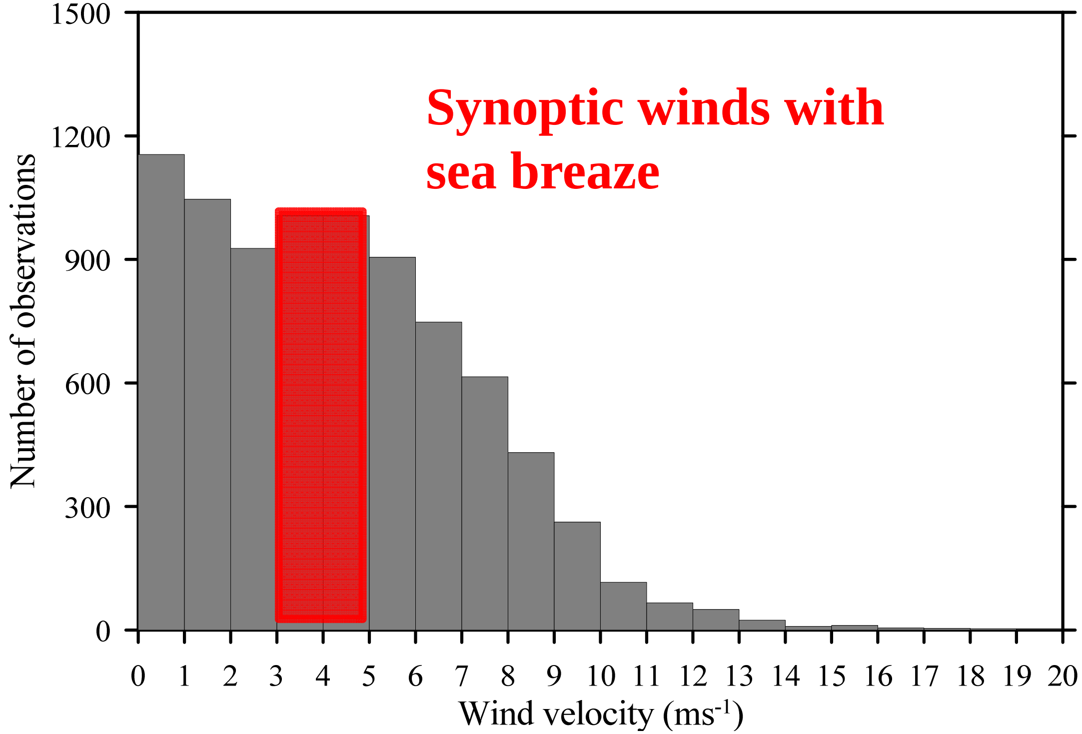
Meteorological analysis

- ✓**Analyzed years**: 2000, 2006, 2007, 2008, 2009
- ✓ **Meteorological analysis:**
  - ✓ annual regime
  - ✓ seasonal regime
  - ✓ diurnal wind circulations (sea breeze & slope winds)
- ✓ **Numerical simulation of the wind field (CALMET)**

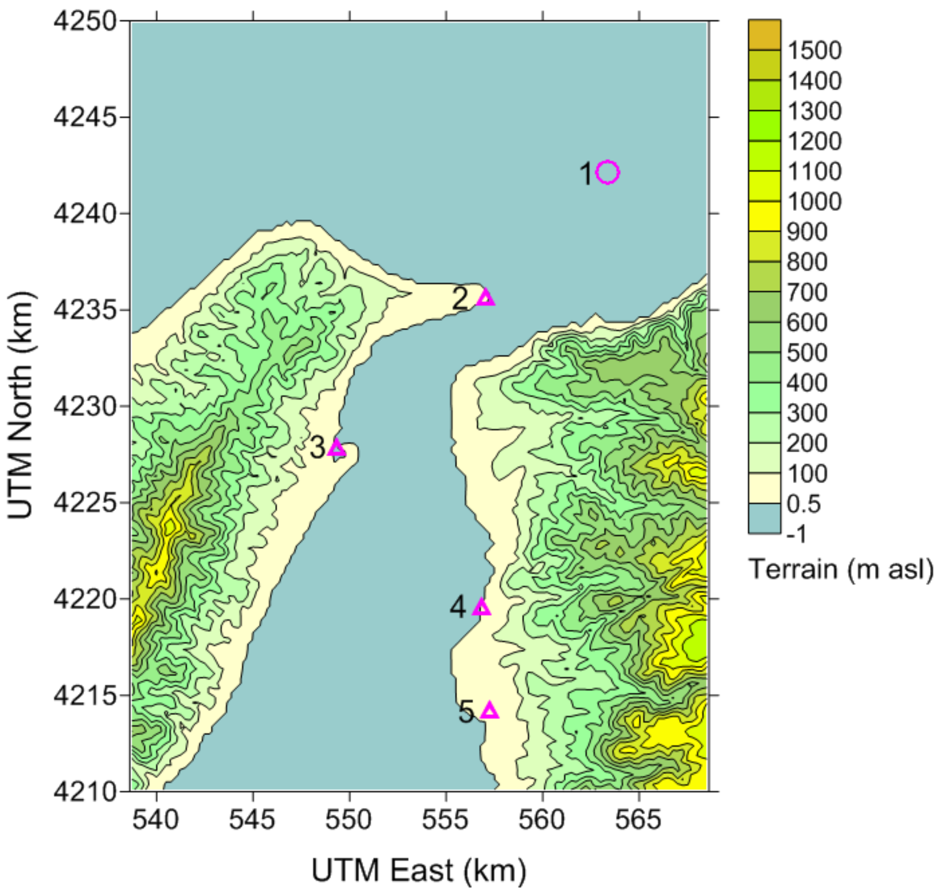
Meteorological analysis

Wind rose and occurrence frequency of the horizontal wind velocity taken at Messina during 2009





Computational domain (CALMET)



(1) NCAR node; (2) Punta Faro; (3) wavemeter Messina st.; (4) waveme ter Reggio Calabria st.; (5) Strait airport.

The computational domain consists of 121x161 horizontal grid points with a constant grid size of 250x250 m^2

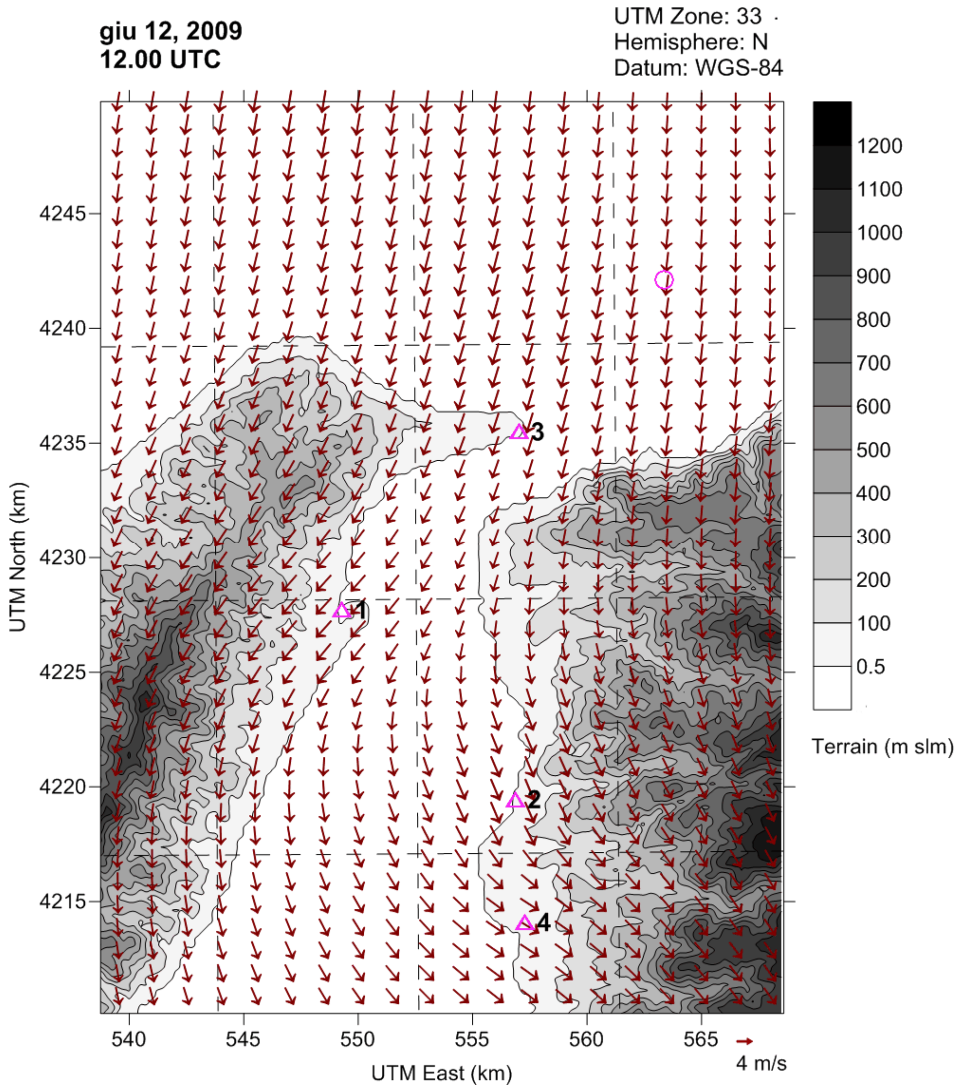
The vertical grid has 11 unevenly spaced levels, i.e.:

- ✓ From z=20 m to z=2500 m above the ground level.

The numerical model CALMET was used to calculate the meteorological input for the dispersion model CALPUFF.

Simulation results (CALMET)

Example: typical summer day



- ✓ Wind field calculated at 10 m above the ground level by CALMET at 12 UTC of 12 June 2009
- ✓ Sea breeze interacts with a northerly synoptic wind
- ✓ The wind is channeled along the strait axis

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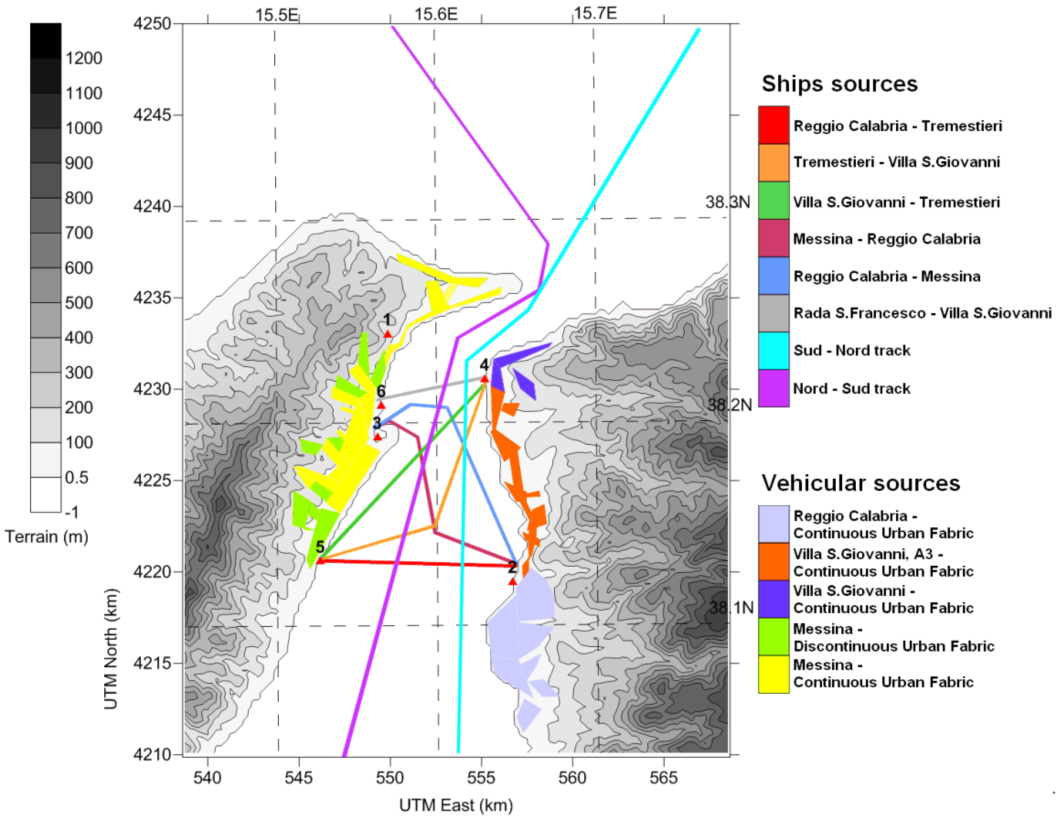
Pollutant sources



- ✓ The incinerator (triangle 1)
- ✓ Ship stationing at harbors (triangles 2-6)
- ✓ Ship traffic (lines)
- ✓ Vehicular traffic

Strengths of the continuous emissions produced by the incinerator and the stationing ships

$g\ s^{-1}$	**Incinerator**	**Reggio Calabria**	**Messina**	**Tremestieri**	**Rada S. Francesco**	**Villa S. Giovanni**
CO	2.30 E-01	6.50 E-02	3.80 E-02	1.40 E-01	2.20 E-01	3.40 E-01
NO_X	2.04 E-01	5.85 E-02	3.42 E-02	1.26 E-01	1.98 E-01	3.06E-001
PM10	1.60 E-01	3.60 E-02	2.10 E-02	8.00 E-02	1.20 E-01	1.90 E-01
C_6H_6	-	5.67 E-04	3.20 E-04	1.20 E-03	1.90 E-03	3.00 E-03

Inverse method

It is based on the assumption that:

✓Under strong and persistent wind conditions and with a steady source, the function that relates the concentration to the source strength, can be approximated by a linear law.

✓Then for multiple sources, by the superposition principle, this relation it's written as:

$$c_i = \sum_{j=1,N} \alpha_{ij} q_j \qquad i = 1, M$$

c_i: concentration at the i-th receptor

q_j: unknown rate of the j-th source

✓In real cases it is not possible to reach a perfect steady state

✓With strong and persistent winds accomulation effects are negligible

Inverse method

$$c_i = \sum_{j=1,N} \alpha_{ij} q_j \qquad i = 1, M$$

c_i: concentration at the i-th receptor

q_j: unknown rate of the j-th source

$$\alpha_{i,j} = \underbrace{\begin{bmatrix} \alpha_{1,1} & \cdots & \alpha_{1,N} \\ \vdots & \ddots & \vdots \\ \alpha_{M,1} & \cdots & \alpha_{M,N} \end{bmatrix}}_{\text{N sources}} \Bigg\} \text{M receptors}$$

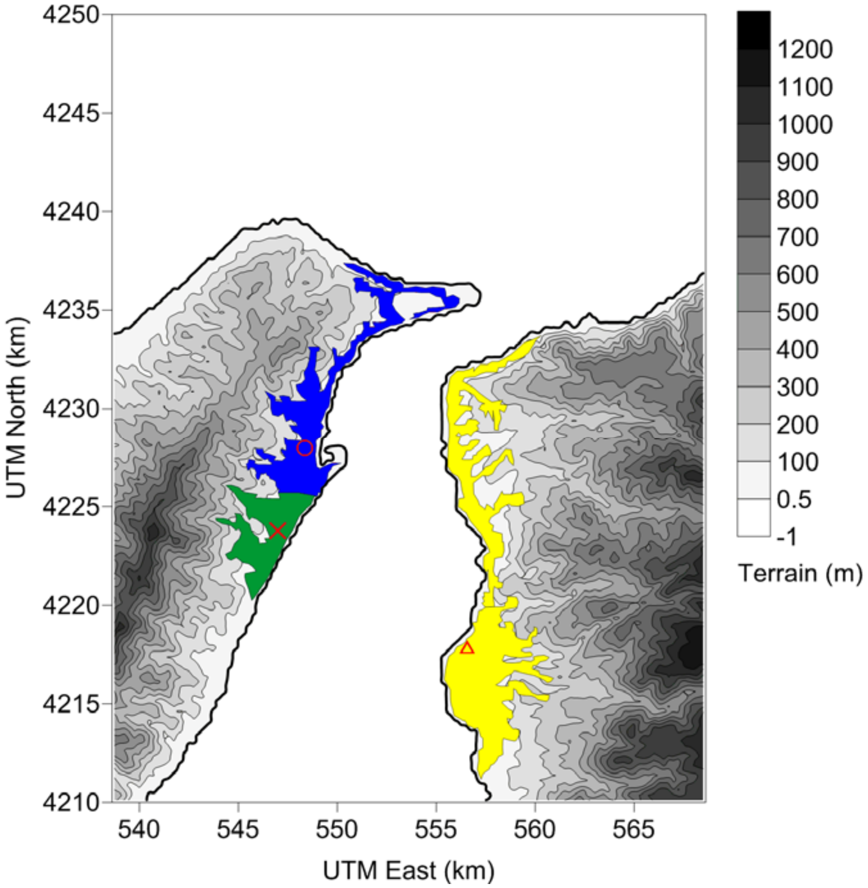
$\alpha_{i,j}$ is a function dependent on:

- ✓ position of the receptor downwind to the source
- ✓ wind intensity
- ✓ diffusion coefficients

$\alpha_{i,j}$ can be determined giving a unit value to the strength of the j-th source and then evaluating the concentration at the i-th receptor using the model CALPUFF

Once all $\alpha_{i,j}$ are known, the linear system can be solved by substituting to c_i the values measured at the i-th receptor.

Inverse method



- Since only three air quality stations were available, only three distinct emission rates were calculated

- Figure shows the three vehicular areal sources and the corresponding monitoring stations:
  - ✓Boccetta air monit. station (circle)
  - ✓Minissale air monit. station (cross)
  - ✓Castello air monit. station (triangle)

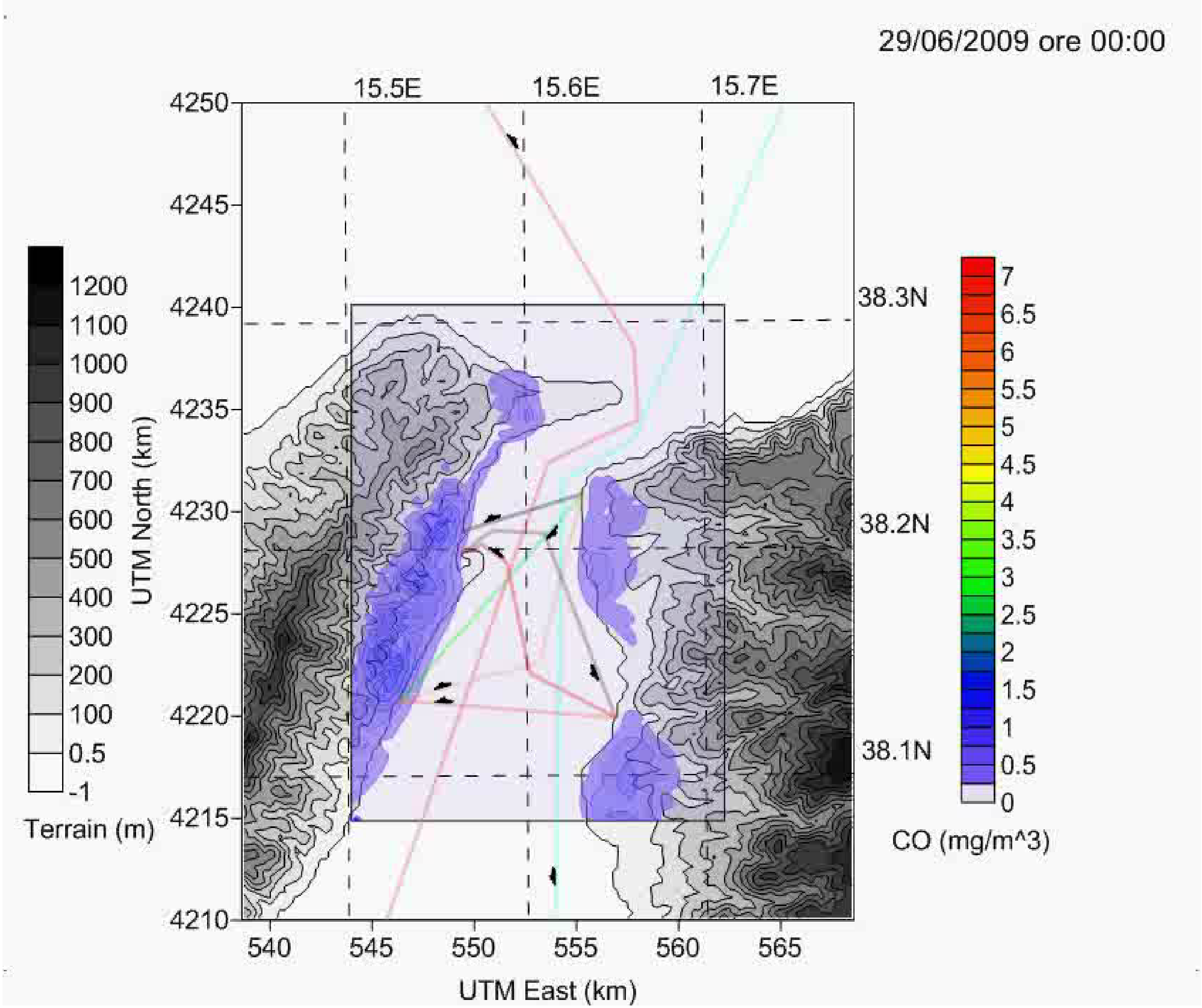
- The estimation of the vehicular emissions was realized by referring to the year 2009

- For each areal source, four strengths were considered, one for every pollutant species:
  - ✓ CO, C_6H_6 ,Pm10, Nox

- ✓ By applying the inverse method is then determined the value of vehicle emissions. From this information we proceeded throughout 2009 to the simulation with the CALPUFF model.

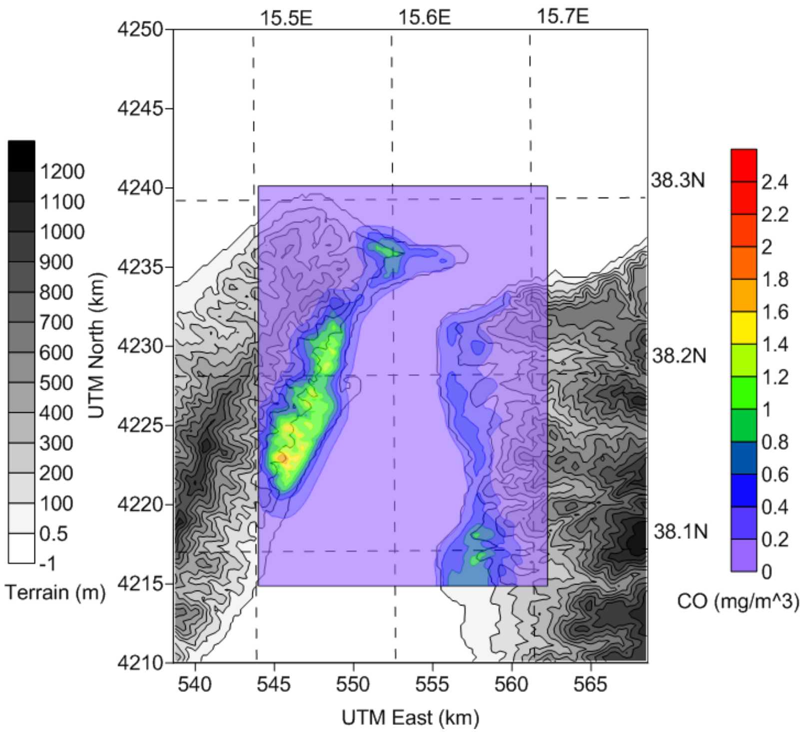
Simulation results (CALPUFF)

CO dispersion in typical summer condition, 29 May – 4 June 2009

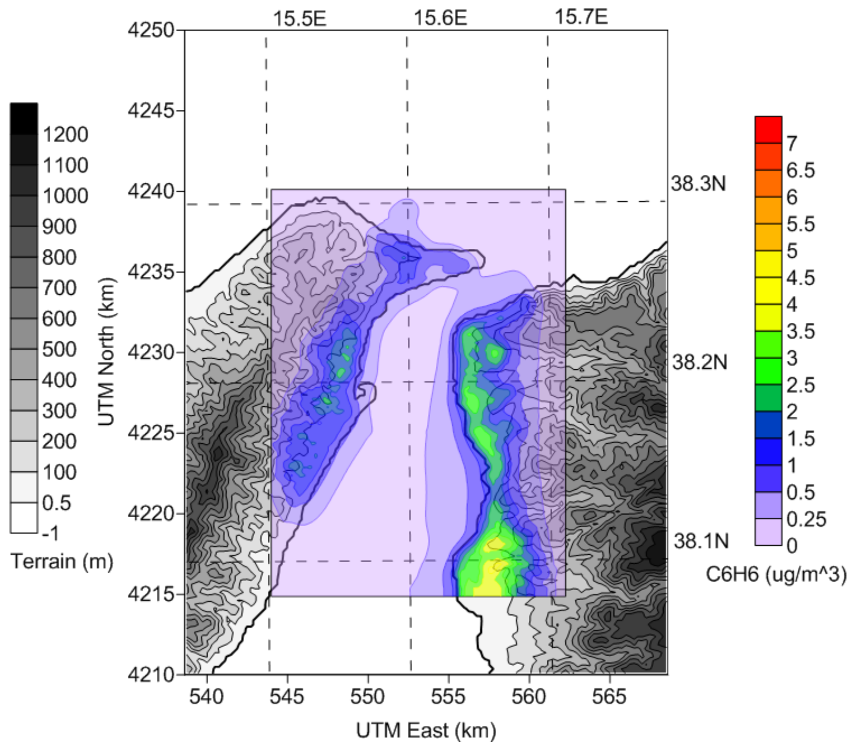


Simulation results (CALPUFF)

Average concentration for the year 2009



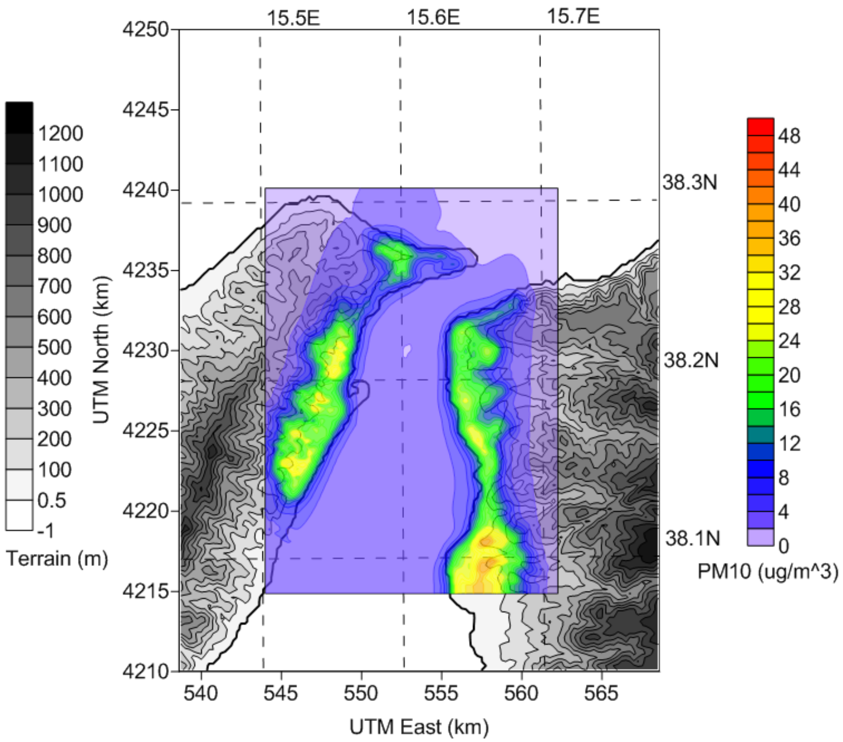
CO (mg/m^3)



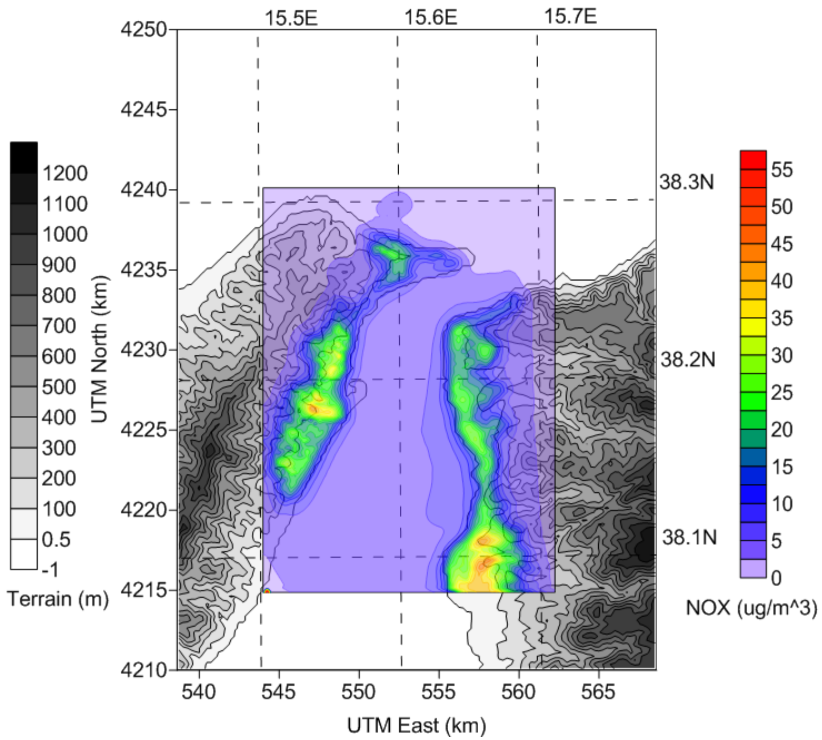
C_6H_6 (μg/m^3)

Simulation results (CALPUFF)

Average concentration for the year 2009



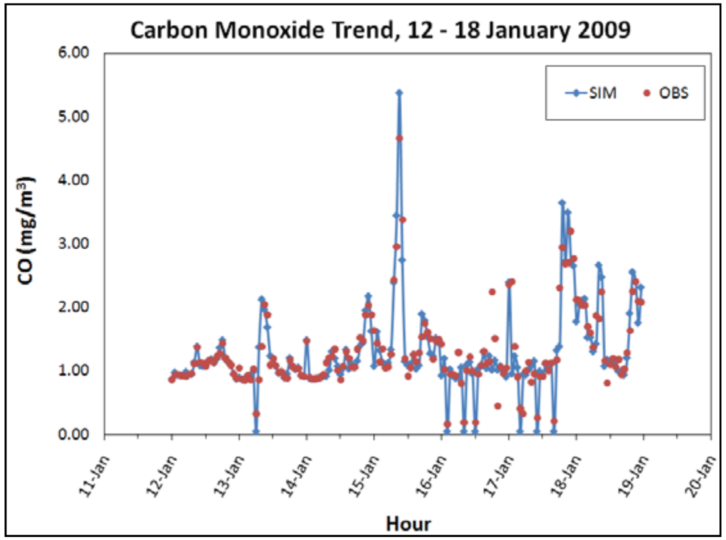
Pm10 ($\mu g/m^3$)



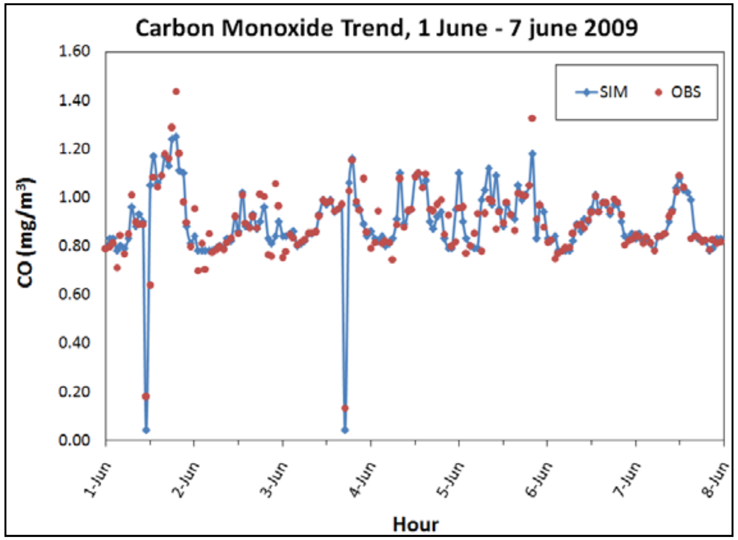
NO_X ($\mu g/m^3$)

CO - Time series

Winter



Summer



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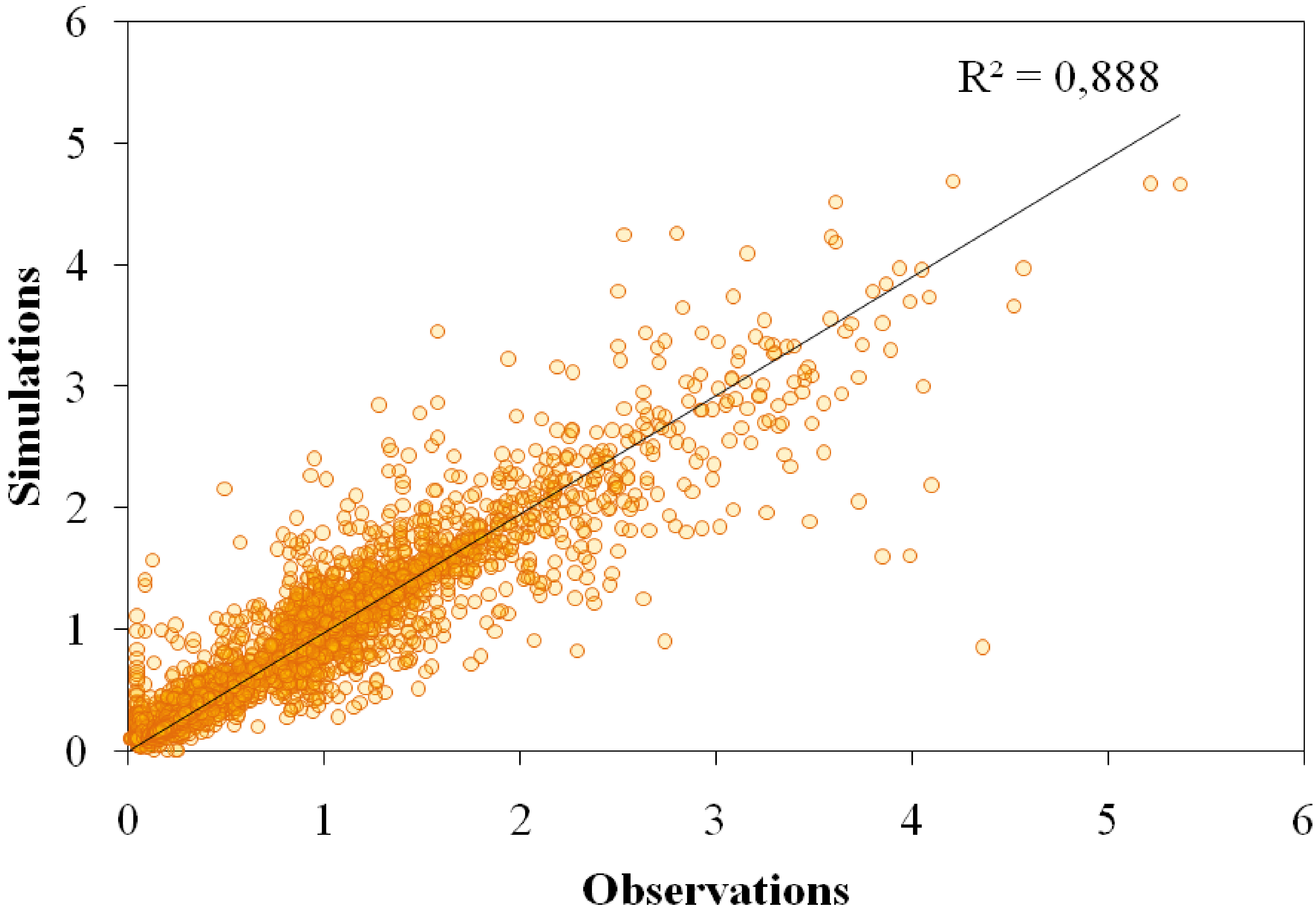
Carbon Monoxide (2009)



Preliminary Validation (2009)

✓Fractional Bias:

('acceptable' model performance values: -0.3 < FB < 0.3)

$$FB = \frac{(\overline{C_o} - \overline{C_S})}{0.5(\overline{C_o} + \overline{C_S})}$$

✓Index of Agreement:

(0<IA<1, 1 indicating the best agreement)

$$IA = 1 - \frac{\sum_{i=1}^{n} \left(C_S^i - C_O^i\right)^2}{\sum_{i=1}^{n} \left(\left|C_S^i - \overline{C_O}\right| + \left|C_O^i - \overline{C_O}\right|\right)^2}$$

Boccetta	**CO**	**PM10**	**C_6H_6**
FB (-2<FB<2)	-2.1E-03	-2.8E-03	-3.4E-03
IA (0<IA<1)	0.972	0.970	0.975

✓The extimated concentrations fit well with the observations for all the pollutant species emitted during 2009

✓The errors are due to the unsteady effects which are not taken in to account by the method

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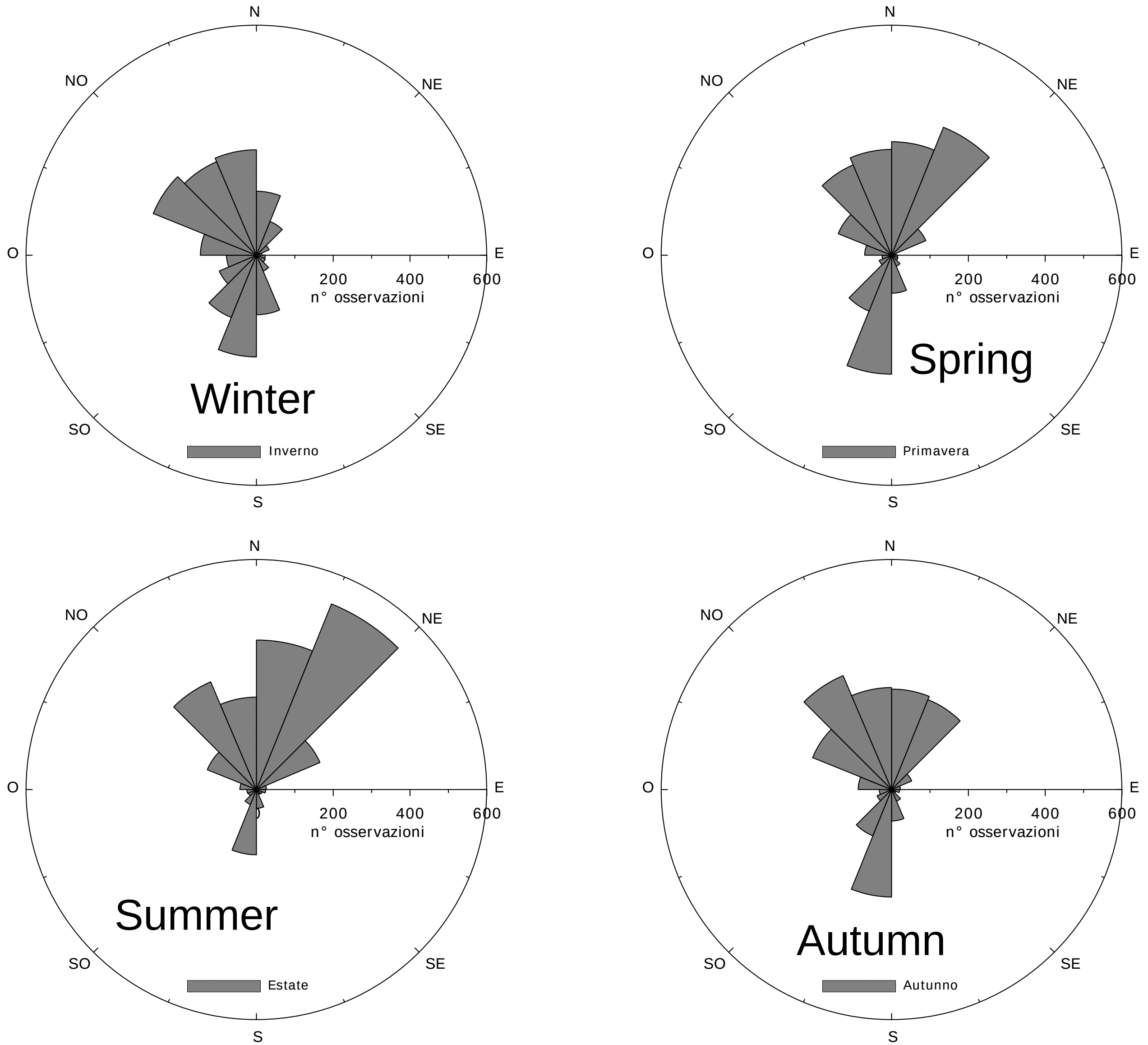
Conclusions

- ✓ An extensive campaign was conducted for 5 years
- ✓ An inverse method based on the model CALPUFF was developed
- ✓ The metrics prove the applicability of the method also in unsteady conditions
- ✓ The proposed technique can be extended to periods when some accumulation phenomena occur

Thank you for your attention!

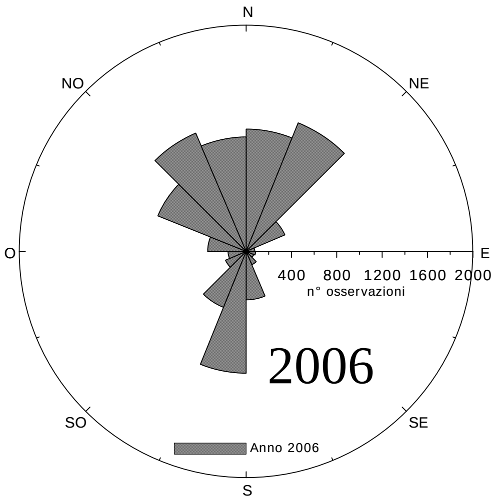
Wind seasonal regime

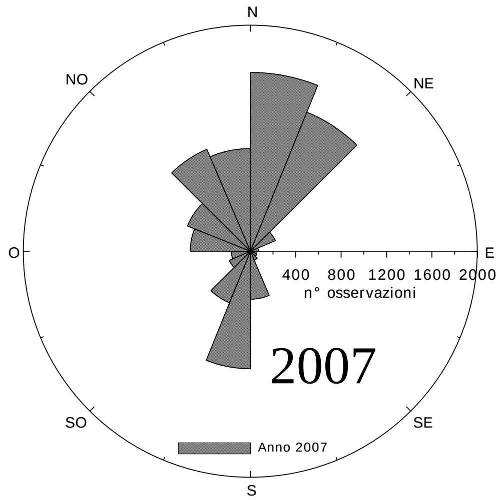
Seasonal trend, Messina wavemeter station; 2009

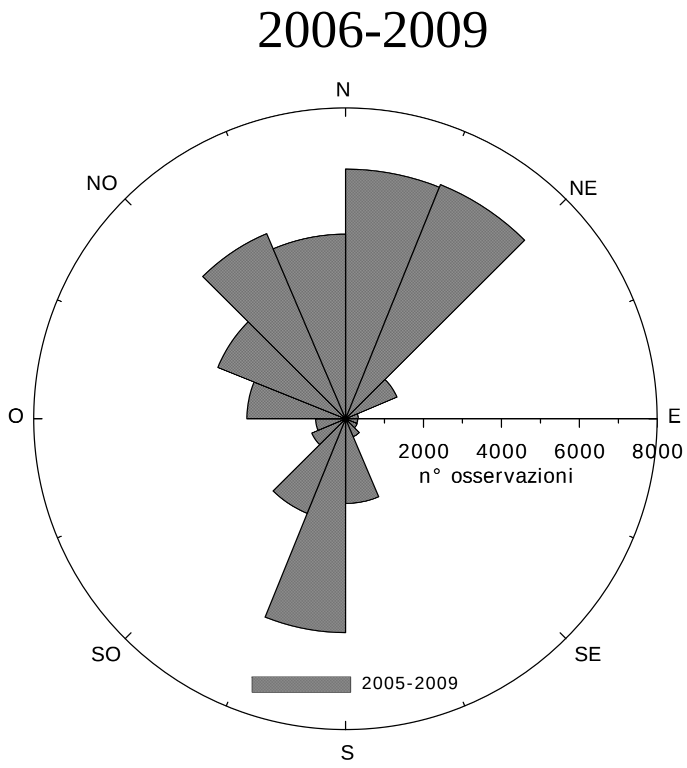


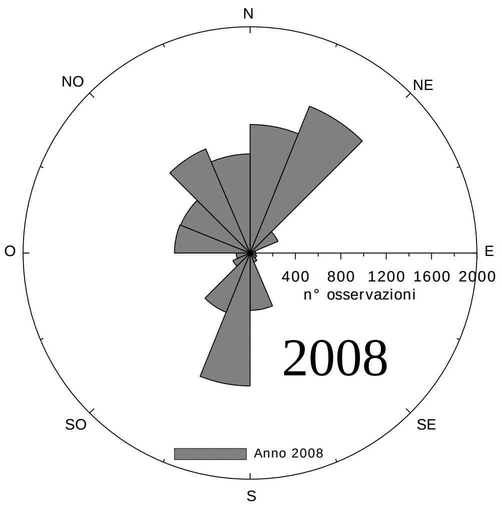
Wind regimes analysis

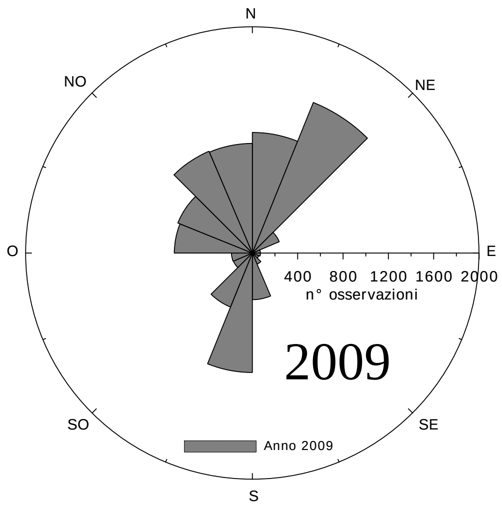
Wind Rose during 2006-2009, at Messina wavemeter station



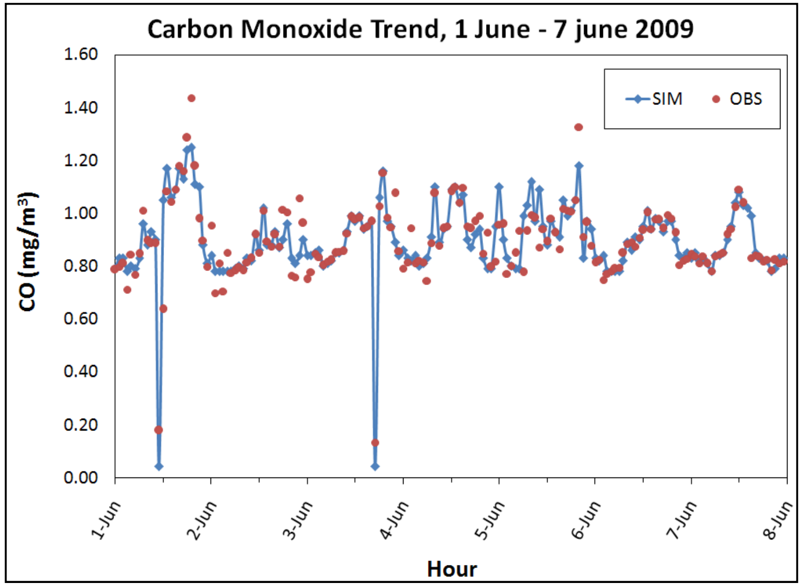


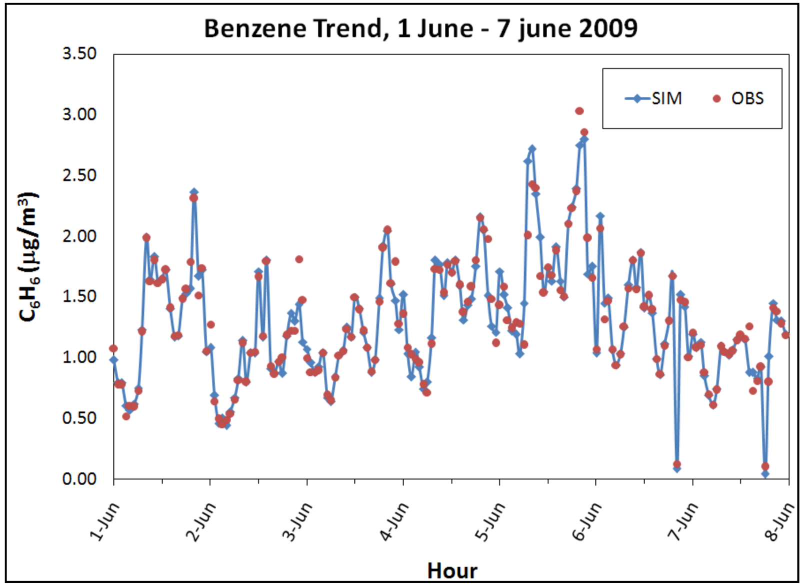




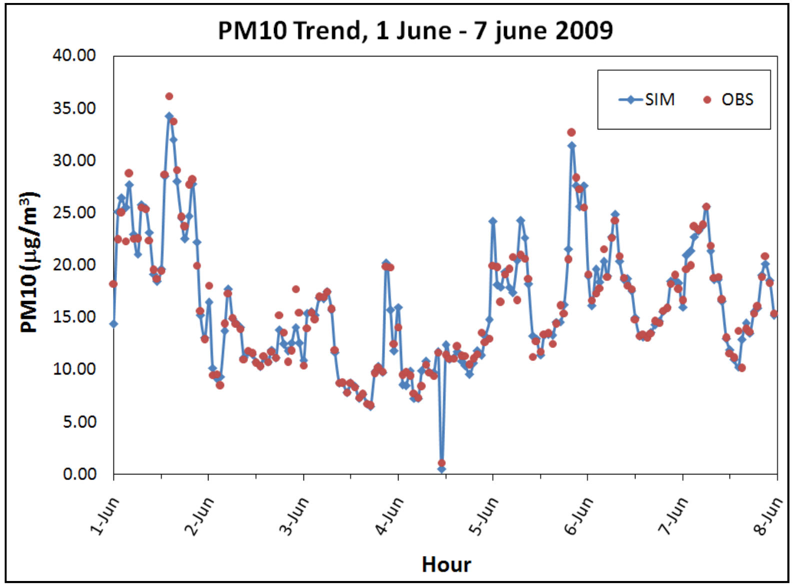


Time series- Summer

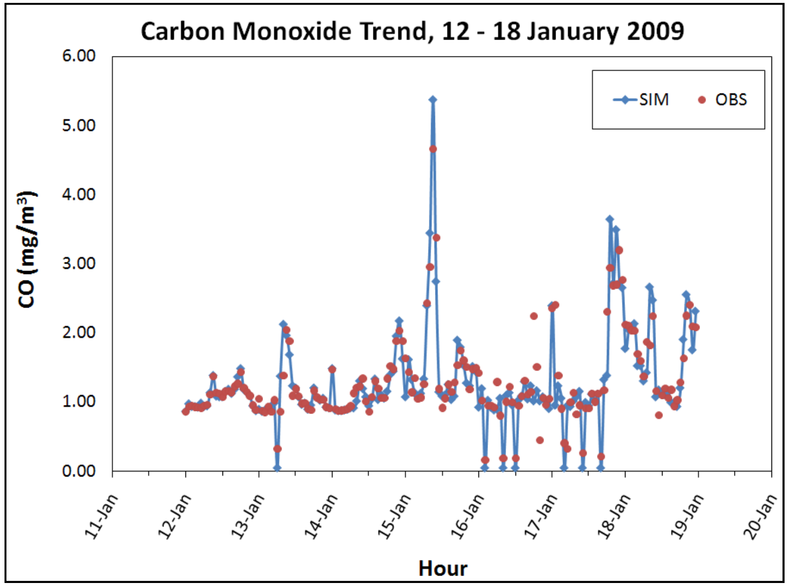


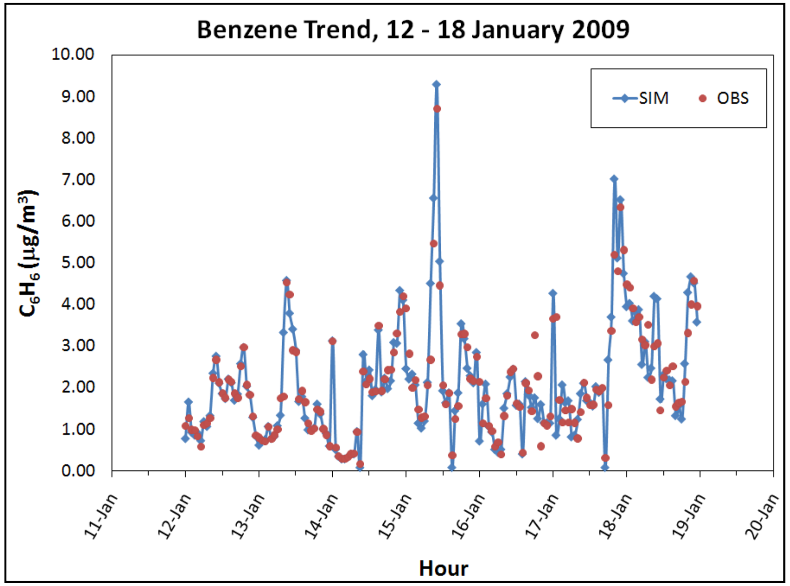


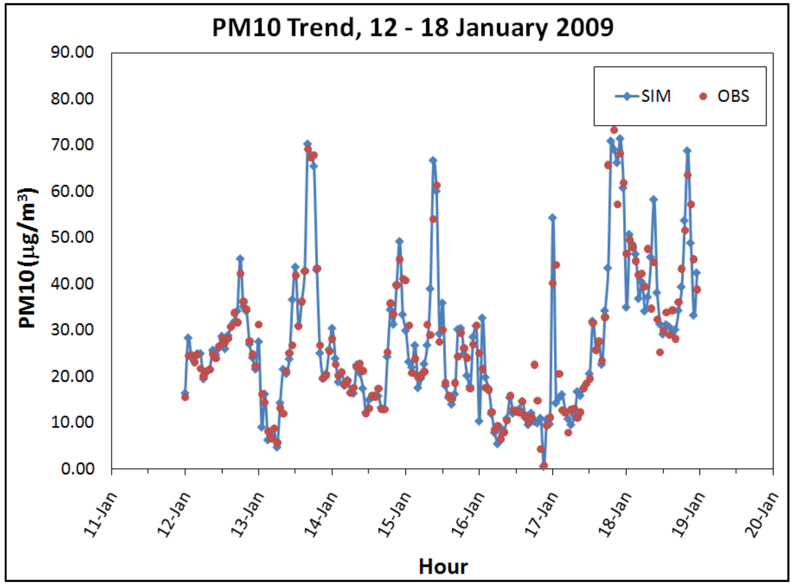
- ✓Simulated values and observation was taken at Boccetta
- ✓Good agreement with observation
- ✓Diurnal cycles



Carbon Monoxide trend - Winter







- ✓ Good agreement with observation
- ✓ Diurnal cycles
- ✓ Values greater respect to the summer trend