European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

3rd International Workshop *EuNetAir* on

New Trends and Challenges for Air Quality Control

University of Latvia - Faculty of Geography and Earth Sciences

Riga, Latvia, 26 - 27 March 2015

Air-quality modelling and chemical weather forecasting at different Scales

ARIANET

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Summary

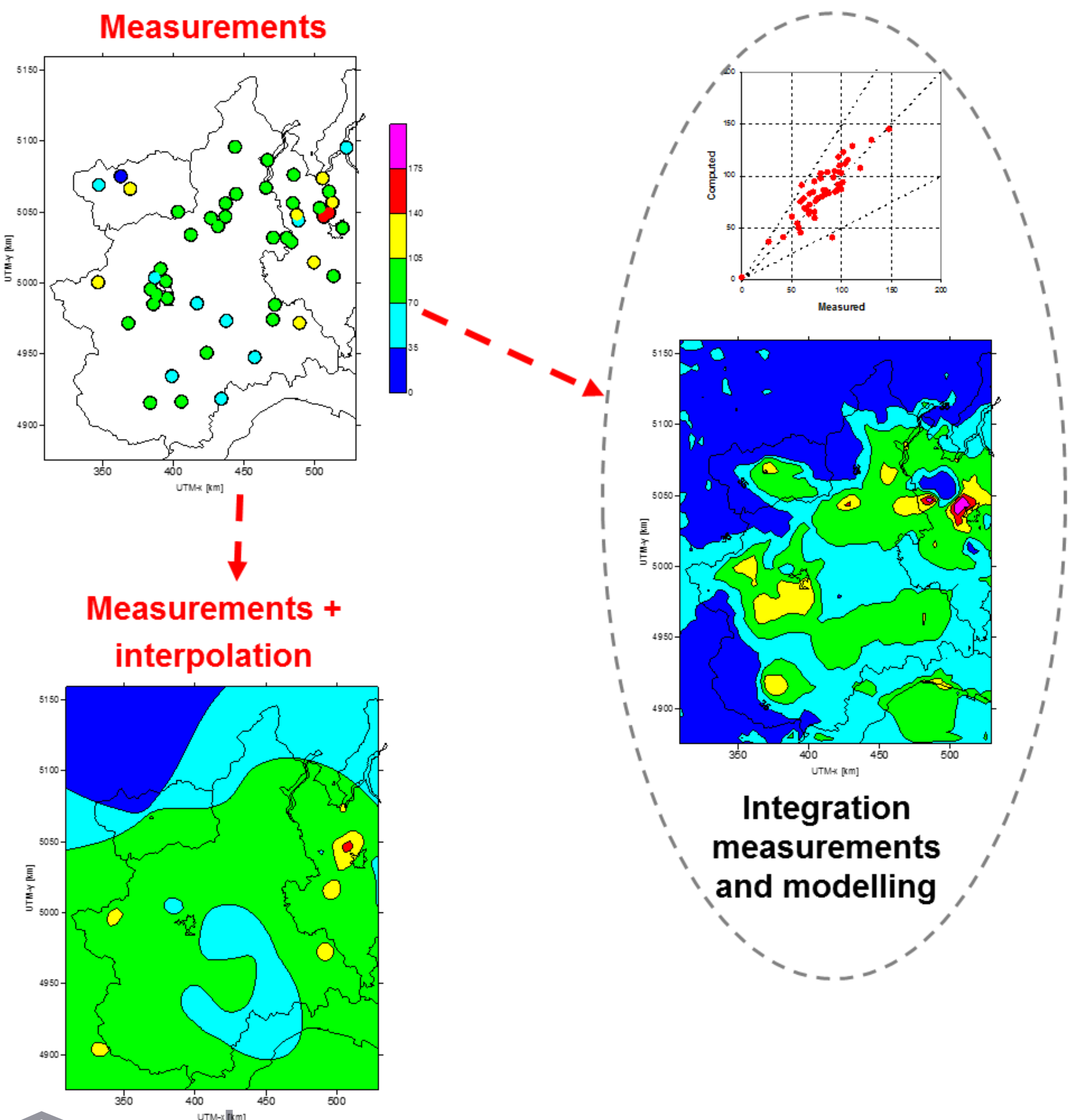
- Data assimilation;
- Uncertainties in measurements and modeling /Comparability of modeled and measured metrics;
- Examples of modelling/measurements integration
- Going toward local scales (some meters horizontal resolution);
- Conclusions and open problems

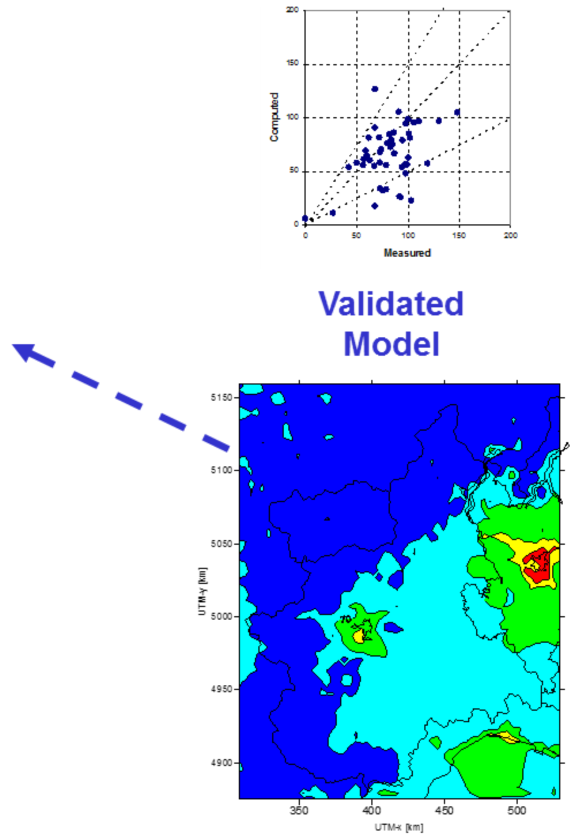
Data assimilation

Data assimilation is the process by which observations are incorporated into a computer model of a real system. […] **observations** of the current state of a system are combined with the results from a numerical model (the **forecast**) to produce an **analysis**, which is considered as 'the best' estimate of the current state of the system (analysis step).

Essentially, the analysis step tries to balance the uncertainty in the data and in the forecast.

Wikipedia
The Free Encyclopedia





Data assimilation

Optimal weight

$$T_a = T_f + \frac{\sigma_f^2}{\sigma_f^2 + \sigma_o^2}(T_o - T_f) = T_f + \frac{1}{1 + \frac{\sigma_o^2}{\sigma_f^2}}(T_o - T_f) = T_f + \frac{1}{1+\varepsilon^2}(T_o - T_f)$$

Innovation

Obs more accurate than forecast: $\sigma_f^2 >> \sigma_o^2 \Rightarrow \varepsilon^2 \rightarrow 0 \Rightarrow T_a \rightarrow T_o$

forecast more accurate than obs: $\sigma_o^2 >> \sigma_f^2 \Rightarrow \varepsilon^2 >> 1 \Rightarrow T_a \rightarrow T_f$

$$\frac{1}{\sigma_a^2} = \frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2}$$

Precision = 1/error variance

T_a prec.= T_1 prec. + T_2 prec.

Uncertainties

in measurements and modeling

An example (Particulate Matter)

Measurements errors:

- random errors (uncertainties): any measurement is made with a finite precision;
- systematic errors (biases): **a method generally (or on average) lead to data that are different from the "true" value** (e.g. reference method for PM mass concentration determination leads to systematically low values with respect to the actual PM mass concentration- in summer where NH4NO3 contributes a significant fraction to PM; EC concentration, there is currently no "true" value, because EC is methodologically defined, negative artifacts may occur due to volatilization of inorganic/organic PM, …*)*

Model uncertainties:

a) **Inputs:**

- **Emissions** (Bottom-up emission inventories are improving with inventories at high spatial and temporal resolution becoming more common)
- **Meteorology** (Winds affect the accuracy of long-range transport; Vertical mixing affects PM surface concentrations; Clouds (and fogs) enhance secondary PM formation but precipitation removes PM from the atmosphere)
- **Boundary and initial conditions** (Use of a global/regional models)

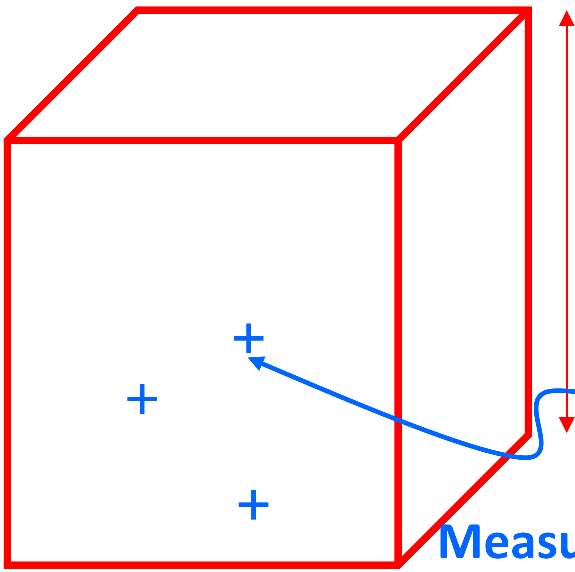
b) **Formulation (some current issues)**

- **Deposition processes**
- **Treatment of SOA** (Missing precursors, large number of condensable products, Approximations for the partitioning constants, …)

Comparability of modeled and measured metrics

How well can point measurements represent grid cell averages ?

Calculated concentrations are averaged within the lowest model layer

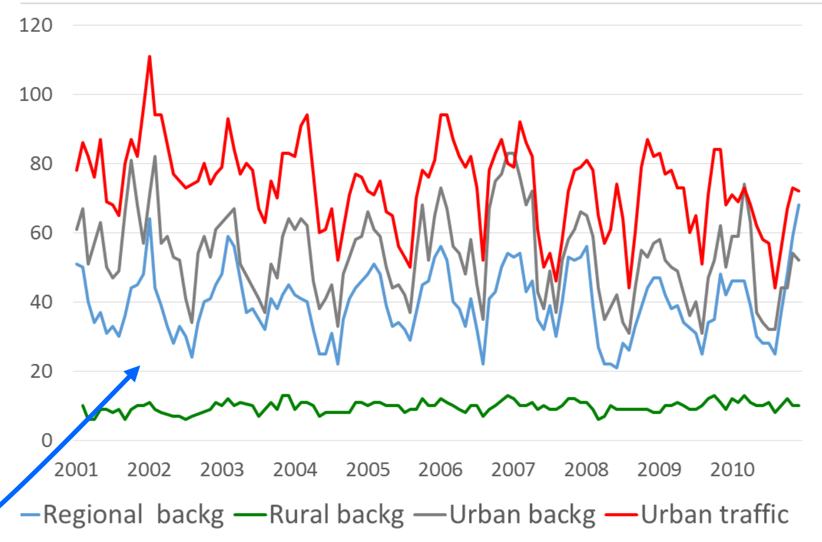


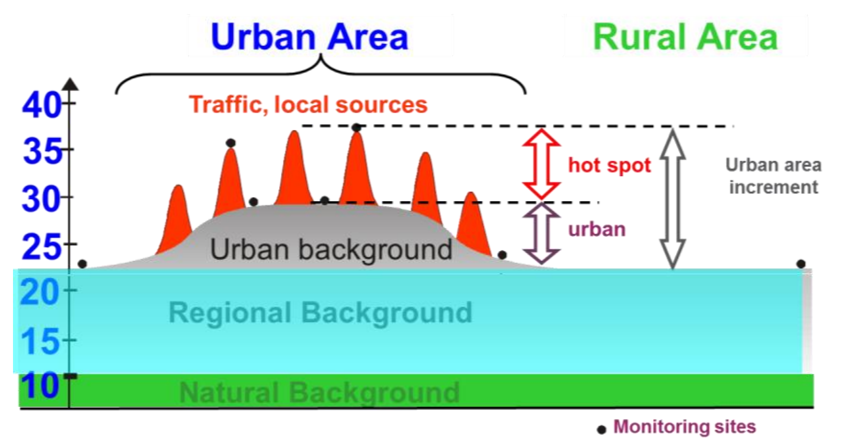
Cell depth ($\Delta z \approx$ 20-50 m)

Horizontal resolution ($\Delta x \approx$ 1-5 km)

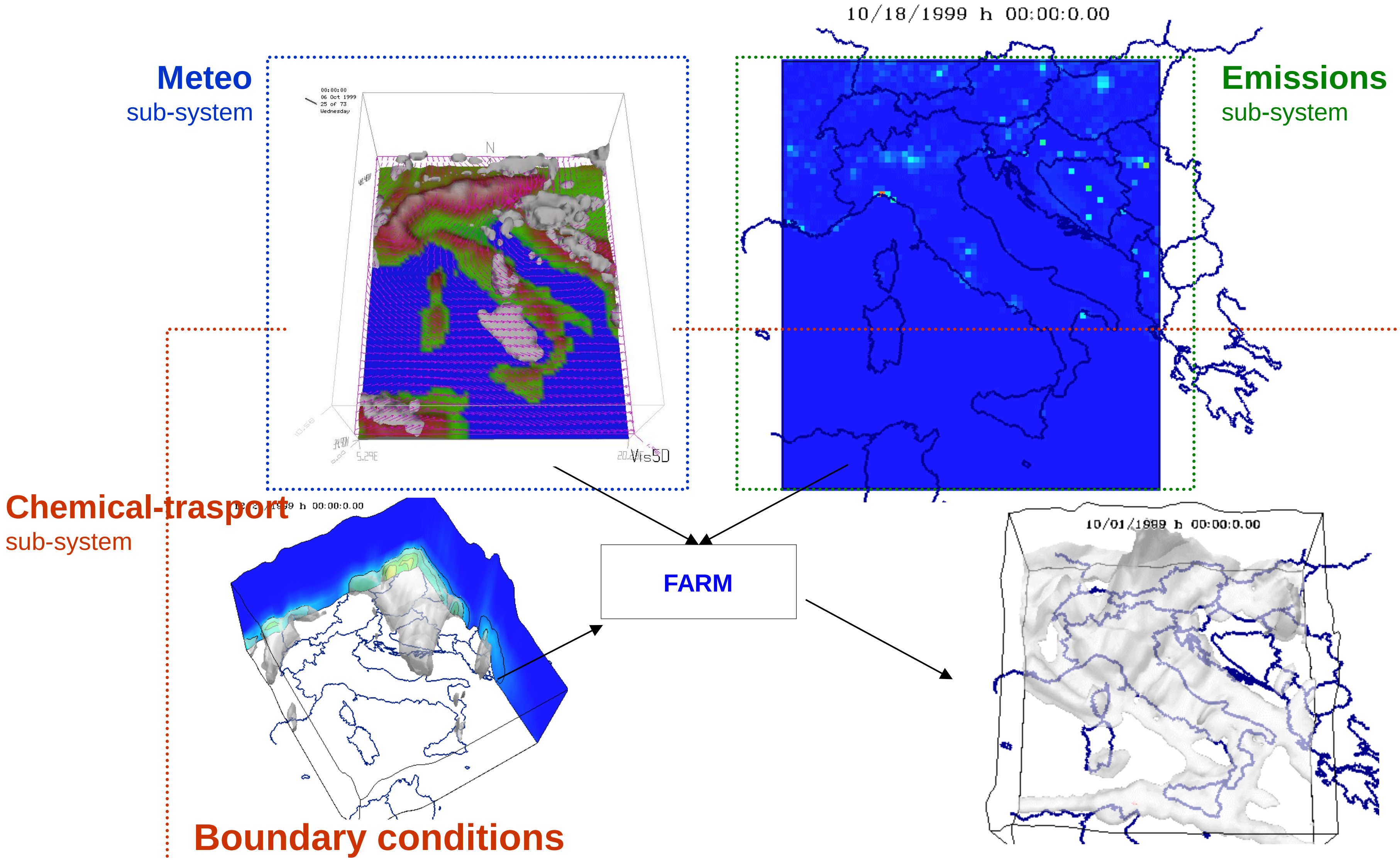
Measurements at ground

(spatial representativeness – L_{repr} - Example: L_{repr}: 10, 4 and 1 km respectively for rural, suburban and urban stations)





An Atmospheric Modelling System



Flexible Air quality Regional Model (FARM)

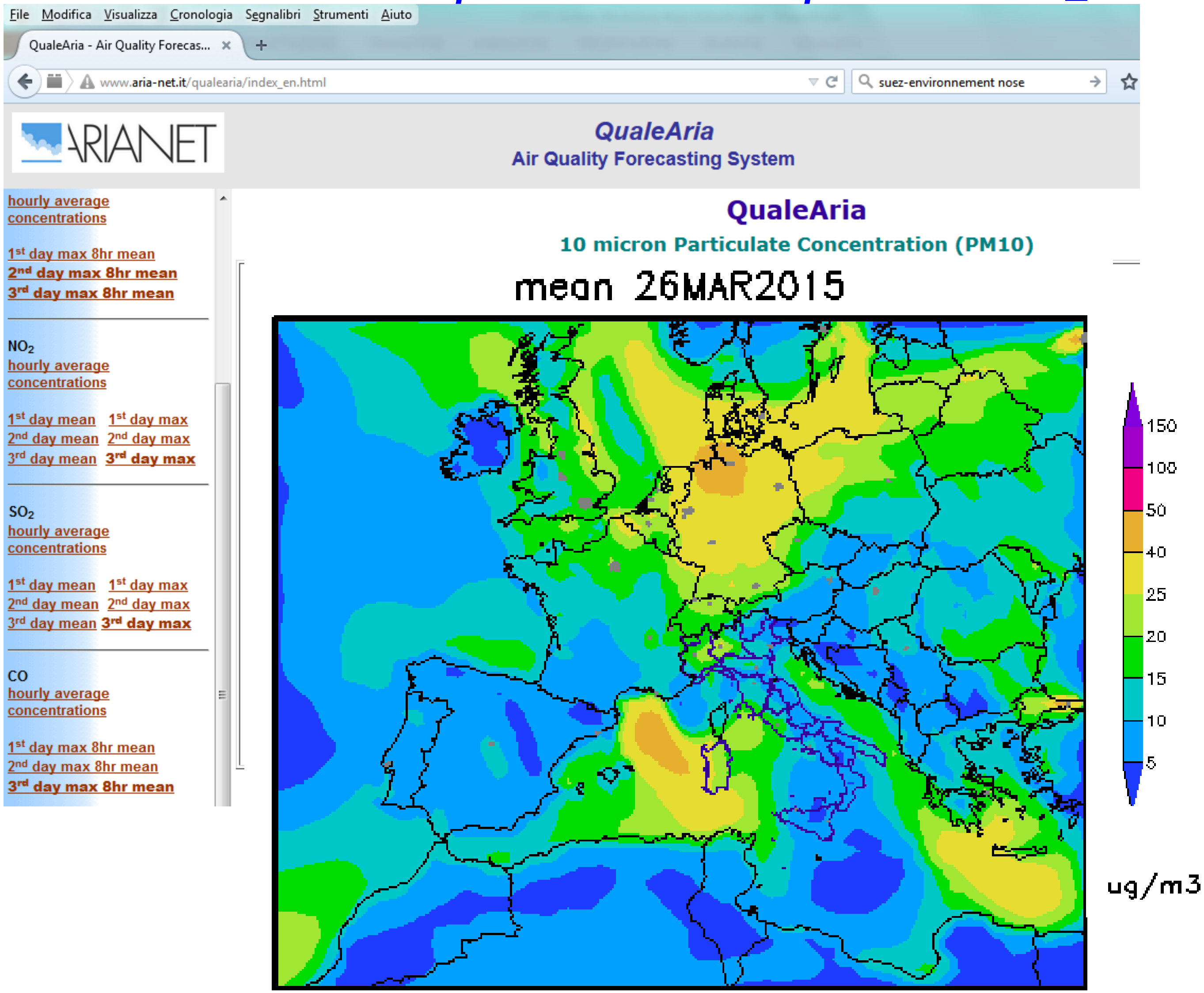
Main features and developments:

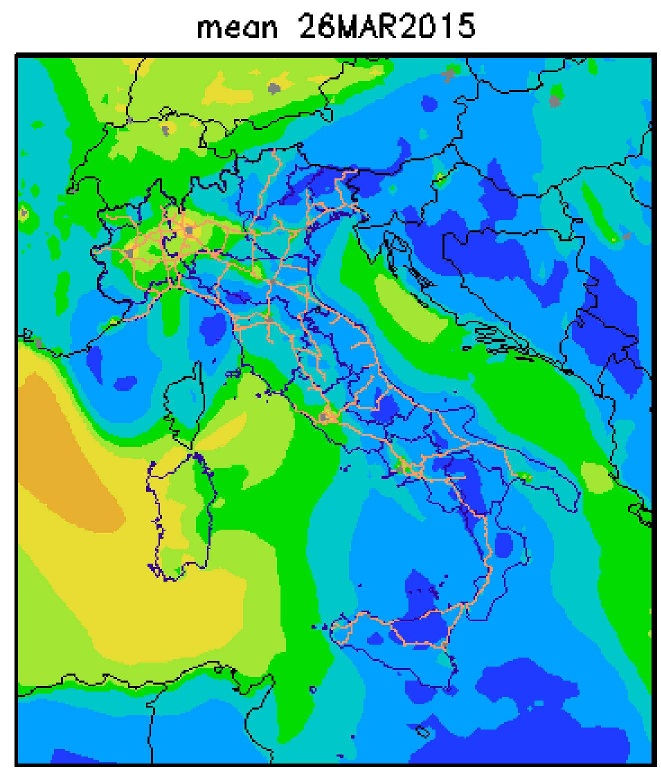
- ✓ Inclusion of **map factors** and **different coordinate systems;**
- ✓ **Emission** of pollutants from area and point sources, with plume rise calculation and mass assignment to vertical grid cells; 3D emissions allowed;
- ✓ **3D dispersion** by advection and turbulent diffusion;
- ✓ Transformation of chemical species by **gas-phase chemistry**, with flexible mechanism configuration through KPP pre-processor (KPP, Kinetic Pre-Processor: Damian et al, 2002; Sandu et al., 2003; Daescu et al. 200);
- ✓ Treatment of **PM**10 and PM2.5;
- ✓ **Dry removal** of pollutants dependent on local meteorology and land-use;
- ✓ Removal through **precipitation scavenging** processes;
- ✓ One and two-way **nesting** on arbitrary number of grids;
- ✓ Treatment of additional inert **tracers;**
- ✓ Inclusion of **data assimilation** techniques;
- ✓ Online calculation of photolysis rates using **TUV** model (Tropospheric Ultraviolet and Visible radiation model; Madronich *et al*, 1989);
- ✓ **Parallel processing** using **OpenMP, MPI and Hybrid** paradigms;
- ✓ **SW management and code optimization.**

FARM is an Open Source CTM available at:
https://hpc-forge.cineca.it/

QualeAria forecast system

http://www.aria-net.it/qualearia/index_en.html





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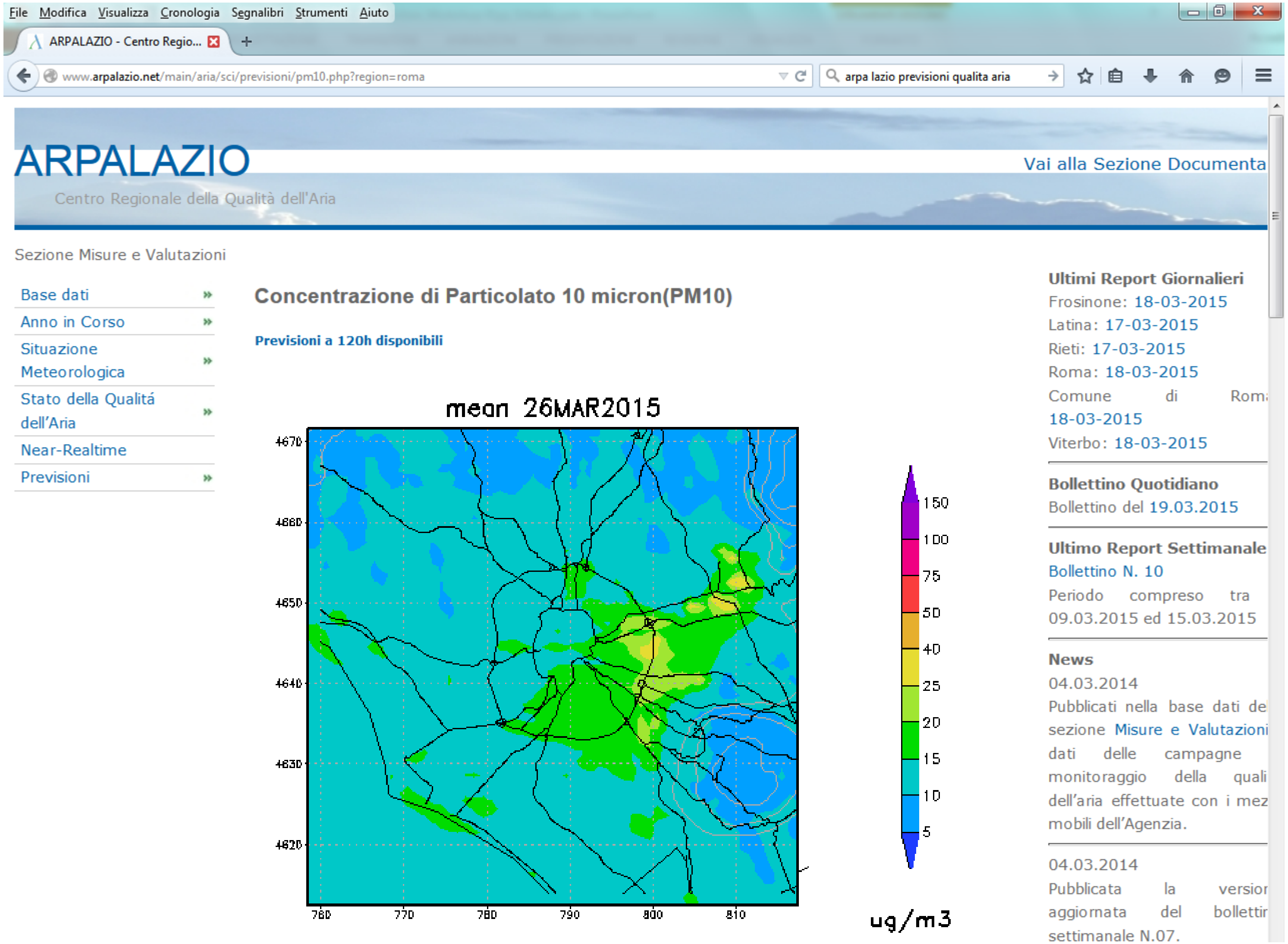
Rome Air Quality Forecast System



http://www.arpalazio.net/main/aria/sci/previsioni/pm10.php?region=roma

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ARPALAZIO
AGENZIA REGIONALE PROTEZIONE AMBIENTALE DEL LAZIO

Bias adjustment forecast techniques

Kalman Filter (KF, Delle Monache *et al.*, JGR 2006):

A recursive algorithm […] in which information from recent past forecasts and observations is used to revise the estimate of the current raw forecast.

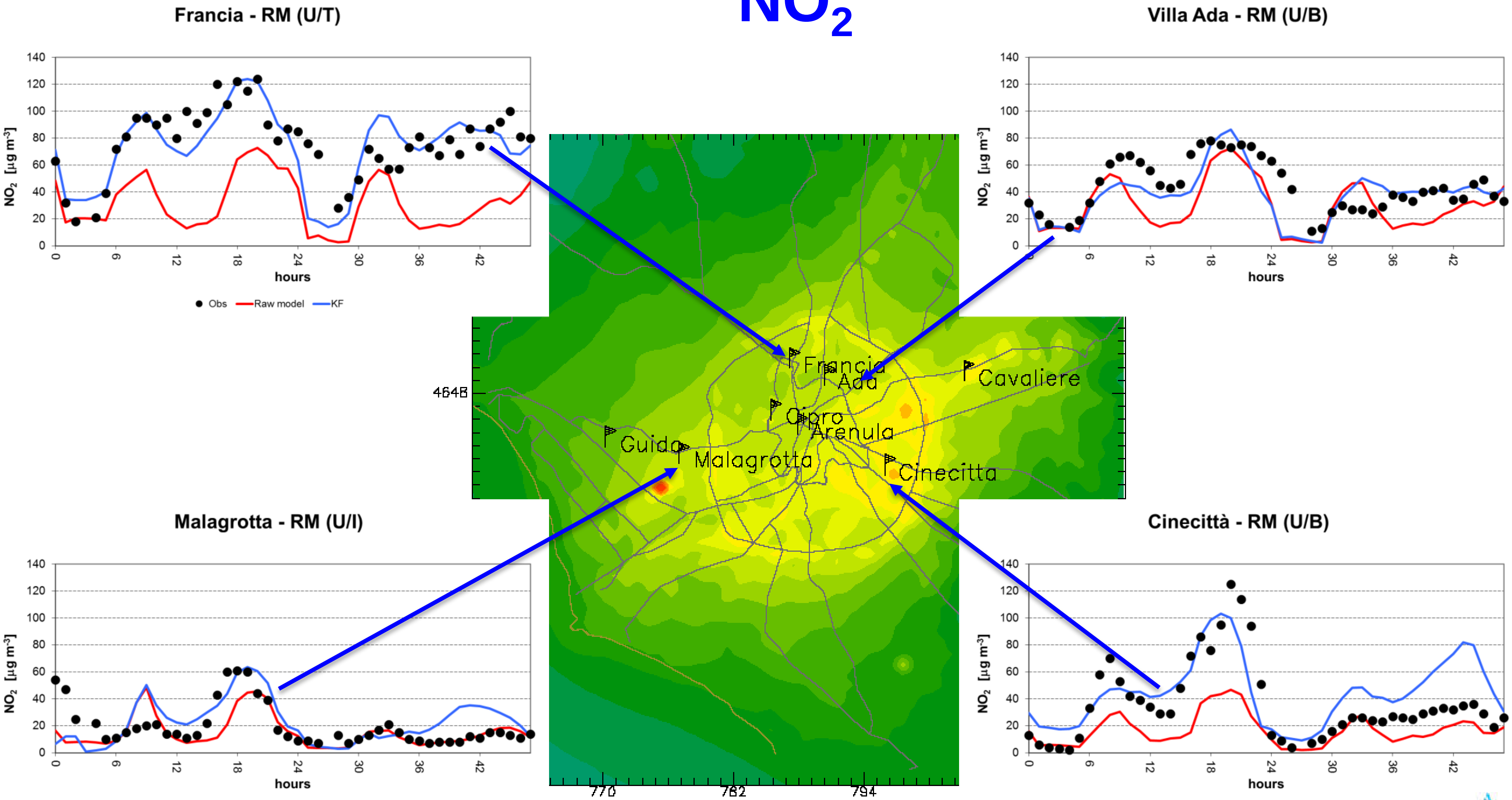
The new KF forecast can be formed with the model forecast as:

$$KF_{t_n} = f_{t_n} - \hat{x}_{t_n}$$

where $\hat{x}_{t_n}$ in an optimal predictor of the forecast bias.

Bias adjustment forecast techniques

NO_2



● Obs — Raw model — KF

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Rome Air Quality Forecast System

ROMATODAY

CRONACA EVENTI ZONE SEGNALA

ZONE Centro Storico Esquilino Eur Ostia Laurentina Trastevere Testaccio San Giovanni Tutte le zone

Blocco del traffico: stop ai veicoli più inquinanti venerdì 9 gennaio

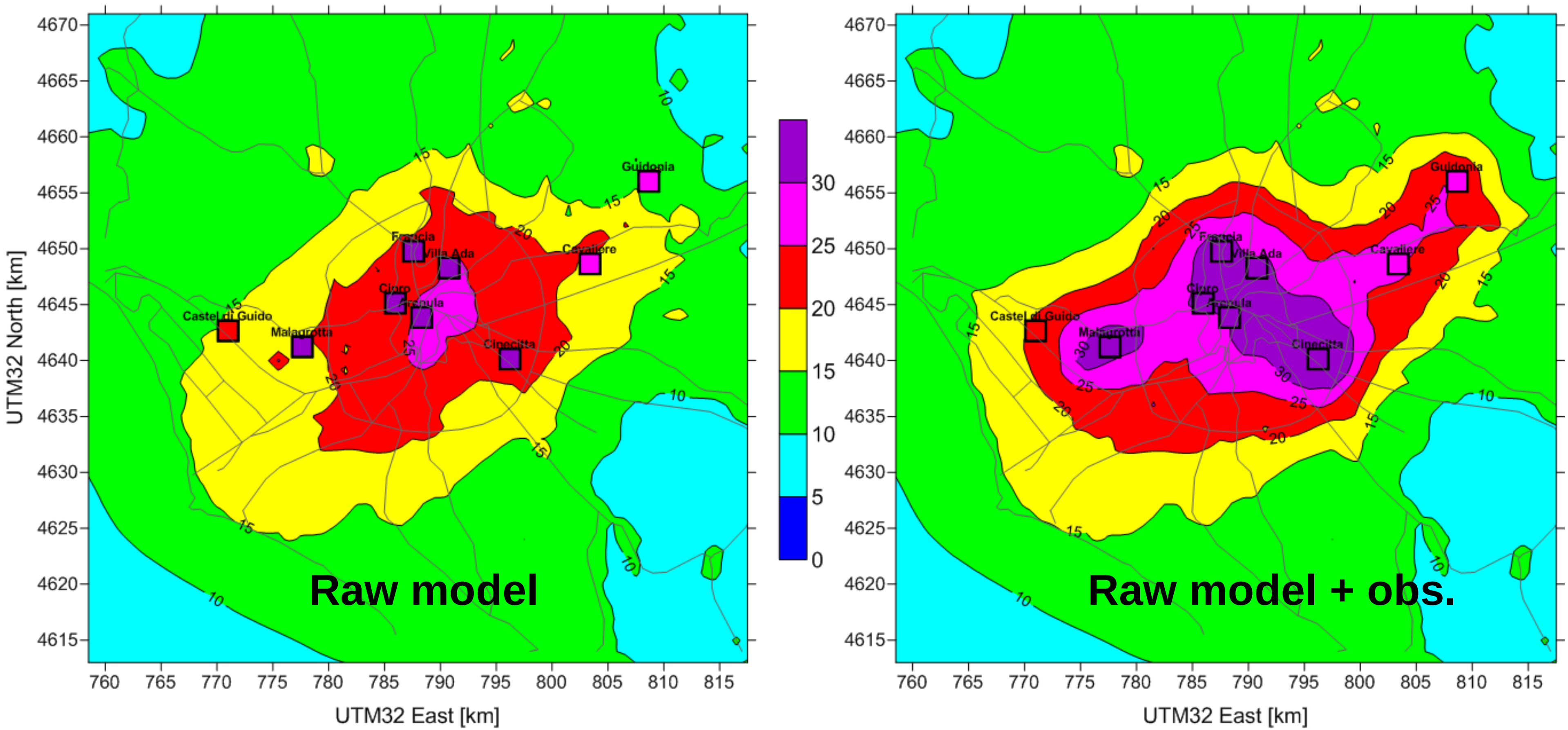
Il blocco per domani, venerdì 9 gennaio, interessa l'area all'interno della Fascia Verde. E le categorie di autoveicoli più inquinanti. Sarà attivo dalle 7 e 30 alle 20.30

RT Redazione · 8 Gennaio 2015 5 Consiglia 339

Ancora smog oltre gli standard. A causa di un'alta concentrazione di inquinanti nell'atmosfera, come rilevato dai superamenti registrati in molte centraline, e considerate le previsioni Arpa, che indicano condizioni di criticità, l'Amministrazione capitolina ha disposto per la giornata di domani, 9 gennaio 2015, dalle 7.30 alle 20.30, il blocco emergenziale della circolazione veicolare all'interno della Fascia Verde.

Life + Project EXPAH
(population EXposure to PAH)

January 2012 - $PM_{2.5}$ Monthly averages [$\mu g\ m^{-3}$]

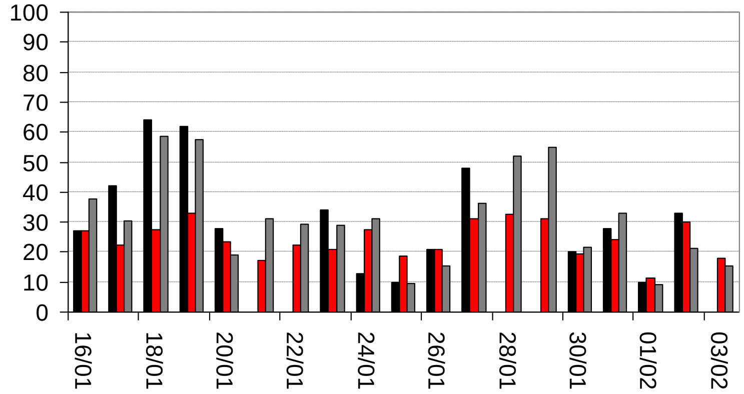


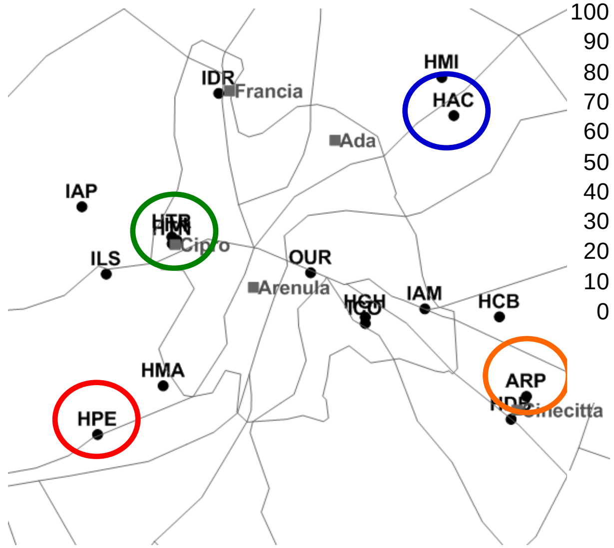
Silibello, C., Bolignano, A., Sozzi, R., Gariazzo, C. (2014) Application of a chemical transport model and optimized data assimilation methods to improve air quality assessment. *Air Quality, Atmosphere & Health*, 7, 3, 283-296.

$PM_{2.5}$ Evaluation at EXPAH sites

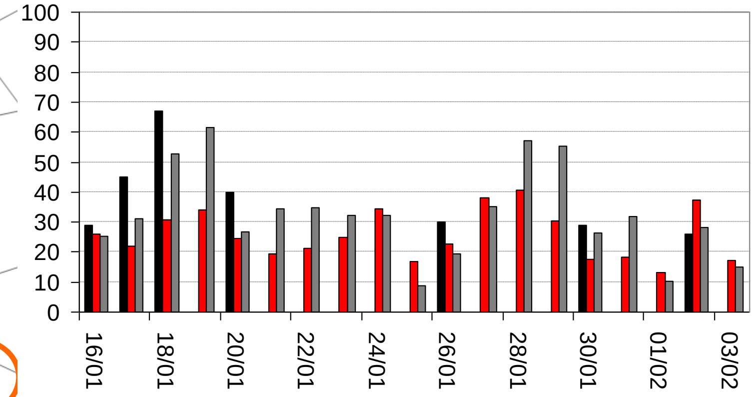
Not used in "data assimilation" process !

HTR

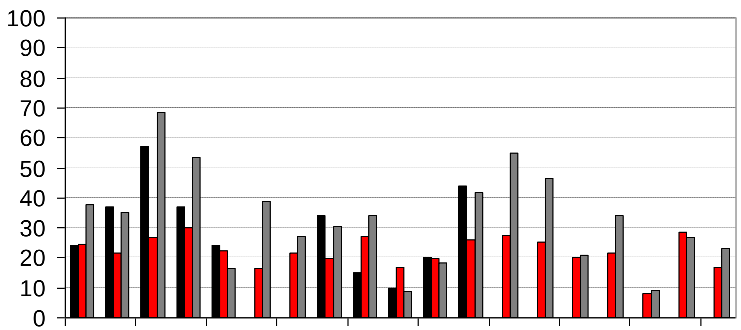




HAC

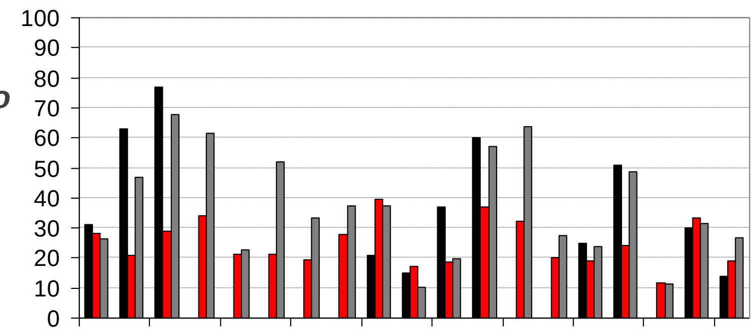


HPE



Black circles (●) and grey squares (■) correspond to EXPAH and Lazio Region monitoring sites.

ARP



■ Measured ■ 100% model ■ Data Fusion

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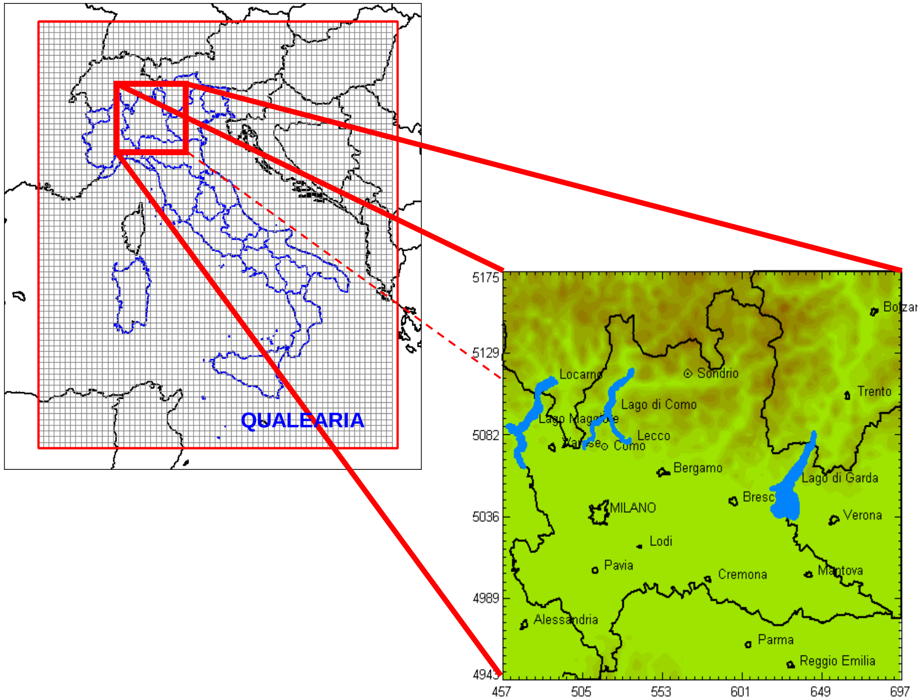
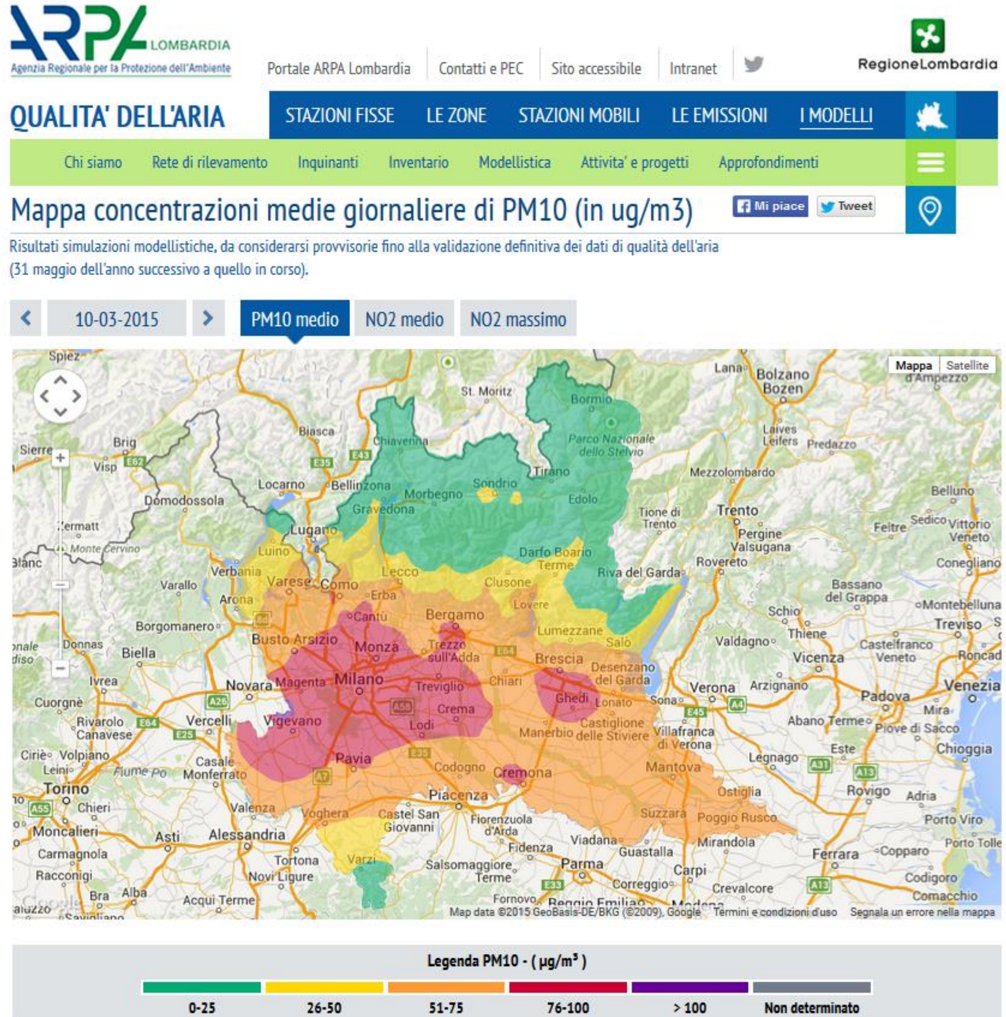
Lombardy (Northern Italy) NRT system



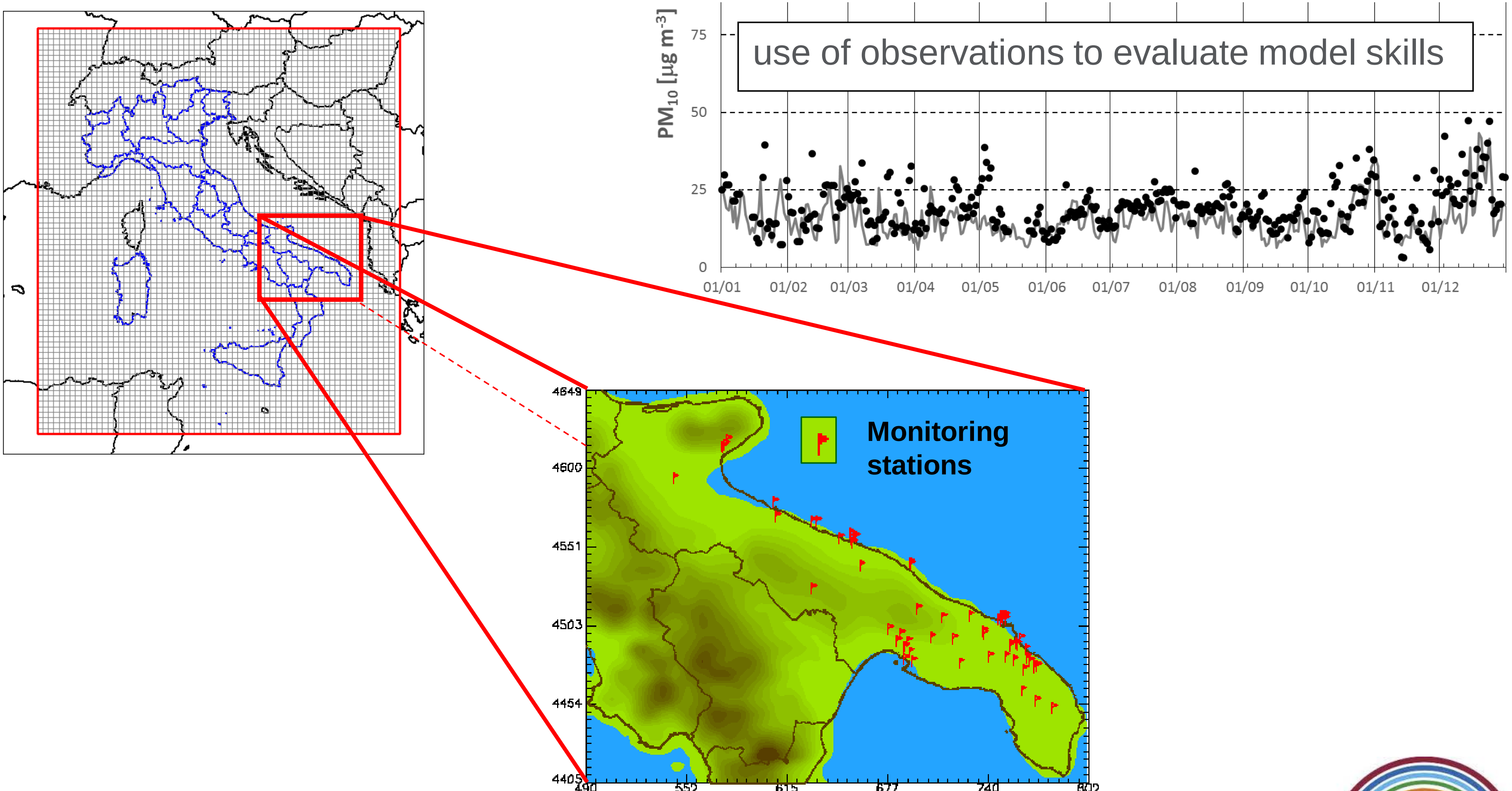


The Regional Environmental Protection Agency (ARPA) uses past (yesterday) concentration fields (provided by FARM model) and observations (from regional monitoring network) to produce Near Real Time (NRT) air quality maps

http://www2.arpalombardia.it/sites/qaria/_layouts/15/qaria/IModelli.aspx

An example of air quality assessment

Apulia Region – Southern Italy



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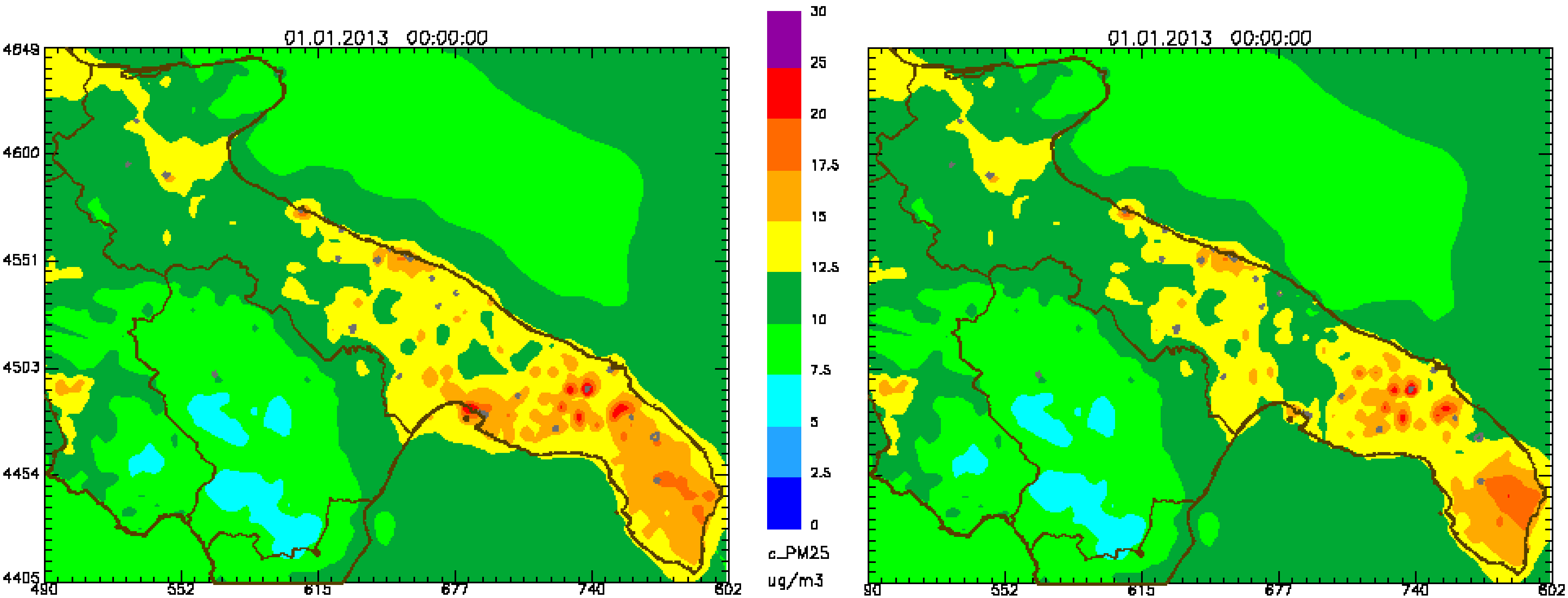
An example of air quality assessment

$PM_{2.5}$

Min = 6.539 – Max = 27.78 [ug/m3]

Min = 6.539 – Max = 27.04 [ug/m3]

integration of model results and observations



Raw model

Raw model + obs.

Yearly average limit value: 25 $\mu g\ m^{-3}$

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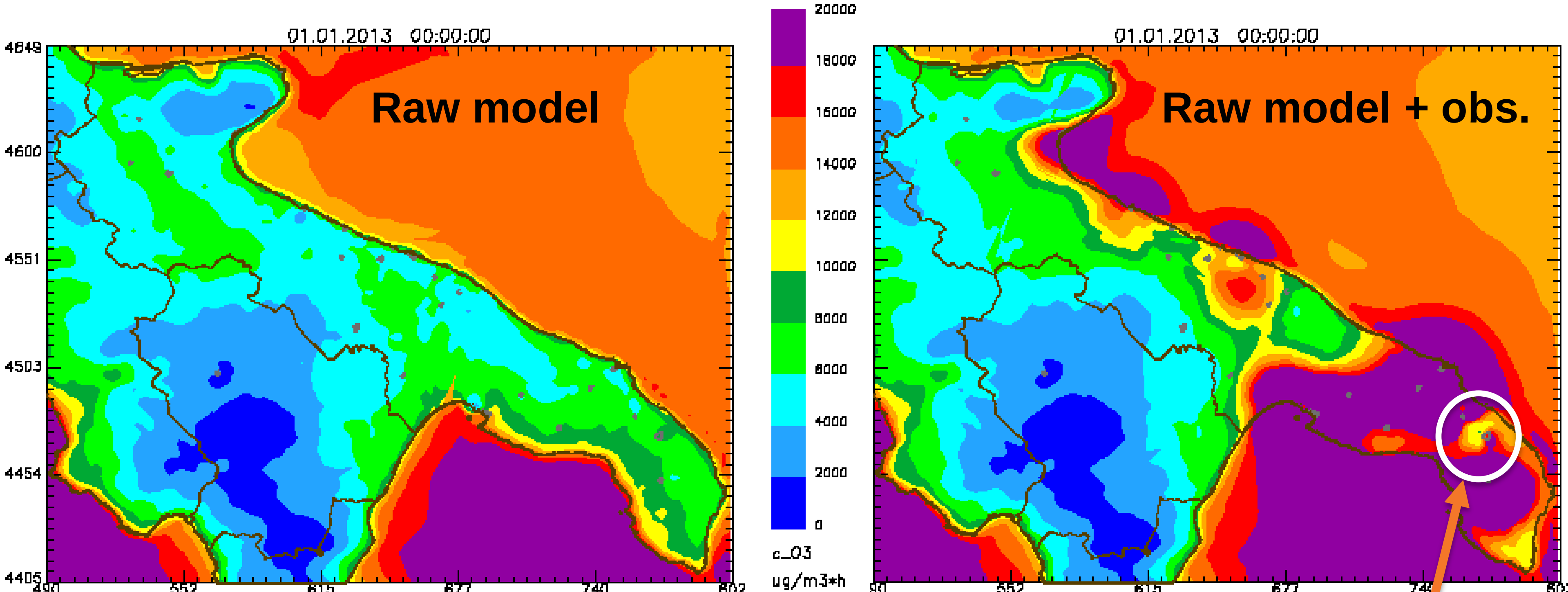
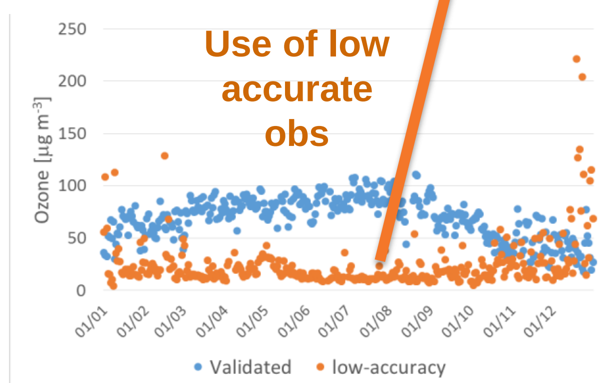
An example of air quality assessment

O_3





AOT40 – limit value 18000 $\mu g\ m^{-3}\ h$

AOT40 means accumulated amount of ozone over the threshold value of 40 ppb

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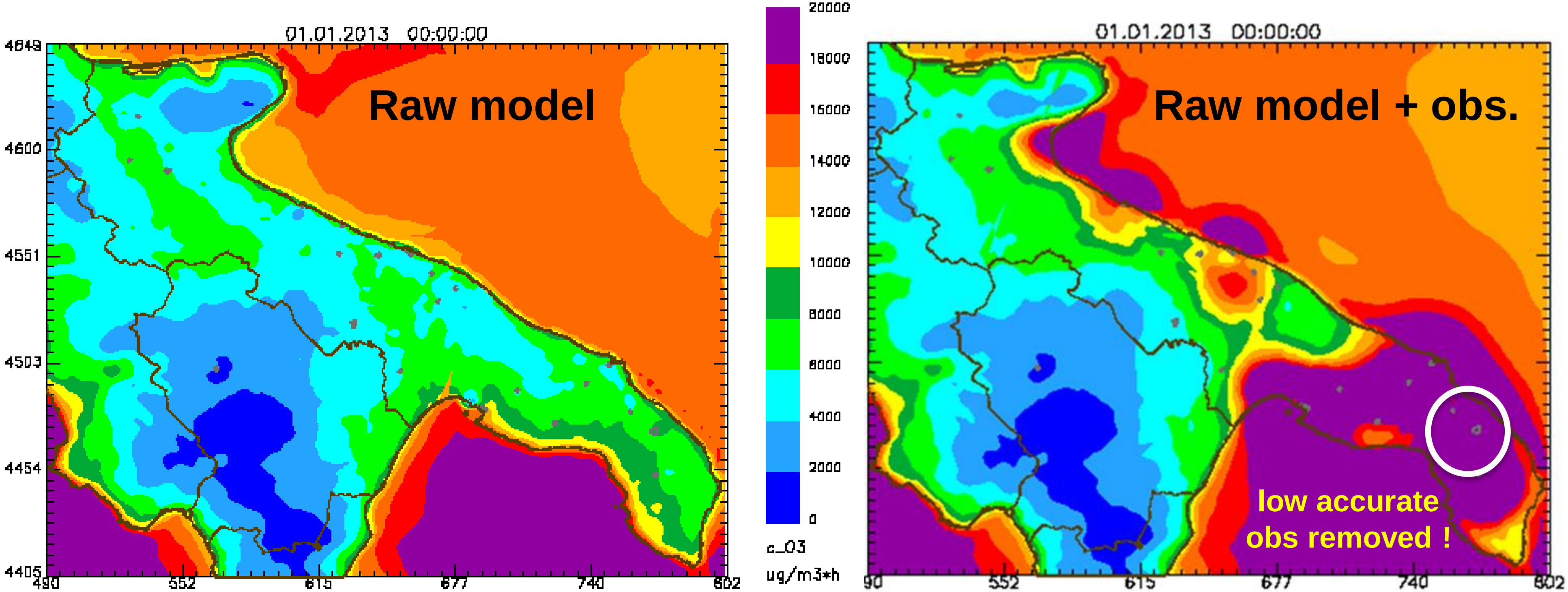
An example of air quality assessment

O_3



AOT40 – limit value 18000 $\mu g\ m^{-3}\ h$

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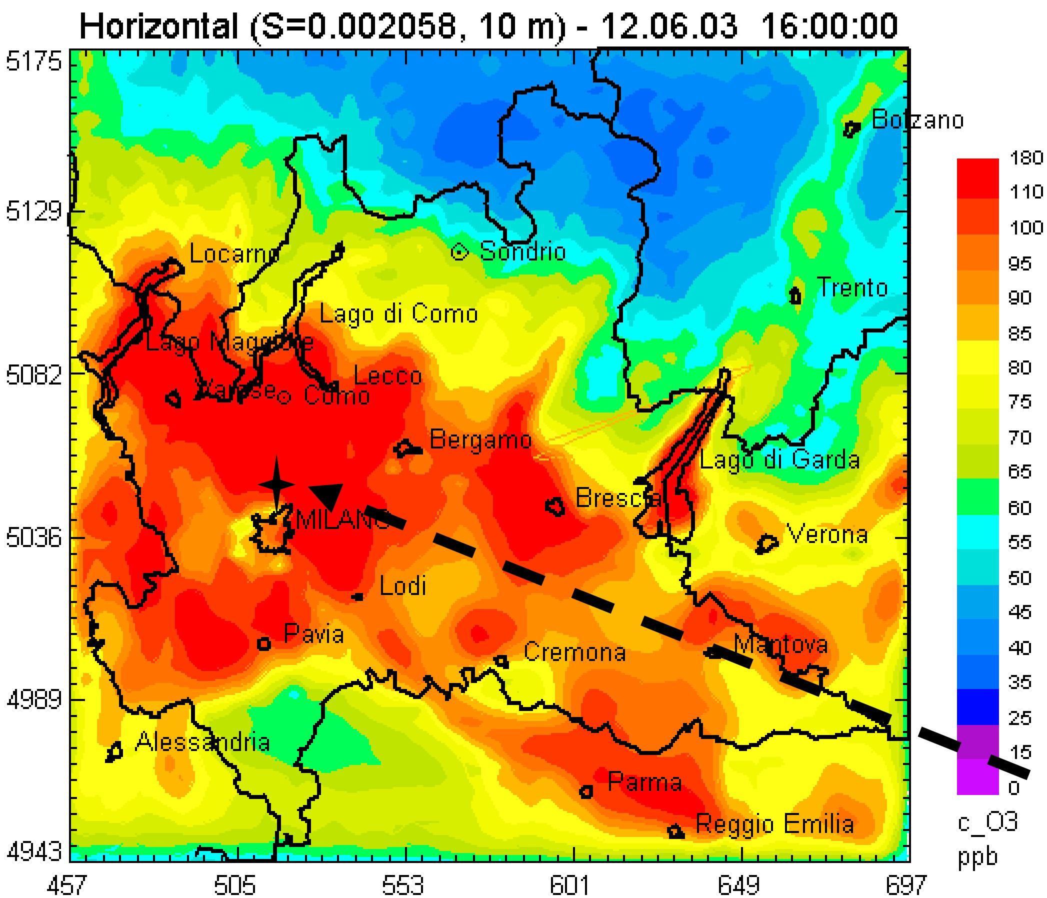
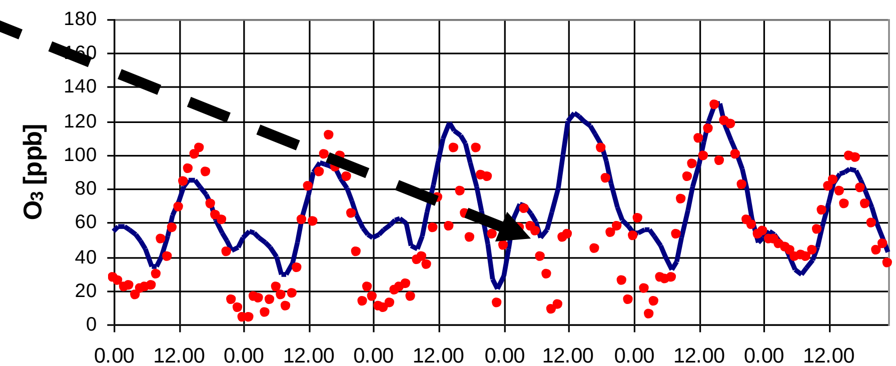
Models support measurements interpretation
"Ozone nocturnal peak"



Computed Measured



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Torino MSS simulation

ELISE
ENVIRONMENT LIVE SENSING

<u>Ongoing</u> project funded by P.O.R./F.E.S.R. 2007-2013

REGIONE PIEMONTE

Total domain : 6 km x 7.2 km – Horizontal resolution: 6x6 m^2

ELISE Partnership:

simularia

aizoon TECHNOLOGY CONSULTING

CSP innovazione nelle ICT

TRUSTECH INNOVATION TECHNOLOGY

POLITECNICO DI TORINO 1859 1906

ISI INSTITUTE FOR SCIENTIFIC INTERCHANGE FOUNDATION

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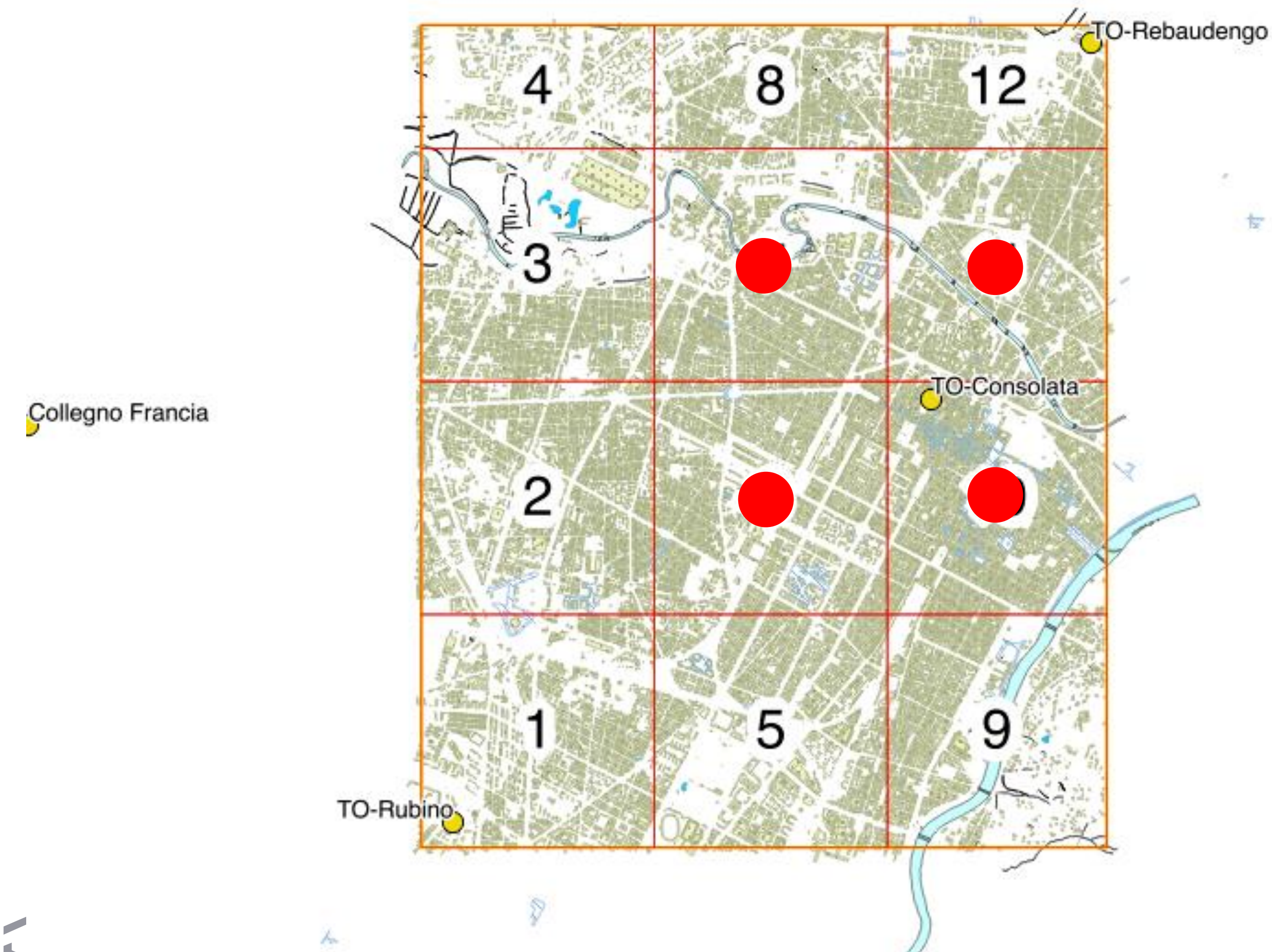
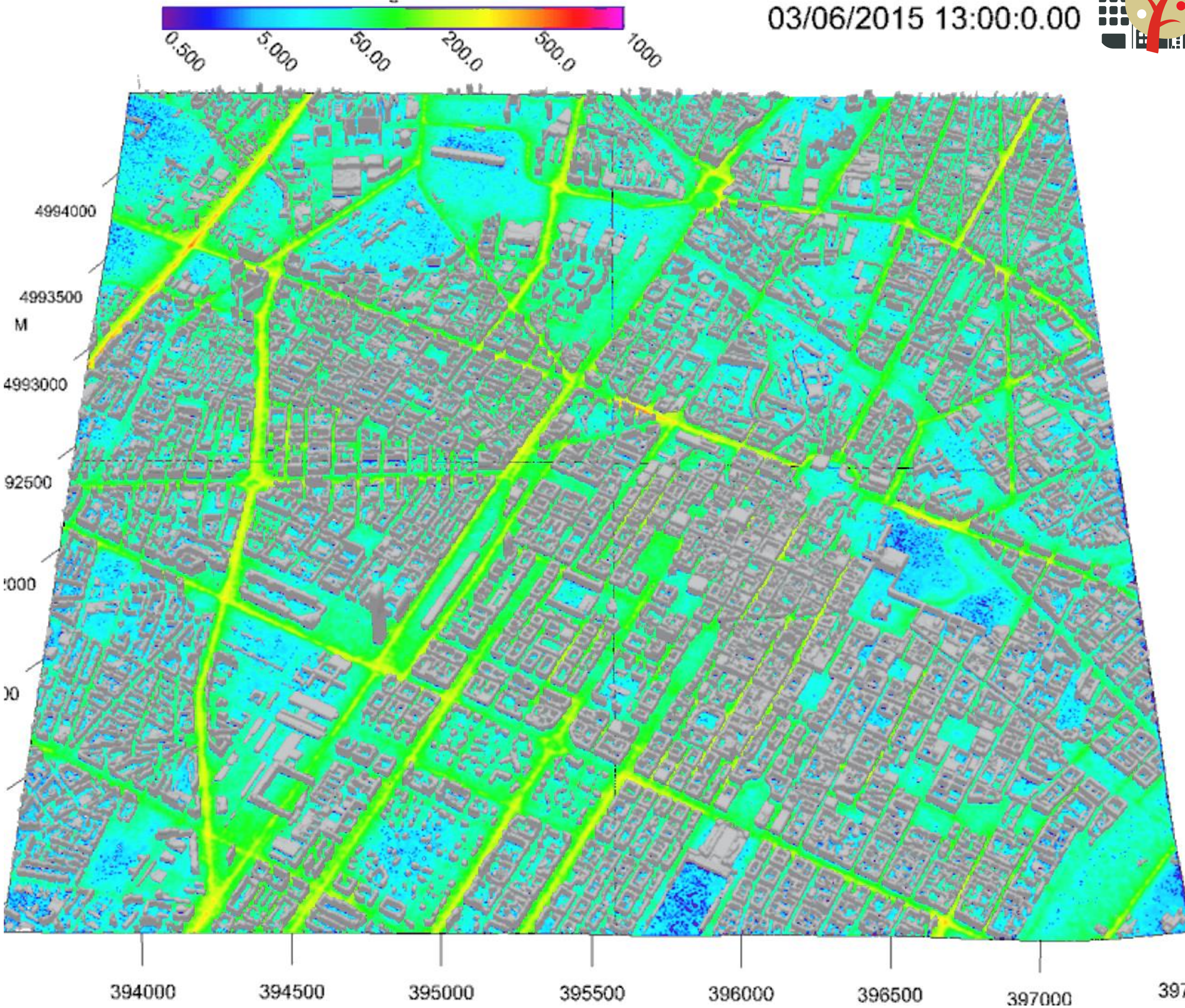
Torino MSS simulation

Domain is splitted into 12 «tiles»: maximum size is 341 x 341 cells



Torino MSS simulation

03/06/2015 13:00:0.00



NOx
µg m^{-3}

hourly NOx ground level concentrations at high resolution on the 4 tiles covered by red points

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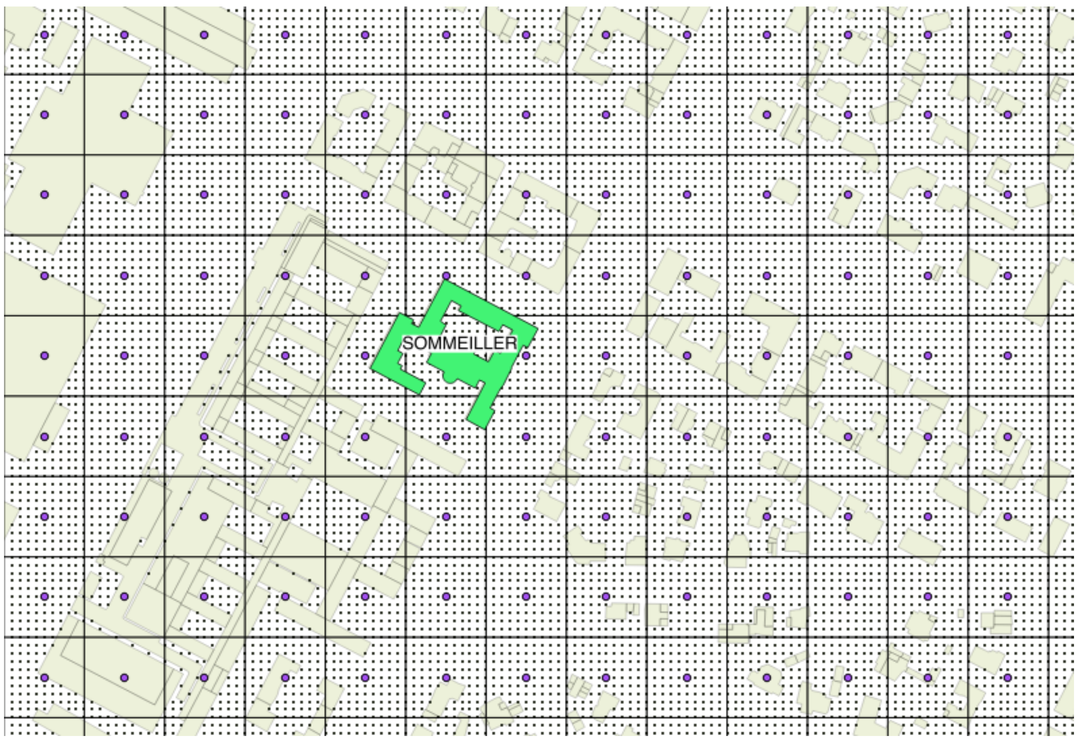
Torino MSS simulation

Between April and June 2015, 150 low-budget mobile NO_2 sensors carried by selected high school students will provide high resolution temporal and spatial monitoring of the city air quality.



Monitoring data, after being time- and space- averaged (1 hour, 60 m cells), will be fed into the modelled fields (computed by ***MSS*** model) in order to providea more realistic picture

Personal exposure
Decision support
Environmental awareness …

CONCLUSIONS AND OPEN PROBLEMS

- The integration of air quality models and observations is a challenging issue for air quality assessment and forecast (**KF techniques**)
- Both observations and models are affected by uncertainties
- The precision of the analysis (product of **DA techniques**) is the sum of the precisions of the observation and model output
- DA reveal critical situations in both modelling and monitoring
- **potential of new sensing technologies: opportunity to deploy a large number of sensors possibly measuring a wide range of pollutants** (smaller scales simulation provide insights about their location)
- **Increase the accuracy**, if needed, of these new sensing technologies to produce more reliable analysis

Acknowledgments

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ARIA TECHNOLOGIES

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