THE "VOTRE AIR" PROJECT: DEVELOPMENT OF A MODELLING TOOL TO ASSESS THE ATMOSPHERIC EXPOSURE IN PARIS

Frédéric Pradelle[1], Fabien Brocheton[1], Benjamin Chabanon[1], Céline Pesin[1], Cécile Honoré[2], Fabrice Dugay[2], Karine Léger[2], François Dambre[2], Vivien Mallet[3] and Anne Tilloy[3]

[1] NUMTECH, Aubière, France
[2] AIRPARIF, Paris, France
[3] INRIA, Rocquencourt, France

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Outline

- Context and objectives of the project
- Principles of the system
  - Details on the traffic emission calculation
  - Details on the assimilation procedure
- Presentation of results
- Conclusions and future work

Context and objectives of the project

- High resolution modelling tools are more and more used to assess local air-quality exposure in cities, including real-time survey.
  - One limitation concerns the emission data : use of standard temporal profiles
  - For survey application, need to couple simulation and observation (assimilation) at urban scale as at regional scale
- Objectives of “Votre Air” project:
  - Develop an operational tool to monitor air-quality and test it over Paris
  - coupling observations and simulations for maps,
  - with real-time traffic emission calculations,
  - and including test of communication tools for public

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Context and objectives of the project

According to a recent opinion survey, for the inhabitants of Paris and its area :

- ✓ **“Environment” is the first concern**
- ✓ **Among “environmental topics”, air quality is the first one**
- ✓ **68 % think that AQ is bad or very bad in Paris**
- ✓ **52 % do not think that AQ is better in other European capitals**
- ✓ **58 % think that “road transports” are responsible for poor AQ**

Context and objectives of the project

Key figures about Paris and Ile de France :

- **City of Paris** (as defined by the 1860 limits)
  - ✓ 2.1 M inhabitants in 1999 (20% of the IDF population)
  - ✓ 105 km2 (<1% of the IDF area)
  - ✓ 20 to 25 000 inhabitants/km^2
- **"Urban unit"** (continuously built area)
  - ✓ 9.6 M inhabitants in 1999
  - ✓ 2700 km2
  - ✓ 3500 inhabitants/km^2

✓4.5 millions of personal vehicles

✓128 millions of km by day

✓Road transport : 50 % for NOx emissions, 45 % for CO, 35 % for VOCs ;

✓Regional emissions : 10 % of NOx national emissions, 12 % of VOCs national emissions.

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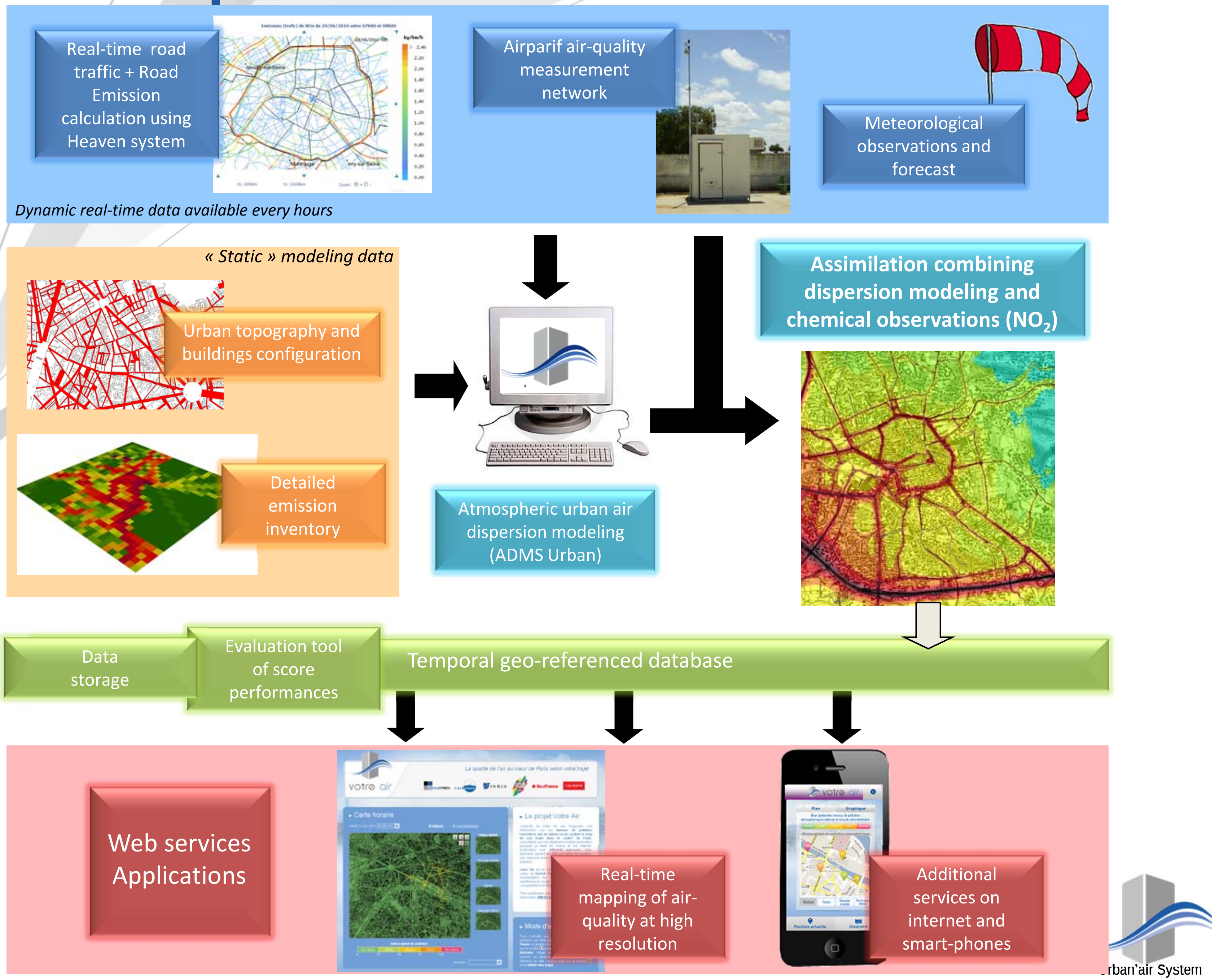
Context and objectives of the project

- Framework :
  - Festival “Futur en seine” = Festival about innovation on numerical applications
  - Cap Digital (business cluster) / Ile France council : Financial support

- Partners :
  - AIRPARIF: non-governmental association in charge of study, survey and forecast of air-quality over “Paris-Ile de France” area
  - INRIA: national research institute on computer science and control
  - NUMTECH: private company on atmospheric modelling

Principles


Real-time road traffic + Road Emission calculation using Heaven system
Airparif air-quality measurement network
Meteorological observations and forecast
Dynamic real-time data available every hours
« Static » modeling data
Urban topography and buildings configuration
Detailed emission inventory
Atmospheric urban air dispersion modeling (ADMS Urban)
Assimilation combining dispersion modeling and chemical observations (NO_2)
Data storage
Evaluation tool of score performances
Temporal geo-referenced database
Web services Applications
Real-time mapping of air-quality at high resolution
Additional services on internet and smart-phones
votre air
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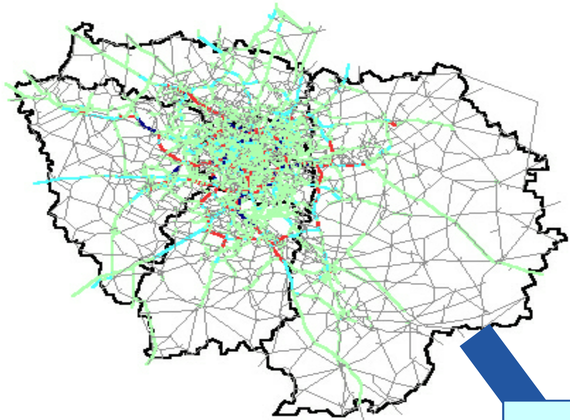
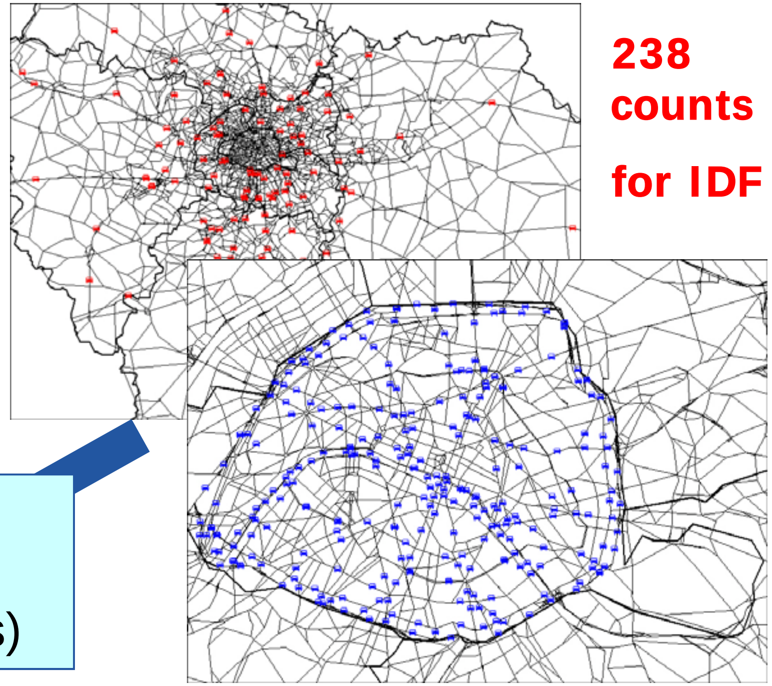
Principles : real-time traffic emission

- **Reference allocated traffic**
for specific hours/days



- **Traffic counts**

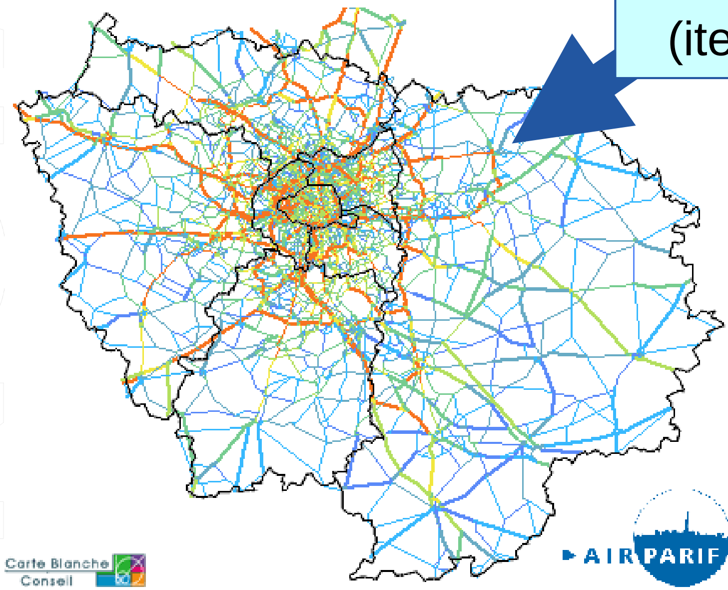


238 counts

for IDF

421 counts for Paris

Traffic
Model
(iterations)

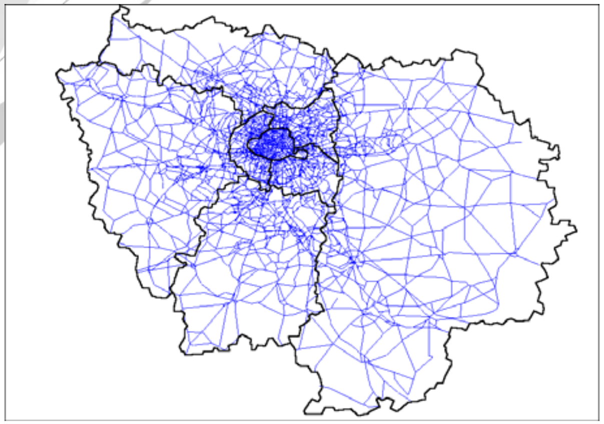


Allocated traffic data
for 10000 km of roads
every hour

Principles : real-time traffic emission

- # of vehicles, average speed
- Cold start %
- Hourly description
- Meteorology

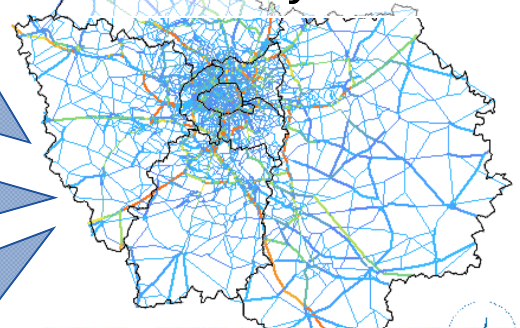
Running fleet based on local and national data (ADEME/INRETS)



- Traffic allocated on the IDF network

Emissions factors (Copert IV)

Traffic emissions every hour



Principles : Assimilation

- Concentrations computed by ADMS urban are temporally independent : analysis state vector cannot be injected in the model for next calculation => choice to use the Best Linear Unbiased Estimator (BLUE method), based on prescribed error covariance matrices

- Urban scale : state error covariance cannot be parameterised as a simple function of the geographical distance (observation close to road network does not provide information in isotropic way) => development of a specific approach

- Computations are done using generic data assimilation library Verdandi (INRIA)

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Principles : Assimilation

- Assimilation :

$$c^a = c^b + K\,(o - Hc^b)$$

$$\text{with } K = B\,H^T\,(H\,B\,H^T + R)^{-1}$$

c^a: analysis state vector

c^b: model state vector

o : observation vector

K : gain matrix

H : observation operator

B : state error covariance matrix

R: observational error covariance matrix

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Principles : Assimilation

Modelling of the state error covariance matrix (B)

- Assumption: high error correlations between receptors on the same road or on connected roads

- Assumption: error correlation between a road's receptor and a background's receptor < error correlation between two (equally close) road's receptors

$$\mathbf{B}_{\mathbf{ij}} = \upsilon_s \exp\left(-\frac{d_{ij}}{L_d}\right)\exp\left(-\frac{|P_i - P_j|}{L_p + \alpha \min(P_i, P_j)}\right)$$

i and j : two receptors

L_d : characteristic distance along the road network

L_p : characteristic distance transverse to the road network

α : scaling coefficient

ν_s : variance

The covariance is assumed to decrease exponentially against the distance along the road and to decrease almost exponentially in the direction transverse to the road.
The correction α min(P_i, P_j) **is added so that the decorrelation length is increased with the distance to the network.**

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Principles : Assimilation

Modelling of observation error covariance matrix (R)

- Diagonal matrix : $R = \nu_o I$

ν_o : observational error variance

Validation of error covariance matrices

- Use of χ^2 test to choose appropriate empirical parameters for error covariance matrices

$$\sum_{n=0}^{T} \frac{\chi_n^2}{F_n} \approx T$$

with $$\chi_n^2 = \left(\mathbf{o}_n - \mathbf{H}_n c_n^b\right)^T S_n^{-1} \left(o_n - H_n c_n^b\right)$$

F_n : number of observations

N represents the time step

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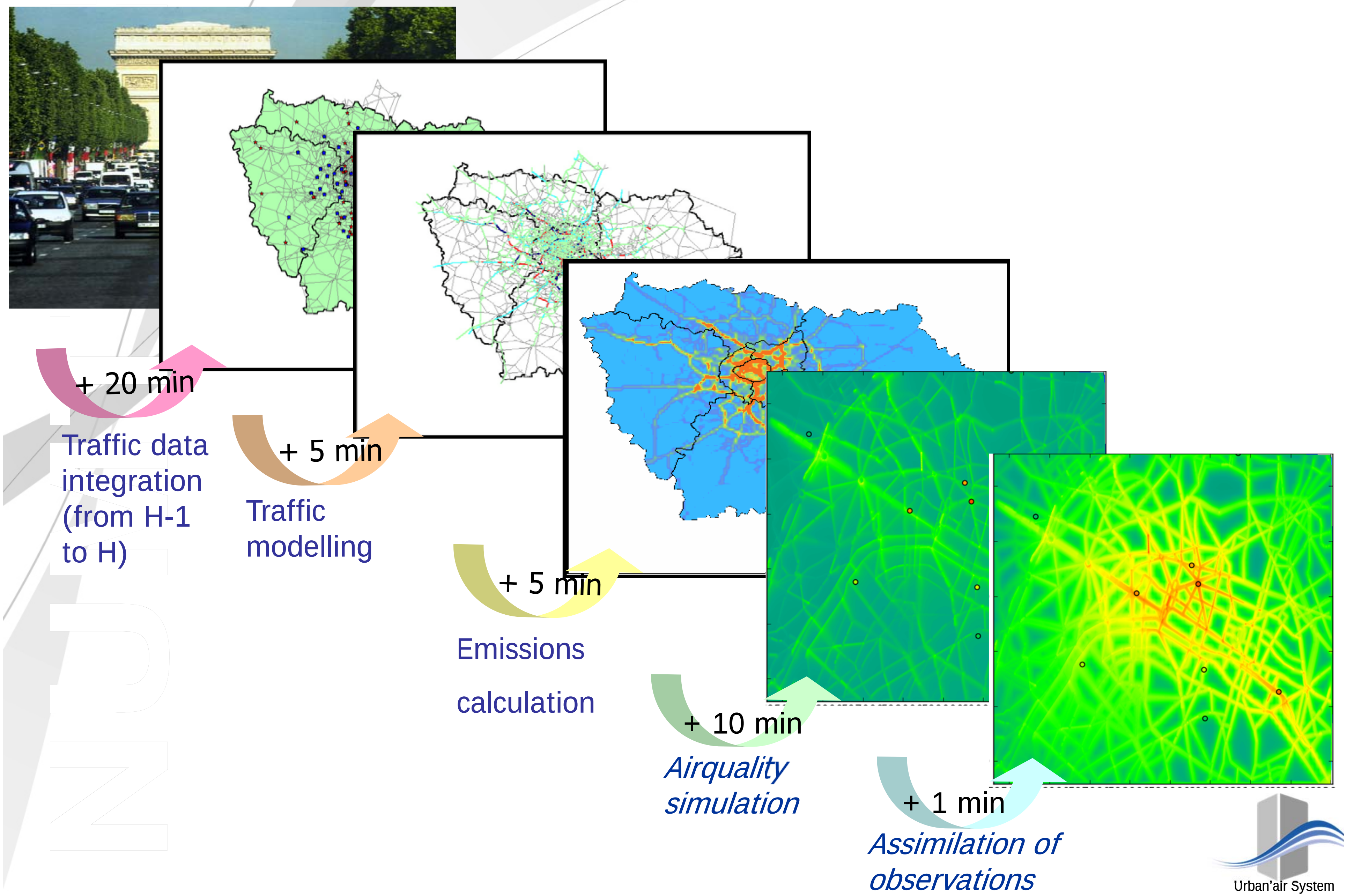
Principles : From traffic to AQ



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Results

- NO_2
- Period : May to June 2011
- 8 stations for the simulated domain

Location	Name	Type	Altitude
Luxembourg	PA06	Urban	12.6 m
Eiffel tower	PA07	Urban	4 m
Flocon street	PA18	Urban	16.1 m
Neuilly	NEUI	Urban	2.6 m
Elysée	ELYS	Traffic	2.1 m
Bonaparte	BONA	Traffic	1.7 m
Célestins	CELE	Traffic	1.6 m
Haussmann	HAUS	Traffic	3.7 m

Results

➢Scores of the model (before assimilation)

Stations	Obs. mean conc. (μg/m³)	Bias (μg/m³)	Corr.	RMSE (μg/m³)	Relative RMSE
PA06	28.8	1.8	0.72	12.3	0.45
PA07	30.6	-9.7	0.69	18.0	0.44
PA18	26.2	-12.0	0.76	17.4	0.46
NEUI	31.0	2.7	0.74	14.2	0.50
ELYS	34.2	-25.2	0.61	33.5	0.56
BONA	37.6	-25.8	0.57	35.4	0.56
CELE	38.3	-38.0	0.54	47.8	0.63
HAUS	34.6	-22.0	0.54	36.6	0.61

- Over all the stations, Correlation = 0.6 and RMSE = 29.2 (60% of the mean observed concentration)

- Over the roads, concentrations are often underestimated

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Results

➢Scores of the assimilation at the station ignored by data assimilation

Stations	Obs. mean conc. ($\mu g/m^3$)	Bias ($\mu g/m^3$)	Corr.	RMSE ($\mu g/m^3$)	Relative RMSE
PA06	28.8	8.1	0.84	12.3	0.45
PA07	30.6	-7.8	0.79	14.8	0.37
PA18	26.2	-9.6	0.80	14.9	0.39
NEUI	31.0	5.0	0.79	13.6	0.48
ELYS	34.2	-17.4	0.81	23.9	0.40
BONA	37.6	-11.7	0.83	20.6	0.33
CELE	38.3	-30.1	0.65	39.8	0.52
HAUS	34.6	-9.4	0.77	22.6	0.40

- L_d= 2 km, L_p= 50 m, α = 1
- ν_o = 100 $\mu g^2 m^{-6}$ (observed error variance = upper bound on uncertainty of measurement from expertise of AIRPARIF)
- ν_s = 650 $\mu g^2 m^{-6}$ (deduced from χ^2 diagnostic)

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Results

➢ Scores of the assimilation at the station ignored by data assimilation

Stations	Obs. mean conc. (μg/m³)	Bias (μg/m³)	Corr.	RMSE (μg/m³)	Relative RMSE
PA06	28.8	8.1	0.84	12.3	0.45
PA07	30.6	-7.8	0.79	14.8	0.37
PA18	26.2	-9.6	0.80	14.9	0.39
NEUI	31.0	5.0	0.79	13.6	0.48
ELYS	34.2	-17.4	0.81	23.9	0.40
BONA	37.6	-11.7	0.83	20.6	0.33
CELE	38.3	-30.1	0.65	39.8	0.52
HAUS	34.6	-9.4	0.77	22.6	0.40

- Bias at traffic stations is reduced most of the time
- No specific trend for urban stations
- Correlation and RMSE are always improved

  (mean decrease of 25% for RMSE)

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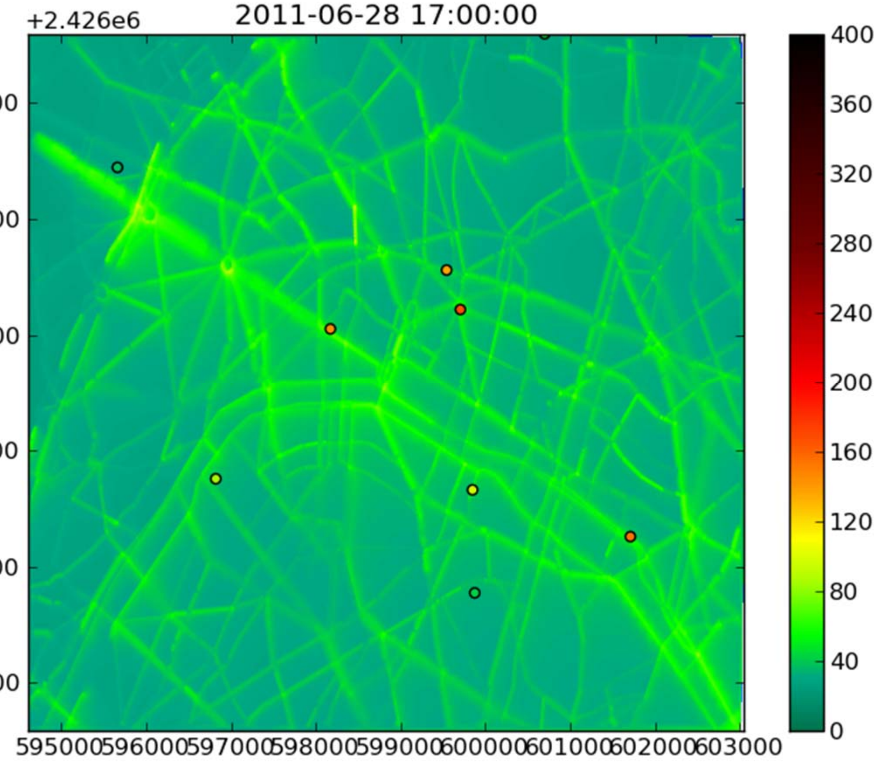
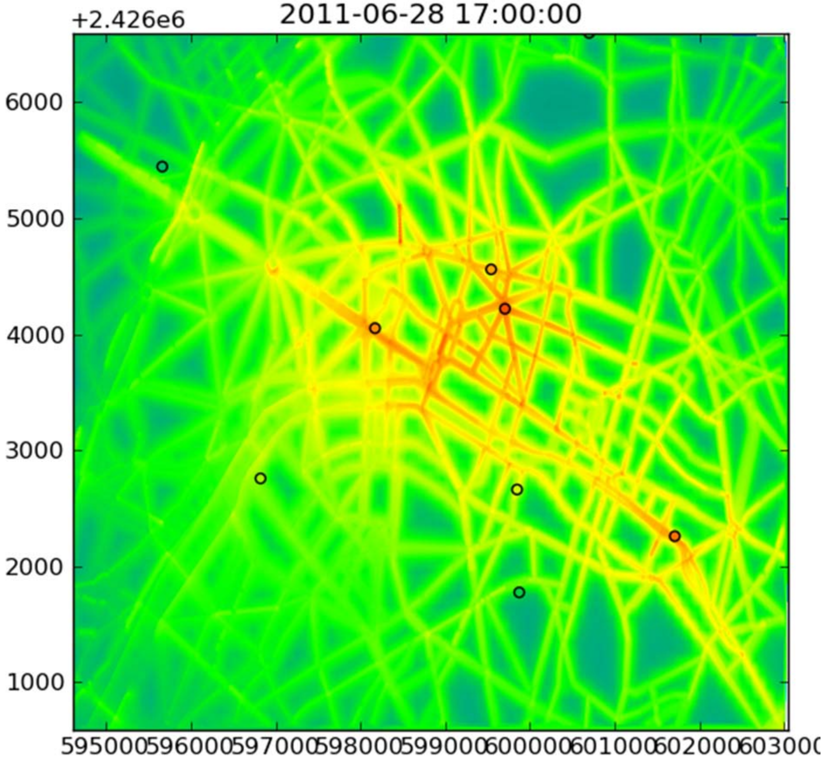
Results

No assimilation



Assimilation



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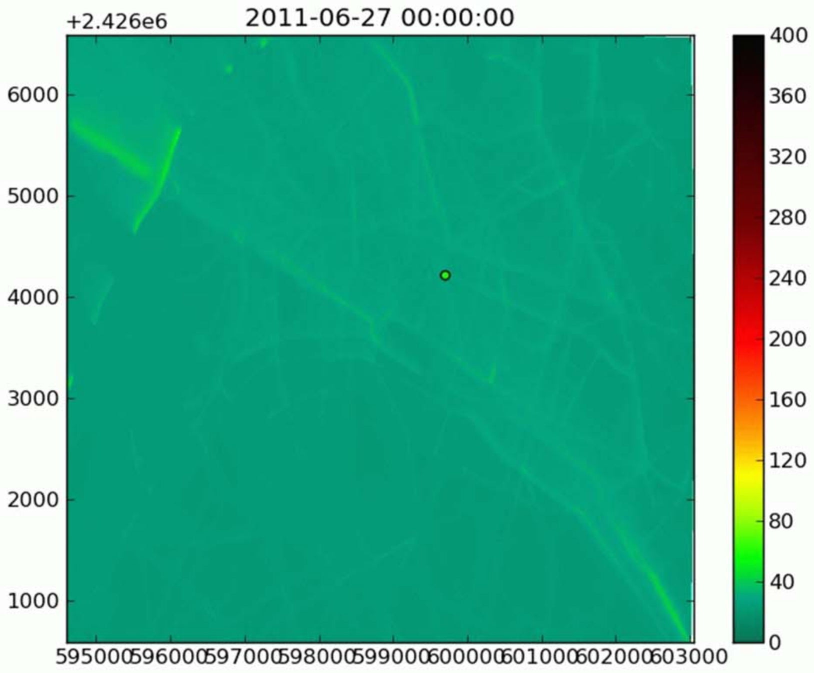
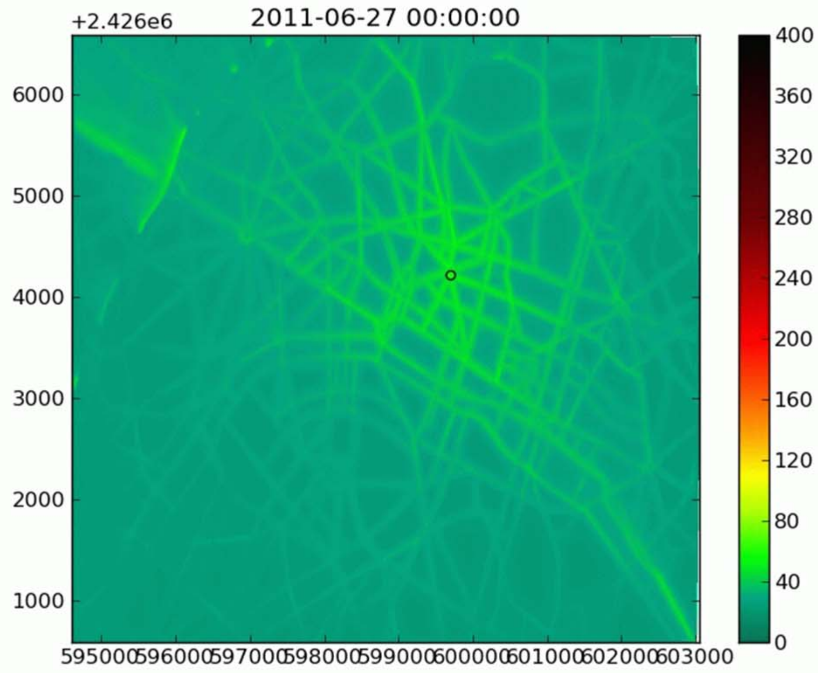
Results

No assimilation



Assimilation



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Conclusions and future work

✓A methodology for assimilation at urban scale has been developed and tested

✓A software application for near real-time survey of air-quality, coupling simulation and observation, has been tested over Paris

✓Presentation to public has been done during a numerical festival (positive interest and feedback)

http://votreair.airparif.fr

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Conclusions and future work

- Validation of urban assimilation approach to another cities, and extension of the methodology (treatment of height of measurement, taking into account tunnels,dependency on meteorology, bias removal)

- Work on non-parametric error modelling, on uncertainty estimation, and ensemble forecast

- Coupling and adapt the method to dense low-cost measurement network and mobile measurement

- Extending the system to whole domain of Paris (with improvement of the modelling)

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NUMTECH

L'ATMODÉLISATION

www.numtech.fr

6, Allée Alan Turing
Parc Technologique de la Pardieu
63170 Aubière France
Tel. : (33) 4 73 28 75 95
Fax : (33) 4 73 28 75 99

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