Long-term exposure to air pollution a 20-year follow-up in a French cohort study

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Long-term exposure to air pollution was associated to mortality in numerous recent studies. Several methods have been developed to assess air pollutants concentrations at fine spatial scale. Most of epidemiological surveys dealing with health effects of outdoor air pollution assign concentrations from air pollution monitoring site as exposure indicator without further spatialization of data and thus cannot take into account local emission conditions such as traffic-related air pollution or dispersion characteristics especially meteorological parameters. This could induce misclassification and affect exposure-risk relationships.

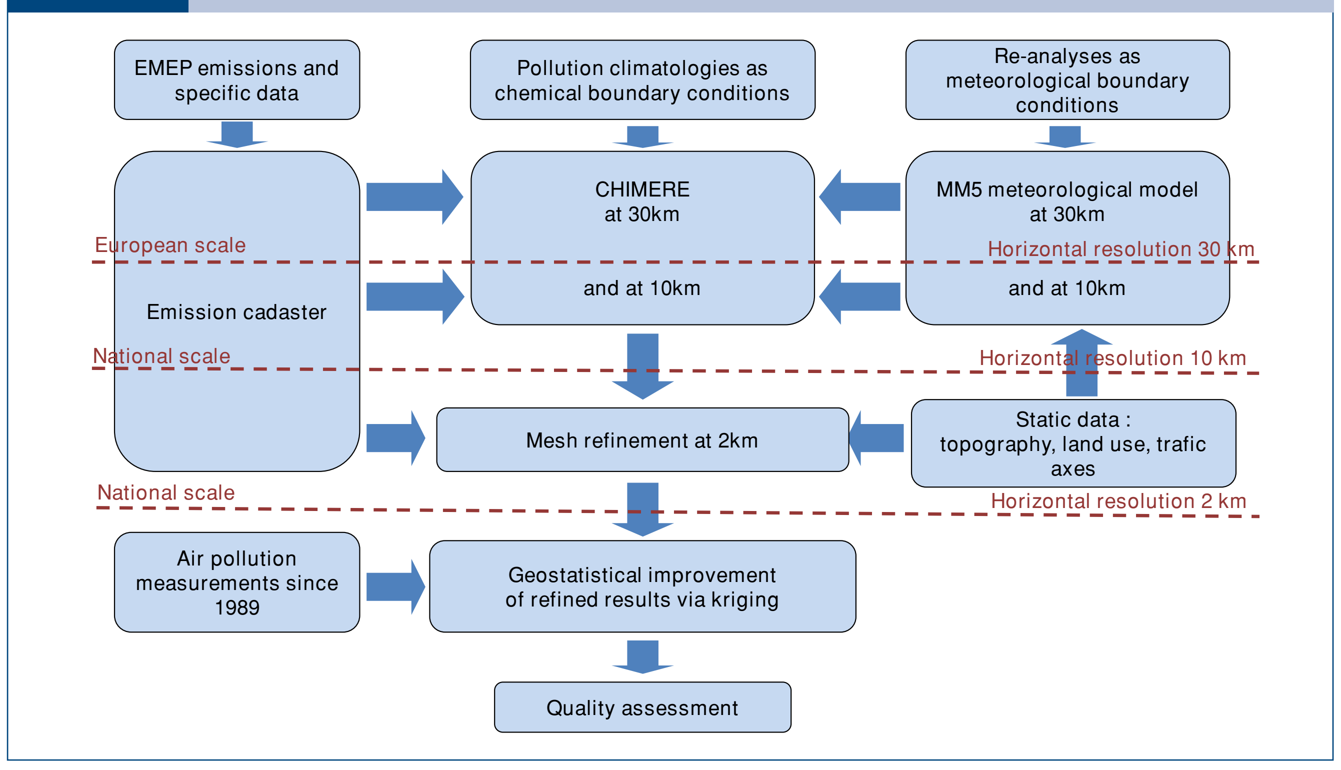
Aims

Our work was part of Gazel-Air project which aims to describe long-term effects of air pollution on morbidity and mortality in the Gazel cohort composed of more than 20.000 subjects among the employees of the national electricity and gas company, Électricité de France-Gaz de France (EDF-GDF) recruited in 1989 (Goldberg *et al.* 2007). We had to provide annual concentrations of PM_{10}, $PM_{2.5}$, NO_2, O_3, SO_2 and C_6H_6 at 2 km resolution over the whole continental France for the years 1989 through 2008.

Materials and methods

Levels of PM_{10}, $PM_{2.5}$, NO_2, O_3, SO_2 and C_6H_6 were assessed for the whole continental France using reconstructed emissions inventories, the chemistry-transport model CHIMERE taking into account meteorological conditions, mesh refinement and data assimilation improved the spatial distribution and accuracy of pollutant concentrations. The modelling strategy is described in figure 1.

FIGURE 1 Schema of the modelling strategy



Mesh refinement

MM5-CHIMERE determinist models were applied at 10 km resolution to all French regions and used to calculate background concentrations of pollutants. However, this grid does not provide information on spatial distribution at postal code scale, especially for municipalities crossed by major roads or nearby industrial sources. To increase the resolution, a method of mesh refinement was applied. It was a spatial interpolation of the results achieved by CHIMERE model on a finer mesh, based on physical and/or physiographic concepts by spatial differentiation of concentrations which allows us to highlight the concentrations gradients nearby emission sources.

The mesh refinement method is based on the interpolation of 3D fields using structured grids by subdividing grid elements into smaller components based on topologic and emissions data. This method was described and validated previously. In the Gazel-air project, the mesh refinement was based on a cadaster at 2 km of resolution taking into account the road network. This resolution has been generalized to all pollutants. In the mesh refinement of NO_2, O_3 and PM_{10}, topology and emissions were considered. In the case of C_6H_6, SO_2 and $PM_{2.5}$, only the topology has been explored.

Data assimilation and geostatistical analyses

The assimilation data aimed to correct the results of determinist model from local measurements. Geostatistical method was applied using local concentrations and two explicative variables: CHIMERE data and Digital Elevation Model (DEM). However, DEM has not been used for SO_2 and C_6H_6, because this variable did not improve the results. The objective was to minimize uncertainties of deterministic modeling and provide a better spatial distribution of the pollution at local and national scale.

To improve data quality, we created virtual stations, reconstructed measurements based on historical existing data and we used passive measurements of benzene to enhance the network of stations nearby emission sources.

Virtual stations

Annual concentrations of air pollutants estimated by CHIMERE model were assigned to additional stations called "virtual stations". They provided information on background air pollution in areas where there were few (or absent) measurements (rural area, mountain...) and whish concentrations from CHIMERE model were relevant. Their localization has been chosen according the type of pollutants. The same approach has been described previously (Beaulant *et al.* 2008).

Reconstructed data

We aimed to increase the number of monitoring stations available for data assimilation especially concentrations in the earliest years of the study which measurements were insufficient. Annual or summer averages of concentrations (for O_3) were calculated from CHIMERE model and from the average value of the model error of each station. This calculation was performed on all available years. The method was validated by comparing the results with actual measurements.

Passive measurements of Benzene

To add more information about benzene exposure nearby local emission sources, we explored passive samples measured by French air quality monitoring associations (AASQA). Data were available from 1996 to 2007. The number of measures was depending on the year of sampling (ex: 8 in 1996, 23 in 2002, 40 in 2005, 79 in 2007…).

Geostatistical analyses by kriging

Geostatistical analysis requires the implementation of a data processing hierarchical system from extraction of local measurements to mapping of assimilated data.

The main geostatistical method to spatialize data is kriging which is a generalized linear regression technique to interpolate the value of a random field at an unobserved location from observations of its value at nearby. In the present study, kriging with external drift (KED) has been applied to characterize the spatiotemporal variability of air pollutants taking into account the altitude (except for SO_2 and C_6H_6) and spatial distribution of air pollutants concentrations described within CHIMERE model and completed by measurements at the local level. Suppose that the interest variable has a modeled structure by other variable (or others variables). The regionalized variable is considered as an indicator explaining the spatial distribution of the air pollution. It is called "external drift". The linear relation between measurement and model is locally fitted by proximity. KED method was used and validated previously in several studies (Pearce *et al.* 2009).

Statistical and spatial analyses

Statistical analyses were performed using MySQL (5.1.49) and R (2.10.0). Spatial data analyses have been performed applying ArcGis (10). Python server (2.7) has been used to extract the data, produce the maps and export raster results.

Results

Assimilated concentrations in the whole continental France have shown a continuous decreasing tendency of most pollutants throughout the period. However, PM_{10}, $PM_{2.5}$ and NO_2 concentrations were still high in some regions (Paris, Étang de Berre, Rhône Valley, Lorraine…). O_3 levels were also high at the end of the period in South-Eastern France.

FIGURE 2 Spatiotemporal evolution of air pollutants concentrations at 2 Km resolution after data assimilation for 1990, 1997, 2001 and 2007 in the whole continental France

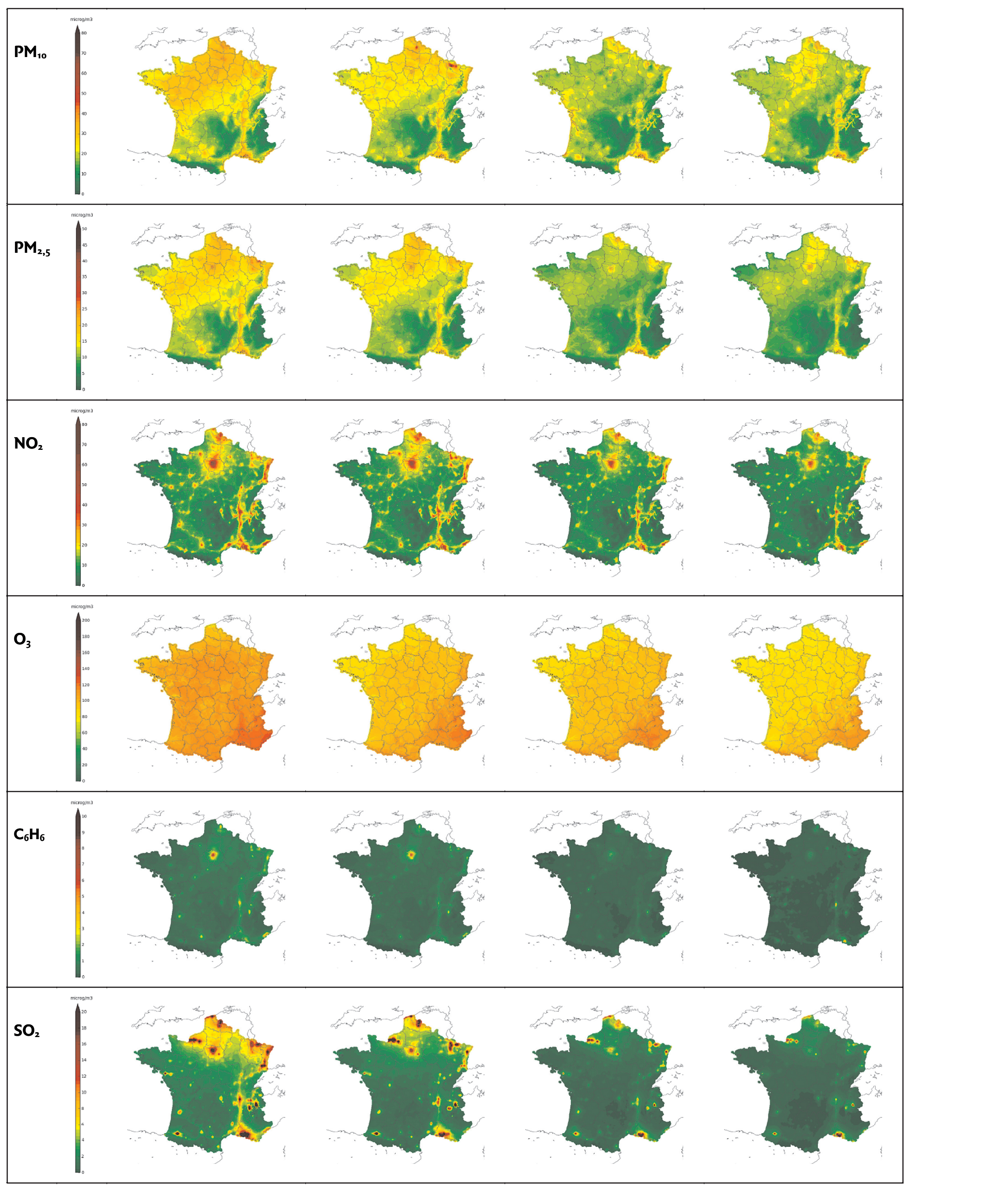
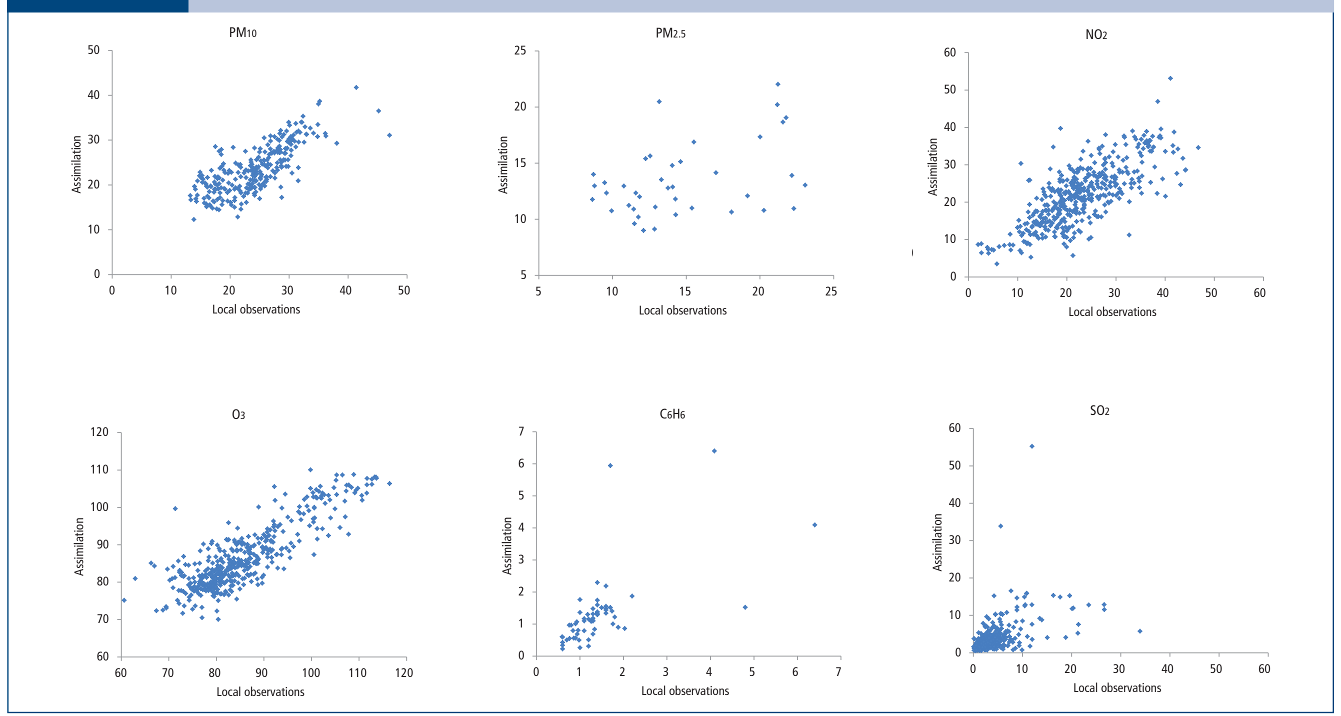


FIGURE 3 Correlation between local observations and assimilated data in 2007



In 2007, correlations between assimilated data and local observations (monitoring stations, reconstructed data and passive measurements of C_6H_6) of PM_{10}, $PM_{2.5}$, NO_2, O_3, SO_2 and C_6H_6 were, respectively, 0.76, 0.42, 0.75, 0.85, 0.48 and 0.62.

Conclusion

Despite the low number of monitoring stations and the few available measurements in the first years of the study period, our method using reconstructed data and geostatistical analyzes after data assimilation ensured a good estimation of air pollutants concentrations at fine scale (2 km resolution) in the whole continental France.

As part of a Gazel-air project, assimilated map allowed us to give a satisfactory prediction of the annual concentration of PM_{10} ,$PM_{2.5}$, NO_2, SO_2 and C_6H_6 (summer concentration for O_3) at 2 km resolution to assess health effects of long-term exposure to air pollution at postal code scale.

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