18th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 October 2017, Bologna, Italy

MULTISCALE AIR QUALITY IMPACT FROM POWER PLANTS IN CITIES

F. Velay-Lasry[1], A. Albergel[1], W. Gao[2], F.H. Geng[2], G. Lacressionière[1], M. Liu[3], A-S Saffre[1], B. R. Schwegler[3], Z.Q.Yu[2], Q. J. Zhang[1]

[1] ARIA Technologies, Boulogne-Billancourt, France
[2] Shanghai Meteorology Bureau, China
[3] Disney Research China, China

Abstract: The use of cleaner fuels rather than coal, which is a main fuel source in China, for highly efficient power production is considered as one of the action for emission control. Within this project, the focus is on the use of a natural-gas-fired "combined cooling, heat and power" (CCHP) power plant. Such an installation is already in service since the opening of the Disney Shanghai in order to provide full electricity and hot water needs to the resort. And if such a system works efficiently for Disney resort, it can be imagined that in a near future CCHP can be used for residential areas, and thus reducing the operation of coal power plants. In this paper, we show how a multi-scale modelling approach allows determining the benefits of the use of a CCHP installation. The modelling is conducted with the WRF/CHIMERE regional models and with the lagrangian model PMSS for street scale effects.

Key words: *Air quality modeling, emission scenario, multi-scale evaluation, CCHP power plant, coal power plant*

INTRODUCTION

China's urbanization continues at a high rate of speed. It is estimated that ~100 million new urban residents are expected in the next years. This growth will imply environmental challenges including air quality. Air quality is and will be a major concern for a long term in China. The global air quality level is improving through recent national air quality control system and action plan for emission reduction. The use of cleaner fuels rather than coal, which is a main fuel source in China, for highly efficient power production is considered as one of the action for emission control.

Within this project, the focus is on the use of a natural-gas-fired "combined cooling, heat and power" (CCHP) power plant which generates simultaneously electricity and useful heating and cooling, thus increasing the overall system efficiency.

The purpose of this study is to assess the impact of a replacement of the Shanghai coal power plant activity with several CCHP installations. Disney research indicates that the optimal physical size for the efficient operation of urban infrastructure systems is on a scale similar to that of Disney's resorts. In this sense, a few CCHP installations could supply energy to the whole Shanghai region. Within this ascertainment 2 scenarios have been tested to answer these questions: what would be the gain in term of air quality if a CCHP supplied energy to a district? And what if all Shanghai agglomeration was fed only by CCHPs, suppressing the activity of the coal power plant?

The 2 scales approach will allow us giving a complete estimate of the benefits of substitution of actual coal-fired power plant by several CCHP installations on air quality. The Eulerian photochemical transport model CHIMERE is used for the regional study, while a micro-scale Lagrangian particle dispersion model PMSS is used for the local scale study. The public global emission inventory HTAP V.2 with a resolution of 0.1° is used and downscales to the smallest nested domain with a resolution of 3 km, centered in Shanghai. On-site measurements of CCHP emissions are used for setting the scenarios.

Validation exercise have been conducted thanks to the hourly averaged measurement data from 7 stations during 6 episodes for all seasons, mainly including heavy pollution days and typical pollution events such as dust episode and photochemical pollution in summer. Besides, measurement campaigns on CCHP emissions and ambient air pollutant concentrations such as NO_x, VOC, O_3, PM_{10} and $PM_{2.5}$ are planned in order to go further in the validation of the models.

Results are presented in this paper for selected days and for the 2 prospective scenarios including the use of CCHP in Shanghai.

MODELING SETUP

One purpose of this study is to conduct a good modeling at the street scale. However, if we want to restitute correctly the flows in such a big city it requires the combination of 2 scales: The regional scale: This is the large agglomeration scale at which we consider a complete inventory of all sources of emissions. The typical dimension of the domain of calculation is a few tens of kilometers with a maximal resolution of 1 km. A complete set of chemical reactions is included in this type of model which allows studying the evolution of primary as well as secondary pollutants such as ozone. In this study, the Eulerian CHIMERE model (Menut et al. 2013) is used at the regional scale. However, this type of model is not able to represent the highest pollution peaks that are measured locally near traffic roads for instance. Indeed this resolution doesn't allow representing the elevated gradient of concentrations observed in the vicinity of traffic roads. In this sense, a modeling at a micro-scale level becomes necessary in order to restitute the highest pollutant peaks and to assess the exposure of people located near main emission areas. For the Shanghai district modeling, we've used the particules lagrangian model SPRAY (Moussafir et al. 2004).

The complete modeling chain is described below:

- **WRF** and **CHIMERE** for the meteorological and chemical modeling respectively at the regional scale, WRF being initialized and forced at the boundaries by GFS fields. The models run on 3 nested domains with increasing resolution (27/9/3km resolution). Running the models on wider domains allow to provide the boundary conditions, i.e the polluted air masses coming at the limits of the domain, to the smaller domains.
- **PMSS** (Parallel Micro Swift Spray) developed by Arianet S.r.l. in collaboration with Aria Technologies SA at the street scale with resolution of 5 meters
    - SWIFT is a 3D wind field model for complex terrain. It produces a mass-consistent wind field using data from a dispersed meteorological network or from a less resolved meteorological model thanks to site landuse and topography data.
    - SPRAY is the particules lagrangian model
- As for the emissions,
    - the **HTAP2** inventory has been used for the regional scale simulations. This inventory has been compiled by the EDGAR Team based on MICS-Asia, EPA-US/Canada and TNO (http://edgar.jrc.ec.europa.eu/htap_v2/).
    - For the street scale, traffic data over the Xuhui district have been provided by the Shanghai Meteorological Bureau (SMB). Then, to estimate vehicle flows over the entire network (on the channels without data), the traffic flow is simulated by means of the CarUSO traffic model (Willumsen L.G., 1978 and Van Zuylen H.J., Willumsen L.G., 1980). As for the traffic emissions, they have been calculated thanks to a modified version of the California Air Resources Board (CARB) EMission Factors (EMFAC) provided by the Hong Kong Environmental Protection Department (EPD) http://www.epd.gov.hk/epd//english/environmentinhk/air/guide_ref/emfac.html. Emission rates used for all motor vehicles, such as private cars to medium and heavy goods vehicles being operated on highways and local roads are thus specific to a Chinese fleet.
    - CCHP emissions were measured on-site in Disney resort and will be used for the scenarios

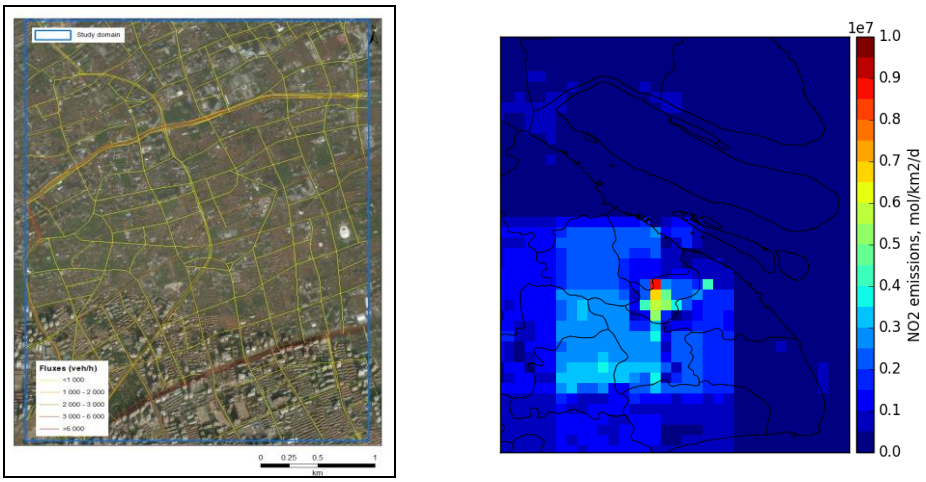

Figure 1. Flux of vehicules over the Xuhui district (left), NO_2 emissions in Shanghai (right)

VALIDATION

Six pollution episodes have been selected over the year 2015 as the most intense and most interesting events. They cover all the meteorological seasons and differ in term of dominant pollutant. Indeed, in simple terms, winter season is mostly characterized by stagnant meteorological conditions enhancing high levels of primary pollutants such as NO_2 and particles. On the contrary, in summer, the high temperatures and intense solar radiation are favorable conditions to the formation of secondary pollutants such as ozone. The validation exercise has been conducted with WRF and CHIMERE models. No model/measurement comparisons are presented for the PMSS model, as the street scale domain defined doesn't include any station.

The WRF model has been tested in various configurations and its performance checked. Two "namelist" configuration files have been used differing by the number of vertical levels, the microphysics processes, the longwave and shortwave radiation processes. Most of the periods are well simulated by the model. The main difficulty for the model is to simulate the lowest wind speed values, this lack of representativeness could lead to miss the associated peak of pollution. The final configuration of WRF includes the following specificities: WRF Single–moment 3–class and 5–class Schemes for microphysics, Yonsei University Scheme (YSU) for planetary boundary Layer, Kain–Fritsch Scheme for cumulus, Dudhia Shortwave Scheme and RRTM Longwave Scheme, Unified Noah Land Surface Model.

This configuration has been used to provide dynamic fields input to CHIMERE. The evaluation of the observation/CHIMERE model comparison shows satisfactory results for most of the episodes in term of detection of an episode. Indeed most of the time the model correctly reproduces the episode and the intensity of the concentrations over the domain, even if some discrepancies are noted for defined stations.

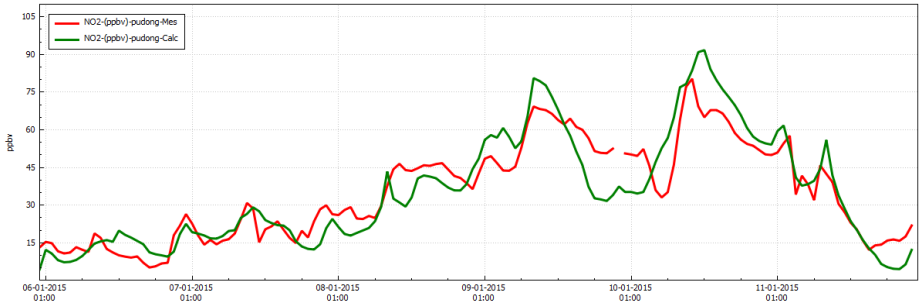

Figure 2: NO2 concentrations simulated at Pudong (January episode)

EMISSION SCENARIO

Two simulations have been performed at the regional scale, based on different emission scenarios. The integration of the CCHP emissions in the inventory follows these assumptions:

- Scenario1: one CCHP installation supplies the electricity needs of Xuhui district (Fig.3). At the same time, we reduce by 5% the emissions from the Waigaoqiao coal power plant.
- Scenario 2: all Shanghai is supplied by CCHP installations. We have estimated that 22 CCHP installations are needed to supply the electricity of Shanghai. Meanwhile, the coal power plant emissions are totally removed.

The new emissions for the Energy sector are summarized in Table 4 for the Scenario 1 and 2.

Figure 3 : Positions of the CCHP installation and the coal power plant of Shanghai

Table 1: Emissions (ton/year) in Reference, Scenario 1 and 2 for Energy sector

		Emission –Energy sector	
	Reference	Scenario 1	Scenario 2
NMVOC	7098.6	7070	6526.9
CO	62658.2	62414	57773.4
NOx	**276099**	**274930**	**255851**
PM10	30101.6	29965.7	27384
PM25	19773.4	19683.1	17968
BC	46.3	46.1	42.4
NH3	0	0	0
OC	2.3	2.34556	2.2
SO2	111713	111310	103650

The NOx emissions decrease from 276099 t/year in the reference case to 274930 t/year in the Scenario 1 (-0.4%), and to 255851 t/year in Scenario 2 (-7.3%).

The dispersion modeling result shows that the 2 scenarios imply a reduction of NO_2 concentrations at the ground level due to the coal power plant emission reduction. The reduction is significant for scenario 2. The introduction of CCHP installations in Shanghai downtown doesn't affect much the air quality at the regional level as the concentration increase by less than 1µg/m3.

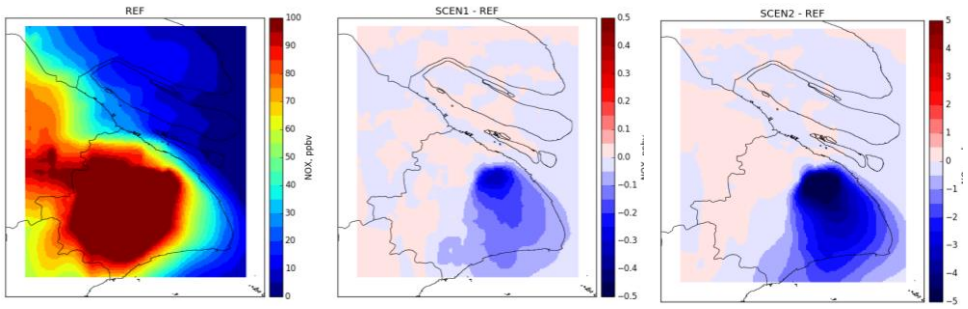

Figure 4: Scenario result over NO2 daily average concentrations (October 2015 episode)

The SPRAY model ran in order to evaluate the impacts of CCHP installations at the street scale level. Two positions of CCHP in the Xuhui district have been studied. One CCHP installation allows providing simultaneously electricity and useful heating and cooling for the district. Its associated NOx emissions reach 0.38 T/day. In comparison, the traffic emissions contribute for 4.2 T/day.
Simulation results for a polluted day in January 2015 and for the worse hour of the day show that CCHP installations do have an impact at street scale. Average concentrations in the CCHP plume are quite low (up to 10µg/m3), but higher concentrations (25-50 µg/m3) are simulated very locally downwind the installation.

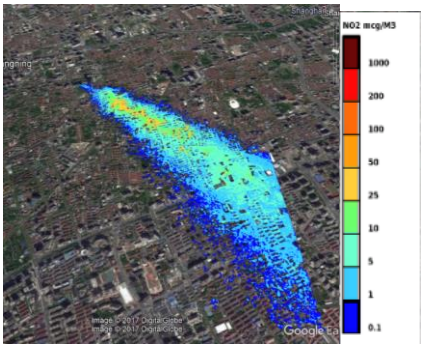

Figure 5: CCHP NO_2 plume in the Xuhui district

CONCLUSION

This paper focused on the use of a natural-gas-fired "combined cooling, heat and power" (CCHP) power plant. The objective was to assess the impact of the introduction of CCHP installations in Shanghai as an alternate solution to the coal power plant. A proactive scenario, with the introduction of 22 installations as a complete substitution of the coal power plant activity has been tested. It shows that stopping the operation of the power plant has a significant benefit on the air quality at the regional level, with a reduction of the NOx plume up to 5 µg/m3 at the ground level and even 10 µg/m3 in altitude which means less pollutants exported at long range distance. Other pollutants such as SO_2 and CO are also impacted. However, when focusing on the district scale, we can note that CCHP emissions generate a NOx plume with 10 µg/m3 in average. In conclusion, CCHP process is a real efficient technology to provide electricity, heating and cooling with a low emission budget especially comparing to a coal power plant. However, the main question raised here is the displacement of the impacts: if NOx concentrations have been substantially reduced over the region, the CCHP plume impacts residential areas as they are necessarily installed within the districts. Further analysis of the results will allow us combining the regional simulations to the local scale ones in order to include the benefit of stopping the coal power plant activity to the local scale results.

Menut L., B. Bessagnet, D. Khvorostyanov, M. Beekmann, N. Blond, A. Colette, I. Coll, G. Curci, G. Foret, A. Hodzic, S. Mailler, F. Meleux, J.L. Monge, I. Pison, G. Siour, S. Turquety, M. Valari, R. Vautard and M.G. Vivanco, 2013: CHIMERE 2013: a model for regional atmospheric composition modelling, *Geo-scientific Model Development*, **6**, 981-1028

Moussafir, J., O. Oldrini, G. Tinarelli, J. Sontowski and C. Dougherty, 2004: A new operational approach to deal with dispersion around obstacles: the MSS (Micro-Swift-Spray) software suite, *9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes Garmisch 1-4 June 2004*

Van Zuylen H.J., Willumsen L.G., 1980: The Most Likely Trip Matrix Estimated from Traffic Counts, *Transportation Research B*, vol.14B, p.281-293.

Willumsen L.G., 1978: Estimation of an O/D Matrix from Traffic Counts. A Review, *Institute of Transport Studies, University of Leeds, England*, Working Paper #99.