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Street Level Air Quality Forecasts for Beijing

Report

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Summary

The *Beijing*air forecast system is CERC's implementation of its *your*Air forecasting system in Beijing. It was set up in a period of three months as a reliable, operational forecasting and alert system. The model set up phase included the creation of a dual language web site with a sign-up facility for the alert service, creation of an emissions inventory, model set up and validation and establishment of the forecasting system with the live data feeds. The system performed very reliably producing forecasts on 99 % of days despite there being occasional problems in the supply of input data. The system was successfully installed and demonstrated at the offices of Beijing EPB and at Beijing Capital Normal University and training was also conducted at these institutes.

The *Beijing*air forecasts showed a good correlation with the measured API values, good prediction of the mean values and a low normalised mean square error. The correlation improved when the model was run in hindcast mode compared with the live forecast mode. During the live forecast mode the latest forecasts of meteorology and background concentrations were not always available although the *Beijing*air system used the latest data available to it to ensure that forecasts were made. During the first week of the forecasting system operation the data feeds were least reliable and in addition adjustments were made to the emissions inventory in order to optimise the forecasts.

Some peak pollution events were underestimated by the forecasting system, in particular those of 24-28 July and 29 August. This has been found to be strongly related to the quality of the background concentrations that significantly drive the ADMS-Urban results. When the background data are not the latest forecasts they are subject to greater uncertainty and this in turn leads to a reduced performance of the *Beijing*air forecasts.

During the Olympic period Beijing experienced uncommonly high rainfall and the *Beijing*air system had not been set up to take washout of pollutants into account. This will have led to some overestimation in ground level concentrations.

Other sources of uncertainty in the modelling concerned the *in situ* monitored data and the emissions inventory. The approximate location of the monitors in Beijing was found but there was no information found on the proximity of the monitors to roads (and to road traffic) nor to vegetation. Similarly, no detailed information was found on the instrumentation used for the monitoring, nor of its quality control.

There was considerable uncertainty in the emissions inventory used by both ADMS-Urban and by Chimère. Improved data on the emissions sources - traffic, industry, heating, etc - would be expected to improve forecasting accuracy.

The analysis has shown that the inclusion of the emission reduction scenarios in the routine forecasts greatly benefited the forecast performance relative to the case with no emission reductions and that the emission reduction had a significant effect on pollution levels during the Olympic Games.

Abbreviations

EPB	Environmental Protection Bureau
MEP	Chinese Ministry of Environmental Protection
KNMI	het Konijnklijk Nederlands Meteorologisch Instituut (Dutch Met. Office)
ESA	European Space Agency
CNU	Beijing Capital Normal University
ECMWF	European Centre for Medium-Range Weather Forecast
CERC	Cambridge Environmental Research Consultants
ADMS	Atmospheric Dispersion Modelling System
API	Air Pollution Index
CO	carbon monoxide
NO	nitrogen monoxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides (NO and NO_2)
O_3	ozone
PM	particulate matter
SO_2	sulphur dioxide
VOC	volatile organic compound

1. Air quality in Beijing and context

This report presents the system setup and the validation of the air quality forecasting system produced by CERC for Beijing (*Beijing*air) over the summer 2008. The forecasting system was launched in early July in Beijing and has since produced operational air quality forecasts at a street level scale. The forecasts are here compared to city-scale forecasts made by the Chinese Ministry of Environmental Protection, measurements using continuous monitors by the Beijing Environmental Protection Bureau, and forecast background concentrations produced by the Dutch Met. Office.

The report includes the following sections: sections 1 and 2 describe the air quality in Beijing and its context together with a general description of emissions controls in Beijing; sources and availability of data are discussed in section 3; section 4 describes input data for Beijingair; measurements and forecasts conducted by the Chinese authorities and the air pollution index used by them are given in section 5 whilst section 6 presents the validation of the forecast made for Beijing before conclusions in section 7.

The high levels of air pollution in Beijing have been a subject of concern for many years. The levels of air pollution can be abnormally high for several days in a row, as shown by the times series of the air pollution index in Beijing of Figure 1, and the visibility in the city can dramatically decrease over a few days due to pollution episodes, as illustrated in Figure 2.

In an effort to make improvements a number of mitigation programmes have been put in place since 1998, such as the restructuring of energy, the control of traffic, the control of construction and the control of industrial pollution. These have included moving industrial emissions away from the city centre, using clean coal, tree planting programmes, adopting more advanced vehicle emissions standards, etc.

However, although local emissions of particulate matter and sulphur dioxide have decreased,

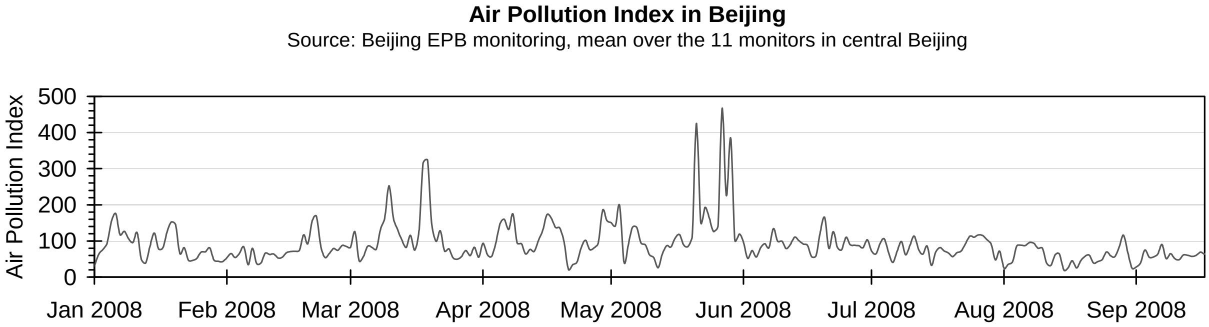


Figure 1 – Beijing air pollution index since January 2008. Time series produced by averaging air pollution indices of eleven monitors located in central Beijing (see section 5.1). [Source: Beijing EPB monitoring data]

the overall pollution levels have remained on average high due to rapid expansion of the urban area, greatly increased levels of road traffic and high regional pollution. Levels of particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) all contribute to high pollution levels.

With Beijing hosting the Olympic Games in 2008, additional efforts were made by the Chinese authorities to reduce the air pollution, as the high levels received publicity across the world and the International Olympic Committee even suggested that events may be moved or rescheduled so that athletes' capabilities would not be significantly impaired.

In such a context, the ability to predict and manage air quality right down to street level was thus of great significance. The Chinese Ministry for Environmental Protection currently issues air quality forecasts for all major cities, but this only gives a broad indication of levels across the city as a whole rather than giving street level detail. The Beijing EPB also issues daily air pollution indices at 27 monitors in the Beijing municipality, but only 11 of them are located in the main urban area where the main Olympic venues were located.

Within the scope of the Dragon 2 programme, CERC's *your*air street level air quality forecasting system has been implemented for Beijing ("*Beijing*air"), in partnership with the European Space Agency (ESA), the Beijing Capital Normal University (CNU) and the Dutch Meteorological Office (het Koninklijk Nederlands Meteorologisch Instituut – KNMI).

The Dragon Programme is a cooperation between ESA and the Ministry of Science and Technology of the People's Republic of China (MOST). The first Dragon programme had a duration of four years and has just concluded. The second Dragon programme will also last four years and formally commenced at the 2008 Beijing Symposium. The Dragon 2 programme includes a project looking at the effect of hosting the Olympic Games, by considering various factors such as quality of life, including air quality.

The aim of *Beijing*air was to publish every day a forecast pollution map of Beijing for the next three days, with emphasis on the Olympic sites and the Olympic period. The Olympic Games started on 8 August and lasted until 24 August. They were followed by the Paralympics from 6 September until 17 September.

The system was initially set up and tested at CERC's offices in Cambridge and officially launched on the 8th of July 2008 in Beijing (Figure 3), when the system was successfully installed at the Beijing EPB and training subsequently given; the system was also installed at CNU. The system (based in Cambridge) produced operational air quality forecasts throughout the Olympic period (17th of September 2008) and beyond.

Figure 2 – View of Beijing on three different days. [Source: BBC]

The area where the forecast was made encompassed the Olympic venues in Beijing, the city area within the 4th ring road and parts of the city around the 5th ring road (see map of Beijing in Figure 4). Pollution sources in and around this zone were explicitly modelled.

Figure 3 – The official launch of the system took place at Beijing EPB on 08/07/2008.

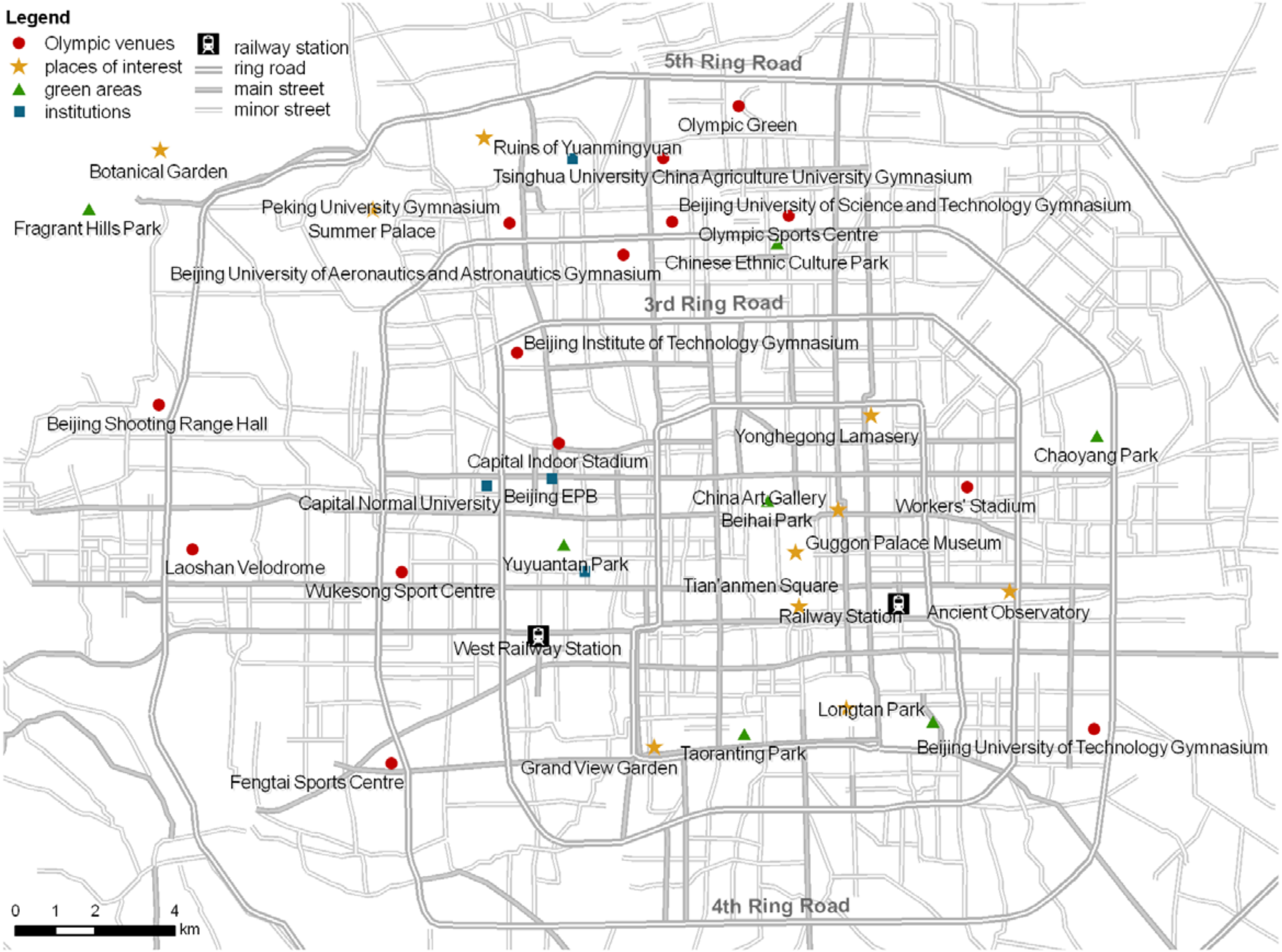


Figure 4 – Olympic venues and places of interest in Beijing.

2. Emissions controls in Beijing

2.1 Since 1998

Since 1998 there have been 13 programmes, costing 60 billion RMB, aimed at improving air quality in Beijing in the face of rapid urban development. They fall under four broad categories: restructuring of energy, control of traffic, control of construction and control of industrial pollution. Some of the actions undertaken are listed below.

As a result of the programmes, the Beijing EPB reports that levels of all major pollutants have gone down despite a growth in traffic of 10 % each year (Figure 5).

Restructuring of energy

- The supply of natural gas has increased from less than 500 million m^3 in 1998 to around 4,000 million m^3 in 2008.
- 44,000 sets of small coal boilers and kitchen ranges in the urban area have been converted to use natural gas. This was completed by 2007.
- 16,000 sets of coal boilers using below 20 tonnes of coal each year have been converted to use gas. This was completed by the end of 2007.

Control of traffic

The number of vehicles in Beijing has increased from less than 1.5 million in 1998 to almost 3.5 million in 2008.

- Beijing has implemented stricter vehicle emissions standards than national standards.
- Since 1999 the European Union's vehicle emissions standards for new vehicles have been adopted, so new vehicles in Beijing must satisfy the same emissions standards as those in the European Union.
- Since 1999 higher fuel standards have been adopted. Unleaded fuel was introduced from 1997, sulphur content was reduced to below 50 ppm and other measures were introduced in order to reach the European Union fuel standard.
- The enforcement of vehicle emissions standards was improved. One method is via roadside checks by 20 teams accompanied by Police who have the power to seize licence plates. They focus on heavy duty vehicles and buses and inspect vehicles registered outside Beijing.
- A new laboratory is being constructed to test Euro II and Euro IV vehicle emissions using

1979 **2008**

Figure 5 – Beijing has seen a rapid growth in the number of vehicles.

United States and European Union methods.

- Storage and transportation of fuel has been improved to reduce emissions of volatile organic compounds. By 2008, 1,400 filling stations and 1,243 tank trucks had completed the retrofitting programme.
- Heavy goods vehicles (lorries and buses) have been classified as yellow sticker or green sticker. A vehicle is given a yellow sticker if it is pre-Euro I for petrol vehicles and pre-Euro III for diesel vehicles. Green sticker vehicles are Euro I or above for petrol vehicles and Euro III or above for diesel vehicles (Figure 6).
- Since 2003 yellow sticker vehicles have not been allowed on or inside the Beijing second ring road.
- Yellow sticker vehicles are inspected twice a year and green sticker vehicles once per year (43 test stations across Beijing).
- Buses and service vehicles that do not meet the green sticker standard have been replaced or modified. In 2007, 2,580 buses were retired from the fleet.
- The replacement of the taxi fleet has been speeded up. 50,000 taxis have gone through the improved programme. There are now 6,000 taxis that use LPG as fuel.
- Over the 20,000 buses in Beijing, over 60 % are Euro II or Euro IV standard. 4,000 use CPG.
- In 2000, 25,000 car carburettors were retrofitted.
- The traffic signalisation has been improved to include information on traffic flow (Figure 7).

Control of construction

- Guidelines on control of dust were issued.
- There are frequent inspections for dust control.

Control of industrial pollution

- Since 1998, the most seriously polluting factories have been closed.
- Some factories have been relocated outside the city centre.
- Factories are required to meet emissions standards.

Figure 6 – Green sticker vehicles are Euro I or above for petrol vehicles and Euro III or above for diesel vehicles.

Figure 7 – The traffic flow information on panels on the roads (green = free flowing).

Other measures

In addition the underground system has been extended and ecological measures have been taken:

- “green shields" have been built to the north-west of Beijing,
- deep ploughing is not permitted after the autumn harvest,
- a target has been set of 49% green coverage of the city.

Figure 8 – Vehicles are restricted to operating on alternate days according to whether the final number on their licence plate is odd or even.

2.2 Olympic period

On 20 July 2008 the final stage of air pollution control measures designed to reduce air pollution was implemented by the Beijing government. They involved the following.

Control of traffic

- Reduction in the use of private cars, with vehicles restricted to operating on alternate days according to whether the final number on their licence plate is odd or even (Figure 8).
- Further reduction in the use of government cars.
- More cleaning of the roads to reduce dust.
- Dedicated lanes for Olympic transport (Figure 9).
- From 1 July 2008 until 20 September 2008 yellow sticker vehicles are not allowed on or inside Beijing's 5th ring road (Figure 10).

Figure 9 – During the Olympics dedicated lanes for vehicles associated with the Olympics should ease congestion.

Figure 10 – Higher polluting vehicles are banned on urban roads from 1 July to 20 September.

Control of construction

- Temporary halt of construction in Beijing during the Olympic period.

Control of industrial pollution

- Suspension of heavily polluting industry.
- Reduction in production for coal-based enterprises.

In addition to these controls, the monitoring of air quality was intensified. Data from many monitors were made available during the Olympic period and new vehicles were used to monitor the air quality around the Olympic venues (see Figure 11).

Figure 11 – One of the vehicles used for air quality monitoring around Olympic venues.

3. Street level air quality forecasting system for Beijing – *Beijing*air

A *your*air air quality forecasting system has been developed for the city of Beijing and took the name of *Beijing*air. *your*air air pollution forecasting systems have the ADMS-Urban model as their central component. ADMS-Urban is an air quality management system for urban planning and air quality reviews, developed by CERC. In the United Kingdom and around the world it has been used successfully and validated in a variety of situations where different sources types are important (for example industrial, traffic and heating sources) and where different factors such as complex topography affect dispersion. In the United Kingdom, ADMS-Urban has been used by over 80 local authorities in conducting their Review and Assessment of air quality under the Local Air Quality Management program. These local authorities included the large urban authorities of the Central and West London Cluster Groups of Boroughs as well as authorities with more rural areas, such as Cheshire and the East Riding of Yorkshire.

Studies carried out with ADMS-Urban include air quality management planning in London and Beijing; decision-making and air quality forecasting in Budapest, Hungary; air quality assessment in Strasbourg, France; modelling of traffic sources in California, United States of America; modelling of domestic coal burning emissions in Belfast, Northern Ireland.

*your*air forecasting systems are driven by boundary conditions from meso-scale models. The link with meso-scale data was developed as part of the ESA's PROMOTE project that aimed to construct and deliver a sustainable and reliable operational service to support informed decisions on the atmospheric policy issues of stratospheric ozone depletion, surface ultraviolet exposure, air quality and climate change. This combination of meso-scale data and ADMS-Urban local scale modelling is already operational in the *your*air forecasting system currently being used in London (http://www.airtext.info) as well as Wakefield (northern England, http://www.cerc.co.uk/YourAir/Wakefield/index.asp). *your*air forecasting systems are currently being established in Vienna and Vilnius.

Figure 12 illustrates the usual structure of a *your*air air quality forecasting system The system is realised in three modules:

- pre-processing of a series of input data, including at least meteorology, background concentrations, and emissions inventory;
- modelling of the pollution sources and dispersion in the city with ADMS-Urban;
- dissemination of results as colour pollution maps, alerts, etc.

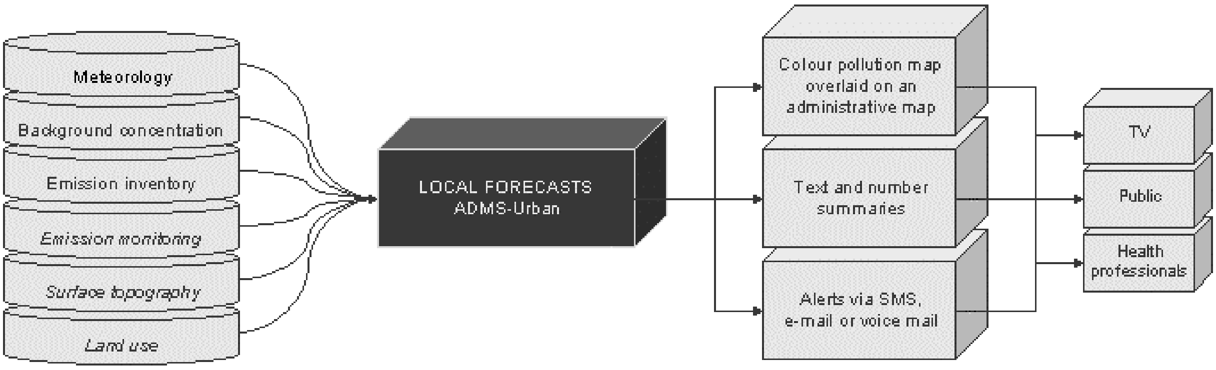


Figure 12 – Diagram of the street level air quality forecasting system.

The input data are typically an emissions inventory for the city, regional background concentrations (pollution advected to the city by the wind and hence not a local source of pollution which could be explicitly modelled), and local meteorological data for the period of forecasting – further information on the *Beijing*air input data is available in section 4. If available, an automatic feed of locally monitored ambient air quality data can be inserted into the system. If relevant, the surface topography and land use are taken into account.

ADMS-Urban runs on standard Windows PCs. If necessary, the city modelled is divided into various sectors on various computers in order to speed up the modelling – typically one sector per computer. The model outputs hourly concentration data for the city over the period of forecasting.

The output concentrations are finally converted into pollution maps overlaid on a street map of the city, and disseminated to the media and public in various ways. With *Beijing*air, the maps were published on-line on a dedicated website (http://www.beijingairquality.cn) illustrated in Figures 13 and 14. Alerts were only implemented for the project team. The website offers various functionalities, such as interactive air quality maps, archived forecast, health information, and information on *Beijing*air.

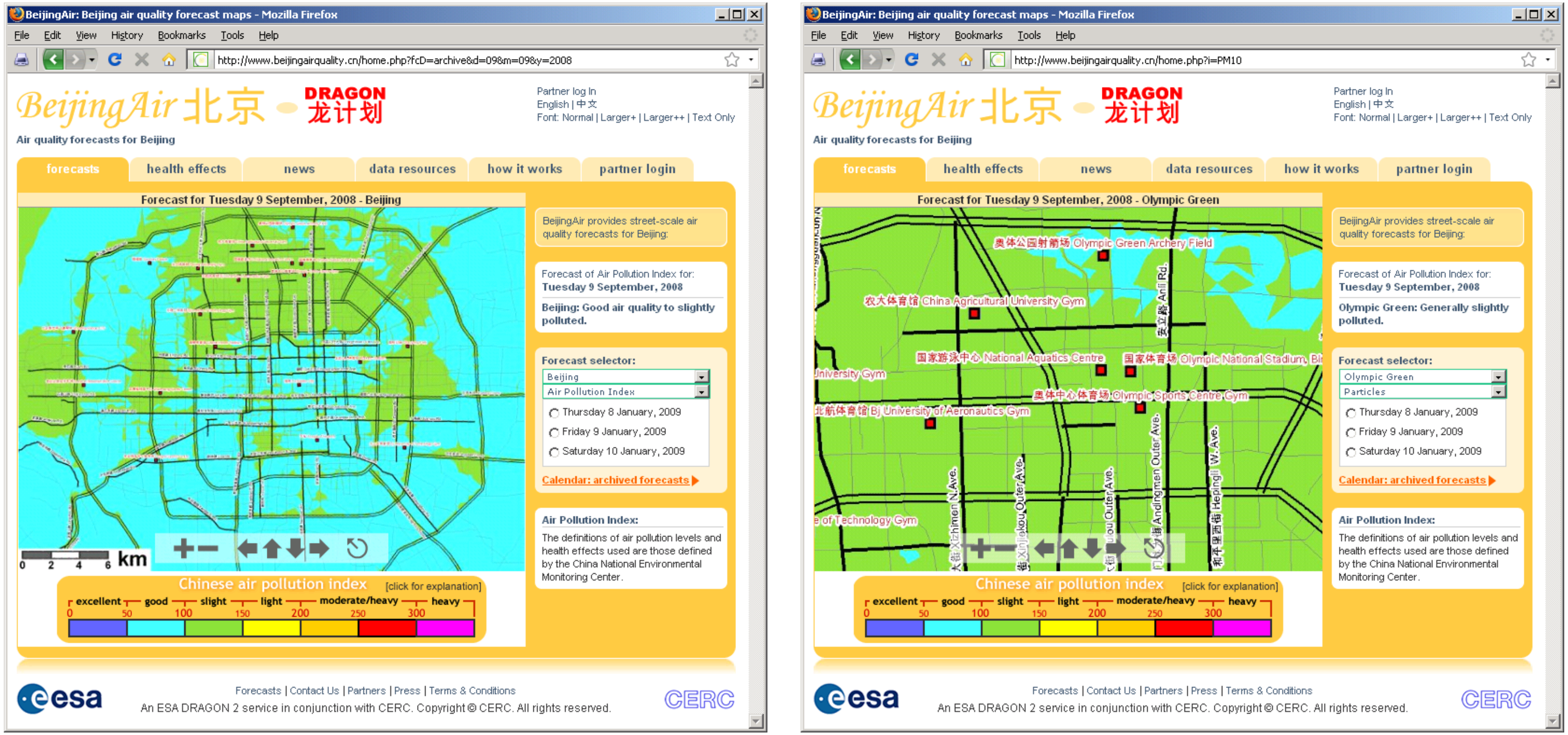


Figure 13 – Street level air quality forecast published on-line at http://www.beijingairquality.cn (English version). Left: home page, air pollution index over the whole of Beijing on Tuesday 9 September 2008; right: home page, particle pollution index over the Olympic Green area for the same day.

Figure 14 – Street level air quality forecast published on-line at http://www.beijingairquality.cn (Chinese version). Left: home page, air pollution index over the whole of Beijing on Tuesday 9 September 2008; right: home page, particle pollution index over the Olympic Green area for the same day.

4. Input data for *Beijing*air

As shown in Figure 12, a *your*air forecasting system uses a wide range of input data. *Beijing*Air used meteorological forecasts, forecasts of regional background concentrations and an emissions inventory. The topography and land use were taken into account by defining a surface roughness of 1 m and a minimum Monin-Obukhov length of 75 m.

The following data sets are described hereafter:

- emissions inventory, i.e. pollution sources modelled by ADMS-Urban (section 4.1);
- forecast of regional background concentrations by KNMI (section 4.2);
- forecast of meteorological conditions by ECMWF (section 4.3).

4.1 Emissions inventory

Emissions data for Beijing were defined for the following source groups: road traffic, power plant, industry, boilers, and other sources.

Table 1 shows the Annual Average Daily Total traffic flows (AADT) which have been estimated for Beijing from observations on particular roads and the overall number of vehicles registered in Beijing. Heavy duty vehicles were restricted within the 5th ring road during the day and therefore separate day- and night-time flows have been assumed for roads encompassed by the 5th Ring Road.

The breakdown of vehicle types is given in Table 2. The fleet composition has been based on the 2000 urban United Kingdom fleet as Beijing has moved to applying Euro standards but it was estimated that the fleet might be a few years older on average than the fleet in a city in the United Kingdom.

SO_2 emissions data for industries, power plants, boilers and other sources were available from an old emissions inventory that was modified to account for the restructuring of energy.

Road		**Day**			**Night**	
Type	Width (m)	Light vehicle AADT	Heavy vehicle AADT	Speed (km/h)	Heavy vehicle AADT	Speed (km/h)
5th ring road	80	121800	7000	20	11200	30
4th ring road	80	174000	10000	20	16000	30
3rd ring road	80	87000	5000	20	8000	30
2nd ring road	80	87000	5000	20	8000	30
Express way	80/100	174000	10000	20	16000	30
Major road	various	52200	3000	20	4800	30
Minor road	20	17400	1000	20	1600	30

Table 1 – Traffic data. AADT = annual average daily total (number of vehicles).

Light duty vehicle
78 % petrol cars
12 % diesel cars
2 % petrol Light Good Vehicles
8 % diesel Light Good Vehicles

Heavy duty vehicle
34 % buses
53 % rigid Heavy Good Vehicles
13 % articulated Heavy Good Vehicles

Table 2 – Vehicle fleet composition.

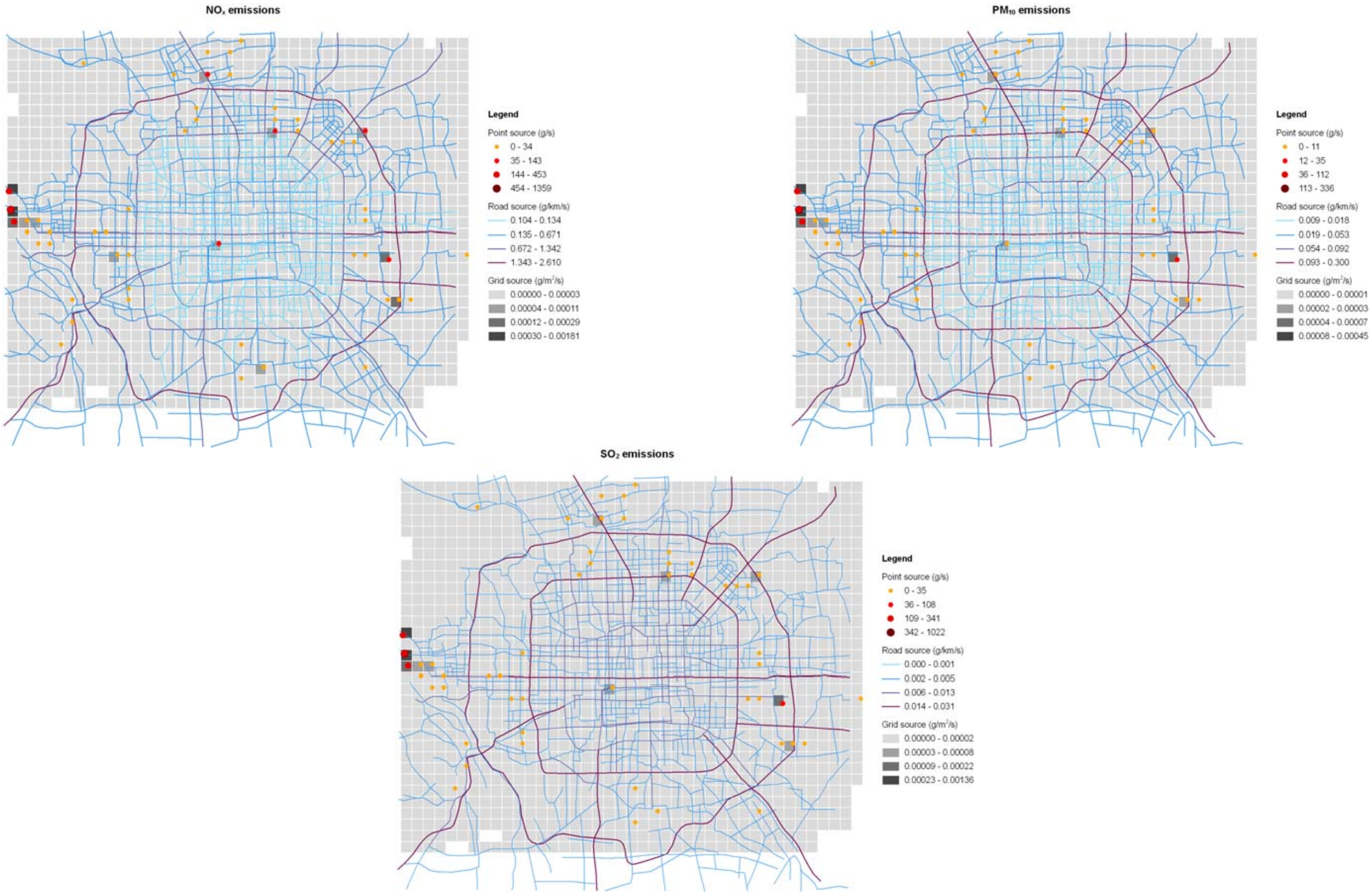


Figure 15 – Modelled NO_x, PM_{10} and SO_2 sources before the Olympics.

Table 3 shows the total emissions of each pollutant in Beijing before the Olympics. Figure 15 shows maps of road, point and grid source emissions of nitrogen oxides (NO_x), PM_{10} and SO_2. Note that the grid source is an accumulation of all modelled sources.

Source group	NO_x emissions (tonne/yr)	PM_{10} emissions (tonne/yr)	SO_2 emissions (tonne/yr)
Boilers	26197	3864	898
Common area	5949	10850	6957
Industry	23810	3511	9961
Power Plant	110000	27170	82720
Roads	43370	4686	635
Total	209300	50090	111200

Table 3 – Total emissions for Beijing.

Olympic period

During the Olympic period, the movement of traffic and the operation of industry were restricted. Based on known information on the emissions controls implemented by the Chinese authorities, these changes were made to the emissions of the forecasting system:

- all pre-EURO III HGVs were removed from the fleet,
- 30 % of light duty vehicles were removed,
- industrial emissions were decreased by 50 % on average.

4.2 Forecast background concentrations (KNMI/Chimère)

In view of the high regional pollution levels in the Beijing area, the pollution at street level significantly depends on both local emissions (e.g. from road traffic, local industry) and regional levels. Whilst ADMS-Urban predicts local dispersion effects, it also requires regional levels as boundary conditions for the modelling of local dispersion and chemical transformation. These boundary conditions were obtained from the Chimère model.

The Chimère model is a multi-scale model primarily designed to produce daily forecasts of ozone (O_3), aerosols and other pollutants, and make long-term simulations for emissions control scenarios. It runs over a wide range of spatial scales ranging from several thousand kilometres (regional scale) to 100-200 kilometres (urban scale) with resolutions varying from 1-2 km to 100 km.

In order to produce a forecast, the Chimère model requires an inventory of emissions and meteorological data. While the met. data are rather straightforward (see section 4.3), the last emissions inventory for China is for 2006 emissions. With the rapid growth of industry and transport, this may be quite unrepresentative of the year 2008. This emissions inventory[1] was prepared by Qiang Zhang and David G. Streets, Decision and Information Sciences Division, Argonne National Laboratory, for the INTEX-B project of the National Aeronautics and Space Administration (NASA). It included the emissions of SO_2, NO_x, CO, volatile organic compounds, PM_{10}, $PM_{2.5}$, black carbon and organic carbon by sector (power, industry, residential, and transportation) at a 0.5° resolution. Note that this 2006 inventory is an update of the 2000 version. As stated by the authors, "*the emission changes between the two*

[1] http://www.cgrer.uiowa.edu/EMISSION_DATA_new/index_16.html

inventories reflect a combination of: (a) actual growth in emissions due to increasing economic development, (b) the effects of replacing the TRACE-P inventory by local inventories in several countries, and (c) improvements and corrections made to the original TRACE-P inventory. The changes should not be viewed solely as real emissions growth. The 2006 inventory values are considered to be a reasonable reflection of the absolute magnitude of emissions in that year, pending re-calculation with actual activity statistics when they become available."

Within the frame of the AMFIC project[2], the Chimère[3] model has been run by the KNMI (Dutch met. office) in order to produce daily forecasts of hourly concentrations in eastern China. The period of forecasting covered today and the next five days in local time, and the extent of the region modelled is illustrated in Figure 16. The forecast was distributed on a 0.25° spatial grid (roughly equivalent to a 40-50 km spacing) and eight vertical levels (from the ground surface to 500 hPa). Numerous species were modelled, including O_3, NO_2, NO, SO_2, CO, PM_{10} and some volatile organic compounds (VOCs). These species were of major interest for *Beijing*air and the Chimère outputs were used as background concentrations for ADMS-Urban.

Specifically, the hourly time series of ground-level concentrations of these species surrounding of Beijing (eight model meshes around the city of Beijing) were extracted from the Chimère output data and merged into a single time series using the wind direction – see Figure 17. Concentrations were also adjusted to compensate for biases in the model, that is:

- concentrations of NO_2, NO, SO_2, CO, $PM_{2.5}$ and VOCs were multiplied by a factor 0.55;
- the concentrations of PM_{10} were multiplied by a factor 0.55 and 10 μg/m^3 added.

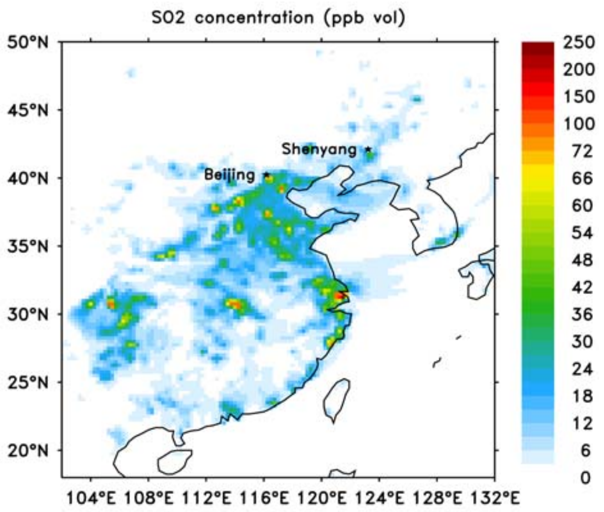


Figure 16 – Region modelled with the Chimère model.

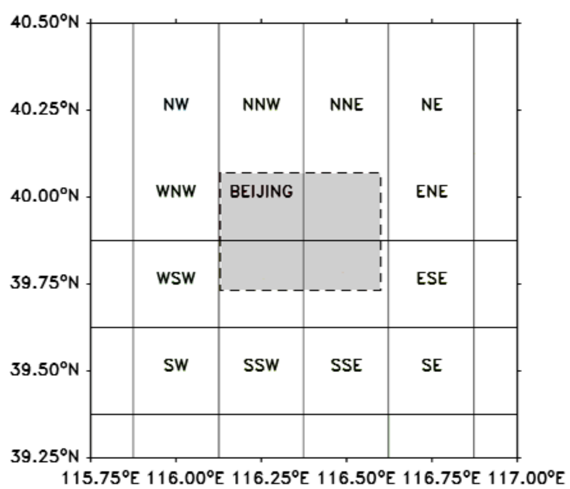


Figure 17 – Zoomed in view of the meshes in/around Beijing.
N = north, S = south, W = west, E = east.

[2] Air Quality Monitoring and Forecasting in China (AMFIC) is a project which aims to *"develop an integrated information system for monitoring and forecasting tropospheric pollutants over China. The system uses satellite and* in situ *air quality measurements and modelling to generate consistent air quality information over China. The data will cover the recent years and the actual situation including an air quality forecast for several days ahead. Air pollutants covered are ozone, nitrogen dioxide, sulphur dioxide, formaldehyde, carbon monoxide, methane and aerosol/particular matter."* Website: http://www.amfic.eu.

[3] http://www.lmd.polytechnique.fr/chimere

4.3 Forecast meteorology (ECMWF)

In addition to the emissions inventory and the background concentrations, ADMS-Urban required meteorological information covering the period of forecasting. This was obtained from ECMWF[4] which made available daily a 10-day forecast over East Asia.

This meteorological forecast was produced at two different resolutions (a coarse grid for synoptic information and a fine grid for boundary-layer information), as illustrated in Figure 18. The temporal resolution was 3 hours for the first three days and 6 hours for the remaining days. Forecast meteorological variables included the wind speed and direction, near-ground air temperature and cloud cover.

These variables were extracted from the ECMWF product at the mesh representing Beijing. They were also linearly interpolated in time to produce hourly time series.

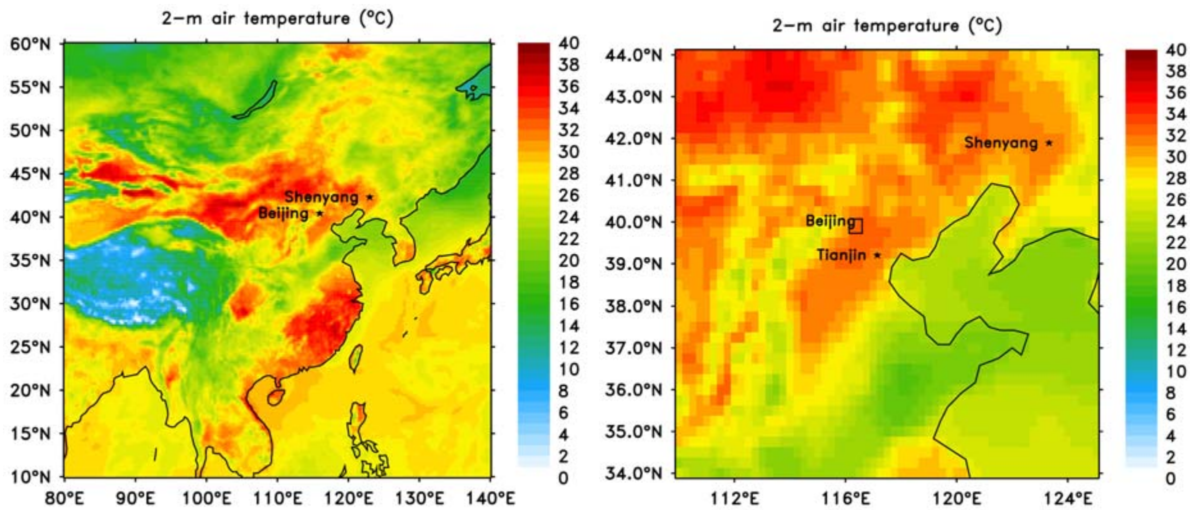


Figure 18 – Modelling extents of the ECMWF products (left: coarse grid, right: high resolution grid).

[4] Note that the Chimère model (see section 4.2) also used the ECMWF products to produce its forecasts of background concentration.

5. Data for validation

The air quality in China is presented in terms of an Air Pollution Index (API). This index is an indicator of how (non-) polluted the air may be and is derived from raw pollutant concentrations. The *Beijing*air air quality forecast shown in this report was converted to API values, as explained in section 5.1.

In order to validate the *Beijing*air forecast, the results were compared to monitored air quality (section 5.2) and the official Chinese forecasts (section 5.3), both of which are expressed as API values. In addition, observed meteorological information was used for determining rain events (section 5.4).

5.1 Air pollution index

The Chinese Environmental Protection Bureaus (EPB) uses an Air Pollution Index (API) for describing the air quality in China and communicating this information to the public. The definition of the API is that of the China Environmental Monitoring Centre and is given below.

An API is an integer associated with a mass concentration of a species and each API range is attributed an air quality label, as indicated in Table 4.

API	Species concentration (μ/m^3)					API range	Air quality label
	SO_2 (daily mean)	NO_2 (daily mean)	PM_{10} (daily mean)	CO (hourly mean)	O_3 (hourly mean)		
50	50	80	50	5000	120	0-50	Excellent
100	150	120	150	10000	200	51-100	Good
200	800	280	350	60000	400	101-150	Slight
						151-200	Light
300	1600	565	420	90000	800	201-250	Moderate
						251-300	Moderate to heavy
400	2100	750	500	120000	1000	>300	Heavy
500	2620	940	600	150000	1200		

Table 4 – API concentration bands for selected species and air quality labels.

API of a species at a particular location and time

The API of a species at a particular site and time is obtained using the following formula:

$$API = API_{low} + \left(API_{high} - API_{low}\right)\cdot\frac{C - C_{low}}{C_{high} - C_{low}},$$

where C is the species concentration at a particular site and time, and the subscripts *low* and *high* refer to the range limit values of Table 4.

Example: for 100 $\mu g/m^3$ of SO_2, $C = 100\ \mu g/m^3$, $C_{low} = 50\ \mu g/m^3$ and $C_{high} = 150\ \mu g/m^3$, $API_{low} = 50$ and $API_{high} = 100$ and $API = 75$.

City-wide daily API

In order to obtain a daily API for a whole city from monitors of various species at several sites, the following calculations apply.

The *daily concentration of a species at a given site*, $\overline{C_{species}}$, is calculated by averaging sub-daily concentrations of the species at this given site, $C_{species,t}$:

$$\overline{C_{species}} = \frac{1}{T}\sum_{t=1}^{T} C_{species,t} \ ,$$

with T the number of measurements over the day. The *daily concentration of a species for the whole city*, $\overline{C_{city,species}}$, is then calculated by averaging the daily concentrations of the species across the sites, $\overline{C_{species,s}}$:

$$\overline{C_{city,species}} = \frac{1}{S}\sum_{s=1}^{S} \overline{C_{species,s}} \ ,$$

where S is the number of sites.

The *daily API of a species for the whole city*, $API_{city,species}$, is obtained using the above API formula.

Finally, the *city-wide daily API*, API_{city}, is defined as the maximum daily API across the species, i.e. $\max(API_{city,species_1}, ..., API_{city,species_N})$ where N is the number of species. The species providing the maximum value of API is called the primary pollutant.

API in this report

The API for this report is based on the following three pollutants: SO_2, NO_2 and PM_{10}. The values are daily values and refer to the period starting at 12:00 of the previous day and ending at 12:00 of the current day.

5.2 Monitored air pollution (EPB)

Daily API and daily API per species were available on the internet. These data cover the municipalities of Beijing and Tianjin, as well as cities in the Hebei province. No other monitored data were found. These daily API are published on-line every day. They were converted to concentration values using the formulas described in section 5.1. For Beijing and Tianjin, it was known that the species monitored consist of SO_2, NO_2 and PM_{10}.

The **Beijing EPB** controls a network of 27 monitors in the Beijing municipality (see Figure 19). Daily API are available on-line[5]. In addition, from 27th of July to 20th September 2008, sub-API for SO_2, NO_2 and PM_{10} for the 27 monitors were also provided. Of these 27 monitors, 11 only are located within the ADMS-Urban modelling domain, as shown in Figure 19, and are of interest for this validation report.

The **Tianjin Environmental Monitoring Centre** (under the authority of the Tianjin EPB) also provides on-line[6] daily API for Tianjin and sub-API of SO_2, NO_2 and PM_{10}. The API is given for the city itself and for the new development zones, and is computed from the stations shown in Figure 19; that used for the validation is the city API which is thought to be the average of the 16 monitors of the municipality. Note that from March 2008, the primary species of the daily API has been PM_{10}.

The **Hebei EPB** also provides on-line[7] daily API for cities in the Hebei province, and in particular for Baoding, Langfang and Tangshan. No sub-API are available, but the website indicates which is the primary species.

[5] API for Beijing: http://www.bjepb.gov.cn/air2008.

[6] API for Tianjin: http://www.tjemc.org.cn/ChaXun/lssjcx.asp.

[7] API for Baoding, Langfang and Tangshan: http://www.hb12369.net/template/kqzlfb.asp.

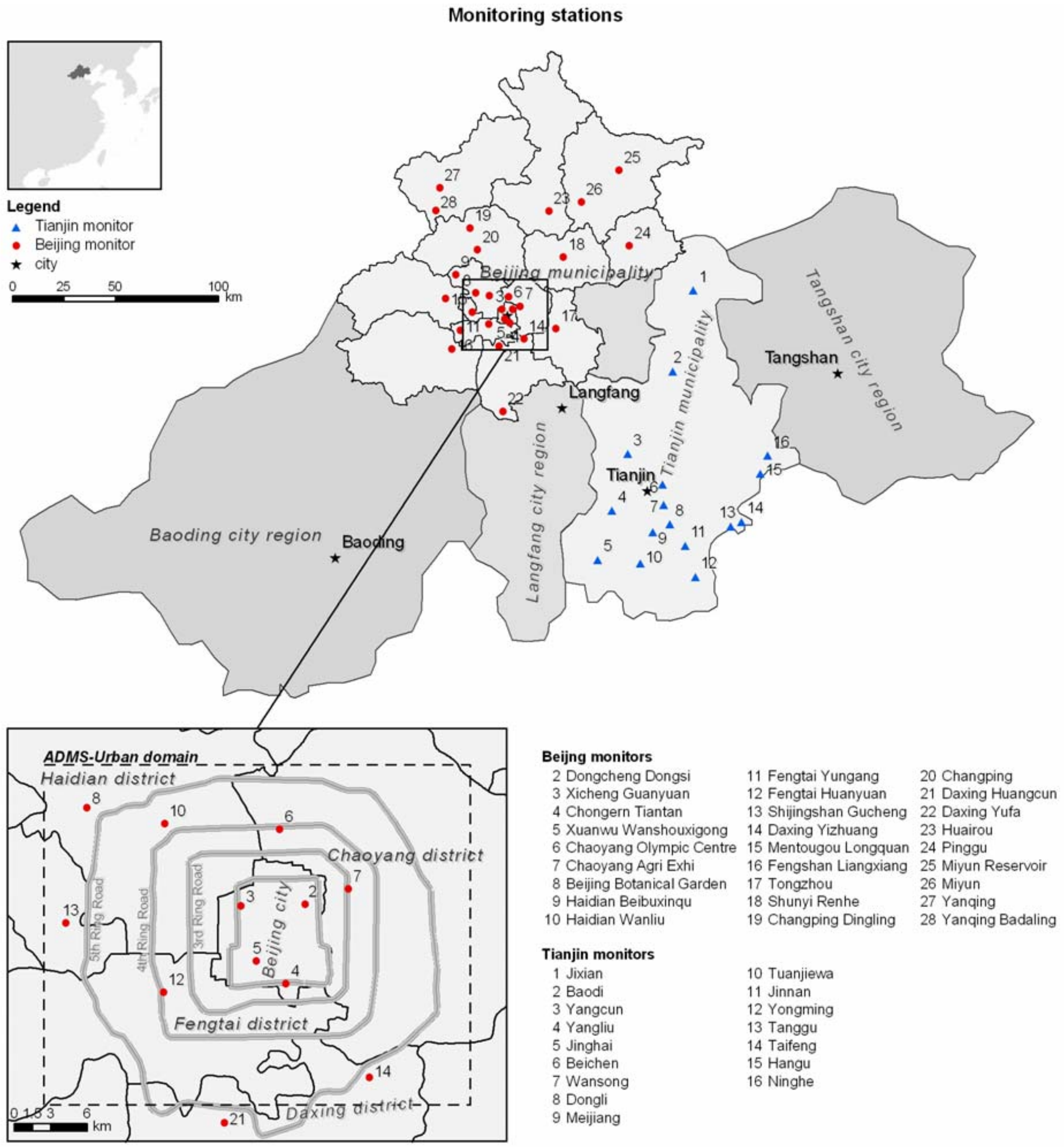


Figure 19 – Location of monitors in the municipalities of Beijing and Tianjin.

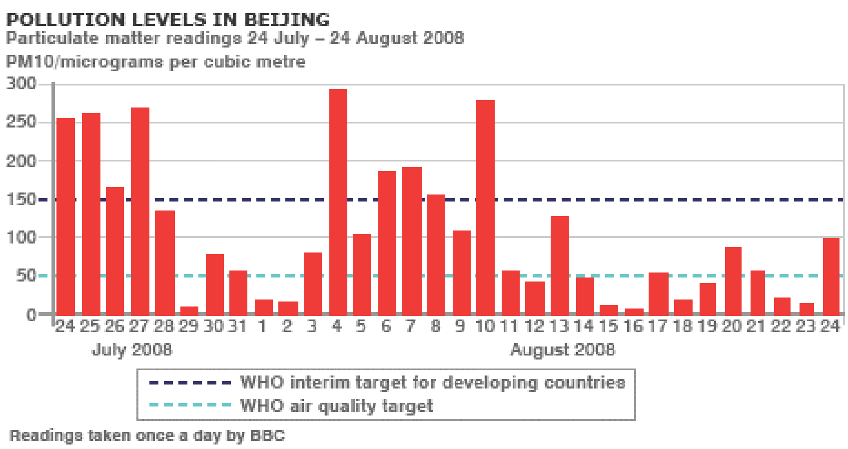


Figure 20 – BBC "snap shot" monitoring of PM_{10} in the centre of Beijing. [Source: BBC]

Despite the reliable daily feed of API from these sources, information about the monitoring was incomplete. Hourly data were not available on-line although the published API is computed from them. Concentrations would have been a very useful measure, but they were not published. Additional information regarding the location of the monitors and the type of monitoring instruments would also have been useful to assess the data quality and help understand differences between modelled and observed values. In particular, the monitor location was not precisely known: no information regarding the proximity of the instruments to roads and the proximity to vegetation were known. In the case of Baoding, Langfang, Tangshan and Tianjin, only a single value is given for the entire city, without information about its calculation (e.g. how many are monitors involved? where are they located?).

In addition to the monitoring carried out by Chinese authorities, "snap shot" measurements were also made by the **BBC** reporter James Reynolds. Every day, from the 8th July until the 21st of August, he recorded PM_{10} concentrations *"at a fixed point along Yonghegong avenue in the centre of Beijing, (…) part of the route of the individual road race in the men's cycling – an important endurance event"*, using *"a hand-held machine that has a 20 % or so margin of error"*. Figure 20 shows the pollution levels he obtained. Note that his measurement is a short period measurement (one reading per day), while the air quality guidelines for PM_{10} are expressed as 24-hour averages.

5.3 Forecast air pollution (MEP)

Forecast concentrations are produced by the Ministry of Environmental Protection (MEP) as the minimum and maximum daily API for the city of Beijing. The forecast is made using the observations over the last day and extrapolated in time using statistical relationships.

5.4 Observed meteorology

Meteorological observations from Weather Underground[8] were used to monitor the local situation, in particular, rainfall. The weather conditions measured at Beijing airport from 5 July to 17 September are reported in Figure 21.

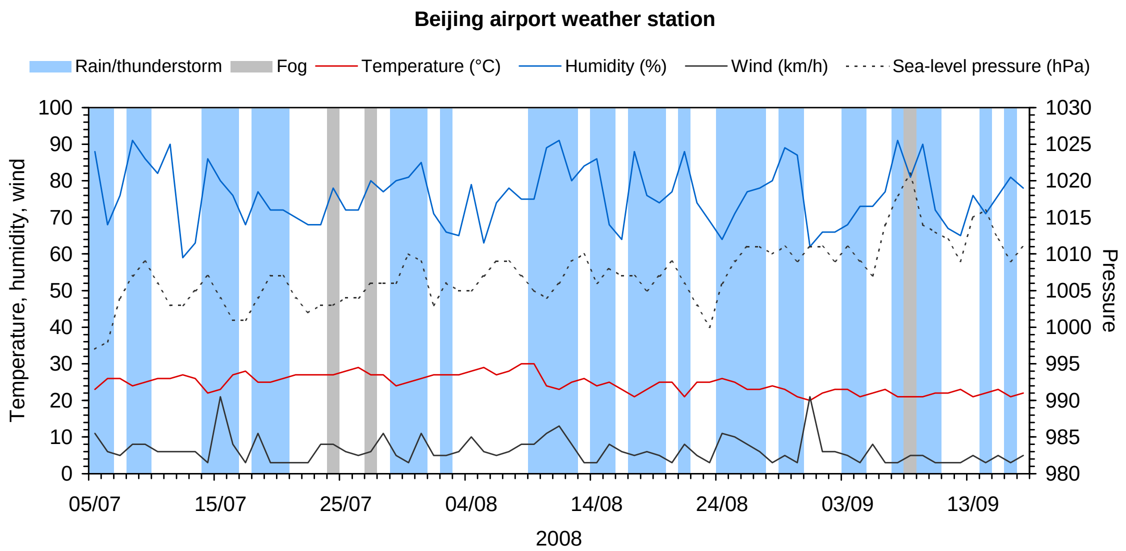


Figure 21 – Beijing airport weather from 5 July to 17 September. Shaded areas indicate occurrences of rain, thunderstorm (and rain) and fog events.

[8] www.wunderground.com

6. Validation of the *Beijing*air air quality forecast

6.1 Observed air quality

Time series of monitored daily API in Beijing versus those in Baoding, Tangshan, Langfang and Tianjin are given in Figures 22 and 23 for March-June and late June-mid-September. Also shown are the BBC measurements.

March to June 2008

The averaged API over the period shown is significantly higher in Beijing than in the other cities. Peaks of pollution are also clearly visible throughout the period, going beyond an API of 200 several times. The correlation of the time series of Tianjin with Beijing is rather strong. Tianjin and Beijing are close proximity so they are likely to be subject to the same meteorological conditions and they may influence each other.

Late June to mid-September 2008

Over the entire period, the Beijing average is found to be lower than during the previous months (API of 71 instead of 113). Apart from Baoding, the correlation between the Beijing data and those of the other cities has decreased, which tends to suggest different meteorological patterns between Beijing and the other regions. The BBC data show a much higher variation than the other series, as expected since they are not daily means, however the broad agreement between the BBC data with those of the Beijing EPB is good (correlation of 0.72 and similar mean values) and there is a visible coherence for the pollution peaks. Note that the statistics for the BBC have been computed using the period for which the BBC data are available instead of the whole period shown on the graph.

Additional correlations and means are given in Table 5 for the periods 20 June-19 July, 20 July-19 August and 20 August-17 September, in order to produce statistics before and after the day the emissions reduction scenario was implemented. Following the final emissions controls on 20 July the mean concentration in all the cities was less than or equal to the mean concentration in the month before. In addition the correlation between concentration levels in Beijing and those in the other cities was notably higher after 20 July (with the exception of Tangshan in the final period) than in the month before 20 July. The decrease in mean concentration was greatest in Beijing (10 $\mu g/m^3$) suggesting that even if regional levels dropped following 20 July due to the prevailing meteorological conditions there was an additional drop in Beijing and the surrounding area and this would be expected due to the emissions controls in Beijing. The second highest decrease was in Langfang, the city closest to Beijing, indicating the influence of reductions in Beijing and/or the effect of its own local controls as cement works in Langfang were shut during the Olympic period.

Period		**Mean**				
From	To	Tangshan	Langfang	Baoding	Tianjin	Beijing
20/06	19/07	60	68	53	67	84
20/07	19/08	54	57	53	63	69
20/08	17/09	56	49	47	62	59
Period		**Correlation with Beijing**				
From	To	Tangshan	Langfang	Baoding	Tianjin	
20/06	19/07	0.52	0.70	0.60	0.16	
20/07	19/08	0.78	0.85	0.86	0.79	
20/08	17/09	0.48	0.80	0.70	0.68	

Table 5 – Means and correlations of monitored API per period.

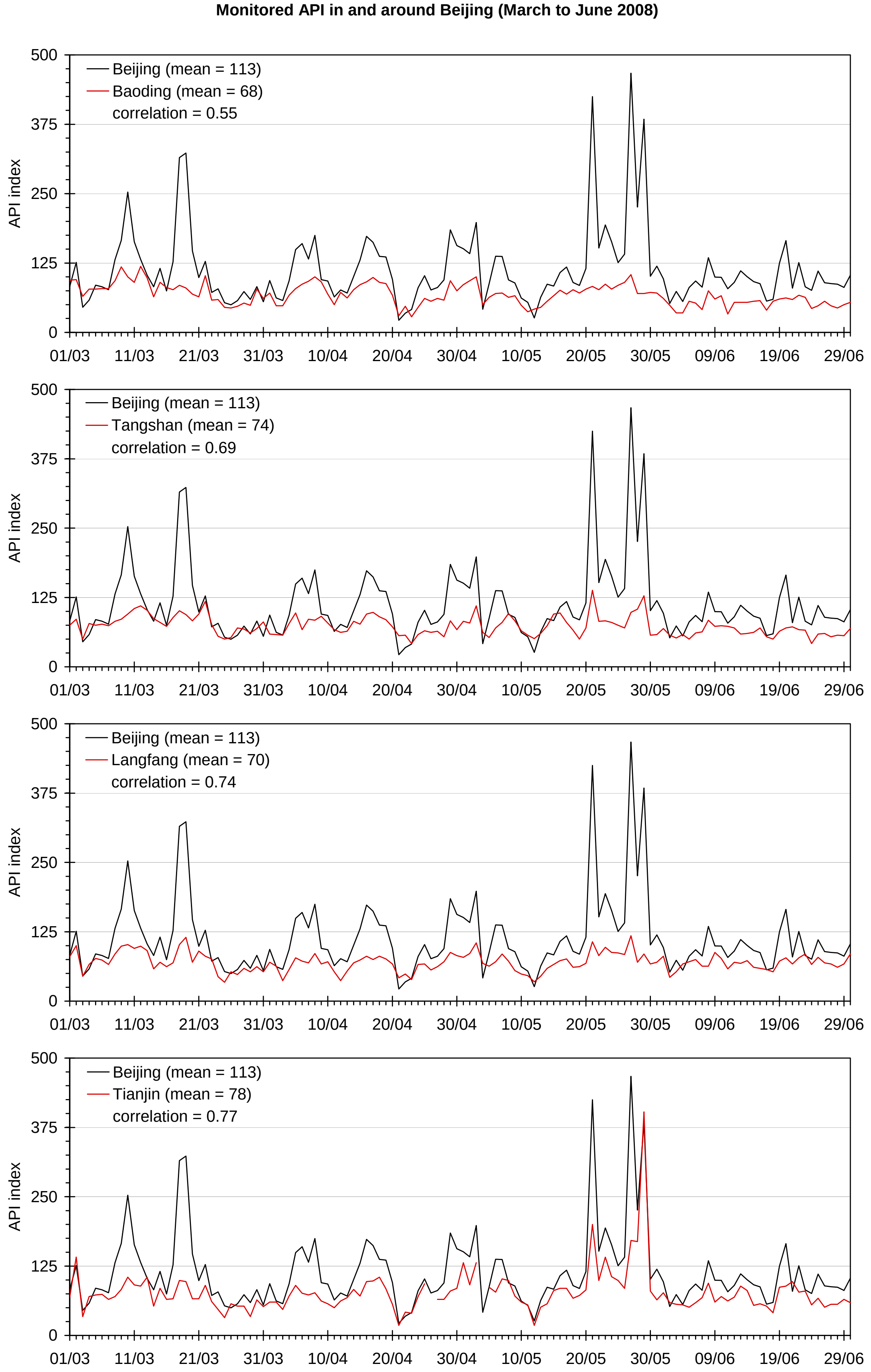


Figure 22 – Monitored daily API in Beijing and surrounding cities from March to June 2008.

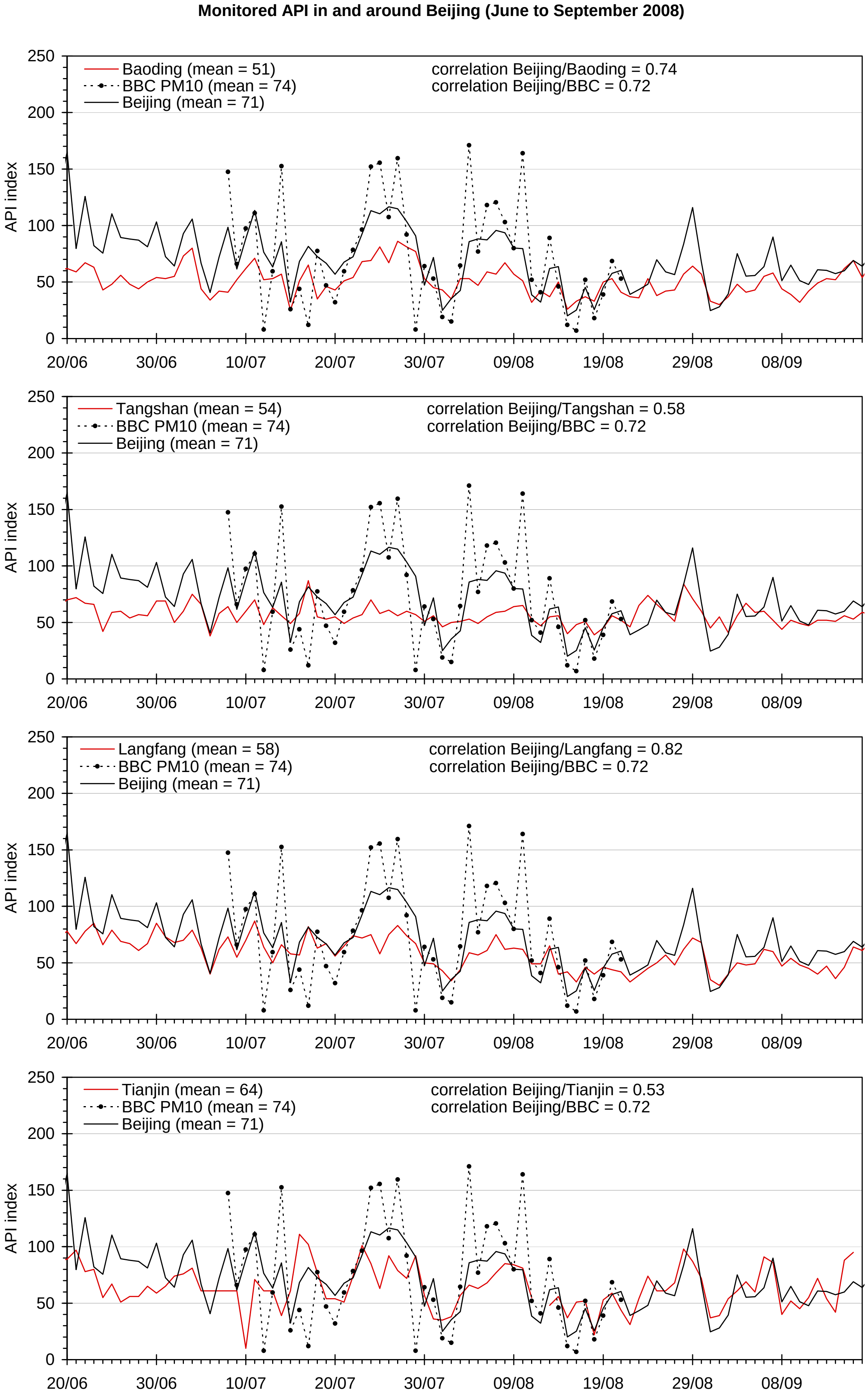


Figure 23 – Monitored daily API in Beijing and surrounding cities from late June to mid-September 2008.

6.2 Forecast air quality versus observations

API for ADMS-Urban and background data

The API of the forecast concentrations are calculated as follows: hourly concentrations per species per receptor (11 receptors) are averaged over 24 hours to obtain daily concentrations per species per receptor (in addition the daily average across the 11 receptors is calculated to get daily concentrations per species for Beijing). These concentrations are converted to API to get daily API per species per receptor. The official API for each receptor is taken as the maximum API of PM_{10}, SO_2. Additionally, the official API per receptor can be averaged to give the official API for Beijing (and also the minimum and maximum across the 11 receptors).

Results

The period of interest for the validation starts on 5 July and ends on 17 September, encompassing the pre-Olympic period (including before the final stage of emissions controls on 20 July), the Olympics (8-24 August) and the Paralympics (6-17 September).

By its nature, the *Beijing*air forecasting system is highly dependent on its input data and the time at which these are available. Intermittently throughout the forecasting period, technical problems led to the impossibility of using the most up-to-date background or meteorology files for the forecast of the day. In 75 days of operation, a forecast was made on 74 days (99 %) – no forecast was made for 27 August due to a computer crash. However, ADMS-Urban could not use the most up-to-date input data on 29 days (39 %), of which on 16 days (21 %) this was due to failures in partners' systems, the reminder being due to failure of delivery of externally required data. In such cases the forecasting system is set up to use the latest input data obtained, usually those of the previous day. The accuracy of the forecast is thence affected. For this reason the forecasts have been reproduced in hindcast mode, once all required input data were obtained. These data are denoted as 'ADMS-Urban results in hindcast mode'.

In addition to these two series of ADMS-Urban forecasts, it was of interest to model the forecasting period in a *business as usual* scenario, i.e. no reduction applied to the emissions from 20 July in the emissions inventory. Note that the Chimère model has implemented an emissions reduction scenario, so the difference in results will only be due to the changes in the ADMS-Urban local emissions inventory. These data are further denoted as ADMS-Urban results in hindcast mode without emissions reduction from 20 July.

Modelled data compared are therefore the daily API forecast by ADMS-Urban in live mode, the daily API forecast by ADMS-Urban in hindcast mode, and the daily API forecast by ADMS-Urban in hindcast mode without the effects of the emissions controls. Among other data sources were considered the daily minimum and maximum API forecast by the MEP, the daily API observed by the Beijing EPB and the API forecast by Chimère. The ADMS-Urban and EPB data sets were restricted to the 11 monitors included in the ADMS-Urban modelling domain. The value presented here is the average over the 11 monitors. The minimum and maximum values refer to the minimum and maximum values over the 11 monitors for a given day. Regarding the MEP data, a simple average of the two values given (estimates of maximum and minimum API) has been performed so as to obtain a single time series comparable with the other data sets. Gaps in time series are usually related to the unavailability of data or the failure of the forecasting system in archiving data.

Time series of API

Figure 24 shows the time series of daily API as forecast by ADMS-Urban (live mode, hindcast mode, hindcast mode without emissions reduction, hindcast mode without chemistry and hindcast mode without chemistry nor background, respectively) and the MEP along with the time series of daily API as observed by the Beijing EPB. Overall, the agreement between modelled and observed data is very good with the averages being very similar.

Looking in more detail, ADMS-Urban tended to overestimate the API in July whilst in August the forecasts are in good agreement with the observations. The largest differences between modelled and observed API occurred at the start of the forecasting period but it should be noted that at the beginning of the forecasting period optimisation of the system was ongoing including adjustments to the emission inventory. During this period, the live forecasts experienced some issues in the feed of meteorological and background data. In addition the emissions inventory was adjusted to optimise the results.

These graphs also show that ADMS-Urban underestimated some peaks of pollution, such as those of 24-27 July and of 29 August. In hindcast mode, this feature persists, suggesting the input data are possibly responsible for this – the background data may have been too low. Note that the agreement between the hindcast and measured data for the first two weeks of July shows a significant improvement over the agreement with live mode. In hindcast mode there is a general improvement for the periods 5-9 August, 22-26 August, 7 September.

Figure 25 shows the same time series of daily API forecast by ADMS-Urban and observed by the Beijing EPB as those of the previous figures, except that the minimum and maximum forecast values over the 11 monitors every day were added to the time series as error bars. They indicate that although the main pollution peaks are missed by ADMS-Urban, the range of API forecast by the model is often good as it encompasses the observed API values – see for example the period 4-10 August.

Figure 26 shows the same time series of daily API forecast by ADMS-Urban and includes the daily API forecast by Chimère. The correlation between the ADMS-Urban and Chimère model results is clearly very strong. It is interesting to notice the effect the background concentrations had on the ADMS-Urban forecasts for the first two weeks of July. The improvement of the forecasts is solely due to the better background data input into ADMS-Urban. To some extent, this might also explain, at least partially, why ADMS-Urban missed some peak pollution events.

Whereas Figures 24-26 show the overall API which corresponds in almost all cases to the PM10 concentration, Figures 27 and 28 also show APIs corresponding to additional pollutants namely SO_2, NO_2 for various hindcast modes. In Figure 27 concentrations are presented together with the observed API index; in Figure 28 forecast total and background only APIs are presented for each pollutant. The general pattern for both total and background concentrations is for the SO_2 index to be a large fraction of the PM_{10} index but the NO_2 index to be relatively small.

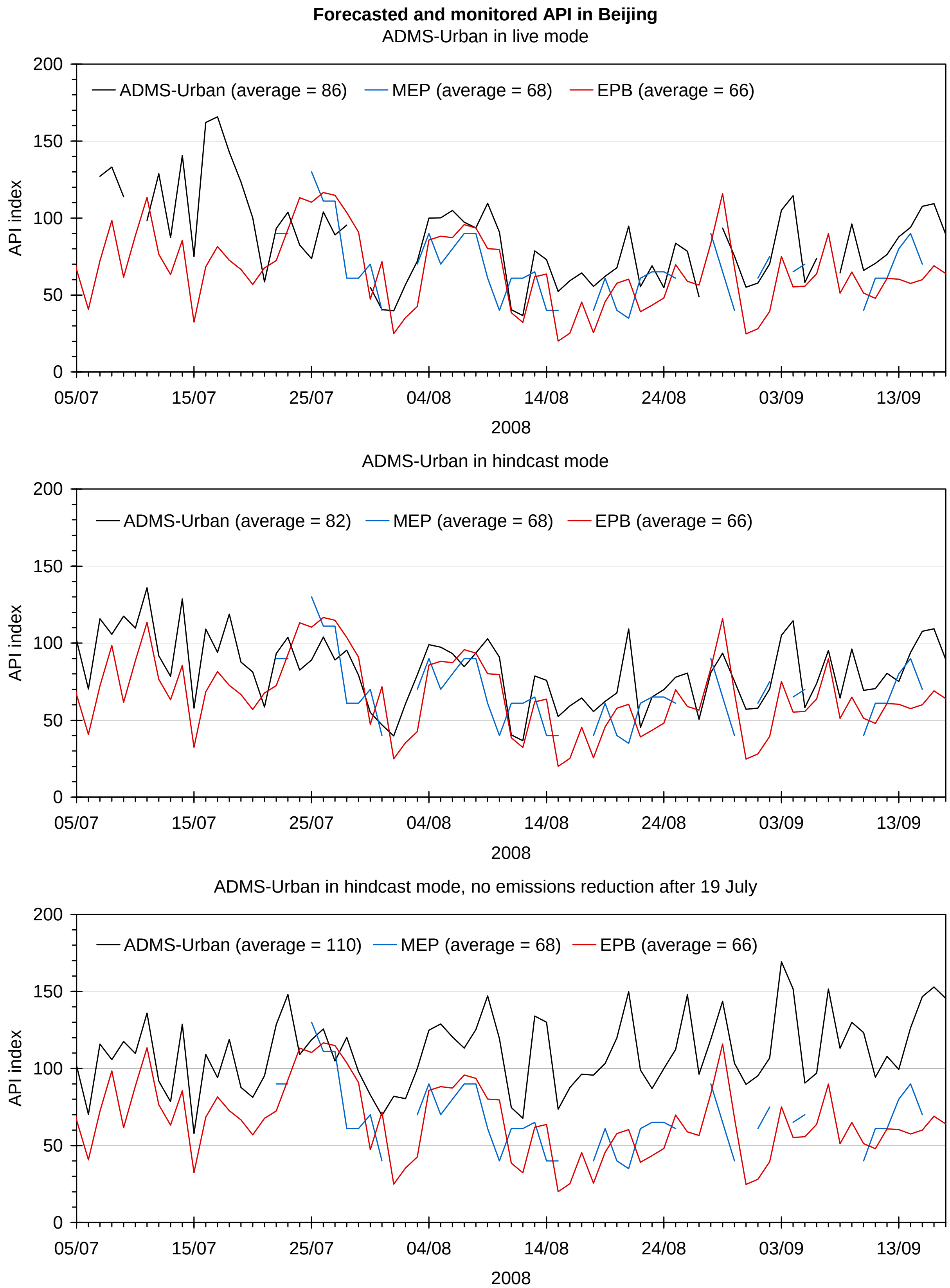
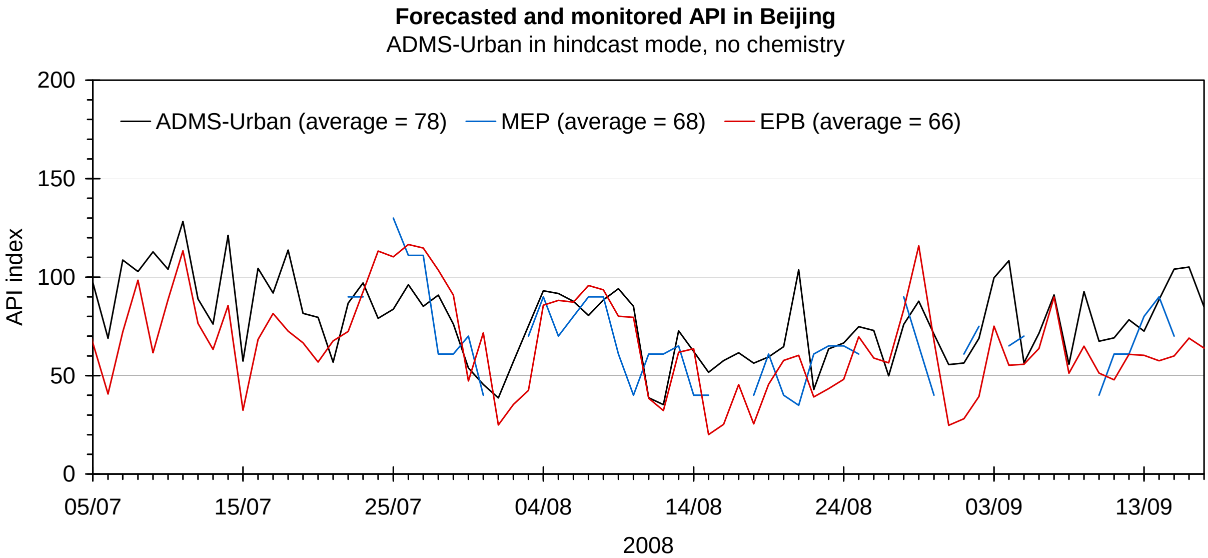


Figure 24 – Time series of daily API forecast by ADMS-Urban (various modes) and MEP, and monitored by the Beijing EPB.



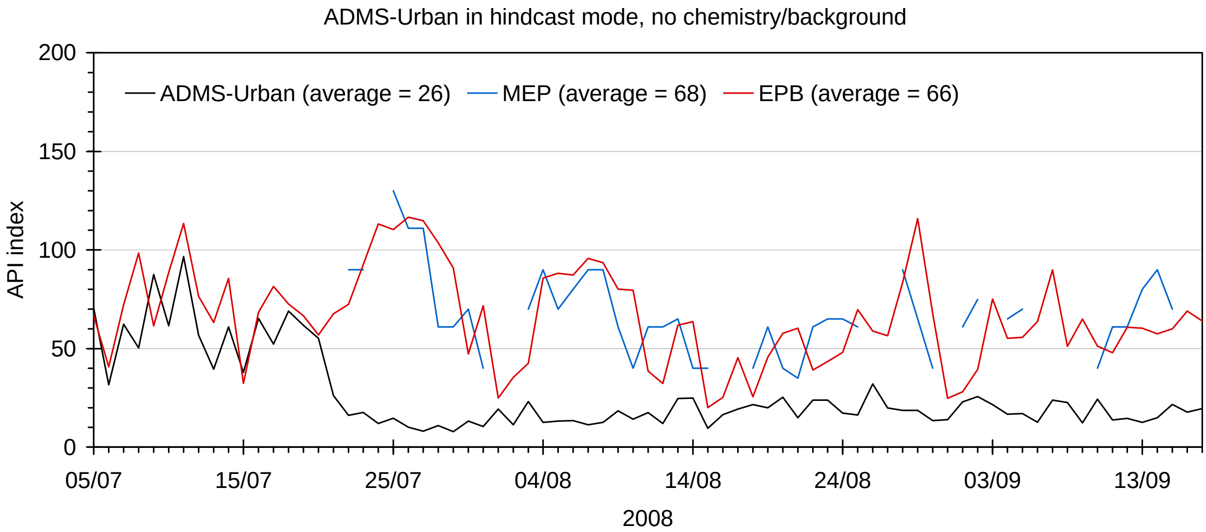


Figure 24 – Time series of daily API forecast by ADMS-Urban (various modes) and MEP, and monitored by the Beijing EPB.

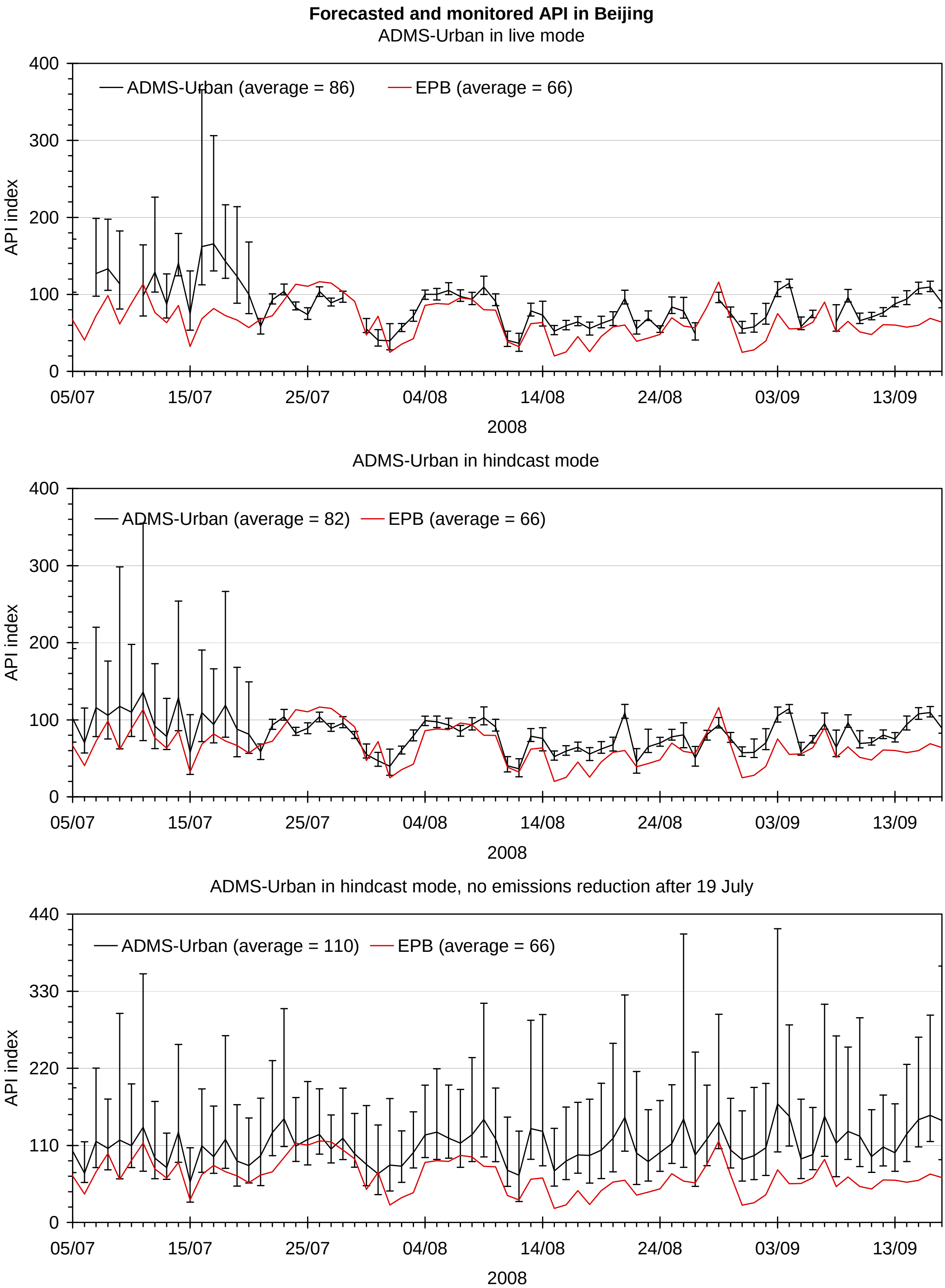


Figure 25 – Time series of daily API as forecast by ADMS-Urban (various modes) and monitored by the Beijing EPB. Bars: minimum and maximum API over the 11 stations inside the ADMS-Urban modelling domain.

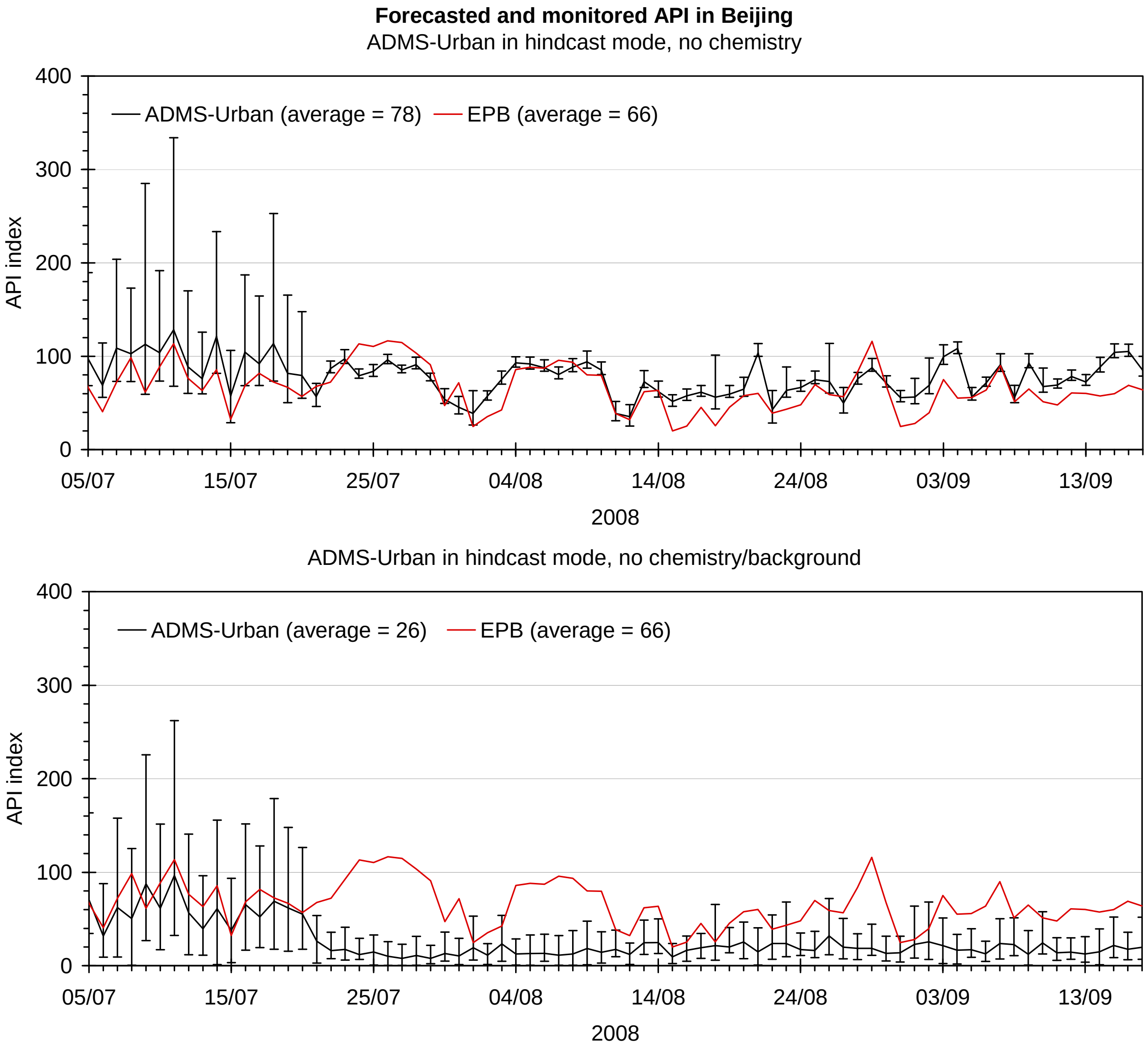


Figure 25 – Time series of daily API as forecast by ADMS-Urban (various modes) and monitored by the Beijing EPB. Bars: minimum and maximum API over the 11 stations inside the ADMS-Urban modelling domain.

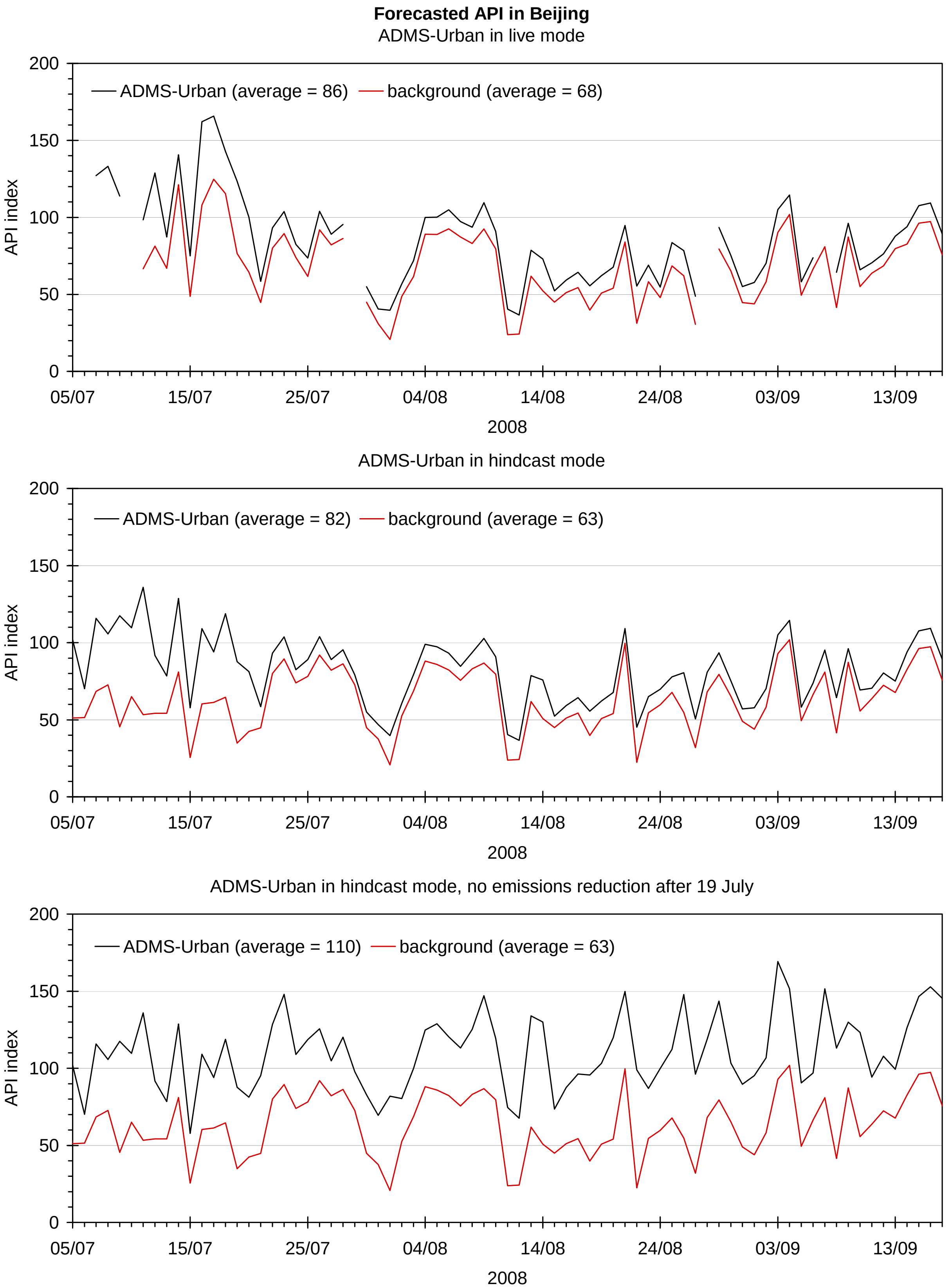


Figure 26 – Time series of daily API forecast by ADMS-Urban (various modes), and corresponding background concentrations.

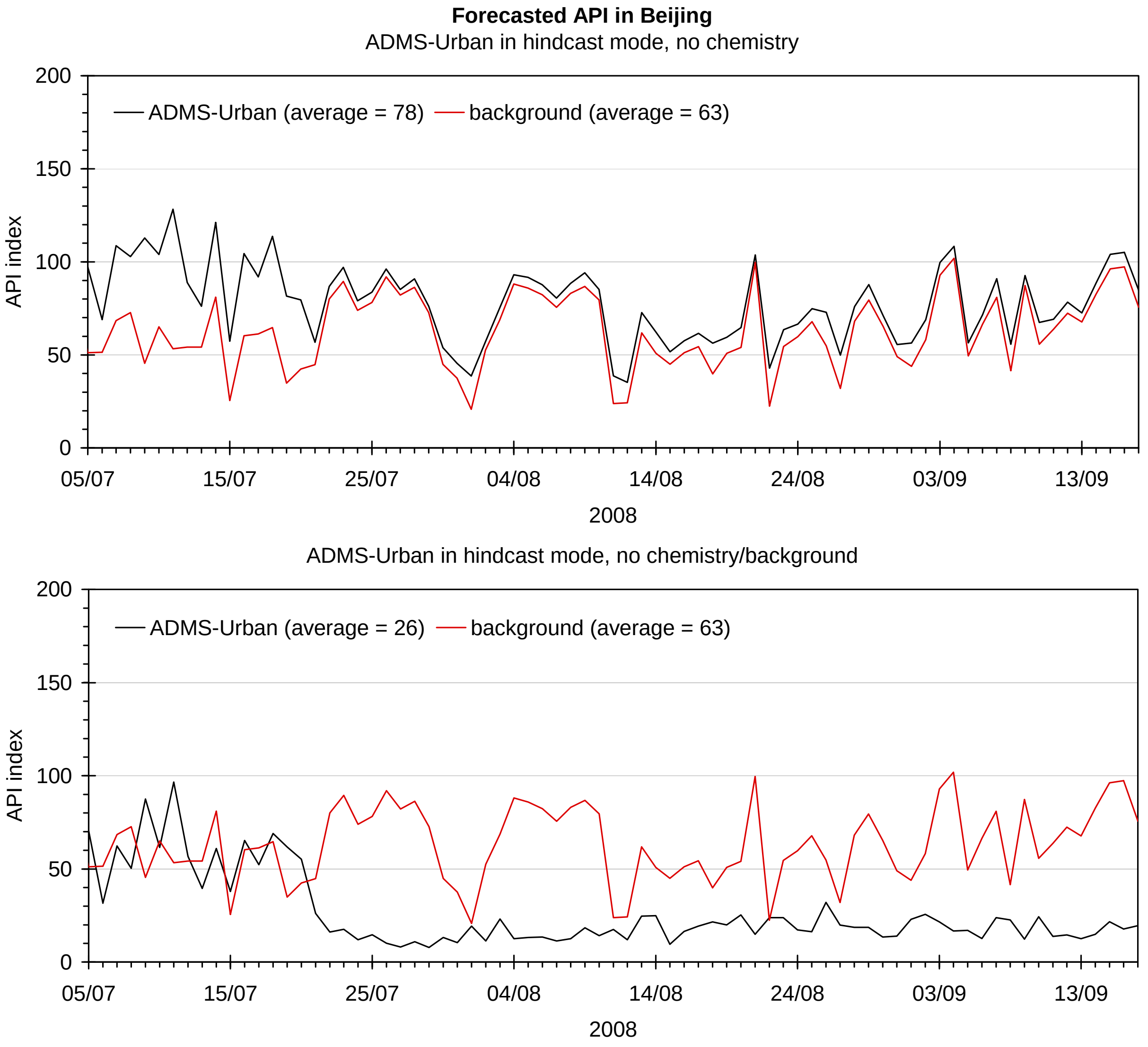


Figure 26 – Time series of daily API forecast by ADMS-Urban (various modes), and corresponding background concentrations.

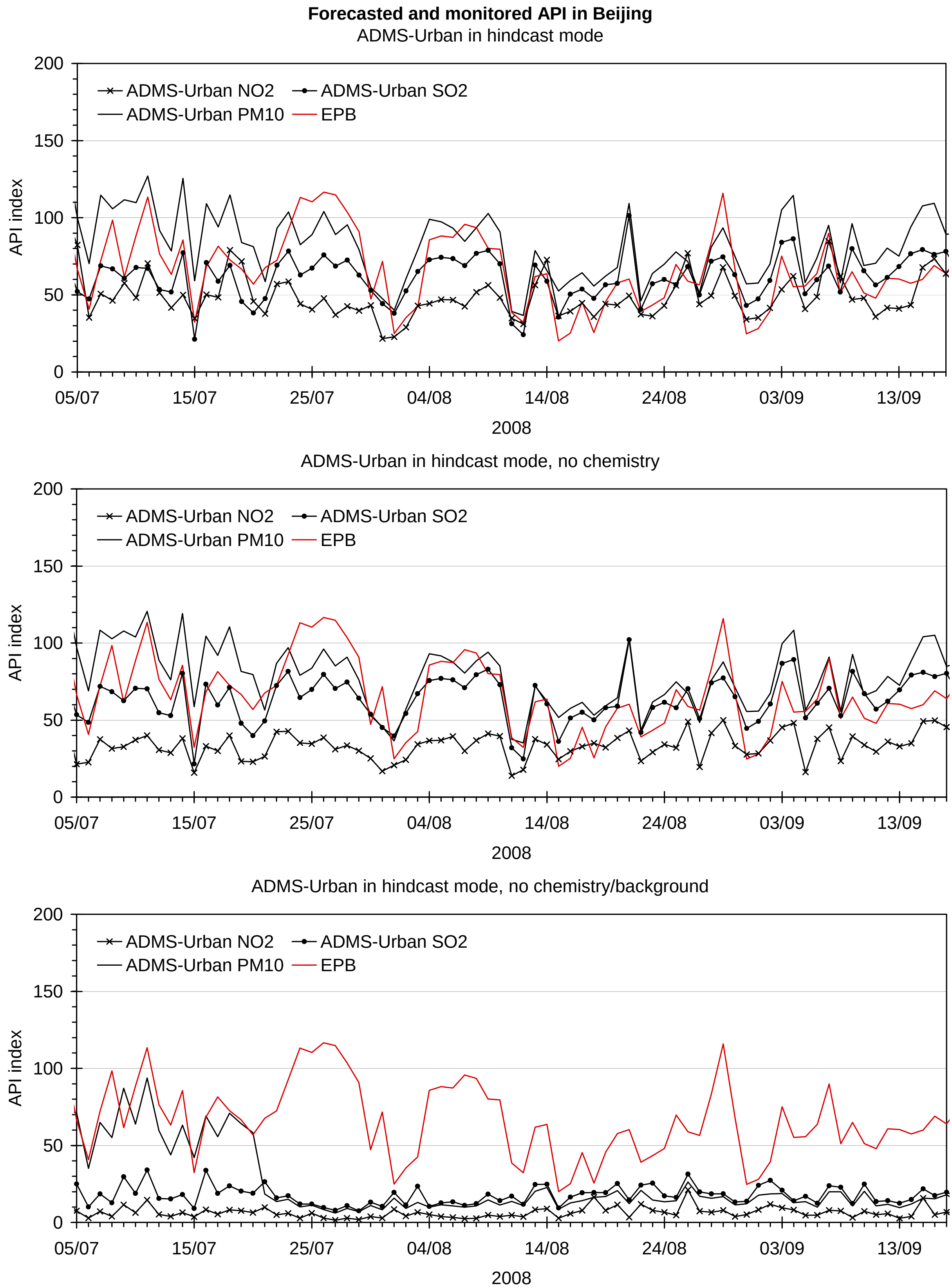


Figure 27 – Time series of daily API as forecast by ADMS-Urban (various modes) and monitored by the Beijing EPB. Species differentiated.

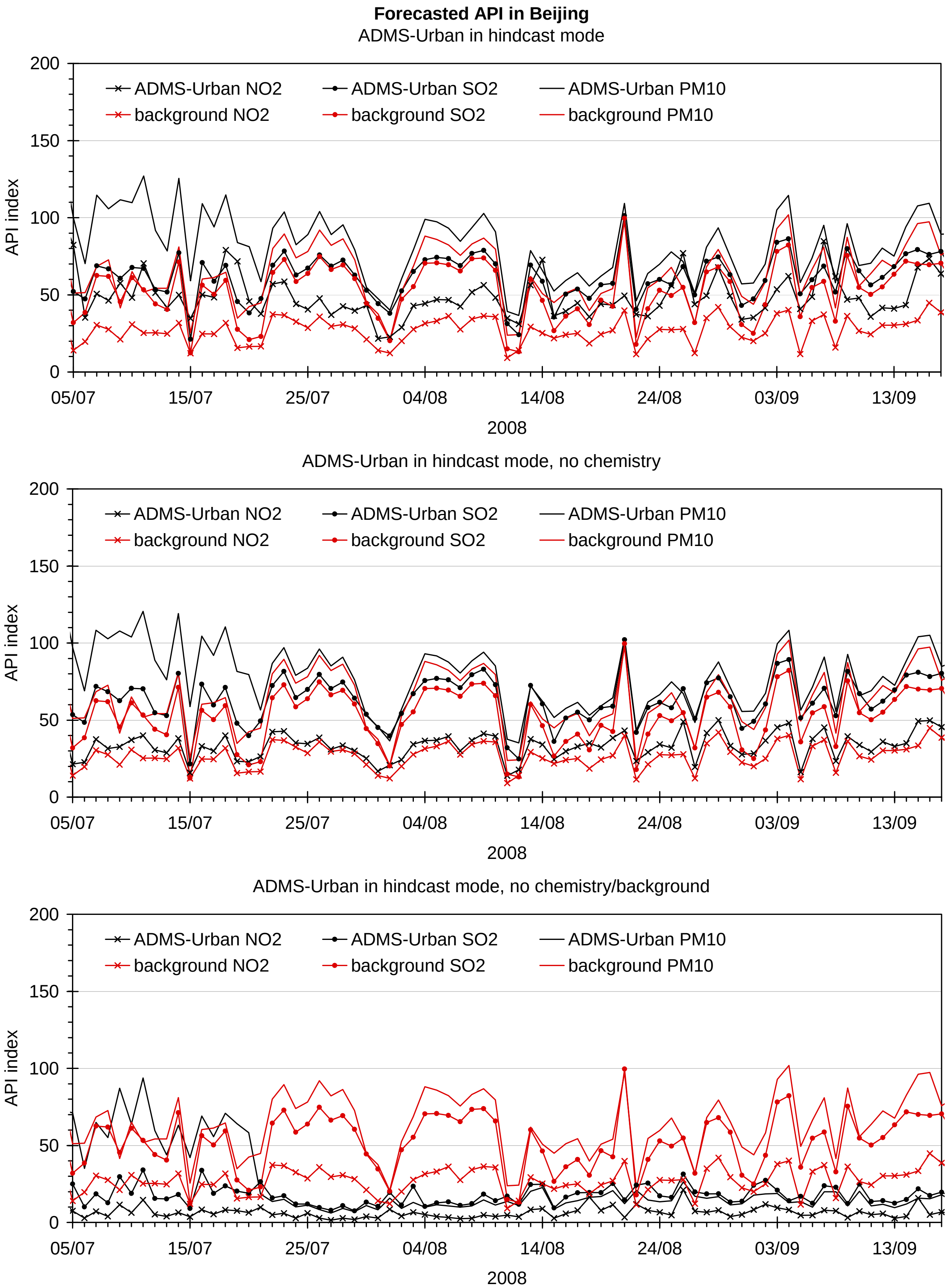


Figure 28 – Time series of daily API forecast by ADMS-Urban (various modes), and corresponding background concentrations. Species differentiated.

Statistics

In order to refine the deductions made in section 6.2 regarding the performance of the *Beijing*air forecasting system, a statistical analysis was carried out on the time series of daily API presented. Results are given in the tables below.

Table 6 lists statistics relevant to each data set, that is, the average, minimum, maximum and standard deviation. Table 7 presents statistics relating pairs of datasets, that is the correlation, covariance and Normalised Mean Square Error (NMSE). The first data set always corresponds to the ADMS-Urban results. The whole period covers data from 5 July to 17 September. The period before 20 July starts on 5 July and ends on 19 July inclusive. The period after 20 July starts on 20 July and ends on 17 September.

Looking at the behaviour of the averaged API forecast live by ADMS-Urban before and after 20 July, the effect of the emissions controls implemented in *Beijing*air from 20 July appears clearly. This is further strengthened by the behaviour of the minimum and maximum values and the ADMS-Urban forecasts in hindcast mode. Indeed, the average decreases to 62, the minimum to 31 and the maximum to 88.

Interestingly, despite the anticipated strong correlation between the ADMS-Urban forecasts and the background concentrations, the Chimère forecasts for the ADMS-Urban hindcast mode do not show such a decrease after the 20th July (the Chimère average actually increases from 56 to 65 and the maximum from 81 to 102). The opposing behaviour of Chimère and ADMS-Urban after 20th July but improved correlation of ADMS-Urban results with the measured APIs suggests ADMS-Urban is less dependent on background concentration than found initially.

The standard deviation also shows an interesting aspect of behaviour of the *Beijing*air system. While the standard deviation was rather high for the live results (when the only available met and background data were older than expected i.e. a forecast for several days ahead), it is constant at 14 in hindcast mode. This indicates the system shows greater variation when not always using the most up-to-date input data, a factor that decreases the accuracy of the forecasts, as already mentioned previously. The range of standard deviations obtained for ADMS-Urban in live mode is close to that obtained for the observed data (EPB) and other forecast data (MEP, Chimère).

The correlations in Table 7 show that ADMS-Urban in hindcast mode showed a better correlation with measured API than in live mode but a worse correlation with the Chimère data. The mean concentration from the Chimère forecasts was lower in hindcast mode than in live mode. As the Chimère forecasts are lower on average, this decreases their relative importance compared with the local inventory and this improved the ADMS-Urban model performance against measured values.

The correlation of the MEP forecasts with the ADMS-Urban forecasts (in any mode) is low.

The NMSE of ADMS-Urban relative to Chimère data is significantly lower than that of ADMS-Urban relative to the EPB or MEP data. Again, this suggests a tight link between the model results and the background concentration. In hindcast mode again, this error is greater, indicating a reduced correlation between the models.

As expected the no emission reduction hindcast statistics generally show much poorer performance relative to the standard hindcast case (higher NMSE, lower correlation). This shows that inclusion of the emission reductions significantly improved the forecasts and also that the emission reductions themselves had a large effect on the API.

Statistics	Data	5 Jul to 19 Jul	20 Jul to 17 Sep	5 Jul to 17 Sep
Number of valid values	ADMS-Urban (live)	13	57	70
	ADMS-Urban (hindcast)	15	60	75
	ADMS-Urban (hindcast, no emissions reduction)	15	60	75
	ADMS-Urban (hindcast, no chemistry)	15	60	75
	ADMS-Urban (hindcast, no chemistry/background)	15	60	75
	EPB	15	60	75
	MEP	0	45	45
	background (live)	10	58	68
	background (hindcast, all)	15	60	75
Average	ADMS-Urban (live)	125	77	86
	ADMS-Urban (hindcast)	102	77	82
	ADMS-Urban (hindcast, no emissions reduction)	102	113	110
	ADMS-Urban (hindcast, no chemistry)	97	74	78
	ADMS-Urban (hindcast, no chemistry/background)	60	18	26
	EPB	73	64	66
	MEP	-	68	68
	background (live)	89	65	68
	background (hindcast, all)	56	65	63
Minimum	ADMS-Urban (live)	75	37	37
	ADMS-Urban (hindcast)	58	37	37
	ADMS-Urban (hindcast, no emissions reduction)	58	68	58
	ADMS-Urban (hindcast, no chemistry)	57	35	35
	ADMS-Urban (hindcast, no chemistry/background)	32	8	8
	EPB	32	20	20
	MEP	-	35	35
	background (live)	49	21	21
	background (hindcast, all)	25	21	21
Maximum	ADMS-Urban (live)	166	114	166
	ADMS-Urban (hindcast)	136	114	136
	ADMS-Urban (hindcast, no emissions reduction)	136	169	169
	ADMS-Urban (hindcast, no chemistry)	128	108	128
	ADMS-Urban (hindcast, no chemistry/background)	97	55	97
	EPB	113	117	117
	MEP	-	130	130
	background (live)	125	102	125
	background (hindcast, all)	81	102	102
Standard deviation	ADMS-Urban (live)	27	21	29
	ADMS-Urban (hindcast)	22	20	22
	ADMS-Urban (hindcast, no emissions reduction)	22	24	24
	ADMS-Urban (hindcast, no chemistry)	20	18	21
	ADMS-Urban (hindcast, no chemistry/background)	17	7	20
	EPB	20	25	24
	MEP	-	21	21
	background (live)	27	21	24
	background (hindcast, all)	14	21	20

Table 6 – Average, minimum, maximum and standard deviation of daily API per data set.

Stat.	Data sets compared		5 Jul to 19 Jul	20 Jul to 17 Sep	5 Jul to 17 Sep
Correlation	ADMS-Urban (live)	EPB	0.33	0.65	0.55
		MEP	-	0.40	0.40
		bgd (live)	0.92	0.97	0.93
	ADMS-Urban (hindcast)	EPB	0.77	0.66	0.66
		MEP	-	0.39	0.39
		bgd (hindcast)	0.63	0.97	0.72
	ADMS-Urban (hindcast, no emissions reduction)	EPB	0.77	0.50	0.50
		MEP	-	0.19	0.19
		bgd (hindcast)	0.63	0.78	0.76
	ADMS-Urban (hindcast, no chemistry)	EPB	0.77	0.64	0.64
		MEP	-	0.39	0.39
		bgd (hindcast)	0.64	0.97	0.72
	ADMS-Urban (hindcast, no chemistry/background)	EPB	0.56	-0.27	0.12
		MEP	-	-0.29	-0.29
NMSE	ADMS-Urban (live)	EPB	0.36	0.12	0.19
		MEP	-	0.12	0.11
		bgd (live)	0.12	0.04	0.06
	ADMS-Urban (hindcast)	EPB	0.14	0.11	0.12
		MEP	-	0.12	0.11
		bgd (hindcast)	0.41	0.04	0.12
	ADMS-Urban (hindcast, no emissions reduction)	EPB	0.14	0.41	0.35
		MEP	-	0.37	0.37
		bgd (hindcast)	0.41	0.34	0.36
	ADMS-Urban (hindcast, no chemistry)	EPB	0.11	0.10	0.10
		MEP	-	0.10	0.09
		bgd (hindcast)	0.35	0.02	0.09
	ADMS-Urban (hindcast, no chemistry/background)	EPB	0.10	2.55	1.40
		MEP	-	2.57	1.74

Table 7 – Correlation and Normalised Mean Square Error (NMSE) of daily API.

7. Discussion

The Beijingair forecast system was set up in a period of three months as a reliable, operational forecasting and alert system. The model set up phase included the creation of a dual language web site with a sign-up facility for the alert service, creation of an emissions inventory, model set up and validation and establishment of the forecasting system with the live data feeds. The system performed very reliably producing forecasts on 99 % of days despite there being occasional problems in the supply of input data. The system was successfully installed and demonstrated at the offices of Beijing EPB and at Beijing Capital Normal University and training was also conducted at these institutes. In this report we have described the *Beijing*air forecasting system, the data sets used as input including their origin and limitations, and the system performance and validation.

The *Beijing*air forecasts showed a good correlation with the measured API values, good prediction of the mean values and a low normalised mean square error. The correlation improved when the model was run in hindcast mode compared with the live forecast mode. During the live forecast mode the latest forecasts of meteorology and background concentrations were not always available although the *Beijing*air system used the latest data available to it to ensure that forecasts were made. During the first week of the forecasting system operation the data feeds were least reliable and in addition adjustments were made to the emissions inventory in order to optimise the forecasts.

Some peak pollution events were underestimated by the forecasting system, in particular those of 24-28 July and 29 August. This has been found to be strongly related to the quality of the background concentrations that significantly drive the ADMS-Urban results. When the background data are not the latest forecasts they are subject to greater uncertainty and this in turn leads to a reduced performance of the *Beijing*air forecasts.

During the Olympic period Beijing experienced uncommonly high rainfall and the *Beijing*air system had not been set up to take washout of pollutants into account. This will have led the model to overestimate ground level concentrations.

Other sources of uncertainty in the modelling concerned the *in situ* monitored data and the emissions inventory. The approximate location of the monitors in Beijing was found but there was no information found on the proximity of the monitors to roads (and to road traffic) nor to vegetation. Similarly, no detailed information was found on the instrumentation used for the monitoring, nor of its quality control.

There was considerable uncertainty in the emissions inventory used by both ADMS-Urban and by Chimère and this is an area in which improved information on the emissions sources - traffic, industry, heating, etc - would be expected to improve forecasting accuracy.

The analysis has shown that the inclusion of the emission reduction scenarios in the routine forecasts greatly benefited the forecast performance relative to the case with no emission reductions and that the emission reduction had a significant effect on pollution levels during the Olympic Games.

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