Using ADMS models for Air Quality Assessment and Management in China

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1. INTRODUCTION

Many cities and regions are undertaking studies of air quality in cities to determine both the current state of the environment and the effect of future economic and environmental strategies in order to manage local air quality. Often these studies are driven by legislation such as the European Union requirement to model agglomerations or the Chinese requirements to study air quality capacity and to forecast air quality. ADMS-Urban is the most widely used advanced dispersion model for urban areas, being used extensively in China and worldwide, providing a practical tool for assessing and managing urban air quality.

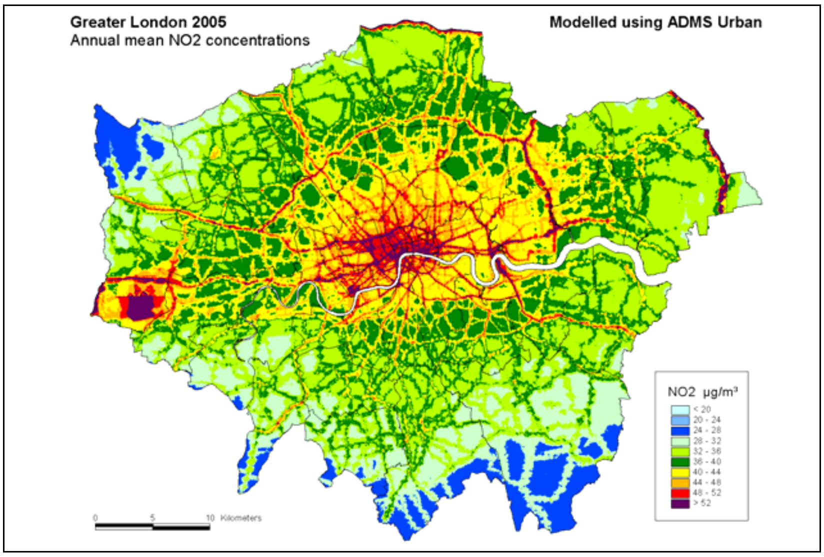

Figure 1. ADMS-Urban predictions of NO_2 concentrations for 2005 for London

ADMS models are now used in the following cities in China: Beijing, Shanghai, Chongqing, Hangzhou, Kunming, Hong Kong, Harbin, Lanzhou, Urumqi and in Liaoning province etc. This paper describes the use of ADMS-Urban in two Chinese cities: Fushun as part of the EU-China LIEP project [1, 2] and Jinan as part of the EU-China EMCP project [3]. It describes the application, process followed, lessons learnt and results gained.

In section 2 we briefly describe the ADMS dispersion models and give an overview of their use in China. Sections 3 and 4 describe in more detail the use of ADMS-Urban in Fushun in Liaoning province and in Jinan in Shangdong province respectively, for studies of urban air quality. Section 5 presents the conclusions.

2. THE ADMS MODELS IN CHINA

In China specifically customised versions of the ADMS models have been made available for different levels of applications. ADMS-Screen is available free of charge and models a single point source using prepared meteorological data to generate a comparison against Chinese air quality standards. ADMS-EIA is version of the model, customised to model many industrial point sources and some road sources, that is available only in China as it has been tailor-made for Chinese environmental impact assessment requirements. ADMS-Urban, the most complex of the models is used for modelling towns, cities, airports, motorways, county regions and large industrial areas.

ADMS-Urban is the most widely used advanced dispersion model for urban areas worldwide [4]. Results from ADMS-Urban studies [5], such as those shown in Figure 1, are used to inform development of policy on air quality, in the development of action plans, investigation of traffic management options, source apportionment studies, assessment of the impact of airports and in more routine air quality assessments of proposed developments.

It is the most complex model, ADMS-Urban, with which this paper is concerned. In addition to its use in Fushun and Jinan described here, ADMS models are being used in Beijing where traffic sources are important, Shanghai where both traffic and industrial sources are important, Chongqing to model the effect of complex terrain (hills), Hangzhou, Kunming, Hong Kong, Harbin, Lanzhou, Urumqi and in Liaoning province etc.

3. MODELLING AIR QUALITY IN FUSHUN

The EU-China Liaoning Integrated Environmental Programme (LIEP) was a major environmental project that ran for five years, concluding this year, 2004. One of the nine components of the project was Air Quality Management and Capacity Building and under this component the following were undertaken at Liaoning Regional EPB (Environmental Protection Bureau) and the EPBs of the five project cities:

(i) assessment of processes, abatement technologies and future options
(ii) assessment of current monitoring and enhancement of monitoring capability
(iii) compilation of an emissions inventory
(iv) set up and validation for use of ADMS-Urban air quality management model
(v) establishment of an economic model for assessment of mitigation options
(vi) establishment of an EIS (Environmental Information System)

The five project cities were Shenyang, Anshan, Benxi, Liaoyang and, the pilot city for air quality modelling, Fushun. This section describes the initial work done in modelling Fushun setting up and validating the model (for the year 2000) and then using it in cost-benefit analysis of pollution mitigation strategies. Here we focus on TSP as the major pollutant.

3.1 About Fushun

Fushun is a city of 1.4 million people (year 2000) lying to the north-east of Shenyang city in Liaoning province. It is an industrialised city with an open cast coal mine and several man-made hills created as a result of the coal mining. Fushun is situated in a river valley and within 15km of the city hills rise to approximately 350m. Its latitude is 42º. The climate is very cold in winter, very hot in summer and windy during the spring. The “heating season” runs from November through to March.

3.2 Ambient monitoring

The pollutants of concern in Fushun were TSP, SO_2 and NO_X, particularly TSP. In 2000 Class III limits for daily air quality were exceeded on occasions; the Class II limit for annual average was exceeded and the Class III Limit approached. When the project started there were five ambient monitoring sites in Fushun: Wang Hua (industrial), Xing Hua (residential), Dong Zhou (residential), Nan Zhan (traffic) and Shui Ku (clean site). Daily average concentrations were measured on 12 days in each of 4 months. Figure 2 shows the location of the five monitoring sites with the roads, rivers, open cast mines and man-made hills and Figure 3 shows the daily average TSP concentration values recorded at the sites during 2000.

Shui Ku is the clean site for Fushun, but it is located within about 5km of the Liaoning and Nan Gang Power Plant, which are amongst the largest emission sources in Fushun. Monitoring data from Shui Ku were used as background data for ADMS-Urban i.e. as a measurement of the long range or remote sources of TSP.

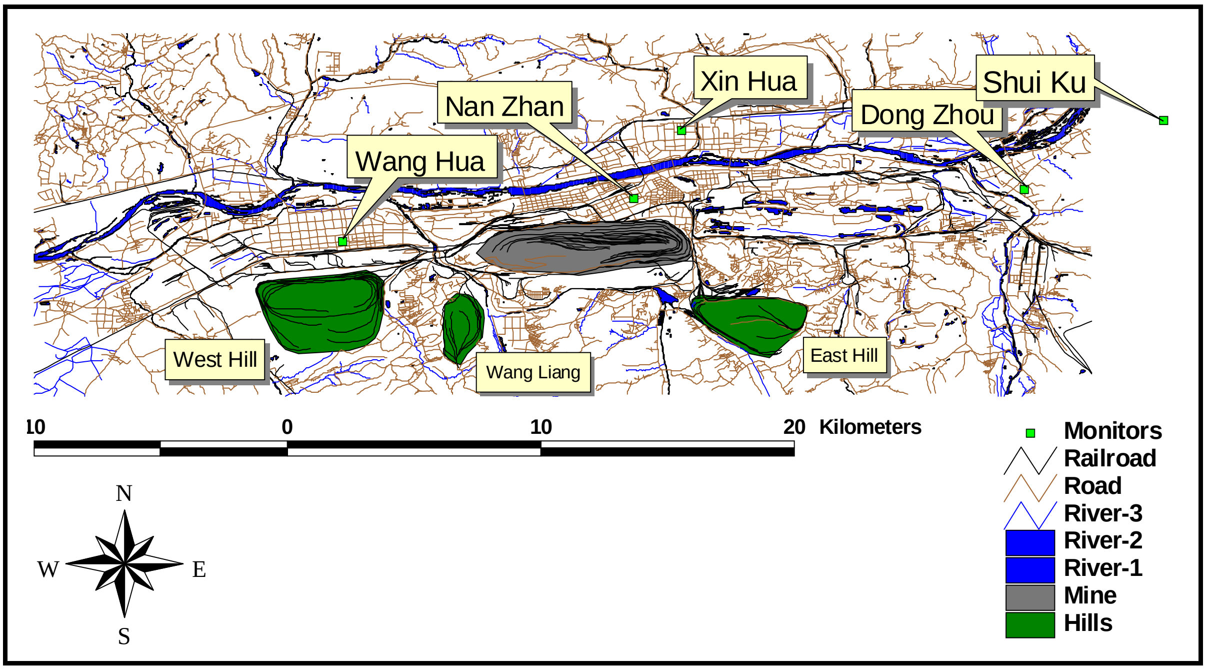

Figure 2. Location of Fushun monitoring sites, man made hills (green) and open cast coal mine (grey)

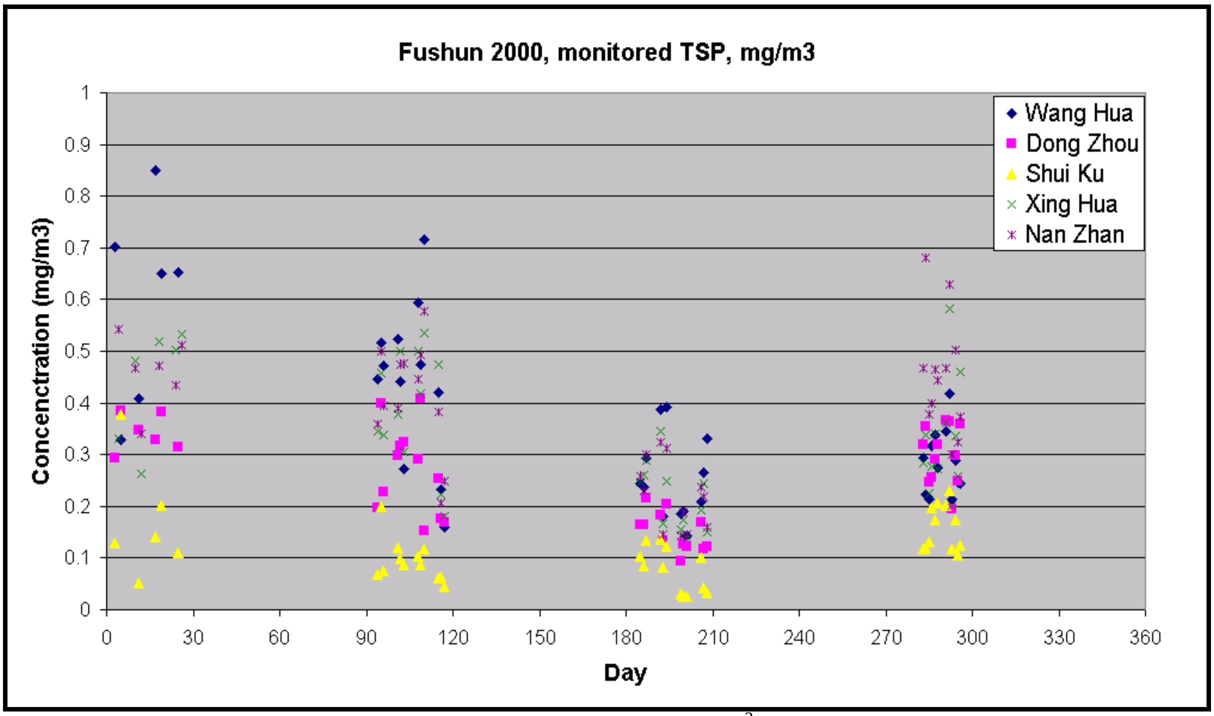

Figure 3. Ambient monitored TSP (mg/m^3), Fushun 2000

3.3 Emissions inventory

An emissions inventory was compiled using CERC's EMIT emissions inventory toolkit. It included the following:

(i) 700 point sources: boilers, kilns and furnaces and process emissions. All except 94 of these stacks were 20m or greater in height. Detailed data were supplied on each point source: stack height, diameter, exit temperature, volume flow rate, days of operation per year, hours of operation per day and information on fuel used in the heating season and non-heating season and emissions in tonnes per year of SO_2, TSP and NO_X. For the boilers information on the boiler type, method of combustion, method of dust control, theoretical and actual efficiencies were also supplied.

(ii) Small boilers, less than 20m in height, supplied as aggregated sources on a $1km^2$ grid

(iii) Small industrial sources, less than 20m in height, supplied as aggregated sources on a $1km^2$ grid

(iv) Emissions from single storey dwellings using coal, calculated from fuel usage data, supplied as aggregated sources on a $1km^2$ grid

(v) Emissions from the three man-made hills and the open cast coal mine (area sources). The man-made hills emit only TSP whereas the open cast coal mine emits TSP, SO_2, NO_X and CO due to natural fires, boilers and vehicles. The emissions are functions of wind speed, with negligible emission below 5m/s. A monthly profile was assumed, setting emissions to be non-zero in the windiest months only, March and April.

(vi) Emissions from 134 major roads – not used in this study

The large point sources are largest emitter (in tonnes/year) of TSP in both the heating and non-heating season.

Diurnal and seasonal profiles were used for all the sources. Generally, industrial point sources that operate 160 or fewer days per year were assumed to operate in the winter only. There are some backup sources operating 50 or fewer days per year which can have significant emissions but of course the time of their emissions cannot be predicted. These sources are difficult to account for accurately, but these too have been assumed to operate in the winter only. The time varying nature of the emission sources could be improved by review in the light of local knowledge.

3.4 Coarse particulates

For TSP, in addition to the TSP emitted by the local sources in the emissions inventory and the long range pollution (as measured at Shui Ku), there is an additional contribution that must be considered that can be termed a local background or coarse particulate fraction. This accounts for wind blown dust from building sites, resuspension of particles from the road surface due to the movement of vehicles etc. This local background will typically be larger i.e. coarser, particles. These local, coarse emissions do not appear in the emissions inventory and have therefore been accounted for separately.

Seasonally varying values between 0.05 and $0.15mg/m^3$ were used for the coarse particulates, with the highest values assumed during the spring when it is dry and windy and during the winter when there are a number of roadside furnaces and cooking stalls that are not included in the inventory. The values in the summer and autumn are low as these are the months when there is most rainfall that will act to reduce this local background. The values were deduced from the validation study itself and by previous chemical analysis of monitored TSP.

3.5 Validation results

The validation was based on a comparison of monitored and modelled daily average concentrations. Table 1 compares the monitored and modelled values of TSP for all five monitoring sites during the four months when monitoring was undertaken. A correlation of 0.75 is obtained and the fraction of model predictions within a factor of 2 of monitored values is 0.97 (=97%).

Figure 3 compares the monitored and modelled values as a scatter plot (left hand plot) and a quantile-quantile plot (right hand plot). A quantile-quantile plot is a comparison of the distributions or, percentiles, of monitored and predicted values and does not compare values at a particular space at a particular time as a scatter plot does.

	Statistic	Monitored	Modelled
Overall	Minimum	0.026 mg/m^3	0.031 mg/m^3
	Maximum	0.850 mg/m^3	0.882 mg/m^3
	Mean	0.282 mg/m^3	0.269 mg/m^3
	Correlation	1.0	**0.75**
	Fraction within a factor of 2	1.0	**0.97**

Table 1. Comparison of monitored and modelled concentrations of TSP(mg/m^3), year 2000

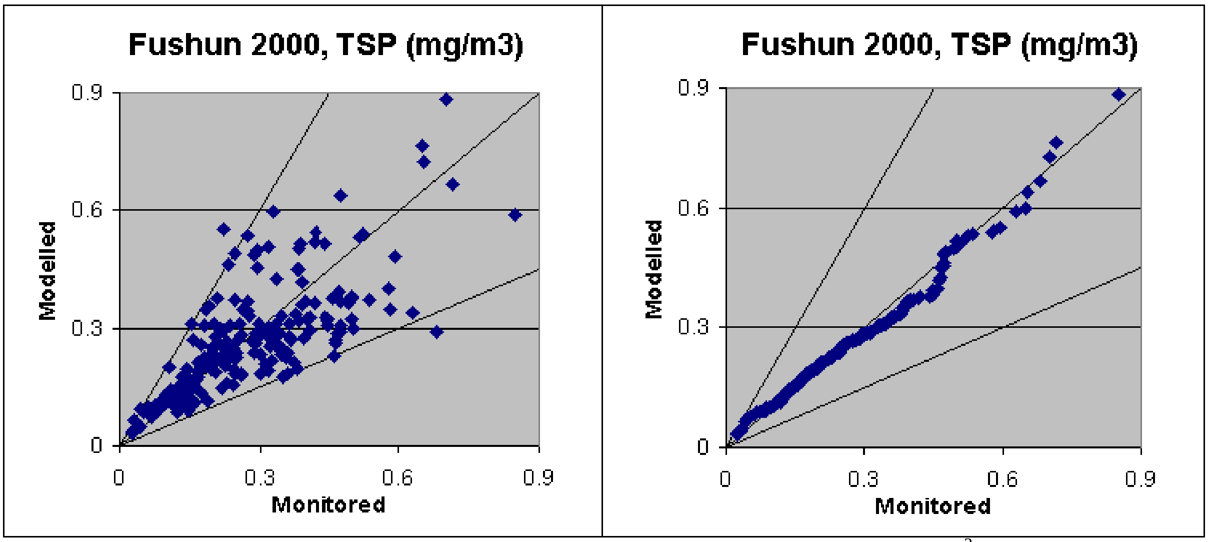

Figure 3. Comparison of monitored and modelled concentrations of TSP (mg/m^3), year 2000

The modelling confirmed the results of chemical analysis that had suggested about 40% of the TSP monitored in Fushun was from remote background sources i.e. outside Fushun, 30% was due to the local coarse particulate emissions from construction etc. and just 30% from the industrial, heating and other sources listed in the emissions inventory. This means that in tackling TSP pollution only limited improvements can be gained by tackling the local industrial and domestic sources. Action is also needed on the coarse particulates e.g. by changing construction practices. Tackling the remote background, however, requires regional or national action.

3.6 Cost-benefit analysis of pollution mitigation strategies

After the model validation phase ADMS-Urban was ready for use in the investigation of pollution mitigation strategies for Fushun with target dates of 2005 and 2010. The strategies included three types of change:

(i) changes that are very likely to occur e.g. population growth, removal of single storey dwellings, move to greater us of CHP (combined heat and power), planting grass on the man-made hills
(ii) changes that are likely to occur for reasons other than improving air quality e.g. industrial modernisation, fuel switching
(iii) changes that could be undertaken specifically to reduce air pollution e.g. fitting of desulphurisation equipment to large plant.

The effect of planting grass on the man-made hills was not modelled in the dispersion model but is an important, practical measure in tackling the local, coarse particulate emissions. Each scenario was modelled and the results input to an economic model. The economic model calculated the costs of the scenario e.g. increase or decrease in use of coal and the benefits e.g. lower health care costs and less work-days lost due to people suffering respiratory problems. The results will be used to inform investment decisions. Broadly speaking expensive mitigation measures for large emitters (tall stacks) were found to have a high cost for little benefit. Lower cost measures to tackle low level emitters had a greater benefit.

3.7 Adaptation of the model for use in China and in Fushun

Before use in the LIEP project ADMS-Urban has been extensively validated [5, 6, 7] for use in urban areas through the studies carried out in the UK and elsewhere in Europe. When using the model in China there are several different considerations, most of which were addressed during the project to make the ADMS models now highly suitable for use in China:

(i) Importance of industrial emissions

In the Liaoning project cities, industrial and heating sources are the dominant pollution sources, whereas in European cities emissions from traffic tend to be most important. The ADMS models have been extensively validated for industrial point emissions so the modelling of point sources is a strength of the model [8]. As a new generation model, the use in ADMS of a skewed-Gaussian for vertical concentration distribution produces significantly better results from tall sources, sources greater than say 50m, than old generation models.

The ADMS-EIA model was created and customised for environmental impact assessments in China to address this issue, modelling up to 1500 point sources for which detailed data are available.

(ii) Seasonal dependence of sources – the heating season

As the winters in Liaoning are very cold, many boilers operate just during the heating season (November-March). These are major contributors to pollution in the cities and it is important to take into account in the modelling work their seasonal and diurnal pattern of operation. ADMS-Urban has therefore been extended to include diurnal and seasonal profiles for all sources.

(iii) *Importance of TSP and SO_2 as pollutants*

In Liaoning and China generally TSP and SO_2 are pollutants of major concern whereas in the UK and EU PM_{10} and NO_X are the pollutants of concern. The ADMS-Urban chemistry scheme was enhanced by including the conversion of SO_2 to sulphate particles which are output as PM_{10} (a component of TSP).

(iv) *Traffic emission factors*

Emissions from traffic were ignored during this study as they were assumed to be small compared with the other emission sources. However, as vehicle numbers grow and pollution from road sources becomes more important, it will become increasingly important to have good information on both the composition of the vehicle fleet and their emissions. In a rapidly developing situation, the fleet composition is likely to change rapidly. As traffic becomes a more significant polluter NO_X and NO_2 will become pollutants of concern and there will be a need for measurements of background ozone and of NO_X and NO_2 at kerbside and roadside monitoring locations.

In Fushun there were several special local issues to consider:

(i) *Special meteorological conditions*

It observed that the wind direction in Fushun changes greatly with height. Near ground measurements show a predominant north-easterly wind and the upper air wind predominant direction is south-westerly. In this studied we tackled this problem by using met data from nearby Shenyang where the predominant wind direction is south-westerly, but it is an issue which merits further investigation, for instance by a measurement campaign at different locations in the city.

(ii) *Man-made hills and open cast coal mine*

Emissions from the man-made hills and open cast coal mine have been carefully estimated but are in fact a function of wind speed. The model cannot currently model wind speed dependent emissions but it is planned to develop this capability

(iii) *Complex terrain*

The effect of complex terrain and differing land uses on dispersion modelling was investigated and the effects of modelling these hills, local to Fushun, was not found to be significant.

In summary the model performed well in the validation study of Fushun and the issues identified could further improve results.

4. MODELLING AIR QUALITY IN JINAN

4.1 About the EMCP project

The EU-China Environmental Management Cooperation Programme (EMCP) is one of the most prominent EC-funded projects in the environmental field in China. One of the four components of the programme is the Local and Municipal Development Project (EMCP/LMD). The purpose of the Local and Municipal Development Project is to develop capacity at local and municipal levels. EMCP/LMD has selected projects at the local level to demonstrate practical, innovative approaches to solving key environmental issues in China. One of these projects is to assist the city of Jinan, Shandong Province, in setting up an advanced Air Quality Management System (AQMS) and it is under this project that the ADMS-Urban model has been set up for Jinan.

4.2 About Jinan

Jinan City, the capital of Shandong Province, is a typical northern, inland city with longstanding air pollution problems. In 1997 it was listed among the ten most polluted cities of China and thus gained wide attention.

Jinan has a total area of 8177km^2 and a total population of 5.75 million. The topography is high to the north and low to the south with low hills, sloping plains and alluvial areas extending northward. In the city area, on the south are low hills and on the north the Yellow River. From southeast to northwest, the topography is sloping like a shallow plate, which is part of the northern vein of the Tai Shan Mountain. Therefore, mountain winds and valley winds have a strong impact on the local air circulation in the city. Ecology in the southern lime hills is fragile; the soil is mostly coarse cinnamon soil; and vegetation is poor, with only 15% forest coverage. Soil in the northern alluvial area is loose, the vegetation is also poor here and there is nearly 60% bare ground, hence there is significant wind-blown dust from the ground.

In order to control air pollution in Jinan, both the provincial and municipal governments have taken a series of measures, including Research and Development and Demonstration of the Comprehensive Technology for Air Pollution Control in Jinan City (1998-2002), the Blue Sky Project in Jinan City (1999-2002), Cleaner Energy Resources Project (2000-2005), etc., which improved the air quality in Jinan to some degree. However, with the main pollutants in its atmosphere still above the state-regulated Class II air quality level, Jinan still fails to meet the state requirements.

Under the Blue Sky programme Jinan developed a basic AQMS, including an air quality monitoring and forecasting system. The requirement of EMCP/LMD was to extend this system into a complete AQMS, a planning and management mechanism covering standard regulations and policy. To fulfil this requirement ADMS-Urban air quality management model and EMIT emissions inventory toolkit have been used to compile an updated local emissions inventory and to set up an air quality management system in Jinan to investigate pollution control options.

4.3 Modelling Jinan

Detailed data were supplied on 1449 point sources. Emissions from small boilers were calculated from the fuel usage and emissions from single storey dwellings heated by coal were calculated as a function of population. These emissions plus emissions from open sources, for instance at factories, were given on a 2km x 2km gridded basis. Some of the major roads were supplied as area sources on a 1km x 1km grid. The pollutants of interest were TSP, SO_2 and NO_X.

Within a month the project team succeeded in compiling a new, updated inventory for 2003 and undertook initial validation work which showed good agreement between monitored and modelled values. The model was used to investigate options for pollution control to inform the review and discussion of the air pollution control plan for Jinan. Initial results for Jinan have also been shown to the participants, stakeholders and experts from the Jinan and other municipal authorities.

There remain several issues that can be tackled in further modelling:

(i) *Meteorological conditions*: it observed that the wind direction in Jinan changes greatly with met site location, from south-easterly at the new met site to south-westerly at the old met site and this needs to be addressed.

(ii) *Advanced features*: complex terrain has not been modelled but an investigation of the terrain effects might help understand issue (i), the change in wind direction.

(iii) *Link to a regional model*: The RAINS-Asia regional model is known to have been installed in some government agencies throughout Asia as a planning tool. It has also been used by the World Bank and the Asian Development Bank to guide project investment decisions. It would be straightforward to use required economic or energy strategy scenarios information from RAINS-Asia as emissions input to ADMS-Urban.

5. CONCLUSION

ADMS-Urban has been set up, validated and used for in air quality management cities in China including Fushun and Jinan. During the last five years the ADMS models have been modified and enhanced to make the model highly suitable for use in China where it is already used in many cities. Once set up for a city the model has shown itself to be a useful air quality management tool, used in the investigation and assessment of pollution mitigation and control strategies.

Some issues were identified that would further improve the model results or that require further investigation, such as anomalous meteorological measurements, modelling of complex terrain, use of emissions that are a function of wind speed, for instance for dust from man-made hills.

The important issues for the future identified which were common to both studies are, firstly, the source of particulates, and, secondly, the future importance of traffic.

In Fushun, which may be fairly typical, the modelling indicated that about 40% of the TSP monitored in Fushun was from remote background sources, 30% was due to the local coarse particulate emissions and just 30% from the industrial, heating and other sources listed in the emissions inventory. This means that in tackling TSP pollution only limited improvements can be gained by tackling the local industrial and domestic sources. Action is also needed on the coarse particulates e.g. changing construction practices, planting to increase ground cover. Tackling the remote background however requires regional or national action.

As vehicle numbers grow and pollution from road sources becomes more important, it will become increasingly important to have good information on both the composition of the vehicle fleet and their emissions. In a rapidly developing situation, the fleet composition is likely to change rapidly. As traffic becomes a more significant polluter NO_X and NO_2 will become pollutants of concern and there will be a need for measurements of background ozone and NO_X and NO_2 at kerbside and roadside monitoring locations.

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7. REFERENCES

[1] Telling S. & Han Wen Cheng, Final Project Report, Lot D1, Project Review, September 1999-August 2004 (2004) *for the Air Quality Modelling/Capacity Building Component of LIEP*. Liaoning EPB, 34 Chongshan East Road, Shenyang, 110032, Liaoning, PR China.

[2] McHugh C., Fushun 2000: ADMS-Urban Air Quality Model Validation, *for the Air Quality Modelling/Capacity Building Component of LIEP*, Jan 2003. CERC, 3 Kings Parade, Cambridge, CB2 1SJ

[3] Sheng Xiang Yu, AQMS demonstration project in Jinan City, Shandong Province, Short-term mission report, (2004), *for EMCP- Local and Municipal Development Project*

[4] CERC, ADMS Technical Specification, (2004), http://www.cerc.co.uk/software/pubs/ADMS3%20techspec.htm

[5] CERC, Validation and sensitivity study of ADMS-Urban for London, (2003) *prepared for DEFRA, National Assembly for Wales, The Scottish Executive and the Department of the Environment, Northern Ireland.*
http://www.airquality.co.uk/archive/reports/cat09/Validation&Sensitivity(22JAN03)10_TR-0191-h.pdf

[6] CERC, Validation of ADMS-Urban and ADMS-Roads Against M4 and M25 Motorway Data, http://www.cerc.co.uk/software/publications.htm

[7] CERC, Validation of ADMS-Roads Using the Caltrans Highway 99 Data Set, http://www.cerc.co.uk/software/publications.htm

[8] Hanna SR, Egan BA, Purdum J and Wagler J (1999) Evaluation of the ADMS, AERMOD and ISC3 Models with the Optex, Duke Forest, Kincaid, Indianapolis and Lovett Field Data Sets**.** *International Journal of Environment and Pollution* (Volume 16, Nos. 1-6, 2001).